Flood Recession and Salt Mobilisation from the Murray Floodplains

PHASE II REPORT

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SKM

Flood Recession and Salt Mobilisation from the Murray Floodplains

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Flood activity can mobilise a significant mass of salt from the floodplain during both the flood and the subsequent recession period. Flood recession salt mobilisation has been a significant concern of the Basin Salinity Management Strategy partners for many years.

The salinity impact of changes to river operations are simulated using the MDBA's daily flow and salinity model: BigMod. The Basin Plan is expected to affect river flows (and hence salinity) during regulated conditions. It is also expected to have significant impacts on the magnitude and timing of flooding and hence flood related salt mobilisation.

BigMod simulates salt loads and salinity from known hydrological and hydrogeological processes. The model calibration process results in a quantity of salt entering the river in each model reach that cannot be explained by known processes, this is termed unassigned ("unaccounted") salt loads. Unaccounted salt loads in the model have been generated by an analysis of historical river salinity data and is re-input to the model as a monthly time-series from 1970 onwards. The unaccounted salt loads are not dependent on flow, that is, they are unable to change with changes to the flow regime. This presents a limitation to the assessment of salinity impacts of actions, including aspects of the Basin Plan that have significant dependence on the magnitude and timing of flooding.

Project scope and objectives

To improve model predictions, and enable more accurate modelling of salinity impacts associated with changing water regimes, the MDBA is undertaking work to assign more of the unaccounted salt loads in the model to known processes operating in the near river environment.

This model improvement work is referred to as the *Flood recession salt mobilisation from the Murray Floodplains Study* and is being delivered in two Phases. The previous phase, Phase I, culminated in the production of a Floodplain Salt Conceptual Model that relates the regional, floodplain and river processes that contribute, mobilise and dilute salt load in floodplain environments. Phase I also produced a series of recommendations to guide future investigations; some of which have been incorporated into the objectives of the current Phase II assessment.

Phase II aimed to attribute components of unaccounted salt loads in BigMod to key processes, reducing uncertainty around the unaccounted salt load component between Lock 7 and Lock 1. The Phase II assessment was delivered by three project partners. Australian Water Environments (AWE) who undertook analysis of historical and BigMod salt load data, Andy Close, engaged by the MDBA, who undertook further data analysis to inform and make improvements to BigMod and SKM who prepared this report as a high level synthesis of the methods and outcomes of Phase II.

Outcomes of Phase II – Data analysis tasks

AWE (2013) investigated approaches to quantify selected unaccounted salt loads across the study area using the Chowilla floodplain and Lock 5 to Morgan floodplain as case studies. The findings of this work are summarised in the following sections.

Chowilla floodplain

The Chowilla floodplain is a significant source of unaccounted salt load input to the Lock 7 to Lock 5 reach. AWE (2013) investigated the relationship between flood recession salt load inflow and a number of flood characteristics, and found that peak flood flow provided the best relationship with salt load. Simple analytical approaches to modelling this relationship in BigMod were considered and it was found (AWE 2013) that a simple groundwater discharge relationship integrated over time plus a regional groundwater contribution provided a good prediction of flood recession salt load inflow for the events tested.

It was recommended, in relation to Chowilla, (AWE 2013) that:

- the proposed relationship be tested and evaluated over a wider range of flow conditions (including additional flood events) to determine its suitability for inclusion into BigMod. This should include incorporating into the relationship of flood suppression of salt by subsequent events; and
- the applicability of the relationship to other comparable floodplain sites such as Pike be considered and tested.

Lock 5 to Morgan – Salt disposal basins

Salt disposal basins collect saline water from irrigation and urban drainage. The basins accumulated saline drainage water during periods of low river flows and discharged it to the River Murray during periods of high flows. Information on historical release events is available for selected salt disposal basins. It was suggested (AWE 2013) that significant salt release events could be identified within the BigMod unaccounted salt load input time-series, and these could potentially be accounted for.

Lock 5 to Morgan – Lake Bonney

Lake Bonney is a large (16 km^2) off-stream water body located upstream of Lock 3. BigMod maintains a water and salinity balance for Lake Bonney which was calibrated for the period 1988 to 1998 based on data available at the time. Analysis of historical data over the period 1970 to 2010 (AWE 2013) suggests that the current model representation may be underestimating the rate of salt accumulation during low river flow periods (and the degree of mixing) and the salt impact prediction could be improved.

It was recommended (AWE 2013) that the representation of Lake Bonney in BigMod be recalibrated, potentially accounting for an additional 20 tonnes per day of salt inflow (currently unaccounted).

Lock 5 to Morgan – Evaporative accumulation and flushing of backwaters

The Lock 5 to Morgan reach contains numerous permanent backwaters and anabranch channels which have a total area of approximately 68 km^2. Many of these systems receive inflows from the River Murray as well as saline groundwater inflows. The resultant surface water evaporates, increasing the concentration of salt in the residual water, which is then flushed out into the river channel when high flows occur. This process affects the timing of salt mobilisation through the landscape and contributes to peak salinity levels during flood and flood recession periods. It was estimated (AWE 2013) that evaporative accumulation could be contributing approximately 26 tonnes per day to the river Murray, acknowledging that this contribution would occur mostly during periods of high flow. AWE (2013) point out that the method of accounting backwater evaporation in BigMod results in derived salt inflows from other sources being lower than actual at times of evaporative accumulation and higher than actual during release events.

It was recommended (AWE 2013) that the characteristics of significant off-stream water bodies be assessed to describe whether they were flow-through or backwater bodies. This may enable selected off-stream water bodies that have significant evaporation accumulation effects to be represented as individual, accounted contributors in BigMod. The decision to include a specific off-stream water body will need to balance the modelling effort required to incorporate the water body against the magnitude of the salt impact accounted.

Outcomes of Phase II – BigMod modelling tasks

Andy Close followed the recommendation of AWE (2013) to develop and test a salt inflow decay plus suppression relationship for post-flood salt recession from the Chowilla floodplain. The relationship was successfully developed and tested using historical data over the period 1970 to 2009. It was found that the developed relationship could account for an average of 59 tonnes/day of salt inflow in the Lock 6 to Lock 5 reach. Including this relationship into BigMod reduced the mass flux of unaccounted salt inflow in the reach from 185 tonnes/day to 126 tonnes/day: a reduction of approximately 32%.

The outcomes of additional work to recalibrate the simulation of Lake Bonney and correct some errors in salinity data was also incorporated into the model. It was found that these model refinements lead to a marginal improvement in calibrated salinities at Morgan. The impact of the model refinements on the salinity impact assessment of The Living Murray and Basin Plan was also tested. It was found that incorporating the model refinements would lead to a small reduction in the assessed benefit of The Living Murray (from $4.4 million/year to $4.3 million/year) but a small increase in the assessed benefit of the Basin Plan (from $8.7 million/year to $8.9 million/year).

Based on these findings, it was recommended (Andy Close) that

- refinements to the model discussed in this section (inclusion of the Chowilla salt inflow decay plus suppression relationship, recalibration of Lake Bonney salt contributions and corrections to salinity data) be adopted into the model and be used for future Basin Salinity Management Strategy Salinity Register modelling assessments;
    - an average of 185 tonnes per day of unaccounted salt inflow enters the river between Lock 6 and Lock 5 (i.e. from Chowilla). This represents 5.6% of total unaccounted salt load to the river. Incorporating the model refinements will reduce the mass of accounted salt inflow in this reach by an average of 59 tonnes per day (to 126 tonnes per day);
- the potential to derive similar salt inflow decay plus suppression relationships for sites in the reach Lock 5 to Morgan be considered; and
- the potential to individually account for backwater systems in the reach Lock 5 to Morgan (such as Gurra Lakes and Ramco Lagoon) be considered.

1. Introduction

1.1 Project background

Flood recession salt mobilisation has been a significant concern of the Basin Salinity Management Strategy partners for many years. Flood activity can mobilise a significant mass of salt from the floodplain, both during the flood and during the subsequent recession, with the nature of salt mobilisation highly dependent on the characteristics of the flood.

The Basin Plan is expected to affect river flows (and hence salinity) during regulated conditions, and is also expected to have significant impacts on the magnitude and timing of flooding and hence flood related salt mobilisation. The MDBA is interested in developing a better understanding of the likely salinity impacts of the Basin Plan and related environmental watering activities.

Salinity impacts on the River Murray are simulated using the MDBA's MSM-BigMod model. This model simulates salt loads and salinity from known hydrological and hydrogeological processes, as well as unassigned ("unaccounted") salt loads. Unaccounted salt loads in the model have been generated by an analysis of historical river salinity data and are input to the model as a monthly time-series from 1970 onwards. The unaccounted salt loads allow the model to be calibrated however, they are unable to change with changes to the flow regime. To improve the model, and enable more accurate modelling of salinity impacts associated with changing water regimes, the MDBA is undertaking work to explain more of the unaccounted salt loads in the model.

This work is referred to as the *Flood recession salt mobilisation from the Murray Floodplains Study* and is being delivered in two Phases. Phase I (the previous phase, AWE (2012)) developed a conceptual model of processes related to flood recession salt mobilisation from floodplains located between Swan Hill and Lock 1. Phase II is the current Phase and is focused on deriving improved flood-salt load relationships for use in the MSM-BigMod model.

1.2 Project scope and objectives

Phase II of the *Flood recession salt mobilisation from the Murray Floodplains Study* aims to attribute components of unaccounted salt loads in BigMod to key processes, reducing the magnitude of the unaccounted salt load component between Lock 7 and Lock 1. In the future, the outcomes of this study may be used to assist the MDBA to develop a set of operational plans for managing high salinity events along the Lower Murray due to changes in flow. The specific objectives of Phase II are to:

1. assess, interrogate, analyse and interpret recent and historical flood related salinity datasets (surface water, backwater and groundwater) during and after high flow events with special reference to developing flow-salt load relationships reach-by-reach for the river between Lock 7 and Lock 1;

2. improve the MDB MSM-BigMod model's daily river salinity predictability by reducing the uncertainty around the unaccounted salt load component from various reaches (incorporating new salt load information, model improvements and calibration);

3. liaise with jurisdictions and coordinate a workshop, record methodologies and write-up a report including each step of the project milestones; and

4. provide relevant technical and operational advice to address floodplain salt mobilisation risks when making flow management decisions.

The Phase II assessment was delivered by three project partners. Australian Water Environments (AWE) undertook analysis of historical and BigMod salt load data to deliver against Objective 1 and Objective 4. Andy Close, engaged by the MBDA, undertook further data analysis to inform, and make improvements to BigMod to deliver against Objective 2. This report, prepared by SKM provides a high level synthesis of the methods and outcomes of Phase II to deliver against Objective 3.

1.3 Findings of the Phase I assessment

The Phase I assessment (AWE 2012) *involved the integration of existing knowledge and the development of a conceptual model to improve understanding of flood recession salt mobilisation*. A brief summary of key conclusions of the Phase I assessment include (for more detail see AWE (2012)):

- The recent low salinity period
  - The ‘salinity holiday’ in the 2000s can be attributed to a range of salt load reduction mechanisms, including drought-induced salt storage in the floodplains, improved irrigation efficiencies, implementation of salt interception schemes and low salinity surface water inputs from Hume Dam.
  - Based on the analysis of salt patterns of the last 30 years, the 2000 to 2009 drought is unlikely to significantly increase the post-flood salt inputs to the river. The post-flood salinity regime and the peak salinity levels will however be affected by flood magnitude and the management of the flood recession.
  - Implementation of salt interception schemes has significantly reduced the occurrence of salinity exceedences in the last two decades.
- Sources of salt
  - Salinity exceedences at Morgan occur mainly in inter-flood periods: 85% of exceedences occur when flow at Morgan is less 5,000 ML/day.
  - Approximately 60% of salt inflow downstream of Euston is sourced from Lock 5 to Morgan, where 75% of salt is exported when flows exceed 7,000 ML/day. Salt addition between Lock 5 to Morgan can be around 10 times higher during high flows than low flows.
  - The Chowilla region appears to contribute large salt loads during the flood recession period (due to groundwater recession). The remaining river reaches between Lock 9 and Lock 5 do not appear to have this salt input process.
  - Connected water bodies are a major source of salt input in the fortnight after flow falls below 20,000 ML/day.

The Phase I assessment also culminated in the development of the Floodplain Salt Conceptual Model (Figure 1), which relates the regional, floodplain and river processes that contribute, mobilise and dilute salt load in floodplain environments. The Floodplain Salt Conceptual Model was complemented by the Floodplain and River Classification Matrix (Figure 2) which provides an indicator of the risk of salt accession to rivers and a map illustrating the indicative timing of salt inputs to the River Murray through a flood cycle (Figure 3).

The Phase I assessment also produced a series of recommendations to guide future investigations. These recommendations were taken into account in developing the objectives of the current Phase II assessment.

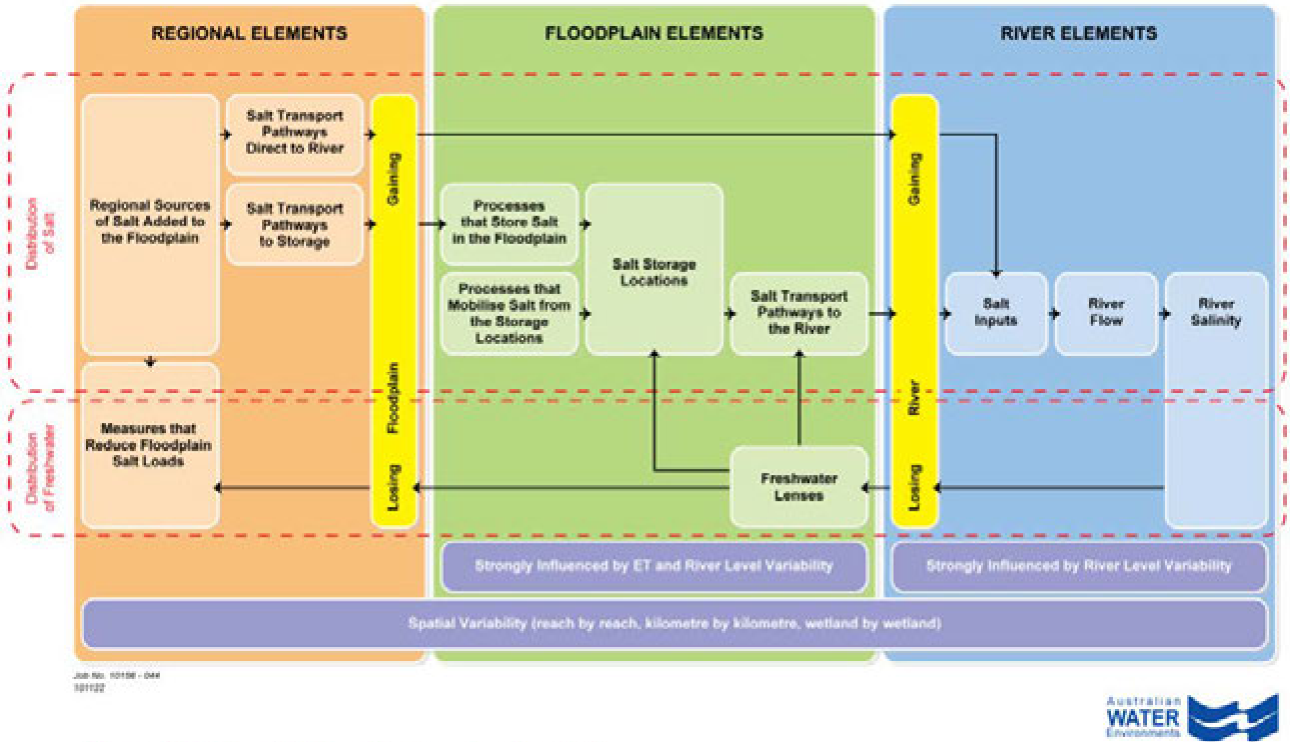

Figure 1: Floodplain salt conceptual model (AWE 2012).

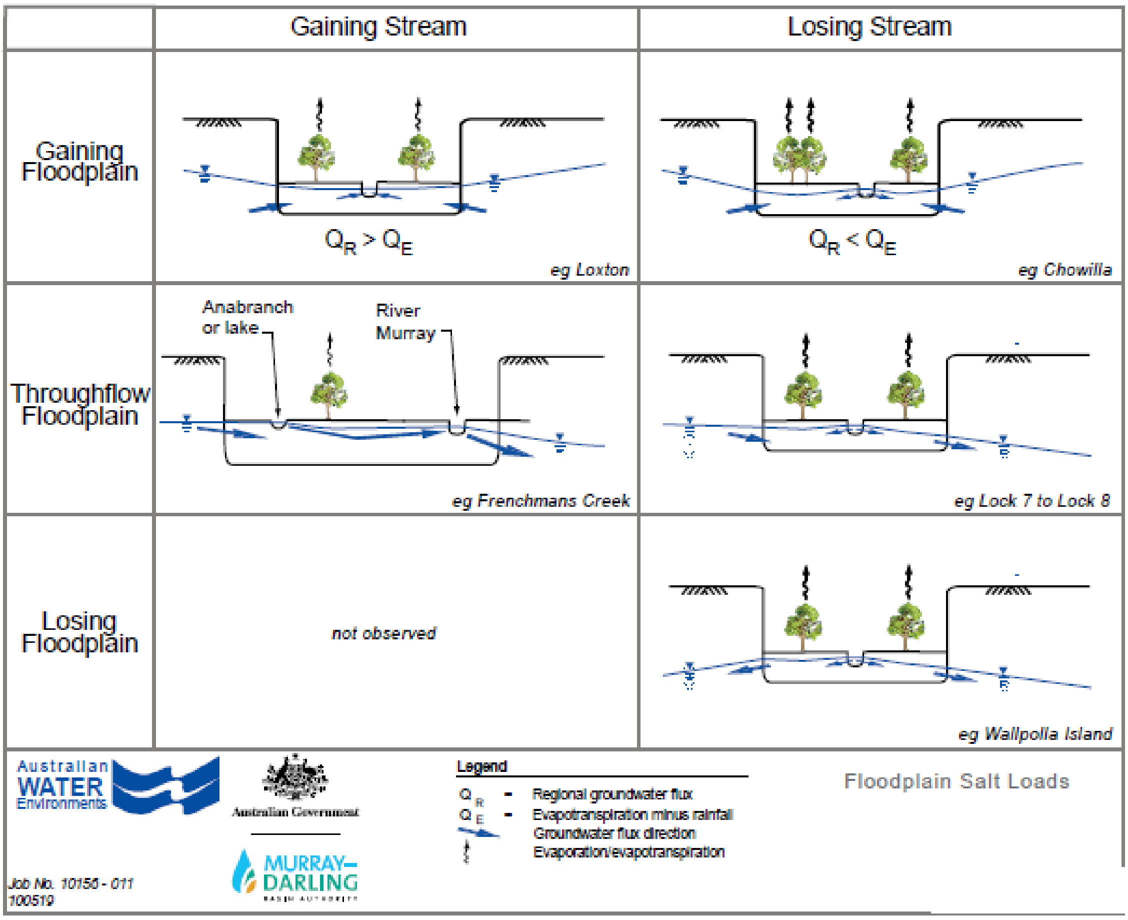

Figure 2: Floodplain and River Classification Matrix (AWE 2012).

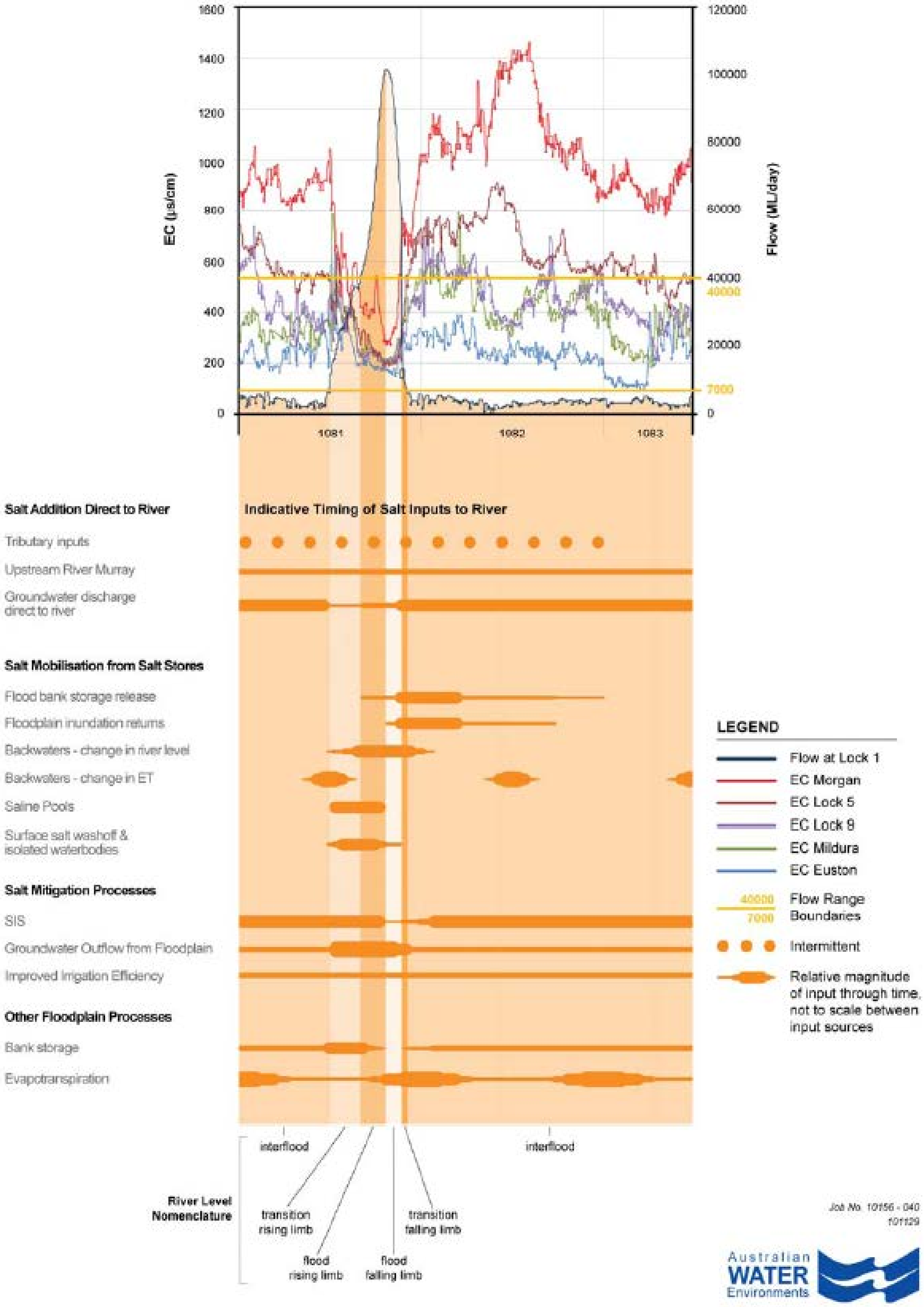

Figure 3: Indicative timing of salt inputs to the River Murray through a flood cycle (AWE 2012).

2. Representation of salt in BigMod

BigMod, with its daily flow and salinity modelling capability, was developed in the early 1990s. It currently simulates streamflow over the 114 year period from 1895 to 2009 and river salinity for the period from 1975 to 2009. However, for preparing the Basin Salinity Management Strategy Salinity Register, only modelled salinity for the period from 1975 to 2000 is analysed.

BigMod simulates salt loads and salinity from known hydrological and hydrogeological processes. This includes salt load and salinity inputs from monitored tributaries and drains, referred to as 'accounted' salt loads. In addition to these accounted sources of salt, salt also enters the river from unmonitored tributaries, drains and effluent systems, as well as groundwater inflows, referred to as 'unaccounted' salt loads. Unaccounted salt loads also reflect errors in the input data and the modelling process due to the nature by which they are derived within the model.

Unaccounted salt loads for input into BigMod were calculated as part of a two-step calibration process (Close 1996, Close and Sharma 2003, MDBC 2006):

- **Step 1: Calibration of salinity routing**

  Salinity routing is undertaken to ensure the travel time of salinity through the river reflects 'on-ground' conditions. Salinity travel time is a function of flow and volume in the reach: increasing reach volume increases salinity travel times, representing pools and deep holes in the river. Salinity travel time was calibrated by adjusting the volume of dead storage in the reach.

  During Step 1 calibration, unaccounted salt load inputs were assumed to be constant.

- **Step 2: Calculation of unaccounted salt load input (magnitude)**

  The mass of unaccounted salt load input was calculated, on a reach-by-reach basis. This was undertaken by routing recorded salinity at the upstream end of the reach to the downstream end of the reach and calculating the mass of salt input required to achieve a match to recorded salinity at the downstream end.

  This calculation was carried out on a daily time-step, based on available historical salinity data over the period 1975 to 2000. The noise in the salinity data can result in highly variable salt load inputs, including short periods of negative salt inputs. This is especially the case at periods of high flow when the increase in salinity between sites is small. To make the variability manageable, the calculation is carried out over long reaches (this was also done due to data availability). The resulting daily unaccounted salt load inputs are then summed to a monthly time-step for input to the model.

The magnitude of unaccounted salt load input to BigMod is summarised, reach-by-reach, in Table 1. Figure 4 shows time-series of unaccounted salt load input for the two reaches that are the focus of this study: Lock 9 to Lock 5 and Lock 5 to Morgan. These summaries show that unaccounted salt loads represent a significant source of salt to BigMod: an average of 3,315 tonnes per day, with 37% of this salt entering the river between Lock 5 and Morgan.

These unaccounted salt loads also allow the model to be calibrated, however they are unable to change with changes to the flow regime. To improve the model, and enable more accurate modelling of salinity impacts associated with changing water regimes, this study is undertaking work to explain more of the unaccounted salt loads in the model.

Table 1: Summary of unaccounted salt input to BigMod, reach-by-reach

Unaccounted salt inflow reach	Average		Median value (tonnes/day)
	Mass Flux (tonnes/day)	% of total	
Hume to Yarrawonga	67.8	2%	56.4
Yarrawonga to Torrumbarry	54.5	2%	14.5
Torrumbarry to Swan Hill	298.7	9%	181.4
Swan Hill to Euston	46.3	1%	13.2
Euston to Mildura	266.8	8%	214.2
Mildura to Lock 9	63.1	2%	0.0
Lock 9 to Lock 5	268.2	8%	207.1
Lock 5 to Morgan	1,212.9	37%	693.0
Morgan to Murray Bridge	162.7	5%	60.2
Murray Bridge to Milang	873.7	26%	589.3

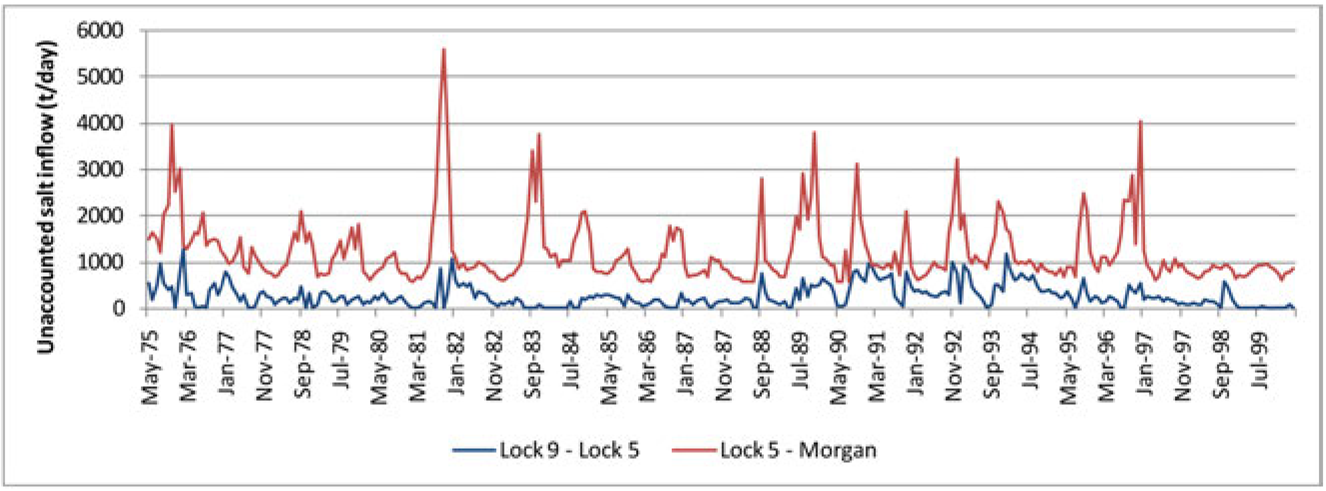

Figure 4: Time-series of unaccounted salt inflow for the region of focus for this Study: Lock 9 to Lock 5 and Lock 5 to Morgan.

3. Attribution of unaccounted salt loads

AWE (2013) investigated approaches to quantify selected unaccounted salt loads across the study area using the Chowilla floodplain and Lock 5 to Morgan floodplain reaches as case study areas. The investigation made use of knowledge gained from the Phase I assessment regarding floodplain salt load processes, results from existing groundwater models as well as analysis of available historical and BigMod salinity and salt load data. The key outcomes of this work are summarised below.

3.1 Chowilla floodplain

The Chowilla floodplain is a significant source of unaccounted salt load input to the Lock 7 to Lock 5 reach. Previous work had identified that peak flood flow was a good predictor of salt load inflow over the flood recession period. AWE (2013) investigated the relationship between flood recession salt load inflow and the following characteristics:

- peak flood flow (R^2 of 0.85)
- peak inundation area (R^2 of 0.66)
- antecedent conditions (cumulative flow over the preceding 450 days) (R^2 of 0.26)
- flood suppression period (flood duration) (R^2 of 0.29)

Other characteristics were also discussed but not investigated including vertical hydraulic conductivity of the floodplain.

The investigation found that peak flood flow provided the best relationship to salt load inflow over the flood recession period. Simple analytical approaches to modelling this relationship in BigMod were considered. It was found that a simple groundwater discharge relationship integrated over time plus a regional groundwater contribution (Equation 1), calibrated to three categories of flood relating to area inundated (to account for varying salinity of different areas of the floodplain) provided a good prediction of flood recession salt load inflow for the events tested. The results of the model are shown in Figure 5 and the calibrated parameters are summarised in Table 2.

$$Cumulative\ salt\ inflow = \int_{t=n}^{t=0} \left[\left(S_1 Q_{0,1} + S_2\left(Q_{0,2} - Q_{0,1}\right)\right) e^{-at} + Q_r\right] dt$$

Equation 1

where Q is discharge, t is time, a is a recession constant, S_i is salinity, $_1$ is used for events with a peak flow greater than 75,000 ML/day where salinities S_r, S_1 and S_2 are applied from Group 1, and $_2$ is used for events with a peak flow less than 75,000 ML/day where salinities S_r and S_1 are applied from Group 2.

It was recommended that (AWE 2013):

- the proposed relationship be tested and evaluated over a wider range of flow conditions (including additional flood events) to determine its suitability for inclusion into BigMod. This should include incorporating flood suppression of salt by subsequent events into the relationship; and
- the applicability of the relationship to other comparable floodplain sites such as Pike be considered and tested.

Table 2: Calibrated parameters for the proposed Chowilla floodplain relationship (AWE 2013)

Model parameter	Peak flow > 75,000 ML/day	Peak flow < 75,000 ML/d	
	Group 1 flood event (Aug 81)	Group 2 flood events (Aug 96, Sep 84, Aug 95)	Group 3 flood events (Oct 86)
Q – initial groundwater discharge (ML/day)	$Q_2 = 40$	$Q_1 = 10$	$Q_0 = 6$
S – groundwater salinity (g/l)	$S_1 = 30$ $S_2 = 45$	$S_1 = 30$	$S_1 = 20$
Q_r – regional groundwater discharge	$Q_r = 7$	$Q_r = 6$	$Q_r = 5$
S_r – regional groundwater salinity	$S_r = 20$	$S_r = 20$	$S_r = 20$
C – constant (applied after integration)	C = 72000	C = 15000	C = 6500

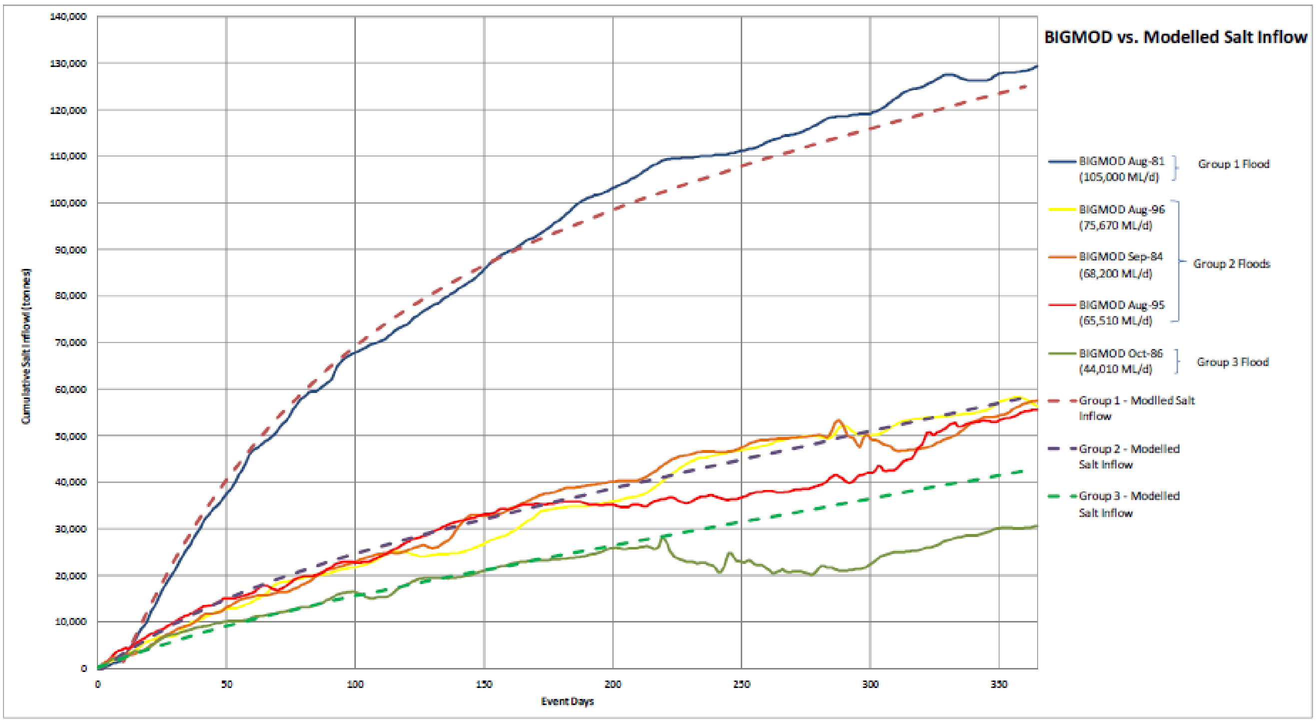

Figure 5: Comparison of BigMod cumulative salt input and modelled (simple analytical model) salt input (AWE 2013).

3.2 Lock 5 to Morgan

Three sources of unaccounted salt load inflow were investigated for the Lock 5 to Morgan reach: salt disposal basins, Lake Bonney, and evaporative accumulation and flushing of backwaters.

Salt disposal basins

Salt disposal basins collect saline water from irrigation and urban drainage. Historically, many salt disposal basins were located in the landscape. The basins collected and accumulated significant volumes of saline drainage water (and hence salt load) during periods of low river flows that were then discharged to the River Murray during periods of high river flow. It was estimated that salt disposal basins contribute approximately 209 tonnes per day of salt to the River Murray between Lock 5 to Morgan over the long-term (AWE 2013), although the timing of this contribution is far from uniform, mostly occurring during periods of high flows.

The characteristics of several major salt disposal basins were discussed in the report, including periods of salt accumulation and significant release events. It was suggested that significant release events could be identified within the BigMod unaccounted salt load input time-series, and thus could potentially be accounted for.

Lake Bonney

Lake Bonney is a large (16 km^2) off-stream water body located upstream of Lock 3. It is connected to the River Murray by a single connective channel. Lake Bonney is the only off-stream water body represented in BigMod as an accounted salt inflow.

Lake Bonney is subject to evaporative accumulation effects and contributes to River Murray salinity during flood recession periods. BigMod maintains a water and salinity balance for Lake Bonney that was calibrated for the period 1988 to 1998 based on data available at the time. Analysis of historical data over the period 1970 to 2010 (AWE 2013) suggests that the current model representation may be underestimating the rate of salt accumulation during low river flow periods and the degree of mixing and could be improved.

It was estimated (AWE 2013) that re-calibrating the representation of Lake Bonney could result in an additional 20 tonnes per day of salt inflow being accounted (currently unaccounted). It was recommended (AWE 2013) that the representation of Lake Bonney in BigMod be recalibrated.

Evaporative accumulation and flushing of backwaters

The Lock 5 to Morgan reach contains numerous permanent backwaters and anabranch channels which have a total area of approximately 68 km^2 - 1.8 times the area of the main river channel. Many of these systems receive inflows from the River Murray as well as saline groundwater inflows. The water then evaporates, increasing the concentration of salt in the residual water. Over time, a significant mass of salt can accumulate in the backwaters, which are then flushed into the river channel when high flows occur.

While the process of evaporative accumulation and flushing does not change the total mass of salt in the system, it does affect the timing of salt mobilisation. This contributes to peak salinity levels during flood and flood recession periods. It was estimated (AWE 2013) that evaporative accumulation could be contributing approximately 26 tonnes per day to the River Murray, acknowledging that this contribution would occur mostly during periods of high flow.

It was recommended (AWE 2013) that the characteristics of significant off-stream water bodies be assessed. This would enable selected off-stream water bodies that have significant evaporation accumulation effects to be represented as individual, accounted contributors in BigMod. The decision to include a specific off-stream water body would need to balance the modelling effort required to incorporate the water body and the magnitude of the impact the water body has on peak salinities. AWE (2013) point out that the method of accounting backwater evaporation in BigMod results in derived salt inflows from other sources being lower than actual at times of evaporative accumulation and higher than actual during release events.

The characteristics of three backwaters were discussed (AWE 2013): Gurra Lakes, Ramco Lagoon and Pike Lagoon. However, further work would be required to determine the evaporative accumulation effect of each backwater on peak salinity and the relative value of incorporating each backwater into BigMod.

Data reliability

Recorded salinity data has been used to inform the calculation of unaccounted salt load inputs to BigMod, as well as investigation activities undertaken as a part of this study. The vast majority of the data provides accurate insight to river salinity and salt mobilisation processes. However, inaccuracies and errors can occur in the data record or at particular sites.

Data cleansing, to identify, and where appropriate, remove suspect data, can improve salinity records, and hence the accuracy of work undertaken using the data.

4. Changes to BigMod modelling of unaccounted salt loads

Andy Close followed the recommendation of AWE (2013) to develop and test a salt inflow decay plus suppression relationship for post-flood salt recession from the Chowilla floodplain. Details of the work undertaken are provided in Appendix B. The key outcomes of this work are summarised below.

4.1 Development of a salt inflow decay plus suppression relationship

The salt inflow decay plus suppression relationship is used to simulate the concept that flood events activate a mass of salt which is subsequently released to the river as the floods recede. The relationship is simulated as a “bucket” of salt, where the size of the bucket of salt activated is a function of flow. A new flood event starts when the salt activated by the current days flow exceeds the salt remaining in the bucket from the last high flow event.

The model describing the release of salt following a flood is given by the relationships:

$$Salt\ flux = mobilised\ salt\ left\ in\ the\ bucket\ yesterday \times decay\ factor \times suppression\ factor$$

Equation 2

$$Mobilised\ salt\ left\ in\ the\ bucket = mobilised\ salt\ left\ in\ the\ bucket\ yesterday - salt\ flux$$

Equation 3

The suppression factor reduces the salt flux when the water level downstream of Lock 6 is higher than a specified reference level as a result of flows during the suppression period that are higher than minimum flows, but not high enough to trigger a new event. If the suppression factor always has a value of 1.0, the salt flux would have the same form as the exponential decay formulation proposed by AWE (2013, see Section 3.1).

The suppression factor was formulated based on an *effective level*:

$$Inital\ suppression\ factor = \frac{(effective\ level - today's\ level)}{(effective\ level\ - reference\ level)}$$

Equation 4

$$Effective\ level =\ reference\ level + (peak\ level - reference\ level) \times \frac{mobilised\ salt\ left\ in\ the\ bucket}{salt\ initially\ mobilised\ by\ the\ flood}$$

Equation 5

A total of 16 flood events with a peak flow greater than 40,000 ML/day upstream of Lock 6 were identified for testing and evaluation. For each event ‘salt mobilised’, ‘decay rate’ and ‘constant flux’ parameters were identified to calibrate the salt flux to the observed data. The ‘salt mobilised’ and ‘decay rate’ were then plotted against peak event flow to derive relationships (Figure 6 and Figure 7).

From the relationship between ‘salt mobilised’ and flow (Figure 6), two parameters were derived relating to the mass of salt activated by the peak flow:

1. **Salt event threshold** – the flow threshold above which events produce extra salt. This was set to a value of 29,244 ML/day, based on the intercept of the line of best fit.

2. **Salt generation factor** – the mass of salt (tonnes) produced per ML of flow above the salt event threshold. This was set to a value of 1.2279 tonnes/ML, based on the slope of the line of best fit.

From the relationship between ‘decay rate’ and flow (Figure 7), two parameters were derived relating to the rate of salt decay following a peak flow event:

3. **Base decay rate** – the rate of salt decay for an event at the salt event threshold. This was set to a value of 0.00213 tonnes/day, based on the intercept of the line of best fit.

4. **Increase in decay rate with flow** – the increase in rate of decay per ML of flow (of the last salt generation event) above the salt event threshold. This was set to a value of 0.000000072 tonnes/ML, based on the slope of the line of best fit.

The **reference level** was calibrated to 16.0 m AHD and compares to a Lock 5 pool level of 16.3 m AHD.

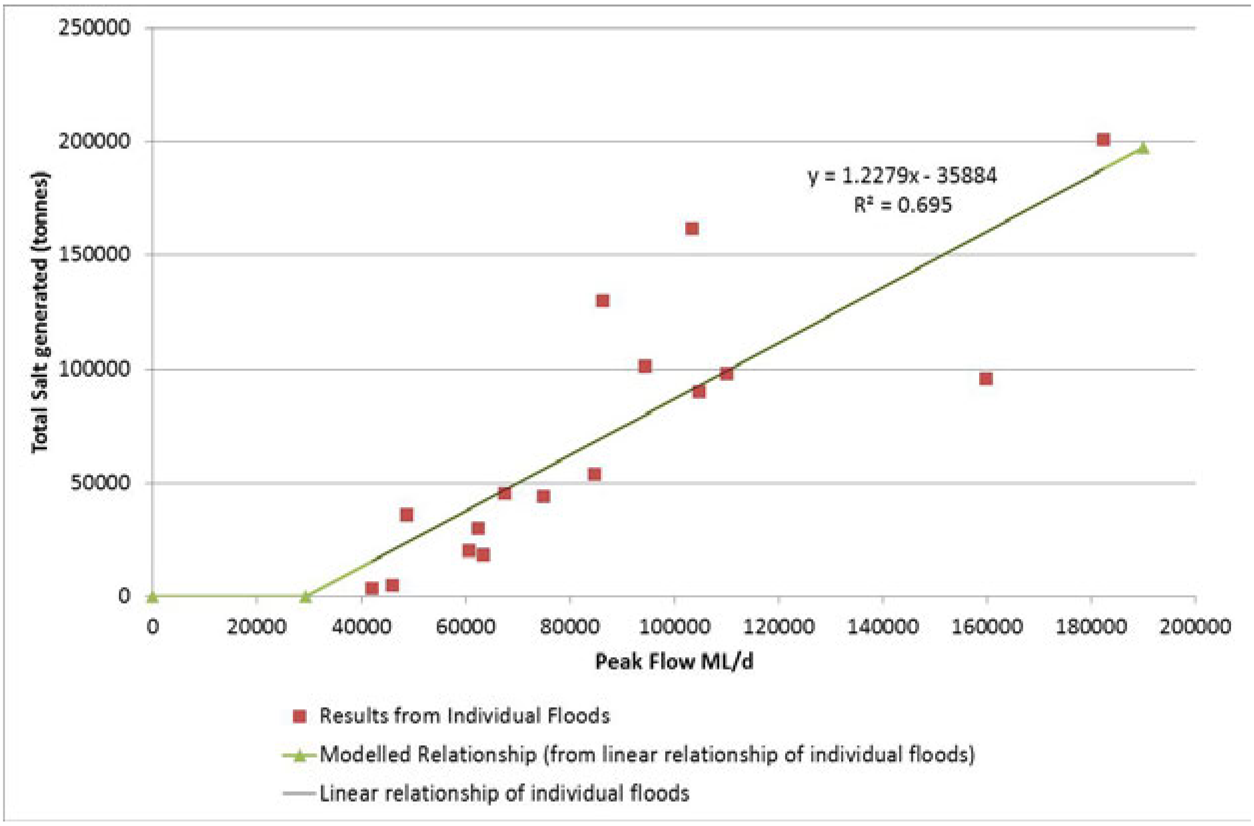

Figure 6: Relationship between peak flow and total salt generation. The parameter "salt generation factor" was set equal to the slope of the relationship. The parameter "salt event threshold" was set equal to the intercept of the relationship divided by the salt generation factor.

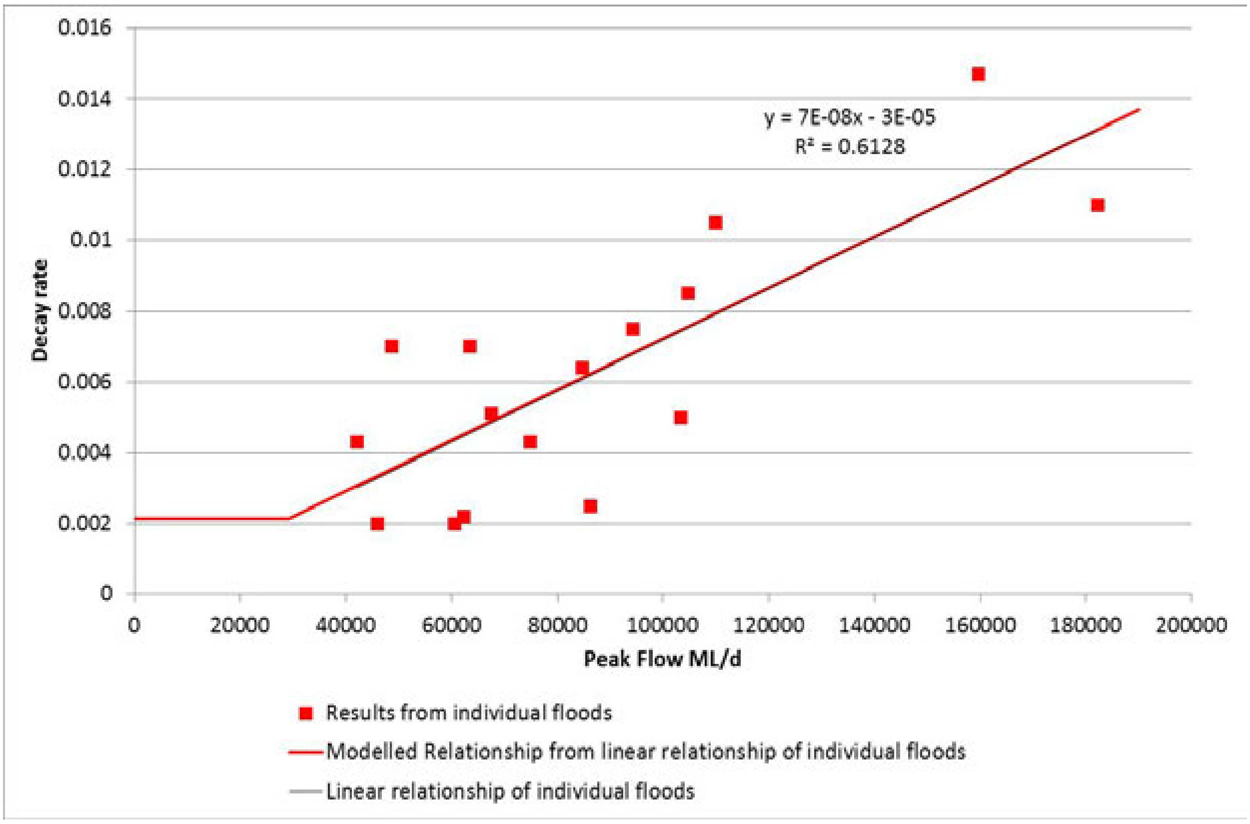

Figure 7: Relationship between peak flow and decay rate. The parameter "base decay rate" was set equal to the intercept of the relationship. The parameter "increase in decay rate with flow" was set equal to the slope of the relationship.

No relationships were developed for the 'constant flux' parameters, although these varied between flood events. This 'constant' flux remains part of the residual unaccounted salt in the reach.

The calibrated parameters were then used to derive a time-series of salt inflow from Chowilla across the full assessment period. The results (Figure 8) show that the proposed relationship and calibration parameters lead to a good estimate of observed salt inflows in terms of both timing and magnitude across the full assessment period. The modelled flux is less than the observed because the model does not include any of the 'constant' fluxes that were included in the analysis of the individual flood events.

