Preliminary Salinity Impact Assessment for Mallee Environmental Watering Projects

WALLPOLLA, HATTAH LAKES, BELSAR-YUNGERA, BURRA CREEK, NYAH AND VINIFERA

- FINAL REPORT 2
- 23 October 2014

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Sinclair Knight Merz
ABN 37 001 024 095
Level 5, 33 King William Street
Adelaide SA 5000 Australia
PO Box 8291
Station Arcade SA 5000 Australia
Tel: +61 8 8424 3800
Fax: +61 8 8424 3810
Web: www.globalskm.com

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Executive Summary

Background

Several locations along the Murray River have been targeted for environmental watering (works and measures) where the aim is to increase the frequency of wetland and floodplain inundation events, increase the amount of ‘flowing’ habitat in anabranches and flush salt from degraded parts of the in-stream and floodplain environment. However, a potential side-effect of the proposed actions is increased salt loads moving to the river and anabranch system, and ultimately an increase in downstream river salinity.

This assessment focused on eight floodplain locations along the Murray River in Victoria where environmental watering is proposed. These included Wallpolla Island, Hattah Lakes, Belsar and Yungera Islands, Burra Creek, Nyah and Vinifera (Figure ES1).

An earlier assessment of potential salinity impacts at Lindsay Island was undertaken and described within (SKM, 2013).

Schedule B of the *Water Act* (2007) requires that any action that causes a significant salinity effect be treated as an accountable action; triggering a detailed assessment and possible entry on either of the Salinity Registers. As a first step, a (semi-quantitative) preliminary assessment of potential salinity impacts forms the basis for possible further targeted quantitative assessment of the measures depending on the size of the impact.

Approach

Salt loads to the river and anabranch system were estimated using a combination of approaches (quantitative and qualitative) including an initial desktop assessment of groundwater and surface water flow and salinity information, and methods including mass balance, flow nets and groundwater mound calculations. Associated salinity impacts at Morgan were derived using the Ready Reckoner developed (by the Murray-Darling Basin Authority) specifically for environmental watering projects.

Where these results were non-negligible, the salt loads were converted into a time series salinity impact in terms of a daily salt load delivered to the Murray and impact on lock 6 and Morgan EC targets. The output data is suitable for for BigMOD runs that would further enhance the assessment of the wetlands.

The magnitude of the EC impact at Morgan is dependent on connection between floodplain aquifers and surface water bodies, groundwater salinity, extent of watering, and operating levels, frequency and timing. The proposed watering activities range from inundation of small wetlands distant from the river system to inundation of hundreds to thousands of hectares (e.g. Wallpolla) near the river and anabranch system.

There are varying frequencies and duration of inundation events, spanning from operation each year (e.g. Nyah) to infrequent 1 in 15 years events (Hattah Lakes, Area 2).

Aspects of the proposed environmental watering regimes (such as extent, frequency and length of inundation) are at varying stages of investigation by the Mallee CMA. Some aspects of the design of environmental watering are only at the concept stage with operational options still being developed. It has been the approach of the Mallee CMA to provide a 'worse case' scenario that would result in the greatest salinity impact, as such providing an upper bound for salinity impact management. Under this approach, the salinity impact estimates calculated in this report may therefore be higher than the resultant impact (if water events are implemented with lesser frequency, duration and extent). In particular the exact timing of the diversion and subsequent release influences the real time impact. This has not been finally determined for many wetlands and so the opportunity exists to refine and optimise any in river impact. In this context the adaptive management approach that has been taken to date for Hattah is an exemplar of the opportunity that exists to continually improve the effectiveness and reduce the impact of works and measures.

Results

The preliminary salinity impact for each area is summarised in Table ES1. These estimates of salinity impacts do not account for implementation of mitigation strategies that could include managing releases to coincide with higher flow in the Murray River, reduced rate of lowering of the weir pool upstream of the regulator or avoidance of watering salinity hotspots. They can be considered conservative or worst cases scenarios.

Uncertainty

There are areas of uncertainty related to assumptions made in the analyses. Where uncertainty was identified with a given parameter, a conservative value was assumed or upper bound used, thereby increasing the magnitude of the estimated salt load.

If the concepts underpinning the analysis are reasonable, then salt loads would tend to be overestimates. Increasing knowledge of spatial variability of recharge rates, nature of surface water – groundwater interaction, lag times between watering events and salt return and distribution of groundwater salinity will assist in increasing certainty in salinity impact estimates.

The magnitude of the salinity impact is highly dependent on the value of groundwater salinity chosen. The approach taken is to choose a groundwater salinity value that is indicative of the groundwater salinity near the receiving water body like the Murray River or an anabranch. In many cases the available data is sparse and in some cases a range of estimates of salinity impacts relevant based on the known range of groundwater salinity and interpretation of the AEM data.

In particular the analysis of watering actions at Wallpolla Mid and Upper assumes that recharged water will return to Wallpolla Creek and if that is the case then the estimate of EC impacts must be made using groundwater salinity values near Wallpolla Creek. The available data in this particular area is very limited creating significant uncertainty. The resultant conservative salt loads have carried through to the time series estimates.

Additional measurement of groundwater salinity along receiving water bodies such as Wallpolla and Chalka Creek is recommended prior to developing future estimates of salinity impacts.

Another key area of uncertainty relates to assumptions on the receiving environment for water recharging the shallow aquifer in inundated areas. More specifically, there is a question of whether this water is returned to the anabranch or the Murray River on the recession. For example, does the water recharged at Belsar return to the Murray or to Narcooyia Creek? This answer will depend on whether gaining conditions develop that allow flow. In most cases there is insufficient data to know whether this will occur.

- **Figure ES1 Location of project areas**

- **Table ES1. Summary of preliminary estimates of impacts to EC at Morgan (shaded cells indicate estimated impact >0.1 EC at Morgan).**

Location	Inundation area	EC impact at Morgan (total of all processes) ^	Discussion point
Wallpolla Island	Lower	0.08	This assumes groundwater salinity of 5mS/cm. The uncertainty regarding salinity value with lack of bore data is a key risk issue.
	Mid	1.1 [a]	
	Upper	0.17 [a]	
	South	0.006 [a]	
Hattah Lakes	Area 1	0.07	
	Area 2	0.02	Unlikely to have an impact because groundwater flow is likely to be away from creek system southwest towards Raak Plains.
Belsar and Yungera Islands	Primary Option	0.07	Uncertainty on whether the Murray River or the anabranch

Location	Inundation area	EC impact at Morgan (total of all processes) ^	Discussion point
	J1 Creek works (secondary option)	0.008	system is the primary receiving environment for groundwater discharge. Analysis assumes both are possible.
	Lake Powell (secondary option)	Negligible	Distant from anabranch and river system so impacts are likely to be negligible.
	Lake Carpul (secondary option)	Negligible	
Burra Creek	Burra Creek North	0.02	Uncertainty on whether the Murray River or the anabranch system is the primary receiving environment for salt. Analysis assumes both are possible.
	Burra Creek South	0.005	
Nyah	Nyah North	0.04	
	Nyah South	0.003	
Vinifera		0.03	
Lindsay Island *	Option 1	5.24	
	Lake Wallawalla West	Negligible	
	Wallawalla East	0.006	
	Crankhandle Wetland complex (upper)	Negligible	
	Crankhandle Wetland complex (lower)	Negligible	

Location	Inundation area	EC impact at Morgan (total of all processes) ^	Discussion point
Lindsay Island *	Crankhandle West (upper)	Negligible	
	Crankhandle West (lower)	Negligible	
	Lindsay South	0.009	
	North West area	Negligible	

NOTES:

1. The proposed environmental watering regimes used in this preliminary salinity assessment were designed to provide an indication of the greatest impact for selected sites or worst case scenarios. This information will be used to inform future decisions regarding operational frequency, duration and extent of inundation for the environmental watering activities at each of these sites and will differ from those described in this report.
2. Conservatism has been built into the preliminary estimates of salinity impact to address areas of uncertainty. These numbers must only be clearly identified and used in conjunction with the assumptions and limitations that underpin the calculations.
3. These preliminary estimates do not account for the implementation of mitigation strategies that may reduce the magnitude of the salinity impact.
4. The preliminary estimates have been calculated using an analytical approach and available data. The quantum of salinity impact described in this report is likely to change when the Basin Plan modelling tool is applied.

^ Based on results from 3.8 kg/ha/day salt wash off estimate and current salinity and groundwater conditions (where relevant)

* Results from Lindsay Island Salinity Impact Assessment (SKM, 2014); for a 1 in 2 year or 1 in 5 year watering event

[a] The results for Wallpolla Mid, Upper and South options use outdated inundation parameters. Refer to Section 3.3 for more information.

The approach in this analysis is to conservatively assume that gaining conditions do develop following a water event (on the recession) and that water can be returned to both the river and anabranch.

This preliminary analysis indicates the majority of actions do not cause significant impacts in terms of EC at Morgan. The impacts for Wallpolla (Mid and Upper) exceed 0.1 EC at Morgan making them accountable actions under BSMS policy.

There are other watering actions such as Area 1 at Hattah and Belsar Yungera with an estimated EC impact at Morgan that is close but below 0.1 EC. In these cases it is recommended that further monitoring and evaluation occurs during and following an event. In particular how the timing of diversion and release fit in with other river actions needs consideration.

The addition of time series results and the consideration of real; time impacts has highlighted that the actual timing of release of the hold phase can have a significant bearing on the real time impact. In most cases when targets are suggested to be exceeded as a result of wetland rlease, the river was close to the target EC already. Shifting of the timing of the release could avoid many of the target exceedences, if there is sufficient operational flexibility.

Key assumptions and limitations

Key assumptions and limitations relating to this preliminary salinity impact estimate include:

- The project has focused on estimation of salt loads that occur over longer periods of time (e.g. several months) and the magnitude of short term salinity spikes has not been assessed. The project focuses on salinity impacts at Morgan to meet the requirements of Schedule B of the Water Act (2007). Real time estimates look at the shorter time periods but typically consider time steps of weeks or a month. Day to day fluctuations within this time are possible.

- The assessment method uses analytical approaches to estimate salinity impacts coupled with conceptualisation of significant salinity processes, and assessment of in-stream salinity records. This approach is considered appropriate for this preliminary assessment.

- The analysis in this project does not take into account the changes to river flow regime and other actions that may arise from implementation of the Basin Plan, which may provide a greater amount of water or dilution flow to the river system at certain times. Preliminary indications are that the changes will not significantly alter this analysis.

- Real time salinity impacts to the local area are not assessed in detail in this project.

- Salinity impacts are undertaken based on measured surface water and groundwater conditions in 2012. Current conditions largely reflect the effects of the drought, although some rise in groundwater levels has occurred since 2010 in response to higher flow events. The impact assessment assumes the Murray River and other watercourses gain groundwater which is considered a conservative assumption leading to a higher estimate of salt impacts.

- Successive water events (coupled with natural flow events) can potentially return base groundwater conditions to pre-drought conditions observed in the 1990s. The salinity impacts from watering actions are likely to be greater if 1990s conditions are reinstated since there are likely to be more gaining river reaches, although the EC impact at Morgan will be offset by the reduced frequency of operation in the longer term. This effect is taken into account in the salinity impact estimates.

To assist with the characterisation of the effects of the Wollpolla Island options the following data gathering should be considered:

- Measure the salt loads emanating from a watering event, and the implications for the magnitude of this salt load as it relates to the frequency of flooding (given that regular watering will mean recharging a 'primed' aquifer system with greater potential to increase the salt load displaced to the river;
- Overcoming the current data gap in a comprehensive understanding of the spatial variability in groundwater salinity particularly in areas such as Wallpolla Mid where a large increase in the assumed groundwater salinity has critical implications for the downstream impact of environmental watering.
- Assess the risk of local impacts (ecological and economic) taking into account the potential need to report against in-stream targets under the Basin Plan and associated Water Resource Plans; and
- Understand the cumulative impacts that may be created (i.e. due to operations at Wallpolla, Mulcra, Lindsay and Chowilla). To fully inform this cumulative assessment, the monitoring program should have linkages with monitoring programs established for downstream environmental watering program actions.

Real Time Results

Using the MDBA Benchmark series the operating rules as described for the wetlands have been converted to EC impacts in the river. In general the impacts from the wetlands are low. Wallpolla Island Mid Option is the only action that has an impact that is accountable. For the purposes of this assessment timing of diversion and return to the river have been kept consistent with the descriptions. Opportunity exists to optimise the salinity impact by adjustment of the timing of the diversion and offtake.

The summary impacts in the River Murray and at the target sites of Lock 6 and Morgan are summarised in Table ES2 below.

(Note that real time salinity impact estimates for Wallpolla Island Mid, Upper and South options use updated wetland inundation parameter values.)

- **Table ES2 Summary of preliminary estimates of real time salinity impacts (shaded cells indicate estimated breach/s of target at Lock 6 or Morgan)**

			Days target breached (over benchmark period) *	
Location	**Inundation area**	**Maximum EC impact in Murray (µS/cm EC) ***	**Lock 6**	**Morgan**
Wallpolla Island	Lower	Not assessed		
	Mid ^	30	0	5
	Upper ^	20	0	0
	South ^	4	0	0
Hattah Lakes	Area 1	6	0	0
	Area 2	1	0	0
Belsar and Yungera Islands	Primary Option	35	0	0
	J1 Creek works (secondary option)	7	0	0
	Lake Powell (secondary option)	Not assessed		
	Lake Carpul (secondary option)	Not assessed		
Burra Creek	Burra Creek North	6	0	0
	Burra Creek South	Not assessed		
Nyah	Nyah North	30	0	0
	Nyah South	Not assessed		
Vinifera		29	0	0

NOTES: 1. Lindsay Island results are reported in SKM 2014.
^ The results for Wallpolla Mid, Upper and South options use updated values for inundation parameters to those used in the preliminary estimates of salinity impacts in Table 11.1.
* The results reported are from a salt wash off estimated load of 3.8 kg/ha/day, 4.96 mS/cm groundwater salinity and/or current salinity and groundwater conditions where relevant.

Monitoring

It is recommended that comprehensive monitoring occur during an initial event at each site and that this information is used to develop a more detailed analysis of salinity impacts. In particular there should be a focus on establishing groundwater salinity values near the receiving water body, confirming (through good time series data) the interaction between surface water and groundwater prior, during and following a watering event, and quantification of salt load at the primary outlet.

In some cases (such as Wallpolla) the monitoring data can be used to undertaken a more detailed analysis of risk using more complex approaches such as numerical modelling.

Business Case

The overall results in this report are considered suitable for the development of the business case, noting the limitations and assumptions listed in the report. The time series results and real time impact assessments have provided a “first pass” assessment of the potential impacts and have identified a number of areas of possible mitigation. The results presented here have not attempted to fully optimise the real time impacts. If these become important for the progression of the business case then further detailed assessment, potentially using a daily river operations model, may be required. Improvement in the impacts of some of the options is possible and has not been fully explored here. Thus should these impacts be considered acceptable it is likely that they could be improved on in practice, with more information and experience in operation.

1. Introduction

1.1. Background

Sinclair Knight Merz Pty Ltd (SKM) was engaged by the Mallee Catchment Management Authority (Mallee CMA) to undertake an assessment of the potential salinity impacts of environmental watering activities at several sites along the Murray River (Figure 1.1). The works and measures involve a range of activities but most include the rehabilitation of environmental assets by flow regulation or the imposition of infrastructure to provide water at critical times, and to hold it on the floodplain as required to meet the ecological needs.

A potential impact of the environmental watering activities is an increase in salt loads moving to the river and ultimately an increase in downstream river salinity. For this reason, Schedule B of the *Water Act* (2007) requires that any action that causes a significant salinity effect be treated as an accountable action; triggering a detailed assessment and possible entry on either of the Salinity Registers. As a first step, a (semi-quantitative) assessment of potential salinity impacts forms the basis for possible further, targeted quantitative assessment of the measures depending on the size of the impact.

The objective of this project is to determine the level of salinity impact (if any) of the proposed works and measures which can be used to gain approvals from the relevant authorities for implementation, and to inform the implementation and operation of structures across the project sites. Assessments were undertaken for the following sites:

- Wallpolla Island;
- Hattah Lakes;
- Belsar and Yungera Islands;
- Burra Creek;
- Nyah; and
- Vinifera.

1.2. Scope of works

The agreed scope of this study comprised:

- A hydrologic description of the location of individual The Living Murray works and measures for environmental watering and their proposed operation;
- A description of the key mechanisms for salt accumulation and release that may occur as a result of each of the proposed works;
- A semi-quantitative salinity impact assessment of the proposed works and measures, and commentary on any cumulative effects;

- Estimate of the time series salt loads suitable for BigMOD and an estimate of the real time salinity effects of the options;
- A description of management approaches that can be used to mitigate potential salinity impacts; and
- Provision of an outline of a monitoring plan for the site of the works and measures, such that, any five year review of operations would be able to provide a better assessment of salinity impact.

1.3. Assumptions and limitations

The project has focused on estimation of salt loads that occur over longer periods of time (e.g. several months) and the magnitude of short term (day to day) salinity increases has not been assessed. The project focuses on salinity impacts at Morgan to meet the requirements of Schedule B of the *Water Act (2007)*. Salt loads are converted to EC impacts at Morgan using the Ready Reckoner developed by Fuller and Telfer (2007).

The assessment method uses simple analytical models of groundwater and/or salt flow to estimate salinity impacts coupled with conceptualisation of significant salinity processes, and assessment of in-stream salinity records. This approach is considered appropriate for this preliminary assessment.

The assessment of salinity impacts does not fully take into account implementation of mitigation strategies that could include managing releases to coincide with higher flow in the Murray River, reducing the rate of lowering of the weir pool upstream of the regulator or avoidance of watering parts of the floodplain with very high salt stores. These effects are complex and will depend on a wide range of options for management in the lower river.

The analysis in this project does not take into account the changes to river flow regime and other actions that may arise from implementation of the Basin Plan, which may provide a dilution flow to the river system at certain times, although preliminary indications available to the authors indicate that the results will not be any worse that defined in this report. Some improvement may be possible.

Real time salinity impacts to the local area are assessed based on the operating rules as currently understood.

Salinity impact assessments are undertaken based on measured surface water and groundwater conditions in 2012. Current conditions (that is, as they were in 2012) largely reflect the effects of the Millennium drought, although some rise in groundwater levels has occurred since 2010 in response to higher flow events.

The impact assessment assumes the Murray River and other watercourses gain groundwater which is considered a conservative assumption leading to a higher estimate of salt impacts. The likely receptor for groundwater discharge was assessed in each specific case based on a consideration of river stage heights and groundwater levels across the floodplain. In all cases it was assumed that at some point spatially, groundwater could discharge to the River or to a floodplain watercourse. Generally, there was no allowance made for discharge from groundwater due to evapotranspiration processes.

Successive water events (coupled with natural flow events) can potentially return base groundwater conditions to pre-drought conditions observed in the 1990s, where groundwater levels were higher than currently observed. The salinity impacts from watering actions are likely to be greater if 1990s conditions are reinstated since there are likely to be more gaining river reaches, although the EC impact at Morgan will be offset by the reduced frequency of operation of works and measures in the longer term. This effect is taken into account in the salinity impact estimates. The extent to which this is likely is not clear, but as a worst case assessment it has been allowed for.

There are areas of uncertainty related to assumptions made in the analyses. Where uncertainty was identified with a given parameter, a conservative value was assumed or upper bound used, thereby increasing the magnitude of the estimated salt load. If the concepts underpinning the analysis are reasonable, then salt loads would tend to be overestimated. Increasing knowledge of spatial variability of recharge rates, nature of surface water – groundwater interaction, lag times between watering events and salt return and distribution of groundwater salinity will assist in increasing certainty in salinity impact estimates. However, in most cases the assessed impact is small to minor and therefore careful consideration of the need to increase certainty is warranted.

- **Figure 1.1: Location of project areas**

2. Additional data

2.1. Monitoring data

Groundwater level and salinity data used in this assessment was sourced from the Victorian Water Resources Data warehouse (GMS database http://www.vicwaterdata.net/vicwaterdata/home.aspx). This provided information on groundwater level and quality, and bore construction. These bore records were checked against the bore data and interpretation recorded in Thorne *et al* (1990).

Additional monitoring has been undertaken by the Mallee CMA (2009 to 2012) at each project site and was provided to SKM. This groundwater level and salinity data is still to be uploaded into the GMS.

Surface water records (salinity and flow) were also obtained via the GMS database and the Murray Darling Basin Authority (MDBA) Live river data website, which provides data for selected sites along the Murray River: (http://www.mdba.gov.au/water/live-river-data).

Data has not been checked for accuracy or validated.

2.2. Spatial datasets

All available spatial data and literature relevant to the project held by the Mallee CMA was provided.

3. Wallpolla Floodplain

3.1. Hydrology

This summary of the hydrology of Wallpolla Island is taken from SKM (2008a) which itself was drawn from a number of studies that have described various hydraulic controls in the Lindsay–Mulcra–Wallpolla floodplain systems (e.g. Egis Consulting, 2004 and REM, 2008).

The following description has been updated to accommodate data collected since 2008.

Technically the Island represents the area between Wallpolla Creek and the Murray River, covering an area of approximately 9,000 ha (Figure 3.1), but as can be seen, the works and measures are planned to cover an area slightly larger than just the Island. For the purposes of this report, the term the Island will continue to be used, but here denotes a slightly broader area encompassing the broader Murray River floodplain and its older terraces. The system is located on the southern bank of the Murray River between river kilometres 829 and 765 in a reach where the River flows predominantly from east to west (Figure 3.3 to Figure 3.5). The Island extends for 29 km from east to west, while Wallpolla Creek is 7 km to the south of the River at the Island's widest point.

The floodplain features a complex network of watercourses, which are linked to each other and to the Murray River at various locations. There are few wetlands and the majority of the floodplain is only inundated by very high river flows.

Lock 9 is located downstream from Wallpolla Island (at 765 river km) and maintains a constant water level of 27.44 mAHD (MDBA, 2008)during normal regulated flows and strongly influences the water regime of watercourses and wetlands in the lower half of the Island (SKM, 2008a). At the Lock 9 weir pool level, low-lying watercourses and wetlands in the western part of the Wallpolla Island floodplain system are permanently inundated. Lock 10 is located on the Murray River approximately 4 km to the east of the Island (at 829 river km) near Upper Kulnine. The upstream connection between Wallpolla Creek and the Murray River is intermittent. The Lock 10 upstream weir pool has a normal pool level of 30.80 mAHD (Department for Water, 2012).

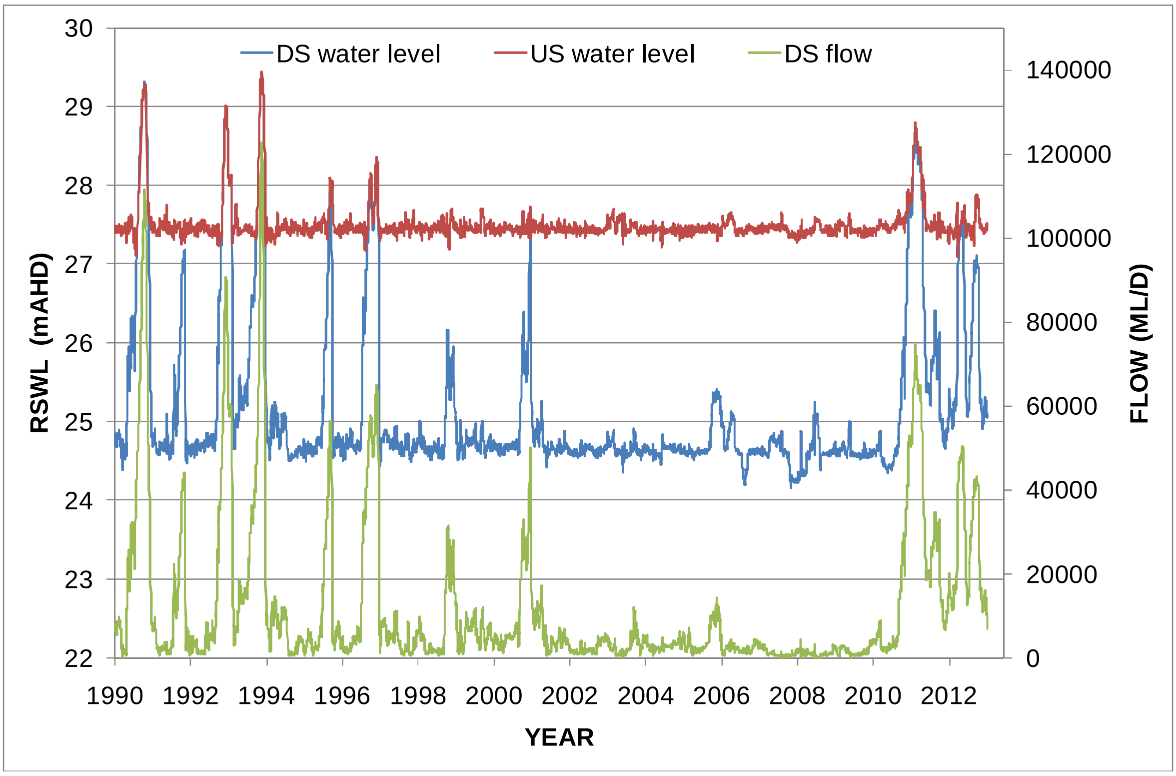
Ultimately, all surface flow across Wallpolla Island returns to the Murray River within the Lock 9 weir pool.

The weirs maintain a stable water level in the Murray River under ‘regulated’ flow conditions. Their stabilising effect is most pronounced directly upstream of the structures. Water levels vary minimally in relation to flow because the weirs are operated to pass more water as River discharge increases.

The river becomes ‘unregulated’ when the weirs are removed to allow high flows to pass without impediment or control. Lock 9 is removed when River discharge exceeds between 48,000 and 58,000 ML/d and is re-instated when discharge falls below 65,000 to 55,000 ML/d (SKM 2008a).

- **Figure 3.1: Location of key features on Wallpolla Island**

Water levels in the Lock 9 weir pool have remained stable, aside from a peak in February 2011. The levels downstream of the Lock experienced seasonal fluctuation (Figure 3.2) over the same period. Increased flow events have been observed through the system since 2010 as is evident in Figure 3.2.



- **Figure 3.2: Surface water level upstream (A4260501) and water level and flow downstream (A4260505) of Lock 9**

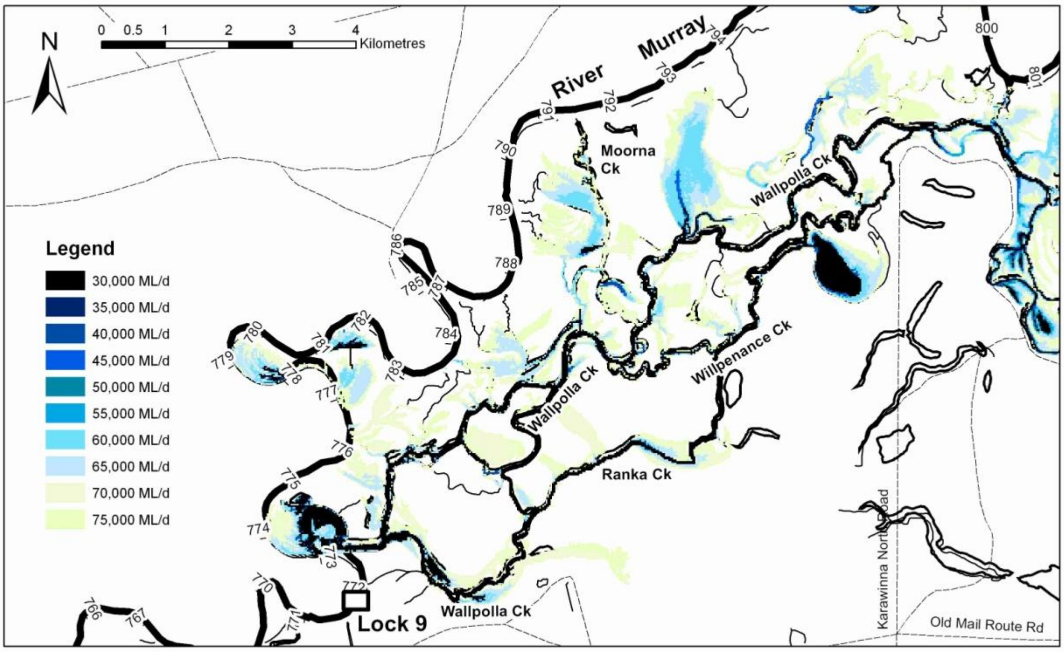
The Wallpolla Island hydraulic model (Water Technology, 2006) provides the extent of inundation at 5,000 ML/d intervals in Murray River flow from 30,000 ML/d to 70,000 ML/d (Figure 3.3 to Figure 3.5) for the Island.

3.1.1. Creek systems

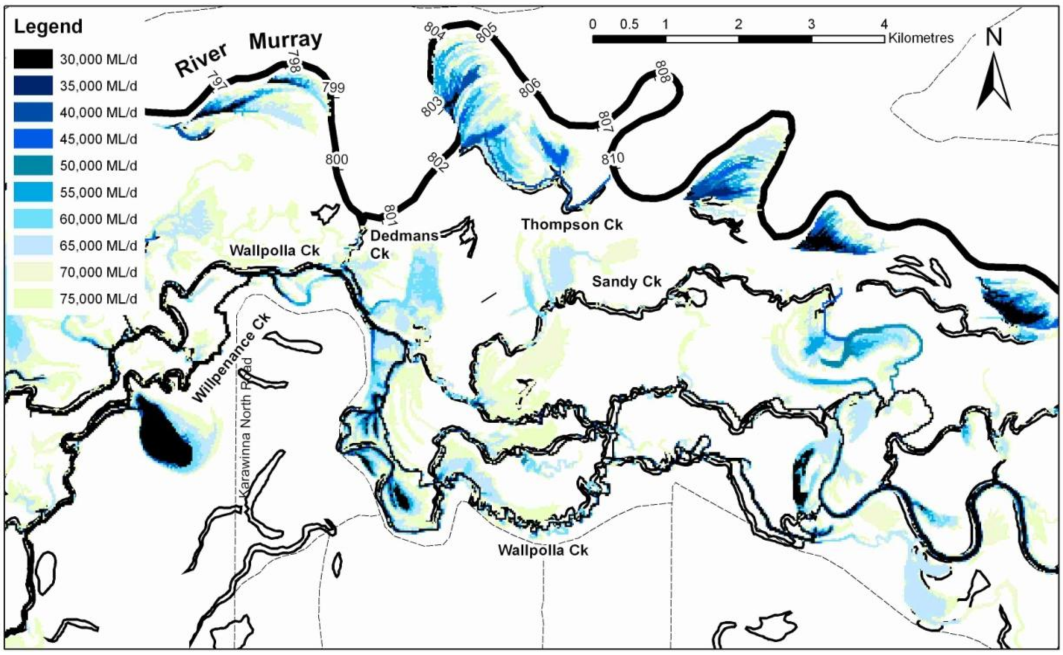
Wallpolla Island can be partitioned into western (Figure 3.3) central (Figure 3.4) and eastern (Figure 3.5) sections. Essentially, there are a series of separate but locally integrated networks of creeks spread across the Island; only Wallpolla Creek flows across the length of the floodplain.

Wallpolla Creek is the longest watercourse on the Island, departing from the Murray River at 829 river km, just below Lock 10, and re-joining the River upstream of the Lock 9 weir pool at 773 river km (Egis Consulting, 2004).

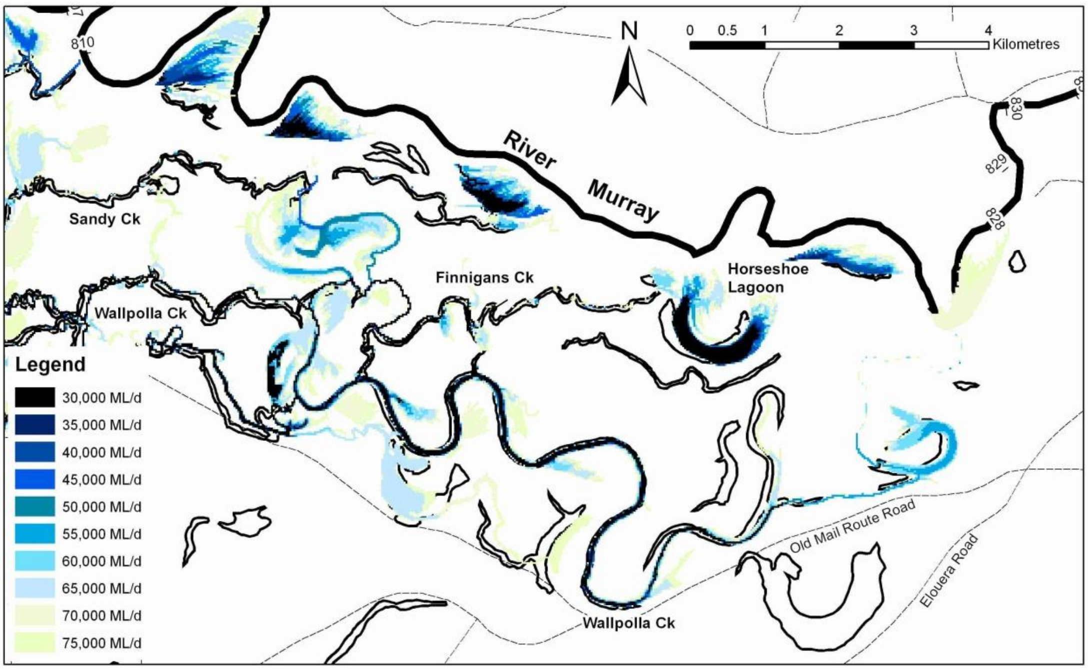
In the western part of the Island, Wallpolla Creek diverges into a number of other watercourses. Willpenance Creek and Ranka Creek branch from Wallpolla Creek to the south, and Moorna Creek branches to the north (Egis Consulting, 2004).



- **Figure 3.3 The extent of inundation at a range of river discharges on western Wallpolla Island with modelled flow measured at Lock 9**



- **Figure 3.4 The extent of inundation at a range of river discharges on central Wallpolla Island with modelled flow measured at Lock 9**



- **Figure 3.5 The extent of inundation at a range of river discharges on eastern Wallpolla Island with modelled flow measured at Lock 9**

The creek system in the lower part of the Island is connected to the Murray River by a number of channels that are ponded at or near pool level. Dedmans Creek connects the River to Wallpolla Creek at the mid-point of the Island (Figure 3.4), at 801 river km, over a distance of 700 m. Moorna Creek connects Wallpolla Creek to the River at 791.5 river km over a distance of 3.5 km. Milky Creek connects the River at 784 river km to Mullroo Creek over a distance of 2 km, just upstream of Lock 9. All three creeks are connected to the Murray River at discharges exceeding 3,000 ML/d (Egis Consulting, 2004).

Dedmans Creek approximately marks the mid-point of the Island and the upstream extent of the weir pool in most floodplain channels. At normal low flows the ponded length of Wallpolla Creek is 25 km.

Wallpolla Creek is the outer-most channel in the eastern part of the island. Two additional channels introduce water to the creek. Sandy Creek diverges from the River at 818 river km and joins Wallpolla Creek near the mid-point of the Island. Sandy Creek begins to flow at 32,700 ML/d at Lock 10. Finnigans Creek diverges from the River further upstream, at 822 river km. It provides water to Horseshoe Lagoon, adjacent to the River, before continuing to join Wallpolla Creek 6 km downstream. Finnigans Creek receives inflow from the Murray River at discharges exceeding 4,000 ML/d (SKM 2004a). Wallpolla Creek receives inflow where it departs from the Murray River at 829 river km at flows of 70,000 ML/d (Egis Consulting, 2004) as measured downstream of Lock 10.

Thompson Creek is located in the upper part of the Island but is not linked to the other creeks. It cuts off a loop of the Murray River between 810 and 802 river km over a distance of 3 km. The creek begins to flow at 20,000 ML/d (Egis Consulting, 2004).

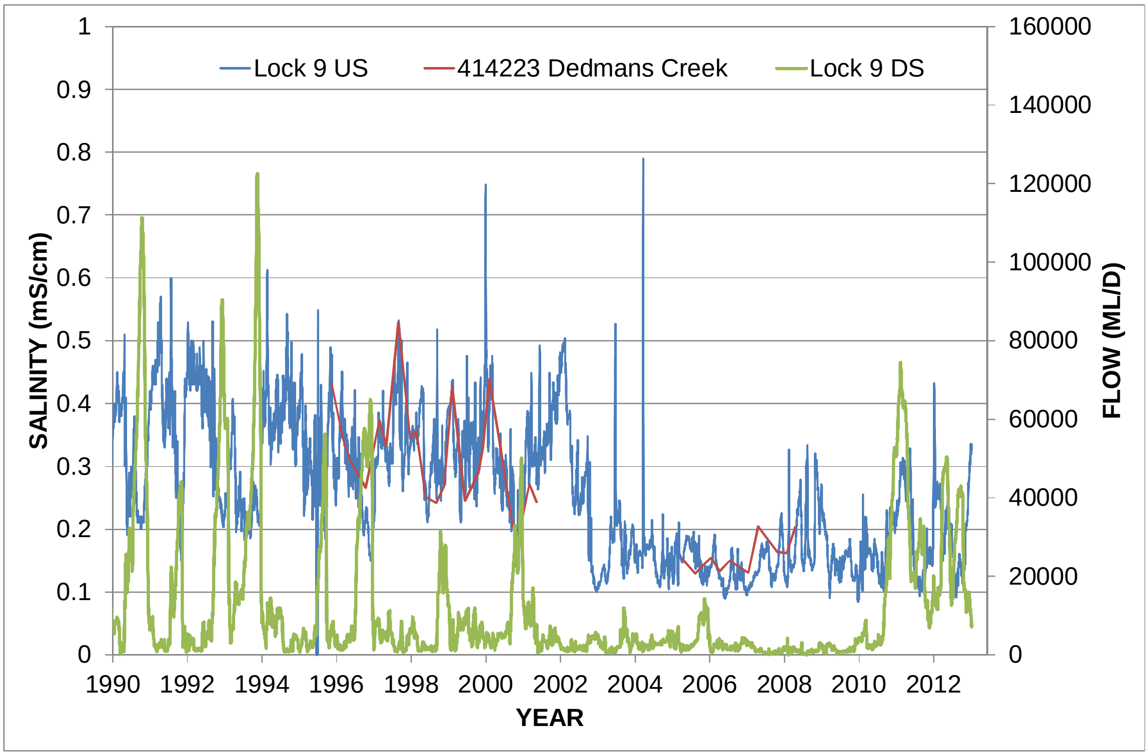
3.1.2. Analysis of surface flow and salinity

A single surface water monitoring gauge is active on Wallpolla Island, located in the centre of the floodplain along Dedmans Creek. Measurements at this gauge are only for salinity and only for a short period of time (1996 to 2008).

Figure 3.6 shows salinity records for central Wallpolla (414223, Dedmans Creek) and downstream Lock 9, compared to Lock 9 downstream flow. The data shows that essentially the two sites have the same salinity.

The flow data in Figure 3.6 shows a number of high flow events up until late 2000, and then a period of very low flows (< 20,000 ML/d). High flow events have been experienced during 2010-2012. A number of very small flow events can also be seen in the time series, and these become important in later analysis of salt load generation.

The salinity data shows a similar trend between mid-floodplain and downstream (Lock 9) conditions during the late 1990s to 2000s. Salinity is not monitored at Lock 10 so a comparison to upstream conditions could not be made. Salinity was at its lowest in Lock 9 during the low flow period between 2003 and 2008.



- **Figure 3.6: Surface water salinity (Lock 9 upstream and 414223 - Dedmans Creek) and surface flow (Lock 9 downstream)**

SKM (2008a) mapped surface water salinity across Wallpolla Island for February 2008 (Figure 3.7). The data show variability in salinity across the Island, a high of 0.8 mS/cm to a low of 0.1 mS/cm Higher values were loosely correlated with outer floodplain sites not well connected to Wallpolla Creek, whereas lower salinity was correlated with the main channel of Wallpolla Creek.

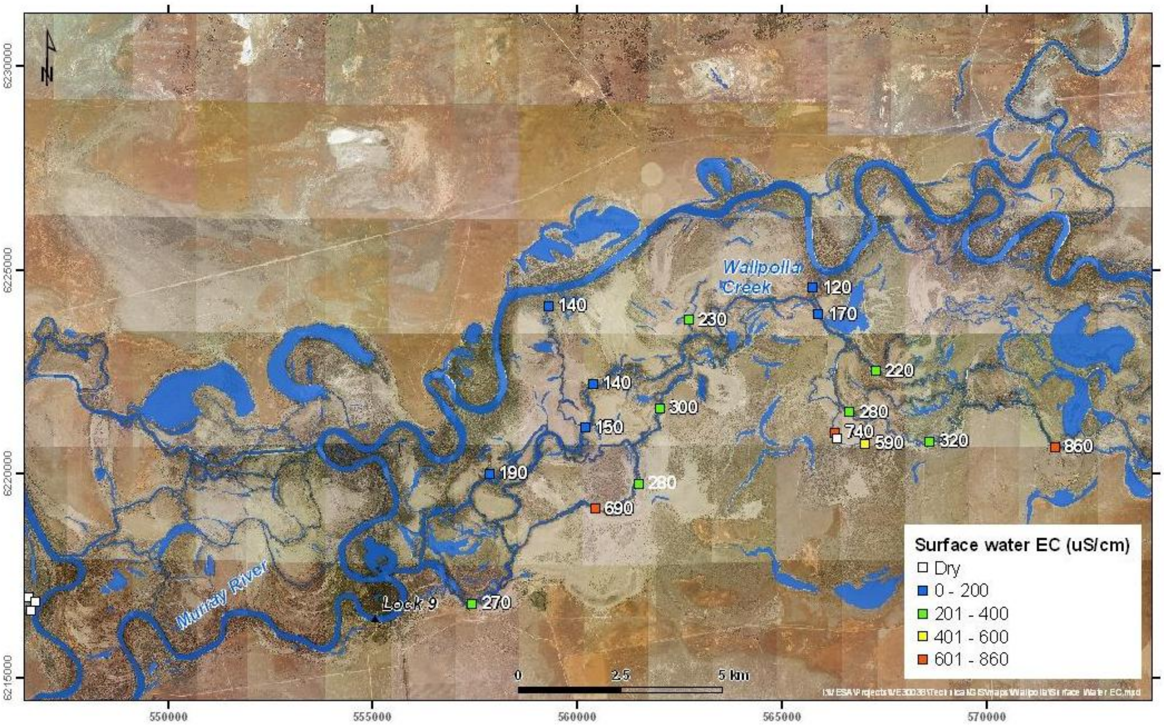


Figure 3.7 Surface water salinity on Wallpolla Island during February 2008 (SKM, 2008a)

3.2. Hydrogeology

3.2.1. Background

The hydrogeological setting of the Wallpolla Island floodplain has been described by a number of studies and the description below is based on the summary contained in REM (2008), who undertook drilling investigations and conceptualisation of floodplain salinity processes, as well as SKM (2008a). Data collected since 2008 has been incorporated into analysis where appropriate.

Initial development of the conceptual framework for the Wallpolla Floodplain came from pioneering work undertaken in the 1980's and published in Thorne et al (1990). This initial study identified the existence of the aquifers in the wide flood plain, and defined the extant of saline water and the relationships between the watertable and river (lock) levels for the first time. In the Wallpolla area the wide and generally flat floodplain results in very flat groundwater gradients. The work published by Thorne et al also included the results of an aquifer pumping test undertaken in the vicinity of Wallpolla island. So since the late 1980's key aspects of the overall groundwater conceptualisation have been in place along with locally relevant estimates of aquifer properties.

During the 1990's the impact of the lock level on local groundwater came to be recognised, in part as a result of irrigation related studies elsewhere in the Mallee (Nyah to the Border Salinity Management Plan) and from inference based on the work undertaken for Chowilla floodplain in SA.

Additional work was undertaken on the geomorphology of the floodplain with Mapping undertaken for the Murray Darling Basin Authority which in turn built on the work of Pels (1969). Three primary river terrace series were recognised in the region. The lower terrace is generally closer to the current river and is often associated with fresher groundwater. The higher (and older) terrace is general the most saline. Analysis of vegetation health distribution started to recognise the impact of microscale topographic differences (see the work by Jolly, for example, Overton and Jolly, 2004)

Additional studies were undertaken by the CMA that considered the range of salt in the surface and potential for salt wash-off that included sites in the Wallpolla area (SKM 2007). Recently the AEM studies have provided detailed insights into the distribution of soils salinity and groundwater salinity across the floodplain (Tan et al 2009)

As the potential for environmental water has become clearer, detailed studies of shallow groundwater and soil conditions have been undertaken. The result of the most recent work is detailed below. There is a long a rich history of groundwater, soil and salinity study in the vicinity of Wallpolla Island dating back to the 1980's. This history provides a sound platform on which to base estimates of the impact of works and measures.

SKM (2008a) developed a hydrogeological cross-section for western Wallpolla Island using recent drilling data (Figure 3.8 and Figure 3.9). The data shows the Coonambidgal Formation ranging in thickness from over 10 m in the south to 3 – 4 m in the north. The usual fine grained clay nature of the Coonambidgal Formation appears to be absent from borehole W3. The Channel Sands appears to vary in thickness significantly along the transect and it is not clear whether this unit is in direct connection with the underlying Parilla Sands. Blanchetown Clay was present to the north at Bore W1 but the current interpretation is that it is probably absent beneath the western Wallpolla floodplain (SKM, 2008b). Thorne *et al* (1990) show that Blanchetown Clay underlies the entire area of Transect E and this probably represents the conditions for the eastern part of the Island.

3.2.2. Groundwater level and depth

Groundwater level data has been collected at several sites across Wallpolla Island. The location of bores that are currently being monitored (2008 to present) is shown in Figure 3.10.

There has been a general decreasing trend in groundwater levels within the Channel Sands over the 10 to 15 years from the 1990's to 2008 due to reduced frequency of flooding events in the Murray River. The fall in groundwater levels has changed the conceptualisation of surface water–groundwater interactions from a 1990s view that groundwater generally discharged to anabranch systems, to a view that river water typically flows to the shallow aquifer which in turn probably discharges via evapotranspiration through floodplain vegetation.

It could be expected that successive induced flood events could cause the 1990s groundwater setting to be reinstated. The length of time (or number of flood events) required for this to happen is unknown. Given that the intent of environmental watering is to flood areas with less water than a “natural” flood it is considered unlikely that the pre 1990 conditions will be established in full. However this has been used as worse case.

Fluctuations in groundwater levels occur as river stage fluctuates, due to leakage from the river when the stage is high. This process is likely to be widespread under the river where it is not influenced by weir pools.

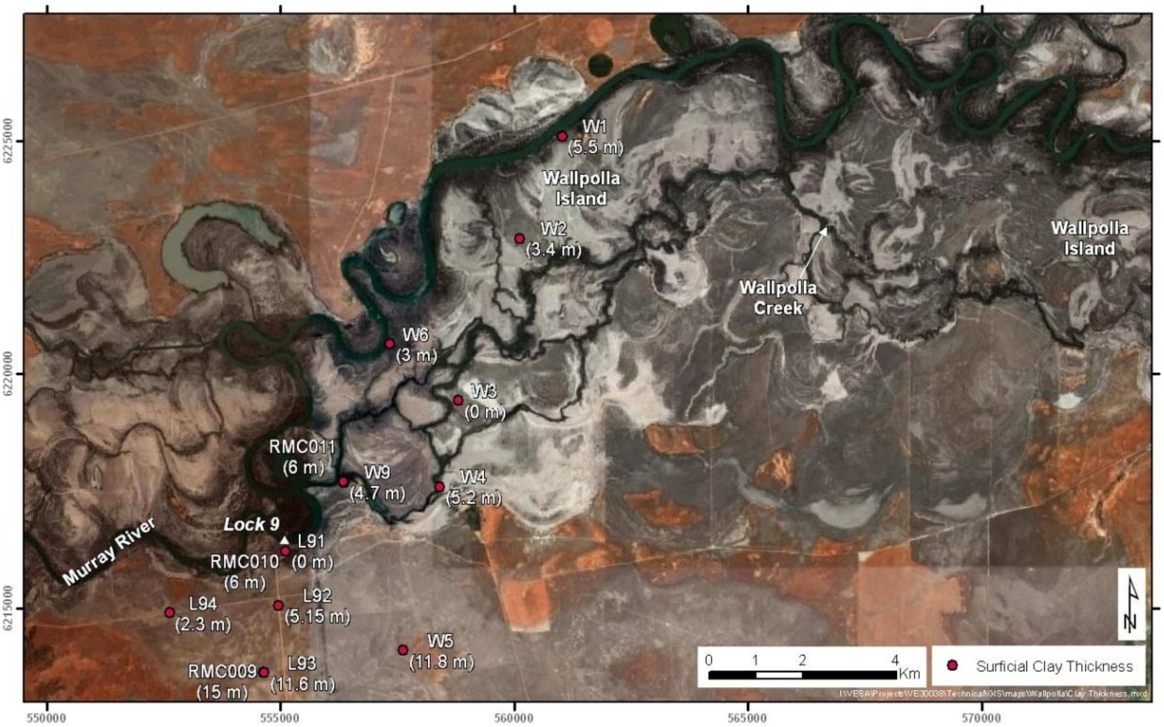
Recent (Feb-May 2012) groundwater elevation data indicates that groundwater levels in some areas of the floodplain have risen by up to 4 m since 2009, and is now at levels around 1 to 2 metres higher than seen in the 1990s in the central part of the Wallpolla floodplain (7901, 7902). Greater frequency of groundwater level measurement may allow a more precise estimate of change in groundwater level due to higher flow.

Summer 2012 groundwater elevation data shows that groundwater level in the Channel Sands ranges from >27 mAHD in the east of the Island (Bore site 4D) to >25 mAHD immediately south of Lock 9. The weir pool water level above Lock 9 is 27.4 mAHD. This infers a steep hydraulic gradient from the River to the Channel Sands aquifer in this area, creating potential for flow of groundwater from the upper weir pool (and lower Wallpolla Creek) to the floodplain and the Murray River down-gradient of Lock 9. The data also indicates that groundwater is probably not discharging directly to the Lock 9 weir pool, rather, if groundwater does discharge, it will be by flow to the very lowest reaches of Wallpolla Creek adjacent Lock 9.

SKM (2008a) reported depth to groundwater of between three to five metres at the western end of the Wallpolla Island floodplain, corresponding with the areas of highest groundwater salinity. The depth to groundwater appears to increase heading away from the Murray River and to the west. This is supported by Feb-May 2012 monitoring records with depth to water of 4.5 mbgl in the west (Bores REM026 and REM027) and 3-5 mbgl in the east (groundwater monitoring sites 4A-4D).

High flow events occurred in the Murray River system between 2010-2012 (Figure 3.6, Lock 9 downstream flow) and consequently through Wallpolla Creek. It is difficult to establish if (or when) groundwater flow patterns have changed over this time due to the infrequent groundwater level monitoring at a reduced number of bores. It is anticipated that watering events and increased stream flows would have induced recharge to the Channel Sands aquifer as a result of the increased hydraulic gradient, but the degree of change cannot be estimated.

Groundwater flow in the Channel Sands to the south-west of Wallpolla Island appears to follow regional flow from east to west (SKM, 2008a). Further north closer to the River, floodplain processes dominate, with flow direction interpreted to be towards the centre of the floodplain from the Murray River and from the east of the floodplain. April 2009 groundwater levels indicate a generally lower groundwater level through the centre of the floodplain (e.g. 24.2 mAHD, Bore 7901 and 25.2 mAHD, Bore 7903). The most recent groundwater level records (March 2011) indicate groundwater levels across the central floodplain have since risen (28.24 mAHD, Bore 7901).



- **Figure 3.8 Surficial clay thickness in bores on western Wallpolla Island (SKM, 2008a)**

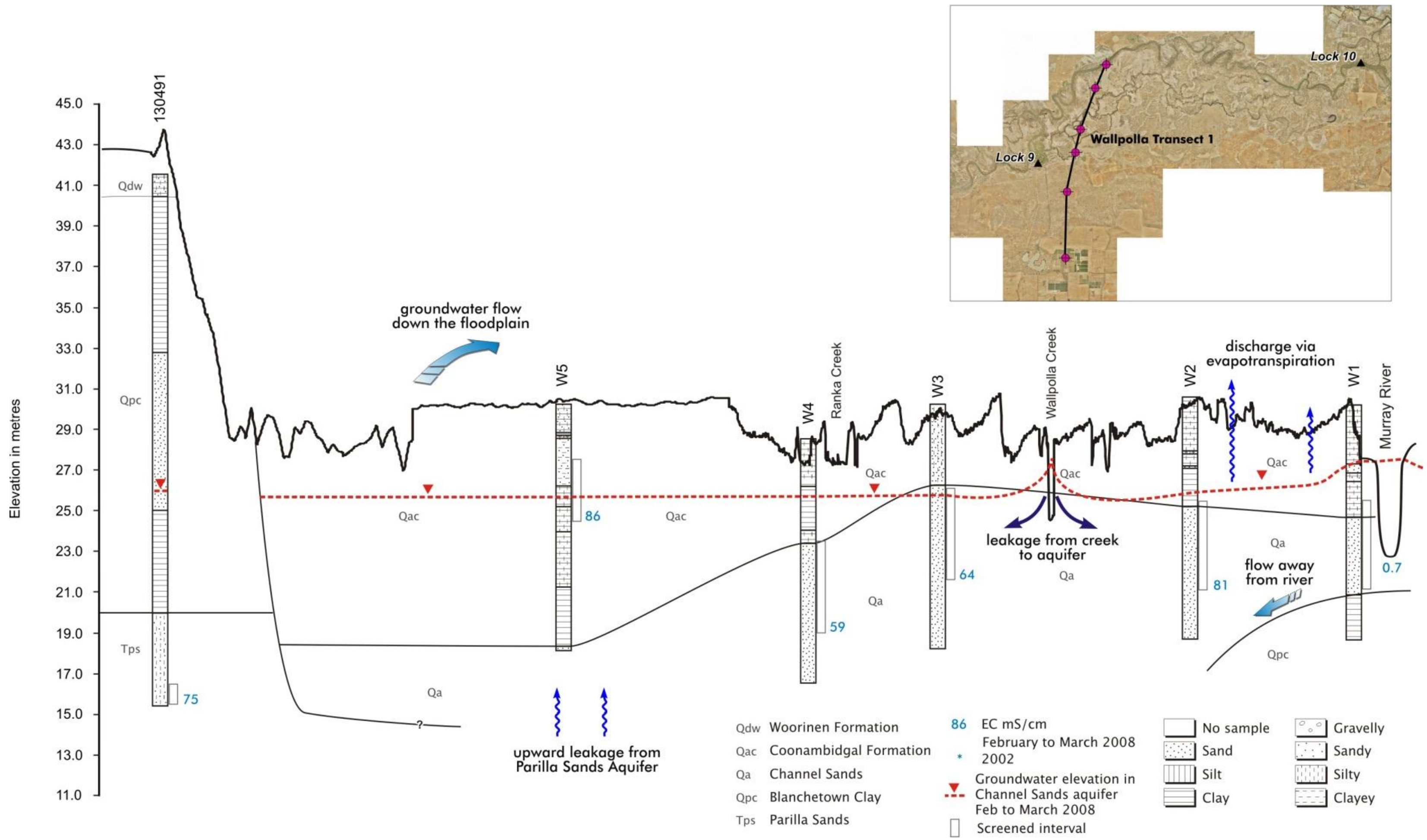


Figure 3.9: Hydrogeological cross-section through western Wallpolla Island under 2008 conditions (SKM, 2008b)

- **Figure 3.10: Current monitoring across Wallpolla Island**

3.2.3. Groundwater salinity

Salinity time series data for selected monitoring sites across Wallpolla Island is presented in Figure 3.11. This indicates that groundwater salinity through the centre of the floodplain varies significantly. Time series records for Bore 7901 and 7903 (located > 2 km apart) show quite different trends (Figure 3.11).

