Addendum to the 5-year Reviews at Waikerie to Morgan, Woolpunda and Pike-Murtho

DEWNR Technical report 2017/18

Government of South Australia
Department of Environment, Water and Natural Resources

Addendum to the 5-year Reviews at Waikerie to Morgan, Woolpunda and Pike-Murtho

Juliette Woods, Judith Kirk, Kittiya Bushaway and Linda Vears

Department of Environment, Water and Natural Resources

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Department of Environment, Water and Natural Resources

GPO Box 1047, Adelaide SA 5001

Telephone	National (08) 8463 6946
	International +61 8 8463 6946
Fax	National (08) 8463 6999
	International +61 8 8463 6999
Website	www.environment.sa.gov.au

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Foreword

The Department of Environment, Water and Natural Resources (DEWNR) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

Acknowledgements

This report is the culmination of many years work. The authors acknowledge all previous authors and peer reviewers involved in the development and peer review of these groundwater models, including those involved on the 5-year Review Panels for each of the models.

Acknowledgments of the assistance in finalising this report include Roger Cranswick (DEWNR) who provided comments on field-based methods of estimating riverbed conductance, Carl Purczel (DEWNR) and Virginia Riches (DEWNR) who provided comments on the Pike Floodplain model and the Eastern Mallee models and DEWNR staff who provided detailed review comments including Chris Li, Kwadwo Osei-Bonsu, Dragana Zulfic, and Diane Favier.

Executive Summary

Salinity remains a significant issue for the Murray-Darling Basin that requires ongoing management as identified in the new Basin Salinity Management Strategy (BSM2030). As part of this ongoing management, the BSM2030 maintains the existing accountability framework under Schedule B to prevent the return to the highly saline conditions of previous decades (MDBMC 2015, p. 7).

The salinity management obligations for each partner government are outlined in Schedule B of the Murray-Darling Basin Agreement. South Australia has been working with the Murray – Darling Basin Authority (MDBA) and the Basin Salinity Management Advisory Panel (BSMAP) to progress three 5-year Reviews of groundwater models which underpin the assessment of 16 accountable actions on the Salinity Registers. The models are:

(1) Waikerie to Morgan Numerical Groundwater Model – Volumes 1 and 2 (Yan et al. 2012)

(2) Woolpunda Numerical Groundwater Model – Volumes 1 and 2 (Woods et al. 2013)

(3) Pike-Murtho Numerical Groundwater Model – Volumes 1 and 2 (Woods et al. 2014)

The 5-year Reviews have been completed in accordance with the current Basin Salinity Management Strategy Operational Protocols, and written advice received from the MDBA. The models were developed in consultation with a 5-year Review Modelling for Salinity Registers Project Team including representatives from the MDBA, SA Water, and Department of Environment, Water and Natural Resources (DEWNR). The updated models and associated documents have been independently peer reviewed and found to be fit for purpose.

Following a number of interjurisdictional workshops in 2016 with the Basin Salinity Management Advisory Panel (BSMAP), South Australia was requested to provide additional information to support the Basin Officials Committee and the MDBA to finalise the amendment of the associated register entries. An additional independent review of this work was also requested.

This report provides the additional information requested and provides an overview of the accountable actions proposed to be updated as a result of these reviews.

The MDBA requested South Australia provide additional information on the following matters:

(4) To compare and contrast the salinity impacts calculated by the updated models with the current register entries for the relevant accountable actions (Section 4)

(5) Describe the changes in the new modelling approach and provide an explanation of why these changes represent an improvement compared to the current method (Section 2)

(6) Clarify the physical and monitoring evidence supporting the revised conceptualisation and quantification of salinity processes (where available) (Section 2)

(7) Provide comparison between the recharge rates and timing assumed for previous models and that assumed for current models (Section 3.2)

(8) Provide the water balances for each of the scenarios for evaluation by the peer reviewers (Appendix 7.1).

(9) Confirm the current chronological sequence of accountable actions for estimating the revised register entries (Section 4)

South Australia was also asked to discuss specific model assumptions relating to river levels, irrigation recharge, floodplain evapotranspiration, Salt Interception Schemes (SIS), and sensitivity and uncertainty analysis. These are discussed in Section 2.

The changes to accountable actions recommended by South Australia for inclusion on the Salinity Registers are summarised in Table 1. The actions are discussed in Section 4, which provides a brief background on the action, identifies the relevant reports and groundwater models used for assessment, a brief summary of how the 2015 salinity register entry is calculated, identifies the t/d for the action from the reviewed model, includes a preliminary estimate of EC and EC equivalent ($) from the MDBA, and indicates where there may be potential changes to the sharing or benefits of the action.

Please note that this table includes actions estimated using a rapid assessment method (SIMRAT) that will be removed and replaced with accredited groundwater model outputs as a result of the five year reviews. It is also important to note that the EC numbers are indicative estimates only and will need to be revised by the MDBA. Bracketed numbers indicate where the difference is a reduction in either t/d (tonnes per day) or EC (electrical conductivity).

Table S-1 Accountable action impacts in 2100 – comparison of 2015 Salinity Register and review results

Register	2015 Salinity Register Entry	2015 Register		Review results		Difference	
		t/d	EC	t/d	EC	t/d	EC
B	SA Mallee Legacy of History - Dryland	181.1	32.8	105.5	5.2	(75.6)	(27.6)
	SA Mallee Legacy of History - Irrigation	541.4	113.3	222.6	22.9	(318.8)	(90.4)
	SA Improved Irrigation Efficiency and Scheme Rehabilitation Register B	-550.4	-115.4	-289.6	-37.5	(260.8)	(77.9)
A	SA Improved Irrigation Efficiency and Scheme Rehabilitation Register A	-105.9	-21.3	-67.8	-13.5	(38.1)	(7.8)
	SA Irrigation Development Based on Footprint Data	287.7	72.8	373.4	71.5	85.7	(1.3)
	SA Irrigation Development Due to Water Trade (SIMRAT)	323.5	32.2	146.0	-8.2	(177.5)	(40.4)
	SA Irrigation Development Based on Site Use Approvals (SIMRAT)	574.2	93.0	107.6	10.1	(466.6)	(82.9)
	Woolpunda SIS	-176.0	-47.4	-253.0	-56.6	77.0	9.2
	Waikerie SIS	-60.0	-12.8	-58.5	-13.5	(1.5)	0.7
	Qualco-Sunlands Groundwater Control Scheme	-29.9	-7.5	-34.2	-8.5	4.3	1.0
	Waikerie Phase 2A SIS	-35.8	-8.9	-15.1	-3.8	(20.7)	(5.1)
	Waikerie Lock 2 SIS	-59.1	-14.4	-27.0	-6.6	(32.1)	(7.8)
	Pike SIS stage 1	-16.7	-3.4	-26.0	-5.4	9.3	2.0
	Murtho SIS	-159.0	-31.7	-106.8	-16.4	(52.2)	(15.3)

The reasons for change in the accountable actions are varied but can be summarised as follows:

- Incorporation of new information on the characteristics of the aquifers from drilling programs
- Improvements in the conceptualisation of the models from improved knowledge and research
- Changes in approach from second generation to third generation models
- Improvements in calibration from second generation to third generation models
- Changes in approach from a simple method to a numerical groundwater model
- Update of irrigation information
- Update of SIS from concept design to 'as constructed'
- Update from provisional estimates to detailed assessment from a numerical groundwater model.

This report also highlights a number of areas that require improvement or further discussion to inform future model reviews under the BSMS2030 implementation and to inform development of new procedures.

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1 Introduction

Salinity remains a significant issue for the Murray-Darling Basin that requires ongoing management as identified in the new Basin Salinity Management Strategy (BSM2030). BSM2030 was released in November 2015 by the Murray-Darling Basin Ministerial Council (MDBMC 2015). As part of this ongoing management, the BSM2030 maintains the existing accountability framework under Schedule B to prevent the return to the highly saline conditions of previous decades (MDBMC 2015, p. 7).

The salinity management obligations for each partner government are outlined in Schedule B of the Murray-Darling Basin Agreement. Once an accountable action is entered onto the Salinity Registers, regular reviews are required. The 5-year Reviews discussed in this report have been completed in accordance with the current Basin Salinity Management Strategy Operational Protocols, and written advice received from the MDBA.

A number of these reviews have been supported by technical reviews of the relevant salt interception schemes. All have been peer reviewed and found to be fit for purpose. The combination of these three 5-year Reviews provides the evidence for updating 13 accountable actions and 16 salinity register entries on the Salinity Registers (Table 1.1).

1.1 5-year groundwater model reviews

South Australia (SA) has been working with the Murray–Darling Basin Authority (MDBA) and the Basin Salinity Management Advisory Panel (BSMAP) to progress three 5-year Reviews of groundwater models, including:

- Waikerie to Morgan Numerical Groundwater Model – Volumes 1 and 2 (Yan et al. 2012)
- Woolpunda Numerical Groundwater Model – Volumes 1 and 2 (Woods et al. 2013)
- Pike-Murtho Numerical Groundwater Model – Volumes 1 and 2 (Woods et al. 2014)

The 5-year Reviews have been completed in accordance with the current Basin Salinity Management Strategy Operational Protocols, and written advice received from the MDBA. The models were developed in consultation with a 5-year Review Modelling for Salinity Registers Project Team (hereafter referred to in this report as the 5-year Review Team) that included representatives from the MDBA, SA Water, and Department of Environment, Water and Natural Resources (DEWNR) groundwater modellers and policy staff.

The updated models and associated documents have been independently peer reviewed and found to be fit for purpose as outlined in the following reports:

- Review of Waikerie to Morgan Groundwater Model (SKM 2012)
- Review of Woolpunda Groundwater Model (SKM 2012)
- Independent Peer Review of Pike-Murtho Numerical Groundwater Model (RPS 2014)

The salinity scenarios used to derive the salt loads of accountable actions for the Salinity Registers have been developed in consultation with MDBA, SA Water, and DEWNR staff and are outlined in section 3. They have been documented and applied consistently across the models since 2008, and are outlined in Section 3 for completeness.

As the groundwater models are developed and updated, the component of the accountable action for that geographic area is also updated on to the Salinity Registers. The summary of the accountable actions that have been reviewed through the 5-year Reviews are outlined in Section 4.

Table 1.1 Accountable actions and 2015 Salinity Register entries affected by the reviews

Accountable Action	Register Entry No.	2014/2015 Salinity Register Entry	Share
REGISTER B			
Mallee Clearance	79	SA Mallee Legacy of History - Dryland	State
Pre-1988 Irrigation	80	SA Mallee Legacy of History - Irrigation	State
Pre-1988 Improved Irrigation and Rehabilitation	81	SA Improved Irrigation Efficiency and Scheme Rehabilitation Register B	State
REGISTER A			
Pre-1988 Improved Irrigation and Rehabilitation	55	SA Improved Irrigation Efficiency and Scheme Rehabilitation Register A	State
Post-1988 Irrigation	49 50 51	SA Irrigation Development Based on Footprint Data SA Irrigation Development Due to Water Trade (SIMRAT) SA Irrigation Development Based on Site Use Approvals (SIMRAT)	State
Woolpunda SIS	1	Woolpunda SIS	Joint
Waikerie 1 SIS	4	Waikerie SIS	Joint
Qualco-Sunlands Groundwater Control Scheme	56	Qualco-Sunlands GWCS	State
Waikerie 2A SIS	8	Waikerie Phase 2A SIS	Joint
Waikerie Lock 2 SIS – Joint	15	Waikerie Lock 2 SIS	98% Joint
Waikerie Lock 2 SIS – State	54	SA component of Waikerie Lock 2 SIS	2% State
Pike SIS	57	Pike SIS stage 1	100% State
Murtho SIS – Joint	17	Murtho SIS	98% Joint
Murtho SIS – State	58	SA component of Murtho SIS	2% State

1.2 Review of accountable actions

This addendum report has been prepared by South Australia to address the additional information requests associated with the five year reviews of the groundwater models.

Following a number of interjurisdictional workshops in 2016 with the Basin Salinity Management Advisory Panel (BSMAP), South Australia was requested to provide additional information to support the Basin Officials Committee and the MDBA to finalise the amendment of the associated register entries. An additional independent review of this work was also requested.

The MDBA requested South Australia provide additional information on the following matters (Appendix 7.2):

- To compare and contrast the salinity impacts calculated by the updated models with the current register entries for the relevant accountable actions (Section 4)
- Describe the changes in the new modelling approach and provide an explanation of why these changes represent an improvement compared to the current method (Section 2)
- Clarify the physical and monitoring evidence supporting the revised conceptualisation and quantification of salinity processes (where available) (Section 2)
- Provide comparison between the recharge rates and timing assumed for previous models and that assumed for current models (Section 3.2)
- Provide the water balances for each of the scenarios for evaluation by the peer reviewers (Appendix 7.1).

South Australia was also asked to:

- Confirm that constant river levels were used for forecasting (Section 2.2.2)
- Confirm the current chronological sequence of accountable actions for estimating the revised register entries (Section 4)
- Note that when conducting future reviews the salinity impact of the Mallee clearance should be fully integrated with other scenarios (Section 2.2.4)

In addition, Victoria has requested that South Australia provide commentary on a number of issues including:

- Recharge rates for irrigation and how they are incorporated into the models (Sections 2.2.4 and 2.2.5)
- Floodplain evapotranspiration and how it has been addressed in the models (Section 2.2.3)
- Explanation of the scenarios and how these are ordered (Section 3)
- River levels and how they have been addressed in the models (Section 2.2.2)
- Discussion around how Salt Interception Schemes (SIS) are represented in the models (Section 2.2.6)
- Explanation of the sensitivity analysis undertaken and consideration of uncertainties in the salt loads (Section 2.2.9)
- The assumptions in MSM-Bigmod relating to salt load and flow (to be addressed by the MDBA).

The report first describes the modelling methodologies (Section 2), then model results (Section 3), followed by detailed explanations of how the model results are used to derive the proposed updates to Salinity Register entries for the accountable actions (Section 4).

In reviewing this report it should be recognised that there has been a significant passage of time since the models were reviewed and updated and they were prepared in accordance with the knowledge and instructions, including advice from the MDBA, at the time. As such it should not be expected that the reviews address more contemporary thinking and new knowledge. These are matters to be considered for future reviews and for the development of the new BSM2030 procedures currently under development.

Any assumptions within MSM-Bigmod must be addressed by the MDBA and are outside of this report and South Australia’s responsibility.

1.3 SIS technical reviews

As part of the 5-year Reviews, the State Constructing Authority (SA Water) is required to undertake a technical or operational review of the salt interception schemes to ensure they are operating as required. These reviews have also been completed, documented and approved for the salt interception schemes at Waikerie and Woolpunda. This includes Waikerie 1 SIS, Waikerie 2A, Waikerie Lock 2 and Woolpunda.

The reports prepared as part of the SIS technical review were considered and endorsed by the Salt Interception Scheme Working Group (SITWG) in November 2016. This includes:

- Waikerie SIS 5-year Review – Technical Summary Report (AWE 2014a)
- Woolpunda SIS 5-year Review – Technical Summary Report (AWE 2014b)
- Woolpunda and Waikerie 5-year Review – Hydrogeology and Scheme Performance (AWE 2014c)
- Waikerie and Woolpunda Salt Interception Scheme – Figure Atlas 2013 (AWE 2013).

A technical review of Murtho was not undertaken as the scheme only commenced operation in 2012, however detailed data atlases (AWE 2012a and AWE 2012b) prepared as part of the construction of the scheme.

The revised numerical groundwater models incorporate information from these data atlases and technical reviews. The information includes conceptual hydrogeology, structural data, potentiometric heads, salinity, aquifer tests, hydrographs and relevant in-stream salinity and geophysics; as well as the review of SIS pumping rates, observed groundwater levels and the salinity of the discharged water prepared by the SIS technical review.

1.4 History of South Australia salinity register model development

Three generations of South Australian numerical groundwater flow models have estimated salt loads to the River Murray in the South Australian Murray-Darling Basin. Model approaches have changed over time, improving as more data became available and the conceptual understanding of the processes and geology increased. Improvements also occurred as computer power increased and more sophisticated modelling methods became practical. Model assumptions have also changed due to discussions and directives from the MDBC and MDBA which reflect the evolving policy context.

The first generation models were created in the 1990s to assess impacts of native vegetation clearance (e.g. Barnett, 1990 and Barnett et al. 2001). They have coarse grids and simple recharge inputs.

The second generation models were the first to be used for Salinity Register entry; developed in the early 2000s and based partly on the first generation models. The second generation models have been used to assess impacts of native vegetation clearance, irrigation, and improvements in irrigation practice. Some of the models were developed to assist in the preliminary design of the salt interception schemes. These models were developed and revised in a number of stages with greater complexity and finer grids than the first generation models.

Third generation models are updated and refined versions of the second generation models. They reflect improvements in model techniques and incorporate new data. Where possible, limitations identified in reviews of their second-generation predecessors were addressed. These models were developed within the directions given by the MDBA and have undergone peer review according to (Basin Salinity Management strategy (BSMS) requirements.

South Australian models developed since 2010 are third generation models, including Loxton-Bookpurnong 2011, and the three models which are subject to this 5 Year Review: Waikerie to Morgan 2012, Woolpunda 2013, and Pike-Murtho 2014. Other South Australian models are yet to be updated to match third generation assumptions.

Detailed descriptions of model genealogy and development are provided in the introductory chapters of Yan et al. (2012), Woods et al. (2013) and Woods et al. (2014).

The development history of Waikerie to Morgan, Woolpunda and Pike-Murtho are provided in Figure 1.1 and Figure 1.2. Section 2 details the differences in assumptions between second and third generation models.

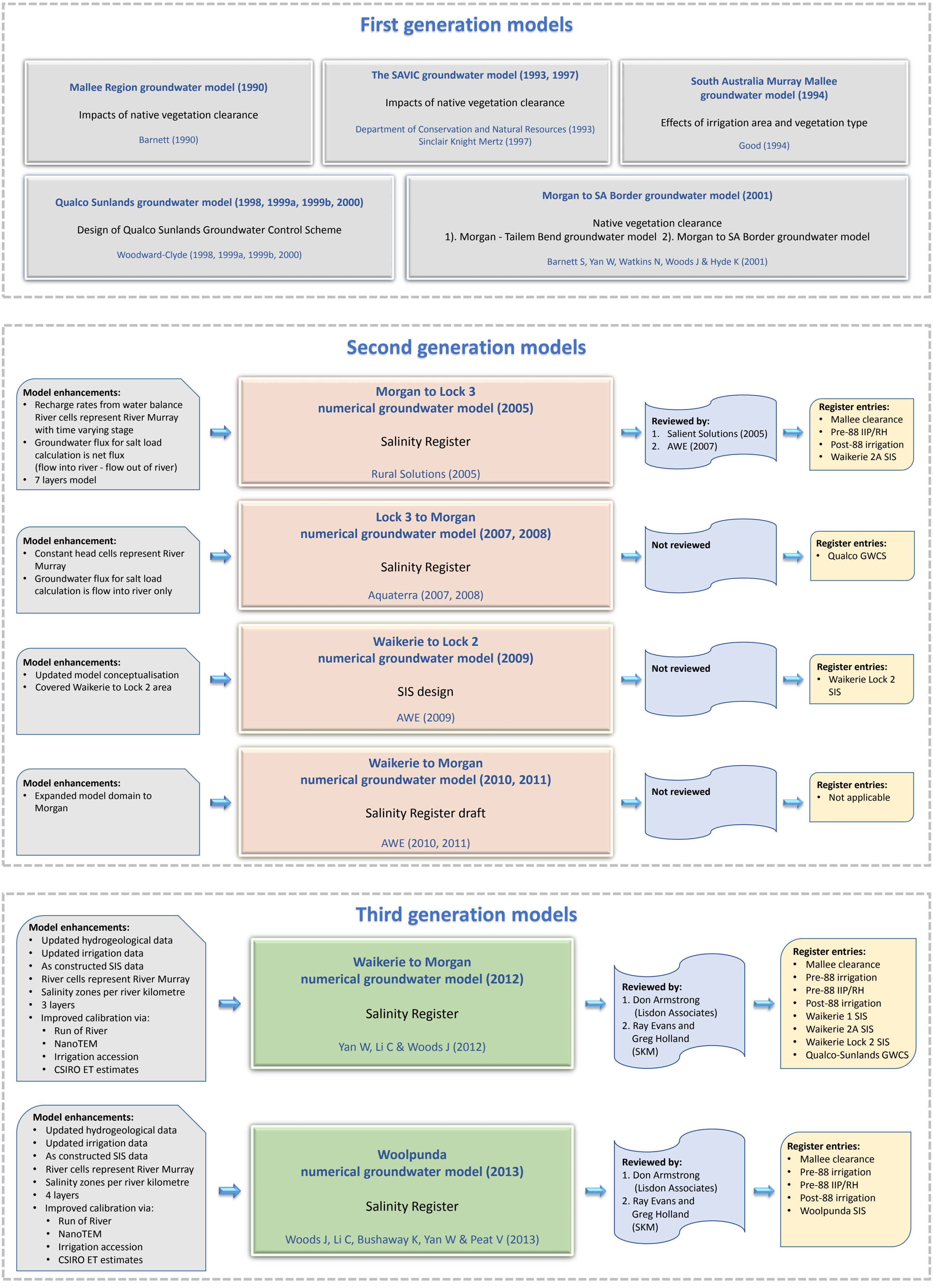


Figure 1.1 Development history of Waikerie to Morgan and Woolpunda numerical groundwater models

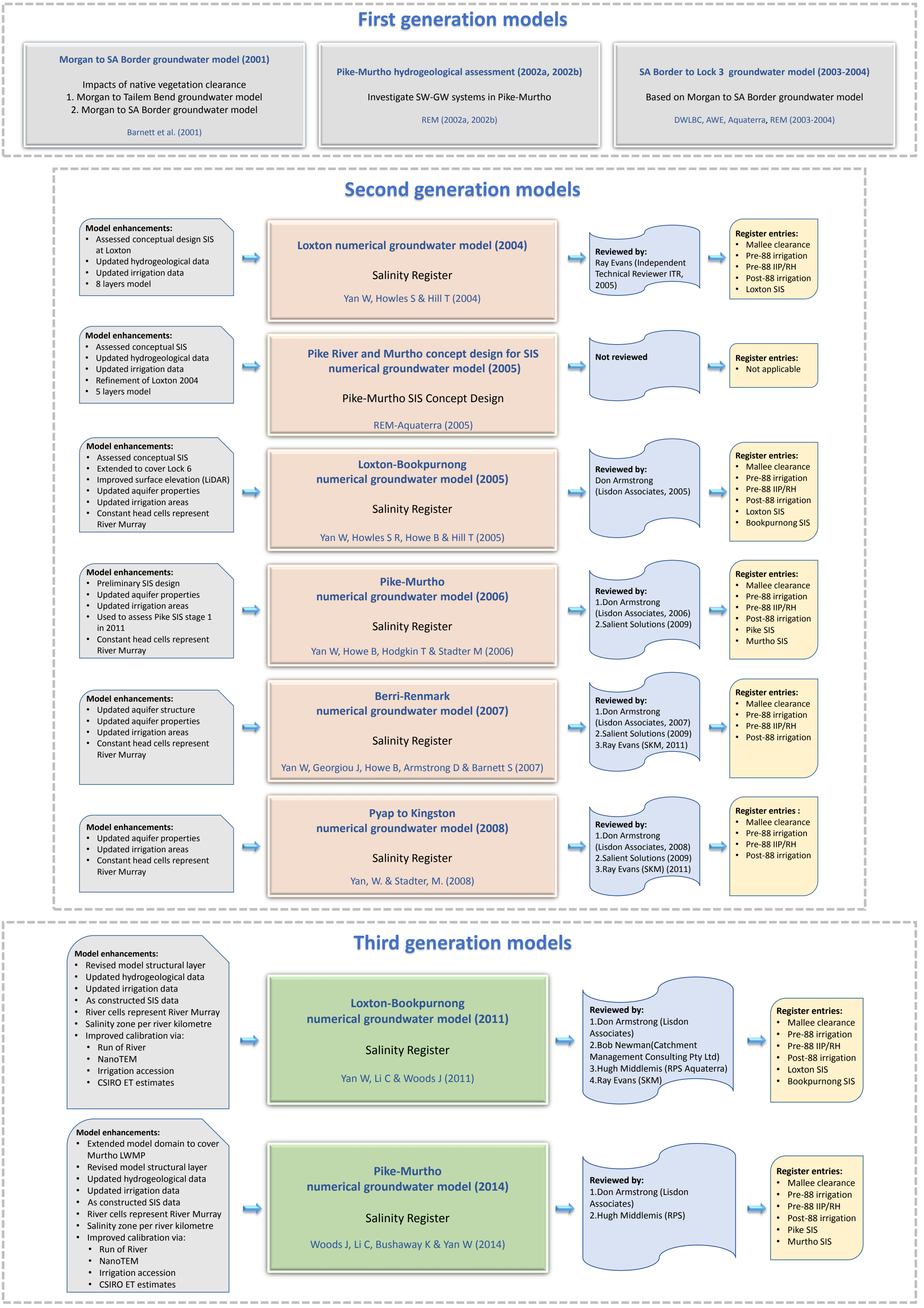


Figure 1.2 Development history of Border to Lock 3 numerical groundwater model and sub-models: Pike-Murtho, Loxton-Bookpurnong, Pyap to Kingston and Berri-Renmark

2 Methodology

The 2015 Salinity Register entries are derived from a variety of methods. Table 2.1 summarises the methods used to estimate changes in salt load due to accountable actions in the Waikerie to Morgan, Woolpunda, and Pike-Murtho regions (referred to as “the study areas” in this report). The methods vary in complexity and accuracy, as discussed in Section 2.1.

Revised salt loads are now proposed as a result of the 5-year Review and the “third-generation” numerical groundwater models of the Waikerie to Morgan (Yan et al. 2012), Woolpunda (Woods et al. 2013), and Pike-Murtho (Woods et al. 2014) study areas. Section 2.2 discusses key assumptions and approaches used in these models, comparing them with earlier numerical models, where appropriate, and discussing possible future approaches.

Section 2.3 briefly compares third generation South Australian models with the Eastern Mallee (EM) models of NSW and Victoria, which simulate groundwater salt loads in an adjacent and geologically-similar region. Many model assumptions are consistent across jurisdictions, or differ only in small details. This provides historical context. In some cases, issues regarding South Australian model assumptions would also apply to the EM models. It is suggested that these issues should be considered a priority for the discussion of BMS2030 procedures and in addressing knowledge gaps.

Table 2.1 Methods used to calculate salt loads for the 2015 Salinity Register entries in Waikerie to Morgan, Woolpunda and Pike-Murtho regions

2015 Salinity Register Entry	Type of assessment	Source/model of 2015 Register entries
SA Mallee Legacy of History – Dryland	2nd generation model	Morgan to Lock 3 2005
SA Mallee Legacy of History – Irrigation		Pike-Murtho 2006
SA Improved Irrigation Efficiency and Scheme Rehabilitation Register A & B		
SA Irrigation Development Based on Footprint Data		
SA Irrigation Development Due to Water Trade SA Irrigation Development Based on Site Use Approvals	Rapid assessment model	SIMRAT
Murtho SIS (Joint and State Component)	2nd generation model	Pike-Murtho 2006
Pike SIS (State Component)	2nd generation model	Pike-Murtho 2006
Woolpunda SIS	MDBC derived in-river flow-salt load relationship	MDBC Technical Report, October 2000
Waikerie SIS	MDBC derived in-river flow-salt load relationship	MDBC Technical Report, October 2000
Waikerie Lock 2 SIS (Joint and State Component)	2nd generation model	AWE Waikerie Lock 2 2009
Waikerie Phase 2A SIS	2nd generation model	Morgan to Lock 3 2005
Qualco-Sunlands Groundwater Control Scheme	2nd generation model	Lock 3 to Morgan 2008[1]

[1] *MDBA 2015 referenced the Morgan to Lock 3 (Rural Solutions 2005) but salt load matches the Lock 3 to Morgan (Aquaterra 2008)*

2.1 Methods used for 2015 Register entries

2.1.1 MDBC's flow–salt load relationship method

Approach

The MDBC flow–salt load relationship method compares salt load accessions to the river as estimated by MSM-Bigmod before and after the commencement of an SIS (MDBC 2000). A regression approach is applied to the estimates to determine scheme benefit at a range of flow levels. It provides scheme benefits as an average over the 25-year benchmark period.

The main limitation of this method is that it cannot distinguish between SIS impacts and impacts caused by any other actions, such as improved irrigation practices. Another limitation is that its accuracy depends on the range of measurements taken before the SIS was constructed as well as the quality of the calibration of the MSM-Bigmod model itself at different flow ranges.

Use and reliability in the study areas

This method is used in the 2015 Salinity Registers to estimate the salt load impact of the Woolpunda and Waikerie 1 SIS. The method's accuracy for Waikerie 1 and Woolpunda SIS is limited by:

- Other accountable actions which also alter salt load, such as the extensive improved irrigation practice (IIP) at Waikerie;
- Lack of measurements prior to the SISs, particularly for flows below 10 000 ML/d (BSMAP meeting 25 Agenda Item 6).
- Poor data quality at some times and locations (see salinity quality codes at Holder) (BSMAP Meeting 25 Agenda Item 6).

2.1.2 SIMRAT

Approach

SIMRAT is designed as a rapid assessment tool for estimating salt load impact from new irrigation developments on the River Murray. SIMRAT estimates the maximum amount of change in river salinity impacts with the smallest set of variables (Fuller et al. 2005). It provides a consistent and deliberately simple approach across the lower River Murray which can be used in areas where there is a high uncertainty in the hydrogeological factors which influence groundwater salt flux to the river. It employs semi-analytic equations where parameters are assigned spatially from a Data Atlas. In South Australia, it estimates flux to the floodplain edge rather than the River Murray.

Use and reliability in the study areas

SIMRAT is accredited for assessing salinity debits due to water trades to greenfield sites and historically has been used within the Pilot Interstate Water Trading area (i.e. Mallee region of Vic, NSW, and SA). The procedures for this application are documented in the BSMS Operational Protocols (MDBC 2005).

South Australia has used SIMRAT in the assessment of applications for permanent water trade (2003/04 to 2008/09) and Site Use Approvals (since 2009/10). It has been used as a rapid assessment approach to estimate and account for the salinity impacts of irrigation resulting from these transactions with the salt load estimates reported annually to the Salinity Registers. SIMRAT estimates are considered temporary until a numerical groundwater model is updated and accredited for the relevant geographic area.

SIMRAT's accuracy in the study areas is limited by its input data and model assumptions. Its assumptions are deliberately simple to enable rapid assessment. The capabilities and limitations of SIMRAT are discussed in detail Woods et al. (2016). The uncertainty in model inputs and outputs is usually high.

Some limitations within the study area include: it assumes a floodplain edge that is straight, which is not a good approximation for Waikerie and Pike-Murtho. It also assumes that the change in saturated thickness between the irrigation area and the floodplain is a small fraction of average saturated thickness, which is not true for Waikerie and its surrounding irrigation areas. In general, SIMRAT will be less accurate than an accredited numerical groundwater model.

2.1.3 Second-generation SA numerical groundwater models

Approach

South Australia's second-generation numerical groundwater models are developed with the industry-standard USGS code MODFLOW. This uses finite difference methods to solve the groundwater flow equation. Numerical models can incorporate detailed input data and simulate a variety of hydrogeological processes. As uncertainty exists in model parameters, the model is calibrated against potentiometric head observations, and then other model outputs are checked against other types of observation. The *Australian Groundwater Modelling Guidelines* (Barnett et al. 2012) describes the modelling process.

The assumptions of a numerical model should reflect the model aim. The level of detail will further depend on data availability and computational constraints. There is also the "problem of non-uniqueness", where it is possible to develop more than one model which provides a good fit to available data and observations.

The second-generation models were limited by the conceptual understanding, data availability, and computational speeds of the mid-2000s. Third-generation models aim to address some of these limitations, as discussed in detail in Section 2.2.

Use and reliability in the study areas

The second-generation **Morgan to Lock 3 model** (Rural Solutions 2005) simulates the Waikerie to Morgan and Woolpunda reaches. It was calibrated to observations up to 2003. It provides the salt loads for Salinity Register entries in these areas with these exceptions:

(i) the Waikerie 1 SIS impact is estimated by the MDBC flow-salt load relationship (Section 2.1)

(ii) the Waikerie Lock 2 SIS is estimated from the AWE Waikerie to Lock 2 groundwater model (AWE 2009a, AWE 2009b)

(iii) SA Irrigation Development Due to Water Trade and Site Use Approvals is estimated using SIMRAT.

The 2005 model was independently peer reviewed by Salient Solutions in 2005 and accredited by the MDBC in 2005. The model is currently the basis for the assessment of salt interceptions schemes (SIS) for Waikerie Phase 2A.

In 2007, SA Water contracted AWE to review the model. The key concerns were that the Morgan to Lock 3 model (AWE 2007):

- Did "not agree with the current state of knowledge of aquifer hydraulic conductivity, aquitard resistivity, stratigraphic unit elevations, and elevation of the alluvial aquifer in relation to the regional aquifers"
- Did not include floodplain processes other than cliff seepage
- Did not include the perched aquifers at Waikerie and Qualco-Sunlands
- Was computationally slow, so neither a sensitivity analysis nor an uncertainty analysis had been performed

- Was not calibrated against observations from the mid-point bores of the SIS, which are critical to estimating near-river groundwater gradients and hence flux to river
- Did not demonstrate that the model could match estimates of pre-scheme salt load or replicate changes in head due to pumping.

A further problem was identified in Aquaterra (2007), in that the 2005 report incorrectly calculated salt loads as the net flux between the river and groundwater, rather than from the groundwater flux to the river.

The large regional scale of the model was one reason for the inherent issues concerning the model. It was recommended that any future modelling work should divide the region into two or more model domains, as the hydrogeology of Woolpunda reach is significantly different from the hydrogeology of the Waikerie to Morgan reach. This has been addressed in the third generation by creating two groundwater models for this area – Waikerie to Morgan and Woolpunda, which has enabled local hydrogeological processes to be better simulated through the use of a higher resolution of features.

The **Morgan to Lock 3** model was modified in 2007 and 2008 by Aquaterra, with the model name changed from Morgan to Lock 3 to Lock 3 to Morgan. The impact of mallee clearance was removed from most scenarios and pumping rates were updated. The error in salt load calculation was corrected. However, the revised model results are only used in the 2015 Salinity Register for Qualco-Sunlands GWCS.

The 2005, 2007, and 2008 models all significantly over-estimate salt loads when compared to Run of River estimates, particularly in the Waikerie and Woolpunda reaches. Aquaterra (2008) notes that model over-estimates salt load as it does not include evapotranspiration on the floodplain. The models were also unable to replicate the naturally-occurring groundwater mounds at Woolpunda under steady-state conditions.

The **Pike-Murtho 2006** model is the source of the current Salinity Register entries in that region. It is also a second-generation South Australian model (Section 2.1.3). It was developed before the Pike SIS and Murtho SIS were fully constructed. Once the schemes were constructed the hydrogeological investigations provided more detailed information on the aquifer systems and their characteristics.

The Pike-Murtho 2006 concept design SIS differs significantly from the as-constructed SIS. The number of as-constructed SIS wells and well spacing are different to those in the concept design and the constructed SIS infrastructure for Murtho is constrained by pipeline capacity. The 2006 model assumed both schemes commenced operation in 2006, when actual scheme operation commenced for Pike in 2012 and Murtho in 2014.

The MDBC commissioned Salient Solutions Australia to undertake a review of the Pike-Murtho 2006 model and provide recommendations concerning potential accreditation under the BSMS protocols. It was found that the model is was well calibrated and fit for purpose. However, there were two remaining modelling issues (Salient Solution Australia, 2006):

- "*Layer 1 general head boundary cells on the south-eastern model boundary are imposing a head condition that is not evident in the observed heads, but this is at the model boundary and does not affect the calibration in the areas closer to the river*." (p. 4)
- "*There was no mention of how groundwater salinity time series data was analysed, especially where there is variation in salinity within the one bore. REM has taken the last observed value of salinity for each bore. As well, there was no mention of the issue of salinity stratification which was also raised by REM*." (p. 4)

2.2 Methods used for revised Register entries

All the proposed revisions to South Australia's Salinity Register entries are derived from South Australia's third-generation groundwater flow models (see Section 3.1 for definitions). The models are:

- Waikerie to Morgan numerical groundwater model 2012 (Yan et al. 2012)
- Woolpunda numerical groundwater model 2013 (Woods et al. 2013)
- Pike-Murtho numerical groundwater model 2014 (Woods et al. 2014).

