Border to Lock 3 Groundwater model upgrade

DEW Technical note 2018/57

Government of South Australia
Department for Environment and Water

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Summary

The ongoing River Murray Groundwater Salinity Modelling and Hydrogeological Advice Project maintains models to support SA accountable actions on the Basin Salinity Management 2030 (BSM2030) Salinity Register. In this study, several options for future Salinity Register model upgrades are trialled by modifying the Border to Lock 3 model. Most options relate to model construction, and they are tested to see whether they change estimates of salt load in simulations of a historical period. A final option relates to scenario assumptions, and is tested to see how it changes estimates of future salt loads. These works will inform upcoming upgrades to SA Salinity Register models.

The sub-models of the Border to Lock 3 model were transferred from the Visual MODFLOW platform to Groundwater Vistas. This is a preliminary step for the upgrade of the Pike-Murtho, Berri-Renmark, Loxton-Bookpurnong, and Pyap to Kingston sub-models. The Groundwater Vistas platform will enable the models to simulate reductions in irrigation area over time, and to simulate all irrigation regions simultaneously.

Transferring model platforms resulted in minimal salt load change in most irrigation districts, with the exception of Renmark. A number of assumptions have changed within the Border to Lock 3 model since the Berri-Renmark sub-model was developed, which cause the difference in salt load. Further investigation is recommended as part of the future model upgrade of the Berri-Renmark sub-model, scheduled for 2020-2011.

The sub-model approach was tested, i.e. the assumption that irrigation recharge and SIS pumping within one project area will not substantially impact the potentiometric head in another project area. A simulation was run which included all irrigation areas and SISs simultaneously. Salt load results confirm the general validity of the sub-model approach. The exception is the Pike-Murtho region, which shows significant impact from adjacent irrigation, as salt load is significantly increased in both Pike and Murtho.

A revised irrigation area was developed by cross-checking between multiple datasets (MSA Crop Data 2013-2014 (MSA), Google Earth Pro imagery dated 2015 (Google Inc.), ArcGIS imagery dated 2014 (ESRI) and SA Land Cover epoch 2010-2015 (DEW)). In general, the updated irrigation area is smaller than previous estimates, including those used in the accredited and Register Entry models.

The Border to Lock 3 model was run with the revised irrigation area in the transient historical scenario in order to gauge the potential impact to the Salinity Register entries. Overall, accredited Salinity Register models had a larger irrigation recharge area and hence larger salt load impact than the revised simulations. In most areas, salt load results are decreased as the irrigation areas decreased. A significant change can be seen in Pike-Murtho and Loxton-Bookpurnong sub-model results.

The impact of revised irrigation areas on Salinity Register calculations will depend on the time period simulated. The sub-models in this report have not yet been recalibrated. During calibration, the recharge volume for historical periods is estimated through inverse modelling, matching observed potentiometric heads, and it is likely that previous overestimates of irrigation area will have been compensated for by underestimating recharge rates. Hence, the changes to historical salt load presented in this report are likely to diminish once the sub-models have been recalibrated. However, salt loads impacts in future years are strongly dependent on irrigation area, as the recharge rate is fixed.

Uncertainty scenarios explore the impact of different irrigation recharge rate assumptions in a future scenario, SA “Scenario 4” with irrigation but without SIS for the next 100 years. Rates of 100 mm/y and 120 mm/y were considered. Higher recharge rates resulted in higher salt load to the river, particularly for the Pike-Murtho and Berri-Renmark sub-models. The combined impact of revised irrigation area and higher irrigation recharge rate led to minimal change in salt loads for the Loxton-Bookpurnong and Pyap to Kingston sub-models.

The project aims to maintain a suite of up to date groundwater models to support accountable actions on the BSMS2030. This work upgrades the Border to Lock 3 groundwater models to support accountable actions on the Salinity Register. It also explores how differing assumptions about irrigation could potentially affect estimated salt loads for the Salinity Registers.

1 Introduction

River salinity is a significant issue for water supply in South Australia (SA) because of the reliance of SA on the lower reaches of the River Murray. Due to the natural geological structure of the Murray-Darling Basin (MDB), the River Murray in SA acts as a drain for salt out of the landscape. Agricultural practices can mobilise additional salt from groundwater to the river. This affects the water quality of the River Murray for industrial, agricultural, ecological and potable use, including the water supply for metropolitan Adelaide.

SA Salinity management in the MDB requires co-cooperation between the Australian Government, Basin states and the Murray-Darling Basin Authority (MDBA). The current MDBA Basin Salinity Management 2030 (BSM2030) strategy commenced in 2015.

Numerical groundwater models are used to estimate the salinity impacts of management actions on the River Murray, which are recorded in the BSM Salinity Register. Figure 1.1 shows the extent of models developed to support South Australia's compliance with Schedule B to the Murray-Darling Basin Agreement (Schedule 1, Water Act, 2007, Commonwealth). The models extend from the SA border to Wellington, and focus on the interaction of the River Murray with the regional groundwater system, including a simplified representation of floodplain processes. Once approved by an independent peer reviewer nominated by the MDBA, the model is said to be "accredited".

The Salinity Register models were developed over a number of years, and model assumptions are based on the available data and assumptions at the time of the most recent model revision. The models were developed using the Visual MODFLOW platform (Waterloo Hydrogeologic). The models are reviewed and updated regularly according to a schedule approved by the MDBA.

Under BSM2030, the modelling protocols are under review. This includes assumptions about the simulation of irrigation recharge, such as footprint extent and recharge rates. Woods et al. (2017) noted that limitations of the Visual MODFLOW software meant that the retirement of irrigated land could not be simulated; this could be addressed by transferring the models to Groundwater Vistas software (Environmental Simulations, 2018). Bushaway and Woods (2018) found that current irrigation datasets have significant limitations which either resulted in over- or under-estimation of irrigation area. The irrigation recharge rate for current irrigation areas is not easily measurable in situ, and values of 100-120 mm/y have been proposed (Fargher et al., 2003).

This work upgrades the Border to Lock 3 groundwater models to support accountable actions on the Salinity Register. It also explores how differing assumptions about irrigation could potentially affect estimated salt loads for the Salinity Registers.

1.1 The Border to Lock 3 model

The Border to Lock 3 model is the accredited Salinity Register model which covers the major irrigation districts of Loxton, Bookpurnong, Pike, Murtho, Berri, Renmark, Pyap, New Residence, Moorook and Kingston. The model domain spans the entire eastern Riverland area, providing a unified hydrogeological representation of the region.

The model domain contains four Salinity Register project areas. Each project area includes a group of irrigation areas and, where present, Salt Interception Schemes (SIS). Model simulations included irrigation and SIS in only one of the four project areas at a time, due to software limitations and for computational efficiency. For this reason, the Border to Lock 3 model is said to have "sub-models" which refer to versions of the main model which concentrate on specific project areas. One issue raised by MDBA Independent Peer Reviewers is whether this sub-model approach is valid, as irrigation in adjacent project areas could influence model results.

Figure 1.1 to Figure 1.3 depict the location of the Border to Lock 3 model, sub-models and irrigation districts within the project areas.

Over the years, substantial fieldwork and modelling studies have been conducted. Field investigations have refined the understanding of both hydrology and hydrogeology within the model domain. Modelling studies have improved the computational representation of features.

Since its initial development, the Border to Lock 3 model has been revised incrementally by project area. In 2006, the Pike-Murtho modelling project was revised to simulate the conceptual design of SIS in the Pike and Murtho regions of the SA Riverland (Yan et al., 2006). The Border to Lock 3 model was revised further in the Berri-Renmark project area in 2007 (Yan et al., 2007), in the Pyap-Kingston project area in 2008 (Yan and Stadter 2008) and in the Loxton-Bookpurnong project area in 2011 (Yan et al., 2011). These revised Border to Lock 3 models from 2006, 2007, 2008 and 2011 are accredited and their results inform the Salinity Register. The model was revised again in the Pike-Murtho project area (Woods et al., 2014); this model has been accredited but its results are yet to be adopted into the Salinity Register.

During each revision, the model is recalibrated against data from within the project area. All hydrogeological changes to the model are retained for subsequent projects. The sub-models will be named as:

1. BL3_PM – Border to Lock 3 model Pike-Murtho sub-zone modelling project
2. BL3_BR – Border to Lock 3 model Berri-Renmark sub-zone modelling project
3. BL3_PK – Border to Lock 3 model Pyap to Kingston sub-zone modelling project
4. BL3_LB – Border to Lock 3 model Loxton-Bookpurnong sub-zone modelling project

Table 1.1 below displays the Border to Lock 3 sub-models with revised year and presence of SIS within the project areas.

Table 1.1 Border to Lock 3 sub-models revised years and irrigation districts

Sub-model	Revised year	SIS present?	Irrigation district
BL3_PM	PM2006, PM2014	Yes	Pike, Murtho
BL3_BR	BR2007	no	Berri, Renmark
BL3_PK	PK2008	no	Kingston, Moorook, New Residence and Pyap
BL3_LB	LB2011	Yes	Loxton, Bookpurnong