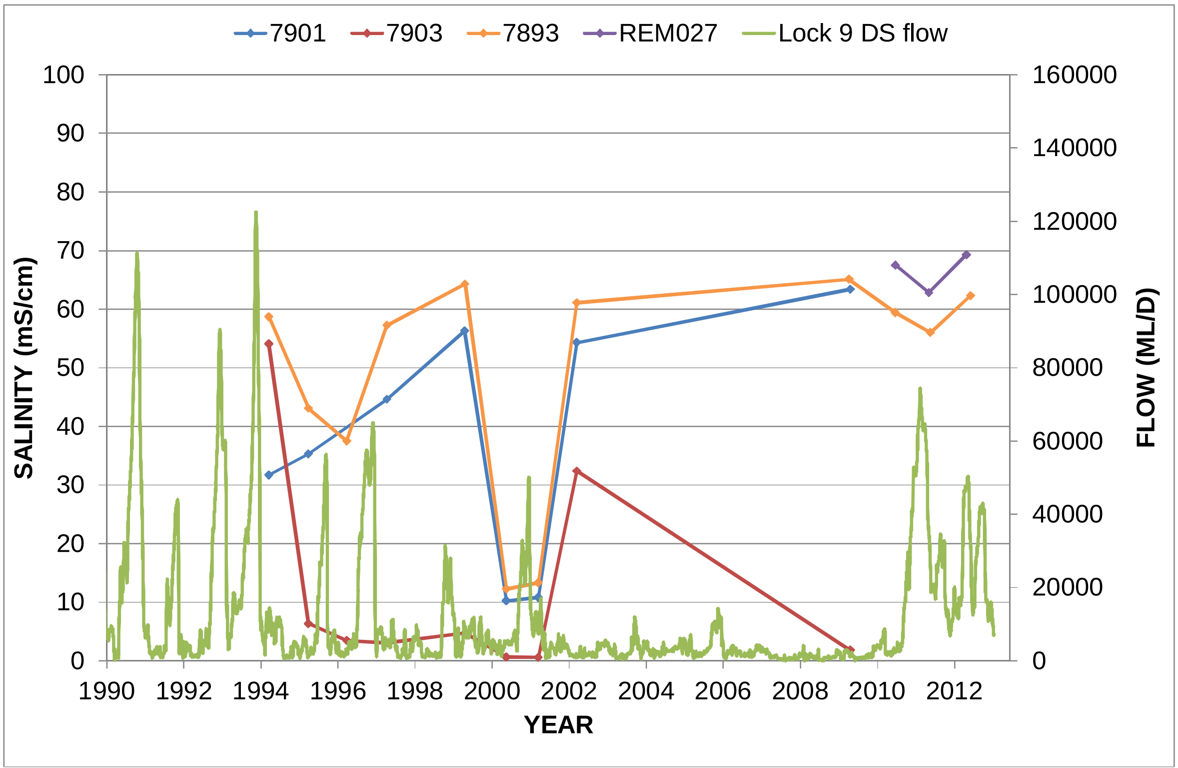
Lowest groundwater salinity was observed during the 2000-2002 period. Post 2010, the same trend in salinity has been observed to the east of the floodplain (Bore 7893) and in the west (REM027).

The high salinities in Bore W3 and Bore W4 adjacent to Wallpolla Creek (see Figure 3.9 for location and salinity levels) compared with the salinities further away from the Creek, indicate that the Creek is not losing a significant volume to groundwater to these locations, despite the head difference of almost two metres between surface water and groundwater (SKM, 2008a). The low salinities adjacent to the Murray River and in Bore W9 (see Figure 3.10) indicate losing conditions (SKM, 2008a). However, salinity in bore 7903, which is adjacent to Wallpolla Creek in its mid-reaches, is substantially fresher than for bores further from the Creek. This indicates that at this site, Wallpolla Creek loses water in substantial quantities. The conclusion from this discussion is that the connection between Wallpolla Creek and the shallow groundwater is complex and changes over small distances.

SKM (2008c) mapped groundwater salinity contours across Wallpolla Island (Figure 3.12) at a macro level. The salinity contours for the Channel Sands aquifer show generally saline conditions across the floodplain with the exception of zones of low salinity groundwater adjacent to the Murray River and Horseshoe Lagoon.

Bores around Wallpolla Creek on the eastern part of the Island show fresher groundwater salinity suggesting that some anabranches and streams act as local recharge sources to the Channel Sands aquifer (SKM, 2008c)

Salinities measured in Feb-Apr 2012 are also shown with the 2008 interpretation (Figure 3.12) and indicate a similar salinity distribution to that mapped in 2008.



- **Figure 3.11: Wallpolla groundwater salinity and Lock 9 downstream flow. See Figure 3.10 for bore locations**

An aerial electromagnetic (AEM) survey was undertaken during Feb-March 2008 (BRS, 2009). An AEM depth slice (as apparent bulk electrical conductivity) averaged over the upper 5 m of saturation in the shallow aquifer is shown in Figure 3.13.

The AEM data infers that a lower salinity zone exists either side of the Murray River and along selected reaches of Wallpolla Creek. These lower salinity areas are representative of zones where there is localised recharge to the groundwater system through the river banks, and the process is consistent with previous conclusions about the complexity of the interactions between the Creek and groundwater.

- **Figure 3.12: Groundwater salinity contours (SKM, 2008c)**

- **Figure 3.13: Wallpolla Island average apparent bulk electrical conductivity for a 5m interval immediately below ground surface**

3.2.4. Groundwater – surface water interaction

The location and magnitude of the salinity impact depends in part of the degree of connection between the shallow floodplain aquifer, and the Murray River and anabranches. Greatest impacts are possible where the surface water system gains groundwater. This section provides a summary of the nature of the connection based on existing information.

Where groundwater levels are higher than surface water heights, river reaches are defined as potentially *connected – gaining* systems. Where groundwater elevations are lower than surface water elevations, river reaches are defined as potentially *connected – losing* systems. Where anabranches are permanently inundated and groundwater elevations are lower than the base of the river bed, river reaches are also defined as potentially *connected – losing* systems.

There are no stream gauges located on Wallpolla Creek (or anabranch systems) so it is not possible to make an accurate comparison between current groundwater and surface water levels. As such, a comparison can only be made with reference to creek bed elevations estimated from LiDAR to classify systems as connected or not connected.

Bain (2007) developed cross-sections showing the bed elevation of Wallpolla Creek from Dedmans Creek down to the Murray River Junction. Three boreholes (W3, W4 and W9) were drilled adjacent to Wallpolla Creek towards the confluence with the Murray River (Figure 3.8 to Figure 3.10). The observation wells are located on the southern side of Wallpolla Creek, upstream from the confluence with the Murray River.

The bed elevation data indicates that Wallpolla Creek is relatively deep just upstream from the Murray River confluence and for the first 2 km upstream; the thalweg is interpreted to be below the base of the Coonambidgal Formation (SKM, 2008a). Therefore, the potential for hydraulic connection with the underlying Channel Sands aquifer is high. This is supported by the salinity in borehole W9, which is relatively low at around 7 mS/cm. For the next few kilometres upstream, the potential for connection with the Channel Sands is reduced as the creek is shallower and the bed is more likely to be in the Coonambidgal Formation. However, there was no record of surficial clay at W3 and inspection of aerial photography indicates the presence of a series of point bars in this area. It is likely that the absence of surficial clay at this location is indicative of the variability of the alluvium across the floodplain. Further upstream, at W2, the Coonambidgal Formation is 3.4 m thick. Given the potential for variability, it is likely there are other reaches further upstream from W3 where the surficial clays are absent.

2008 standing water levels in all of the observation wells at the western end of Wallpolla Island indicate that the Murray River and anabranches such as Wallpolla Creek are likely to be losing to groundwater from Dedmans Creek down to Lock 9 (SKM, 2008a). This is supported by most salinity measurements taken from observation wells W1 (0.6 mS/cm) and W6 (0.2 mS/cm) adjacent to the Murray River and also by the salinity in W9 (7 mS/cm) adjacent to the lower Wallpolla Creek. However, salinities in W4 (59 mS/cm) and W3 (64 mS/cm) further up Wallpolla Creek are much higher and do not indicate that the creek is losing to the floodplain groundwater (SKM, 2008a).

SKM (2008a) assessed groundwater discharge to Wallpolla Creek for the length of the Creek downstream of Dedmans Creek (downstream Wallpolla Mid inundation area). Here modelled creek water levels were used as a best estimate of current conditions. Results showed that groundwater levels were above bed elevation, but below surface water level hence *connected–losing* conditions prevailed.

SKM (2008c) mapped the nature of surface water–groundwater interaction for the Wallpolla floodplain (Figure 3.14) using 2008 groundwater elevations, surface water stage heights and bathymetric data, where available. Under 2008 conditions, it was interpreted that Murray River and Wallpolla Creek (and anabranches) are connected with and losing to the groundwater system in dry conditions (SKM, 2008c).

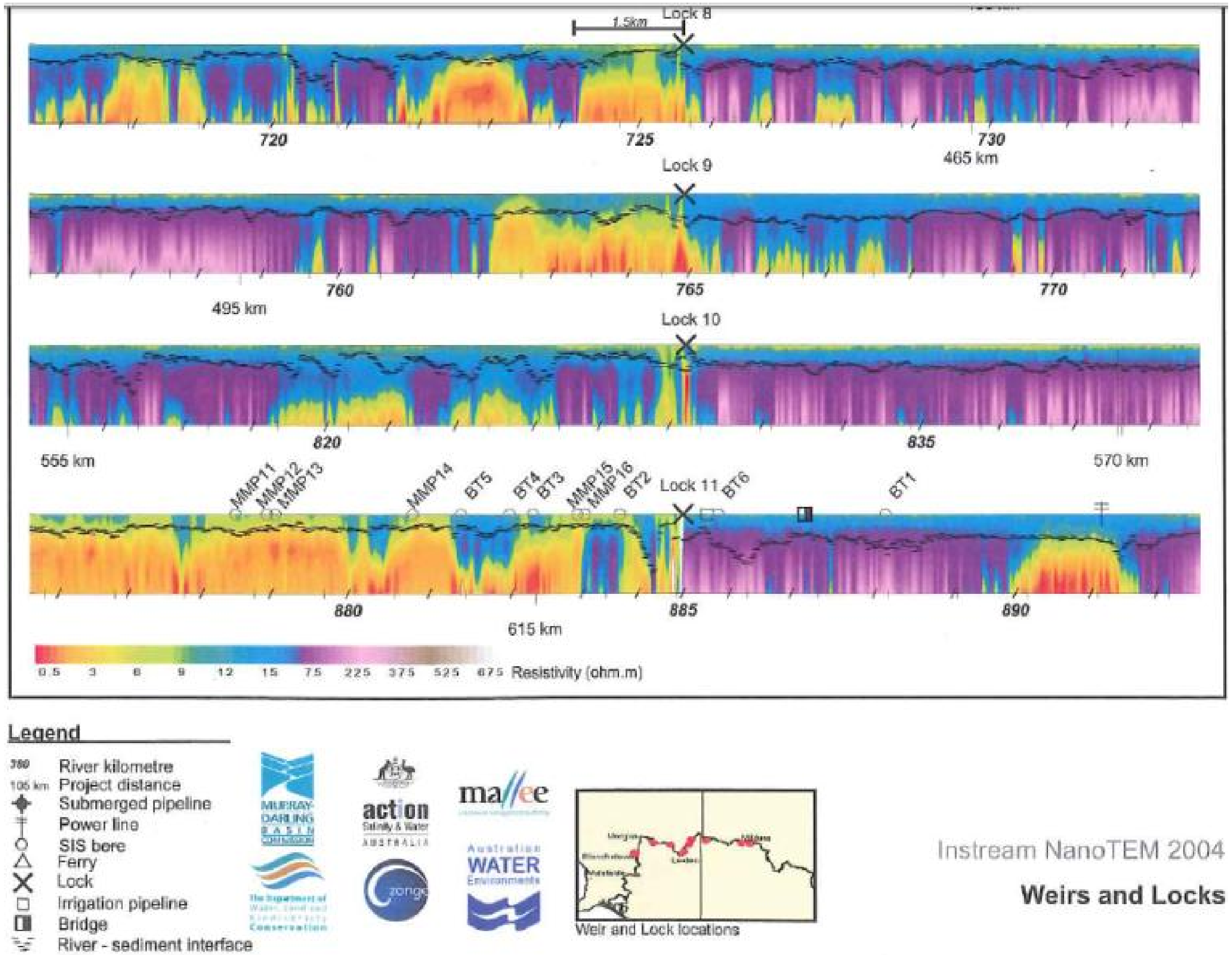
Recent monitoring data suggests potential variability in the nature of groundwater – surface water connection. For example, Bore 7903 measured a groundwater level in the Channel Sands of 25.4 mAHD (April 2009) and 28.94 mAHD (March 2011), compared to a bed elevation in Wallpolla Creek of 28.9 mAHD. The latter groundwater level is within the likely capillary fringe zone, hence high potential for connection remains.

Stage height in Wallpolla Creek would need to be quantified to accurately assess the nature of connection between surface water and groundwater level in the Channel Sands.

For this assessment, Wallpolla Creek is therefore conservatively assumed to be in connection with the groundwater in the Channel Sands aquifer.

The 2004 NanoTEM (Telfer *et al*., 2004; Figure 3.15) survey shows vertical profiles displaying the resistivity data collected along the Murray River. Low resistivities (red to yellow) indicate areas that are conductive, (that is, they are interpreted to hold saline water and/or be composed of clay). The resistive areas (blue through purple) are interpreted to be generally fresh water in sands (Telfer *et al*., 2006). For Wallpolla Island, the NanoTEM indicates that that the vertical profile is quite resistive indicating generally fresh groundwater inferring predominantly losing conditions. Typically, the area immediately downstream of the Locks has a low resistivity. This is particularly evident downstream of Lock 10, where this extends for a 10 km stretch of River.

- **Figure 3.14: Interpreted gaining and losing reaches (SKM, 2008c)**



- **Figure 3.15: Vertical profile of 2004 Nano TEM survey along Murray River**

3.3. Environmental works and measures

Alluvium (2013) outlined potential areas that may benefit from inundation and flow control (presented in Figure 3.16 and summarised in Table 3.1). The associated works and measures related to their inundation are discussed below. This includes four focus areas – Wallpolla Lower, Mid, Upper and South. Wallpolla Lower comprises two individual locations; one associated with Lock 9 weir pool manipulation (+/- 0.5 metres), the second associated with the use of regulators on the western boundary of Wallpolla Mid inundation area.

A schematic of the key water levels on the floodplain is presented in Figure 3.17.

(Note that since the analysis reported in Sections 3.3 to 3.5 was undertaken, the works and measure for Wallpolla Island Mid, Upper and South options have been slightly modified. The values and figures shown in in these sections are the original inundation areas, volumes and top water levels available at the time of analysis and are those used in the potential salinity impact assessment, unless otherwise stated. The inundation parameters have since been updated from analysis of Wallpolla Island options by Water Technology (2014a, b) and GHD (2014). The updated values are included in Table 3.2 below and have been used in time series analysis in Section 10. Appendix F presents the updated inundation mapping from Mallee CMA (2014).)

3.3.1. Wallpolla Lower

This option proposes the installation of two regulators between Wallpolla Mid and Lower, along with manipulation of water levels in Lock 9. Water levels in Lock 9 may be lowered to provide flowing habitat or raised to provide additional inundation (additional area inundated: 193 ha associated with the use of Regulators W1 and W2 (Alluvium, 2013).

3.3.2. Wallpolla Mid

This option proposes the installation of a major regulating weir (Structure 1) on Wallpolla Creek (retain water), a major weir at Finnigans Creek (inlet), plus other levees (a total of 10 kms), culverts (seven) and other minor works. This option would be operated to a top water level of 31.0 m AHD. Natural watering is proposed for this site: some inundation would occur at Murray River flows of 20,000 ML/day, full watering would occur at Murray River flows of 70,000 ML/day (Alluvium, 2013). This option would inundate an area of 3,292 ha; 2,622 ha more than a pre-works event of 70,000 ML/day, and would require a total water volume of 29.9 GL to fill (Alluvium, 2013).

3.3.3. Wallpolla Upper

This option proposes the installation of a weir/regulator (Structure 4) on Wallpolla Creek to retain water in the area, along with other minor weirs, levees and culverts. This option would be operated to a top water level of 32.0 mAHD. Environmental watering will be achieved via pumping (temporary infrastructure). Natural watering can also occur at Murray River flows above approximately 50,000 ML/day, full watering would occur at Murray River flows of 70,000 ML/day.

This option would inundate an area of 804 ha, 612 ha more than a pre-works event of 70,000 ML/day and would require a total water volume of 6.4 GL to fill (Alluvium, 2013).

3.3.4. Wallpolla South

This option proposes the operation of pumps (temporary) to pump water from Wallpolla Mid (31.0 m AHD) to Wallpolla South (to a top water level of 32.0 m AHD). Minimal works are required (temporary sand bags at one site) and water will naturally drain back to Wallpolla Mid. This option will inundate an additional area of 668 ha with no additional water use (Alluvium, 2013).

- **Table 3.1: Summary of Wallpolla Island environmental watering options and outdated inundation parameters, used in potential salinity impact assessment**

Option	Filling Method	Dependencies	Volume to fill*	Top water level (m AHD)	Area inundate (ha)
Wallpolla Island – Lower	Gravity	Water level in Lock 9	N/A	N/A	Lock 9 raised (0.5 metres)– 432 Lock 9 lowered (0.5 metres)– n/a
	Gravity	Wallpolla Island – Robsons Road	N/A	N/A	193
Wallpolla Island – Mid	Pumping	Nil	29.9 GL^	31.0^	3,292^
Wallpolla Island - Upper	Gravity	Murray River water levels	6.4 GL^	32.0	785^
Wallpolla Island - South	Pumping	Wallpolla Island – Mid	Nil^	30.6	668

Notes: * Excludes losses

^ These values have since been updated – refer below.

- **Table 3.2: Summary of Wallpolla Island environmental watering options and UPDATED inundation parameters, used in real time analysis**

Option	Filling Method	Dependencies	Volume to fill*	Top water level (m AHD)	Area inundate (ha)
Wallpolla Island – Lower	Gravity	Water level in Lock 9	N/A	N/A	Lock 9 raised (0.5 metres)– 432 Lock 9 lowered (0.5 metres)– n/a
	Gravity	Wallpolla Island – Robsons Road	N/A	N/A	193
Wallpolla Island – Mid	Pumping	Nil	10,738 ML^	30.0^	1,019^
Wallpolla Island - Upper	Gravity	Murray River water levels	910 ML^	32.0	861^
Wallpolla Island - South	Pumping	Wallpolla Island – Mid	3,416 ML^	30.6	688

Notes: * Excludes losses

^ These updated values differ from values used in potential salinity impact analysis when Sections 3.3 to 3.5 were written. Values are from Water Technology 2014a, b, and GHD 2014 (inundated areas only).

3.3.5. Watering regime

Documentation of options provided for this project did not provide discussion on water regimes, and minimal discussion on watering requirements. Table 3.3 details likely timing and frequency of inundation events as outlined by Mallee CMA. For the purpose of this assessment, calculations have been based on watering events commencing in October.

- **Table 3.3: Proposed Wallpolla Island watering regime**

Option	Inundation frequency	Timing	Inundation duration (months)
Wallpolla Lower	7 in 10 years	Spring/Summer/Autumn	6 2 (raising Lock 9)
Wallpolla Mid	5 in 10 years	Spring/Summer/Autumn	5
Wallpolla Upper	4 in 10 years	Spring/Summer/Autumn	3

Option	Inundation frequency	Timing	Inundation duration (months)
Wallpolla South	4 in 10 years	Spring/Summer/Autumn	3

3.4. Potential salinity impacts

3.4.1. Approach

The in-river salinity impacts (at Morgan in South Australia) potentially caused by the proposed actions at Wallpolla Island were assessed relative to a *basecase* scenario. The *basecase* is represented by current regulated conditions where the Lock 9 weir pool (held at 27.4 mAHD) allows significant permanent flow to the lower reaches of Wallpolla Creek and its tributaries.

The existing hydrogeological conceptual model for Wallpolla Creek floodplain suggests that under the *basecase* there is little groundwater flow to the River and anabranch system (i.e. mainly losing river conditions prevail).

The approach to the assessment requires conversion of salt load to EC at Morgan described in Fuller & Telfer (2007), with resultant EC impacts at Morgan (determined using the Ready Reckoner) reflecting the impact of an operation over the 25 year Benchmark Period and the time of year the salt load occurs.

The scenarios to be tested are summarised in Table 3.4. This also contains a summary of the key floodplain processes relevant to the watering action as well as a proposed assessment method. Greater detail on these aspects is provided in the following section.

The approach allows for the incremental salt impact of each option to be assessed. The cumulative effect, in a spatial rather than temporal sense, is taken to be the sum of salt impacts across all watering actions.

Appendix A contains details of the steps in the impact analysis undertaken, while Appendix B contains tables all the input data used in calculations.

- **Figure 3.16: Wallpolla Island environmental watering locations (Note that the inundation extents for Wallpolla Mid and Upper options are OUTDATED on this plan. Refer to Appendix F for updated extents.)**

- **Figure 3.17: Wallpolla Island schematic of operating levels (Note that the top water level for Wallpolla Mid option is OUTDATED on this plan. Refer to Table 3.2 for updated values.)**

3.4.1.1. Identifying salt discharge processes

The conceptualisation of the hydrogeological setting described in previous sections was used to identify processes and areas believed to be at greater risk of causing increased salt load to the river, bearing in mind the proposed actions and associated floodplain processes involved.

This involved consideration of the:

- Potential for recharge to groundwater; taking account of surface geology and depth to groundwater level in the Channel Sands;
- Potential for increasing groundwater hydraulic gradients and hence increased discharge;
- Potential for salt mobilisation from bank storage, previously dry creeks and wetlands, and previously disconnected backwaters;
- Potential for mobilisation of salt from in-channel sources; and
- Proximity of the inundated areas to the receiving water courses.

3.4.1.2. Impact on floodplain processes and approach to analysis

The works and measures proposed at Wallpolla Island will result in areas of the floodplain being inundated with water. Watering sites will be gravity fed to a top water level elevation of 31.0 mAHD (Wallpolla Mid), 32.0 mAHD (Wallpolla Upper) and 30.6 mAHD (Wallpolla South). The top water level was not reported for Wallpolla Lower.

Key assumptions used regarding the Wallpolla Island operation are:

- Designed to inundate approximately 625 ha (Wallpolla Lower- combination of raising Lock 9 and Robsons Road inundation), 3,290 ha (Wallpolla Mid), 785 ha (Wallpolla Upper) and 668 ha (Wallpolla South);
- Operation initially 4 in 10 years (Wallpolla Upper and South), 5 in 10 years (Wallpolla Mid) and 7 in 10 years (Wallpolla Lower);
- Timed to commence in Spring (October); and
- Total duration of operation assessed to be between 3 and 6 months of inundation.

The following salt mobilisation processes are relevant to each stage of the inundation process:

<u>During the fill stage</u>

- Wash-off of salt from floodplain soils;
- The salt held in the river channel and mobilisation of salt in previously stranded backwaters to be held in the in-stream store up gradient of the environmental regulators; and

- Inflow of saline groundwater in surface water features down gradient of the environmental regulator because surface water flow in these downstream areas is likely to be lower during operation of the environmental regulator.

<u>During the hold stage</u>

- Inundation of the floodplain areas and recharge to the underlying shallow saline groundwater within the floodplain aquifer, creating groundwater mounds beneath inundated areas; and
- Lateral outflow from filled anabranches to the floodplain aquifer.

<u>During the spill/evaporation stage</u>

- Lateral inflow of groundwater to the anabranches on the recession;
- Displacement of saline groundwater to the river and anabranch reaches on the recession where mounded groundwater levels remain higher than surface water levels; and
- Release of the in-stream store within the Wallpolla Creek system of saline water created during the fill stage.

Fill Stage

The raising of the Lock 9 weir pool during the <u>fill stage</u> will result in increased surface flow to lower Wallpolla Creek and its tributaries (Ranka Creek, Moorna Creek and Willpenance Creek). Alluvium (2013) indicated that much of the Wallpolla Lower proposed site is already inundated under the current Lock 9 water level (27.4 mAHD). As such, there should be little difference in surface water levels between *basecase* conditions and that resulting from raising Lock 9.

Inundation for Wallpolla Lower (associated with Robsons Road) and Wallpolla South will occur following release from Wallpolla Mid regulators. The inundation water level (and hence the area of inundation) will depend on how long the regulators remain open and whether additional water is pumped to the site.

The use of regulators associated with Wallpolla Mid and Upper (i.e. Structure 1 and Structure 4) will result in increased surface flow to upper Wallpolla Creek and commencement of flow to any upstream tributaries which are dry under *basecase* conditions. For Wallpolla Mid, the area will be inundated to a level of 31.0 mAHD, approximately 2.1 m higher than the estimated (average) bed level in the adjacent stretch of Wallpolla Creek (28.9 mAHD). For Wallpolla Upper, the area will be inundated to a level of 32.0 mAHD, approximately 2–3 m higher than the estimated average bed level of the adjacent stretch of Wallpolla Creek (29-30 mAHD). Stage height in Wallpolla Creek is not known.

Surface flow at each site could result in salt wash-off from floodplain soils, and mobilisation of salt stored along creek beds into the main Wallpolla Creek channel.

Manipulation of the flow regime through the above actions could result in the mobilisation of salt from any in-channel stores during the fill stage when it would otherwise have been stored until flushed during a period of higher flow

The inundation of the floodplain will also cause some mobilisation from salt stored in floodplain soils.

ANALYSIS APPROACH – FILL STAGE
Historical flood data linking flows, the area of floodplain inundation and subsequent salt loads in the river post-flooding suggests a total salt flux of 38 kg/ha/day for Lindsay River (Mike Dudding, pers. Comm – reported by SKM (2010a)). Of the total salt flux, the proportion due to wash-off is thought to be approximately 10%; thus reducing the salt flux for this process to 3.8 kg/ha/day. In addition, values of 1 and 5 kg/ha/day were derived during the calibration of a real time salt and water balance model for Chowilla (SKM, 2010b). These salt flux rates are typical of locations downstream of Wallpolla Island; as such these are considered representative only for this assessment.
The magnitude of the salt load associated with lower surface water flow down gradient of the regulator is not considered significant relative to other processes and is not quantified.

Hold Stage

Once the target water level is reached within each structure/project, the water will be held on the floodplain by flow control structures. During the hold stage there will be a continuation of lateral and vertical outflow (infiltration) of surface water to the floodplain aquifer that began in the fill stage.

Using a conservative approach, it may be assumed that during inundation of the floodplain, surface water features are in connection with the underlying Channel Sands aquifer.

Under this assumed connection between surface water and groundwater (*connected – losing*) across Wallpolla Island, water stored in the river banks could mix with saline groundwater that may be released back to the River in the spill stage (on the recession).

Raising the Lock 9 weir pool will increase the hydraulic gradient around Lock 9 to the Murray River downstream of Lock 9. A corresponding increase in the flux of groundwater and associated salt load to the downstream channel is likely.

There is the potential for diffuse recharge to the Channel Sands aquifer beneath the environmental watering sites. The rate of infiltration across the floodplain will vary depending on clay content of soils. Usually the clayey parts of the Coonambidgal Formation limit infiltration (for example, measurement of chloride profiles across Chowilla Floodplain before and after floods has shown little movement of salt within heavy clay, indicating low recharge) but infiltration would be greater in sandy zones. There will be greater recharge through creek beds where they cut into the Channel Sands.

Overton and Jolly (2004) estimate a recharge rate of 1 mm/day through floodplain soils at Chowilla when the typical floodplain soils are saturated. However, SKM (2002) required a lower recharge rate (0.03 mm/day) to calibrate a groundwater model of Lindsay Island. A value of 0.5 mm/day is chosen for this assessment to be consistent with previous assessments of salinity impacts in the region (e.g. SKM, 2008).

Under *basecase* conditions, it is assumed that there is some groundwater flow towards the lower reaches of Wallpolla Creek beneath the western floodplain and then to the Murray River below Lock 9. The large area of inundation proposed (in particular Wallpolla Mid) could, over successive events, increase groundwater levels in this area to increase the hydraulic gradient (potentially creating gaining conditions), where saline groundwater is displaced towards Wallpolla Creek, its tributaries and ultimately to the Murray River. However, no surface water level monitoring occurs on Wallpolla Creek. This means it is not possible to accurately define the level of groundwater level rise necessary to induce discharge to the Creek. In addition to EC impact at Morgan, this increased salt load also has the potential to impact any irrigators that rely on surface water diversions. This was therefore highlighted for further investigation.

Groundwater salinity varies significantly across Wallpolla Island, as evident in the salinity contours and AEM coverage presented previously. For example, groundwater displaced to the River is quite fresh, while groundwater monitored in Bore 7901 (located centrally to Wallpolla Mid) had a reported groundwater salinity of 63.4 mS/cm (April, 2009). Similarly, at Wallpolla Upper, current (2012) salinity values range between <1 to 60 mS/cm. Multiple salinity values will be used in calculations to capture the varying groundwater salinity that may be discharging to Wallpolla Creek. The Murray River downstream of Lock 9 will be the receiving environment.

ANALYSIS APPROACH – HOLD STAGE.

A flow net will be used to estimate the groundwater flux induced by the head difference across Lock 9, and around the off takes from the Lock 9 weir pool to Wallpolla Creek.

The rate of recharge to the shallow groundwater system is estimated to be 0.5 mm/day, based on analysis of recharge rates by REM (2006) and previous work by CSIRO on the Chowilla floodplain (refer SKM, 2010). This rate of recharge is assumed to include the volume of water that recharges the aquifer laterally.

If the waterbody is connected to groundwater (that is, underlain by fully saturated material) then a mass balance approach can be used to estimate the total volume of groundwater that may eventually discharge to the surface water system (assuming some is lost because of evapotranspiration). If the waterbody is underlain by an unsaturated zone above the groundwater level then there is a need to estimate the rate of rise and fall of groundwater levels using a method from Hantush (1967). If the groundwater level is estimated to rise above the surface water level then the rate of discharge to a river reach can be calculated using a flow net analysis.

Spill & Evaporation Stage

Salt that has accumulated in-stream during the fill stage will be released during the spill stage.

If it is conservatively assumed that Wallpolla Creek and the groundwater level in the Channel Sands are in connection, then once surface water levels decline in Wallpolla Creek and major tributaries, there will be potential for the inflow of saline groundwater to the anabranch system that is derived from the following processes that occurred during the hold stage:

- Diffuse recharge and groundwater level mounding; and
- Lateral outflow from anabranches to the Channel Sands aquifer.

Floodplain groundwater levels are lower now than during the 1990s due to lack of floods to recharge the groundwater system such that the anabranch system is losing water to the underlying aquifer. A number of inundation events will be required at a frequency similar to 1980 to 1990 flows before groundwater levels return to their former heights. At this time groundwater discharge to surface water features may again be possible.

For the purpose of this analysis it is conservatively assumed that immediately on the cessation of the hold stage 100% of the recharged water (on a monthly time step) will eventually return to the receiving feature (in this instance Wallpolla Creek and anabranch system). As the water held in the feature diminishes, the percentage return to Wallpolla Creek at each time step in the analysis is assumed to diminish at a set rate to mimic the fall in groundwater gradients and consequent decline in groundwater discharge. This process occurs over a 12 month period at which time all discharge ceases.

In reality, the volume of groundwater discharged maybe lower than 100% of recharge if water is lost to evapotranspiration. It is likely that evapotranspiration is a major component of groundwater discharge in these floodplain environments, however, it has not been accounted for in the assessments below. In some cases evapotranspiration may account for all groundwater discharge and in these cases the long term sustainability of the environmental assets must be questioned.

The percentage discharged under current conditions is likely to be much lower because of poor connection with the river system (that is, groundwater levels lower than receiving features) and a significant width of the floodplain leading to increased opportunity for evapotranspiration.

Wallpolla South inundation area is located 3.5 km south of Wallpolla Creek and is therefore unlikely to have a significant salinity impact due to the distance between the site of recharge and discharge and the likely impact of evapotranspiration.

ANALYSIS APPROACH – SPILL AND EVAPORATION STAGE

The mass of salt released from in-stream storage in the spill stage is calculated under current conditions. A nominal 100 EC difference will be adopted between upstream and downstream surface water salinity. These EC values are multiplied by an assumed in-stream water volume to estimate salt load.

The salt load from wash-off is calculated using the approach described in the fill stage.

The volume of recharge to the groundwater from a floodplain watering event displaces a lesser volume of higher salinity groundwater to the adjacent watercourse. If the recharge volume can be calculated, then a corresponding salt load to the river can be inferred. This is similar to the nomogram approach described in the Murray Darling Basin Commission (MDBC) Salinity Impact Assessment Framework for the Living Murray Environmental Works and Measures Program (Fuller & Telfer, 2007). It is expected this salt load will occur over a 12 month period following inundation.

It is assumed 100% of recharge is discharged to the river system during the period of inundation and it is also assumed this accounts for the groundwater that is discharged as a result of diffuse recharge via the floodplain aquifer. It is further assumed that the rate of discharge will fall in a decreasing manner from 100% immediately at the end of the inundation period to zero in month 12 following the hold stage. This decay in the rate of return of recharge water reflects diminishing area of inundation and diminishing hydraulic gradient to the surface water system.

- **Table 3.4: Floodplain process and analytical methods used for Wallpolla Island**

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
Wallpolla Lower inundated with raising of Lock 9 weir pool by 0.5 metre (27.9 mAHD) over 432 ha (plus 193 ha when W1 and W2 regulators are operating)	Surface salt wash-off Salt in surface water mobilised during draining of creeks Recharge of shallow saline groundwater and displacement of saline groundwater to Wallpolla Creek and anabranches	Surface flush estimated from assumed value of salt storage per hectare of floodplain. In –channel release of salt load Flow net analysis to estimate impact of raising Lock 9 weir pool. Mound build up estimated and flow net is used to estimated salt load from mound to Creek	Low	Limited bore data available to verify groundwater salinity, groundwater flow and response to recharge.
Wallpolla Mid. Inundate to a level of 31.0 mAHD over an area of 3,292 ha	Surface salt wash-off Salt in surface water mobilised during draining of creeks Recharge of shallow saline groundwater and displacement of saline groundwater to Wallpolla Creek	Surface flush estimated from assumed value of salt storage per hectare of floodplain. In –channel release of salt load Mass balance approach for the inundated area.	Low	Limited bore data available to verify groundwater salinity, groundwater flow and response to recharge.
Wallpolla Upper. Inundate to a level of	Surface salt wash-off Salt in surface water	Surface flush estimated from	Low	Limited bore data available to verify

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
32.0 mAHD over an area of 824 ha	mobilised during draining of creeks Recharge of shallow saline groundwater and displacement of saline groundwater to Wallpolla Creek	assumed value of salt storage per hectare of floodplain. In –channel release of salt load Mass balance approach for the inundated area.		groundwater salinity, groundwater flow and response to recharge.
Wallpolla South. Inundate to a level of 30.6 mAHD over an area of 669 ha	Surface salt wash-off Recharge of shallow saline groundwater and displacement of saline groundwater to Wallpolla Creek	Surface flush estimated from assumed value of salt storage per hectare of floodplain. Mound build up estimated and flow net is used to estimated salt load from mound to creek	Low	Limited bore data available to verify groundwater salinity, groundwater flow and response to recharge.

3.5. Results and discussion

(Note that these results use outdated inundation parameters for Wallpolla Mid, Upper and South options. Refer to Table 3.2 for updated values.)

3.5.1. Salt wash off

Estimated salt flux associated with the initial wash-off of salt was calculated for the maximum area of inundation excluding the areas of watercourse; Wallpolla Lower (193 ha), Wallpolla Mid (2,705 ha), Wallpolla Upper (639 ha) and Wallpolla South (669 ha). The calculation was undertaken assuming salt capture of 1, 3.8 and 5 kg/ha/day.

Estimates of salt load and EC impacts at Morgan are summarised in Table 3.5 for each process.

- **Table 3.5: Predicted salt load and EC impact at Morgan (relative to the *basecase*)**

Salt wash-off rate (kg/ha/day)	Salt load (t/d)	EC impact at Morgan
Lower (Rodsons Road only)		
1	0.19	0.0013
3.8	0.73	0.0048
5	0.97	0.0063

Salt wash-off rate (kg/ha/day)	Salt load (t/d)	EC impact at Morgan
Mid		
1	2.7	0.013
3.8	10.3	0.048
5	13.5	0.063
Upper		
1	0.64	0.0024
3.8	2.4	0.0090
5	3.2	0.012
South		
1	0.67	0.0025
3.8	2.5	0.0095
5	3.4	0.012

Key assumptions:

- Release of water occurs at a constant rate over a 30 day period in Spring (October);
- Instantaneous transfer of salt from the whole of the inundated area to Wallpolla Creek occurs (that is, reaches equilibrium within one day);
- There is no significant salt load delivered to Wallpolla Creek through salt wash-off under *basecase* conditions; and
- Salt flux rates of 1, 3.8 and 5 kg/ha/d are typical of downstream conditions (i.e. Lindsay and Chowilla floodplain). As such these are representative values only and the impact may well be less than indicated or may reduce over time with increased watering frequency.

3.5.2. In channel release

The magnitude of the salinity impact at Wallpolla Island due to transport of salt stored in the stream channel upstream of the regulators is proportional to the assumed difference in salinity upstream and downstream (100 EC). The channel geometry of Wallpolla Creek and anabranches was assumed to be 20 m wide and 5 m deep for the purpose of this assessment.

The EC impact at Morgan is calculated to be 0.07 (Wallpolla Lower), 0.05 (Wallpolla Mid) and 0.01 (Wallpolla Upper). While the process of in channel release for each individual area is not considered significant, the cumulative impact across the entire area would be considered significant (>0.1 EC).

Key assumptions:

- Release of salt to the system downstream of the regulator occurs at a constant rate over a 30 day period in Spring (October);
- Instantaneous transfer of salt occurs from the whole of channel system to Murray River;
- Conservatively assumed that all salt contained in the channel is released although some salt may remain in the channel under normal flow;
- The geometry of the channel along its length is assumed to be uniform and can be represented by a rectangular section that is 20 metres wide and 5 metres deep; and
- There is no significant salt load delivered to the Wallpolla Creek through salt wash-off for the *basecase*.

3.5.3. Floodplain inundation (recharge and displacement)

Floodplain inundation at Wallpolla Mid will be achieved by inundating to a top water level of 31.0 mAHD resulting in an area of inundation of 2,705 ha of floodplain. Inundation at Wallpolla Upper will be achieved by inundating to a top water level of 32.0 mAHD resulting in an area of inundation of 785 ha of floodplain.

A conservative estimate of the salt load and EC impact at Morgan is made assuming initially 100% of the recharged water is discharged to Wallpolla Creek and anabranches from groundwater during the period of inundation. The amount of diffuse recharge eventually discharging to Wallpolla Creek from Wallpolla Mid is assumed to gradually decline from 100% in the 5th month to zero in the 12th month following inundation. For Wallpolla Upper discharge to the Creek will be at 100% until the 3rd month as this site has a shorter duration of inundation.

Values of less than 100% for the amount of recharge that ends up discharging to the feature may be expected where evapotranspiration from groundwater occurs before it reaches Wallpolla Creek. Therefore, this conservative scenario may represent the cumulative effect of a series of induced and natural floods causing groundwater levels to rise in the vicinity of Wallpolla Island and creating gaining river conditions.

Groundwater salinity varies significantly across Wallpolla Island, as evident in the salinity contours and AEM coverage presented previously, ranging from fresh conditions along the Murray River to over 60 mS/cm across the floodplain. As such, multiple salinity values were used in the assessment as a way of providing an indication of the likely upper and lower values for discharge to Wallpolla Creek. Results are summarised in Table 3.6.

- **Table 3.6: EC impact at Morgan for varying groundwater salinities**

Location	1 mS/cm	5 mS/cm	60 mS/cm
Wallpolla Mid	0.19	0.95	11.4
Wallpolla Upper	0.03	0.15	1.83

Further assessment or modelling would be required to determine if/when higher salinity groundwater would potentially discharge into the Murray River. For the purpose of this assessment it is recommended that a salinity value of 5 mS/cm is used. The amount of salt potentially discharging to the river is constrained by the amount of salt that discharges from Wallpolla Creek historically. Historical Run of River surveys do not show any substantial salt signal immediately downstream of Lock 9, thus providing some sense of the likely magnitude of this process. That is, if groundwater of high salinity is in contact with Wallpolla Creek, one might expect that previous floods would have generated salt loads that were observable in the historical record.

Key assumptions:

- The recharge due to inundation would last 5 months (Wallpolla Mid) and 3 months (Wallpolla Upper);
- Saline groundwater will discharge to Wallpolla Creek for a 12 month period (based on observation of this process in other floodplains – e.g. Chowilla);
- The amount of diffuse discharge to the Creek will decline linearly at the end of the inundation period from 100% to zero;
- The salinity of groundwater discharging remains constant over this period;
- Groundwater salinity discharging to Wallpolla Creek is 5 mS/cm, but could increase over time following successive watering events;
- Recharge rate is uniform spatially and temporally in the area of inundation; and
- There is no significant salt load delivered to Wallpolla Creek through diffuse recharge and displacement of saline groundwater under the *basecase*.

3.5.4. Increased groundwater flux to Murray River around Lock 9

A flow net analysis was undertaken to assess the flux of groundwater around Lock 9 under *basecase* and after raising the weir pool level. For the analysis, it was assumed that along flow paths >1000 m in length (consistent with SKM, 2009), any flux in groundwater would be lost by evapotranspiration, meaning only paths of <1000m in length were considered in the assessment. Whilst evapotranspiration is likely to lower groundwater levels within this zone, a conservative approach is taken here, using a linear gradient between the upper and lower weir pools which likely over-estimates potential salt loads to the Murray River.

Along flow paths that were >1000 m in length, groundwater levels were assumed to have declined to *basecase* conditions due to losses to evapotranspiration, thereby generating no additional groundwater discharge and therefore salt load to the Murray River. This is consistent with approaches for assessment of salt load to the Murray outlined in the Salinity Impact Assessment Framework – Living Murray Works and Measures (Fuller & Telfer, 2007).

It was also assumed that the Murray River surface water level below Lock 9 was constant over time at 24.7 mAHD.

The flow net analysis indicated that raising the Lock 9 weir pool by 0.5 m (from 27.4 to 27.9 mAHD) would result in an increased flux of groundwater (~15%) from the upper to lower weir pool.

A salt load increase (from a *basecase* value of around 0.19 t/day) of 0.03 t/day for the period of raised weir pool levels was calculated, which is insignificant as the corresponding salinity impact at Morgan was calculated to be 0.002 EC.

Key assumptions:

- The gradient between upper and lower weir pool levels reaches a maximum value quickly and is maintained at the maximum value for the total period of operation (2 months) plus a further 100 days following completion of the spill stage (to allow for a slow relaxation of the gradient back to the *basecase*); and
- The salinity of groundwater discharging to the lower weir pool remains constant over this period (assumed to be 1 mS/cm).

3.5.5. Retention of water

For Wallpolla Lower (Robsons Road site) the starting groundwater level is assumed to be 24.2 mAHD (measured approximately 7 km to the north-east of the area; Bore 7901, March 2012). Groundwater mound rise calculations estimated rise in groundwater levels of 1.35 m (to 25.6 mAHD) after 300 days as a result of inundation of this watering area (top water level not reported).

For Wallpolla South, the starting groundwater level is assumed to be 28.65 mAHD (Bore 7911, March 2012) with an estimated rise of 2.07 m (to 30.7 mAHD) after 300 days as a result of filling this area to a level of 30.6 mAHD. This assumes that the groundwater level would be above the natural surface (LiDAR coverage not available for this site so cannot estimate likely surface elevation). As such, mound rise was conservatively capped at 30.4 mAHD for the flow net calculation.

It is assumed that the groundwater level beneath Wallpolla Island will fall at a constant rate for the following 300 day period.

The salt load from a mound beneath the watering sites to the Murray River is estimated based on the stage height in the River (27.4 mAHD). The bed level for the stretch of Wallpolla Creek adjacent Wallpolla Mid was estimated from LiDAR (28.9 mAHD), while Willpenance Creek adjacent Robsons Road had a bed level estimated to be 27.6 mAHD. Stage height information is not available for the creek systems. As this assessment is based on the creek bed elevation, these are likely to result in an over-estimate of EC impact at Morgan.

The flux of groundwater and salt load was estimated at 30 day time steps during the period of groundwater level rise and fall. Each monthly salt load was converted to an EC impact at Morgan. The salt load was calculated using a salinity value of 5 mS/cm for Robsons Road and Wallpolla South.

For Robson's Road, estimated mound rise was not large enough to raise groundwater levels above the estimated bed level in Willpenance Creek (27.6 mAHD)

For Wallpolla South, calculation show the salt load to Wallpolla Creek rises to a maximum value of 0.04 t/d after 300 days and the total EC impact at Morgan during the rise and fall of the mound is estimated to be 0.005 EC. However, given the distance between Wallpolla South and Wallpolla Creek (3.5 km) it is likely that a greater proportion of groundwater flux will be lost to evapotranspiration.

The salt load calculations were re-run assuming the starting groundwater level beneath Robsons Road is close to 1994 levels (27.7 mAHD) taken from Bore 7901. A flow net analysis estimates the salt load toward to the Murray River to reach a maximum of 0.001 t/d after 300 days with an impact of 0.06 EC at Morgan for Robsons Road.

For Wallpolla South, the 1992 groundwater level was less than current levels (27.09 mAHD) so EC impact at Morgan would be less than under the current scenario. These impacts are insignificant.

Key assumptions:

- The salinity of groundwater discharging to Wallpolla Creek remains constant over time;
- Groundwater levels due to mounding rise and fall at a constant rate over 300 days;
- The salt load for the '1990s case' was estimated assuming that groundwater levels beneath the inundation areas fall at a constant rate over the 300 days; and
- Groundwater salinity discharging to Wallpolla Creek is 5 mS/cm, but could increase over time following successive watering events.

3.5.6. Total salinity impact

The total salinity impact at Morgan of implementation of environmental watering at Wallpolla Island is estimated to be 0.07 EC at Morgan for Wallpolla Lower, 1.0 EC for Wallpolla Mid, 0.16 EC for Wallpolla Upper and 0.005 EC for Wallpolla South.

The components of the salt load and EC impacts relative to the *basecase* are summarised in Table 3.7. The largest component of the salinity impact is associated with the displacement of groundwater due to diffuse recharge following inundation. These calculations are considered conservative as they assume uniform salinity and that a significant percentage of the recharged water is returned the Murray River.

The analysis for Wallpolla Mid and Upper assumes that recharged water will return to Wallpolla Creek and if that is the case then the estimate of EC impacts must be made using groundwater salinity values near Wallpolla Creek. The available data is sparse creating significant uncertainty in these estimates.

The groundwater salinity contours indicates broad areas of high salinity groundwater. This is largely confirmed by the AEM coverage but the AEM also highlights some areas that may contain lower salinity groundwater along Wallpolla Creek. The analysis of EC impacts has been undertaken assuming a range in groundwater salinity values to highlight the level of uncertainty in this analysis.

While estimates of EC impacts can become very high if there is high salinity groundwater it is more likely the impact will be at the lower end of the range. Historically there haven't been large salt loads from the Lock 9 to Lock 10 reach indicating any future water events are likely to result in modest impacts.

- **Table 3.7: Summary of salinity processes and EC impact associated with Wallpolla Island**

Salinity process	EC impact at Morgan			
	Wallpolla Lower	Wallpolla Mid	Wallpolla Upper	Wallpolla South
Salt wash-off	0.005	0.05	0.009	0.001
Recharge and displacement	N/A	0.95	0.15	N/A
In-channel release[1]	0.07	0.05	0.01	N/A
Retention of water lake/wetland	Nil (Robsons Road) Nil (area north of	N/A	N/A	0.005

Salinity process	EC impact at Morgan			
	Wallpolla Lower	Wallpolla Mid	Wallpolla Upper	Wallpolla South
	Lock 9)			
Flow Net around Lock 9	0.002	N/A	N/A	N/A
TOTAL	**0.08**	**1.1** [2]	**0.17** [2]	**0.006** [2]

[1] Based on difference in river salinity of 100 EC

[2] These results use outdated inundation parameters. Refer to Section 3.3 for more information.

3.6. Cumulative impacts

It is expected that multiple watering events will occur at each site over time.

It is known that groundwater levels below the Wallpolla floodplain are lower now than during the 1990s when more frequent flooding occurred. It is also known from monitoring that the amount of salt within Wallpolla Creek that could be mobilised is lower now than in the 1990s. This suggests that the salt load impact of environmental watering may be less now than if it occurred under conditions representative of the 1990s. This is mostly because there would be more parts of the Wallpolla Creek system that operated as gaining reaches in response to groundwater at 1990s levels.

It is expected that successive watering events coupled with natural flood events could return groundwater conditions to that seen in the 1990s. This '1990s condition' can be viewed as being representative of the 'cumulative impact' of implementation of a large scale sequence of watering events, that is, it represents the maximum salt impact condition.

The ability to quantify the cumulative impact using the analytical approaches used in this project is limited.

The groundwater salinity across Wallpolla Island varies, with highly saline conditions experienced in the centre of the floodplain. This is supported by the 2008 groundwater contours, NanoTEM and AEM data where the majority of the floodplain is represented by highly saline groundwater. Only a narrow band of 'fresher' groundwater exists immediately adjacent the Murray River; hence discharge to the River will be of low salinity but that to Wallpolla Creek (and tributaries) will be considerably higher.

Should larger impacts occur with time, these may be offset by less frequent operation of each site and shorter duration of watering events.

3.7. Potential for flux of saline groundwater to wetlands or low lying areas

Groundwater levels adjacent to the Murray River can rise by up to 2 m in response to 30,000–40,000 ML/d floods (REM, 2007). This has the potential to displace groundwater toward low-lying areas of the floodplain near the Murray River. However, groundwater level responses to river flow and inundation rapidly diminish with distance from the Murray River and floodplain anabranches

It could also be expected that similar responses could be seen in shallow groundwater near inundated areas.

Attributes of low lying areas at risk from rising (or discharging) groundwater associated with inundation are:

- Relatively close to the inundated area (say within 500 metres);
- Shallow groundwater (less than 3 metres); and
- Saline groundwater (greater than 50, 000 EC).

The spatial coverage of the extent of inundation areas, groundwater depth (SKM, 2008c) and groundwater salinity (Figure 3.11) were combined to highlight areas where potential for discharge of saline groundwater is greater. These areas or 'hotspots' should be monitored closely as part of the monitoring program. The analysis indicates there are areas outside the area of inundation that could be affected (Figure 3.18).

3.8. Potential New South Wales salinity impacts

The potential mechanisms for delivery of salt load to the Murray River, from the NSW floodplain, due to raising the Lock 9 by 0.5 metres weir pool include:

- saline groundwater flow around (NSW side of) Lock 9 and towards low lying areas;
- saline groundwater inflow directly to the Murray River;
- saline groundwater inflow to anabranches;
- surface salt wash-off; and
- saline surface water inflow from backwaters on weir pool drawdown;

Saline groundwater flow around Lock 9 is discussed in Section 3.5.4 and this shows this process to result in negligible salt loads to the Murray River. Groundwater salinity upstream of Lock 9 is inferred to be relatively low (SKM, 2008d).

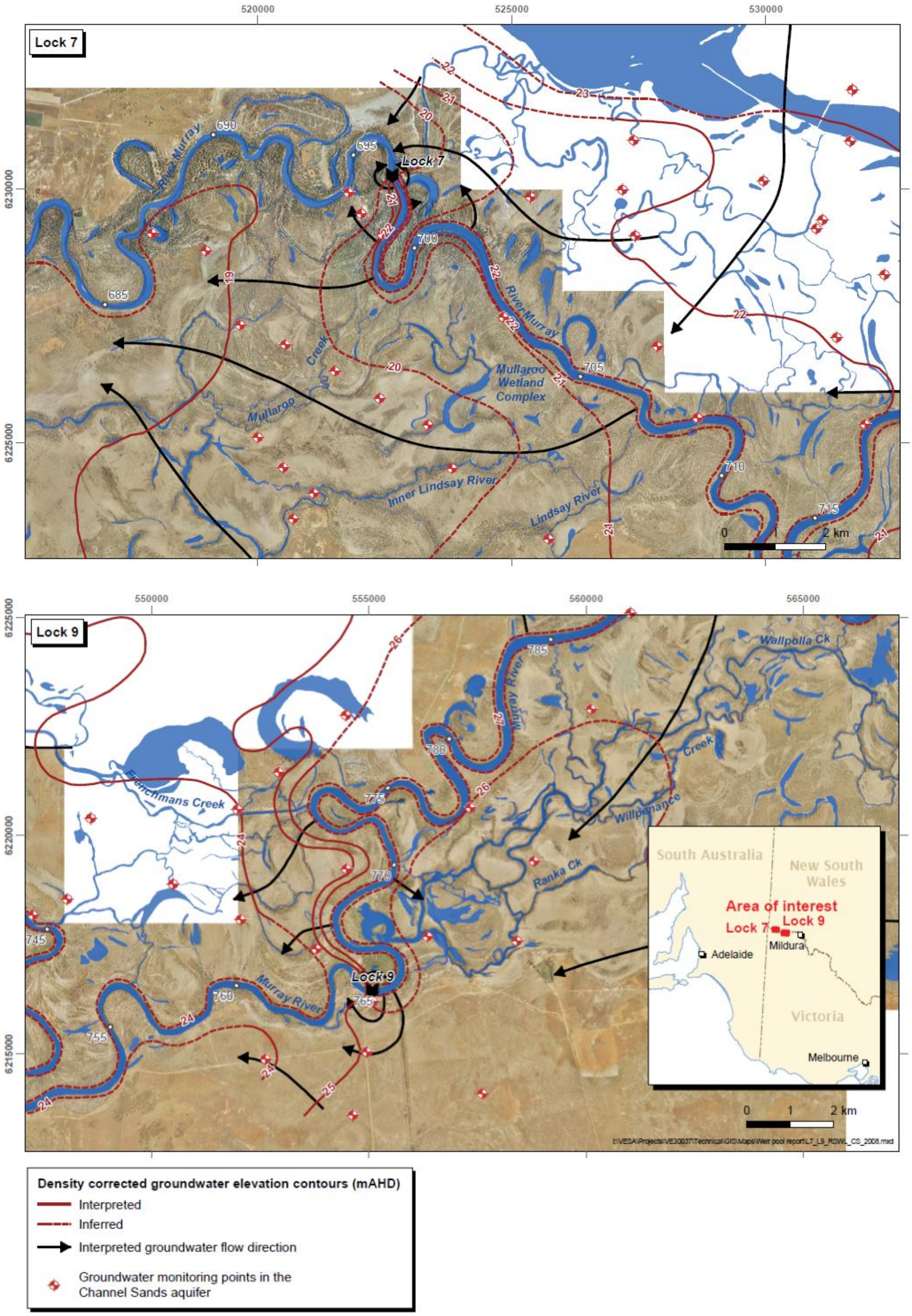
Anabranches (like Frenchmans Creek) are also assumed to be losing to the floodplain and hence unlikely to contribute a significant salt load back to channels on the recession limb. This process was therefore not assessed further for the NSW side for similar reasons.

Surface salt wash-off is considered unlikely to contribute significantly to salt load as there isn't likely to be significant inundation of the floodplain associated with raising the Lock 9 weir pool. Salt wash-off from flow through and into previously dry anabranches may increase, but this is considered a low impact in light of the minimal expected extent of such inundation and the short period over which the weir pool will be elevated.

Given that the groundwater level in the Channel Sands across the floodplain (less than 5 metres below ground level) is generally below the water level in the Murray River, it is likely that any connected backwaters east of Lock 9 would be losing to groundwater (as inferred by groundwater patterns in Figure 3.19 produced by SKM, 2008d). In addition, backwaters that are connected to the Murray River at or just above the weir pool level, there is likely to be limited interchange with fresher river water. The salinity of the backwater is therefore assumed to largely be driven by evaporative concentration of surface water. The higher river levels with a raised Lock 9 weir pool could lead to mobilisation of this higher salinity water and subsequent release to the Murray River when weir pool levels recede. Under current conditions, this is considered the principal mechanism for the delivery of salt to the river during weir pool raising events and hence is discussed further below.

Further analysis is needed to confirm the backwaters in NSW that are connected to the Murray River and may be affected by weir pool manipulation at Lock 9. In addition there will be a need to evaluate the interaction that may occur with the operation of Lake Victoria and Frenchman Creek which is connected to the Lock 9 weir pool.