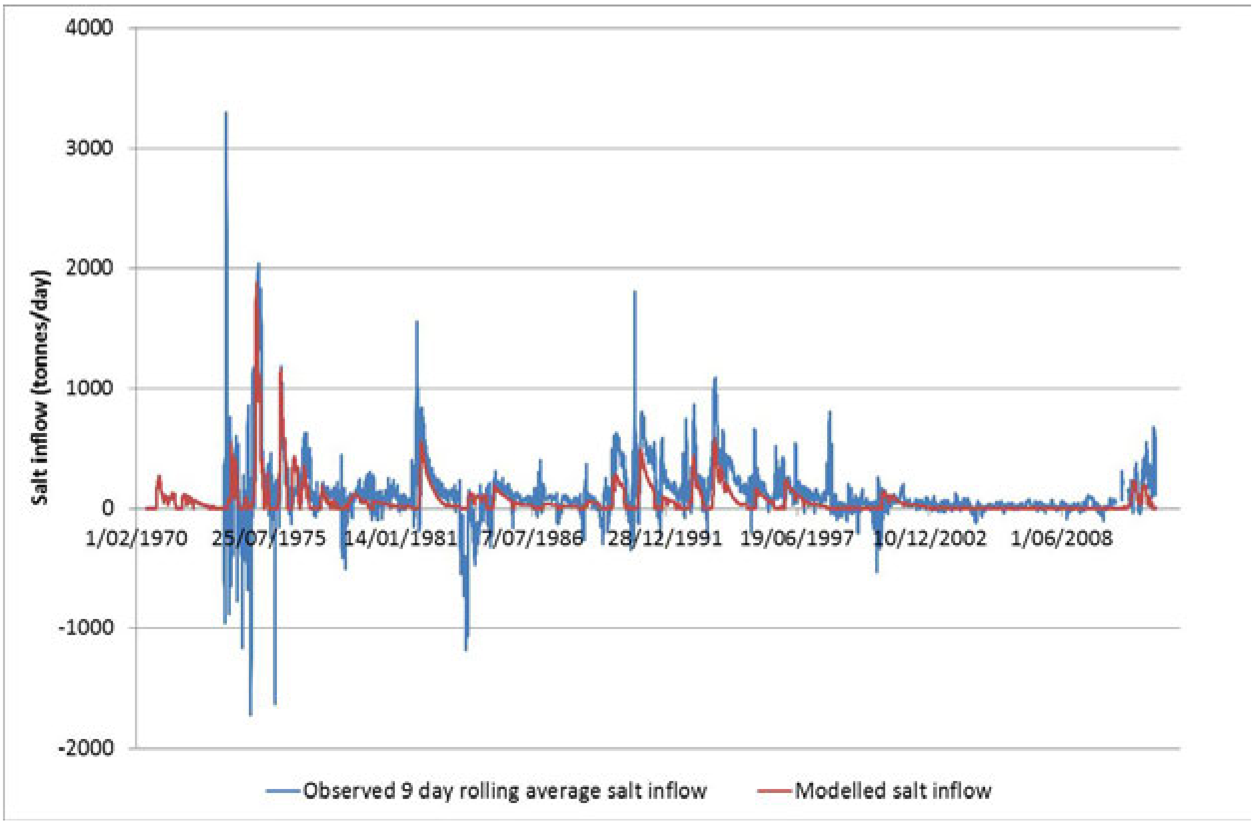

Figure 8: Comparison of observed and calculated salt inflow from Chowilla (daily time-step).

4.2 Other model refinements

Lake Bonney

AWE (2013) noted that improving the calibration of Lake Bonney in BigMod could reduce the mass of unaccounted salt inflow. To date, Lake Bonney has been partially accounted in BigMod, whereby the evaporative concentration effect of Lake Bonney was accounted for, but groundwater salt inflows to Lake Bonney remained part of the unaccounted salt inflows for the reach Lock 5 to Morgan.

Andy Close followed the recommendation of AWE (2013) to refine the simulation of Lake Bonney. This was undertaken by 'fixing' salt inflows from Lake Bonney in BigMod to observed data. By doing so, all salt inflow contributions from Lake Bonney will be accounted for when re-deriving the unaccounted salt inflows (Section 4.3) in the updated model.

Data corrections

In re-deriving the unaccounted salt inflows for all reaches and undertaking any necessary balancing (smoothing) of negative salt inflows (Section 4.3), several errors were found in the observed historical data. In particular, it was observed that there were errors in the temperature adjustments for salinity data at Heywoods and Yarrawonga following the installation of a continuous data logger in approximately 2001. Factors to correct for these errors were derived and applied to generate new 'temperature corrected' salinity data for these sites.

Additionally, minor data errors at other sites were corrected where found.

4.3 Incorporating changes into BigMod

The Chowilla salt inflow decay plus suppression relationship and calibrated parameters were incorporated into BigMod to explicitly represent the flood recession salt contribution from Chowilla Floodplain. To incorporate the relationship into the model the following procedure was adopted:

- unaccounted salt inflows for the reach Lock 9 to Lock 5 was spilt into two reaches: Lock 9 to Lock 6 and Lock 6 to Lock 5;
- the relationship and calibration parameters were 'coded' into the model as a salt inflow for the reach Lock 6 to Lock 5;
- raw unaccounted salt loads for all reaches were re-calculated with the contribution of Chowilla to the reach Lock 6 to Lock 5 now accounted for; and
- any necessary balancing (smoothing) of negative salt inflows was undertaken.

In re-deriving the unaccounted salt loads, the impact of recalibrating Lake Bonney and the salinity data corrections was taken into account.

Incorporating the salt inflow decay plus recession relationship into the model reduced the historic Lock 6 to Lock 5 unaccounted salt inflow from 185 tonnes/day to 126 tonnes/per day: a reduction of 59 tonnes/day (approximately 32%).

4.4 Impact of the relationship on MSM-BigMod calibration

Any changes to the salinity calibration of MSM-BigMod may have implications for the assessment of baseline conditions and the impact of accountable actions under the Basin Salinity Management Strategy. For this reason, it is important to understand any impacts of including the new salt inflow decay plus recession relationship for Chowilla (plus the other model refinements) on the salinity calibration of MSM-BigMod.

The revised calibration of BigMod (only) and MSM-BigMod was assessed and compared to the calibration of the original model. Calibration was assessed for the period July 1970 to June 2009 for BigMod only and July 1983 to June 2009 for MSM-BigMod. The testing found that incorporating the new relationship lead to a marginal improvement in the calibration of modelled salinities at Morgan (an increase in R^2 between modelled and observed salinities of 0.011 for BigMod only and 0.000 for MSM-BigMod).

4.5 Impact of the relationship on the assessed salinity benefit of The Living Murray and Basin Plan

The main aim of incorporating the new salt inflow decay plus recession relationship for Chowilla into BigMod is to increase the proportion of salt load calculated dynamically in the model (and thus based on modelled flows) rather than read from an input file of unaccounted salt inflows. This is being undertaken to allow potentially more accurate assessment of the salinity impact of works and programs that may result in changes to the flow regime.

Two major changes to the flow regime are The Living Murray program and the Basin Plan. The impact of the new salt inflow decay plus recession relationship for Chowilla (plus the other model refinements) on the assessment of these actions has been tested. The testing found that incorporating the model refinements lead to a small reduction in the assessed benefit of The Living Murray (salinity benefit reduced from $4.4 million/year to $4.3 million/year) but a small increase in the assessed benefit of the Basin Plan (salinity benefit increased from $8.7 million/year to $8.9 million/year).

4.6 Recommendations

Based on the work summarised in this section, it is recommended (Andy Close) that:

- refinements to the model discussed in this section (inclusion of the Chowilla salt inflow decay plus suppression relationship, recalibration of Lake Bonney salt contributions and corrections to salinity data) be adopted into the model and be used for future Basin Salinity Management Strategy Salinity Register modelling assessments;
- the potential to derive similar salt inflow decay plus suppression relationships for sites in the reach Lock 5 to Morgan be considered; and
- the potential to individually account for backwater systems in the reach Lock 5 to Morgan (such as Gurra Lakes and Ramco Lagoon) be considered.

5. Conclusions and recommendations

Unaccounted salt load inputs represent a significant source of salt to BigMod: an average of 3,315 tonnes per day. An average of 1,212.9 tonnes per day enters the river between Lock 5 and Morgan, representing 37% of total salt entering the river and 60% of total salt entering the river downstream of Euston. These unaccounted salt loads allow the model to be calibrated; however they are unable to change with changes to the flow regime. To improve the model, and enable more accurate modelling of salinity impacts associated with changing water regimes, the *Flood recession salt mobilisation from the Murray Floodplains Study* has undertaken work to explain more of the unaccounted salt loads in the model.

AWE (2013) investigated approaches to quantify selected unaccounted salt loads across the study area using the Chowilla floodplain and Lock 5 to Morgan floodplain as case studies. This work found that:

- **Chowilla floodplain**

  A simple analytical approach could be used to represent the flood recession salt load inflow for the Chowilla floodplain, based on peak flood flow. A relationship was developed and tested for selected events and found to provide a good prediction of flood recession salt load inflow for the events tested. It was recommended that (AWE 2013):

  - the proposed relationship be tested and evaluated over a wider range of flow conditions (including additional flood events) to determine its suitability for inclusion into BigMod. This should include incorporating flood suppression of salt by subsequent events into the relationship; and

  - the applicability of the relationship to other comparable floodplain sites such as Pike be considered and tested.

- **Lock 5 to Morgan Salt disposal basins**

  Information on historical release events is available for selected salt disposal basins. This information could be used to identify significant release events within the BigMod unaccounted salt load input time-series, and thus account for them.

- **Lock 5 to Morgan: Lake Bonney**

  Analysis of historical data over the period 1970 to 2010 (AWE 2013) suggests that the current model representation may be underestimating the rate of salt accumulation during low river flow periods and the degree of mixing could be improved. It was recommended (AWE 2013) that the representation of Lake Bonney in BigMod be recalibrated, potentially accounting for an additional 20 tonnes per day of salt inflow (currently unaccounted).

- **Lock 5 to Morgan: Evaporative accumulation and flushing of backwaters**

  It was recommended (AWE 2013) that the characteristics of significant off-stream water bodies be assessed. This may enable selected off-stream water bodies that have significant evaporation accumulation effects to be represented as individual, accounted contributors in BigMod. The decision to include a specific off-stream water body will need to balance the modelling effort required to incorporate the water body and the magnitude of the impact the water body has on peak salinities.

Andy Close followed the recommendation of AWE (2013) to develop and test a salt inflow decay plus suppression relationship for post-flood salt recession from the Chowilla floodplain. The relationship was successfully developed and tested using historical data over the period 1970 to 2009. It was found that the developed relationship could account for an average of 59 tonnes/day of salt inflow in the Lock 6 to Lock 5 reach. Including this relationship reduced the mass flux of unaccounted salt inflow in the reach from 185 tonnes/day to 126 tonnes/day: a reduction of approximately 32%.

The new relationship was incorporated into MSM-BigMod. The outcomes of additional work to recalibrate the simulation of Lake Bonney and correct some errors in salinity data was also incorporated into the model. It was found that these model refinements lead to a marginal improvement in calibrated salinities at Morgan. The impact of the model refinements on the salinity impact assessment of The Living Murray and Basin Plan was also tested. It was found that incorporating the model refinements would lead to a small reduction in the assessed benefit of The Living Murray (from $4.4 million/year to $4.3 million/year) but a small increase in the assessed benefit of the Basin Plan (from $8.7 million/year to $8.9 million/year).

Based on these findings, it was recommended (Andy Close) that

- refinements to the model discussed in this section (inclusion of the Chowilla salt inflow decay plus suppression relationship, recalibration of Lake Bonney salt contributions and corrections to salinity data) be adopted into the model and be used for future Basin Salinity Management Strategy Salinity Register modelling assessments;
    - an average of 185 tonnes per day of unaccounted salt inflow enters the river between Lock 6 and Lock 5 (i.e. from Chowilla). This represents 5.6% of total unaccounted salt load to the river. Incorporating the model refinements will reduce the mass of accounted salt inflow in this reach by an average of 59 tonnes per day (to 126 tonnes per day);
- the potential to derive similar salt inflow decay plus suppression relationships for sites in the reach Lock 5 to Morgan be considered; and
- the potential to individually account for backwater systems in the reach Lock 5 to Morgan (such as Gurra Lakes and Ramco Lagoon) be considered.

6. References

AWE (2013) *River Murray salt mobilisation: characterisation of selected unaccounted salt loads*, May 2013, report prepared by Australian Water Environments for the Murray-Darling Basin Authority

AWE (2012) *River Murray floodplain salt mobilisation and salinity exceedances at Morgan*, August 2012, report prepared by Australian Water Environments for the Murray-Darling Basin Authority, MDBA publication No 53/12

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Close A and Sharma P (2003) *Hydrologic models used for water resource and salinity management in the River Murray System*, 28th International Hydrology and Water Resources Symposium, Wollongong 10-14 November 2003

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Appendix A. AWE Report

Murray Darling Basin Authority

RIVER MURRAY SALT MOBILISATION: CHARACTERISATION OF SELECTED UNACCOUNTED SALT LOADS

June 2013

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List of Abbreviations

Abbreviation	Definition
AEM	Airborne Electromagnetic/Aerial Electromagnetic
AWE	Australian Water Environments
BOM	Bureau of Meteorology
BRS	Bureau of Rural Sciences
BSMS	Basin Salinity Management Strategy
CMA's	Catchment Management Authorities
CSIRO	Commonwealth Scientific and Industrial Research Organisation
d	Day
DfW	Department for Water (South Australia)
DHI	Company Name
DSE	Department of Sustainability and Environment (Vic)
EC	Electrical Conductivity (Expressed in this report in microsiemens per centimetre) – a measure of water salinity
EM	Electromagnetic
ENSYM	Environmental Systems Modelling Platform
FIM	Refer to RiM-FIM
GIS	Graphic Information System
GL	Giga Litre
ha	Hectare
HYDRUS	Software package for simulating the one-dimensional movement of water in variably-saturated media
IAG	Independent Audit Group
k'v	Vertical hydraulic conductivity
km	Kilometre
L	Litre
LiDAR	Light Detection and Ranging – Optical remote sensing technology
mAHD	Metres Australian Height Datum
MDBA	Murray–Darling Basin Authority
MDBC	Murray–Darling Basin Commission
MDBMC	Murray–Darling Basin Ministerial Council
mg	Milligram
MIKE-FLOOD	Refer to Glossary
ML	Mega Litre
mm	Millimetre
MODFLOW	Refer to Glossary
MODFLOW/MT3D	Solute transport model for MODFLOW
MS (1 etc)	Milestone
MSM	Monthly Simulation Model
MSM_Bigmod	Refer to Glossary
Mt	Mega tonne
MURLEV	Part of the River Murray Flow and Salt Transport (RMFST) computer model
NanoTEM	Refer to Glossary
NEC	Company Name
NSW	New South Wales
P1, P2, P3, P4	Period 1 (July 1970 to June 1979), Period 2 (July 1979 to June 1989), Period 3 (July 1989 to June 1999) Period 4 (July 1999 to June 2009).
p a	per annum
PPK	Company Name

REM	Resource and Environmental Management
RiM-FIM	River Murray Flood Inundation Model
RMFST	River Murray Flow and Salt Transport
RoR	Run of River
SA	South Australia
SIMRAT	Computer model which assesses unconfined aquifer discharge responses
SIS	Salt interception scheme
SKM	Sinclair Knight Merz
SUTRA	Refer to Glossary
t	Tonne
TM	Thematic Mapper used on Landsat Satellite
URS	Company Name
WAVES	Water, Atmosphere, Vegetation, Energy and Solutes. Computer model. Refer to Glossary
WINDS	Based on WAVES but is simplified to consider only salinity impacts.
WQSM	Water Quality and Salinity Management (Plan)
Ωm	Ohm metre - measure of resistivity

Glossary

Accounted salt inflows/outflows
A BIGMOD term used for salt inflows to the River Murray from tributaries and drains which are quantified using flow and salinity data. Salt inflows from other unquantified sources are referred to as unaccounted salt inflows. Outflows are those extracted for consumptive use (e.g. irrigation, stock and domestic uses).

AEM
Data collected during airborne electromagnetic (AEM) surveys undergo a process of inversion to yield estimates of spatial changes in ground conductivity. Bulk conductivity is affected by material properties, water salinity, porosity, saturation and temperature.

Anabranches
Branches of river that leave the main stream and rejoin it downstream.

Backwaters
Bodies of water that are held back by a dam or weir.

Bank storage
The water absorbed into the banks of a stream or river channel, when the river stage rises above the water table in the bank formations, then returns to the channel when the stage falls below the water table. See also flood bank storage and inter-flood bank storage.

Bank recharge
The process by which a stream or river recharges the aquifer through its banks when the stream level is higher than the adjacent groundwater.

Benchmark period
1975 to 2000. The Basin Salinity Target established under the BSMS is to maintain the average daily salinity at Morgan, South Australia, at a simulated level of less than 800 EC for at least 95% of the time, modelled with the same climate conditions as those observed over the benchmark period, under the current land and water management regime.

BSMS
Basin Salinity Management Strategy: the 15 year plan for communities and governments in cooperating to control salinity in the Murray–Darling Basin. The strategy establishes targets for the river salinity in each major tributary valley and across the Murray–Darling system. The strategy was agreed by the Murray–Darling Basin Ministerial Council on the 17th September 2001.

CMA
Catchment Management Authorities (CMAs) are responsible for managing natural resources at the catchment scale in the state of Victoria. Victoria has 10 catchment management areas.

Diffuse recharge
The process in which overbank flows recharge the groundwater through the soil surface of the floodplain.

ENSYM
Environmental Systems Modelling Platform (ENSYM) is a computer program that utilises spatial information such as climate data, elevation, vegetation type, soil type and land use to model outputs including surface water/groundwater dynamics and native habitat changes. It was developed by the Department of Sustainability and Environment (DSE) Victoria.

Evaporation
Water converting into a gaseous state (or vapour) from the water surface. Potential evaporation is the amount of evaporation that would occur if sufficient water source was available.

Evaporative Accumulation
The effect of evaporation from backwaters drawing water from the river and accumulating the salt that enter with River water in the backwater. Whilst not changing the total salt budget, this does generate a salinity effect due to the timing of storage and release.

Evapotranspiration
Evaporation plus transpiration.

Flood bank storage
Storage of water and salt in the riverbank and adjacent aquifer caused by increases in river level due to a flood.

Flood inundation
The inundation of land that is normally dry through overbank flow from a body of water such as a river.

Flood recession
The period after a flood peak when river flow continues to decrease.

Floodplain
Land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge. It includes the floodway, which consists of the stream channel and adjacent areas that carry flood flows, and the flood fringe, which are areas covered by the flood, but which do not experience a strong current.

Floodplain Inundation Groundwater Recession
(See Groundwater Recession)

Freshwater lens
A body of freshwater that sits on top of and within more saline water due to differences in density.

Gaining floodplain
Reaches where the regional groundwater system is discharging into the floodplain alluvium.

Gaining stream
Reaches of river where groundwater is discharging from the floodplain alluvial sediments into the river.

Groundwater recession
The asymptotic decrease in groundwater flow to the river following a temporal maximum inflow immediately following the river hydrograph, due to depletion of groundwater held in storage in the floodplain following a period of floodplain inundation.

Hydraulic conductivity
The property of soil or rock that describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation.

Inter-flood bank storage
When a losing river condition is established in a gaining floodplain due to high evapotranspiration losses, the water losses through the river-bed and bank are classified in this report as “Inter-Flood bank storage”. The losses are stored and subsequently returned to the river after overbank flooding re-establishes a groundwater gradient to the river.

Localised recharge
The process in which the floodwater infiltrates through isolated areas of the floodplain at a higher rate. These isolated areas may be depressions that fill during flooding, old levee banks or dunes with a thin or absent surface clay layer, or old meanders.

Losing floodplain
Reaches where the groundwater flow is from the floodplain sediments to the regional groundwater system.

Losing stream
Reaches of river where the river is losing water to the floodplain alluvial sediments.

MDBA
The Murray–Darling Basin Authority (MDBA) is the regulatory body responsible for managing the Murray–Darling Basin's water resources in the national interest since December 2008.

MDBC
The Murray–Darling Basin Commission (MDBC) was the executive arm of the Murray–Darling Basin Ministerial Council and held this responsibility over the period 1992 to 2008. The functions of the MDBC were subsumed by the Murray–Darling Basin Authority in 2008.

MIKE-FLOOD
A commercial software package which simulates floods involving any combination of rivers, floodplains and urban drainage systems.

MODFLOW
A modular, finite-difference, flow model that uses computer code to solve the groundwater flow equation. The program is used to simulate the flow of groundwater through aquifers.

MSM-Bigmod
MSM-Bigmod are two computer based models that work together. Output from MSM (Monthly Simulation Model) feeds into Bigmod (daily simulation model). The models route flow and salinity in the River Murray and associated storages. Models are used for water accounting, planning and flow and salinity forecasting. MSM-Bigmod can simulate the operation of the River Murray system to investigate what would happen under a given set of conditions.

Murray–Darling Basin
The entire tract of land drained by the Murray and Darling rivers, covering parts of Queensland, New South Wales, Victoria and South Australia, and the whole ACT.

NanoTEM
A geophysical method that measures the resistivity of subsurface materials. This resistivity will be affected by material properties, porosity and saturation of the materials and water salinity.

Pool level
A relatively constant level of entitlement flow that is maintained for a given reach of river which is controlled by locks or weirs.

Recharge
The process of aquifer replenishment, usually from rainfall, irrigation accessions and losses from surface water bodies such as river and lakes.

Root zone drainage
The amount of water which passes below the part of the soil profile where plant roots are active.

Run of River
A technique that directly measures river salinity along a stretch of river over a number of consecutive days. Information collected together with flow data is used to calculate salt inflow to the river for each kilometre.

Salt Recession
Salt loads associated with groundwater recession.

Saturated zone
The zone in which the pore spaces in rock or soil are filled with water at a pressure which is greater than atmospheric pressure. The water table is identified as the top of the saturated zone in an unconfined aquifer.

SUTRA
A computer program that simulates fluid movement and the transport of either energy or dissolved substances in a subsurface environment. SUTRA numerically solves equations for fluid-density-dependent saturated or unsaturated groundwater flow by using the finite element method.

Throughflow floodplain
Reaches where the regional groundwater flow lines show that groundwater flows beneath or through the floodplain. In these reaches, the floodplain alluvium is potentially gaining water from the upgradient side, but is losing water to the regional groundwater system on the downgradient side.

Transpiration
The amount of water evaporated by vegetation through leaves for growth. As with evaporation, it is estimated, based on weather data, plant variety and other indicators.

Unaccounted salt inflows
A BIGMOD term used for salt inflows to the River Murray from all groundwater inflows and unaccounted surface water discharges. Many discharges to the river are either un-regulated or not measured, such as discharges from evaporation basins in SA (e.g. Disher Creek Basin and Berri Basin), and outflow from anabranches and lagoons (e.g. Wachtels Lagoon, Gurra Gurra Lakes, Pike River). Accounted salt inflows/outflows are the product of flow and salinity from tributaries and drains, and the extraction for consumptive use (irrigation, stock and domestic uses). Unaccounted salt inflow does not indicate whether the salt source is accountable or not in relation to the MDBA Salinity Registers.

Unsaturated zone
The zone between ground surface and the water table, which includes the root zone, intermediate zone and capillary fringe. Pore spaces in the rock or soil contain water at less than atmospheric pressure. Also known as the vadose zone.

Watertable
The groundwater level in an unconfined aquifer. The porous medium is saturated with water below the water table.

WAVES
A soil-vegetation-atmosphere model that uses Basin-wide datasets and a historical climate dataset to produce estimates of groundwater recharge.

Weir pool
A body of water held behind a weir.

Executive Summary

Introduction

This study was commissioned by the Murray-Darling Basin Authority (MDBA) to investigate further, new paradigms identified in an earlier report 'River Murray Floodplain Salt Mobilisation Processes and Salinity Exceedances at Morgan' (AWE 2011). This report outlined a range of new understandings and identified key data gaps regarding floodplain salt mobilisation processes. A series of recommendations from this initial work have been used to guide the current analysis.

The following study focuses on the analysis of unaccounted MSM-BIGMOD salt inflows and the physical processes that control salt inflow from groundwater and backwaters during floods. Salt mobilisation during floods was not investigated in the previous study and analysis suggests it is a major source of salt inflow to the River. MSM-BIGMOD unaccounted salt inflow data contains useful information that to date has been underutilised. Analysis of this data will help to constrain processes that contribute salt to the river and attribute components of unaccounted salt inflows to known sources.

In its present form this report shouldn't be seen to describe the Authority or State policy with regard to the Basin-wide salt mobilisation processes or operation of the river.

Background and Approach

The quantification of salinity impacts from flood recession requires a thorough understanding of interactions between floodplain features both dynamically and spatially. Floodplain processes are some of the more complicated drivers of in-stream salinity and although aspects of floodplain processes have been studied for some time, our understanding of them is still in its early stages.

In 2011, Australian Water Environments (AWE) conducted a detailed analysis of River Murray floodplain salt mobilisation processes and salinity exceedances at Morgan for the MDBA, due to concerns that salinity at Morgan would be extreme following an extended low flow period in the River Murray. This analysis lead to a range of new understandings, identification of key data gaps regarding floodplain salt mobilisation and a series of recommendations that have been used to guide this current body of work. Salt mobilisation during floods was not investigated by the 2011 study, however that study identified it is a major source of salt inflow to the River.

The key component of this study is the analysis of BIGMOD 'unaccounted salt loads' to identify if there are consistent and/or recognisable patterns controlling salt inflows to the River Murray and to identify the anthropogenic or natural causes or processes controlling this salt release. Once these processes are isolated, this study aims to develop approaches that facilitate examination of the BIGMOD unaccounted salt inflows and provide some quantification of the sources of salt. It may then be possible to develop rules that will adequately quantify one or more of these processes within BIGMOD.

The approach was developed to maximise the use of existing data sets with a focus on the major contributors to unaccounted salt inflow to the River between Lock 7 and Morgan. The approach adopted for the Lock 7 to Lock 5 reach of the river varies slightly to that adopted for the Lock 5 to Morgan reach due to the differing processes that drive salt inflow.

In the previous study (AWE 2011) it was identified that:

- The Chowilla floodplain was the dominant source of unaccounted salt inflow within the Lock 9 to Lock 5 river reach; and
- The Lock 5 to Morgan reach has the highest level of salt inflow, accounting for 60% of the total salt inflow between Euston and Murray Bridge and that backwaters and anabranches play a key role in the timing of these salt inflows.

These findings were further explored in this study and key results are presented below.

Chowilla

Characterisation of Selected Unaccounted Salt Loads Lock 7 to Lock 5:

Within the Lock 7 to Lock 5 reach the Chowilla floodplain is the dominant source of unaccounted salt inflow and is the “type locality” for inundation induced groundwater recessions. Previous work identified that peak flow during a flood is a good indicator of salt inflow during the post-flood period. Analysis of the correlation between salt inflow and other flood characteristics such as peak inundated area, antecedent conditions and suppression time was also conducted but the strongest correlation remained between cumulative salt inflow and peak flow.

Following this, cumulative flow and cumulative salt inflow curves from the Chowilla floodplain were developed for each flood since 1977. These were then used to identify any consistent, recognisable patterns and the processes that may control salt inflow. From the analysis of cumulative flow and cumulative salt inflow curves it was identified that:

- Salt inflow during a flood is quite variable;
- A “typical” salt inflow pattern can be identified from flood recessions that extend for 180 days or more;
- Cumulative salt inflow increases with peak flow;
- Salt inflow suggests a trigger is activated by flood peaks above 80,000 ML/d where modest additional increases in flow result in significant increases in salt inflow. By way of example, the August 1981 flood has a peak flow 30% above 80,000 ML/day with a corresponding salt inflow increase of 120%;
- Analysis of flow and inundation area of the Chowilla floodplain suggested that there is a correlation between the rapid increase in salt load and areas inundated by flows exceeding 77,000 ML/d; and
- The cause of the observed step increase in salt inflow, which is shown in Figure ES.1 below, has not been conclusively identified, although this may be related to the vertical hydraulic conductivity of the clay of the Coonambidgal Formation or the salinity variation observed between eastern and western sections of the floodplain.

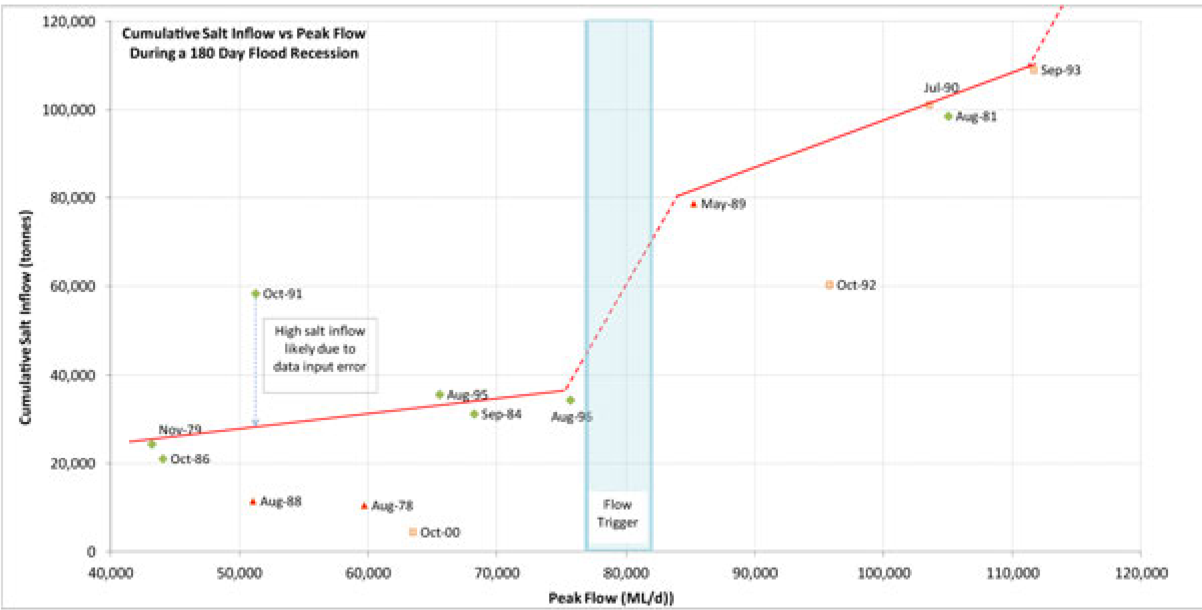

FIGURE ES.1: CUMULATIVE SALT INFLOW VS. PEAK FLOW DEMONSTRATING STEP WISE SALT INFLOW CONCEPTUAL MODEL

A simple analytical model was developed based on the application of the Cooper and Rorabaugh (1963) equation where groundwater discharge to a river from the underlying aquifer can be described as:

$$Q = Q_0 e^{-at}$$

Where Q is discharge (L^3/T), Q_0 is initial discharge (L^3/T), t is time (T) and a is a recession constant (T^{-1}).

Integration of the equation gives cumulative groundwater flow over a given time period. The equations were parameterised using outcomes from the AWE MODFLOW model for the Murtho/Chowilla reach and the flow was segmented into a base flow component and a flood recession component based on peak flow. The flow was multiplied by observed groundwater salinities to give a series of cumulative salt inflow (SI) curves for calibration against salt inflow derived from BIGMOD outputs. Cumulative salt inflow from a series of flood events was able to be replicated using this approach.

Comparisons of the natural log analytical model and the BIGMOD salt inflows are given in Figure ES.2 below. Results from the analytical model are promising and suggest that it can be used to replicate salt inflow under "typical" conditions but would require further testing to determine if this analytical model is suitable for incorporation into BIGMOD.

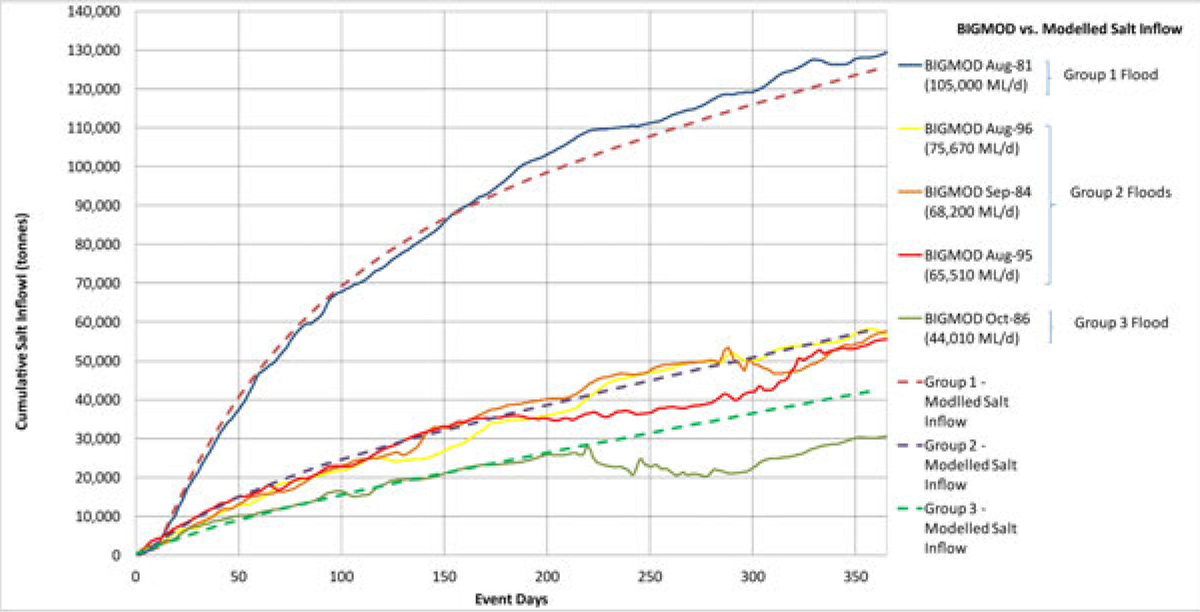

FIGURE ES.2: BIGMOD CUMULATIVE SALT INFLOW VS. MODELLED SALT INFLOW

Recommendations for Future Analysis

It is recommended that future analysis be undertaken incorporate the following:

- Test the applicability of the ‘simple analytical’ model at other comparable floodplain sites downstream (e.g. Pike);
- Extend the natural log analytical model to cater for suppression of salt inflows by higher flows;
- Improve the detail of the conceptual model, particularly to identify the cause of the step function of delivery of salt inflow; and
- Initiate monitoring programs to assess salinity impacts of watering events and impacts from the Chowilla Regulator which does affect the eastern floodplain and may activate the step function of salt delivery that has been observed during flood events where flow exceeds 75,000 ML/d.

Characterisation of Selected Unaccounted Salt Loads Lock 5 to Morgan:

The Lock 5 to Morgan reach contains a significant amount of permanent backwaters and anabranches and this large amount of permanent water on the floodplain, combined with gaining floodplain conditions, is considered to be a key factor controlling the pattern of salt inflow. This reach also has significant areas of irrigation development. Drainage from these developments is directed to a number of different disposal basins, some of which are located within the floodplain.

Key conclusions from the analysis for Lock 5 to Morgan reach are:

- Irrigation Drainage Disposal Basins:
  - Historically, drainage to these basins accumulated during times of low flow with high salinity water released during high river flows or when the basins were flushed during large flood events;
  - Prior to 2000 a long-term average of 209 t/d flowed to disposal basins located on the floodplain. The five most significant disposal basins account for 93% of this salt

  load and the two largest Disher Creek and Berri account for 57% and 17% respectively;
  - Release of salt from disposal basins occurred mainly at higher flows and significant release events can be identified in the historical salinity record and BIGMOD generated unaccounted salt inflows;
  - Noora Basin was established to allow transfer of flows from Disher Creek and Berri out of the floodplain and since its commissioning in 1983, salt releases to the River from Disher Creek and Berri only occur when they are flushed by a flood or through the opportunistic disposal of salt to the River during high flows; and
  - Salt inflow from other basins, which historically disposed a long-term average of 56 t/d of salt, would have declined due to reduced irrigation drainage volumes.
- Lake Bonney:
  - Lake Bonney is the only permanent water body within the Lock 5 to Morgan reach "accounted" by BIGMOD and is a major store of salt that is released during flood recessions; and
  - Salt inflow calibration could be improved by updating the "accounting" method for Lake Bonney. This would result in the net movement of 20 t/d of salt from the unaccounted salt inflows to the accounted salt inflows and also improve the timing and impact of Lake Bonney outflows on modelled Salt Inflow and EC.
- Salt Accumulation through Evaporative Accumulation:
  - Evaporative accumulation is the process by which evaporation from backwaters draws water from the River into the backwater and the salt in the water accumulates in the backwater until a flow event results in outflow from the backwater. Whilst not changing the total salt budget, this does generate a salinity effect due to the timing of the releases which are usually associated with higher flows;
  - Assuming an average River salinity of 400 EC, evaporative accumulation from backwaters in this reach which have a total area of 42.35 km^2 (excluding Lake Bonney) has the potential to store 9,320 tonnes of salt per year (26 tonnes per day on average);
  - The storage of salt over many months and release in much a shorter timeframe will provide peak salt inflow;
  - The method of accounting backwater evaporation in BIGMOD results in calculated salt inflow from other sources being lower than actual at times of evaporative accumulation and high than actual during release events;
  - Saline groundwater inflow to backwaters will similarly be accumulated when high evaporation rates draw water from the River into the backwater which is then released when an outflow event occurs; and
  - The characteristics of each significant off-stream water body should be assessed to identify whether it is a backwater or a flow through an anabranch, the relative contribution of groundwater inflow and the mechanism of connection to the River. This would enable the building of a robust assessment of salt inflow variation due to backwaters.
- Detailed Review of Flood Events:
  - A review of three separate flood events identified that patterns of raw salinity data and salt inflow observed during these events were consistent with the flushing of backwaters, operation of disposal basins and opportunistic release of salt during high river flows;

- o Detailed analysis of when backwaters commence outflow would enable discrimination between which backwater caused specific observed rises in salinity; and
- o Data suggests that a Chowilla type pattern of salt inflow during flood recession occurs from the Pike River floodplain however, this is currently masked by other significant sources of inflow in this sub-reach.

Review of Salinity Data Reliability

The vast bulk of the BIGMOD record and its salt inflow interpretation is consistent with anecdotal and empirical evidence, and the results from processed-based groundwater models. This review seeks to highlight that, with careful attention, the already useful BIGMOD model can be refined, to strip out erroneous or poorly representative data, to increase the accuracy of the model.

The quality of raw salinity data is critical to the calculation of salt inflow. Current best practice for collection of salinity data is to use fixed, pontoon-mounted, EC Toroidal Coil stations at numerous locations along the River Murray where it has been assessed the River is well mixed. Much of the historical data was collected manually with samples taken close to the bank which can be non-representative of the average channel salinity. Salt inflow analysis is based on the EC differential between stations and thus any significant data issues result in the calculation of negative salt loads.

Negative salt inflows occasionally occur in BIGMOD, and may be used as error/uncertainty estimates. Salinity data can be non-representative for a number of reasons, the most significant of which include:

- Instrument error;
- Poor (inconsistent) mixing;
- Site location providing a non-representative sample; or
- Data management errors.

Throughout this study, and the detailed analysis of BIGMOD salt inflow, it was often the case, when salt inflow was suspected to be unusual, the occurrence could be correlated with suspect data from a location for a specific period or even single samples. It is considered a process specifically designed to identify suspect raw salinity data, based on BIGMOD salt inflow and comparison of data from adjacent/subsequent sampling locations could provide a much improved data set.

When using the salt inflow analysis to calibrate the process it is important to refine the data first so calibration is to the best possible salt inflow estimates.

Some general conclusions can be made from the analysis, which include:

- The vast bulk of the BIGMOD records and its salt inflow interpretation is consistent with anecdotal and empirical evidence, and the results for processed based groundwater models;
- Analysis of unaccounted salt inflow provides the opportunity to identify suspect data and thus improve the veracity of MSM-BIGMOD outputs;
- In-stream monitoring pontoons, although requiring calibration and maintenance, provide an essential data source for assessing salt inflow to the River particularly through MSM-BIGMOD data inputs and model calibration; and
- In-stream salinity pontoons within the South Australian extent of the River Murray are generally considered to provide a reliable, representative source of in-stream salinity data with few exceptions.

Conclusions and Recommendations

This study has identified a number of processes that control salt inflow to the River Murray and attributed components of unaccounted salt inflow to specific sources, significantly:

- A simple analytical model has been developed to replicate salt inflow during flood recessions from Chowilla but further investigation is required to determine if this is suitable for incorporation to BIGMOD;
- Major unaccounted salt inflow in the reach Lock 5 to Morgan can be attributed to irrigation disposal basins;
- Calibration of the process of salt inflow from Lake Bonney could be improved. This would result in the net movement of 20 t/d of salt from the unaccounted salt inflows to the accounted salt inflows and also improve the timing and impact of Lake Bonney outflows on modelled salt inflow and EC; and
- Evaporative accumulation in backwaters has the capacity to store significant amounts of river salt and groundwater inflow salt during times of low flow and release it to the River at high rates during higher flow events. The salinity impact may still only be moderate as the high flows dilute the salt inflow.

It is recommended that:

- Further analysis be undertaken on the analytical model incorporating the following:
    - Test the applicability of the simple analytical model at other comparable floodplain sites downstream (e.g. Pike);
    - Test the variation of initial groundwater discharge parameters for floods with a peak flow that differs from those already analysed;
    - Extend the natural log analytical model to cater for suppression of salt inflows by higher flows;
    - Improve the conceptual model process detail, particularly the cause of the step function of delivery of salt inflow and this could be investigated further; and
    - Initiate monitoring programs to assess salinity impacts of watering events and impacts from the Chowilla Regulator which does affect the eastern floodplain and may activate the step function of salt delivery that has been observed during flood events where flow exceeds 75,000 ML/d.
- Lake Bonney calibration be updated;
- The characteristics of each significant off-stream water body be assessed to identify whether it is a backwater or a through-flow anabranch, the contribution of salt through groundwater inflow and the mechanism of connection to the River which will in turn enable the building of a robust assessment of salt inflow variation due to backwaters;
- A process specifically designed to identify suspect raw salinity data be undertaken to provide a much improved raw salinity data set; and
- In-stream EC monitoring, which has proved invaluable for assessing salt inflow process, be continued.

1 Introduction

The Murray Darling Basin Authority (MDBA) engaged Australian Water Environments (AWE) to further investigate and analyse the salt load of the River Murray specifically the lower reaches of the River. This study aims to build upon the knowledge gained from previous studies and to analyse salt inflow during floods and flood recessions and identify linkages between patterns in salt inflow and flood characteristics.

In 2011, AWE conducted a detailed analysis of River Murray floodplain salt mobilisation processes and salinity exceedances at Morgan for the MDBA due to concerns that salinity at Morgan would be extreme following the extended low flow period in the River Murray. This report involved the collation and analysis of a significant number of varied data sets including analysis of regional data sets, review of existing research and detailed analysis of MSM-BIGMOD data outputs. This lead to a range of new understandings, identification of key data gaps regarding floodplain salt mobilisation and a series of recommendations that have been used to guide this current body of work.

The previous study (also known as the Stage 1 report for the purpose of this report) primarily focused on the Lower Murray floodplain between Euston and Murray Bridge and salinity exceedances at Morgan. Key outcomes from this report included:

1. Collation of current findings on biophysical processes in the Lower River Murray floodplain, including surface-groundwater hydrology.
2. Reporting of key geographic areas and features that drive, and are impacted by, floodplain salt mobilisation.
3. A conceptual model that can demonstrably assist in understanding floodplain salt mobilisation and evaluation of mitigation strategies under current and future water management regimes.
4. Reporting of potential river operational strategies e.g., using dilution flows to avoid and mitigate post-flood salt accession to the River Murray.
5. A 'road map' for future investigations which will improve planning and prioritisation for the MDBA.

The quantification of salinity impacts from flood recession requires a thorough understanding of interactions between floodplain features both dynamically and spatially. Floodplain processes are some of the more complicated drivers of in-stream salinity and although aspects of floodplain processes have been studied for some time, our understanding of them is still in its early stages. A series of knowledge gaps and recommendations were identified in the Stage 1 report including:

1. How the broad-scale salinity impacts estimated from MSM-BIGMOD data relate to the small-scale features and transient effects which impact water quality for critical human needs, irrigation and environmental assets. Floodplain processes will vary reach by reach, kilometre by kilometre, and wetland by wetland.
2. The timing, rate and processes controlling groundwater discharge to backwaters and other surface water bodies on the floodplain are poorly understood and quantified, however salt release from these connected water bodies is thought to be a major mechanism in the Lower Murray Floodplain salt balance.

3. The processes controlling release of water and salt from the backwaters and anabranches, particularly in the Lock 5 to Morgan reach, need additional attention. Data is required to quantify the sources and rates of salt mobilisation at the sub-reach and at individual water body scale.
4. The role of the unsaturated zone and the saturated zone in storing salt during a drought, and salt mobilisation from the unsaturated zone. The unsaturated zone is often cited as the salt storage location during inter-flood periods, however salt storage and release mechanisms in the floodplain unsaturated zone appear to be incompletely conceptualised and sparsely quantified.
5. Recharge rates through the Coonambidgal Clays, and distribution of rates across the floodplain during inundation and also in inter-flood periods, are almost completely unquantified.
6. Recharge rates to groundwater in irrigated regions adjacent to the floodplain and within the floodplain.
7. Emplacement mechanisms and rates, size, shape, persistence and stability of freshwater lenses, and the degree of protection they afford the River to groundwater recession salt inputs.
8. Floodplain evapotranspiration rates, which are known to vary according to soil type, vegetation type, groundwater salinity and climate, but for which there is no agreed method of estimating on the regional scale.

The following analysis focuses on the first three knowledge gaps concerning BIGMOD outputs and the processes controlling salt inflow from groundwater and backwaters during floods. Salt mobilisation during floods was not investigated in the previous study and analysis suggests it is a major source of salt inflow to the River. MSM-BIGMOD unaccounted salt inflow data contains useful information that to date has been underutilised and will help to constrain processes that contribute to salt inflow.

This analysis aims to identify mechanisms by which salt inflow occurs during and following flood events through the use of historical in-stream monitoring data, BIGMOD outputs, existing groundwater models and the floodplain conceptual model within the above mentioned reaches. It is anticipated that analysis of in-stream salinity data and additional analysis of unaccounted salt inflow data will provide advances in conceptualisation and quantification of key salt mobilisation processes during flood events. Through this analysis, known sources of unaccounted salt load will be identified within each reach and their likely salt contribution quantified. This study also attempts to identify linkages between patterns in salt inflow and flood characteristics such as peak flow, cumulative volume, suppression period, pre-history, groundwater recession and river stage. This process is designed to provide insight to potential rules that may be applied to predict salt inflow during flood events and reduce unaccounted salt inflows arising from MSM-BIGMOD. This will lead to an update of the floodplain salt conceptual model as a tool for systemising floodplain process and salinity response.

The Chowilla floodplain and the Lock 5 to Morgan floodplain and their corresponding River Murray reaches are used as case studies in this analysis. It is anticipated that they will provide additional insight to these processes as:

- The flood response within the Lock 5 to Morgan reach is different to that observed in the upstream reach between Lock 9 and Lock 5;
- Salt inflow between Lock 5 and Morgan peaks during a flood event but is comparatively low during the recession;
- The magnitude of salt inflow in this reach is similar to that observed from Chowilla;
- Outflow from a number of anabranches and unregulated or unmeasured basins occurs within Lock 5 to Morgan reach;
- Salt inflow from Chowilla dominates the total salt inflow within the Lock 5 to Lock 9 reach; and
- Salt inflows from Chowilla represent a 'typical' example of a flood recession salt inflow response.

The key component of this study is the analysis of BIGMOD unaccounted salt loads to identify if there are consistent, recognisable patterns controlling salt inflows to the River Murray, and to identify the anthropogenic or natural causes or processes controlling the salt release. Once these processes can be isolated, this study can then develop approaches that facilitate examination of the BIGMOD Unaccounted Salt Loads and some quantification of the sources of salt. It may then be possible to develop some simple rules that will adequately quantify one or more processes within BIGMOD.

2 Background

2.1 Floodplain Salt Conceptual Model

A major outcome of the Stage 1 report was the development of the Floodplain Salt Conceptual Model that encompassed a range processes and salt delivery pathways that had not been previously conceptualised in one place (refer to Figure 2.1). The aim of the conceptual model was to improve the current understanding of salt sources, storage locations within the floodplain, mobilisation processes, transport pathways to the River and their resulting salinity impacts. The model also aimed to provide a framework for future investigation, quantification and documentation. The Floodplain Conceptual Model consists of a number of elements including:

- Regional elements consisting of sources of salt to the floodplain and mitigation measures that reduce these inputs;
- At some locations regional salt passes through the floodplain direct to the River from the regional sources and other regional salt inputs salt stores within the floodplain;
- Floodplain elements that address the storage and mobilisation of salt within the floodplain and surface waters; and
- River elements that include salt inflow, river flow rate and salinity.

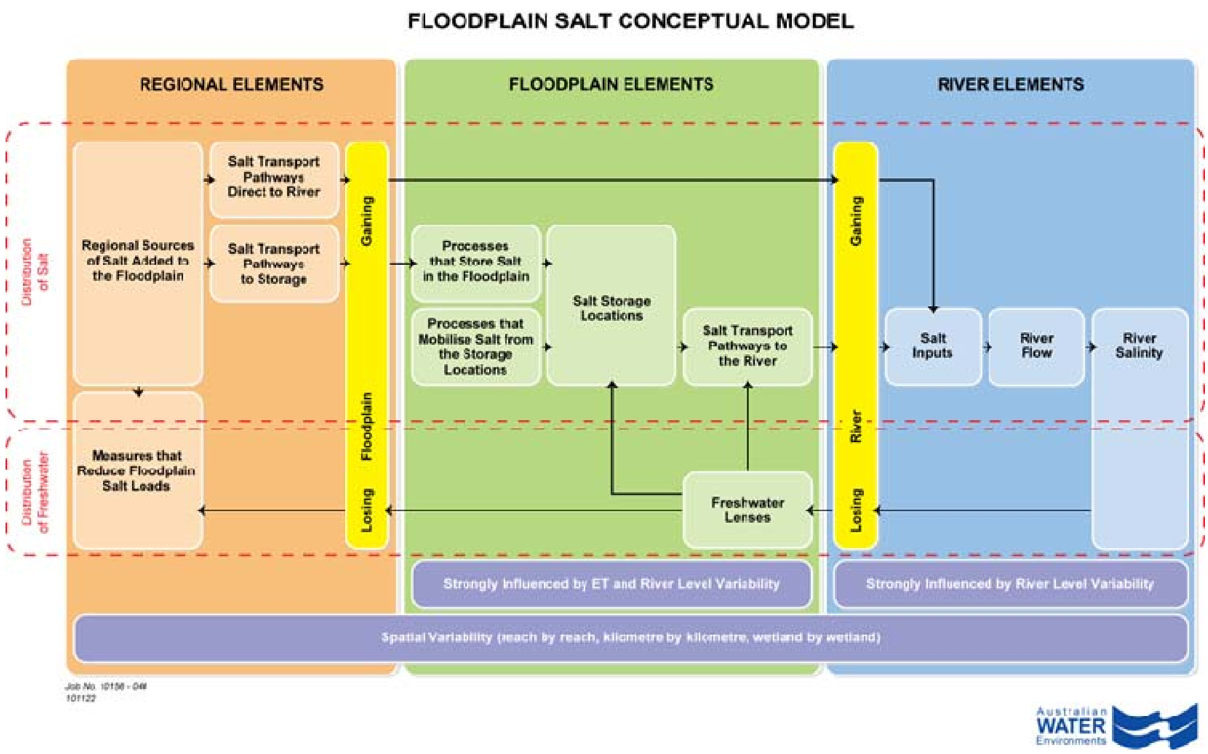

FIGURE 2.1: FLOODPLAIN SALT CONCEPTUAL MODEL (AWE 2011)

The likely timing of activation of key floodplain salt processes and delivery mechanisms is detailed in Figure 2.2 below. The upper section of the graph shows flow data from Morgan and salinity data at five key salinity stations over the 1981 flood, including data pre and post flood. The lower part of the figure illustrates the likely timing of salt inflow to the River from a variety of floodplain processes. The variable thickness of the horizontal bars is used to indicate the changes in rate with changing River flow with thick bars signifying maximum rates and thin bars representing reduced rates.