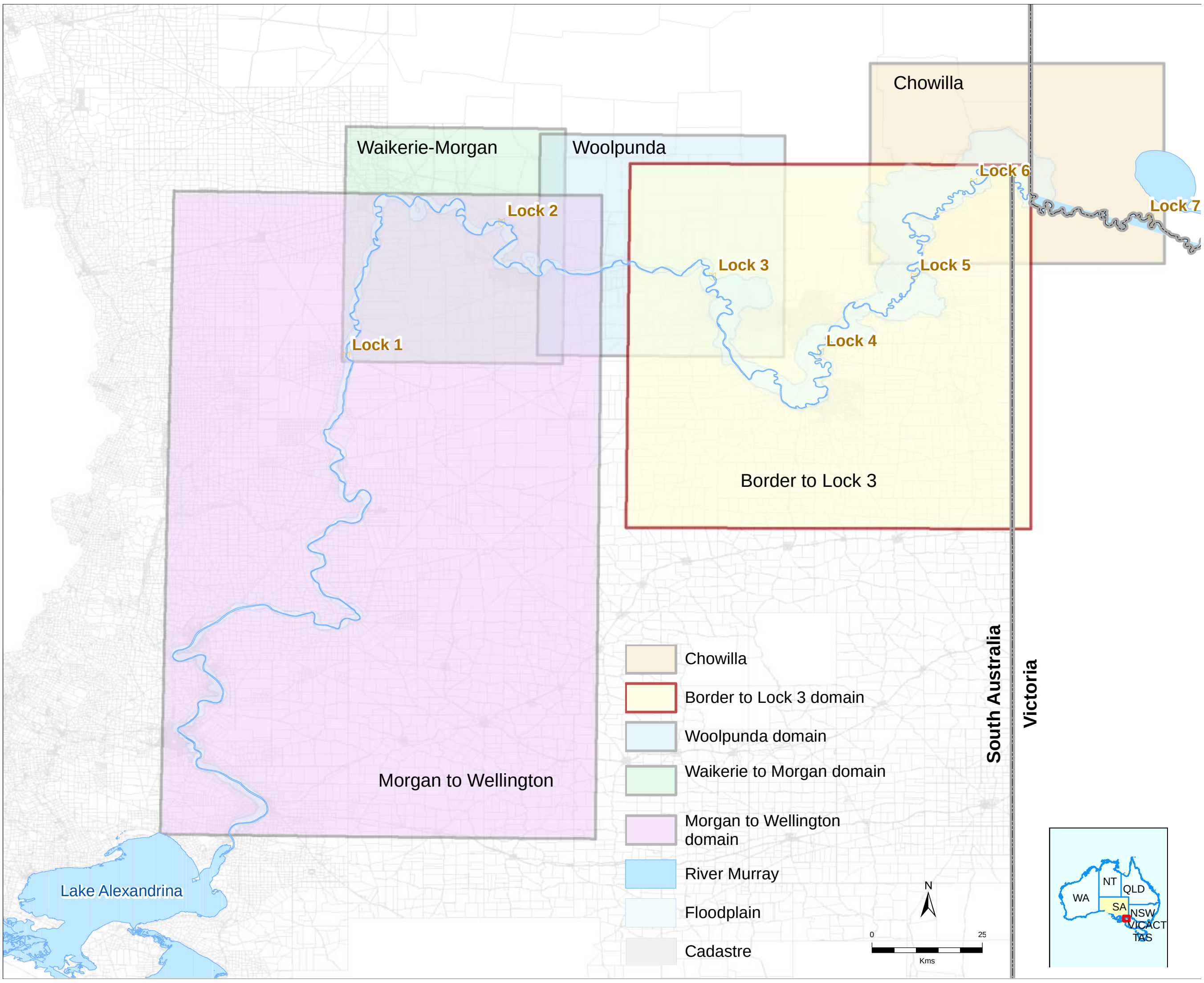

Figure 1.1 Location of the SA Salinity Register models

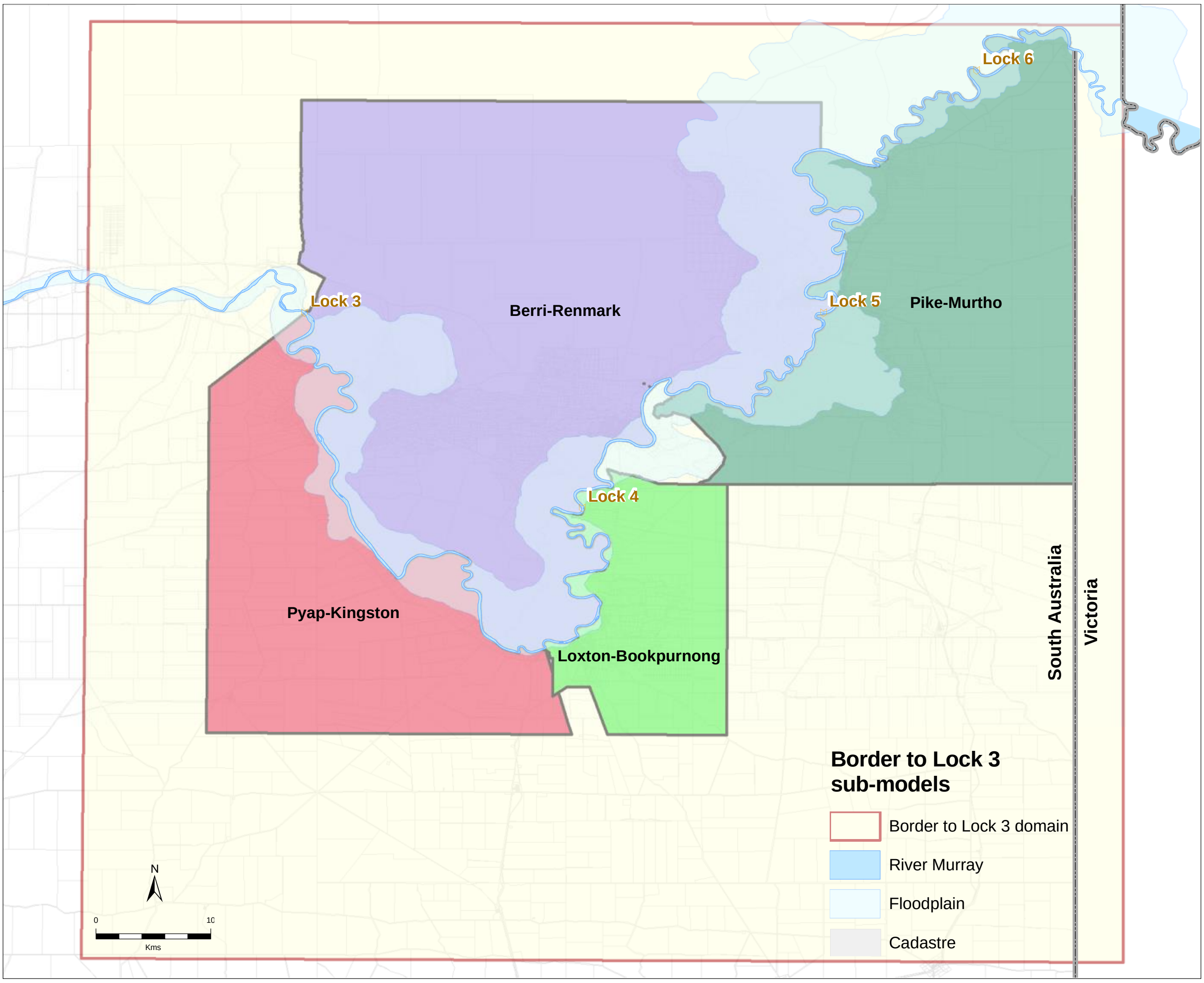

Figure 1.2 The Border to Lock 3 model domain and project areas

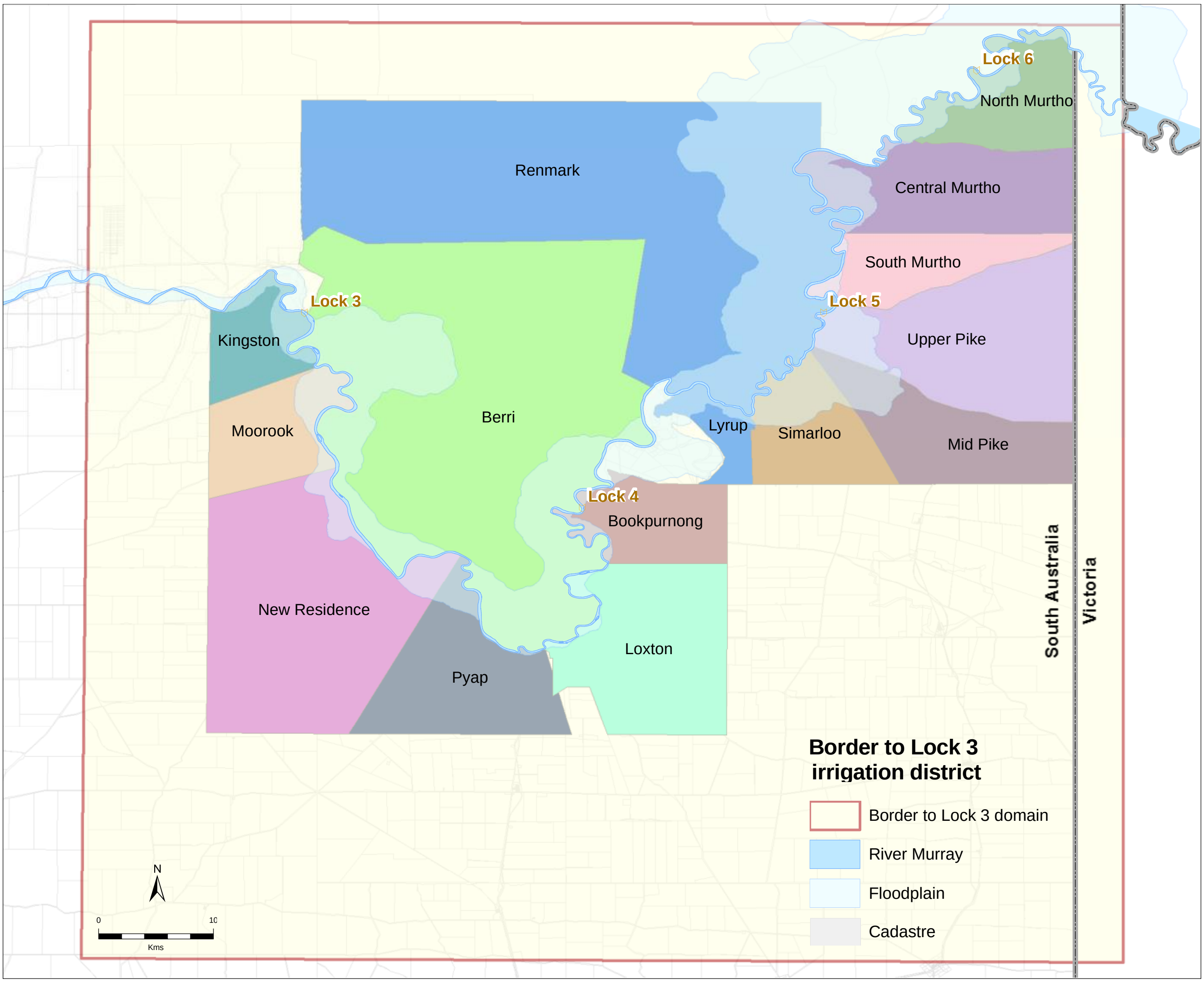

Figure 1.3 Irrigation districts within the Border to Lock 3 model

1.2 The Border to Lock 3 sub-zone models and scenarios

The sub-models have been developed from 2007 to 2014, with later models employing more sophisticated assumptions (Table 1.2). There have been three generations of Salinity Register groundwater models (Woods et al., 2017). The Border to Lock 3 model contains second and third generation models; key differences are how the River Murray is represented and the extent of the salt load calculation zones.

The second generation models represent the River Murray's main channel with constant head cells which provide a potentially infinite source of groundwater flux to/from the river. The third generation models represent the River Murray and its anabranches by utilising 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. River cells allow a more realistic flux constrained by river stage, riverbed bottom elevation and riverbed conductance.

Salt load calculations in the model are made by multiplying flux to river by a specified salinity value for each salinity zone. Second generation models' salinity zones are much coarser than the third generation models', typically spanning several kilometres. Third generation models use salinity zones which span one river kilometre each.

The Berri-Renmark 2007 and the Pyap to Kingston 2008 are second generation models. The Loxton-Bookpurnong 2011 and the Pike-Murtho 2014 are third generation models. Third generation models are updated and refined versions of the second generation models which incorporate new data and modelling improvements.

The submodels are due for review and upgrades as follows: Loxton-Bookpurnong in 2018-2019, Berri-Renmark and Pyap-Kingston in 2020-2021, and Pike-Murtho in 2021-2022.

Table 1.2 Border to Lock 3 sub-models and key differences

Sub-models	Latest references	Model representation of River Murray	Zone for salt load calculation
PM2014 (3rd generation)	Woods et al. 2014	River cells	River kilometre
BR2007 (2nd generation)	Yan et al. 2007	Constant heads	Coarser scale up to 5 km
PK2008 (2nd generation)	Yan et al. 2008	Constant heads	Coarser scale up to 5 km
LB2011 (3rd generation)	Yan et al. 2011	River cells	River kilometre

The definitions for scenarios and terms used in this work are consistent with the other South Australian Salinity Register modelling work. Table 1.3 summarises the scenarios considered in this report. "CY" refers to "current year", the time of model development. "CY100" means "100 years after current year".

Table 1.3 Scenario definitions used by the Border to Lock 3 sub-models

Scenario	Description	Simulation period	Irrigation development
Transient Calibration model (TR)	Historical	1880-CY (2014 as the Pike-Murtho model)	Footprint of irrigation history
Scenario 4 (S4)	Current irrigation	1988-CY100 (2114 as the Pike-Murtho model)	Pre-1988 + Post 1988

1.3 Purpose of the study

This study is a component of the work undertaken for the River Murray Groundwater Salinity Modelling and Hydrogeological Advice Project (2017-18). The project aims to maintain a suite of up-to-date SA groundwater models to support accountable actions on the BSMS2030 Salinity Register.

In this study, several options for future Salinity Register model upgrades are trialled by modifying the Border to Lock 3 model. Most options relate to model construction, and they are tested to see whether they change estimates of salt load in simulations of a historical period. A final option relates to scenario assumptions, and is tested to see how it changes estimates of future salt loads. These works will inform upcoming upgrades to SA Salinity Register models. Specifically, this study aims to:

1. Transfer sub-models of the Border to Lock 3 model from the Visual MODFLOW platform to Groundwater Vistas. This is a preliminary step for the upgrade of the Pike-Murtho, Berri-Renmark, Loxton-Bookpurnong, and Pyap to Kingston sub-models. It will enable the models to simulate reductions in irrigation area over time. As the sub-models were developed at different times, this requires some assumptions to be updated. The impact of the changes in assumptions on salt load is evaluated.

2. Determine whether the sub-model approach leads to different salt loads than a scenario in which all irrigation areas are simulated simultaneously.

3. Develop a more accurate irrigation footprint up to and including 2015, based on multiple datasets, as per recommendations in Bushaway and Woods (2018).

4. Compare model predictions made by the multiple-dataset update of the irrigation footprint to that of the 2015 update to the accredited Salinity Register models (Bushaway et al., 2015).

5. Determine sensitivity of salt load impacts to the river as a result of differing assumptions about future irrigation recharge.

2 Model platform update

Visual MODFLOW (Waterloo Hydrogeologic, 2018) and Groundwater Vistas (Environmental Simulations, 2018) are two software programs providing pre- and post- processing tools for MODFLOW simulations. The SA Salinity Register models were developed using Visual MODFLOW, but the program has limitations for simulating recharge. It does not allow recharge zones to reduce in size over time, for example if land is retired from irrigation. It also has a relatively low limit on the total number of recharge zones, which meant that it was not possible to simulate all irrigations areas simultaneously in the Border to Lock 3 model. Due to these and other limitations, the Border to Lock 3 model was migrated to Groundwater Vistas.

2.1 Method

As discussed in Section 1.1, the Border to Lock 3 model has four sub-zone models. The most recently updated version of the Border to Lock 3 model is the Pike-Murtho sub-zone model (Woods et al., 2014).

Firstly, the Pike-Murtho model was translated from Visual MODFLOW to Groundwater Vistas. This formed the base of the Border to Lock 3 2018 (BL32018) model.

Secondly, irrigation recharge, SIS pumping, and salinity (flux budget) zones were imported from the three remaining sub-models. This had to be carefully managed as the sub-models use different stress periods (Table 2.1). It is noted that the Pyap to Kingston model contains two transient historical models with stress periods from 1880-1960 and 1960-2106. The model results from 1960 to 2006 are obtained from Scenario 4.

Five versions of BL32018 were created (Table 2.1). Four simulate one sub-model area each, so that the Groundwater Vistas results can be directly compared with the Visual MODFLOW sub-models. The fifth version simulates all the sub-model irrigation areas and SIS simultaneously.

Model outputs from Visual MODFLOW were compared with those from Groundwater Vistas, to check that the conversion had occurred accurately (Table 2.2). The transient historical simulation runs were used.

Table 2.1 Realignment of the sub-models stress period

Visual MODFLOW			Groundwater Vistas		
Model name	**Simulation period**	**Number of stress periods**	**Model name**	**Simulation period**	**Number of stress periods**
PM2014_TR	1880-2014	52	BL32018_TR_PM	1880-2014	52
BR2007_TR	1880-2006	44	BL32018_ TR_BR	1880-2014	52
PK2008_TR	1880-2006	60	BL32018_ TR_PK	1880-2014	52
LB2011_TR	1920-2011	92	BL32018_ TR_LB	1880-2014	52
Not simulated	n/a	n/a	BL32018_Allarea (combined all districts)	1880-2014	52

Table 2.2 Models used in salt load results comparison to check the platform update

Visual MODFLOW	Groundwater Vistas
PM2014_TR	BL32018_TR_PM
BR2007_TR	BL32018_TR_BR
LB2011_TR	BL32018_TR_LB
PK2008_TR	BL32018_TR_PK

2.2 Results

The Border to Lock 3 sub-models were developed in different years with different assumptions. For this reason, the sub-models undergo one or two changes when they become part of BL32018:

1. Model assumptions change to those of the Pike-Murtho 2014 model (Woods et al. 2014)
2. Model platform changes to Groundwater Vistas

Salt load results from the model platform update are presented by irrigation district starting from Lock 6 to Lock 3 in Figure 2.1 to Figure 2.10.

The Pike-Murtho sub-model undergoes only a platform change to Groundwater Vistas. Its salt load estimates before and after conversion to Groundwater Vistas should match almost exactly. Figure 2.1 and Figure 2.2 confirm that the conversion has occurred correctly and that there is no difference between the Visual MODFLOW and Groundwater Vistas versions.

The Berri-Renmark sub-model undergoes some significant changes to model assumptions, as this is a second generation Salinity Register model upgraded to third generation assumptions. The differences include:

- Changing initial conditions
- Changing river representation from constant head cells to river cells
- Extending the Border to Lock 3 model domain to the north to include the entire Murtho Land and Water Management Plan (LWMP) which is directly opposite the Renmark irrigation district, and
- Updating model structural contours for the Loxton-Clay-Bookpurnong Formation aquitard in the Pike-Murtho region

These differences lead to a small reduction in salt load for the Berri reach, but there is a large divergence between the Visual MODFLOW and Groundwater Vistas salt loads for Renmark (Figure 2.3 and Figure 2.4). The water budgets of the two models were compared, and it was confirmed that the recharge inflows had been correctly converted. The precise reason for the divergence is unclear at present and will be investigated during the next major review of the Berri-Renmark area, scheduled for 2020-2021.

The Loxton-Bookpurnong sub-model is third generation, employing many of the same assumptions as the Pike-Murtho 2014 model. As expected, Figure 2.5 to Figure 2.6, show that there is a close match between the Visual MODFLOW and Groundwater Vistas estimates of salt load. The salt load is slightly less than the original model in Bookpurnong area, perhaps due to starting heads used in the Loxton-Bookpurnong model differing from those in the Pike-Murtho model which is the base model for the Border to Lock 3 2018 model.

The Pyap-Kingston sub-model is second generation, so discrepancies are expected between the Visual MODFLOW and Groundwater Vistas estimates of salt load. This is observed (Figure 2.7 to Figure 2.10), but the salt load to the river is small, leading to negligible impact. It is noted that salt load entering the river at New Residence in BL32018_PK is less than the PK2008 model: this could be because groundwater flux to constant head cells is generally higher than river cells.

In summary, the conversion to Groundwater Vistas was completed as expected, except that a salt load discrepancy at Renmark requires future investigation.