- **Figure 3.18: Low lying areas with potential of receiving discharged saline groundwater**



- **Figure 3.19: Groundwater elevation in the Channel Sands aquifer around Lock 7 and Lock 9 (SKM, 2008d)**

3.9. Monitoring

The proposed monitoring program is comprised of groundwater and surface water monitoring and aims to provide data that can be used to better define the mechanisms and magnitude of salinity impact arising from the proposed environmental watering events. The monitoring data should form the basis of five-yearly reviews as required under the Basin Salinity Management Strategy, allowing refinement of the salinity impact estimates.

The monitoring program reflects the need to gather data both for the improvement of understanding of the key processes, but also to allow independent review of accountability for operating any works and measures. Monitoring should also be maintained to assess the benefits of environmental watering.

In order to measure salinity impact from the floodplain operations, monitoring periods should be chosen to cover current conditions, floodplain operations, and post-operation conditions. The former provides the opportunity to assess baseline conditions, including salt loads against which to measure the impact of operations. The latter is important because it is likely that the floodplain response would be delayed, with salinity impacts extending beyond the period of floodplain operations. Continuous monitoring will ensure that all impacts due to actions can be assessed against *basecase* conditions as well as highlight any changes in the baseline over time.

All groundwater levels should be expressed relative to Australian Height Datum to allow comparison of groundwater and surface water data.

3.9.1. Groundwater monitoring

Water level and salinity data from groundwater monitoring wells completed in the Channel Sands aquifer in the vicinity of inundation areas, retention sites and other identified impact hotspots should be collected before, during and after each environmental watering event. This is most important for wells that are situated adjacent an inundation area and near the potential receiving surface waters. Salinity measurements at the very top of the saturated thickness (adjacent the discharging site) will allow an assessment of the salt content of the water that will be moving as a result of the action and indicate any freshening of groundwater that may occur.

Table 3.8 shows the groundwater monitoring bores targeted under the program. This has been based upon the distribution of bores that are currently being monitoring for groundwater level and/or salinity by Mallee CMA and other REM bores in the vicinity of Wallpolla Lower.

The distribution of bores in the current monitoring network provides adequate coverage of the environmental watering sites. At Wallpolla Upper inundation region for example, there are a number of existing monitoring points that will provide useful data associated with watering events. These would aid in understanding the relationship between Wallpolla Creek and Horseshoe Lagoon with the groundwater level in the Channel Sands aquifer as a result of groundwater mounding under the inundation area. The Channel Sands aquifer is likely to become confined as a result of the floodplain inundation.

Five additional groundwater monitoring sites have been proposed to assist with measuring change at Wallpolla Mid, Wallpolla Lower (Robsons Road) and Wallpolla South.

All bores are recommended to be monitored for groundwater level and salinity at daily intervals before, during and after events that change the hydraulic regime and at weekly intervals at other times.

- **Table 3.8: Groundwater monitoring sites across Wallpolla Island**

Bore ID	Alternative Bore ID	Easting	Northing	Proposed monitoring parameters (water level, salinity, loggers)
Channel Sands monitoring				
7901		569621	6223777	Level, salinity
7902		570342	6221754	Level (logger), salinity
7903		570342	6221754	Level (logger), salinity
2C-1		577410	6221833	Level, salinity
2C-4		577594	6221936	Level, salinity
2D-2S		578016	6221512	Level, salinity
4A-5		575666	6220100	Level, salinity
4B-5		577005	6219692	Level, salinity
4C-4		578718	6219670	Level (logger), salinity
4D-1		578730	6219604	Level (logger), salinity
4E-1		576923	6218368	Level, salinity
W1	REM031	561025	6225098	Level, salinity
W2	REM032	561024	6222909	Level, salinity
W3	REM033	558799	6219426	Level, salinity
W4	REM030	558408	6217586	Level, salinity
W6	REM035	557337	6220644	Level, salinity
W9	REM034	556352	6217680	Level, salinity

Bore ID	Alternative Bore ID	Easting	Northing	Proposed monitoring parameters (water level, salinity, loggers)
Parilla Sands monitoring				
7914		549148	6214214	Level, salinity
2D-2D		578016	6221512	Level, salinity
Suggested additional monitoring bores (Channel Sands)				
Bore 1		561148	6219194	Level (logger), salinity
Bore 2		564137	6221153	Level (logger), salinity
Bore 3		565809	6223669	Level (logger), salinity
Bore 4		566484	6219515	Level (logger), salinity
Bore 5		566957	6218671	Level (logger), salinity

The frequency of monitoring should ideally be daily to weekly depending on the rate of water level response (if any) in a given monitoring well. If changes in standing water level attributable to floodplain watering are observed, then monitoring frequency should be increased accordingly. It is recommended that the high priority groundwater observation wells are monitored for water level daily, especially just before, during and post inundation. At the very least, under *basecase*, regulated conditions, observations should be collected at least every three months from these wells.

Consideration should be given to the use of automatic down-hole loggers for recording responses to watering events, which are especially useful where wells may become stranded. Additional benefits include recording of subtle impacts that may not be seen from relatively sparse observations. Bores suggested for logger installation include Bore 7902, Bore 7903, Bore 4C-1, Bore 4D-1 and the suggested new monitoring bores. This distribution will provide comprehensive data collection across the inundation areas.

The key will be to identify the peak groundwater level as a result of inundation, but also to record the initial *basecase* and post inundation response as the lake water levels recede. If data loggers are available, the most beneficial locations would therefore be in the bores adjacent to the area of inundation, as listed above.

If costs cannot be met for monitoring it is recommended that fewer locations are chosen and an emphasis placed on collecting more comprehensive time series data.

3.9.2. Surface water monitoring

Ideally, surface water monitoring would provide sufficient data to calculate salt load to reaches of flowing anabranches or the Murray River adjacent to areas of floodplain watering. This is possible when pre-existing surface water monitoring stations are available.

A single surface water monitoring gauge is active on Wallpolla Island, located in the centre of the floodplain along Dedmans Creek. This gauge holds a short period of record, spanning 1996 to 2008 and is only monitored for salinity. It is recommended that this station also monitors flow and level.

It would be useful to gain additional surface water data (flow, level and salinity) along Wallpolla Creek (or tributaries), in particular associated with proposed regulator sites.

Currently, surface water observations across the Wallpolla Creek floodplain are considered relatively sparse and sporadic. Table 3.9 lists existing sites and associated parameters for measurement.

- **Table 3.9: Existing surface water monitoring sites**

Site ID and description	Monitoring parameters
414223 – Dedmans Creek	Salinity
4260501/5 – Lock 9	US/DS water levels, flow, daily-read salinity
425010 – Lock 10	DS water levels, flow, daily-read salinity

To reduce uncertainties relating to *basecase,* inundation across the Wallpolla Island floodplain and associated NSW floodplain, as well as their level of connection to the surface water network, observations and survey of specific wetlands would improve the conceptualisation of the *basecase* conditions. In particular, observations around any wetlands and depressions considered to be potential sources of significant salt load to the river would inform future refinements of the salinity impacts of watering actions. It is assumed that water level data will be collected at each regulator.

It is recommended that stage height monitoring be undertaken at a series of locations along Wallpolla Creek and the anabranch systems (expressed relative to Australian Height Datum). Where existing groundwater monitoring bores are cited along creek lines, it would be useful to gauge stage height to aid in comparison between surface water and groundwater levels at a particular location.

Surface water observations are especially important at the inlet and outlet structures (i.e. Structure 1 at Wallpolla Mid). Surface water salinity and flow should be monitored at such locations to assess the impact of watering events and calculate likely salt loads to the system. Flow gauges should be installed at the inlet and outlet structures. Monitoring should occur before, during and after the watering event. The length of time and frequency of monitoring can be assessed as data is collected and assessed. Initially monitoring should occur at a monthly frequency.

- **Figure 3.20: Wallpolla Island suggested monitoring locations**

4. Hattah Lakes

4.1. Hydrology

4.1.1. Overview

The following summary and analysis is based on the approach developed by SKM (2008a) and updated with data from a targeted program by SKM (2010).

The Hattah Lakes floodplain is a wetland system made up of numerous perennial and intermittent shallow lakes, streams and temporary swamps bordered by riverine forests (Figure 4.1). The system is a natural flood mitigation area, storing excess water (that is subsequently released through evapotranspiration and groundwater recharge) and sediments and nutrients washed in from the surrounding catchments (MDBC, 2007).

The site lies to the west of the Murray River south of Colignan (Figure 4.1). The majority of the lakes are fed and interconnected through Chalka Creek, an anabranch which diverts from the Murray River around river km 1050 and re-joins the Murray River approximately 50 km downstream. Lake Cantala is the only exception; receiving inflows from both Cantala Creek, a second tributary of the Murray which is connected to the main channel between the inlet and outlet of Chalka Creek, and from overland flow from the other lakes in the east during large flood events.

Under natural conditions, the hydrological regimes of the individual lakes would have varied widely, with some holding water almost constantly to some being inundated 1 in 4 years and/or with dry spells of up to 12 years (MDBC, 2005a). On average, the threshold flow to fill Lake Hattah would be met 30% of the time, meaning that water would naturally flow into the lake 100 days every year on average (SKM, 2006). However, following modification and regulation of the Murray River flow, as well as earthworks and structural changes within the Hattah Lakes system itself, the natural regime of the lakes has changed. Under current conditions, the critical threshold for Lake Hattah is met only ~13% of the time (SKM, 2006).

Modifications of the system have included deepening and re-grading of Chalka Creek channel and the installation of a regulator (Messengers regulator) at the creek's inlet in order to prevent floodwater from receding back to the Murray River. Within the network of Lakes itself, changes have included *construction of a channel between Lakes Lockie and Hattah, and the installation of an earthen bank and a drop-board regulator between Lakes Hattah and Little Hattah* (MDBC, 2006).

Current works being undertaken to enable improved management of water regimes within Hattah Lakes as outlined by GHD (2012) include:

- Four regulators; Chalka Creek South off take (Messengers), Kramen Creek, Lake Cantala and Chalka Creek North (Oateys);
- Pump station at Messengers Regulator transferring water to Chalka Creek South;

- Creek lowering within Chalka Creek South;
- Levees located along the eastern perimeter of Lake Cantala, a breakout area north of Messengers Regulator and along the northern perimeter of Lake Bitterang, to retain floodwaters within the central lake systems;
- Supply pipeline to Lake Kramen; and
- Refurbishment of the existing Little Lake Hattah Regulator.

Flow into the Hattah Lakes system is dependent on Murray River flow rates and under regular, low flow conditions the majority, if not all the lakes are dry. Operation of Euston Weir (Lock 15), located upstream of the site, is the primary influence on Murray River stream flow adjacent to Hattah Lakes.

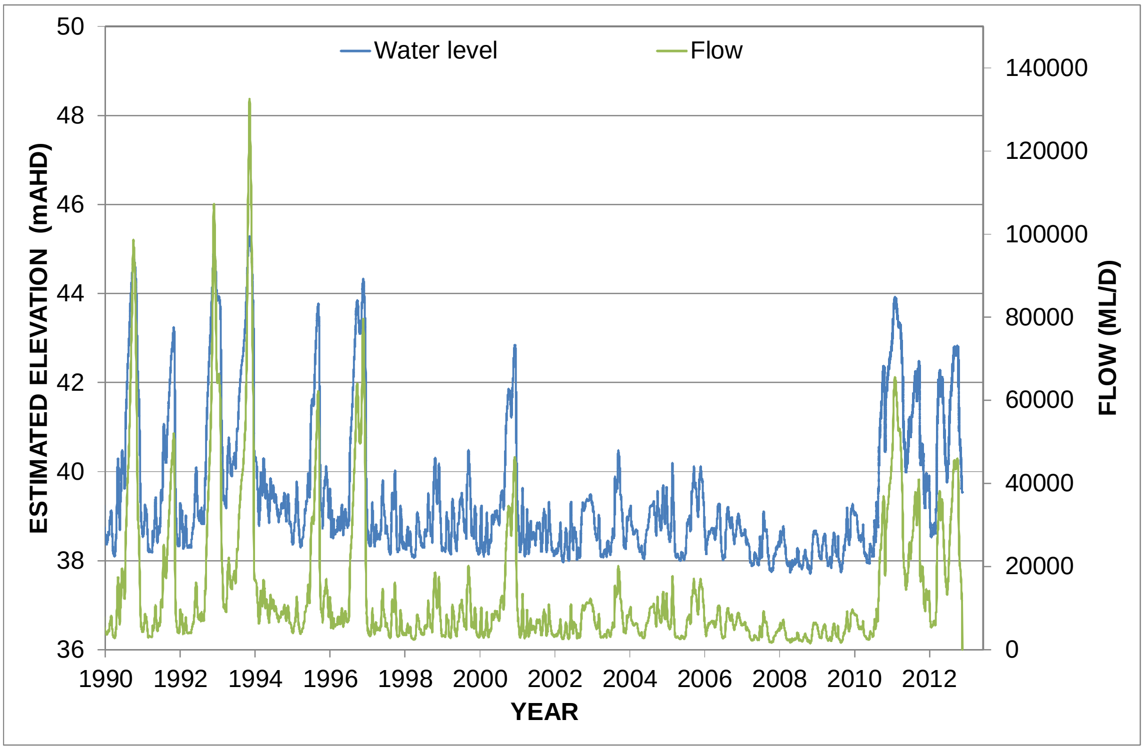
Murray River water levels are recorded at Colignan (Figure 4.2) located approximately 5 km downstream and have been monitored since the 1970s. The GMS database only provided these records as a stage height rather than elevation relative to Australia Height Datum. The elevation listed in GMS for this stream gauge was equivalent to bank height. As such, LiDAR was used to estimate bed level (36.8 mAHD) and from this the likely absolute elevation of stage height in the Murray River was estimated.

Based on this method, records show historical levels at Colignan to range between 38.38 to 45.06 mAHD. There was much less seasonal variation in water levels during the 2000s (38.4 to 39.6 mAHD), when the climate was relatively dry. However, during recent high flow events between 2010 and 2012, seasonal variation has again increased (38.7 and 43.71 mAHD), averaging 40.6 mAHD for March 2012, (Figure 4.2). This level is estimated for average flow conditions.

For the purpose of this assessment, this is assumed to be the best estimate of the absolute stage height in the Murray River adjacent the Hattah Lakes inundation areas.

The minimum stage height recorded at Colignan was 37.7 mAHD in October 2008 when daily flow was measured at 1546 ML/d. This may represent a worst case scenario for stage height adjacent Hattah Lakes.

- **Figure 4.1: Location of key features at Hattah Lakes**



- **Figure 4.2: Surface water level and inferred flow at Colignan (414207)**

4.1.2. River channel cross-sections

Topographical cross-sections were extracted from DEM data provided by the Mallee CMA, and used for comparison with groundwater levels to determine the likelihood of surface water and groundwater interaction. In addition, Murray River bed levels adjacent the site were interpreted from the 2006 NanoTEM survey (Telfer *et al.*, 2006). These thalwegs, estimated at between 34 and 37 mAHD adjacent to the river in this reach, are illustrated in Figure 4.3, Figure 4.4 and Figure 4.5 and (along with data on groundwater level and estimated stage height) were used to inform inferences of potential interaction of the river with groundwater.

Across the floodplain, the bed elevations of the lakes vary, with the deepest found in Lake Hattah at 38.6 mAHD.

4.1.3. Floodplain inundation

Surface water modelling undertaken by SKM in 2006 (SKM, 2006a) determined a relationship between the flow at Euston Weir and the level within the Lakes system and was used to determine the approximate flows needed to inundate the three water regime classes (based on the presence of key species of vegetation) defined on the flood plain.

The Hattah Lakes system is inundated in a specific sequence, in response to different flows within the main Murray channel. Under current regulated *basecase* conditions, Murray River water only enters the Hattah system when flow at Euston is above 36,700 ML/day: the critical flow at which water enters Chalka Creek, and subsequently Lake Lockie. Primary flows (received as direct off-take from the Chalka and Cantala distributaries) are received by approximately 12 of the lakes, while the other lakes rely on secondary flow (as a result of spill over from other lakes or tributaries within the system). The critical flow and hence the frequency of inundation of all the other lakes varies depending on their relative position in the system. Several days after inflow to Chalka Creek, Lake Lockie receives water. All of the southern lakes are then filled via Lake Lockie, typically taking a further three weeks (MDBC, 2005a and citations within). After Lake Lockie, water flows into Lakes Hattah and Little Hattah, followed by Lake Bulla, and then, in order, Lake Arawak, Lake Marramook, Lake Brockie, Lake Boich, Lake Tullamook, Lake Nip Nip and finally, Lake Kramen (MDBC, 2005a).

Lake Bitterang is the last lake to fill, with flood water only reaching it over a month after the beginning of flooding, if the level is sufficiently high (DSE, 2003). After filling, flows spread across the floodplain, with the extent (and hence the water level) dictating which vegetation classes are watered. The Lake Boolca and Dry Lakes area in the far north-west of the Hattah Lakes system sits higher in the landscape than the central lakes area of the National Park. Murray River water only enters this area via overspill from Lake Bitterang when flow at Euston is above 80,000 ML/day (GHD, 2012). Critical flows of 180,000 ML/day have been reported for the lakes to fill (MDBA, 2012). Once flood waters recede, the water retained in the lakes is gradually lost through evaporation and infiltration. The majority of the lakes, being relatively shallow, dry up within two years if no further flows are received. However, Lake Hattah and Lake Mournpall may retain water for up to two and seven years, respectively (DSE, 2003).

4.1.4. Surface water salinity

Water salinity within the Murray River has been recorded continuously at Colignan since 1992 over which time levels have varied between approximately 20 to 800 EC. In recent years, salinity levels have generally reduced with less seasonal variation.

One surface water monitoring station measuring salinity is present within the Hattah Lakes System, which is located at Lake Hattah. Data has been collected from this site between 1993 and 2008, therefore covering a period of high (1990s) and low (2008) flows in the Murray River over which discharge in the river exceeded the critical level for flow into Chalka Creek, and therefore into Lakes Lockie and Hattah (discussed below), three times. Salinity levels in the Lakes varied over that time between 0.18 to 3.8 mS/cm, with greatest salinity levels concentrated in a peak in early1999. As this is approximately two years since the previous inundation (assuming critical flows are correct), the peak in salinity is likely to be due to evaporative concentration of salt in the surface water.

For the purpose of this assessment, the *basecase* scenario assumes the lakes are dry.

4.2. Hydrogeology

4.2.1. Background

The following geological summary is based on SKM (2006, 2009 and 2011) and references therein.

Cross-sections from bores directly to the south (Figure 4.3 and Figure 4.4) and north (Figure 4.5) of the lakes give an indication of the local geology and hydrogeology across the Lakes system (modified from Thorne *et al*, 1990). Data from monitoring bores drilled across the Hattah Lakes System in 2011 provide local information to support the conceptualisation discussed below and presented in Figure 4.3 and Figure 4.4 and Figure 4.5.

Unlike much of the Mallee region, the floodplain around Hattah Lakes has an additional surface layer across much of the floodplain. This comprises sand and clay sediments, which make up the Woorinen Formation (and the Lowan Sands): reasonably free draining deposits that form distinctive east to west trending dunes (or parabolic dunes), defining the undulating topography in the area.

On the floodplain, the basal unit filling the trench beneath the Woorinen Formation and the Lowan Sands is the Channel Sands which is overlain with the finer grained Coonambidgal Formation. The latter contains fined grained silts and clays ranging in thickness up to 5 m across the floodplain. The Channel Sands is made up of fine to coarse-grained sands and is in direct connection with the Murray River. On the higher ground, beyond the boundary of the floodplain, the Woorinen Formation is directly underlain by Blanchetown Clay, which is likely to vary in thickness across the site. The extent and thickness of the Blanchetown Clay will be a key control on the possible salt impact of floodplain watering activities. The clay separates the Channel Sands and Parilla Sand across the majority of the Hattah Lakes system, however, the clay is known to be intermittent across the Mallee region (Figure 4.3, Figure 4.4 and Figure 4.5). Cross-sections show the clay to range from 20 m in the north of the site (Figure 4.3) to a thickness of 5 m to the south (Figure 4.5). However, log data near Lake Hattah (Figure 4.6) indicates the Blanchetown Clay to have thickness of at least 32 metres occurring at a depth of 9 mbgl. Southeast of the site, Lake Kramen has completely incised the Clay layer which may facilitate hydraulic connectivity between the Channel Sands and Parilla Sand aquifers (Figure 4.5).

URS (2005) identified a thin sand layer within the Blanchetown Clay at Nowingi, west of Hattah Lakes while undertaking works for the proposed Long Term Containment Facility (LTCF), (SKM, 2009).

The NanoTEM survey (Telfer *et al.*, 2006) undertaken in this area also shows a change in resistivity of the channel substrates mid-reach, which may be an indication of where the Blanchetown Clay is absent beneath the channel. This is supported by log data from MW1, which records Channel Sands directly overlying the Parilla Sands.

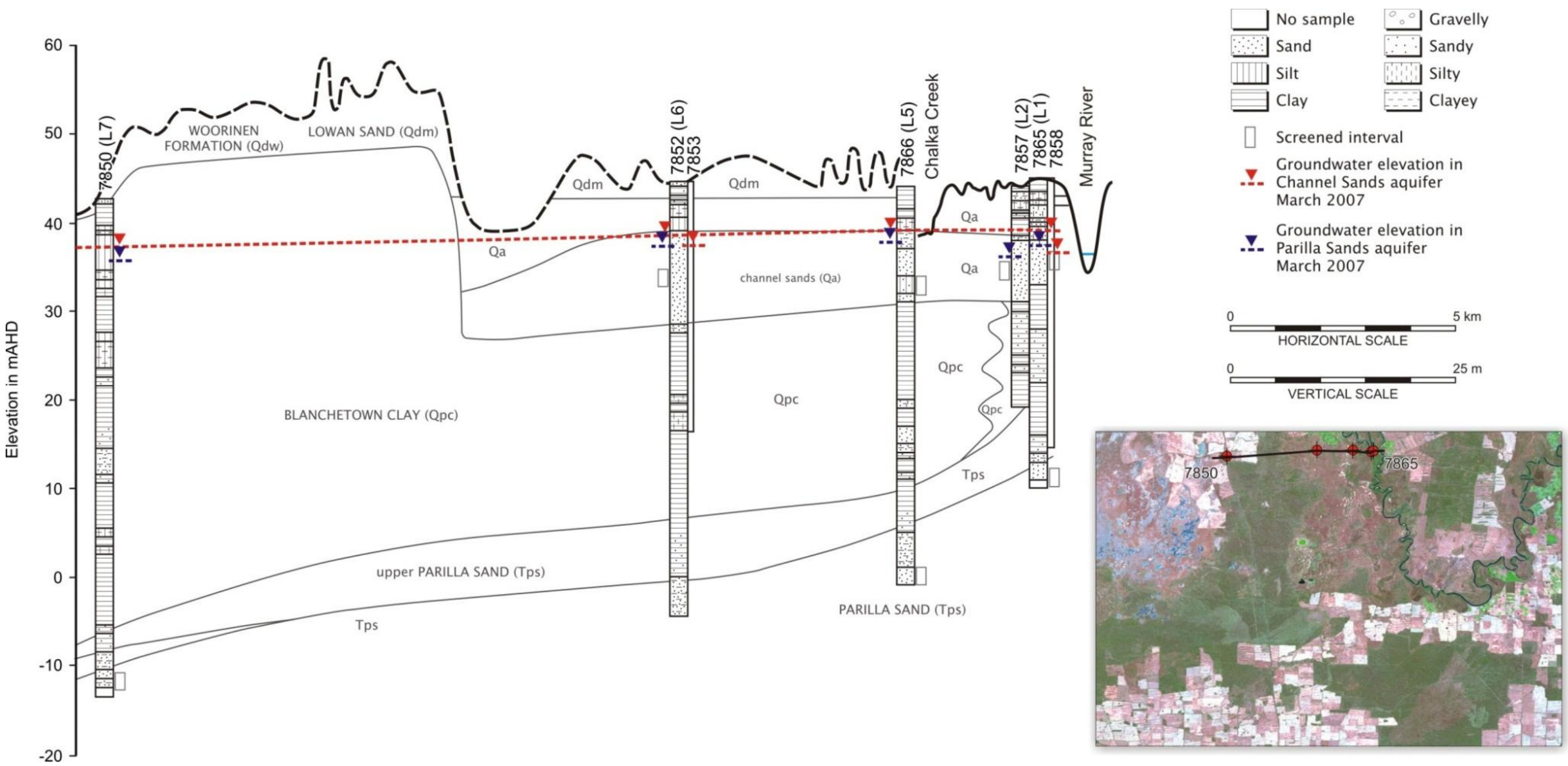
4.2.2. Groundwater levels and flow

Groundwater level data has been collected at several sites within the Hattah Lakes system. The locations of currently monitored bores across and surrounding the system between 2008 to present are shown in Figure 4.6. In 2011, SKM was engaged by Goulburn-Murray Water (GMW) to install and construct 7 monitoring bores (Bores MW1-MW5b) across Hattah Lakes (Figure 4.6), (SKM, 2011). Recent (Feb-May 2012) groundwater elevation data was reviewed and compared to that used in earlier studies (data from Feb-March 2008; SKM, 2009). These new data indicate that groundwater levels across the floodplain have generally risen; increasing by 0.12 metres near Lake Hattah in the south-west of the system and 0.77 m (Bore 26266) close to the Murray River near the Chalka Creek inlet. In Bore 26261 (Parilla Sands) a 3.08 m increase was observed. In the northern portion of Hattah Lakes, groundwater level has remained relatively stable or shown a decline; observed in each aquifer systems.

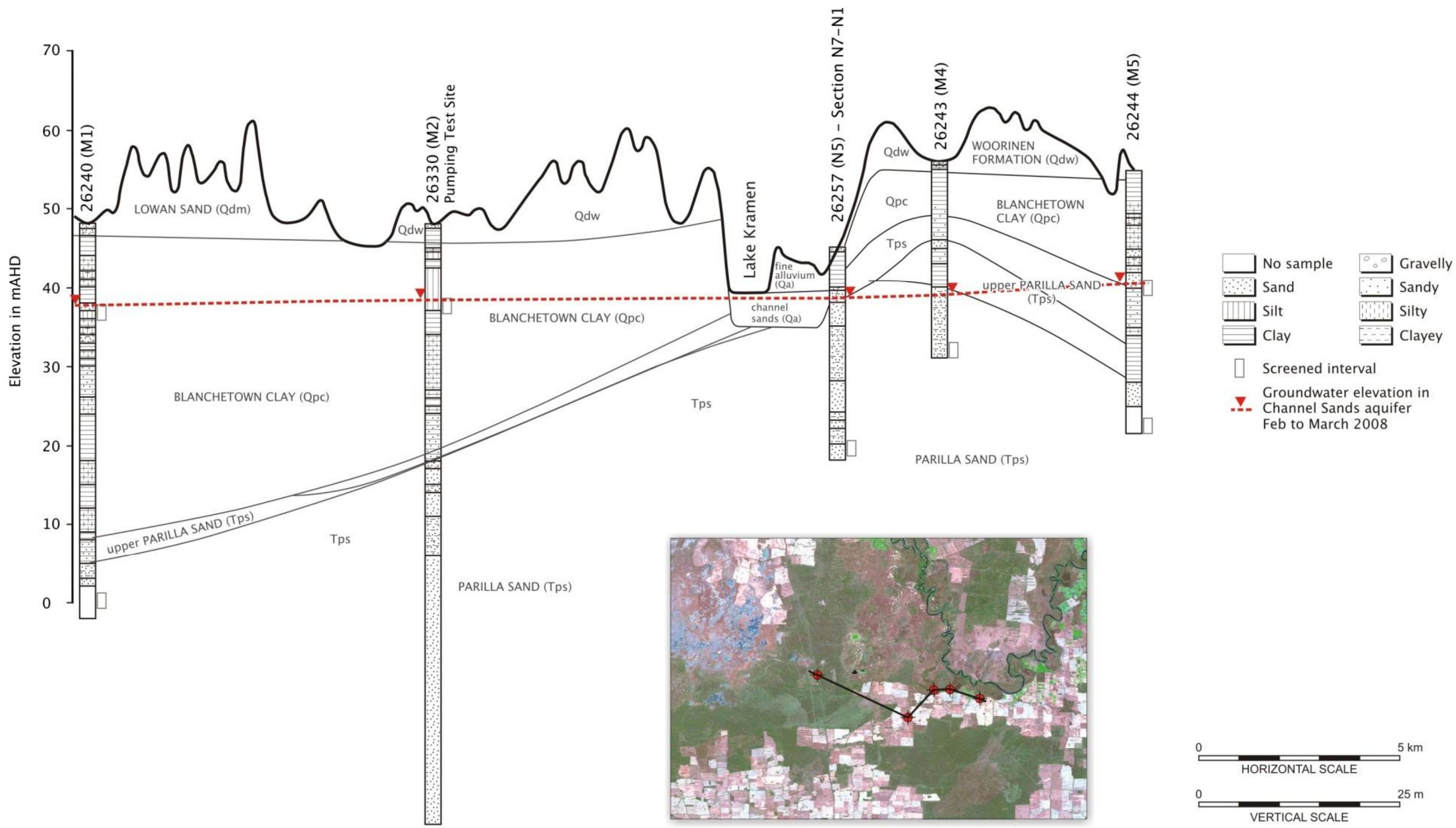
A selection of groundwater level hydrographs from bores completed in different formations is plotted in Figure 4.6. Groundwater levels (Feb-Mar 2012) range between 37.29 mAHD in the central-north of the floodplain to 38.69 mAHD in the north-west. The highest levels are generally associated with known areas of irrigation (e.g. Colignan) which appears to have resulted in a localised groundwater mound. South of the lakes groundwater levels (Feb-Mar 2012) range between 37.33 mAHD to the south-east of the lakes and 41.06 mAHD also in the south east closer to the Murray River.

Regional groundwater flow is generally in a west, northwest direction underneath the site (SKM, 2006). However, irrigation development to the north of Hattah Lakes is likely facilitating gradients in a south-east direction towards the Murray River.

Monitoring data (collected south of the inundation areas) within the Hattah Lakes system in Feb-Mar 2012 range between 33.75 mAHD in MW 5 (refer Figure 4.6) and 37.32 mAHD in MW2 in the centre of the Hattah Lakes floodplain. Data suggest groundwater flows away from the centre of the floodplain (MW2) eastwards, towards the river (MW1) and westwards towards the edge of the floodplain (MW5). Comparative levels to the north and south of the lakes suggest groundwater flow towards the lakes; an indication that the lakes act as discharge features.



■ **Figure 4.3: Hydrogeological cross-section north of Hattah Lakes (SKM 2009; based on Thorne *et al*, 1990)**



- **Figure 4.4: Hydrogeological cross-section south of Hattah Lakes (SKM 2009; based on Thorne *et al*, 1990)**

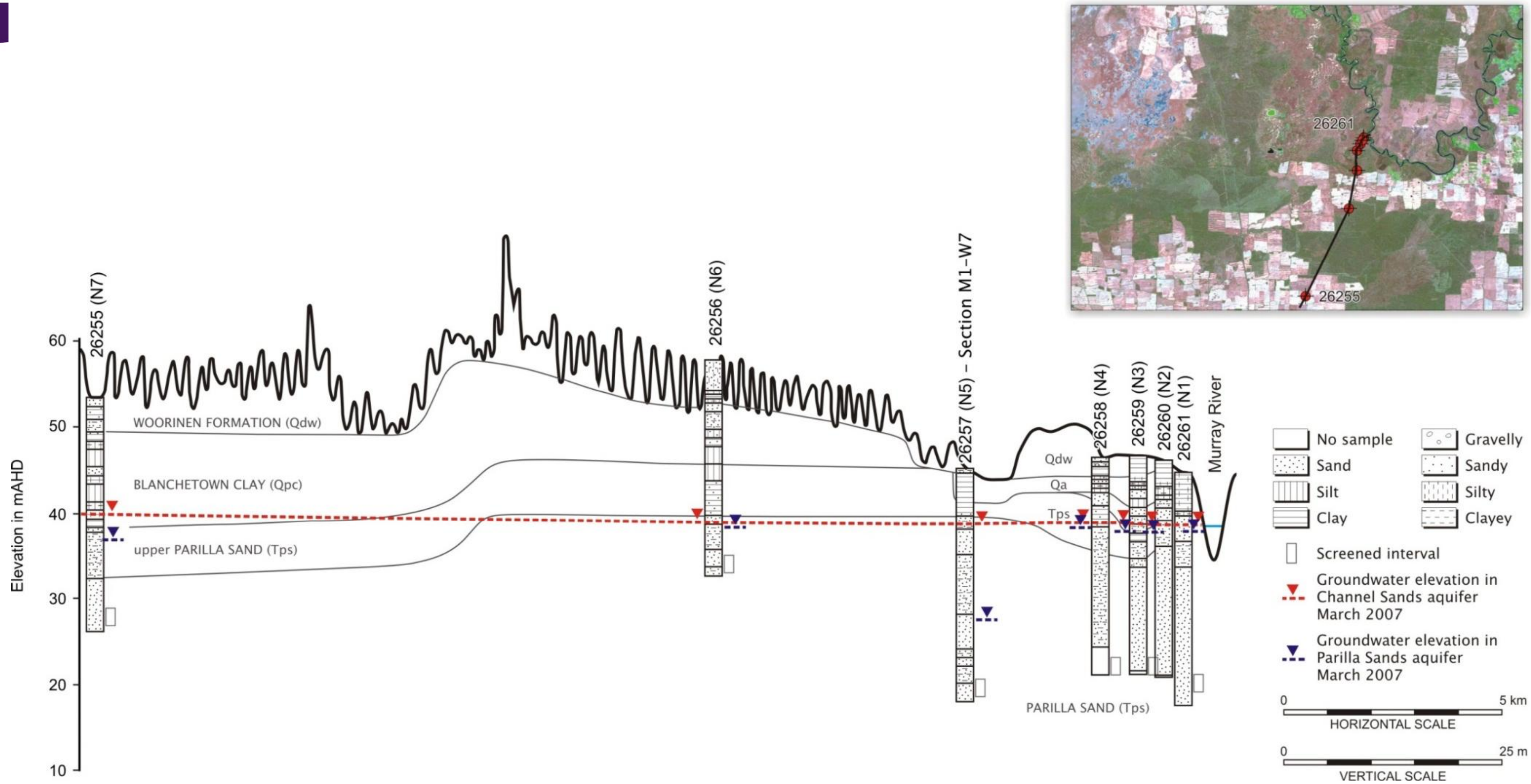
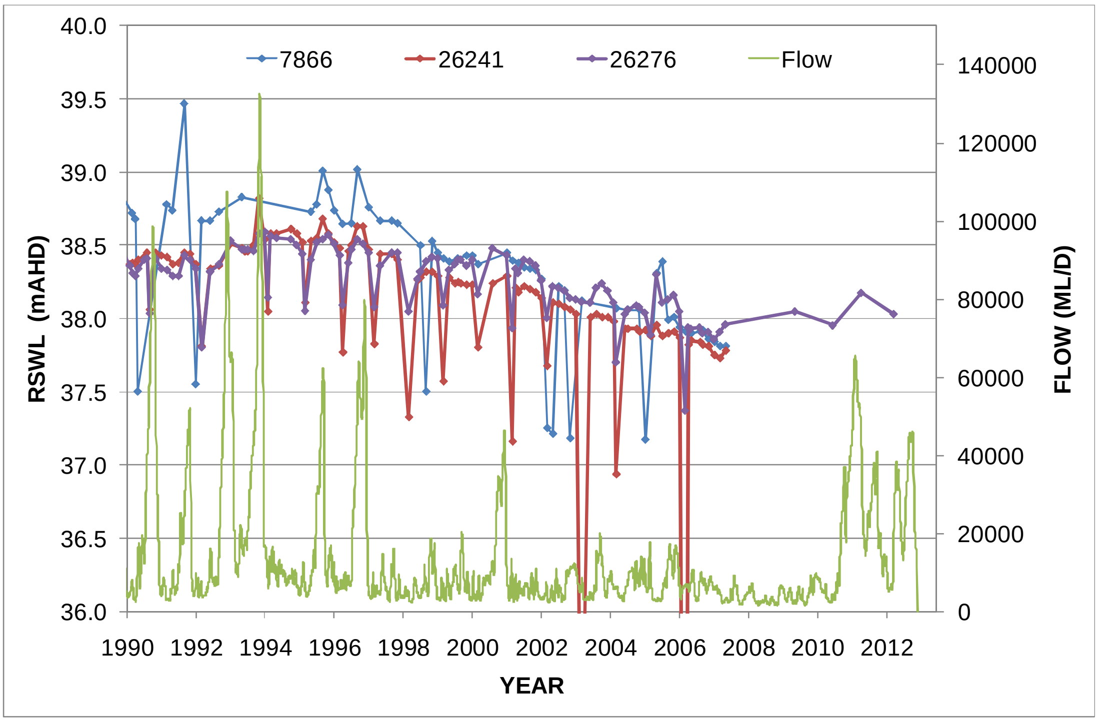


Figure 4.5: Hydrogeological cross-section south of Hattah Lakes (SKM 2009; based on Thorne *et al*, 1990)

- **Figure 4.6: Current monitoring at Hattah Lakes**

Historical data show groundwater levels were generally declining, with decreasing seasonal variation, attributed to the prevailing drought conditions affecting the majority of the Murray-Darling Basin, before recent wetter conditions since 2010. Bore hydrographs in close proximity to the Murray River reveal seasonal fluctuation in water levels corresponding with similar trends in the River (e.g. Bore 7858). Water levels in bores screened close to the River south of the lakes show corresponding trends with that of Murray River levels at Colignan both in the Channel Sands (Bore ID 26266) and Parilla Sand (Bore ID 26261) aquifers. In contrast, those screened in the regional aquifer north of the lakes are less responsive. Similarly, bores screened within the Parilla Sand aquifer at greater distance from the river both north and south of the lakes show groundwater levels remain relatively constant compared to those of the Channel Sands, thereby highlighting the confining nature of the Blanchetown Clay.

Figure 4.7 shows the water level fluctuation in three bores in the Hattah Lakes area. Bores 26241 and 26276, located south of the Hattah Lakes area near its western margin, and bore 7866, which is adjacent Chalka Creek in the north. Groundwater levels and associated fluctuations in these bores are generally high during the early 1990s corresponding with a number of large floods. Over time the water levels (and the ranges of fluctuation) fall until 2010, which marks the start of a wetter period with several subsequent large flow events. Also, the water levels show short term fluctuation associated with individual high flow events. The maximum amplitude of these fluctuations is, however, small (less than 0.5 m).



- **Figure 4.7: Selected groundwater elevation in the vicinity of Hattah Lakes and surface water discharge (Colignan)**

Groundwater levels in bores completed in the thin sand within the Blanchetown Clay, under the LTCF to the west of the Hattah area, show westerly flow at that site, presumably reflecting flow from higher heads nearer the River to the groundwater discharge areas around Raak Plain.

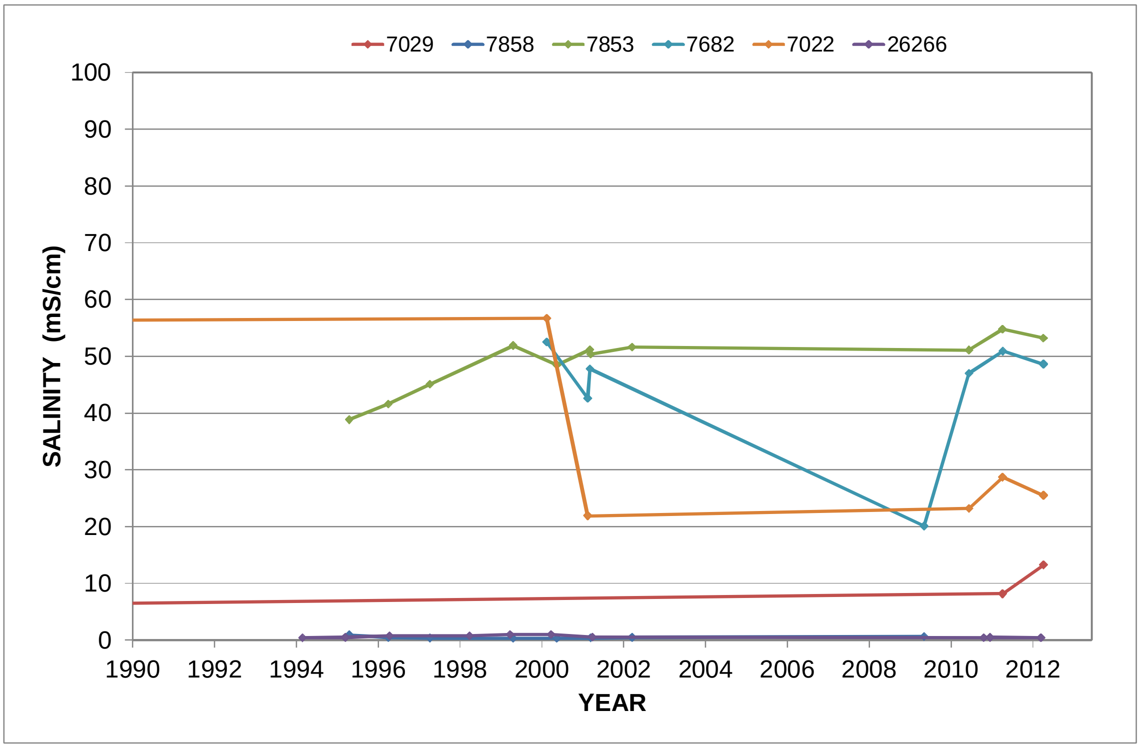
4.2.3. Groundwater salinity

Groundwater salinity data are available only from monitoring bores installed in 2011 (MW1-MW5b; Figure 4.6). In other areas of the floodplain, and pre 2011, groundwater salinity data is limited; both temporally and spatially. Raw data retrieved from GMS were used for this assessment.

Figure 4.8 shows time series salinity records for groundwater bores screened in the Channel Sands aquifer. Closer to the Murray River, groundwater appears to be relatively fresh (Bore 7858 in the north and Bore 26266 in the south). In general, salinity increases with distance from the River which is an indication of net losing river conditions in this area. These conditions are consistent with a study in this reach of the Murray River which reported the presence of a fresh groundwater lens beneath the Murray River (Cartwright *et al*, 2010). This lens is thought to contract and expand in relation to surface water levels in the channel; providing baseflow in times of low flow and gaining from the river in high flows. Congruently, under current conditions the River stage height lies above the relative groundwater elevations in the vicinity of the River in the northern transect. In the south, close to the Chalka Creek inlet (Bore 26266) and the central area close to Cantala Creek inlet (Bore MW1), data highlights the freshness of groundwater close to the River (0.43 and 0.30 mS/cm, respectively). Moving away from the River, salinity within the Channel Sands increases, with levels of 29 mS/cm (Bore MW3a) in the centre of the floodplain to greater than 53 mS/cm (Bore 7853) to the north, within the irrigation area.

An aerial electromagnetic (AEM) survey was undertaken during Feb-March 2008 (BRS, 2009). An AEM depth slice (as apparent bulk electrical conductivity) averaged over the upper 30 m of saturation in the shallow aquifer is shown in Figure 4.9.

The AEM data infers that a lower salinity zone exists either side of the Murray River and Chalka Creek. These lower salinity areas are representative of zones where there is localised recharge to the groundwater system through the river banks, and the process is consistent with previous conclusions about the complexity of the interactions between surface water and groundwater.



- **Figure 4.8: Hattah Lakes groundwater salinity**

- **Figure 4.9: Average apparent bulk electrical conductivity for a 30 m interval immediately below groundwater surface**

4.2.4. Groundwater – surface water interaction

The location and magnitude of the salinity impact depends in part of the degree of connection between the shallow floodplain aquifer, and the Murray River and anabranches. Greatest impacts are possible where the surface water system gains groundwater. This section provides a summary of the nature of the connection based on existing information.

Where groundwater levels are higher than surface water heights, river reaches are defined as potentially *connected – gaining* systems. Where groundwater elevations are lower than surface water elevations, river reaches are defined as potentially *connected – losing* systems. Where anabranches are permanently inundated and groundwater elevations are lower than the base of the river bed, river reaches are also defined as potentially *connected – losing* systems.

Groundwater bores screened in the Channel Sands close to the River show corresponding trends with surface water levels recorded in the Murray River at Colignan (e.g. Bores 26266 and 7858; Figure 4.7).

These trends are an indication of hydraulic connectivity between the River and the groundwater in the shallow aquifer.

Murray River bed levels were estimated to lie between 34 and 35 mAHD in this reach. In the north, this is congruent with hydraulic connectivity of the River and the Channel Sands but not with the regional Parilla Sands. A Blanchetown Clay confining layer is found at depths of 20 mAHD in this northern reach, between the river bed and the regional aquifer (Figure 4.3). However, in the south, the river bed is shown to incise the Blanchetown Clay layer, facilitating connection of surface water and groundwater of both the Channel Sands and Parilla Sand aquifers (Figure 4.5). Log data available adjacent the Murray River (MW1), near the Cantala Creek inlet confirms this, with an absence of Blanchetown Clay in this area. Fresh groundwater measured in bores close to the River suggests this connection to be under losing conditions in the reach adjacent to Hattah Lakes.

Across the floodplain, lake beds are generally higher than 39 mAHD (SKM, 2009). Groundwater elevations in the Channel Sands aquifer generally range between 36 and 37 mAHD, suggesting that the Channel Sands is not currently connected with any surface water present in the lakes. Recent (March 2012) records indicate groundwater levels of around 39 mAHD, but these are from bores adjacent the northern irrigation area and along the River rather than adjacent wetland/lake bodies.

Bed level in Chalka Creek (in the vicinity of Area 1 inundation area) was estimated from LiDAR to be around 39.3 mAHD, approximately 2-3 m above the current groundwater level and 1-2 m above historic 1990s groundwater levels. This is indicative of losing conditions. Average March 2012 stage height in the Murray River was estimated to be 40.6 mAHD.

Stage height in Chalka Creek would need to be quantified to accurately assess the nature of connection between surface water and groundwater level in the Channel Sands.

Due to the uncertainty of groundwater levels in the northern areas of the floodplain and the elevation of thalwegs, a conservative approach has been adopted.

It is assumed under *basecase* conditions that surface water features are in connection (at least in part) with the Channel Sands aquifer (*connected – losing* systems) in the northern floodplain areas.

The 2006 NanoTEM (Telfer *et al*., 2006; Figure 4.10) survey shows the vertical profiles displaying the resistivity data collected along the Murray River. Low resistivities (red to yellow) indicate areas that are conductive, (that is, they are interpreted to hold saline water and/or be composed of clay). The resistive areas (blue through purple) are interpreted to be generally fresh water in sands (Telfer *et al*., 2006). Hattah Lakes is sited between 1040 and 1055 river km. Here, the vertical profile is quite resistive indicating generally fresh groundwater inferring predominantly losing conditions.

4.3. Environmental works and measures

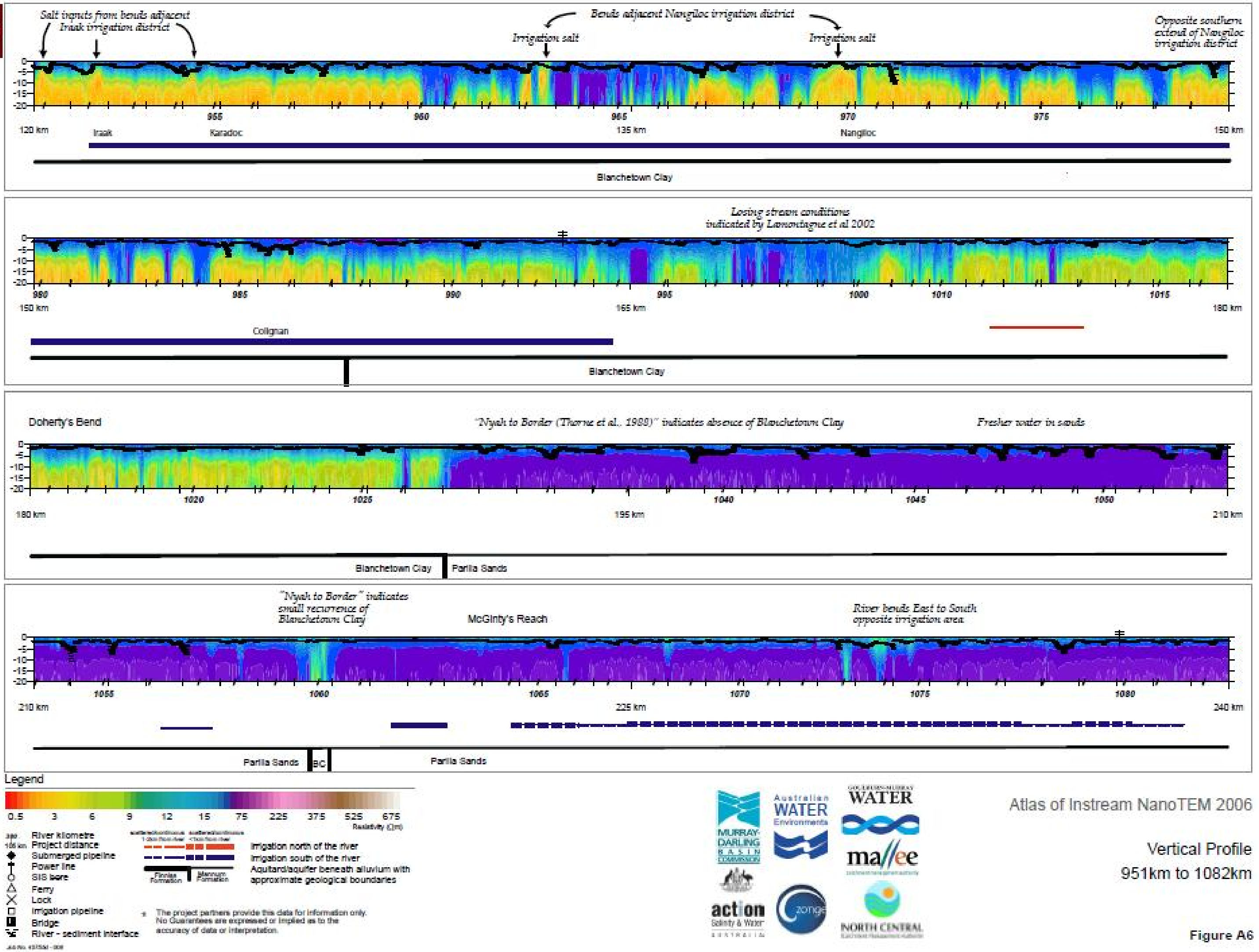
Several works outlined in GHD (2012) are currently being undertaken across the Hattah Lakes system as part of a program to allow improved management of water regimes. Salinity impacts associated with these works and associated environmental watering regimes have been assessed and discussed previously by SKM (2009).

Additional areas that may benefit from inundation and flow control have since been identified (presented in Figure 4.11 and summarised in Table 4.1) and the associated works and measures related to their inundation are discussed below. The environmental watering of these areas will occur only when upstream areas (discussed in SKM, 2009) of the floodplain are sufficiently inundated.

A schematic of the key water levels on the floodplain is presented in Figure 4.12.

4.3.1. Hattah Lakes Area 1 (Chalka Creek North floodplain)

This option proposes the installation of an inlet regulator on Chalka Creek North (K10 Regulator) plus two additional retaining structures (River Track Causeway and K10 Levee). The Chalka Creek North regulator will be operated to allow water released from the upstream Hattah Lakes system through Oateys regulator to flow into the Chalka Creek North floodplain to achieve a top water level of 43.5 m AHD, inundating a total area of 420 ha (Table 4.1). . There will be a release of water from Area 1 to the Murray River via the Chalka Creek downstream regulator.



▪ Figure 4.10: Vertical profile of 2006 Nano TEM survey along Murray River, map reference 15

4.3.2. Hattah Lakes Area 2 (Floodplain north of Bitterang Levee)

This option proposes the construction of a regulator within the Bitterang Levee to allow water pooled behind the levee in Lake Bitterang to be released to the northern floodplain area including Lake Boolca and Dry Lakes (i.e. inlet works for the site). This option would be operated in conjunction with inundation of Lake Bitterang at a top water level of 45.0 m AHD (Table 4.1). Assuming gravity releases only, this option would inundate a total area of approximately 300 ha. If pumping from the southern side of Bitterang levee was used to supplement this option (possible at levels below 45 mAHD in Lake Bitterang), the total area inundated could increase to approximately 710 ha. The inundated area in Hattah Lakes Area 2 will dry through evaporation and seepage.

The operation of this option will be dependent on water levels in Bitterang Lake and the presence of the Bitterang Levee regulator).

4.3.3. Hattah Lakes Area 3 (Isolation of Lake Bitterang)

This option proposes the installation of a regulator between Chalka Creek North and Lake Bitterang to allow environmental watering events to be excluded from Lake Bitterang. The lake may otherwise be subject to over-watering as a result of environmental works and measures proposed under The Living Murray. The regulator may be operated to exclude environmental watering events up to 44.0 m AHD, above which inundation will occur.

- **Table 4.1: Summary of Hattah Lakes environmental watering options**

Option	Filling method	Dependencies	Top water level (m AHD)	Area inundate (ha)
Hattah Lakes Area 1 (Chalka Creek North floodplain)	Gravity	Operation of Oateys Regulator	43.5	420
Hattah Lakes Area 2 (Floodplain north of Bitterang Levee)	Gravity	Water level in Lake Bitterang	45.0[1]	710[2]
Hattah Lakes Area 3 (Isolation of Lake Bitterang)	n/a – exclusion rather than inundation			

[1] – In Lake Bitterang;

[2] – Maximum inundation area based on gravity release and pumping across Bitterang Levee regulator

4.3.4. Watering Regime

Documentation of options provided for this project did not provide discussion on water regimes, and minimal discussion on watering requirements. Table 4.2 details likely timing and frequency of inundation events as outlined by Mallee CMA.

It is important to note that Area 1 and Area 2 are only likely to flood when other areas across Hattah Lakes are also in flood.

- **Table 4.2: Proposed Hattah Lakes watering regime**

Option	Inundation frequency	Timing	Inundation duration (months)
Area 1	5 in 10 years	August	3
Area 2	1 in 15 years	September	3

4.4. Potential salinity impacts

4.4.1. Approach

The in-river salinity impacts (at Morgan in South Australia) potentially caused by the proposed actions at Hattah Lakes were assessed relative to a *basecase* scenario. Under current conditions, flows in the Murray River adjacent to Hattah Lakes are insufficient to initiate flows in to Chalka Creek and hence the system is assumed to be dry initially.

The approach to the assessment requires conversion of salt load to EC at Morgan described in Fuller & Telfer (2007), with resultant EC impacts at Morgan (determined using the Ready Reckoner) reflecting the impact of an operation over the 25 year Benchmark Period and the time of year the salt load occurs.

The scenarios to be tested are summarised in Table 4.3. This also contains a summary of the key floodplain processes relevant to the watering action as well as a proposed assessment method. Greater detail on these aspects is provided in the following section.

The approach allows for the incremental salt impact of each option to be assessed. The cumulative effect is taken to be the sum of salt impacts across all watering actions.

Appendix A contains details of the steps in the impact analysis, while Appendix B contains tables of input data used in calculations.

4.4.1.1. Identifying salt discharge processes

The conceptualisation of the hydrogeological setting described in previous sections was used to identify processes and areas believed to be at greater risk of causing increased salt load to the river, bearing in mind the proposed actions and associated floodplain processes involved.

This involved consideration of the:

- Potential for recharge to groundwater; taking account of surface geology and depth to groundwater level in the Channel Sands;
- Potential for increasing groundwater hydraulic gradients and hence increased discharge;
- Potential for salt mobilisation from bank storage, previously dry creeks and wetlands, and previously disconnected backwaters;
- Potential for mobilisation of salt from in-channel sources; and
- Proximity of the inundated areas to the receiving water courses.

4.4.1.2. Impact on floodplain processes and approach to analysis

The works and measures proposed at Hattah Lakes will result in areas of the floodplain being inundated with water. At Area 1 and Area 2, inundation will be gravity fed from upstream floodplain areas to a top water level elevation of 43.5 and 45.0 mAHD respectively. Flow from Area 2 is conservatively assumed to be toward Chalka Creek for this assessment.