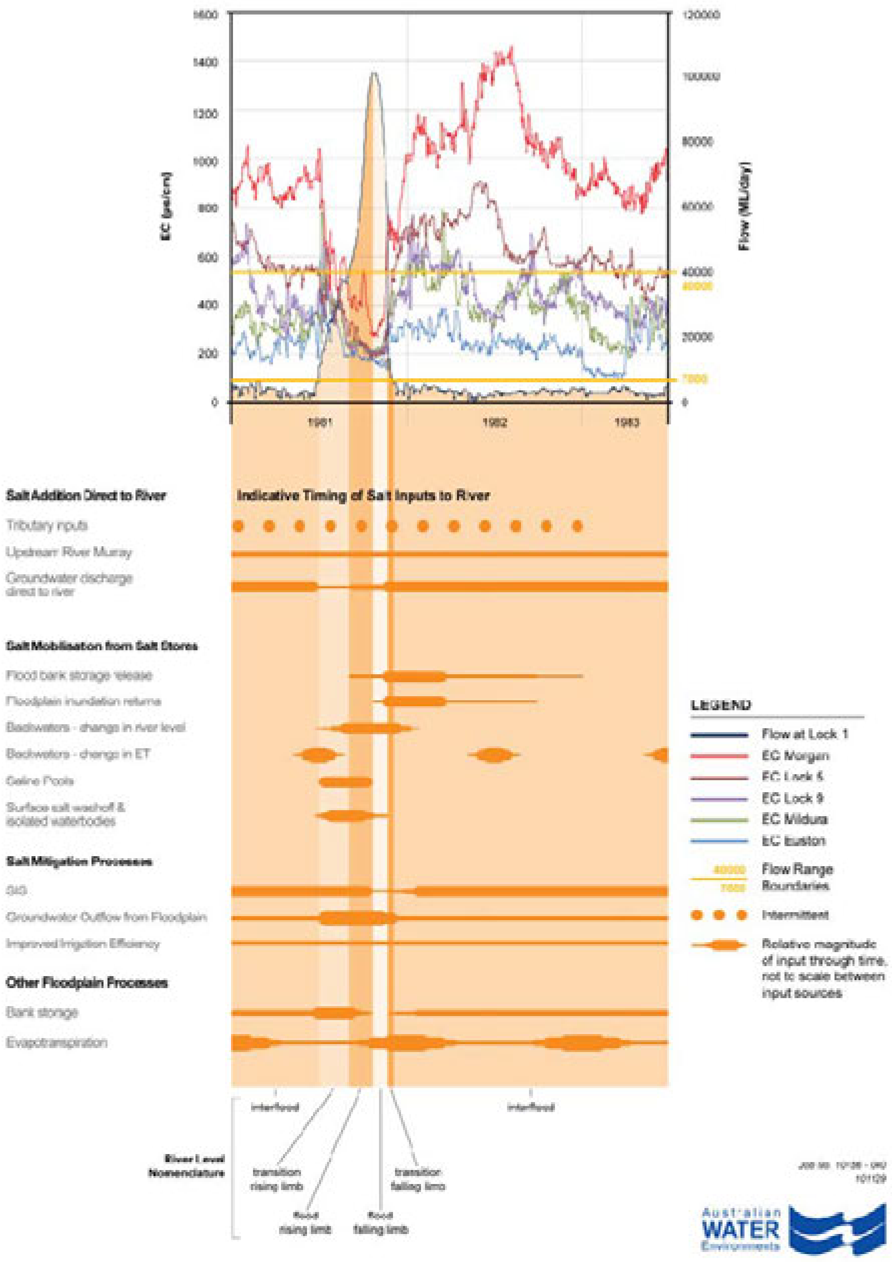

FIGURE 2.2: INDICATIVE TIMING OF SALT INPUTS TO THE RIVER MURRAY THROUGH A FLOOD CYCLE (AWE 2011)

The development of a floodplain salt predictive model was not included in Stage 1 as significant major data sources were not evaluated. The previous study did not exhaustively interrogate the BIGMOD accounted and unaccounted salt load data sets. It suggested that these data sets provide significant potential to gain additional understanding of temporal and spatial patterns of salt delivery to the River. The Stage 1 report recommended the analysis of data from additional river reaches to identify major patterns of salt delivery and contributing process as well as further interrogation of data from the reaches where preliminary findings had been described. The Stage 1 report also recommended the use of data sources outside the MDBA including SA in-stream flow and salinity data, backwater data and salinity data from tributaries above and below Morgan to better verify and quantify 'known' unaccounted salt inflows. The previous study suggested that floodplain processes should be investigated by developing predictive models that consider:

- Groundwater-backwater-river interactions;
- Floodplain inundation and salt transport between Lock 5 and Lock 3;
- Floodplain inundation and salt transport in Sunraysia;
- Salt storage and release between the floodplain surface, unsaturated zone and unsaturated zone;
- Relationships between the floodplain vertical hydraulic conductivity and recharge rates through the Coonambidgal Formation; and
- Freshwater lenses.

2.2 MSM-BIGMOD

The MDBA uses two models that operate jointly to simulate operation of the River Murray system for the purposes of water accounting, planning and salinity forecasting (MDBC 2002). Outputs from the MSM (Monthly Simulation Model) provide inputs to BIGMOD (daily simulation model). MSM-BIGMOD uses measured river flow and salinity data and 'accounted' salt inputs and extractions over time to calculate unaccounted salt inflow. The 'accounted' salt loads are the product of flow and salinity data from tributaries and drains, and extraction volumes for the consumptive use of water. The unaccounted salt loads are the salt inflows required to be added to the system to balance the salt budget in the model. Many inputs to the river system are unregulated or unmeasured forming sources of unaccounted salt loads. These include discharge from evaporation basins in SA (e.g. Disher Creek and the Berri Basin) and outflows from anabranches and lagoons (e.g. Wachtels Lagoon, Gurra Gurra Lakes and Pike River). BIGMOD uses unaccounted salt inflow to obtain a best fit to observed salinity data and includes all groundwater inflows and unaccounted surface water inputs. The model accounts for salt inputs and outputs on a reach by reach basis. Its calibration is reasonable given the overall uncertainties regarding salinity processes in the lower River Murray.

BIGMOD calculates salt inflow using the following process:

- A marker is established at the upstream site each day and is assigned the observed salinity at that site;
- That marker is routed downstream with its salinity adjusted for evaporative losses and inflow from 'accounted' sources, such as a tributaries and monitored drains;

- Additional records are kept for each marker of the time elapsed since the marker left the upstream site and the increase in salinity that would result from salt inflows of 1 tonne/day per kilometre;
- At the downstream site, the unaccounted salt inflow is calculated by Salt inflow = Number of kilometres*(Downstream Measured salinity – Modelled salinity)/Increase in salt load for 1t/d/km; and
- Salt inflow is then attributed to the date that the marker reached the downstream site less half the modelled travel time.

Previous analysis identified that unaccounted salt loads add ten times more salt to the River than the 'accounted' salt inflows and comprise 35% of the total salt load to the River. Floodplains, groundwater and backwaters are thought to be the major source of these unaccounted salt inflows highlighting the importance of understanding floodplain processes and the mechanisms of salt inflow (AWE 2011). Analysis of BIGMOD outputs provides insight into the temporal and spatial patterns of salt inflow to the River Murray. From these patterns, potential causative processes can be conceptualised however, the outputs of themselves do not provide discrimination between the various processes leading to the unaccounted salt inflow.

Salt inflow analysis in the Stage 1 report split the River into two reaches, Lock 9 to Lock 5 and Lock 5 to Morgan and found significantly different patterns of salt inflow between them. This temporal difference in the pattern of salt inflow between adjacent reaches of river suggests different processes control the mobilisation of salt between the Lock 9 and Lock 5 reach compared to Lock 5 to Morgan reach.

The Lock 9 to Lock 5 reach demonstrated low background levels of salt inflow, a strong response to time since flooding and long lasting groundwater recession suggesting that flood related processes are active in this reach. The Lock 6 to Lock 5 reach includes inputs from the Chowilla Creek anabranch which bypasses Lock 6. Previous analysis of post-flood salt export from Chowilla suggested that salt inflow during the inter-flood period is dependent on the size of the flood rather that the duration of the preceding inter-flood period. This indicates that salt accumulation within the floodplain does not significantly affect salt export rates. This analysis focuses on salt inflow during floods and flood recessions and seeks to identify linkages between patterns in salt inflow and flood characteristics.

Within the Lock 5 to Morgan reach salt inflow was characterised by high background salt inflow levels and peak salt inflow with peak inflow three times greater than upstream. Peaks in salt inflow were also of short duration with high salt inflows occurring during high river flows. This high, early salt inflow suggests significant salt mobilisation processes are active within this reach in addition to groundwater inputs from floodplain inundation. It was proposed that this high salt inflow was derived from backwaters and anabranches but requires further analysis to verify as no systematic data collection or analysis of this process has occurred. Very little is known about the salinity interaction between backwaters and the River within the Lock 5 to Lock 3 reach. Additional analysis is required to discriminate sources of unaccounted salt during floods and flood recession. The relative importance of flood inundation groundwater recession salt loads, backwater salt loads and groundwater hydraulic responses to small changes in pool level are unquantified.

2.3 Approach

To meet the project objectives within the allotted budget and timeframe, the following approach was developed to maximise the use of existing data sets and focus on the major contributors to unaccounted salt inflow. The approach adopted for the Lock 9 to Lock 5 reach varies slightly to that adopted for the Lock 5 to Morgan reach due to the differing processes that drive salt inflow. However, in both reaches the key component of this study is the analysis of BIGMOD unaccounted salt inflows and their attribution to specific sources.

In the previous study, the Chowilla floodplain was identified as the dominant source of unaccounted salt inflow within the Lock 9 to Lock 5 river reach (AWE 2011). Unaccounted salt inflow generated by the Chowilla floodplain will therefore be the focus of analysis within this reach and will be investigated using the following approach:

- Analysis of unaccounted salt inflow data to identify patterns of inflow during flood events and subsequent flood recessions;
- Identify relationships between salt inflow patterns and physical processes such as flood duration, inundated area, peak flow during a flood, historical flow regime etc; and
- Where correlations exist between physical processes and salt inflow, identify simple mathematical expressions that can be used to describe salt inflow patterns.

The previous study identified that the dominant source of unaccounted salt inflow within the Lock 5 to Morgan reach was likely to be backwaters and anabranches, particularly those used as disposal basins. Unaccounted salt inflow within the Lock 5 to Morgan reach will be investigated using the following approach:

- Analysis of salt inflow data to identify patterns of inflow during flood events and subsequent flood recessions;
- Identify backwaters that are the likely major contributors to unaccounted salt inflow;
- Compare patterns in salt inflow with monitoring and operational data from backwaters to establish relationships between salt inflow and physical processes or management strategies occurring at these sites;
- Attribute components of unaccounted salt inflow to specific sites; and
- Attempt to quantify their contributions to unaccounted salt inflow from BIGMOD.

It is unlikely that the contribution of backwaters and disposal basins to unaccounted salt inflow can be described by a simple mathematical relationship as their input is often influenced by management decisions. However, an improved understanding of the processes occurring at specific sites may provide insight into how they may be modelled differently within BIGMOD and how physical processes relate to BIGMOD outputs e.g. storage of salt from the river channel in wetlands producing negative salt inflows. This analysis will improve understanding of historical salt inflow trends by attributing components of unaccounted salt inflow to particular sources thereby reducing the components of unaccounted salt inflow that are unknown or unquantified in BIGMOD.

Throughout this study, it is envisaged that detailed analysis of BIGMOD data will identify errors in raw salinity monitoring data used as model inputs. It is therefore likely that data review, identification of errors and data cleansing will be conducted and documented throughout the process of the study.

The aim of this analysis is to improve understanding of unaccounted salt inflow during floods by attributing components to specific sources or physical processes. This study does not seek to test fully the applicability of simple analytical models for their immediate incorporation into BIGMOD but instead outlines a process by which these can be identified, tested and potentially implemented. Figure 2.3 shown below outlines the approach of this study as described above. Green boxes denote key aims of this study and purple boxes indicate potential directions of future work and the process by which results from this analysis may be incorporated into BIGMOD.

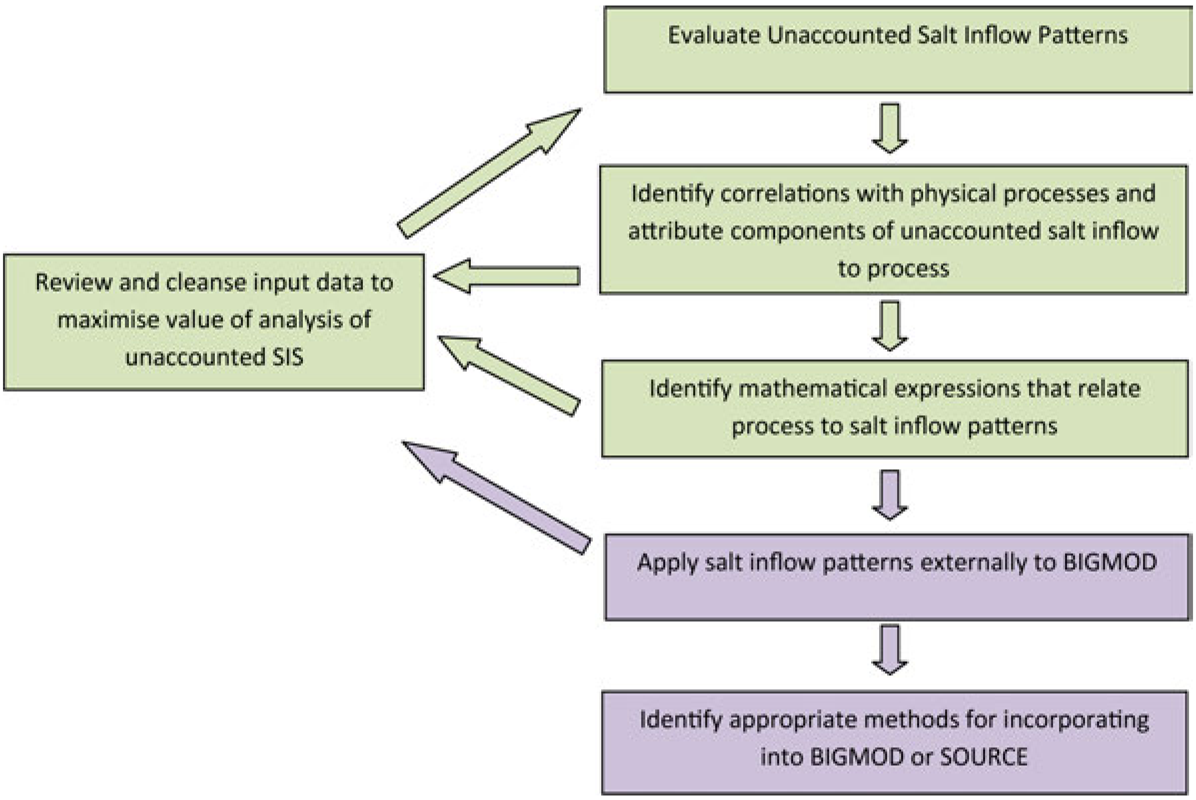

FIGURE 2.3: METHODOLOGY FOR EVALUATING FITNESS FOR BIGMOD MODIFICATION

3 Chowilla

3.1 Background

The Chowilla floodplain provides the “type locality” for inundation induced groundwater recessions and there is an extensive history of groundwater investigations, with numerous PhD’s and ongoing investigations for environmental watering at this location. The Chowilla floodplain is not affected by irrigation, only minimally affected by land clearance, and there are no permanent backwater lagoons on the floodplain. Figure 3.1 presents average salt inflow data from BIGMOD for all post flood periods (once flows have fallen below 20,000 ML/d) plotted cumulatively from Lock 9. It can be observed that there is no salt inflow between Locks 9 and 8, only 50 t/d entering the river between Locks 8 and 7 (i.e. the difference between the Lock 8 and Lock 7 curves) and a further 50t/d added to the river between Locks 7 and 6. However, between Lock 6 and Templeton an asymptotically declining salt inflow pattern can be observed, that commences at approximately 500t/d and declines to 150t/d after 300 days of recession (AWE 2011).

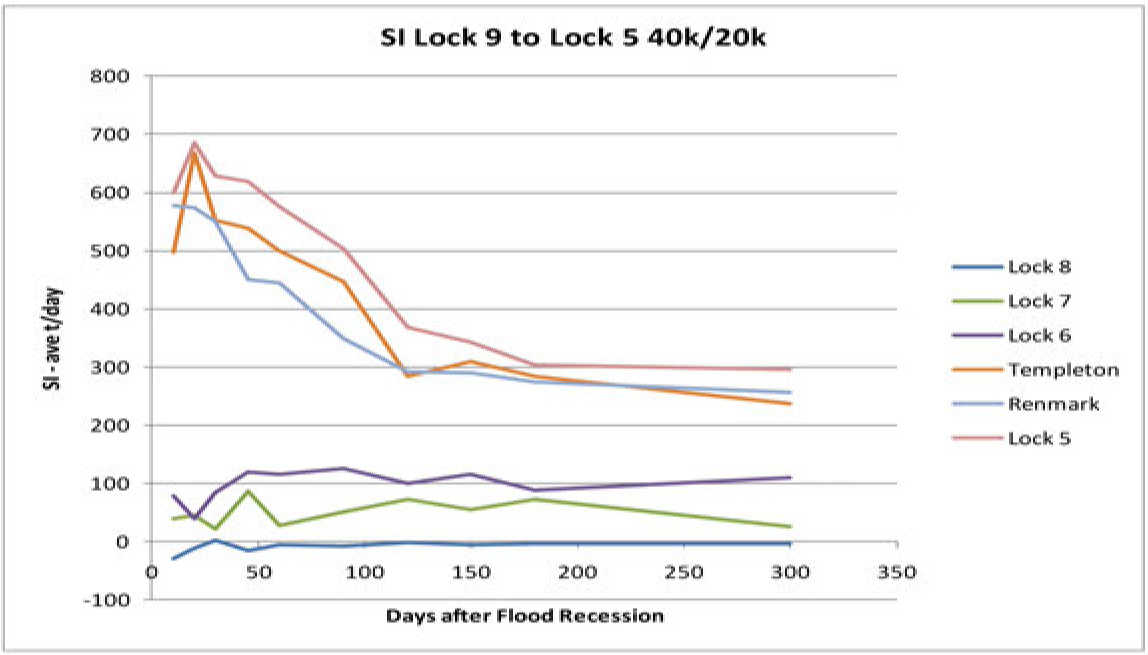

FIGURE 3.1: SALT INFLOW (LOCK 9 TO LOCK 5) VS TIME AFTER FLOOD RECESSION FLOWS FALL BELOW 20GL/D (AWE 2011)

Figure 3.2 below presents results from a groundwater model of the Murtho floodplain which is located immediately south of Chowilla and is characterised by a similar floodplain width. Results illustrate that the 1981 flood recession lasted for approximately 12 months after the flood peak occurred (as reported in AWE 2011). The shape and duration of the modelled groundwater recession curve and the BIGMOD average salt inflow recession curve are similar, reinforcing the correlation between salt inflow patterns and groundwater recession.

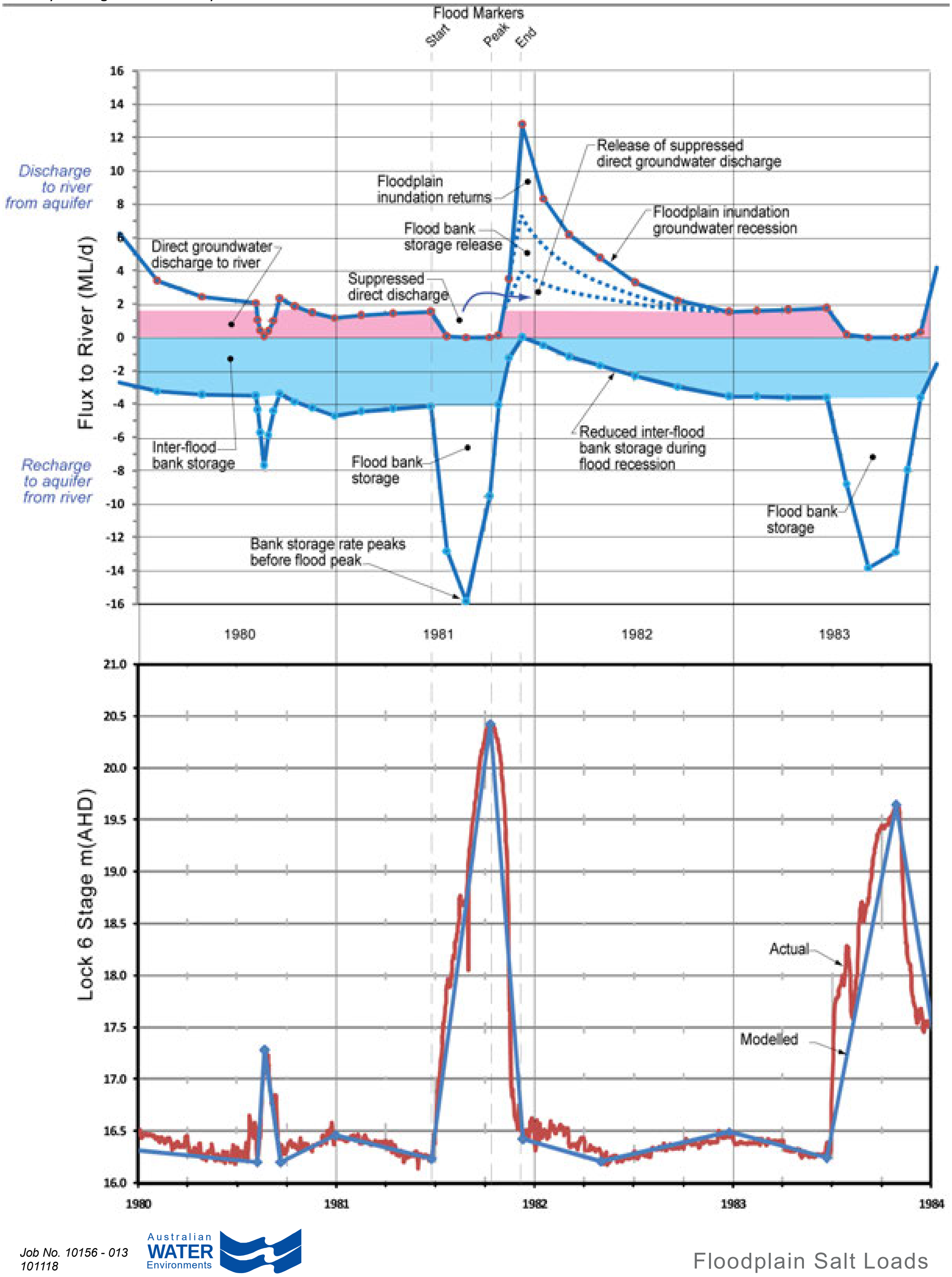

FIGURE 3.2: MODELLED GROUNDWATER INFLOWS AND OUTFLOWS DURING THE 1981 FLOOD ILLUSTRATING KEY COMPONENTS OF SATURATED ZONE SALT MOBILISATION (AWE 2011)

Previous work indicates that peak flow is a good indicator of total salt inflow during the post-flood period. AWE (2011) calculated that the average salt inflow in the 120 days following a flood recession varies linearly with flood peak, refer to Figure 3.3. This figure also illustrates that most of the salt inflow in the Lock 9 to Lock 5 reach occurs adjacent Chowilla (Lock 6 to Templeton). Overton *et al*. (2005) also concluded that the total salt inflow for the 365 days following a flood varies linearly with maximum flow, refer to Figure 3.4. Overton *et al*. (2005) provide indications of the effect of antecedent and post-flood conditions, highlighting in particular that the inter-flood duration had little effect on the post-flood salt inflows. Salt loads appear well correlated with flood peak.

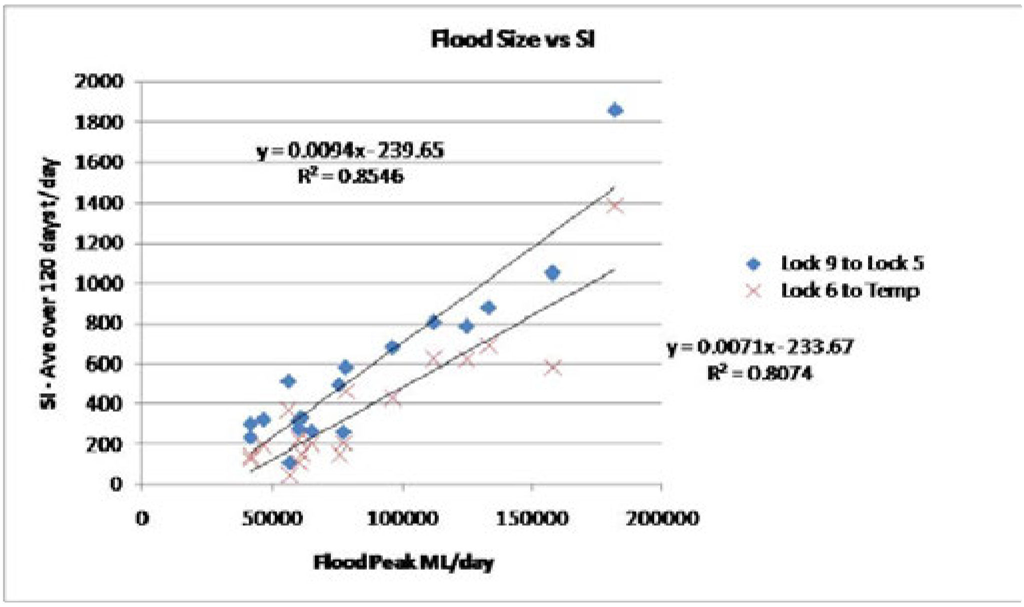

FIGURE 3.3: LINEAR RELATIONSHIP BETWEEN FLOOD PEAK FLOW AND SALT INFLOW (120 DAYS) (AWE 2011)

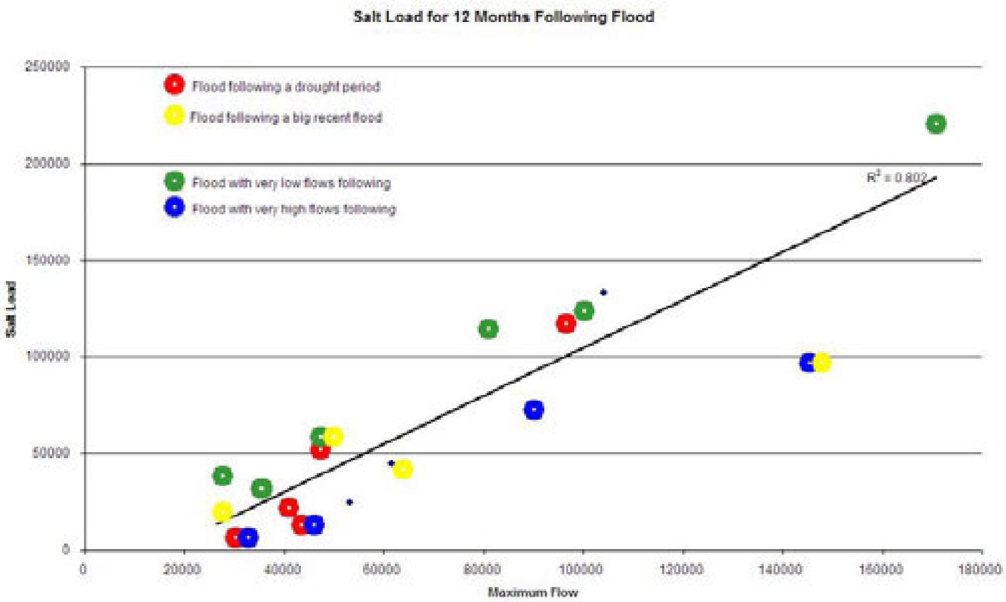

FIGURE 3.4: LINEAR RELATIONSHIP BETWEEN SALT LOAD (TONNES PER DAY) AND RIVER FLOW (ML/DAY) FOR CHOWILLA (FROM OVERTON *ET AL*. 2005)

3.2 Cumulative Flow and Salt Inflow

The following graphs illustrate the cumulative flow (Figure 3.5) and cumulative salt inflow (Figure 3.6) from the Chowilla reach. Flood events are shown in order according to peak flow which is also labelled in the legend. The analysis is limited to the period where flow to SA data is available (i.e. post 1977). Salt inflow is calculated as the difference between salt inflow between Lock 9 to Lock 6, and Lock 9 to Templeton from MSM-BIGMOD unaccounted salt inflow data (or downstream Chowilla Creek once that station was implemented).

The bottom left quadrant of the graph represents cumulative flow during the flood event (i.e. flow is totalled from when it first exceeds 40,000ML/d until it drops below 40,000ML/d). These curves trend upward until they pass through (0,0) which denotes the point at which flow drops below 40,000ML/d following the flood peak (flood recession). It can be observed that a major inflection point occurs in all the curves at this time with flat slopes indicating low flows during the recession. The majority of curves for each flood event follow the same trend after the inflection point (0,0). The exceptions to this are May 89, August 83, August 88 and August 78 floods, where flows remained relatively high during the recession (i.e. above allocation flow) causing them to deviate from the 'typical' response.

An increase in slope can be observed on many of the curves as time passes during the recession. This steepening of slope indicates increased river flows and in many cases the commencement of a subsequent flood. A comparison of slopes during the flood event (pre-0,0,) with those during the flood recession (post-0,0) will indicate which curves represent high flows and which represent floods. This influences analysis of the correlation between river flow characteristics and salt inflows, as discussed later. Many of the floods show an increase in flow during the recession after 270 days, and a smaller number show increases in flows from as early as 60 days.

The cumulative salt inflow plots shown in Figure 3.6 are presented in the same manner: negative days represent the flood period (i.e. flows above 40,000 ML/d) and positive days represent days after the flood has ended (i.e. 40,000 ML/d indicating the flood has ended), extending for 365 days irrespective of flow).

The key items to note are:

1. Salt inflows during the flood are quite variable.
2. The cumulative salt loads trace relatively smooth curves, and deviation below the curve occurs once flows increase above the base cumulative flow trend (i.e. when the cumulative flow curve steepens due to increased river flows). This occurs because the increasing flow corresponds to increasing water levels in the River and anabranches that in turn suppress groundwater discharge and therefore salt inflow to the river.

3. Flood recessions that extend for 270 days or more are very useful for identifying a "typical" salt inflow pattern. Once higher flows intervene, the salt inflow is suppressed by the rising river level. Based on the cumulative flow curves, it can be expected that the salt inflow curves for the November 79, August 81, September 84, August 95, August 96, October 91 and October 86 flood events will provide the typical salt inflow pattern during the recession for at least 180 days and even 365 days in some instances. The cumulative flow and cumulative salt load curves for these "typical" flood events are illustrated in Figure 3.7 and Figure 3.8.

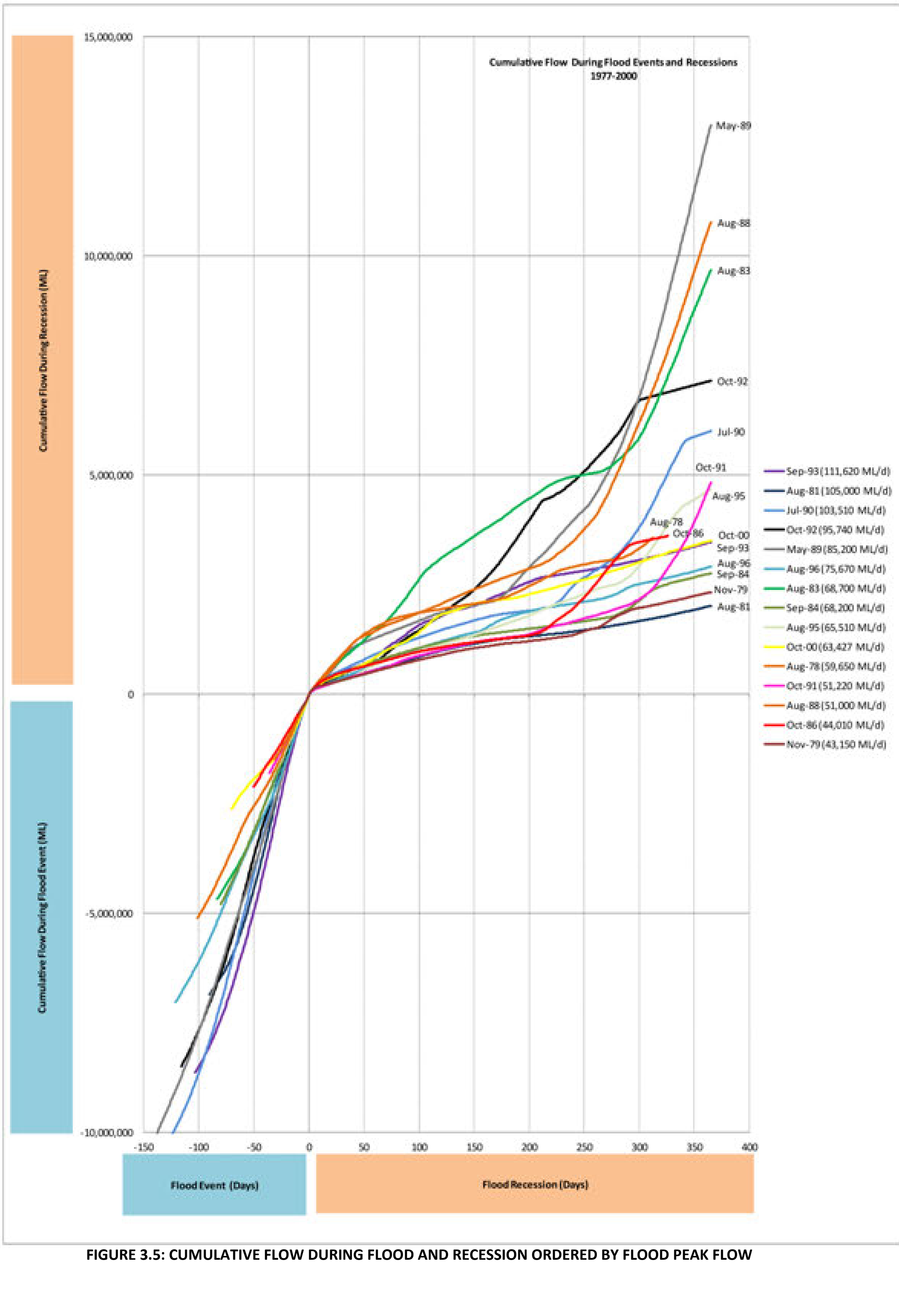

FIGURE 3.5: CUMULATIVE FLOW DURING FLOOD AND RECESSION ORDERED BY FLOOD PEAK FLOW

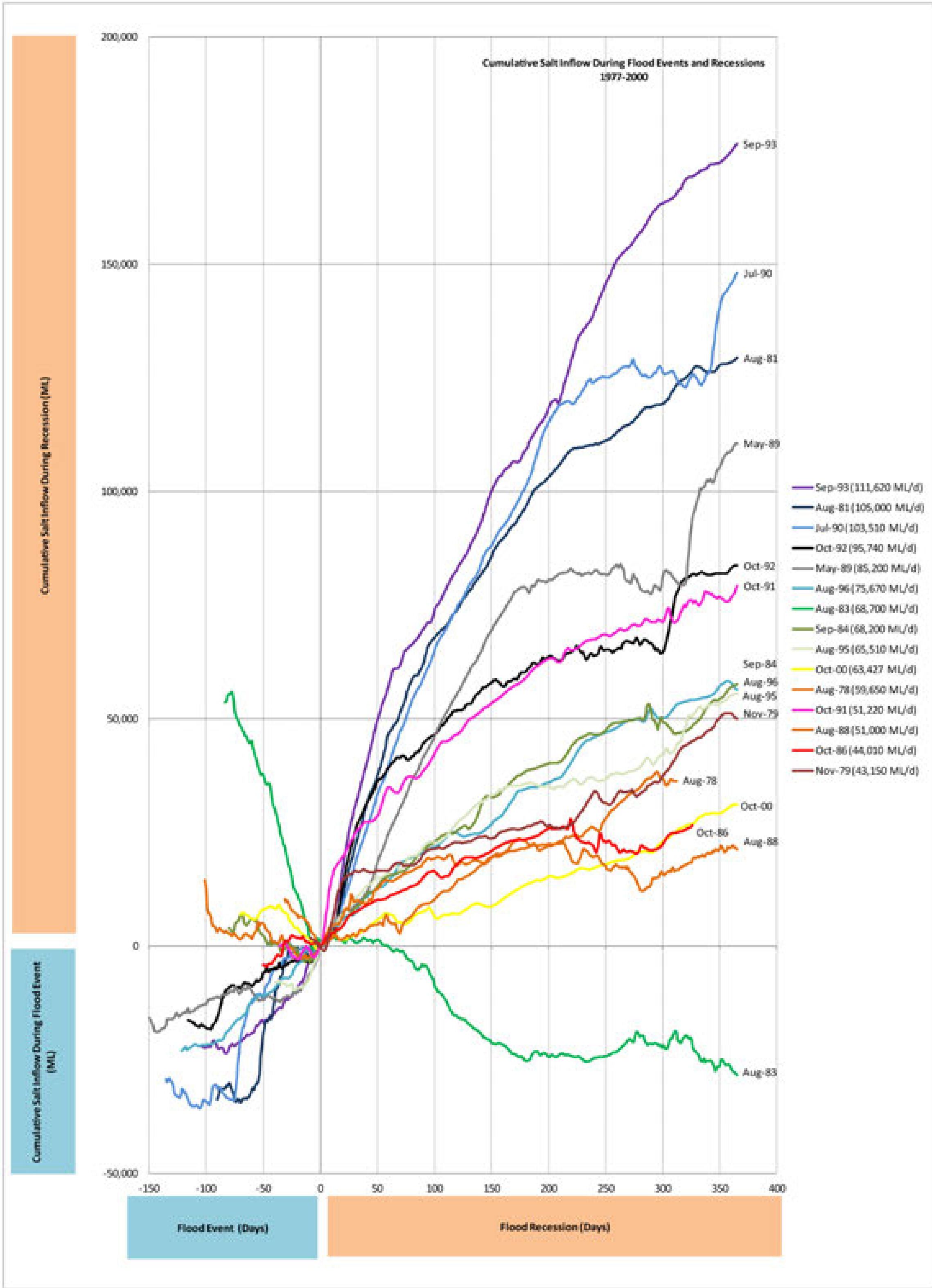

FIGURE 3.6: CUMULATIVE SALT INFLOW DURING FLOOD AND RECESSION ORDERED BY FLOOD PEAK FLOW

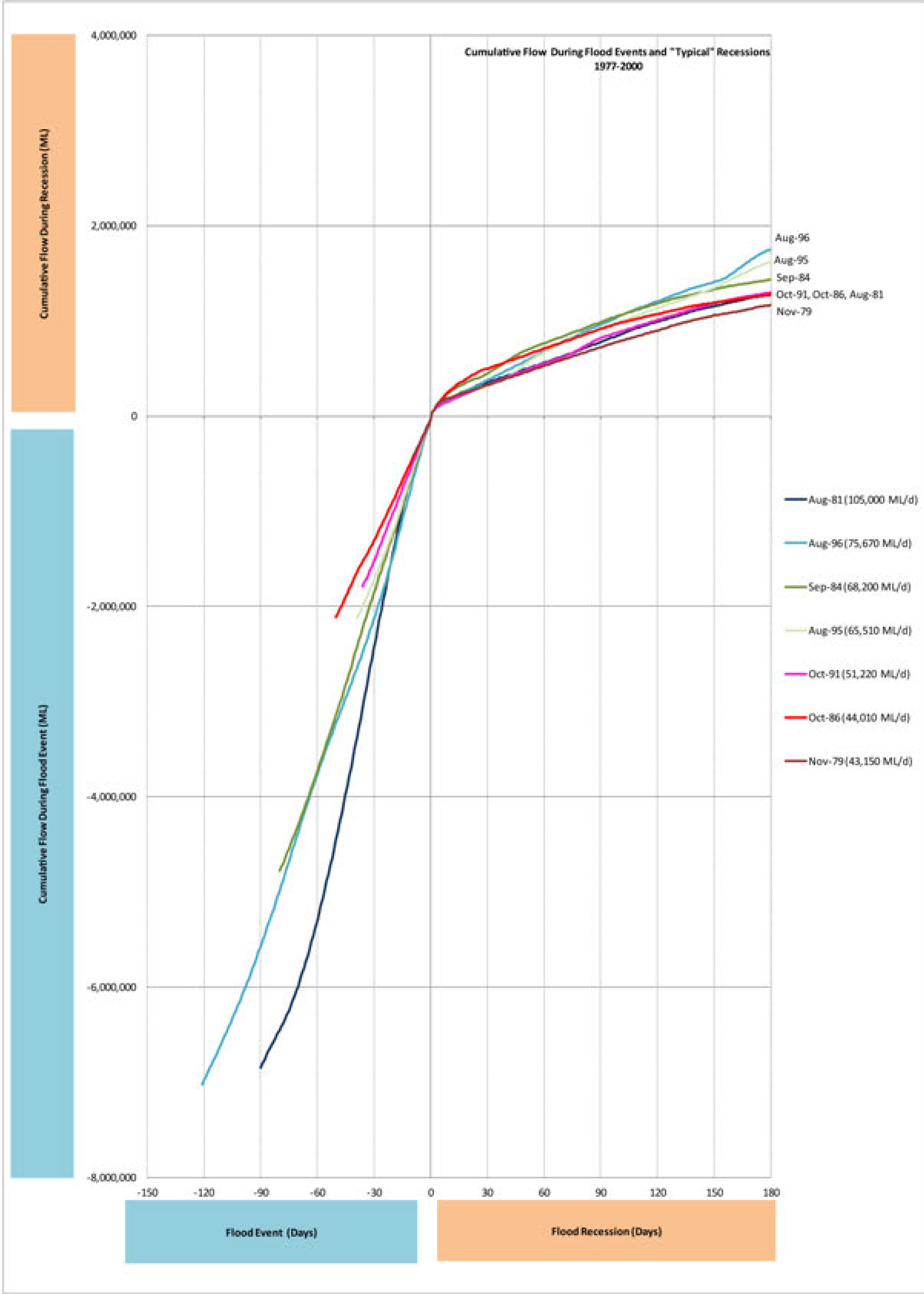

FIGURE 3.7: CUMULATIVE FLOW DURING FLOOD AND "TYPICAL" RECESSIONS

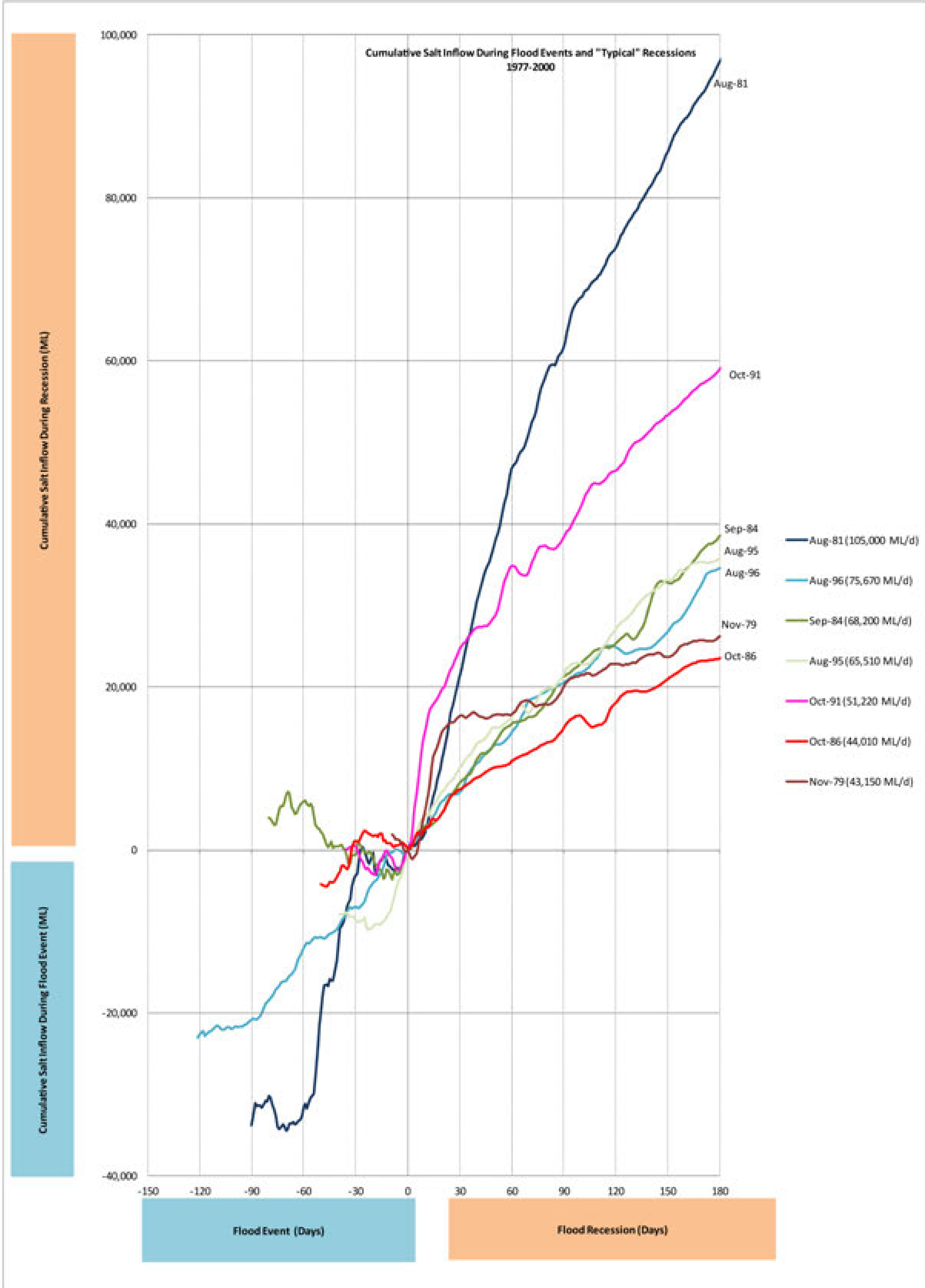

FIGURE 3.8: CUMULATIVE SALT LOAD DURING FLOOD AND "TYPICAL" RECESSIONS

The key items to note in Figure 3.6 (i.e. 'Cumulative salt inflow during flood and recession ordered by flood peak flow') are that:

1. Salt inflows follow a smooth curve before being suppressed by an increase in river flow. All curves seem to be of the same form/shape, suggesting a common controlling process.
2. Cumulative salt load increases with increasing peak flow.
3. The October 86 flood, which barely exceeds the 40,000 ML/d flood threshold, has the lowest salt inflow.
4. The three floods in August 96 (75,670 ML/d), September 84 (68,200 ML/d) and August 95 (65,510 ML/d) have virtually identical cumulative salt inflow traces. The October 91 trace is atypical in the first 30 days, but if that atypical salt input was removed the October 91 trend would also parallel these three other floods. This suggests that there is no significant difference in the salt mobilisation processes between flow ranges of 51,000ML/d and 75,000ML/d.
5. The cumulative salt inflow curve for the October 1991 flood shows an atypical salt inflow response and suggests a potential input data error. Figure 3.9 (below) presents instream salinity data between Lock 7 and Lock 5 during the 1991 flood. From this data it can be observed that only one salinity measurement was taken at Templeton (station used to calculate salt inflow from Chowilla in the above graphs) during the first week of the flood. The salinity measurement during this time is quite high and not observed in the downstream stations. This suggests that the atypical salt inflow response during the 1991 flood recession is due to erroneous input data.
6. Similarly, the cumulative salt inflow curve for the November 1979 flood event also shows an atypical salt inflow response suggesting a possible data error. Figure 3.10 (below) presents the instream salinity monitoring data between Lock 7 and Lock 5 for the flood event. At this time, monitoring data at Templeton was collected on a weekly basis and during the flood recession salinity was high, matching that measured downstream at Lock 5. This high salinity combined with elevated river flows during the recession is likely to have caused the higher than expected salt inflows calculated for early recession time period of this event. Some additional high salinity measurements recorded at Templeton during the first month of the recession are also likely to have contributed to this.
7. Salt Inflow data for the August 1983 event indicates negative inflow throughout the majority of the flood recession. The recession period for this flood event is unique compared to the other floods analysed. River flow during the recession remains elevated (>20,000 ML/d) for 8 months following the flood peak, effectively suppressing salt inflow during this time and then the September 84 flood event commences.
8. Salt inflow from the August 1981 flood (105,000 ML/d) is significantly higher than the preceding floods – for a flow increase of 30% there is a salt load increase of 120%. This suggests some trigger point is crossed that mobilises a significant new salt source at these higher flows.

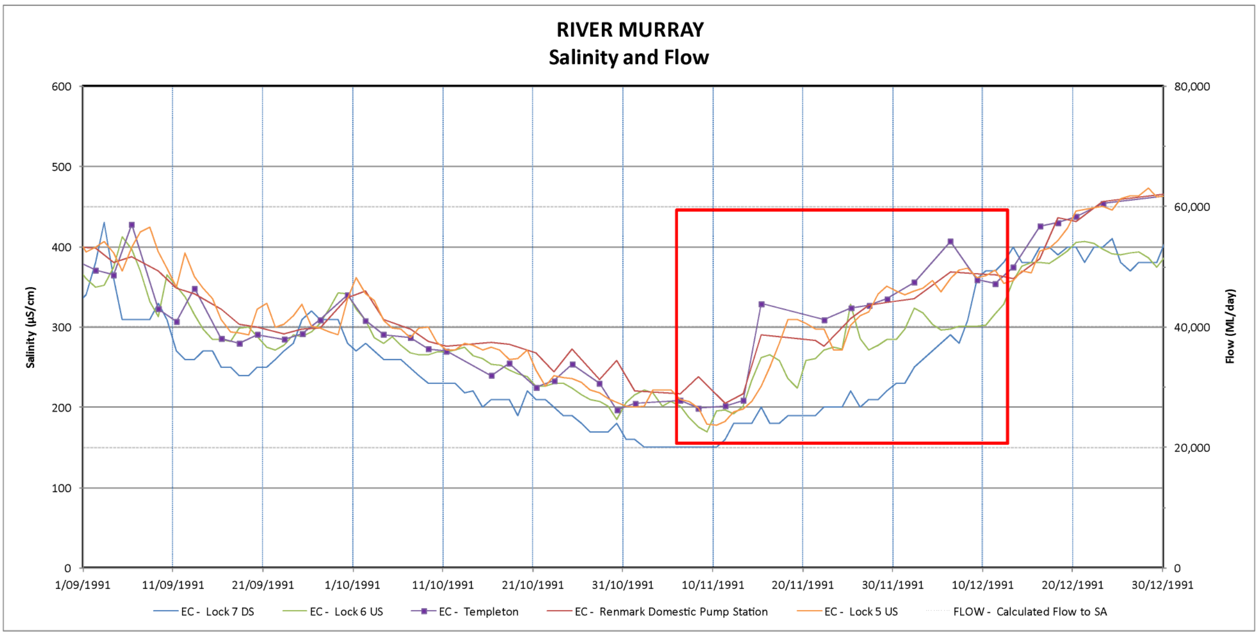

FIGURE 3.9: INSTREAM SALINITY MONITORING DATA LOCK 7 TO LOCK 5 DURING 1991 FLOOD EVENT.