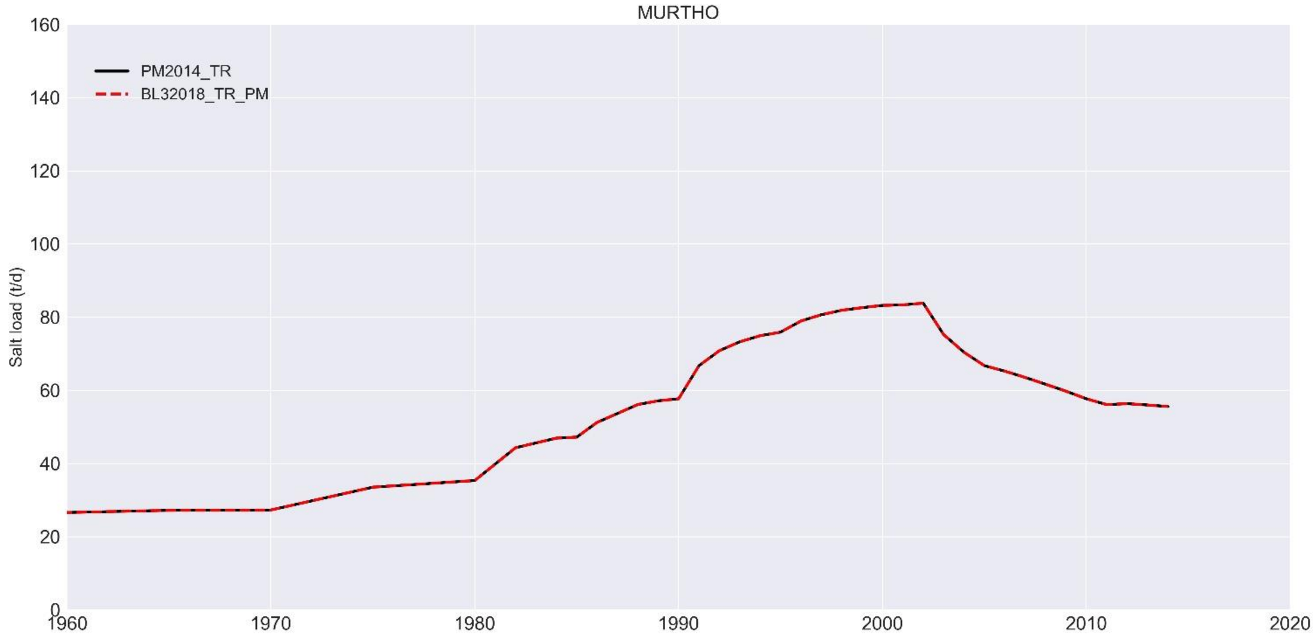

Figure 2.1 Murtho salt load results from model translation

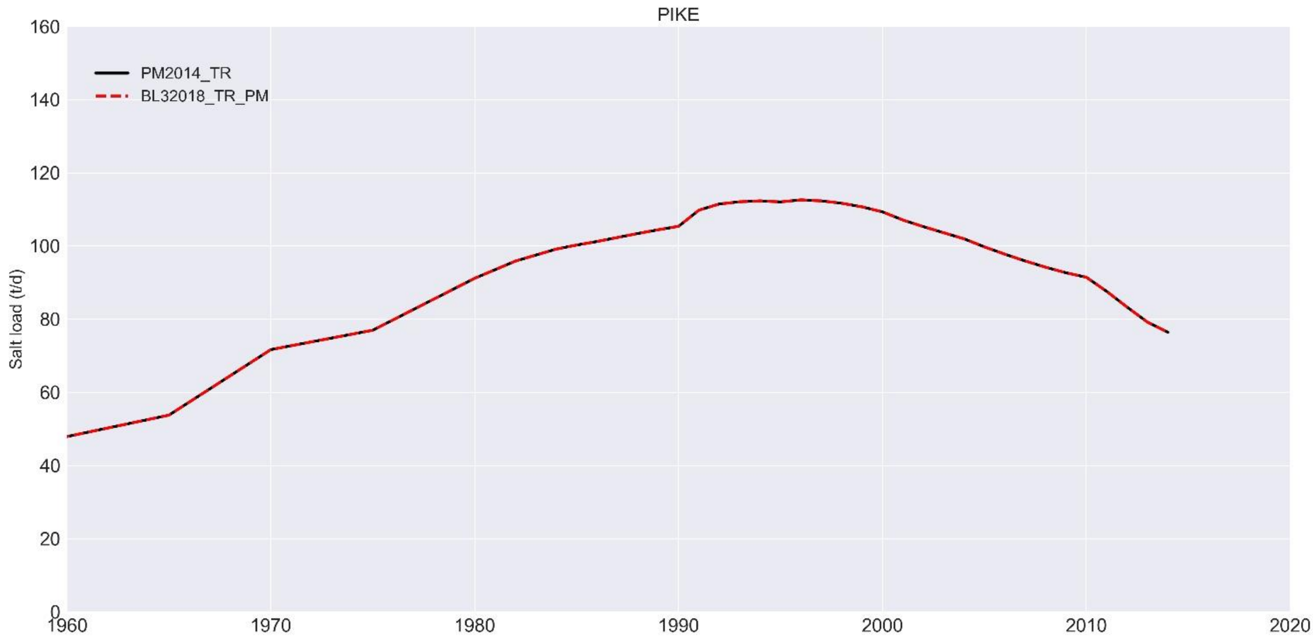

Figure 2.2 Pike salt load result from model translation

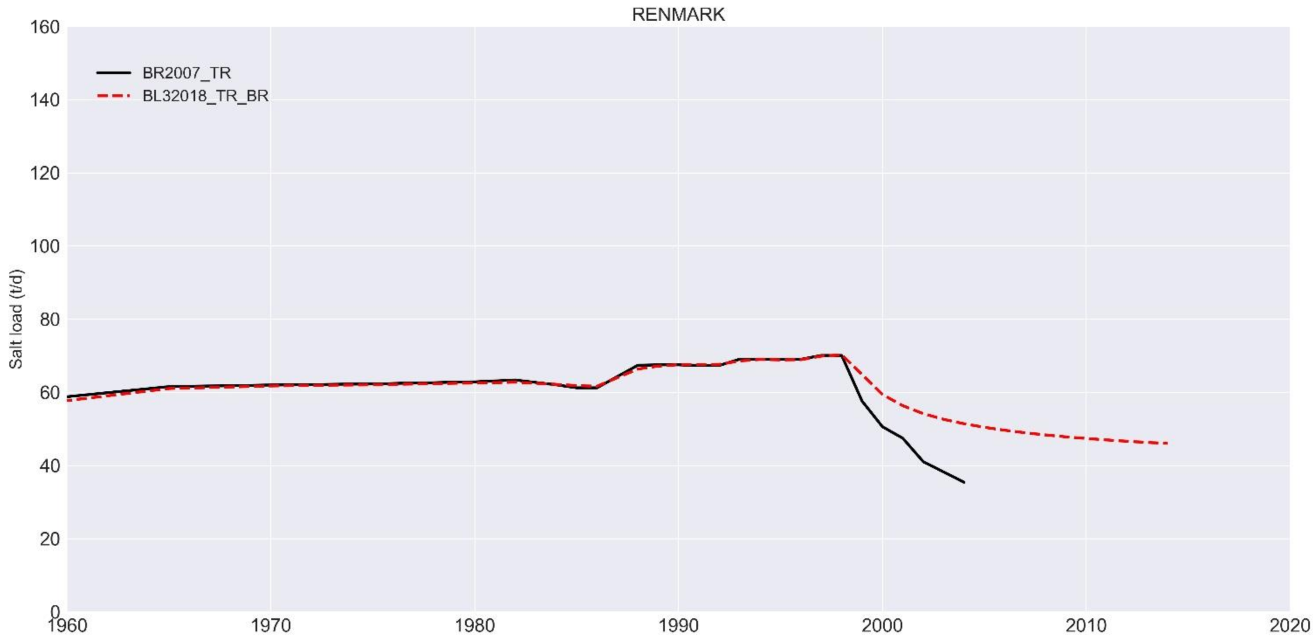

Figure 2.3 Renmark salt load result from model translation

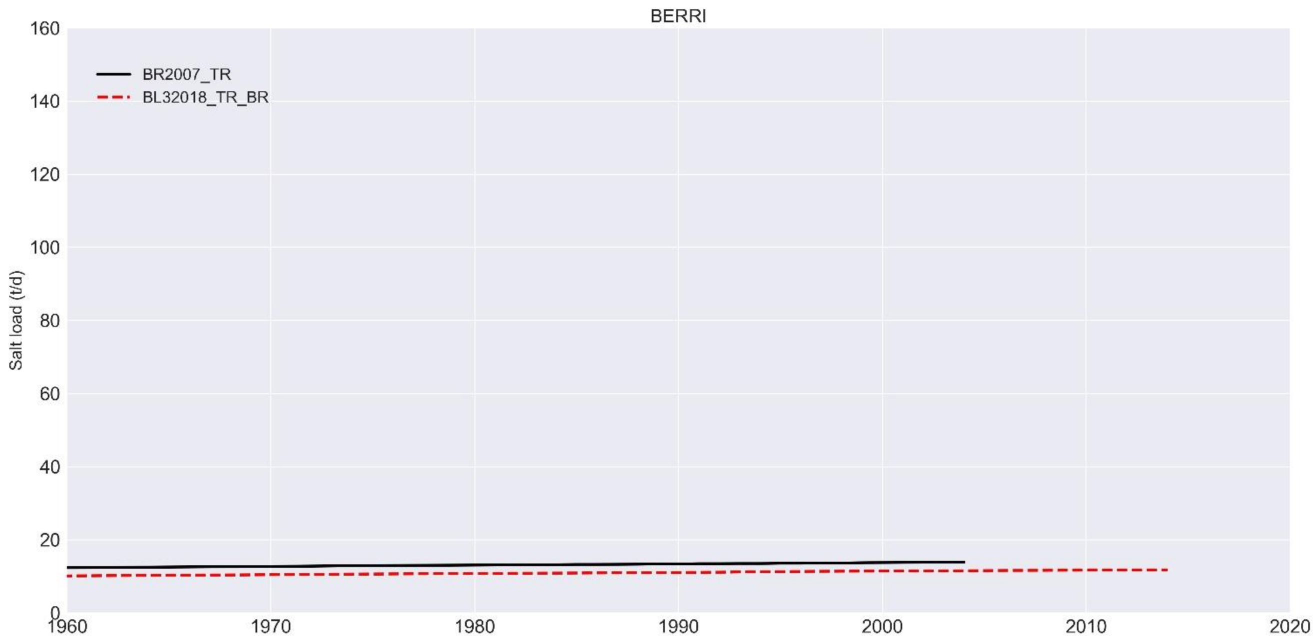

Figure 2.4 Berri salt load result from model translation

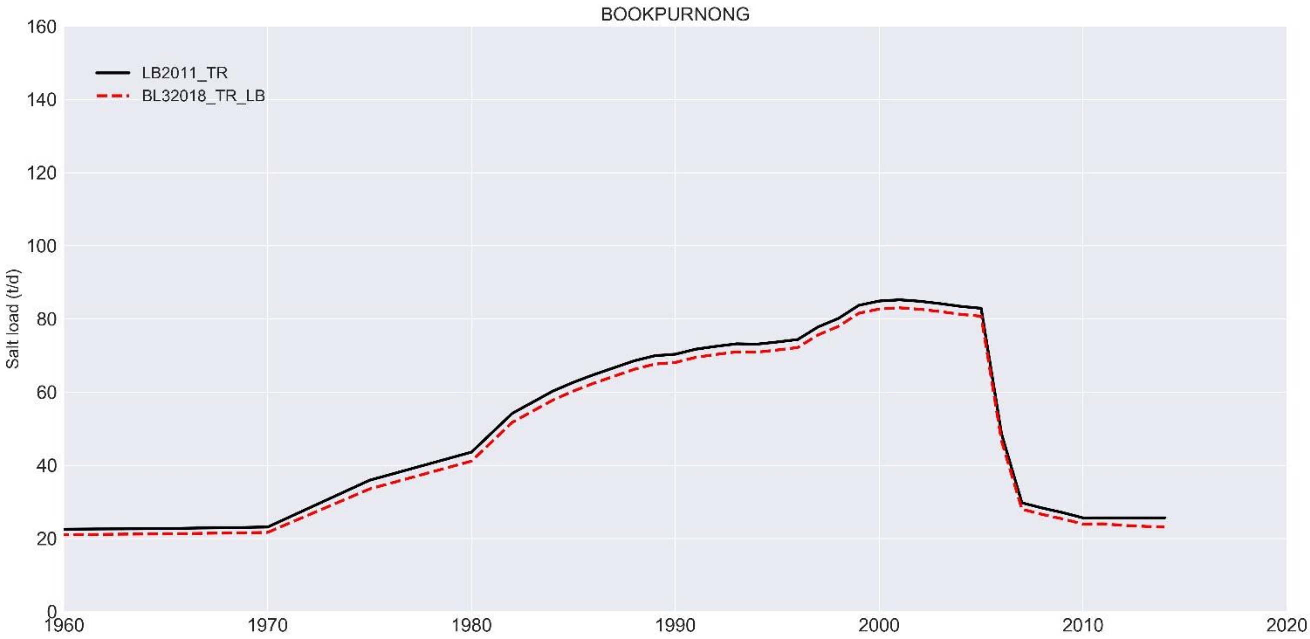

Figure 2.5 Bookpurnong salt load result from model translation

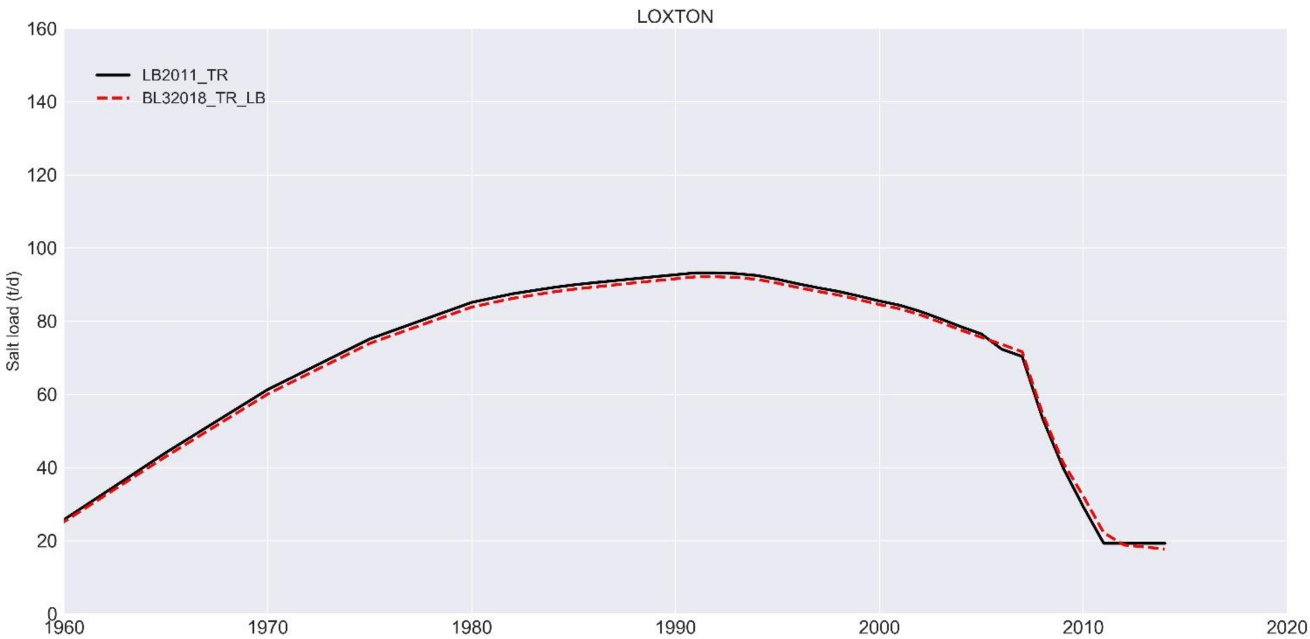

Figure 2.6 Loxton salt load result from model translation

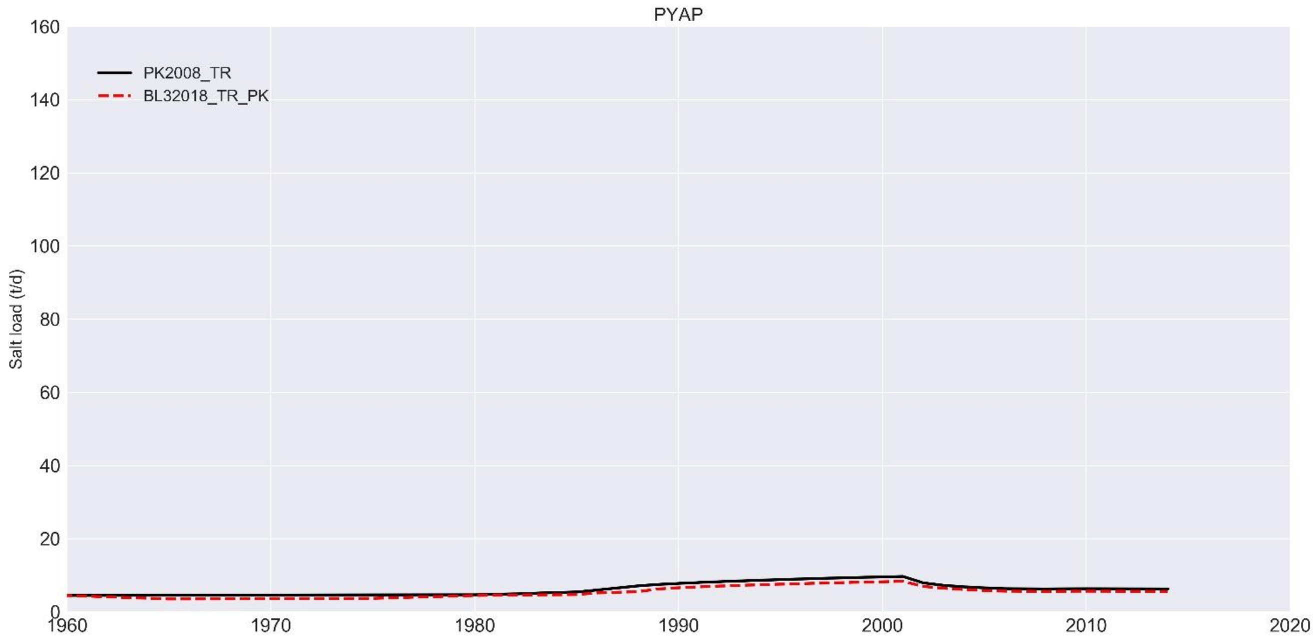

Figure 2.7 Pyap salt load result from model translation

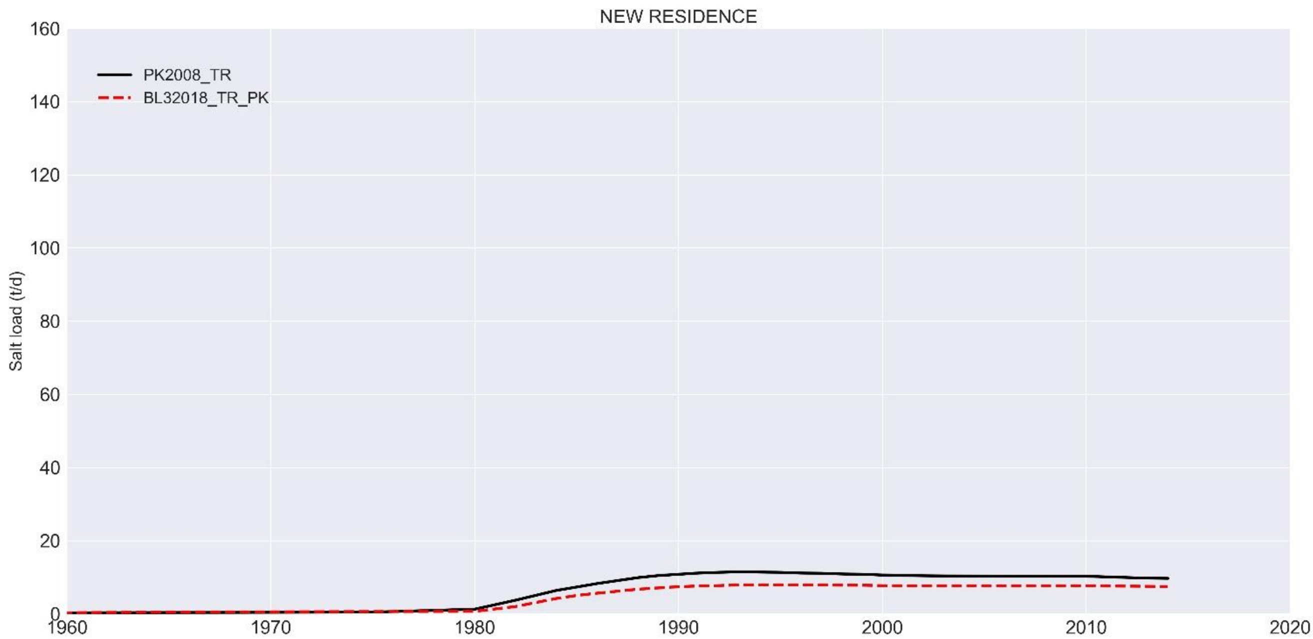

Figure 2.8 New Residence salt load result from model translation

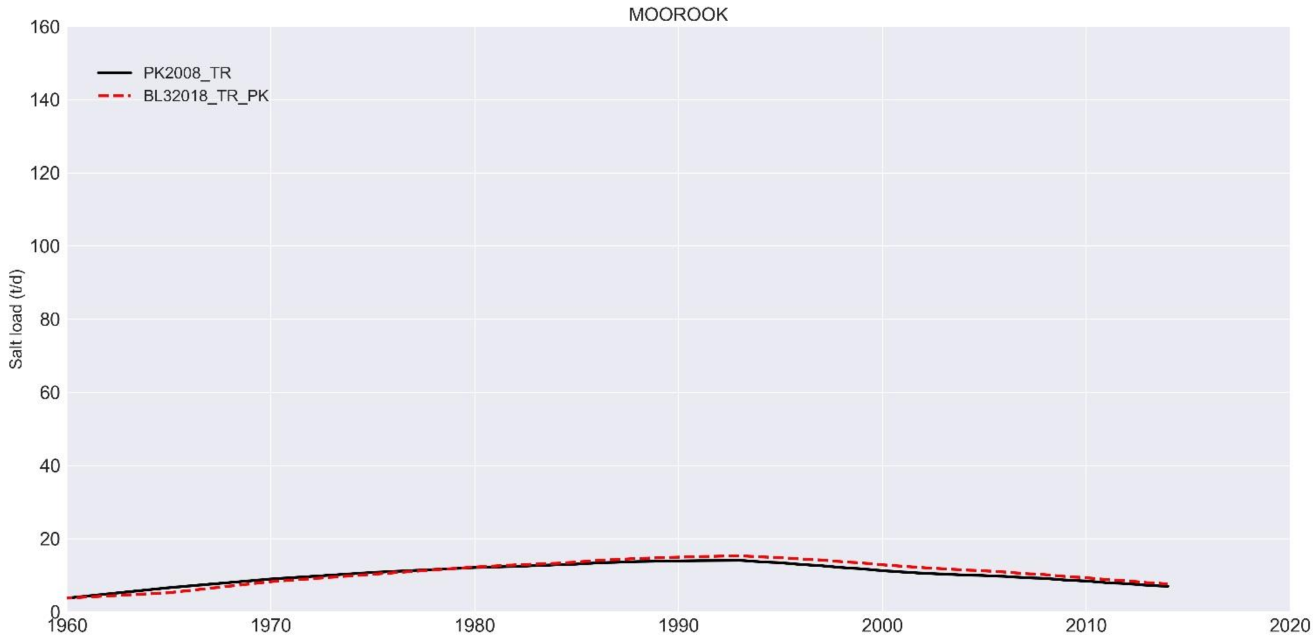

Figure 2.9 Moorook salt load result from model translation

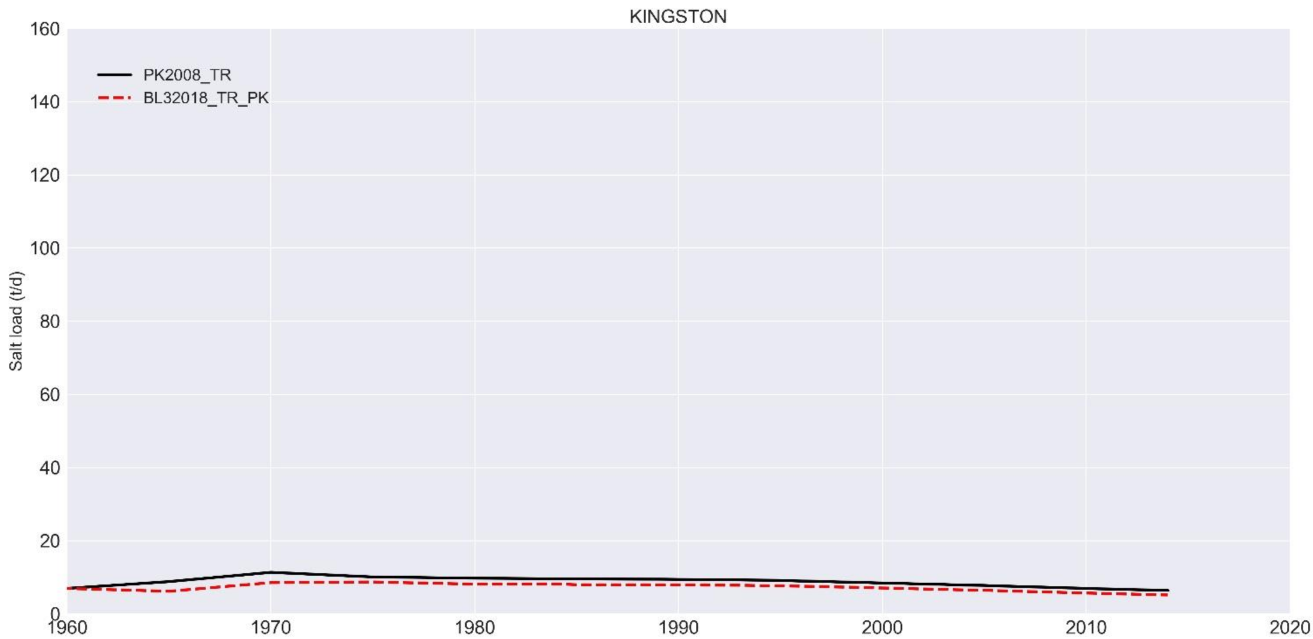

Figure 2.10 Kingston salt load result from model translation

3 Sub-model approach

3.1 Method

Previously, the Border to Lock 3 model was simulated using a "sub-model by sub-model" approach, where irrigation recharge and SIS pumping are simulated within one active sub-model project area at a time. This was because Visual MODFLOW had limitations on the maximum number of recharge zones.

The sub-model approach assumes that groundwater flux to the river in a project area is not influenced by irrigation and SIS outside the sub-model project area. The validity of this assumption can be examined using the Groundwater Vistas models described in Section 2, as Groundwater Vistas allows a much larger number of recharge zones.