Chalka Creek is considered to be the receiving feature for this assessment.

Key assumptions used regarding the Hattah Lakes operation include:

- Designed to inundate approximately 420 ha (Area 1) and 710 ha (Area 2) ;
- Operation initially 5 in 10 years (Area 1) and 1 in 15 years (Area 2);
- Timed to commence in August (Area 1) and September (Area 2); and
- Total duration of operation assessed to be 3 months of inundation.

The following salt mobilisation processes are relevant to each stage of the inundation process:

<u>During the fill stage</u>

- Wash-off of salt from floodplain soils at Area 1;
- The salt held in the river channel and mobilisation of salt in previously stranded backwaters to be held in the in-stream store up gradient of the environmental regulators; and
- Inflow of saline groundwater to surface water features down gradient of the environmental regulator because downstream areas are completely dry or surface water levels are lower in these areas during operation of the environmental regulator.

<u>During the hold stage</u>

- Inundation of floodplain areas and recharge to the underlying shallow saline groundwater within the floodplain aquifer, creating groundwater mounds beneath inundated areas; and
- Lateral outflow from filled anabranches to the floodplain aquifer.

During the infiltration/evaporation stage

- Lateral inflow of groundwater to the anabranches on the recession; and
- Displacement of saline groundwater to the river and anabranch reaches on the recession where mounded groundwater levels are higher than surface water levels.
- Release of the in-stream store within Chalka Creek system of saline water created during the fill stage.

Fill Stage

The use of flow control structures associated with Area 1 during the fill stage will result in commencement of surface flow in Chalka Creek north of Oateys regulator (water inflow via Oateys regulator) and subsequent inundation of the surrounding floodplain. The area will be inundated to a level of 43.5 mAHD; approximately 4.2 m higher than the estimated bed level of Chalka Creek downstream of the Chalka Creek North regulator (K10 regulator) and is assumed to be dry during environmental watering events. Water build up behind the North Chalka Creek regulator will result in a hydraulic gradient (4.2 m) between the upstream side and the downstream reach of the structure. Assuming there is a connection of Chalka Creek with the shallow groundwater aquifer in this area, this may increase saline groundwater flux around the structures to downstream areas, which could ultimately flow to the Murray River.

Inundation of Area 2 will occur following inundation of Lake Bitterang, either through gravity releases through the proposed Bitterang levee regulator and/or pumping from Oateys (regulator) pool across the levee. The inundation water level (and hence the area of inundation) will depend on whether water is pumped and on the rate of pumping.

Surface flow could result in salt wash-off from floodplain soils, and mobilisation of salt stored along creek beds into the main Chalka Creek channel.

Manipulation of the flow regime through the above actions could result in the mobilisation of salt from any in-channel stores during the fill stage when it would otherwise have been stored until flushed during a period of higher flow

The inundation of the floodplain will also cause some mobilisation from salt stored in floodplain soils.

ANALYSIS APPROACH – FILL STAGE.

Historical flood data linking flows, the area of floodplain inundation and subsequent salt loads in the river post-flooding suggests a total salt flux of 38 kg/ha/day for Lindsay River (Mike Dudding, pers. Comm – reported by SKM (2010a)). Of the total salt flux, the proportion due to wash-off is thought to be approximately 10%; thus reducing the salt flux for this process to 3.8 kg/ha/day. In addition, values of 1 and 5 kg/ha/day were derived during the calibration of a real time salt and water balance model for Chowilla (SKM, 2010b). These salt flux rates are typical of locations downstream of Wallpolla Island; as such these are considered representative only for this assessment.

The magnitude of the salt load associated with lower surface water flow down gradient of the regulator is not considered significant relative to other processes and is not quantified.

Hold Stage

Once the target water level is reached within each structure/project, the water will be held on the floodplain by flow control structures. During the hold stage there will be a continuation of lateral and vertical outflow (infiltration) of surface water to the floodplain aquifer that began in the fill stage.

Using a conservative approach, it may be assumed that during inundation of the floodplain, surface water features are in connection with the underlying Channel Sands aquifer. The maximum inundation level of 43.5 mAHD for Area 1 is approximately 4.2 m higher than the estimated creek bed level in Chalka Creek (39.3 mAHD). Inundation could therefore create a hydraulic gradient that displaces saline groundwater towards Chalka Creek downstream of Area 1; potentially developing a *connected-gaining* situation.

Modelled levels for Area 2 inundation on the northern side of Bitterang levee itself range between 44.94 and 45.11 mAHD; between 5.64 and 5.81 m higher than the estimated bed level of Chalka Creek in Area 1 and between 4.34 and 4.51 m higher than interpolated stage height in the closest reach of the Murray River. However, Area 2 is separated from the Chalka Creek by approximately 4-5 km of floodplain making it likely that evapotranspiration of shallow groundwater would intercept any increase in groundwater flux towards the river across this distance and so is likely to pose very low risk. Evapotranspiration of shallow groundwater is likely to result in some accumulation of salts in the unsaturated zone that may be mobilised in future flood events.

The area of inundation proposed for Area 1 and Area 2 could, over successive events, increase groundwater levels in this area to increase this hydraulic gradient (potentially creating gaining conditions), where saline groundwater is displaced towards Chalka Creek downstream of the regulator. However, no surface water level monitoring occurs on Chalka Creek. This means it is currently not possible to accurately define the level of groundwater level rise required to induce discharge to Chalka Creek. As such, only bed elevations for Chalka Creek estimated from LiDAR are available.

In addition to EC impact at Morgan, an increased salt load also has the potential to impact irrigators that rely on surface water diversions in the local area. This potential salt impact occurrence has been highlighted for further investigation.

ANALYSIS APPROACH – HOLD STAGE.

The rate of recharge to the shallow groundwater system is estimated to be 0.5 mm/day, based on analysis of recharge rates by REM (2006) and previous work by CSIRO on the Chowilla floodplain (refer SKM, 2010). This rate of recharge is assumed to include the volume of water that recharges the aquifer laterally.

If the waterbody is connected to groundwater (that is, underlain by fully saturated material) then a mass balance approach can be used to estimate the total volume of groundwater that may eventually discharge to the surface water system (assuming some is lost because of evapotranspiration). If the waterbody is underlain by an unsaturated zone above the groundwater level then there is a need to estimate the rate of rise and fall of groundwater levels using a method from Hantush (1967). If the groundwater level is estimated to rise above the surface water level then the rate of discharge to a river reach can be calculated using a flow net analysis.

Infiltration and evaporation stage

Once surface water levels decline in Chalka Creek, there will be potential for the inflow of saline groundwater to the system that is derived from the following processes that occurred during the hold stage:

- Diffuse recharge and groundwater level mounding; and
- Lateral outflow from anabranches to the Channel Sands aquifer.

Floodplain groundwater levels are lower now than during the 1990s due to the lack of floods that recharge the groundwater system. A number of inundation events will be required at a frequency similar to 1980 to 1990 flows before groundwater levels return to their former heights. At this time groundwater discharge to surface water features may again be possible.

For the purpose of this analysis it is conservatively assumed that immediately on the cessation of the hold stage 100% of the recharged water (on a monthly time step) will eventually return to the receiving feature (in this instance Chalka Creek). As the water held in the feature diminishes, the percentage return to the creek at each time step in the analysis is assumed to also diminish at a set rate to mimic the fall in groundwater gradients and consequent decline in groundwater discharge. This process occurs over a 12 month period at which time all discharge ceases.

In reality, the volume of groundwater discharged may be lower than 100% of recharge if water is lost to evapotranspiration. It is likely that evapotranspiration is a major component of groundwater discharge in these floodplain environments, however, it has not been accounted for in the assessments below. In some cases evapotranspiration may account for all groundwater discharge and in these cases the long term sustainability of the environmental assets must be questioned. The percentage discharged under current conditions is likely to be much lower because of poor connection with the river system (that is, groundwater levels lower than receiving features) and a significant width of the floodplain leading to increased opportunity for evapotranspiration.

ANALYSIS APPROACH – INFILTRATION AND EVAPORATION STAGE

The mass of salt released from in-stream storage in the spill stage is calculated under current conditions. A nominal 100 EC difference will be adopted between upstream and downstream surface water salinity. These EC values are multiplied by an assumed in-stream water volume to estimate salt load.

The salt load from wash-off is calculated using the approach described in the fill stage.

The volume of recharge to the groundwater from a floodplain watering event displaces a lesser volume of higher salinity groundwater to the adjacent watercourse. If the recharge volume can be calculated, then a corresponding salt load to the river can be inferred. This is similar to the nomogram approach described in the Murray Darling Basin Commission (MDBC) Salinity Impact Assessment Framework for the Living Murray Environmental Works and Measures Program (Fuller & Telfer, 2007). It is expected this salt load will occur over a 12 month period following inundation.

It is assumed 100% of recharge is discharged to the river system during the period of inundation and it is also assumed this accounts for the groundwater that is discharged as a result of diffuse recharge via the floodplain aquifer. It is further assumed that the rate of discharge will fall in a decreasing manner from 100% immediately at the end of the inundation period to zero in month 12 following the hold stage. This decay in the rate of return of recharge water reflects diminishing area of inundation and diminishing hydraulic gradient to the surface water system.

▪ **Table 4.3: Floodplain process and analytical methods used for Hattah Lakes**

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
Hattah Lakes Area 1 (Chalka Creek North floodplain). Inundate to a level of 43.5 mAHD over an area of 420 ha	Salt in surface water mobilised during draining of creeks Recharge of shallow saline groundwater and displacement of saline groundwater to Chalka Creek.	In –channel release of salt load Mass balance approach for the inundated area. Mound build up estimated and flow net is used to estimated salt load from mound to creek	Low	Limited bore data available to verify groundwater salinity, groundwater flow and response to recharge.
Hattah Lakes Area 2 (Floodplain north of Bitterang Levee).	Recharge of shallow saline groundwater and displacement of	Mass balance approach for the inundated area.	Low	Limited bore data available to verify groundwater salinity,

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
Inundate to a level of 45.0 mAHD over an area of 710 ha	saline groundwater to Chalka Creek.	Mound build up estimated and flow net is used to estimated salt load from mound to creek		groundwater flow and response to recharge.

- **Figure 4.11: Hattah Lakes environmental watering locations**

- **Figure 4.12: Hattah Lakes schematic of operating levels**

4.5. Results and assumptions

4.5.1. Salt wash off

Estimated salt flux associated with the initial wash-off of salt was calculated for the maximum area of inundation for Area 1 (393 ha). The calculation was undertaken assuming salt capture of 1, 3.8 and 5 kg/ha/day.

Estimates of salt load and EC impacts at Morgan are summarised in Table 4.4 for each process, and these indicate that impacts from salt wash-off are negligible.

- **Table 4.4: Predicted salt load and EC impact at Morgan (relative to the *basecase*)**

Salt wash-off rate (kg/ha/day)	Salt load (t/d) ^	EC impact at Morgan ^
1	0.39	0.0014
3.8	1.5	0.0054
5	2.0	0.0071

Note: ^ These values have been corrected since the previous version (Final, September 2013) of the report. The previously reported results were considered to be negligible.

Key assumptions:

- Release of water occurs at a constant rate over a 30 day period in August);
- Instantaneous transfer of salt from the whole of the inundated area to Chalka Creek occurs (that is, reaches equilibrium within one day);
- There is no significant salt load delivered to Chalka Creek through salt wash-off under *basecase* conditions; and
- Salt flux rates of 1, 3.8 and 5 kg/ha/d are typical of downstream conditions (i.e. Lindsay and Chowilla floodplain). As such these are representative values only.

4.5.2. In channel release

The magnitude of the salinity impact at Hattah Lakes due to transport of salt stored in the stream channel upstream of the regulators is proportional to the assumed difference in salinity upstream and downstream (100 EC). The channel geometry of Chalka Creek was assumed to be 10 m wide and 5 m deep for the purpose of this assessment.

The EC impact at Morgan is calculated to be 0.003 for Area 1.

Key assumptions:

- Release of salt to the system downstream of the regulator occurs at a constant rate over a 30 day period in August;
- Instantaneous transfer of salt occurs from the whole of channel system to Murray River;
- Conservatively assumed that all salt contained in the channel is released although some salt may remain in the channel under normal flow;
- The geometry of the channel along its length is assumed to be uniform and can be represented by a rectangular section that is 10 metres wide and 5 metres deep; and
- There is no significant salt load delivered to the Chalka Creek through salt wash-off for the *basecase*.

4.5.3. Floodplain inundation (recharge and displacement)

Floodplain inundation at Area 1 will be achieved by inundating to a top water level of 43.5 mAHD resulting in an area of inundation of 393 ha of floodplain. Inundation at Area 2 will be achieved by inundating to a top water level of 45.0 mAHD resulting in an area of inundation of 710 ha of floodplain.

A conservative estimate of the salt load and EC impact at Morgan is made assuming initially 100% of the recharged water is discharged to Chalka Creek from groundwater during the first four months following inundation. The amount of diffuse recharge eventually discharging to the Creek is assumed to gradually decline from 100% in the 3rd month to zero in the 12th month following inundation.

Values of less than 100% for the amount of recharge that ends up discharging to the feature may be expected where evapotranspiration from groundwater occurs before it reaches Chalka Creek. As well, it is unlikely 100% of recharge from Area 2 will discharge to Chalka Creek because there is likely to be flow to the west as shown by hydraulic gradients further south in the Hattah area.

Groundwater salinity in the Channel Sands aquifer that discharges to Chalka Creek varies significantly across Hattah Lakes, as evident in Figure 3.10. Bore 7866 on the northern extent of Area 1 is screened in the Parilla Sands aquifer but has a groundwater salinity comparable to that of the Channel Sands (4.96 mS/cm, April 2012). Bore MW3a is located 7 km upstream along Chalka Creek and has a reported salinity of 29.0 mS/cm (February, 2012). As such, both salinity values were used in the assessment as a way of providing an indication of the likely upper and lower values for discharge to Chalka Creek. Results are summarised inTable 4.5.

Table 4.5: EC impact at Morgan for varying groundwater salinities

Location	4.96 mS/cm	29 mS/cm
Area 1	0.07	0.42
Area 2	0.02	0.1

Further assessment or modelling would be required to determine if/when higher salinity groundwater would potentially discharge into Chalka Creek. For the purpose of this assessment it is recommended that a salinity value of 4.96 mS/cm is used.

Key assumptions:

- The recharge due to inundation would last 3 months;
- Saline groundwater will discharge to the Creek for a 12 month period (based on observation of this process in other floodplains – e.g. Chowilla);
- The amount of diffuse discharge to the Creek will decline linearly at the end of the inundation period from 100% to zero;
- The salinity of groundwater discharging remains constant over this period;
- Groundwater salinity discharging to Chalka Creek is 4.96 mS/cm, but could increase over time following successive watering events;
- Recharge rate is uniform spatially and temporally in the area of inundation; and
- There is no significant salt load delivered to Chalka Creek through diffuse recharge and displacement of saline groundwater under the *basecase*.

4.5.4. Retention of water

As a comparison another method was used to estimate the EC impact. This method involves estimating the height of groundwater levels beneath the inundated area and using these to generate a new groundwater gradient (and hence discharge) to the River.

The starting groundwater level beneath Area 1 is assumed to be 36.1 mAHD (measured approximately 5 km to the north-west of the area; Bore 7858, May 2009). Groundwater mound rise calculations estimated a rise in groundwater levels of 2.12 m (to 38.2 mAHD) after 300 days beneath Area 1 as a result of filling this area to a level of 43.5 mAHD.

Given the shape of Area 2, combined with the 4-5 km width of floodplain to the Chalka Creek, mound rise calculations were not applicable to this site.

It is assumed that the groundwater level will fall at a constant rate in the following 300 day period.

The salt load from a mound beneath Area 1 to Chalka Creek below the regulator is estimated using the creek bed elevation of 39.3 mAHD, which itself is estimated from LiDAR. Stage height information is not available for Chalka Creek. As this assessment is based on the creek bed elevation, this is likely to result in an over-estimate of EC impact at Morgan.

The flux of groundwater and salt load was estimated at 30 day time steps during the period of groundwater level rise and fall. Each monthly salt load was converted to an EC impact at Morgan. The salt load was calculated using a salinity value of 4.96 mS/cm (measured approximately 1.8 km to the north-east of the inundation area in Bore 7866, April 2012).

Estimated mound rise was not large enough to raise groundwater levels above the bed level in Chalka Creek (average 39.3 mAHD in the vicinity of Area 1).

The salt load calculations were re-run assuming the starting groundwater level beneath Area 1 is close to 1994 levels (37.4 mAHD) taken from Bore 7858. Mound rise calculations showed the groundwater level to be above the Creek bed level after 300 days (39.5 mAHD; only 20 cm above bed level). Based on this alone, a flow net analysis estimates the salt load to Chalka Creek to reach a maximum of 0.002 t/d after 300 days with an impact of 1.3×10^{-3} EC at Morgan under 5 in 10 year event.

However, it is likely that stage height in the Creek would exceed 20 cm in height when inundated. This would suggest losing conditions would prevail at this site and there would be no groundwater discharge to the Creek based on 1990s groundwater levels.

Key assumptions:

- The salinity of groundwater discharging to Chalka Creek below the regulator remains constant over time;
- Groundwater levels due to mounding rise and fall at a constant rate over 300 days;
- The salt load for the '1990s case' was estimated assuming that groundwater levels beneath the inundation areas fall at a constant rate over the 300 days; and
- Groundwater salinity discharging to Chalka Creek is 4.96 mS/cm, but could increase over time following successive watering events.

4.5.5. Total salinity impacts

The total salinity impact at Morgan of implementation of environmental watering at Hattah Lakes is estimated to 0.07 EC for Area 1 and 0.02 EC for Area 2, based on 5 in 10 and 1 in 15 year frequency respectively.

The components of the salt load and EC impacts relative to the *basecase* are summarised in Table 4.6. The largest component of the salinity impact is associated with the displacement of groundwater due to diffuse recharge following inundation, but even this impact is insignificant. This calculation is considered conservative as it assumes uniform salinity values across the inundation area.

Even though estimates of salinity impacts are provided for Area 2 it is likely that a portion of the recharge in this area would flow to the west, driven by elevated groundwater levels in the irrigation to the north. Thorne *et al*. (1990) presents groundwater contours (March 1987) which indicate this south-westerly groundwater flow direction towards Raak Plains.

The estimate of low EC impacts at Morgan is largely because groundwater along the northern end of Chalka Creek is assumed to be low salinity, as indicated by groundwater salinity measurements collected from a bore near the creek. Additional measurement of groundwater salinity along Chalka is recommended prior to developing future estimates of salinity impacts.

The discharge of saline groundwater to Chalka Creek will be mitigated by holding water in-place while it evaporates and seeps away, rather than releasing water at the outlet and creating a groundwater gradient to Chalka Creek on the recession. The slow fall in surface water levels in Chalka will mean they will remain in equilibrium with the nearby groundwater level resulting in a smaller flux of groundwater to the creek.

- **Table 4.6: Summary of salinity processes and EC impact associated with Hattah Lakes**

Salinity process	EC impact at Morgan	
	Area 1	Area 2
Salt wash off	Negligible	Negligible
In channel release	0.003	N/A
Recharge and displacement	0.07	0.02
Retention of water lake/wetland	N/A	N/A
TOTAL	**0.07**	**0.02**

Over time, and subsequent flooding events, the *basecase* groundwater level is likely to gradually increase, which may result in gaining stream conditions becoming more pronounced and extensive along this reach, especially if irrigation in the area continues to increase groundwater levels in the north, thereby sustaining a localised groundwater flow towards the Murray River.

There may be some potential for discharge of saline groundwater to wetlands if groundwater levels rise in low lying areas. These areas cannot be identified at this stage due to lack of data on groundwater depth.

4.6. Cumulative impacts

It is expected that multiple watering events will occur at each site over time.

It is known that groundwater levels below the Hattah Lakes floodplain are lower now than during the 1990s when more frequent flooding occurred, but the amount of salt within the Chalka Creek that could be mobilised is lower now than in the 1990s. This suggests that the salt load impact of environmental watering may be less now than if it occurred under conditions representative of the 1990s.

It is expected that successive watering events coupled with natural flood events could return groundwater conditions and salt store to that seen in the 1990s. This '1990s condition' can be viewed as being representative of the 'cumulative impact' of implementation of a large scale sequence of watering events, that is, it represents the maximum salt impact condition.

The ability to quantify the cumulative impact using the analytical approaches used in this project is limited.

The cumulative impact (in terms of EC impacts at Morgan) is estimated to be less than 0.1 EC at Morgan.

4.7. Off-stream impacts

Schedule B requires that an assessment be made of the short and long term risks of impacting on the salinity status of off-stream environments.

The discharge complexes in this region are already saline and any increase in flux to the sites will not salinise the sites *per se*. Secondly, the flux to the west though increasing over the current flux rate, may only approach the historical flux rate due to *normal* rates of flooding across the floodplain. It can be argued that any impacts to saline areas to the west are commensurate with *natural* conditions over the time since the Murray River was regulated.

4.8. Monitoring

The proposed monitoring program is comprised of groundwater and surface water monitoring and aims to provide data that can be used to better define the mechanisms and magnitude of salinity impact arising from the proposed environmental watering events. The monitoring data should form the basis of five-yearly reviews as required under the Basin Salinity Management Strategy, allowing refinement of the salinity impact estimates.

The monitoring program reflects the need to gather data both for the improvement of understanding of the key processes, but also to allow independent review of accountability for operating any works and measures. Monitoring should also be maintained to assess the benefits of environmental watering.

In order to measure salinity impact from the floodplain operations, monitoring periods should be chosen to cover current conditions, floodplain operations, and post-operation conditions. The former provides the opportunity to assess baseline conditions, including salt loads against which to measure the impact of operations. The latter is important because it is likely that the floodplain response would be delayed, with salinity impacts extending beyond the period of floodplain operations. Continuous monitoring will ensure that all impacts due to actions can be assessed against *basecase* conditions as well as highlight any changes in the baseline over time.

All groundwater levels should be expressed relative to Australian Height Datum to allow comparison of groundwater and surface water data.

4.8.1. Groundwater monitoring

Water level and salinity data from groundwater monitoring wells completed in the Channel Sands aquifer in the vicinity of inundation areas, retention sites and other identified impact hotspots should be collected before, during and after each environmental watering event. This is most important for wells that are situated adjacent an inundated area and near the potential receiving surface waters. Salinity measurements at the very top of the saturated thickness (adjacent the discharging site) will allow an assessment of the salt content of the water that will be moving as a result of the action and indicate any freshening of groundwater that may occur.

Table 4.7 shows the groundwater monitoring bores targeted under the program. This has been based upon the distribution of bores that are currently being monitoring for groundwater level and/or salinity by Mallee CMA.

In general, the current bore distribution spans the length of the Hattah Lakes floodplain. Monitoring at these bores will provide useful information for areas not affected by watering events. It will be useful to gain additional information at the vicinity of the proposed inundation areas. The location of proposed additional monitoring bores is presented on Figure 4.6, which forms an east-west transect between Area 1 and Area 2. An additional bore is suggested downstream of the Area 1 below the regulator. New bores associated with Area 1 would be the priority, given the initial frequency of watering events proposed for Area 1 (5 in 10 years) over that at Area 2 (1 in 15 years).

All bores are recommended to be monitored for groundwater level and salinity at daily intervals before, during and after events that change the hydraulic regime and at weekly intervals at other times.

- **Table 4.7: Groundwater monitoring sites at Hattah Lakes**

Bore ID	Easting	Northing	Proposed monitoring parameters (water level, salinity, loggers)
Channel Sands			
7022	624432.2	6174063	Level, salinity
7027	623340.2	6176545	Level, salinity
7029	627314.2	6175837	Level, salinity
7682	621603.2	6170509	Level, salinity
7853	625421.2	6171877	Level (logger), salinity
MW1	634769	6164352	Level, salinity
MW3a	628956	6163210	Level, salinity
Blanchetown clay			
26276	625921.2	6151577	Level, salinity
7014	615488.2	6177016	Level, salinity
7017	616469.2	6170351	Level, salinity
7021	619303.2	6176906	Level, salinity
7856	630621.2	6171877	Level, salinity
MW2	631918	6160713	Level, salinity
MW4	626737	6160922	Level, salinity
MW5	622632	6159545	Level, salinity
7852	625421.2	6171877	Level, salinity
Parilla Sands			
7852	625421.2	6171877	Level, salinity
7866	630621.2	6171877	Level, salinity
26243	638721.2	6150077	Level, salinity
26257	636121.2	6149977	Level, salinity
26258	636121.2	6152977	Level, salinity

Bore ID	Easting	Northing	Proposed monitoring parameters (water level, salinity, loggers)
26259	636621.2	6153977	Level, salinity
26260	636921.2	6154477	Level, salinity
26261	637121.2	6154877	Level, salinity
MW3b	628962	6163223	Level, salinity
MW5a	622632	6159545	Level, salinity
Suggested additional monitoring bores			
Bore 1	623568	6168997	Level, salinity
Bore 2	627936	6168974	Level (logger), salinity
Bore 3	629545	6168926	Level (logger), salinity
Bore 4	631778	6168901	Level (logger), salinity
Bore 5	631346	6170774	Level (logger), salinity

The frequency of monitoring should ideally be daily to weekly depending on the rate of water level response (if any) in a given monitoring well to a watering event. If changes in standing water level attributable to floodplain watering are observed, then monitoring frequency should be increased accordingly. It is recommended that the high priority groundwater observation wells are monitored for water level daily, especially just before, during and post inundation. At the very least, under *basecase*, regulated conditions, observations should be collected at least every three months from these wells.

Consideration should be given to the use of automatic down-hole loggers for recording responses to watering events, which are especially useful where wells may become stranded. Additional benefits include recording of subtle impacts that may not be seen from relatively sparse observations. In response to the planned inundation areas for this assessment, data loggers are suggested for sites immediately down gradient; 7853 and 7029, 7856 (Blanchetown Clay) and four new monitoring sites (Bores 2 – 5).

The key will be to identify the peak groundwater level as a result of inundation, but also to record the initial *basecase* and post inundation response as the lake water levels recede. If data loggers are available, the most beneficial locations would therefore be in the bores closest to the area of inundation, as listed above.

If costs cannot be met for monitoring it is recommended that fewer locations are chosen and an emphasis placed on collecting more comprehensive time series data.

4.8.2. Surface water monitoring

Ideally, surface water monitoring would provide sufficient data to calculate salt load to reaches of flowing anabranches or the Murray River adjacent to areas of floodplain watering. This is possible when pre-existing surface water monitoring stations are available.

A single surface water monitoring gauge is active adjacent Hattah Lakes and is located at Colignan, north of the inundation areas. This gauge holds a short period of record, spanning 1996 to 2008 and is only monitored for salinity. Table 4.8 details site information.

It would be useful to gain additional surface water data (flow, level and salinity) along Chalka Creek, in particular associated with proposed regulator sites.

- **Table 4.8: Existing surface water monitoring sites**

Site ID and description	Monitoring parameters
414207 – Colignan	Water level, flow, salinity

To reduce uncertainties relating to *basecase,* inundation across the Hattah Lakes floodplain and associated NSW floodplain, as well as the level of connection to the surface water network, observations and survey of Chalka Creek and wetlands would improve the conceptualisation of the *basecase* conditions. In particular, observations around any wetlands or depressions considered to be potential sources of significant salt load to the River would inform future refinements of the salinity impacts of watering actions. It is assumed that water level data will be collected at each regulator. An assessment is needed for possible areas of surface discharge due to the paucity of data in the areas of Hattah proposed for inundation.

It is recommended that stage height monitoring be undertaken at a series of locations along Chalka Creek (expressed relative to Australian Height Datum). Where existing groundwater monitoring bores are sited along creek lines, it would be useful to gauge stage height to aid in comparison between surface water and groundwater levels at a particular location.

Surface water observations are especially important at the inlet and outlet structures (i.e. K10 Regulator at Area 1). Surface water salinity and flow should be monitored at such locations to assess the impact of watering events and calculate likely salt loads to the system. Flow gauges should be installed at the inlet and outlet structures. Monitoring should occur before, during and after the watering event. The length of time and frequency of monitoring can be assessed as data is collected and assessed. Initially monitoring should occur at a monthly frequency.

- **Figure 4.13: Hattah Lakes suggested monitoring locations**

5. Belsar and Yungera

5.1. Hydrology

Belsar and Yungera Islands are located approximately 20 km upstream of the Euston Weir, near Robinvale (GHD, 2012). Belsar Island represents the area between Narcooyia and Bonyaricall Creeks and the Murray River, while Yungera Island is bounded to the south by Yungera Creek (Figure 6.1). The system is located on the southern bank of the Murray River where the River flows predominantly from east to west. Significant hydrological features in this area include Lake Powell and Lake Carpul, situated to the south-west of the Islands and Lake Carphole on Belsar Island adjacent the River. The system of creeks and waterways which form Belsar and Yungera Islands are predominantly influenced by water levels in the Euston Weir.

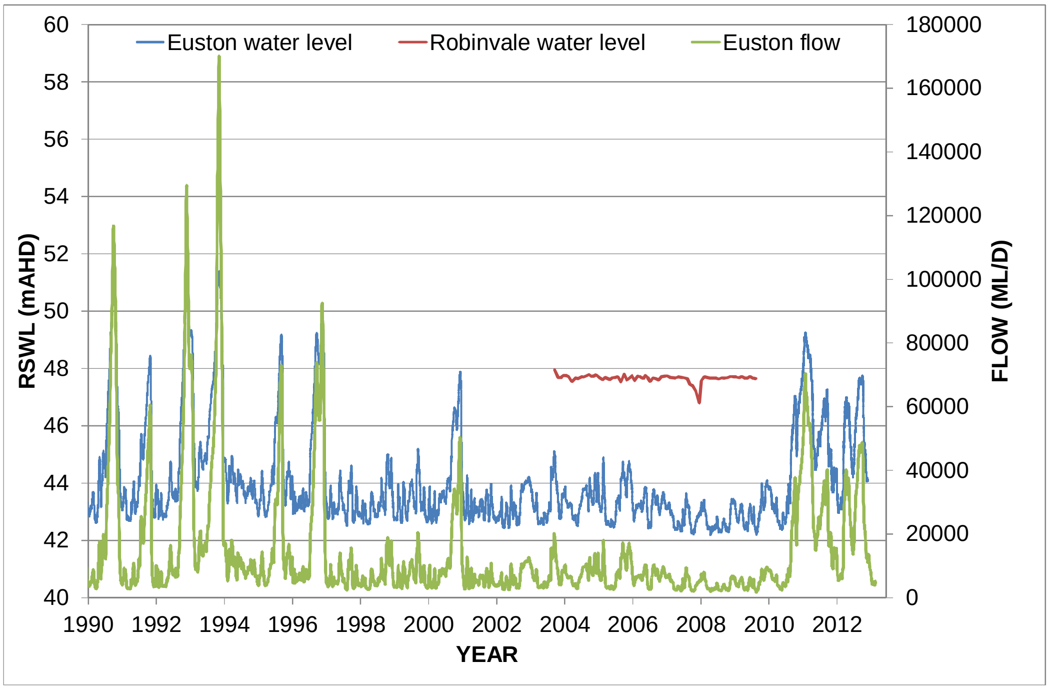
Ultimately, all surface flow across Belsar and Yungera Islands returns to the Murray River via Narcooyia and Bonyaricall Creeks.

Water levels downstream of Euston Weir experience seasonal fluctuation (Figure 5.2). Surface water levels at Robinvale (414205) have remained relatively stable over the short period of record available. This gauge is located 14 river km upstream of Euston Weir/Lock 15 and is under influence from the weir pool. Increased flow events have been observed through the system since 2010. The latest monitoring data indicates that stage height in the River at Robinvale is approximately 47.6 mAHD.

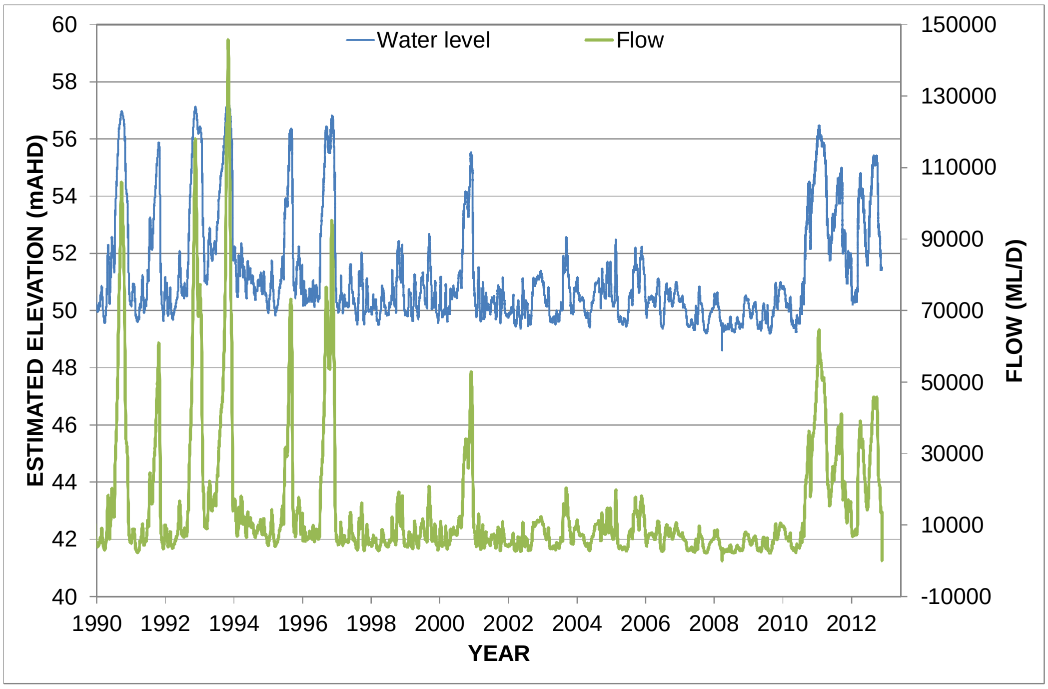
This same trend in Murray River water level and flow has been experienced at Boundary Bend (gauge 414201), located approximately 13 km upstream of Yungera (Figure 5.3). The GMS database only provided these records as depth rather than relative to Australia Height Datum. The elevation listed in GMS for this stream gauge was equivalent to bank height. LiDAR was used to estimate bed level (48.6 mAHD) and subsequently likely stage height in the Murray River (50.0 mAHD, March 2012). This level is estimated for average flow conditions.

The minimum stage height recorded at Boundary Bend was 49.2 mAHD in March 1988 when daily flow was measured at 1,551 ML/d. Water level at Robinvale remains stable as is under influence from Euston weir pool. This equates to an estimated stage height adjacent Belsar Yungera of 48.2 mAHD. This may represent a worst case scenario for stage height adjacent Belsar Yungera.

- **Figure 5.1: Location of key features at Belsar Yungera**



▪ **Figure 5.2: Surface water level at Robinvale (414205) and water level and flow downstream of Euston Weir (414203)**



▪ **Figure 5.3: Surface water level and flow upstream at Boundary Bend (414201)**

There is no stream gauge in the vicinity of Belsar Yungera. For the purpose of this assessment, stage height in the Murray River adjacent Belsar Yungera is conservatively assumed to be 50.0 mAHD using an interpolation between the upstream (Boundary Bend) and downstream (Robinvale) gauges.

5.1.1. Creek Systems

Narcooyia Creek spans 17 km in length across Belsar and Yungera and is managed primarily as an irrigation channel for water users in its middle and upper reaches (GHD, 2012).

Bonyaricall Creek is a tributary off the lower section of Narcooyia Creek. This Creek is under the influence of Euston Weir, but exhibits sections of disconnection from the weir pool as siltation has gradually increased in extent along the Creek (GHD, 2012). Some irrigation infrastructure is established on Bonyaricall he Creek.

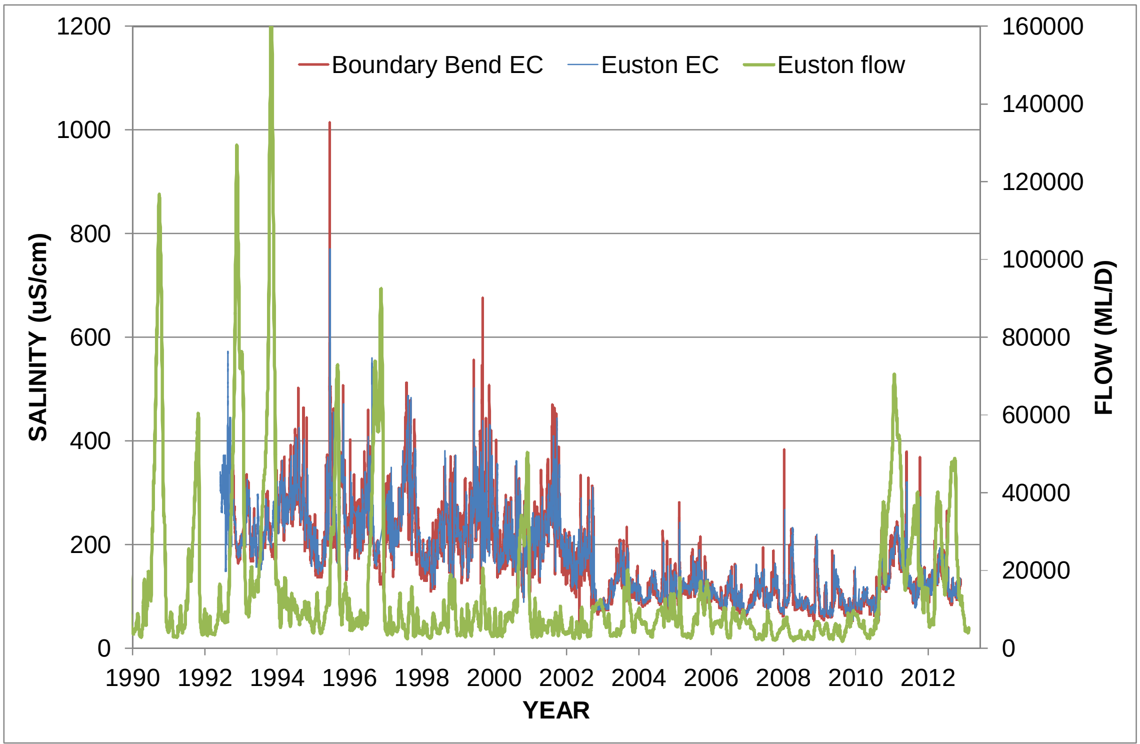
Lake Powell and Lake Carpul are ephemeral wetlands on the floodplain and are highly dependent on flood waters from the Murray River for inundation (GHD, 2012), which occurs via a floodway via Boonyaricall Creek. Watering began in late July 2011 to fill both Lake Powell and Carpul (Mallee CMA, 2013).

5.1.2. Analysis of surface flow and salinity

Figure 5.4 shows salinity records at upstream and downstream sites together with Lock 15 downstream flow.

Flow data shows a number of high flow events up until early 2000, and then a period of very low flows (< 20,000 ML/d). High flow events have been experienced since 2010.

The data shows that salinity at Boundary Bend (upstream) and Euston Weir (downstream) behave in the same manner. During the 1990s higher flow period, salinity ranged between 0.2 and 0.4 mS/cm. Murray River salinity was at its lowest during the low flow period between 2003 and 2010.



- **Figure 5.4: Surface water salinity upstream (414201)and salinity and flow downstream (414203)**

5.2. Hydrogeology

5.2.1. Background

The Murray River incised through the Mallee landscape late in the Quaternary period in response to sea level falls, producing a relatively narrow trench typically 5 to 10 km wide. This trench backfilled as base levels were re-established.

On the floodplain, the basal unit filling the trench beneath the Woorinen Formation is the Channel Sands which is overlain with the finer grained Coonambidgal Formation. The latter contains fined grained silts and clays ranging in thickness up to 5 m across the floodplain. The Channel Sands is made up of fine to coarse-grained sands and is in direct connection with the Murray River.

The Channel Sands aquifer lies directly above the regionally extensive Parilla Sands aquifer but is separated by varying thicknesses of Blanchetown Clay. Where present, the Clay can act as an aquitard and reduce the vertical interaction between the Channel Sands and Parilla Sand. The extent and thickness of the Blanchetown Clay will be a key control on the possible salt impact of floodplain watering activities.

Thorne *et al,* (1990) prepared hydrogeological cross-sections which span the length of the Murray River from the South Australian border through to Nyah.

Transect S from Thorne *et al* (1990) is sited 2 km to the east of Yungera Island. Here the Murray River is incised into the Channel Sands aquifer, which has an approximate thickness of 15 m (Figure 5.5). In the vicinity of the River, the underlying Blanchetown Clay is about 5m thick, and is further underlain by Parilla Sand.

For the purpose of this assessment it is assumed that the Channel Sands aquifer is present across the whole of the works and measures area.

5.2.2. Groundwater level

Groundwater level data has been collected at several sites across Belsar and Yungera Islands. The location of bores that are currently being monitored (2008 to present) is shown in Figure 5.6. Four bores are monitored in the immediate vicinity, but are located on the edges of the floodplain. No monitoring is occurring within the floodplain. Data indicated that there has been a slight increase in groundwater levels since 2010.

Summer 2012 groundwater elevation data for the Channel Sands aquifer shows that the groundwater level in the shallow aquifer is between 49 and 51 mAHD in the east of the floodplain, and 48 mAHD in the west.

Depth to groundwater in the Channel Sands ranges from 4-6 m bgl (March 2012).

High flow events occurred in the Murray River system between 2010 and 2012. It is difficult to establish if (or when) groundwater flow patterns have changed over this time due to the infrequent groundwater level monitoring and overall lack of monitoring bores in the area. It is anticipated that watering events and increased flows would have induced recharge to the Channel Sands aquifer as a result of the increased hydraulic gradient, but the degree of change cannot be estimated.

Groundwater timeseries data indicates a rise in groundwater level in bores either side of Belsar and Yungera Islands post 2010 (Figure 5.6). Recent rise in groundwater levels could be attributed to increased surface water flow through the system, however there is a lack of surface water monitoring sites in this area to confirm this is the case.

- **Figure 5.5: Transect S (Thorne *et al,* 1990)**

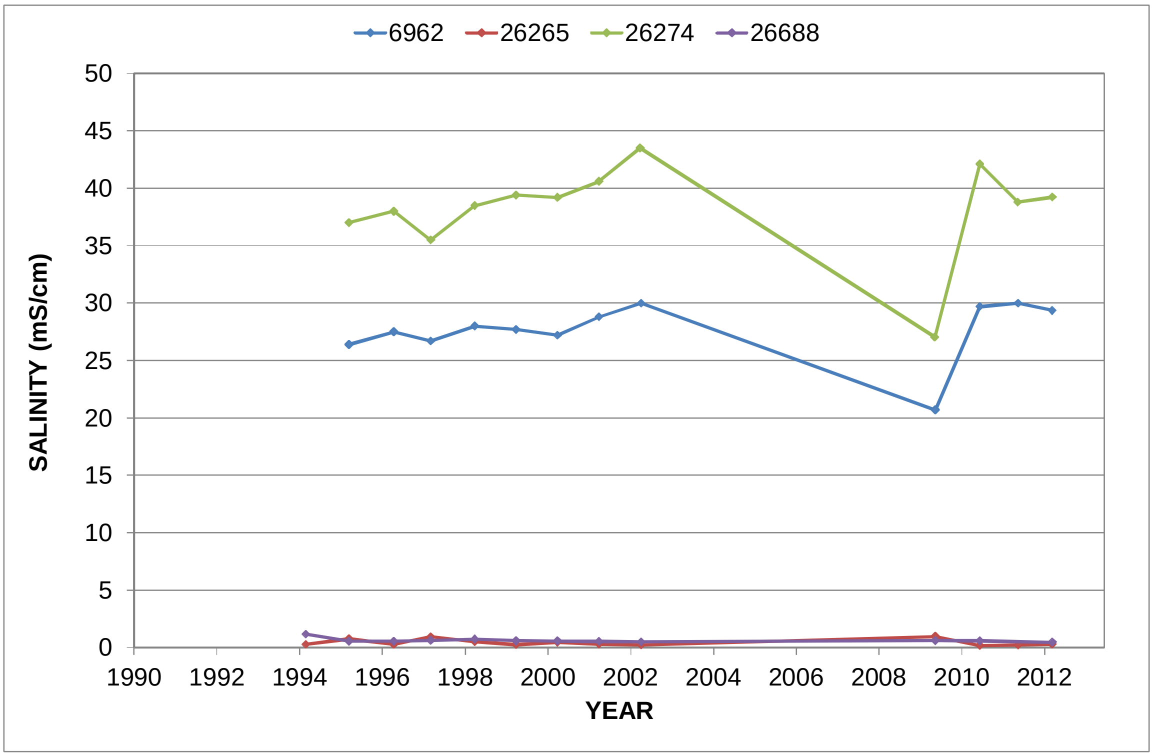
- **Figure 5.6: Current monitoring at Belsar Yungera**

Fluctuations in groundwater levels occur as river stage fluctuates, due to leakage from the River when the stage is high. This process is likely to be widespread in close proximity to the River where it is not influenced by weir pools. This is evident in Bore 26265 located on Yungera Island, adjacent the Murray River.

5.2.3. Groundwater salinity

Figure 5.7 shows groundwater salinity time series data for selected monitoring sites across Belsar and Yungera Islands.

Lowest groundwater salinity was observed in the east of the area in Bore 26265 (adjacent the Murray River) and Bore 26688 (< 2 km south of the River) with Feb-Apr 2012 groundwater salinity levels < 0.5 mS/cm respectively. This correlates to Murray River salinity suggesting losing conditions in this region (Figure 5.4). Further south of the River (Bore 6962), and to the west of Belsar Island (Bore 26274), higher groundwater salinity is observed. A similar trend was observed in both, with declining salinity levels between 2002 and 2009, followed by a distinct increase after this time in both bores.



■ **Figure 5.7: Belsar Yungera groundwater salinity**

An aerial electromagnetic (AEM) survey was undertaken during Feb-March 2008 (BRS, 2009). An AEM depth slice (as apparent bulk electrical conductivity) averaged over the upper 30 m of saturation in the shallow aquifer is shown in Figure 5.8.

The AEM data infers that a lower salinity zone exists either side of the Murray River and along the length of Narcooyia Creek and anabranches. These lower salinity areas are representative of zones where there is localised recharge to the groundwater system through the river banks. Some higher salinity areas are inferred to exist; for example adjacent Lake Powell and in the east of the target area.

5.2.4. Groundwater – surface water interaction

The location and magnitude of the salinity impact depends in part of the degree of connection between the shallow floodplain aquifer, and the Murray River and anabranches. Greatest impacts are possible where the surface water system gains groundwater. This section provides a summary of the nature of the connection based on existing information.

Where groundwater elevations are higher than surface water elevations, river reaches are defined as potentially *connected – gaining* systems. Where groundwater elevations are lower than surface water elevations, river reaches are defined as potentially *connected – losing* systems. Where the anabranches are permanently inundated and groundwater elevations are lower than the base of the river bed, river reaches are also defined as potentially *connected – losing* systems.

Bed elevations for watercourses across Belsar and Yungera (Narcooyia, Bonyaricall and Yungera Creeks) were extracted from a LiDAR coverage and show the base generally ranges between 47 and 50 mAHD across the floodplain. March 2012 groundwater monitoring indicates a groundwater level of 44.5 mAHD to the east of Yungera Island (Bore 26688). The estimated depth to groundwater level in the Channel Sands beneath Yungera and Narcooyia Creek suggests likely losing conditions prevail with bed elevations above the groundwater level.

Groundwater salinity at this site is in the order of 0.5 mS/cm suggesting discharge from the Murray River to the Channel Sands aquifer at this location.

There is potential for hydraulic connection between the creeks and groundwater if the groundwater level is above that of the creek bed level. However, the current lack of monitoring in the Channel Sands aquifer means the nature of interaction cannot be accurately quantified.

Stage height in the creek systems would need to be quantified to accurately assess the nature of connection between surface water and groundwater level in the Channel Sands.

For this assessment, Narcooyia, Bonyaricall and Yungera Creeks are conservatively assumed to be in connection with the groundwater in the Channel Sands aquifer.

The 2006 NanoTEM (Telfer *et al*., 2006; Figure 5.9) survey shows the vertical profiles displaying the resistivity data collected along the Murray River. Low resistivities (red to yellow) indicate areas that are conductive, (that is, they are interpreted to hold saline water and/or be composed of clay). The resistive areas (blue through purple) are interpreted to be generally fresh water in sands (Telfer *et al*., 2006). Belsar and Yungera Islands are sited between 1170 and 1185 river km. Here, the vertical profile is quite resistive indicating generally fresh groundwater and predominantly losing conditions.

- **Figure 5.8: Average apparent bulk electrical conductivity for a 30 m interval immediately below groundwater surface**

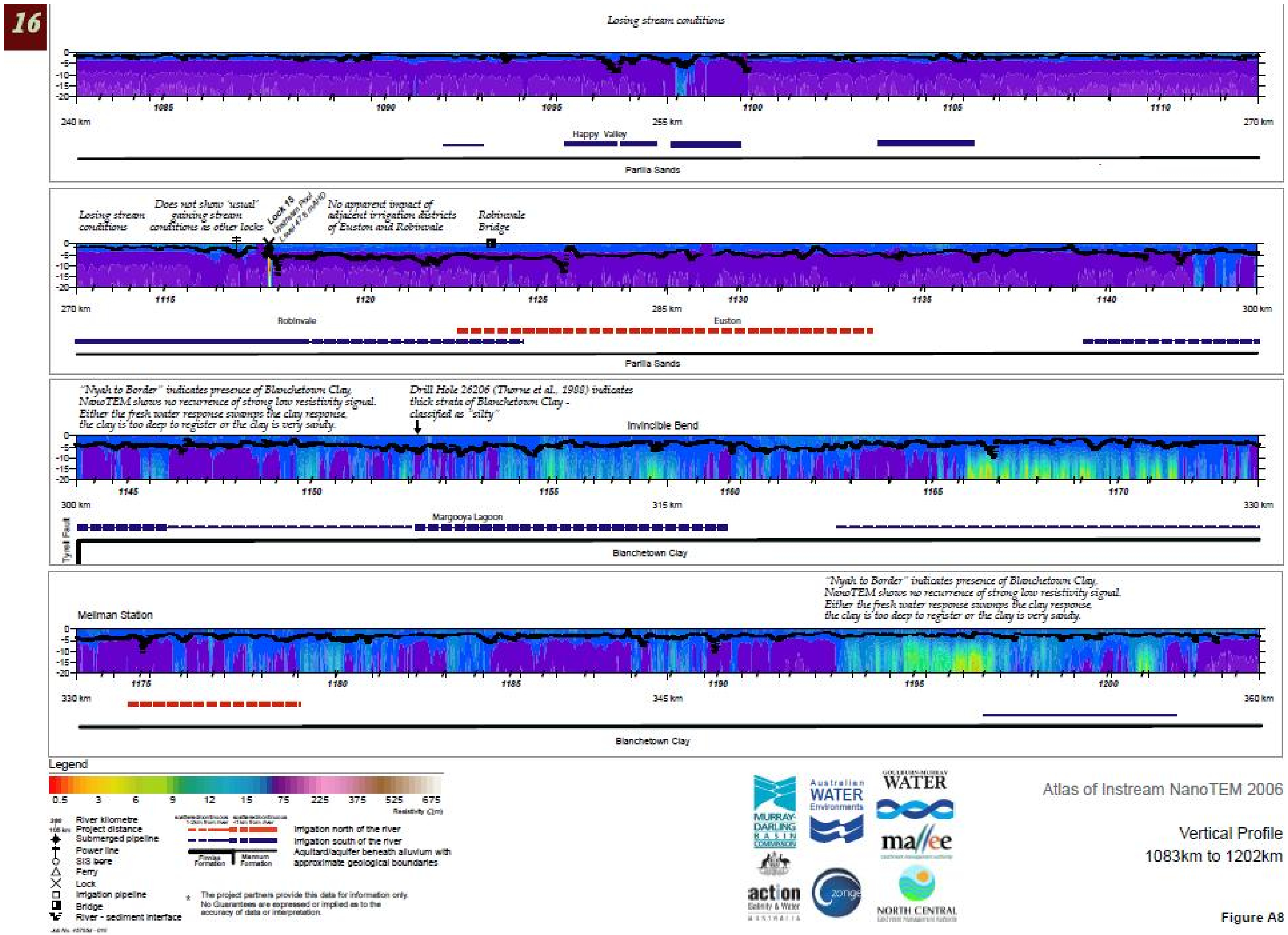


Figure 5.9: Vertical profile of 2006 Nano TEM survey along Murray River, map reference 16

5.3. Environmental works and measures

GHD (2013) outlined potential areas that may benefit from inundation and flow control (presented in Figure 5.10 and summarised in Table 5.1). The associated works and measures related to their inundation are discussed below. This includes the Primary option (spanning the majority of the Island area) and secondary/complementary options which may include J1 Creek, Lake Powell and Lake Carpul.

A schematic of the key water levels on the floodplain is presented in Figure 5.11.

5.3.1. Belsar Yungera Floodplain – primary option

This option proposes the installation of two major environmental regulators at the upstream and downstream ends of Narcooyia Creek, a large regulator on Yungera Creek, channel works to connect Narcooyia Creek overflow to the Lake Powell inflow channel and additional support infrastructure (i.e. minor regulators, culverts and levees). The options would be operated to a top water level of 52.3 m AHD, inundating a total area of 2,093 ha.

Environmental watering will be achieved via pumping. To fill the system will require pumping at a rate of 500 to 800 ML/day for approximately 3 months. Total volume to fill is approximately 18.8 GL, excluding losses.

5.3.2. Belsar Yungera Floodplain – secondary option

Three complementary/secondary options are also being considered for the Belsar Yungera Floodplain site:

- J1 Creek works: this option proposes upgrading the two outlet culverts to Narcooyia Creek, plus installation of a regulator in the upper catchment and inlet works to increase the area inundated by Belsar Yungera Floodplain watering activities. The outlet works would be operated to a top water level of 52.9 m AHD, increasing the area inundated by 313 ha while the upper catchment regulator would be operated to a top water level of 53.3 m AHD, increasing the area inundated by 38 ha. The inlet works provide risk and access benefits.
- Lake Powell: this option proposes the installation of a low flow pipe beneath the Murray Valley Highway to allow flow to enter Lake Powell at lower inundation levels, as well as gated culverts to confine water in the lake (when desired). This option would be operated in conjunction with the primary option to improve watering efficiency (faster fill time), but does not increase the area inundated.
- Lake Carpul: this option proposes channel works (lowering) to allow water to commence to flow into Lake Carpul from Lake Powell at lower levels, allowing more efficient (faster) filling. The option would be operated in conjunction with the primary option to improve watering efficiency, but does not increase the area inundated.

- **Table 5.1: Summary of Belsar Yungera environmental watering options**

Option	Filling Method	Dependencies	Volume to fill*	Top water level (m AHD)	Area inundate (ha)
Belsar Yungera Floodplain – primary option	Pumping	Nil	18.8 GL	52.3	2,093
Belsar Yungera Floodplain – J1 creek works	Pumping	Belsar Yungera Floodplain – primary option Can be operated independently	3.38 GL**	52.9 (outlet) / 52.3 (upper catchment)	351***
Belsar Yungera Floodplain – Lake Powell	n/a – efficiency measure	Belsar Yungera Floodplain – primary option	Nil	n/a	n/a
Belsar Yungera Floodplain – Lake Carpul	n/a – efficiency measure	Belsar Yungera Floodplain – primary option	Nil	n/a	n/a

* Excludes losses

** Based on volume to fill void space from GHD (2013)

*** Based on area impacted above 52.3 m AHD from GHD (2013)

5.3.3. Watering regime

Documentation of options provided for this project did not provide discussion on water regimes, and minimal discussion on watering requirements. Table 5.2 details likely timing and frequency of inundation events as outlined by Mallee CMA. For the purpose of this assessment, calculations have been based on watering events commencing in August.

- **Table 5.2: Proposed Belsar Yungera watering regime**

Option	Inundation frequency	Timing	Inundation duration (months)
Belsar Yungera	5 in 10 years	Winter/Spring	6

5.4. Potential salinity impacts

5.4.1. Approach

The in-river salinity impacts (at Morgan in South Australia) potentially caused by the proposed actions at Belsar and Yungera Islands were assessed relative to a *basecase* scenario.