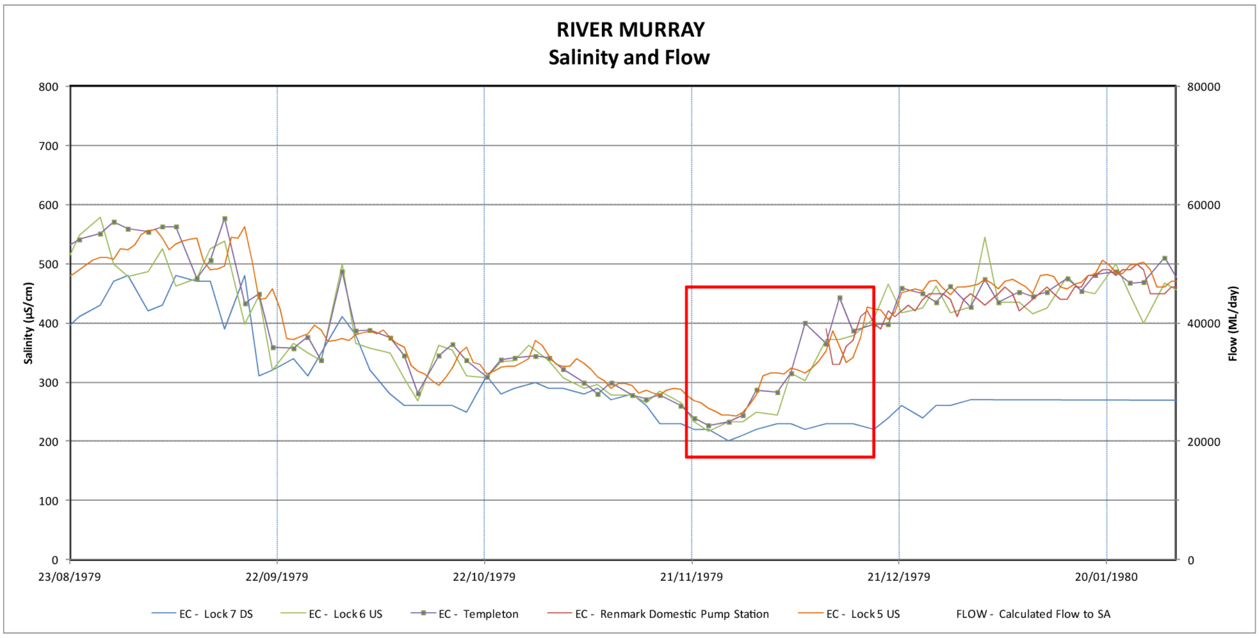

FIGURE 3.10: INSTREAM SALINITY MONITORING DATA LOCK 7 TO LOCK 5 DURING THE 1979 FLOOD EVENT.

The source of the trigger points or thresholds has been examined by looking at the inundated area versus flow for the Chowilla floodplain. Figure 3.11 and Figure 3.12 illustrate that there are three small flow bands where rapid increases in area occur with a correspondingly small increase in flow. These three bands occur at the following flows:

- The first commences at flows between 46,000 ML/d and 50,000 ML/d;
- The second can be observed as a small step between 72,000 and 73,000 ML/d when Coombool Swamp fills; and
- The third is a very significant increase in inundated area at flows of between 77,000 and 82,000 ML/d.

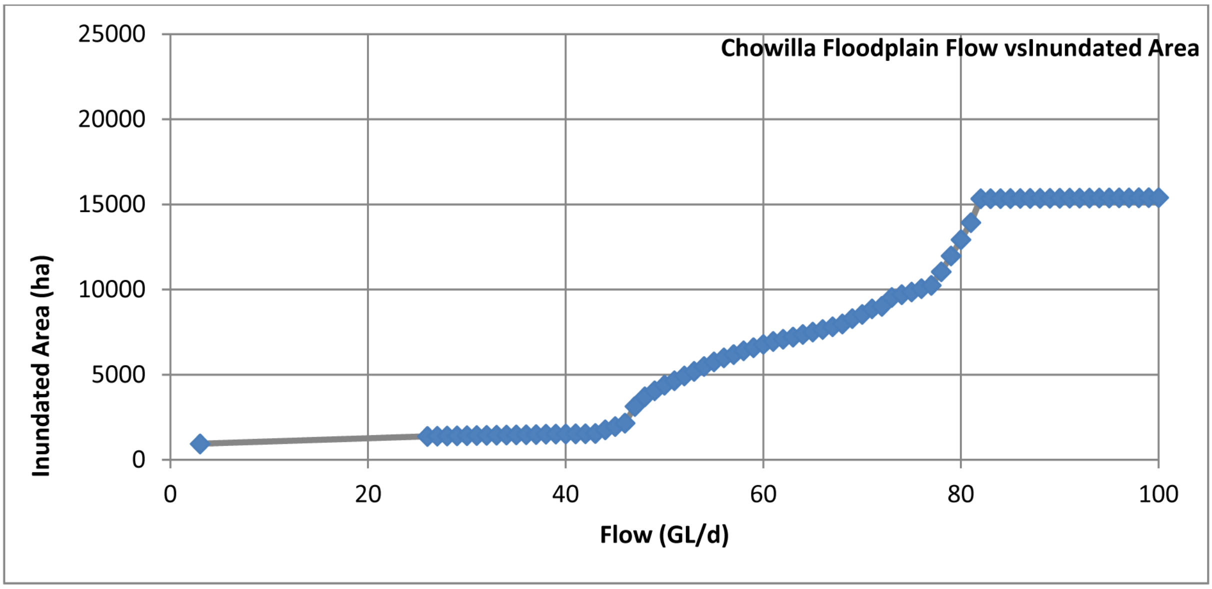

FIGURE 3.11: INUNDATED AREA VS FLOW FOR THE CHOWILLA FLOODPLAIN (AFTER RIMFIM MODEL)

The floodplain areas that are inundated by each of these three flow bands are illustrated in Figure 3.12.

- The low flow band occurs on the western side of the floodplain predominantly downstream Lock 6;
- Coombool Swamp is highlighted in yellow and is the major contributor to the mid flow band;
- The high flow band is distributed across the floodplain but biased towards the eastern, upstream section of the floodplain; and
- Inundation area increases only marginally above flows of 82,000 ML/d.

There appears to be a correlation between the area inundated by flows exceeding 77,000 ML/d and the rapid increase in salt load. The source of this rapid increase in salt inflow has not yet been identified. It may be sourced from a specific location (e.g. Tilmy Swamp) or it may be the cumulative effect of recharge across the entire area inundated by high flows (orange-red).

RPS Aquaterra (2012) present a map of groundwater salinity inferred from an AEM survey of the floodplain (Figure 3.13). Similarly, Figure 3.14 presents AEM data at watertable overlain with salinity monitoring data. A summary of this groundwater salinity data for the Monoman Formation is presented in Table 3.1 (below). It can be observed that groundwater salinity on the eastern side of the floodplain is higher with an average of 66,964 µS/cm compared to that on the western side with an average of 46,258 µS/cm. This pattern of salinity is also supported more broadly by AEM data. The western section of the Chowilla floodplain becomes inundated at lower flows and floods more frequently than the eastern side. Groundwater mobilised as a result of inundation of the western section of the floodplain by low flow floods is of lower salinity than that mobilised by less frequent, high flow flood events to the east. This variation in groundwater salinity between the eastern and western sections of the floodplain and the difference in flow required to inundate these sections of floodplain may explain the significant increase in salt inflow that occurs when river flow exceeds 77,000 ML/d.

TABLE 3.1: GROUNDWATER SALINITY STATISTICS FOR THE CHOWILLA FLOODPLAIN

EC Statistics (µS/cm)	Chowilla - Western Floodplain	Chowilla – Eastern Floodplain
Minimum	586	16,000
Maximum	82,517	88,200
Average	46,258	66,964
Average (g/L)	30	43

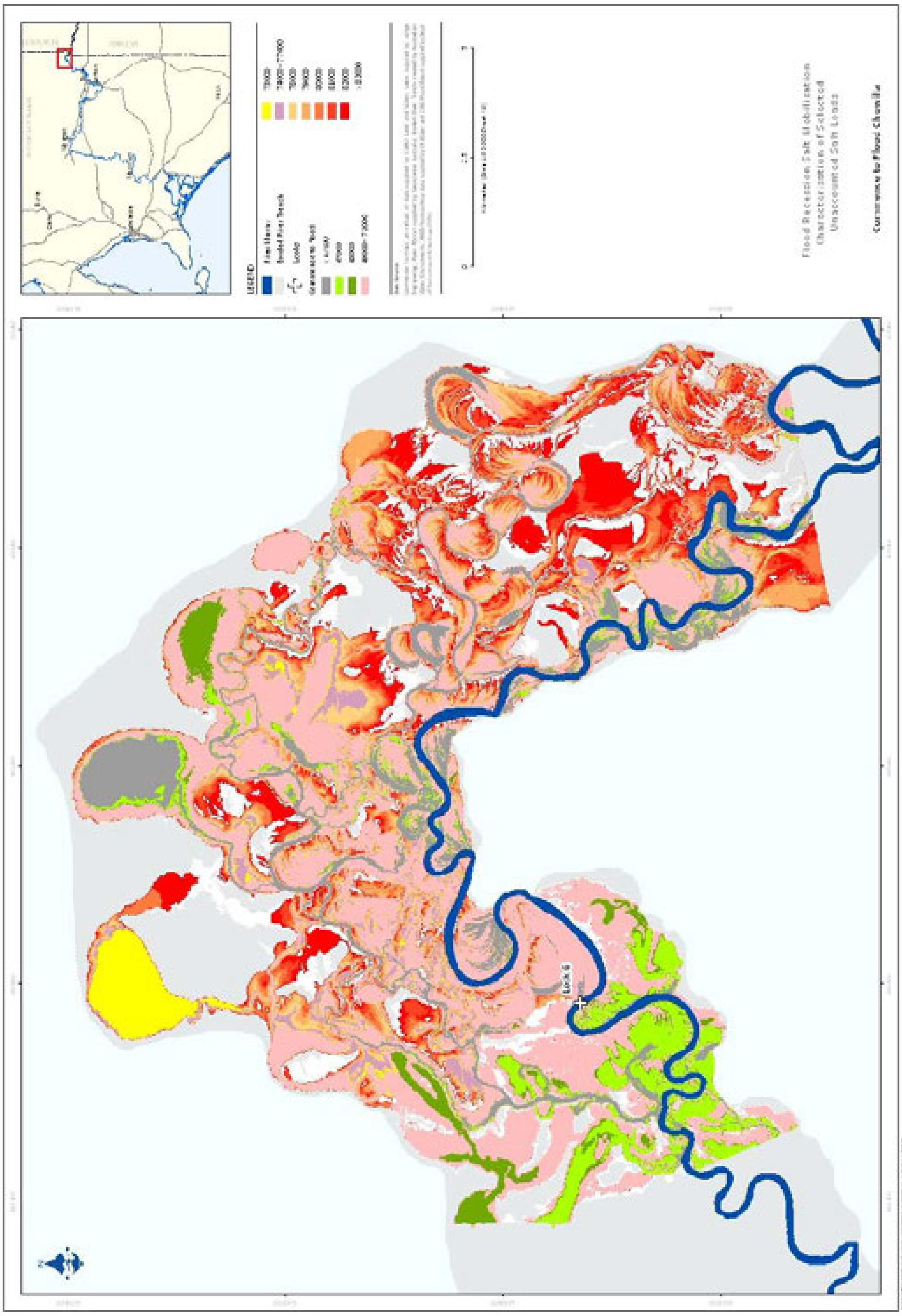

FIGURE 3.12: INUNDATED AREA VS FLOW FOR THE CHOWILLA FLOODPLAIN (AFTER THE RIMFIM MODEL)

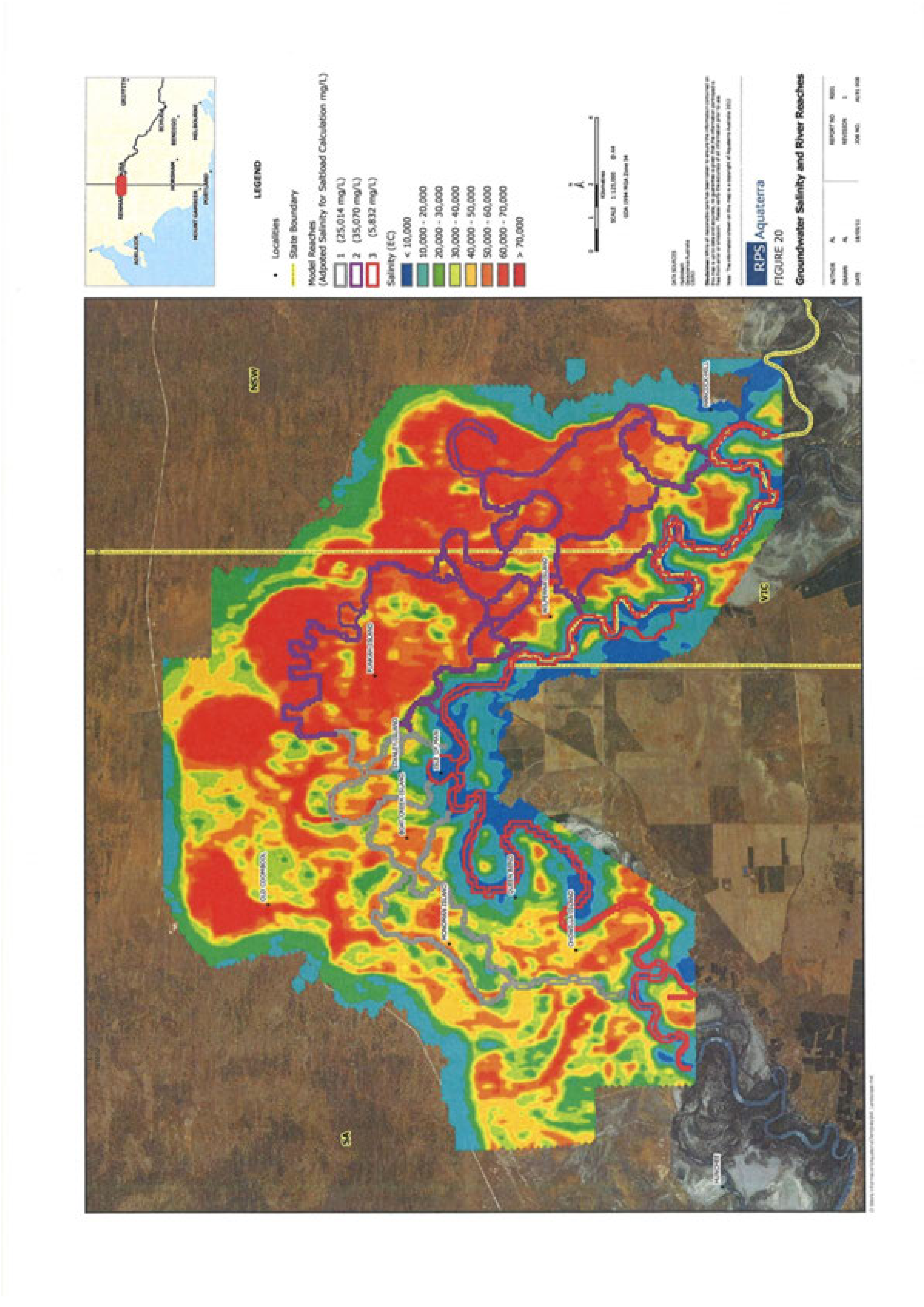

FIGURE 3.13: CHOWILLA GROUNDWATER SALINITY FROM AEM DATA (RPS AQUATERRA 2012)

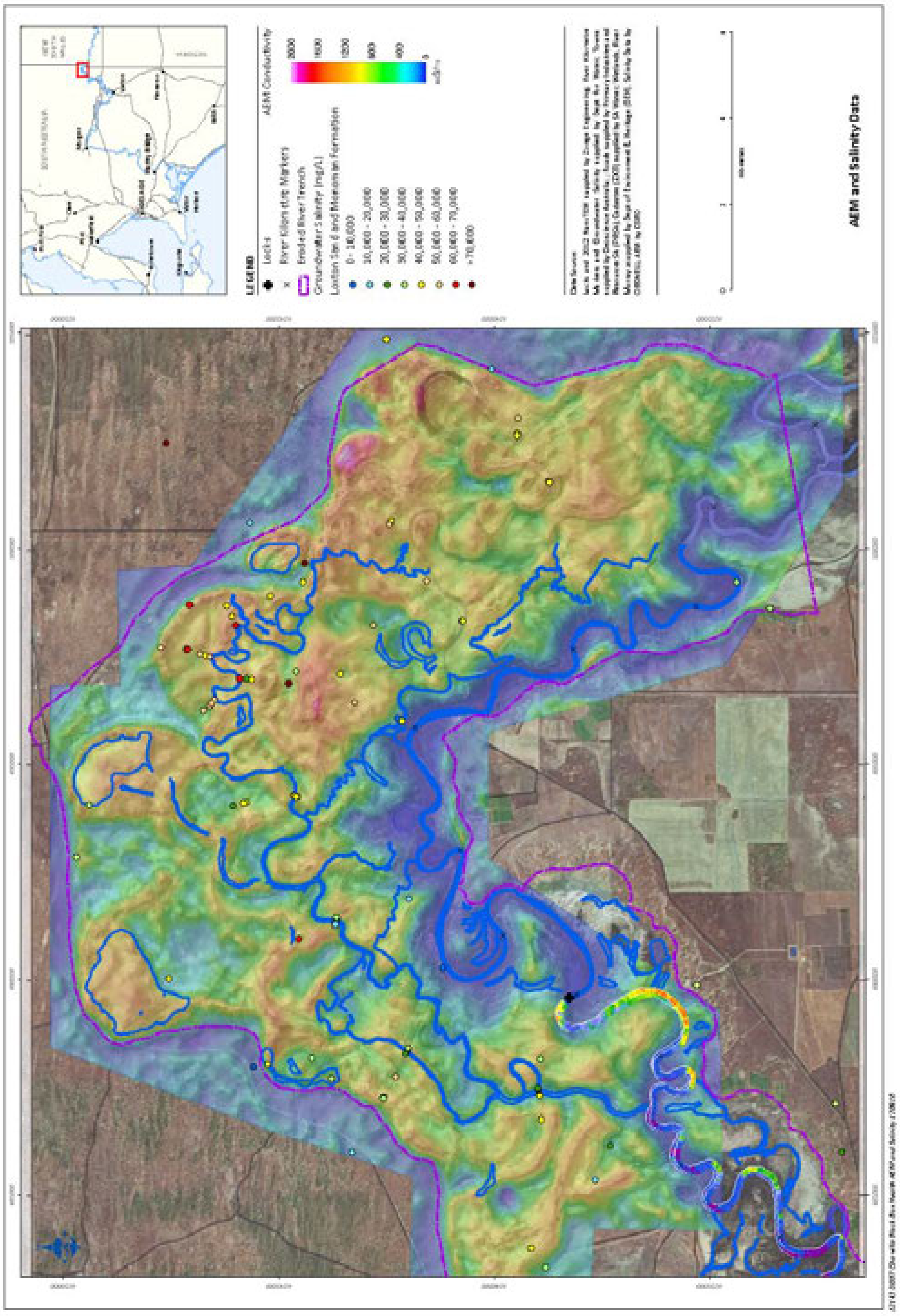

FIGURE 3.14: AEM AND SALINITY MONITORING DATA FOR THE CHOWILLA FLOODPLAIN

3.3 Salt Inflow: Correlations with Factors other than Peak Flow

The above analysis has described the relationship between salt inflow, peak flow and cumulative flow during floods and their subsequent recessions. The following analysis examines the relationship between salt inflow and other flood characteristics including inundated area, antecedent conditions and suppression time, to confirm that cumulative and peak flow are the best predictors of salt inflow.

In the following analysis flood events are grouped by colour according to their cumulative flow 'type' curve as follows:

- Green data points represent floods that display a "typical" flood recession curve;
- Orange data points represent floods that initially follow the "typical" type curve but then deviate due to an increase in flow during the recession period (at approximately 50 days); and
- Red data points reflect flood events that do not follow the cumulative flow "typical" type curve (3 in total) where flows during the recession remain high (i.e. above allocation flows) for a long period of time.

It should also be noted that the August 1983 flood event has not been included in the plots or linear regression calculations presented below as salt Inflow data for this event indicates negative inflow throughout the flood recession. The recession period for this flood event is unique compared to the other floods analysed. River flow during the recession remains elevated (>20,000 ML/d) for 8 months following the flood peak, effectively suppressing salt inflow during this time, before the September 1984 flood event commences.

3.3.1 Peak Inundated Area

Previous analysis of flood events identified a linear relationship between salt inflow and flood peak (AWE 2011 and Overton *et al*. 2005). As the peak flow rate determines the area of inundation, a linear relationship also exists between peak inundated area and cumulative salt inflow although, the correlation is not as strong. In this example salt inflow was totalled over the duration of a 180 day flood recession (i.e. once flow to SA has fallen below 40,000ML/d) after the flood peak. The 180-day flood recession time was chosen to prevent salt inflow calculations being affected by subsequent floods. Figure 3.15 plots cumulative salt inflow and peak inundation area for the Chowilla floodplain. Linear regression analysis of this data gives an R squared coefficient of 0.66 suggesting some correlation between these factors so that as inundation area increases so does salt inflow.

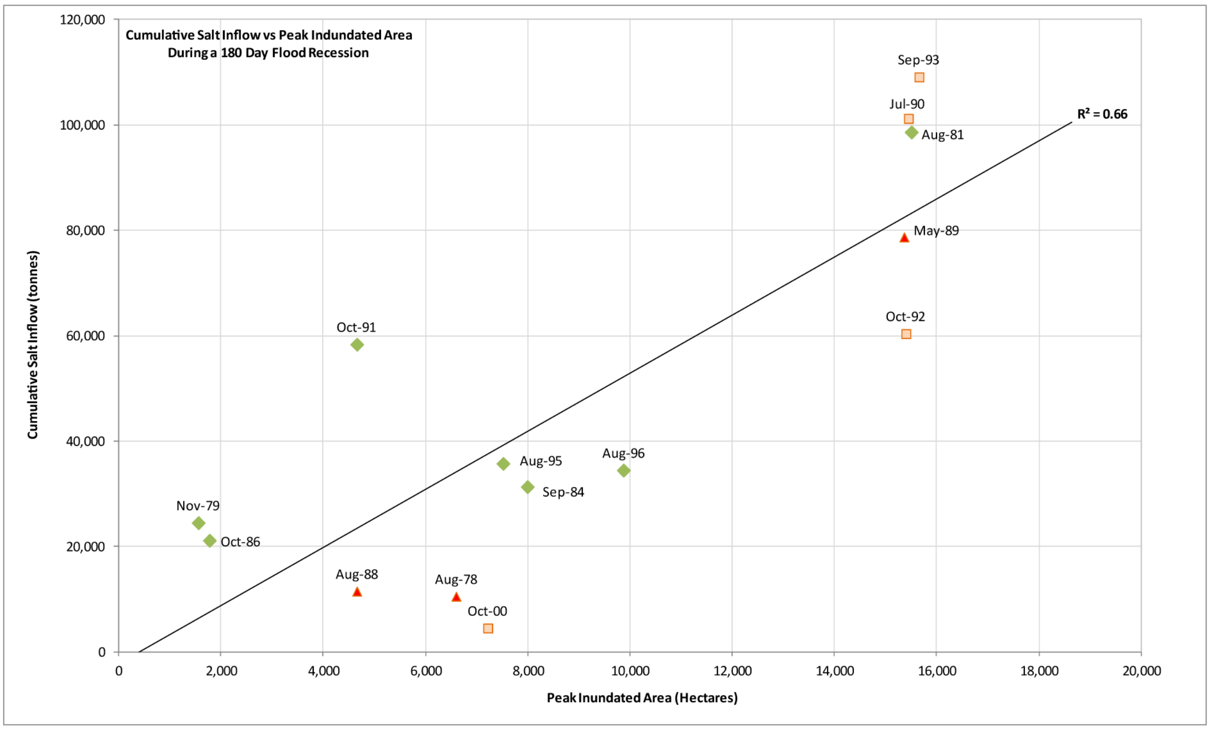

FIGURE 3.15: CUMULATIVE SALT INFLOW VS PEAK INUNDATED AREA FOR 180 DAY FLOOD RECESSION

3.3.2 Antecedent conditions

Early hypotheses of flood salt mobilisation processes operating within the Chowilla floodplain suggested that the primary source of salt was that stored in floodplain soils. In this case, it would be likely that floods following long periods of drought would generate higher salt inflows than those that occurred during periods of high flooding frequency due to the extended accumulation time between flood events. However, salt inflow analysis presented in Overton *et al*. (2005) found no correlation between salt inflows generated from floods and the antecedent flow regime (Figure 3.4). The relationship (or lack thereof) between cumulative salt inflow and cumulative flow prior to a flood event is also presented in Figure 3.16. This plots the cumulative salt inflow during a 180 day flood recession against the cumulative flow over the 450 days leading up to the flood event . From this data it can be observed that there is no correlation between the antecedent flow regime and salt inflow.

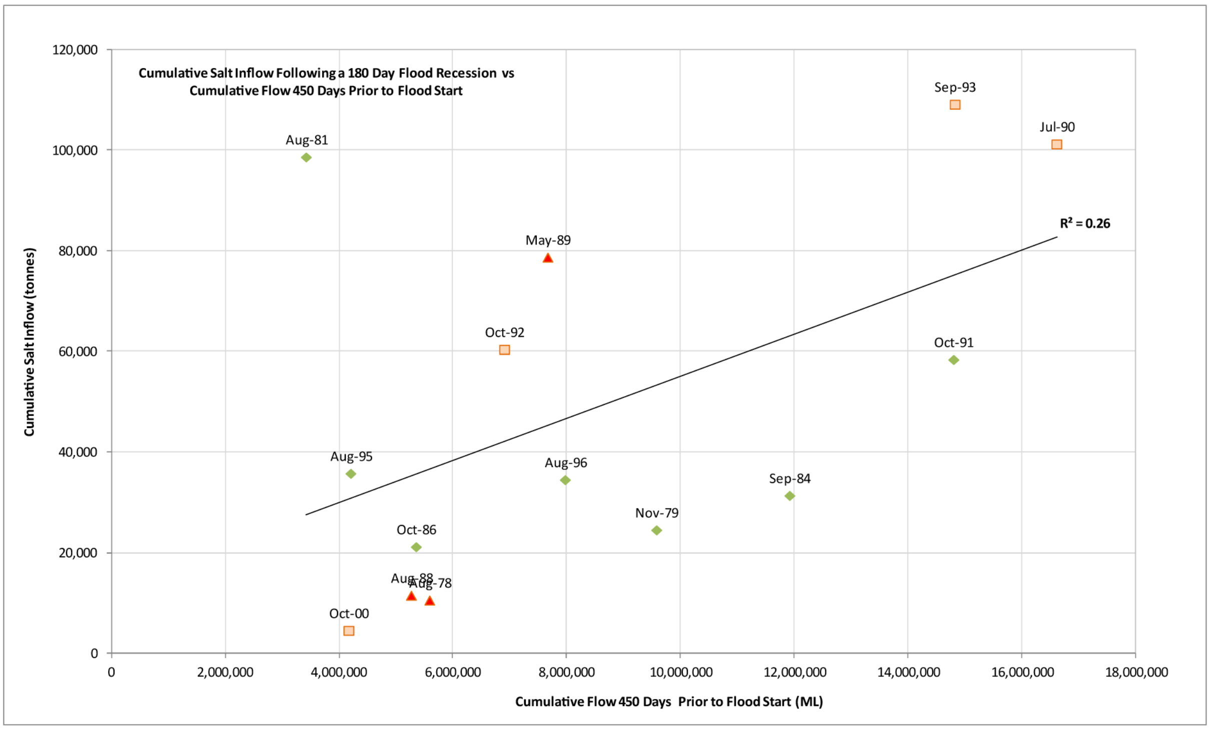

FIGURE 3.16: CUMULATIVE SALT INFLOW AND ANTECEDENT FLOW REGIME

3.3.3 Vertical Conductivity of the Floodplain

It has been hypothesised that localised recharge during flood events was the dominant source of salt mobilisation within the floodplain (Jolly *et al*. 1994; Overton *et al*. 2005). In this case, groundwater levels rise in the floodplain as the result of localised recharge and generated salt loads through long flood recessions. However, it is difficult to predict salt loads arising from localised recharge due to the complexity of the processes and the limited data available to identify likely zones of local recharge.

The rate of floodplain infiltration will be controlled principally by the vertical hydraulic conductivity of the Coonambidgal Formation (the generally clayey or silty surficial unit in the floodplain). However, the relationship between salt inflow and vertical hydraulic conductivity is difficult to evaluate due to poor data availability.

Modelling of the Chowilla floodplain by Jolly *et al*. (1994), recognised the spatial variability of the floodplain vertical hydraulic conductivity. This study concluded that, based on calibration to groundwater trends during the flood, uniform recharge across the entire floodplain was not the primary driver of the observed groundwater trends, and a remote recharge zone was required to provide an acceptable calibration. Yan *et al*. (2005) in modelling the Chowilla floodplain, applied different recharge rates based on three broad floodplain soil classifications.

To date, extensive infiltration of floodwaters through the Coonambidgal Clay has not been verified by empirical data. To the contrary, paired pre- and post-flood soil salinity profiles at the same site at Chowilla suggest that infiltration did not occur (Akeroyd *et al*., 1998). The hypothesis that infiltration of floodwaters from overbank flow is a dominant contributor to rises in floodplain water levels and to the groundwater recession flux, will not be further evaluated in this study. Zones of high vertical conductivity may provide a mechanism by which to explain the sudden increase in salt inflow to the River for flows exceeding 77,000 ML/d however, this cannot be verified using current data sets.

3.3.4 Salt Inflow and Suppression Time

During inter-flood periods, groundwater flux to River occurs where gaining stream conditions prevail and this flux represents direct groundwater discharge to River. In reaches where losing stream conditions occur, water is lost from the river to the floodplain through bank storage. Reaches that experience gaining stream conditions are commonly those close to the source of regional groundwater inflow (i.e. river reaches adjacent cliffs or narrow floodplains). Whereas reaches that experience losing stream conditions are generally distant from the floodplain edge (i.e. river reaches adjacent wide floodplains). Losing reaches are caused by evaporation from the floodplain, which depresses the groundwater head in the floodplain to below river level.

In gaining reaches, during the rising limb of a flood, direct groundwater discharges to the river and connected surface water bodies is suppressed. A rise in the river stage reduces or reverses the gradient between the river and floodplain aquifer. This suppresses groundwater discharge and causes a rise in groundwater levels in both the floodplain and highland aquifers. Groundwater flux to the river recommences during the falling limb of a flood, as water levels fall the gradient and hence flux, between the aquifer and the river increase. In this case, the location of suppressed groundwater discharge is likely to occur where losing stream conditions are present during the inter-flood period and the development of freshwater lenses is likely to be minor or non-existent. Groundwater that has been suppressed during the rising limb of a flood is likely to be saline but may be partially mixed with fresh water held as bank storage.

Figure 3.17 presents the relationship between cumulative salt inflow and suppression time for the river reach between Lock 6 and Templeton. In this example, the suppression time has been calculated as the number of days between river flows firstly exceeding and subsequently falling below 40,000ML/d. The cumulative salt inflow is totalled over a 180-day flood recession. Data suggests that in this section of river suppression time (flood duration) is not significantly related to salt inflow as correlation between factors is poor.

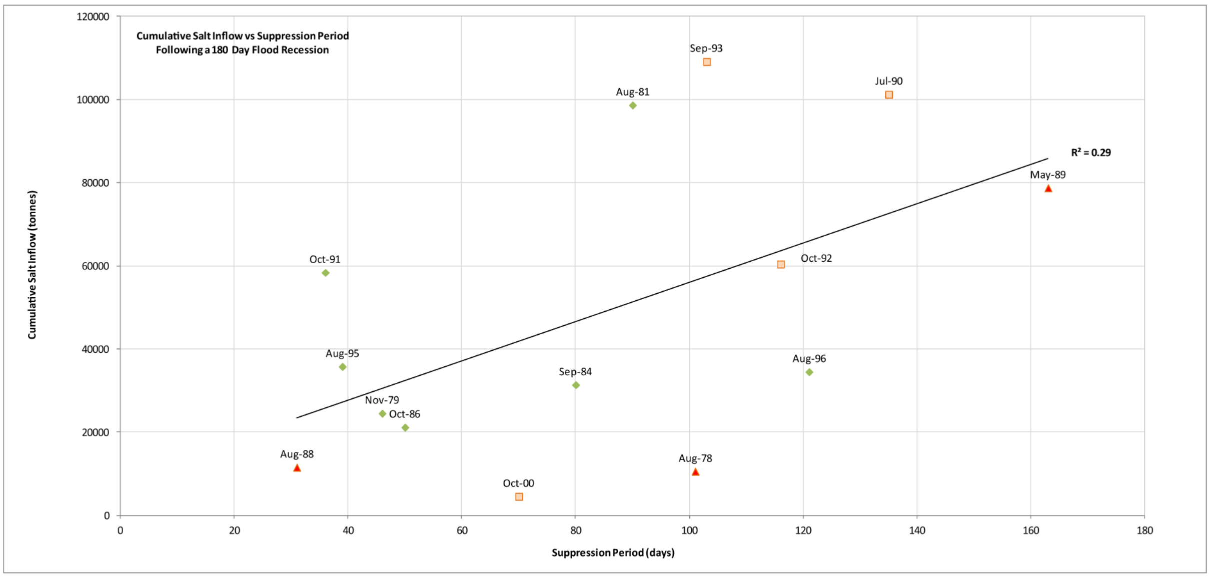

FIGURE 3.17: RELATIONSHIP BETWEEN CUMULATIVE SALT INFLOW AND SUPPRESSION TIME FOLLOWING A 180 DAY FLOOD RECESSION

3.4 Summary of Correlation Coefficients

A summary of the strength of correlations between salt inflow and other flood characteristics is presented in Table 3.2 below. This suggests that peak flow is the best correlative for cumulative salt inflow. As this is the strongest relationship, it will be tested through the application of a simple model to determine if cumulative salt inflow can be replicated using peak flow.

TABLE 3.2: SUMMARY OF CORRELATION BETWEEN SALT INFLOW AND OTHER FLOOD CHARACTERSITICS

Flood Characteristic	Correlation Coefficients
Peak Flow	0.85 (from AWE 2011)
Area Inundated	0.66
Antecedent Flow Regime	0.26
Suppression Time	0.29

3.5 Conceptual Model of Step Wise Salt Inflow

The correlation between peak flow and cumulative salt inflow during flood recession has been established and data suggests that this relationship may be described by a step function (refer to Figure 3.18 below). Cumulative salt inflow is similar for floods that have a peak flow of less that 77,000ML/d, particularly those that display a “typical” cumulative flow curve (green data points). This suggests that salt mobilisation during the recession of these floods is controlled by the same process. However, a significant increase in salt inflow occurs for a relatively small increase in river flow (i.e. a step increase) when peak flow exceeds 77,000ML/d. This step increase is also observed in the relationship between flow and inundation area of the Chowilla floodplain where a significant increase in inundated area occurs for flows of between 77,000ML/d and 82,000ML/d. This suggests that flows of this magnitude trigger a mechanism of salt inflow that mobilises a new and significant store of salt that is not otherwise mobilised by floods of a lesser magnitude. The source of this salt has not been conclusively identified however it may relate to the vertical hydraulic conductivity of floodplain deposits or the salinity of groundwater beneath the inundation area. The role of vertical hydraulic conductivity is difficult to assess based on existing data sets. Salinity data has been assessed and suggests that groundwater is more saline beneath the eastern section of the floodplain, which coincidently is only inundated by high flow floods. This correlates well with the step wise salt inflow conceptual model.

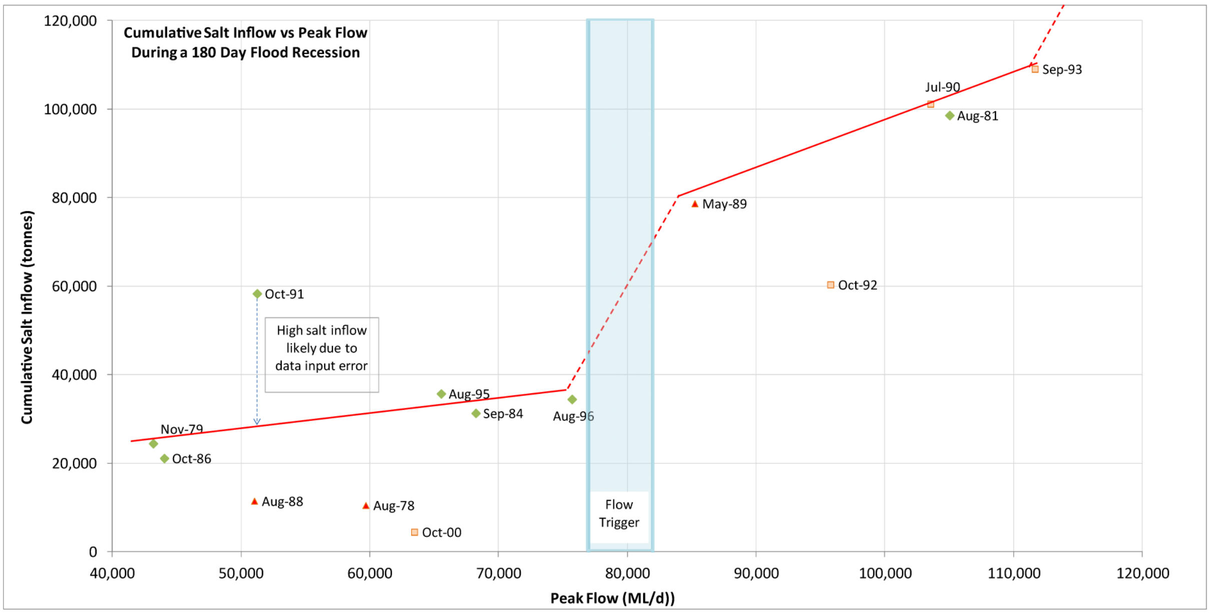

FIGURE 3.18: CUMULATIVE SALT INFLOW VS. PEAK FLOW DEMONSTRATING STEP WISE SALT INFLOW CONCEPTUAL MODEL

4 Modelling BIGMOD Unaccounted Salt Loads at Chowilla

4.1 Analytical models

Surface water management and planning within the Murray Darling Basin has historically been undertaken through the use of river system models such as MSM-BIGMOD. However, these models vary between the Basin States making a basin wide approach to management difficult. These models also tend to have limited capacity to simulate salt inflow processes from wetlands and floodplains. As a result a new integrated, basin wide approach is being developed through the eWater CRC known as the Source IMS. This modelling framework aims to incorporate all the capabilities of the existing river system models while also providing additional functionality.

4.1.1 “Groundwater-Surface water link" (GW-SW Link) module

In literature, groundwater-surface water interactions are modelled at different levels of complexity (Rassam and Werner 2008). As part of the eWater CRC/National Water Commission “Groundwater-Surface Water Interaction Tool (GSWIT)” project, the “GW-SW link” module was developed and integrated into the river operation-planning model “Source Rivers”. This model explicitly accounts for the interactions between groundwater and surface water. The GW-SW Link Module is an intermediate-complexity model that uses analytical solutions of various groundwater processes to estimate the exchange of flux between a river and the underlying aquifer (Jolly *et al*. 2010; Rassam 2011). In terms of estimating groundwater discharge to river, a range of different river-aquifer configurations are implemented within the Link model including The Glover and Balmer (1954) solution, The Hall and Moench (1972) solution, The Knight *et al*. (2005) solutions and The Hunt (2003) solution. The Link model provides a significant improvement in modelling the interactions between groundwater and surface water in existing river models. A trial of this model in the Namoi River Basin showed a reasonable match to the predicted exchange flux from by an existing calibrated Upper Namoi MODFLOW model (see Figure 4.1).

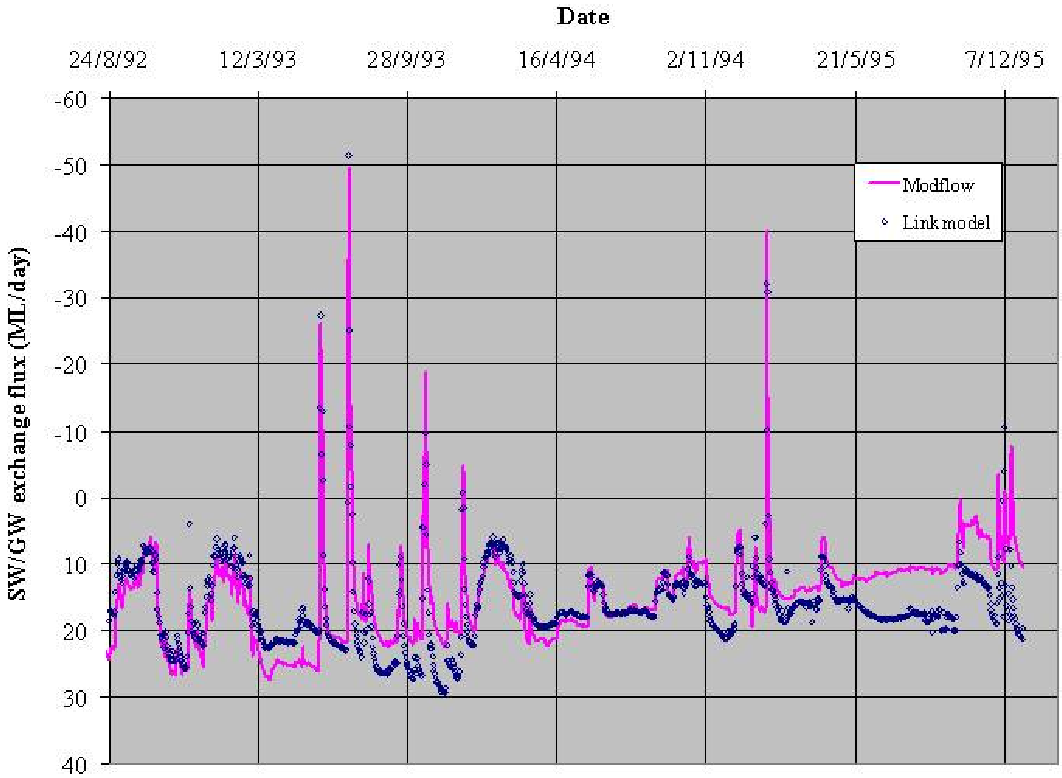

FIGURE 4.1: PRELIMINARY TRIAL RESULTS OF THE GROUNDWATER LINK MODEL AND CALIBRATED MODFLOW MODEL IN THE BOGGABRI TO NARRABRI REACH OF THE NAMOI RIVER (JOLLY *ET AL*. 2010)

4.1.2 Simple Approach

Considering that the GW-SW link model has been developed with the application of vastly superior budgets compared to that allocated for this task, AWE has not attempted to copy or replicate that approach. Rather the focus has been on assessing very simple approaches that might be useful in the interim (i.e. before BIGMOD is superseded by the Rivers model). The key focus for this study is to understand the spatial distribution, timing and processes controlling salt inflows so that more complex models may more rapidly or more accurately reflect the physical hydrogeology, groundwater flow and salt inflow processes that occur during and following flood events.

A 'simple' approach has been employed to describe processes contributing to unaccounted salt loads from the MSM-BIGMOD model according to the following process detailed below:

1. Calculate flux from groundwater to river.
2. Calculate salt inflow from groundwater to river.
3. Calculate cumulative salt inflow from groundwater.

Firstly, the flux of groundwater to the river was calculated through application of the Cooper and Rorabaugh (1963) equation where groundwater discharge to a river from the underlying aquifer can be described as:

$$Q = Q_0 e^{-at} \qquad (4.1a)$$

Where Q is discharge (L^3/T), Q_0 is initial discharge (L^3/T), t is time (T) and a is a recession constant (T^{-1}).

This equation is valid for a finite width, uniform, homogenous, isotropic aquifer which is drained by an intersecting stream.

Secondly, salt inflow to the river was then calculated from the groundwater discharge curve, using the following equation:

$$S = S_0 e^{-at} \qquad (4.2a)$$

Where *S* is salt input to the river (M/T) and $S_0 = sQ_0$ is the initial salt input (where *s* is the salinity of groundwater discharge (M/L^3))

Thirdly the cumulative salt inflow can be calculated through integrating the salt input curve expressed as:

$$SI = \int S_0 e^{-at} dt = \int sQ_0 e^{-at}\, dt = -\frac{sQ_0}{a} e^{-at} + c \qquad (4.3a)$$

Where *SI* is cumulative salt inflow (M) and *c* is a constant (M).

4.2 Application at Chowilla

The analytical approach described above has been applied at Chowilla to determine if a simple process-based model can replicate the pattern of unaccounted salt inflow from MSM-BIGMOD.

4.2.1 Calculating Groundwater Discharge to River

As part of Murtho SIS investigations, AWE developed a numerical model of flow and solute transport that replicates historical climatic sequences (high and low flow events) between 1975 and 2010. This model has been used to estimate groundwater discharge to the river and to produce a flood recession groundwater curve for the August 1981 flood event (Figure 4.2). The groundwater model was calibrated to the Murtho study area only, and although the Chowilla floodplain is adjacent the Murtho study area, results should be interpreted with this in mind.

An initial groundwater flux to river of 33 ML/d was calculated from the model. This initial flux was then applied to equation 4.1 above and a curve fitting approach employed to produce a good match to results from the Murtho model. This approach produced a groundwater discharge recession constant (*a*) of 0.019. The groundwater discharge recession constant was kept at 0.019 throughout the following analysis. This allowed a sensitivity analysis of the physical parameters required to obtain a best fit to cumulative salt inflow curves from MSM-BIGMOD results.

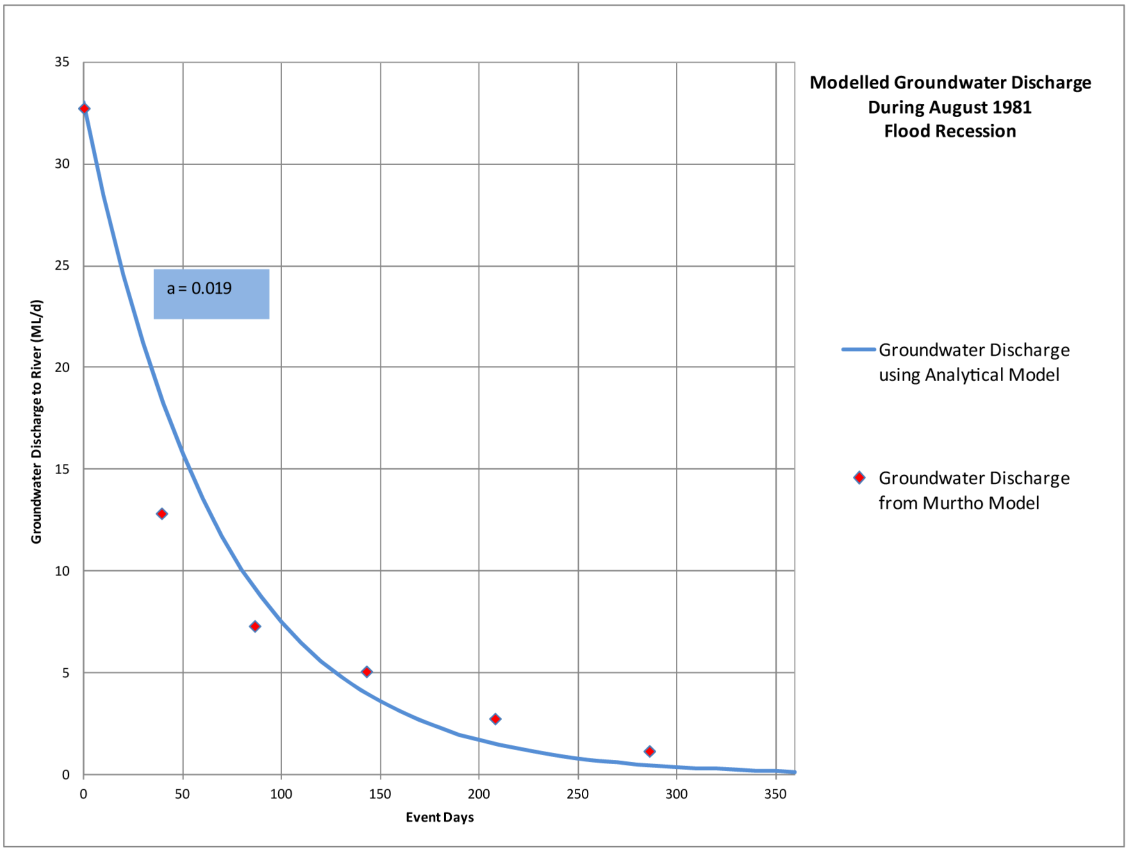

FIGURE 4.2: GROUNDWATER DISCHARGE TO RIVER DURING THE 1981 FLOOD RECESSION FROM MURTHO FLOOD MODEL

4.2.2 BIGMOD Cumulative Flow Type Curves

Cumulative salt flow curves for 15 flood events are presented in Figure 3.5, from which a “typical” flood recession curve was identified. The majority of flood events follow this type curve, at least during the early component of the flood recession.