The historical transient scenario was run in the Groundwater Vistas models, i.e. the five versions of BL32018 given in Table 2.1. Four models simulate only one active project area at a time, and the fifth simulates all the project areas' irrigation and SIS simultaneously.

3.2 Results

Results are presented as salt load to the river in Figure 3.1 to Figure 3.10.

Simulation of all irrigation areas within the Border to Lock 3 model shows no change in salt load when compared to the Berri-Renmark, Loxton-Bookpurnong and Pyap to Kingston sub-models.

However, including all irrigation districts significantly increases salt load to the River from the Pike and Murtho areas (Figure 3.1 and Figure 3.2) due to the influence of the adjacent long-established Renmark and Berri irrigation areas.

On the opposite side of the river, including all irrigation areas has no impact on salt load from the Berri-Renmark reaches. This is possibly due to a comprehensive drainage system within the region, but should be investigated in future model update when the Berri-Renmark model is revised.

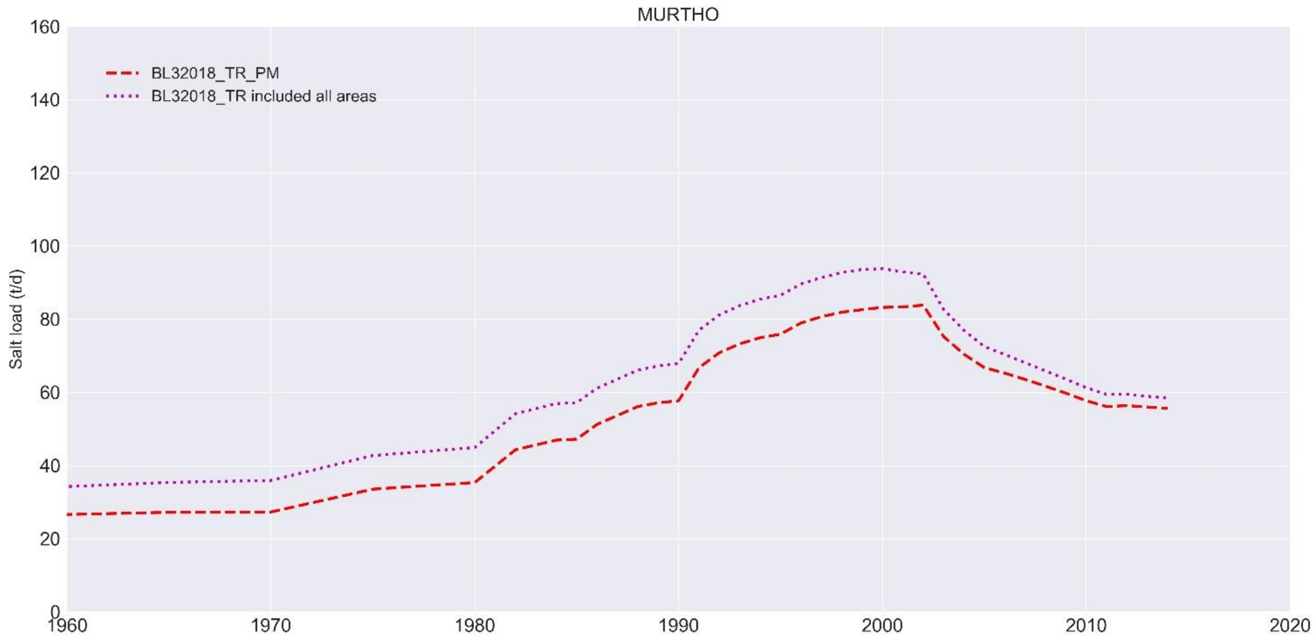

Figure 3.1 Murtho salt load results between individual sub-model approach and combined sub-model approach

Figure 3.2 Pike salt load results between individual sub-model approach and combined sub-model approach

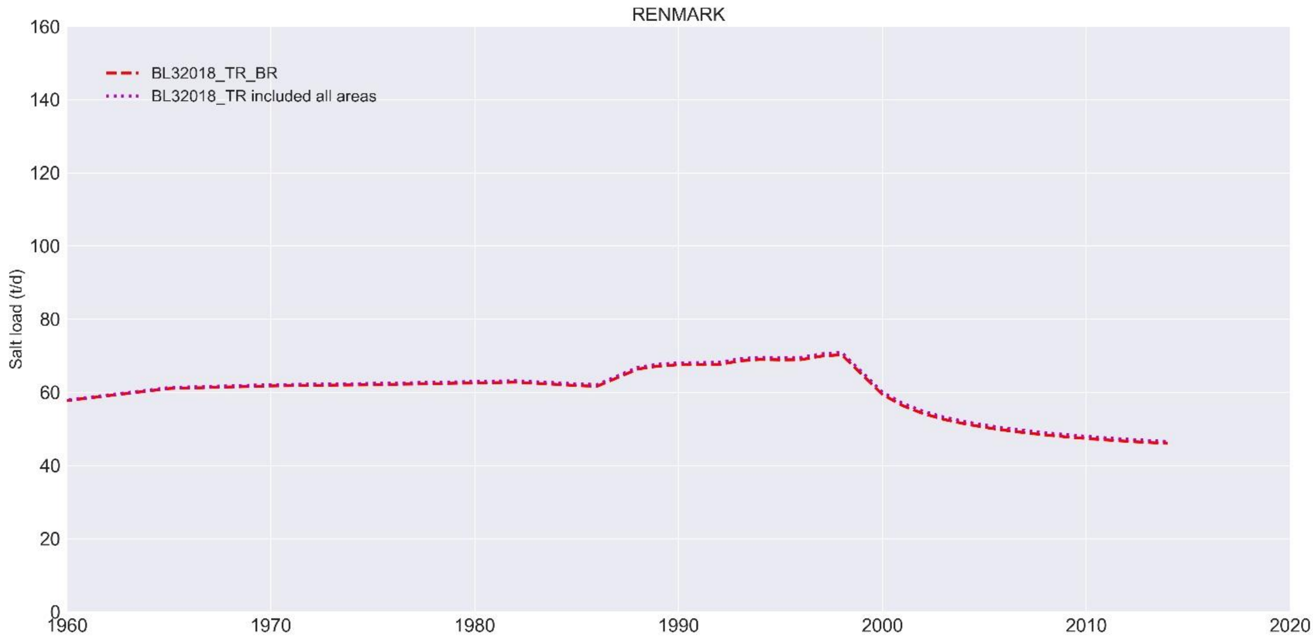

Figure 3.3 Renmark salt load results between individual sub-model approach and combined sub-model approach