The approach to the assessment requires conversion of salt load to EC at Morgan described in Fuller & Telfer (2007), with resultant EC impacts at Morgan (determined using the Ready Reckoner) reflecting the impact of an operation over the 25 year Benchmark Period and the time of year the salt load occurs.

The scenarios to be tested are summarised in Table 5.3. This also contains a summary of the key floodplain processes relevant to the watering action as well as a proposed assessment method. Greater detail on these aspects is provided in the following section.

The approach allows for the incremental salt impact of each option to be assessed. The cumulative effect is taken to be the sum of salt impacts across all watering actions.

Appendix A contains details of the steps in the impact analysis, while Appendix B contains tables of input data used in calculations.

5.4.1.1. Identifying salt discharge processes

The conceptualisation of the hydrogeological setting described in previous sections was used to identify processes and areas believed to be at greater risk of causing increased salt load to the river, bearing in mind the proposed actions and associated floodplain processes involved.

This involved consideration of the:

- Potential for recharge to groundwater; taking account of surface geology and depth to groundwater level in the Channel Sands;
- Potential for increasing groundwater hydraulic gradients and hence increased discharge;
- Potential for salt mobilisation from bank storage, previously dry creeks and wetlands, and previously disconnected backwaters;
- Potential for mobilisation of salt from in-channel sources; and
- Proximity of the inundated areas to the receiving water courses.

5.4.1.2. Impact on floodplain processes and approach to analysis

The works and measures proposed at Belsar and Yungera Islands will result in areas of the floodplain being inundated with water. Inundation will occur via pumping to a top water level elevation of 52.3 mAHD (and 52.9 mAHD at the J1 Creek outlet).

The main creek systems (Narcooyia, Yungera and Bonyaricall Creeks) and the Murray River are considered to be receiving environments for this assessment.

Key assumptions used regarding the Belsar Yungera operation include:

- Designed to inundate approximately 2,093 ha (Primary Option), 351 ha (J1 Creek);
- Operation initially 5 in 10 years;
- Timed to commence in Winter (August); and
- Total duration of operation assessed to be 6 months of inundation.

The following salt mobilisation processes are relevant to each stage of the inundation process:

<u>During the fill stage</u>

- Wash-off of salt from floodplain soils;
- The salt held in the creek channels and mobilisation of salt in previously stranded backwaters to be held in the in-stream store up gradient of the environmental regulators; and
- Inflow of saline groundwater in surface water features down gradient of the environmental regulator because surface water flow in these downstream areas is likely to be lower during operation of the environmental regulator.

<u>During the hold stage</u>

- Inundation of floodplain areas and recharge to the underlying shallow saline groundwater within the floodplain aquifer, creating groundwater mounds beneath inundated areas; and
- Lateral outflow from filled creeks and anabranches to the floodplain aquifer.

<u>During the spill and evaporation stage</u>

- Lateral inflow of groundwater to the anabranches on the recession; and
- Displacement of saline groundwater to the river and creek systems on the recession where mounded groundwater levels remain higher than surface water levels.

Fill Stage

The use of regulators associated with the Primary and Secondary options during the <u>fill stage</u> will result in increased surface flows through Narcooyia, Yungera and Bonyaricall Creeks. Surface flow could result in salt wash-off from floodplain soils, and mobilisation of salt stored along creek beds, potentially discharging into the Murray River.

Surface flow through usually dry channels (under regulated conditions) could result in salt wash-off from floodplain soils, and mobilisation of salt stored along creek beds into the main Narcooyia and Yungera Creek channels.

The inundation of the floodplain will also cause some mobilisation from salt stored in floodplain soils.

ANALYSIS APPROACH – FILL STAGE
Historical flood data linking flows, the area of floodplain inundation and subsequent salt loads in the river post-flooding suggests a total salt flux of 38 kg/ha/day for Lindsay River (Mike Dudding, pers. Comm – reported by SKM (2010a)). Of the total salt flux, the proportion due to wash-off is thought to be approximately 10%; thus reducing the salt flux for this process to 3.8 kg/ha/day. In addition, values of 1 and 5 kg/ha/day were derived during the calibration of a real time salt and water balance model for Chowilla (SKM, 2010b). These salt flux rates are typical of locations downstream of Belsar and Yungera Islands. As such these are considered representative only for this assessment. The magnitude of the salt load associated with lower surface water flow down gradient of the regulator is not considered significant relative to other processes and is not quantified.

Hold Stage

Once the target water level is reached within each structure/project, the water will be held on the floodplain by flow control structures. During the hold stage there will be a continuation of lateral and vertical outflow (infiltration) of surface water to the floodplain aquifer that began in the fill stage. In light of the assumed connected-losing conditions between surface water and groundwater across Belsar Yungera, water stored in the creek banks could mix with saline groundwater that may be released back to the creeks during the spill stage (on the recession).

It is likely that evapotranspiration would intercept any increase in groundwater flux across this width of floodplain and so is probably very low risk, though some accumulation of salts in the unsaturated zone may result.

There is the potential for diffuse recharge to the Channel Sands aquifer beneath the environmental watering sites.

The area of inundation proposed could, over successive events, increase groundwater levels in this area to reverse the hydraulic gradient (and create gaining conditions), where saline groundwater is displaced towards the creek systems, and/or the Murray River. However, as no surface water level monitoring occurs across Belsar and Yungera Islands, it is not possible to accurately define the level of groundwater level rise necessary to induce discharge to the creeks.

Bore 26688 adjacent the Murray River had a reported groundwater salinity of 0.48 mS/cm (March 2012). Bore 26274 located adjacent Lake Powell reported a salinity of 39.2 mS/cm (March 2012). Groundwater discharging to the main creek channel is likely to be relatively fresh in most cases; as such a groundwater salinity of 0.48 mS/cm is used. This choice is supported by the generally fresher conditions under the Creek system as inferred by the AEM data.

ANALYSIS APPROACH – HOLD STAGE.

The rate of recharge to the shallow groundwater system is estimated to be 0.5 mm/day, based on analysis of recharge rates by REM (2006) and previous work by CSIRO on the Chowilla floodplain (refer SKM, 2010). The rate of recharge is assumed to include the volume of water that recharges the aquifer laterally. If the waterbody is connected to groundwater (that is, underlain by fully saturated material) then a mass balance approach can be used to estimate the total volume of groundwater that may eventually discharge to the surface water system (assuming some is lost because of evapotranspiration). If the waterbody is underlain by an unsaturated zone above the groundwater level then there is a need to estimate the rate of rise and fall of groundwater levels using a method from Hantush (1967). If the groundwater level is estimated to rise above the surface water level then the rate of discharge to a river reach can be calculated using a flow net analysis.

Spill and Evaporation Stage

Salt that has accumulated in-stream during the fill stage will be released during the spill stage.

Once surface water levels decline in the Narcooyia, Yungera and Bonyaricall Creeks, there will be potential for the inflow of saline groundwater to the anabranch system that is derived from the following processes that occurred during the hold stage:

- Diffuse recharge and groundwater level mounding; and
- Lateral outflow from anabranches to the Channel Sands aquifer.

Floodplain groundwater levels are lower now than during the 1990s due to lack of floods to recharge the groundwater system such that the anabranch system is losing water to the underlying aquifer. A number of inundation events will be required at a frequency similar to 1980 to 1990 flows before groundwater levels return to their former heights. At this time groundwater discharge to surface water features may again be possible.

In reality, the volume of groundwater discharged maybe lower than 100% of recharge if water is lost to evapotranspiration. It is likely that evapotranspiration is a major component of groundwater discharge in these floodplain environments, however, it has not been accounted for in the assessments below. In some cases evapotranspiration may account for all groundwater discharge and in these cases the long term sustainability of the environmental assets must be questioned.

ANALYSIS APPROACH – SPILL AND EVAPORATION STAGE
The mass of salt released from in-stream storage in the spill stage is calculated under current conditions. A nominal 100 EC difference will be adopted between upstream and downstream surface water salinity. These EC values are multiplied by an assumed in-stream water volume to estimate salt load.

The salt load from wash-off is calculated using the approach described in the fill stage. The volume of recharge to the groundwater from a floodplain watering event displaces a lesser volume of higher salinity groundwater to the adjacent watercourse. If the recharge volume can be calculated, then a corresponding salt load to the river can be inferred. This is similar to the nomogram approach described in the Murray Darling Basin Commission (MDBC) Salinity Impact Assessment Framework for the Living Murray Environmental Works and Measures Program (Fuller & Telfer, 2007). It is expected this salt load will occur over a 12 month period following inundation.

It is assumed 100% of recharge is discharged to the river system during the period of inundation and it is also assumed this accounts for the groundwater that is discharged as a result of diffuse recharge via the floodplain aquifer. It is further assumed that the rate of discharge will fall in a decreasing manner from 100% immediately at the end of the inundation period to zero in month 12 following the hold stage. This decay in the rate of return of recharge water reflects diminishing area of inundation and diminishing hydraulic gradient to the surface water system.

- **Table 5.3: Floodplain process and analytical methods used for Belsar and Yungera**

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
Primary Option. Inundate to a level of 52.3 mAHD over an area of 2,093 ha	Surface salt wash-off Salt in surface water mobilised during draining of creeks Recharge of shallow saline groundwater and displacement of saline groundwater to Narcooyia, Yungera and Bonyaricall Creeks and anabranches.	Surface flush estimated from assumed value of salt storage per hectare of floodplain. In –channel release of salt load Mass balance approach for the inundated area.	Low	Limited bore data available to verify groundwater salinity, groundwater flow and response to recharge.
J1 Creek Inundate to a level of 52.9 and 52.3 mAHD over an extended area of 351 ha	Surface salt wash-off Salt in surface water mobilised during draining of creeks Recharge of shallow saline groundwater and displacement of saline groundwater to Narcooyia and Yungera Creeks and anabranches.	Surface flush estimated from assumed value of salt storage per hectare of floodplain. In –channel release of salt load Mass balance approach for the inundated area.	Low	Limited bore data available to verify groundwater salinity, groundwater flow and response to recharge.
Lake Powell	Surface salt wash-off Recharge of shallow saline groundwater and displacement of	Surface flush estimated from assumed value of salt storage per hectare of	Low	Limited bore data available to verify groundwater salinity, groundwater flow and

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
	saline groundwater to Bonyaricall Creek	floodplain. Mound rise and flow net analysis to estimate flow to creek		response to recharge.
Lake Carpul	Surface salt wash-off Recharge of shallow saline groundwater and displacement of saline groundwater to Narcooyia Creek	Surface flush estimated from assumed value of salt storage per hectare of floodplain. Mound rise and flow net analysis to estimate flow to creek	Low	Limited bore data available to verify groundwater salinity, groundwater flow and response to recharge.

- **Figure 5.10: Belsar Yungera environmental watering locations**

- **Figure 5.11: Belsar Yungera schematic of operating levels**

5.5. Results and discussion

5.5.1. Salt wash off

Estimated salt flux associated with the initial wash-off of salt was calculated for the area of inundation; Primary option (1,546 Ha), J1 Creek (351 ha), Lake Powell (128 ha) and Lake Carpul (68 ha) excluding the area of watercourse. The calculation was undertaken assuming salt capture of 1, 3.8 and 5 kg/ha/day.

Estimates of salt load and EC impacts at Morgan are summarised in Table 5.4 for each process, and these indicate that impacts from salt wash-off are negligible.

- **Table 5.4: Predicted salt load and EC impact at Morgan (relative to the *basecase*)**

Salt wash-off rate (kg/ha/day)	Salt load (t/d) ^	EC impact at Morgan ^
Primary Option		
1	1.6	0.0056
3.8	5.9	0.021
5	7.7	0.028
J1 Creek		
1	0.35	0.0013
3.8	1.3	0.0048
5	1.8	0.0063
Lake Powell		
1	0.13	4.63×10^{-4}
3.8	0.49	0.0017
5	0.64	0.0023
Lake Carpul		
1	0.068	2.4×10^{-4}
3.8	0.26	9.3×10^{-4}
5	0.34	0.0012

Note: ^ These values have been corrected since the previous version (Final, September 2013) of the report. The previously reported results were considered to be negligible.

Key assumptions:

- Release of water occurs at a constant rate over a 30 day period in August;
- Instantaneous transfer of salt from the whole of the inundated area to Narcooyia, Yungera and Bonyaricall Creeks and/or Murray River occurs (that is, reaches equilibrium within one day);
- There is no significant salt load delivered to Narcooyia, Yungera and Bonyaricall Creeks and/or Murray River through salt wash-off under *basecase* conditions; and
- Salt flux rates of 1, 3.8 and 5 kg/ha/d are typical of downstream conditions (i.e. Lindsay and Chowilla floodplain). As such these are considered representative values only.

5.5.2. In channel release

The magnitude of the salinity impact at the Primary Option and J1 due to release of salt stored in the stream channel is proportional to the assumed difference in salinity upstream and downstream (100 EC). The channel geometry was assumed to be 20 m wide and 5 m deep for the purpose of this assessment. There is overlap in area between the Primary option and J1Creek. Operation of J1 Creek would not create additional in-channel release.

The EC impact at Morgan is calculated to be 0.04 (Primary option). This impact is insignificant.

Key assumptions:

- Release of salt to the system downstream of the regulator occurs at a constant rate over a 30 day period in August;
- Instantaneous transfer of salt occurs from the whole of channel system to Murray River;
- Conservatively assumed that all salt contained in the channel is released although some salt may remain in the channel under normal flow;
- The geometry of the channel along its length is assumed to be uniform and can be represented by a rectangular section that is 20 metres wide and 5 metres deep; and
- There is no significant salt load delivered to the Narcooyia, Yungera and Bonyaricall Creeks and/or Murray River through salt wash-off for the *basecase*.

5.5.3. Floodplain inundation (recharge and displacement)

Floodplain inundation due to the Primary Option will be achieved by inundating to a top water level of 52.3 mAHD resulting in an area of inundation of 1,546 ha of floodplain. Inundation at the J1 Creek site will be achieved by inundating to a top water level of 52.9 mAHD at the outlet and 52.3 mAHD up-catchment resulting in an area of inundation of 351 ha of floodplain.

A conservative estimate of the salt load and EC impact at Morgan is made assuming initially 100% of the recharged water is discharged to Narcooyia, Yungera and Bonyaricall Creeks and/or the Murray River from groundwater during the first four months following inundation. The amount of diffuse recharge eventually discharging to the creeks and River is assumed to gradually decline from 100% in the 4^{th} month to zero in the 12^{th} month following inundation.

Values of less than 100% for the amount of recharge that ends up discharging to the feature may be expected where evapotranspiration from groundwater occurs before it reaches Narcooyia, Yungera and Bonyaricall Creeks or Murray River. Therefore, this conservative scenario may represent the cumulative effect of a series of induced and natural floods causing groundwater levels to rise in the vicinity of Belsar and Yungera Islands and creating gaining river conditions.

Salinity used in this calculation was representative of that recorded in Bore 26688, March 2012 (0.48 mS/cm), representing fresh groundwater conditions discharging to the creek systems and/or Murray River.

It is estimated this process will result in an EC impact at Morgan of 0.03 (Primary option) and 0.007 (J1 Creek). These impacts are insignificant.

Key assumptions:

- The recharge due to inundation would last 6 months;
- Saline groundwater will discharge to creek system and/or Murray River for a 12 month period (based on observation of this process in other floodplains – e.g. Chowilla);
- The amount of diffuse discharge to the creeks and River will decline linearly at the end of the inundation period from 100% to zero;
- The salinity of groundwater discharging remains constant over this period;
- Groundwater salinity discharging to the creek channels and River is fresh (0.48 mS/cm), but could increase over time following successive watering events;
- Recharge rate is uniform spatially and temporally in the area of inundation; and
- There is no significant salt load delivered to the Narcooyia, Yungera and Bonyaricall Creeks and/or Murray River through salt wash-off for the *basecase*.

5.5.4. Retention of water

The starting groundwater level beneath Lake Powell is assumed to be 48.4 mAHD (measured; Bore 26274, March 2012). Groundwater mound rise calculations estimated a rise in groundwater levels of 1.25 m (to 49.7 mAHD) after 300 days as a result of inundating Lake Powell (top water level not reported). The distance from the centre of the Lake to Bonyaricall Creek is approximately 2.5 km.

For Lake Carpul the starting groundwater level is also assumed to be 48.4 mAHD (measured 4 km north-east; Bore 26274, March 2012). Groundwater mound rise calculations estimated a rise in groundwater levels of 0.86 m (to 49.28 mAHD) after 300 days as a result of inundation of this watering area (top water level not reported). The distance from the centre of Lake Carpul to Narcooyia Creek is approximately 4 km.

It is assumed that the groundwater level will fall at a constant rate for the following 300 day period.

The salt load from a mound beneath the watering sites to the Creeks is estimated using the bed level estimated from LiDAR (47.6 mAHD, Bonyaricall Creek and 48.1 mAHD, Narcooyia Creek). This suggests that groundwater level beneath Lake Powell and Lake Carpul is higher than the bed level in the Creeks. Stage height information is not available for the creek systems. As this assessment is based on the creek bed elevation only, this is likely to result in an over-estimate of EC impact at Morgan.

The flux of groundwater and salt load was estimated at 30 day time steps during the period of groundwater level rise and fall. Each monthly salt load was converted to an EC impact at Morgan. The salt load was calculated using a groundwater salinity value of 0.48 mS/cm (measured in Bore 26688, March 2012) to represent groundwater salinity adjacent the creeks and Murray River.

For Lake Powell, calculations show the salt load to Bonyaricall Creek rises to a maximum value of < 0.001 t/d after 300 days and the total EC impact at Morgan during the rise and fall of the mound is estimated to be 8.1×10^{-5} EC, which is insignificant.

Mound rise at Lake Carpul is unlikely to result in salt flux to Narcooyia Creek. A high proportion of groundwater flux will be lost to evaporation over the 4km width of floodplain.

Key assumptions:

- The salinity of groundwater discharging to Murray River remains constant over time;
- Groundwater levels due to mounding rise and fall at a constant rate over 300 days; and
- Groundwater salinity discharging to the creeks and River is 0.48 mS/cm, but could increase over time following successive watering events

5.5.5. Total salinity impacts

The total salinity impact at Morgan of implementation of environmental watering at Belsar and Yungera Islands is estimated to be 0.07 EC at Morgan for the Primary Option, 0.008 for J1 Creek, and negligible for Lake Powell and Lake Carpul

The components of the salt load and EC impacts relative to the *basecase* are summarised in Table 4.6. The largest component of the salinity impact is associated with the displacement of groundwater due to diffuse recharge following inundation, but even this impact is insignificant. This calculation is considered conservative as it assumes uniform salinity values across the inundation area.

- **Table 5.5: Summary of salinity processes and EC impact associated with Belsar Yungera**

Salinity process	EC impact at Morgan			
	Primary Option	J1	Lake Powell	Lake Carpul
Salt wash-off	Negligible	Negligible	Negligible	Negligible
In-channel release[1]	0.04	N/A	N/A	N/A
Recharge and displacement	0.03	0.008	N/A	N/A
Retention of water lake/wetland	N/A	N/A	8.1×10^{-5}	Nil
TOTAL	**0.07**	**0.008**	**Negligible**	**Negligible**

Based on difference in river salinity of 100 EC

5.6. Cumulative impacts

It is expected that multiple watering events will occur at these sites over time.

Groundwater monitoring records for bores in the Channel Sands aquifer indicate groundwater levels have remained relatively stable over the period of record, dating back to 1990s levels when more frequent flooding occurred. At several sites (e.g. Bore 6962), recent monitoring data suggests the groundwater level is in fact higher than historic levels.

This suggests that the salt load impact of environmental watering is likely representative of the 1990s conditions. It is likely that successive watering events coupled with natural flood events would not create any significant increases in salt store to that seen in the 1990s. As such, cumulative impacts are likely to be negligible at this site.

Should larger impacts occur with time, these will be offset by a less frequent operation and shorter duration of watering events.

5.7. Monitoring

The proposed monitoring program is comprised of groundwater and surface water monitoring and aims to provide data that can be used to better define the mechanisms and magnitude of salinity impact arising from the proposed environmental watering events. The monitoring data should form the basis of five-yearly reviews as required under the Basin Salinity Management Strategy, allowing refinement of the salinity impact estimates.

The monitoring program reflects the need to gather data both for the improvement of understanding of the key processes, but also to allow independent review of accountability for operating any works and measures. Monitoring should also be maintained to assess the benefits of environmental watering.

In order to measure salinity impact from the floodplain operations, monitoring periods should be chosen to cover current conditions, floodplain operations, and post-operation conditions. The former provides the opportunity to assess baseline conditions, including salt loads against which to measure the impact of operations. The latter is important because it is likely that the floodplain response would be delayed, with salinity impacts extending beyond the period of floodplain operations. Continuous monitoring will ensure that all impacts due to actions can be assessed against *basecase* conditions as well as highlight any changes in the baseline over time.

All groundwater levels should be expressed relative to Australian Height Datum to allow comparison of groundwater and surface water data.

5.7.1. Groundwater monitoring

Water level and salinity data from groundwater monitoring wells completed in the Channel Sands aquifer in the vicinity of inundation areas, retention sites and other identified impact hotspots should be collected before, during and after each environmental watering event. This is most important for wells that are situated adjacent an inundation area and near the potential receiving surface waters. Salinity measurements at the very top of the saturated thickness (adjacent the discharging site) will allow an assessment of the salt content of the water that will be moving as a result of the action and indicate any freshening of groundwater that may occur.

Table 5.6 shows the groundwater monitoring bores targeted under the program. This has been based upon the distribution of bores that are currently being monitoring for groundwater level and/or salinity by Mallee CMA.

There is a poor distribution of monitoring infrastructure across Belsar and Yungera Islands at present, with current monitoring only targeting areas to the east and west of the Islands. An existing bore (40058), is not currently being monitored but was captured in the GMS database. This bore has been included in the suggested monitoring network. It will be useful to gain additional information in the vicinity of the proposed inundation areas. The location of suggested additional monitoring bores for the Channel Sands is presented on Figure 5.12, which target the northern and southern extent of the inundation area, and the length of Narcooyia Creek.

All bores are recommended to be monitored for groundwater level and salinity at daily intervals before, during and after events that change the hydraulic regime and at weekly intervals at other times.

- **Table 5.6: Groundwater monitoring sites at Belsar Yungera**

Bore ID	Easting	Northing	Current monitoring parameters (water level/salinity)
Channel Sands			
26265	685721	6159277	Level, salinity
26274	671421	6159077	Level (logger), salinity
26688	685821	6157477	Level, salinity
Suggested additional monitoring bores (Channel Sands)			
40058	675971	6160237	Level, salinity
Bore 1	675214	6162747	Level, salinity
Bore 2	673654	6161045	Level (logger), salinity
Bore 3	674222	6158435	Level, salinity
Bore 4	677909	6158180	Level (logger), salinity
Bore 5	680746	6156677	Level (logger), salinity
Bore 6	683412	6157897	Level, salinity

The frequency of monitoring should ideally be daily to weekly depending on the rate of water level response (if any) in a given monitoring well. If changes in standing water level attributable to floodplain watering are observed, then monitoring frequency should be increased accordingly. It is recommended that the high priority groundwater observation wells are monitored for water level daily, especially just before, during and post inundation. At the very least, under *basecase*, regulated conditions, observations should be collected at least every three months from these wells.

Consideration should be given to the use of automatic down-hole loggers for recording responses to watering events, which are especially useful where wells may become stranded. Additional benefits include recording of subtle impacts that may not be seen from relatively sparse observations. Bores suggested for logger installation includes Bore 26274 and three of the suggested new sites; Bores 2, 4 and 5.

The key will be to identify the peak groundwater level as a result of inundation, but also to record the initial *basecase* and post inundation response as the lake water levels recede. If data loggers are available, the most beneficial locations would therefore be in the bores closest to the area of inundation, as listed above.

If costs cannot be met for monitoring it is recommended that fewer locations are chosen and an emphasis placed on collecting more comprehensive time series data.

5.7.2. Surface water monitoring

Ideally, surface water monitoring would provide sufficient data to calculate salt load to reaches of flowing anabranches or the Murray River adjacent to areas of floodplain watering. This is possible when pre-existing surface water monitoring stations are available.

No surface water monitoring sites exist at Belsar and Yungera Islands. Downstream gauges on the Murray River are located at Robinvale and Euston. Upstream, a stream gauging station is located on the Murray River at Boundary Bend,

It would be useful to gain additional surface water data along Narcooyia, Yungera and Bonyaricall Creeks (or tributaries) and the Murray River, in particular associated with proposed regulator sites.

Table 5.7 lists existing sites and associated parameters for measurement.

- **Table 5.7: Existing surface water monitoring sites**

Site ID and description	Monitoring parameters
414201 – Boundary Bend	Water level, flow, salinity
414205 – Robinvale	Water level
414203/9 – Euston Weir	US/DS water levels, flow, daily-read salinity

To reduce uncertainties relating to *basecase,* inundation across the Belsar and Yungera Islands and associated NSW floodplain, as well as their level of connection to the surface water network, observations and survey of specific wetlands would improve the conceptualisation of the *basecase* conditions. In particular, observations around any wetlands or depressions considered to be potential sources of significant salt load to the River would inform future refinements of the salinity impacts of watering actions. It is assumed that water level data will be collected at each regulator.

It is recommended that stage height monitoring be undertaken at a series of locations along Narcooyia, Yungera and Bonyaricall Creeks and the Murray River (expressed relative to Australian Height Datum). Where the suggested new groundwater monitoring bores are sited adjacent creek lines, it would be useful to gauge stage height to aid in comparison between surface water and groundwater levels at a particular location.

Surface water observations are especially important at the inlet and outlet structures. Surface water salinity and flow should be monitored at such locations to assess the impact of watering events and calculate likely salt loads to the system. Flow gauges should be installed at the inlet and outlet structures. Monitoring should occur before, during and after the watering event. The length of time and frequency of monitoring can be assessed as data is collected and assessed. Initially monitoring should occur at a monthly frequency.

- **Figure 5.12: Belsar Yungera suggested monitoring locations**

6. Burra Creek

6.1. Hydrology

Burra Creek is an anabranch of the Murray River located between Piangil in Victoria and Tooleybuc in New South Wales (Figure 6.1). The Creek departs from the Murray River at 1,323 river km, near Tooleybuc and follows a meandering northerly path over 54 km before re-joining the River at 1,287 river km, just upstream of Major Mitchell Lagoon (REM, 2006). The land between the Burra Creek and the Murray River is known as Macreadie Island (REM, 2006). In the assessment of floodplain areas between Nyah and Robinvale by Ecological Associates (2006), Burra Creek and the adjacent floodplain was classified as the Burra Creek Floodplain Management Unit (FMU).

The river frontage is part of the Murray River Reserve. The creek lies within an 80 m wide Crown Land water frontage reserve. The Burra Forest is a Parks Victoria reserve covering approximately one third of Macreadie Island at the downstream (northern) end. The remainder of the floodplain is freehold and is used for grazing, and irrigated and dryland agriculture. There are grazing leases for public land in the Murray River and Burra Creek reserve.

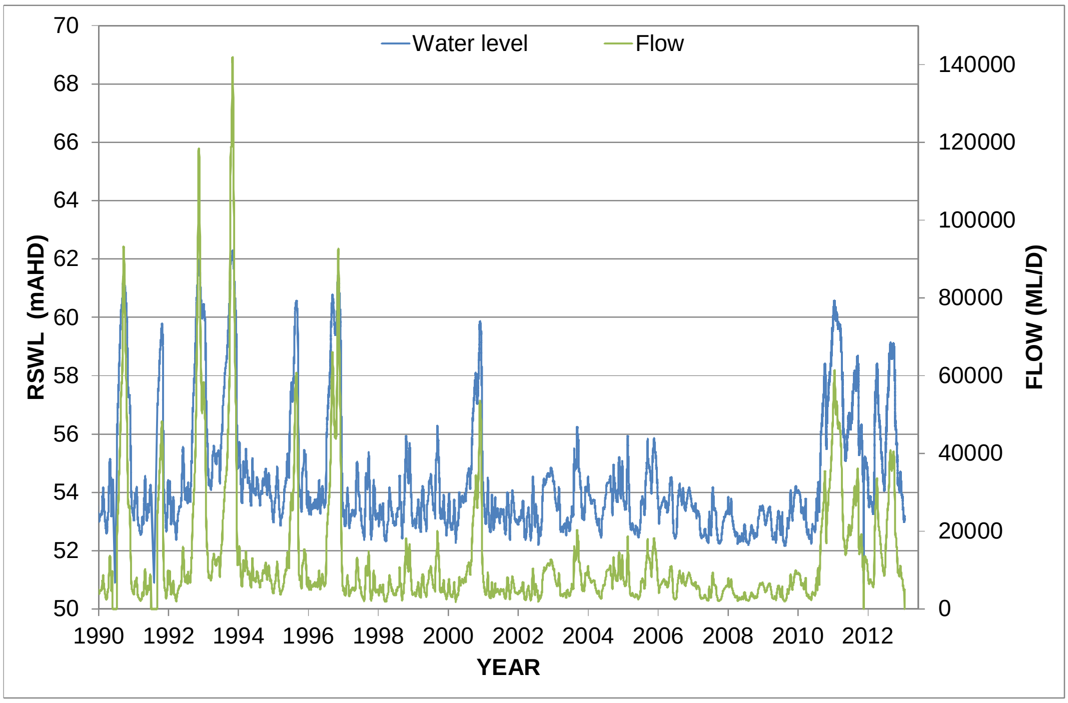
Under natural conditions Burra Creek would have delivered water from the Murray River to wetlands and forested areas within the floodplain during low peaks in river flow (REM, 2006). Flow within Burra Creek has been greatly disrupted by both river regulation and the construction of various impediments to flow within the channel. The water regime of the floodplain has also been impacted by the construction of levee banks parallel to the creek to prevent floodplain inundation.

A monitoring gauge is located downstream of Burra Creek (414200) adjacent to the township of Kenley, referred to as Wakool Junction. The GMS database only provided these records as a stage height rather than elevation relative to Australia Height Datum. The elevation listed in GMS for this stream gauge was equivalent to bank height. LiDAR was used to estimate bed level (52.5 mAHD) and from this the likely absolute elevation of stage height in the Murray River was estimated. Average March 2012 monitoring data indicate a River water level of 56.5 mAHD (Figure 6.2). The Murray River water level adjacent Burra Creek floodplain is likely to be comparable to this downstream level. This level is estimated for average flow conditions.

The minimum stage height recorded at the Wakool Junction gauge was 50.9 mAHD in March 1988 (flow records were not available). This may represent a worst case scenario for stage height adjacent Burra Creek.

- **Figure 6.1: Location of key features at Burra Creek**

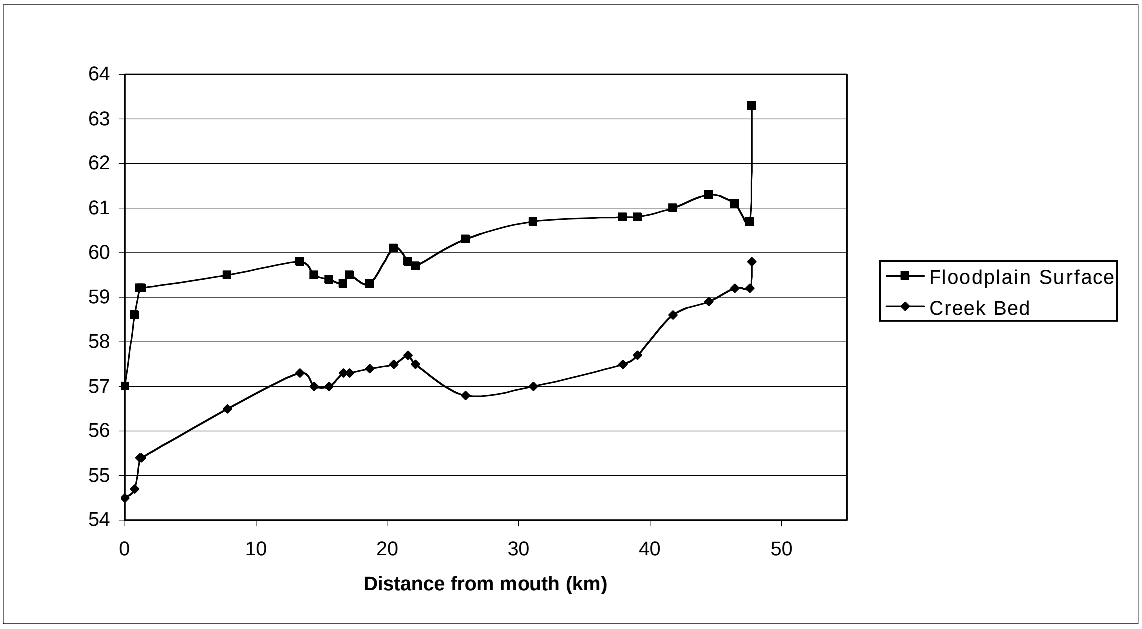
Gauging station 409235 (Piambie Pumps) is located centrally to Burra Creek floodplain but has been inactive since 1999. Two additional monitoring gauges are located at Whyerie (409236) and south of Goodnight Road (409234) but are only monitored for salinity; gauges have also been inactive since 1999.



- **Figure 6.2: Surface water level and flow at Wakool Junction (414200)**

6.1.1. Floodplain levels

REM (2006) extracted the levels of the bed of Burra Creek and the adjacent floodplain from LiDAR to illustrate potential relationships with surface water flow (Figure 6.3). The natural surface of the channel at the downstream end (1294.3 river km) would allow water to enter at Murray River discharge exceeding 12.5 ML/d while water would enter at 1318 river km at 25,000 ML/d (REM, 2006). An additional, minor effluent is located at 1319.5 river km, which, in the absence of impediments to flow, would permit inflows to Burra Creek at 28,000 ML/day (REM, 2006).



- **Figure 6.3 Burra Creek bed level and adjacent floodplain surface (mAHD) (REM, 2006)**

6.2. Hydrogeology

6.2.1. Background

The Murray River incised through the Mallee landscape late in the Quaternary period in response to sea level falls, producing a relatively narrow trench typically 5 to 10 km wide. This trench backfilled as base levels were re-established.

On the floodplain, the basal unit filling the trench beneath the Woorinen Formation is the Channel Sands which is overlain with the finer grained Coonambidgal Formation. The latter contains fined grained silts and clays ranging in thickness up to 5 m across the floodplain. The Channel Sands is made up of fine to coarse-grained sands and is in direct connection with the Murray River.

The Channel Sands aquifer lies directly above the regionally extensive Parilla Sands aquifer but is separated by varying thicknesses of Blanchetown Clay. Where present, the Clay can act as an aquitard and reduce the vertical interaction between the Channel Sands and Parilla Sand. The extent and thickness of the Blanchetown Clay will be a key control on the possible salt impact of floodplain watering activities.

Thorne *et al,* (1990) prepared hydrogeological cross-sections which span the length of the Murray River from the South Australian border through to Nyah.

Transect W from Thorne *et al,* (1990) lies along the north edge of Burra Swamp. This shows that the Murray River is incised into the Channel Sands. Blanchetown Clay underlies the Channel

Sands beneath wider floodplain, but pinches out and becomes absent between the Swamp and the River (Figure 7.4). Transect X is sited along the southern edge of Burra Creek and indicates a similar arrangement of hydrogeological units to that of Transect W (Figure 7.5).

6.2.2. Groundwater level

Groundwater level data has been collected at several sites adjacent to the Burra Creek floodplain. The location of bores that are currently being monitored (2008 to present) is shown in (Figure 6.6).

Summer 2012 groundwater elevation data shows that the groundwater level in the Channel Sands ranges from 54 mAHD in the north of the floodplain (Bore 26268), to around 57 mAHD in the south near Piangil (Bore 26269). Only four bores in the current network are monitoring the Channel Sands aquifer.

Depth to groundwater in the Channel Sands ranges from 4-5 m bgl adjacent to the Murray River (Bore 26268, Bore 26269) to over 6 m bgl at the northern edge of Burra Swamp (Bore 26197, 5 km west of the River). The majority of current bores in the area are monitoring the deeper Parilla Sand aquifer.

Given the lack of monitoring bores in the area, it is not possible to determine if and/or where higher stream flow within the Murray River has induced recharge to the Channel Sands aquifer in recent times, within the vicinity of the floodplain.,.

Fluctuations in groundwater levels occur as river stage fluctuates, due to leakage from the river when the stage is high. This process is likely to be widespread under the river where it is not influenced by weir pools. This is evident in Bore 26268 located at the northern end of Burra Creek, adjacent to the Murray River.

Over the period of record groundwater level fluctuation is evident in the Channel Sands aquifer. In general, groundwater level within the Channel Sands aquifer has shown little variation between 1990s and current levels, despite the high River flow events that have occurred.

There has been a general downward trend in groundwater levels within the Parilla Sands from the 1990's to present in bores west of the floodplain (e.g. Bore 26291, Bore 26185).

Of note, monitoring bores located on the northern and southern ends of Burra Swamp (Bore 26197 and Bore 26175) indicate stable groundwater levels between 1990 and 2008. After 2010 a rise of up to 2 m was observed in both the Channel Sands and Parilla Sand aquifers.

- **Figure 6.4: Transect W (Thorne *et al,* 1990)**

- **Figure 6.5: Transect X (Thorne *et al,* 1990)**

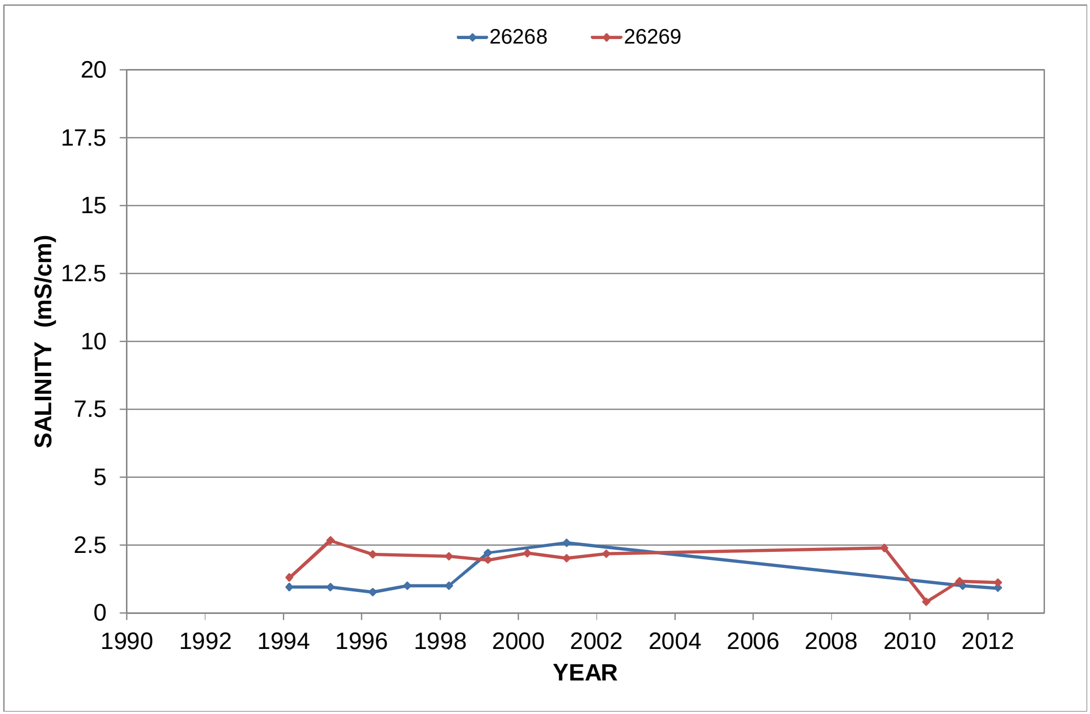
- **Figure 6.6: Current monitoring at Burra Creek**

6.2.3. Groundwater salinity

Salinity time series data for selected monitoring sites across Burra Creek floodplain is presented in Figure 6.7.

This shows that groundwater screened in the Channel Sands aquifer closer to the Murray River appears to be relatively fresh (Bore 26268, Bore 26269), with salinity increasing with distance from the river; an indication of net losing river conditions in this area.

In the underlying Parilla Sands aquifer groundwater salinity remained relatively stable prior to 2002. There was a gap in monitoring until 2009 (at which point records indicated salinity had declined). This was followed with a subsequent increase in groundwater salinity between 2010 and 2012, observed along the edge of Burra Creek floodplain in Bores 26173, 26185 and 26191.



■ **Figure 6.7: Burra Creek groundwater salinity**

An aerial electromagnetic (AEM) survey was undertaken during Feb-March 2008 (BRS, 2009). An AEM depth slice (as apparent bulk electrical conductivity) averaged over the upper 30 m of saturation in the shallow aquifer is shown in Figure 7.8.

The AEM data infers that a lower salinity zone exists along a narrow band either side of the Murray River. The AEM infers higher salinity environment where inundation is proposed but this is averaged over a 30 metre slice and may not be indicative of shallow groundwater salinity patterns in this area. The lower salinity areas are representative of zones where there is localised recharge to the groundwater system through the river banks.

6.2.4. Groundwater – surface water interaction

The location and magnitude of the salinity impact depends in part of the degree of connection between the shallow floodplain aquifer, and the Murray River and anabranches. Greatest impacts are possible where the surface water system gains groundwater. This section provides a summary of the nature of the connection based on existing information.

Where groundwater elevations are higher than surface water elevations, river reaches are defined as potentially *connected – gaining* systems. Where groundwater elevations are lower than surface water elevations, river reaches are defined as potentially *connected – losing* systems. Where the anabranches are permanently inundated and groundwater elevations are lower than the base of the river bed, river reaches are also defined as potentially *connected – losing* systems.

The bed elevations of Burra Creek extracted from LiDAR range from 54.5 mAHD at the mouth up to > 59 mAHD at its head (Figure 6.3). March 2012 groundwater monitoring indicates a groundwater level of 54 mAHD near the confluence of Burra Creek and the Murray River, which infers that groundwater is below the bed elevation and not discharging to Burra Creek.

An active surface water monitoring site is located downstream of the floodplain adjacent Kenley (Gauge 414200). March 2012 surface water level is 57.7 mAHD which is significantly higher than the measured groundwater level of 54 mAHD in the adjacent Channel Sands monitoring bore (Bore 26268).

This gradient, combined with the low groundwater salinity at this site (0.93 mS/cm), suggests likely surface water discharge to the underlying Channel Sands aquifer in this area.

The GMS database holds records for other existing monitoring bores across the floodplain (i.e. bores along Transect X). Monitoring data suggests the groundwater level in the Channel Sands central to the floodplain was approximately 52.5 mAHD during early 2007 (e.g. Bore 26270, March 2007). At this time, groundwater level was well below the base of the adjacent stretch of Burra Creek (57 mAHD, estimated from LiDAR).

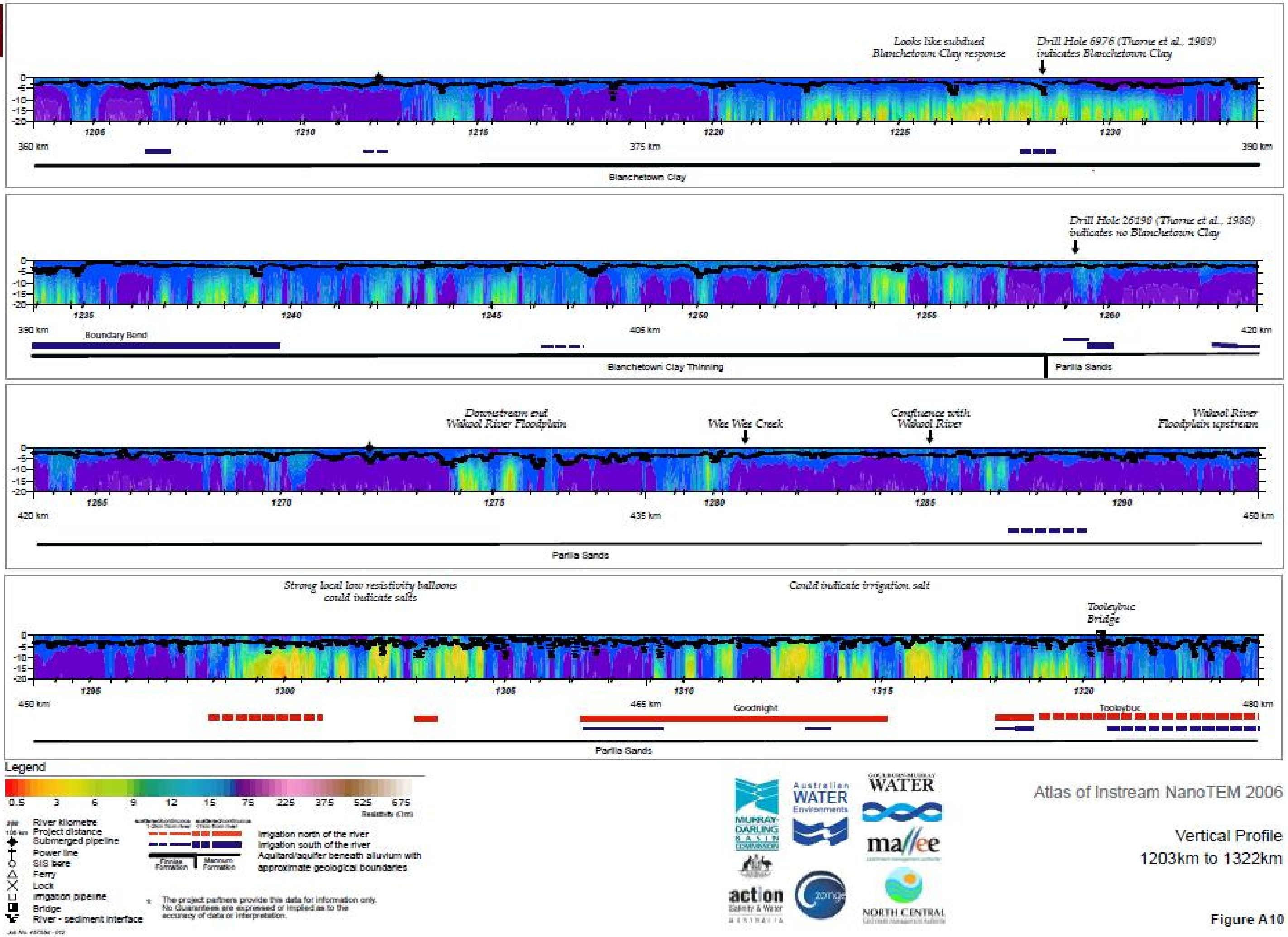
Stage height in Burra Creek would need to be quantified to accurately assess the nature of connection between surface water and groundwater level in the Channel Sands.

For this assessment, Burra Creek is conservatively assumed to be in connection with the groundwater in the Channel Sands aquifer.

The 2006 NanoTEM (Telfer *et al*., 2006; Figure 6.9) survey shows the vertical profiles displaying the resistivity data collected along the Murray River. Low resistivities (red to yellow) indicate areas that are conductive, (that is, they are interpreted to hold saline water and/or be composed of clay).

The resistive areas (blue through purple) are interpreted to be generally fresh water in sands (Telfer *et al*., 2006). Burra Creek is cited near the Wakool River junction. Here, the vertical profile is quite resistive indicating generally fresh groundwater and predominantly losing conditions.

- **Figure 6.8: Average apparent bulk electrical conductivity for a 30 m interval immediately below groundwater surface**



- **Figure 6.9: Vertical profile of 2006 Nano TEM survey along Murray River, map reference 17**

6.3. Environmental works and measures

Alluvium (2012a) outlined potential areas that may benefit from inundation and flow control (presented in Figure 6.10 and summarised in Table 6.1). The associated works and measures related to their inundation are discussed below and comprise two target areas; Burra North and Burra South.

A schematic of the key water levels on the floodplain is presented in Figure 6.11.

6.3.1. Burra North

This option proposes the installation of an inlet structure at the culvert on Burra Creek adjacent to the Timbercorp irrigation channel and a retaining structure (with outlet regulator) at the downstream end of Burra Creek to keep water on the floodplain. Some work will also be required to raise the river road to act as an embankment. Water for this option would be supplied from the Timbercorp irrigation channel (at the inlet works site), utilising existing pumping infrastructure (from the Murray River into the channel). Alluvium (2012a) considered three infrastructure configurations (retaining structures):

- Sub-option 1: a top water level of 58.5 mAHD inundating a total area of 173 ha
- Sub-option 2: a top water level of 58.7 mAHD inundating a total area of 325 ha
- Sub-option 3: a top water level of 58.9 mAHD inundating a total area of 443 ha

Sub-option 2 was identified as the preferred option based on cost per ha inundated. At the end of an environmental watering event, stored water would be released to the Murray River via the regulator.

6.3.2. Burra South

This option proposes the operation of a pump at the southern end of the site to pump water directly from the Murray River onto the floodplain. Levee works (with outlet regulator) will need to be constructed at the northern end of the site to retain the water on the floodplain. Alluvium (2012a) considered three infrastructure configurations (levee height):

- Sub-option 1: a top water level of 59.1 mAHD inundating a total area of 92 ha
- Sub-option 2: a top water level of 59.3 mAHD inundating a total area of 123 ha
- Sub-option 3: a top water level of 59.4 mAHD inundating a total area of 147 ha

Sub-option 2 was identified as the preferred option based on cost per ha inundated and the limited construction footprint. At the end of an environmental watering event, stored water would be released to the Murray River via the regulator.

Table 6.1: Summary of Burra Creek environmental watering options

Option	Filling Method	Dependencies	Top water level (m AHD)	Area inundated (ha)
Burra North	Gravity (irrigation channel)	Nil	58.7	325
Burra South	Pumping (Murray River)	Nil	59.3	123

6.3.3. Watering Regime

Documentation of options provided for this project did not provide discussion on water regimes, and minimal discussion on watering requirements. Table 6.2 details likely timing and frequency of inundation events as outlined by Mallee CMA. For the purpose of this assessment, calculations have been based on watering events commencing in August.

Table 6.2: Proposed Burra Creek watering regime

Option	Inundation frequency	Timing	Inundation duration (months)
Burra Creek North	8 in 10 years	Winter/spring	6
Burra Creek South	5 in 10 years	Winter/spring	5

6.4. Potential salinity impacts

6.4.1. Approach

The in-river salinity impacts (at Morgan in South Australia) potentially caused by the proposed actions at Burra Creek were assessed relative to a *basecase* scenario.

The approach to the assessment requires conversion of salt load to EC at Morgan described in Fuller & Telfer (2007), with resultant EC impacts at Morgan (determined using the Ready Reckoner) reflecting the impact of an operation over the 25 year Benchmark Period and the time of year the salt load occurs.

The scenarios to be tested are summarised in Table 6.3. This also contains a summary of the key floodplain processes relevant to the watering action as well as a proposed assessment method. Greater detail on these aspects is provided in the following section.

The approach allows for the incremental salt impact of each option to be assessed. The cumulative effect is taken to be the sum of salt impacts across all watering actions.

Appendix A contains details of the steps in the impact analysis, while Appendix B contains tables of input data used in calculations.

6.4.1.1. Identifying salt discharge processes

The conceptualisation of the hydrogeological setting described above was used to identify processes and areas believed to be at greater risk of causing increased salt load to the river, bearing in mind the proposed actions and associated floodplain processes involved.

This involved consideration of the:

- Potential for recharge to groundwater; taking account of surface geology and depth to groundwater level in the Channel Sands;
- Potential for increasing groundwater hydraulic gradients and hence increased discharge;
- Potential for mobilisation of salt from in-channel sources; and
- Proximity of the inundated areas to the receiving water courses.

6.4.1.2. Impact on floodplain processes and approach to analysis

The works and measures prosed at Burra Creek will result in areas of the floodplain being inundated with water. In Burra North this will occur via an irrigation channel while for Burra South water will be pumped from the Murray River to elevations of 58.7 and 59.3 mAHD respectively.

Burra Creek and the Murray River are considered to be receiving environments for this assessment.

Key assumptions used regarding the Burra Creek operation are:

- Designed to inundate approximately 325 ha (North) and 123 ha (South);
- Operation initially 8 in 10 years (North) and 5 in 10 years (South);
- Timed to commence in Winter (August); and
- Total duration of operation assessed to be between 6 months (North) and 5 months (South).

The following salt mobilisation processes are relevant to each stage of the inundation process:

<u>During the fill stage</u>

- Wash-off of salt from floodplain soils;
- The salt held in the River channel and mobilisation of salt in previously stranded backwaters to be held in the in-stream store up gradient of the environmental regulator; and

- Inflow of saline groundwater in surface water features down gradient of the environmental regulator because surface water flow in these downstream areas is likely to be lower during operation of the environmental regulator.

During the hold stage

- Inundation of the floodplain areas and recharge to the underlying shallow saline groundwater within the floodplain aquifer, creating groundwater mounds beneath inundated areas; and
- Lateral outflow from filled anabranches to the floodplain aquifer.

During the spill stage

- Lateral inflow of groundwater to the anabranches on the recession;
- Displacement of saline groundwater to Burra Creek and Murray River on the recession where mounded groundwater levels remain higher than surface water levels; and
- Release of the in-stream store within the Burra Creek system of saline water created during the fill stage.

Fill Stage

The use of regulators associated with Burra Creek North and South during the fill stage will result in increased flows to Burra Creek.

The inundation of the floodplain will also cause some mobilisation from salt stored in floodplain soils.

ANALYSIS APPROACH – FILL STAGE

Historical flood data linking flows, the area of floodplain inundation and subsequent salt loads in the river post-flooding suggests a total salt flux of 38 kg/ha/day for Lindsay River (Mike Dudding, pers Comm – reported by SKM (2010a)). Of the total salt flux, the proportion due to wash-off is thought to be approximately 10%; thus reducing the salt flux for this process to 3.8 kg/ha/day. In addition, values of 1 and 5 kg/ha/day were derived during the calibration of a real time salt and water balance model for Chowilla (SKM, 2010b). These salt flux rates are typical of locations downstream of Buloke Swamp; as such these are considered representative only for this assessment.

The magnitude of the salt load associated with lower surface water flow down gradient of the regulator is not considered significant relative to other processes and is not quantified.

Hold Stage

Once the target water level is reached within each structure/project, the water will be held on the floodplain by flow control structures. During the hold stage there will be a continuation of lateral and vertical outflow (infiltration) of surface water to the floodplain aquifer that began in the fill stage. In light of the assumed connection between surface water and groundwater (connected – losing) across Burra Creek, water stored in the river banks could mix with saline groundwater that may be released back to the anabranch system or Murray River in the spill stage (on the recession).

It is likely that evapotranspiration would intercept any increase in groundwater flux across this width of floodplain and so is likely to be very low risk, though some accumulation of salts in the unsaturated zone may result.

There is the potential for diffuse recharge to the Channel Sands aquifer beneath the inundated areas created under Burra Creek North and South.

The area of inundation proposed could, over successive events, increase groundwater levels in this area to reverse the hydraulic gradient where saline groundwater is displaced towards Burra Creek and/or to the Murray River. No surface water level monitoring occurs on Burra Creek, which means it is not possible to accurately define the level of groundwater rise necessary to induce discharge to Burra Creek.

ANALYSIS APPROACH – HOLD STAGE.

The rate of recharge to the shallow groundwater system is estimated to be 0.5 mm/day, based on analysis of recharge rates by REM (2006) and previous work by CSIRO on the Chowilla floodplain (refer SKM, 2010). This rate of recharge is assumed to include the volume of water that recharges the aquifer laterally.

If the waterbody is connected to groundwater (that is, underlain by fully saturated material) then a mass balance approach can be used to estimate the total volume of groundwater that may eventually discharge to the surface water system (assuming some is lost because of evapotranspiration). If the waterbody is underlain by an unsaturated zone above the groundwater level then there is a need to estimate the rate of rise and fall of groundwater levels using a method from Hantush (1967). If the groundwater level is estimated to rise above the surface water level then the rate of discharge to a river reach can be calculated using a flow net analysis.

Spill Stage

Salt that has accumulated in-stream during the fill stage will be released during the spill stage.

Once surface water levels decline in the Burra Creek, there will be potential for the inflow of saline groundwater to the anabranch system that is derived from the following processes that occurred during the hold stage:

- Diffuse recharge and groundwater level mounding; and
- Lateral outflow from anabranches to the Channel Sands aquifer.