4.2.3 Cumulative Salt Inflow from BIGMOD

Groundwater discharge to river and the resulting salt inflow occurs where gaining stream conditions are present and the rate of discharge is dependent upon a number of factors in particular; river flow. Groundwater discharge to the river can be separated into a number of components including:

- Direct groundwater discharge to river that occurs under a ‘normal’ flow regime where gaining stream conditions persist;
- Release of suppressed direct groundwater discharge following a flood peak;
- Groundwater recession induced by floodplain inundation after flood events; and
- River bank storage release.

In this analysis direct groundwater discharge to river that occurs under 'normal' flow conditions is termed regional flow. As a result of this regional flow component, the above equations have been modified to account for an additional salt input from regional groundwater flow as follows:

$$Q = Q_0 e^{-at} + Q_r \qquad (4.1b)$$

$$SI = -\frac{sQ_0}{a} e^{-at} + Q_r s_r t + c \qquad (4.3b)$$

Where Q_r is the regional groundwater discharge to the river (L^3/T), s is salinity of groundwater after a flood event, s_r is the salinity of regional groundwater discharge and c is a constant (M).

Two values of groundwater salinity were introduced to equation 4.3b to reflect that groundwater discharge to the river after a flood event is usually higher in salinity compared to that of the regional groundwater discharge.

Earlier analysis described in Section 3.5 indicates peak flow is the best correlative for cumulative salt inflow and this relationship can be described by a step wise delivery function. In addition, Figure 3.18 indicates there is a large increase in cumulative salt inflow for floods where peak flow exceeds 75,000 – 80,000 ML/d. Lower flow flood events that experience peak flows below 75,000 ML/d tend to inundate the western floodplain only. When flood peaks exceed 75,000ML/d the eastern section of floodplain becomes inundated. Analysis of salinity monitoring data for the Monoman Formation aquifer indicates that the salinity of groundwater is more saline beneath the eastern floodplain compared to the western floodplain with average values of 43 g/L and 30 g/L respectively (Table 3.1). Therefore, for flood events where peak flow exceeds 75,000 ML/d (e.g. Aug-81 flood event), groundwater discharge to the river was separated into three components each of different salinity. The cumulative salt inflow was then calculated as:

$$SI = \int \{[s_1 Q_{01} + s_2(Q_{02} - Q_{01})] e^{-at} + Q_r\} dt = -\frac{s_1 Q_{01}}{a} e^{-at} - \frac{s_2(Q_{02} - Q_{01})}{a} e^{-at} + s_r Q_r t + c \qquad (4.3c)$$

Where s_1 is the salinity of the groundwater discharge component mobilised by floods of less than 75,000 ML/d (~30 g/L), s_2 is the salinity of the groundwater discharge component mobilised by floods exceeding 75,000ML/d (~45g/L), s_r is the salinity of regional groundwater discharge (s_r ~ 20 g/L), Q_0 is initial groundwater discharge and c is a constant (M).

$_1$ denotes flood event with peak flow above 75,000 ML/d where salinities s_r, s_1 and s_2 are applied (Group 1)

$_2$ denotes flood event with peak flow below 75,000 ML/d where salinities s_r and s_1 are applied (Group 2)

Figure 4.3, presents modelled groundwater discharge recession curves for flood peaks above and below the salt delivery trigger point. These curves are based on the groundwater discharge curve for the August 1981 flood recession and groundwater flux estimates from the Murtho model (Figure Figure 4.2). The regional component of groundwater discharge is represented in blue. Regional inflow accounts for a component of groundwater discharge during all flood recessions. Additional groundwater discharge induced by floods where peak flow is less than 75,000ML/d is represented by purple. Finally, the component of groundwater discharge to river mobilised by floods where the peak exceeds 75,000ML/d is presented in red. Each component of the groundwater flux to river is labelled with the salinity applied to calculate salt inflow.

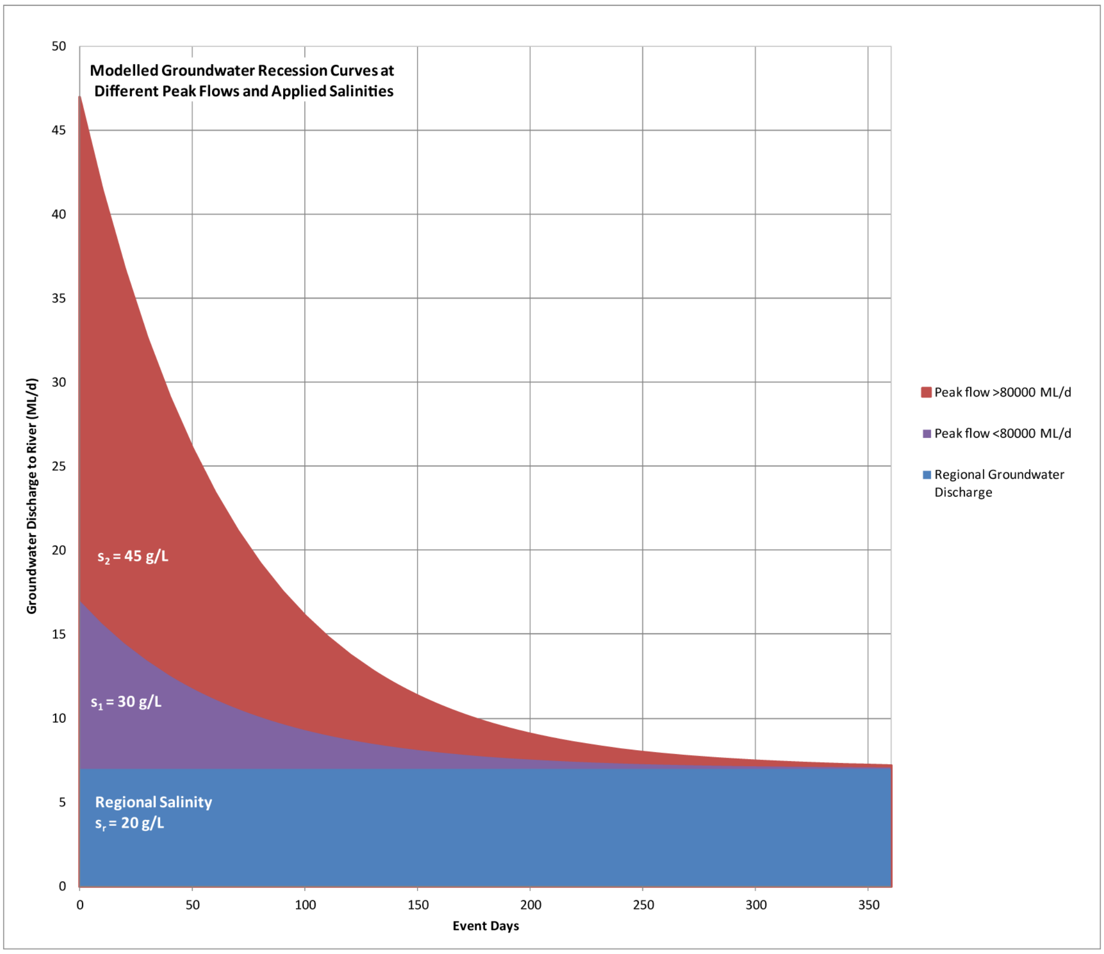

FIGURE 4.3: MODELLED GROUNDWATER RECESSION CURVES AT DIFFERENT PEAK FLOWS AND CORRESPONDING SALINITIES

Cumulative salt inflow was then calculated using these groundwater discharge curves and their corresponding salinities for floods of different magnitudes. Modelled cumulative salt inflow curves were matched to MSM-BIGMOD outputs for three groups of floods. The flood events chosen for analysis are those which displayed a "typical" cumulative flow response during recession (i.e. not influenced by subsequent floods or high flows during recession). The results of this curve matching and the parameters used to calculate the salt inflow curves are presented in Figure 4.4 and Table 4.1. Through this analysis the salinity of discharge components was kept constant and the initial groundwater flux and regional groundwater flux varied. The salinity applied to the October 1986 flood (s_1) was kept at the regional value of 20g/L as this flood only just exceeded the 40,000ML/d flood classification that this analysis applies.

The comparison between modelled cumulative salt inflow curves and MSM-BIGMOD data presented in Figure 4.4 indicates it is possible to replicate cumulative salt inflow for floods of different magnitude and the parameters produced fall within a reasonable range.

TABLE 4.1: SUMMARY OF PARAMETERS DERIVED FROM CURVE MATCHING BIGMOD AND MODELLED SALT INFLOW

Model Parameters	Peak Flow > 75,000 ML/d	Peak Flow < 75,000 ML/d	
	Group 1 Flood Event (Aug-81)	Group 2 Flood Events (Aug-96, Sep-84, Aug-95)	Group 3 Flood Event (Oct-86)
Initial Groundwater Discharge Q (ML/d)	Q_2 = 40	Q_1= 10	Q_0 = 6
Groundwater Salinity s (g/L)	30 for components < 75,000ML/d (s_1) & 45 for components > 75,000ML/d (s_2)	30 (s_1)	20 (s_1)
Regional Component of Groundwater Discharge Qr (ML/d)	7	6	5
Regional Groundwater Salinity Sr (g/L)	20	20	20
c	72000	15000	6500

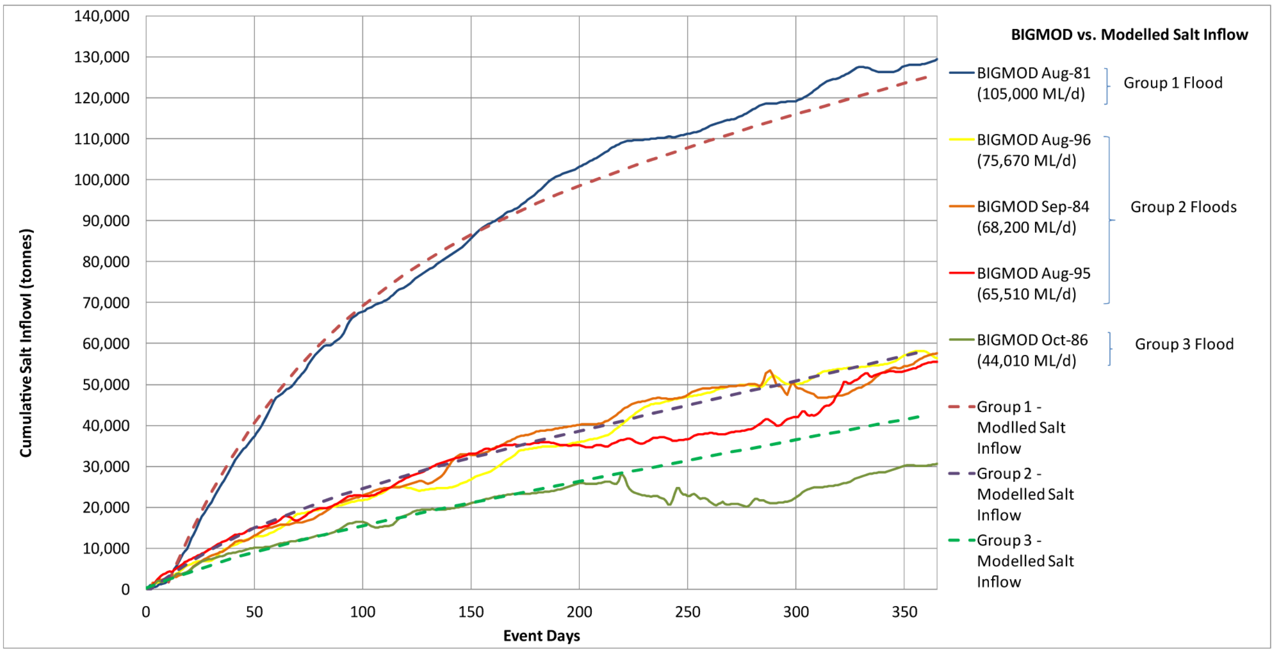

FIGURE 4.4: BIGMOD CUMULATIVE SALT INFLOW VS. MODELLED SALT INFLOW

4.3 Next Steps

The above analysis has demonstrated that cumulative salt inflow can be replicated for floods which display a “typical” cumulative flow response during recession. However, this approach can only be applied to identify the potential salt inflow from a flood recession if there are no subsequent floods during the recession. Future analysis could focus on developing an equation that can replicate suppression of salt inflow caused by additional floods during the recession time. In this case the problem is non-linear and determination of whether the superposition principle can produce a reasonable solution needs to be further investigated.

Future analysis may incorporate the following:

- Test the applicability of this approach at other comparable floodplain sites downstream (e.g. Pike);
- Test the variation of initial groundwater discharge parameter for floods with a peak flow that differs from those already analysed;
- Extend the analytical model to replicate the suppression of groundwater inflow resulting from subsequent floods;
- Improve the detail of the conceptual model and in particular identify the cause of the step delivery function; and
- Initiate monitoring programs designed to assess salinity impacts of watering events and the Chowilla Regulator which does affect the eastern floodplain and may activate the step function of salt delivery.

5 Lock 5 to Morgan

5.1 Reach Overview

The most significant salt inflow between Euston and Murray Bridge occurs between Lock 5 and Morgan, representing 60% of the total inflow whilst making up only 25% of the total distance (AWE 2011). Salt inflow for the Lock 5 to Morgan reach between 1970 and 2009 is presented in Figure 5.1. This data gives a forty-year average salt inflow of 1063 tonnes/day (or 4.3 tonnes/day/km).

A significant baseline salt inflow occurs within the Lock 5 to Morgan reach which has been the target of several Salt Interception Schemes (SIS) since 1990. These include the Woolpunda, Waikerie, Bookpurnong and Loxton SISs, which combined have an instream benefit of approximately 380 tonnes per day. These SISs therefore target approximately 35% of the overall salt inflow within this reach.

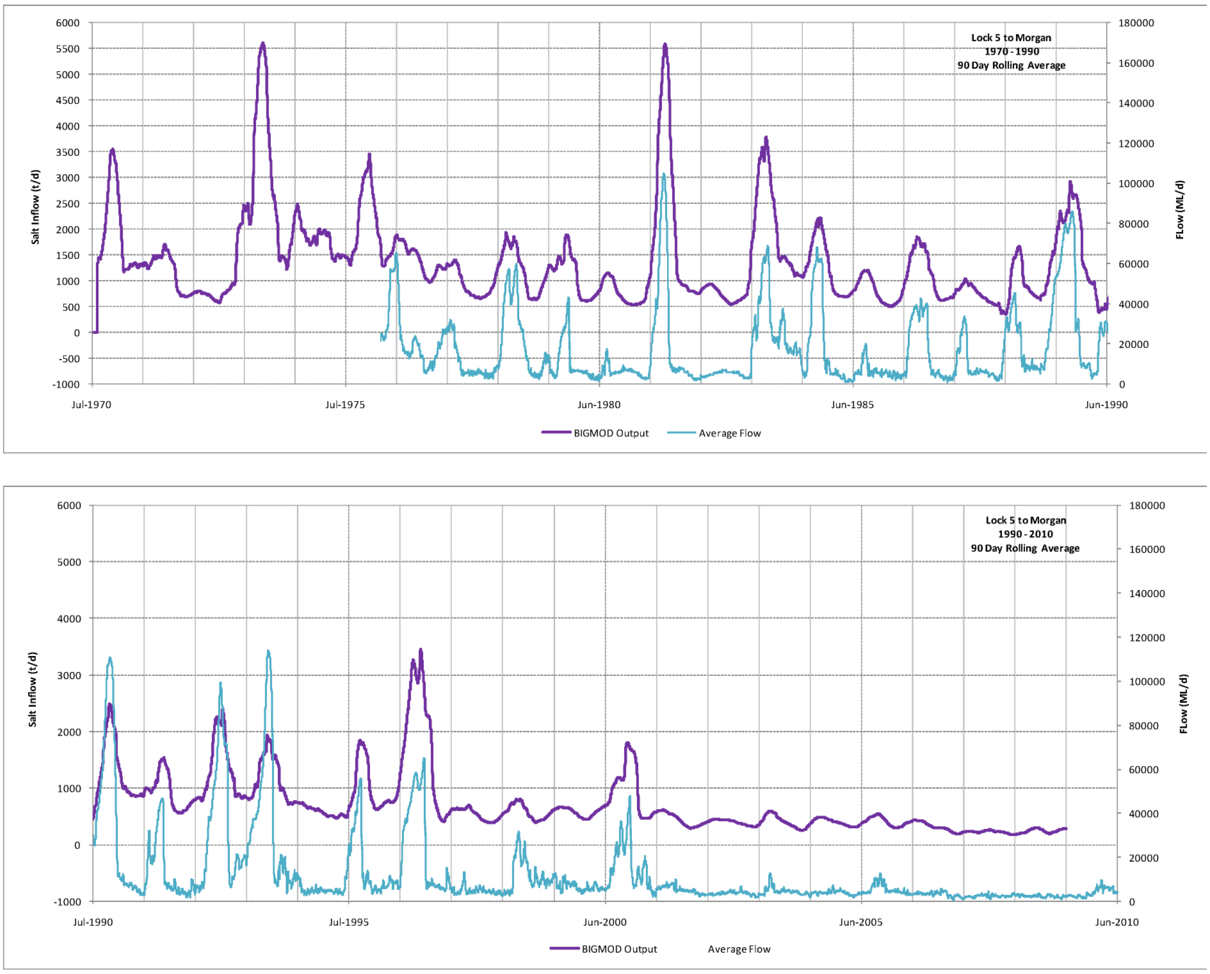

FIGURE 5.1: BIGMOD SALT INFLOW LOCK 5 TO MORGAN 1970 TO 2009

Salt inflow varies with the river flow regime and it can be observed that salt inflow increases significantly during high river flows. Temporal and spatial changes to salt inflow within the Lock 5 to Morgan reach are summarised below in Table 5.1 and Table 5.2. Salt inflow data is presented as a cumulative total from Lock 5 to the specified downstream station. Table 5.1 presents salt inflow data in five-year periods between 1974 and 2009 and includes details of significant backwaters, disposal basins and SIS located within the reach. The contribution of these backwaters and disposal basins to unaccounted salt inflow will be discussed further in the following sections. As salt inflow is strongly influenced by river flow regime, Table 5.2 provides a comparison between three four-year time periods where a similar, low flow river regime was experienced. This is designed to highlight variations to baseline salt inflow. It is noted in Figure 5.1 and Table 5.2 that salt inflow does not always increase at the downstream station. This is due to poor data, which is discussed further in the following sections.

TABLE 5.1: CUMULATIVE SALT INFLOW FROM LOCK 5

Period	Lock 5 to	Berri	Lock 4	Lock 3	Woolpunda PS	Waikerie PS	Lock 2	Cadell	Morgan	
From	To	t/day	t/day	t/day	t/day	t/day	t/day	t/day	t/day	Comment on Period
1/07/1974	30/06/1979	283	N/A	1235	941	1545	N/A	1575	1476	
1/07/1979	29/06/1984	272	N/A	1235	1074	1326	N/A	1087	1397	
30/06/1984	29/06/1989	241	N/A	624	679	968	863	923	989	Noora, Low Flows
30/06/1989	30/06/1994	338	260	977	1049	1288	1304	1694	1261	High Flows Woolpunda, Waikerie
1/07/1994	30/06/1999	175	178	421	582	574	577	685	903	
1/07/1999	29/06/2004	169	199	430	471	497	515	502	564	Low Flows
30/06/2004	30/06/2009	105	122	234	256	314	292	354	321	Low Flows
Sites in Reach		Disher Creek	Gurra	Berri Basin, Lake Bonney		Ramco Lagoon				
SIS in Reach			40% Booki	60% Booki, Loxton	30% Woolpunda	70% Woolpunda 30% Waikerie	70% Waikerie			

TABLE 5.2: CUMULATIVE SALT INFLOW – FOUR YEAR PERIODS WITH LOW FLOWS

Period	Lock 5 to	Berri	Lock 4	Lock 3	Woolpunda PS	Waikerie PS	Lock 2	Cadell	Morgan	Comment on Period
From	To	t/day	t/day	t/day	t/day	t/day	t/day	t/day	t/day	
13/03/1977	12/03/1981	171	#DIV/0!	742	772	1092	#DIV/0!	1089	1048	Pre Noora
13/03/1985	12/03/1989	238	#DIV/0!	582	613	847	852	835	889	Post Noora, Pre SIS
30/06/1997	29/06/2001	212	231	490	541	516	518	486	672	Post W/W SIS
Sites in Reach		Disher Creek	Gurra	Berri Basin, Lake Bonney		Ramco Lagoon				
SIS in Reach			40% Booki	60% Booki, Loxton	30% Woolpunda	70% Woolpunda 30% Waikerie	70% Waikerie			

Within the Lock 5 to Morgan reach, the only salt inflow “accounted” in BIGMOD is that from Lake Bonney. The lake is a large off-stream water body with a single inlet-outlet channel that joins the river just upstream of Lock 3. The Lake’s water level is maintained by inflows from the Lock 3 upstream weir pool with outflows only occurring during the recession of significant flood events. Detailed analysis of Lake Bonney is provided in Section 5.3.2.

The Lock 5 to Morgan reach contains approximately 67.65km^2 of permanent backwaters and anabranches which is 1.78 times the area of the main river channel. Conversely between Euston and Lock 5, off stream backwaters and anabranches only account for 25% of the main river channel area. This large amount of permanent water on the floodplain combined with gaining floodplain conditions is considered to be a key factor controlling the pattern of salt inflow to the river between Lock 5 and Morgan. Identification of processes and quantification of their contribution to unaccounted salt inflow within the reach will be the focus of the following sections.

5.2 BIGMOD Analysis Technique

Comprehension of two processes within BIGMOD is important for the understanding of how salt inflow is calculated and how this salt inflow is then used to calculate modelled EC values. These two processes are:

- Water lost through evaporation from the very significant area of off-stream permanent water bodies is accounted for inflow relationships. The salt associated with this volume of water is assumed to remain in the River and to be present at the next downstream station. This representation is reasonable for flow through anabranches but does not represent the processes associated with backwaters. The impact of backwaters is discussed in detail in Section 5.3.3; and
- Salt inflow between stations is calculated on a daily basis. However, due to high variability and frequent negative values within data sets, salt inflow is re-introduced to BIGMOD as monthly averages and assigned to portions of the overall reach based on standard percentages. This process is followed to ensure that salt inflow is re-introduced as positive values to allow calculation of modelled EC values. Negative salt inflow values are not well handled by BIGMOD during the calculation of modelled EC values (Close, A. pers.comm. 2013). The impact of using this methodology is discussed in the following sections.

5.3 Processes Impacting Salt Inflow

5.3.1 Disposal Basins

The Lock 5 to Morgan reach of the River consists of significant areas of irrigation and urban development. Drainage from these developments is directed to a number of different disposal basins, some of which are located within the floodplain. Historically, drainage to these basins accumulated during times of low flow with high salinity water released during high river flows or when the basins were flushed during large flood events.

A review of South Australian drainage basins located upstream of Morgan was conducted in 2002 (Ken Smith Technical Services 2002). This reported that 17 of a total 21 basins were located within the River Murray floodplain. The information provided in Table 5.3 (below) has been calculated from information presented in Ken Smith Technical Services (2002) and presents details of the five most significant floodplain drainage basins with inputs to these basins accounting for 94% of the total assessed salt inputs.

TABLE 5.3: LOCK 5 TO MORGAN – KEY DISPOSAL BASINS

Basin	Salt Inflow to Basin (t/d)	Outflow Location	Comment
Disher creek	118	544 km: Between Lock 5 and Berri	Can be transferred to Noora Basin since 1983
Berri	35	482 km via Katarapko Creek : Between Habel Landing and Moorook	Can be transferred to Noora Basin since 1983
Katarapko Island	19	488 km: between Loxton and Habel Landing	-
Bookmark Creek	10	555 km; Between Lock 5 and Berri upstream of Disher Creek	-
Cadell	12	330 km: Between Cadell and Morgan	-
Others	15	-	-
Total	**209**	**-**	**-**

Disher Creek Basin

Disposal basin operational data (supplied by DEWNR, 2013), suggests that Disher Creek held considerable tonnages of salt prior to the implementation of salt transfer to the Noora Basin. Steady accumulation occurred from 1976 to June 1981 when 28,000 tonnes of salt was held by the basin. This salt was subsequently released by the 1981 flood event. This release of saline water from Disher Creek can be readily identified in both the instream salinity record and BIGMOD unaccounted salt inflows. A detailed analysis of salt inflow during the 1981 flood is presented in Section 5.3.5.1.

The salt held in Disher Creek and the corresponding water level is presented in Figure 5.2. Prior to the commissioning of the Noora Basin, the rate of salt accumulation in Disher Creek was 20 tonnes per day during the inter-flood period between 1976 and 1977. This is significantly less than the stated inflows of 118 t/d in Table 5.3. This low rate of salt accumulation and a steady basin water level suggests that ongoing releases of water to the river must have occurred in order to maintain water levels below maximum operating levels. Operating rules in place during this time allowed the bypass of inflows and releases into the river when flow exceeded 15,000ML/day and if the salt input did not increase downstream salinity above 450 EC.

Prior to 1983, Disher Creek could be filled to 1.5m above river level and this is likely to have induced groundwater inflows. This component of salt inflow has not been assessed.

Following the introduction of disposal to the Noora Basin, salt held in Disher Creek only exceeded 10,000 tonnes on one occasion between 1983 and 2007. This occurred in 1999 and salt was subsequently transferred to the Noora Basin. Flushing events can be identified in basin salinity data as occasions when salinity declined to below 1,000 EC. Each flushing event released some 6,000 tonnes of salt to the River.

The analysis described above could be replicated for the Berri Disposal Basin.

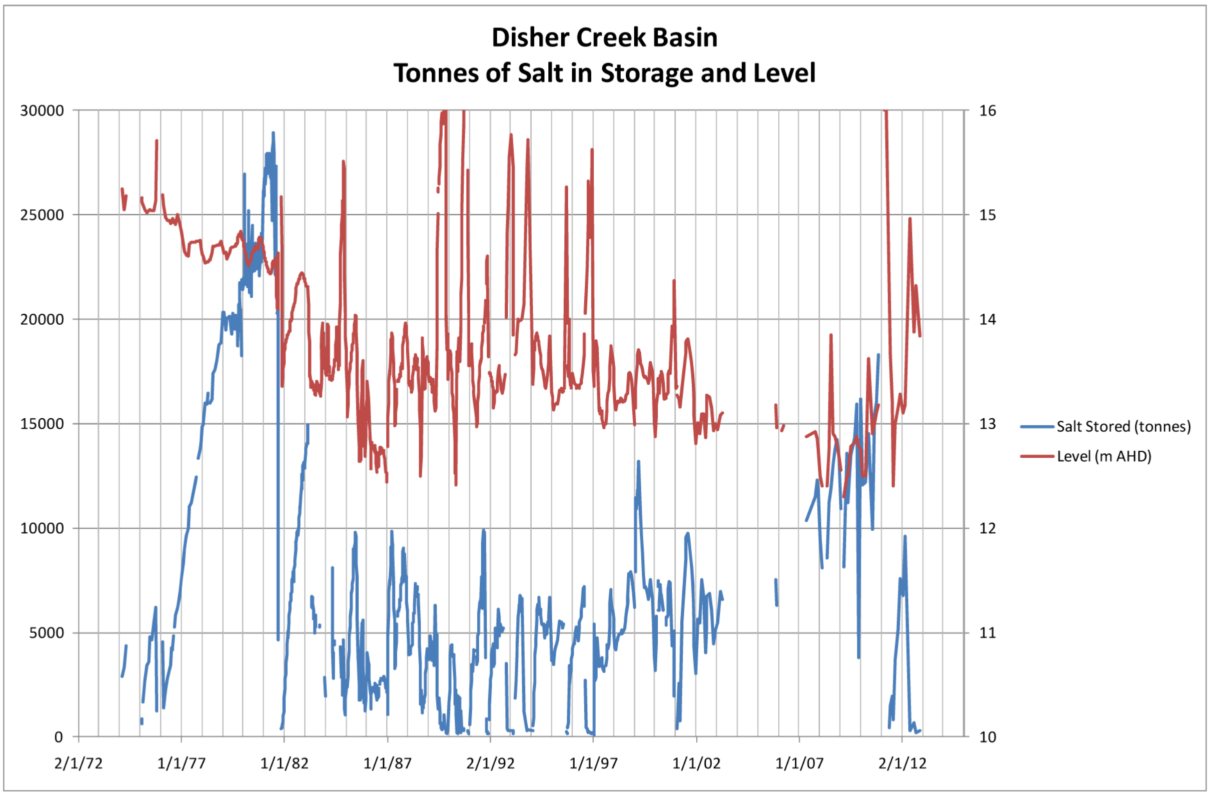

FIGURE 5.2: DISHER CREEK BASIN – SALT STORED AND LEVEL

Noora Basin

The Noora Basin was commissioned in 1983 to facilitate the transfer of saline water stored on the floodplain in the two largest floodplain basins (Disher Creek and Berri) away from the River to reduce salt inflow, especially during low flows. The average rate of salt pumped to the Noora Basin between 1983 and 2006 was 33,000 tonnes per year (90 tonnes per day). During this time, the Noora Basin received salt from the Disher Creek and Berri disposal basins suggesting that 90 of the 153 tonnes disposed of at these two locations was transferred out of the floodplain leaving 63 tonnes/day disposed of via the River.

Since 1983, Disher Creek and Berri Basin both transferred saline water to the Noora Basin and ongoing operating rules allowed disposal to the River when flows exceeded 25,000 ML/day and salinity impacts were below thresholds.

The annual transfer of salt to the Noora Basin is presented in Figure 5.3. It can be observed that in low flow years, when there was little opportunity for river disposal, the annual transfer average was 60,000 tonnes (164 tonnes/day) and closely correlates to the total assessed annual inflows for the two basins of 153 tonnes/day. Transfer volumes and tonnages declined after 2002, reflecting reduced irrigation drainage volumes.

BIGMOD provides an assessment of the "impact" of salt inflow following the commissioning of the Noora Basin, which appears to be based on a benefit of 60 t/day during medium flow events, and a salt impact of 30 tonnes/day during low flows. This is significantly different to the assessment given above and could be updated.

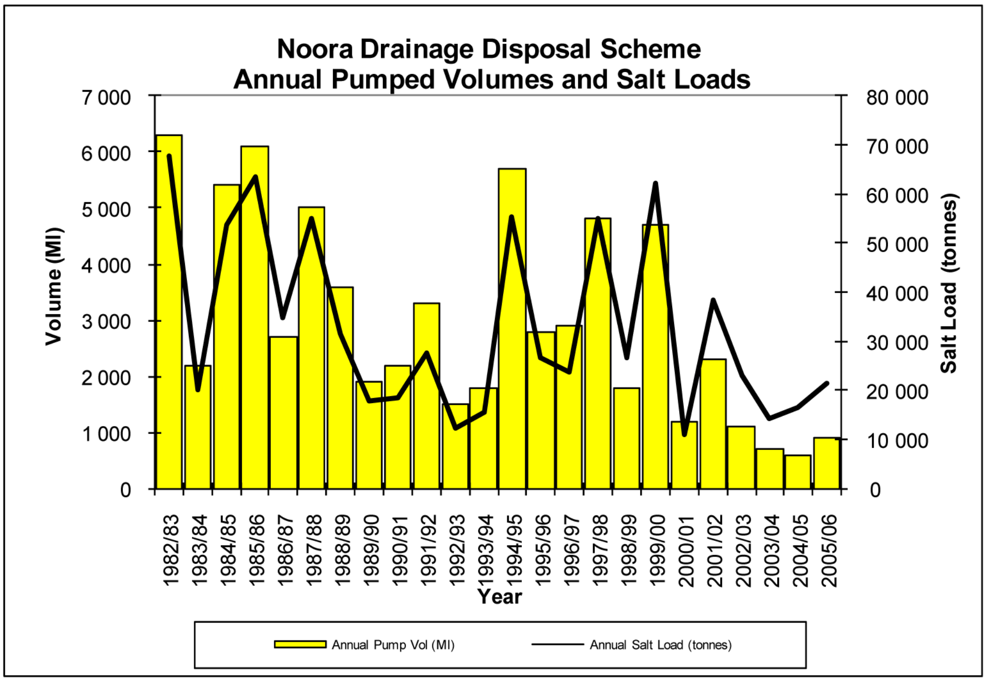

FIGURE 5.3: TRANSFER OF SALT TO NOORA BASIN

Disposal Basin Summary

Prior to 1983 disposal basins were contributing a long-term average of 209 tonnes per day of salt inflow to the River. This salt was released preferentially during times of high river flow. Analysis of salt stored in Disher Creek indicates that, due to the limited capacity of the basin, releases appear to have occurred on a regular basis.

Following the commissioning of the Noora Basin in 1983, the salt inflow from the Disher Creek and Berri Basins into the River during low flows was reduced to zero. There were still opportunistic disposals during higher river flows, as permitted by the operating rules.

With reduced drainage volumes and the ample capacity of the Noora Basin it can be anticipated that going forward the salt inflow from Disher Creek and Berri Basin will be low, except when flushed by a flood or opportunistic disposal of salt to the River during high flows.

Salt inflow from other basins, which historically disposed some 56 tonnes/day of salt on average, would also be expected to decline due to reduced irrigation drainage volumes.

5.3.2 Lake Bonney

Lake Bonney is the largest off-stream water body located within the Lock 5 to Morgan reach, accounting for 25% of the total off-stream area. The characteristics of other off-stream wetlands vary, primarily due to their type of connection to the River. Some off-stream water bodies experience permanent flow through and may be considered anabranches. Other water bodies have an inlet sill that converts a backwater to a flow through anabranch once the River level exceeds the inlet sill elevation. Lake Bonney displays characteristics that are typical of an off-stream wetland with a single inlet-outlet channel which include:

- During times of steady river flow, inflow to the Lake is caused by evaporation from the lake's surface;

- Salt in the Lake accumulates salt through inflow from the river as well as from saline groundwater inflows; and
- Outflow from the Lake only occurs on the falling limb of a flood or if the Lock 3 upstream weir pool level is lowered.

The water level in Lake Bonney is very stable as it is connected to the River immediately upstream of Lock 3 via Chambers Creek.

Key parameters for the area and volume of Lake Bonney applied in the following calculations include:

- Area – 16,000,000 m^2
- Volume – 58,900,000 $m^{3.}$

A comparison of measured salinity data and BIGMOD modelled salinity data for Lake Bonney is presented in Figure 5.4. Data for both the Lake and the inlet-outlet channel (Chambers Creek) is presented with measured salinity data denoted by series beginning with 'b-'. The salinity measurements for Lake Bonney presented in the figures above were taken at the Barmera Jetty. Other studies, that include multiple point sampling, concluded that due to water circulation within the Lake, the jetty provides a suitable site for the measurement of representative salinity for Lake Bonney (Barry Porter, pers. comm. 2013). Comparison of measured and modelled data suggests that within BIGMOD Lake Bonney has been calibrated to the period between 1988 and 1998, as there is reasonable correlation between data sets during this time. However, seven flood events occurred during this period making accurate calibration difficult. The rate of salt accumulation in the model when the Lake is acting purely as a backwater appears to be less than the monitored concentration trends and the degree of mixing between the River and the water body appears to be understated.

The observed salinity concentration rate over the two years following the 1st of July 1998 is 606 EC per year compared to the modelled concentration rate of 390 EC per year. Data indicates that the average river salinity between June 1998 and June 2000 was 500 EC. Evaporation would cause an increase in salinity of approximately 172 EC per year, which equates to a salt load increase of 5,280 tonnes per year (15 tonnes per day) being drawn from the River. The remaining increase in salinity can be attributed to saline groundwater inflows of approximately 40 tonnes per day. The modelled salinity increase 390 EC/year equates to the evaporative accumulation plus a groundwater inflow of 20 tonnes/day.

The period between 1998 and 2003 is shown in Figure 5.5 and during this period a double peak flood occurred with flows of 41,000 ML/day and 63,000 ML/day during November 2000 and February 2001. The November 2000 mixing event can be observed as a period of minor salinity reduction before salinity begins to increase again and returns to the minor trend line. This event suggests that, as the Lake level rises, groundwater inflow is suppressed however when waters recede a period of increased salt accumulation follows. This can be attributed to the suppressed groundwater discharging to the Lake at a higher rate during the recession.

The second event that occurred in February 2001 was also marked by a decrease in Lake salinity due to the inflow of a large volume of fresh river water. Once salt accumulation was re-established during the flood recession a lateral shift in the accumulation line of approximately 250 EC can be observed. This equates to the loss of 11,000 tonnes of salt due to Lake discharge. Modelled data indicates a very minor, much less significant mixing event over this time.

Salt inflow calibration could be improved by updating the "accounting" method for Lake Bonney. This would result in the net movement of 20t/d of salt from the unaccounted salt inflows to the accounted salt inflows. This would also improve the timing and impact of Lake Bonney outflows on modelled EC.

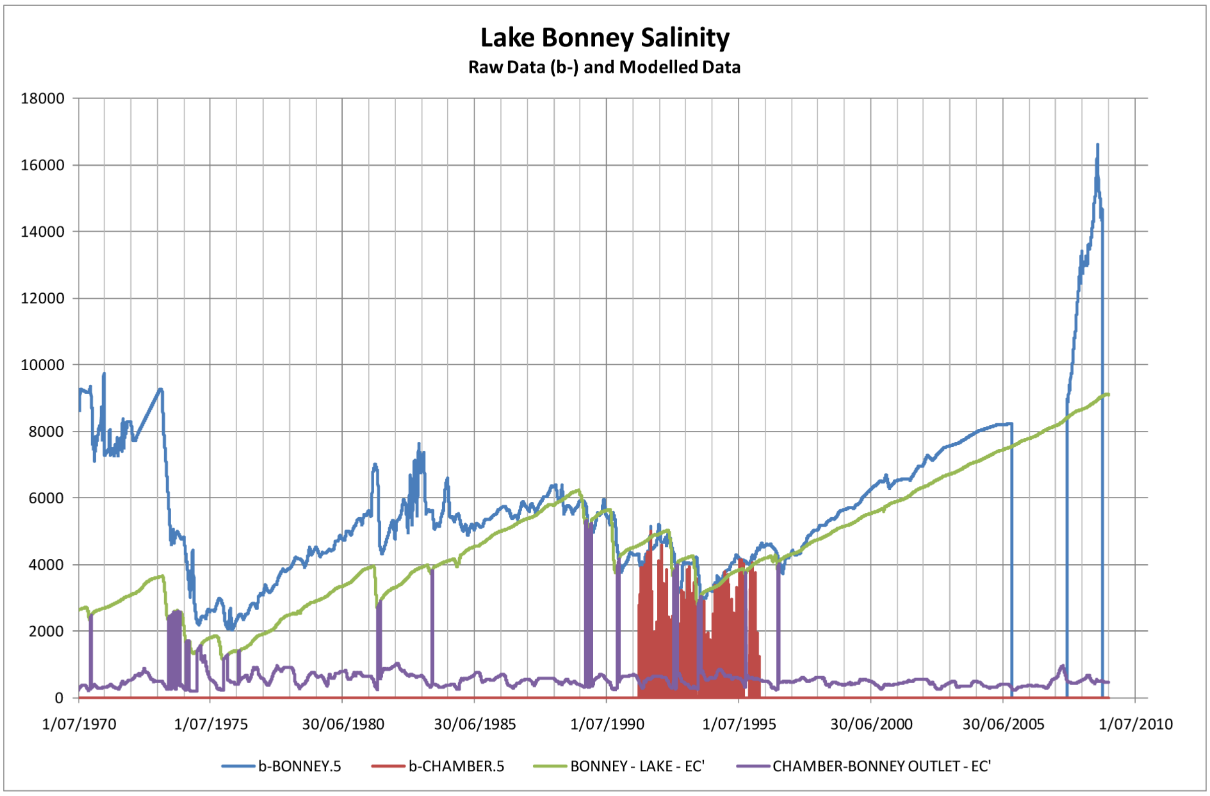

FIGURE 5.4: LAKE BONNEY MEASURED AND MODELLED SALINITY

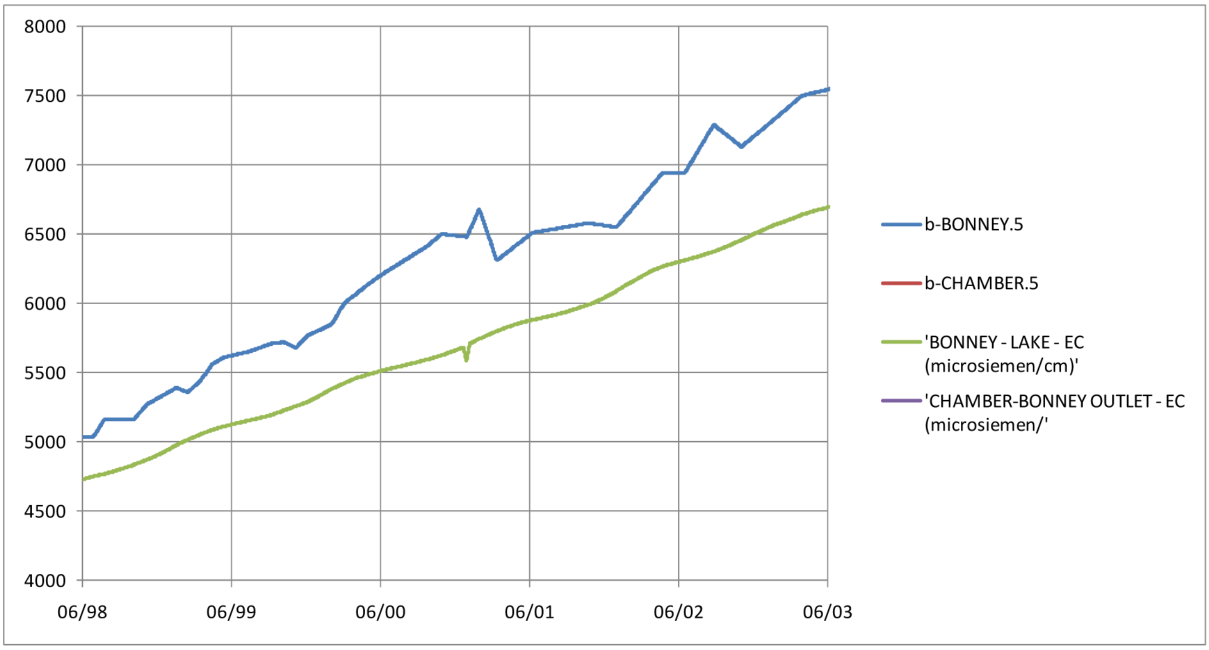

FIGURE 5.5: LAKE BONNEY SALT ACCUMULATION AND OUTFLOW TO THE RIVER 1998 TO 2003

5.3.3 Evaporative Accumulation

As discussed above, the Lock 5 to Morgan reach of the River has a high proportion of off-stream permanent water. The majority of which is located in backwaters with a single, permanent connection to the River. The water level in these backwaters is maintained by inflows from the River, which replaces evaporative loses. The salt, which enters with river flow, accumulates in the backwater until an outflow event occurs. This process effectively stores salt from the River in floodplain water bodies for later disposal to the River. This process is termed evaporative accumulation and is the effect of evaporative concentration in backwaters deferring salt transport downstream that whilst not changing the total salt budget, does generate a salinity effect due to the timing of the release. By assuming an average river salinity of 400 EC, evaporative accumulation from backwaters in this reach with a total area of 42.35 km^2 (excluding Lake Bonney) has the potential to store 9,320 tonnes of salt per year (26 tonnes per day on average).

BIGMOD allows for evaporation when determining river flows but does not allow for salt storage in backwaters. If there are no other sources of salt inflow and evaporative accumulation occurs, the model will create a negative salt inflow to replicate salt storage in the backwater. If there are other sources of salt inflow, they will be reported as lower because of storage in the backwater. Given the seasonal cycle of evaporation, the impact of backwater storage would be largest during summer reducing salt inflow by 93t/d and be negligible during winter. When the backwater eventually releases the salt, it will produce an impact on downstream salinities and be accounted in BIGMOD as salt inflow.

The long-term cumulative impact of backwater evaporative accumulation and release on overall salt inflow is negligible however, it will produce seasonal impact as most salt releases are associated with flood events and the apparent salt inflow at other times will be reported as lower than actual. The storage of salt over many months and release in much a shorter timeframe will also provide peak salt inflow values. If salt is stored at a rate of 26 tonnes/day for 11 months and released uniformly over 1 month a salt inflow of 312 t/d would result during the release period.

The Stage 1 report identified an annual variation in salt inflow during the low flow period between 2001 and 2009 (Figure 5.6 below). The process described above may contribute to this observed variation that has amplitude of 100 to 200 t/d. However, salt inflow peaks in August and is at a minimum between April and May suggesting that the annual variation is the result of changes in direct groundwater inflow.

Three backwaters have been analysed and are discussed in the following sections.

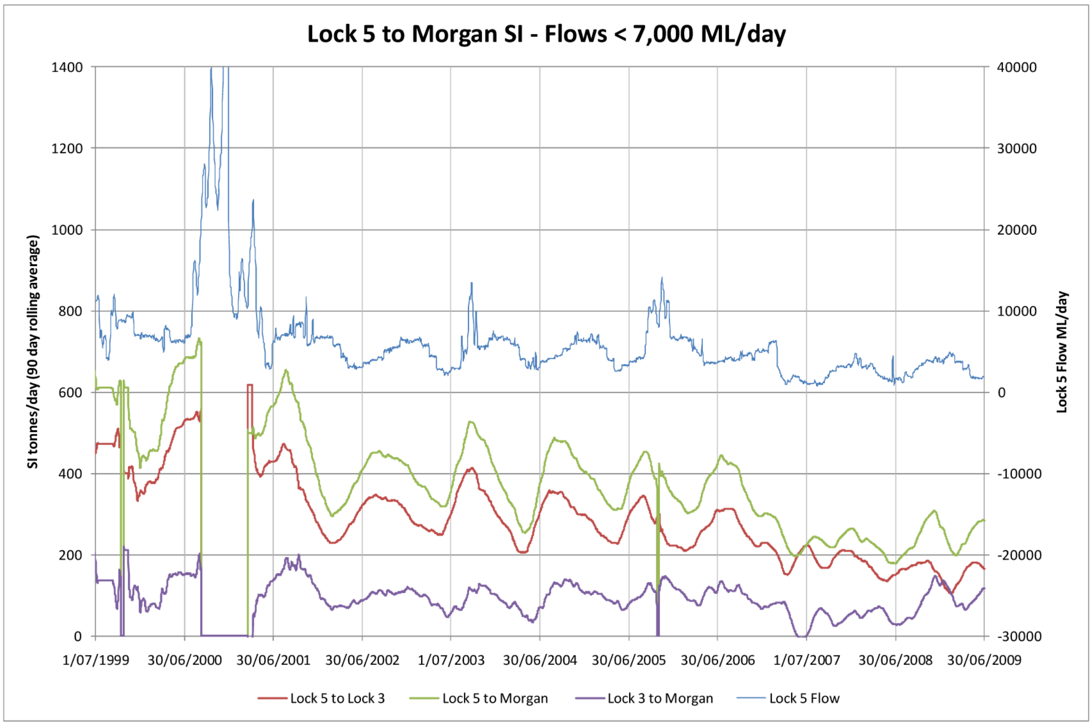

FIGURE 5.6: LOCK 5 TO MORGAN ANNUAL CYCLE OF SALT INFLOW VARIATION

5.3.3.1 Gurra Lakes

Gurra Lakes is located immediately upstream of Lock 4 and has a permanent connection to the River. The lake complex is the second largest backwater between Lock 5 and Morgan being one-third the size of Lake Bonney. Gurra Lakes is also the largest unaccounted backwater in BIGMOD. A hydrogeological assessment including a salt and water balance was conducted for Gurra Lakes in 2002 and identified the following characteristics (AWE 2001):

- Area - 6,300,000 m^2;
- Volume – 4,209,000 m^3;
- Downstream permanent inlet-outlet at River km 521;,
- Upstream inlet with a capacity of approximately 500 ML/day which until 2000 became active at 60,000 ML/day and since 2000 is active at flows of 45,000 ML/day; and
- Flushing time of approximately 8 days.

The salt and water balance from this study assessed the groundwater inflow to be 2.2 t/d and water drawn from the River due to evaporation contributing an annual average of 3.8 tonnes/day (AWE 2001). If the Lake was flushed annually it would contribute a salt inflow of 275 tonnes/day for the 8 days of the initial flushing. If the Lake was flushed every two years this rate would double to 550 tonnes/day.

5.3.3.2 Ramco Lagoon

Ramco Lagoon, is located within the extent of the Waikerie SIS and was investigated as part of Ken Smith Technical Services (2002) and the Waikerie Stage 2A SIS (AWE, 2000). The following key characteristics were identified in these two reports:

- Area 750,000 m^2;
- An upstream inlet active at flows of 85,000 ML/day pre 1991 and 60,000 ML/day post 1991;
- Drainage water salt inflows of 7 t/day in AWE (2000) compared to 0.1 t/day (3ML/year) in Ken Smith (2002). The Ken Smith rate is for late 1980 and early 1990 where as AWE has since indentified that drainage water has become very saline due to native highly saline groundwater entering some of the drains;
- Groundwater inflows 40 t/day (AWE, 2000); and
- Evaporative concentration, annual average of 0.5 tonnes/day peaking at 2 tonnes/day in summer (AWE, 2000).

AWE (2000) identified that groundwater inflow to Ramco Lagoon combined with annual variations in evapotranspiration (ET) were resulting in salt loads to the River during winter. Groundwater inflow to Ramco was considered to be uniform throughout the year based on piezometer data that suggested upward gradients caused saline groundwater discharge to the Lagoon. However, ET rates varied so that in summer they exceeded the rate of groundwater inflow causing inflow of water from the River to the Lagoon and the addition of salt. In winter, evaporation rates declined so that groundwater inflow exceeded ET and the Lagoon inlet-outlet channel became saline as water discharged to the River. The inflows of drainage water and groundwater in winter were sufficient to provide outflows and export of salt to the River during this season. The quantum of salt inflow from Ramco Lagoon was sufficient to warrant an extension of the existing Waikerie SIS borefield to prevent its occurrence. These processes are conceptualised in Figure 5.7 where the depicted salinity of the Lagoon is for the start of each season.