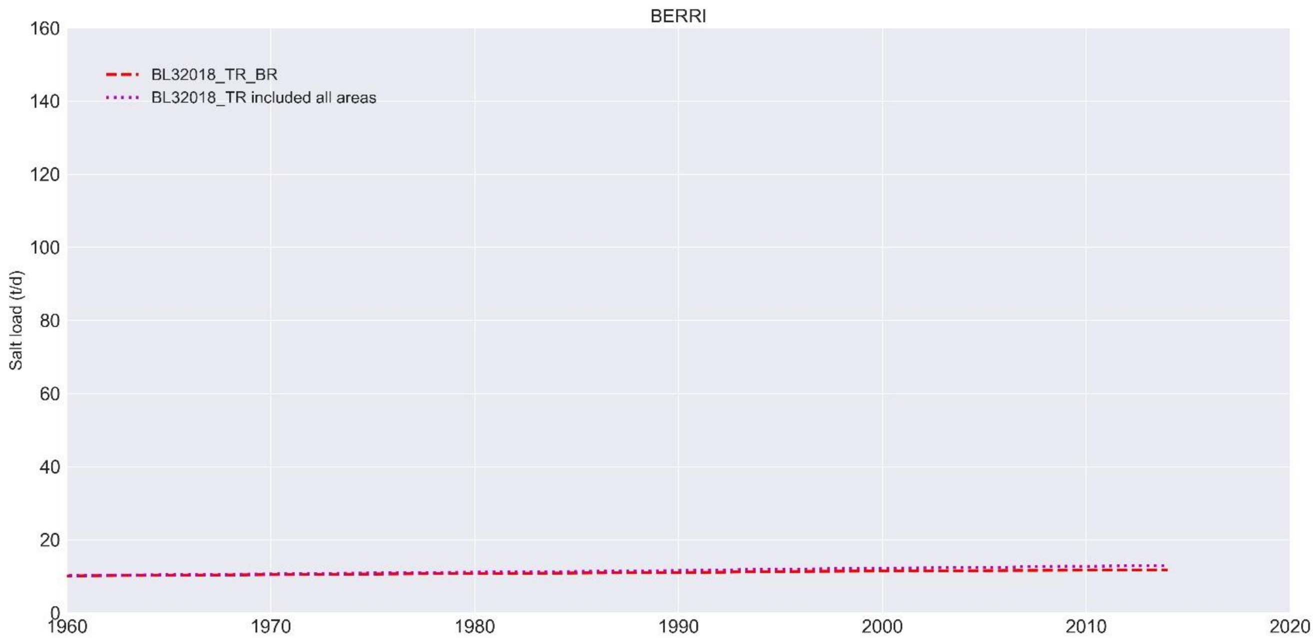

Figure 3.4 Berri salt load results between individual sub-model approach and combined sub-model approach

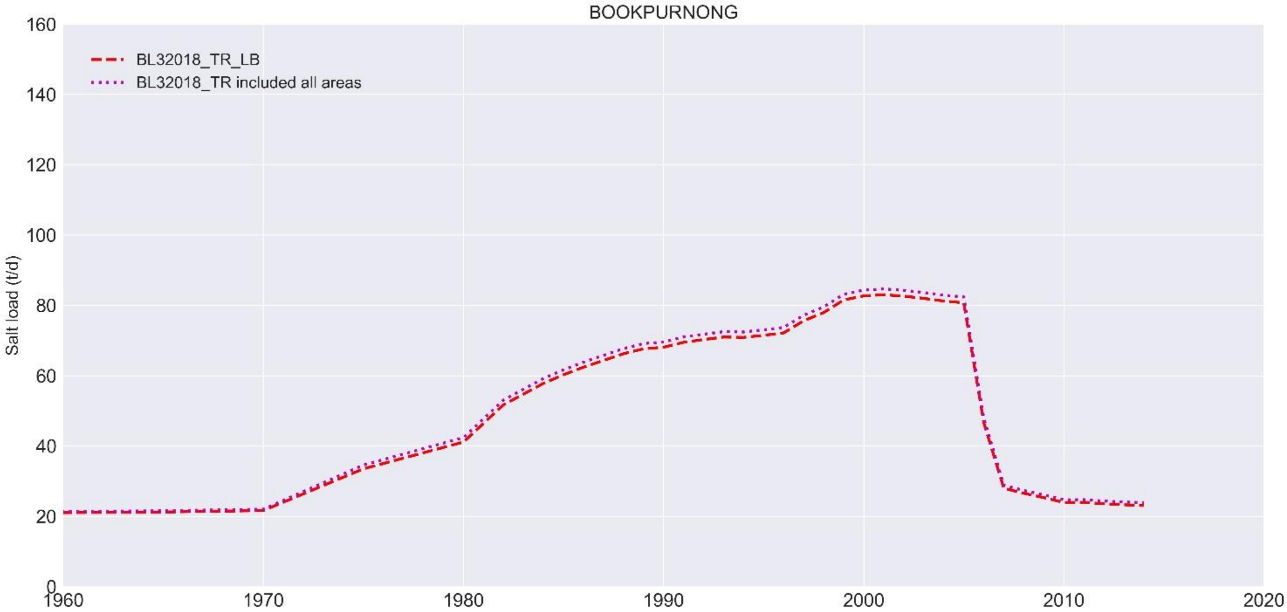

Figure 3.5 Bookpurnong salt load results between individual sub-model approach and combined sub-model approach

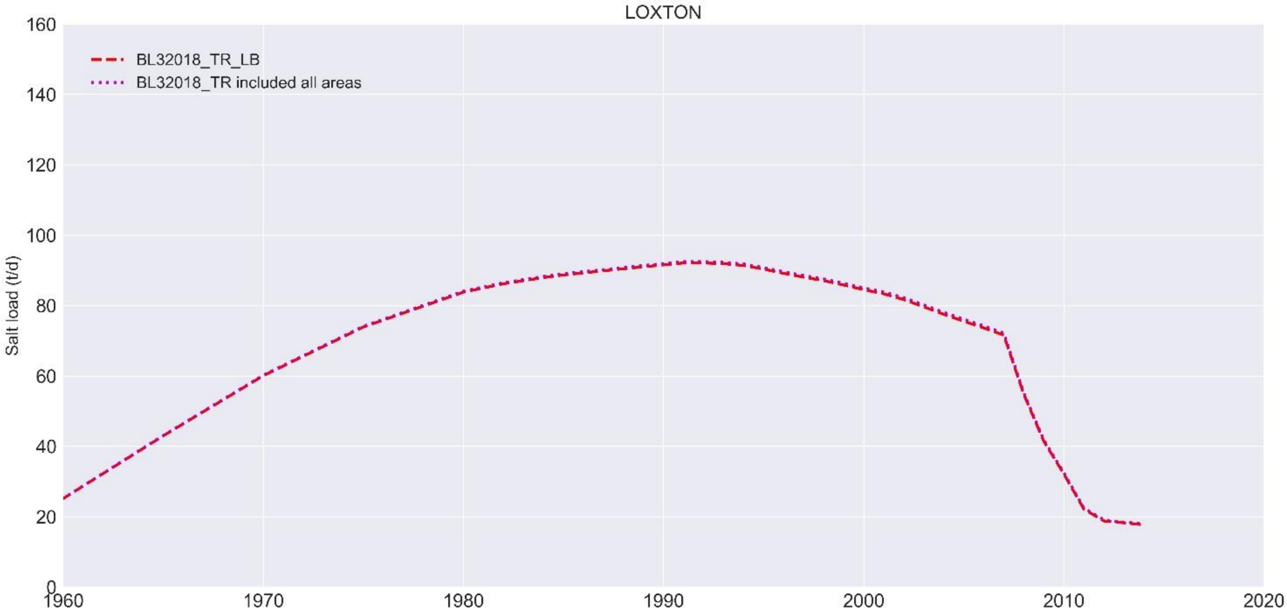

Figure 3.6 Loxton salt load results between individual sub-model approach and combined sub-model approach

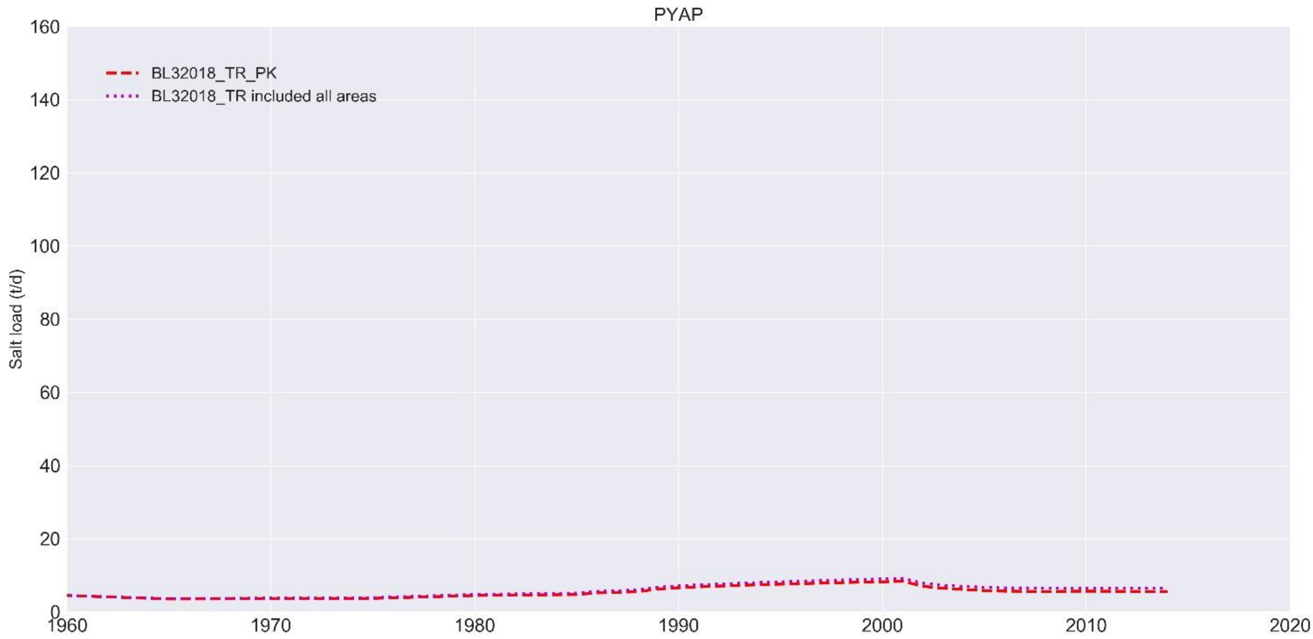

Figure 3.7 Pyap salt load results between individual sub-model approach and combined sub-model approach

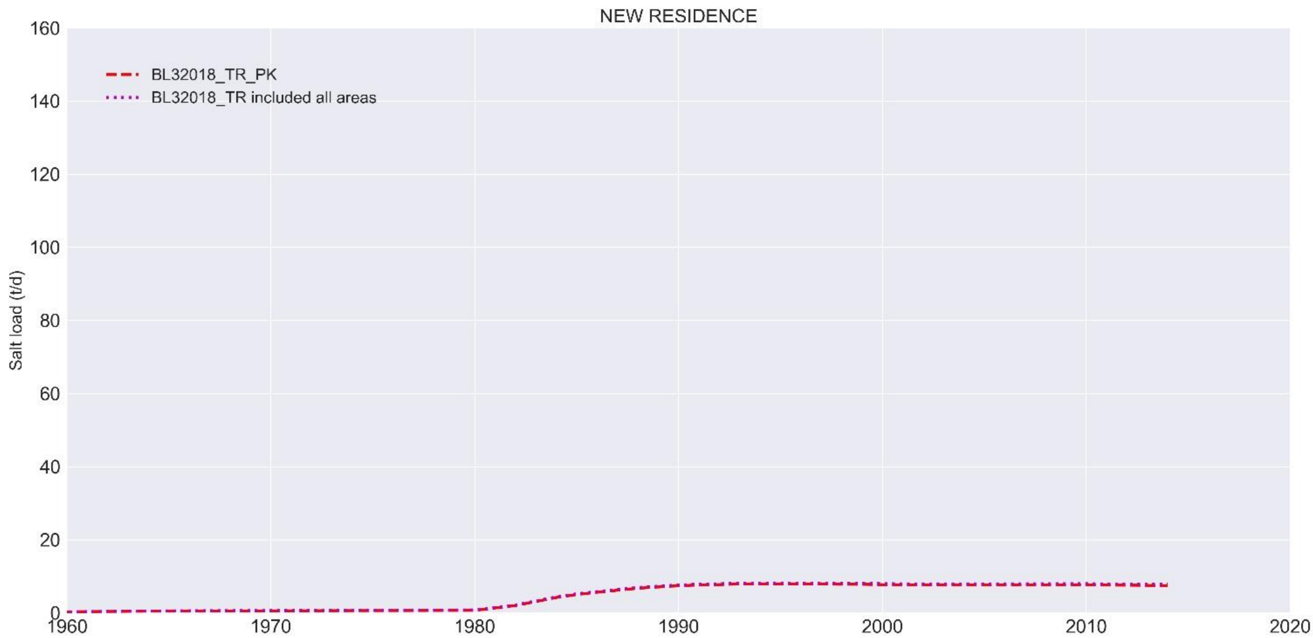

Figure 3.8 New Residence salt load results between individual sub-model approach and combined sub-model approach

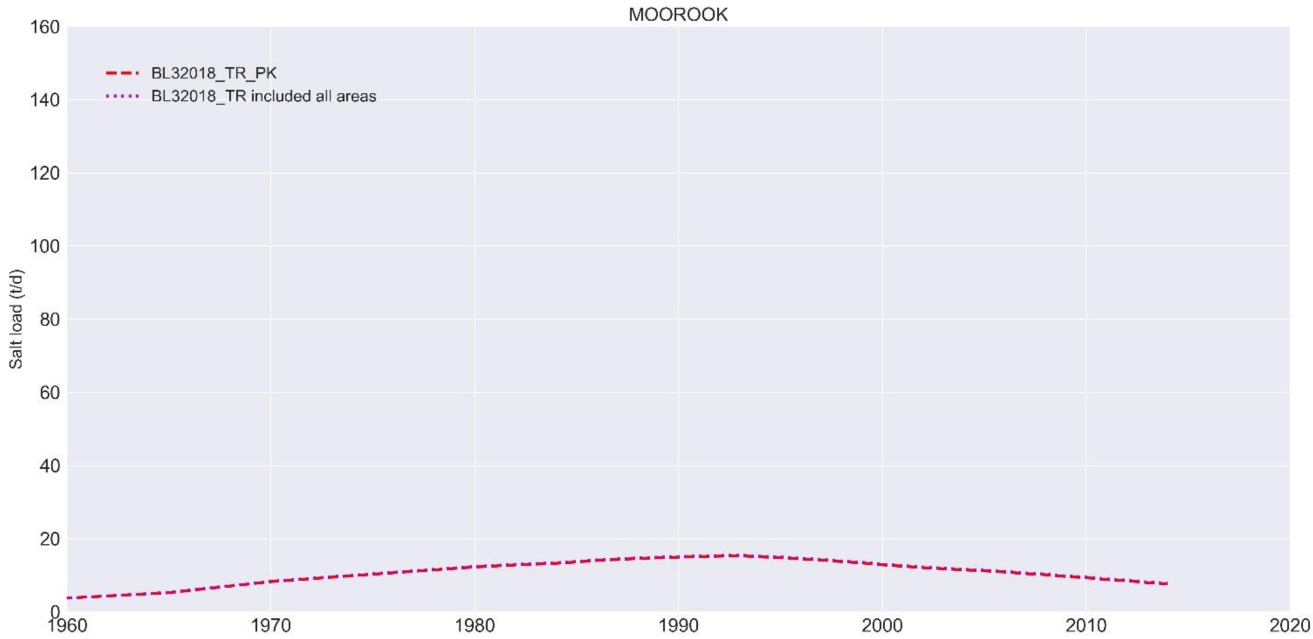

Figure 3.9 Moorook salt load results between individual sub-model approach and combined sub-model approach

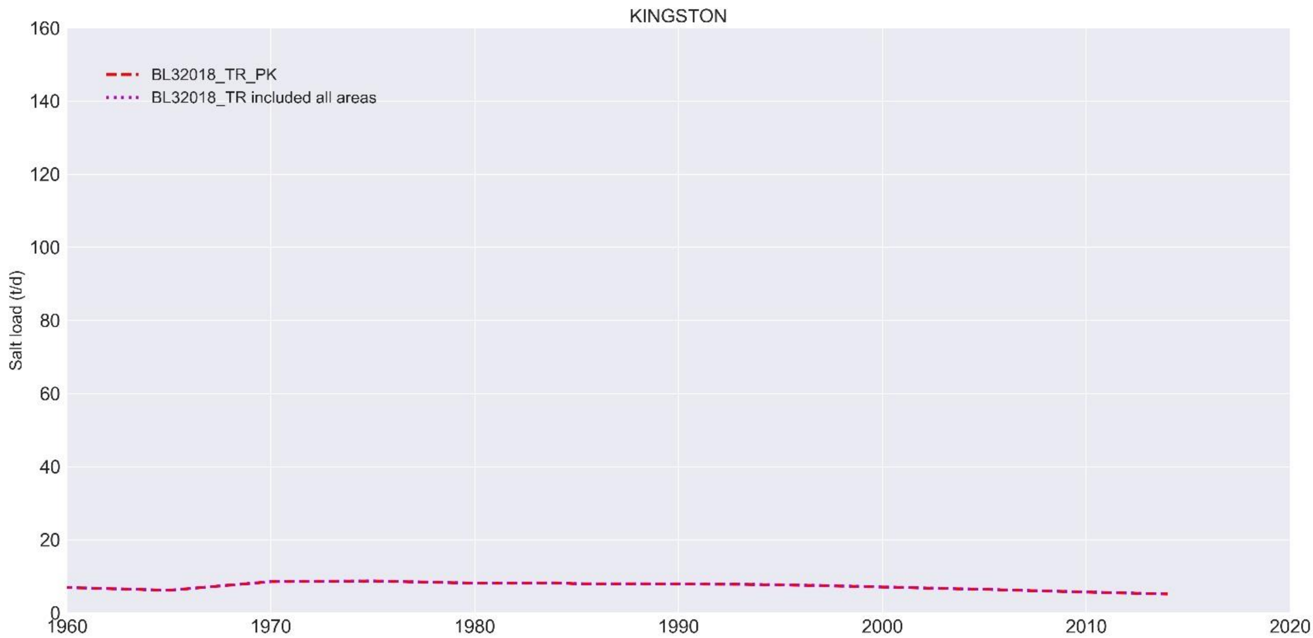

Figure 3.10 Kingston salt load results between individual sub-model approach and combined sub-model approach

4 Improved irrigation mapping

Each sub-model uses the irrigation data available at the time of construction. As the models differ in year of construction, some work is required to update to a consistent irrigation data set.