These models were all based on their predecessor second-generation models, but updated to include new hydrogeological information and with some revised methods of representing processes. Much of the new hydrogeological information was gathered as part of SIS Technical 5-year Reviews and is published in a series of technical atlases (AWE (2012a), AWE (2012b) and AWE (2013)).

All the models were developed with input from the 5-year Review Team, which included representatives from the MDBA, SA Water, and DEWNR policy staff as well as the DEWNR groundwater modellers. All major decisions regarding model design and scenario design were discussed and approved by this team. The MDBA commissioned peer reviews of the models from independent reviewers as required under Schedule B. All three models were found to be of a high standard and fit for purpose.

Table 2.2 summarises the key differences between second-generation and third-generation SA groundwater flow models. Table 2.3 summarises additional differences that are specific to particular models and locations. The reasons and evidence for these changes are discussed in detail in the following sections.

Table 2.2 Key differences between second-generation and third-generation SA groundwater flow models

2nd generation	3rd generation	Reason	Supporting data
Stratigraphy and aquifer parameters based on data available c. 2005.	Stratigraphy and aquifer parameters revised	Additional data available, sometimes leading to revised conceptual understanding. Recommended by model reviewers.	Bore logs and aquifer tests
River Murray represented by constant-head cells. (The Morgan to Lock 3 model is an exception and uses river cells.)	River Murray represented by river cells	This is a more realistic approach as it allows groundwater to flow through underneath the river within the floodplain sediments.	Potentiometric head maps show floodplain throughflow, e.g. Murtho
Irrigation based on data available c. 2005.	Irrigation information updated	Additional data available, reflecting drought and recovery.	Mapped irrigation area over time, irrigation accession estimates from external consultant
SIS based on data available c. 2005, including conceptual design only of Pike and Murtho SIS.	SIS simulated as constructed	Additional data available; some major changes to SIS design at Pike and Murtho.	SA Water records
Groundwater salinity assigned in coarse reaches.	Groundwater salinity assigned in finer reaches	Provides greater detail in estimating salt flux.	Review of regional groundwater salinity data near the floodplain edge
Calibration based on limited number of observation wells.	Calibration based on an expanded number of observation wells	Should improve estimates of potentiometric head and hence of flux to river. Recommended by model reviewers.	Hydrographs
Limited comparison of model results with datasets other than potentiometric head.	Model results compared to a variety of observations	Additional lines of evidence to minimize the problem of non-uniqueness.	Run of River salt loads, floodplain ET estimates, irrigation accession estimates, and NanoTEM geophysics
Limited sensitivity and uncertainty analysis.	Expanded sensitivity and uncertainty analysis	Indicates the key parameters. Explores how some model assumptions affect model outputs.	Not applicable

Table 2.3 Location-specific differences between second-generation and third-generation SA groundwater flow models

Morgan to Lock 3 2005 model	Waikerie to Morgan 2012 model and Woolpunda 2013 model	Reason
The model has 7 layers	The models have 3 layers	The Hamley Fault means that the water table lies in the lower units of the Murray Group at Woolpunda, but in the upper units (or above) from Waikerie to Morgan. The 2005 model spans both these areas, so needs to simulate 7 layers. The 2012 and 2013 models span smaller domains on either side of the Fault, so each model need only simulate the stratigraphic units that drive local interaction with the river.
The model domain is large with coarser grid size	The model domain is smaller with finer grid size	Allowed for finer spatial discretization and detail.
ET not simulated except at Stockyard Plains.	ET simulated	ET controls potentiometric head in the floodplain, hence controls flux to river. Recommended by model reviewers.
The river is modelled with a time-varying specified stage elevation for calibration simulations but is constant for predictive scenarios	The river is held constant at pool level for both calibration simulations and predictive scenarios.	Consistency between calibration and scenario conditions; agreed by 5-year Model Review Team.
Pike-Murtho 2006 model	**Pike-Murtho 2014 model**	**Reason and evidence**
The model domain excluded an irrigation area above Lock 6 and Chowilla Creek	The model domain extended northward to cover the entire Murtho Land and Water Management Plan	Reviewer recommendation: It aids communication of the conceptual model graphic to show the key model features, as identified in the report text. This included Chowilla Creek, as it is a significant addition to the model, noting that it is the only part of the model on the "northern" side of river that is included for Pike-Murtho purposes.

2.2.1 Stratigraphy and aquifer parameters

Method

The third-generation models incorporated data and improved conceptualisations that were not available at the time of the construction of the second-generation models. This led to revised model domains, stratigraphy, layering, and aquifer parameters. Much of the supporting data is presented in AWE (2012a), AWE (2012b), AWE (2013) and AWE (2007) discusses improvements to the conceptual model in the Waikerie to Morgan region.

Comparison with second generation models

For the Pike-Murtho model, structural contours and aquifer parameters were revised, as many additional bore logs and aquifer tests had been performed during the construction of the SISs, as documented in Pike and Murtho data atlases (AWE 2012a, AWE 2012b). The key revised parameter was the hydraulic conductivity of the Loxton Sands aquifer, which was revised upwards based on aquifer tests (AWE 2012a, 2012b).

The Morgan to Lock 3 model was replaced by two models because it spans two distinct hydrogeological regions. In the Waikerie to Morgan study area, the current watertable lies above the Murray Group, and the primary driver of groundwater salt into the river is irrigation. In the Woolpunda study area, the watertable lies within the Murray Group, and the primary driver of groundwater salt into the river is upwards leakage from the Renmark Group. To improve the SA Salinity Register modelling, the SIS Technical Expert Panel and the 5 Year Review Team agreed to replace this model with two models of smaller extents: the Waikerie to Morgan 2012 model (Yan et al. 2012) and the Woolpunda 2013 model (Woods et al. 2013).

The Renmark Formation hydraulic conductivity used in the Morgan to Lock 3 model was effectively 100–300 m/d, considerably higher than 1.4 m/d obtained from an aquifer test (Magarey and Howles, 2009) and a prior modelling study which had a range of 0.25–20 m/d (Barnett and Osei-Bonsu, 2006). The revised value, adopted by the Woolpunda model is 10 m/d and was adopted as it is a better match to the aquifer test and prior modelling estimates. The Waikerie to Morgan model does not simulate the Renmark Formation, as the Ettrick Formation acts an aquitard in the study area, minimizing the hydraulic connection between the Renmark Formation and Murray Group (Yan et al. 2012; Figure 1.1, p. 11).

The Glenforslan Formation hydraulic conductivity used in the Morgan to Lock 3 model was 0.6–8 m/d. A review (AWE 2007) of aquifer test results at Qualco-Sunlands showed that high values of hydraulic conductivity were recorded only in karstic areas: elsewhere, hydraulic conductivity estimates ranged from 0.04–1.21 m/d (AWE 2013). The review recommended that the value be revised in future models, hence the Waikerie to Morgan model adopts the log-mean of non-karstic data, 0.2 m/d, as the regional value for Qualco-Sunlands. The Glenforslan Formation is not saturated in the Woolpunda study area, so it is not simulated in the Woolpunda model.

Future options

As is current practice, model stratigraphy and aquifer parameters should reflect the latest data at the time of the review. This is a standard that should be included in the revised BSM2030 modelling procedures.

The Waikerie to Morgan model could be redeveloped to directly simulate the semi-perched aquifer in the Loxton Sands. While this would be a clearer representation of the hydrogeology, it may be computationally unstable and it is not clear whether this would improve the accuracy of the model.

In developing procedures under BSM2030, consideration could be given to requiring future model reviews to include recommendations for gathering further information. This could include identifying key locations where data is sparse and should be improved. Alternatively, a 'data worth analysis' could be employed as part of future model developments. This is a method to determine what data would be needed to reduce the model's predictive uncertainty. For example, it may show that an aquifer test at a key location would reduce uncertainty.

2.2.2 River representation

Method

The River Murray, including its anabranches, is simulated using MODFLOW river cells. River cells are positioned in model layers where a stratigraphic unit is in contact with the river. The river stage is held constant at pool level, due to policy and modelling considerations. Initially this assumption was made due to discussions with the MDBA regarding the Morgan to Wellington Model, where river levels were to be held constant for the historical simulations (SKM, 2010) and scenario simulations (A Close (MDBA), 2010 pers. comm., 15 March).

The rationale for this approach is that the numerical groundwater models should not simulate the impacts of climate, as the model purpose is to evaluate anthropogenic impacts only. Since then, all South Australian Salinity Register models have assumed constant pool level for river reaches. This assumption was confirmed in discussions with the 5-year Review Team as each model was developed. More fundamentally, river conditions should be the same for calibration and for scenarios, otherwise the scenario results may be impacted by the change. Hence if the river level is assumed to be at pool level in the scenarios, it should be held at pool level in the calibration.

Riverbed elevations are estimated from bathymetry measurements taken during NanoTEM surveys in 2004 (Telfer et al. 2005), but the details differ from model to model, as methods improved over time to better represent detail. In the Waikerie to Morgan model, a constant river depth of 5 m was assumed, an approximation to observations.

In later models, i.e. for Woolpunda and Pike-Murtho, the river depth varies spatially according to a moving average of NanoTEM bathymetry.

Conductance values are assigned depending on data availability. Where there are observation wells close to the river, conductance is determined during calibration by matching the hydrograph. Where there is no near-river information available for calibration, values are assigned based on calibrated reaches. In general, anabranches are assigned lower conductance values than the main channel. Conductance is varied during sensitivity analysis (see Table 6.1 and Figure 6.2 Yan et al. 2012, Table 6.1 and Figure 6.2(a) Woods et al. 2013, Table 6.1 and Figure 6.2–6.3 Woods et al. 2014).

Comparison with second generation models

The Pike-Murtho 2006 model represented the River Murray's main channel with constant head cells. These were replaced with river cells in the 2015 model, as the latter approach is more realistic. Constant head cells provide an unconstrained source of groundwater flux to/from the river, whereas river cells allow more realistic flux constrained by river stage, riverbed bottom elevation and riverbed conductance. River cells allow the potentiometric head in an aquifer under a river to differ from the specified head in the river, and enable the model to simulate throughflow in a floodplain under the river, for example, as observed at Murtho (observations in AWE 2012b; model results in Figure 4.2 Woods et al. 2014).

The Morgan to Lock 3 model differed from other second-generation models in that it used river cells to represent the River Murray. River stages were assigned a time-varying specified stage elevation and limited detail is provided (Rural Solutions 2005) but it is likely that annual mean stage elevations were applied between Locks 1 and 2, without backwater curves. In the Waikerie to Morgan 2012 and Woolpunda 2013 models, the river stage is held constant.

The parameters used to describe the River Murray in the third generation models of the region differ little from those used in the second generation models (Table 2.4). Note that models are generally insensitive to conductance unless it is changed by an order of magnitude or more, so the conductance values of the models can be considered close.

Future options

It is recommended that river cells continue to be used in preference to constant head cells. A discussion on how to use bathymetry data to best assign riverbed elevation should be included in the development of procedures for BSM2030. Riverbed conductance can be challenging to estimate using field based methods which aim to quantify the vertical and lateral hydraulic conductivity of the near river sediments. It may be that riverbed conductance will continue to be determined entirely through calibration and remain unconstrained by field based measurements.

River levels could be simulated in a number of ways. In future models, river representation should depend on whether the models are to simulate short-term salinity impacts, and how the groundwater model outputs are imported into MSM-Bigmod/Source. In addition, the assumptions adopted for calibration should be the same as the assumptions used for scenarios, otherwise the salt load predictions may be systematically biased. South Australia proposes that the impact of river level representation on salt loads estimates be investigated using existing models, and discussed by the MDBA and jurisdictions, to inform BSM2030 modelling procedures.

Table 2.4 Model settings for the River Murray for previous and current models

Model generation	Morgan to Lock 3 2005 2nd		Waikerie to Morgan 2012 3rd		Woolpunda 2013 3rd	
River reach	**River stage (m AHD)**	**Riverbed conductance (m^2/d)**	**River stage (m AHD)**	**Riverbed conductance (m^2/d)**	**River stage (m AHD)**	**Riverbed conductance (m^2/d)**
Upstream of Lock 3	9.8	1000	n/a	n/a	9.8	500
Upstream of Lock 2	6.1-8.8	1000	6.1	500-1500	6.1	500
Upstream of Lock 1	3.2-4.4	1000	3.2	500-1500	n/a	n/a
Downstream of Lock 1	0.98	1000	n/a	n/a	n/a	n/a

Model generation	Pike-Murtho 2006 2nd		Pike-Murtho 2014 3rd	
River reach	**River stage (m AHD)**	**Riverbed conductance (m^2/d)**	**River stage (m AHD)**	**Riverbed conductance (m^2/d)**
Upstream of Lock 6	19.3	n/a	19.2	1500
Upstream of Lock 5	16.3	n/a	16.3	1500
Upstream of Lock 4	13.2	n/a	13.2	1500
Upstream of Lock 3	9.8	n/a	9.8	1500

2.2.3 Groundwater evapotranspiration

Method

Evapotranspiration (ET) was included in all third generation models as it is a key driver within the floodplain, controlling the depth to water and hence the gradient and flux between groundwater and the river. Its importance is demonstrated in potentiometric head observations, which show areas within floodplains where head is below both river level and regional groundwater head. For example, near Waikerie as documented in AWE, 2013; through much of the Murtho-Renmark floodplain as documented in AWE, 2012b, and western Pike Floodplain and the Disher Creek region, as per the *WaterConnect* database, accessed November 2016.

The critical importance of ET was confirmed in numerical experiments simulating a generic South Australian River Murray floodplain, where even small changes in ET parameters led to large changes in river-groundwater interaction, such as a river changing from gaining to losing conditions (Riches et al. 2016). To omit ET is to fundamentally change the nature of groundwater flow in South Australian River Murray floodplains.

MODFLOW's EVT package is used to simulate evapotranspiration from groundwater. It calculates the "actual evapotranspiration" (AET), which is the volume of water removed from groundwater through evaporation and transpiration. The EVT package assumes that AET declines linearly with depth to water: if the watertable lies at the ground surface, then the AET is at a maximum equal to the "potential evapotranspiration" (PET), declining linearly with depth to water until it is zero if the watertable is at or below a specified extinction depth. PET is a parameter and model input; AET is the model output. The PET rate does not vary spatially, as the available data was not detailed enough to support PET zones. The PET rate and extinction depth are varied during calibration to obtain a good match to observed potentiometric head in the floodplain. The AET (i.e. the rate from the model water balance) in the floodplain is then divided by the floodplain area and compared with an estimate of floodplain AET obtained by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) from field studies (Holland, 2011): this is used to check that the AET is the correct order of magnitude. PET is included in sensitivity analyses.

This method is a compromise between conceptual simplicity and the true complexity of floodplain processes. It reflects the lack of data available on floodplain ET at the time of model development and also computational constraints.

The Pike-Murtho 2014 model has a PET rate of 1100 mm/y, based on Bureau of Meteorology estimates (2001), and the extinction depth is 2 m. This allows good calibration to floodplain observations of potentiometric head. The calculated floodplain AET is 60–80 mm/y, which compares very well to the 60–80 mm/y AET observed for a portion of Clark's Floodplain (Holland, 2011).

Woods et al. (2014) reports that the Waikerie to Morgan 2012 model also employs a PET rate of 1100 mm/y. DEWNR has recently discovered that, due to a software error, the model instead had a PET rate of 150 mm/y (see Visual MODFLOW Classic Interface Readme https://www.waterloohydrogeologic.com/visual-modflow-classic-readme/ fixed in v.4.6.0.160 (February 2012)). The model calibrates well to floodplain observations of potentiometric head and calculate floodplain AET as 30–35 mm/y, which compares well to the 60–80 mm/y AET observed for a portion of Clark's Floodplain (Holland, 2011), noting that a close match is not expected due to the differing conditions between floodplains and that the variability is not known. Note that the software error is only found in Waikerie to Morgan 2012 model.

The Woolpunda 2013 model has a specified PET rate of 250 mm/y and an extinction depth of 1.5 m. The floodplain at Woolpunda is narrow and is without observation wells. ET rates were varied during calibration to obtain a good match for near-river observation wells in the highland, and to Run of River estimates of groundwater salt loads to the river. The AET rate is calculated by the model as 88 mm/y. Model outputs were very sensitive to ET rate. It is noted that similar parameters were adopted for the Pyap to Kingston numerical groundwater model 2008 (Yan and Stadter 2008) and the Loxton-Bookpurnong numerical groundwater model 2011 (Yan et al. 2011), both of which show good calibration to floodplain hydrographs and other metrics.

Comparison with second generation models

The Morgan to Lock 3 model does not simulate ET except at Stockyard Plain disposal basin. The 2005 model report notes that this limits accuracy in simulating potentiometric head, e.g. near Ramco Lagoon, and that the lack of floodplain processes means that the model is likely to overestimate salt loads (Rural Solutions 2005). The 2007 revision of the model also does not include ET in the floodplain. Aquaterra (2007) notes that "*Part of the reason why the model over-estimates the salt load is because the model does not include evapotranspiration on the floodplain (i.e. all modelled flows reporting to the floodplain end up in the river), as this limitation has not yet been addressed by model upgrades (although it is recommended).*"

The Pike-Murtho 2006 model assigned PET rates of 200–250 mm/y and 1.5 m extinction depth for the whole model domain. This was determined during calibration, by comparing observed and modelled potentiometric head in the floodplain, which is strongly influenced by ET. As the Pike-Murtho 2014 model included significantly more observation wells on the floodplain, its higher calibrated PET value of 1100 mm/y is considered to be more accurate.

Future options

Evapotranspiration is a key driver within the floodplain, controlling the depth to water and hence the gradient and flux between groundwater and the river. It depends on climate, soil type, plant cover, groundwater salinity, depth to the watertable and highly transient atmospheric conditions; however, it is not currently known how PET and AET vary with these features.

Concerns received from BSMAP argue "*that the representation of ET is poor in the models and that much more information and understanding about ET is available*" (see Appendix 7.3, p. 2). South Australia notes that no better representation of ET has been developed, and that the new data on ET only became available after the models were completed. South Australia has been proactive in resolving this issue by investigating ET through a study of generic floodplain modelling (Woods, 2015b), conducting a first analysis of coarse-scale remote sensing data (Woods, 2015a; Wood et al. 2016), undertaking the development of a detailed model of Pike Floodplain (Purczel et al. 2016), and discussions with Flinders University to develop a research plan for Murray floodplain ET.

Addressing this knowledge gap would improve the robustness and defensibility of groundwater modelling of the River Murray floodplain. South Australia recommends that ET be considered a priority under the BSM2030 knowledge gap on environmental watering and floodplain dynamics.

In Appendix 7.3 it is also argued that "*by specifically including ET in the current models, a proportion of the flow from surrounding areas is lost to ET. In the real world, this salt is parked in the floodplain and tends to be mobilised during floods. In the models there is no mechanism for the release of this salt*." (see Appendix 7.3, p. 2). However this is a misunderstanding of the model assumptions. The models simulate a type of long-term condition which ignores transient floodplain processes. As the models are calibrated to match salt load observations this should be adequate for long-term trends. The models simulate neither the storage of salt in the floodplain nor its sporadic release during floods. The simulation of these floodplain processes in full would require a highly detailed groundwater flow and solute transport which includes transient changes in river level, ET, and groundwater salinity. A possible prototype is under development for the South Australian Riverland Floodplain Integrated Infrastructure Program for the Pike Floodplain (Purczel et al. 2016). It is noted that the Eastern Mallee models of Victoria and New South Wales also simulate ET, so this issue would also apply to the Register entries of other jurisdictions.

2.2.4 Dryland recharge

Method

The RCH MODFLOW module is used to represent watertable groundwater recharge from native vegetation conditions, dryland clearing and irrigation development (irrigation is discussed separately below).

Recharge due to dryland clearance is simulated using areas and rates developed by CSIRO and the Department of Environment and Heritage (DEH) (Cook et al. 2004; Wang et al., 2005). Clearance of native vegetation is presumed to have started in 1920. This has resulted in increased recharge rates to the groundwater table in dryland areas (Woods et al. 2014, p. 142). Lag times and recharge rates are estimated using data layers of groundwater depth, and thickness of the Blanchetown Clay layer (Woods et al. 2014, p. 32). A background value for recharge under native vegetation of 0.1 mm/y is applied, based on Allison et al. (1990).

Due to technical constraints, recharge due to dryland clearance is included only in the scenario used to assess its salinity impacts (Scenario 2). It is not included in the calibration model or in other scenarios. The model GUI used at the time of model development had a limit on the total number of recharge zones that could be defined. The number of dryland clearance zones and irrigation zones needed exceeded this maximum (see Figure 3.17 Yan et al. 2012, Figure 3.17 Woods et al. 2013, Figure 3.20 Woods et al. 2014). However, this is unlikely to have materially affected calibration as Scenario 2 indicates that the salt loads to the river due to land clearance are negligible to the present day (see Figure 6.7a–6.7b Woods et al. 2013). For example, in the Waikerie to Morgan model in year 2012, 6.7 t/d of salt load to the river is attributed to land clearance, compared to 102 t/d due to irrigation (see Figure 5.2 Yan et al. 2012).

Comparison with second generation models

The approach and the data used are identical.

Future options

DEWNR is now using a GUI, Groundwater Vistas, which has no limit on the number of recharge zones. As such, future models could include the impacts of dryland recharge in the historical model used for calibration and in transient future scenarios.

The areas and rates of dryland clearance recharge developed by CSIRO and Department of the Environment and Heritage (DEH) have not been reviewed since they were first developed in 2005. Middlemis and Knapton (2015) reviewed trends in observation wells that were expected to show a rise in potentiometric head due to dryland clearance. They found that few wells showed a rising trend. Woods et al. (2015) reviewed the vertical time-lag algorithm used in the estimates and found it had a very high uncertainty and recommended that the method and parameters should be thoroughly reviewed. This knowledge gap has been identified as a priority under BSM2030 to try and reduce the uncertainty associated with this accountable action.

2.2.5 Irrigation recharge

Method

The RCH MODFLOW module is used to represent watertable groundwater recharge from irrigation development. It is assumed that some proportion of irrigation accession water percolates past the root zone. Some of this water remains in the unsaturated zone, as evidenced from soil science (Cook et al. 2003) and from many observed perched aquifers.

In South Australia, it may take years or decades for root zone drainage at a new irrigation site to reach the watertable, i.e. there is a "lag-time", as the depth to water can be tens of metres and there are the low-permeability Blanchetown Clay and other units in the unsaturated zone (Fuller et al. 2005; Woods et al. 2015). Some sample evidence for long initial lag-times is from Woolpunda, where the watertable is yet to rise under an irrigation area established in 1990 (Woods et al. 2013). Lag times have also been investigated using unsaturated zone modelling (Lisdon Associates, 2010) and Woods et al. (unpublished International Association of Hydrogeologists conference presentation, 2013), showing that lag times are much lower at established irrigation areas, once the unsaturated zone has been wet up. Recharge zones and rates are developed as described below.

Recharge zones are based primarily on maps showing irrigation development over time (see Section 3.7.3 Yan et al. 2012 and Woods et al. 2013; Section 3.8.4 Woods et al. 2014). These may be sub-divided if there are significant changes in recharge lag-time in an irrigation area, as indicated by lag-time maps derived from SIMRAT (which is the same algorithm used for dryland clearance estimates). As irrigation continues to develop, more model irrigation recharge areas become active to simulate the irrigation area expanding (Woods et al. 2014, p. 14).

In the Waikerie to Morgan model, recharge zones may be wider than the irrigation footprint, as potentiometric head observations indicate there is a large semi-perched aquifer in the Loxton Sands that spreads over the Bookpurnong Beds (Yan et al. 2012) before recharging the Glenforslan aquifer (the model simulates the Glenforslan aquifer but not the Loxton Sands). Once an irrigation area commences it remains irrigated in perpetuity; no irrigated land is "retired".

Historical recharge rates over time are determined during calibration from measured groundwater levels, i.e. via inverse modelling. Recharge rates are assumed to decline over time, due to known improvements in irrigation efficiency. Recharge rates determined through calibration vary from 550 mm/y for the early years of long-established irrigation areas to 75 mm/y for some recent irrigation areas. Note that in Woolpunda, long lag-times mean that the watertable is yet to respond to increased recharge from historical irrigation (see Section 2.6.3.2, Figure 4.5(g)-PAC12[LM] and Figure 4.5(j)-PGK21[LM] Woods et al. 2013), so irrigation recharge rates could not be determined via inverse modelling.

The Waikerie to Morgan 2012 model simulates drainage bores as part of irrigation recharge. The drainage bores were constructed across the Waikerie and Qualco irrigation areas to dispose of excess root zone drainage to deeper groundwater aquifers (Yan et al. 2012, p. 48). The drainage bore water is simulated as part of the recharge in the groundwater model by increasing the recharge rate and shortening the time lags in known locations of drainage bores. This inverse modelling approach is considered adequate given the lack of available data on drainage bore fluxes (Yan et al. 2012, p. 83).

Total recharge applied in an area in the calibrated model is then compared to independent estimates of irrigation accession volume to confirm that modelled recharge is within an appropriate range (see Figures 4.21 – 4.23 Yan et al. 2012, Figures 4.15-4.16 Woods et al. 2013, and Figure 4.21 Woods et al. 2014). The accession estimates (Fordham et al. 2012; Vears 2013; Laroona Environmetrics 2013, 2014) are based on water balance methodology which traces water moving through landscape. The starting inputs are volumes from rainfall and irrigation application, from which are subtracted:

- Transmission and seepage losses from open irrigation channels prior to rehabilitation to conversion to pressurised underground pipe infrastructure
- Losses due to water uptake by crops and losses due to evaporation
- Losses due to drainage collection through caissons or drainage schemes.

Note that accession volumes should exceed the groundwater recharge, as some of the accession water remains in the pore spaces of the unsaturated zone and within perched aquifers. Additionally, the accession rates differ from recharge rates, due to unsaturated zone processes, including movement through a clay layer such as the Blanchetown Clay, which is extensive within the South Australian Riverland (see Figure 2.8 Woods et al. 2014). As such, the groundwater recharge rates of 75– 550 mm/y are also broadly consistent with other estimates of accession (root zone drainage) of 106– 540 mm/y derived from an agronomic approach in CMC (2010).

Future irrigation rates were decided in discussion with the 5-year Review Team and incorporate advice from an expert on Riverland irrigation. Rates are assumed to be 100 mm/y for permanent irrigation and 60 mm/y for Woolpunda's pivot irrigation. If the calibrated model indicates rates less than 100 mm/y, then the lower rates are adopted. Rates are held constant and do not vary by current crop type or by irrigation method. If irrigation is new to a location, then SIMRAT estimates of lag times are applied. If the irrigation is part of an established irrigation area, then a zero lag time is assumed.

Comparison with second generation models

The Morgan to Lock 3 model estimated irrigation recharge rates as annual rainfall plus total irrigation scheme diversions, combined with assumptions regarding irrigation water use efficiency and root zone drainage (Rural Solutions 2005). Lag-times were calculated by SIMRAT by assuming a recharge rate of 120 mm/y (Rural Solutions 2005); this means that the lag-times are likely to be overestimated, as lags are shorter for higher recharge rates such as those common historically.

The Pike-Murtho 2006 numerical groundwater model (Yan et al. 2006) uses the same methodology for irrigation recharge as the third generation models. The 2006 model also simulated irrigation at Loxton-Bookpurnong and included the salinity impact of this region on the adjacent Pike-Murtho reach. The impact of Loxton-Bookpurnong irrigation on Pike-Murtho should be addressed in the next update of the Loxton-Bookpurnong model.

The third generation models are based on more frequent maps of irrigation development over time and of course include more recent years (Table 2.5).

Table 2.5 summarises GIS analysis of model irrigated areas from the model last simulation year. It can be seen that Morgan to Lock 3 2005 model contains a slightly larger irrigation area than the combined Waikerie to Morgan 2012 and Woolpunda 2013 model due to an improvement in model resolution in the newer models. The 2005 model included recharge assumption rate of 120 mm/y and is 20 mm/y higher than the current models recharge assumption of 100 mm/y for the future scenario prediction (
Table 2.6). The current recharge assumption is considered more accurate as outlined above.

The Pike-Murtho 2014 model contains more irrigation footprint data up to 2014 which is larger than that of the Pike-Murtho 2006 model which included irrigation footprint data up to 2005. This confirms the comment in the

Pike-Murtho 2006 report that the uncertainty at that time is irrigation area (see chapter 8 - Yan et al. 2006). Current irrigation footprint data shows major irrigation expansion in Murtho.

Table 2.5 Irrigation development years

Model	Irrigation development year (GIS data)
Morgan to Lock 3 2005 model	1920, 1940, 1960, 1970, 1988, 1995, 1997, 1999, 2001 and 2003
Waikerie to Morgan numerical groundwater model 2012	1920, 1940, 1956, 1960, 1970, 1976, 1980, 1984, 1995, 1997, 1999, 2001 and 2003 to 2008 yearly data
Woolpunda numerical groundwater model 2013	1972, 1980, 1988, 1995, 1997, 1999, and 2001 to 2011 yearly data
Border to Lock 3 model	
Pike-Murtho numerical groundwater model 2006	Decadal intervals since 1920 to 2005, including Loxton-Bookpurnong irrigation
Pike-Murtho numerical groundwater model 2014	1894, 1930, 1940, 1945, 1950, 1960, 1965, 1970, 1975, 1980, 1985, 1988, 1990, 1995, 1997, 1999, 2000, 2001, 2003 to 2011 yearly data

Table 2.6 Summary of irrigation recharge settings and assumptions between previous and current models

Model	Most recent irrigation area (ha)	Irrigation recharge rates	Irrigation recharge assumptions
Morgan to Lock 3 numerical groundwater model 2005	16 023 Modelled footprint data up to 2003	Early years recharge 300 mm/y Later years fixed at 120 mm/y	Water balance; SIMRAT lag–times
Waikerie to Morgan numerical groundwater model 2012	10 630 Modelled footprint data up to 2008	Early years recharge 550 mm/y (flood irrigation on the floodplain) Later years fixed at 100 mm/y or less for some zones	Calibration; SIMRAT lag-times; comparison to independent accession volume estimate
Woolpunda numerical groundwater model 2013	4804 Modelled footprint data up to 2011	Permanent irrigation 100 mm/y (recent irrigation development) Pivot irrigation 60 mm/y	Accession estimate; SIMRAT lag-times, comparison to independent accession volume estimate
Border to Lock 3 model			
Pike-Murtho numerical groundwater model 2006	6940 Modelled footprint data up to 2005	Early years recharge 500 mm/y (flood irrigation on the floodplain) Later years fixed 100 mm/y	REM-Aquaterra 2005 calculated; Water balance + calibration; SIMRAT lag-times
Pike-Murtho numerical groundwater model 2014	10 030 Modelled footprint data up to 2011 Major irrigation expansion in Murtho	Early years recharge 520 mm/y (flooded irrigation on the floodplain) Later years fixed 100 mm/y	Based on PM2006 + calibration; SIMRAT lag–times; comparison to independent accession volume estimate

Future options

Accurately calculating irrigation recharge over time requires significant data on a number of parameters other than irrigated area and hydrogeological information. Estimation of irrigation and accession volumes over history is difficult with limited information available on crop type, irrigation methods, and water use efficiency. The movement of accessions draining through the unsaturated zone is also difficult to estimate, due to the stratigraphic complexity (with multiple and/or thick clay layers), very minimal information on unsaturated zone parameters, and gaps in the scientific knowledge of unsaturated zone processes. South Australia has identified this as an issue at the BSM2030 Knowledge Gaps workshop. Issues that should be considered as the knowledge gaps are addressed and as the

BSM2030 model procedures are developed are discussed below. It should be emphasised that the suggested actions would need to evaluated and prioritized against the likely improvement in Register entry certainty.

The MDBA and jurisdictions could consider whether a consistent approach to future irrigation rates is possible across the Mallee region. Estimates of future irrigation recharge could be based on detailed agronomic estimates of root zone drainage, with lag-times derived from unsaturated zone modelling, but it is not clear whether the additional effort required would significantly improve salt load estimates.

The uncertainty in lag-times could be estimated through measurements and modelling of the unsaturated zone, although the uncertainty is likely to remain high. Lag-times related to irrigated area retirement, new green fields irrigation, and improved practices could build on initial studies by Lisdon Associates (2010) and Woods et al. (2013), and as recommended in the SIMRAT review (Woods et al. 2015).

Retirement of areas from irrigation may need to be addressed in the models in the future and is a knowledge gap identified under BSM2030. In South Australian models, once an irrigation area commences it remains irrigated in perpetuity. This assumption was set partially as a precautionary approach as required under Schedule B to estimate future impacts of irrigation, and partially due to the groundwater modelling platform at the time. Where inverse modelling is used to estimate past recharge rates, this should be a good match to the physical reality, as drainage spreads laterally over the low-conductivity Blanchetown Clay in the unsaturated zone, so that the recharge under a small retired area surrounded by continuing irrigation areas will not return to pre-irrigation rates. However the recharge will be a lower rate than if irrigated. A consistent approach to land retirement should be discussed and agreed between the MDBA and the jurisdictions.

Irrigation areas have not been mapped consistently over the modelled period. A comparison of Mapping Services South Australian irrigation data against other data sources showed a discrepancy of up to 27 000 ha over the South Australian Riverland. Some of this will be due to differences in mapping method, some to do with model representation and some will be due to retirement of irrigation land. This may mean that the third generation models may be over-estimating the current irrigation area and hence the future salt load impacts. The assumption is therefore likely to over-estimate future recharge and salt loads, given that a fixed recharge rate is applied across the whole modelled footprint.

A consistent and cost effective estimate of irrigated area could potentially be achieved through the use of LANDSAT data. Consideration of a consistent approach and how this can improve historical modelled irrigation impacts, as well as represent future risk should be discussed with the MDBA and relevant jurisdictions.

2.2.6 Salt interception and groundwater control schemes

Method

Salt interception and groundwater control schemes are simulated to match their operation. As such, the methodologies used in third generation models were developed in discussion with SA Water's SIS manager. In South Australia, most scheme wells are operated so that the potentiometric head level at mid-point observation wells reach a specified target level. The exception is the Murtho SIS, which is heavily constrained by the size of the pump and pipe infrastructure (see Section 3.6.6 Yan et al. 2012, Section 3.6.4 Woods et al. 2013, Section 3.7.4 Woods et al. 2014).

In the historical (calibration) simulations, the schemes' wells are simulated using the Well Package, with pump rates obtained from SA Water records.

In scenario simulations, all SISs except Murtho are represented using the Drain Package, where the drain level and conductance are chosen so that the potentiometric head reaches the target level. This reflects the fact that the pump rate will be varied over time in future so that the scheme maintains target levels so that the pump rates cannot be determined in advance. A check is performed to see if the resulting volume going to the drains exceeds pump and pipe capacity (see Section 5 Yan et al. 2012, Woods et al. 2013 and Woods et al. 2014).

For scenario simulations at Murtho SIS, the scheme is simulated with wells. The pumping rates were specified by SA Water and remain constant from 2014 to 2114 (Woods et al. 2014). The Murtho SIS differs from other schemes in South Australia in that its pumping volume is limited by the pipeline capacity and the pumping volume may not be sufficient to lower the groundwater level at mid-point wells to the pool level in the long-term, when all the accession drainage from the current and future irrigation areas have reached the watertable.

The Qualco-Sunlands Groundwater Control Scheme (QSGCS) is treated in a combination of ways in scenarios. Three QSGCS pumping wells (Q1, Q2 and Q3) are located near the river and are operated like other SIS bores, so these are simulated using the Drain Package. The twelve remaining wells are simulated by the Well Package, because the nominal target level for most of the pumping wells is 3 m below ground level in the Loxton Sands (P Forward (SA Water) 2012 pers. comm., 1 February), and the Loxton Sands, which is not simulated in the model. The pumping rates adopted in the scenarios are the medians of the recorded pumping rates (see Section 3.6.6 Yan et al. 2012).

Comparison with second generation models

The Morgan to Lock 3 model has been used in the 2015 Salinity Register for assessment of the Waikerie Phase 2A SIS (Table 2.1). The model simulates all SISs using the Well Package, for both historical and future pumping. Future pump rates were based on past average pump rates. Note that this may over-estimate pumping, as SIS production wells are typically pumped at higher rates when first commissioned in order to sooner reach target potentiometric heads at mid-point observation wells (P Forward (SA Water) 2012 pers. comm.).