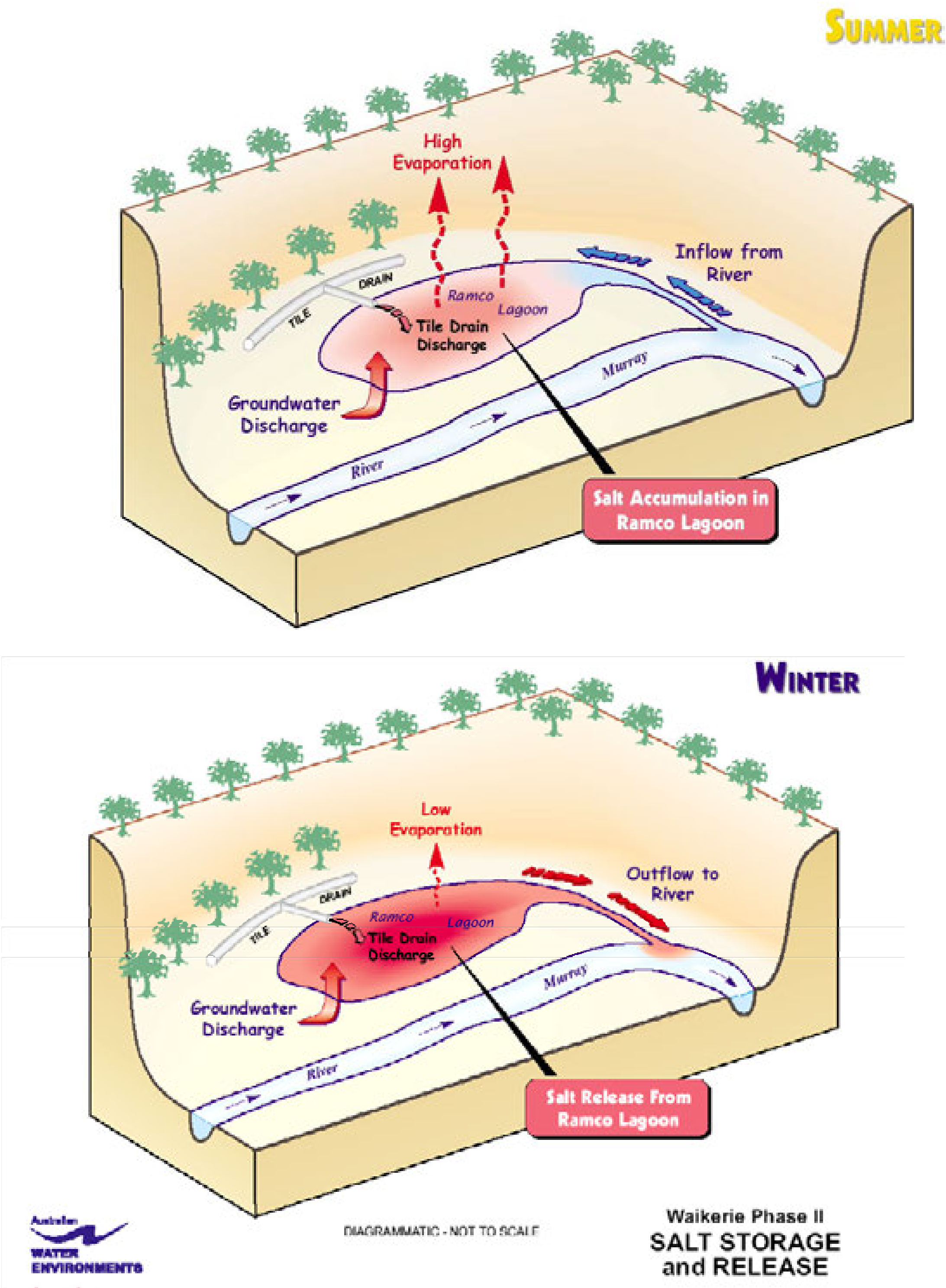

FIGURE 5.7: RAMCO LAGOON TYPICAL BACKWATER (FROM AWE 2000)

5.3.3.3 Pike Lagoon

Pike Lagoon is located on the Pike River floodplain downstream of Lock 5. A close-spaced EC survey of the Pike-Mundic complex was conducted by DEWNR in May 2010, following an extensive period of low River flows. The results from this survey are presented in Figure 5.8. The Pike system experiences a daily flow of 300 ML from the Lock 5 weir pool. The majority of the system acts as a flow through anabranch and salinity in these sections reflects River salinity. However, much higher salinities were recorded in the Northern Arm of Pike Lagoon. Analysis of the rise in salinity in the Northern Arm indicates that this section behaves as a backwater with no upstream inflow. The measured rise in salinity is consistent with the process of evaporative accumulation with very little due to saline groundwater inflow.

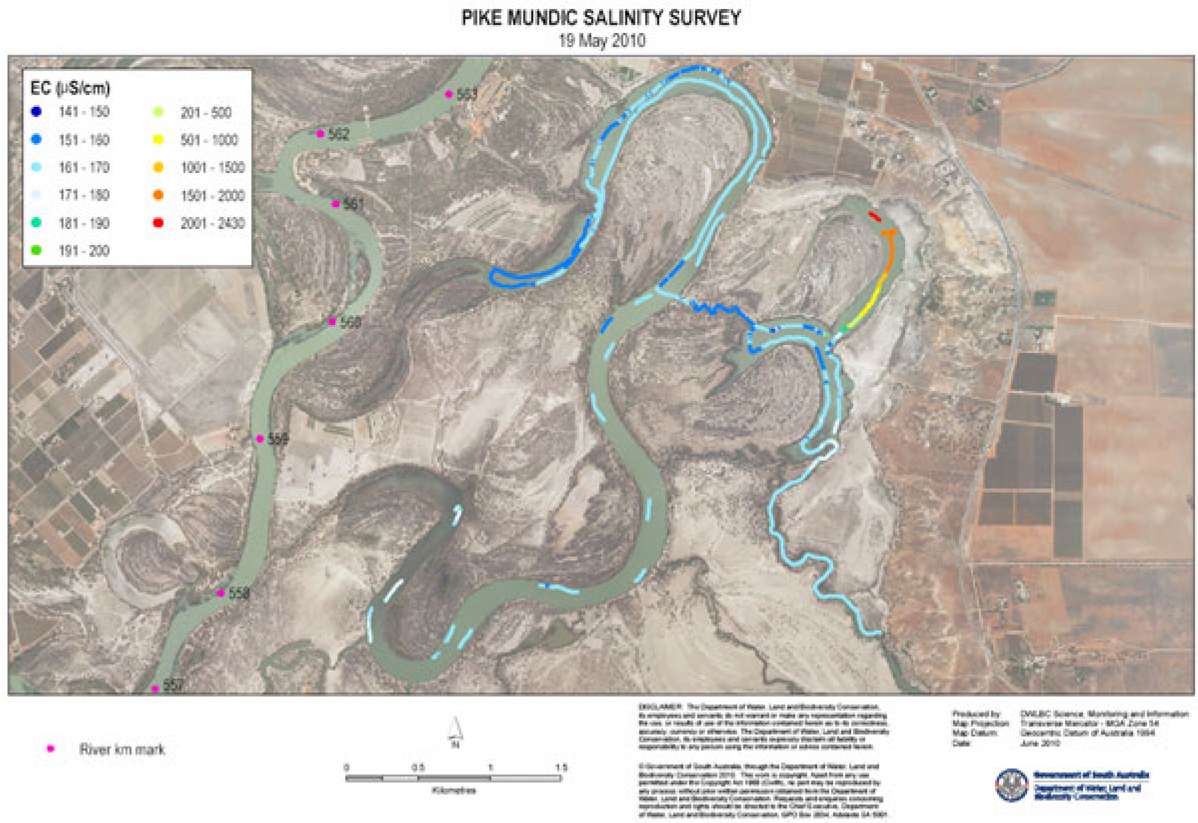

FIGURE 5.8: PIKE LAGOON SALINITY SURVEY

5.3.4 Backwater to Anabranch conversion

The process of backwaters behaving like anabranches (e.g. Gurra Lakes) during times of high river flow is replicated at many other sites along the Lock 5 to Morgan reach. All experience salt accumulation due to evaporation with the quantum being approximately proportional to the area. The amount of groundwater inflow also varies significantly between sites with those adjacent to irrigation areas likely to experience greater groundwater inflow. Some backwaters may also receive water direct from irrigation drainage schemes. Backwaters will also vary according to their connection to the River as described by the following:

- A single inlet-outlet channel (e.g. Lake Bonney);
- A downstream permanent connect, with an upstream sill that activates above certain flows (e.g. Gurra Lakes);
- A small upstream connection that experiences no outflow during periods of low flow and high evaporation and outflow during periods of low evaporation and/or higher flows;
- Drainage or groundwater inflow that is insufficient to provide outflow during times of high evaporation but that provides outflow during periods of low evaporation, (e.g. Ramco Lagoon);
- Permanent flow through an upstream inlet and permanent outflow to the River where the salinity of outflow may increase due to evaporation and groundwater inflow (e.g. Pike River, Toolunka Lagoon); and
- Some backwaters may show a combination of these characteristics.

The characteristics of each significant off-stream water body should be assessed to identify whether it is a backwater or a flow through anabranch, the relative contribution of groundwater inflow and the mechanism of connection to the River. This would enable the building of a robust assessment of salt inflow variations.

5.3.5 Review of Flood Events

The processes and issues described above can be observed and to some extent quantified by analysis of the salinity record, BIGMOD outputs of salt inflow and BIGMOD modelled EC. To demonstrate this process three flood events have been examined in detail and are described in the following sections. The method of collection of salinity data varies and the quality of the data is impacted by both the sampling method and the sampling location (refer to discussion in Section 6).

5.3.5.1 1981 Flood

The 1981 flood occurred prior to the implementation of salt transfer to the Noora Basin and commissioning of SISs within the Lock 5 to Morgan reach. Salinity monitoring data collected over the flood event is presented in Figure 5.9, with salt inflows calculated by BIGMOD presented using a ten day rolling average in Figure 5.10 and comparison between BIGMOD modelled salinity and measured salinity in Figure 5.11.

Key observations include:

- Salt inflow calculated by BIGMOD is consistent with the raw salinity data;
- Lock 3 monitoring data was only collected weekly during this period. Values were not consistent with upstream and downstream stations producing a very high (false) spike in salt inflow; and
- Operational data indicates that there was a release of salt from Disher Creek in August and the Basin was flushed by the flood in early October. These events are clearly visible in the raw data and calculated salt inflow record within the Lock 5 to Berri reach. The salinity spike and cumulative salt inflow are observed in downstream stations as expected.

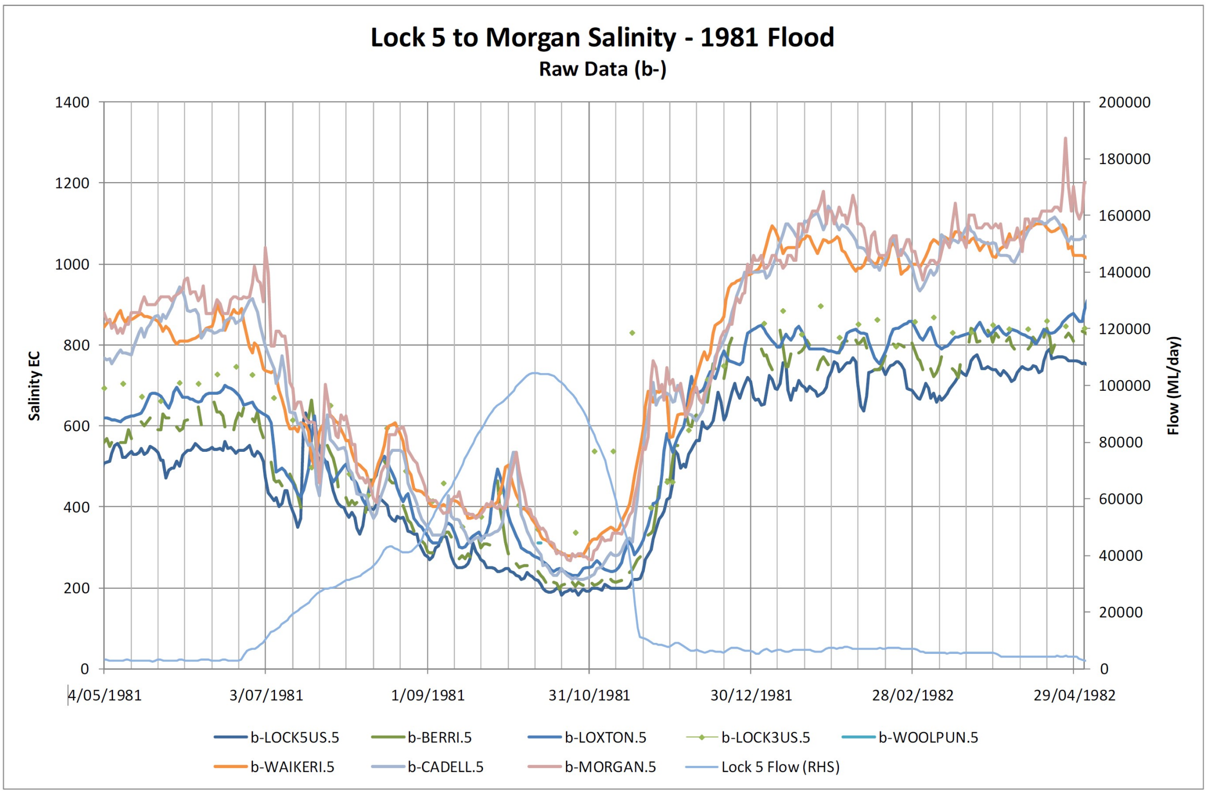

FIGURE 5.9: RAW SALINITY DATA FOR THE 1981 FLOOD

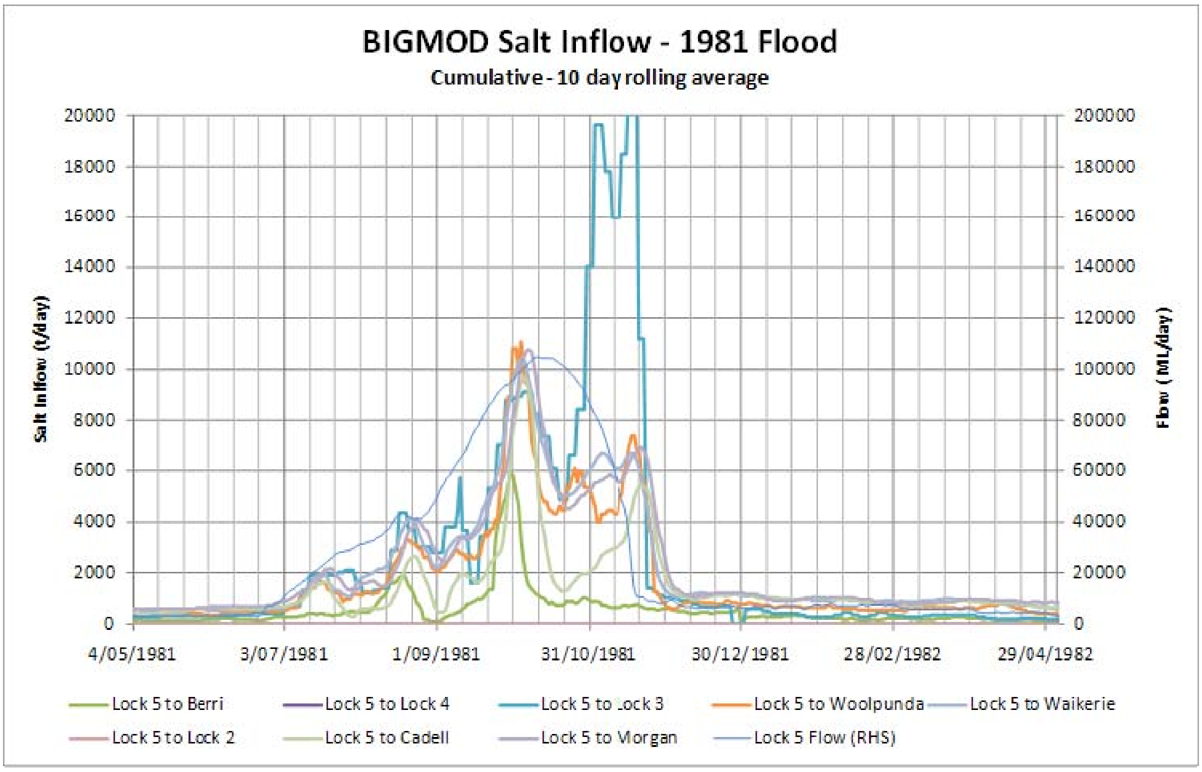

FIGURE 5.10: BIGMOD CALCULATED SALT INFLOW FOR THE 1981 FLOOD

- During the flood, EC data for Cadell is consistently below the upstream station at Waikerie and at times Woolpunda indicating likely errors. This is also reflected by the calculated salt inflow data. Salt inflow data before and after the flood is consistent with upstream and downstream stations;
- From a comparison of the modelled and raw EC data it can be observed that:
  - Modelled and raw data for Lock 5 match as the model is reset at the upstream end of each reach which is Lock 5;
  - The two EC spikes that are observed in the raw monitoring data for Berri due to salt release and flushing of Disher Creek are not evident in the modelled EC data set. This is due to the way BIGMOD models EC using monthly averages of salt inflow and distributes it to reaches by predetermined percentages;
  - Modelled EC after the flood shows a much more uniform increase in salinity between Lock 3 and Morgan when compared to raw data, again most likely due to the spatial distribution of the calculated salt inflow; and
  - The modelled EC data has an accentuated salinity spike downstream of Lock 3 immediately after the flood. This is possibly due to a combination of :
    - The way Lake Bonney is accounted for both in timing and quantum. Figure 5.4 shows a significant outflow from Lake Bonney during the 1981 flood recession, if the timing of this release is slightly delayed it would be introduced into a much lower flow river thus producing a false salinity spike; and/or
    - The high salt inflow that occurs during the flood is observed to finish on the 22nd or 23rd of November where it remains at a low level for the last week of the month. When this is averaged for the month, a high salt inflow will be applied for the last week of November to calculate modelled EC. As flow in the river is low at 10,000 ML/day at the same time, this will produce a big impact on modelled EC. It is also observed that the false peak in EC occurs at Lock 3 and Woolpunda on the 30th of November, after which the salt inflow applied for December is much lower.

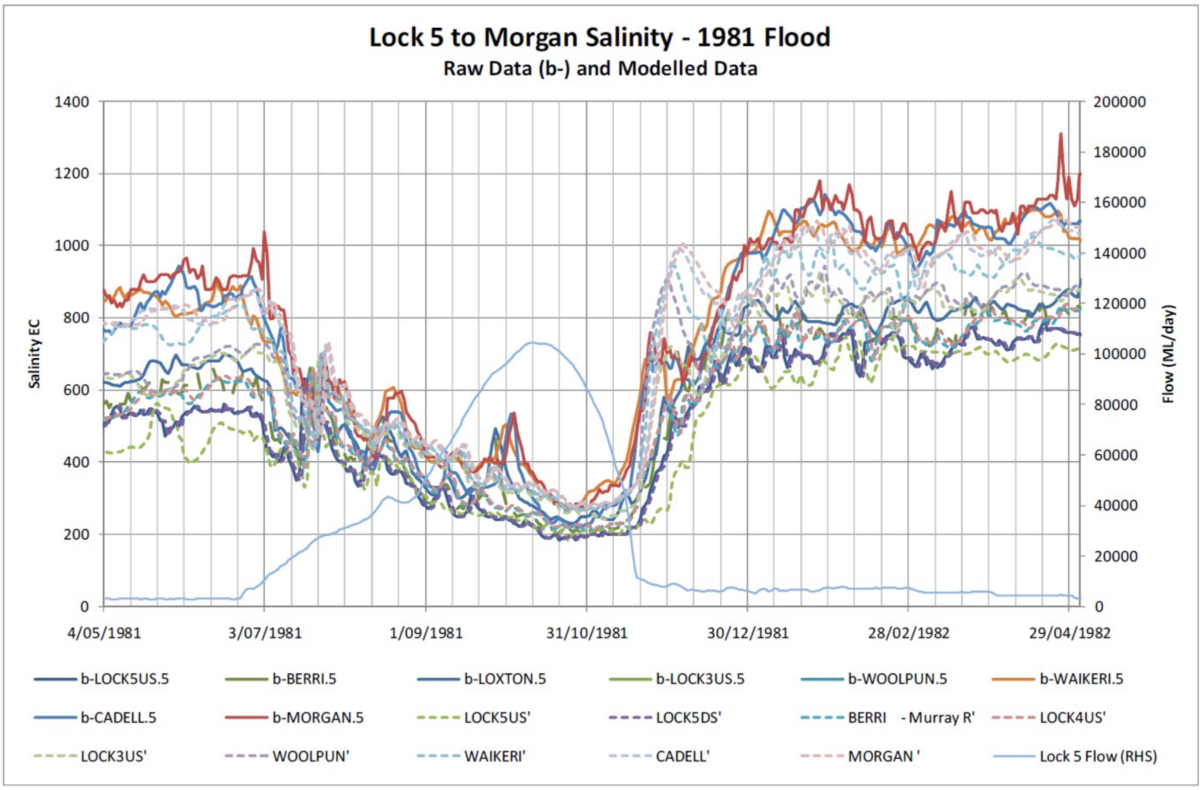

FIGURE 5.11: RAW SALINITY AND BIGMOD CALCULATED SALINITY FOR THE 1981 FLOOD

5.3.5.2 1989 Flood

The 1989 flood occurred after the implementation of salt transfer to Noora but prior to the commissioning of SIS in the reach. Raw salinity data and BIGMOD generated salinities for the 1989 flood event are presented in Figure 5.12 and the salt inflows produced by BIGMOD are shown in Figure 5.13.

Data from the 1989 flood indicates:

- A very high salinity peak occurred on the 28th of May between Loxton and Lock 3 that persists in the salinity records of the downstream stations suggesting it is a real event. This corresponds to a Lake Bonney lowering trial where the Lock 3 weir pool level was lowered by 0.4m to an elevation of 9.4mAHD over the period of a week;
- The high EC peak observed at Morgan on the 25th of April represents a single daily reading and may be due to a local discharge event. This peak is not observed in the Swan Reach data downstream;
- A very concentrated EC spike downstream of Loxton between the 10th and 20th of November and a correspondingly high assessed salt inflow;
- A false modelled EC spike after a true spike in EC was not observed in this data set as was observed during the 1981 flood event. Whilst modelled ECs are higher than the raw data in last week of November (after the flood), flows were at 30,000 ML/day which reduces the EC impact of any salt inflow differences;

- Salt inflow takes a step increase on the 13th of June between Berri and Lock 3, and appears to remain elevated for the remainder of the flood event at 1,600 tonnes/day. Raw salinity data seems to indicate that this increase occurs mainly between Berri and Loxton; and
- Salt inflow appears to take another step on the 1st of August when river flows are at 70,000 ML/day however, on this occasion it occurs downstream of the Woolpunda Pump Station.

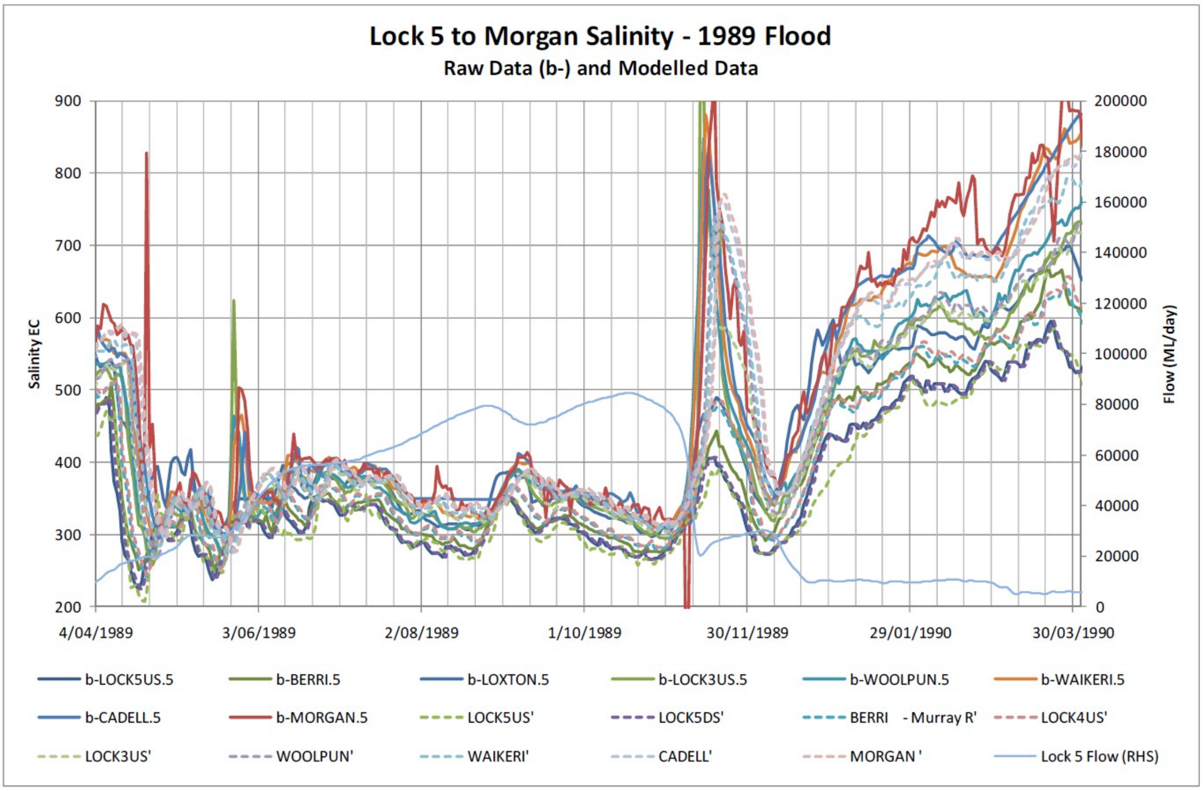

FIGURE 5.12: SALINITY DATA FOR THE 1989 FLOOD

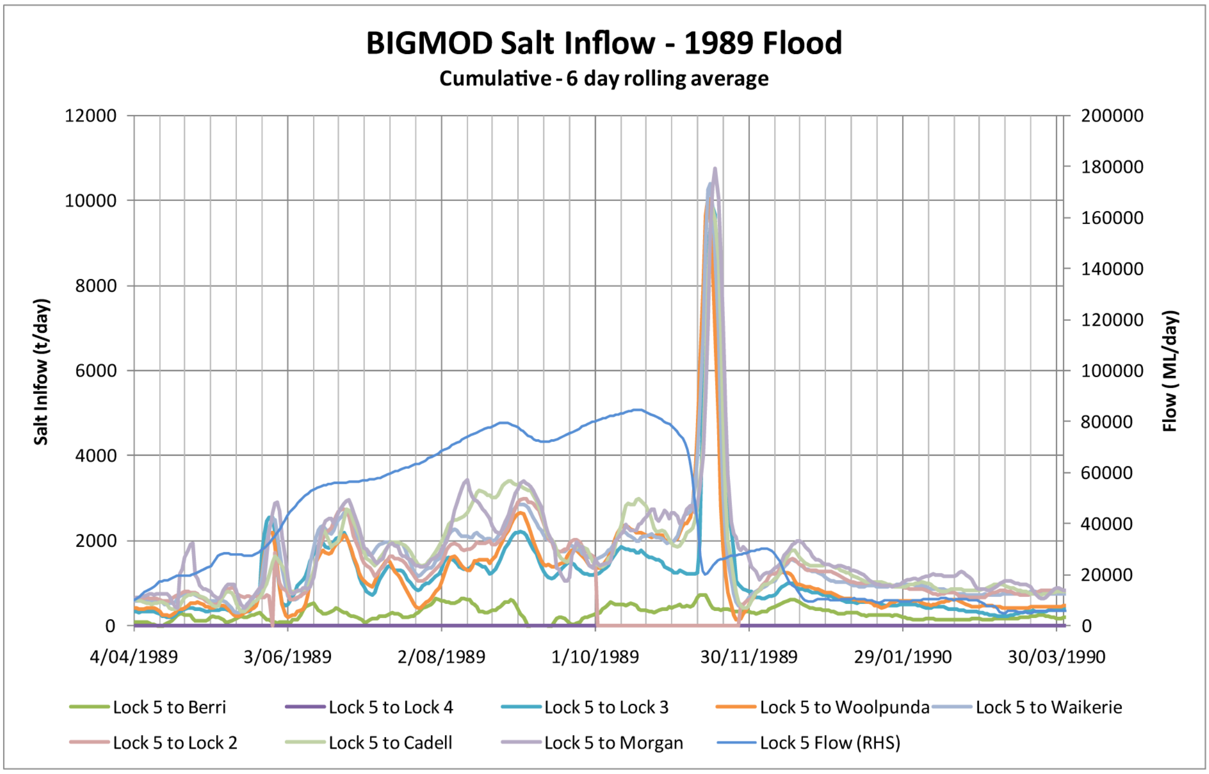

FIGURE 5.13: BIGMOD CALCULATED SALT INFLOW FOR THE 1989 FLOOD

5.3.5.3 1992 Flood

The 1992 flood occurred after the implementation of salt transfers to the Noora Basin and following the commissioning of the Woolpunda SIS and the initial part of the Waikerie SISs. The Woolpunda SIS was commissioned in stages taking a number of years to become fully effective. Raw salinity data and BIGMOD modelled salinities for the 1992 flood event are presented in Figure 5.14 with salt inflow assessed by BIGMOD shown in Figure 5.15.

Data from the 1992 flood event indicates:

- Overall, salt inflow is lower particularly between Berri and Lock 3. Raw EC data for Loxton suggests that a significant portion of salt inflow occurs between Berri and Loxton which was the target zone for the Bookpurnong and Loxton SISs constructed between 2005 and 2009. This reach also contains Gurra Lakes and data may indicate that backwaters in this zone play a significant role; and
- Salt inflow increases and decreases during the flood as water level rises, this may correlate to the "activation" and subsequent flushing of backwaters, as per Gurra Lakes. This complex can release up to 550 tonnes/day of salt (two years storage) (refer Section 5.3.3.1) over an eight day flushing period after which salt inflow from this source would cease.

A more detailed view of raw salinity data and salt inflow during the 1992 flood event between the 20th of November 1992 and the 29th of January 1993 is presented in Figure 5.16 and Figure 5.17.

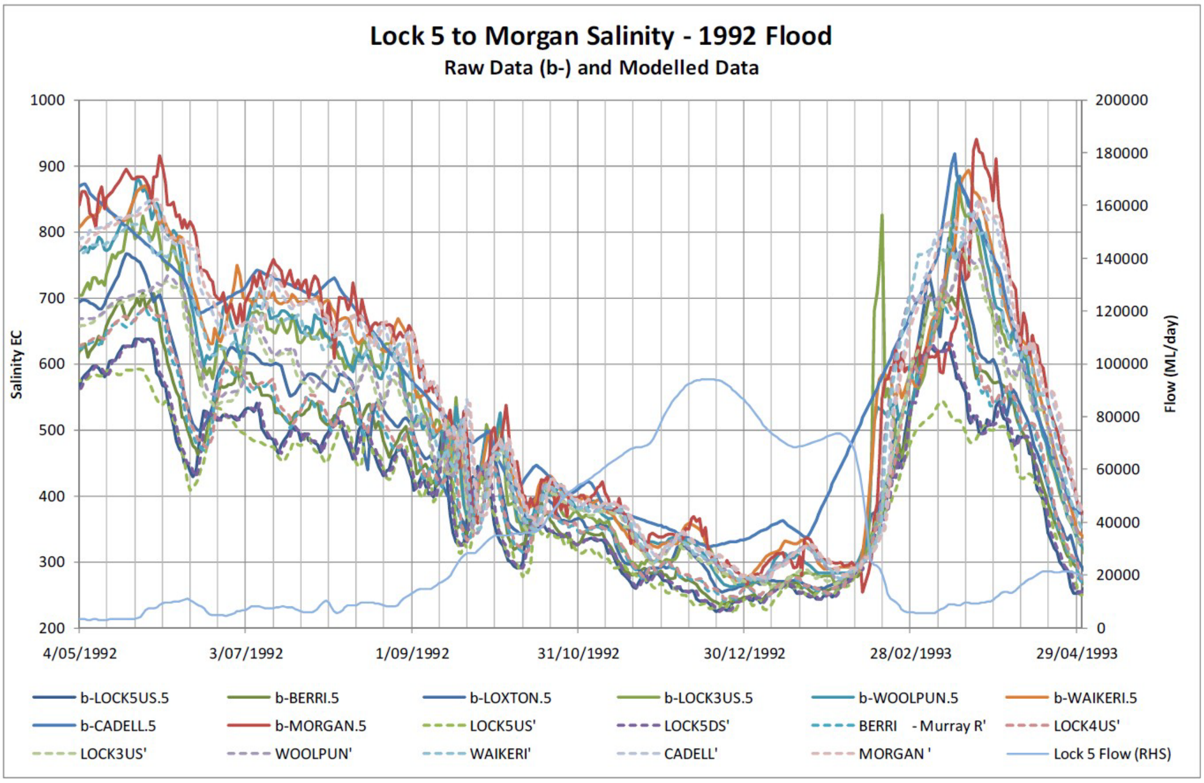

FIGURE 5.14: SALINITY DATA FOR THE 1992 FLOOD

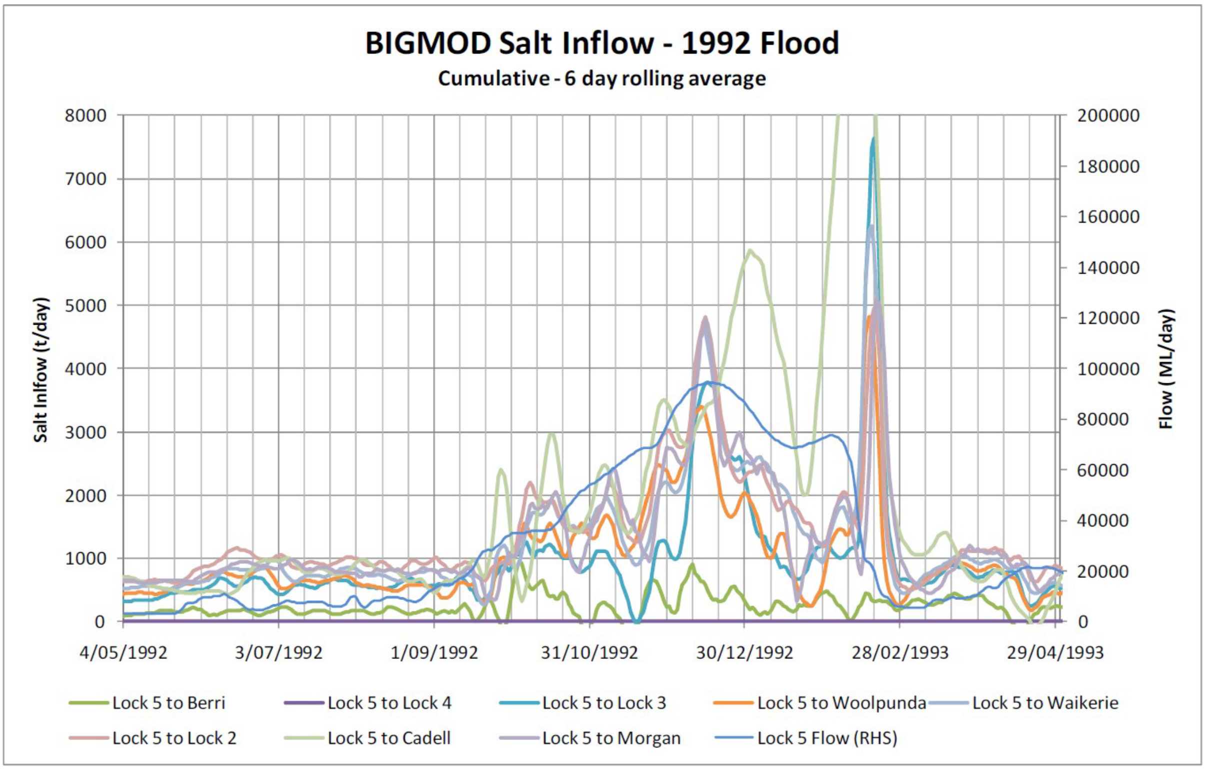

FIGURE 5.15: BIGMOD CALCULATED SALT INFLOW FROM THE 1992 FLOOD

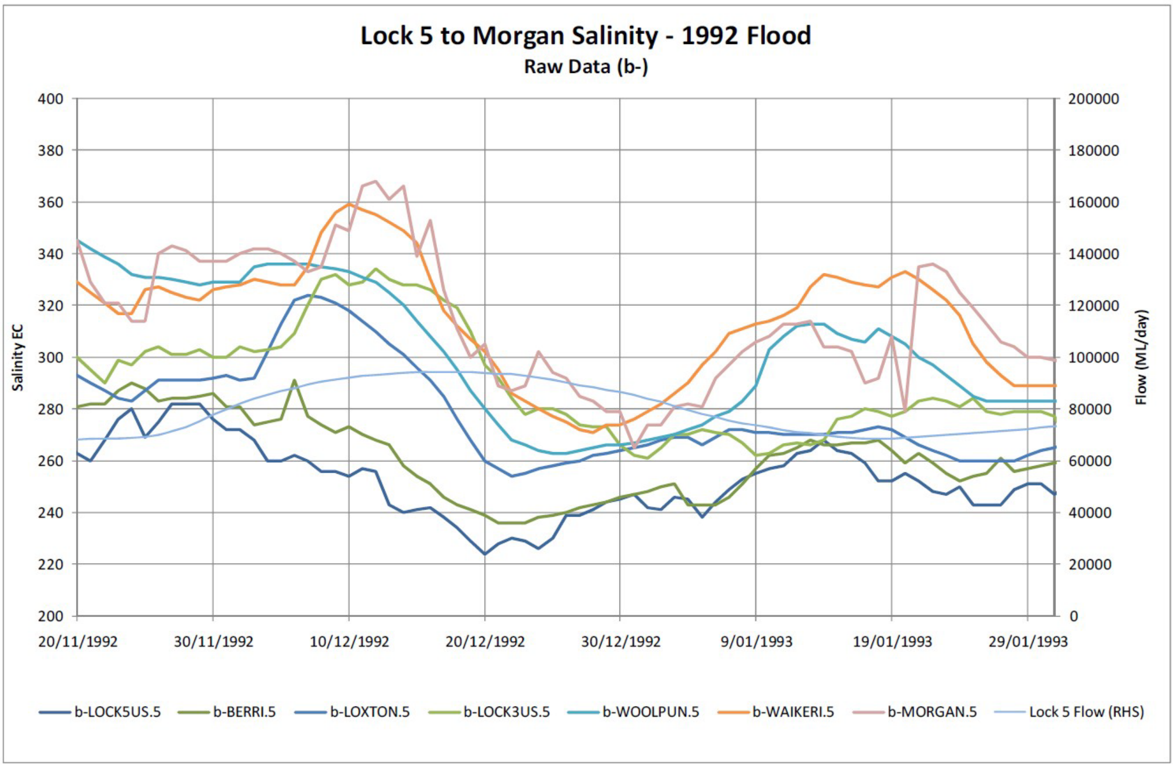

FIGURE 5.16: LOCK 5 TO MORGAN RAW SALINITY DATA FOR THE 1992 FLOOD

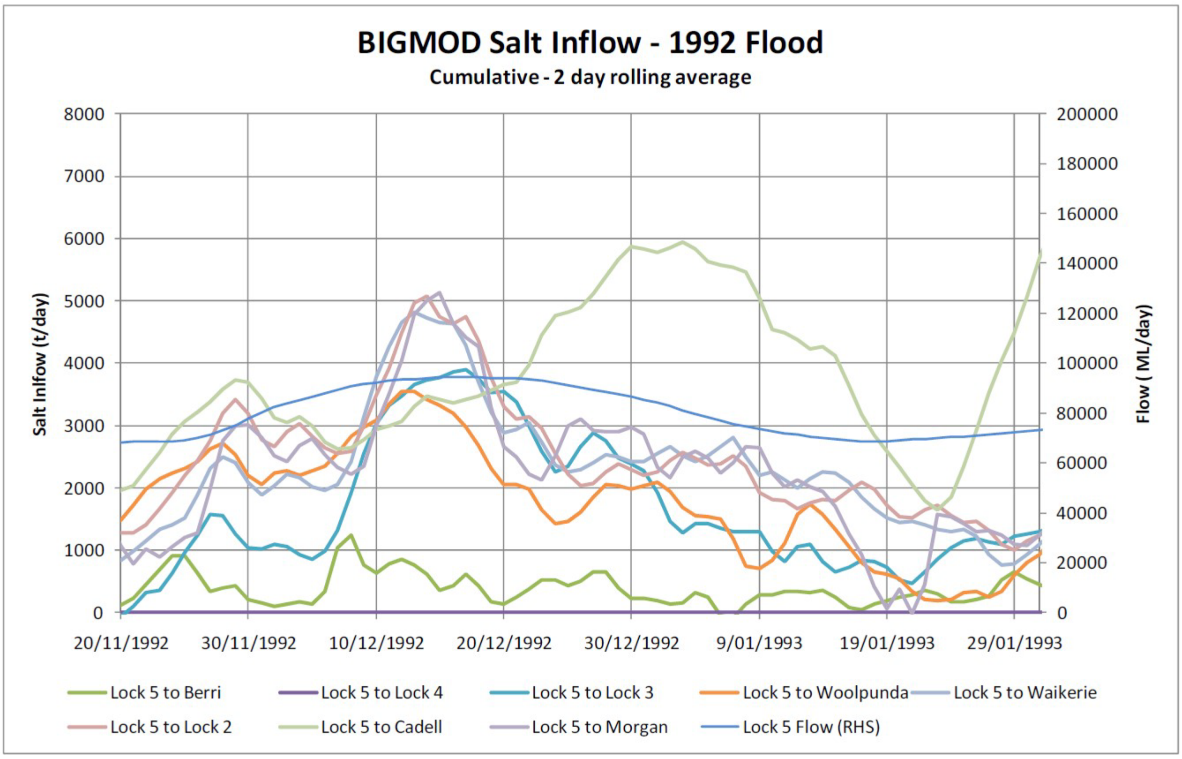

FIGURE 5.17: BIGMOD CALCULATED SALT INFLOW LOCK 5 TO MORGAN FOR THE 1992 FLOOD

These figures show:

- A sharp increase in salinity at Loxton commencing on the 4th of December, peaking four days later before decreasing;
- Flow at Lock 5 increasing and exceeded 85,000 ML/day on the 4th of December; and
- Salt inflow for the Berri to Lock 3 reach began to increase on the 7th of December by between 1,000 to 1,500 tonnes/day when the salinity peak reached Lock 3.

These observations are consistent with the flushing of lagoons within this reach. Detailed analysis of when lagoons "Start to Flow" would enable discrimination between which lagoons cause specific rises in salinity.

5.3.6 Stage

Water level has an immediate and significant impact of groundwater inflow. Minor increases in water level can suppress groundwater inflows for a period with the suppressed salt inflow then flowing out when water levels drop. Fluctuations in water level can occur due to flow changes and the operation of weirs.

The suppression of groundwater was clearly observed in the Lake Bonney example described above in Section 5.3.2.

5.3.7 Pike River

The data suggest that a Chowilla type, salt inflow flood recession occurs in the reach between Lock 5 and Berri, due to the Pike River anabranch and associated floodplain. This is currently masked by other significant sources of salt inflow from disposal basins and backwaters. It is anticipated that when these other components of salt inflow are attributed to specific sources, the remaining salt loads could be attributed to Pike River. The pattern of salt inflow could be expected to be similar in shape, but smaller, to the recession curve which has been developed for Chowilla in Section 4.

5.3.8 BIGMOD Run to April 2012

Recent runs of BIGMOD incorporate a number of additional instream salinity stations. The most recent run extends up to April 2012 when the River was still in flood with a flow of 55,000 ML/day to South Australia. This data could not be used to provide any additional insight into flood recession processes at this stage and has not been included in this report.

5.4 Summary of Salt Inflow Accounting

A summary of the "Identified Process" discussed in this report is provided in Table 5.4 (below) with values representing the long-term average impact. Additional work is required to describe the salt inflow impact on a real time basis.

TABLE 5.4: SALT INFLOW AND ATTRIBUTED SOURCES

	Average Salt Inflow (tonnes/day)		
Time Period	**1977- 1981**	**1985 - 1989**	**1997 - 2001**
Reach Total	1048	889	486
Disposal Basins	200	75	100
Pike River (TBA)			
Lake Bonney	20	20	20
Waikerie/Woolpunda SIS	280	280	0
Bookpurnong/Loxton SIS	100	100	100
Gurra Lakes	2	2	2
Remainder	446	362	264

5.5 Assessment of Manual Monitoring Data

A manual monitoring program was conducted by DEWNR at a series of backwater sites within the Lock 5 to Morgan reach to collect data during the 2010-2011 flood recession. The aim of this program was to collect data that informed understanding of salt mobilisation processes occurring following flood events. This data is presented below in conjunction with continuous instream EC recordings to aid interpretation. Some initial observations include:

Katarapko Creek

Manual sampling sites are located on either side of the Katarapko Creek Outlet, upstream at the Loxton B Boat Ramp and downstream at Milichs Landing (Figure 5.18). Data collected during the 2011 flood and recession provides four comparative samples however, monitoring data is too limited to provide robust analysis but suggests that flow through Katarapko Creek dilutes the salt load in the main river channel.

Yatco Moorook

Salinity data measured at the northern end (near river) of Yatco Lagoon is approximately 100 EC higher than that measured in the River immediately downstream at the Moorook IPS (Figure 5.19). This suggests that salinities increases as water flows through Yatco Lagoon. Some estimation of flow through the wetland would be required to quantify salt inflow.

Loveday Basin

Insufficient monitoring data is available to provide comment for this site.

Lake Bonney and Tributaries

Manual sampling at sites along this section of floodplain was too infrequent to provide meaningful analysis except for those located at the Lake Bonney Jetty and Nappers Bridge (Figure 5.20). Other sites located on inlet creeks follow data patterns observed at Nappers Bridge. In October 2011, salinity values at Nappers Bridge were significantly lower than at Lake Bonney but still well above River salinity suggesting some flow into Lake Bonney of mixed Chambers Creek water. Long-term data measured at the Lake Bonney Jetty indicates EC increases of approximately 500 EC per annum when the Lake is connected to the River and increases in excess of 5,000 EC per annum when it is disconnected.

Banrock Station

Only two data points are available measured at each end of Banrock Station with monitoring sites located at the inlet and outlet channels (Figure 5.20). Salinities at these locations were almost identical.

Generally, the manual data points collected to date are too infrequent to allow meaningful analysis but data collected over an extended period could prove useful. It is likely that data collection was hampered by a series of flood peaks, which followed during 2012 the recession of which has only just occurred.

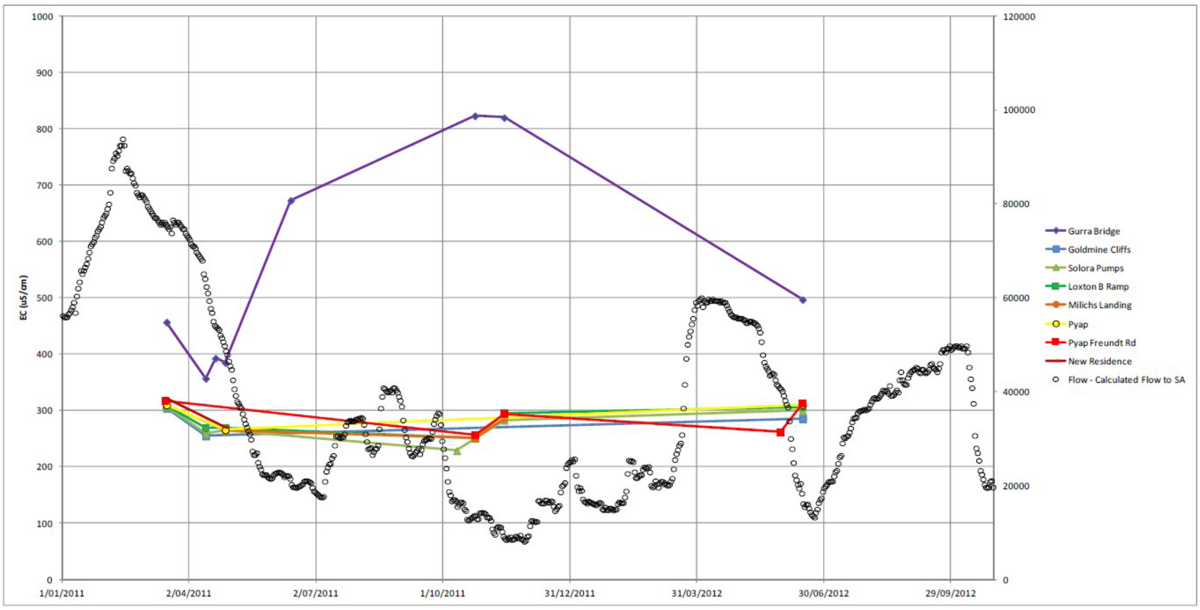

FIGURE 5.18: MANUAL MONITORING DATA AND INSTREAM CONTINUOUS DATA BETWEEN GURRA LAKES AND PYAP

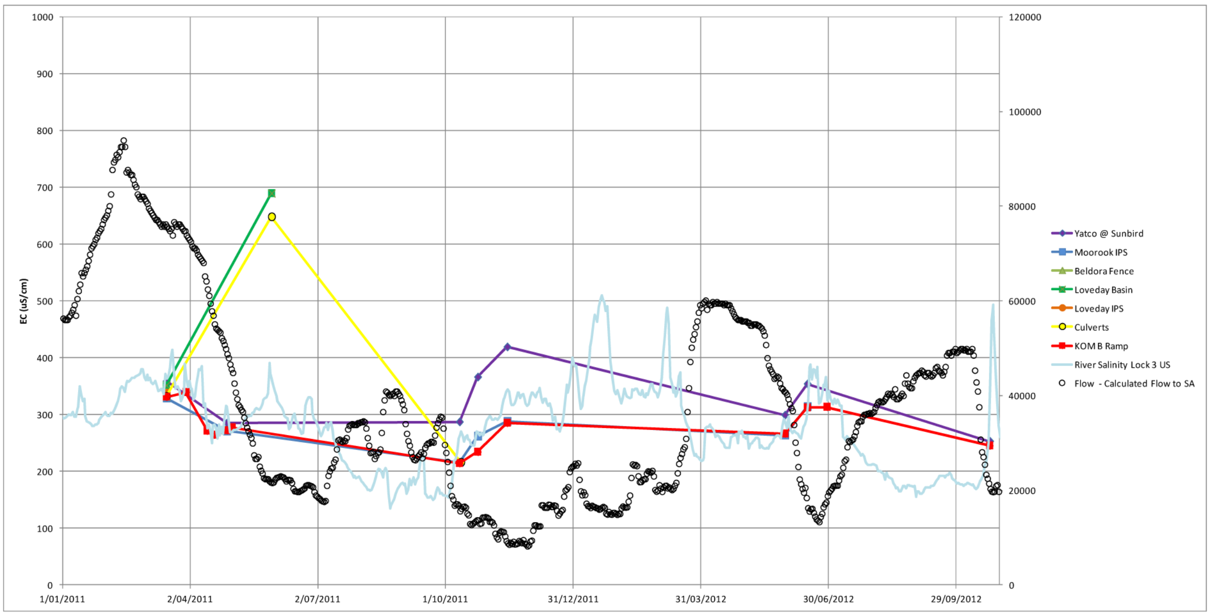

FIGURE 5.19: MANUAL MONITORING DATA AND CONTINUOUS INSTREAM MONITORING DATA ADJACENT YATCO, MOOROOK AND LOVEDAY.