Bushaway et al. (2015) developed a consistent dataset across the SA MDB for 2014 (Bushaway et al., 2015). The 2015 irrigation area dataset differs from the irrigation areas used in the accredited models and in the models used to generate Salinity Register entries.

Bushaway and Woods (2018) reviewed available datasets for mapping irrigation areas. All were found to have limitations. The best available, MSA Crop Data, was last updated for 2014. The report recommended that multiple datasets be used to create an accurate irrigation footprint.

This section develops a more accurate irrigation footprint for historical period to 2014. It compares the revised mapping of 2014 irrigation to the 2015 mapping of 2014, and to the mappings used in the Salinity Register Entry models and the accredited models.

4.1 Irrigation extent 2014, estimated in 2015

The 2015 mapping uses the same methodology as the Salinity Register models. This section describes the methodology applied to simulate historical (TR) and current (S4) irrigation areas, summarised from Bushaway et al. (2015).

Data

Two datasets are used to derive model irrigation recharge area:

1. DEH irrigation eras (1880-2003)
2. MSA Crop Data (2004-2014)

Methodology

Recharge zones are primarily based on GIS shapefiles showing irrigation development over time (Table 4.1). The polygon shapefiles used in the models are derived from DEH irrigation eras from 1880-2003 and yearly MSA Crop Data from 2004-2014. The polygons are directly mapped to model rectangular grid cells in each model.

For the third generation models, MSA Crop Data 'CROPCATEGO' attribute filtered out "vacant land and land in transition'.

For the 2015 update to the accredited models, new polygons identified were added to the existing model irrigation areas to represent an expansion of irrigation area over time.

Table 4.1 Irrigation development years

Accredited Model	Updated irrigation development year (GIS data)
Pike-Murtho (2014)	1894, 1930, 1940, 1945, 1950, 1960, 1965, 1970, 1975, 1980, 1985, 1988, 1990, 1995, 1997, 1999, 2000, 2001, 2003 to 2014 yearly data
Berri-Renmark (2007)	1920, 1940, 1955, 1960, 1970, 1988, 1997, 1999, 2001, 2003 and 2014
Loxton-Bookpurnong (2011)	1920, 1940, 1961, 1965, 1970, 1972, 1974, 1980, 1984, 1986, 1988, 1995, 1997, 1999, 2001 and 2003 to 2014 yearly data

Pyap to Kingston (2008)	1880, 1920, 1940, 1956, 1960, 1970, 1988, 1995, 1997, 1999, 2001, 2003, 2005 and 2014

4.2 Irrigation extent 2014, estimated in 2018

The previous irrigation data review (Bushaway and Woods, 2018) identified that there is no single dataset suitable for representing current irrigation on ground. It recommends that in the absence of the development of a single dataset for this purpose, MSA Crop Data shapefiles be used as a basis, then cross-checked against other datasets.

Data

Irrigation extent 2018 is created using a number of datasets to help identify irrigated and non-irrigated areas, these datasets are:

1. MSA Crop Data surveyed 2013-2014 with time stamp (MSA)
2. SA Land Cover data epoch 2010-2015 (DEW)
3. ArcGIS imagery dated September 2014 (ESRI)
4. Google Earth Pro imagery dated November 2015 (Google Inc.)

Methodology

MSA Crop Data 2013-14 with time stamp is the most up-to-date version that contains year planted information to 2014. However, some information within the shapefile is not up-to-date. The dataset is analysed to identify irrigated areas and cleared lands based on the attribute information described in the following:

- 'YEARPLANTE' identifies crop start year
- 'CROPCATEGO' identifies crop type and land use type
- 'IRRIGATION' identifies irrigation system i.e. pivot, drip system etc.
- 'IRRIGATI_1' identifies current status of irrigation system i.e. not irrigated or irrigated

These four attributes are used to filter out non-irrigated area. For example, unidentified numbers from ''YEARPLANTE' are removed. There are 867 classes in 'CROPCATEGO" and 54 classes are identified as non-irrigated lands and removed. Further analysis includes removing "System Removed" from 'IRRIGATION' and "Not irrigated" from 'IRRIGATI_1'.

MSA Crop Data 2013-14 irrigated area was compared to other datasets to identify:

- existing or current irrigation areas (the existing polygons are unchanged)
- new irrigation areas (new polygons are added)
- retired or non-irrigated lands (polygons are removed)

This method includes the modification of polygons to match actual irrigation boundaries.

The spatial distribution of the current irrigated areas within the Border to Lock 3 model is presented in Figure 4.1. The figure compares current (S4) irrigation, 2014 area estimated in 2015 and 2018. Retirement of irrigation areas can be seen throughout the Border to Lock 3 area.

For consistency, irrigation areas below Lock 3 should be updated using the same approach. The dataset could also be extended to the most recent year i.e. 2018 footprint.

4.3 Comparison

Figure 4.1 shows the spatial distribution of the 2015 and 2018 estimates of the 2014 irrigation footprint, and the irrigation extent used in the accredited models within the Border to Lock 3 model domain. It can be seen that the 2014 area, updated in 2015 has the largest area. The main differences between the 2015 and 2018 estimates are due to the retirement of mainly temporary irrigation located in North Murtho, Central Murtho and Pyap.

Figure 4.2 compares the total areas. In general, the 2015 estimate is larger than the Register Entry model area, which is expected due to the growth in irrigation between the time of model development and 2014. The 2018 estimate is smaller than both Register Entry models and the 2015 estimate in most irrigation districts. There is a large reduction of irrigation area in the order of 1000 ha that can be seen in Renmark, Berri and Loxton, due to small areas being reclassified as not irrigated.

Figure 4.3 to Figure 4.6 provide more detail, spatially comparing accredited model areas to the 2018 estimate of 2014 irrigation. Significant reduction in area occurs in North Murtho and Pyap irrigation districts where temporary irrigation has ceased operation. Historical irrigation on the floodplain within the Simarloo irrigation district is also removed to reflect irrigation retirement. Land retirement and land in transition have generally occurred in all areas.

In the Pyap to Kingston area, part of the irrigation area is located on inactive cells. Visual MODFLOW allows irrigation areas to be imported for inactive cells whereas Groundwater Vistas does not. This resulted in some area reduction as shown in Figure 4.7.

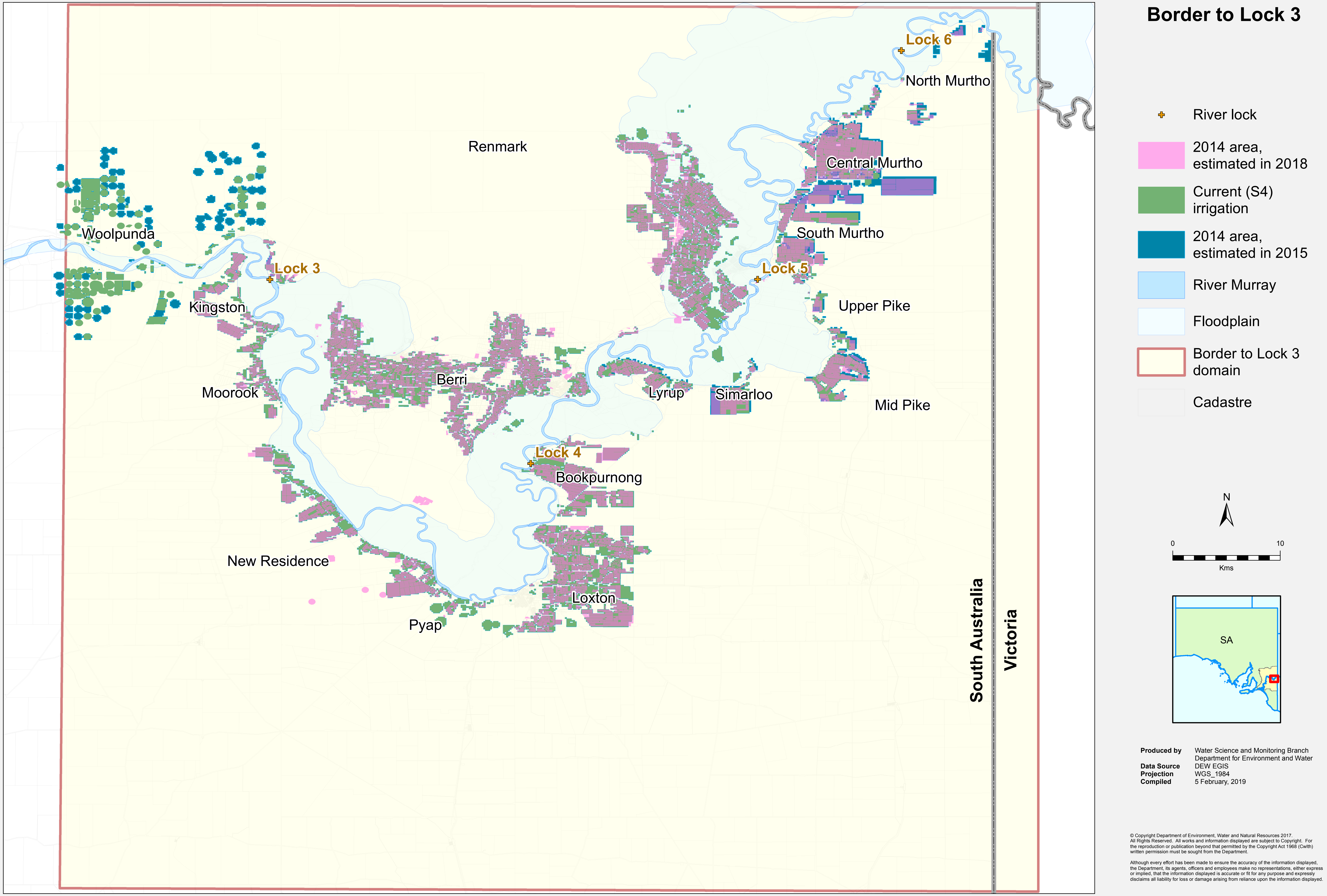

Figure 4.1 Spatial distribution of 2014 irrigation (as estimated in 2015 and 2018) and current (S4) irrigation within the Border to Lock 3 model

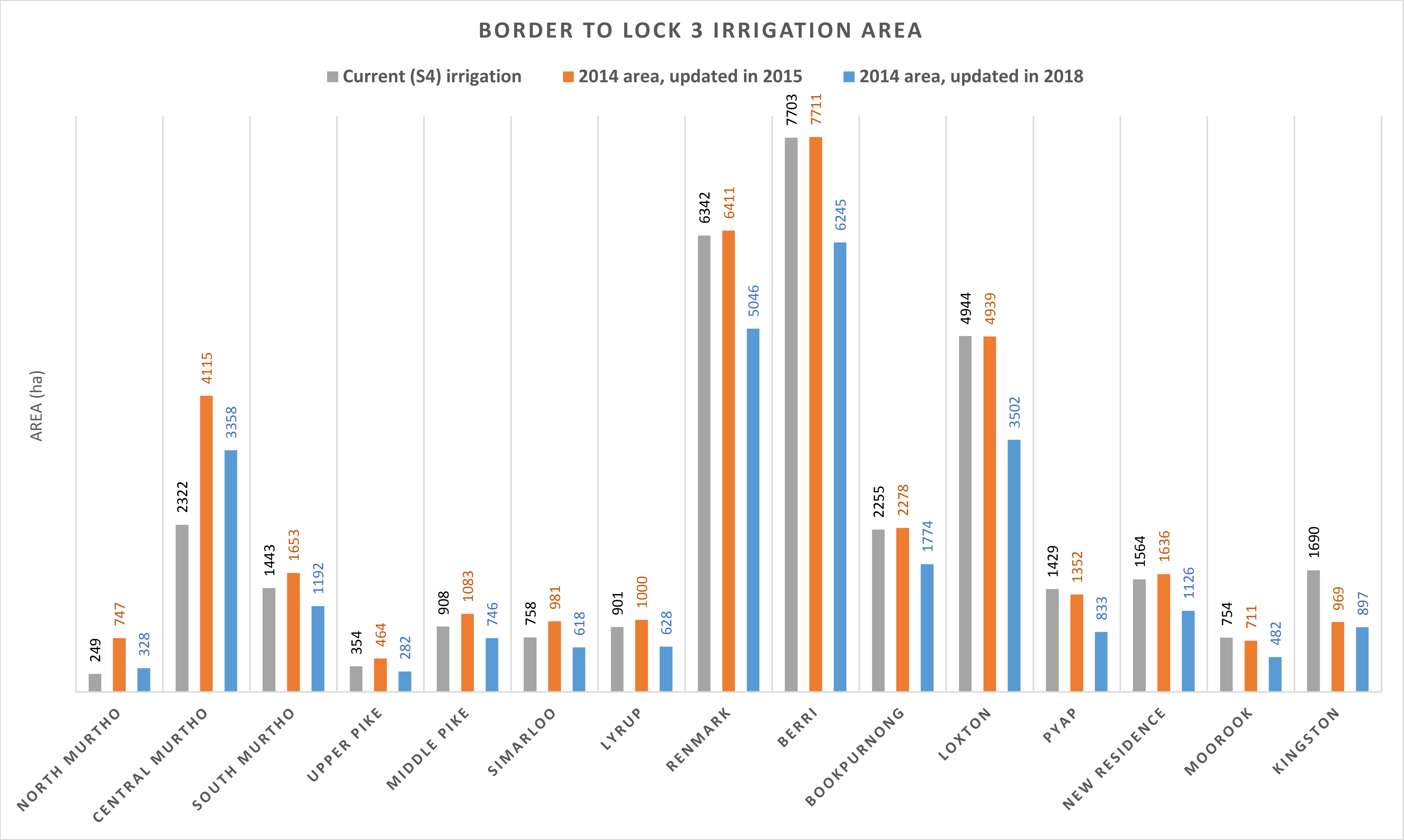

Figure 4.2 Comparison between 2014 irrigation areas, updated in 2015 and 2018 and current (S4) irrigation