The Pike-Murtho 2006 model was developed while the Pike and Murtho SISs were at a concept design stage and were yet to be finalised, whereas the 2014 model simulates the SISs as constructed. There are major differences between the concept design and as-constructed design of the SISs.

The final concept design has 22 floodplain and 42 highland production wells at Murtho and 15 floodplain and 40 highland production wells at Pike (see Figure 54-55 Yan et al. 2006). Actual construction of SIS resulted in 23 SIS wells at Murtho and four production wells at Pike (see Figure 2.15 Woods et al. 2014). It is noted that the 2015 Salinity Register results are based on additional scenarios run in 2011 which simulate a four well Pike SIS. The SISs were also commissioned several years later than originally modelled in 2006, with an assumption that the SIS commenced pumping in 2006. The Pike-Murtho 2014 model instead simulates SIS commencement in the years it actually occurred, Pike SIS in 2012 and Murtho SIS in 2014.

Future options

The scenario simulations in the third generation of South Australia models assume that SISs are managed in ways that represent ideal operation, from 1988 to one hundred years from the present day. In workshop discussions, it was questioned whether SIS should be simulated in future to reflect actual operation of the schemes which in practice, may stop pumping due to flooding or maintenance. This is a discussion for resolution by BSMAP and the MDBA as part of the protocol review under BSM2030. Agreement should be reached on how ideal operation versus actual operation should be simulated in future model updates. Consideration of how to simulate the new "responsive" approach to SIS operation should also be made with an agreed approach to representation of SIS and GCS pumping agreed between the MDBA and BSMAP.

2.2.7 Salt load calculation

Method

Salt loads from groundwater to the River Murray (including anabranches) are calculated by multiplying flux by salinity for each river kilometre (see Section 3.8 and Figures 3.22–3.24 Yan et al. 2012, Section 3.8 and Figure 3.20

Woods et al. 2013, Section 3.9 and Figures 3.22a–3.22b Woods et al. 2014). The flux is the outflow from the floodplain aquifer to the river cell boundary condition. The assigned salinity for a given river kilometre reach does not change over time.

In discussion with the MDBA, it was decided that assigned salinities should be based on observation well samples of regional groundwater adjacent to the floodplain. An exception is made where a river lock has significantly lowered near-river groundwater salinity (see Figure 2.9 Yan et al. 2012, Figure 2.9 Woods et al. 2013, and Figures 2.7a–2.7b Woods et al. 2014).

Comparison with second generation models

Second generation models use the same approach, except that salinity zones were much coarser than one kilometre. The Morgan to Lock 3 2005 model erroneously used net flux to the river for its calculations. Table 2.7 shows the range of salinity values used for salt load calculation in the second and third generation models.

Table 2.7 Range of Salinity values used in the previous and current models

Model	Area	Salinity values (mg/L)		
		Minimum	Maximum	Average
Morgan to Lock 3 numerical groundwater model 2005	Woolpunda	16 000	23 000	19 142
	Cadell/Qualco	10 000	22 000	16 000
	Waikerie	10 000	25 000	14 666
Waikerie to Morgan numerical groundwater model 2012	Holder to Lock 2	7370	31 892	16 613
	Lock 2 to Hogwash	8500	32 300	24 204
	Hogwash to Morgan	1000	20 000	8403
Woolpunda numerical groundwater model 2013	Woolpunda	14 606	24 413	20 662
Border to Lock 3 model				
Pike-Murtho numerical groundwater model 2006	Murtho	9000	43 000	26 083
	Pike	8000	41 000	21 286
Pike-Murtho numerical groundwater model 2014	Murtho	1352	42 420	22 663
	Pike	910	46 900	17 732

Future options

Groundwater salinity assumptions and settings have significant impact on model salt load results. The current methodology is again a compromise between conceptual simplicity and the true complexity of the dynamics. It allows for lateral changes in salinity but not changes in salinity with depth nor over time. It is a deliberately conservative approach so that salt loads are not underestimated.

It is proposed that salinity assumptions be discussed between the MDBA and the jurisdictions so that future models are based on a documented consensus. Some approaches would be simple to implement, while others would require considerable investment which has been out of scope to date. Adjustments that could be considered in future include:

- Use of AEM data to assign salinity based on patterns observed in electrical resistivity (noting that care would be required in interpreting the AEM data, as resistivity depends on soil type and saturation as well as salinity).
- continuing to use regional groundwater salinities, but allow them to change over time, for example groundwater salinity may decrease where significant volumes of irrigation-derived recharge have begun to mix with native groundwater (e.g. at Loxton and Lyrup). There are two challenges here: it would be difficult

to assign historical values and a method would need to be agreed regarding how groundwater salinity might change in the future.

- Using floodplain aquifer salinity instead of regional aquifer salinity, noting this would require more detailed modelling and monitoring as floodplain groundwater salinity may change over time due to a number of processes e.g. evapoconcentration and mixing with river waters. This approach was investigated in Riches et al. (2015) and is currently being explored in the Pike Floodplain model (Purczel et al. 2016).
- Simulating salinity changes with depth, due to processes described above and also to density-driven flow. Some limited simulation of salinity changes with depth could be achieved by splitting the Monoman Formation into multiple layers. It is not clear whether this would have any impact on salt load estimates, but this is being investigated in the Pike Floodplain Groundwater model (Purczel et al. 2016). Density-driven flow and transport is notoriously difficult to simulate accurately (Woods, 2004) and is computationally highly intensive, so it is not recommended for regional-scale simulations. However, it has been successfully used for small-scale simulations of the River Murray floodplain (Jolly et al. 1994; Werner and Laattoe 2016).

2.2.8 Calibration and validation

Method

The numerical models are manually calibrated to achieve a good match to observed hydrographs (see chapter 4 of Yan et al. 2012, Woods et al. 2013 and Woods et al. 2014).

Which parameters are varied most during calibration depends on the expected reliability of their initial estimates. In many cases, this means choosing between hydraulic conductivity or recharge (a common example of the "problem of non-uniqueness" under near-equilibrium conditions). In South Australia, the hydraulic conductivity, estimated from aquifer tests, is usually assumed to be more reliable than recharge estimates, due to the large depth of water and the complexity of unsaturated zone processes. For this reason, recharge rates are usually treated as a calibration parameter (Section 2.2.5). In areas with a shallow watertable, then recharge estimates may be more reliable and the hydraulic conductivity is treated as the main calibration parameter.

At many locations the aquifer system is not in equilibrium, due to changes in irrigation recharge and SIS pumping, so a satisfactory calibration under both unstressed and stressed conditions should be a good indicator of a well-constrained model, particularly if it matches well to other kinds of data.

Other model outputs are compared, qualitatively or quantitatively, with a variety of observations:

- Run of River (RoR) data, to provide a check on flux and salt load calculations
- Geophysical surveys (in-river NanoTEM) data to provide a check on the simulation of gaining and losing reaches in the River Murray
- Estimated accession volumes for each irrigation district to provide a check on irrigation recharge
- Actual groundwater ET estimates from Holland (2011) to provide a check on groundwater ET parameters.

Comparison with second generation models

The number of observation wells used for model calibration in the third generation models is higher than the second generation models (Table 2.8). The model calibration performance (scaled root mean square, SRMS) is also better than the previous generation, especially given that there are more observations and wells included. Note that the Morgan to Lock 3 2005 model report omits some suspect monitoring points from the calibration statistics (Rural Solutions 2005).

Second generation model result comparison was limited to only Run of River data to provide a check on flux and salt load calculations.

Table 2.8 Calibration performance comparison between the second and third generation models

Model	Number of observation wells used for calibration	SRMS (%)				
		1980	1988	2000	2005	2010
Morgan to Lock 3 2005 model, Waikerie to Morgan reach	75	n/a	5	7.8	n/a	n/a
Waikerie to Morgan 2012 model	92	4.3	7.8	5.8	9.0	7.5
Morgan to Lock 3 2005 model, Woolpunda reach	19	n/a	5.0	2.8	n/a	n/a
Woolpunda 2013 model	86	2.9	2.8	2.7	2.8	3.0
Border to Lock 3 model						
Pike-Murtho 2006	80	10.4	7.3	6.6	6.9	8.0
Pike-Murtho 2014	101	8.2	5.9	4.1	3.8	4.0

Future options

The MDBA and relevant jurisdictions could consider what datasets provide useful comparisons with model outputs, as part of the development of model procedures. The calibration objective function could include more than one data type. A combination of manual calibration and automated calibration (e.g. using PEST) could be considered.

2.2.9 Sensitivity and uncertainty analysis

Method

Sensitivity and uncertainty analyses were performed for each model, as given inTable 2.9. The parameters were chosen based on expert opinion. A sensitivity analysis (S) varies a single parameter within reasonable bounds while other parameters are held constant at their calibration value to gauge the impact on the calibration to potentiometric head and the match to Run of River salt loads in the historical calibration model. An uncertainty analysis (U) varies a single parameter within reasonable bounds to gauge the impact on the scenario salt loads. An uncertainty analysis on River Murray level in the Pike-Murtho 2014 model was done at the request of the reviewer, but was not documented in the report (see Pike-Murtho 2014 issues log 20140429 p. 5, RPS 2014).

Future options

A more formal approach for the sensitivity and uncertainty analysis could be considered for future models. The National Water Commission Groundwater Modelling Guidelines (Barnett et al. 2012) describe a number of approaches. It is suggested that the MDBA consider running a pilot project on a selected model to determine the best approach, in consultation with the jurisdictions.

A request to complete a formal sensitivity and uncertainty analysis for the 2012, 2013 and 2014 models was received (Appendix 7.3). Given the models have already been accredited by independent peer reviewers, and that this level of analysis has not required of other Salinity Register models, South Australia does not consider this necessary.

Table 2.9 Sensitivity and uncertainty analyses

	WM2012	WP2013	PM2014
Aquifer and aquitard parameters			
Unconfined regional aquifer horizontal hydraulic conductivity	S	S	S
Unconfined regional aquifer specific yield	-	S	S
Unconfined regional aquifer specific storage	-	S	-
Regional aquitard vertical hydraulic conductivity	S	S	S
Floodplain aquifer horizontal hydraulic conductivity	-	-	S
Confined regional aquifer hydraulic conductivity	-	S	-
Groundwater salinity (TDS, mg/L)	U	-	U
Boundary condition parameters			
Potential groundwater ET rate	-	S	S
Groundwater ET extinction depth	S	S	S
River Murray riverbed conductance	S	S	S
Anabranch riverbed conductance	-	-	S
River Murray level	S	U	undocumented
Scenario assumptions			
Impact of Mallee clearance	-	U	-
Irrigation recharge rate	U	-	-
Irrigation recharge lag time	-	-	U
Impact of irrigation recharge from an adjacent area	-	-	U

2.3 Brief comparison with Eastern Mallee models

The models described in this document were developed for the assessment of Salinity Register entries in South Australia. The nearest equivalent models outside South Australia are the Eastern Mallee (EM) groundwater models, which are used for some Salinity Register entries in Victoria and New South Wales. EM1.2 (Aquaterra 2007) was used to determine Legacy of History impacts while EM 2.3 (Aquaterra 2009) was used to determine some Reduced Irrigation Salinity Impacts (RISI) and SIS entries.

The EM models simulate climatic and hydrogeological conditions which are very similar to those of the South Australian models. It is useful to consider their methodology when considering South Australian model assumptions and how future Salinity Register models could be improved and made consistent across states. The EM models employ very similar approaches to the South Australian models with some exceptions. The discussion below considers key model aspects raised in the context of the South Australian Five Year Model Reviews, but is not exhaustive.

Stratigraphy and aquifer parameters are updated with each model revision to reflect all available relevant data and conceptual interpretations. This identical to South Australian models.

Rivers are represented using river cells in both EM and South Australian models. In EM models' historical simulations used for calibration, river levels vary according to annual averages, while pool levels are adopted for scenarios. South Australia uses constant river levels for both historical and scenario simulations (Section 2.2.2).

Evapotranspiration is included. Unlike the South Australian models, the EM2.3 model has ET parameters which vary spatially, based on vegetation type and groundwater salinity. This is likely to be a superior methodology provided it can be demonstrated it provides a good match to field observations of actual ET. Unfortunately, the details of the method are not given in the report, nor is the modelled AET compare to field observations (Aquaterra 2009).
Dryland recharge due to mallee clearance is simulated in the EM1.2 model using an approach identical to the South Australian models. The EM2.3 model does not include mallee clearance as it was held to have minimal impact on scenario results when compared to irrigation impacts.

Irrigation recharge rates in the EM and South Australian models are derived from similar datasets but the approaches differ due to different circumstances in South Australia compared to New South Wales and Victoria. In South Australia, most irrigation occurs in "highland" areas where there are clay layers within a thick unsaturated zone. Consequently, there are large lag-times between irrigation and aquifer recharge, as well as localised perched aquifers, and the relationship between irrigation accessions and groundwater recharge is complex. In New South Wales and Victoria, irrigation occurs in areas with a shallower unsaturated zone, so large lag-times are rare, and irrigation accessions will be a reasonable approximation for groundwater recharge.

Water balances are used to estimate irrigation accessions for all EM and South Australian models. As discussed in Section 2.2.5, the calibration approach should depend on whether hydraulic conductivity or recharge estimates are believed to be more reliable. In the EM models, recharge estimates are considered more reliable. Initial estimates of irrigation recharge are found by multiplying the drainage by an irrigation efficiency factor, then the model is calibrated by varying conductivity, with minor adjustments made to irrigation recharge later.

In South Australia, the complicated and lengthy unsaturated zone dynamics mean that recharge estimates are considered less reliable than hydraulic conductivity data, hence the model is calibrated by varying recharge, with minor adjustments to hydraulic conductivity. The South Australia models use the estimated irrigation accessions as a check rather than a model input.

In the EM2.3 model, an irrigation area can increase or decrease in size over time. In the South Australia models, an irrigation area remains irrigated once commenced.

The EM2.3 model assumes no lag time between irrigation development and groundwater recharge, with the exception of Karadoc area, based on observations (RPS Aquaterra 2013). This is not an appropriate assumption for highland areas of South Australia, where delays of several decades have been observed in areas such as Woolpunda and parts of Murtho (Woods et al. 2013, Woods et al. 2014).

In the EM2.3 model, future recharge rates are based on the rates used for the last year of the calibration period. This method that assumes that current rates are likely to continue and do not reflect temporary influences such as drought. The South Australia models hold future recharge rates constant at 100 mm/y due to the multi-decadal lag-times. It is recommended that the MDBA and BSMAP discuss whether a consistent methodology is appropriate as part of the development of the BSM2030 procedures.

SIS are simulated in EM models using pumping wells. The pumping rates used for the future are based on the last year of the calibration period: this approach is not suitable for most South Australia SIS, which are operated to reach target levels rather than target pump rates (see Section 2.2.6).

Salt load is calculated identically in both EM and South Australian models. Groundwater salinity zones in EM models are informed by trends in electrical resistivity at depth where AEM data is available. This is a potentially useful refinement, as discussed in Section 2.2.7.

Model outputs from EM models are calibrated using hydrographs. Other model outputs are compared to geophysical surveys (in-river NanoTEM) and Run of River data. This is similar to the South Australian model approach, except that South Australian models also include a comparison with field estimates of AET.

3 Scenarios and results

3.1 Scenario definitions

South Australia has developed a number of scenarios to identify and estimate the impact of accountable actions in the groundwater models. These scenarios have been developed in consultation with MDBA and DEWNR staff (Woods et al. 2014, p. 138). The standard scenario suite is given in Table 3.1 and includes a brief description of each scenario. Rehabilitation of irrigation distribution channels (RH) and improved irrigation practices (IIP) are included as well as scenarios that distinguish between different stages of SIS development, including concept design, revised design, and as-constructed. The SIS in Pike and Murtho have been built, but they are classified as "revised design" until they are technically reviewed after 5-years operation. The SIS in Woolpunda and Waikerie are well-established, with many years of data since their construction, so are represented "as-constructed".

The application of these standard scenarios across the groundwater model suite allows for the calculation of accountable actions across the South Australian Murray-Darling Basin by combining the results from actions for the different model areas. This approach is used for Mallee clearance, irrigation development impacts (pre and Post-1988), improvements in irrigation practices, and rehabilitation of irrigation supply systems.

The combination of scenarios is undertaken by the MDBA to calculate the estimated impact of accountable actions in EC (electrical conductivity) and equivalent EC in dollars ($). The detail of these combinations and the resulting values for the accountable actions are outlined in Section 4.

Table 3.1 Standard South Australia Salinity Register Model Scenarios

Scenario	Description	Irrigation development area	IIP	SIS
Calibrated model	Historical	Footprint of irrigation history	Yes	Yes
Scenario 1	Natural system (post-locking, pre-irrigation)	None	-	No
Scenario 2	Mallee clearance	None (but includes Mallee clearance area)	-	No
Scenario 3A	Pre-1988 irrigation without IIP or RH	Pre-1988	No	No
Scenario 3C	Pre-1988 irrigation with IIP and RH	Pre-1988	Yes	No
Scenario 4	Current Irrigation	Pre-1988 + Post-1988	Yes	No
Scenario 6	Concept Design SIS	Pre-1988 + Post-1988 + Future development	Yes	Concept design
Scenario 7A	Current irrigation plus revised SIS	Pre-1988 + Post-1988	Yes	Revised design
Scenario 7B	Pre-1988 irrigation with IIP and RH plus revised SIS	Pre-1988	Yes	Revised design
Scenario 7C	Current plus future irrigation plus revised SIS	Pre-1988 + Post-1988 + Future development	Yes	Revised design
Scenario 8A	Current irrigation plus constructed SIS	Pre-1988 + Post-1988	Yes	As constructed
Scenario 8B	Pre-1988 irrigation with IIP and RH plus constructed SIS	Pre-1988	Yes	As constructed
Scenario 8C	Current plus future irrigation (best estimate) plus constructed SIS	Pre-1988 + Post-1988 + Future development	Yes	As constructed

A number of additional scenarios have been generated to enable calculation of specific accountable actions such as salt interception schemes. For example, in Waikerie to Morgan groundwater model, there have been a number of additional scenarios run under Scenario 8A to allow for the estimate of the additive impact of each salt interception scheme as constructed. These are documented in Table 3.2 with more detail on each of these scenarios found in the technical report for the Waikerie to Morgan Groundwater Model 2012 (see Section 5.9, p. 151 Yan et al. 2012).

Scenario 3B used to be part of the standard suite but is no longer simulated. Its purpose was to simulate the impact of improved irrigation practices without rehabilitation. However, there is no reliable methodology to separate the impacts of improved irrigation practices from rehabilitation of the irrigation supply systems.

Table 3.2 Additional South Australia Salinity Register Model Scenarios

Scenario	Description	Irrigation development area	IIP	SIS
Scenario S3B	Pre-1988 irrigation with IIP, no RH	Pre-1988	Yes	No
Waikerie to Morgan				
Scenario 8A(i)	Current irrigation plus constructed SIS	Pre-1988 + Post-1988	Yes	Waikerie 1 only
Scenario 8A(ii)	Current irrigation plus constructed SIS	Pre-1988 + Post-1988	Yes	Waikerie 1 + QSGCS
Scenario 8A(iii)	Current irrigation plus constructed SIS	Pre-1988 + Post-1988	Yes	Waikerie 1 + QSGCS + Waikerie 2A
Scenario 8A(iv)	Current irrigation plus constructed SIS	Pre-1988 + Post-1988	Yes	Waikerie 1 + QSGCS + Waikerie 2A + Waikerie Lock 2
Scenario 8B(i)	Pre-1988, with IIP & RH plus constructed SIS	Pre-1988	Yes	Waikerie 1 only
Scenario 8B(ii)	Pre-1988, with IIP & RH plus constructed SIS	Pre-1988 + Post-1988	Yes	Waikerie 1 + QSGCS
Scenario 8B(iii)	Pre-1988, with IIP & RH plus constructed SIS	Pre-1988 + Post-1988	Yes	Waikerie 1 + QSGCS + Waikerie 2A
Scenario 8B(iv)	Pre-1988, with IIP & RH plus constructed SIS	Pre-1988 + Post-1988	Yes	Waikerie 1 + QSGCS + Waikerie 2A + Waikerie Lock 2

3.2 Scenario inputs: Recharge rates

The section below provides comparisons of modelled recharge rates for the previous and updated models. These rates are summed across entire irrigation areas and are expressed as ML/y. As per Table 3.1 and Table 3.2, the scenarios use various recharge regimes. Three are plotted in Figure 3.1 to Figure 3.3. All include some form of irrigation:

- Pre-1988 irrigation footprint, rates fixed from 1988, with no rehabilitation or improved irrigation practice (Scenario 3A)
- Pre-1988 irrigation footprint, rates change after 1988 to reflect rehabilitation and improved irrigation practice (Scenarios 3C and 8B)

- Pre-1988 and post-1988 irrigation footprint and rates, based on calibration and future assumptions as described in Section 2.2.5 (Scenarios 4, 7A and 8A).

Recharge inputs for Scenarios 1 and 2 are not plotted as they are unchanged between the second and third generation numerical models (Section 2.2.5). “Future development” irrigation is not plotted as this is not used for 2015 Register entries or the proposed updated Salinity Register entries.

Waikerie to Morgan 2012

In comparison with scenarios of the Morgan to Lock 3 2005 model, the Waikerie Morgan 2012 model recharge has a steeper onset, a lower peak, and lower future values (Figure 3.1).

For the early decades of the simulation, there is a lack of detailed irrigation efficiency history, and monitoring in this area did not commence until the 1990s. The Morgan to Lock 3 model calculated lag-times assuming recharge rates of 120 mm/y; as historical recharge rates are likely much higher, the lag-times should be shorter (Section 2.2.5). The 2012 model estimates lag-times through matching the observed shape of the groundwater mounds in recent decades, and so has adopted an earlier onset to the recharge. Hence, while there remains considerable uncertainty, this recharge is supported by the model calibration.

The future recharge for “Pre-1988, no RH and IIP” is similar for both models. Time-lags mean that the final recharge is not the same as the recharge in 1988.

The future recharge for the other regimes is approximately 25% lower in the 2012 model than in the 2005 model. A 20% reduction is expected due to a change in assumptions about irrigation efficiency in future years: in the 2005 model, the future irrigation recharge is fixed at 120 mm/y, whereas the 2012 model assumes 100 mm/y, to be consistent with other South Australia models. The remaining decrease in recharge will be due to a combination of factors, as the models differ in numerous ways (Section 2.2). Also, the 2012 model is based on more detailed and more recent irrigation information, where there has been a small decline in irrigation area (Section 2.2.5).

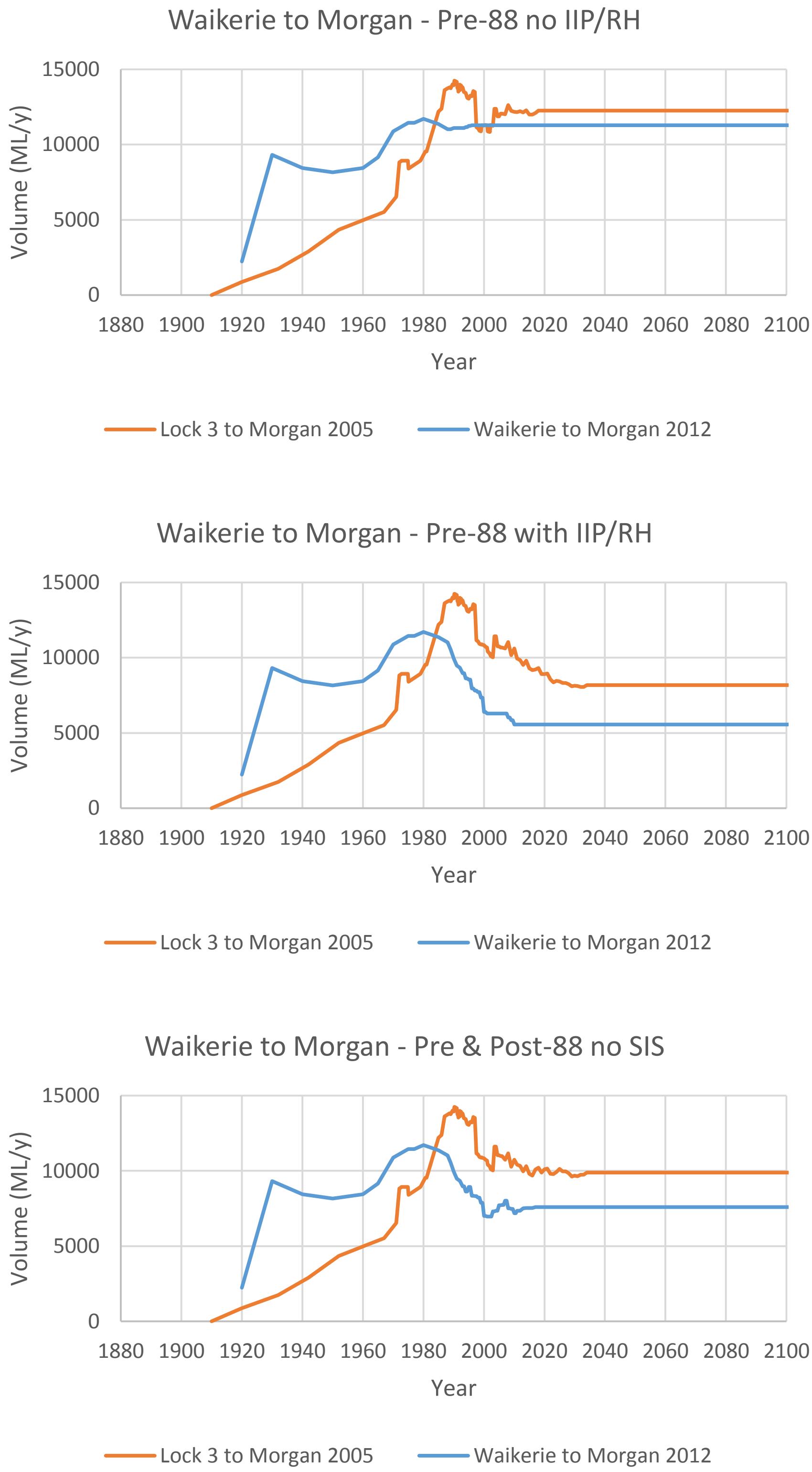


Figure 3.1 Modelled recharge rate comparison

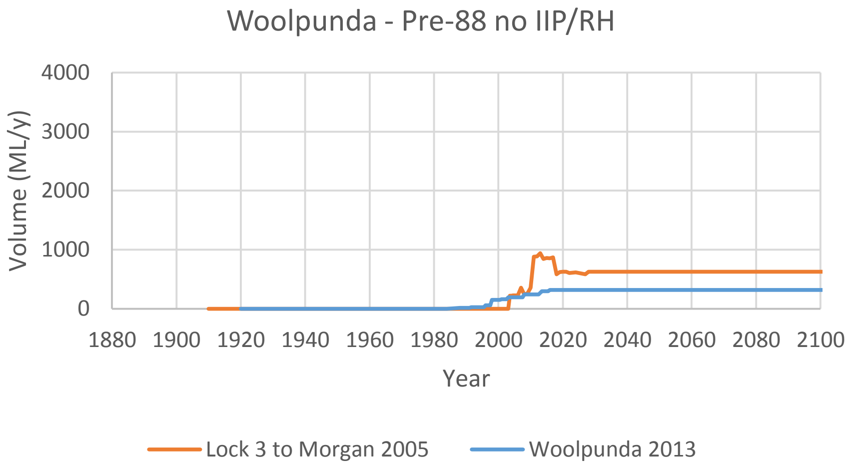
Woolpunda 2013

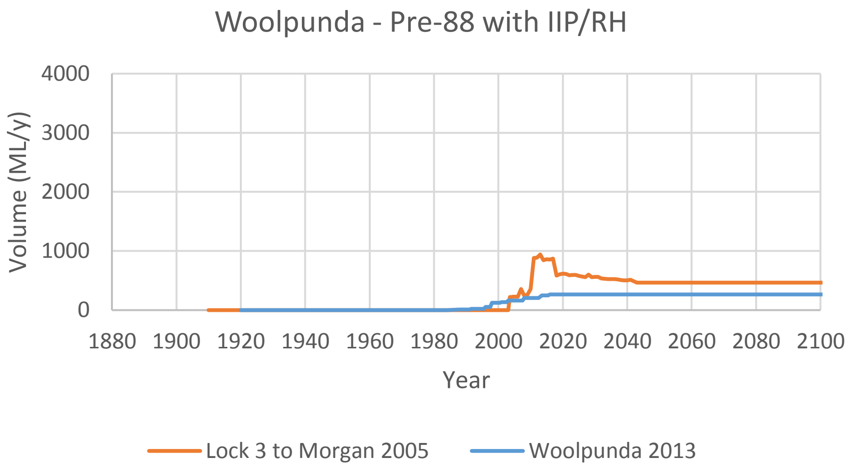
Irrigation recharge at Woolpunda cannot currently be determined from model calibration. This is because most irrigation is recent, there are multi-decadal time-lags between irrigation accession and aquifer recharge and as a result the hydrographs in the region are yet respond to irrigation. Hence recharge from irrigation at Woolpunda must be estimated from irrigation accession estimates and estimated time-lags (Section 2.2.5).

The 2005 model assumes a sharp increase in recharge after 2010 (Figure 3.2). This was a reasonable and conservative assumption at the time of model construction, but this recharge has not been observed in recent hydrographs.

The Woolpunda 2013 model bases recharge on an assessment of irrigation accession by Vears (2013). In the Pre-1988 recharge regimes, the revised irrigation accession estimates approximately halve the recharge when compared to the 2005 model. Part of the reduction is due to changes in the assumed future irrigation efficiency: in the 2005 model, the irrigation recharge is fixed at 120 mm/y, whereas the 2013 model assumes 100 mm/y, to be consistent with other South Australian models.

The shape of the recharge curves in the "Pre-1988 and Post-1988" regime depend on assumptions regarding both irrigation area and recharge. Irrigation has expanded since the 2005 model was developed (Figure 2.14 Woods et al. 2013). This increase offsets the decline in recharge caused by the change in irrigation efficiency assumptions, so that the final recharge rates are similar between models.





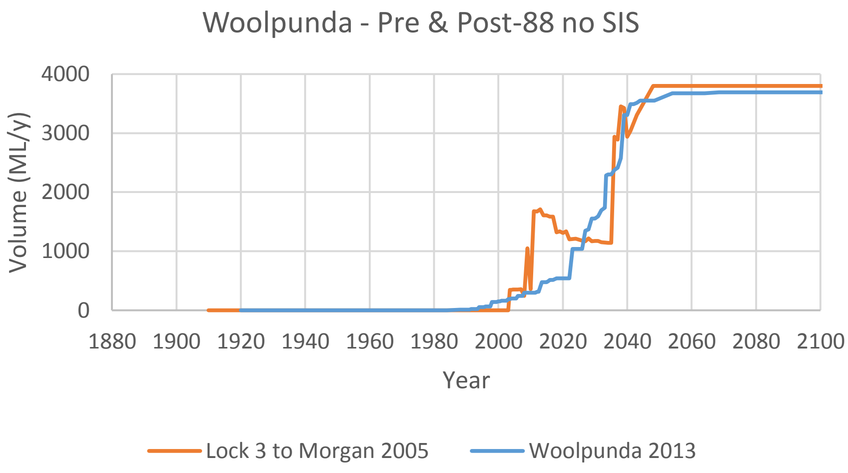


Figure 3.2 Woolpunda modelled recharge rate comparison

Pike-Murtho 2014

The recharge in the Pike-Murtho 2006 and Pike-Murtho 2014 models have varying trends to approximately 2020 (Figure 3.3). For the early decades, there is a lack of detailed irrigation efficiency history, and monitoring of the irrigation-induced groundwater mounds did not commence until the 1990s. However, the 2014 model is well-calibrated in recent decades, and the shape of the groundwater mounds depends on earlier recharge. Hence, while there remains considerable uncertainty, this recharge is supported by the model calibration.

In pre-1988 scenarios, the irrigation area is fixed to that of 1988, so future recharge rates differ due to irrigation efficiency and time-lags estimated during calibration. When compared with the 2006 model, the 2014 model has lower future recharge rates in some cases and higher in others. As the 2014 model is based on more recent data (Section 2.2) and is better calibrated (Table 2.8), it is presumed that its recharge rates are more accurate, although uncertainties remain.

For the "Pre-1988 and Post-1988" regime, the future recharge rates are much higher for the 2014 model than the 2006 model. Much of this can be attributed to the expansion in irrigation that has occurred, particularly at Murtho, since 2006 (Table 2.6). The total irrigated area for Pike and Murtho combined in 2003 was 6 940 ha, increasing to 10 030 ha by 2011, a 45% increase. The final recharge rate in the 2014 model is 56% greater than the recharge in the 2006 model.

Figure 3.3 Pike - Murtho irrigation recharge comparison

3.3 Scenario outputs: Salt loads

Waikerie to Morgan and Woolpunda

The modelled salt loads presented here are those used to derive entries for the 2015 Salinity Register, compared with the proposed updates from the Waikerie 2012 and Woolpunda 2013 models. Table 2.1 gives the sources of the 2015 Salinity Register entries, which are based on the MDBC's flow-salt load relationship (Section 2.1), the Morgan to Lock 3 2005 model including the Lock 3 to Morgan 2008 revision (Sections 2.1.3) and the Waikerie Lock 2 model (AWE 2009).

Figure 3.4 plots salt loads for those scenarios where 2015 Salinity Register entries are based on the Morgan to Lock 3 model. In Section 3.2, it was possible to plot the recharge for the Waikerie to Morgan reach and the recharge for Woolpunda irrigation areas separately. This cannot be done for salt loads for the Morgan to Lock 3 2005 model, as its report does not record salt loads by irrigation area; instead it reports on salt loads above and below Lock 2. Hence, to compare like with like, Figure 3.4 plots salt loads summed over both the Waikerie to Morgan and Woolpunda reaches.

For these scenarios, the revised salt loads are lower (Figure 3.4). This is expected, given that the 2005 model is known to over-estimate salt loads when compared to Run of River observations. At Waikerie, "*the model may be calibrated to a target* [pre-scheme] *salt load that is too high for Waikerie, by up to a factor of two*" (Rural Solutions 2005). At Woolpunda, the 2005 model can overestimate salt loads by 50 t/d or more (Table 5.6 Rural Solutions 2005). In contrast, the Waikerie to Morgan 2012 and Woolpunda 2013 models match Run of River observations reasonably well (Section 4.4.2 Yan et al. 2012, Figure 4.14 Woods et al. 2013). However, there is some difficulty in interpretation as the models simulate different river conditions, which strongly affects salt load. Thus it is an improvement that the salt loads predicted by the more recent models are substantially lower than those of the Morgan to Lock 3 2005 model.

The improvement is clear in Scenario 1 (natural system, post-locking but pre-irrigation). The models are very different in terms of structure, parameters, and features, so it is difficult to determine which combination of assumptions has caused the improvement. It could be due to improved aquifer parameters from model calibration, as the 2012 and 2013 models are calibrated to many more observation bores (Table 2.8). It is also likely to be influenced by the inclusion of ET in these model, given that an uncertainty analysis shows that modelled salt loads at Woolpunda are sensitive to the maximum specified ET rate (Figure 6.2(a) Woods et al. 2013). Changes in groundwater salinity distribution will also affect the salt loads (Section 2.2.7).

In the 1980s and early 1990s of Scenarios 2, 3A, 3B/C, and 4, the Morgan to Lock 3 model has highly-variable salt loads. This is due to the model simulating annual changes in river level. River levels are held constant in future years, so this variability does not occur then.

For the Mallee clearance of Scenario 2, the salt loads at early times are close to Scenario 1 (apart from the variability due to river level changes mentioned above). The Morgan to Lock 3 2005 model predicts a 20% steeper rise in future salt loads than the 2012 and 2013 models. As the same recharge rates are used in both models, the difference in salt loads must be due to other model assumptions.

For Scenarios 3B/3C and scenario 4 with irrigation but without SIS, the difference in salt loads is roughly proportional to the difference in recharge rates for the two models (Section 3.2).