For the purpose of this analysis it is conservatively assumed that immediately on the cessation of the hold stage 100% of the recharged water (on a monthly time step) will eventually return to the receiving feature (in this instance Burra Creek and/or the Murray River). As the water held in the feature diminishes, the percentage return to the Creek and River at each time step in the analysis is assumed to also diminish at a set rate to mimic the fall in groundwater gradients and consequent decline in groundwater discharge. This process occurs over a 12 month period at which time all discharge ceases.

In reality, the volume of groundwater discharged may be lower than 100% of recharge if water is lost to evapotranspiration. It is likely that evapotranspiration is a major component of groundwater discharge in these floodplain environments, however, it has not been accounted for in the assessments below. In some cases evapotranspiration may account for all groundwater discharge and in these cases the long term sustainability of the environmental assets must be questioned. The percentage discharged under current conditions is likely to be much lower because of poor connection with the river system (that is, groundwater levels lower than receiving features) and a significant width of the floodplain leading to increased opportunity for evapotranspiration.

ANALYSIS APPROACH – SPILL STAGE

The mass of salt released from in-stream storage in the spill stage is calculated under current conditions. A nominal 100 EC difference will be adopted between upstream and downstream surface water salinity. These EC values are multiplied by an assumed in-stream water volume to estimate salt load.

The salt load from wash-off is calculated using the approach described in the fill stage.

The volume of recharge to the groundwater from a floodplain watering event displaces a lesser volume of higher salinity groundwater to the adjacent watercourse. If the recharge volume can be calculated, then a corresponding salt load to the river can be inferred. This is similar to the nomogram approach described in the Murray Darling Basin Commission (MDBC) Salinity Impact Assessment Framework for the Living Murray Environmental Works and Measures Program (Fuller & Telfer, 2007). It is expected this salt load will occur over a 12 month period following inundation. .

It is assumed 100% of recharge is discharged to the river system during the period of inundation and it is also assumed this accounts for the groundwater <u>that is discharged as a result of</u> diffuse recharge via the floodplain aquifer. It is further assumed that the rate of discharge will fall in a decreasing manner from 100% immediately at the end of the inundation period to zero in month 12 following the hold stage. This decay in the rate of return of recharge water reflects diminishing area of inundation and diminishing hydraulic gradient to the surface water system.

- **Table 6.3: Floodplain process and analytical methods used for Burra Creek**

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
Burra Creek North Inundate to a level of 58.7 mAHD over an	Surface salt wash-off Salt in surface water mobilised during	Surface flush estimated from assumed value of salt	Low	Limited bore data to verify groundwater salinity, groundwater

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
area of 325 ha	draining of creeks Recharge of shallow saline groundwater and displacement of saline groundwater to Burra Creek and Murray River.	storage per hectare of floodplain. In –channel release of salt load Mass balance approach for the inundated area. Mound build up estimated and flow net is used to estimated salt load from mound to Burra Creek and Murray River		flow and response to recharge.
Burra Creek South Inundate to a level of 59.3 mAHD over an area of 123 ha	Surface salt wash-off Recharge of shallow saline groundwater and displacement of saline groundwater to Burra Creek and Murray River.	Surface flush estimated from assumed value of salt storage per hectare of floodplain. Mass balance approach for the inundated area. Mound build up estimated and flow net is used to estimated salt load from mound	Low	Limited bore data to verify groundwater salinity, groundwater flow and response to recharge.

- **Figure 6.10: Burra Creek environmental watering locations**

- **Figure 6.11: Burra Creek schematic of operating levels**

6.5. Results and discussion

6.5.1. Salt wash off

Estimated salt flux associated with the initial wash-off of salt was calculated for the area of inundation; Burra Creek North (273 Ha) excluding the area of watercourse and Burra Creek South (123 ha). The calculation was undertaken assuming salt capture of 1, 3.8 and 5 kg/ha/day.

Estimates of salt load and EC impacts at Morgan are summarised in Table 6.4 for each process and these indicate that impacts from salt wash-off are negligible.

- **Table 6.4: Predicted salt load and EC impact at Morgan (relative to the *basecase*)**

Salt wash-off rate (kg/ha/day)	Salt load (t/d) ^	EC impact at Morgan ^
Burra Creek North		
1	0.27	0.0016
3.8	1.0	0.0060
5	1.4	0.0076
Burra Creek South		
1	0.12	4.4×10^{-4}
3.8	0.47	0.0017
5	0.62	0.0022

Note: ^ These values have been corrected since the previous version (Final, September 2013) of the report. The previously reported results were considered to be negligible.

Key assumptions:

- Release of water occurs at a constant rate over a 30 day period in Spring (October);
- Instantaneous transfer of salt from the whole of the inundated area to Burra Creek and/or Murray River occurs (that is, reaches equilibrium within one day);
- There is no significant salt load delivered to Burra Creek and/or Murray River through salt wash-off under *basecase* conditions; and
- Salt flux rates of 1, 3.8 and 5 kg/ha/d are typical of downstream conditions (i.e. Lindsay and Chowilla floodplain). As such these are representative values only.

6.5.2. In channel release

The magnitude of the salinity impact at Burra Creek North due to release of salt stored in the stream channel upstream of the regulator (Structure B1) is proportional to the assumed difference in salinity upstream and downstream (100 EC). The channel geometry was assumed to be 5 m wide and 1 m deep for the purpose of this assessment.

The EC impact at Morgan is calculated to be $1.3x10^{-3}$. This impact is insignificant.

Key assumptions:

- Release of salt to the system downstream of the regulator occurs at a constant rate over a 30 day period in Spring (October);
- Instantaneous transfer of salt occurs from the whole of channel system to Murray River;
- Conservatively assumed that all salt contained in the channel is released although some salt may remain in the channel under normal flow;
- The geometry of the channel along its length is assumed to be uniform and can be represented by a rectangular section that is 5 metres wide and 1 metres deep; and
- There is no significant salt load delivered to the Burra Creek and/or Murray River through salt wash-off for the *basecase*

6.5.3. Floodplain inundation (recharge and displacement)

Floodplain inundation at Burra Creek North will be achieved by inundating to a top water level of 58.7 mAHD resulting in an area of inundation of 273 ha of floodplain. Inundation at Burra Creek South will be achieved by inundating to a top water level of 59.3 mAHD resulting in an area of inundation of 123 ha of floodplain.

A conservative estimate of the salt load and EC impact at Morgan is made assuming initially 100% of the recharged water is returned to Burra Creek and the Murray River from groundwater during the period of inundation. The amount of diffuse recharge eventually discharging to Burra Creek and/or the Murray River from Burra Creek North is assumed to gradually decline from 100% in the 6^{th} month to zero in the 12^{th} month following inundation. For Burra Creek South discharge will be at 100% until the 5^{th} month as this site has a shorter duration of inundation.

Values of less than 100% for the amount of recharge that ends up discharging to the feature may be expected where evapotranspiration from groundwater occurs before it reaches Burra Creek and/or the Murray River. Therefore, this conservative scenario may represent the cumulative effect of a series of induced and natural floods causing groundwater levels to rise in the vicinity of Burra Creek floodplain and creating gaining river conditions.

Bore 26268 had a reported groundwater salinity of 0.93 mS/cm (April 2009), and is located on the northern edge of Burra Creek North inundation area. This value has been used to represent both Burra North and Burra South.

It is estimated this process results in an EC impact at Morgan of 0.02 (Burra Creek North) and 0.005 (Burra Creek South). These impacts are insignificant.

Key assumptions:

- The recharge due to inundation would last 6 months (Burra North) and 5 months (Burra South);
- Saline groundwater will discharge to Burra Creek and Murray River for a 12 month period (based on observation of this process in other floodplains – e.g. Chowilla);
- The amount of diffuse discharge to Burra Creek and Murray River will decline linearly at the end of the inundation period from 100% to zero;
- The salinity of groundwater discharging remains constant over this period;
- Groundwater salinity discharging to Burra Creek and Murray River is fresh (0.93 mS/cm), but could increase over time following successive watering events;
- Recharge rate is uniform spatially and temporally in the area of inundation; and
- There is no significant salt load delivered to Burra Creek or Murray River through diffuse recharge and displacement of saline groundwater under the *basecase*.

6.5.4. Retention of water

For Burra Creek North, the starting groundwater level is assumed to be 54.0 mAHD (Bore 26268, March 2012) with an estimated rise of 1.6 m (to 55.6 mAHD) after 300 days for the area between Burra Creek and the Murray River as a result of filling this area to a level of 58.7 mAHD. For the inundation area west of Burra Creek, estimated mound rise was 0.8 m (to 54.8 mAHD).

For Burra Creek South, the starting groundwater level is assumed to be 54.0 mAHD (Bore 26268, March 2012) with an estimated rise of 1.2 m (to 55.2 mAHD) after 300 days as a result of filling this area to a level of 59.3 mAHD.

It is assumed that the groundwater level will fall at a constant rate for the following 300 day period.

The salt load from a mound beneath the watering sites is estimated using the bed level estimated from LiDAR (55.7 mAHD at Burra Creek North and 56.7 mAHD at Burra Creek South). Stage height information is not available for Burra Creek. As this assessment is based on the creek bed elevation only, this is likely to result in an over-estimate of EC impact at Morgan.

The flux of groundwater and salt load was estimated at 30 day time steps during the period of groundwater level rise and fall. Each monthly salt load was converted to an EC impact at Morgan. The salt load was calculated using a groundwater salinity value of 0.93 mS/cm (measured in Bore 26268, April 2009) to represent groundwater salinity adjacent Burra Creek and the Murray River

Estimated mound rise was not large enough to raise groundwater levels at either site above the assumed water level in the Murray River (56.5 mAHD) or above the bed level in Burra Creek (approx. 55.7 mAHD in the North to 56.7 mAHD in the South).

1990s groundwater levels were similar to current conditions, suggesting that historically there would have been little or no groundwater discharge to Burra Creek or the Murray River.

Key assumptions:

- The salinity of groundwater discharging to Murray River remains constant over time;
- Groundwater levels due to mounding rise and fall linearly over 300 days;
- The salt load for the '1990s case' was estimated assuming that groundwater levels fall linearly over the 300 days; and
- Groundwater salinity discharging to Burra Creek and the Murray River is 0.93 mS/cm, but could increase over time following successive watering events

6.5.5. Total salinity impacts

The total salinity impact at Morgan of implementation of environmental watering at Burra Creek is estimated to be 0.02 EC at Morgan for Burra Creek North and 0.005 EC for Burra Creek South, based on 8 in 10 and 1 in 2 year frequency respectively.

The components of the salt load and EC impacts relative to the *basecase* are summarised in Table 6.5. The largest component of the salinity impact is associated with the displacement of groundwater due to diffuse recharge following inundation, but even this impact is insignificant. This calculation is considered conservative as it assumes uniformly high salinity values and assumes a significant percentage of the recharged water is returned the Murray River.

- **Table 6.5: Summary of salinity processes and EC impact associated with Burra Creek**

Salinity process	EC impact at Morgan	
	Burra Creek North	Burra Creek South
Salt wash-off	Negligible	Negligible
In-channel release[1]	$1.3x10^{-3}$	N/A

Salinity process	EC impact at Morgan	
	Burra Creek North	Burra Creek South
Recharge and displacement	0.02	0.005
Retention of water lake/wetland	N/A	N/A
TOTAL	**0.02**	**0.005**

1 Based on difference in river salinity of 100 EC

6.6. Cumulative impacts

It is expected that multiple watering events will occur at these sites over time.

Groundwater monitoring records for bores in the Channel Sands aquifer indicate groundwater levels have remained relatively stable over the period of record, dating back to 1990s levels when more frequent flooding occurred.

This suggests that the salt load impact of environmental watering is likely representative of the 1990s conditions. It is likely that successive watering events coupled with natural flood events would not create any significant increases in salt store to that seen in the 1990s. As such, cumulative impacts are likely to be negligible at this site.

Should any larger impacts occur with time, these will be offset by a less frequent operation and reduced duration of watering events.

6.7. Monitoring

The proposed monitoring program is comprised of groundwater and surface water monitoring and aims to provide data that can be used to better define the mechanisms and magnitude of salinity impact arising from the proposed environmental watering events. The monitoring data should form the basis of five-yearly reviews as required under the Basin Salinity Management Strategy, allowing refinement of the salinity impact estimates.

The monitoring program reflects the need to gather data both for the improvement of understanding of the key processes, but also to allow independent review of accountability for operating any works and measures. Monitoring should also be maintained to assess the benefits of environmental watering.

In order to measure salinity impact from the floodplain operations, monitoring periods should be chosen to cover current conditions, floodplain operations, and post-operation conditions. The former provides the opportunity to assess baseline conditions, including salt loads against which to measure the impact of operations. The latter is important because it is likely that the floodplain response would be delayed, with salinity impacts extending beyond the period of floodplain operations. Continuous monitoring will ensure that all impacts due to actions can be assessed against *basecase* conditions as well as highlight any changes in the baseline over time.

All groundwater levels should be expressed relative to Australian Height Datum to allow comparison of groundwater and surface water data.

6.7.1. Groundwater monitoring

Water level and salinity data from groundwater monitoring wells completed in the Channel Sands aquifer in the vicinity of inundation areas, retention sites and other identified impact hotspots should be collected before, during and after each environmental watering event. This is most important for wells that are situated adjacent an inundation area and near the potential receiving surface waters. Salinity measurements at the very top of the saturated thickness (adjacent the discharging site) will allow an assessment of the salt content of the water that will be moving as a result of the action and indicate any freshening of groundwater that may occur.

Table 6.6 shows the groundwater monitoring bores targeted under the program. This has been based upon the distribution of bores that are currently being monitoring for groundwater level and/or salinity by Mallee CMA.

There is a poor distribution of monitoring infrastructure across Burra Creek at present, with current monitoring of the Channel Sands aquifer only targeting the north and south of the floodplain. It will be useful to gain additional information in the vicinity of the proposed inundation areas. The location of suggested additional monitoring bores for the Channel Sands is presented on

Figure 6.12. For Burra Creek North three bores are suggested; on the western extent, adjacent Burra Creek and adjacent the Murray River. For Burra Creek South, monitoring points are sited either side of the inundation area. These will aid in assessing maximum groundwater levels and infer direction of flow.

All bores are recommended to be monitored for groundwater level and salinity at daily intervals before, during and after events that change the hydraulic regime and at weekly intervals at other times.

- **Table 6.6: Groundwater monitoring sites at Burra Creek**

Bore ID	Easting	Northing	Proposed monitoring parameters (water level/salinity)
Channel Sands			
26183	707792	6118445.4	Level, salinity
26268	712221	6137277.2	Level, salinity
Parilla Sands			
26173	710028	6130021.8	Level, salinity
26175	708553	6130213	Level, salinity
26188	712000	6137100	Level, salinity
26191	710245	6136678	Level, salinity
Suggested additional monitoring bores (Channel Sands)			
Bore 1	711379	6135074	Level (logger), salinity
Bore 2	712478	6134171	Level (logger), salinity
Bore 3	713161	613433	Level (logger), salinity
Bore 4	710951	6128780	Level (logger), salinity
Bore 5	711657	6128711	Level (logger), salinity

The frequency of monitoring should ideally be daily to weekly depending on the rate of water level response (if any) in a given monitoring well. If changes in standing water level attributable to floodplain watering are observed, then monitoring frequency should be increased accordingly. It is recommended that the high priority groundwater observation wells are monitored for water level daily, especially just before, during and post inundation. At the very least, under *basecase*, regulated conditions, observations should be collected at least every three months from these wells.

Consideration should be given to the use of automatic down-hole loggers for recording responses to watering events, which are especially useful where wells may become stranded. Additional benefits include recording of subtle impacts that may not be seen from relatively sparse observations. Bores suggested for logger installation include the suggested additional monitoring sites; Bore 1, 2 and 3.

The key will be to identify the peak groundwater level as a result of inundation, but also to record the initial *basecase* and post inundation response as the lake water levels recede. If data loggers are available, the most beneficial locations would therefore be in the bores closest to the area of inundation, as listed above.

If costs cannot be met for monitoring it is recommended that fewer locations are chosen and an emphasis placed on collecting more comprehensive time series data.

6.7.2. Surface water monitoring

Ideally, surface water monitoring would provide sufficient data to calculate salt load to reaches of flowing anabranches or the Murray River adjacent to areas of floodplain watering. This is possible when pre-existing surface water monitoring stations are available.

A single surface water monitoring gauge is active adjacent Burra Creek and is located at Wakool Junction, north of the inundation areas. Table 6.7 details site information.

Table 6.7: Existing surface water monitoring sites

Site ID and description	Monitoring parameters
414200 – Wakool Junction	Water level, flow, salinity

To reduce uncertainties relating to *basecase,* inundation across the Burra Creek and associated NSW floodplain, as well as their level of connection to the surface water network, observations and survey of specific wetlands would improve the conceptualisation of the *basecase* conditions. In particular, observations around any wetlands or depressions considered to be potential sources of significant salt load to the River would inform future refinements of the salinity impacts of watering actions. It is assumed that water level data will be collected at each regulator.

It is recommended that stage height monitoring be undertaken at a series of locations along Narcooyia, Yungera and Bonyaricall Creeks and the Murray River (expressed relative to Australian Height Datum). Where the suggested new groundwater monitoring bores are sited adjacent creek lines, it would be useful to gauge stage height to aid in comparison between surface water and groundwater levels at a particular location.

Surface water observations are especially important at the inlet and outlet structures. Surface water salinity and flow should be monitored at such locations to assess the impact of watering events and calculate likely salt loads to the system. Flow gauges should be installed at the inlet and outlet structures. Monitoring should occur before, during and after the watering event. The length of time and frequency of monitoring can be assessed as data is collected and assessed. Initially monitoring should occur at a monthly frequency.

- **Figure 6.12: Burra Creek suggested monitoring locations**

7. Nyah Forest

7.1. Hydrology

The project area referred to as Nyah is representative of the Nyah State Forest and Nyah Recreation Reserve covering an area of over 900 ha. This is located west of the Murray River between the townships of Woodwood in the North and Nyah in the South (Figure 7.1). The State Forest is bounded to the east by the Murray River and to the west by the Murray Valley Highway.

Parnee-Malloo Creek is an anabranch of the Murray River. The creek departs from the river at around 1356 river km and follows a meandering northerly path over 16 km through the centre of the State Forest before re-joining the River at approximately 1340 km (REM, 2005). The river frontage is part of Parks Victoria Murray River Reserve.

Gauging station 409206 (Nyah) is located south of the State Forest, adjacent the township of Nyah and has a flow record spanning 2005 to 2009. March 2009 river level was 60.14 mAHD. Given the increased flow events observed through the system since 2010, current river level is likely to slightly higher than the 2009 record, however this cannot be accurately quantified.

The minimum stage height measured at Nyah was 59.68 mAHD in June 2007. This may represent the worst case scenario for stage height adjacent Nyah.

A monitoring gauge is located on Parnee-Malloo Creek at Nyah golf course (409241) but has been inactive since 2008. This gauge was monitored for water quality only.

7.2. Hydrogeology

7.2.1. Background

The Murray River incised through the Mallee landscape late in the Quaternary period in response to sea level falls, producing a relatively narrow trench typically 5 to 10 km wide. This trench backfilled as base levels were re-established.

On the floodplain, the basal unit filling the trench beneath the Woorinen Formation is the Channel Sands which is overlain with the finer grained Coonambidgal Formation. The latter contains fined grained silts and clays ranging in thickness up to 5 m across the floodplain. The Channel Sands is made up of fine to coarse-grained sands and is in direct connection with the Murray River.

The Channel Sands aquifer lies directly above the regionally extensive Parilla Sands aquifer. The Blanchetown Clay is absent. On the higher ground to the west, beyond the boundary of the floodplain, the Woorinen Formation is directly underlain by the Shepparton Formation. Here, the Channel Sands becomes absent.

- **Figure 7.1: Location of key features at Nyah**

Thorne *et al,* (1990) prepared hydrogeological cross-sections which span the length of the Murray River from the South Australian border through to Nyah.

Transect Z from Thorne *et al,* (1990) lies to the south of the inundation area, adjacent the township of Nyah. Here the Murray River is incised into the Channel Sands aquifer (approximate thickness of 10m) and is shown to be limited in spatial extent, with the trench being quite narrow compared to other sites. Approximately 0.5 km west of the Murray River, the Channel Sands formation becomes absent (Figure 7.2).

7.2.2. Groundwater level

Groundwater level data has been collected within Nyah State Forest. The location of bores that are currently being monitored (2008 to present) is shown in Figure 7.3. There are currently only two bores located in the vicinity of this floodplain area (409241 and 408702) but these have no groundwater level or salinity data available at time of assessment. Mallee CMA records indicate these sites were inaccessible/not located during recent monitoring rounds. The GMS database did not return any results for these two bores. As such the understanding of groundwater levels immediately beneath Nyah is not known at this time.

Several other bores are located further south toward Vinifera and to the west near the township of Nyah, but predominately target the deeper Parilla Sands aquifer.

Summer 2012 groundwater elevation data is not available for the shallow aquifer across the Nyah floodplain. Two bores to the south are targeting the Channel Sands (26182, 26271). May 2009 groundwater levels put the groundwater level at approximately 57 mAHD.

Depth to groundwater in the Channel Sands is around 5-6 mbgl, (measured at Bores 26182, 26271).

High flow events occurred in the Murray River system between 2010-2012. It is difficult to establish if (or when) groundwater flow patterns have changed over this time due to the infrequent groundwater level monitoring and overall lack of monitoring bores in the area

Groundwater levels in the Parilla Sands aquifer have remained relatively stable since 1990 (i.e. Bore 26158 which has maintained a groundwater level of around 60 mAHD).

Anecdotal evidence from studies undertaken as part of the Nyah ID renewal project identified that drainage from irrigation in the Nyah north extension was affecting the floodplain and vegetation in the vicinity. Drainage from this area is a possible source of salt. Over the decades of monitoring the consistent pattern that has been that the river elevation is generally higher than that inland and behind the Nyah ID. As a result the general pattern of groundwater flow is away from the river an little has changed this.

- **Figure 7.2: Transect Z (Thorne *et al,* 1990)**

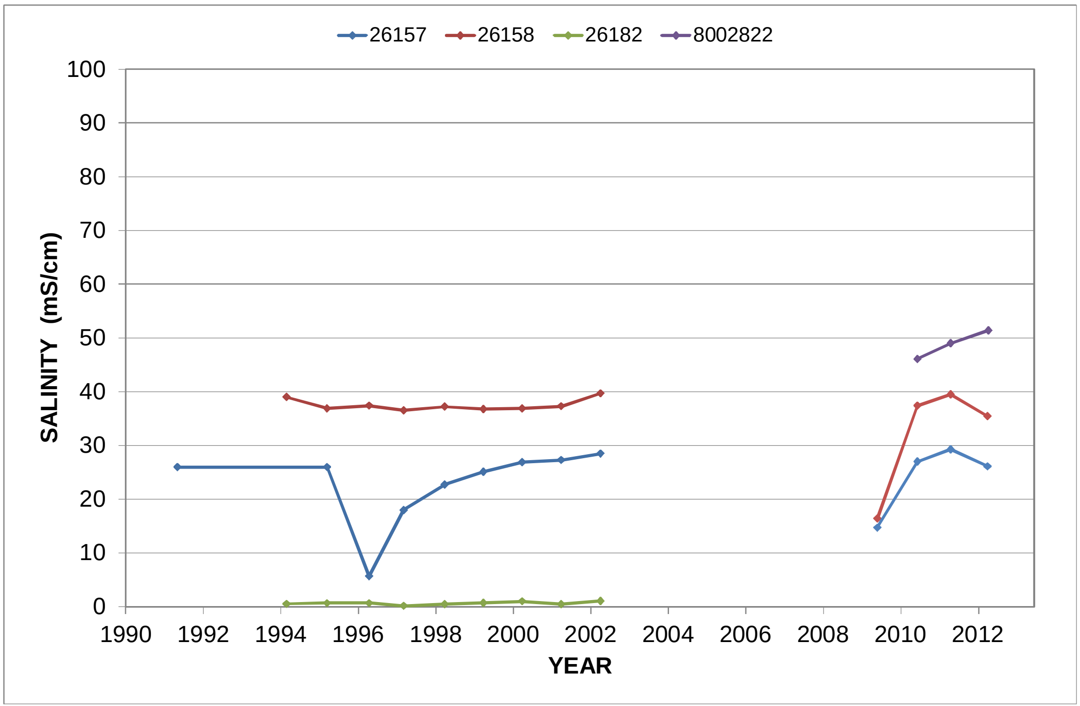
- **Figure 7.3: Current monitoring at Nyah**

7.2.3. Groundwater salinity

Salinity time series data for selected monitoring sites across Burra Creek floodplain is presented in Figure 7.4.

This shows that groundwater screened in the Channel Sands aquifer closer to the Murray River appears to be relatively fresh (Bore 26182). It is likely that salinity increases with distance from the river, but there are not enough monitoring points to confirm this. Bore 26182 has not been monitored for salinity since 2002, but groundwater is likely to have remained relatively fresh.

Bores located to the west of the floodplain in the Parilla Sands aquifer (26157, 26158) shows a similar overall trend in data. A gap in monitoring occurred between 2002 and 2009 so it is unknown what happened during this time. After 2010 a rise in groundwater salinity was observed.



- **Figure 7.4: Nyah groundwater salinity**

An aerial electromagnetic (AEM) survey was undertaken during Feb-March 2008 (BRS, 2009). An AEM depth slice (as apparent bulk electrical conductivity) averaged over the upper 30 m in the shallow aquifer from ground surface is shown in Figure 8.5.

The AEM data infers that a lower salinity zone exists either side of the Murray River and over an extensive area of the Nyah floodplain. These lower salinity areas are representative of zones where there is localised recharge to the groundwater system through the river banks.

7.2.4. Groundwater – surface water interaction

The location and magnitude of the salinity impact depends in part of the degree of connection between the shallow floodplain aquifer, and the Murray River and anabranches. Greatest impacts are possible where the surface water system gains groundwater. This section provides a summary of the nature of the connection based on existing information.

Where groundwater elevations are higher than surface water elevations, river reaches are defined as potentially *connected – gaining* systems. Where groundwater elevations are lower than surface water elevations, river reaches are defined as potentially *connected – losing* systems. Where the anabranches are permanently inundated and groundwater elevations are lower than the base of the river bed, river reaches are also defined as potentially *connected – losing* systems.

The bed elevations of Parnee-Malloo Creek extracted from LiDAR show the base ranges from 60 m AHD at the mouth up to 62.5mAHD upstream at its head. March 2012 groundwater monitoring is not available across the Nyah floodplain.

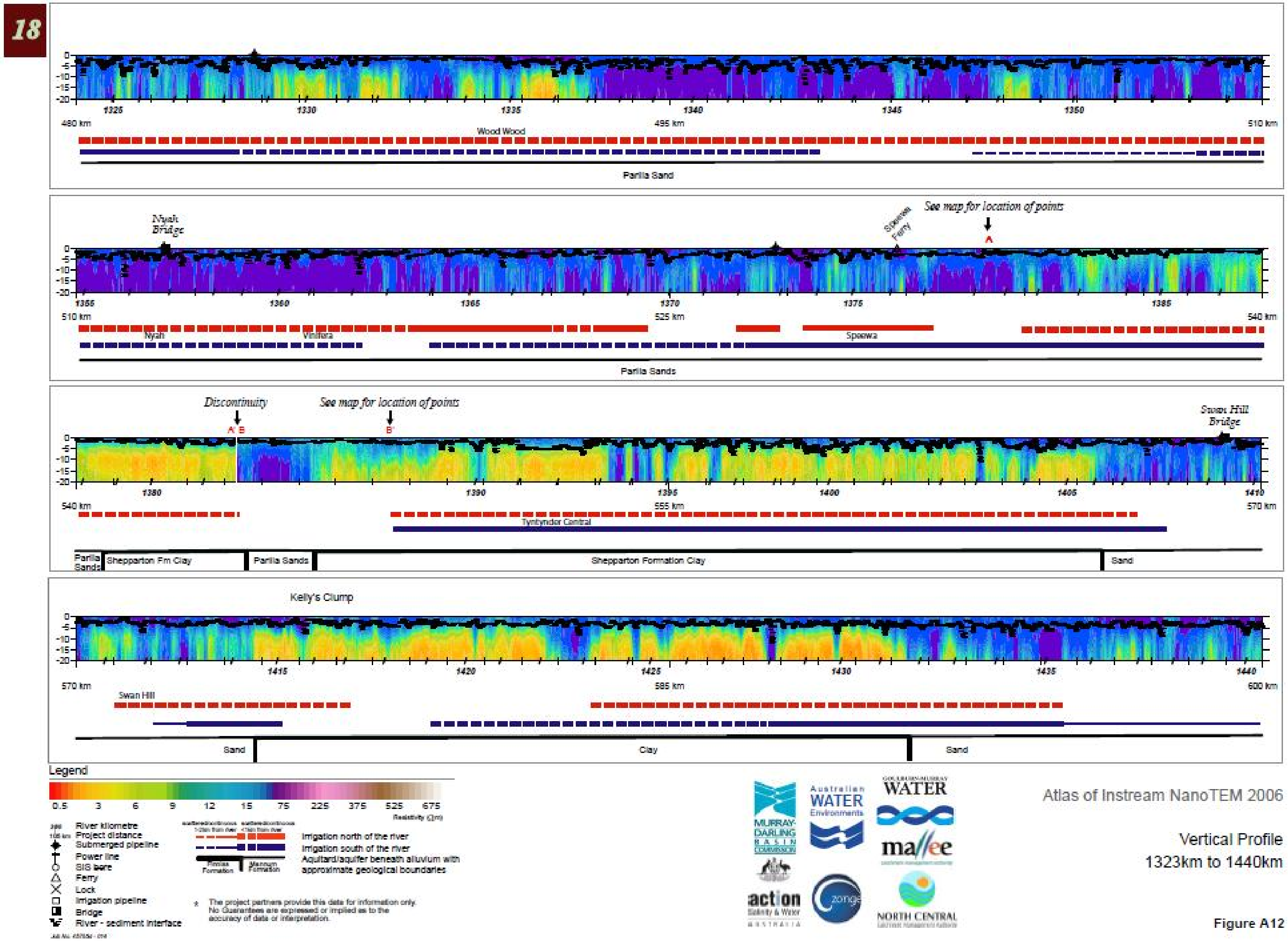
Groundwater levels to the south of the site in the Channel Sands indicate the groundwater level was at 57 mAHD in March 2009 Based on this groundwater level alone, it suggests that the groundwater level is below Murray River stage height (>60.1 mAHD) and the base of Parnee-Malloo Creek.

Stage height in Parnee-Malloo Creek and groundwater levels in the Channel Sands would need to be quantified to accurately assess the nature of connection between surface water and groundwater level in the Channel Sands.

For this assessment, Parnee-Malloo Creek is conservatively assumed to be in connection with the groundwater in the Channel Sands aquifer.

The 2006 NanoTEM (Telfer *et al*., 2006; Figure 7.6) survey shows the vertical profiles displaying the resistivity data collected along the Murray River. Low resistivities (red to yellow) indicate areas that are conductive, (that is, they are interpreted to hold saline water and/or be composed of clay). The resistive areas (blue through purple) are interpreted to be generally fresh water in sands (Telfer *et al*., 2006). For Nyah, there is a long stretch of water course in the vertical profile which is quite resistive. This suggests generally fresh groundwater and likely losing conditions.

- **Figure 7.5: Average apparent bulk electrical conductivity for a 30 m interval immediately below groundwater surface**



- **Figure 7.6: Vertical profile of 2006 Nano TEM survey along Murray River, map reference 18**

7.3. Environmental works and measures

Alluvium (2012b) outlined potential areas that may benefit from inundation and flow control (presented in Figure 7.7 and summarised in Table 7.1). The associated works and measures related to their inundation are discussed below and comprise two target areas; Burra North and Burra South.

A schematic of the key water levels on the floodplain is presented in Figure 7.8.

7.3.1. Nyah North

This option proposes the installation of levees (primarily through road raising and road toping) at the northern end of the site to allow overbank flows from the Murray River to be retain on the Nyah North floodplain area. Alluvium (2012b) considered four infrastructure configurations (levee height):

- Sub-option 1: a top water level of 62.5 m AHD inundating a total area of 150 ha
- Sub-option 2: a top water level of 62.8 m AHD inundating a total area of 298 ha
- Sub-option 3: a top water level of 63.0 m AHD inundating a total area of 386 ha
- Sub-option 4: a top water level of 63.2 m AHD inundating a total area of 476 ha

Sub-option 2 was initially identified as the preferred option, based on a requirement to minimise the levee footprint. However, discussion with Mallee CMA indicated sub-option 4 is to be assessed during this scope of work. Documentation of this option does not include discussion outlet works.

Alluvium (2012b) also noted that environmental water could be pumped into the site. This would require the installation of a regulator to replace the existing culvert at the upstream inlet on Parnee-Malloo Creek. The regulator would be used (closed) to retain water on the floodplain during pumped watering events.

7.3.2. Nyah South

This option proposes upgrading an existing culvert on up the upstream end of Parnee-Malloo Creek to allow overbank flows from the Murray River onto the Nyah South floodplain. Levees would also need to be constructed (by raising the existing road) at the northern end of the site to retain water on the floodplain. Alluvium (2012b) considered four infrastructure configurations (levee height):

- Sub-option 1: a top water level of 63.6 m AHD inundating a total area of 20 ha
- Sub-option 2: a top water level of 63.8 m AHD inundating a total area of 41 ha
- Sub-option 3: a top water level of 64.0 m AHD inundating a total area of 60 ha

Sub-option 3 is identified as the preferred option, based on cost per ha inundated. Documentation of this option does not include discussion outlet works.

Alluvium (2012b) also noted that environmental water could be pumped onto the site from the Murray River, with a potential pumping location at the northern end of the sites. This pump site could serve as an alternative pump site for Nyah watering.

- **Table 7.1: Summary of Nyah environmental watering options**

Option	Filling Method	Dependencies	Top water level (m AHD)	Area inundated (ha)
Nyah North	Gravity (Murray River)	Water levels in the Murray River	63.2	476
	Optional pumping with additional works	Nil		
Nyah South	Gravity (Murray River)	Water levels in the Murray River	64.0	60
	Optional pumping	Nil		

7.3.3. Watering Regime

Documentation of options provided for this project did not provide discussion on water regimes, and minimal discussion on watering requirements. Table 7.2 details likely timing and frequency of inundation events as outlined by Mallee CMA. For the purpose of this assessment, calculations have been based on watering events commencing in August.

- **Table 7.2: Proposed Nyah watering regime**

Option	Inundation frequency	Timing	Inundation duration (months)
Nyah North	10 in 10 years	Winter/spring	6
Nyah South	5 in 10 years	Winter/spring	5

7.4. Potential salinity impacts

7.4.1. Approach

The in-river salinity impacts (at Morgan in South Australia) potentially caused by the proposed actions at Nyah were assessed relative to a *basecase* scenario.

The approach to the assessment requires conversion of salt load to EC at Morgan described in Fuller & Telfer (2007), with resultant EC impacts at Morgan (determined using the Ready

Reckoner) reflecting the impact of an operation over the 25 year Benchmark Period and the time of year the salt load occurs.

The scenarios to be tested are summarised in Table 7.3. This also contains a summary of the key floodplain processes relevant to the watering action as well as a proposed assessment method. Greater detail on these aspects is provided in the following section.

The approach allows for the incremental salt impact of each option to be assessed. The cumulative effect is taken to be the sum of salt impacts across all watering actions.

Appendix A contains details of the steps in the impact analysis, while Appendix B contains tables of input data used in calculations.

7.4.1.1. Identifying salt discharge processes

The conceptualisation of the hydrogeological setting described above was used to identify processes and areas believed to be at greater risk of causing increased salt load to the river, bearing in mind the proposed actions and associated floodplain processes involved.

This involved consideration of the:

- Potential for recharge to groundwater; taking account of surface geology and depth to groundwater level in the Channel Sands;
- Potential for increasing groundwater hydraulic gradients and hence increased discharge;
- Potential for mobilisation of salt from in-channel sources; and
- Proximity of the inundated areas to the receiving water courses.

7.4.1.2. Impact on floodplain processes and approach to analysis

The works and measures prosed at Nyah will result in areas of the floodplain being inundated with water. In Nyah North and Nyah South this will occur via the use of levees at the northern end of the sites to raise water levels to a top elevation of 62.8 and 64 mAHD respectively.

Parnee-Malloo Creek and the Murray River are considered to be receiving environments for this assessment.

Key assumptions used regarding the Nyah floodplain operation are:

- Designed to inundate approximately 476 ha (North) and 60 ha (South);
- Operation initially 10 in 10 years (North) and 5 in 10 years (South);
- Timed to commence in Winter (August); and

- Total duration of operation assessed to be between 6 months (North) and 5 months (South).

The following salt mobilisation processes are relevant to each stage of the inundation process:

During the fill stage

- Wash-off of salt from floodplain soils; and
- The salt held in the creek and river channel and mobilisation of salt in previously stranded backwaters to be held in the in-stream store up gradient of the levees.

During the hold stage

- Inundation of the floodplain areas and recharge to the underlying shallow saline groundwater within the floodplain aquifer, creating groundwater mounds beneath inundated areas; and
- Lateral outflow from filled anabranches to the floodplain aquifer.

During the spill/evaporation stage

- Displacement of saline groundwater to the Parnee-Malloo Creek and /or the Murray River on the recession where mounded groundwater levels remain higher than surface water levels; and
- Release of the in-stream store within the Parnee-Malloo Creek system of saline water created during the fill stage.

Fill Stage

The use of levees and culverts associated with Nyah North and South during the fill stage will result in increased surface flows to Parnee-Malloo Creek.

Surface flow through usually dry channels (under regulated conditions) could result in salt wash-off from floodplain soils into the main Parnee-Malloo Creek channel and ultimately the Murray River.

The inundation of the floodplain will also cause some mobilisation from salt stored in floodplain soils.

ANALYSIS APPROACH – FILL STAGE
Historical flood data linking flows, the area of floodplain inundation and subsequent salt loads in the river post-flooding suggests a total salt flux of 38 kg/ha/day for Lindsay River (Mike Dudding, pers. Comm – reported by SKM (2010a)). Of the total salt flux, the proportion due to wash-off is thought to be approximately 10%; thus reducing the salt flux for this process to 3.8 kg/ha/day. In addition, values of 1 and 5 kg/ha/day were derived during the calibration of a real time salt and water balance model for Chowilla (SKM, 2010b). These salt flux rates are typical of locations

downstream of Buloke Swamp; as such these are considered representative only for this assessment.

The magnitude of the salt load associated with lower surface water flow down gradient of the regulator is not considered significant relative to other processes and is not quantified.

Hold Stage

Once the target water level is reached within each structure/project, the water will be held on the floodplain by flow control structures. During the hold stage there will be a continuation of lateral and vertical outflow (infiltration) of surface water to the floodplain aquifer that began in the fill stage. . Water stored in the river banks could mix with groundwater that may be released back to the River in the spill stage (on the recession). Monitoring records and the AEM data indicate groundwater at Nyah is relatively fresh, hence likely to result in minimal EC impact at Morgan as a result of groundwater discharge.

There is the potential for diffuse recharge to the Channel Sands aquifer beneath the inundated area created under Nyah North and South. The area of inundation proposed could, over successive events, increase groundwater levels in this area to reverse the hydraulic gradient where saline groundwater is displaced towards Parnee-Malloo Creek and ultimately to the Murray River. However, no surface water level monitoring occurs on Parnee-Malloo Creek. This means it is not possible to accurately define the level of groundwater level rise necessary to induce discharge to the Creek. As such, only bed elevation estimated from LiDAR is available. In addition to EC impact at Morgan, this increased salt load also has the potential to impact any irrigators that rely on surface water diversions. This was therefore highlighted for further investigation.

ANALYSIS APPROACH – HOLD STAGE.

The rate of recharge to the shallow groundwater system is estimated to be 0.5 mm/day, based on analysis of recharge rates by REM (2006) and previous work by CSIRO on the Chowilla floodplain (refer SKM, 2010). This rate of recharge is assumed to include the volume of water that recharges the aquifer laterally.

If the waterbody is connected to groundwater (that is, underlain by fully saturated material) then a mass balance approach can be used to estimate the total volume of groundwater that may eventually discharge to the surface water system (assuming some is lost because of evapotranspiration). If the waterbody is underlain by an unsaturated zone above the groundwater level then there is a need to estimate the rate of rise and fall of groundwater levels using a method from Hantush (1967). If the groundwater level is estimated to rise above the surface water level then the rate of discharge to a river reach can be calculated using a flow net analysis.

Spill and Evaporation Stage

Salt that has accumulated in-stream during the fill stage will be released during the spill stage.

Once surface water levels decline in the Parnee-Malloo Creek, there will be potential for the inflow of saline groundwater to the anabranch system that is derived from the following processes that occurred during the hold stage:

- Diffuse recharge and groundwater level mounding; and
- Lateral outflow from anabranches to the Channel Sands aquifer.

For the purpose of this analysis it is conservatively assumed that immediately on the cessation of the hold stage 100% of the recharged water (on a monthly time step) will eventually return to the receiving feature (in this instance Parnee-Malloo Creek). As the water held in the feature diminishes, the percentage return to the Creek at each time step in the analysis is assumed to diminish at a set rate to mimic the fall in groundwater gradients and consequent decline in groundwater discharge. This process occurs over a 12 month period at which time all discharge ceases.

In reality, the volume of groundwater discharged maybe lower than 100% of recharge if water is lost to evapotranspiration. It is likely that evapotranspiration is a major component of groundwater discharge in these floodplain environments, however, it has not been accounted for in the assessments below. In some cases evapotranspiration may account for all groundwater discharge and in these cases the long term sustainability of the environmental assets must be questioned.

ANALYSIS APPROACH – SPILL AND EVAPORATION STAGE

The mass of salt released from in-stream storage in the spill stage is calculated under current conditions. A nominal 100 EC difference will be adopted between upstream and downstream surface water salinity. These EC values are multiplied by an assumed in-stream water volume to estimate salt load.

The salt load from wash-off is calculated using the approach described in the fill stage.

The volume of recharge to the groundwater from a floodplain watering event displaces a lesser volume of higher salinity groundwater to the adjacent watercourse. If the recharge volume can be calculated, then a corresponding salt load to the river can be inferred. This is similar to the nomogram approach described in the Murray Darling Basin Commission (MDBC) Salinity Impact Assessment Framework for the Living Murray Environmental Works and Measures Program (Fuller & Telfer, 2007). It is expected this salt load will occur over a 12 month period following inundation. .

It is assumed 100% of recharge is discharged to the river system during the period of inundation and it is also assumed this accounts for the groundwater that is discharged as a result of diffuse recharge via the floodplain aquifer. It is further assumed that the rate of discharge will fall in a decreasing manner from 100% immediately at the end of the inundation period to zero in month 12 following the hold stage. This decay in the rate of return of recharge water reflects diminishing area of inundation and diminishing hydraulic gradient to the surface water system.

- **Table 7.3: Floodplain process and analytical methods used for Nyah**

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
Nyah North Inundate to a level of 62.8 mAHD over an area of 298 ha	Surface salt wash-off Salt in surface water mobilised during draining of creeks Recharge of shallow saline groundwater and displacement of saline groundwater to the creek and Murray River.	Surface flush estimated from assumed value of salt storage per hectare of floodplain. In –channel release of salt load Mass balance approach (based on estimate of recharge and local salinity) for the inundated area. Mound build up estimated and flow net is used to estimated salt load from mound to creek	Low	Limited bore data to verify groundwater salinity, groundwater flow and response to recharge.
Nyah South Inundate to a level of 64 mAHD over an area of 60 ha	Surface salt wash-off Recharge of shallow saline groundwater and displacement of saline groundwater to the creek and Murray River.	Surface flush estimated from assumed value of salt storage per hectare of floodplain. Mass balance approach (based on estimate of recharge and local salinity) for the inundated area. Mound build up estimated and flow net is used to estimated salt load from mound to creek	Low	Limited bore data to verify groundwater salinity, groundwater flow and response to recharge.

- **Figure 7.7: Nyah environmental watering locations**

- **Figure 7.8: Nyah schematic of operating levels**

7.5. Results and discussion

7.5.1. Salt wash off

Estimated salt flux associated with the initial wash-off of salt was calculated for the area of inundation; Nyah North (415 Ha) and Nyah South (60 ha) less the area of watercourse. The calculation was undertaken assuming salt capture of 1, 3.8 and 5 kg/ha/day.

Estimates of salt load and EC impacts at Morgan are summarised in Table 7.4 for each process, and these indicate that impacts from salt wash-off are negligible. These estimates are based on the Ready Reckoner value for August.

- **Table 7.4: Predicted salt load and EC impact at Morgan (relative to the *basecase*)**

Salt wash-off rate (kg/ha/day)	Salt load (t/d) ^	EC impact at Morgan ^
Nyah North		
1	0.42	0.0015
3.8	1.5	0.0052
5	2.1	0.0075
Nyah South		
1	0.06	2.2×10^{-4}
3.8	0.21	7.6×10^{-4}
5	0.30	0.0011

Note: ^ These values have been corrected since the previous version (Final, September 2013) of the report. The previously reported results were considered to be negligible.

Key assumptions:

- Release of water occurs at a constant rate over a 30 day period in Spring (October);
- Instantaneous transfer of salt from the whole of the inundated area to Parnee-Malloo Creek and/or Murray River occurs (that is, reaches equilibrium within one day);
- There is no significant salt load delivered to the Parnee-Malloo Creek and/or Murray River through salt wash-off under *basecase* conditions; and
- Salt flux rates of 1, 3.8 and 5 kg/ha/d are typical of downstream conditions (i.e. Lindsay and Chowilla floodplain). As such these are representative values only.

7.5.2. In channel release

The magnitude of the salinity impact at Nyah North due to release of salt stored in the stream channel upstream of the culvert is proportional to the assumed difference in salinity upstream and downstream (100 EC). The channel geometry was assumed to be 5 m wide and 1 m deep for the purpose of this assessment.

The EC impact at Morgan is calculated to be 0.001. This impact is insignificant.

Key assumptions:

- Release of salt to the system downstream of the regulator occurs at a constant rate over a 30 day period in Spring (October);
- Instantaneous transfer of salt occurs from the whole of channel system to Parnee-Malloo Creek;
- Conservatively assumed that all salt contained in the channel is released although some salt may remain in the channel under normal flow;
- The geometry of the channel along its length is assumed to be uniform and can be represented by a rectangular section that is 5 metres wide and 1 metres deep; and
- There is no significant salt load delivered to the Parnee-Malloo Creek and/or Murray River through salt wash-off for the *basecase*

7.5.3. Floodplain inundation (recharge and displacement)

Floodplain inundation at Nyah North will be achieved by inundating to a top water level of 62.8 mAHD resulting in an area of inundation of 415 ha of floodplain. Inundation at Nyah South will be achieved by inundating to a top water level of 64 mAHD resulting in an area of inundation of only 60 ha of floodplain.

A conservative estimate of the salt load and EC impact at Morgan is made assuming initially 100% of the recharged water is returned to Parnee-Malloo Creek from groundwater during the period of inundation. The amount of diffuse recharge eventually discharging to Parnee-Malloo Creek and/or the Murray River from Nyah North is assumed to gradually decline from 100% in the 6th month to zero in the 12th month following inundation. For Nyah South discharge to the River will be at 100% until the 5th month as this site has a shorter duration of inundation.

Values of less than 100% for the amount of recharge that ends up discharging to the feature may be expected where evapotranspiration from groundwater occurs before it reaches Parnee-Malloo Creek and/or the Murray River. Therefore, this conservative scenario may represent the cumulative effect of a series of induced and natural floods causing groundwater levels to rise in the vicinity of the inundation area and creating gaining river conditions.

Bore 26182 had a reported groundwater salinity of 1.06 mS/cm (April 2002), and is located south of the inundation areas, adjacent the township of Nyah. This value has been used to represent both Nyah North and Nyah South.

It is estimated this process results in an EC impact at Morgan of 0.04 (Nyah North) and 0.003 (Nyah South). These impacts are insignificant.

Key assumptions:

- The recharge due to inundation would last 6 months (Nyah North) and 5 months (Nyah South);
- Saline groundwater will discharge to the Murray River for a 12 month period (based on observation of this process in other floodplains – e.g. Chowilla);
- The amount of diffuse discharge to Parnee-Malloo Creek and the Murray River will decline linearly at the end of the inundation period from 100% to zero;
- The salinity of groundwater discharging remains constant over this period;
- Groundwater salinity discharging to Parnee-Malloo Creek and the Murray River is fresh (1.06 mS/cm), but could increase over time following successive watering events;
- Recharge rate is uniform spatially and temporally in the area of inundation; and
- There is no significant salt load delivered to the Murray River through diffuse recharge and displacement of saline groundwater under the *basecase*.

7.5.4. Retention of water

For Nyah North the starting groundwater level is assumed to be 56.98 mAHD (Bore 26182, March 2009). Groundwater mound rise calculations estimated a rise in groundwater levels of 2.5 m (to 59.5 mAHD) after 300 days as a result of filling this area to a top water level of 62.8 mAHD.

For Nyah South the starting groundwater level is assumed to be 56.98 mAHD (Bore 26182, March 2009). Groundwater mound rise calculations estimated a rise in groundwater levels of 1.4 m (to 58.4 mAHD) after 300 days as a result of filling this area to a top water level of 64.0 mAHD.

It is assumed that the groundwater level beneath Nyah floodplain will fall at a constant rate for the following 300 day period.

The salt load from a mound beneath the watering sites is estimated based on the stage height in the River (60.1 mAHD). The bed level for Parnee-Malloo Creek was estimated from LiDAR (60 mAHD at Nyah North and 62.5 mAHD at Nyah South). Stage height information is not available for Parnee-Malloo Creek. As this assessment is based on the creek bed elevation only, these are likely to result in an over-estimate of EC impact at Morgan.

The flux of groundwater and salt load was estimated at 30 day time steps during the period of groundwater level rise and fall. Each monthly salt load was converted to an EC impact at Morgan. The salt load was calculated using a salinity value of 1.06 mS/cm, Bore 26268, April 2009 (Appendix B).

Estimated mound rise was not large enough at either site to raise groundwater levels above the assumed water level in the Murray River (60.1 mAHD) or above the bed level in Parnee-Malloo Creek (average 60 mAHD in the North up to 62.5 mAHD in the South).

The salt load calculations were re-run assuming the starting groundwater level beneath Nyah is close to 1994 levels (59.6 mAHD). A flow net analysis estimates the salt load toward to Murray River to reach a maximum of 0.003 t/d after 300 days with an impact of 4.5×10^{-4} EC at Morgan (Nyah North) and 0.005 t/d with an impact of 2.7×10^{-4} EC at Morgan (Nyah South). These impacts are insignificant.

Mound rise at Nyah North was not great enough to raise the groundwater level above the bed level in Parnee-Malloo Creek.

Key assumptions:

- The salinity of groundwater discharging to Parnee-Malloo Creek and the Murray River remains constant over time; and
- Groundwater levels due to mounding rise and fall linearly over 300 days.
- The salt load for the ‘1990s case’ was estimated assuming that groundwater levels fall linearly over the 300 days; and
- Groundwater salinity discharging to Parnee-Malloo Creek and the Murray River is 1.06 mS/cm, but could increase over time following successive watering events

7.5.5. Total salinity impacts

The total salinity impact at Morgan of implementation of environmental watering at Nyah is estimated to be 0.04 EC at Morgan for Nyah North and 0.003 EC for Nyah South, based on 8 in 10 and 5 in 10 year frequency respectively.

The components of the salt load and EC impacts relative to the *basecase* are summarised in Table 7.5. The largest component of the salinity impact is associated with the displacement of groundwater due to diffuse recharge following inundation, but even this impact is insignificant. This calculation is considered conservative as it assumes uniform salinity and assumes a significant percentage of the recharged water is returned the Murray River.

- **Table 7.5: Summary of salinity processes and EC impact associated with Nyah**

Salinity process	EC impact at Morgan	
	Burra Creek North	Burra Creek South
Salt wash-off	Negligible	Negligible
In-channel release[1]	0.001	N/A
Recharge and displacement	0.04	0.003
Retention of water lake/wetland	N/A	N/A
TOTAL	**0.04**	**0.003**

Based on difference in river salinity of 100 EC

7.6. Cumulative impacts

It is expected that multiple watering events will occur at these sites over time.

There are no groundwater monitoring bores in close proximity to Nyah North or Nyah South. It is therefore difficult to make a comparison between current groundwater levels in the Channel Sands aquifer with earlier 1990s levels (when more frequent flooding occurred).

South of the inundation areas, adjacent Nyah township, monitoring records in the Channel Sands indicate the groundwater level was up to 4 m higher during the 1990s (Bore 26271).

It is expected that successive watering events coupled with natural flood events could return groundwater conditions and salt store to that seen in the 1990s. This '1990s condition' can be viewed as being representative of the 'cumulative impact' of implementation of a large scale sequence of watering events, that is, it represents the maximum salt impact condition.

Should larger impacts occur with time, these will be offset by a less frequent operation and shorter duration of watering events.

7.7. Monitoring

The proposed monitoring program is comprised of groundwater and surface water monitoring and aims to provide data that can be used to better define the mechanisms and magnitude of salinity impact arising from the proposed environmental watering events. The monitoring data should form the basis of five-yearly reviews as required under the Basin Salinity Management Strategy, allowing refinement of the salinity impact estimates.

The monitoring program reflects the need to gather data both for the improvement of understanding of the key processes, but also to allow independent review of accountability for operating any works and measures. Monitoring should also be maintained to assess the benefits of environmental watering.

In order to measure salinity impact from the floodplain operations, monitoring periods should be chosen to cover current conditions, floodplain operations, and post-operation conditions. The former provides the opportunity to assess baseline conditions, including salt loads against which to measure the impact of operations. The latter is important because it is likely that the floodplain response would be delayed, with salinity impacts extending beyond the period of floodplain operations. Continuous monitoring will ensure that all impacts due to actions can be assessed against *basecase* conditions as well as highlight any changes in the baseline over time.

All groundwater levels should be expressed relative to Australian Height Datum to allow comparison of groundwater and surface water data.

7.7.1. Groundwater monitoring

Water level and salinity data from groundwater monitoring wells completed in the Channel Sands aquifer in the vicinity of inundation areas, retention sites and other identified impact hotspots should be collected before, during and after each environmental watering event. This is most important for wells that are situated adjacent an inundation area and near the potential receiving surface waters. Salinity measurements at the very top of the saturated thickness (adjacent the discharging site) will allow an assessment of the salt content of the water that will be moving as a result of the action and indicate any freshening of groundwater that may occur.

Table 7.6 shows the groundwater monitoring bores targeted under the program. This has been based upon the distribution of bores that are currently being monitoring for groundwater level and/or salinity by Mallee CMA. The only two bores identified to be monitoring the Channel Sands are located further south of the inundations areas, adjacent Nyah hence not included in this section. Two other bores are cited at Nyah North and South (409241 and 408702), but aquifer information was not available at time of assessment.

Given the poor distribution of monitoring infrastructure across Nyah floodplain at present, it will be useful to gain additional information in the vicinity of the proposed inundation areas. The location of suggested additional monitoring bores for the Channel Sands is presented on Figure 7.9. Bores 1 and 3 have been selected to collect data adjacent Parnee-Malloo Creek. Bore 2 is located at the western extent of Nyah North. If existing Bores 409241 and 408702 are no longer viable or do not target the Channel Sands, then additional monitoring bores are suggested in the vicinity of these also.

All bores are recommended to be monitored for groundwater level and salinity at daily intervals before, during and after events that change the hydraulic regime and at weekly intervals at other times.

- **Table 7.6: Groundwater monitoring sites at Nyah**

Bore ID	Easting	Northing	Current monitoring parameters (water level/salinity)
Unknown aquifer			
408702	716735	6105987	Level (logger), salinity
409241	715275	6109993	Level, salinity
Suggested additional monitoring bores			
Bore 1	714845	6112036	Level (logger), salinity
Bore 2	715639	6108633	Level (logger), salinity
Bore 3	716945	6107071	Level (logger), salinity

The frequency of monitoring should ideally be daily to weekly depending on the rate of water level response (if any) in a given monitoring well. If changes in standing water level attributable to floodplain watering are observed, then monitoring frequency should be increased accordingly. It is recommended that the high priority groundwater observation wells are monitored for water level daily, especially just before, during and post inundation. At the very least, under *basecase*, regulated conditions, observations should be collected at least every three months from these wells.