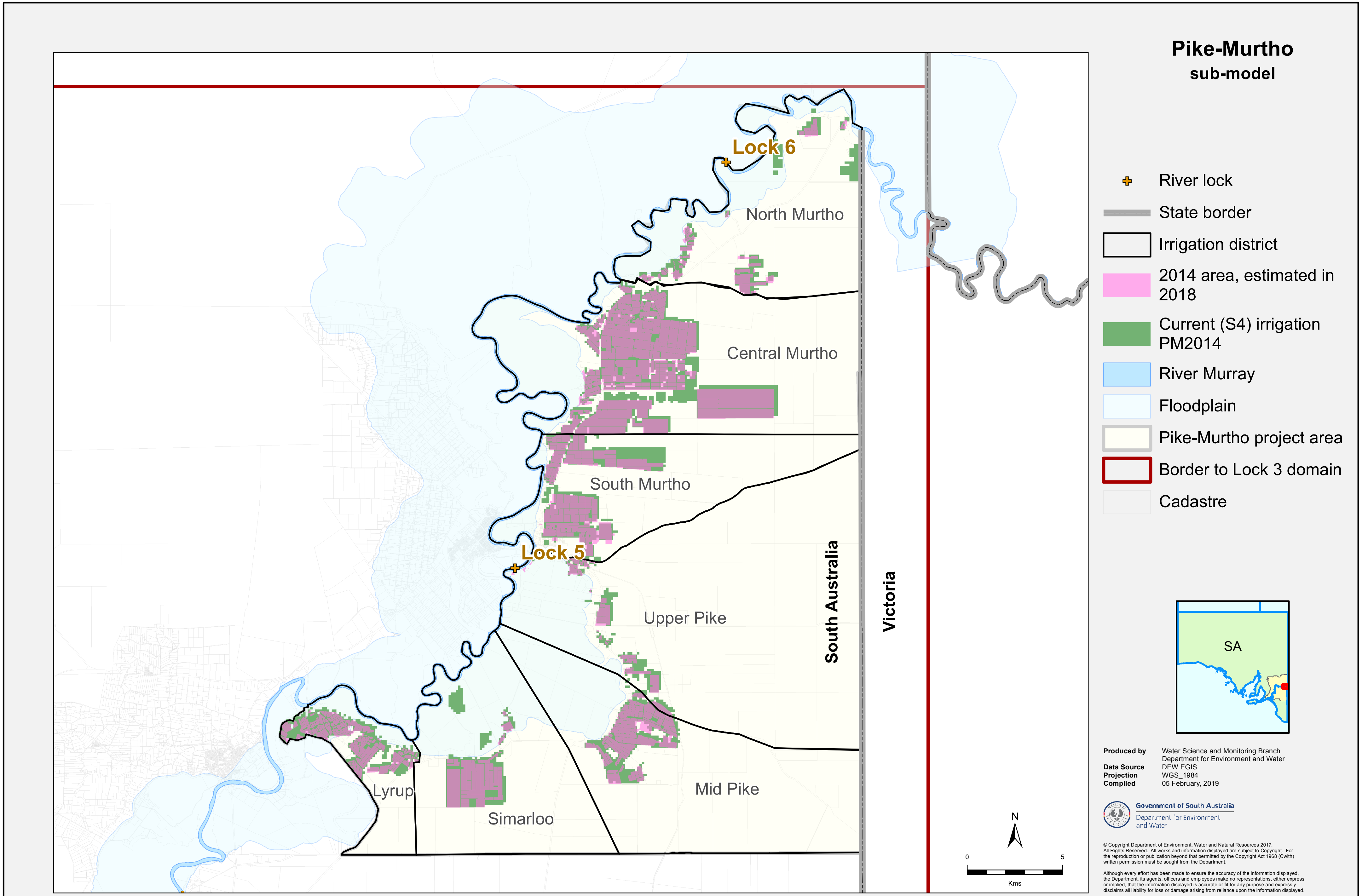

Figure 4.3 Comparison of 2015 updated to the accredited models and 2018 updated irrigation areas at Pike-Murtho

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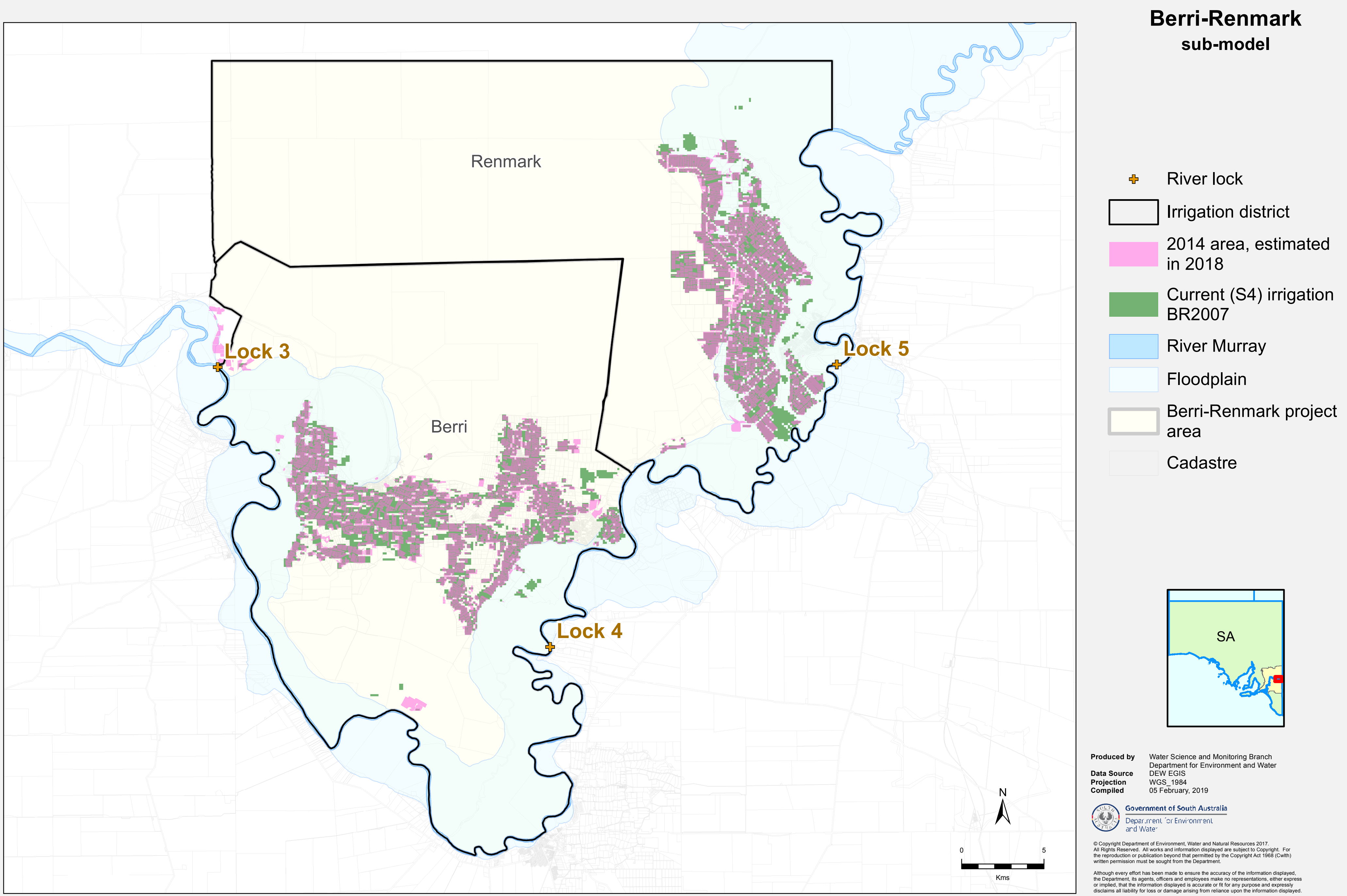

Figure 4.4 Comparison of 2015 updated to the accredited models and 2018 updated irrigation areas at Berri-Renmark

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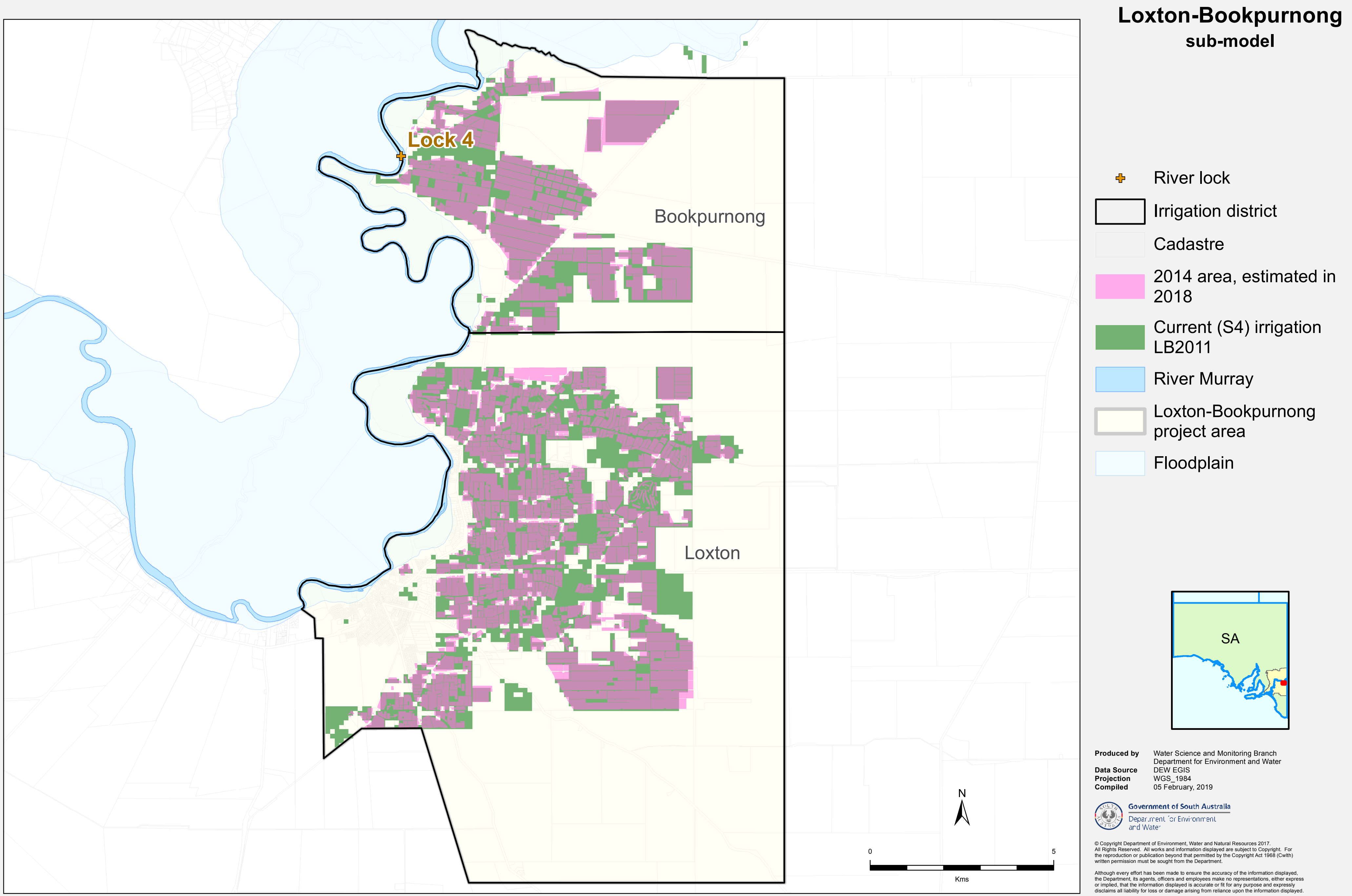

Figure 4.5 Comparison of 2015 updated to the accredited models and 2018 updated irrigation areas at Loxton-Bookpurnong

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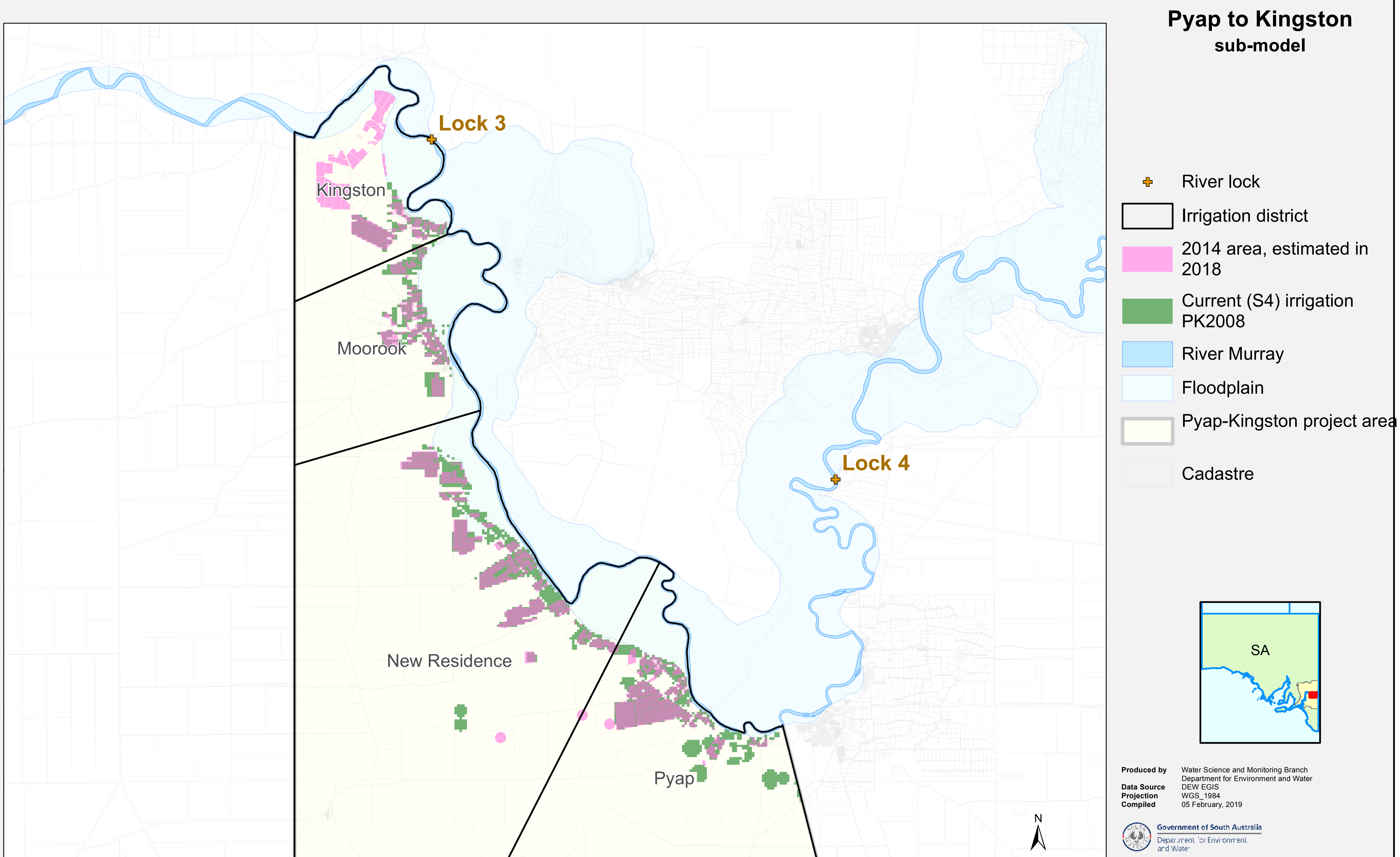

Figure 4.6 Comparison of 2015 updated to the accredited models and 2018 updated irrigation areas at Pyap to Kingston