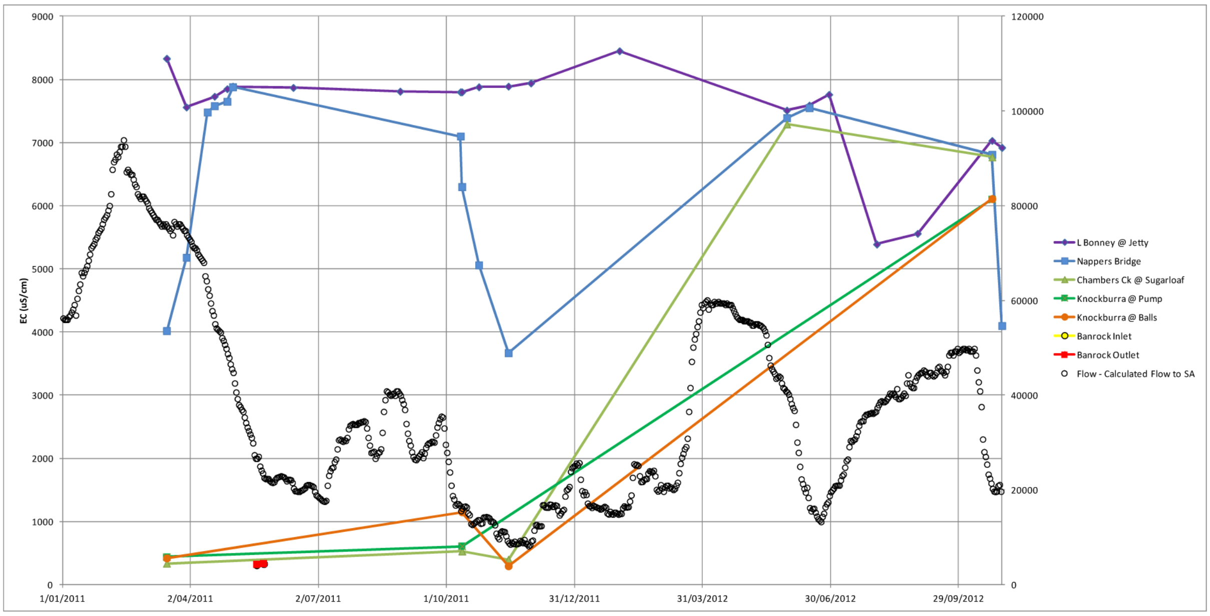

FIGURE 5.20: MANUAL MONITORING DATA AND INSTREAM CONTINUOUS MONITORING DATA ADJACENT LAKE BONNEY AND BANROCK STATION

6 Input Data Reliability

In-stream salinity is a product of the prevailing salt inflow and stream flow and is measured in a variety of ways. Current practice is to use fixed, pontoon-mounted, EC Toroidal Coil stations at numerous locations along the River Murray. These instruments require regular calibration and maintenance but provide an essential data source for assessing salt inflow to the River particularly through MSM-BGIMOD data inputs and model calibration. Instream salinity pontoons within the South Australian extent of the River Murray are generally considered to provide a reliable, representative source of in-stream salinity data with few exceptions.

Historically, various groups, including local personnel of the State Water Laboratory, on a daily or weekly basis, measure many instream monitoring points manually. The manual samples were often taken from, or close to the bank, lock, pumping station or other structure. Samples taken close to the bank can be non-representative of the average channel salinity. Sampling locations were also selected based on access, which may not be where the River is well mixed. Site locations may also have varied due to the manual collection methodology.

The Stage 1 report presented an overview of the match between BIGMOD salinities and observed salinities over the benchmark period. Detailed analysis suggested that in most instances the pattern identified by BIGMOD was supported by the observed salinities. The vast amount of data against which BIGMOD calibrates and the model's output of salt inflow provides a comprehensive data set to assess the temporal and spatial variability of salt load inputs to the River.

Salt inflow analysis can at times however provide questionable results that are present in both MSM-BIGMOD unaccounted salt inflows and in salt inflows that are calculated manually using in-stream flow and salinity data and a travel time based on river geometry. This suggests that input data can be of variable quality.

Negative salt inflows occasionally occur in BIGMOD, and may be used as error/uncertainty estimates. Salinity data can be non-representative for a number of reasons, the most significant of which include:

- Instrument error,
- Poor (inconsistent) mixing,
- Site location providing a non-representative sample or
- Data management errors.

River dynamics can also make salt inflow analysis more difficult, particularly during times of high variation in background salinity, rapid changes in river flow and when salt inflow is low compared to other variables.

In calculating salt inflow, it is important to determine what input data provides a reliable record on which to base the assessment. Figure 6.1 presents calculated salt inflow between Lock 3 and Morgan, with specific reference to salt inflow between Lock 3 and Lock 2. Theoretically, salt inflow should increase at each successive downstream station and follow a similar pattern to those upstream when calculated using the same reference point. Figure 6.1 indicates that this holds true for most stations along this reach of river except at the Lock 2 station. Salt inflow data for Lock 2 should sit between the Sunlands and Hogwash Bend time series however, it is quite variable and often drops below the upstream stations. This analysis of salt inflow between Lock 3 and Morgan suggests that salinity monitoring data collected at Lock 2 is not reliable between 1995 and 2000.

Salt inflow between 1970 and 2010 has been assessed with respect to data quality and key conclusions from this analysis include:

- Comparing salt inflow between a series of stations provides insight as to which data may be poor;
- Manual sampling locations at Waikerie and Cadell Pump Stations generally provide poor data, as does Lock 2 between 1996 and mid-2001, as demonstrated in Figure 6.1;
- Several questionable data points (five at Lock 3 and two at Lock 2) occur between the 18th and 25th of September 2003 (Figure 6.2). During this time, there was a rapid drop in background EC (500 EC to 250 EC over four days) and relative high river flow (~15,000ML/day). It is considered that these manual data points cannot be representative of the average River salinity at the time, for a multitude of reasons as discussed above;
- Time series data also suggests that other stations experience periods where data does not appear consistent with patterns observed at upstream and downstream locations;
- Where the travel time between in-stream stations is less than a day, the timing of sampling (i.e. 9am at each station) can result in the daily-calculated salt inflow reflecting the background salinity profile. This can cause negative salt inflow results where the background salinity variation is larger than salt inflow; and
- Results from salt inflow analysis during flood events can be more volatile due to:
  - Over bank flows and flows from lagoons containing high salinity water which may not be well mixed at monitoring station locations, e.g. data recorded at Overland Corner is influenced by flows off the adjacent floodplain, data recorded at Sunlands is impacted by flows out of Ramco Lagoon and Lock 3 is affected by flows from Lake Bonney and Chambers Creek;
  - Flood events are often associated with rapid changes in background salinity which make travel time assumptions and sampling frequency more critical;
  - EC differentials are low for a given salt inflow due to the higher dilution and thus the noise to signal ratio is increased;
  - Poor access to normal sampling locations, and
  - A high flow rate magnifies any noise as salt inflow is calculated by multiplying the salinity differential by flow.

The removal of questionable data points leaves a comprehensive set of reliable records on which analysis can be based. Reliable pontoon Toroidal Coil stations have been progressively installed along the Lock 3 to Morgan reach since 1987 as follows:

- The Holder (392km) monitoring pontoon was installed in 1987 at the downstream end of the Woolpunda SIS and upstream off the Waikerie SIS;
- The Upstream Sunlands Pump Station (373.6km) pontoon was installed at the downstream end of the original Waikerie SIS extent; and
- A pontoon was installed at Hogwash Bend (347.5km) in 1997 which is located downstream of the Waikerie Lock 2 SIS extent.

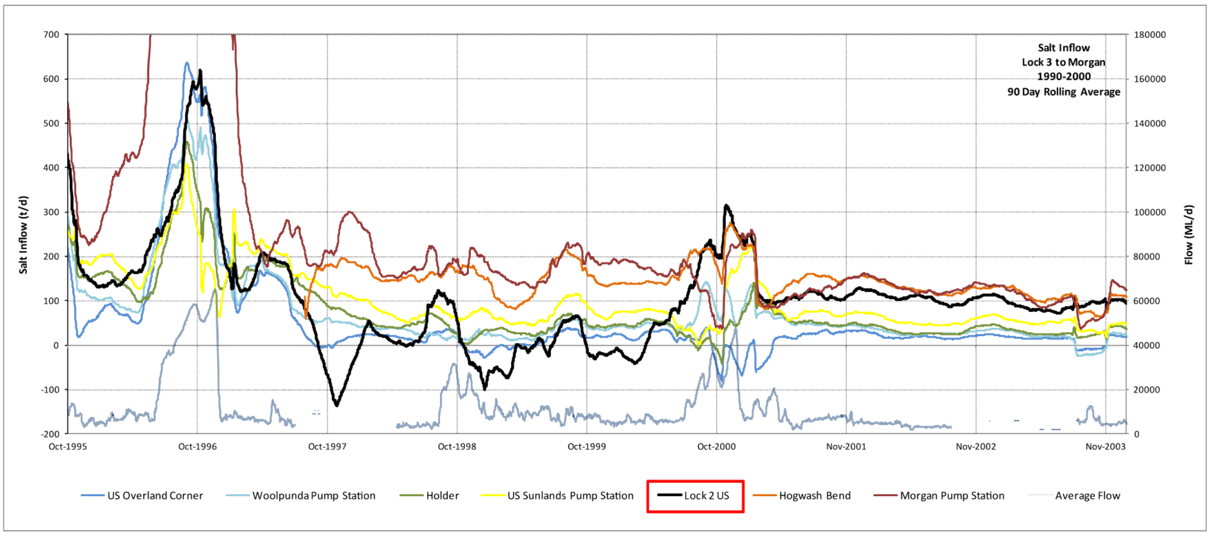

FIGURE 6.1: SALT INFLOW BETWEEN LOCK 3 AND MORGAN ILLUSTRATING VARIABLE DATA QUALITY AT THE LOCK 2 STATION

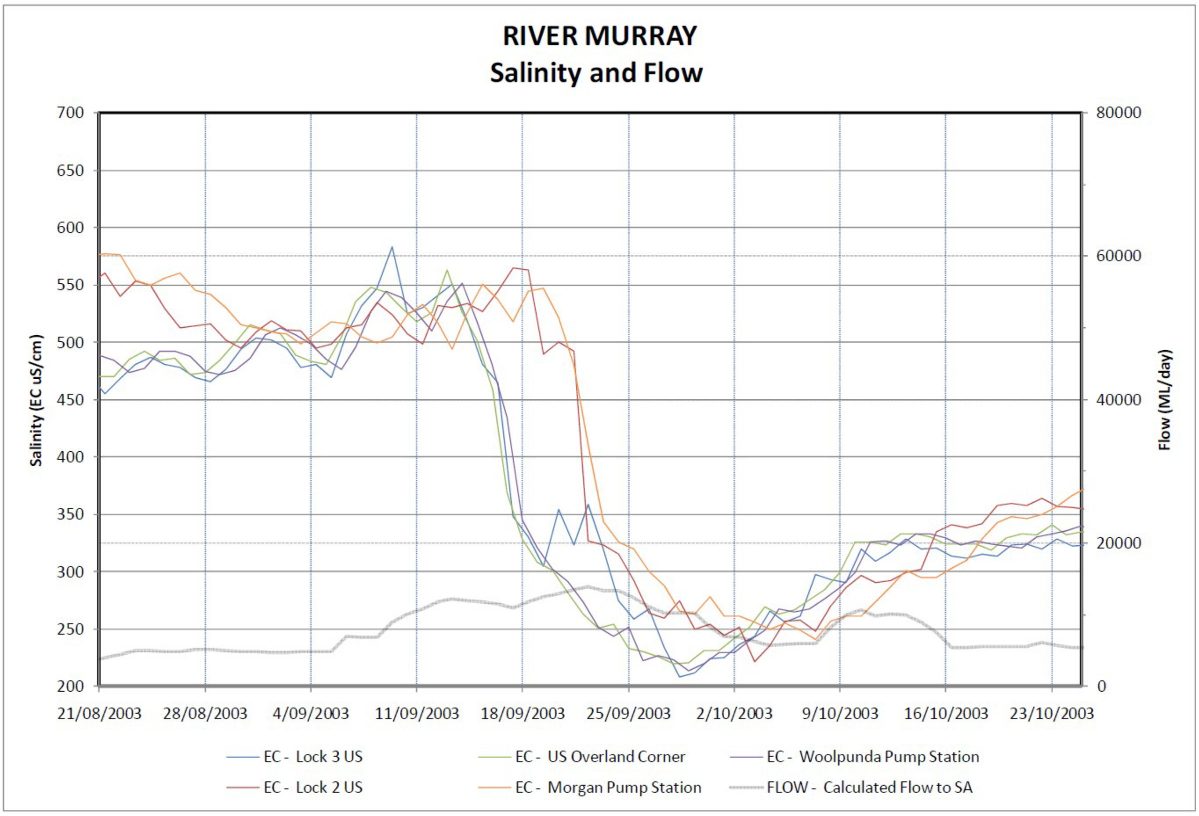

FIGURE 6.2: SALINITY DATA LOCK 3 TO MORGAN AUGUST TO OCTOBER 2003

Another example of questionable raw salinity data is presented in Figure 6.3 showing salinity data for stations between Lock 3 and Morgan. This data suggests that:

- From February 1996 the Morgan salinity is significantly higher and more erratic than that would be expected given the salinity at upstream stations;
- There is no difference between stations for some period of time;
- The magnitude of the salinity difference between Lock 2 and Morgan is of the order of 100 EC, and remains approximately the same for 10,000 ML/day and 50,000 ML/day flows indicating it is not caused by a uniform salt inflow;
- The pattern is not replicated in any other period; and
- The magnitude of the calculated salt inflow is up to 2,000 tonnes/day.

Several surface water features are located on the floodplain between Lock 2 and Morgan (i.e. Schiller's Lagoon and the Markaranka Floodplain) which could contribute significant salt loads to the River between these stations. A review of salinity data from Lock 1 over the same time period indicates that salinities at the downstream station were significantly lower when compared to those from Morgan. Whilst sampling location or local inflows may play a roll, it suggests that high salinity records at Morgan over this time period are the result of instrument error. In October 1997 an instream toroidal coil salinity station was installed at Morgan and results from that time on are more representative. It would appear that BIGMOD uses the toroidal coil data from the time it is available.

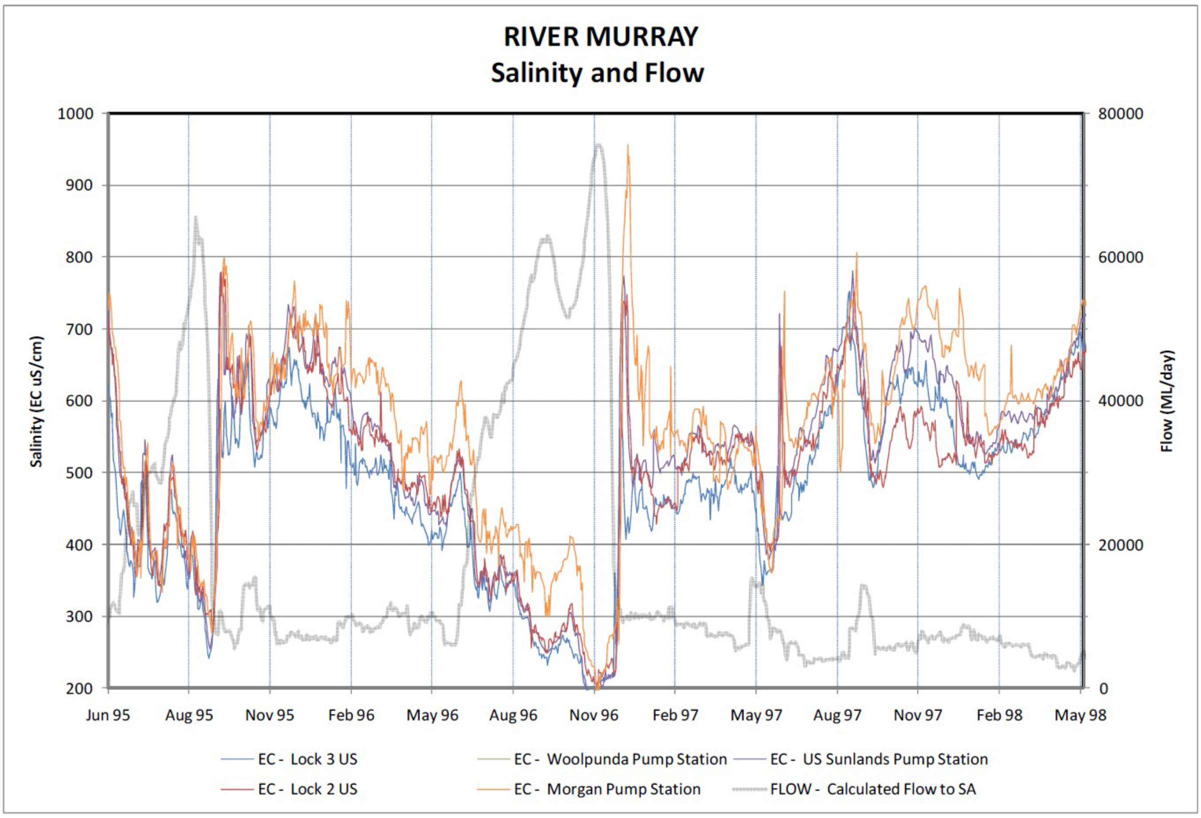

FIGURE 6.3: SALINITY LOCK 3 TO MORGAN JUNE 1995 TO MAY 1998

The examples described above are **not** provided to demonstrate that BIGMOD results are not useful. Indeed, the opposite is true: **the vast bulk of the BIGMOD record and its salt inflow interpretation is consistent with anecdotal and empirical evidence, and the results for processed based groundwater models.** What this section seeks to highlight is that with careful attention, the already useful BIGMOD model can be cleansed to strip out erroneous or poorly representative data to increase the accuracy of the model. Cleansing raw salinity data, as described above, presents an opportunity to improve the veracity of MSM-BIGMOD outputs by providing a reliable input and calibration data set. This is especially true for salinity recorded at Morgan as this is used as the benchmark to assess salinity impacts throughout the Murray Darling Basin via the Basin Salinity Management Strategy.

7 Conclusions

This study has identified a number of processes that control salt inflow to the River Murray and attributed components of unaccounted salt inflow to specific sources, significantly:

- A simple analytical model has been developed to replicate salt inflow during flood recessions from Chowilla but further investigation is required to determine if this is suitable for incorporation to BIGMOD;
- Major unaccounted salt inflow in the reach Lock 5 to Morgan can be attributed to irrigation disposal basins;
- Calibration of the process of salt inflow from Lake Bonney could be improved. This would result in the net movement of 20 t/d of salt from the unaccounted salt inflows to the accounted salt inflows and also improve the timing and impact of Lake Bonney outflows on modelled salt inflow and EC; and
- Evaporative accumulation in backwaters has the capacity to store significant amounts of River salt and groundwater inflow salt during times of low flow and release it to the River at high rates during higher flow events. The salinity impact may still only be moderate as the high flows dilute the salt inflow.

It is recommended that:

- Further analysis be undertaken on the analytical model incorporating the following:
  - Test the applicability of the simple analytical model at other comparable floodplain sites downstream (e.g. Pike);
  - Extend the natural log analytical model to cater for suppression of salt inflows by higher flows;
  - Improve the conceptual model process detail, particularly the cause of the step function of delivery of salt inflow and this could be investigated further; and
  - Initiate monitoring programs to assess salinity impacts of watering events and impacts from the Chowilla Regulator which does affect the eastern floodplain and may activate the step function of salt delivery that has been observed during flood events where flow exceeds 75,000 ML/d.
- Lake Bonney calibration be updated;
- The characteristics of each significant off-stream water body be assessed to identify whether it is a backwater or a through-flow anabranch, the contribution of salt through groundwater inflow and the mechanism of connection to the River which will in turn enable the building of a robust assessment of salt inflow variation due to backwaters;
- A process specifically designed to identify suspect raw salinity data be undertaken to provide a much improved raw salinity data set; and
- In-stream EC monitoring, which has proved invaluable for assessing salt inflow process, be continued.

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Appendix B. BigMod modelling work – Andy Close

Andy Close was engaged by the MDBA to undertake extensive data analysis and modelling work and develop a flood recession salt inflow relationship for the Chowilla Floodplain. The starting point for this work was the finding by AWE (2013) that a simple groundwater decay relationship provided a good prediction of flood recession salt load for a selection of events analysed plus the recommendation (AWE 2013) that the applicability of a decay relationship be tested and evaluated over a wide range of flow conditions and that suppression of salt by subsequent flood events be incorporated into the relationship.

To meet the objectives of this project, Andy Close developed a salt inflow decay plus suppression relationship for possible inclusion into MSM-BigMod through a five step process:

- Step 1: Testing and calibration of a salt inflow decay plus suppression relationship for individual events
- Step 2: Evaluation of calibration parameters from individual events to determine suitable calibration parameters for the period of record
- Step 3: Incorporate the salt inflow decay plus recession relationship into BigMod
- Step 4: Test the impact of the relationship on the calibration
- Step 5: Test the impact of the relationship on the assessment of The Living Murray and Basin Plan

This Appendix documents the methods and outcomes of each Step.

B.1 Step 1: Testing and calibration of a salt inflow decay plus suppression relationship for individual events

The salt inflow decay plus suppression relationship is used to simulate the concept that flood events activate a mass of salt which is subsequently released to the river as the floods recede. The relationship is simulated as a “bucket” of salt, where the size of the bucket of salt activated is a function of flow. A new flood event starts when the salt activated by the current days flow exceeds the salt remaining in the bucket from the last high flow event.

The model describing the release of salt following a flood is given by the relationships:

$$Salt\ flux = mobilised\ salt\ left\ in\ the\ bucket\ yesterday \times decay\ factor \times suppression\ factor$$

Equation 6

$$Mobilised\ salt\ left\ in\ the\ bucket = mobilised\ salt\ left\ in\ the\ bucket\ yesterday - salt\ flux$$

Equation 7

The suppression factor reduces the salt flux when the water level downstream of Lock 6 is higher than a specified reference level as a result of flows during the suppression period that are higher than minimum flows, but not high enough to trigger a new event. If the suppression factor always has a value of 1.0, the salt flux would have the same form as the exponential decay formulation proposed by AWE (2013).

The suppression factor was formulated based on an *effective level*:

$$Inital\ suppression\ factor = \frac{(effective\ level - today's\ level)}{(effective\ level\ - reference\ level)}$$

Equation 8

$$Effective\ level =\ reference\ level + (peak\ level - reference\ level) \times \frac{mobilised\ salt\ left\ in\ the\ bucket}{salt\ initially\ mobilised\ by\ the\ flood}$$

Equation 9

A total of 16 flood events with a peak flow greater than 40,000 ML/day upstream of Lock 6 were identified for testing and evaluation. For each event 'salt mobilised', 'decay rate' and 'constant flux' parameters were identified to calibrate the salt flux to the observed data. The results of the calibration for each flood event (including graphs for each event and calibration parameters) are shown in Figure 15 to Figure 31 at the end of this Appendix. These results show that the proposed relationship was capable of producing good results for individual flood recession events.

B.2 Step 2: Evaluation of calibration parameters from individual events to determine suitable calibration parameters for the period of record

The calibration parameters from the individual events were collated and analysed to determine suitable calibration parameters for the entire period of record assessed.

From the relationship between 'salt mobilised' and flow (Figure 9), two parameters were derived relating to the mass of salt activated by the peak flow:

1. **Salt event threshold** – the flow threshold above which events produce extra salt. This was set to a value of 29,244 ML/day, based on the intercept of the line of best fit.

2. **Salt generation factor** – the mass of salt (tonnes) produced per ML of flow above the salt event threshold. This was set to a value of 1.2279 tonnes/ML, based on the slope of the line of best fit.

From the relationship between 'decay rate' and flow (Figure 10), two parameters were derived relating to the rate of salt decay following a peak flow event:

3. **Base decay rate** – the rate of salt decay for an event at the salt event threshold. This was set to a value of 0.00213 tonnes/day, based on the intercept of the line of best fit.

4. **Increase in decay rate with flow** – the increase in rate of decay per ML of flow (of the last salt generation event) above the salt event threshold. This was set to a value of 0.000000072 tonnes/ML, based on the slope of the line of best fit.

The **reference level** was calibrated to 16.0 m AHD and compares to a Lock 5 pool level of 16.3 m AHD.

No relationships were developed for the 'constant flux' parameters, although these varied between flood events. This 'constant' flux remains part of the residual unaccounted salt in the reach.

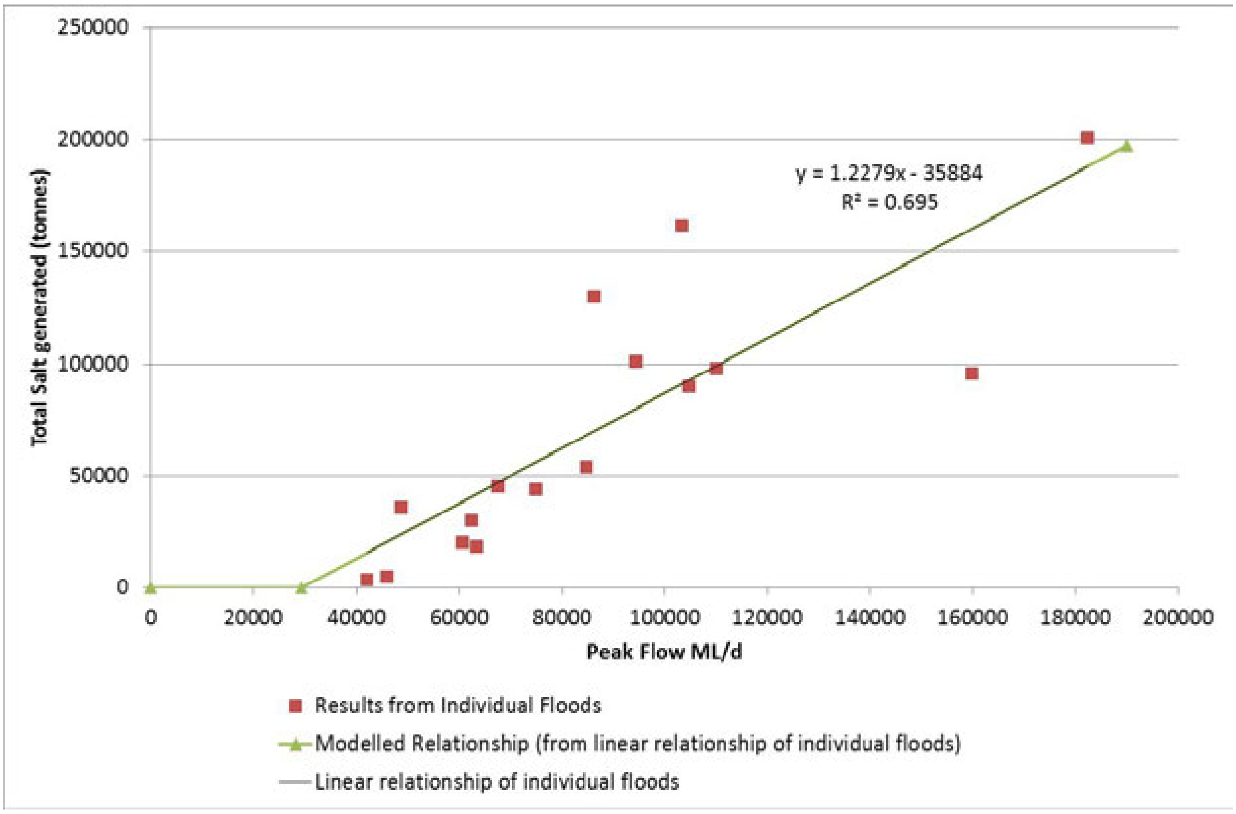


Figure 9: Relationship between peak flow and total salt generation. The parameter "salt generation factor" was set equal to the slope of the relationship. The parameter "salt event threshold" was set equal to the intercept of the relationship divided by the salt generation factor.

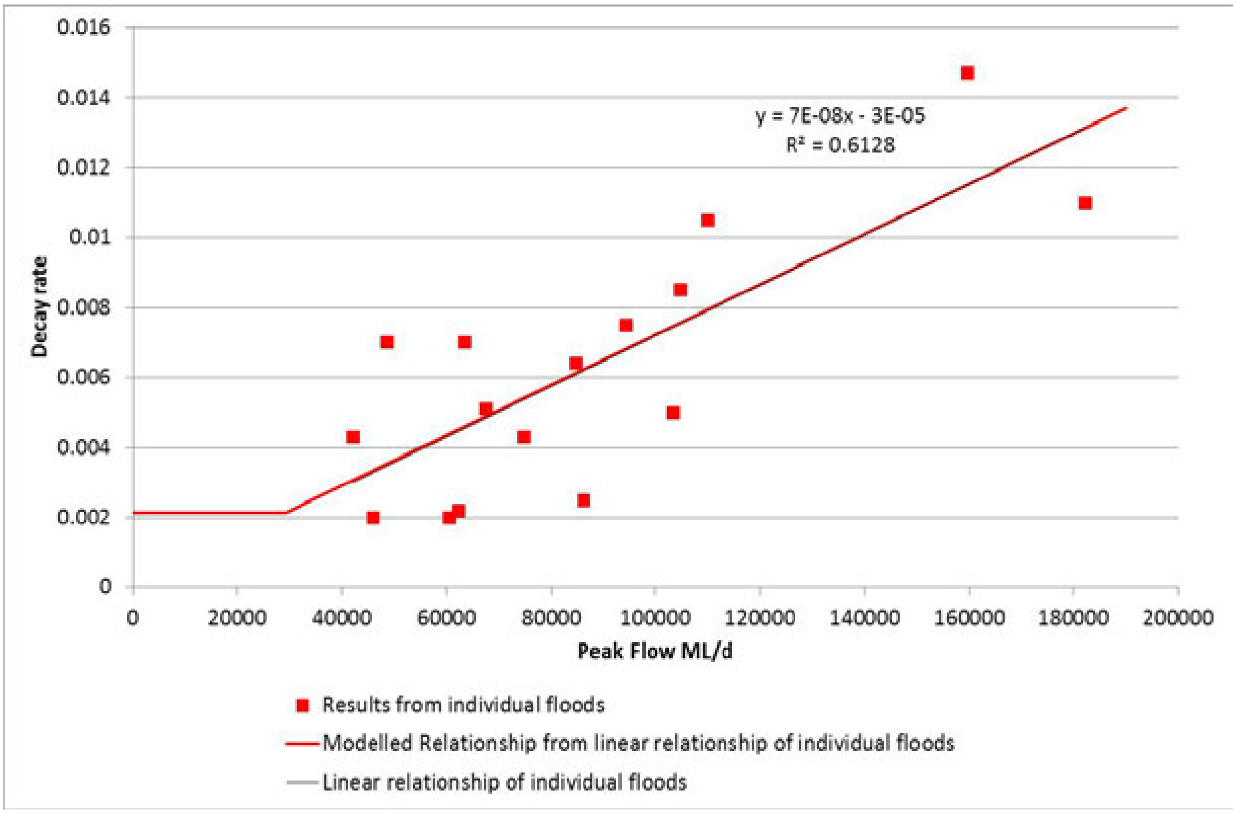


Figure 10: Relationship between peak flow and decay rate. The parameter "based decay rate" was set equal to the intercept of the relationship. The parameter "increase in decay rate with flow" was set equal to the slope of the relationship.

The calibrated parameters were then used to derive a time-series of salt inflow from Chowilla across the full assessment period. The time-series of results are shown in Figure 11 to Figure 13. These figures show that the proposed relationship and calibration parameters lead to salt inflows being generated in the flood recession period and the pattern and magnitude of the salt inflows are a good estimate in comparison to recorded data across the full assessment period (RMSS of 260).

Variations to the calibration parameters were investigated to determine if the relationship could be improved. However, investigations were not able to achieve a significant improvement to the fit of the overall relationship, so the calibration parameters listed above were retained.

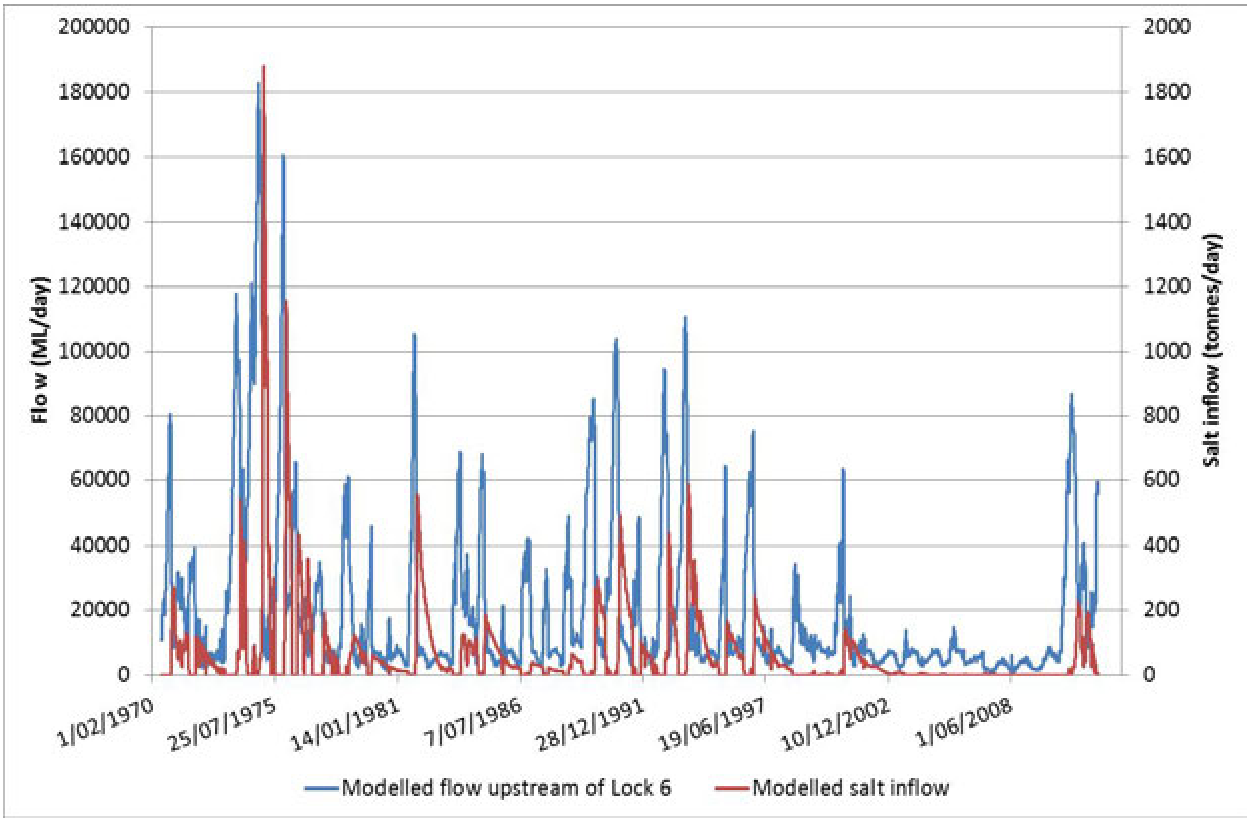


Figure 11: Time-series plot of modelled flow upstream of Lock 6 and salt inflow calculated by the proposed relationship.

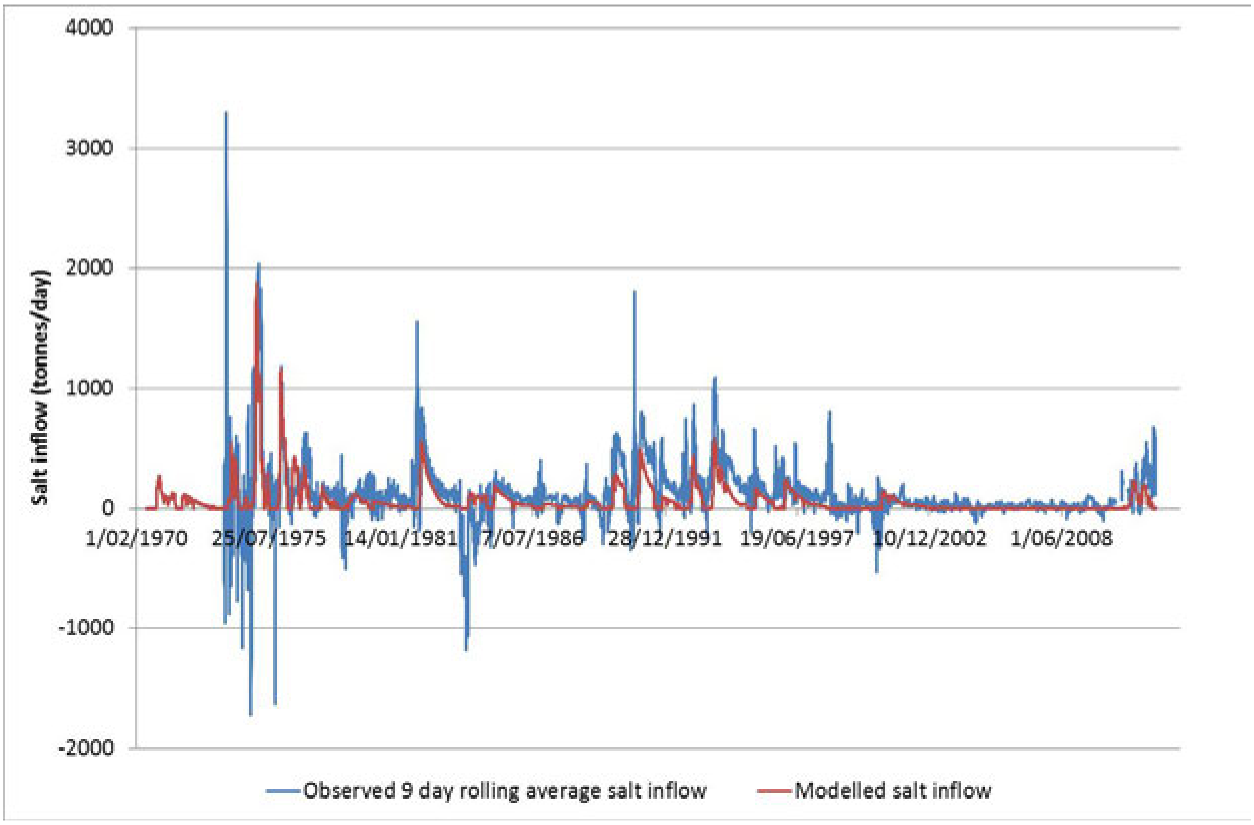


Figure 12: Comparison of observed and calculated salt inflow from Chowilla (daily time-step).

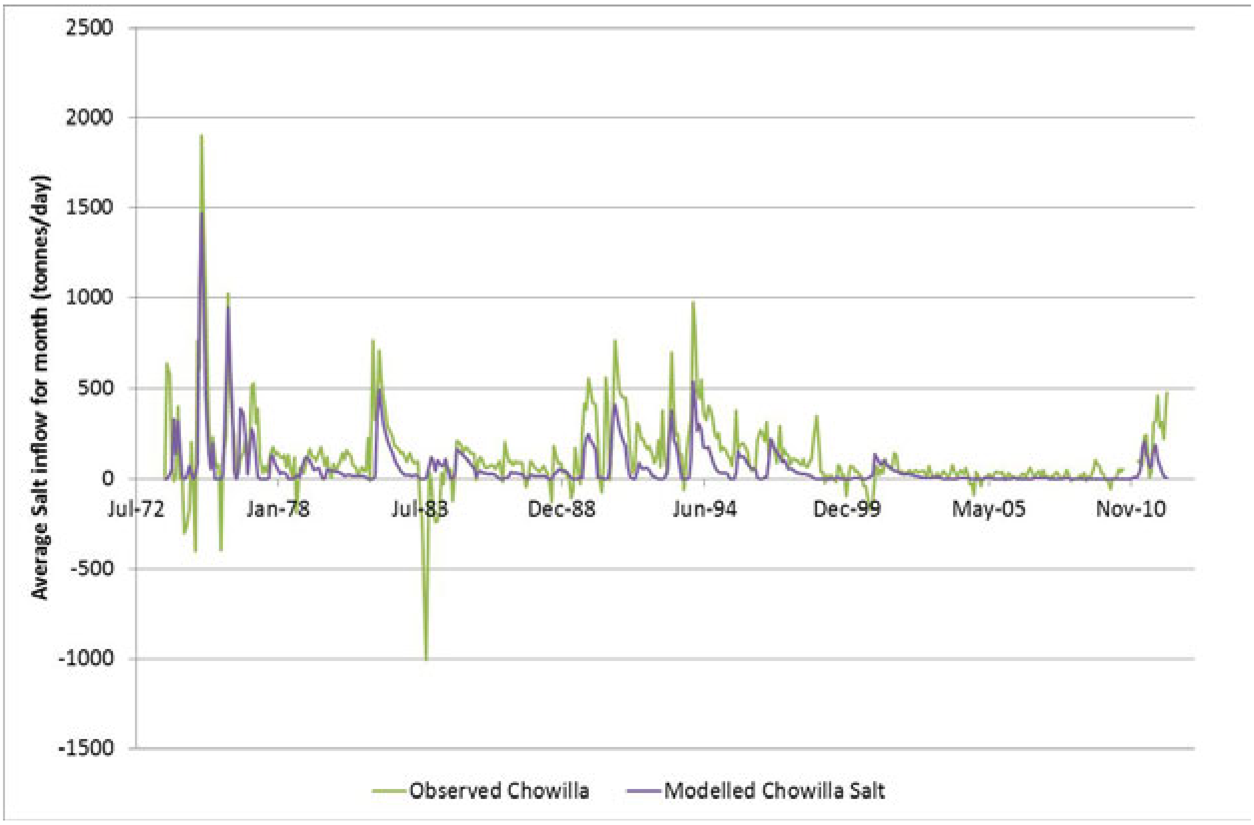


Figure 13: Comparison of observed and calculated salt inflow from Chowilla (monthly time-step).

Other model refinements

Lake Bonney

AWE (2013) noted that improving the calibration of Lake Bonney in BigMod could reduce the mass of unaccounted salt inflow. To date, Lake Bonney has been partially accounted in BigMod, whereby the evaporative concentration effect of Lake Bonney was accounted for, but groundwater salt inflows to Lake Bonney remained part of the unaccounted salt inflows for the reach Lock 5 to Morgan.

Andy Close followed the recommendation of AWE (2013) to refine the simulation of Lake Bonney. This was undertaken by 'fixing' salt inflows from Lake Bonney in BigMod to observed data. By doing so, all salt inflow contributions from Lake Bonney will be accounted for where re-deriving the unaccounted salt.

Figure 14 shows the timing of salt outflows from Lake Bonney: it is these outflows that have been 'fixed' in the model as an accounted salt inflow (and thus removed from the Lock 5 to Morgan unaccounted salt inflow). This 'fixed; Lake Bonney outflow has an average mass flux of 53 tonnes/day.

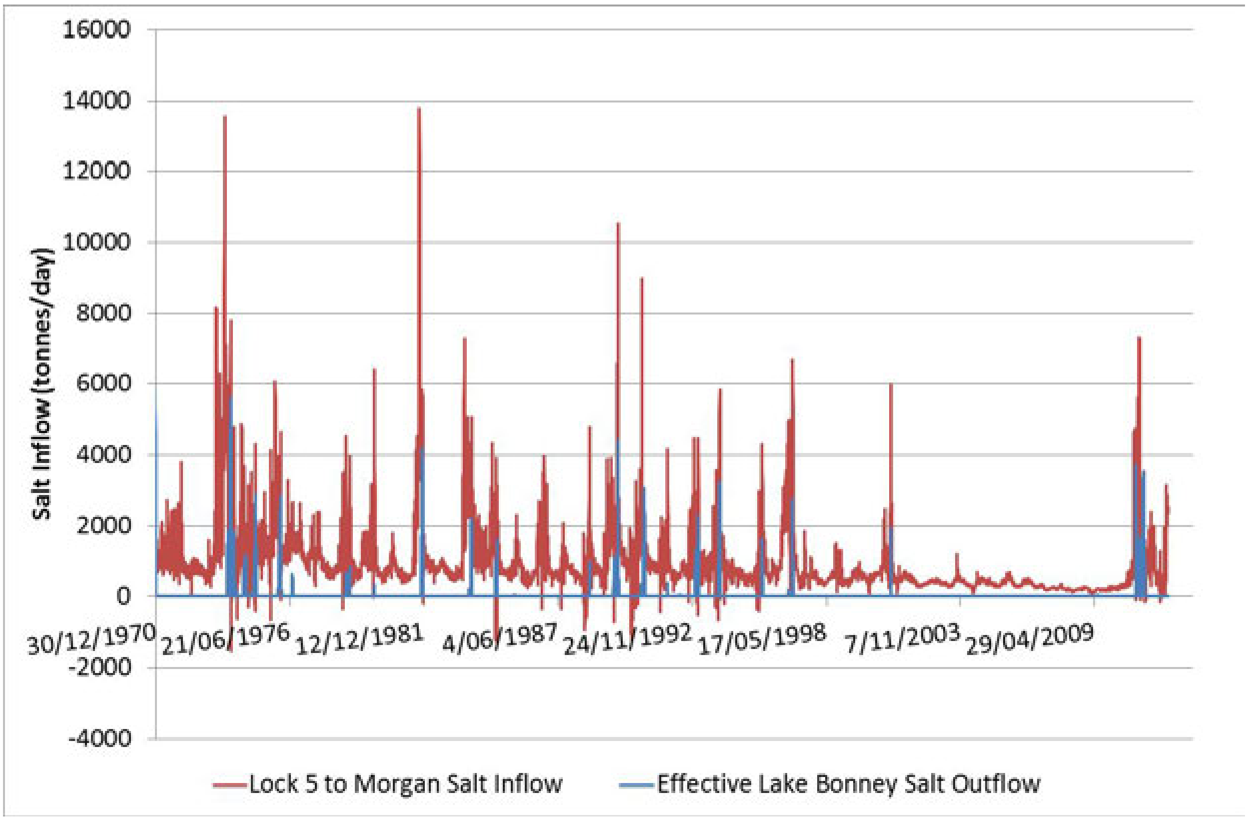


Figure 14: Timing of salt outflows from Lake Bonney.

Data corrections

In re-deriving the unaccounted salt inflows for all reaches and undertaking any necessary balancing (smoothing) of negative salt inflows (Section 4.3), several errors were found in the observed historical data. In particular, it was observed that there were errors in the temperature adjustments for salinity data at Heywoods and Yarrawonga following the installation of a continuous data logger in approximately 2001. Factors to correct for these errors were derived and applied to generate new 'temperature corrected' salinity data for these sites.

Additionally, minor data errors at other sites were corrected where found.

B.3 Step 3: Incorporate the salt inflow decay plus recession relationship into BigMod

The flood recession salt contribution from Chowilla Floodplain was previously incorporated into the unaccounted salt inflows for Lock 9 to Lock 5. The relationship and calibration parameters developed in Step 2 were incorporated into BigMod to explicitly represent the flood recession salt contribution from Chowilla Floodplain. Incorporating the relationship into the model required the follow tasks to be undertaken:

- unaccounted salt inflows for the reach Lock 9 to Lock 5 were spilt into two reaches: Lock 9 to Lock 6 and Lock 6 to Lock 5. This required some changes to the model code to read in unaccounted salt inflow information for an additional reach, and also affected balancing (smoothing) of negative salt inflows across the system;
- the relationship and calibration parameters were 'coded' into the model as an salt inflow for the reach Lock 6 to Lock 5;
- raw unaccounted salt loads for all reaches were re-calculated (historical loads calculated using historical data) with the contribution of Chowilla to the reach Lock 6 to Lock 5 now accounted for;
- the raw (historical) unaccounted salt loads were converted into Year 2010 conditions unaccounted salt loads by adding and subtracting the effects of the actions on the Basin Salinity Management Strategy Salinity Register (as per standard procedures); and
- any necessary balancing (smoothing) of negative salt inflows was undertaken.

In re-deriving the unaccounted salt loads, the impact of recalibrating Lake Bonney and the salinity data corrections was taken into account.

Incorporating the salt inflow decay plus recession relationship into the model reduced the historic Lock 6 to Lock 5 unaccounted salt inflow from 185 tonnes/day to 126 tonnes/per day: a reduction of 59 tonnes/day (approximately 32%).

B.4 Step 4: Test the impact of the relationship on the calibration

Any changes to the salinity calibration of MSM-BigMod may have implications for the assessment of baseline conditions and the impact of accountable actions under the Basin Salinity Management Strategy. For this reason, it is important to understand any impacts of including the new salt inflow decay plus recession relationship for Chowilla (plus the other model refinements) on the salinity calibration of MSM-BigMod.

Once the new salt inflow decay plus recession relationship for Chowilla was built into BigMod along with the other model refinements (and residual unaccounted salt inflows were re-derived), the impact of the new relationship on BigMod and MSM-BigMod calibration was tested. The results of this testing are shown in Table 3 and Table 4. These results show that incorporating the new relationship leads to a marginal improvement in the calibration of modelled salinities at Morgan.

Table 3: Impact of the new Chowilla salt inflow decay plus recession relationship on BigMod calibration (BigMod only, July 1970 to June 2009) (green results indicate an improvement in calibration while red results indicate a worsening of calibration).

Site	Comparison between modelled and observed salinity			Difference between new and original models		
	Mean difference	RMSS of error	R^2	Mean difference	RMSS of error	R^2
Yarrawonga	0.0	9.2	0.575	-1.4	-4.6	0.397
Torrumbarry	5.1	19.4	0.785	0.8	-1.6	0.028
Swan Hill	-2.1	77.5	0.757	-1.8	-3.9	0.024
Stevens Weir	-2.2	21.9	0.178	-0.4	-1.1	0.036
Kyalite	11.3	141.6	0.447	8.5	9.7	-0.025
Wakool Junction	7.2	57.0	0.721	5.1	-2.0	0.017
Red Cliffs	-3.2	65.8	0.673	-5.5	-1.1	0.008
Merbein	0.4	75.2	0.700	-7.6	-1.7	0.011
Lock 9	10.6	68.3	0.749	10.1	-0.4	0.008
Renmark	5.1	57.9	0.841	-6.3	-1.7	0.013
Berri	5.6	65.1	0.845	-5.1	-0.6	0.008
Morgan	3.2	91.0	0.864	-4.9	-1.3	0.011
Murray Bridge	10.8	111.4	0.809	5.1	-2.1	0.023
Milang	-127.7	427.6	0.948	-8.4	-8.0	0.000

Table 4: Impact of the new Chowilla salt inflow decay plus recession relationship on MSM-BigMod calibration (July 1983 to June 2009) (green results indicate an improvement in calibration while red results indicate a worsening of calibration).