Consideration should be given to the use of automatic down-hole loggers for recording responses to watering events, which are especially useful where wells may become stranded. Additional benefits include recording of subtle impacts that may not be seen from relatively sparse observations. Bores suggested for logger installation include the suggested additional monitoring sites; Bore 1, 2 and 3 and existing Bore 408702.

The key will be to identify the peak groundwater level as a result of inundation, but also to record the initial *basecase* and post inundation response as the lake water levels recede. If data loggers are available, the most beneficial locations would therefore be in the bores closest to the area of inundation, as listed above.

If costs cannot be met for monitoring it is recommended that fewer locations are chosen and an emphasis placed on collecting more comprehensive time series data.

7.7.2. Surface water monitoring

Ideally, surface water monitoring would provide sufficient data to calculate salt load to reaches of flowing anabranches or the Murray River adjacent to areas of floodplain watering. This is possible when pre-existing surface water monitoring stations are available.

A single surface water monitoring gauge is located on Parnee-Malloo Creek at Nyah golf course. This gauge has been inactive since 2008. A second gauging site is located upstream of the inundation area near the township of Nyah. Table 7.7 details site information.

Table 7.7: Existing surface water monitoring sites

Site ID and description	Monitoring parameters
409206	Water level, salinity
409241	Salinity

To reduce uncertainties relating to *basecase*, inundation across the Nyah floodplain and associated NSW floodplain, as well as their level of connection to the surface water network, observations and survey of specific wetlands would improve the conceptualisation of the *basecase* conditions. In particular, observations around any wetlands and depressions considered to be potential sources of significant salt load to the River would inform future refinements of the salinity impacts of watering actions. It is assumed that water level data will be collected at each regulator.

It is recommended that stage height monitoring be undertaken along Parnee-Malloo Creek and the Murray River (expressed relative to Australian Height Datum). Where the suggested new groundwater monitoring bores are sited adjacent creek lines, it would be useful to gauge stage height to aid in comparison between surface water and groundwater levels at a particular location.

Surface water observations are especially important at the inlet and outlet structures. Surface water salinity and flow should be monitored at such locations to assess the impact of watering events and calculate likely salt loads to the system. Flow gauges should be installed at the inlet and outlet structures. Monitoring should occur before, during and after the watering event. The length of time and frequency of monitoring can be assessed as data is collected and assessed. Initially monitoring should occur at a monthly frequency.

- **Figure 7.9: Nyah suggested monitoring locations**

8. Vinifera

8.1. Hydrology

The project area referred to as Vinifera is representative of the Vinifera State Forest which is approximately 250 ha in area and located south of the Murray River near the township of Vinifera (Figure 8.1). The State Forest is bounded on the north by the Murray River and between the river chainage of 1370 km upstream and 1356 km downstream (REM, 2005).

A watercourse meanders in an east-west direction through the centre of the State Forest spanning approximately 5 km in length. The river frontage is part of Parks Victoria Murray River Reserve.

Gauging station 409206 (Nyah) is located downstream, adjacent the township of Nyah and has a period of record spanning 2005 to 2009. March 2009 river level was 60.14 mAHD. Given the increased flow events observed through the system since 2010, current river level is likely to slightly higher than the 2009 record, however this cannot be accurately quantified.

The minimum stage height measured at Nyah was 59.68 mAHD in June 2007. This may represent the worst case scenario for stage height adjacent Nyah.

8.2. Hydrogeology

8.2.1. Background

The Murray River incised through the Mallee landscape late in the Quaternary period in response to sea level falls, producing a relatively narrow trench typically 5 to 10 km wide. This trench backfilled as base levels were re-established.

On the floodplain, the basal unit filling the trench beneath the Woorinen Formation is the Channel Sands which is overlain with the finer grained Coonambidgal Formation. The latter contains fined grained silts and clays ranging in thickness up to 5 m across the floodplain. The Channel Sands is made up of fine to coarse-grained sands and is in direct connection with the Murray River.

The Channel Sands aquifer lies directly above the regionally extensive Parilla Sands aquifer. The Blanchetown Clay is absent. On the higher ground to the west, beyond the boundary of the floodplain, the Woorinen Formation is directly underlain by the Shepparton Formation. Here, the Channel Sands becomes absent.

- **Figure 8.1: Location of key features at Vinifera**

Thorne *et al,* (1990) prepared hydrogeological cross-sections which span the length of the Murray River from the South Australian border through to Nyah.

Transect Z from Thorne *et al,* (1990) lies to the south of the inundation area, adjacent the township of Nyah (Figure 7.2). Here the Murray River is incised into the Channel Sands aquifer (approximate thickness of 10m) and is shown to be limited in spatial extent, with the trench being quite narrow compared to other sites. Approximately 0.5 km west of the Murray River, the Channel Sands formation becomes absent.

8.2.2. Groundwater level

Groundwater level data has been collected at Vinifera. The location of bores that are currently being monitored (2008 to present) is shown in Figure 8.2. No bores are located on the Vinifera floodplain, as such the understanding of groundwater levels immediately beneath Vinifera is not known.

Two bores targeting the Channel Sands (26182 and 26271) are located on the north-western edge of the inundation area. Several other bores are targeting the deeper Parilla Sands aquifer.

Summer 2012 groundwater elevation data is not available for the Channel Sands aquifer across the Vinifera floodplain, but Bores 26182 and 26271 indicate the May 2009 groundwater level was approximately 57 mAHD.

Depth to groundwater in the Channel Sands is around 5-6 mbgl, (measured at Bores 26182, 26271).

Groundwater levels in the Parilla Sands aquifer have remained relatively stable since 1990 (i.e. Bore 26158 which has maintained a groundwater level of around 60 mAHD).

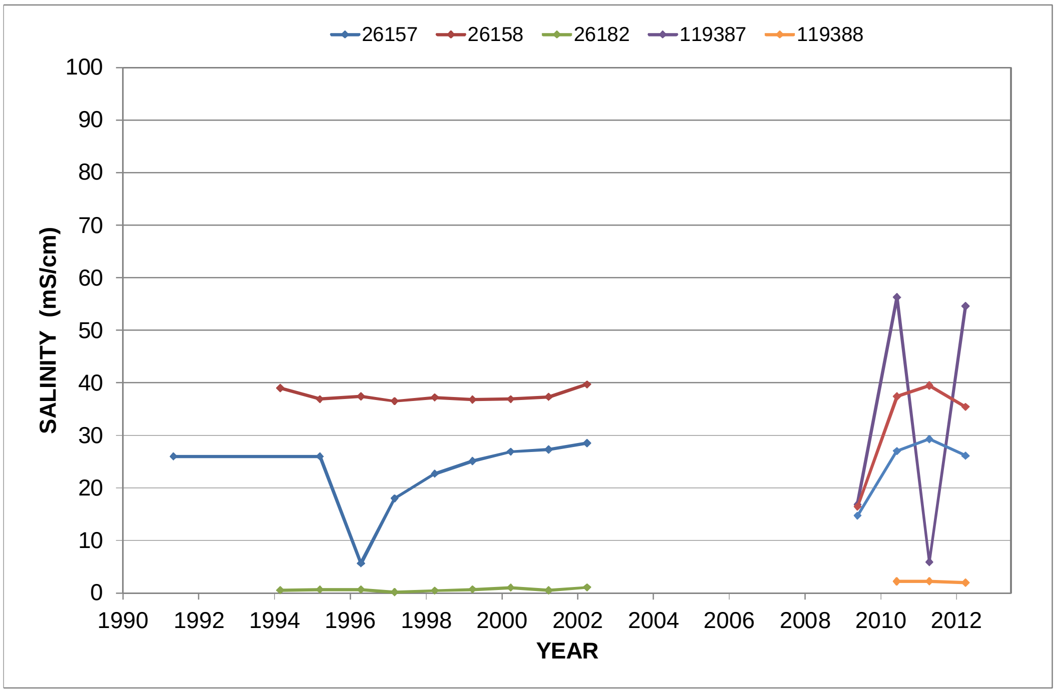
8.2.3. Groundwater salinity

Salinity time series data for selected monitoring sites in the vicinity of Vinifera is presented in Figure 8.3.

This shows that groundwater screened in the Channel Sands aquifer closer to the Murray River appears to be relatively fresh (Bore 26182). It is likely that salinity increases with distance from the river, but there are not enough monitoring points to confirm this. Bore 26182 has not been monitored for salinity since 2002, but groundwater is likely to have remained relatively fresh.

Bores located to the west of the floodplain in the Parilla Sands aquifer (26157, 26158) show a similar overall trend in data. A gap in monitoring occurred between 2002 and 2009 so it is unknown what happened during this time. After 2010 a rise in groundwater salinity was observed.

- **Figure 8.2: Current monitoring at Vinifera**



■ **Figure 8.3: Vinifera groundwater salinity**

An aerial electromagnetic (AEM) survey was undertaken during Feb-March 2008 (BRS, 2009). An AEM depth slice (as apparent bulk electrical conductivity) averaged over the upper 30 m of saturation in the shallow aquifer is shown in Figure 8.4.

The AEM data infers that a lower salinity zone exists either side of the Murray River. These lower salinity areas are representative of zones where there is localised recharge to the groundwater system through the river banks. The AEM coverage did not cover the entire extent of the Vinifera inundation area.

8.2.4. Groundwater – surface water interaction

The location and magnitude of the salinity impact depends in part of the degree of connection between the shallow floodplain aquifer, and the Murray River and anabranches. Greatest impacts are possible where the surface water system gains groundwater. This section provides a summary of the nature of the connection based on existing information.

Where groundwater elevations are higher than surface water elevations, river reaches are defined as potentially *connected – gaining* systems. Where groundwater elevations are lower than surface water elevations, river reaches are defined as potentially *connected – losing* systems. Where the anabranches are permanently inundated and groundwater elevations are lower than the base of the river bed, river reaches are also defined as potentially *connected – losing* systems.

- **Figure 8.4: Average apparent bulk electrical conductivity for a 30 m interval immediately below groundwater surface**

The bed elevation for the anabranch was extracted from LiDAR and shows the base of the watercourse at around 62 mAHD. March 2012 groundwater monitoring is not available at Vinifera. Earlier groundwater monitoring indicates a groundwater level of approximately 57 mAHD in March 2009 (Bore 26182) to the north-west of Vinifera. Based on this groundwater level alone, it suggests that the groundwater level is well below the Murray River stage height (>60.1 mAHD) and the base of the creek.

1990s records put the groundwater level in the Channel Sands around 1.5 m higher (59.6 mAHD), but still well below base of the anabranch.

There is potential for hydraulic connection between watercourses and groundwater if the groundwater level is above that of the creek bed level. However, the current lack of monitoring in the Channel Sands aquifer means the nature of interaction cannot be accurately quantified.

Stage height in the anabranch and groundwater levels in the Channel Sands would need to be quantified to accurately assess the nature of connection between surface water and groundwater level in the Channel Sands.

For this assessment, the anabranch is conservatively assumed to be in connection with the groundwater in the Channel Sands aquifer.

The 2006 NanoTEM (Telfer *et al*., 2006; Figure 7.6) survey shows the vertical profiles displaying the resistivity data collected along the Murray River. Low resistivities (red to yellow) indicate areas that are conductive, (that is, they are interpreted to hold saline water and/or be composed of clay). The resistive areas (blue through purple) are interpreted to be generally fresh water in sands (Telfer *et al*., 2006).For Vinifera, there is a long stretch of water course in the vertical profile which is quite resistive. This suggests generally fresh groundwater and likely losing conditions.

8.3. Environmental works and measures

Alluvium (2012c) outlined potential areas that may benefit from inundation and flow control (presented in Figure 8.5 and summarised in Table 8.1). The associated works and measures related to their inundation are discussed below and comprise two target areas; Burra North and Burra South.

A schematic of the key water levels on the floodplain is presented in Figure 8.6.

8.3.1. Option description

This option proposes the construction of an inlet regulator and levees at the northern end of the site to allow Murray River overbank flows onto the floodplain and then retain water as Murray River flows recede. Additional levee works will also be required at the southern end of the site to retain water on the floodplain (with a regulator to facilitate water movement from adjacent areas). Alluvium (2012c) considered four infrastructure configurations (levee height):

- Sub-option 1: a top water level of 63.8 m AHD inundating a total area of 202 ha
- Sub-option 2: a top water level of 64.0 m AHD inundating a total area of 256 ha
- Sub-option 3: a top water level of 64.2 m AHD inundating a total area of 305 ha
- Sub-option 4: a top water level of 64.4 m AHD inundating a total area of 340 ha

Sub-option 2 was initially identified as the preferred option based on a requirement to minimise the levee footprint. However, discussion with Mallee CMA indicates sub-option 4 is to be assessed during this scope of work. At the end of an environmental watering event, stored water would be released to the Murray River via the northern regulator (inlet regulator).

- **Table 8.1:Summary of Vinifera watering option**

Option	Filling Method	Dependencies	Top water level (m AHD)	Area inundate (ha)
Vinifera	Gravity (Murray River)	Water levels in the Murray River	64.4	340

8.3.2. Watering regime

Documentation of options provided for this project did not provide discussion on water regimes, and minimal discussion on watering requirements. Table 8.2 details likely timing and frequency of inundation events as outlined by Mallee CMA. For the purpose of this assessment, calculations have been based on watering events commencing in August.

- **Table 8.2: Proposed Vinifera watering regime**

Option	Inundation frequency	Timing	Inundation duration (months)
Vinifera	10 in 10 years	Winter/spring	6

8.4. Potential salinity impacts

8.4.1. Approach

The in-river salinity impacts (at Morgan in South Australia) potentially caused by the proposed actions at Vinifera were assessed relative to a *basecase* scenario.

The approach to the assessment requires conversion of salt load to EC at Morgan described in Fuller & Telfer (2007), with resultant EC impacts at Morgan (determined using the Ready Reckoner) reflecting the impact of an operation over the 25 year Benchmark Period and the time of year the salt load occurs.

The scenarios to be tested are summarised in Table 8.3. This also contains a summary of the key floodplain processes relevant to the watering action as well as a proposed assessment method. Greater detail on these aspects is provided in the following section.

The approach allows for the incremental salt impact of each option to be assessed. The cumulative effect is taken to be the sum of salt impacts across all watering actions.

Appendix A contains details of the steps in the impact analysis, while Appendix B contains tables of input data used in calculations.

8.4.1.1. Identifying salt discharge processes

The conceptualisation of the hydrogeological setting described above was used to identify processes and areas believed to be at greater risk of causing increased salt load to the river, bearing in mind the proposed actions and associated floodplain processes involved.

This involved consideration of the:

- Potential for recharge to groundwater; taking account of surface geology and depth to groundwater level in the Channel Sands;
- Potential for increasing groundwater hydraulic gradients and hence increased discharge;
- Potential for mobilisation of salt from in-channel sources; and
- Proximity of the inundated areas to the receiving water courses.

8.4.1.2. Impact on floodplain processes and approach to analysis

The works and measures prosed at Vinifera will result in areas of the floodplain being inundated with water. This will occur via the use of levees at the northern end of the sites to raise water levels to a top elevation of 64 mAHD.

The anabranch system and the Murray River are considered to be receiving environments for this assessment.

Key assumptions used regarding the Vinifera operation are:

- Designed to inundate approximately 340 ha;
- Operation initially 10 in 10 years;
- Timed to commence in Winter (August); and

- Total duration of operation assessed to be between 6 months.

The following salt mobilisation processes are relevant to each stage of the inundation process:

During the fill stage

- Wash-off of salt from floodplain soils; and
- The salt held in the river channel and mobilisation of salt in previously stranded backwaters to be held in the in-stream store up gradient of the regulator.

During the hold stage

- Inundation of the floodplain areas and recharge to the underlying shallow saline groundwater within the floodplain aquifer, creating groundwater mounds beneath inundated areas; and
- Lateral outflow from filled anabranches to the floodplain aquifer.

During the spill and evaporation stage

- Displacement of saline groundwater to the anabranch and/or the Murray River on the recession where mounded groundwater levels remain higher than surface water levels; and
- Release of the in-stream store within the creek system of saline water created during the fill stage.

Fill Stage

The use of regulators associated Vinifera during the fill stage will result in increased flows to the Creek system.

In light of the previous reports of saline surface water pools (Dudding, 1992), manipulation of the flow regime through these actions could result in the mobilisation of salt from these in-channel stores during the fill stage when it would otherwise have been stored until flushed during a period of higher flow.

The inundation of the floodplain will also cause some mobilisation from salt stored in floodplain soils.

ANALYSIS APPROACH – FILL STAGE

Historical flood data linking flows, the area of floodplain inundation and subsequent salt loads in the river post-flooding suggests a total salt flux of 38 kg/ha/day for Lindsay River (Mike Dudding, pers. Comm – reported by SKM (2010a)). Of the total salt flux, the proportion due to wash-off is thought to be approximately 10%; thus reducing the salt flux for this process to 3.8 kg/ha/day. In addition, values of 1 and 5 kg/ha/day were derived during the calibration of a real time salt and water balance model for Chowilla (SKM, 2010b). These salt flux rates are typical of locations downstream of Buloke Swamp; as such these are considered representative only for this assessment.

The magnitude of the salt load associated with lower surface water flow down gradient of the regulator is not considered significant relative to other processes and is not quantified.

Hold Stage

Once the target water level is reached within each structure/project, the water will be held on the floodplain by flow control structures. During the hold stage there will be a continuation of lateral and vertical outflow (infiltration) of surface water to the floodplain aquifer that began in the fill stage. Water stored in the river banks could mix with groundwater that may be released back to the River in the spill stage (on the recession). Monitoring records and the AEM data indicate groundwater around Vinifera is relatively fresh, hence likely to result in minimal EC impact at Morgan as a result of groundwater discharge.

There is the potential for diffuse recharge to the Channel Sands aquifer beneath the inundated area created under Vinifera. The area of inundation proposed could, over successive events, increase groundwater levels in this area to reverse the hydraulic gradient where saline groundwater is displaced towards creek and ultimately to the Murray River. However, no surface water level monitoring occurs on creek. This means it is not possible to accurately define the level of groundwater level rise necessary to induce discharge to the creek. As such, only bed elevation estimated from LiDAR is available. In addition to EC impact at Morgan, this increased salt load also has the potential to impact any irrigators that rely on surface water diversions. This was therefore highlighted for further investigation.

ANALYSIS APPROACH – HOLD STAGE.

The rate of recharge to the shallow groundwater system is estimated to be 0.5 mm/day, based on analysis of recharge rates by REM (2006) and previous work by CSIRO on the Chowilla floodplain (refer SKM, 2010). This rate of recharge is assumed to include the volume of water that recharges the aquifer laterally.

If the waterbody is connected to groundwater (that is, underlain by fully saturated material) then a mass balance approach can be used to estimate the total volume of groundwater that may eventually discharge to the surface water system (assuming some is lost because of evapotranspiration). If the waterbody is underlain by an unsaturated zone above the groundwater level then there is a need to estimate the rate of rise and fall of groundwater levels using a method from Hantush (1967). If the groundwater level is estimated to rise above the surface water level then the rate of discharge to a river reach can be calculated using a flow net analysis.

Spill and Evaporation Stage

Salt that has accumulated in-stream during the fill stage will be released during the spill stage.

Once surface water levels decline in the creek, there will be potential for the inflow of saline groundwater to the anabranch system that is derived from the following processes that occurred during the hold stage:

- Diffuse recharge and groundwater level mounding; and
- Lateral outflow from anabranches to the Channel Sands aquifer.

For the purpose of this analysis it is conservatively assumed that immediately on the cessation of the hold stage 100% of the recharged water (on a monthly time step) will eventually return to the receiving feature (in this instance the anabranch). As the water held in the feature diminishes, the percentage return to the anabranch at each time step in the analysis is assumed to diminish at a set rate to mimic the fall in groundwater gradients and consequent decline in groundwater discharge. This process occurs over a 12 month period at which time all discharge ceases.

In reality, the volume of groundwater discharged maybe lower than 100% of recharge if water is lost to evapotranspiration. It is likely that evapotranspiration is a major component of groundwater discharge in these floodplain environments, however, it has not been accounted for in the assessments below. In some cases evapotranspiration may account for all groundwater discharge and in these cases the long term sustainability of the environmental assets must be questioned.

ANALYSIS APPROACH – SPILL AND EVAPORATIONSTAGE

The mass of salt released from in-stream storage in the spill stage is calculated under current conditions. A nominal 100 EC difference will be adopted between upstream and downstream surface water salinity. These EC values are multiplied by an assumed in-stream water volume to estimate salt load.

The salt load from wash-off is calculated using the approach described in the fill stage.

The volume of recharge to the groundwater from a floodplain watering event displaces a lesser volume of higher salinity groundwater to the adjacent watercourse. If the recharge volume can be calculated, then a corresponding salt load to the river can be inferred. This is similar to the nomogram approach described in the Murray Darling Basin Commission (MDBC) Salinity Impact Assessment Framework for the Living Murray Environmental Works and Measures Program (Fuller & Telfer, 2007). It is expected this salt load will occur over a 12 month period following inundation. .

It is assumed 100% of recharge is discharged to the river system during the period of inundation and it is also assumed this accounts for the groundwater that is discharged as a result of diffuse recharge via the floodplain aquifer. It is further assumed that the rate of discharge will fall in a decreasing manner from 100% immediately at the end of the inundation period to zero in month

12 following the hold stage. This decay in the rate of return of recharge water reflects diminishing area of inundation and diminishing hydraulic gradient to the surface water system.

- **Table 8.3: Floodplain process and analytical methods used for Vinifera**

Description	Salinity process	Analysis method	Relative level of certainty	Source of certainty
Vinifera Inundate to a level of 64 mAHD over an area of 256 ha	Surface salt wash-off Recharge of shallow saline groundwater and displacement of saline groundwater to anabranch and Murray River	Surface flush estimated from assumed value of salt storage per hectare of floodplain. Mass balance approach for the inundated area. Mound build up estimated and flow net is used to estimated salt load from mound to anabranch and Murray River	Low	Limited bore data to verify groundwater salinity, groundwater flow and response to recharge.

- **Figure 8.5: Vinifera environmental watering location**

- **Figure 8.6: Vinifera schematic of operating levels**

8.5. Results and discussion

8.5.1. Salt wash off

Estimated salt flux associated with the initial wash-off of salt was calculated for the area of inundation; (340 ha) less the area of watercourse. The calculation was undertaken assuming salt capture of 1, 3.8 and 5 kg/ha/day.

Estimates of salt load and EC impacts at Morgan are summarised in Table 8.4 for each process, and these indicate that impacts from salt wash-off are negligible. These estimates are based on the Ready Reckoner value for August.

- **Table 8.4: Predicted salt load and EC impact at Morgan (relative to the *basecase*)**

Salt wash-off rate (kg/ha/day)	Salt load (t/d)	EC impact at Morgan
1	0.34	0.0024
3.8	1.2	0.0086
5	1.7	0.12

Note: ^ These values have been corrected since the previous version (Final, September 2013) of the report. The previously reported results were considered to be negligible.

Key assumptions:

- Release of water occurs at a constant rate over a 30 day period in Spring (October);
- Instantaneous transfer of salt from the whole of the inundated area to the creek and/or Murray River occurs (that is, reaches equilibrium within one day);
- There is no significant salt load delivered to the anabranch and/or Murray River through salt wash-off under *basecase* conditions; and
- Salt flux rates of 1, 3.8 and 5 kg/ha/d are typical of downstream conditions (i.e. Lindsay and Chowilla floodplain). As such these are representative values only.

8.5.2. Floodplain inundation (recharge and displacement)

Floodplain inundation at Vinifera will be achieved by inundating to a top water level of 64 mAHD resulting in an area of inundation of 340 ha of floodplain.

A conservative estimate of the salt load and EC impact at Morgan is made assuming initially 100% of the recharged water is discharged to the Murray River from groundwater during the period of inundation. The amount of diffuse recharge eventually discharging to the River is assumed to gradually decline from 100% in the 6th month to zero in the 12th month following inundation.

Values of less than 100% for the amount of recharge that ends up discharging to the feature may be expected where evapotranspiration from groundwater occurs before it reaches the Murray River. Therefore, this conservative scenario may represent the cumulative effect of a series of induced and natural floods causing groundwater levels to rise in the vicinity of the inundation area and creating gaining river conditions.

Bore 26182 had a reported groundwater salinity of 1.06 mS/cm (April 2002), and is located north-west of the inundation area, adjacent the township of Nyah. This value has been used to represent Vinifera.

It is estimated this process results in an EC impact at Morgan of 0.03. This impact is insignificant.

Key assumptions:

- The recharge due to inundation would last 6 months;
- Saline groundwater will discharge to the Murray River for a 12 month period (based on observation of this process in other floodplains – e.g. Chowilla);
- The amount of diffuse discharge to the Murray River will decline linearly at the end of the inundation period from 100% to zero;
- The salinity of groundwater discharging remains constant over this period;
- Groundwater salinity discharging to the River is fresh (1.06 mS/cm), but could increase over time following successive watering events;
- Recharge rate is uniform spatially and temporally in the area of inundation; and
- There is no significant salt load delivered to the Murray River through diffuse recharge and displacement of saline groundwater under the *basecase*.

8.5.3. Retention of water

For Vinifera the starting groundwater level is assumed to be 56.98 mAHD (Bore 26182, March 2009). Groundwater mound rise calculations estimated a rise in groundwater levels of 1.74 m (to 58.7 mAHD) after 300 days as a result of filling this area to a top water level of 64.0 mAHD.

It is assumed that the groundwater level beneath Vinifera will fall at a constant rate for the following 300 day period.

The salt load from a mound beneath the watering sites is estimated based on the stage height in the River (60.1 mAHD). The bed level for anabranch was estimated from LiDAR (62.3

mAHD). Stage height information is not available for the anabranch. As this assessment is based on the bed elevation only, these are likely to result in an over-estimate of EC impact at Morgan.

The flux of groundwater and salt load was estimated at 30 day time steps during the period of groundwater level rise and fall. Each monthly salt load was converted to an EC impact at Morgan. The salt load was calculated using a salinity value of 1.06 mS/cm, Bore 26268, April 2009 (Appendix B).

Estimated mound rise was not large enough to raise groundwater levels above the assumed water level in the Murray River (60.1 mAHD) or above the bed level of the anabranch (average 62.3 mAHD).

The salt load calculations were re-run assuming the starting groundwater level beneath Vinifera is close to 1994 levels (59.6 mAHD). A flow net analysis estimates the salt load toward to Murray River to reach a maximum of 0.008 t/d after 300 days with an impact of 1.0×10^{-3} EC at Morgan. This impact is insignificant.

Mound rise was not great enough to raise groundwater level above the bed level in the anabranch.

Key assumptions:

- The salinity of groundwater discharging to Murray River remains constant over time; and
- Groundwater levels due to mounding rise and fall linearly over 300 days.
- The salt load for the ‘1990s case’ was estimated assuming that groundwater levels fall linearly over the 300 days; and
- Groundwater salinity discharging to the anabranch and the Murray River is 1.06 mS/cm, but could increase over time following successive watering events

8.5.4. Total salinity impacts

The total salinity impact at Morgan of implementation of environmental watering at Vinifera is estimated to be 0.03 EC at Morgan, based on an annual watering frequency.

The components of the salt load and EC impacts relative to the *basecase* are summarised in Table 8.7. The largest component of the salinity impact is associated with the displacement of groundwater due to diffuse recharge following inundation, but even this impact is insignificant. This calculation is considered conservative as it assumes uniform salinity and assumes a significant percentage of the recharged water is returned the Murray River.

▪ **Table 8.5: Summary of salinity processes and EC impact**

Salinity process	EC impact at Morgan
Salt wash-off	Negligible
Recharge and displacement	0.03
Retention of water lake/wetland	N/A
TOTAL	**0.03**

[1] Based on difference in river salinity of 100 EC

8.6. Cumulative impacts

It is expected that multiple watering events will occur at these sites over time.

There are no groundwater monitoring bores in close proximity to Vinifera. It is therefore difficult to make a comparison between current groundwater levels in the Channel Sands aquifer with earlier 1990s levels (when more frequent flooding occurred).

North-west of the inundation areas, monitoring records in the Channel Sands indicate the groundwater level was up to 4 m higher during the 1990s (Bore 26271).

It is expected that successive watering events coupled with natural flood events could return groundwater conditions and salt store to that seen in the 1990s. This '1990s condition' can be viewed as being representative of the 'cumulative impact' of implementation of a large scale sequence of watering events, that is, it represents the maximum salt impact condition.

It is expected that successive watering events coupled with natural flood events could return groundwater conditions and salt store to that seen in the 1990s. This '1990s condition' can be viewed as being representative of the 'cumulative impact' of implementation of sequence watering events, that is, it represents the maximum salt impact condition.

Should larger impacts occur with time, these will be offset by a less frequent operation and shorter duration of watering events.

8.7. Monitoring

The proposed monitoring program is comprised of groundwater and surface water monitoring and aims to provide data that can be used to better define the mechanisms and magnitude of salinity impact arising from the proposed environmental watering events. The monitoring data should form the basis of five-yearly reviews as required under the Basin Salinity Management Strategy, allowing refinement of the salinity impact estimates.

The monitoring program reflects the need to gather data both for the improvement of understanding of the key processes, but also to allow independent review of accountability for operating any works and measures. Monitoring should also be maintained to assess the benefits of environmental watering.

In order to measure salinity impact from the floodplain operations, monitoring periods should be chosen to cover current conditions, floodplain operations, and post-operation conditions. The former provides the opportunity to assess baseline conditions, including salt loads against which to measure the impact of operations. The latter is important because it is likely that the floodplain response would be delayed, with salinity impacts extending beyond the period of floodplain operations. Continuous monitoring will ensure that all impacts due to actions can be assessed against *basecase* conditions as well as highlight any changes in the baseline over time.

All groundwater levels should be expressed relative to Australian Height Datum to allow comparison of groundwater and surface water data.

8.7.1. Groundwater monitoring

Water level and salinity data from groundwater monitoring wells completed in the Channel Sands aquifer in the vicinity of inundation areas, retention sites and other identified impact hotspots should be collected before, during and after each environmental watering event. This is most important for wells that are situated adjacent an inundation area and near the potential receiving surface waters. Salinity measurements at the very top of the saturated thickness (adjacent the discharging site) will allow an assessment of the salt content of the water that will be moving as a result of the action and indicate any freshening of groundwater that may occur.

Figure 8.2 shows the groundwater monitoring bores targeted under the program. This has been based upon the distribution of bores that are currently being monitoring for groundwater level and/or salinity by Mallee CMA. The only two bores identified to be monitoring the Channel Sands are located to the north-east of the inundations area.

Given the poor distribution of monitoring infrastructure across Vinifera floodplain at present, it will be useful to gain additional information in the vicinity of the proposed inundation areas. The location of suggested additional monitoring bores for the Channel Sands is presented on Figure 8.7. Bores 1 and 2 have been selected to collect data in the central and eastern portions of the inundation area.

All bores are recommended to be monitored for groundwater level and salinity at daily intervals before, during and after events that change the hydraulic regime and at weekly intervals at other times.

- **Table 8.6: Groundwater monitoring sites at Vinifera**

Bore ID	Easting	Northing	Proposed monitoring parameters (water level/salinity)
Channel Sands			
26182	717270	6103946	Level, salinity
26271	717200	6103700	Level (logger), salinity
Parilla Sands			
26155	717149	6103770	Level, salinity
119388	717320	6102769	Level, salinity
Suggested additional monitoring bores (Channel Sands)			
Bore 1	718438	6101831	Level (logger), salinity
Bore 2	720165	6102011	Level (logger), salinity

The frequency of monitoring should ideally be daily to weekly depending on the rate of water level response (if any) in a given monitoring well. If changes in standing water level attributable to floodplain watering are observed, then monitoring frequency should be increased accordingly. It is recommended that the high priority groundwater observation wells are monitored for water level daily, especially just before, during and post inundation. At the very least, under *basecase*, regulated conditions, observations should be collected at least every three months from these wells.

Consideration should be given to the use of automatic down-hole loggers for recording responses to watering events, which are especially useful where wells may become stranded. Additional benefits include recording of subtle impacts that may not be seen from relatively sparse observations. Bores suggested for logger installation include the suggested new locations; Bores 1 and 2, as well as Bore 26271 located on the downstream end. This distribution will provide broad data collection across the inundation area.

The key will be to identify the peak groundwater level as a result of inundation, but also to record the initial *basecase* and post inundation response as the lake water levels recede. If data loggers are available, the most beneficial locations would therefore be in the bores closest to the area of inundation, as listed above.

If costs cannot be met for monitoring it is recommended that fewer locations are chosen and an emphasis placed on collecting more comprehensive time series data.

8.7.2. Surface water monitoring

Ideally, surface water monitoring would provide sufficient data to calculate salt load to reaches of flowing anabranches or the Murray River adjacent to areas of floodplain watering. This is possible when pre-existing surface water monitoring stations are available.

A single surface water monitoring gauge is located at Nyah, situated north of Vinifera. This gauge has been inactive since 2009. Table 8.7 contains details of site information.

- **Table 8.7: Existing surface water monitoring sites**

Site ID and description	Monitoring parameters
409206	Water level, salinity

To reduce uncertainties relating to *basecase,* inundation across the Vinifera floodplain and associated NSW floodplain, as well as their level of connection to the surface water network, observations and survey of specific wetlands would improve the conceptualisation of the *basecase* conditions. In particular, observations around any wetlands and depressions considered to be potential sources of significant salt load to the River would inform future refinements of the salinity impacts of watering actions. It is assumed that water level data will be collected at each regulator.

It is recommended that stage height monitoring be undertaken along anabranch and the Murray River (expressed relative to Australian Height Datum). Where the suggested new groundwater monitoring bores or existing bores are sited adjacent creek lines, it would be useful to gauge stage height to aid in comparison between surface water and groundwater levels at a particular location.

Surface water observations are especially important at the inlet and outlet structures. Surface water salinity and flow should be monitored at such locations to assess the impact of watering events and calculate likely salt loads to the system. Flow gauges should be installed at the inlet and outlet structures. Monitoring should occur before, during and after the watering event. The length of time and frequency of monitoring can be assessed as data is collected and assessed. Initially monitoring should occur at a monthly frequency.

- **Figure 8.7: Vinifera suggested monitoring locations**

9. Areas of uncertainty and Mitigation Measures

9.1. Areas of Uncertainty

There are uncertainties related to assumptions made in the analyses. Where uncertainty was identified with a given parameter, a conservative value was assumed or upper bound used, thereby increasing the magnitude of the resultant salt load. If the concepts underpinning the analysis are reasonable, then the estimated salt loads would be considered conservative and overestimate the level of impact.

The most important uncertainties include:

Spatial variability of recharge rate across the floodplain

Across each inundation area, recharge rates are likely to be affected by the presence and extent of the Coonambidgal Formation. The lithology is known to be variable and is an important factor in the estimation of groundwater derived salt loads. For these calculations 0.5 mm/day was applied as the recharge rate across the entire area of inundation.

Fluctuations in surface water levels

Groundwater flux and hence salt load is dependent on the surface water level in the adjacent watercourses. Timing and duration of these fluctuations (based on modelled river levels and gauging data) will determine whether the river is gaining or losing and hence uncertainty around these levels will affect the resultant EC impact at Morgan.

In some cases, there were no gauged data on river stage height adjacent to the works and measures site. In these instances, stage height was extrapolated to the site and this introduces errors. In other cases, the nearest gauge site did not have stage data as absolute elevation; elevation was estimated using LiDAR data. This estimation also introduced errors. Some assessments then extrapolated the estimated absolute stage height data to the works and measures site.

Timing, duration and volume of groundwater (and salinity thereof) displaced to river

The duration of impacts applied to the Ready Reckoner was estimated based on the surface area at maximum inundation and uniform depth across that area. There is associated uncertainty with the duration of inundation used. In reality there would be a time lag before maximum inundation is reached (which was not accounted for in the duration estimation) and hence before recharge occurred across the whole area, as well as before the infiltrated water reaches the groundwater level and begins to cause a rise in elevation.

Quantity lost to evapotranspiration and evaporation

Throughout the period of inundation, a proportion of surface water will be lost to evaporation. In addition, any fluxes to the river will be impacted by evaporation and evapotranspiration from overlying vegetation. For these calculations it was assumed the percentage of recharge returned to the river ranged from 100% to less than 10% over time.

Groundwater salinity

The magnitude of the salt load is related to the assumed groundwater salinity value. In some cases there are salinity measurements but in many cases salinity values are extrapolated over a wide area. In order to account for this uncertainty, a conservative approach was taken in the analyses whereby the higher salinity was assumed.

9.2. Opportunity for Adaptive Management and Mitigation Measures

All of the sites listed in the report have some degree of uncertainty associated with the details of groundwater and river interaction. The section above defines a number of key areas. There are however significant opportunities to manage the way that salt is generated and to mitigate the overall impacts. These apply to all of the options identified in this report.

Key Mitigation Measure 1 – Timing of Diversion

In the assessments present in this report the timing of diversion has been optimised for the environmental benefits. Generally the rising limb of the flow hydrography in the lower Murray is associated with increasing salinity. An option to mitigate the effect of the diversion and release of water is to diver smaller wetlands earlier and before any significant increase in salinity in the river resulting from flooding upstream. Bringing fresher water into the wetlands will minimise the impact of the salt on release

Key Mitigation Measure 2 – Timing of Release

Release of water into a falling river will have a more significant impact the lower the flow into which the release occurs. Where possible, release into a higher river will minimise the local impacts of the release. This may not affect the overall salt loads from a basin perspective but can have significant locally beneficial impacts. This option will be particularly important for the Wallpolla options.

Key Mitigation Measure 3 – Rate of release

Should the release of water from a wetland need to occur into a very low river flow the local effects can be mitigated by slowing the rate of release. In some cases this may be used in conjunction with measure 2. A longer release period than has been assumed for this analysis will minimise the local impacts of salt release.

10. Time Series Results

The salinity impacts calculated and described in the sections above were converted to salinity time series using the operating rules described in the preceding sections (and given in Appendix C). A separate digital file has been prepared that provides the salinity time series for each wetland.

In addition, the potential impact in the Murray River has been estimated using the MDBA benchmark flow series (MSM BIGMOD data May 1975 to April 2000; MDBA 2014) and the time series salt loads. A spreadsheet model was developed that enabled a daily diversion, hold or return of water and salt. The rates of salt uptake and discharge were as described in the relevant sections above.

The summary of the impacts of each proposed measure is given in below for the River Murray immediately downstream of the wetland outfall, at Lock 6 and Morgan. These impact estimates are based on full mixing in the river and are indicative only. The values and assumptions used in the calculations are included in Appendix C. Official impact results will be provided by undertaking runs of the MSM BIGMOD river model with these salt loads incorporated.

Time series salt loads for the Burra Creek South and Nyah South were not calculated because of their removal from potential watering activity plans. Salt loads for Wallpolla Floodplain Lower option, and Belsar and Yungera Island options Lake Powell and Lake Carpul were also not calculated as these scenarios were found to be negligible (refer Sections 3.5 and 5.5 above).

10.1. Wallpolla Floodplain

Table 10.1 to Table 10.3 and Figure 10.1 to Figure 10.3 below present the results of the time series calculations for the Wallpolla Floodplain options (excluding the Lower option which was determined to be of negligible salinity impact). The impact on EC in the River Murray relative to salinity targets at Lock 6 and Morgan are also given where relevant.

Wallpolla South option is planned to operate with the Mid option, and apart using saline water from Mid Wallpolla pool, the results below consider the impact of the South option separately.

Note that inundated areas and pool volumes were used in the time series calculations have been updated from those used in the preliminary salinity impact analysis in Sections 3.3 to 3.5 above. The values are given by Water Technology (2014a, b) and GHD (2014). Table 3.2 in Section 3.3 above provides the updated values.

Table 10.1: Summary of time series results for Wallpolla Floodplain – Mid Option, for various salt wash off estimates

	Salt wash off (kg/ha/day)		
	1	3.8	5
Maximum additional salt load (t/d)	105	113	116
Maximum EC impact in River Murray (EC µS/cm) ^	25	30	30
Lock 6 and Morgan salinity targets			
Days target at Lock 6 exceeded [1]	0	0	0
Maximum exceedance of target at Lock 6 (EC) [1]	-	-	-
Days target at Morgan exceeded [1]	5	5	6
Maximum exceedance of target at Morgan (EC) [1]	4	6	7

Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)

[1] Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. These days are excluded from this summary and only days where the works and measures caused an exceedence are reported. Lock 6 target – 580 µS/cm EC; Morgan target – 830 µS/cm EC

Table 10.2: Summary of time series results for Wallpolla Floodplain – Upper Option, for various salt wash off estimates

	Salt wash off (kg/ha/day)		
	1	3.8	5
Maximum additional salt load (t/d)	11	13	14
Maximum EC impact in River Murray (EC µS/cm) ^	13	20	22

Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)

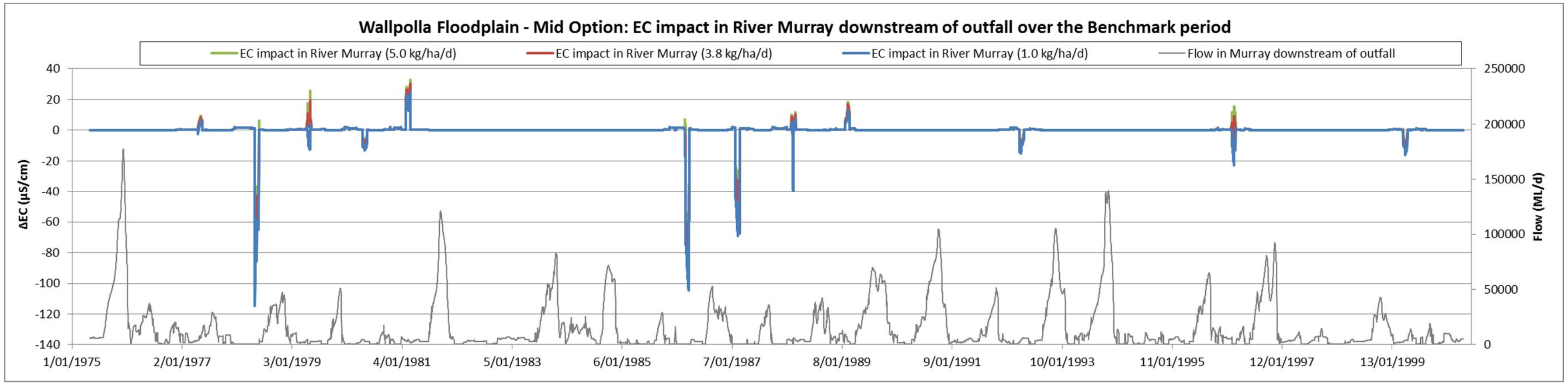
1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.

- **Table 10.3: Summary of time series results for Wallpolla Floodplain – South Option, for various salt wash off estimates**

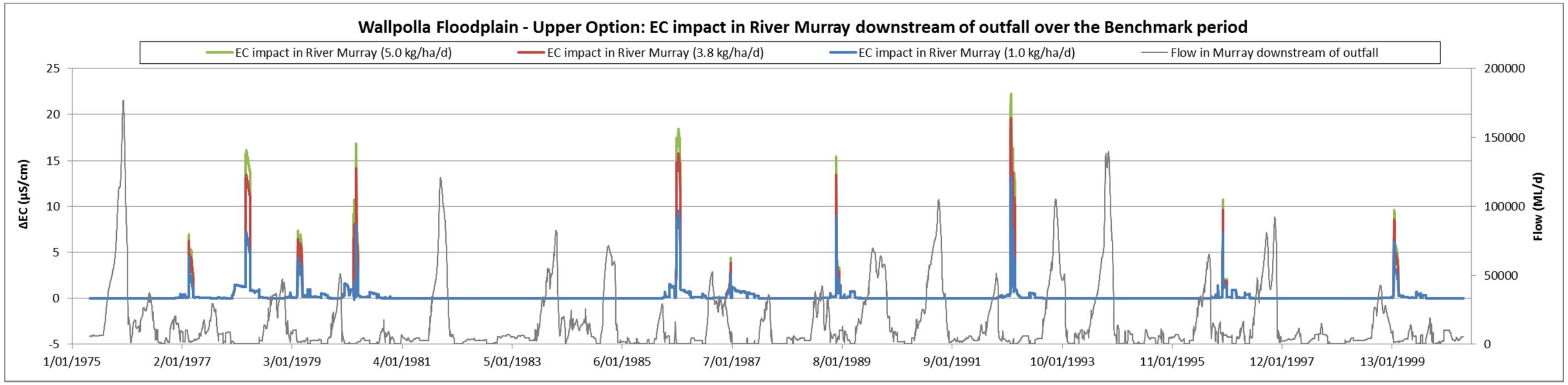
	Salt wash off (kg/ha/day)		
	1	3.8	5
Maximum additional salt load (t/d)	31	33	33
Maximum EC impact in River Murray (EC µS/cm) ^	3	4	4

Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)

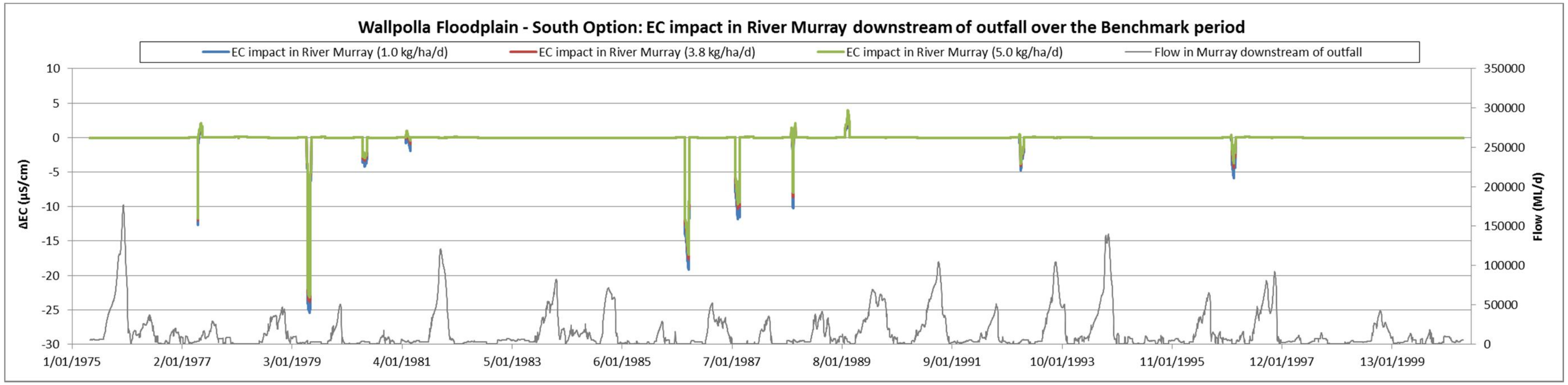
1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.



- **Figure 10.1: EC impact in River Murray downstream of outfall from** Wallpolla Floodplain Mid Option**, for various salt wash off estimates**



- **Figure 10.2: EC impact in River Murray downstream of outfall from** Wallpolla Floodplain Upper Option**, for various salt wash off estimates**



- **Figure 10.3: EC impact in River Murray downstream of outfall from** Wallpolla Floodplain South Option**, for various salt wash off estimates**

10.2. Hattah Lakes

Table 10.4 and Table 10.5, and Figure 10.4 and Figure 10.5 below present the results of the time series calculations for the Hattah Lakes options. Neither option Area 1 nor Area 2 for Hattah Lakes caused an exceedance to the salinity targets at Lock 6 or Morgan over the Benchmark Period.

- **Table 10.4: Summary of time series results for Hattah Lakes – Area 1, for various salt wash off estimates**

	Salt wash off (kg/ha/day)		
	1	3.8	5
Maximum additional salt load (t/d)	57	58	59
Maximum EC impact in River Murray (EC µS/cm) ^	6	6	6

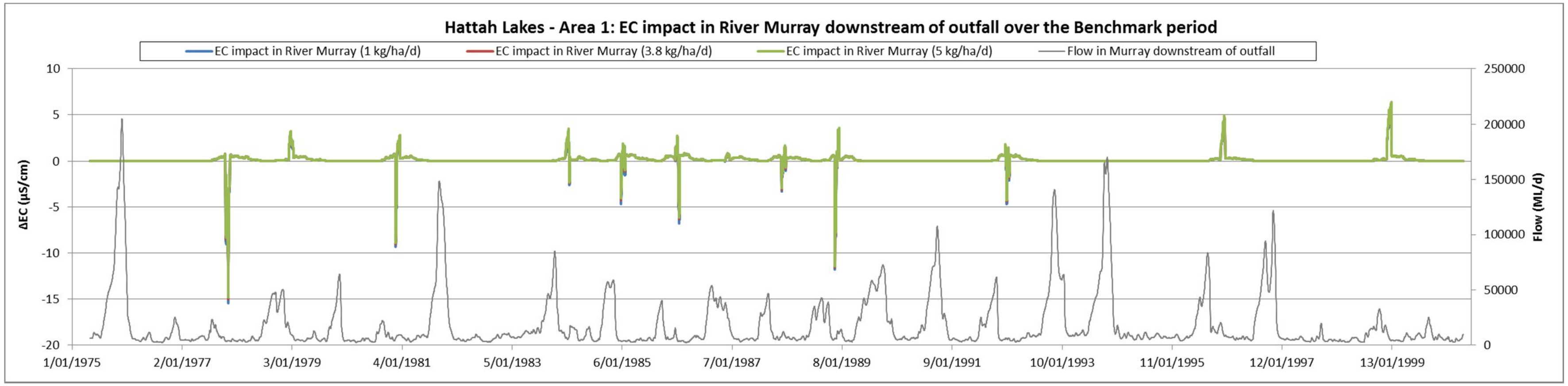
Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)

1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.

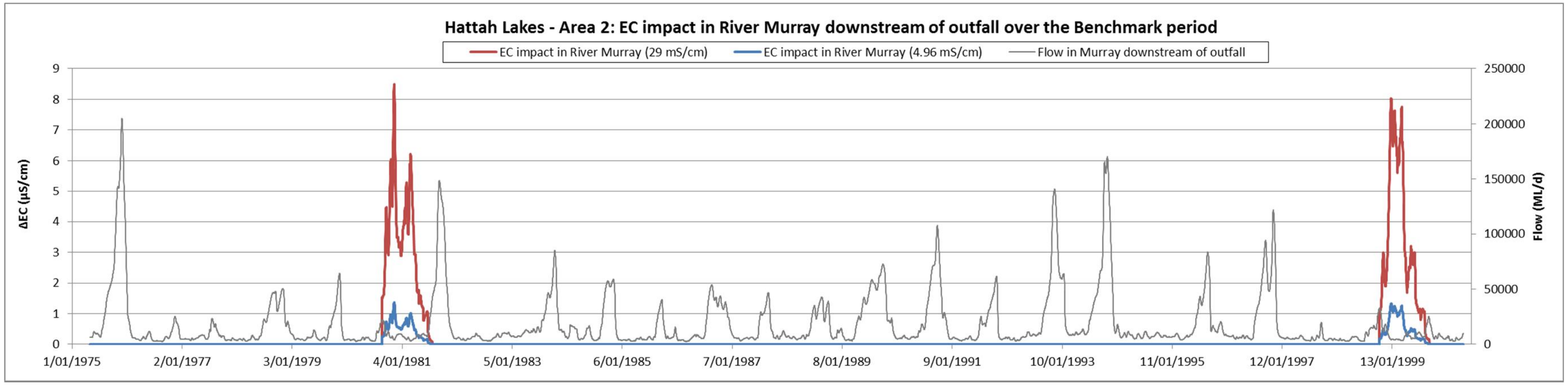
- **Table 10.5: Summary of time series results for Hattah Lakes – Area 2, for various groundwater salinities**

	Groundwater salinity (mS/cm)	
	4.96	29
Maximum additional salt load (t/d)	4	21
Maximum EC impact in River Murray (EC µS/cm)	1	8

Notes: 1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.



- **Figure 10.4: EC impact in River Murray downstream of outfall from** Hattah Lakes Area 1 Option**, for various salt wash off estimates**



- **Figure 10.5: EC impact in River Murray downstream of outfall from** Hattah Lakes Area 2 Option**, for various salt wash off estimates**

10.3. Belsar and Yungera

Table 10.6 and Table 10.7, and Figure 10.6 and Figure 10.7 below present the results of the time series calculations for the Belsar and Yungera options (excluding the Lake Powell and Lake Carpul options which were determined to be of negligible salinity impact). Neither the Primary option nor J1 for Belsar and Yungera caused an exceedance to the salinity targets at Lock 6 or Morgan over the Benchmark Period.

Option J1 is planned to operate with the Primary Option, however the results below only consider the impact of Option J1 separately.

- **Table 10.6: Summary of time series results for Belsar and Yungera Primary Option, for various salt wash off estimates**

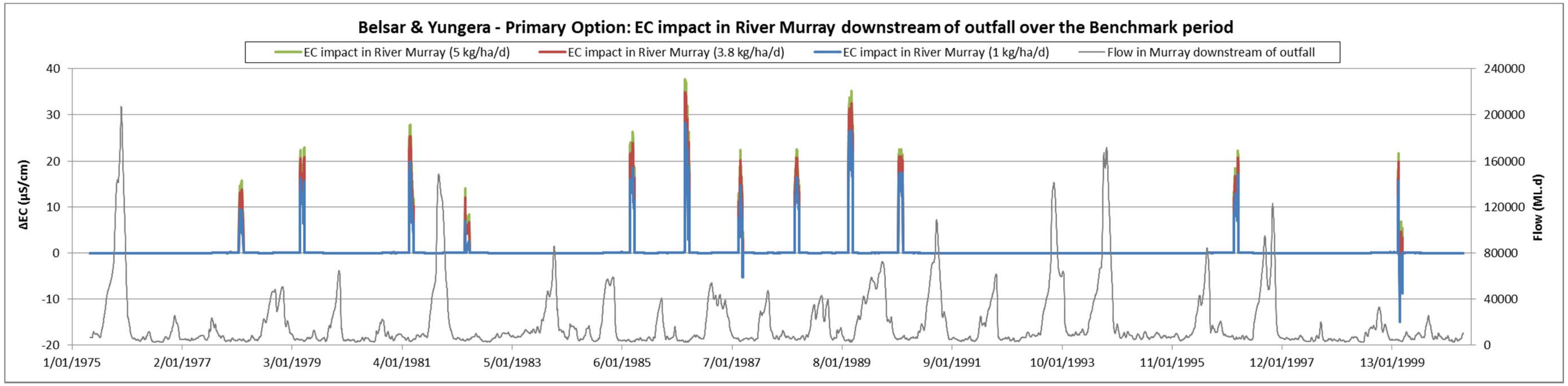
	Salt wash off (kg/ha/day)		
	1	3.8	5
Maximum additional salt load (t/d)	163	176	182
Maximum EC impact in River Murray (EC µS/cm) ^	28	35	38

Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)
1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.

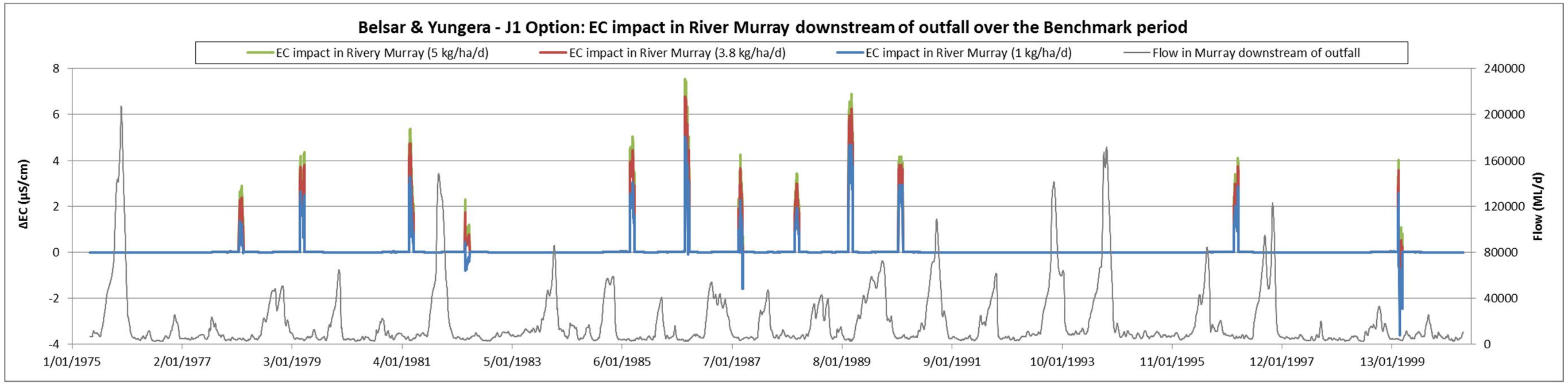
- **Table 10.7: Summary of time series results for Belsar and Yungera J1 Option, for various salt wash off estimates**

	Salt wash off (kg/ha/day)		
	1	3.8	5
Maximum additional salt load (t/d)	28	30	32
Maximum EC impact in River Murray (EC µS/cm) ^	5	7	8

Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)
1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.