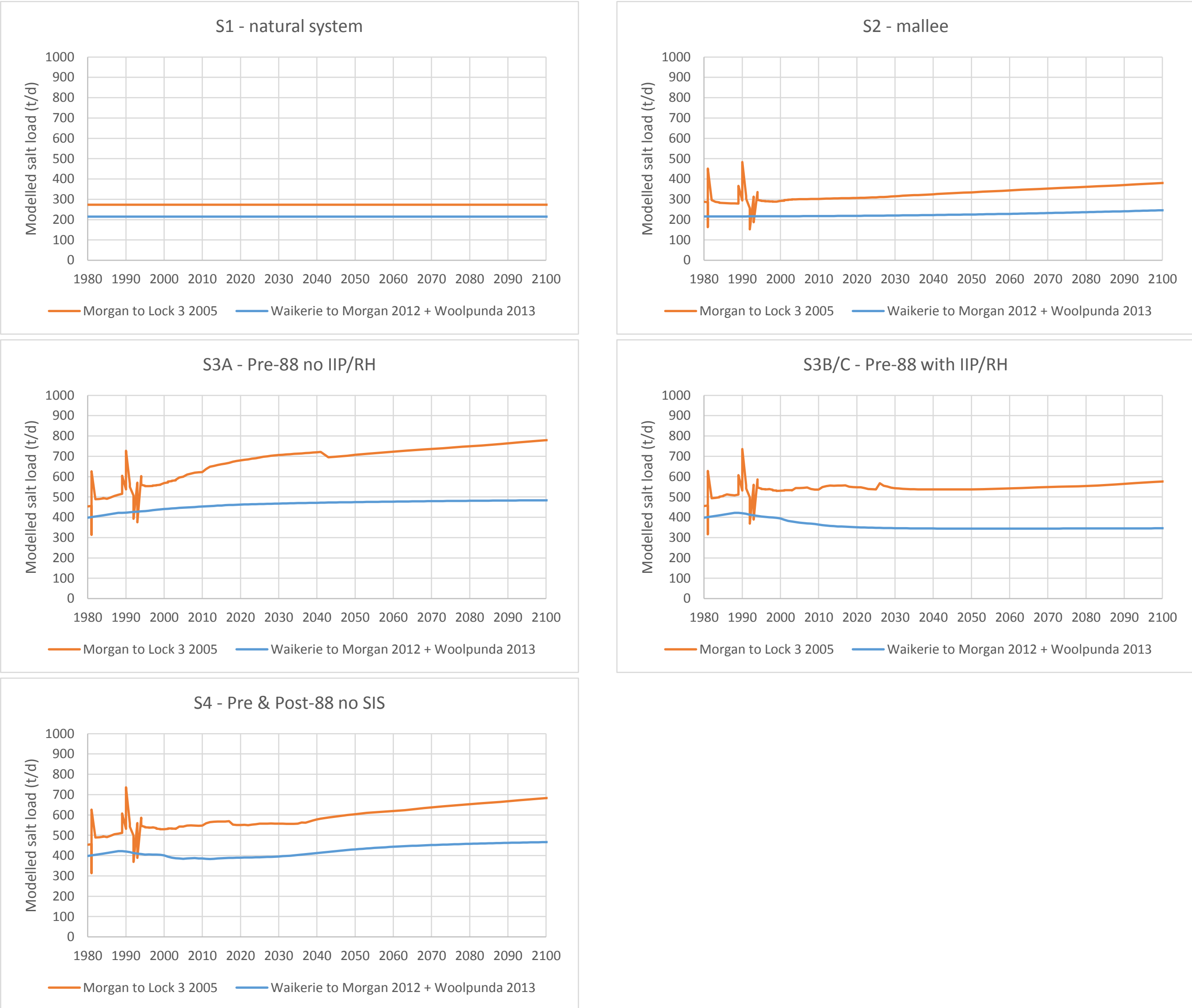
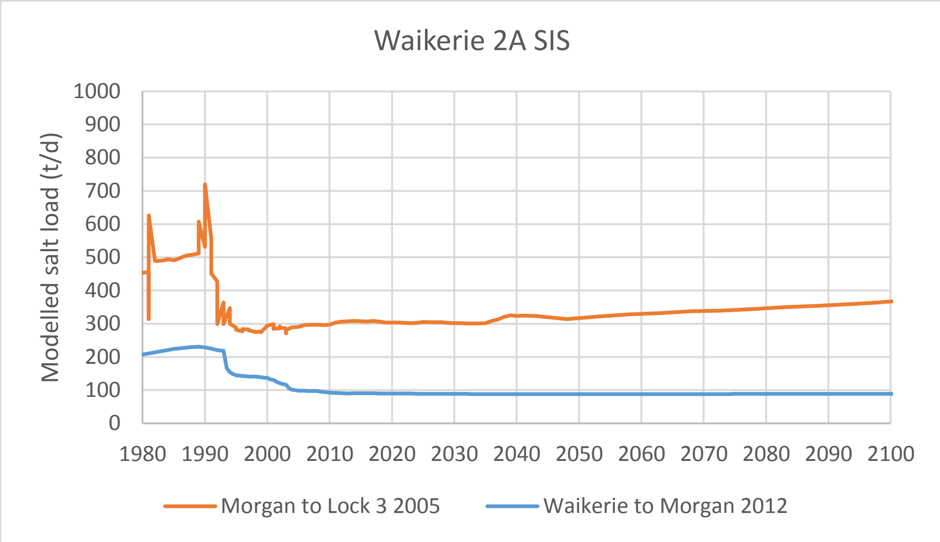


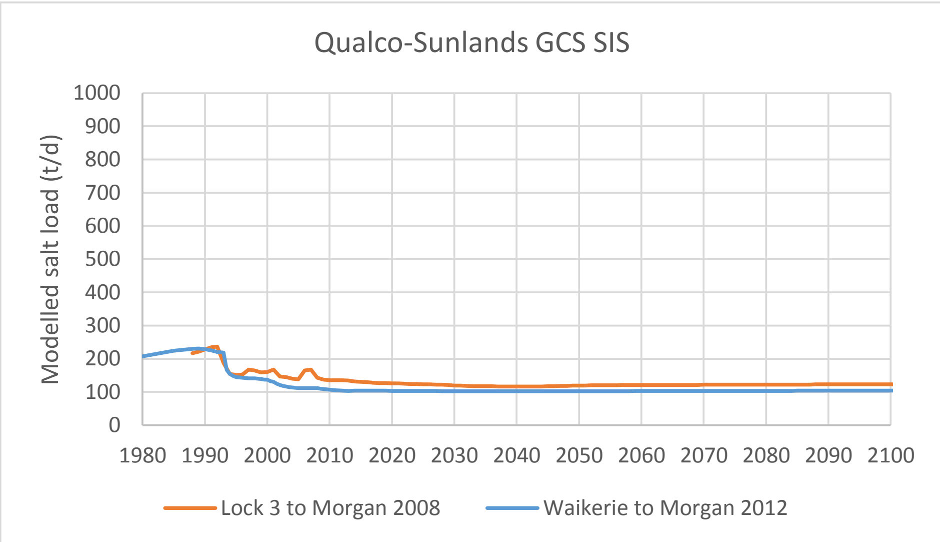
Figure 3.4 Modelled salt load comparison between Waikerie to Morgan 2012 and Woolpunda 2013 models and the Morgan to Lock 3 2005 model

Figure 3.5 plots salt loads for scenarios with current irrigation and SIS schemes (i.e. Scenarios 6, 7A or 8A, depending on the developmental stage of SIS construction at the time of model construction), where the 2015 Register entries depend on a numerical groundwater model.

The top figure shows salt load results for the Waikerie 2A SIS, where 2015 Salinity Register entries are based on the Morgan to Lock 3 model (Rural Solutions 2005), in comparison to the updated Waikerie to Morgan 2012 model. The salt loads from the Morgan to Lock 3 2005 model vary sharply in 1980s and 1990s as the model simulates changes in river level as well as changes in irrigation recharge and SIS pumping.

The middle figure shows salt load results for Qualco-Sunlands GCS, where 2015 Salinity Register entries are based on the Lock 3 to Morgan model (Aquaterra 2008), in comparison to the updated Waikerie to Morgan 2012 model. These salt loads are very similar between models. The bottom figure shows salt load results for the Waikerie Lock 2 SIS, where 2015 Salinity Register entries are based on the Waikerie Lock 2 model of AWE (2009), in comparison to the Waikerie to Morgan 2012 model. Salt loads are similar from the mid-2000s.





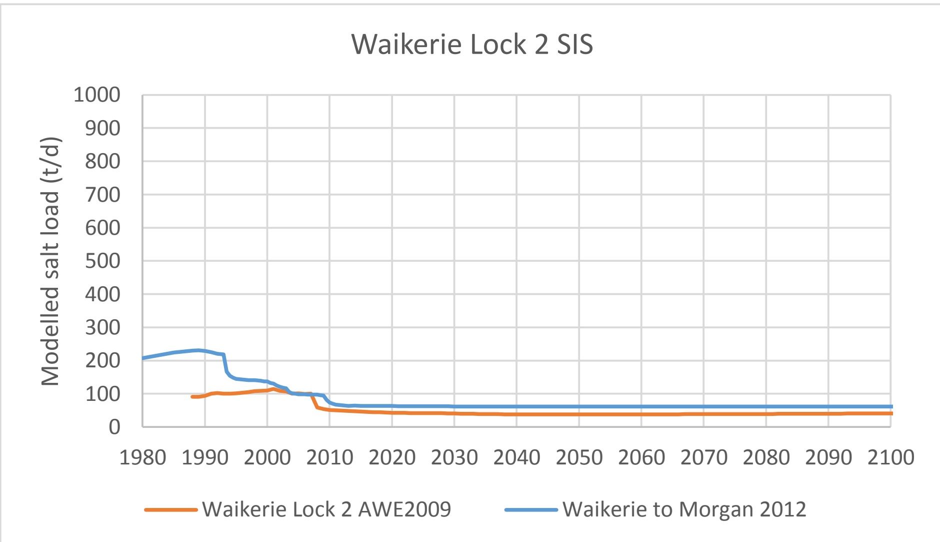


Figure 3.5 Modelled salt load comparison for Waikerie 2A SIS, Qualco-Sunlands GCS and Waikerie Lock 2 SIS

Figure 3.6 plots salt loads for those scenarios where 2015 Salinity Register entries are based on the MDBC's flow-salt load relationship, i.e. those for the Waikerie 1 and Woolpunda SIS. Figure 3.7 compares estimates of the change in salt load due to SIS. For the Waikerie 1 SIS, the flow-salt load relationship estimates a fixed reduction of salt load of 60 t/d. The Waikerie 2012 model estimate is very similar, initially as high as 70 t/d once the SIS is fully operational, then becoming 60 t/d in the long-term. For the Woolpunda SIS, the flow-salt load relationship estimates a fixed reduction of salt load of 176 t/d; the Woolpunda SIS 2013 model matches this initially, but then increases over time to 256 t/d. The Woolpunda SIS 2013 estimate of SIS intercepted salt load increases over time as the model simulates increasing irrigation recharge over time.

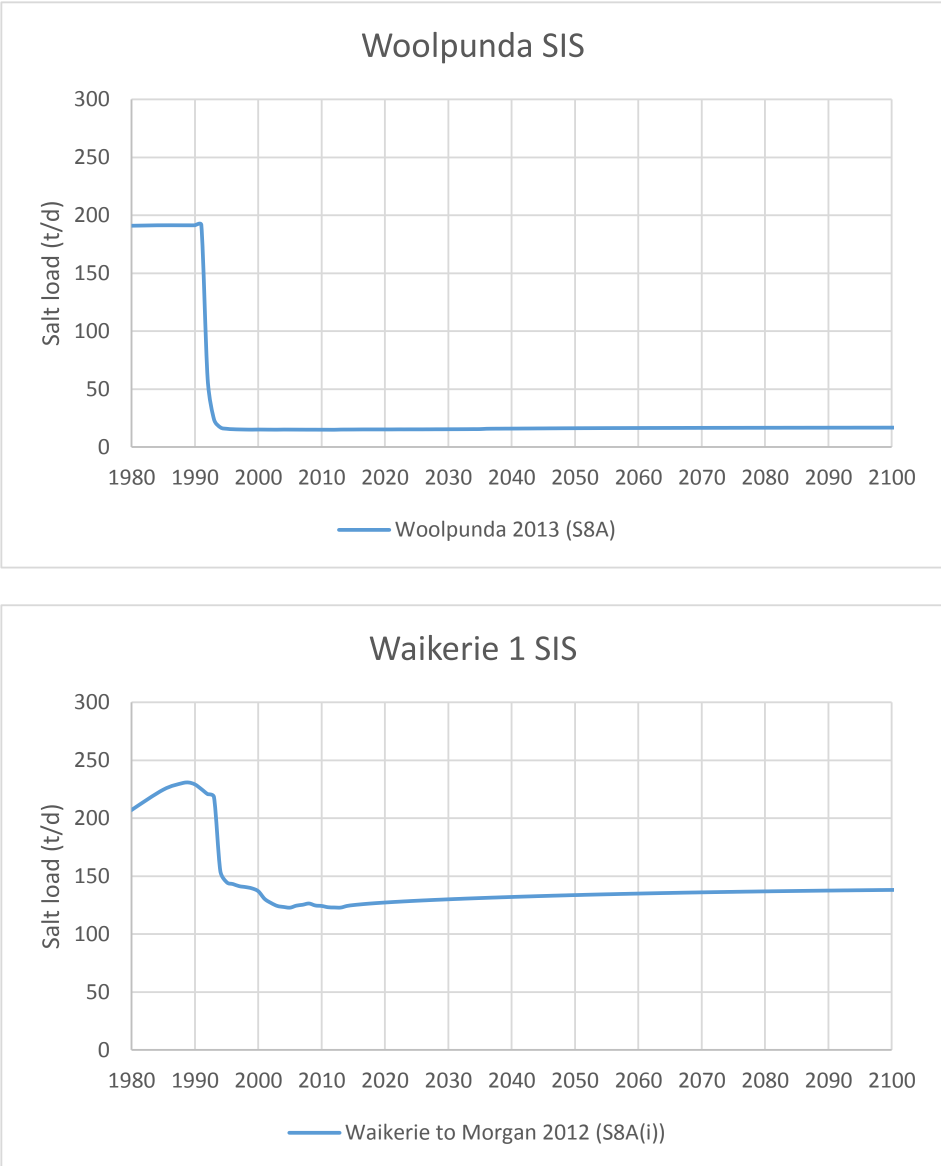
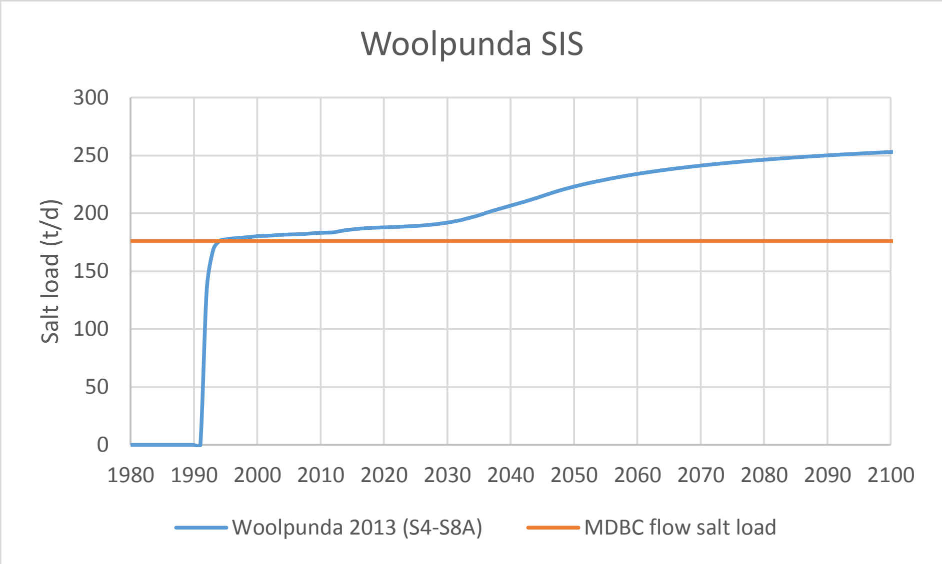


Figure 3.6 Modelled salt load comparison for Woolpunda and Waikerie 1 SIS



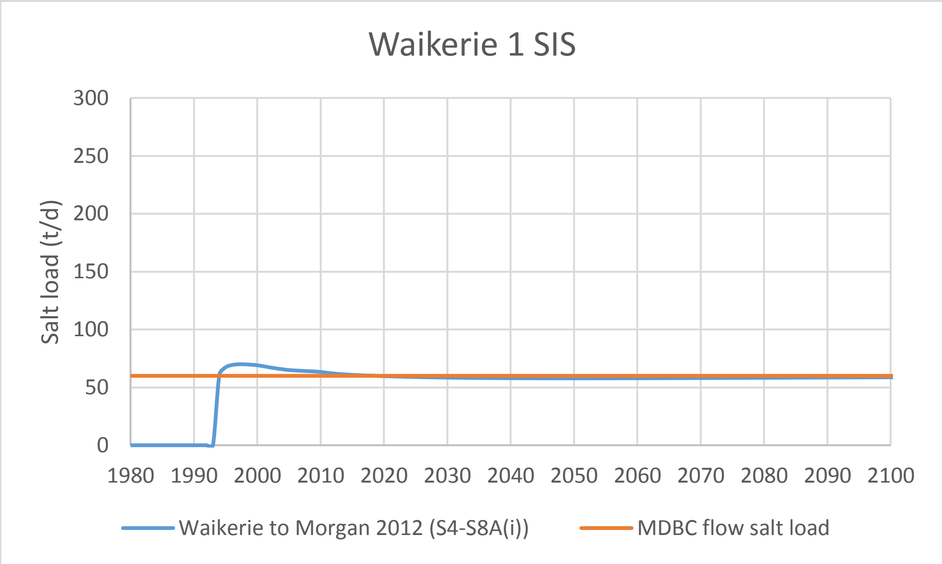


Figure 3.7 Reduction in salt load due to Woolpunda and Waikerie 1 SIS, as estimated by MDBC flow salt load, and the 2012 and 2013 models

Pike-Murtho 2014

Figure 3.8 and Figure 3.9 compare the modelled salt loads between the Pike-Murtho 2006 and Pike-Murtho 2014 models. It can be seen that in most scenarios, Pike-Murtho 2014 model salt loads are lower than those of the Pike-Murtho 2006 model. The lower salt loads of the Pike-Murtho 2014 model are partly due to an improved understanding of floodplain processes. In the 2006 model, the river is represented using constant head cells, which means flow is not permitted under the river within the floodplain aquifer, so flux to the river is over-estimated (Section 2.2.2). Through-flow under the river can be inferred from potentiometric head maps of Pike and Murtho.

The problem is corrected in the 2014 model, which represents the river using river cells. The 2014 model also has an improved simulation of groundwater ET in the floodplain (Section 2.2.3). The total actual groundwater ET has significantly increased from the Pike-Murtho 2006 model, which also reduces groundwater flux entering the river. The 2014 model is well-calibrated to potentiometric head observations in the floodplain, and it also provides a good match to Run of River estimates of salt load, and to CSIRO estimates of actual groundwater ET. This supports the 2014 model's representation of the floodplain and its surface water-groundwater interaction.

It is noted that the Pike-Murtho 2006 model included Loxton – Bookpurnong irrigation area in the model simulation and hence salt load impact to Pike area is approximately 20 t/d higher than the 2014 model where this issue has been corrected.

The salt loads for the SIS scenarios reflect the SIS design at the time of simulation (Section 2.2.6). In the 2006 model, the SIS begins pumping in 2006; in practice, the Pike SIS commenced in 2012 and the Murtho SIS in 2014. The 2014 model reflects the change in start dates, so salt loads decline later in the 2014 model than the 2006 model. Future salt loads differ between the models as the constructed SIS employ different numbers of pumping bores and pumping rates than presumed in the 2006 model. Note however that the 2015 Salinity Register results are based on additional scenarios run in 2011 which simulate a four well Pike SIS.

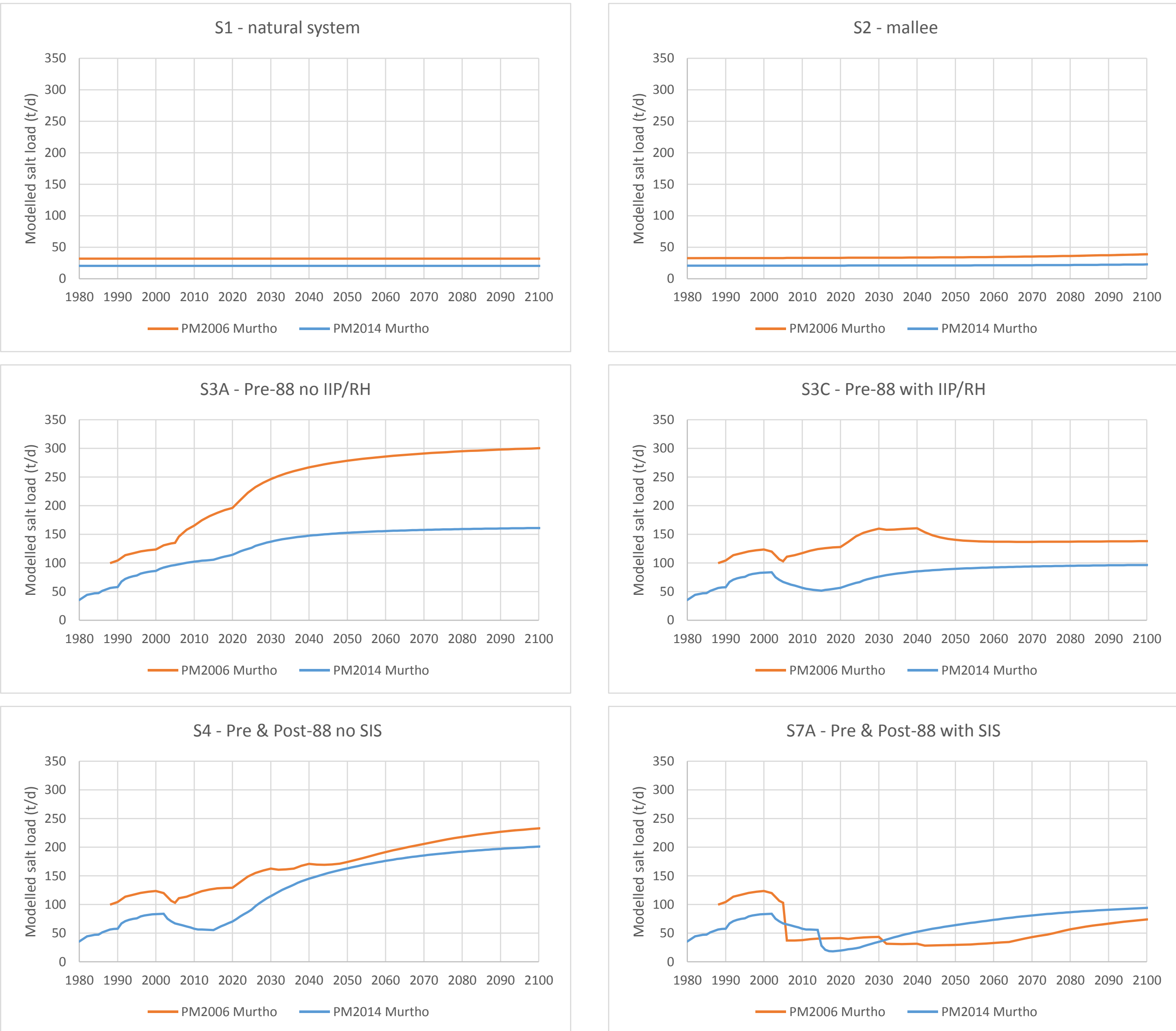


Figure 3.8 Murtho modelled salt load comparison for all scenarios

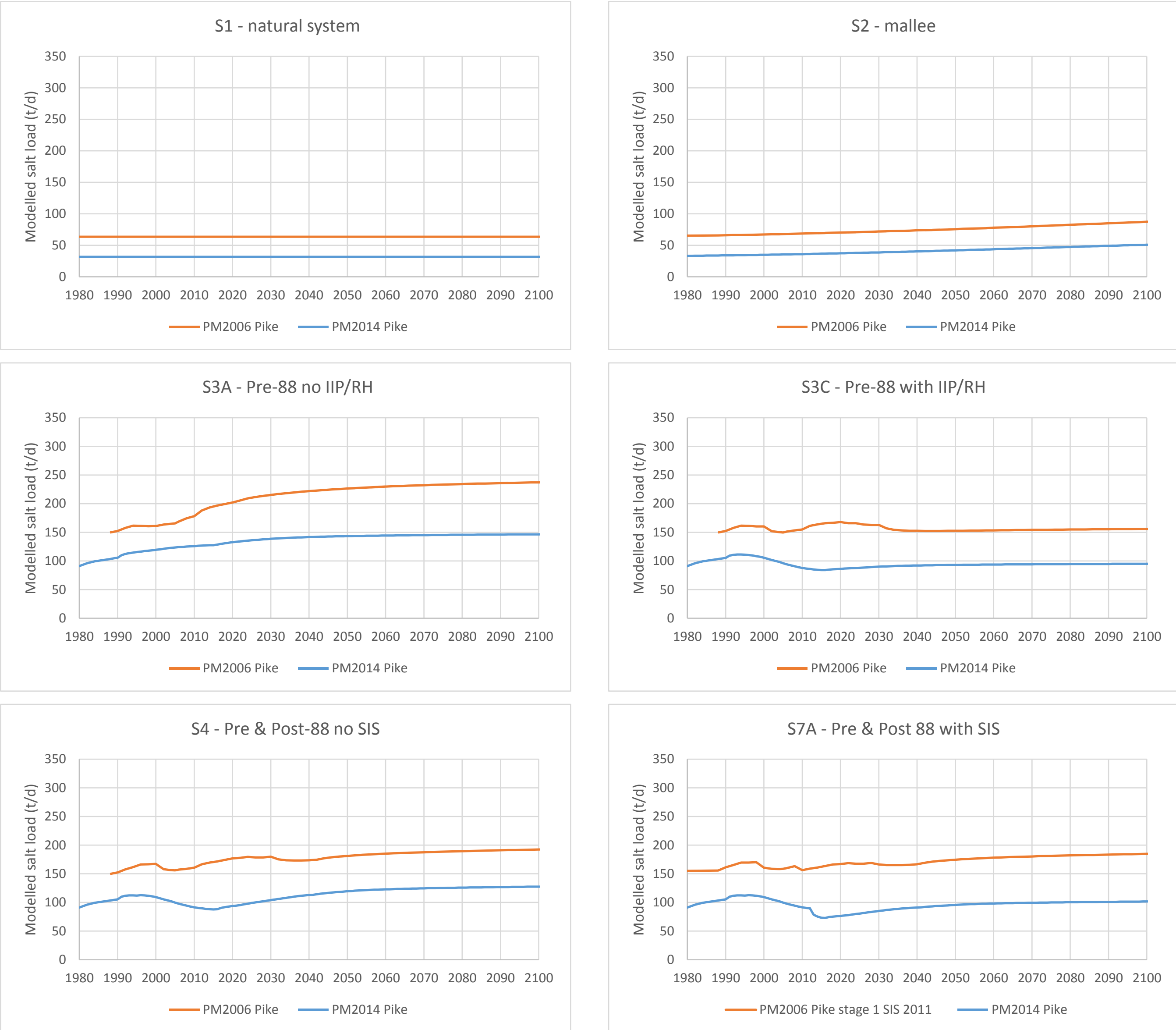


Figure 3.9 Pike modelled salt load comparison for all scenarios

4 Accountable Actions

As discussed in Section 3 above, the scenarios used to assess accountable actions have been developed in consultation with MDBA and DEWNR staff and have been documented and applied consistently across the models. The scenarios are used by the MDBA to determine the salinity effect EC and Equivalent EC ($) for the Salinity Registers from the model output provided by South Australia in t/d. Some scenarios are used on their own for accountable actions (e.g. Scenario 2 represents Mallee Legacy of History for Dryland). Other accountable actions are derived from two scenarios paired together to get a result. The combinations are outlined in Table 4.1 below.

Table 4.1 Summary of accountable actions and supporting model scenarios

Order of Action	Accountable Action	Method to interpret	Action Type	Register	Sharing	Comments
1.	South Australia Mallee Legacy of History – Dryland	Change in S2 from 2000	Debit	B	South Australia	The change in impact after 2000 is accountable on the Salinity Registers.
2.	South Australia Mallee Legacy of History – Irrigation	Change in S3A from 2000	Debit	B	South Australia	The change in impact after 2000 is accountable on the Salinity Registers.
3.	South Australia Irrigation Scheme Rehabilitation and Improved Irrigation Efficiency	Paired comparison (S3A – S3C)	Credit	A & B	South Australia	Scenario 3A and 3C both assume irrigation footprint does not expand after 1988. 3A assumes no IIP or rehabilitation where as 3C includes both. By subtracting the pre-1988 impact (S3C) from the impact (S3A) of 'no improved irrigation practice' the benefit of the improved irrigation practices can be determined.
4.	South Australia Irrigation Development 1988 – current year	Paired comparison (S4 – S3C)	Debit	A	South Australia	Scenario 4 includes all irrigation until the year of model development. The impact of post-1988 irrigation is calculated by subtracting the impact of pre-1988 irrigation from current impact. Both scenarios include actual improved irrigation practices.
5.	Salt Interception Schemes (SIS) - Woolpunda SIS - Waikerie I SIS - QSGCS - Waikerie 2A SIS - Waikerie Lock 2 SIS - Pike SIS - Murtho SIS	Paired comparison (S4 - S8A or S-4 - S7A)	Credit	A	S&DS BSMS South Australia	The benefit of the SIS scheme is determined by subtracting the salt load to river with the SIS (S7A or S8A) from the scenario depicting current impact without SIS (Scenario 4). Where there is more than one SIS/GCS in an area the stacked comparison between paired scenarios is undertaken (Table 3.2).

As groundwater models are developed and updated, the component of the accountable action for that geographic area is also updated on to the Salinity Registers. For example, the geographic extent of the groundwater models for Waikerie-Morgan, Woolpunda and Pike-Murtho will be combined to update the Mallee Legacy of History – dryland. Whereas the update for the Woolpunda SIS will only use the Woolpunda groundwater model.

As each groundwater model is accredited, the MDBA incorporate the salt loads generated into MSM-Bigmod and produce a *Model Run Report* outlining the predicted salinity impact for each relevant accountable action using the scenarios outlined in Section 3. Numbers generated by the MDBA include the salinity effect (EC), the Salinity Cost Effect ($m/y), 95%-ile Morgan Salinity Effect, any predicted increase in Diversion (GL) and increase in Barrage Flow (GL/year) for key reporting dates of 2000, 2015, 2050 and 2100.

As a result there are a number of different MDBA model run results being used to determine the changes to the accountable actions in this report including from November 2013, November 2014, December 2015, and March 2016. South Australian officials have used this information to estimate the overall net changes to accountable actions from the MSM-Bigmod model runs. The approach of compiling the net change to the action for Salinity Effect (EC) and Salinity Cost Effect ($) was confirmed by the MDBA.

It is important to be clear that these figures are estimates only and the final figures will only be known once the MDBA undertake the model runs and aggregate the changes for the Salinity Register.

It has also been identified that the salt loads for Renmark between Lock 4 and Lock 5, have not been included in some actions when the conversion to EC and $ for the Pike-Murtho groundwater model was undertaken by the MDBA[1]. While the numbers are comparatively small to other actions (approximately 0.2 t/d in 2015 increasing to approximately 8 t/d in 2100) the omission does have a small impact on the differences resulting from the groundwater model review. The salt load has been excluded for the Mallee Legacy of History – Dryland and Irrigation Pre-1988, as well as the action for Improved Irrigation Efficiency and Irrigation Scheme Rehabilitation. The MDBA have indicated that such issues will be remedied in the calculation of the Salinity Registers.

This section of the report provides a brief summary of each of the accountable actions that will change as a result of the 5-year Reviews. It includes an overview of the following elements:

- Background – description of the action
- Revised model and relevant reports– identifies which of the groundwater models is used to calculate the accountable action and highlights the relevant technical reports included in the submission for accreditation
- Scenarios used – documents which scenario or pair of scenarios is used by the MDBA to derive the impact of the accountable action (Scenarios are defined in Table 3.1 and Table 3.2.)
- Register entry –
    - includes the 2015 register entry and identifies the previous model used
    - compares the review results from 5-year Reviews in t/d, salinity effect (EC) and Salinity Cost Effect ($) with the 2015 register entry
    - the difference is new model minus the old model results
- Reasons for Change – provides a brief overview of the evidence used to support the changes to accountable actions. More detail on the evidence used is included in Sections 2 and 3 of this report as well as the groundwater model technical reports
- Sharing of Salinity debit/credit – outlines the sharing arrangements for the accountable action and identifies any potential changes.

[1] * marks the columns in the tables that are impacted by this decision.

4.1 Mallee Legacy of History – Dryland

4.1.1 Background

Removal of the native vegetation has altered the hydrological balance of the Mallee area and has resulted in increased water percolating below the root zone (Allison et al. 1990). Research shows that this increase in recharge has caused increased hydraulic gradients towards the River Murray which increased flows of salinity groundwater into the River and the floodplains (Cook et al. 2004; Barnett et al. 2006).

Mallee vegetation is extremely water efficient and the amount of water that drains below the root zone to recharge the unconfined aquifer is extremely small (Cook et al. 2004, p. 14). A background value for recharge under native vegetation of 0.1 mm/y is applied, based on Allison et al. (1990). Recharge due to dryland clearance is simulated using areas and rates developed by CSIRO and DEH (Cook et al. 2004; Wang et al. 2005). Section 2.2.4 provides a brief description of how this is implemented in the numerical models.

The recharge estimates of Wang et al. (2005) are extrapolations from fieldwork conducted in the Mallee. The calculations of recharge rates use maps of land clearance since 1920, depth to groundwater, and thickness of the Blanchetown Clay aquitard datasets. Maps of the resulting recharge zones are included in the model reports (see Figure 3.17 Yan et al. 2012, Figure 3.17 Woods et al. 2013 and Figure 3.20 Woods et al. 2014).

4.1.2 Revised models used and relevant reports.

The updated assessment of this accountable action is based on the three revised groundwater models:

- *Waikerie-Morgan Numerical Groundwater Model 2012*
- *Woolpunda Numerical Groundwater Model 2013*
- *Pike-*Murtho *Numerical Groundwater Model 2014*

All models have been independently peer reviewed and found fit-for-purpose. A standard set of assumptions have been used for all the groundwater models.

Reports including evidence for this action include:

- *Waikerie to Morgan Numerical Groundwater Model 2012 – Volumes 1 and 2 (Yan et al. 2012)*
- *Woolpunda Numerical Groundwater Model 2013 – Volumes 1 and 2 (Woods et al. 2013)*
- *Pike-Murtho Numerical Groundwater Model 2014 – Volumes 1 and 2 (Woods et al. 2014)*
- *SIS Technical review reports (AWE 2014 (a)), (AWE 2014 (b)), (AWE 2013).*

4.1.3 Reasons for change

The approach and the recharge inputs data used for calculating Mallee Legacy of History – Dryland have not changed since the second generation model. Changes in the salt load calculation reflect:

- Incorporation of new information on the characteristics of the aquifers from drilling programs
- Improvements in the conceptualisation of the models from improved knowledge and research
- Changes in approach from second generation to third generation models such as the representation of the floodplain
- Improvements in calibration from second generation to third generation models.

4.1.4 Scenarios used for assessment

This action is assessed using **Scenario 2** which simulates the impact of native vegetation clearance on River Murray salt loads since 2000 (Woods et al. 2014, p. 82). This is used to determine the impact post 2000 for the action for key reporting dates (MDBA 2015).

4.1.5 Register Entry for Mallee Legacy of History – Dryland

The 2015 register entry for Mallee Legacy of History - Dryland is based on the previously accredited second generation models, the Loxton/Bookpurnong third generation groundwater model, and the annual increment increases from those accredited model results (MDBA 2015b). This results in a 2015 register entry of 181.1 t/d or 32.8 EC at 2100 (Table 4.2).

The updated model review results (t/d) are shown in Table 4.3 and highlight a decrease in the predicted impact of Mallee Legacy of History – Dryland on the River Murray across all three reviewed groundwater models.