Site	Comparison between modelled and observed salinity			Difference between new and original models		
	Mean difference	RMSS of error	R^2	Mean difference	RMSS of error	R^2
Yarrawonga	-1.0	9.7	0.527	-1.5	-4.1	0.382
Torrumbarry	4.2	20.4	0.746	0.6	-3.2	0.061
Swan Hill	4.1	75.4	0.710	1.9	-3.3	0.024
Stevens Weir	-3.1	21.5	0.138	-0.5	-0.7	0.025
Kyalite	11.7	121.7	0.264	6.6	1.7	0.010
Wakool Junction	10.2	62.1	0.646	4.8	-1.5	0.016
Red Cliffs	0.2	71.7	0.595	-4.6	0.1	-0.001
Merbein	5.3	76.2	0.625	2.4	0.5	-0.005
Lock 9	11.3	69.1	0.670	10.9	1.8	-0.013
Renmark	0.7	56.0	0.790	-11.8	-1.1	0.003
Berri	4.2	63.2	0.771	-3.9	-0.1	0.003
Morgan	-2.9	84.8	0.795	-7.1	-0.1	0.000
Murray Bridge	3.9	98.6	0.766	-5.4	-1.3	0.014
Milang	-175.8	538.9	0.960	-6.8	-7.1	0.000

B.5 Step 5: Test the impact of the relationship on the assessment of The Living Murray and Basin Plan

The main aim of incorporating the new salt inflow decay plus recession relationship for Chowilla into BigMod is to increase the proportion of salt load calculated dynamically in the model (and thus based on modelled flows) rather than read from an input file of unaccounted salt inflows. This is being undertaken to allow potentially more accurate assessment of the salinity impact of works/programs etc that may result in changes to the flow regime.

Two major changes to the flow regime are The Living Murray (TLM) program and the Basin Plan. The impact of the new salt inflow decay plus recession relationship for Chowilla (plus the other model refinements) on the assessment of these actions has been tested. The results of this testing are shown in Table 5 and Table 6. These results show that incorporating the model changes lead to a small reduction in the assessed benefit of The Living Murray (salinity benefit reduced from $4.4 million/year to $4.3 million/year) but a small increase in the assessed benefit of the Basin Plan (salinity benefit increased from $8.7 million/year to $8.9 million/year).

Table 5: Impact of the new Chowilla salt inflow decay plus recession relationship on the assessment of the recovery and use of 500 GL for The Living Murray program (green results indicate an improvement in calibration while red results indicate a worsening of calibration).

Site	Without new Chowilla relationship		With new Chowilla relationship	
	Benchmark values	Change in value – TLM recovery and use	Benchmark values	Change in value – TLM recovery and use
Average salinity (EC)				
Yarrawonga	63.54	0.11	63.14	0.09
Torrumbarry	116.70	4.11	115.72	4.11
Swan Hill	270.84	4.31	267.76	4.39
Stevens Weir	83.85	0.00	83.28	0.00
Kyalite	296.08	-7.66	284.16	-3.37
Wakool Junction	278.09	1.10	270.91	1.53
Red Cliffs	309.41	-0.95	304.32	-0.73
Merbein	334.38	-2.76	327.16	-2.28
Lock 9	361.09	-5.84	351.83	-4.93
Renmark	416.79	-12.56	402.39	-11.86
Berri	452.53	-17.20	438.39	-16.52
Morgan	520.22	-27.73	511.52	-27.55
Murray Bridge	554.50	-32.65	543.04	-32.16
Milang	670.38	-24.46	668.13	-26.09
Weir 32	478.50	17.35	478.50	17.35
Burtundy	495.93	30.97	492.93	30.97
Anabranch Outflow	781.81	-297.85	781.81	-297.85
Morgan 96th percentile salinity (EC)	799	-67	781	-60
Salinity benefit ($m/year) (2005 $)	-94.8	4.4	-91.8	4.3

Table 6: Impact of the new Chowilla salt inflow decay plus recession relationship on the assessment of the Basin Plan with 2750 GL recovered (green results indicate an improvement in calibration while red results indicate a worsening of calibration)

Site	Without new Chowilla relationship		With new Chowilla relationship	
	Benchmark values	Change in value – TLM recovery and use	Benchmark values	Change in value – TLM recovery and use
Average salinity (EC)				
Yarrawonga	63.61	0.12	63.20	0.07
Torrumbarry	120.74	7.65	119.76	7.65
Swan Hill	274.92	-13.36	271.95	-13.73
Stevens Weir	83.87	-1.15	83.28	-1.22
Kyalite	287.94	-21.06	276.96	-19.22
Wakool Junction	278.76	-15.58	272.02	-15.14
Red Cliffs	307.80	-25.32	302.82	-24.58
Merbein	330.87	-30.97	324.02	-29.72
Lock 9	354.92	-22.40	346.44	-21.36
Renmark	403.97	-30.90	390.20	-31.26
Berri	435.01	-36.76	421.47	-37.63
Morgan	491.85	-51.14	483.19	-53.85
Murray Bridge	520.88	-63.46	509.74	-65.35
Milang	644.22	-118.16	640.25	-118.97
Weir 32	497.83	7.29	497.83	7.29
Burtundy	524.70	-16.09	542.70	-16.09
Anabranch Outflow	485.90	248.17	485.90	248.17
Morgan 96th percentile salinity (EC)	732	-16	722	-36
Salinity benefit ($m/year) (2005 $)	-90.2	8.7	-87.3	8.9

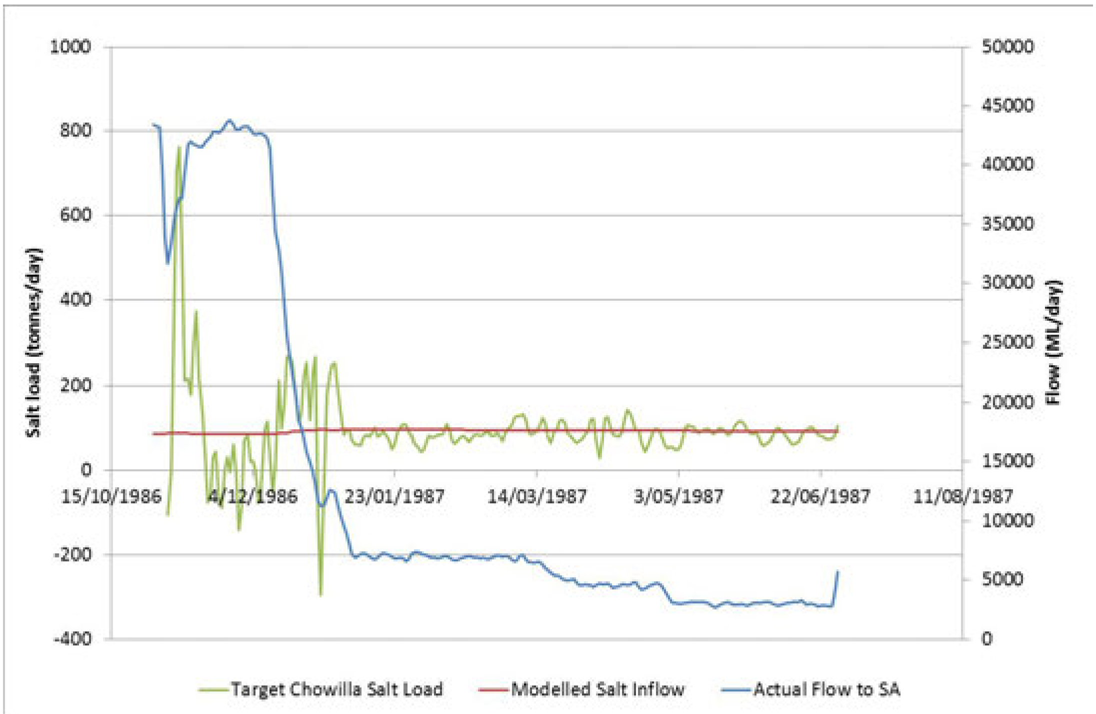
B.6 Recommendations

Based on the outcomes of the model refinement work presented in this Appendix, it was recommended that:

- refinements to the model discussed in this section (inclusion of the Chowilla salt inflow decay plus suppression relationship, recalibration of Lake Bonney salt contributions and corrections to salinity data) be adopted into the model and be used for future Basin Salinity Management Strategy Salinity Register modelling assessments;
    - an average of 185 tonnes per day of unaccounted salt inflow enters the river between Lock 6 and Lock 5 (i.e. from Chowilla). This represents 5.6% of total unaccounted salt load to the river. Incorporating the model refinements will reduce the mass of accounted salt inflow in this reach by an average of 59 tonnes per day (to 126 tonnes per day);
- the potential to derive similar salt inflow decay plus suppression relationships for sites in the reach Lock 5 to Morgan be considered; and
- the potential to individually account for backwater systems in the reach Lock 5 to Morgan (such as Gurra Lakes and Ramco Lagoon) be considered.

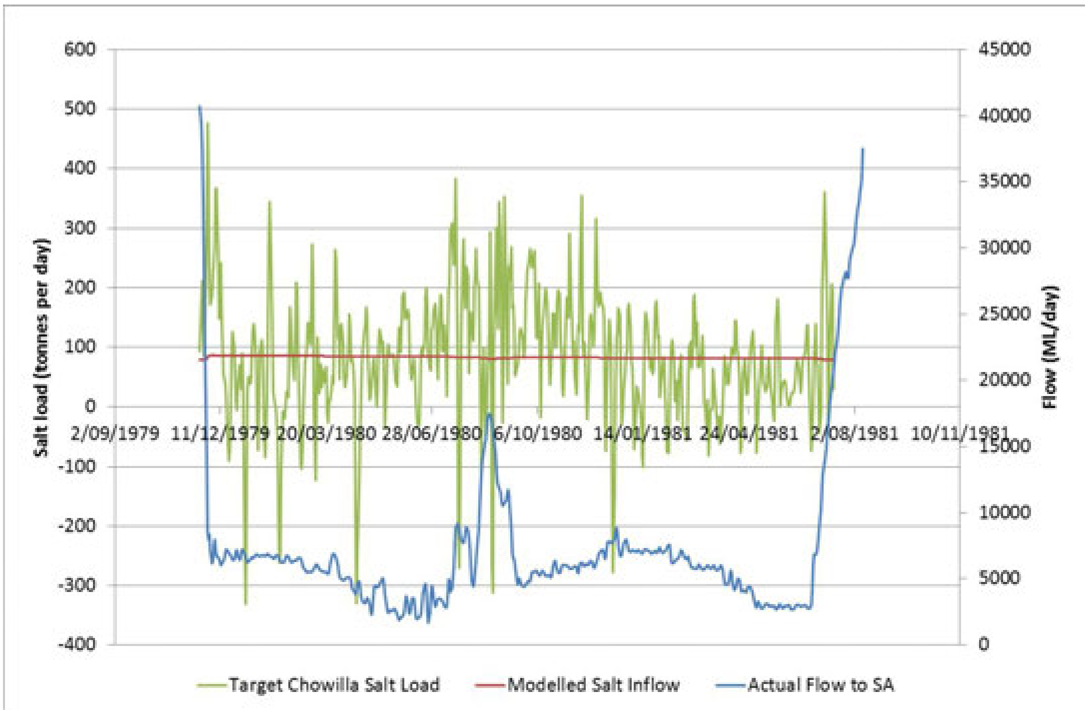
B.7 Calibration plots for individual events

The following plots illustrate the calibration of the salt inflow decay plus suppression relationship for the Chowilla Floodplain to individual recorded flood events. The plots show flow (*Actual Flow to SA*) in ML/day, actual salt inflow from the floodplain (*Target Chowilla Salt Load*), calculated from observed data and salt inflow estimated by the calibrated relationship (*Modelled Salt Inflow*). Comparing *Actual Flow to SA* and *Target Chowilla Salt Load* shows the nature of the flood recession salt load input in terms of the timing and magnitude of salt inflow. Comparing *Target Chowilla Salt Load* and *Modelled Salt Inflow* shows the quality of the calibration of the salt inflow decay plus suppression relationship.



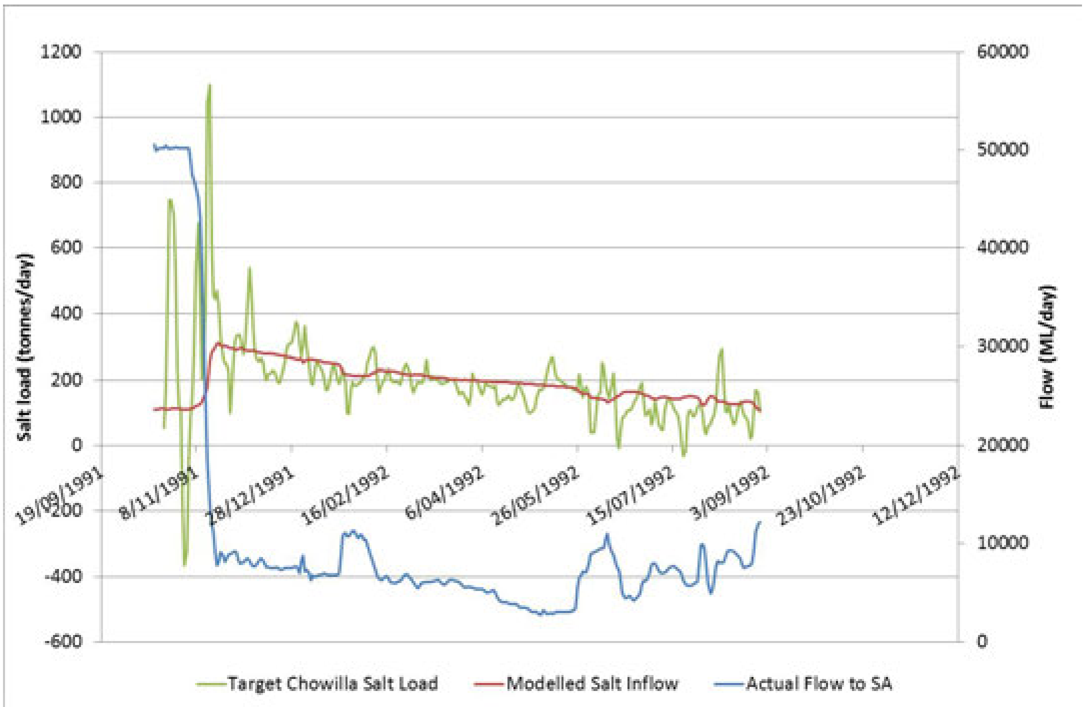
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	3400
Salt decay rate	0.0043
Lock 6 reference level (m AHD)	16.0
Constant	86.1
RMSS	**96.7**

Figure 15: Evaluation of event: peak flow of 42,017 ML/day.



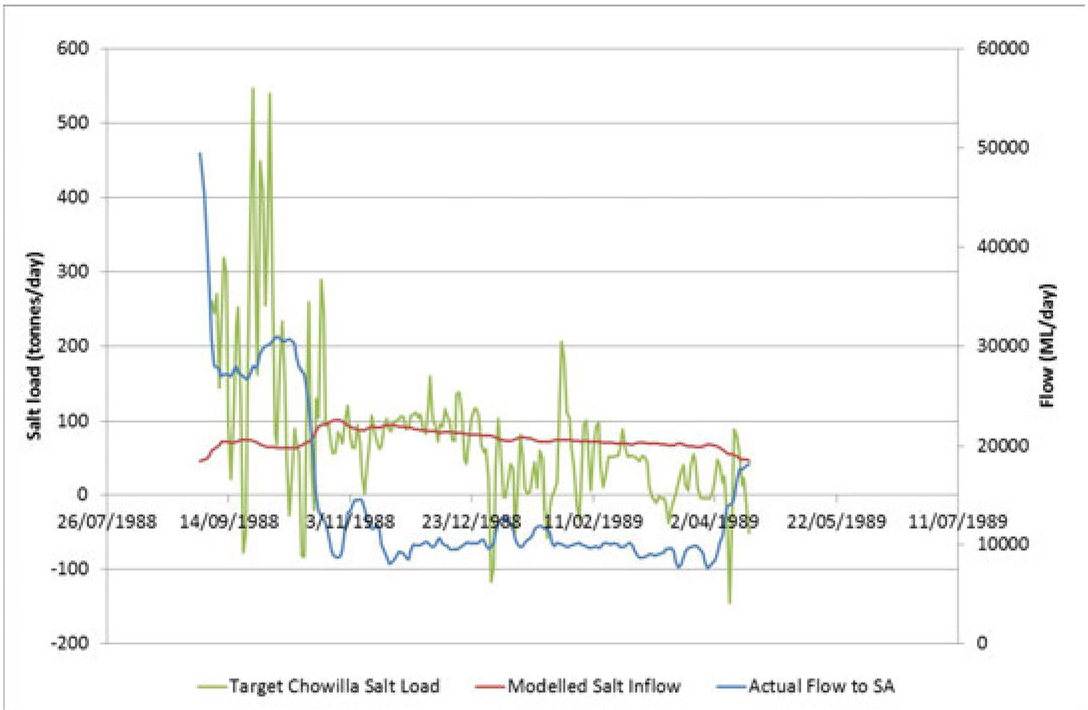
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	5000
Salt decay rate	0.002
Lock 6 reference level (m AHD)	16
Constant	77.5
RMSS	**105.4**

Figure 16: Evaluation of event: peak flow of 45,943 ML/day.



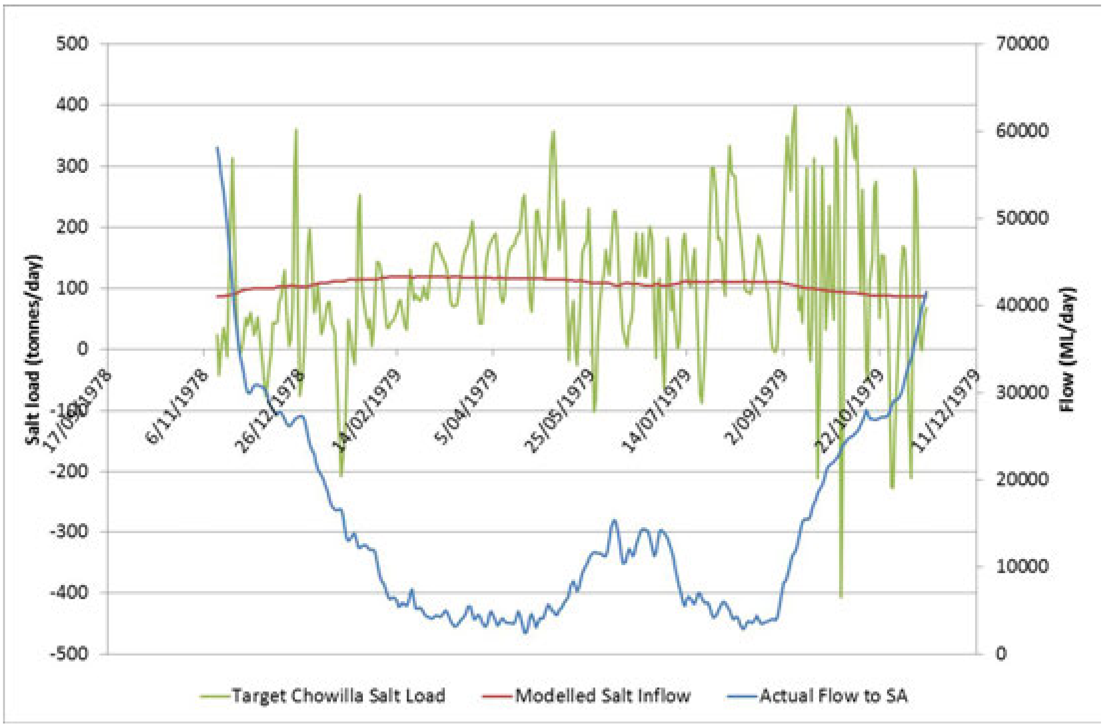
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	36000
Salt decay rate	0.007
Lock 6 reference level (m AHD)	16
Constant	110.5
RMSS	**129.0**

Figure 17: Evaluation of event: peak flow of 48,673 ML/day.



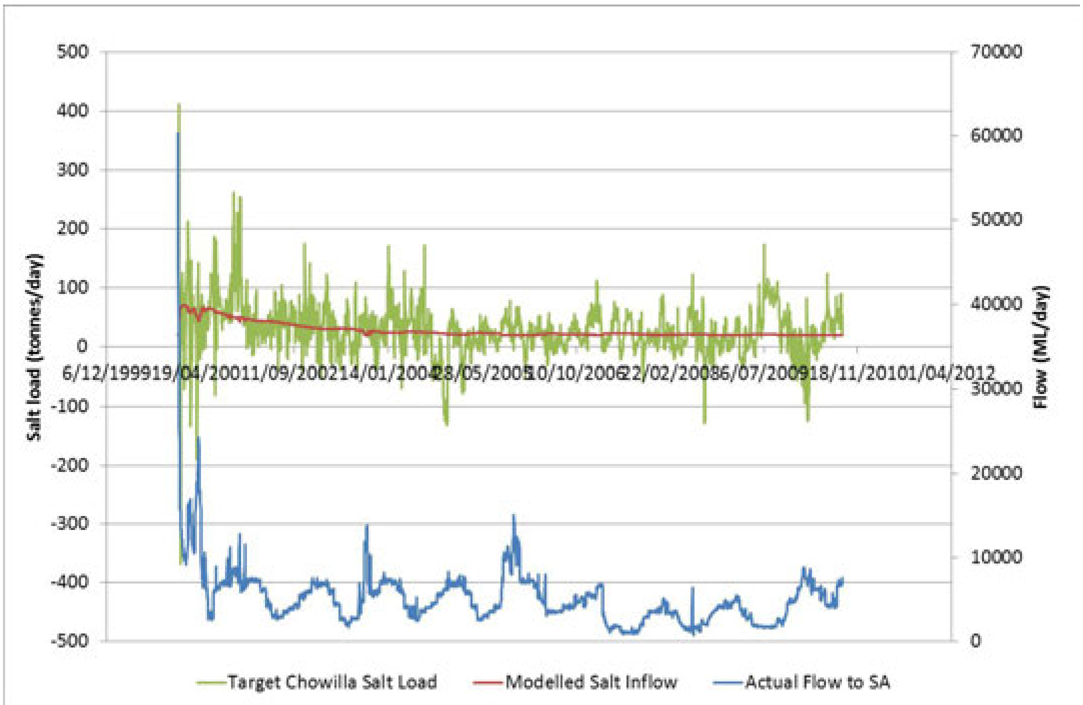
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	11,700
Salt decay rate	0.007
Lock 6 reference level (m AHD)	16
Constant	46
RMSS	**96.1**

Figure 18: Evaluation of event: peak flow of 48,888 ML/day.



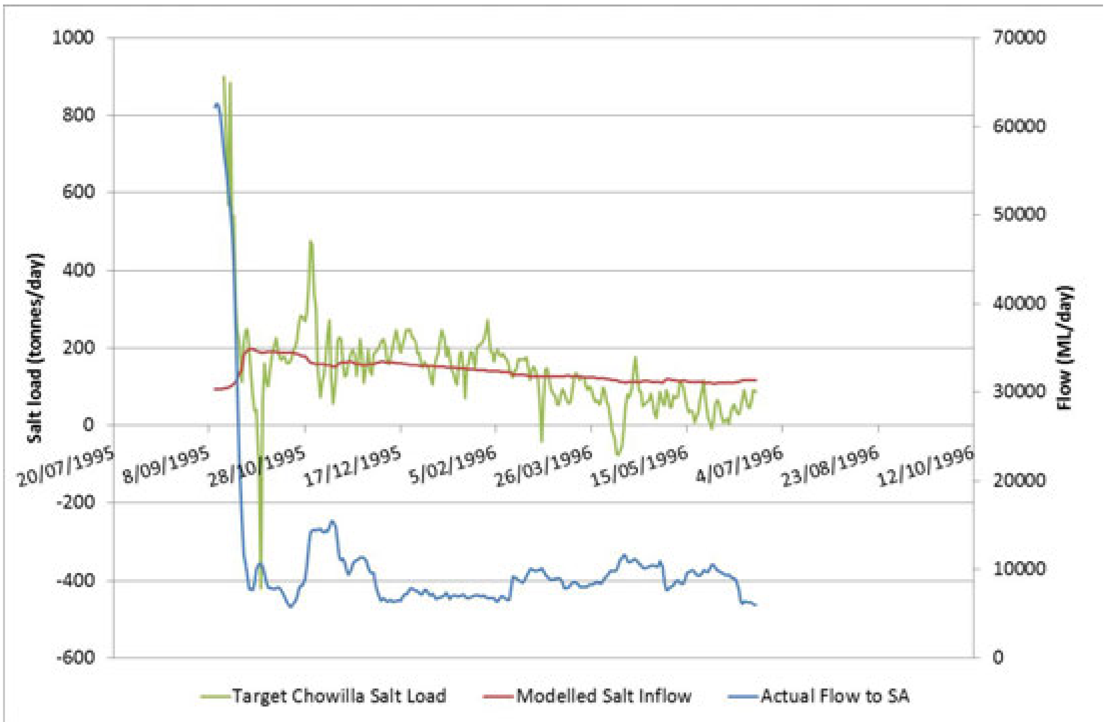
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	20,300
Salt decay rate	0.002
Lock 6 reference level (m AHD)	16
Constant	86.3
RMSS	**112.1**

Figure 19: Evaluation of event: peak flow of 60,675 ML/day.



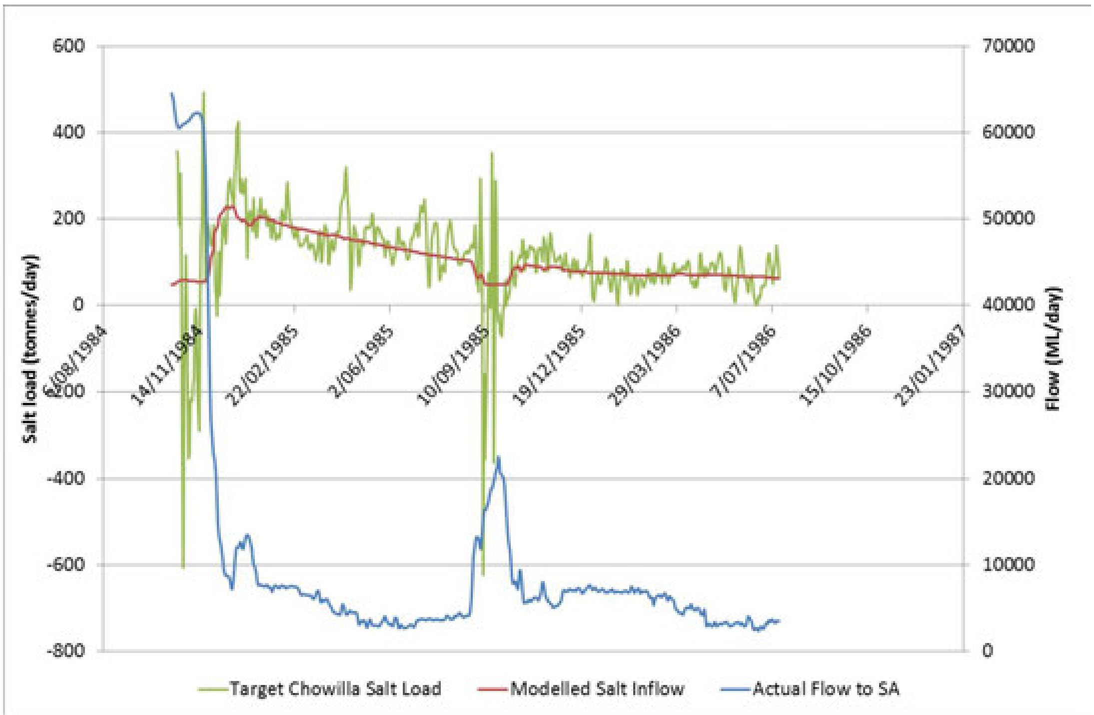
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	30,000
Salt decay rate	0.0022
Lock 6 reference level (m AHD)	16
Constant	19
RMSS	**40.9**

Figure 20: Evaluation of event: peak flow of 62,396 ML/day.



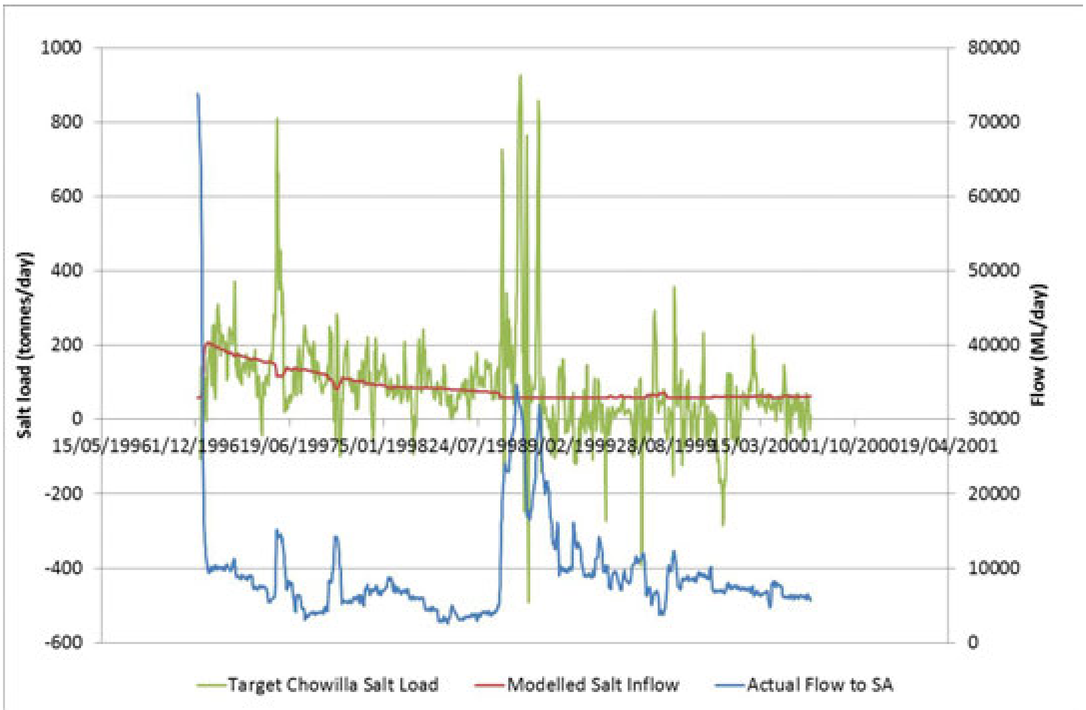
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	18,000
Salt decay rate	0.007
Lock 6 reference level (m AHD)	16
Constant	93.2
RMSS	**120.1**

Figure 21: Evaluation of event: peak flow of 63,481 ML/day.



Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	45,300
Salt decay rate	0.0051
Lock 6 reference level (m AHD)	16
Constant	47.4
RMSS	**86.5**

Figure 22: Evaluation of event: peak flow of 67,549 ML/day.

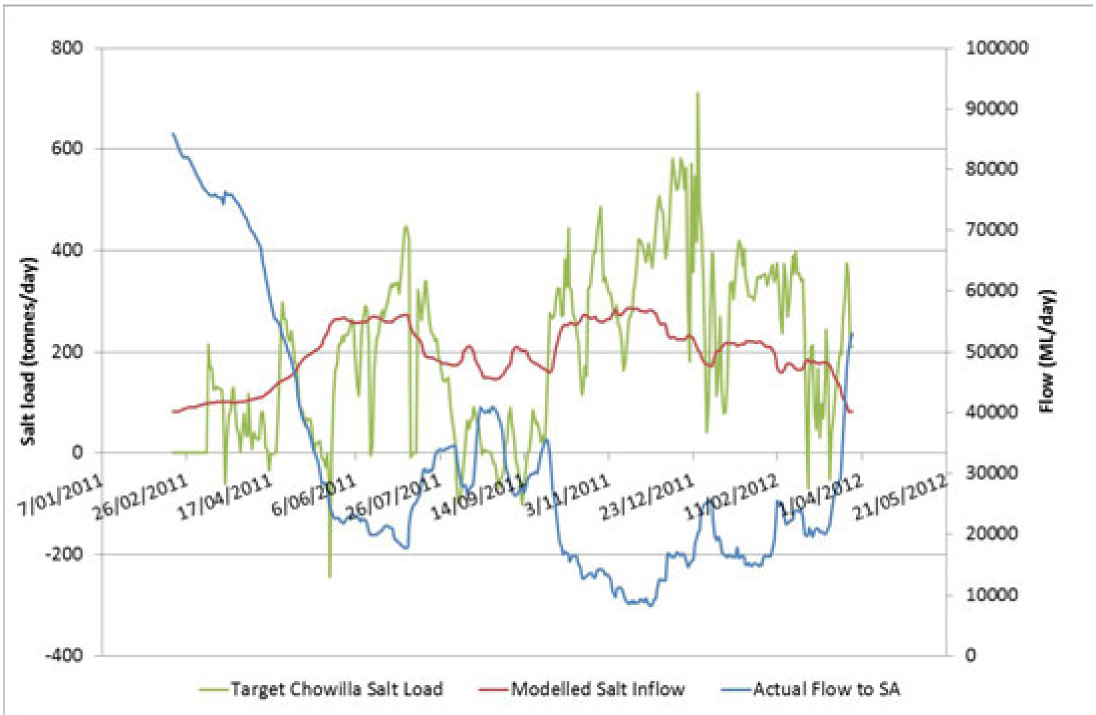


Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	44,000
Salt decay rate	0.0043
Lock 6 reference level (m AHD)	16
Constant	57
RMSS	**127.1**

Figure 23: Evaluation of event: peak flow of 74,865 ML/day.

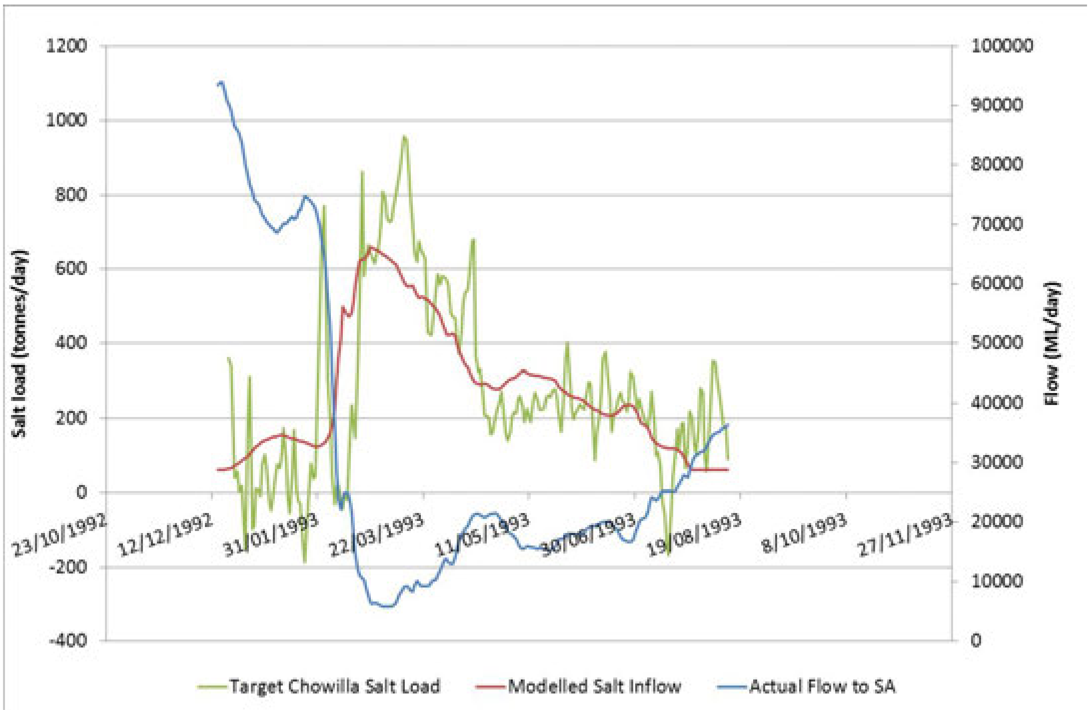
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	53,800
Salt decay rate	0.0064
Lock 6 reference level (m AHD)	16
Constant	276.5
RMSS	**133.2**

Figure 24: Evaluation of event: peak flow of 84,699 ML/day.



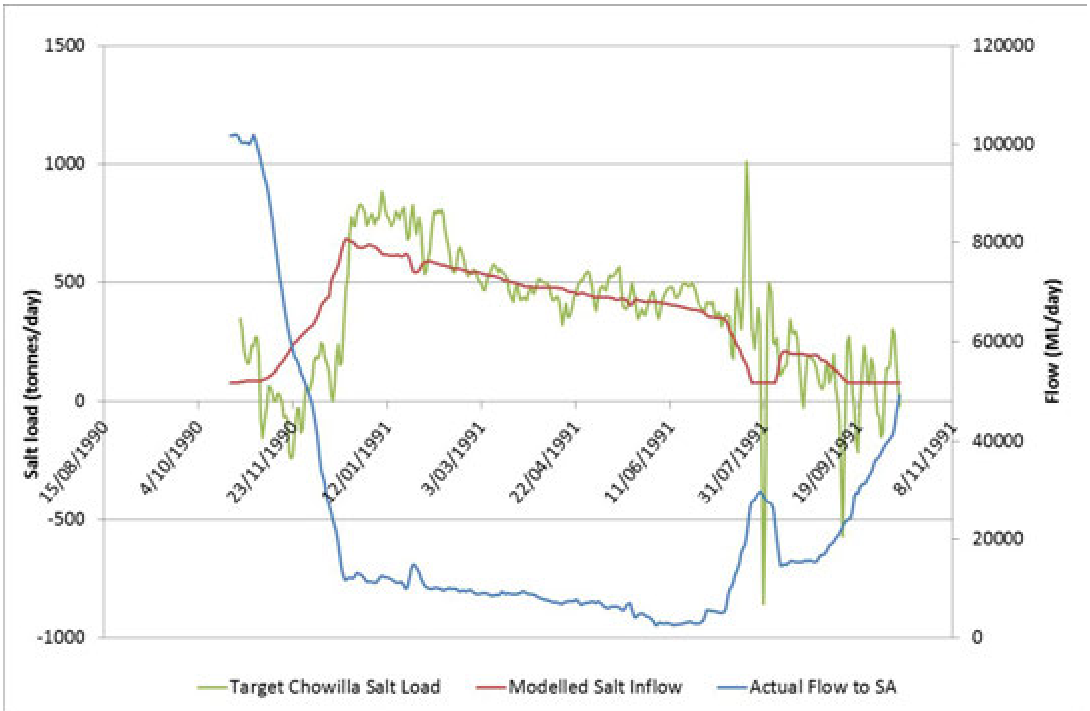
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	130,000
Salt decay rate	0.0025
Lock 6 reference level (m AHD)	16
Constant	81.2
RMSS	**144.8**

Figure 25: Evaluation of event: peak flow of 86,334 ML/day.



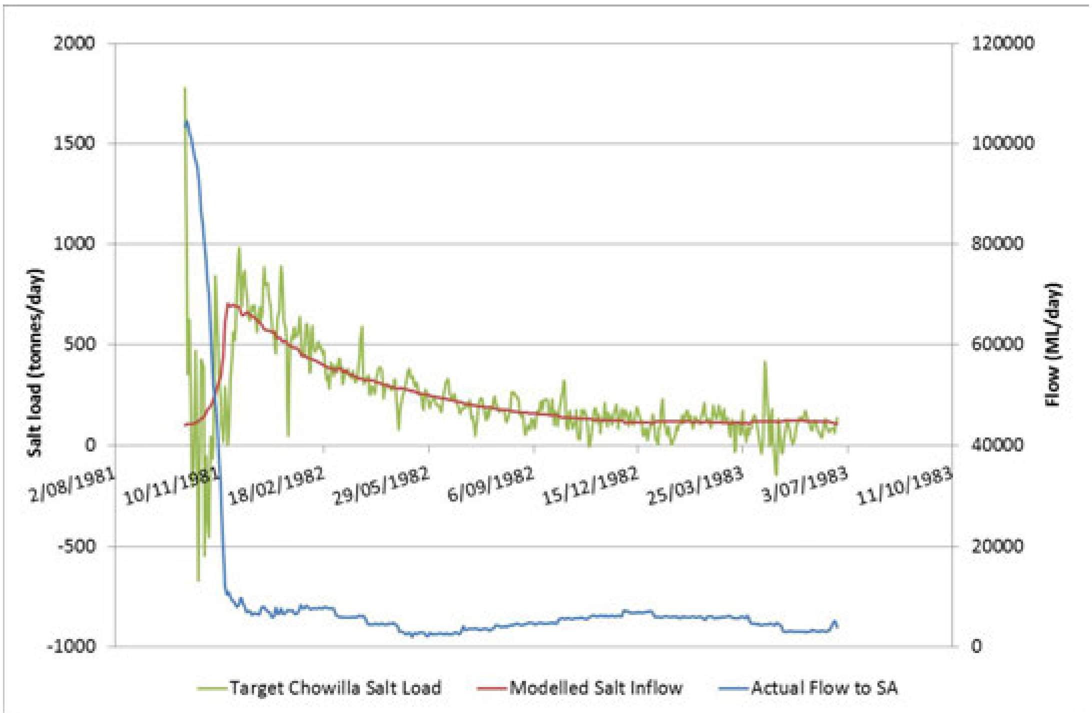
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	101,000
Salt decay rate	0.0075
Lock 6 reference level (m AHD)	16
Constant	61.1
RMSS	**166.4**

Figure 26: Evaluation of event: peak flow of 94,430 ML/day.



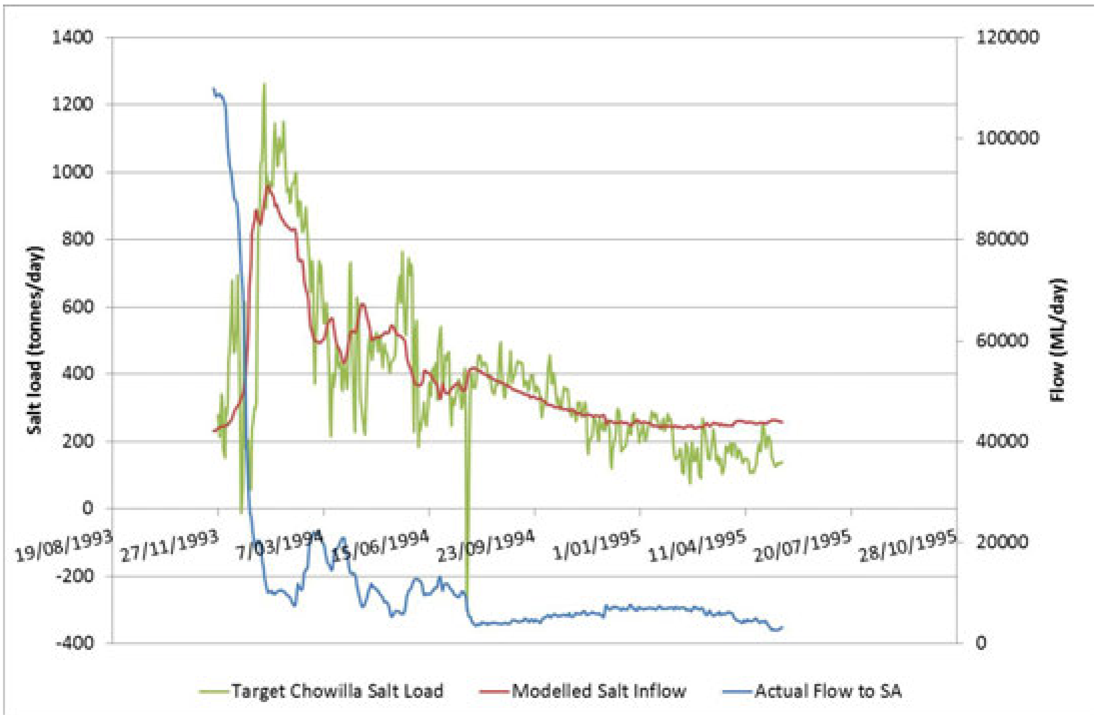
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	162,000
Salt decay rate	0.005
Lock 6 reference level (m AHD)	16
Constant	79.1
RMSS	**180.0**

Figure 27: Evaluation of event: peak flow 103,316 ML/day.



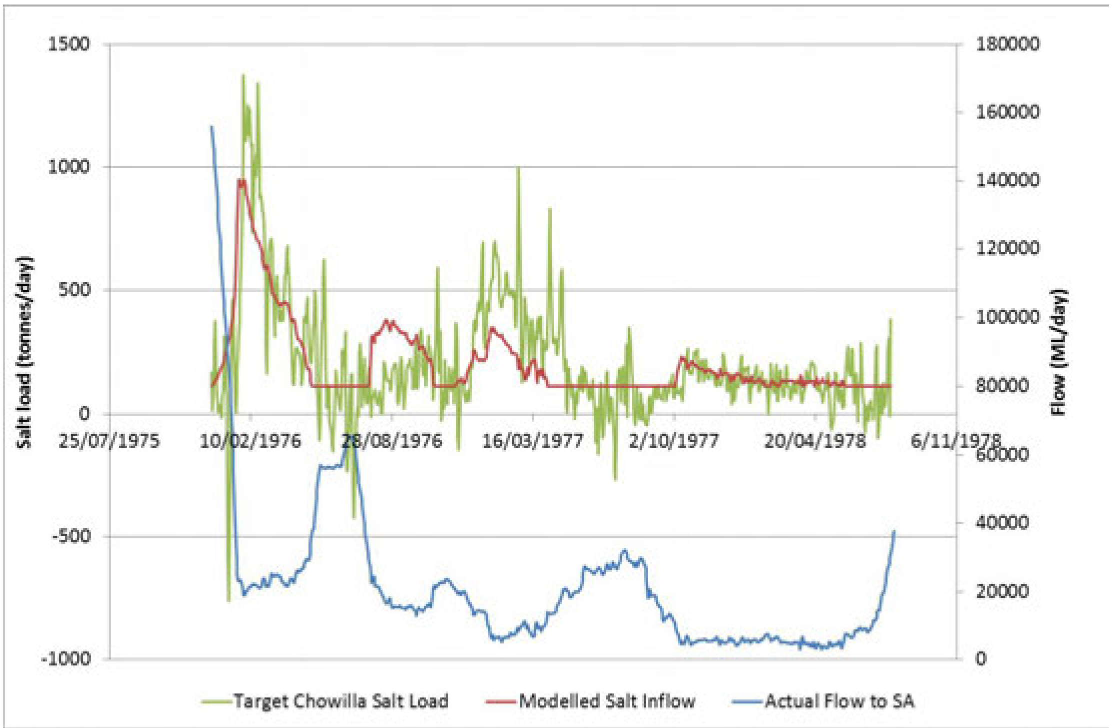
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	90,000
Salt decay rate	0.0085
Lock 6 reference level (m AHD)	16
Constant	105
RMSS	**156.6**

Figure 28: Evaluation of event: peak flow of 104,764 ML/day.



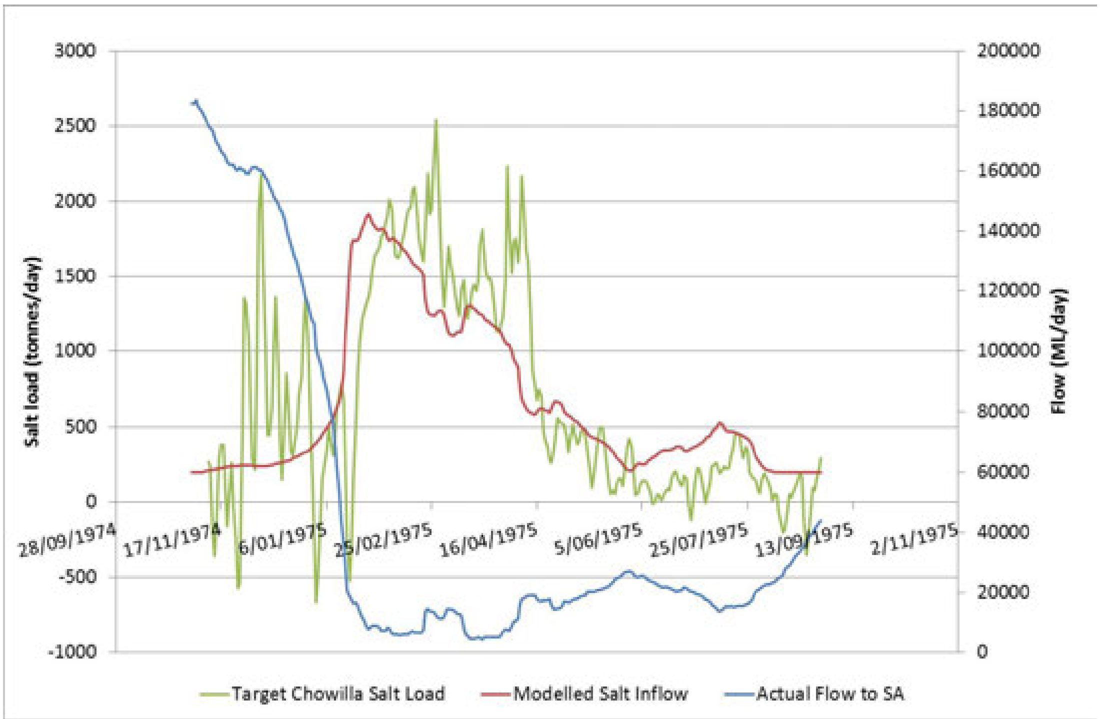
Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	98,000
Salt decay rate	0.0105
Lock 6 reference level (m AHD)	16
Constant	230.5
RMSS	**195.5**

Figure 29: Evaluation of event: peak flow of 109,996 ML/day.



Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	96,000
Salt decay rate	0.0147
Lock 6 reference level (m AHD)	16
Constant	113.3
RMSS	**174.7**

Figure 30: Evaluation of event: peak flow of 159,790 ML/day.



Parameter	Calibrated value
Salt generated by event (informs salt generation factor)	201,000
Salt decay rate	0.001
Lock 6 reference level (m AHD)	16
Constant	196.2
RMSS	**484.8**

Figure 31: Evaluation of event: peak flow of 183,436 ML/day.