- **Figure 10.6: EC impact in River Murray downstream of outfall from** Belsar and Yungera Primary Option**, for various salt wash off estimates**



- **Figure 10.7: EC impact in River Murray downstream of outfall from** Belsar and Yungera J1 Option**, for various salt wash off estimates**

10.4. Burra Creek

Table 10.8 and Figure 10.8 below present the results of the time series calculations for the Burra Creek North option (the South option was removed from potential watering activity plans). The Burra Creek North option did not cause an exceedance to the salinity targets at Lock 6 or Morgan over the Benchmark Period.

- **Table 10.8: Summary of time series results for Burra Creek North Option, for various salt wash off estimates**

	Salt wash off (kg/ha/day)		
	1	3.8	5
Maximum additional salt load (t/d)	15	16	16
Maximum EC impact in River Murray (EC µS/cm) ^	6	6	6

Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)
1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.

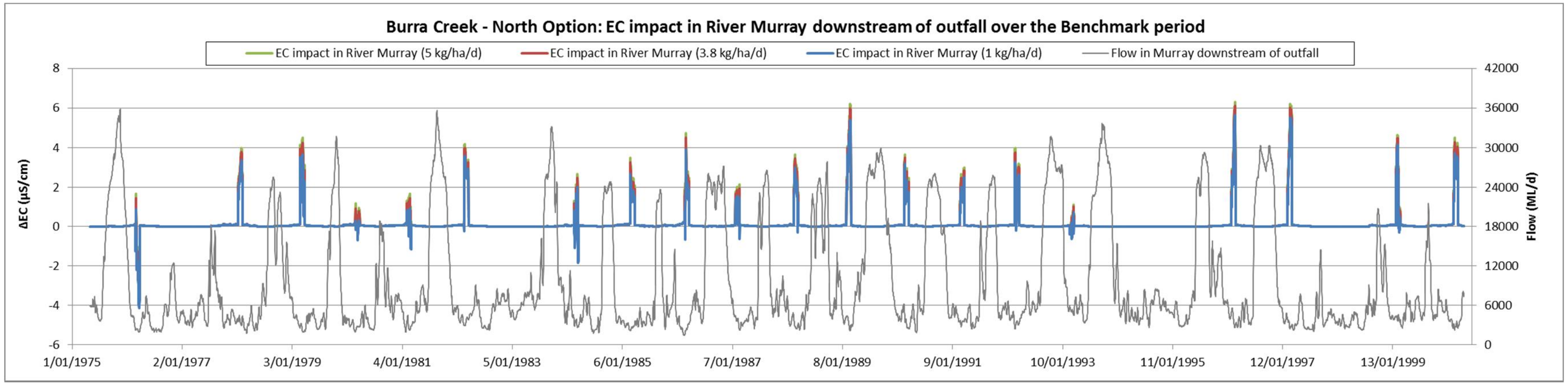
10.5. Nyah Forest

Table 10.9 and Figure 10.9 below present the results of the time series calculations for the Nyah Forest North option (the South option was removed from potential watering activity plans). The Nyah North option did not cause an exceedance to the salinity targets at Lock 6 or Morgan over the Benchmark Period.

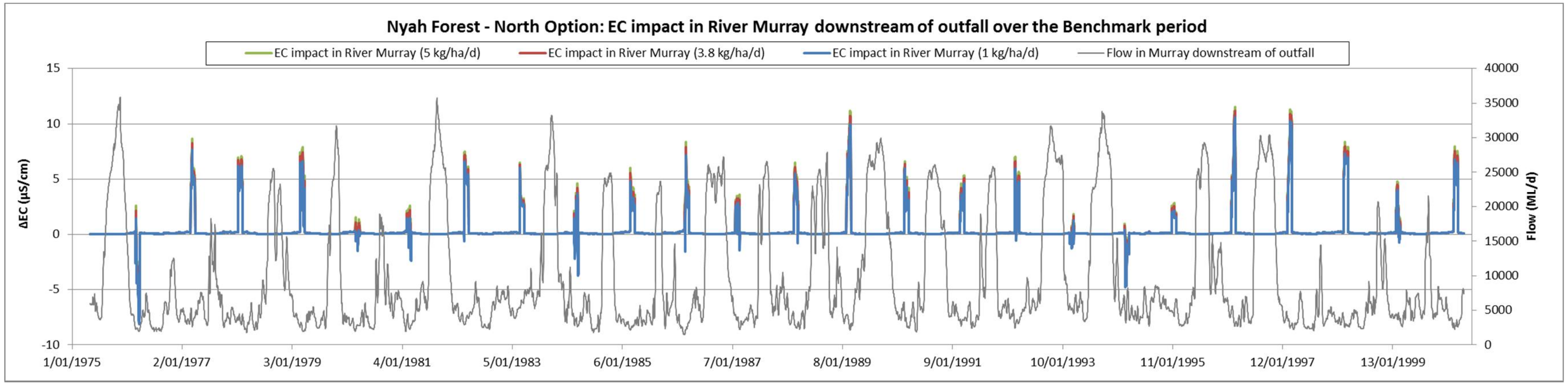
- **Table 10.9: Summary of time series results for Nyah Forest North Option, for various salt wash off estimates**

	Salt wash off (kg/ha/day) *		
	1	3.8	5
Maximum additional salt load (t/d)	11	11	12
Maximum EC impact in River Murray (EC µS/cm) ^	29	30	31

Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)
* These results are relevant for both current and 1990s salinity and groundwater level conditions
1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.



- **Figure 10.8: EC impact in River Murray downstream of outfall from** Burra Creek North Option**, for various salt wash off estimates**



- **Figure 10.9: EC impact in River Murray downstream of outfall from** Nyah Forest North Option**, for various salt wash off estimates (relevant for both current and 1990s salinity and groundwater level conditions)**

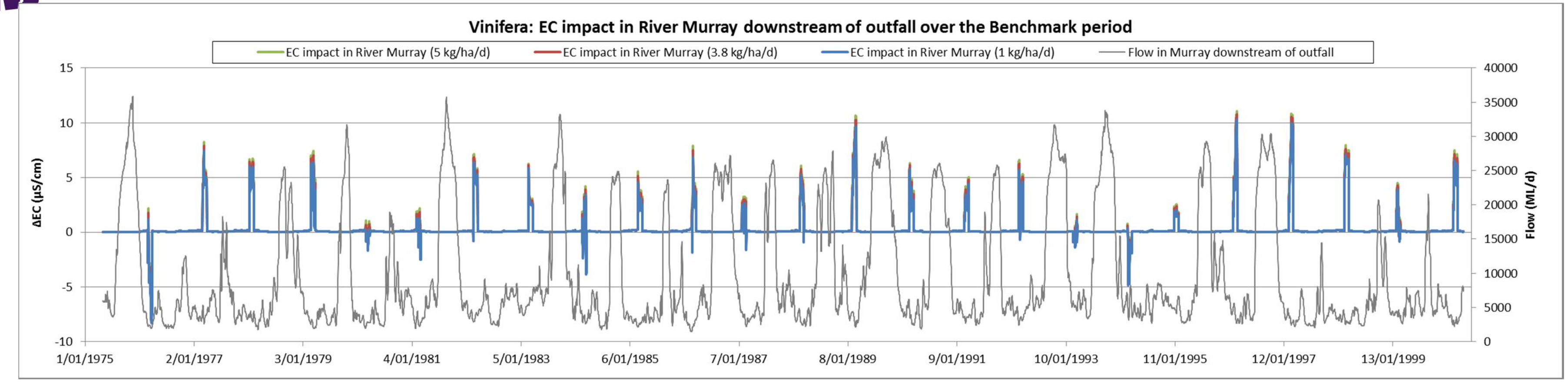
10.6. Vinifera

Table 10.10and Figure 10.10 below present the results of the time series calculations for the Vinifera option. The Vinifera option did not cause an exceedance to the salinity targets at Lock 6 or Morgan over the Benchmark Period.

- **Table 10.10: Summary of time series results for Vinifera, for various salt wash off estimates**

	Salt wash off (kg/ha/day) *		
	1	3.8	5
Maximum additional salt load (t/d)	10	11	11
Maximum EC impact in River Murray (EC µS/cm) ^	28	29	30

Notes: ^ This includes some periods of freshening of Murray water (-ΔEC)
* These results are relevant for both current and 1990s salinity and groundwater level conditions
1 Note that background salinity over the Benchmark period exceeded targets at both Lock 6 and Morgan on many occasions. The works and measure under this option as modelled did not cause EC target breaches at Lock 6 or Morgan over the benchmark period.



- **Figure 10.10: EC impact in River Murray downstream of outfall from** Vinifera Option**, for various salt wash off estimates**

10.7. Discussion of time series results

Analysis of time series results has provided new insights into the potential for real time impacts and the possible differences between the local effects and real time effects at downstream target sites.

A key observation that has emerged from the assessment of time series impacts is that for all of the sites considered in this report the biggest single salinity impact is the detention of existing salt load onto the floodplain and its later release. The addition of salt to the held water in most cases is negligible. Even for the Wallpolla options the impact of the additional salt load is modest (although still potentially accountable). What has been observed during the assessment is that the actual salinity in the inflowing water at the time of diversion can have a real time effect later on. This effect can be either positive or negative in terms of salinity impact in the River Murray. Early spring (rising river) flows and the holding of these on the floodplain means that Murray river salinity can change during the hold phase. Then, depending on the contrast between salinity at the time of inflow and release, the impact in the Murray can be either to freshen or to increase salinity. The graphs in the sections above show a number of events where release back to the Murray River can freshen the river at the time of release. In other circumstances the river can be made more saline.

This gives a real opportunity to manage the impacts of the environmental watering program by selective diversion and release of water based on the actual salinity in the Murray River. This will provide additional complexity to the management of the watering, but provide tangible measures to mitigate the impact of any additional salt if the release can be timed to coincide with a salt slug that is moving down the river.

Of course the any additional salt need to be allowed for, but at many times the release of held water can locally freshen the river.

It is recommended that the opportunity to shorten or lengthen the hold period be considered where release can offer the opportunity to freshen the river. The actual salinity at the time of diversion is a key determinant of the real time release impact and needs to be considered in the rules of operation.

The additional salt loads from these options generally do not affect the targets at Lock 6 or Morgan. Where these targets are adversely affected, the River was already very close to exceeding these targets and an additional few EC units in the river push it over the edge. If the river into which water is released were a few EC lower, the exceedences would not occur or be as great.

This observation leads to an opportunity to combine the release of water from the hold phase from multiple sites to optimise the overall impact. Whilst it was outside of the scope of this work, there is a potential that the cumulative impact of release from a number of wetlands covered with this report could be neutral or positive for the river. This could be achieved by releasing into the river when the salinity is higher than the held water and by concurrently releasing water from a wetland with low salt pick up with one with higher salt pick up.

Such coordination of wetland release will be very complex and will require a high degree of sophistication in management, including the ability to closely monitor travel times and salt slugs during the release phases. Despite the complexity, there are potential mitigating advantages to be had by managing release schedules for multiple wetlands.

Consideration should be given over time to the management of environmental watering release schedules to make the most of the potential to cancel out or mitigate the in-river salinity effects of wetlands with competing impacts.

In order to be able to accurately account for the real time impacts of salt during the release phases, it will be important to have detailed and specific records of the salinity (and flow; the salt load) that is diverted during each event. It is recommended that consideration be given to flow and salinity logging of inflow, especially for large volume diversions. This will enable the held salt load to be known and tracked and will facilitate planning for the release phase.

The overall results in this report are considered suitable for the development of the business case, noting the limitations and assumptions listed in the report. The time series results and real time impact assessments have provided a “first pass” assessment of the potential impacts and have identified a number of areas of possible mitigation. The results presented here have not attempted to fully optimise the real time impacts. If these become important for the progression of the business case then further detailed assessment, potentially using a daily river operations model, may be required. Improvement in the impacts of some of the options is possible and has not been fully explored here. Thus should these impacts be considered acceptable it is likely that they could be improved on in practice, with more information and experience in operation.

11. Conclusions and recommendations

This analysis of salinity impacts associated with proposed water actions at the discussed watering locations has been completed in line with Schedule B (*Water Act*, 2007) and it is believed to be commensurate with those requirements. The level of uncertainty associated with these calculations is considered appropriate in light of the assumptions made and data limitations and the overall level of impact derived.

The preliminary salinity impact for each area, including Lindsay Island (SKM, 2014) is summarised below Table 12.1. These scenarios do not account for implementation of mitigation strategies that could include managing releases to coincide with higher flow in the Murray River, reduced rate of lowering of the weir pool upstream of the regulator or avoidance of watering salinity hotspots.

(Note that the results in Table 11.1 for Wallpolla Island Mid, Upper and South options use outdated wetland inundation parameter values.)

- **Table 11.1 Summary of preliminary estimates of impacts to EC at Morgan (shaded cells indicate estimated impact >0.1 EC at Morgan)**

Location	Inundation area	EC impact at Morgan (total of all processes) ^
Wallpolla Island	Lower	0.08
	Mid	1.1 *
	Upper	0.17 *
	South	0.006 *
Hattah Lakes	Area 1	0.07
	Area 2	0.02
Belsar and Yungera Islands	Primary Option	0.07
	J1 Creek works (secondary option)	0.008
	Lake Powell (secondary option)	Negligible
	Lake Carpul (secondary option)	Negligible
Burra Creek	Burra Creek North	0.02
	Burra Creek South	0.005
Nyah	Nyah North	0.04
	Nyah South	0.003
Vinifera		0.03
Lindsay Island [a]	Option 1	5.24
	Lake Wallawalla West	Negligible

Location	Inundation area	EC impact at Morgan (total of all processes) ^
	Wallawalla East	0.006
	Crankhandle Wetland complex (upper)	Negligible
	Crankhandle Wetland complex (lower)	Negligible
	Crankhandle West (upper)	Negligible
	Crankhandle West (lower)	Negligible
	Lindsay South	0.009
	North West area	Negligible

NOTES:

* The results reported are from a salt wash off estimated load of 3.8 kg/ha/day and current salinity and groundwater conditions where relevant.

^ The results for Wallpolla Mid, Upper and South options use outdated inundation parameters. The values differ from those used in time series calculations, reported in Table 11.2.

[a] Results from Lindsay Island Salinity Impact Assessment (SKM, 2014); for a 1 in 2 year or 1 in 5 year watering event

1. The proposed environmental watering regimes used in this preliminary salinity assessment were designed to provide an indication of the greatest impact for selected sites or worst case scenarios. This information will be used to inform future decisions regarding operational frequency, duration and extent of inundation for the environmental watering activities at each of these sites and will differ from those described in this report.
2. Conservatism has been built into the preliminary estimates of salinity impact to address areas of uncertainty. These numbers must only be clearly identified and used in conjunction with the assumptions and limitations that underpin the calculations.
3. These preliminary estimates do not account for the implementation of mitigation strategies that may reduce the magnitude of the salinity impact.
4. The preliminary estimates have been calculated using an analytical approach and available data. The quantum of salinity impact described in this report is likely to change when the Basin Plan modelling tool is applied.

The analysis of real time impacts suggests that proposed environmental watering activities are likely to have a minor salinity impact immediately downstream of all wetlands assessed (up to 35 EC). Only the Wallpolla Island Mid Option is likely to breach the salinity target at Morgan (830 µS/cm EC), and only on a handful of days over the 25 year benchmark period. Table 11.2 summarises these results. It should be noted that background salinity in the River Murray breached Morgan targets on over 200 days in this period. Most of the watering activities were also shown to have a freshening effect on Murray salinity over the modelled period (- EC impact).

(Note that real time salinity impact estimates for Wallpolla Island Mid, Upper and South options use updated wetland inundation parameter values.)

Table 11.2 Summary of preliminary estimates of real time salinity impacts (shaded cells indicate estimated breach/es of target at Lock 6 or Morgan)

Location	Inundation area	Maximum EC impact in Murray (µS/cm EC) *	Days target breached (over benchmark period) *	
			Lock 6	Morgan
Wallpolla Island	Lower	Not assessed		
	Mid ^	30	0	5
	Upper ^	20	0	0
	South ^	4	0	0
Hattah Lakes	Area 1	6	0	0
	Area 2	1	0	0
Belsar and Yungera Islands	Primary Option	35	0	0
	J1 Creek works (secondary option)	7	0	0
	Lake Powell (secondary option)	Not assessed		
	Lake Carpul (secondary option)	Not assessed		
Burra Creek	Burra Creek North	6	0	0
	Burra Creek South	Not assessed		
Nyah	Nyah North	30	0	0
	Nyah South	Not assessed		
Vinifera		29	0	0

NOTES:
1. Lindsay Island results are reported in SKM 2014.
^ The results for Wallpolla Mid, Upper and South options use updated values for inundation parameters to those used in the preliminary estimates of salinity impacts in Table 11.1.
* The results reported are from a salt wash off estimated load of 3.8 kg/ha/day, 4.96 mS/cm groundwater salinity and/or current salinity and groundwater conditions where relevant.

The time series analysis shows that the bulk of the salt load delivered to the River Murray from watering events is likely to come from salt carried into the wetlands by the flooding water rather than from entrained salt in the floodplains themselves. The salinity impact on the Murray may be managed by selective timing of water release from the wetlands. The salinity impacts from the proposed works and measures, and the time series results presented here, are found to be heavily reliant on the timing (with respect to River Murray flow and salinity) of fill and release for floodplain watering.

The salinity impacts from watering actions are likely to be greater if 1990s conditions are reinstated due to the potential to create more gaining river reaches (although the EC impact at Morgan will be offset by the reduced frequency of operation in the longer term). This will be most evident at sites like Wallpolla and Hattah Lakes, where a decline in groundwater level has been observed since 1990s. At other sites further upstream (i.e. Burra Creek) the decline in groundwater level over time is not as prominent or is unable to be determined due to lack of groundwater data. Here, watering events are not anticipated to lead to significant rise in groundwater levels.

There is no analysis of the timeframe needed to reach 1990s groundwater levels and this scenario is presented as being representative of a worst case or cumulative effect following successive operations.

It is recommended that more detailed analysis of risks to irrigators is undertaken and that operational planning considers these risks.

It is further recommended that a rigorous monitoring program of events is implemented. The monitoring program should support the following:

- Measure the salt loads emanating from an initial watering event, and the implications for the magnitude of this salt load as it relates to the frequency of flooding;
- Assess the risk of local impacts (ecological and economic) taking into account the potential need to report against in-stream targets under the Basin Plan and associated Water Resource Plans; and
- Understand the cumulative impacts that may be created (i.e. due to operations at Wallpolla, Mulcra, Lindsay and Chowilla). To fully inform this cumulative assessment, the monitoring program should have linkages with monitoring programs established for other environmental watering program actions.
- Monitoring and measuring the salinity and salt load that is diverted into the wetlands so that the impact of release can be planned
- Monitoring in the River Murray to be able to time the release of held water (this may be adequate but the current monitoring should be assessed.

Further assessment is required around meeting Basin Plan targets. It is understood that the magnitude of salinity impact estimates described in this report will partly depend on the modelling tools used to quantify the potential salinity impacts.

The addition of time series assessment and an analysis of real time impacts have highlighted the importance of the timing of both diversion and release. For many events through the benchmark period, release of stored water can locally freshen the Murray River. The complexity of the operations of multiple wetlands needs to be considered. It may be appropriate for the Mallee CMA to consider developing a river operations simulation for the Mallee reach to test the management options for multiple wetlands. There is the potential for effective mitigation of impacts by selective combination of release times for different wetlands.

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13. Appendix A - Impact Analysis Steps

***(i). Salt wash off*.**

1 - select suitable salt flux.

2 - use total area of inundated areas (minus watercourses)

3 - determine salinity impact at Morgan using Ready Reckoner (Fuller & Telfer, 2007) and convert to relevant frequency of events

(ii). Recharge and displacement

1 - use total area of inundated areas (minus watercourses)

2 - groundwater salinity based on average of bores located near river/creek

3 - use recharge rate of 0.5mm/d

4 - assume recharge return of 100% during inundation, then decreases in linear fashion to 0% after 12 months

5 - determine salinity impact at Morgan using Ready Reckoner (Fuller & Telfer, 2007) and convert to relevant frequency of events

(iii). In channel salt release

1 - calculate total length of watercourse within the inundation footprint

2 - calculate volume of water in river

3 - calculate difference between upstream and downstream in stream salinity (under current and 1990 conditions). A default of 100 EC difference was applied to each scenario

4 - calculate salt load

5 - determine salinity impact at Morgan using Ready Reckoner (Fuller & Telfer, 2007) and convert to relevant frequency of events

(iv). Recharge from inundation displacing saline groundwater from the Channel Sands aquifer adjacent watercourse (Murray River or other tributary)

The following assumptions were made for each wetland area:

1 - Channel Sands and Parilla Sands aquifer thickness interpreted from previous reports and/or cross sections (e.g. Thorne *et al.,* 1990).

2 - base of wetland estimated from DEM coverage;

3 - March 2012 groundwater level and salinity records used where possible. Otherwise, earlier groundwater records were used.

4 – mound rise occurs over 300 days, followed by 300 days of mound decline (approx. 20 months total)

Groundwater mound rise

1. calculate an equivalent radius for a circular approximation of inundation area

2. calculate the potential unconfined groundwater mound rise using analytical solution from Hantush (1967)

Darcy calculations

3. calculate likely flux to river using Darcy flux equation, with head difference taken as maximum elevation following inundation (determined using groundwater mound calculation) minus that of the known surface water level or estimated bed level in adjacent watercourse

4. calculate equivalent salt load from estimated groundwater salinity and determine salinity impact at Morgan using Ready Reckoner (Fuller & Telfer, 2007), assuming all salt load to Lindsay River flows to Murray. Convert to relevant frequency of events.

14. Appendix B - Input data and Example calculations

WALLPOLLA ISLAND – Wallpolla Lower (Lock 9)

In channel salt release

River length	52,754		m
Width	20		m
Depth	5		m

Flow around Lock 9

Current weir pool	27.44		mAHD
Raised weir pool	27.9		mAHD
Salinity	450		mg/L
Hydraulic conductivity	10		m/d

WALLPOLLA ISLAND – Wallpolla Lower (Robsons Road)

***Salt wash off*.**

Salt flux	1, 3.8, 5		kg/ha/t
Total area	193		ha

Inundation input data

Aquifer specific yield:	0.05		
Recharge rate	0.0005		m/d
Inundation area:	193		ha
Approx. base of aquifer	13		mAHD
Average frontage	5000		m
Width of flow path	1060		m
Murray River level:	27.4		mAHD
Willpenance Creek bed level:	27.6		mAHD
	Current	1994	
Groundwater level:	24.2	27.7	mAHD
Groundwater salinity:	5		mS/cm

WALLPOLLA ISLAND – Wallpolla Mid

Note that these values relating to inundation area, volume and top pool level have been updated since this analysis was undertaken.

***Salt wash off*.**

Salt flux	1, 3.8, 5		kg/ha/t
Total area	2,705		ha

In channel salt release

River length	49,127	m
Width	20	m
Depth	5	m

Recharge and displacement

Area	2,705	ha
Groundwater salinity	5	mS/cm
Recharge rate	0.5	mm/d

WALLPOLLA ISLAND – Wallpolla Upper

Note that these values relating to inundation area, volume and top pool level have been updated since this analysis was undertaken.

***Salt wash off*.**

Salt flux	1, 3.8, 5	kg/ha/t
Total area	639	ha

In channel salt release

River length	17,203	m
Width	20	m
Depth	5	m

Recharge and displacement

Area	639	ha
Groundwater salinity	5	mS/cm
Recharge rate	0.5	mm/d

WALLPOLLA ISLAND – Wallpolla South

Note that these values relating to inundation area, volume and top pool level have been updated since this analysis was undertaken.

***Salt wash off*.**

Salt flux	1, 3.8, 5	kg/ha/t
Total area	669	ha

Inundation input data

Aquifer specific yield:	0.05	
Recharge rate	0.0005	m/d
Inundation area:	669	ha
Approx. base of aquifer	13	mAHD
Average frontage	3433	m
Width of flow path	5100	m

Wallpolla Creek bed level:	28.9		mAHD
	Current	1994	
Groundwater level:	28.65	27.09	mAHD
Groundwater salinity:	5		mS/cm

HATTAH LAKES – AREA 1

***Salt wash off*.**

Salt flux	1, 3.8, 5	kg/ha/t
Total area	393	ha

Recharge and displacement

Area	393	ha
Groundwater salinity	4.96	mS/cm
Recharge rate	0.5	mm/d

In channel salt release

Creek length	7,964	m
Width	10	m
Depth	5	m

Inundation input data

Aquifer specific yield:	0.05	
Recharge rate	0.0005	m/d
Inundation area:	393	ha

Approx. base of aquifer	28		mAHD
Murray River level:	40.6		mAHD
Average frontage to MR	2340		m
Width of flow path to MR	385		m
Chalka Creek bed level:	39.3		mAHD
Average frontage to Creek	330		m
Width of flow path to Creek	2760		m
	Current	1994	
Groundwater level:	36.1	37.4	mAHD
Groundwater salinity:	4.96		mS/cm

HATTAH LAKES – AREA 2

***Salt wash off*.**

Salt flux	1, 3.8, 5	kg/ha/t
Total area	710	ha

Recharge and displacement

Area	710	ha
Groundwater salinity	4.96	mS/cm
Recharge rate	0.5	mm/d

Inundation input data

Aquifer specific yield:	0.05		
Recharge rate	0.0005		m/d
Inundation area:	248		ha
Approx. base of aquifer	28		mAHD
Chalka Creek bed level:	39.3		mAHD
Average frontage	2351		m
Width of flow path	4513		m
	Current	1994	
Groundwater level:	37.3	38.3	mAHD
Groundwater salinity:	4.96		mS/cm

BELSAR & YUNGERA – Primary option (minus Lake Powell, Lake Carpul)

***Salt wash off*.**

Salt flux	1, 3.8, 5	kg/ha/t
Total area	1546	ha

Recharge and displacement

Area	1546	ha
Groundwater salinity	0.48	mS/cm

Recharge rate	0.5		mm/d
In channel salt release			
River length	50,360		m
Width	20		m
Depth	5		m
BELSAR & YUNGERA – J1 Creek			
Salt wash off**.**			
Salt flux	1, 3.8, 5		kg/ha/t
Total area	351		ha
Recharge and displacement			
Area	351		ha
Groundwater salinity	0.48		mS/cm
Recharge rate	0.5		mm/d
BELSAR & YUNGERA – Lake Powell			
Salt wash off**.**			
Salt flux	1, 3.8, 5		kg/ha/t
Total area	128		ha
Inundation input data			
Aquifer specific yield:	0.05		
Recharge rate	0.0005		m/d
Inundation area:	128		ha
Approx. base of aquifer	40		mAHD
Creek bed level:	47.6		mAHD
Average frontage	2550		m
Width of flow path	1050		m
	Current	1994	
Groundwater level:	48.42	-	mAHD
Groundwater salinity:	0.48		mS/cm
BELSAR & YUNGERA – Lake Carpul			
Salt wash off**.**			
Salt flux	1, 3.8, 5		kg/ha/t
Total area	68		ha
Inundation input data			

Aquifer specific yield:	0.05		
Recharge rate	0.0005		m/d
Inundation area:	68		ha
Approx. base of aquifer	40		mAHD
	Current	1994	
Groundwater level:	48.42	-	mAHD
Groundwater salinity:	0.48		mS/cm

BURRA CREEK - NORTH

***Salt wash off*.**

Salt flux	1, 3.8, 5	kg/ha/t
Total area	273	ha

Recharge and displacement

Area	273	ha
Groundwater salinity	0.93	mS/cm
Recharge rate	0.5	mm/d

In channel salt release

River length	22,500	m
Width	5	m
Depth	1	m

Inundation input data

Aquifer specific yield:	0.05		
Recharge rate	0.0005		m/d
Inundation area:	207		ha
Approx. base of aquifer	45		m
Murray River level:	56.5		mAHD
Average frontage to MR	2187		m
Width of flow path to MR	1,496		m
Burra Creek bed level:	55.7		mAHD
Average frontage to Creek	448		m
Width of flow path to Creek	700		m
	Current	1994	
Groundwater level:	54.0	53.4	mAHD
Groundwater salinity:	0.93		mS/cm

BURRA CREEK - SOUTH

***Salt wash off*.**

Salt flux	1, 3.8, 5		kg/ha/t
Total area	123		ha
Recharge and displacement			
Area	123		ha
Groundwater salinity	0.93		mS/cm
Recharge rate	0.5		mm/d
Inundation input data			
Aquifer specific yield:	0.05		
Recharge rate	0.0005		m/d
Inundation area:	123		ha
Approx. base of aquifer	45		mAHD
Murray River level:	56.5		mAHD
Average frontage to MR	263		m
Width of flow path to MR	2414		m
Burra Creek bed level:	55.7		mAHD
Average frontage to Creek	595		m
Width of flow path to Creek	2414		m
	Current	1994	
Groundwater level:	54	53.4	mAHD
Groundwater salinity:	0.93		mS/cm
NYAH - NORTH			
***Salt wash off*.**			
Salt flux	1, 3.8, 5		kg/ha/t
Total area	415		ha
Recharge and displacement			
Area	415		ha
Groundwater salinity	1.06		mS/cm
Recharge rate	0.5		mm/d
In channel salt release			
River length	17,533		m
Width	5		m
Depth	1		m
Inundation input data			
Aquifer specific yield:	0.05		

Recharge rate	0.0005		m/d
Inundation area:	415		ha
Approx. base of aquifer	54		mAHD
Murray River level:	60.1		mAHD
Average frontage to MR	500		m
Width of flow path to MR	500		m
Parnee-Malloo Creek bed level:	62.3		mAHD
Average frontage to Creek	700		m
Width of flow path to Creek	500		m
	Current	1994	
Groundwater level:	56.98	59.6	mAHD
Groundwater salinity:	1.06		mS/cm

NYAH - SOUTH

***Salt wash off*.**

Salt flux	1, 3.8, 5	kg/ha/t
Total area	60	ha

Recharge and displacement

Area	60	ha
Groundwater salinity	1.06	mS/cm
Recharge rate	0.5	mm/d

Inundation input data

Aquifer specific yield:	0.05		
Recharge rate	0.0005		m/d
Inundation area:	60		ha
Approx. base of aquifer	54		mAHD
Murray River level:	60.1		mAHD
Average frontage to MR	290		m
Width of flow path to MR	1137		m
	Current	1994	
Groundwater level:	56.98	59.6	mAHD
Groundwater salinity:	1.06		mS/cm

VINIFERA

***Salt wash off*.**

Salt flux	1, 3.8, 5	kg/ha/t
Total area	340	ha

Recharge and displacement

Area	340		ha
Groundwater salinity	1.06		mS/cm
Recharge rate	0.5		mm/d

In channel salt release

River length	5,747		m
Width	5		m
Depth	1		m

Inundation input data

Aquifer specific yield:	0.05		
Recharge rate	0.0005		m/d
Inundation area:	340		ha
Approx. base of aquifer	54		mAHD
Murray River level:	60.1		mAHD
Average frontage to MR	477		m
Width of flow path to MR	3,370		m
	Current	1994	
Groundwater level:	56.98	59.6	mAHD
Groundwater salinity:	1.06		mS/cm

1. Salt wash off

Option	Area	1	3.8	5	kg/ha/d	
Lower (robsons)	193	0.193	0.733	0.965		t (total for 30 days)
		0.006	0.024	0.032		Salt load (t/d)
		4.19E-05	1.59E-04	2.09E-04		EC Impact
Mid	2705	2.705	10.28	13.53		t (total for 30 days)
		0.090	0.343	0.451		Salt load (t/d)
		4.19E-04	1.59E-03	2.10E-03		EC Impact
Upper	639	0.64	2.43	3.20	t	t (total for 30 days)
		0.021	0.081	0.107	t/d	Salt load (t/d)
		7.92E-05	3.01E-04	3.96E-04	EC	EC Impact
south	669	6.69E-01	2.54	3.35		t (total for 30 days)
		0.022	0.085	0.112		Salt load (t/d)
		8.30E-05	3.15E-04	4.15E-04		EC Impact

Fuller & Telfer	(Oct)	0.31	
		0.372	4 in 10
		0.465	5 in 10
		0.651	7 in 10

2. Recharge and displacement

Wallpolla Mid						
Recharge rate	5.00E-04	m/day				
Area	2705	ha			5	mS/cm
Input volume	13525	m3/day			3000	mg/l
	13.525	ML/d			3	t/ML
Input time	120	days				
Total volume	1623000	m3				
	1623	ML				
Salinity	3	t/ML				
Output salt	4869	t				
Salt per month	405.75					
Per day	13.53	t/d				
	Month	Salinity impact	Salt load factor	salt load (	Adjusted EC	
Inundation	Oct	0.31	1	13.53	0.0419	
	Nov	0.38	1	13.53	0.0514	
	Dec	0.53	1	13.53	0.0717	
	Jan	0.63	1	13.53	0.0852	
Drying	feb	0.69	1	13.53	0.0933	
	mar	0.92	0.9	11.59	0.1067	
	apr	0.82	0.7	9.66	0.0792	
	may	0.71	0.6	7.73	0.0549	
	jun	0.5	0.4	5.80	0.0290	
	jul	0.38	0.3	3.86	0.0147	
	aug	0.3	0.1	1.93	0.0058	
	sep	0.27	0.0	0.00	0.0000	
					0.634	Total
					0.951	5 in 10

3. In channel release

Wallpolla Mid					
Width	20			EC factor (Oct)	
Depth	5			0.31	
Length	49127			0.465	5 in 10 years
Volume (m3)	4912700				
L	4912700000				
ML	4912.7				
Salinity	100	EC			
	60	mg/L			
Salt load	294.762	t	over 30 days		
	9.8254	t/d			
	0.046	7 in 10			

4. Flow net around Lock 9

Flow Net Analysis for groundwater flow around Lock 9						
Assume Channel Sands aquifer is confined by upper and						
lower Lock 9 pool levels						
	Victoria	NSW				
no. cells	2	2				
H0	27.9	27.9	m AHD Lock 9 weir pool			
H1	24.7	24.7	m AHD ds Lock 9			
deltaH	3.2	3.2	m			
d	6	6	m depth of Channel Sands			
k	10	10	m/day			
Path 1:						
L	295	275	m approx length of flowpath			
i	0.010847	0.01163636	hydraulic gradient			
Q	0.650847	0.69818182	m3/day/m			
Path 2:						
L	885	662	m			
i	0.003616	0.00483384	hydraulic gradient			
Q	0.216949	0.29003021	m3/day/m			
	200	200	m width of flow path			
Qcell	87	99	m3/day			
Qtot	174	198	m3/day			
Q	371	m3/day	0.371201728			
salinity	0.6	t/ML	450	mg/L		
salt load	**0.22**	**t/day**				
salt load	0.188	t/day (base case)				
Raising Lock 9					oct	0.31
H0	27.9	m AHD			nov	0.38
deltaH	3.2	m			dec	0.53
deltaH (basec	1.19	ratio of flux to base case			jan	0.63
Q	371	m3/day			feb	0.69
salt load	0.223	t/day				
increment	0.03	t/day	*difference to basecase*			2.54
impact	0.002	7 in 10				5.334

5. Mound Rise

Wallpolla South

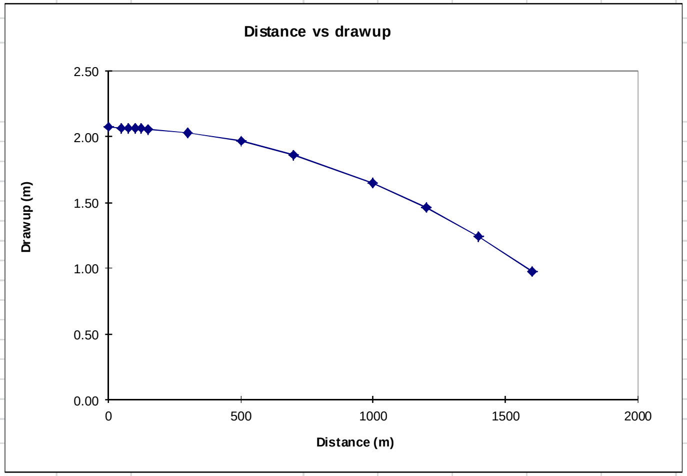
Calculate watertable mound (unconfined rise) from circular (vertical) recharge area

(from Walton, 1988, formulae from Hantush, 1967)

	INPUTS
Radius of circular recharge area = Rm (m):	1459
Recharge Rate (m/day):	0.0005
Hi = initial height of watertable above aquiclude (m):	15.65
average height of Hi and Hm (iterative)	16.65
Specific Yield:	0.05
Kh:	10
time of calculation (days):	300

for r < Rm

Distance (r) from centre of mound (m)	u0	W(u)	gw level	gw level change (m)	GW level (mAHD)
1	5.33E-01	5.22E-01	17.7	**2.0691**	30.7191
50	5.33E-01	0.52175312	17.7	2.0681	30.7181
75	5.33E-01	0.52175312	17.7	2.0668	30.7168
100	5.33E-01	0.52175312	17.7	2.0650	30.7150
125	5.33E-01	0.52175312	17.7	2.0627	30.7127
150	5.33E-01	0.52175312	17.7	2.0598	30.7098
300	5.33E-01	0.52175312	17.7	2.0318	30.6818
500	5.33E-01	0.52175312	17.6	1.9653	30.6153
700	5.33E-01	0.52175312	17.5	1.8651	30.5151
1000	5.33E-01	0.52175312	17.3	1.6502	30.3002
1200	5.33E-01	0.52175312	17.1	1.4626	30.1126
1400	5.33E-01	0.52175312	16.9	1.2382	29.8882
1600	5.33E-01	0.52175312	16.6	0.9755	29.6255



for r >= Rm

Distance (r) from centre of mound (m)	u	W(u)	gw level	gw level change (m)	
1700	7.23E-01	0.3577629	16.5	0.8076	19.8076
1800	8.11E-01	0.3046133	16.4	0.7037	19.7037
2000	1.00E+00	0.21903172	16.2	0.5301	19.5301
2200	1.21E+00	0.15563881	16.0	0.3947	19.3947
2500	1.56E+00	0.09099373	15.9	0.2477	19.2477
2700	1.82E+00	0.0625352	15.8	0.1785	19.1785
3000	2.25E+00	0.03465773	15.8	0.1062	19.1062

6. Flow net

Wallpolla South									
Flow to Wallpolla Creek									
Time (days)	Mound rise (m)	GW elevation due to mound	Head difference based on 37.7mAHD	Frontage (distance to river from centre of mound)	Width of flow path	i (hydraulic gradient)	Q (m3/d)	Salt load (t)	t/d
30	0.05	28.650	-0.25	3433	5100	-0.00007	-74	-0.223	-0.007428
60	0.62	28.650	-0.25	3433	5100	-0.00007	-74	-0.223	-0.007428
90	0.88	29.534	0.63	3433	5100	0.00018	188	0.565	0.018847
120	1.12	29.769	0.87	3433	5100	0.00025	258	0.775	0.025820
150	1.32	29.975	1.07	3433	5100	0.00031	319	0.958	0.031930
180	1.51	30.156	1.26	3433	5100	0.00037	373	1.120	0.037331
210	1.67	30.319	1.42	3433	5100	0.00041	422	1.265	0.042151
240	1.81	30.400	1.50	3433	5100	0.00044	446	1.337	0.044567
270	1.95	30.400	1.50	3433	5100	0.00044	446	1.337	0.044567
300	2.07	30.400	1.50	3433	5100	0.00044	446	1.337	0.044567
330	2.07	30.400	1.50	3433	5100	0.00044	446	1.337	0.044567
360	1.95	30.400	1.50	3433	5100	0.00044	446	1.337	0.044567
390	1.81	30.400	1.50	3433	5100	0.00044	446	1.337	0.044567
420	1.67	30.319	1.42	3433	5100	0.00041	422	1.265	0.042151
450	1.51	30.156	1.26	3433	5100	0.00037	373	1.120	0.037331
480	1.32	29.975	1.07	3433	5100	0.00031	319	0.958	0.031930
510	1.12	29.769	0.87	3433	5100	0.00025	258	0.775	0.025820
540	0.88	29.534	0.63	3433	5100	0.00018	188	0.565	0.018847
570	0.62	28.650	-0.25	3433	5100	-0.00007	-74	-0.223	-0.007428
600	0.05	28.650	-0.25	3433	5100	-0.00007	-74	-0.2228	-0.007428
				EC impact	11.43			17.387	t/600 days
					13.716	7 in 10		0.04	t/d
								0.005	Impact

15. Appendix C - Real Time Salt Load Method and Assumptions

15.1. Disaggregation steps

(i) Determine watering events

1 – using daily flow data for the benchmark period (MDBA 2014), break into periods depending on watering frequency, e.g. 1 in 2 years for 3 cycles – 1975-6, 1977-8 , 1979-80, then 1 in 6 years – 1981-86, 1987-92, 1993-98, 1999-2000

2 – determine the watering events in each period, e.g. for 1 in 2 year events, the largest flow in the watering period over both years (e.g. within June to August); for # in # year events (5 in 10 years), the lesser of the peak flows in these years

3 – these peak days become day 1 of the hold period for the watering events (i.e. fill occurs in flood build-up)

(ii) Calculate salt loads and flows

1 – calculate watering event daily salt loads and flows for all contributing processes (those whose salt impacts aren't negligible)

a – salt wash off

Total salt wash is accumulated in pool water over the fill period at the given rate, and released at a constant rate over the release period

(Note that most salt wash off salinity impacts were initially found to be negligible, but corrected calculations show an increased impact, and salt wash off was included in the time series calculations)

b – groundwater recharge and displacement

Recharge begins to be released at the start of the hold period at a rate dependent on the salt load factor over the following 12 months

(Note that the salt load factor method used in the initial salinity estimates for recharge release does not release all salt and water accumulated by the salinity process. For consistency, this method is carried through to the time series calculations)

c – in channel release

In channel salt is released at a constant rate over the release period

d – mound rise

Salt and water from mound rise begins to be released at the start of the hold period at the calculated rate over the following 600 days. There is no release for the first 30 days

e – salt flux back to River Murray

Salt flux to the River Murray begins at the start of the fill period and continues for the following year at a constant rate

2 – calculate background salt load of inundating water from the EC of River Murray (average EC over fill period) and the total inundated pool volume for the watering event.

3 – calculate total salt load discharging into the outfall channel of the wetland, and the River Murray downstream of the outfall (sum of all relevant processes)

4 – calculate the resultant salinity in River Murray downstream of the outfall from background and additional salt load and flow

5 – determine the change in EC (ΔEC) from the works and measures in the River Murray immediately downstream of the wetland outfall (assuming full mixing of waters)

6 – add this ΔEC to background Murray River salinity at Lock 6 and Morgan, and compare the resultant final EC to salinity targets

15.2. Input data and assumptions used in time series calculations

Wallpolla Floodplain

Note that this analysis used updated values for inundation area, volume and top pool level from those used in the preliminary salinity impact analysis. These parameters and all related parameters relevant to salinity processes for Wallpolla Floodplain options have been updated to undertake the time series calculations. Where an updated value was not given (i.e. salt wash off inundated area), the value used in calculations has been modified by the percentage change in a related updated parameter (i.e. total inundated area). The updated values used in updated salinity process calculations are given below.

WALLPOLLA MID

***Salt wash off*.**

Total area	837	ha

Recharge and displacement

Area	837	ha

In channel salt release

River length	15,207	m

WALLPOLLA UPPER

***Salt wash off*.**

Total area	701	ha

Recharge and displacement

Area	701	ha

In channel salt release

River length	18,869	m

Watering events (flood peak dates) ^	30/09/1975 – 1 in 2 year event
	19/09/1978 – 1 in 2 year event
	29/09/1979 – 1 in 2 year event
	30/09/1985 – 1 in 6 year event
	10/09/1987 – 1 in 6 year event
	15/09/1995 – 1 in 6 year event
Duration of events	Fill – 100 days
	Hold – 21 days
	Release – 35 days (GHD 2012)
	Flood peak is timed for start of hold period

Scenario 2 – Option 2 Lake Wallawalla West

Watering events (flood peak dates) ^	19/09/1978 – 1 in 5 year event
	30/09/1985 – 1 in 5 year event
	10/09/1987 – 1 in 5 year event
	15/09/1995 – 1 in 10 year event
	Coinciding with selected events in Option 1
Duration of events	Fill – 28 days
	Hold – 21 days
	Release – 35 days (GHD 2012)
	Timed to coincide with release period from Option 1

Scenario 2 – Option 3 Lake Wallawalla East

Watering events (flood peak dates) ^	19/09/1978 – 1 in 5 year event
	30/09/1985 – 1 in 5 year event
	10/09/1987 – 1 in 5 year event
	15/09/1995 – 1 in 10 year event
	Coinciding with selected events in Option 1

Duration of events	Fill – 6 days Hold – 21 days Release – 35 days (GHD 2012) Timed to coincide with release period from Option 1

Scenario 2 – Option 6 Lindsay South

Watering events (flood peak dates) ^	19/09/1978 – 1 in 5 year event 30/09/1985 – 1 in 5 year event 10/09/1987 – 1 in 5 year event 15/09/1995 – 1 in 10 year event Coinciding with selected events in Option 1
Duration of events	Fill – 20 days Hold – 21 days Release – 35 days (GHD 2012) Timed to coincide with release period from Option 1

Notes: ^ over the Benchmark period using BIGMOD flows (MDBA 2014)

16. Appendix D - Assessment of Schedule B clause against key themes

In order to identify key clauses relevant to the submission of environmental watering actions, each clause has been assessed as to its relevance against key themes. Clauses highlighted in yellow are those considered particularly pertinent to a submission as a proposed Schedule B accountable action.

Clause	Register Entry		JW&M	State Actions	Former salinity& drainage works	Models	Monitoring/ Reporting/ Review	EoV targets/Baseline conditions	Basin Target	Protocols
	JW&M	Other accountable actions including environmental watering								
4(1)				√						
4(2)								√		
5(1-9)								√	√	
6(1-7)								√		
7									√	
8								√		
9 (1-4)								√		
9(5)								√	√	
9(6)								√		
10(1)	√		√						√	
10(2)			√						√	

Clause	Register Entry		JW&M	State Actions	Former salinity& drainage works	Models	Monitoring/ Reporting/ Review	EoV targets/Baseline conditions	Basin Target	Protocols
	JW&M	Other accountable actions including environmental watering								
10(3)	√									
11	√									
12 (1-4)			√							
12(5)			√	√						
13	√		√		√					
14			√							
15(1)	√	√								
15(2)	√	√								√
15(3)	√	√			√					
15(4)	√	√								√
16 (1-4)	√	√		√						

Clause	Register Entry		JW&M	State Actions	Former salinity& drainage works	Models	Monitoring/ Reporting/ Review	EoV targets/Baseline conditions	Basin Target	Protocols
	JW&M	Other accountable actions including environmental watering								
17 (1-4)	√	√	√	√						√
18 (1-4)		√		√						√
19(1-2)	√	√	√	√						
20(1-3)		√		√						
21(1-2)	√	√	√	√						
22(1-3)		√		√						
23(1-5)		√		√						
24(1-3)	√	√	√	√						
25(1-2)							√	√		
26								√		
27(1)			√				√			

Clause	Register Entry		JW&M	State Actions	Former salinity& drainage works	Models	Monitoring/ Reporting/ Review	EoV targets/Baseline conditions	Basin Target	Protocols
	JW&M	Other accountable actions including environmental watering								
27(2)				√			√			
27(3-4)			√	√			√			
28(1)	√		√				√			
28(2)		√		√			√			
29(1-2)			√	√			√	√		
30(1-2)								√		
31							√			
32	√	√	√				√			
33(1-6)			√	√			√	√		
34							√			
35							√			

Clause	Register Entry		JW&M	State Actions	Former salinity& drainage works	Models	Monitoring/ Reporting/ Review	EoV targets/Baseline conditions	Basin Target	Protocols
	JW&M	Other accountable actions including environmental watering								
36(1-4)	√	√				√				
37(1-3)		√		√		√		√		
38(1-8)	√	√				√		√	√	
39(1-2)						√	√			
40-41										√
42										
43(1-2)	√	√								
44(1-3)	√	√					√	√		
45							√			
46							√			
47		√		√						

Clause	Register Entry		JW&M	State Actions	Former salinity& drainage works	Models	Monitoring/ Reporting/ Review	EoV targets/Baseline conditions	Basin Target	Protocols
	JW&M	Other accountable actions including environmental watering								
48			√				√			
49					√		√			

17. Appendix E - Extract from MDBC Meeting

Extract from MDBC Meeting 96 Minutes (26 August 2008)

The Murray-Darling Basin Commission:

a) endorsed the following BSMS/TLM High Level Principles:

   i. The governments signed up to the TLM IGA are jointly responsible for the salinity impacts (credits and debits) of TLM environmental watering, including both the dilution impacts of water delivery along the Murray River channel, and the salt mobilisation arising from environmental watering events;

   ii. That the governments signed up to the TLM IGA are jointly responsible for the salinity impacts (credits and debits) of TLM water recovery actions post 23 August 2003 (consistent with the TLM Business Plan 2007); and

   iii. Investment to offset TLM salinity impacts (if any) will be considered in terms of the combined impact of all TLM actions.

b) noted that "jointly responsible" under recommendation (a) means that any credit or debit arising from the combined impact of all TLM actions will be attributed equally between New South Wales, South Australia, Victoria and the Commonwealth, consistent with the approach for attributing the 61 EC Joint Work and Measures Program as prescribed in the BSMS Operational Protocols

18. Appendix E -Template for Register submission

The development of effective governance arrangements for the BSMS Salinity Registers requires clear and transparent reporting. Many of the Register entries involve the use of models (which requires approval from Commission) and the presentation of salinity or salt load, and/or flow regimes for input into MSM BIGMOD.

Each report therefore should provide a summary of consolidated information (as an Executive Summary or Appendix) that can be readily reviewed by the Commission office to clarify the key pieces information underpinning the Register entry.

These structure and information required within this summary are as follows:

Purpose

The purpose of the report should be provided in the context of Schedule B. It should therefore clearly state whether it is a submission for:-

a) A Proposal (new entry) (Cl 17)
b) A Rolling Five Year Review (of existing entry) (Cl 33)
c) A new model (Cl 37)
d) Review of Model(s) (Cl 39)

Background

A brief summary should be provided on the background:-

Do the outcomes of the salinity assessment impact upon baseline conditions, or Register A or Register B, and what is the basis for this assessment?

a) What type of action is it? e.g. SIS, environmental flows, irrigation efficiency improvements etc.
b) Any previous documentation superseded by this report.

Detailed Information

The methodology for calculating salinity or salt loads, and flows for input into MSM BIGMOD or a tributary river salt transport model) which may include:

a) A groundwater &/or surface water model (and the version) used in the analysis.
b) If a model was used, whether it has been accredited or altered since accreditation.
c) Advice as to changes in the data used within an existing approved methodology or accredited model.

MSM BIGMOD input time series salt loads (t/d) and/or flow (ML/d) data for the benchmark period (1975-2000) at 2000, 2015, 2050 and 2100 reach by reach for:

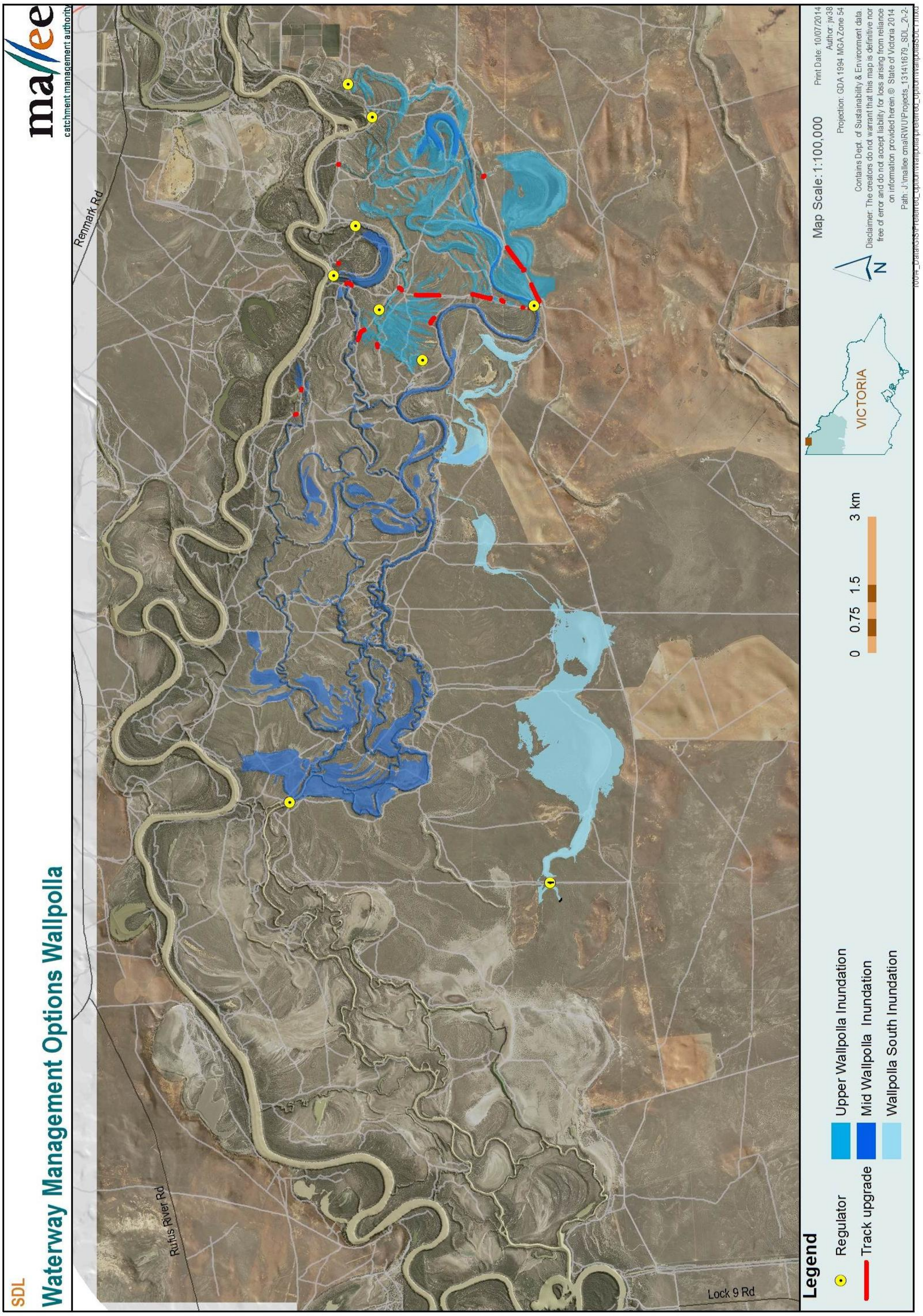
a) Current conditions (baseline model run)
b) Current conditions with predicted change in salinity or salt load, and flows as a result of the action(s) being implemented.

The salinity results of any preliminary in-river impact assessments carried out using MSM BIGMOD.

a) The likely error band and recommended "certainty" rating for the register entry arising from any sensitivity testing conducted on the salt load or flow regimes provided for input into MSM BIGMOD.

19. Appendix F – Updated Wallpolla options inundation extents

SINCLAIR KNIGHT MERZ
SKM



- **Figure 19.1: Updated inundation extents for Wallpolla Floodplain options Mid, Upper and South (Source: MCMA, 2014).**