The net result for Mallee Legacy of History – Dryland from all the groundwater models, including the three reviews, is a decrease in potential tonnes of salt being delivered to the River Murray from 181.1 t/d to 105.5 t/d at 2100 (see Table 4.2). The potential register impact is a decrease from 32.8 EC (2015 register) to 5.2 EC at 2100 based on indicative MDBA modelling. It should be noted that the MDBA did not provide a compiled result for each entry.

The revised 2100 salt load (t/d) is a 40% reduction from the previous estimate, however the conversion to EC implies this could be an 83% reduction in EC.

Table 4.2 Comparison of results for Mallee Legacy of History – Dryland

Total Accountable Action	**2015 Salinity Register**			**Review results**			**Difference**		
	t/d	**EC**	**$m**	**t/d**	**EC**	**$m**	**t/d**	**EC**	**$m**
2000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000
2015	21.7	4.1	-0.414	9.5	-0.5	0.010	(12.2)	(4.6)	(0.424)
2050	79.8	14.5	-1.748	41.4	1.1	-0.588	(38.4)	(13.4)	(1.160)
2100	181.1	32.8	-4.007	105.5	5.2	-1.625	(75.6)	(27.6)	(2.382)

Note: The estimates in this table are subject to change based on revised MDBA modelling. Brackets denote a reduction.

Table 4.3 Comparison of results for Mallee Legacy of History – Dryland by groundwater model

By model area	**2015 Salinity Register (t/d)**			**Review results (t/d)**			**Difference (t/d)**		
	Waikerie to Morgan	**Wool-punda**	**Pike-Murtho**	**Waikerie to Morgan**	**Wool-punda**	*** Pike-Murtho**	**Waikerie to Morgan**	**Wool-punda**	**Pike-Murtho**
2000	0	0	0	0.0	0	0	0.0	0.0	0.0
2015	4.3	8.6	2.8	1.3	0.35	1.9	(3.0)	(8.3)	(0.9)
2050	22.6	19.6	12.2	7.2	1.5	7.3	(15.4)	(18.1)	(4.9)
2100	43.7	44.8	34.6	19.4	10.2	17.9	(24.3)	(34.6)	(16.7)

Note: Brackets denote a reduction.

4.1.1 Sharing of salinity debit

The sharing arrangements for the impacts of Mallee Legacy of History – Dryland are calculated in accordance with Schedule B. As a delayed salinity action (one that occurred pre-1988 but for which the impact does not begin to occur until after 1988) part of the action is entered onto Register B, for the component that occurs post 1 January 2000 with the remainder of the impact being part of the baseline (MDBC 2005). The debit recorded on Register B as a South Australian action is offset jointly between Victoria, New South Wales, South Australia and the Commonwealth. There is no change to the sharing arrangements for this action.

4.2 Mallee Legacy of History – Irrigation Pre-1988

4.2.1 Background

The history of irrigation development is discussed in each of the groundwater model reports (Section 2.4.3.2 Yan et al. 2012; Section 2.6.3.2 Woods et al. 2013; Section 2.6.3.2 Woods et al. 2014) and includes maps of expansion in crop area over time (1890 onwards).

4.2.2 Revised models used and relevant reports

The updated assessment of this accountable action is based on the three revised groundwater models:

- *Waikerie-Morgan Numerical Groundwater Model 2012*
- *Woolpunda Numerical Groundwater Model 2013*
- *Pike*-Murtho *Numerical Groundwater Model 2014*

All models have been independently peer reviewed and found fit-for-purpose. The relevant reports for this action include:

- *Waikerie to Morgan Numerical Groundwater Model 2012 – Volumes 1 and 2 (Yan et al. 2012)*
- *Woolpunda Numerical Groundwater Model 2013 – Volumes 1 and 2 (Woods et al. 2013)*
- *Pike-Murtho Numerical Groundwater Model 2014 – Volumes 1 and 2 (Woods et al. 2014)*
- *SIS Technical review reports (AWE 2014 (a)) (AWE 2014 (b)) (AWE 2013).*

4.2.3 Reasons for change

The total recharge rate due to pre-1988 irrigation, without any improvements in irrigation efficiency or system rehabilitation is shown in Section 3.2. This has three components, each based on different data:

- the 1988 irrigation footprint, mapped from aerial photography (Vears 2013)
- recharge rates in irrigation areas where the accessions have reached the watertable, estimated from inverse modelling
- recharge rates in irrigation areas where the accessions have not reached the watertable, estimated from agronomic assumptions (Laroona Environmetrics 2012).

In South Australia it is not possible to estimate groundwater recharge directly from irrigation data, due to the significant depth to water and complexity of processes in the unsaturated zone. Section 2.2.5 discusses how recharge from irrigation is estimated using inverse modelling and matching the model outputs with observed potentiometric heads. The results of the model calibration are summarised in Section 2.2.8 but are documented more fully in the modelling reports. To minimise the problem of non-uniqueness, model results are also cross-checked against other datasets (Section 2.2.8). This includes a comparison between the recharge rates estimated by the model to independent estimates of irrigation accessions.

In some locations, such as Woolpunda, recharge from irrigation is yet to have reached the watertable, judging from observation well hydrographs. Inverse modelling cannot then be used to estimate recharge. Instead, 100 mm/y is assigned for permanently irrigated areas and 60 mm/y for pivot irrigation areas, based on the advice of experts and confirmed with the 5-year Review Team.

The peer reviewer noted that South Australia has prioritised efforts to improve irrigation recharge estimates with substantial work on understanding irrigation accessions (SKM 2012). This provided an independent line of evidence for estimating irrigation accessions underlying irrigation areas and applies a water balance approach to each irrigation area using available information such as rainfall, crop area, and pumped volumes (Fordham et al. 2011). The independent estimates of irrigation accessions are provided with the modelling reports as appendices (i.e.

Waikerie to Morgan Numerical Groundwater Model – Volume 2: Appendix C-1 is the report by Fordham et al. 2011 and Woolpunda Numerical Groundwater Model – Volume 2: Appendix C-1 is the report by Vears 2013).

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research
- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models.

4.2.4 Scenarios used for assessment

This action is assessed using **Scenario 3A**: Change since 2000 which simulates the impact of pre-1988 irrigation on River Murray salt loads (Woods et al. 2014 p. 82).

4.2.5 Register Entry for Mallee Legacy of History – Irrigation pre-1988

The 2015 register entry for Mallee Legacy of History – Irrigation pre-1988 is based on previously accredited second generation models, the Loxton-Bookpurnong third generation groundwater model, and the annual increment increases from those accredited models (MDBA 2015b). This results in a 2015 register entry of 541.4 t/d or 113.3 EC at 2100 (Table 4.4).

The model review results (t/d) in Table 4.5 show a decrease in the predicted impact of Mallee Legacy of History – Irrigation pre 1988 on the River Murray across all three groundwater models.

The net result for Mallee Legacy of History – Irrigation Pre-1988 from all the groundwater models, including the three reviews (Table 4.5), is a decrease in potential tonnes of salt being delivered to the River Murray from 541.4 t/d to 222.6 t/d at 2100 (see Table 4.4). The potential register impact is a decrease from 113.3 EC on the 2015 Registers to 22.9 EC in the review results based on indicative MDBA modelling. It should be noted that the MDBA did not provide a compiled result for each accountable action.

Table 4.4 Comparison of results for Mallee Legacy of History – Irrigation Pre-1988

Total Accountable Action	**2015 Salinity Register**			**Review results**			**Difference**		
	t/d	**EC**	**$m**	**t/d**	**EC**	**$m**	**t/d**	**EC**	**$m**
2000	0.0	0.0	0.000	0.0	0.0	0.000	0.0	0.0	0.000
2015	238.3	46.6	-6.121	95.8	6.3	-1.651	(142.5)	(40.3)	(4.470)
2050	427.8	86.9	-11.959	193.1	23.0	-4.150	(234.7)	(63.9)	(7.809)
2100	541.4	113.3	-14.252	222.6	22.9	-4.569	(318.8)	(90.4)	(9.683)

Note: The estimates in this table are subject to change based on revised MDBA modelling. Brackets denote a reduction.

Table 4.5 Comparison of results for Mallee Legacy of History – Irrigation Pre-1988 by groundwater model

By model area	**2015 Salinity Register (t/d)**			**Review results (t/d)**			**Difference (t/d)**		
	Waikerie to Morgan	**Wool-punda**	**Pike-Murtho**	**Waikerie to Morgan**	**Wool-punda**	*** Pike-Murtho**	**Waikerie to Morgan**	**Wool-punda**	**Pike-Murtho**
2000	0	0	0	0	0	0	0.0	0.0	0.0
2015	54.6	37.9	95.4	12.9	5	27.5	(41.7)	(32.9)	(67.9)
2050	83.9	54.6	220.6	26.2	7.9	90.3	(57.7)	(46.7)	(130.3)
2100	123.1	87.6	253.3	35.2	8.2	101.8	(87.9)	(79.4)	(151.5)

*Note: The estimates in this table are subject to change based on revised MDBA modelling. *Salt loads for Renmark between lock 4 and 5 not included. Brackets denote a reduction.*

4.2.6 Sharing of salinity debit

The sharing arrangements for the impacts of pre-1988 irrigation development are calculated in accordance with Schedule B. As a delayed salinity action (one that occurred pre-1988 but for which the impact does not begin to occur until after 1988 is entered onto Register B, for the component that occurs post 1 January 2000 with the remainder of the impact being part of the baseline (MDBC 2005).

The debit recorded on Register B as a South Australian action is offset jointly between Victoria, New South Wales, South Australia and the Commonwealth. There is no change to the sharing arrangements for this action.

4.3 Improved Irrigation Efficiency and Irrigation Scheme Rehabilitation

4.3.1 Background

Improvements in irrigation efficiency have been occurring for many decades in South Australia. These improvements have included on farm efficiencies from reducing the overall volume applied to better meet the requirements of the plants, changes to irrigation systems on farm, as well as improvements in delivery of water to the farm gate. Significant improvements in irrigation efficiency have occurred since the 1970s when the South Australian Department of Agriculture developed a new methodology to estimate drainage from irrigated horticulture (PIRSA 2015).

New technologies, supported by on-farm research and trials, led to extension programs and implementation across irrigation districts in the Riverland (PIRSA 2015). This in turn allowed expansion of irrigated area due to improved efficiencies and water use (PIRSA 2015). Rehabilitation of irrigation supply systems from open supply channels to pressurised pipes occurred in some districts in the 1970's and early 1980's, with the final districts rehabilitated between 1994 and 2002 (Kirk et al. 2004, p 74).

4.3.2 Revised models used and relevant reports

The updated assessment of this accountable action is based on the three revised groundwater models:

- *Waikerie-Morgan Numerical Groundwater Model 2012*
- *Woolpunda Numerical Groundwater Model 2013*
- *Pike-*Murtho *Numerical Groundwater Model 2014*

All models have been independently peer reviewed and found fit-for-purpose. The relevant reports for this action include:

- *Waikerie to Morgan Numerical Groundwater Model 2012 – Volumes 1 and 2 (Yan et al. 2012)*
- *Woolpunda Numerical Groundwater Model 2013 – Volumes 1 and 2 (Woods et al. 2013)*
- *Pike-Murtho Numerical Groundwater Model 2014 – Volumes 1 and 2 (Woods et al. 2014)*

4.3.3 Reasons for change

This action is for pre-1988 rehabilitation of irrigation supply systems and improvements in irrigation practices. The total recharge rate due to pre-1988 irrigation, with improved irrigation efficiency and system rehabilitation, is given in Section 3.2.

The evidence supporting the recharge used is discussed in Section 2.2.5. The recharge rates adopted for this action are those obtained in the calibrated model as being from pre-1988 irrigation. Rates decline over time following trends obtained from inverse modelling. The exception is Woolpunda, as inverse modelling cannot yet be used (Section 2.2.5) as recharge from irrigation is yet to have reached the watertable.

As discussed in Section 2.2.5, irrigation accessions have been reviewed as part of the groundwater model development and documented as an independent line of evidence for estimating irrigation accessions underlying irrigation areas based on direct measurement of irrigation application, rainfall inputs and losses during transportation (Fordham et al. 2011, p. 3). This approach considered water applied, and documented evidence that demonstrated the decrease in irrigation accessions by up to 25% in the late 2000s (Laroona Environmetrics 2011).

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research
- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- changes in approach from a simple method to numerical groundwater models
- update of irrigation information

4.3.4 Scenarios used for assessment

Previous estimations have calculated the salt loads from improved irrigation efficiency and irrigation scheme rehabilitation as separate actions using Scenario 3B – Scenario 3A and Scenario 3C – Scenario 3B (MDBA 2015).

The new approach simplifies this calculation for Improved Irrigation Efficiency and Irrigation Scheme Rehabilitation. This action is assessed using **Scenario 3C – Scenario 3A** which simulates the combined impact on River Murray salt loads (Woods et al. 2014, p. 82).

4.3.5 Register Entry for Improved Irrigation Efficiency and Irrigation Scheme Rehabilitation

The current entry on the salinity register is based on the previously accredited second generation models, the Loxton/Bookpurnong third generation groundwater model, and the annual increment increases from those accredited model results (MDBA 2015b). This results in an entry of 656.3 t/d or 136.7 EC at 2100 on the 2015 Salinity Register (Table 4.6).

The model review results (t/d) in Table 4.7 show a decrease in the predicted impact of Improved Irrigation Efficiency and Irrigation Scheme Rehabilitation on the River Murray across all three groundwater models.

The net result for Improved Irrigation Efficiency and System Rehabilitation from all the groundwater models, including the three reviews show there is an overall decrease of potential tonnes of salt being delivered to the River Murray from -656.3 t/d to -357.4 t/d in 2100. This includes an additional 20 t/d in the Pike area (Lock 5 to Lock 4 salt load) as Loxton-Bookpurnong irrigation recharge was wrongly included in the 2015 estimate.

The potential register impact is a decrease from of -136.7 EC on the 2015 Registers down to a credit of -51 EC at 2100 (see Table 4.7). It should be noted that the MDBA did not provide a compiled result for each entry.

Table 4.6 Comparison of results for improved irrigation efficiency and rehabilitation

Total Accountable Action	**2015 Salinity Register**			**Review results**			**Difference**		
	t/d	**EC**	**$m**	**t/d**	**EC**	**$m**	**t/d**	**EC**	**$m**
2000	-94.8	-20.2	2.162	-152.5	-2.8	0.49	(57.7)	17.4	(1.672)
2015	-357.6	-71.7	9.165	-449.1	-39.3	5.810	(91.5)	32.4	(3.355)
2050	-582.5	-120.1	15.779	-826.2	-48.8	6.986	(243.7)	71.3	(8.793)
2100	-656.3	-136.7	17.102	-955.2	-51.0	7.289	(298.9)	85.7	(9.813)

Note: The estimates in this table are subject to change based on revised MDBA modelling. Brackets denote a reduction.

Table 4.7 Comparison of results for improved irrigation efficiency and rehabilitation by groundwater model

By model area	2015 Salinity Register (t/d)			Review results (t/d)			Difference (t/d)		
	Waikerie to Morgan	Wool-punda	Pike-Murtho	Waikerie to Morgan	Wool-punda	* Pike-Murtho	Waikerie to Morgan	Wool-punda	Pike-Murtho
2000	-20.1	-18.0	-19.6	0.0	0.0	0.0	20.1	18.0	19.6
2015	-61.2	-43.7	-133.7	-56.2	-1.4	-89.5	5.0	42.3	44.2
2050	-86.6	-83.0	-258.1	-82.8	-1.9	-99.3	3.8	81.1	158.8
2100	-111.2	-92.3	-290.0	-90.5	-2.0	-102.1	20.7	90.3	187.9

Note: Brackets denote a reduction.

4.3.1 Sharing arrangements

The impacts of improved irrigation efficiency and rehabilitation are a state action and are calculated in accordance with Schedule B. As an action that occurred after 1988 but has an impact on a pre–1988 action, the credit can be recorded on Register B (see p. 201, MDBA 2015). Currently the credit associated with this action is split between Register A and B in accordance with the methodology outlined by the MDBA (MDBA, 2015 p.21).

The debit recorded on Register B as a South Australian action is offset jointly between Victoria, New South Wales, South Australia and the Commonwealth. South Australia may request to change the split across the registers depending on the final register numbers once completed by the MDBA.

4.4 Irrigation Development 1988 – Current Year

4.4.1 Background

Irrigation development post-1988 has particularly been driven by private investment (Rolls, 2007, p. 3). Irrigated footprint has been mapped from available aerial photography, satellite imagery and date of commencement for key irrigation districts (Vears 2013). This mapping has then been used in the groundwater model to adjust recharge rates and to simulate expansion of irrigation over time. More specific information on irrigation development for each region is included in each of the groundwater model reports.

Irrigation development has been mostly on highland areas for Pike and Murtho with the exception of some floodplain irrigation at Lyrup (Woods et al. 2014). Development in Pike and Murtho commenced in the 1950s and expanded steadily until the early 2000s when there was some reduction in North Murtho and Pike as a response to the Millennium Drought (Woods et al. 2014). The exception in this area was Central Murtho.

For Waikerie and Morgan groundwater model, irrigation development is well established mainly on the highland with irrigation commencing in the mid-1890s at Holder, Waikerie and Ramco, with Cadell commencing in 1920 (Yan et al. 2012). There is some floodplain irrigation at Cadell, Qualco and eastern Toolunka (Yan et al. 2012). The Woolpunda irrigation area did not expand significantly until power was delivered for the construction of the SIS in early 1990. The hydrographs in the area suggest that recharge in the area has yet to reach the water table.

4.4.2 Revised models used and relevant reports

The updated assessment of this accountable action is based on the three revised groundwater models:

- *Waikerie-Morgan Numerical Groundwater Model 2012*
- *Woolpunda Numerical Groundwater Model 2013*
- *Pike-*Murtho *Numerical Groundwater Model 2014*

All models have been independently peer reviewed and found fit-for-purpose. The relevant reports for this action include:

- *Waikerie to Morgan Numerical Groundwater Model 2012 – Volumes 1 and 2 (Yan et al. 2012)*
- *Woolpunda Numerical Groundwater Model 2013 – Volumes 1 and 2 (Woods et al. 2013)*
- *Pike-Murtho Numerical Groundwater Model 2014 – Volumes 1 and 2 (Woods et al. 2014).*

4.4.3 Reasons for change

There are currently three approaches to estimating the impacts of Irrigation Development 1988 – Current Year:

1. **Irrigation – Modelled Footprint** – this uses an estimated irrigated area in accredited groundwater models to estimate the salt load. It assumes that irrigation, once established, continues into perpetuity.
2. **Irrigation – Water Trade** – this represents the remaining interstate water traded between 2003/04 to 2008/09 assessed using SIMRAT (MDBA 2015). It assumes the total volume traded translates into irrigated area on ground and represents the pre-unbundling situation.
3. **Irrigation – Site Use Approval –** Water licensing was unbundled in the SAMDB on 1 July 2009, which changed how irrigation licenses were issued (DEWNR 2014). The assessment of potential salinity impacts of the area for which land was approved to be used for irrigation (SUA) has been done using SIMRAT. This does not necessarily correspond to actual area irrigated. These assessments are reported through the Annual Reporting process and are considered interim entries on the Salinity Registers until a numerical groundwater model is accredited for the corresponding area.

As the groundwater models are accredited, the Water Trade and Site Use Approval estimates using SIMRAT are replaced with the Modelled Footprint to avoid double counting where irrigation development has progressed. This also recognises that SIMRAT was designed to be a rapid assessment tool (Woods et al. 2016). This requires the MDBA to remove these salt loads from the corresponding reaches in BIGMOD for the Water Trade and Site Use Approval estimates and replace them with the salt loads from the accredited groundwater model.

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research
- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- update of irrigation information
- update from provisional estimates using SIMRAT to detailed assessment from numerical groundwater model.

How irrigation development is represented in the groundwater models has been identified as an area for consideration under future five year reviews, to determine whether this is an adequate representation of future salinity risk for South Australia.

4.4.4 Scenarios used for assessment

This action is assessed using **Scenario 4 – Scenario 3C** which simulates the impact of Irrigation Development 1988 – Current Year on River Murray salt loads (Woods et al. 2014 p. 82).

4.4.5 Register Entry for South Australia Irrigation Development post 1988 based on Footprint

The 2015 register entry for Irrigation Development post 1988 - footprint is based on previously accredited second generation models (representing post-1988 irrigation development up to 2002/03), Loxton-Bookpurnong third generation groundwater model (representing post-1988 irrigation development up to 2010/11) and the annual increment increases from those accredited models (MDBA 2015b). This results in a 2015 entry of 287.6 t/d or 72.8 EC at 2100 (Table 4.8).

The model review results (t/d) in Table 4.9 show an increase in the predicted impact of Irrigation Development post 1988 - footprint on the River Murray for Waikerie-Morgan and Pike-Murtho groundwater models, and a decrease in impact for Woolpunda.

The net result for Irrigation Development post 1988 - footprint from all the groundwater models including the three reviews is an increase in the tonnes of salt being delivered to the River Murray from 287.6 t/d to 373.4 t/d at 2100 (Table 4.8). The potential register impact is a decrease in debit of 72.8 EC on the 2015 Registers down to 71.5 EC at 2100 based on indicative MDBA modelling[2] (see Table 4.10). It should be noted that MDBA did not provide a compiled result for each accountable action.

Table 4.8 Comparison of results for South Australia Irrigation Development based on modelled footprint

Total Accountable Action	**2015 Salinity Register**			**Review results**			**Difference**		
	t/d	**EC**	**$m**	**t/d**	**EC**	**$m**	**t/d**	**EC**	**$m**
2000	-14.1	-3.6	0.343	20.2	-12.8	1.102	34.3	(9.2)	0.759
2015	26.7	5.8	-0.667	54.5	11.4	-1.093	27.8	5.6	(0.426)
2050	189.9	33.9	-4.495	283.2	43.1	-6.318	93.2	9.2	(1.823)
2100	287.6	72.8	-9.183	373.4	71.5	-9.822	85.7	(1.3)	(0.639)

Note: The estimates in this table are subject to change based on revised MDBA modelling. Brackets denote a reduction.

Table 4.9 Comparison of results for South Australia Irrigation Development based on modelled footprint by Groundwater Model

By model area	**2015 Salinity Register (t/d)**			**Review results (t/d)**			**Difference (t/d)**		
	Waikerie to Morgan	**Wool-punda**	**Pike-Murtho**	**Waikerie to Morgan**	**Wool-punda**	*** Pike-Murtho**	**Waikerie to Morgan**	**Wool-punda**	**Pike-Murtho**
2000	-1.0	-5.1	5.2	24.7	1.1	7.6	25.7	6.2	2.4
2015	1.5	2.3	8.8	28.3	3.5	8.6	26.8	1.2	(0.2)
2050	1.0	46.2	47.1	47.1	39.2	101.2	46.1	(7.0)	54.1
2100	-0.8	85.3	88.8	51.2	69.4	138.4	52.0	(15.9)	49.6

Note: It is not clear how the 2015 Salinity Register entry has been derived. Brackets denote a reduction.

4.4.6 Register Entry for South Australia Irrigation Development post 1988 - Due to Water Trade

The 2015 entry on the Salinity Registers is based on SIMRAT assessment of South Australia irrigation development due to water trade (2003/04 to 2008/09) (MDBA 2015). This results in a 2015 register entry of 323.5 t/d or 32.3 EC at 2100 (Table 4.10).

The reviewed models support the removal of SIMRAT salinity impacts of water trades for the corresponding area from the registers (to be replaced with footprint from the groundwater numerical models). South Australia relies on the MDBA office to undertake this task. Removal of the relevant water trades from the register decreases the entry from 323.5 t/d to 146.0 t/d in 2100 (Table 4.10).

[2] These apparently counterintuitive figures highlight that these are estimates only and the final figures will only be known once the MDBA undertake the model runs and aggregate the changes for the Salinity Register.

The Revised Entry column in Table 4.10 shows the residual SIMRAT based salt loads for trades that will remain on the Salinity Registers. In addition there appears to be a discrepancy from the MDBA calculations which overestimates 83 t/d in 2100 below Lock 1. This requires clarification with the MDBA.

Table 4.10 Adjusted SIMRAT results for South Australia Irrigation Development post 1988 - due to water trade (2003-2009)

Total Accountable Action	2015 Salinity Register			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	0.1	0.1	-0.015	-0.1	0.4	-0.008	(0.2)	0.3	0.007
2015	21.2	0.5	-0.153	19.5	0.0	-0.099	(1.7)	(0.5)	0.054
2050	135.1	16.2	-2.570	75.2	2.2	-0.527	(59.9)	(14.0)	2.043
2100	323.5	32.2	-5.372	146.0	-8.2	0.443	(177.5)	(40.4)	5.815

Note: The estimates in this table are subject to change based on revised MDBA modelling. Brackets denote a reduction.

4.4.7 Register Entry for South Australia Irrigation Development Post 1988 – Based on Site Use Approvals

The 2015 entry on the Salinity Registers is based on SIMRAT estimates for South Australia Irrigation Development post 1988 – based on site use approvals from 2009/10 onwards. Additional site use approval assessments are reported annually through South Australia's Basin Salinity Management Strategy Annual Report (MDBA 2015). Site use approvals represent the area of land that can be potentially irrigated, however it is often much larger than the water use associated with it.

The assessment of site use approvals using SIMRAT has resulted in an entry of 574.2 t/d or 93 EC at 2100 on the 2015 Salinity Register (Table 4.11).

The reviewed models support the removal of SIMRAT salinity impacts of water trades for the corresponding area from the registers. South Australia relies on the MDBA office to undertake this task. Removal of the relevant water results from the register decreases the entry from 574.2 t/d to 107.6 t/d in 2100 (Table 4.11). In addition there are some clarifications required from the MDBA where Murray Bridge to Wellington salt loads from SIMRAT may have been overestimated by 32 t/d in 2050 and 125 t/d in 2100.

Table 4.11 Adjusted SIMRAT results for South Australia Irrigation Development post 1988 - based on site use approvals outside review area

Total Accountable Action	2015 Salinity Register			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	0.0	0.0	0.027	0.0	-0.1	0.027	0.0	(0.1)	0.000
2015	1.8	0.3	-0.058	0.2	0.1	-0.006	(1.6)	(0.2)	0.052
2050	113.0	16.9	-2.359	22.1	-2.9	0.208	(90.9)	(19.8)	2.567
2100	574.2	93.0	-12.626	107.6	10.1	-0.741	(466.6)	(82.9)	11.885

Note: The estimates in this table are subject to change based on revised MDBA modelling. Brackets denote a reduction.

4.4.8 Sharing arrangements

The impacts of post-1988 irrigation are a state action and are calculated in accordance with Schedule B. There are no sharing arrangements associated with this debit.

4.5 Woolpunda SIS

4.5.1 Background

Woolpunda SIS was one of the first joint venture schemes designed in South Australia to intercept the natural inflow of groundwater entering the River Murray along the River Murray between Lock 2 and Lock 3 (see Figure 2.6, p. 40 Woods et al. 2013, Appendix 7.5). The scheme was designed with 49 production wells along a 33 kilometre reach between Holder and Overland Corner and was constructed between 1989 and 1990 (AWE 2013, p. 6).

The Woolpunda reach has a natural groundwater mound in the Murray Group due to the upwelling of groundwater from the Renmark Group. Groundwater salinities of this aquifer are between 12000 to 27000 mg/l (Woods et al 2013, p.18), which results in high naturally induced salt accessions to the River Murray of approximately 200 t/d to the River in this area (Woods et al 2013, p. 1).

The purpose of the Woolpunda SIS is to reduce salt loads into the River Murray by reducing the midpoint groundwater heads to pool level, thereby flattening or slightly reversing the horizontal groundwater gradients. (Woods et al. 2013, p. 39). The production bores were designed to target the Mannum Formation and intercept discharge flux from the aquifer before it enters the floodplain aquifer and/or the River Murray (Woods et al. 2013, p. 43), and decrease salinity at Morgan by 47 EC by intercepting 95% of the groundwater inflows (Woods et al. 2013, p. 39). The scheme was constructed under the Salinity and Drainage Strategy and was commissioned in four stages between 1991 and 1993 (Woods et al. 2013, p. 39).

4.5.2 Revised model used and relevant reports

Assessment of this accountable action has been undertaken using the *Woolpunda Numerical Groundwater Model 2013* (Woods et al. 2013) which was reviewed and found fit-for-purpose for predicting salt loads to the river using the scenarios documented in the report (SKM 2013, p. 15).

Relevant reports for this accountable action include:

- *Woolpunda Numerical Groundwater Model 2013 – Volumes 1 and 2 (Woods et al.2013)*
- *Review of the Woolpunda Groundwater Model (SKM 2013)*
- *SIS Technical review reports (AWE 2014b) (AWE 2013)*

4.5.3 Reasons for change

The Woolpunda 2013 model simulates historical pumping using MODFLOW's Well Package (Woods et al. 2013, p. 69), with pumping rates based on high-quality data. Metered flow data provided by SA Water from 2003 to 2012 was used to calculate the average flow over six month periods for each pumping well, and assumes full operation at all times. As discussed in Section 2.2.6, SIS are simulated in the groundwater models to match their operation.

Calibration results provide evidence that the model responds appropriately to SIS pumping. Model outputs provide a good match to observed potentiometric head near the pumping wells and also matches Run of River estimates of salt load to the river (Section 2.2.8).

The prior method of assessment was a flow-salt load relationship, and an accredited numerical groundwater model should provide a more accurate assessment for the reasons given in Section 2.1. The impact of SIS depends on the salt load caused by irrigation. As irrigation has expanded in recent years, there is more salt for the SIS to intercept.

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research

- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- changes in approach from a simple method to numerical groundwater models
- update of irrigation information
- update from provisional estimates to detailed assessment from numerical groundwater model.

4.5.4 Scenarios used for assessment

This action is assessed using **Scenario 8A – Scenario 4** which provides the benefit of the salt interception scheme as constructed. The benefits are calculated using historical pumping rates and forward projections and have been assigned to Register A. The as-constructed SIS may not be able to control 100% of the salt due to technical or economic constraints (Woods et al. 2013, p. 112).

4.5.5 Register Entry for Woolpunda SIS

The 2015 register entry for Woolpunda SIS is based on the MDBC flow-salt load relationship described in Section 2 and uses in-river data to attribute benefit to the salt interception schemes. This method is also used for the 2015 register entry of Waikerie 1 SIS. This method fixes the tonnes per day removed by the SIS throughout time at 176 t/d or a credit of 47.4 EC (see Table 4.12).

The model review results (t/d) in Table 4.12 show an increase in overall benefit of the SIS by 2100 due to capacity within the scheme to intercept increased post-1988 impacts (Table 4.12).

While the tonnes per day removed by Woolpunda are similar in 2000 between current entries and the review results, the EC conversion in MSM-Bigmod has resulted in 4.3 t/d difference converting to a decrease in benefit of 5.6 EC (Table 4.12). This requires clarification with the MDBA.

4.5.1 Sharing arrangements

Woolpunda SIS is currently a Joint Scheme under the Salinity and Drainage Strategy (Murray-Darling Basin Ministerial Council, 1989). The sharing arrangements for the benefits of Woolpunda SIS are in accordance with the Salinity and Drainage Strategy (Appendix 7.4). Under this agreement, New South Wales and Victoria each receive 18.75% share of the benefit recorded on Register A and the River receives 62.5% share of the benefit from South Australia and the Commonwealth's shares (Aquaterra 2010, p. 55). South Australia receives no salinity credits for Woolpunda, having assigned them to the River under the Salinity and Drainage Strategy (Aquaterra 2010, p. 55).

Table 4.12 Comparison of results for Woolpunda SIS

Woolpunda SIS	2015 Salinity Register*			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	-176.0	-47.4	3.890	-180.3	-41.8	3.791	(4.3)	5.6	(0.099)
2015	-176.0	-47.4	3.890	-186.1	-41.6	3.688	(10.1)	5.8	(0.202)
2050	-176.0	-47.4	3.890	-223.1	-49.9	4.317	(47.1)	(2.5)	0.427
2100	-176.0	-47.4	3.890	-253.0	-56.6	4.710	(77.0)	(9.2)	0.820

** Source: MDBA Registers Report 2015. Brackets denote a reduction*

Results of the review indicate there could be a change in the assignment of benefits of the scheme given the balance of the salt picked up by the scheme has changed between pre-1988 and post-1988 influences. The benefits for the scheme could be adjusted using the following approach (MDBA 2015, p.65, based on the method agreed at BSMAP meeting 10, 2011):

S8A - S4 = Total benefit
S8B - S3C = Joint benefit
State share = Total benefit - Joint benefit or = [(S8A - S4)] - [(S8B - S3C)]

Applying this calculation results in a potential change to the benefits of the scheme from a Joint Scheme (where the joint venture funds 100% of the costs) to a Joint/Shared Scheme (where a State contributes directly to a portion of the operational costs and the Joint venture funds the remainder).

4.6 Waikerie 1 SIS

4.6.1 Background

Waikerie 1 salt interception scheme was designed to control the natural groundwater accessions into the River Murray. The major component of the total salt load was identified as being largely due to upward leakage to the river and floodplain from the Lower Mannum Formation with the remainder from the Monoman Formation (Yan et al. 2012, p. 54). Both have been increased due to irrigation development in the area (AWE 2014a). The Waikerie 1 SIS was designed to target this mechanism of salt discharge to the river and was commissioned in 1992 (AWE 2014a).

The scheme was commissioned with 17 bores between the Sunlands Pump Station and Holder (AWE 2014a, p. 14) and was designed to achieve a potentiometric head of around river pool level at the midpoint observation bores (Yan et al. 2012, p. 51). Run of River surveys in 2004 showed that saline groundwater was still discharging between bores 4 and 7 and an additional 3 bores were commissioned in 2004. These were constructed at the same time as Waikerie 2A and provided a reduction of an additional 10 t/d of salt inflows in the reach (AWE 2014a, p. 15).

Waikerie 1 SIS has been operating since 1992 and is situated in a responsive hydrogeological setting which has resulted in a varied performance (AWE 2014, p. 72). The recent technical review of the SIS suggests that Waikerie 1 SIS is performing close to the target it was designed for and is reducing salt inflows by 82% along the reach (AWE 2014a, p. 51.

4.6.2 Revised model used and relevant reports

Assessment of this accountable action has been undertaken using the *Waikerie-Morgan Numerical Groundwater Model 2012* (Yan et al. 2012) which was reviewed and found fit-for-purpose for predicting salt loads to the river using the scenarios documented in the report (SKM 2012, p. 23).

The peer reviewer noted the level of rigour provided is considered to be of a high standard and that the degree of certainty is therefore likely to be high relative to predictions from many other BSMS models (Sinclair Knight Mertz 2012, p.23-24).

Relevant reports for this accountable action include:

- *Waikerie to Morgan Numerical Groundwater Model 2012 – Volumes 1 and 2 (Yan et al.al.2012);*
- *Peer Review (SKM 2012);*
- *SIS Technical review reports (AWE 2014a) (AWE 2013).*

4.6.3 Reasons for change

The Waikerie-Morgan 2012 model simulates historical pumping using MODFLOW's Well Package, with pumping rates based on high-quality data. Future SIS operation is simulated so that the scheme meets its target levels in mid-point observation bores, which assumes that SIS operators vary pump rates over time. This is achieved in the model by representing the SIS with drain cells which are simulated to match their operation (Section 2.2.6).

Representation of the groundwater systems have been improved based on the information collected in the SIS technical review, which has also been incorporated into the groundwater model (Section 2.2). Calibration results provide evidence that the model responds appropriately to SIS pumping. Model outputs provide a good match to observed potentiometric head near the pumping wells and also matches Run of River estimates of salt load to the river (2.2.8).

The prior method of assessment was a flow-salt load relationship, and an accredited numerical groundwater model provides a more accurate assessment for the reasons given in Section 2.1.

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research
- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- changes in approach from a simple method to numerical groundwater models
- update of irrigation information
- update from provisional estimates to detailed assessment from numerical groundwater model.

4.6.4 Scenarios used for assessment

This action is assessed using **Scenario 8A (i) – Scenario 4** which provides the benefit of the salt interception scheme as constructed. The standard scenario of 8a was separated into difference sub-cases which represent the history of SIS construction in the area (Table 3.2). Waikerie 1 SIS was constructed first, followed by the Qualco Sunlands Groundwater Control Scheme, Waikerie IIA and the Waikerie Lock 2 SIS (Yan et al. 2012, p. 141).

4.6.5 Register Entry for Waikerie Salt Interception Scheme

The 2015 register entry for Waikerie 1 SIS is based on the MDBC flow-salt load relationship described in Section 2 and uses in-river data to attribute benefit to the salt interception schemes. This method is also used for the 2015 register entry of Woolpunda SIS. This approach fixes the salt load (t/d) removed throughout time at 60 t/d for Waikerie 1 SIS or a credit of 12.8 EC (Table 4.13).

The review results (t/d) refine the total benefit of the scheme compared to the previous MDBA salt inflow method, but overall the results are similar to the 2015 entry. The tonnes per day removed by Waikerie 1 in 2100 are only 0.8 t/d less than the previous estimate, however the EC conversion in MSM-Bigmod has resulted in 1.3 EC impact (Table 4.13). This requires clarification with the MDBA.

Table 4.13 Comparison of results for Waikerie 1 SIS

Waikerie 1 SIS	2015 Salinity Register*			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	-60.0	-12.8	1.057	-69.1	-16.0	1.431	(9.1)	(3.2)	0.374
2015	-60.0	-12.8	1.057	-60.8	-14.1	1.261	(0.8)	(1.3)	0.204
2050	-60.0	-12.8	1.057	-57.6	-13.4	1.211	2.4	(0.6)	0.154
2100	-60.0	-12.8	1.057	-58.5	-13.5	1.108	1.5	(0.7)	0.051

Note: The estimates in this table are subject to change based on revised MDBA modelling. Bracket denotes a reduction.

4.6.6 Sharing arrangements

Waikerie 1 SIS is currently a Joint Scheme under the Salinity and Drainage Strategy (Murray-Darling Basin Ministerial Council, 1989). The benefits are shared as NSW and Victoria each receive an 18.75% share of the benefit recorded on Register A, and the River receives 62.5% share of the benefit from South Australia and the Commonwealth's shares (Aquaterra 2010, p. 55). South Australia receives no salinity credits for Waikerie 1 SIS, having assigned them to the River under the Salinity and Drainage Strategy (Aquaterra 2010, p. 55).
Results of the review indicate there may be a need to change the sharing arrangements of the scheme given the balance of the salt picked up by the scheme has changed between pre-1988 and post-1988 influences. The benefits for the scheme could be adjusted using the following approach (MDBA 2015, p.65):

S8A (i) - S4 = Total benefit
S8B (i) - S3C = Joint benefit
State share = Total benefit - Joint benefit or = [(S8A(i) - S4)] - [(S8B(i) - S3C)]

This would suggest a potential change to the benefits of the scheme from a Joint Scheme (where the joint venture funds 100% of the costs) to a Joint/Shared Scheme (where a State contributes directly to a portion of the operational costs and the Joint venture funds the remainder).

4.7 Qualco-Sunlands Groundwater Control Scheme

4.7.1 Background

The Qualco-Sunlands Groundwater Control Scheme (QSGCS) was developed to reduce the local groundwater mound, alleviate water logging in the district and reduce saline groundwater discharge into the River. *The Ground Water (Qualco Sunlands) Control Act 2000 (South Australia)* was introduced to provide the legislative framework for the construction of the scheme as well as the ongoing operations and maintenance costs of the scheme.

The operation of Qualco-Sunlands GCS has not been technically reviewed as required for Joint Works as it is a State Action. However as it is geographically in the same location as the Waikerie salt interception schemes, and it has been included in the 5-year review of the groundwater model (Yan et al. 2012).

4.7.2 Revised models used and relevant reports

Assessment of this accountable action has been undertaken using the *Waikerie-Morgan Numerical Groundwater Model 2012* (Yan et al. 2012) which was reviewed and found fit-for-purpose for predicting salt loads to the river using the scenarios documented in the report (SKM 2012, p. 23).

The peer reviewer noted the level of rigour provided is considered to be of a high standard and that the degree of certainty is therefore likely to be high relative to predictions from many other BSMS models (SKM 2012, p. 23–24). It was also noted that the alignment of the scenarios with the register entries was still under discussion between South Australia and the MDBA at the time of the review (SKM 2012, p. 25).

Relevant reports for this accountable action include:

- *Waikerie to Morgan Numerical Groundwater Model 2012 – Volumes 1 and 2 (Yan et al. 2012)*
- *Peer Review (SKM 2012)*
- *SIS Technical review reports (AWE 2014a) (AWE 2013).*

4.7.3 Reasons for change

The Waikerie-Morgan 2013 model simulates historical pumping using MODFLOW's Well Package (Woods et al. 2013, p. 69), with pumping rates based on high-quality data. Both the SIS and the groundwater control scheme in Qualco are simulated to match their operation as discussed in Section 2.2.6. Future operation is simulated using both the Well Package and the Drain Package, due to the way the scheme is operated (Section 2.2.6).

The Qualco-Sunlands Groundwater Control Scheme (QSGCS) is treated in a combination of ways in scenarios. Three pumping wells (Q1, Q2 and Q3) are located near the river and are operated like other SIS bores, so these are simulated using the Drain Package. The twelve remaining wells are simulated by the Well Package, because they cannot be simulated with the Drain Package. The nominal target level for most of the pumping wells is above the Glenforslan Formation in sediments which the model does not simulate directly, and the Drain Package does not permit the base of a drain to lie above the cell's top elevation. The pumping rates adopted in the scenarios are the medians of the recorded pumping rates (see Section 3.6.6 Yan et al. 2012).

Representation of the groundwater system in the model has been improved based on the information collected in the SIS technical reviews of the adjacent Waikerie SISs (Section 2.2). Calibration results provide evidence that the model responds appropriately to GCS pumping. Model outputs provide a good match to observed potentiometric head near the pumping wells and also matches Run of River estimates of salt load to the river (Section 2.2.8).

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research
- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- update of irrigation information.

4.7.4 Scenarios used for assessment

This action is assessed using the following scenario which simulates the impact of Qualco-Sunlands GCS on River Murray salt loads (Yan et al. 2012 p. 157):

Scenario 8A(ii) - Scenario 8A(i)

4.7.5 Register Entry for Qualco-Sunlands Groundwater Control Scheme

The 2015 register entry for Qualco-Sunlands Groundwater Control Scheme is based on annual increment increases from the previously accredited groundwater model. The 2015 Register descriptions references Rural Solutions 2005 as the source of salt load for Qualco-Sunlands GCS. However, the model was re-run by Aquaterra in 2007 and 2008 and it was renamed to Lock 3 to Morgan. Salt load results from Aquaterra 2008 is being used in 2015 Register entry for Qualco-Sunlands GCS. This results in a 2015 register entry of 29.9 t/d or 8.5 EC at 2100 (Table 4.14).

The results from the groundwater model refine the total benefit of the scheme compared to the previous entry. Overall the tonnes per day removed by Qualco-Sunlands GCS in 2100 are 4.3 t/d more than the previous estimate, which converts in MSM-Bigmod to an increase of 1.3 EC in credit (Table 4.14).

Table 4.14 Comparison of results for Qualco-Sunlands GCS

Qualco-Sunlands 100% SA State	2015 Salinity Register			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	-7.2	-1.8	0.121	-20.1	-4.9	0.339	12.9	3.1	0.218
2015	-15.8	-4.0	0.270	-20.9	-5.2	0.358	5.1	1.2	0.088
2050	-25.8	-6.5	0.442	-31.4	-7.8	0.551	5.6	-1.3	0.109
2100	-29.9	-7.5	0.500	-34.2	-8.5	0.583	4.3	1	0.083

Note: The estimates in this table are subject to change based on revised MDBA modelling. Bracket denotes a reduction.

4.7.6 Sharing arrangements

Qualco-Sunlands GCS is a state salinity action constructed post-1988 and as such is a credit is recorded on Register A for South Australia. There are no changes to the sharing arrangements for Qualco-Sunlands GCS which is calculated in accordance with Schedule B.

4.8 Waikerie 2A SIS

4.8.1 Background

Waikerie 2A SIS is located on the southern side of the River Murray and overlaps Waikerie 1 SIS near Ramco Lagoon. It was constructed at the same time as the additional bores at Waikerie 1 SIS, and was commissioned in 2003 (Yan et al. 2012, p. 49). The scheme has 9 pumping wells including three designed to reduce groundwater inflows to Ramco Lagoon, with the rest on the Qualco Peninsula (AWE 2014, p. 15; Yan et al. 2012, p. 49).

The SIS targets a leaky-confined aquifer system and as such, groundwater levels respond quickly to changes in pumping regimes (AWE 2014a, p. 55). Operating since 2003, the Waikerie 2A SIS was closest to target groundwater levels in 2009, but has since been influenced by high river flows and a total scheme shutdown in mid-2011 for maintenance to the collector main.

4.8.2 Revised models used and relevant reports

Assessment of this accountable action has been undertaken using the *Waikerie-Morgan Numerical Groundwater Model 2012* (Yan et al. 2012) which was reviewed and found fit-for-purpose for predicting salt loads to the river using the scenarios documented in the report (SKM 2012, p. 23).

The peer reviewer noted the level of rigour provided is considered to be of a high standard and that the degree of certainty is therefore likely to be high relative to predictions from many other BSMS models (SKM 2012, p. 23–24). It was also noted that the alignment of the scenarios with the register entries was still under discussion between South Australia and the MDBA at the time of the review (SKM 2012, p. 25).

Relevant reports for this accountable action include:

- *Waikerie to Morgan Numerical Groundwater Model 2012 – Volumes 1 and 2 (Yan et al. 2012)*
- *Peer Reviews (SKM 2012)*
- *SIS Technical review reports (AWE 2014a; AWE 2013).*

4.8.3 Reasons for change

Waikerie 2A has been represented in the model in a similar way to the other salt interception schemes in the area. The evidence used for Waikerie 2A is as described for Waikerie 1 (Section 4.6.3). The Waikerie-Morgan model simulates historical pumping using MODFLOW's Well Package, with pumping rates based on high-quality data and the calibration results provide evidence that the model responds appropriately to SIS pumping. Model outputs provide a good match to observed potentiometric head near the pumping wells and also matches Run of River estimates of salt load to the river (Section 2.2.8).

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research
- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- update of irrigation information.

4.8.4 Scenarios used for assessment

This action is assessed using **Scenario 8A(iii) – Scenario 8A(ii)** which simulates the impact of the Waikerie 2A salt interception scheme on River Murray salt loads (Yan et al. 2012, p. 153).

4.8.5 Register Entry for Waikerie 2A Salt Interception Scheme

The 2015 register entry for the Waikerie 2A Salt Interception Scheme is based on annual increment increases from the previously accredited groundwater model (Rural Solutions 2005). This model estimates the salt load removed for Waikerie 2A SIS as 35.8 t/d in 2100 or a credit of 8.9 EC (Table 4.15).

The review results (t/d) reduce the total benefit of the scheme from 35.8 t/d to 15.1 t/d in 2100, less than half of the original previous estimate. The MDBA modelling converts this to a 5.1 EC decrease in the credit previously generated (Table 4.15).

Table 4.15 Comparison of results for Waikerie 2A Salt Interception Scheme

Waikerie 2A SIS	2015 Salinity Register			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	-32.1	-8.0	0.582	-13.5	-3.4	0.292	(18.6)	(4.6)	(0.290)
2015	-33.1	-8.2	0.603	-13.5	-3.3	0.292	(19.6)	(4.9)	(0.311)
2050	-43.2	-10.7	0.817	-14.2	-3.6	0.316	(29.0)	(7.1)	(0.501)
2100	-35.8	-8.9	0.657	-15.1	-3.8	0.332	(20.7)	(5.1)	(0.325)

Note: The estimates in this table are subject to change based on revised MDBA modelling. Bracket denotes a reduction.

4.8.6 Sharing arrangements

Waikerie 2A SIS is currently a Joint Scheme under the Salinity and Drainage Strategy (Murray-Darling Basin Ministerial Council, 1989). The benefits are shared as NSW and Victoria each receive 18.75% of the benefit recorded on Register A and the River receives 62.5% share of the benefit from South Australia and the Commonwealth's shares (Aquaterra 2010, p. 55). South Australia receives no salinity credits for Waikerie 2A SIS, having assigned them to the River under the Salinity and Drainage Strategy (Aquaterra 2010, p. 55).

Results of the review indicate there may be a need to change the sharing arrangements of the scheme. The benefits for the scheme could be adjusted using the following approach (MDBA 2015, p. 65):

S8A(iii) - S8A(ii) = Total benefit
S8B(iii) - S8B(ii) = Joint benefit
State share = Total benefit - Joint benefit or = [(S8A(iii) - S8A(ii)] - [S8B(iii) - S8B(ii)]

Applying this calculation suggests a potential change to the benefits of the scheme from a Joint Scheme (where the joint venture funds 100% of the costs) to a Joint/Shared Scheme (where a State contributes directly to a portion of the operational costs and the Joint venture funds the remainder).

4.9 Waikerie Lock 2 SIS

4.9.1 Background

Waikerie Lock 2 SIS was commissioned in 2009 and has 7 pumping wells (Yan et al. 2012, p. 49). This salt interception scheme is located immediately downstream of Lock 2 and is in a similar area to the three production bores constructed for Qualco-Sunlands GCS.

The SIS bores are designed to achieve a potentiometric head approximately at river pool level and pump from the Lower Mannum Formation aquifer, as well as the Glenforslan and Upper Mannum Formations (Yan et al. 2012, p. 51). The groundwater pumped by all the Waikerie schemes is disposed at the Stockyard Plain Disposal Basin approximately 15 kilometres west of Waikerie township (AWE 2014, p. 15).

4.9.2 Revised models and relevant reports

Assessment of this accountable action has been undertaken using the *Waikerie-Morgan Numerical Groundwater Model 2012* (Yan et al. 2012) which was reviewed and found fit-for-purpose for predicting salt loads to the river using the scenarios documented in the report (SKM 2012, p. 23).

The peer reviewer noted the level of rigour provided is considered to be of a high standard and that the degree of certainty is therefore likely to be high relative to predictions from many other BSMS models (SKM 2012, p. 23–24). It was also noted that the alignment of the scenarios with the register entries was still under discussion between South Australia and the MDBA at the time of the review (SKM 2012, p. 25).

Reports relevant to this action include:

- *Waikerie to Morgan Numerical Groundwater Model 2012 – Volumes 1 and 2 (Yan et al. 2012)*
- *Peer Reviews (SKM 2012)*
- *SIS Technical review reports (AWE 2014a; AWE 2013).*

4.9.3 Reasons for change

Waikerie Lock 2 has been represented in the model in a similar way to the other salt interception schemes in the Waikerie-Morgan model. The evidence used for Waikerie Lock 2 is as described for Waikerie 1 (Section 4.6.3).

The Waikerie-Morgan model simulates historical pumping using MODFLOW's Well Package, with pumping rates based on high-quality data and the calibration results provide evidence that the model responds appropriately to SIS pumping. Model outputs provide a good match to observed potentiometric head near the pumping wells and also matches Run of River estimates of salt load to the river (Section 2.2.8).

Representation of the groundwater systems in the Waikerie area have been improved based on the information collected in the SIS technical review, which in turn has been incorporated into the groundwater model, as well as the actual pumping rates from SA Water.

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research

- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- update of irrigation information.

4.9.4 Scenarios used for assessment

This action is assessed using the following scenario which simulates the impact of Waikerie Lock 2 SIS on River Murray salt loads (Yan et al. 2012, p. 82):

Scenario 8A(iv) - Scenario 8A(iii)

4.9.5 Register Entry for Waikerie Lock 2 Salt Interception Scheme

The 2015 register entry is for Waikerie Lock 2 SIS is based on annual increment increases from the previously accredited AWE Waikerie to Lock 2 groundwater model (AWE 2009) which assumes 100% interception. This model estimates the salt load removed at 59.1 t/d in 2100 for Waikerie Lock 2 SIS or a credit of 14.4 EC (Table 4.16).

The results from the groundwater model updates the total benefit of the scheme compared to the 2015 entry. Overall the tonnes per day removed by Waikerie Lock 2 SIS in 2100 is estimated to be 27.0 t/d, less than half of the original previous estimate of 59.1 t/d. MSM-Bigmod converts this to be a 7.8 EC decrease in the credit previously generated (Table 4.16).

Table 4.16 Comparison of results for Waikerie Lock 2 Salt Interception Scheme

Waikerie Lock 2 SIS	2015 Salinity Register			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	-56.6	-13.9	0.951	-25.8	-6.3	0.440	(30.8)	(7.6)	(0.511)
2015	-44.7	-11.0	0.740	-26.8	-6.5	0.443	(17.9)	(4.5)	(0.297)
2050	-54.1	-13.3	0.905	-26.5	-6.5	0.443	(27.6)	(6.8)	(0.462)
2100	-59.1	-14.4	0.951	-27.0	-6.6	0.430	(32.1)	(7.8)	(0.521)

Note: The estimates in this table are subject to change based on revised MDBA modelling. Bracket denotes a reduction.

4.9.1 Sharing arrangements

Waikerie Lock 2 SIS is shared scheme under the Basin Salinity Management Strategy (Appendix 7.4). The benefits of the Joint component are shared in accordance with Schedule B with NSW receiving 28.75%, Victoria 26.25% and South Australia receiving 45% of the scheme benefit. Results of the review indicate may need to be a change in the assignment of benefits. The benefits for the scheme could be adjusted using the following approach (MDBA 2015, p. 65):

S8A(iv) - S8A(iii) = Total benefit

S8B(iv) - S8B(iv) = Joint benefit

State share = Total benefit - Joint benefit or = [S8A(iv) - S8A(iii)] - [S8B(iv) - S8B(iv)]

Applying this calculation suggests a potential change to the benefits of the scheme.

4.10 Pike SIS – Stage 1

4.10.1 Background

Stage 1 of the Pike SIS was designed as a highland SIS scheme and consists of 4 production bores and 2.7 kilometres of pipeline connecting into the Noora Disposal Basin (MDBA 2015). It is located on the southern highland adjacent to the Pike floodplain at Simarloo. Pike was designed to intercept high salinity regional groundwater from the Loxton

Sands aquifer entering the floodplain by aiming to maintain a potentiometric head of approximately river pool level at the mid-point observation wells (Woods et al. 2014, p. 45). This reduces the instream salt loads by reducing the natural groundwater heads which are steepened by irrigation recharge in the area.

Irrigation commenced in the Pike-Murtho area in 1880 and expanded significantly in the 1950s. The impact of irrigation on the aquifers is dependent on the presence and thickness of the Blanchetown Clay.

4.10.2 Revised model and relevant reports

Assessment of this accountable action has been undertaken using the *Pike-Murtho Numerical Groundwater Model 2014* (Woods et al. 2014) which was independently reviewed and found fit-for-purpose.

Relevant reports for this accountable action include:

- *Pike-Murtho Numerical Groundwater Model 2014 – Volumes 1 and 2 (Woods et al. 2014)*
- *Peer Reviews (RPS 2104)*
- *Pike River Salt Interception Figure Atlas (AWE 2012b).*

4.10.3 Reasons for change

The Pike-Murtho model simulates historical pumping of SIS using MODFLOW's Well Package, with pumping rates based on high-quality data. Water from the salt interception scheme is disposed at Noora Disposal Basin which is also represented in the groundwater model. The modelled pump rates for each bore within the SIS are included in the modelling reports (Woods et al. 2014, Appendices A-6 to A-7). Representation of the groundwater systems have been improved based on the information collected during SIS construction (AWE 2012b), which has also been incorporated into the groundwater model (Section 2.2).

Future Pike SIS operation is simulated so that the scheme meets its target levels in mid-point observation bores, which assumes that SIS operators vary pump rates over time. This is achieved in the model by representing the SIS with drain cells (Section 2.2.6).

The Pike-Murtho 2006 model was developed while the Pike SIS was at a concept design stage, while the 2014 model simulates the SIS as constructed. The Pike-Murtho 2006 model was re-run in 2011 to assess the Pike stage 1 SIS as constructed scheme. Four Pike SIS wells became operational in 2010 while actual scheme was commissioned in 2012. Additional recharge zones were added to the model in 2011 to simulate the irrigation development areas up to 2008. The salt load results were used to enter the scheme onto the Salinity Registers in 2012 and is the basis for the entry on the 2015 Salinity Register.

Calibration results provide evidence that the model simulates the hydrogeology appropriately, but no data was available at the time of model construction to show how potentiometric head has changed due to SIS pumping. Model outputs provide a good match to observed potentiometric head and also matches Run of River estimates of salt load to the river (Section 2.2.8). The next 5-year Review will provide a more robust test of model accuracy with regard to SIS pumping as well as a technical review of the operation.

The impact of SIS depends on the salt load caused by irrigation. As irrigation has expanded in recent years, there is more salt for the SIS to intercept. In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research
- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- update of irrigation information
- update of SIS from concept design to as constructed.

4.10.4 Scenarios used for assessment

This action is assessed using **Scenario 7A – Scenario 4** which simulates the impact of the constructed salt interception scheme on River Murray salt loads (Woods et al. 2014, p. 139).

4.10.5 Register Entry for Pike Salt Interception Scheme

The 2015 register entry for Pike SIS is based on annual increment increases from the previously accredited groundwater model the Pike-Murtho sub-zone model (Yan et al. 2006). This was reviewed by the MDBA as fit for purpose given the current data availability and was used to assist the conceptual design of the SIS in the Pike, as well as for the preliminary salinity register entry (Woods et al. 2014, p. 1). This results in an entry of 16.7 t/d or 3.2 EC credit at 2100 on the 2015 Salinity Register (Table 4.17).

The model review results (t/d) in Table 4.17 show an increase in the predicted impact of Pike SIS to 26.0 t/d in 2100. The MDBA modelling converts this to 5.4 EC in 2100.

Table 4.17 Comparison of results for Pike SIS

Pike SIS 100 % SA State	2015 Salinity Register			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	-6.7	-1.4	0.215	-10.5	-2.1	0.328	3.8	0.7	0.113
2015	-15.4	-3.2	0.490	-14.4	-3.0	0.457	(1.0)	(0.2)	(0.033)
2050	-15.8	-3.3	0.505	-23.9	-4.9	0.762	8.1	1.6	0.257
2100	-16.7	-3.4	0.463	-26.0	-5.4	0.734	9.3	2.0	0.271

Note: The estimates in this table are subject to change based on revised MDBA modelling. Bracket denotes a reduction.

4.10.6 Sharing arrangements

The Pike SIS is a South Australian state scheme constructed post-1988 and as such 100% of the benefit is recorded on Register A for South Australia. There are no changes to the sharing arrangements for this action.

4.11 Murtho SIS

4.11.1 Background

The Murtho SIS was designed to intercept groundwater entering the River Murray from above Pike Anabranch up to the South Australian Border. It is a region with wide floodplains in relatively good health as well as extensive anabranches and irrigation along the river. The scheme was designed to offset the irrigation impacts from the region as well as protect the floodplain from the predicted increase in groundwater inflows over time (REM-Aquaterra 2005). Over 54 kilometres of pipeline were required to collect the water pumped and delivered via Dishers Creek out to Noora Disposal Basin.

The Approval Submission was based on a concept design for the construction of 52 bores, with 31 on highland and 21 on the floodplain for an average 30 year benefit of 99.4 t/d. Following approval for construction of Murtho, the drilling undertaken in the area provided additional information revealing considerable spatial variation in the stratigraphy, lithology and hydraulic properties of the hydrogeology. It was also found that bores upstream generally had a higher flow than those drilled downstream resulting in fewer production bores required to achieve target groundwater levels.

This new understanding of the hydrogeology for Murtho resulted in a redesign of the bore field from the original conceptual design. Final construction resulted in 23 bores (21 on the highland and 2 on the floodplain) with an estimated benefit of 16 t/d as an interpolated result. The constructed version of Murtho is modelled in the 2014 groundwater model.

Construction of Murtho SIS commenced in 2008 and was completed in December 2013. The scheme was commissioned in early 2014 and entered onto the Salinity register an interim number until the Pike-Murtho groundwater model 2014 was approved by the MDBA (River Murray Water Committee, Meeting 22 – Decision Register, 27 May 2014).

4.11.2 Revised models used and relevant reports

The updated assessment of this accountable action is based on the revised groundwater model:

- *Pike*-Murtho *Numerical Groundwater Model 2014*

The model has been independently peer reviewed and found fit-for-purpose. Relevant reports for this accountable action include:

- *Pike-Murtho Numerical Groundwater Model 2014 – Volumes 1 and 2 (Woods et al. 2014);*
- *Peer Reviews (RPS 2014)*
- *SIS Technical review reports.*

4.11.3 Reasons for change

As discussed in Section 2.2.6, SIS are simulated to match their operation. The Pike-Murtho model simulates historical pumping using MODFLOW's Well Package, with pumping rates based on high-quality data.

Unlike other SIS modelled, the future operation of Murtho SIS is simulated with wells rather than drain cells (Section 2.2.6). The Murtho SIS differs from other schemes in that its pumping volume is limited by the pipeline capacity and it is known that the volume may not be sufficient to lower the groundwater level at mid-point wells to the pool level in the long-term. This is particularly the case when all the accession drainage from the current and future irrigation areas have reached the watertable. The pumping rates were specified by SA Water and remain constant from 2014 to 2114 and are included in the modelling reports (Woods et al. 2014, Appendices A-6 to A-7).

The Pike-Murtho 2006 model was developed while the Murtho SIS was at a concept design stage, while the 2014 model simulates the SIS as constructed. There are differences between the concept design and as-constructed design of the SISs. The SIS was also commissioned several years later than originally modelled. In the 2006 model, the SIS begin pumping in 2006 but in actuality the Murtho SIS started in 2014.

Representation of the groundwater systems have been improved based on the information collected during SIS construction, which has also been incorporated into the groundwater model (Section 2.2).

Calibration results provide evidence that the model simulates the hydrogeology appropriately, but no data is available to show how potentiometric head has changed due to SIS pumping. Model outputs provide a good match to observed potentiometric head and also matches Run of River estimates of salt load to the river (2.2.8). The next 5-year Review will provide a more robust test of model accuracy with regard to SIS pumping.

The impact of SIS depends on the salt load caused by irrigation. As irrigation has expanded in recent years, there is more salt for the SIS to intercept.

In summary the salt loads for this action have changed due to a combination of:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research

- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- update of irrigation information
- update of SIS from concept design to as constructed.

4.11.4 Scenarios used for assessment

This action is assessed using **Scenario 7A – Scenario 4** which provides the total benefit of the Murtho salt interception scheme as constructed.

4.11.5 Register Entry for Murtho Salt Interception Scheme

Murtho Salt Interception Scheme (SIS) was authorised for construction by the Murray-Darling Basin Ministerial Council in March 2008 (Meeting number 44) (MDBA 2015). The scheme was declared effective by the Ministerial Council in accordance with Clause 64 of the Murray-Darling Basin Agreement in October 2014 (Meeting 21). At this time the MDBA requested that the scheme be entered onto the salinity registers using the existing groundwater model (Yan et al. 2006) developed to support the concept design of the SIS scheme (P. Pfeiffer (MDBA) 2014, pers com.).

The scheme benefit at Morgan was estimated to be 20.2 EC based on a 30 year average benefit. This was calculated from the prevention of 99.4 t/d of salt from entering the river, and assumed the Murtho SIS commenced pumping in 2006 (MDBA 2015, p. 77). Cost sharing arrangements for Murtho SIS were agreed at 98% Joint Works and 2% State Action. On this basis, the River Murray Water Committee (Meeting 22 – 27 May 2014) declared Murtho SIS effective but explicitly recognised it was an interim entry to be reviewed once the revised Pike-Murtho Numerical Groundwater Model 2014 was approved as fit for purpose (RMWC-Confirmed Decision Register - Meeting 22).

Salinity Register entries are now calculated using an interpolation of benefits at the year of reporting rather than a thirty year average. This changed the agreed assessment of 20.2 EC to a total of 17.9 EC (17.3 EC Joint Works benefit and 0.6EC State Action) as calculated for the 2014 Salinity Registers (MDBA 2015, p. 77).

The model review results (t/d) in Table 4.18 show a reduction in the predicted benefit of Murtho SIS from 159.0 t/d to 106.8 t/d in 2100. The MDBA modelling converts this to be a 15.3 EC reduction in the credit previously estimated (Table 4.18).

Table 4.18 Comparison of results for Murtho SIS

Murtho SIS	2015 Salinity Register			Review results			Difference		
	t/d	EC	$m	t/d	EC	$m	t/d	EC	$m
2000	-67.8	-14.0	2.509	-27.1	-4.5	0.888	(40.7)	(9.5)	(1.621)
2015	-86.6	-17.6	3.319	-27.1	-4.4	0.831	(59.5)	(13.2)	(2.488)
2050	-144.5	-30.5	5.945	-99.1	-15.2	3.053	(45.4)	(15.3)	(2.892)
2100	-159.0	-31.7	5.808	-106.8	-16.4	2.946	(52.2)	(15.3)	(2.862)

Note: The estimates in this table are subject to change based on revised MDBA modelling. Bracket denotes a reduction.

4.11.6 Sharing arrangements

Murtho SIS is shared scheme under the Basin Salinity Management Strategy (MDBC 2005). Under this agreement New South Wales receives 28.75% share of the benefit, Victoria 26.25% and South Australia receives 45% of the scheme benefit. Results of the review indicate there may need to be a change in the assignment of benefits of the scheme. The benefits for the scheme could be adjusted using the following approach (MDBA 2015, p. 65):

S7A - S4 = Total benefit
S7B - S3C = Joint benefit
State share = Total benefit - Joint benefit or = [(S7A - S4)] - [(S7B - S3C)]

Applying this calculation suggests a potential change to the benefits of the scheme.

5 Discussion and recommendations

Groundwater model development in South Australia has followed a rigorous and consistent approach developed over a number of years in consultation with MDBA and SIS Operators.

Detailed numerical groundwater models were developed for Waikerie to Morgan, Woolpunda, and Pike-Murtho between 2012 and 2014 to estimate salt loads to the River Murray for accountable actions in these areas of South Australia. These models represent the third generation of models estimating the potential salinity impacts on the River Murray and address the issues raised in reviews of the second generation models. In addition the models have been updated to incorporate the latest additional data on stratigraphy, aquifer properties, irrigation, and SIS construction and operation.

5.1 Accountable Action Summary

South Australia submits these groundwater model results to be used to update the Salinity Register entries for the relevant accountable actions. A summary of the results is provided in Table 5.1 noting that the EC numbers are a preliminary estimate only and subject to revision once the MDBA undertakes its modelling determination.

The results are generated from third generation models and represent a more accurate representation of salinity impacts (as outlined in section 2) with the main improvements including:

- change from a flow-salt relationship method, which cannot distinguish between causes of salinity changes in the river to a numerical groundwater model;
- use of numerical groundwater models to replace entries based on SIMRAT, a semi-analytic model that uses minimal input data and broad assumptions; and
- improvements in data and conceptualisation including changes that address peer reviewer comments on second generation models.

The models were developed with input from a Five Year Review Model Team, which included representatives from the MDBA (policy and technical staff), SA Water (SIS operators) and DEWNR (technical and policy staff). The models have all independently reviewed, found 'fit for purpose' and accredited for Salinity Register assessments.

Model assumptions are guided by the Operational Protocols and the Salinity Registers which require Basin States to record accountable actions and to provide an estimate of future risk. How potential future development is represented in the groundwater models has been identified as an area for consideration under future five year reviews, including how to ensure an acceptable representation of future salinity risk for South Australia.

All groundwater models, including the 2012-14 models necessarily simplify some complexities, due to limitations in available data, knowledge gaps, and computational constraints. The assumptions used in the review models are similar to those adopted for the Eastern Mallee models of Victoria and New South Wales, with most of the exceptions due to differing hydrogeological conditions between the states.

The reasons for changes in the salt load estimates for the accountable actions are varied but can be summarised as follows:

- incorporation of new information on the characteristics of the aquifers from drilling programs
- improvements in the conceptualisation of the models from improved knowledge and research
- changes in approach from second generation to third generation models
- improvements in calibration from second generation to third generation models
- changes in approach from a simple method to numerical groundwater models

- update of irrigation information
- update of sis from concept design to as constructed
- update from provisional estimates to detailed assessment from numerical groundwater models

The changes resultant from the reviews indicate potential changes in SIS schemes from Joint to Shared as a result of increasing impacts of post-1988 irrigation. It is considered that these changes and how they relate to the ongoing costs of operating and maintaining SIS is an issue to be discussed at BSMAP. Any changes to the cost shares of operating and maintaining SIS will require Ministerial Council approval.

Table 5.1 Accountable Action Impacts at 2100 – 2015 Register and review results

Register	2015 Salinity Register Entry	2015 Register		Review results		Difference	
		t/d	EC	t/d	EC	t/d	EC
B	SA Mallee Legacy of History - Dryland	181.1	32.8	105.5	5.2	(75.6)	(27.6)
	SA Mallee Legacy of History - Irrigation	541.4	113.3	222.6	22.9	(318.8)	(90.4)
	SA Improved Irrigation Efficiency and Scheme Rehabilitation Register B	-550.4	-115.4	-289.6	-37.5	(260.8)	(77.9)
A	SA Improved Irrigation Efficiency and Scheme Rehabilitation Register A	-105.9	-21.3	-67.8	-13.5	(38.1)	(7.8)
	SA Irrigation Development Based on Footprint Data	287.7	72.8	373.4	71.5	85.7	(1.3)
	SA Irrigation Development Due to Water Trade (SIMRAT)	323.5	32.2	146.0	-8.2	(177.5)	(40.4)
	SA Irrigation Development Based on Site Use Approvals (SIMRAT)	574.2	93.0	107.6	10.1	(466.6)	(82.9)
	Woolpunda SIS	-176.0	-47.4	-253.0	-56.6	77.0	9.2
	Waikerie SIS	-60.0	-12.8	-58.5	-13.5	(1.50	0.7
	Qualco-Sunlands Groundwater Control Scheme	-29.9	-7.5	-34.2	-8.5	4.3	1.0
	Waikerie Phase 2A SIS	-35.8	-8.9	-15.1	-3.8	(20.70	(5.1)
	Waikerie Lock 2 SIS	-59.1	-14.4	-27.0	-6.6	(32.10	(7.8)
	Pike SIS stage 1	-16.7	-3.4	-26.0	-5.4	9.3	2.0
	Murtho SIS	-159.0	-31.7	-106.8	-16.4	(52.20	(15.3)

5.2 Conversion from tonnes to EC

The salt load results in tonnes per day from the reviewed models are provided to the MDBA for processing the EC and equivalent EC ($) impact on the Salinity Registers for each accountable action. Results in tonnes per day are graphically compared with EC in Figure 5.2 and Figure 5.3 for irrigation and SIS respectively.

This review has identified a number of issues that require clarification from the MDBA as to how the South Australian model results have been incorporated into the MDBA models. This combined with the register reports being run over multiple years, due to the completion dates of the groundwater models, has meant that there is a high likelihood that the register numbers for these actions will change once entered onto the Salinity Registers.

The issues that require assistance from the MDBA to clarify or resolve include:

- salt loads from the existing Renmark model are not included in some of the MDBA calculations for the Pike Murtho reaches

- conversions from tonnes per day into EC's by the MDBA models appearing inconsistent and at times do not appear consistent with the expected outcome based on the magnitude of the tonnes per day result (Figure 5.2)
- MSM-Bigmod and the groundwater models have different time and spatial scales which leads to difficulties in incorporating the groundwater model results into MSM-Bigmod. Depending on the approach used, this can lead to systematic errors in calculation of salinity to the River or negative EC numbers (P Sharma (MDBA) 2016 pers.comm., June 2016).
- whether SIMRAT numbers are being correctly removed from the MDBA models when replaced by new accredited groundwater model results.

Some matters may require consideration of an agreed approach for future groundwater models under the revised procedures currently being developed for the BSM2030.

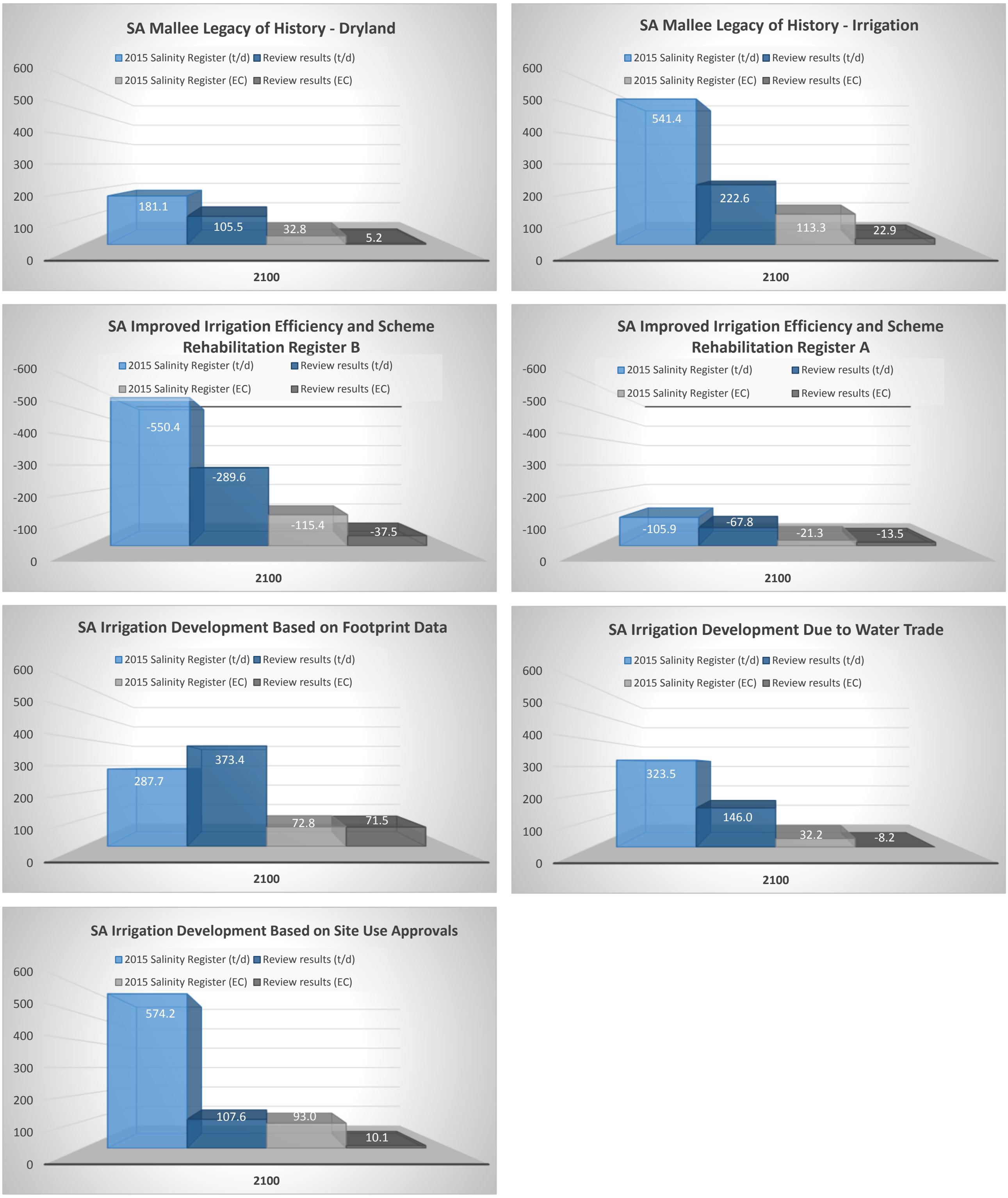


Figure 5.1 Comparison of salt load and EC in 2100 between 2015 Salinity Register and review results for Pre and Post-1988 irrigation

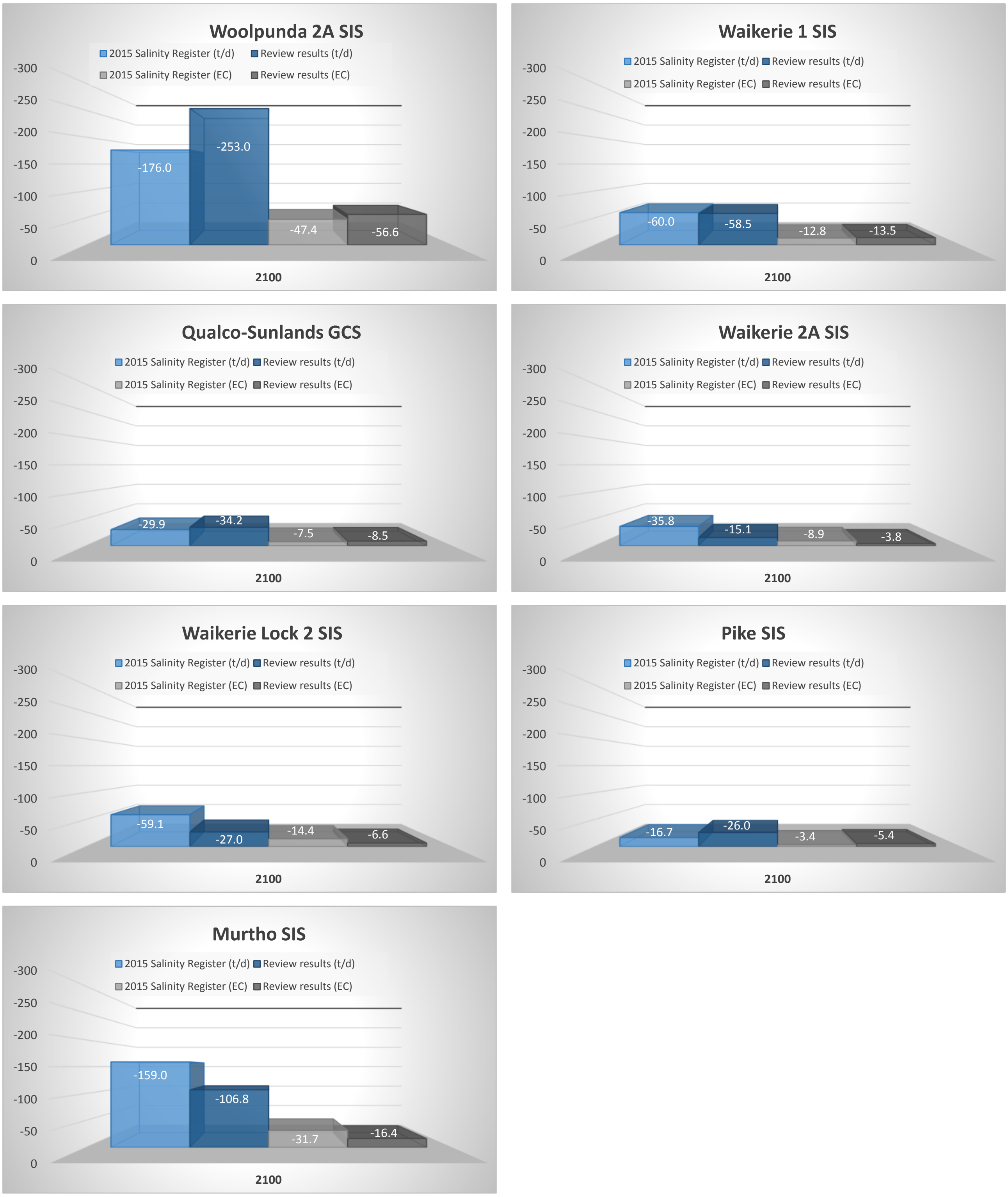


Figure 5.2 Comparison of salt load and EC in 2100 between 2015 Salinity Register and review results for South Australia salt interception schemes

5.3 Future directions

The adoption of the new Basin Salinity Management 2030 strategy provides an opportunity to review the procedures for modelling, accountable action assessment, the peer review process and Salinity Register operation to ensure the assumptions made are in line with the outcomes sought, and to facilitate consistency across the states where appropriate. In addition BSM2030 has identified key knowledge gaps to be addressed, that may reduce the uncertainty associated with salinity impact assessments into the future including time lags for recharge and the impacts of Mallee clearance.

Through the review process, South Australia has identified several issues for consideration regarding the approach to review and update of groundwater models. Many of these will also impact other jurisdictions and as such, should be considered as part of the review and development of procedures as part of the implementation of the BSM2030. Issues identified include:

- clearly articulating the aim(s) and expected accuracy of the model
- consistency in representation of key hydrogeological features (see Section 2)
- requirement for a consistent approach to model uncertainty and identification of rectifiable data gaps
- how the register could better acknowledge the uncertainty in estimates of future risk
- how to address significant time lags which make it difficult to estimate potential impacts with accuracy
- how best to represent future development, irrigation retirement and temporary irrigation areas in the models
- how groundwater models can be adapted/adopted to inform real time salinity management
- clear definition and application of model confidence ratings on the Salinity Registers
- discussion, agreement and documentation of how outputs from groundwater models can best be integrated into the MDBA models and the associated quality assurance processes.

BSMAP should also consider the value of a cross jurisdictional forum to discuss and agree on key groundwater modelling decisions between the MDBA and the jurisdictions. This forum could discuss and recommend to BSMAP:

- the role of the MDBA in development of groundwater models
- the role of the independent reviewers and when best to engage them in process
- the role of the jurisdictions and how best to inform them of the work being undertaken in individual jurisdictions
- the process undertaken to accredit a model including the independent peer review
- the process undertaken to update and approve accountable actions onto the Salinity Register
- establishing a process to update the modelling assumptions when policy changes.

There is an opportunity to establish these processes and document the expectations for future groundwater model development as part of the procedure review for the BSM2030. A Salinity Register Modelling Panel could be established including technical experts across the jurisdictions as well as representatives from the MDBA to guide the development of these procedures. Documenting expectations clearly by an interjurisdictional group, will provide a solid foundation and clear direction for the next generation of groundwater models in all states.

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7 Appendix

7.1 Model mass balance comparison

7.1.1 Mass balance comparison between Morgan to Lock 3 and combined mass balance of Waikerie to Morgan 2012 and Woolpunda 2013 models

Table 7.1 Scenario 1: Lock 3 to Morgan 2008

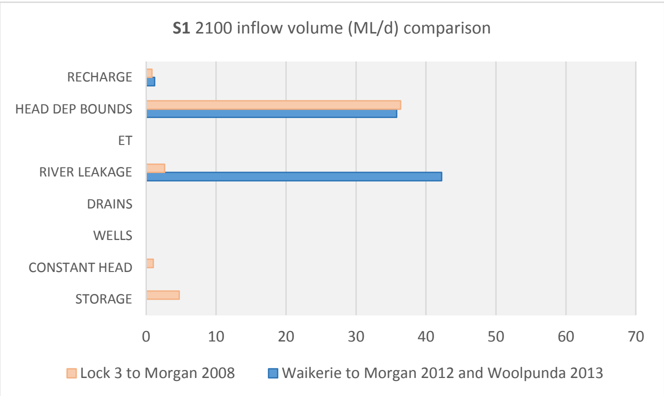
Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	4.7	4.7	4.7	4.7
CONSTANT HEAD	1.0	1.0	1.0	1.0
WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	2.6	2.6	2.6	2.6
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	36.4	36.4	36.4	36.4
RECHARGE	0.8	0.8	0.8	0.8
TOTAL IN	45.6	45.6	45.6	45.6

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.6	0.6	0.6	0.6
CONSTANT HEAD	0.2	0.2	0.2	0.2
WELLS	0.0	0.0	0.0	0.0
DRAINS	0.5	0.5	0.5	0.5
RIVER LEAKAGE	19.4	19.4	19.4	19.4
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	25.3	25.3	25.3	25.3
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	46.0	46.0	46.0	46.0

Table 7.2 Scenario 1: Waikerie to Morgan 2012 and Woolpunda 2013

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.0	0.0	0.0	0.0
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	42.2	42.2	42.2	42.2
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	35.8	35.8	35.8	35.8
RECHARGE	1.2	1.2	1.2	1.2
TOTAL IN	*79.3*	*79.3*	*79.3*	*79.3*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.0	0.0	0.0	0.0
CONSTANT HEAD	0.3	0.3	0.3	0.3
WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	14.1	14.1	14.1	14.1
ET	56.9	56.9	56.9	56.9
HEAD DEP BOUNDS	8.0	8.0	8.0	8.0
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*79.3*	*79.3*	*79.3*	*79.3*



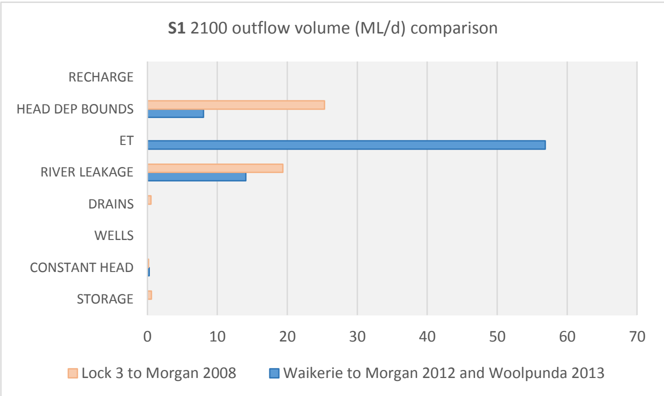


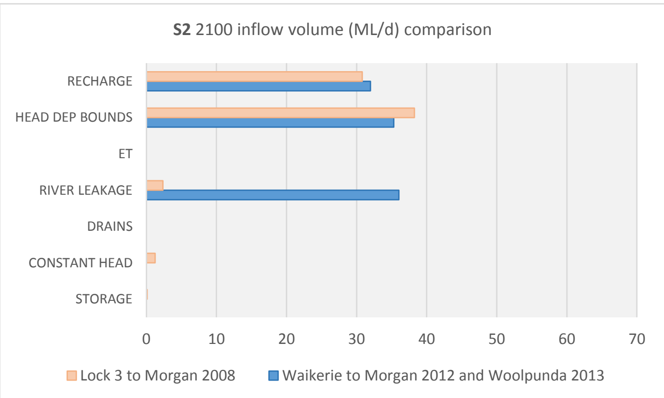
Figure 7.1 Scenario 1 inflow volume comparison for year 2100

Table 7.3 Scenario 2: Lock 3 to Morgan 2008 model

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	2000	2015	2050	2100	Year	2000	2015	2050	2100
STORAGE	2.9	1.0	0.3	0.1	STORAGE	7.5	8.6	10.0	17.4
CONSTANT HEAD	1.4	1.3	1.3	1.2	CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	0.0	0.0	0.0	0.0	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	0.6	0.6	0.9	1.1
RIVER LEAKAGE	2.5	2.5	2.4	2.3	RIVER LEAKAGE	20.6	21.8	25.4	30.2
ET	0.0	0.0	0.0	0.0	ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	36.7	37.0	37.8	38.3	HEAD DEP BOUNDS	25.3	25.1	24.8	24.6
RECHARGE	8.3	11.3	19.1	30.8	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*51.8*	*53.1*	*60.9*	*72.8*	*TOTAL OUT*	*54.0*	*56.2*	*61.0*	*73.3*

Table 7.4 Scenario 2: Waikerie to Morgan 2012 and Woolpunda 2013 models

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	2000	2015	2050	2100	Year	2000	2015	2050	2100
STORAGE	0.0	0.0	0.0	0.0	STORAGE	8.1	10.3	10.9	11.7
CONSTANT HEAD	0.0	0.0	0.0	0.0	CONSTANT HEAD	0.5	1.1	2.6	3.9
WELLS	0.0	0.0	0.0	0.0	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	0.0	0.0	0.1	0.1
RIVER LEAKAGE	41.3	40.5	38.2	36.0	RIVER LEAKAGE	14.2	14.3	14.8	16.4
ET	0.0	0.0	0.0	0.0	ET	57.1	57.2	57.5	58.0
HEAD DEP BOUNDS	41.1	39.4	37.5	35.3	HEAD DEP BOUNDS	8.1	8.3	9.5	13.1
RECHARGE	5.6	11.3	19.7	32.0	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*88.0*	*91.2*	*95.5*	*103.3*	*TOTAL OUT*	*88.0*	*91.2*	*95.5*	*103.3*



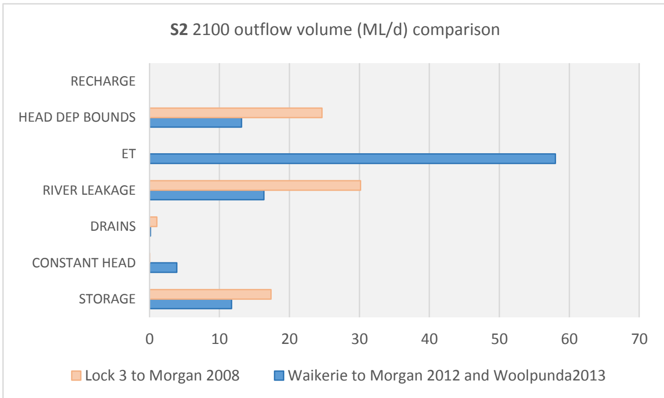


Figure 7.2 Scenario 2 inflow volume comparison for year 2100

Table 7.5 Scenario 3A: Lock 3 to Morgan 2008 model

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**	**Year**	**2000**	**2015**	**2050**	**2100**
STORAGE	15.6	2.1	1.0	0.3	STORAGE	17.7	8.7	6.2	3.4
CONSTANT HEAD	1.3	1.3	1.3	1.2	CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	0.2	0.2	0.2	0.2	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	4.2	3.8	4.2	4.4
RIVER LEAKAGE	2.5	2.5	2.4	2.4	RIVER LEAKAGE	41.3	43.1	44.5	45.7
ET	0.0	0.0	0.0	0.0	ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	36.8	37.9	38.4	38.6	HEAD DEP BOUNDS	25.3	24.9	24.6	24.5
RECHARGE	31.8	36.0	35.3	35.3	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*88.2*	*79.9*	*78.6*	*78.0*	*TOTAL OUT*	*88.6*	*80.5*	*79.5*	*78.0*

Table 7.6 Scenario 3A: Waikerie to Morgan 2012 and Woolpunda 2013 models

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**	**Year**	**2000**	**2015**	**2050**	**2100**
STORAGE	0.3	0.0	0.0	0.0	STORAGE	10.8	8.0	5.1	2.7
CONSTANT HEAD	0.0	0.0	0.0	0.0	CONSTANT HEAD	1.9	2.1	2.6	3.0
WELLS	0.0	0.0	0.0	0.0	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	0.5	0.6	0.6	0.6
RIVER LEAKAGE	37.5	37.4	37.3	37.0	RIVER LEAKAGE	30.1	31.0	31.8	32.3
ET	0.0	0.0	0.0	0.0	ET	58.6	58.7	58.8	58.8
HEAD DEP BOUNDS	40.2	38.7	37.6	37.1	HEAD DEP BOUNDS	8.7	8.8	9.1	9.6
RECHARGE	32.6	32.9	33.0	33.0	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*110.6*	*109.1*	*107.9*	*107.1*	*TOTAL OUT*	*110.6*	*109.1*	*107.9*	*107.0*

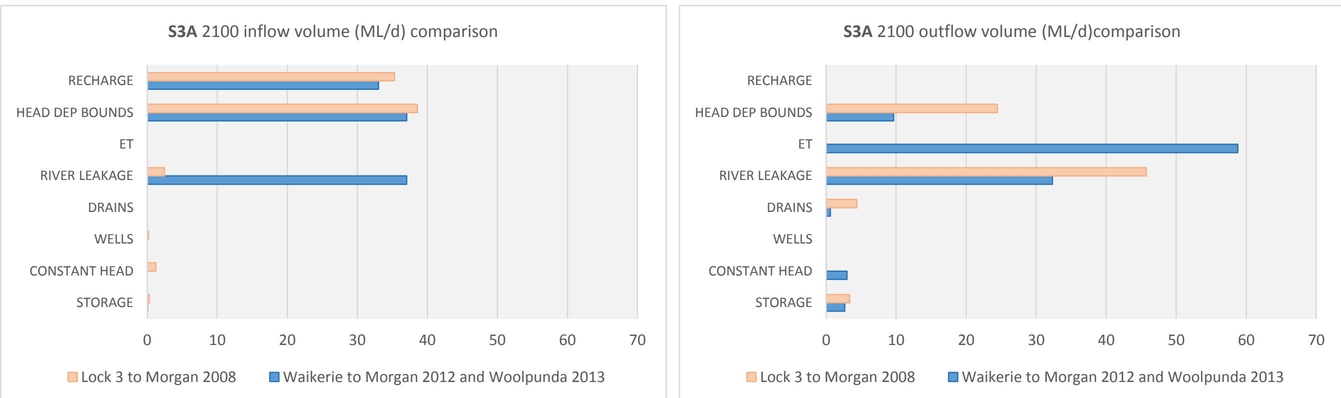


Figure 7.3 Scenario 3A inflow volume comparison for year 2100

Table 7.7 Scenario 3C: Lock 3 to Morgan 2008 model

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	4.8	3.8	1.5	0.5
CONSTANT HEAD	1.3	1.3	1.3	1.3
WELLS	0.2	0.2	0.2	0.2
DRAINS	0.0	0.0	0.0	0.0
ET	0.0	0.0	0.0	0.0
RIVER LEAKAGE	2.5	2.5	2.5	2.5
HEAD DEP BOUNDS	36.8	37.9	38.3	38.4
RECHARGE	30.6	29.2	23.7	23.7
TOTAL IN	*76.2*	*74.8*	*67.4*	*66.5*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	5.5	6.1	3.6	2.6
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	0.0	0.0	0.0	0.0
DRAINS	4.3	3.5	2.8	2.8
ET	0.0	0.0	0.0	0.0
RIVER LEAKAGE	41.4	40.9	37.9	37.9
HEAD DEP BOUNDS	25.3	24.9	24.6	24.6
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*76.6*	*75.4*	*68.9*	*67.9*

Table 7.8 Scenario 3C: Waikerie to Morgan 2012 and Woolpunda 2013 models

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	4.1	2.6	0.2	0.0
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	37.7	38.0	38.0	37.8
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	40.2	38.8	37.9	37.6
RECHARGE	21.7	17.2	17.2	17.2
TOTAL IN	*103.8*	*96.5*	*93.4*	*92.6*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	8.9	5.7	3.2	1.6
CONSTANT HEAD	1.6	1.3	1.5	1.8
WELLS	0.0	0.0	0.0	0.0
DRAINS	0.5	0.4	0.4	0.4
RIVER LEAKAGE	26.0	22.6	21.7	21.8
ET	58.2	58.0	57.9	57.9
HEAD DEP BOUNDS	8.6	8.6	8.7	8.9
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*103.8*	*96.5*	*93.4*	*92.5*

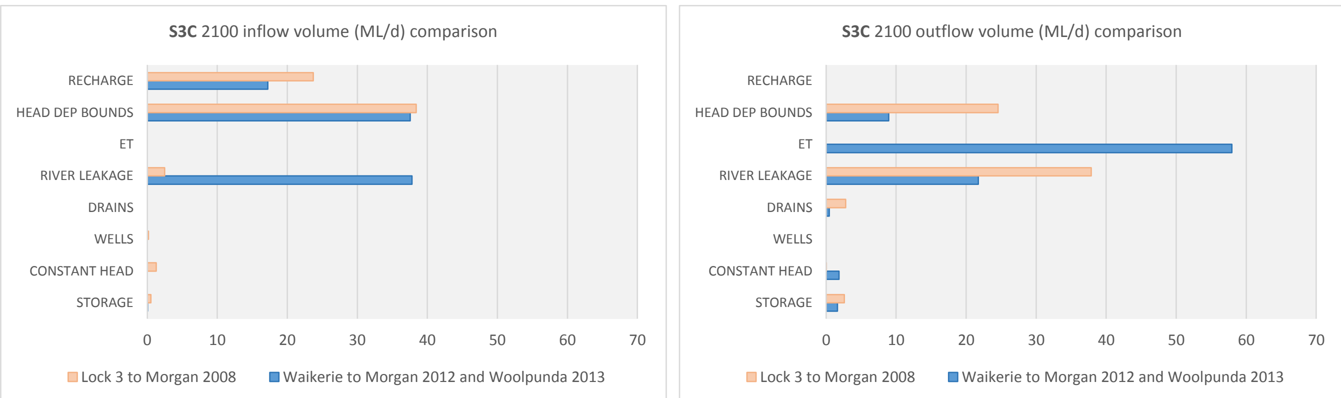


Figure 7.4 Scenario 3C inflow volume comparison for year 2100

Table 7.9 Scenario 4: Lock 3 to Morgan 2008 model

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**	**Year**	**2000**	**2015**	**2050**	**2100**
STORAGE	4.8	3.8	1.0	0.1	STORAGE	5.5	8.9	10.6	5.3
CONSTANT HEAD	1.3	1.3	1.3	1.2	CONSTANT HEAD	0.0	0.0	0.0	0.1
WELLS	0.2	0.2	0.2	0.2	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	4.3	3.6	4.4	3.7
RIVER LEAKAGE	2.5	2.3	2.2	2.1	RIVER LEAKAGE	41.5	41.2	42.8	45.7
ET	0.0	0.0	0.0	0.0	ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	36.8	37.8	38.3	38.5	HEAD DEP BOUNDS	25.3	24.9	24.6	24.4
RECHARGE	30.6	32.6	37.4	37.4	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*76.2*	*78.1*	*80.4*	*79.5*	*TOTAL OUT*	*76.6*	*78.7*	*82.4*	*79.2*

Table 7.10 Scenario 4: Waikerie to Morgan 2012 and Woolpunda 2013 models

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**	**Year**	**2000**	**2015**	**2050**	**2100**
STORAGE	4.0	1.8	0.1	0.0	STORAGE	9.1	7.5	10.3	5.8
CONSTANT HEAD	0.0	0.0	0.0	0.0	CONSTANT HEAD	1.7	1.6	1.9	2.3
WELLS	0.0	0.0	0.0	0.0	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	0.5	0.5	0.5	0.5
RIVER LEAKAGE	37.5	37.5	37.1	36.7	RIVER LEAKAGE	26.8	24.9	27.1	29.0
ET	0.0	0.0	0.0	0.0	ET	58.3	58.2	58.5	58.7
HEAD DEP BOUNDS	40.2	38.8	37.7	36.8	HEAD DEP BOUNDS	8.6	8.6	8.7	9.3
RECHARGE	23.2	23.2	32.1	32.1	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*105.0*	*101.2*	*107.0*	*105.6*	*TOTAL OUT*	*105.0*	*101.2*	*107.0*	*105.6*

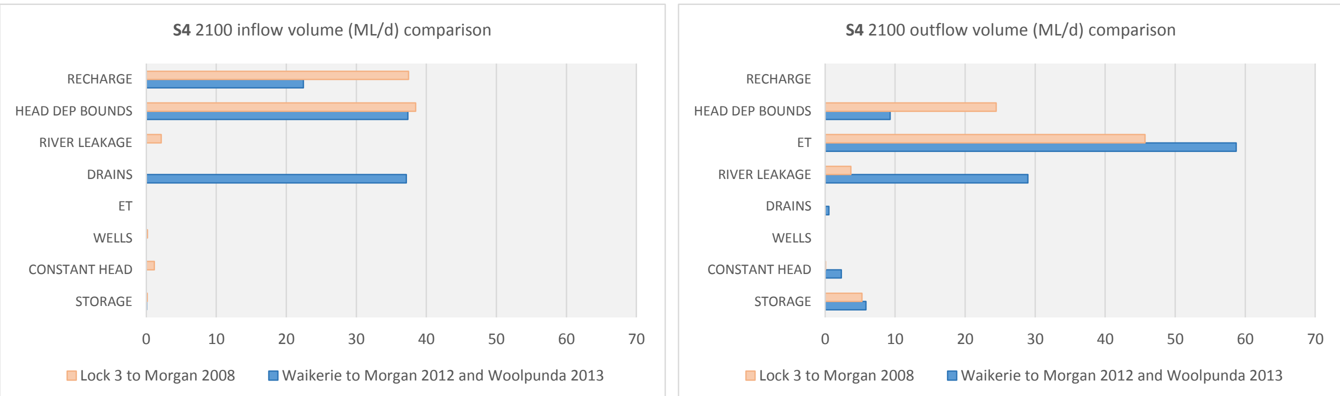


Figure 7.5 Scenario 4 inflow volume comparison for year 2100

Table 7.11 Scenario 8A: Lock 3 to Morgan 2008 model

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	7.5	4.7	0.9	0.2
CONSTANT HEAD	1.3	1.4	1.3	1.2
WELLS	0.2	0.2	0.2	0.2
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	3.9	4.7	3.9	2.7
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	37.0	38.3	39.1	39.2
RECHARGE	30.6	32.6	39.7	40.0
RESERV. LEAKAGE	5.6	6.6	4.9	3.9
TOTAL IN	*86.2*	*88.4*	*89.9*	*87.5*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	11.1	14.4	15.2	8.5
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	16.8	18.3	18.3	18.3
DRAINS	3.8	3.3	3.2	3.4
RIVER LEAKAGE	29.9	28.7	30.0	33.4
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	25.2	24.8	24.4	24.3
RECHARGE	0.0	0.0	0.0	0.0
RESERV. LEAKAGE	0.0	0.0	0.0	0.0
TOTAL OUT	86.9	89.5	91.2	87.9

Table 7.12 Scenario 8A: Waikerie to Morgan 2012 and Woolpunda 2013 models

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	8.8	5.4	0.5	0.0
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	39.2	39.9	39.7	39.3
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	40.4	39.1	38.5	38.0
RECHARGE	23.2	23.2	32.1	32.1
TOTAL IN	*111.7*	*107.6*	*110.8*	*109.5*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	8.9	5.7	7.2	3.9
CONSTANT HEAD	1.7	1.5	1.6	1.8
WELLS	0.0	0.0	0.0	0.0
DRAINS	22.2	24.1	25.6	26.8
RIVER LEAKAGE	13.0	8.9	8.9	9.0
ET	57.3	56.9	57.0	57.1
HEAD DEP BOUNDS	8.5	8.4	8.4	8.7
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*111.7*	*107.6*	*110.8*	*109.5*

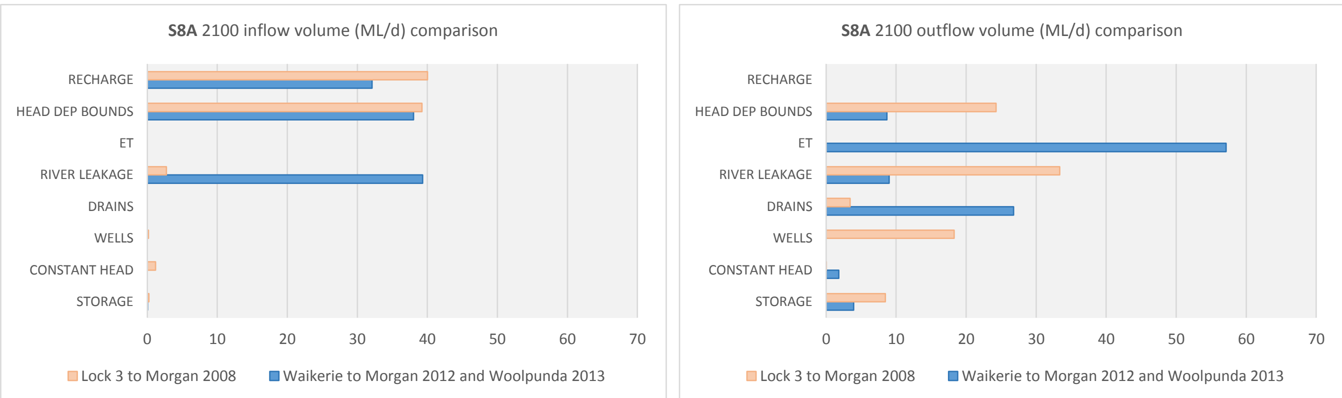


Figure 7.6 Scenario 8A inflow and outflow volume comparison for year 2100

7.1.2 Mass balance comparison between Pike-Murtho 2006 and Pike-Murtho 2014 models

Table 7.13 Scenario 1: Pike-Murtho 2006

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.3	0.3	0.3	0.3
CONSTANT HEAD	61.4	61.4	61.4	61.4
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	37.1	37.1	37.1	37.1
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	15.1	15.1	15.1	15.1
RECHARGE	1.3	1.3	1.3	1.3
TOTAL IN	115.1	115.1	115.1	115.1

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.0	0.0	0.0	0.0
CONSTANT HEAD	29.0	29.0	29.0	29.0
DRAINS	3.5	3.5	3.5	3.5
RIVER LEAKAGE	4.4	4.4	4.4	4.4
ET	75.3	75.3	75.3	75.3
HEAD DEP BOUNDS	3.0	3.0	3.0	3.0
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	115.1	115.1	115.1	115.1

Table 7.14 Scenario 1: Pike-Murtho 2014

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.0	0.0	0.0	0.0
CONSTANT HEAD	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	123.3	123.3	123.3	123.3
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	15.2	15.2	15.2	15.2
RECHARGE	1.7	1.7	1.7	1.7
TOTAL IN	140.3	140.3	140.3	140.3

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.0	0.0	0.0	0.0
CONSTANT HEAD	0.0	0.0	0.0	0.0
DRAINS	3.7	3.7	3.7	3.7
RIVER LEAKAGE	19.4	19.4	19.4	19.4
ET	115.2	115.2	115.2	115.2
HEAD DEP BOUNDS	1.9	1.9	1.9	1.9
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	140.3	140.3	140.3	140.3

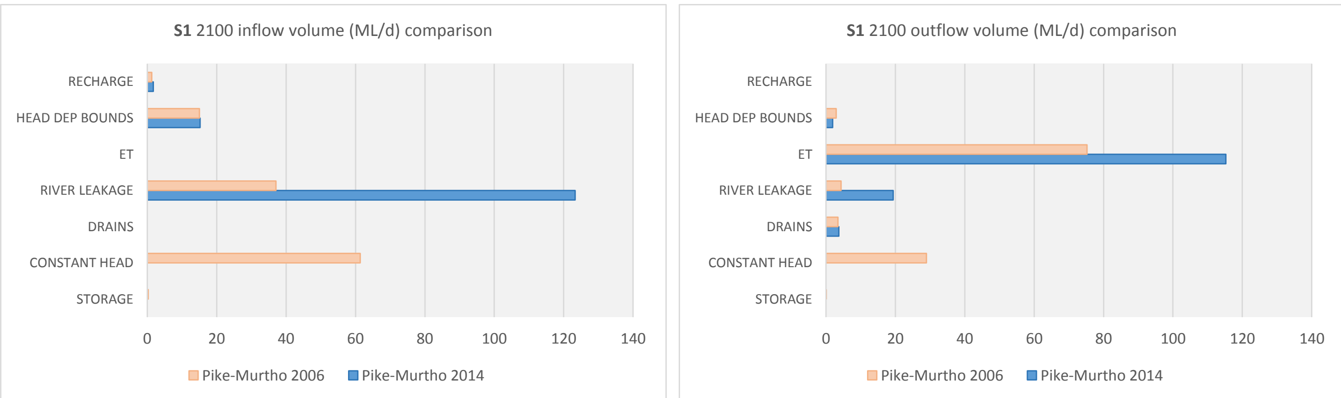


Figure 7.7 Scenario 1 inflow volume comparison for year 2100

Table 7.15 Scenario 2: Pike-Murtho 2006

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.1	0.0	0.0	0.0
CONSTANT HEAD	61.0	60.8	60.4	59.4
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	36.8	36.7	36.3	35.5
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	14.7	14.4	13.8	12.4
RECHARGE	9.8	14.4	26.4	55.0
TOTAL IN	*122.4*	*126.4*	*136.9*	*162.3*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	5.3	8.5	16.2	33.1
CONSTANT HEAD	29.4	29.6	30.1	31.9
DRAINS	4.0	4.2	4.7	5.5
RIVER LEAKAGE	4.5	4.6	4.9	5.5
ET	76.2	76.5	77.3	79.4
HEAD DEP BOUNDS	3.0	3.1	3.7	7.0
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*122.4*	*126.4*	*136.9*	*162.3*

Table 7.16 Scenario 2: Pike-Murtho 2014

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.0	0.0	0.0	0.0
CONSTANT HEAD	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	122.8	122.4	121.5	119.3
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	14.8	14.5	13.6	12.2
RECHARGE	10.3	15.0	26.5	47.4
TOTAL IN	*147.9*	*152.0*	*161.6*	*178.9*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	5.3	8.5	14.0	19.8
CONSTANT HEAD	0.0	0.0	0.0	0.0
DRAINS	4.4	4.7	5.2	5.9
RIVER LEAKAGE	19.7	19.9	20.6	22.2
ET	116.3	116.6	117.4	119.1
HEAD DEP BOUNDS	2.1	2.2	4.3	11.8
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*147.9*	*152.0*	*161.5*	*178.9*

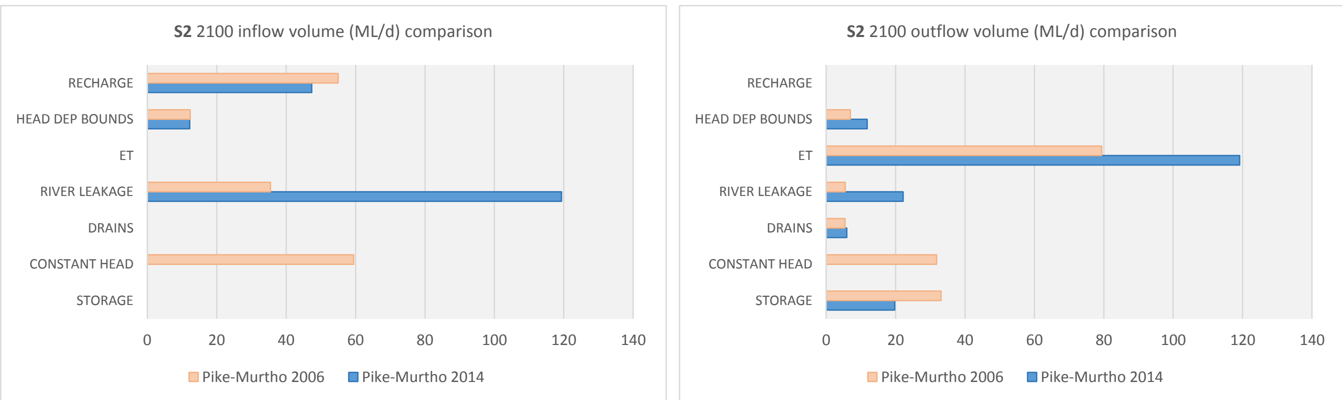


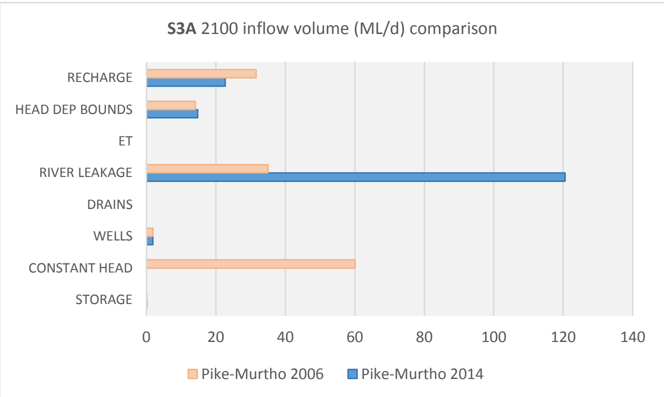
Figure 7.8 Scenario 2 inflow volume comparison for year 2100

Table 7.17 Scenario 3A: Pike-Murtho 2006

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**	**Year**	**2000**	**2015**	**2050**	**2100**
STORAGE	1.1	2.8	0.4	0.0	STORAGE	11.7	8.8	5.8	3.4
CONSTANT HEAD	60.1	60.3	60.2	60.1	CONSTANT HEAD	40.8	39.9	41.5	42.0
WELLS	1.9	1.9	1.9	1.9	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	4.3	4.3	4.5	4.6
RIVER LEAKAGE	36.2	35.4	35.1	35.0	RIVER LEAKAGE	8.9	10.2	12.3	12.9
ET	0.0	0.0	0.0	0.0	ET	76.2	76.2	76.5	76.7
HEAD DEP BOUNDS	14.7	14.6	14.3	14.1	HEAD DEP BOUNDS	3.0	3.0	3.0	3.1
RECHARGE	30.8	27.5	31.6	31.6	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*144.8*	*142.5*	*143.5*	*142.7*	*TOTAL OUT*	*144.8*	*142.5*	*143.5*	*142.7*

Table 7.18 Scenario 3A: Pike-Murtho 2014

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**	**Year**	**2000**	**2015**	**2050**	**2100**
STORAGE	0.0	0.0	0.0	0.0	STORAGE	3.4	2.7	2.7	1.3
CONSTANT HEAD	0.0	0.0	0.0	0.0	CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	1.9	1.9	1.9	1.9	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	4.6	4.7	5.1	5.3
RIVER LEAKAGE	121.9	121.4	120.8	120.6	RIVER LEAKAGE	27.5	28.8	31.5	32.1
ET	0.0	0.0	0.0	0.0	ET	117.4	117.9	118.9	119.2
HEAD DEP BOUNDS	15.2	15.1	15.0	14.8	HEAD DEP BOUNDS	1.9	1.9	2.0	2.0
RECHARGE	15.8	17.6	22.7	22.7	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*154.7*	*156.1*	*160.3*	*159.9*	*TOTAL OUT*	*154.7*	*156.0*	*160.3*	*159.9*



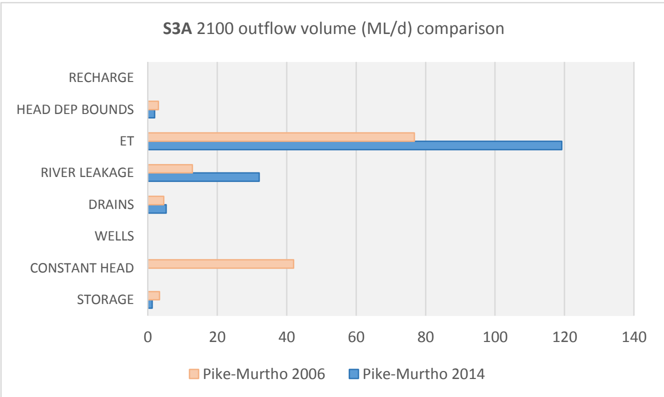


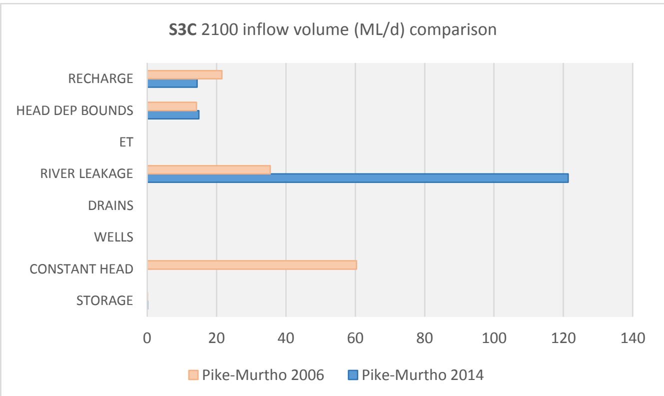
Figure 7.9 Scenario 3A inflow volume comparison for year 2100

Table 7.19 Scenario 3C: Pike-Murtho 2006

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**	**Year**	**2000**	**2015**	**2050**	**2100**
STORAGE	1.5	3.3	1.0	0.0	STORAGE	11.2	6.8	3.5	2.1
CONSTANT HEAD	60.1	60.4	60.4	60.3	CONSTANT HEAD	41.1	38.0	37.5	37.4
WELLS	1.8	0.0	0.0	0.0	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	4.3	4.0	4.0	4.1
RIVER LEAKAGE	36.1	35.5	35.5	35.5	RIVER LEAKAGE	8.9	8.6	8.4	8.5
ET	0.0	0.0	0.0	0.0	ET	76.2	76.1	76.3	76.5
HEAD DEP BOUNDS	14.7	14.5	14.4	14.2	HEAD DEP BOUNDS	3.0	3.0	3.0	3.0
RECHARGE	30.5	22.9	21.5	21.5	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*144.8*	*136.5*	*132.7*	*131.6*	*TOTAL OUT*	*144.8*	*136.5*	*132.7*	*131.6*

Table 7.20 Scenario 3C: Pike-Murtho 2014

Inflow volume (ML/d)					Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**	**Year**	**2000**	**2015**	**2050**	**2100**
STORAGE	0.5	0.8	0.0	0.0	STORAGE	2.5	0.9	1.9	0.9
CONSTANT HEAD	0.0	0.0	0.0	0.0	CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	1.8	0.0	0.0	0.0	WELLS	0.0	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0	DRAINS	4.3	4.1	4.3	4.4
RIVER LEAKAGE	122.0	122.1	121.5	121.4	RIVER LEAKAGE	26.4	23.7	25.7	26.1
ET	0.0	0.0	0.0	0.0	ET	117.1	116.6	117.1	117.3
HEAD DEP BOUNDS	15.2	15.2	15.0	14.9	HEAD DEP BOUNDS	1.9	1.9	2.0	2.0
RECHARGE	12.7	9.3	14.4	14.4	RECHARGE	0.0	0.0	0.0	0.0
TOTAL IN	*152.3*	*147.3*	*151.0*	*150.7*	*TOTAL OUT*	*152.3*	*147.3*	*151.0*	*150.7*



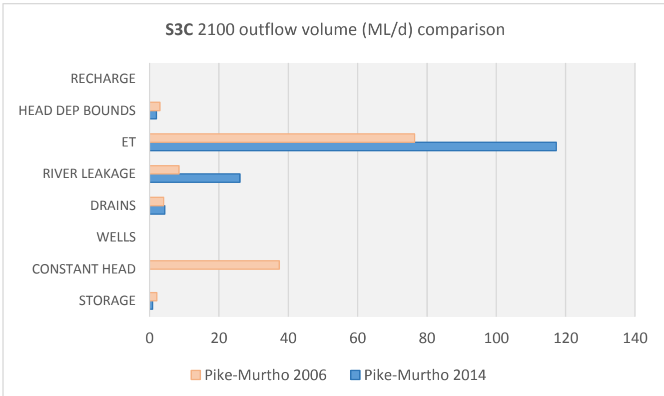


Figure 7.10 Scenario 3C inflow volume comparison for year 2100

Table 7.21 Scenario 4: Pike-Murtho 2006

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	1.2	2.9	0.4	0.0
CONSTANT HEAD	60.1	60.4	60.3	60.1
WELLS	1.8	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	36.1	35.5	35.4	35.3
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	14.7	14.6	14.4	14.1
RECHARGE	31.6	23.8	27.7	29.4
TOTAL IN	*145.6*	*137.1*	*138.2*	*138.9*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	11.8	7.0	6.3	4.2
CONSTANT HEAD	41.0	38.1	38.5	40.0
WELLS	0.0	0.0	0.0	0.0
DRAINS	4.4	4.0	4.2	4.3
RIVER LEAKAGE	9.3	9.0	9.8	10.7
ET	76.2	76.1	76.4	76.6
HEAD DEP BOUNDS	3.0	3.0	3.0	3.1
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*145.6*	*137.1*	*138.2*	*138.9*

Table 7.22 Scenario 4: Pike-Murtho 2014

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.5	0.7	0.0	0.0
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	1.8	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	122.0	122.0	120.3	119.8
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	15.2	15.1	14.9	14.5
RECHARGE	13.4	10.1	29.1	29.1
TOTAL IN	*152.8*	*148.0*	*164.4*	*163.4*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	2.6	1.0	8.6	3.8
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	0.0	0.0	0.0	0.0
DRAINS	4.4	4.2	5.1	5.7
RIVER LEAKAGE	26.7	24.1	30.5	32.7
ET	117.2	116.7	118.3	119.1
HEAD DEP BOUNDS	1.9	1.9	2.0	2.2
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*152.8*	*148.0*	*164.4*	*163.4*

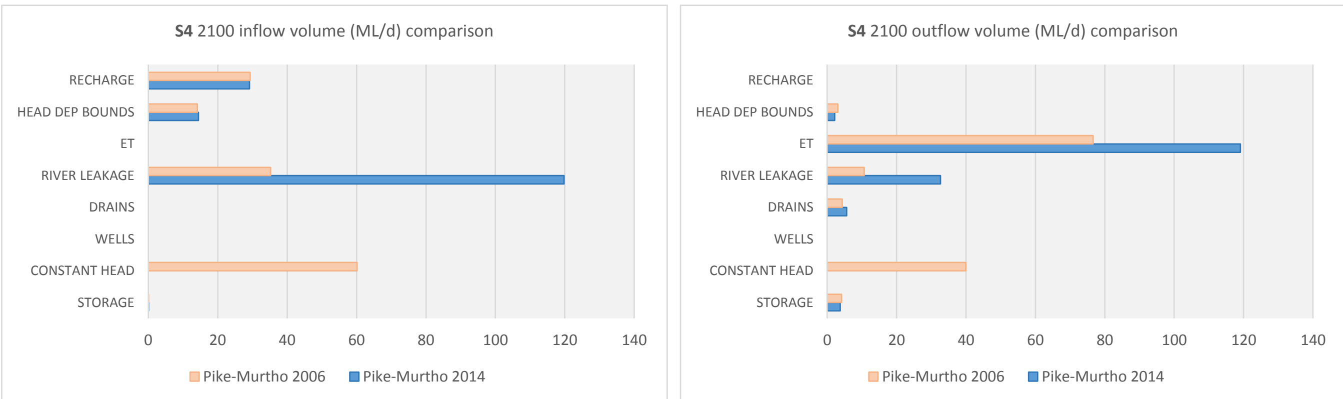


Figure 7.11 Scenario 4 inflow volume comparison for year 2100

Table 7.23 Scenario 7A/S6: Pike-Murtho 2006

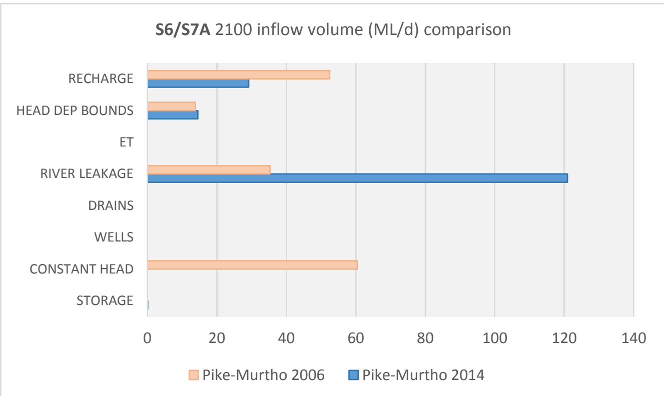
Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	1.2	2.7	0.0	0.0
CONSTANT HEAD	60.1	61.2	61.3	60.4
WELLS	1.8	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	36.1	36.4	35.9	35.3
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	14.7	14.6	14.4	13.8
RECHARGE	31.6	32.9	38.7	52.5
TOTAL IN	*145.6*	*147.7*	*150.3*	*162.0*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	11.8	14.8	10.6	11.2
CONSTANT HEAD	41.0	35.4	36.0	38.2
WELLS	0.0	0.0	0.0	0.0
DRAINS	4.4	13.1	17.6	24.4
RIVER LEAKAGE	9.3	5.4	6.5	7.8
ET	76.2	76.0	76.5	77.3
HEAD DEP BOUNDS	3.0	3.0	3.0	3.1
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*145.6*	*147.7*	*150.3*	*162.0*

Table 7.24 Scenario 7A/S6: Pike-Murtho 2014

Inflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	0.5	6.5	0.0	0.0
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	1.8	0.0	0.0	0.0
DRAINS	0.0	0.0	0.0	0.0
RIVER LEAKAGE	122.0	123.0	122.0	120.9
ET	0.0	0.0	0.0	0.0
HEAD DEP BOUNDS	15.2	15.1	15.0	14.6
RECHARGE	13.4	10.1	29.1	29.1
TOTAL IN	*152.8*	*154.8*	*166.1*	*164.6*

Outflow volume (ML/d)				
Year	**2000**	**2015**	**2050**	**2100**
STORAGE	2.6	0.9	7.7	3.5
CONSTANT HEAD	0.0	0.0	0.0	0.0
WELLS	0.0	8.9	8.9	8.9
DRAINS	4.4	5.0	5.9	6.3
RIVER LEAKAGE	26.7	21.4	23.9	25.4
ET	117.2	116.6	117.8	118.4
HEAD DEP BOUNDS	1.9	1.9	2.0	2.2
RECHARGE	0.0	0.0	0.0	0.0
TOTAL OUT	*152.8*	*154.8*	*166.1*	*164.6*



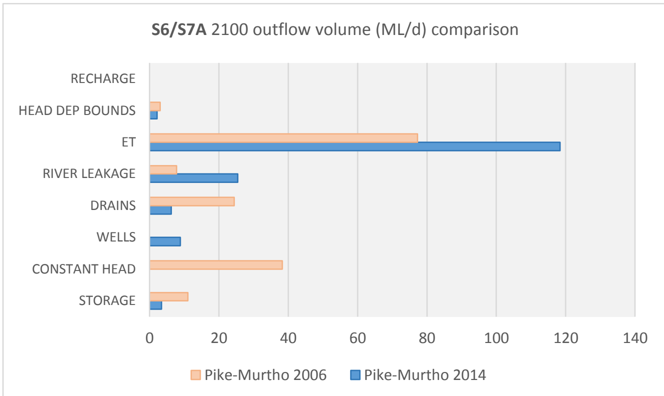


Figure 7.12 Figure Scenario 7A/S6 inflow volume comparison for year 2100

Attachment A

Subsequent to workshops held in Adelaide on the 31 March 2015 and 16 September 2015 and discussions at Basin Salinity Advisory Panel meeting 26 in Canberra on 30 September 2015, the MDBA is providing the following recommendations to South Australia to progress the review of 16 salinity register entries:

1) It is recommended that South Australia provide clear documentation addressing the specific written concerns raised by jurisdictions as outlined below and as further detailed in Attachment B.

    a. compare and contrast the salinity impacts calculated by the updated models with the salinity impacts calculated by the methods used for estimation of current register entries;
    b. provide an explanation of how key aspects of the new modelling approaches (i.e. conceptualisation, inputs and parameterisation) differs to those used in the modelling or assessment of current register entries and why these changes represent an improvement compared to current methods;
    c. provide supporting physical and monitoring evidence in support of revised conceptualisation and quantification of salinity processes (where available);
    d. provide comparison between the recharge rates and timing assumed for previous models and that assumed for current models; and,
    e. provide the water balances for each of the scenarios for evaluation by the peer reviewers.

2) Confirm that constant river levels were used for forecasting in groundwater models when those models were used for assessing accountable actions for the Salinity Registers.

3) Confirm that the current chronological sequence of accountable actions as described for the Waikerie to Morgan 2012 model, Woolpunda 2013 and Pike-Murtho 2014 models has been used as the basis for estimating the revised register entries.

4) Note that when conducting future reviews the salinity impact of Mallee clearance should be fully integrated with other scenarios which are being used for separating the impacts of other accountable actions.

5) Follow the process outlined in this paper for finalising the revisions to the register entries affected by the South Australian review.

Background

6) South Australia submitted three models which have been independently reviewed in accordance with the MDBA requirements and have been recommended to be “fit for purpose” through an independent peer review process.

7) Results derived from the three revised models inform the revision of 16 salinity register entries which include South Australian State Actions and Joint Actions.

8) South Australia has prepared summary documents outlining each of the register entries supported by the updated models and documented how the salt loads from model scenario runs have been used for reviewing and revising the register entries.

9) South Australia has provided to the MDBA documentation towards fulfilling its obligations in accordance with Schedule B (cl.33, 38 & 39) of the Murray-Darling Basin Agreement and the BSMS Operational Protocol which provides direction for reviews (Section 5.7) with regard to Pike-Murtho 2014, Woolpunda 2013 and Waikerie to Morgan 2012 models.

10) However, the peer review reports for Woolpunda 2013 and Waikerie to Morgan 2012 models noted that the alignment of modelling scenarios for revision of register entries impacted by the models was not reviewed as part of the peer review.

11) Jurisdictions have noted the findings of the independent peer review of the three models as “fit-for-purpose” for only part of the process that is necessary to adjust register entries.

12) Jurisdictions have provided their concerns through written advice and workshops (31 March and 16 September 2015), held for resolving the outstanding issues associated with application of updated models.

13) Discussions held at Basin Salinity Management Advisory Panel workshop on 16 September 2015 also requested that the MDBA provide guidance on

    a. the river level boundary conditions to be used in the groundwater model runs for determining salt load accessions to the river; and,
    b. advice on the scenario sequencing to be used in the assessment of register entries affected by the South Australian reviews.

Issues

14) The three models (Pike-Murtho 2014, Woolpunda 2013 and Waikerie to Morgan 2012) have implications for salinity impact of 16 salinity register entries. Some of these register entries involve actions that are jointly funded by other jurisdictions and have implications for their register balance.

15) There is recognition that updated models can result in substantial changes in the salt load accessions to the river compared to the previous modelled assessments and this has a significant effect on register entries.

16) Due to large number of register entries affected and the magnitude of the changes in register entries, jurisdictions have requested that justification for these changes need to be fully explained and documented including explanation as to why they are better than the previous register entries.

Use of constant river levels in groundwater models

17) The boundary conditions used in groundwater models was discussed at the BIGMOD workshop on 17 September 2015 in Adelaide. The workshop suggested that a protocol update for Basin Salinity Management 2030 strategy be made in connection with using constant river levels for forecasting salinity impacts and using the best available river level information for model calibration. Until such a protocol is made the MDBA provides the following advice to South Australia.

18) If the historical river levels are used in the groundwater models in prediction mode, then the salinity impact of accountable actions cannot be isolated from the impact of the transition to average river levels which are not accountable. This is particularly

relevant for legacy of history assessments when the salt load at the year 2000 is particularly relevant.

19) Therefore, the MDBA recommends that constant river levels and constant climate are required when those models are used (in the prediction mode) to assess accountable actions for the Salinity Registers.

20) However, this does not extend to using constant climate and constant river levels in the history match model run that is used for the purpose of calibration and accreditation of the groundwater models. The best available information including variable river levels may be used for the purpose of model calibration.

Estimating salt accession to the River - Scenario sequencing issues

21) The scenario sequencing for the estimation of salt accessions to the river adopted by South Australia for the Waikerie to Morgan river reach as shown in Table 1 is sufficient for estimating the revised register entries.

Table 1. Scenario Sequence in Waikerie to Morgan 2012 model

Scenario	Name	IIP	Irrigation Development	SIS
S1	Natural System	No	No	No
S2	Mallee Clearance	No	No	No
S3A	Pre-1988	No	1988	No
S3C	S3A+IIP	Yes	1988	No
S4	S3C+Post-88	Yes	Pre-1988 + Post-1988	No
S8A(i)	S4+SIS (Waikerie I)	Yes	Pre-1988 + Post-1988	Yes
S8A(ii)	S8A(I)+SIS (Waikerie I+QSTGCS)	Yes	Pre-1988 + Post-1988	Yes
S8A(iii)	S8A(i)+SIS (Waikerie (I , IIA)+QSTGCS)	Yes	Pre-1988 + Post-1988	Yes
S8A(iv)	S8A(i)+SIS (Waikerie (I,IIA,Lock 2)+QSTGCS)	Yes	Pre-1988 + Post-1988	Yes
S8B(i)	S3C+SIS (Waikerie I)	Yes	1988	Yes
S8B(ii)	S3C+SIS (Waikerie I+QSTGCS)	Yes	1988	Yes
S8B(iii)	S3C+SIS (Waikerie(I, IIA)+QSTGCS)	Yes	1988	Yes
S8B(iv)	S3C+SIS (Waikerie(I,IIA, Lock2)+QSTGCS)	Yes	1988	Yes

22) However, the current scenarios considers Mallee clearance (S2) as a separate scenario and has not been fully integrated into the rest of the scenario sequence. Thus the MDBA recommends that in future reviews, the salinity impact of Mallee clearance should be fully integrated with other scenarios which are being used for separating the impacts of other accountable actions.

23) The scenarios sequencing presented in the Table 1 are also applicable for Woolpunda and Pike-Murtho river reaches.

Process for finalising the revised register entries.

24) South Australia to provide additional documentation in line with the recommendations outlined in this document.

25) The MDBA will provide the additional documentation from South Australia to the independent peer reviewers appointed to review the application of updated groundwater models and modelling scenarios for revising the register entries.

26) Upon considering the advice of the independent peer reviewers and the Basin Salinity Management Advisory panel, the Authority will approve the changes to the register entries resulting from the South Australian reviews of accountable actions.

27) At the same time, the MDBA advises the Salt Interception Technical Working Group about the outcome of the review process.

28) If there are any changes to the sharing arrangements of the Salinity and Drainage Strategy credits as a result of these reviews, the Authority will make a determination on those changes, in accordance with Schedule B, upon recommendation of the Basin Officials Committee.

29) The revisions to the register entries will be included in the Salinity Registers following resolution of issues related to the review of affected accountable actions.

Australian Government

MURRAY–DARLING BASIN AUTHORITY

MDBA ref: D15/82055

23 December 2015

Ms Judith Kirk
Manager - Salinity
Department of Environment Water & Natural Resources
PO Box 1047
Adelaide South Australia 5001

Review of accountable actions in South Australian River reaches

Dear ~~Ms Kirk~~ Judith

It was agreed a recent workshop and Basin Salinity Management Advisory Panel (BSMAP) meeting that the MDBA would document the remaining information South Australia must provide to support progressing the amendment of 16 salinity register entries. These register entries are supported by three groundwater models which have been revised and updated (Pike-Murtho, Woolpunda and Waikerie to Morgan models).

Significant changes to the register entries have been proposed as a result of these reviews. This will have a significant impact on the register balances of other jurisdictions. Due to the number of register entries affected and magnitude of the proposed changes, there is a need for clarity and rigour in the documentation of how the modelling outcomes are interpreted and subsequently used for revising the register entries.

This letter requests South Australia to provide specific information, as outlined in Attachment A, to support Basin Officials Committee and the Authority to finalise the amendment of these register entries.

Should you have any further questions about this matter, please feel free to contact the MDBA officer Asitha Katupitiya (Phone: 02 6279 0585, E-mail: asitha.katupitiya@mdba.gov.au).

Yours sincerely,

Mike Makin
A/g General Manager, Water Resources Planning

cc. New South Wales office of water, Department Primary Industries
Victoria, Department of Environment Land Water & Planning

SA Accountable Action and Model Review Workshop - 17 September 2015- Comments from Victoria

The meeting highlighted a number of issues as well as addressing some concerns that had been raised. The opportunity to take the time to discuss the ways in which the scenarios were constructed was very useful and it was well worth the effort to arrange and conduct the meeting. The presentations and discussions at this meeting and the meeting in March have provided a considerable amount of information relevant to the assessment of the accountable actions not contained or difficult to ascertain from the modelling reports.

Given the large changes proposed in register entries and the implications for the joint SIS schemes, Victoria is of the view that the additional documentation to support the review and adjustment of the accountable actions should:

- compare and contrast the salinity impacts calculated by the updated models with the salinity impacts calculated by the methods used for estimation of current register entries
- provide an explanation of how key aspects of the new modelling approaches (i.e. conceptualisation, inputs and parameterisation) differs to those used in the modelling or assessment of current register entries and why these changes represent an improvement compared to current methods
- provide supporting physical and monitoring evidence in support of revised conceptualisation and quantification of salinity processes.

The key points arising from the meeting in terms of the process required to finalise the review of the accountable actions are:

Key point 1 - recharge is determined by inverse modelling

What Victoria found from the meeting:

Model recharge rates and changes in recharge over time in the model are determined by inverse modelling combined with the mapped irrigation footprint. The studies of irrigation accessions are not used to drive (or control) model recharge.

What this means:

Our concern that the distribution of recharge/accessions that is described in the (Meissner) report was not realistic appears to have been addressed, as it was stated there is no direct connection between model recharge and the (Meissner) accession figures- the assumptions and issues around accession estimates and distributions do not unduly influence the model or the results. However, the modelled recharge rates are solely dependent on the observed hydrographs. Thus they are constrained by the locations and length of record of the hydrographs.

Where this approach is limited is that it provides very limited information on which to project irrigation recharge in the scenarios. In particular IIP can only be determined by observation of hydrograph response.

Next steps:

Further work for the review of accountable actions: The additional information presented in the meeting about the use of the Meissner work and accessions should be clearly documented in material to be provided to the peer reviewer. Comparisons should be provided between the recharge rates and timing assumed for previous models and that assumed for current models.

Peer review: The peer reviewers should specifically consider and address the basis on which recharge rates are defined in the scenarios. How have they determined how recharge will change over time ? What is the basis of the future rate (i.e. as accession rates reach the water table) ? The peer reviewers should provide specific advice on whether the scenario recharge rates are reasonable.

Key point 2 – Floodplain ET processes are poorly modelled and yet are important

What Victoria found from the meeting:

We confirmed that groundwater ET in the floodplain has been included in many of the model areas for the first time. We confirmed and agreed in the meeting that the representation of ET is poor in the models and that much more information and understanding about ET is available. We also found out that the modelled salt loads are very sensitive to changes in ET parameters. We also confirmed that the three models are not consistent in treatment of ET parameters. There was unresolved argument as to whether this was important.

What this means:

Inclusion of groundwater ET on the floodplain effectively reduces the salt load estimated to reach the river for the same lateral or upward flux. In the earlier models ET had not been specifically incorporated as it had been generally agreed that any salt load that discharged to the floodplain would eventually find its way to the river. Thus, for a long term salinity evaluation ignoring floodplain ET would allow all of the salt entering the floodplain to reach the river.

By specifically including ET in the current models, a proportion of the flow from surrounding areas is lost to ET. In the real world, this salt is parked in the floodplain and tends to be mobilised during floods. In the models there is no mechanism for the release of this salt. This is compounded by the flat river level that is used. Important processes of bank storage and flood recession are not included in the models and thus the salt load that these processes provide is not included.

Overall, the way that ET has been included in the model will tend to lower the salt loads that are predicted to enter the river and thus are likely to lower the predicted salt load. This would have a tendency to lower the salinity impact on the register for the modelled actions. It is possible this is the reason that the Mallee clearing impacts are greatly reduced.

Next steps:

Further work for the review of accountable actions: SA should provide the water balances for each of the scenarios for evaluation by the peer reviewers. Current model documentation only includes the combined results of all the scenarios.

Peer review: The peer reviewers should carefully examine how ET varies between the scenarios that have been modelled and how it varies over time and how this affects the salt loads associated with each of the scenarios. They should then provide advice on how this approach differs from the previous approach and whether this is considered to be fit for purpose for assessment of the register entries.

Matters for BSMAP: After the technical advice is received, there is a policy decision to be made by BSMAP as to whether this potentially significant change in conceptual approach is adequate. Victoria's preliminary view is that a sub-model or some additional step is needed to add salt back to this estimate to allow for the amount returned in flood events and fairly represent the amount of salt load reaching the river.

Key point 3 – Irrigation impacts occur slowly but recharge benefits from IIP occur quickly

What Victoria found from the meeting:

The models incorporate long lag times between when irrigation commences and when recharge reaches the watertable. Conversely, they include rapid reductions in recharge in response to IIP.

What this means:

The models have pushed out the impact of irrigation in many cases into future years whilst they have brought forward benefits from IIP much earlier. This has the effect of reducing the groundwater impact of irrigation overall. This generally lowers the overall salt load effect of irrigation.

This appears to be the main reason why the pre-88 irrigation impacts have reduced: they have been bought forward and the recharge is less than previously modelled.

It also explains why the effect of IIP is greater as reductions in recharge occur earlier (and ET effects cut over the top further reducing the modelled effect).

Next Steps:

Peer review: The peer reviewers need to assess whether the approach used to set the future recharge rates (as accessions reach the water table) for the scenarios is appropriate in light of the results.

Key point 4 - MDBA appears to have concerns about the scenario order

What Victoria found from the meeting:

MDBA modelling staff expressed concern about the way in which the unpacked scenarios were collated. There was a lot of confusion in terms (For example, RISI was used when IIP was meant) and there appeared to be internal contradictions in expectations and approach within the MDBA.

What this means:

This is concerning as SA have emphasized their adherence to MDBA requirements. It appears that verbal advice given by MDBA officers may not represent the official technical position, particularly in regard to the construction of scenarios.

The application of constant river head in assessing salinity impacts appears to have been misinterpreted and consequently the model has been calibrated against constant river height. This is inconsistent with MDBA modelling advice that the constant river head assumption was to be applied in assessing the impacts for the 2000, 2015, 2050 and 2100 scenarios. No advice from MDBA modellers had been given to apply this assumption to the calibration of the model.

Next Steps:

MDBA and BSMAP: The MDBA should assess the mechanism of construction of the scenarios and the order of scenarios and provide a consolidated organisational view to BSMAP which the model approach can then be tested against. The proposed Operational Procedures for BSM2030 should address the use of constant river head in assessing accountable actions after confirmation through BSMAP.

Peer Review. The peer review should consider whether the way the constant river level assumption has been applied is acceptable and whether it has a material effect on the estimated salt loads.

Key point 5 - Key items have had the fundamental basis of the register entry changed

What Victoria found from the meeting:

The main reason for some of the changes in the salinity effects are a result of changes to the fundamental basis and assumptions about how the action will operate and when these changes to the assumptions are modelled, the resultant salt benefits are very different from the current register entry. This is not a result of the model changes, although the model changes may contribute to the final EC number. An example is the Pike-Murtho SIS, which has had significant changes to the pump capacity (restricted by pipeline size) and exclusion of future irrigation. It was also stated in the meeting that the salinity assessment for the business case included the impact of future expansion in the Murtho areas. This is an important issue for Victoria as if this was the case it appears that the assessment provided to support the business case and currently on the register is not consistent with Schedule B and BSMS protocols.

What this means:

The proposed changes are not related to the model, the scenarios or the fit-for-purpose assessment of the model. The changes are a result of a policy decision to present these impacts in this way.

Next Steps:

Further work for the review of accountable actions : Additional model runs should be undertaken that present the salinity estimate of the affected register items under the assumptions that are on the register. The difference between the two modelled approaches can then be clearly assessed against the modelled impact of the changes in operational basis. This should then be written up in the proposal for the change in the register entries.

Key Point 6 -The groundwater models are non-unique and modelled salt loads are sensitive to parameters

What Victoria found from the meeting:

There are a number of factors that have been used to calibrate the models and these are constrained by real world measurements. It nevertheless has been shown that large changes in modelled groundwater flow to the Murray and hence the modelled salt load can result from changes in model input parameters. The model reports do not deal with this observation in a consistent way. Model calibration has largely been assessed on the basis of RMS error for groundwater level. The majority of groundwater level measurements are outside the floodplain. This generally shows that the irrigation impacts are tracked. But as the way that irrigation recharge has been modelled, it is expected that a good fit could be achieved. What is not as clear is how the salt load varies as a result of changes.

Next Steps:

Further work for the review of the accountable actions: To assess the scenarios we need to get a better understanding of the salt load changes that result from parameter changes in the model. Formal sensitivity and uncertainty analysis of the models is recommended, which specifically address the sensitivity and uncertainty in salt load. This is a task that could be guided by the peer reviewers.

Key Point 7 –BIGMOD Assumptions about saltload and flow

What Victoria found from the meeting:

Assumptions about flow and saltload used in BIGMOD in estimating the EC impact at Morgan have changed. The outcomes of this are particularly evident in the case of the proposed decrease in salinity effect for Woolpunda SIS.

Next Steps: The peer review should consider the validity of this approach and whether it is an improvement to the approach used for the current register entry and fit for purpose.

7.4 The sharing arrangements

Credit Sharing for Joint Works and Measures

Salinity & Drainage Strategy Works and Measures	Percent	Register
NSW receives 15/80's of the total 80 EC program	18.75%	A
Vic receives 15/80's of the total 80 EC program	18.75%	A
The River receives 50/80's (SA's 15/80 and Cwlth's 35/80)	62.5%	n/a
SA receives	0%	n/a

Basin Salinity Management Strategy Works and Measures

NSW receives:	Percent	Register
- State Share to Register A = 10/61 or 16.39%	16.39%	A
- State Share to Register B = 5.25/61 or 8.61%	8.61%	B
- Cwlth Share to Register B = 15% of (15.25/61 or 25%) or 3.75%	3.75%	B
	28.75%	
Vic receives:		
- State Share to Register A = 10/61 or 16.39%	16.39%	A
- State Share to Register B = 5.25/61 or 8.61%	8.61%	B
- Cwlth Share to Register B = 5% of (15.25/61 or 25%) or 1.25%	1.25%	B
	26.25%	
SA receives:		
- State Share to Register A = 10/61 or 16.39%	16.39%	A
- State Share to Register B = 5.25/61 or 8.61%	8.61%	B
- Cwlth Share to Register B = 80% of (15.25/61 or 25%) or 20%	20.00%	B
	45.00%	

Appendix 7.6 Salt interception scheme locations within South Australia

Government of South Australia

Department of Environment, Water and Natural Resources