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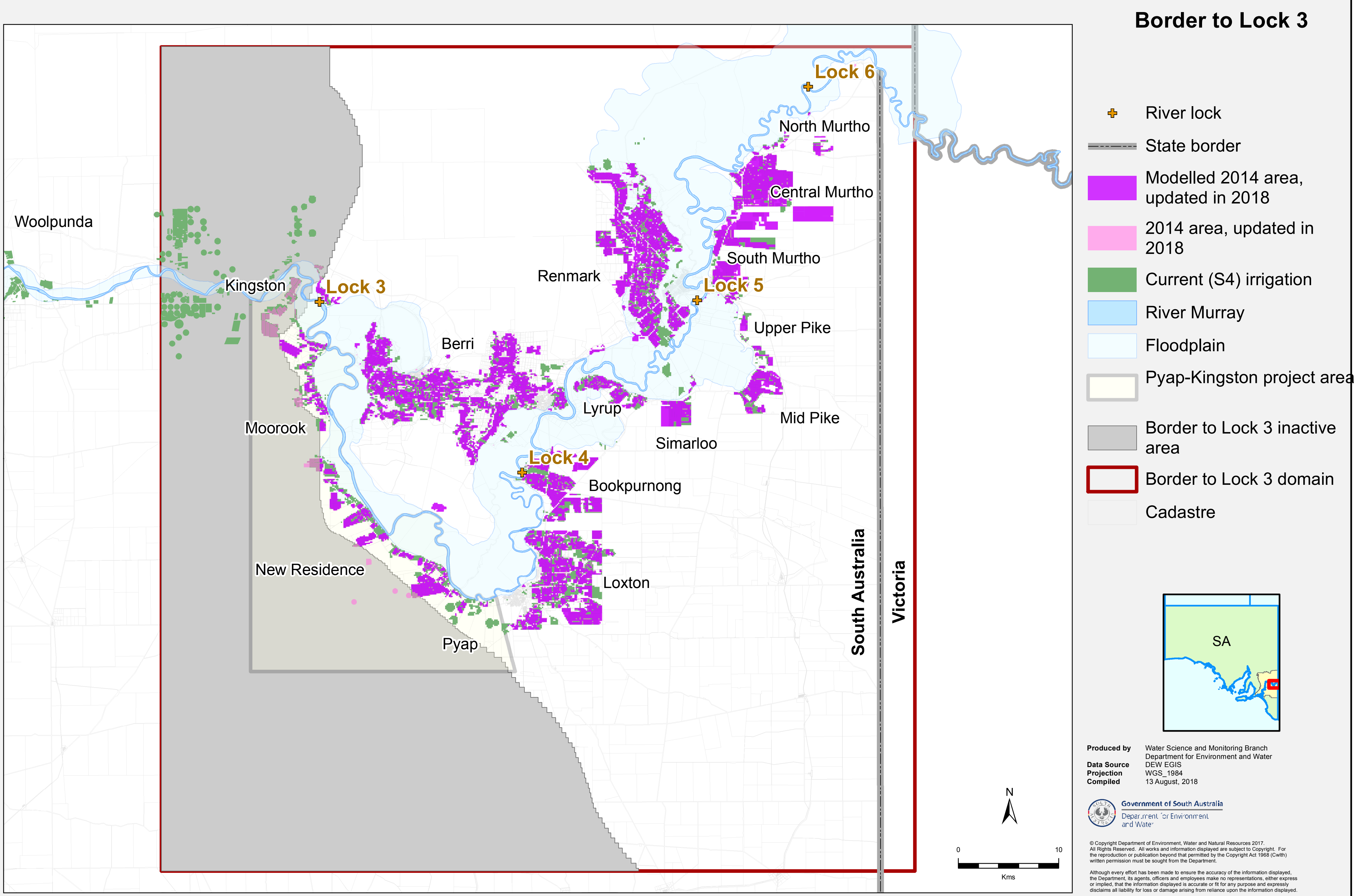

Figure 4.7 Irrigation areas located on inactive cells

File ID: P:\Projects_GW\Regional\Murray_Basin\GW_Modelling_RMurray\Border_Lock3_2018\Data\GIS\MXDs\Fig4_3_Comparison_area_change_PM_2.mxd User ID : kbushaway

5 Impact of improved irrigation footprint on salt load estimates

5.1 Method

Starting from the five versions of BL32018 listed in Table 2.1, each irrigation district is updated using the 2018 estimate of 2014 irrigation area (Section 4.2) to create the models given in Table 5.1.

The 2018 estimate of 2014-15 irrigation footprint is spatially joined to model recharge area shapefile containing irrigation zones, irrigation rate and lag time from the existing irrigation. For a new area, recharge rate and lag time is based on a nearby zone, irrigation start year is assigned based on ArcGIS imagery dated in 2014 i.e. assumed irrigation start year is 2014.

Table 5.1 Simulated update recharge models

Groundwater Vistas model	Simulation period	Update irrigation
BL32018_updatePM	1880-2014 (52 SP)	Update irrigation area in Pike-Murtho
BL32018_updateBR	1880-2014 (52 SP)	Update irrigation area in Berri-Renmark
BL32018_updatePK	1880-2014 (52 SP)	Update irrigation area in Pyap to Kingston
BL32018_updateLB	1880-2014 (52 SP)	Update irrigation area in Loxton-Bookpurnong
BL32018_updateAllarea	1880-2014 (52 SP)	Update irrigation area for all districts

5.2 Results

Salt loads to the River Murray are plotted in Figure 5.1 to Figure 5.10 to compare transient historical simulations:

(i) Sub-model approach, using the irrigation areas of the accredited Salinity Register models (Table 2.1)

(ii) All irrigation areas simulated simultaneously, using the irrigation areas of accredited Salinity Register models (already presented in Section 3.2)

(iii) Sub-model approach, updated to include the 2018 estimate of 2014 irrigation area; and also Run of River estimates

Updating irrigation areas in the Pike - Murtho sub-model shows a significant reduction of irrigation area in Murtho and therefore salt load is smaller than the Register entry models. There is less of a difference for Pike.

Updating irrigation areas in the Berri-Renmark sub-model shows a small salt load reduction in the Renmark area only of approximately 5 t/d after year 2000.

Updating irrigation areas in the Loxton-Bookpurnong sub-model reduces salt load to the river from both Loxton and Bookpurnong reaches. Updated irrigation area salt load matches RoR better than the previous results in both Bookpurnong and Loxton reaches.

Updating irrigation areas in the Pyap to Kingston sub-model shows a small increase in salt load in Pyap, New Residence and Moorook. Salt load increase in Kingston is negligible.

5.2.1 Pike-Murtho sub-model

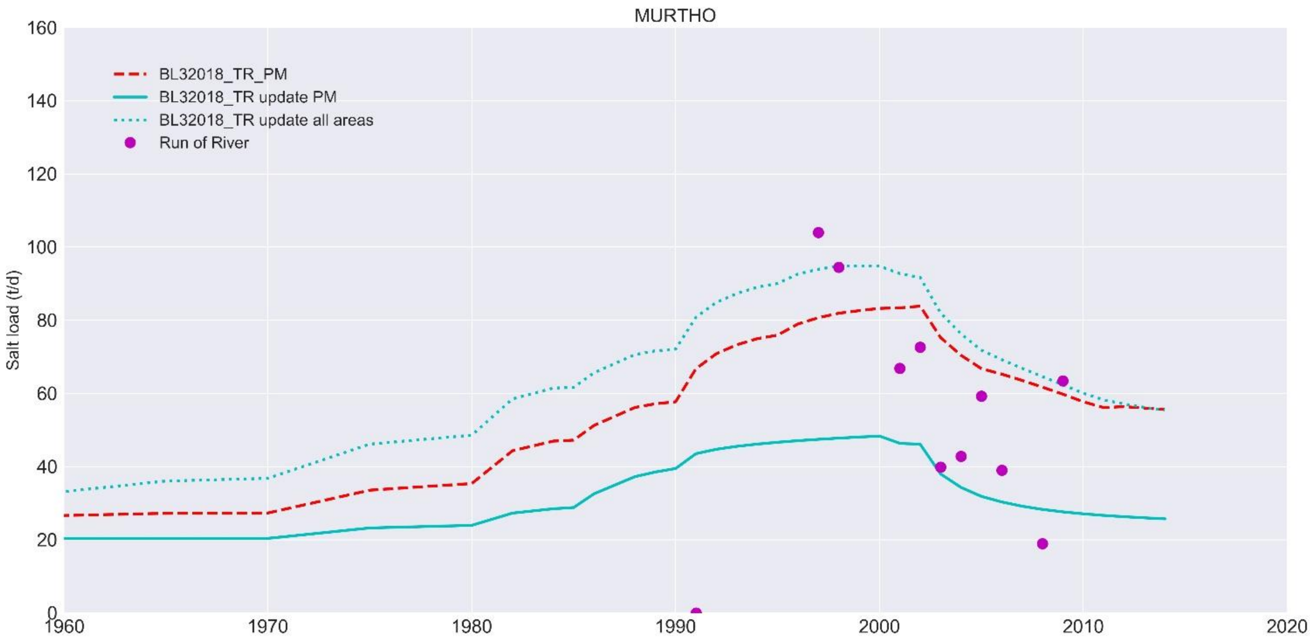

Figure 5.1 Murtho salt load results between accredited models and 2018 updated irrigation footprints

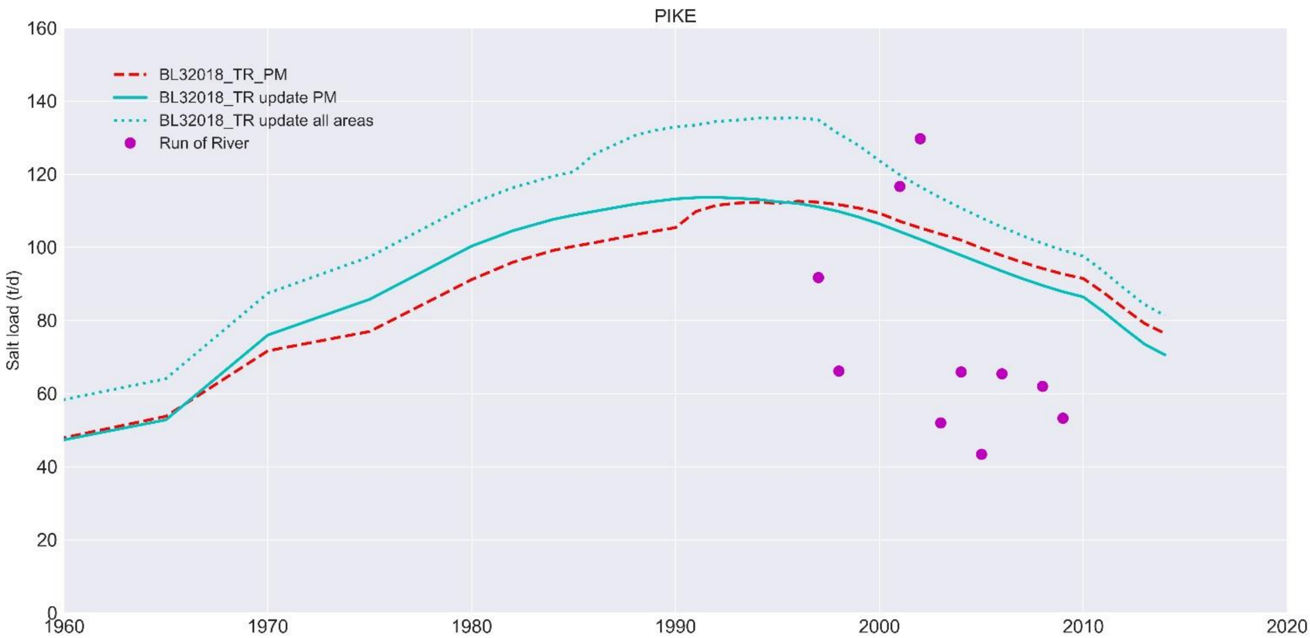

Figure 5.2 Pike salt load results between accredited models and 2018 updated irrigation footprints

5.2.2 Berri-Renmark sub-model

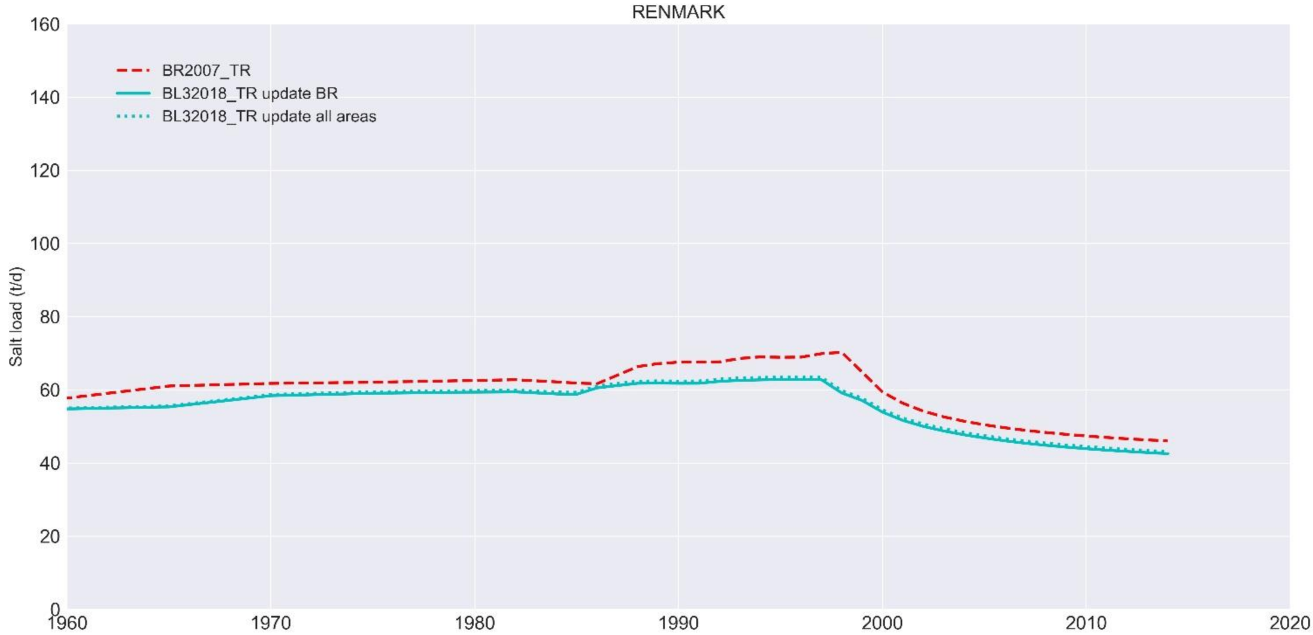

Figure 5.3 Renmark salt load results between accredited models and 2018 updated irrigation footprints

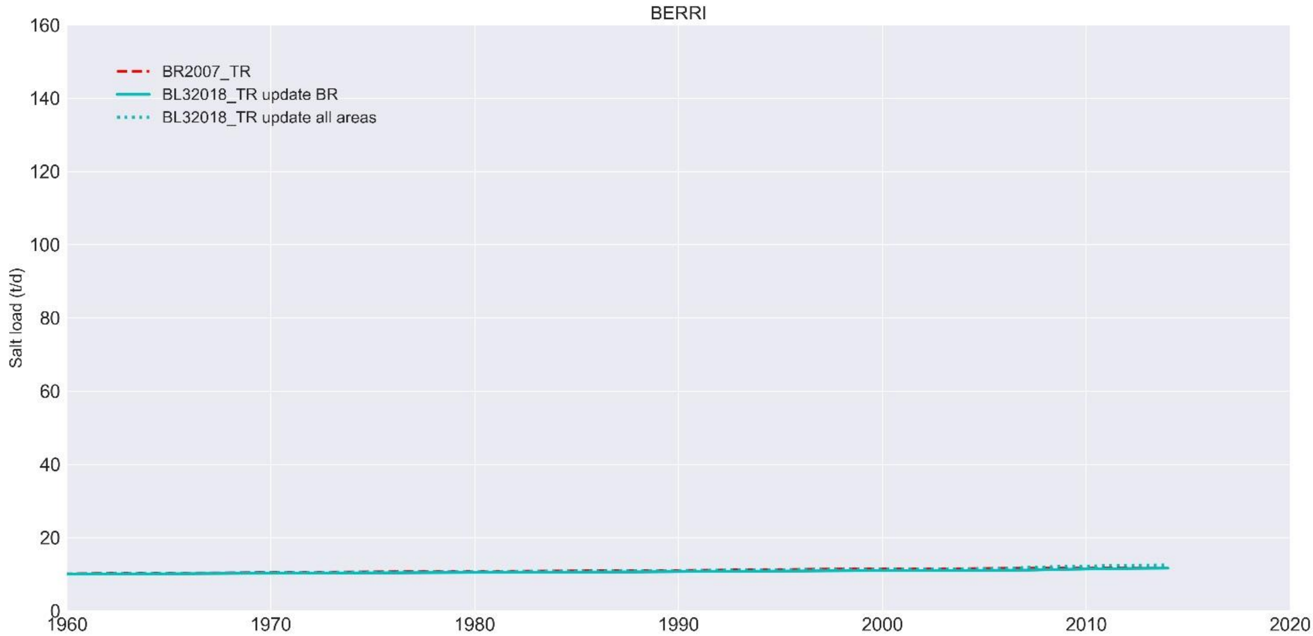

Figure 5.4 Berri salt load results between accredited models and 2018 updated irrigation footprints

5.2.3 Loxton-Bookpurnong sub-model

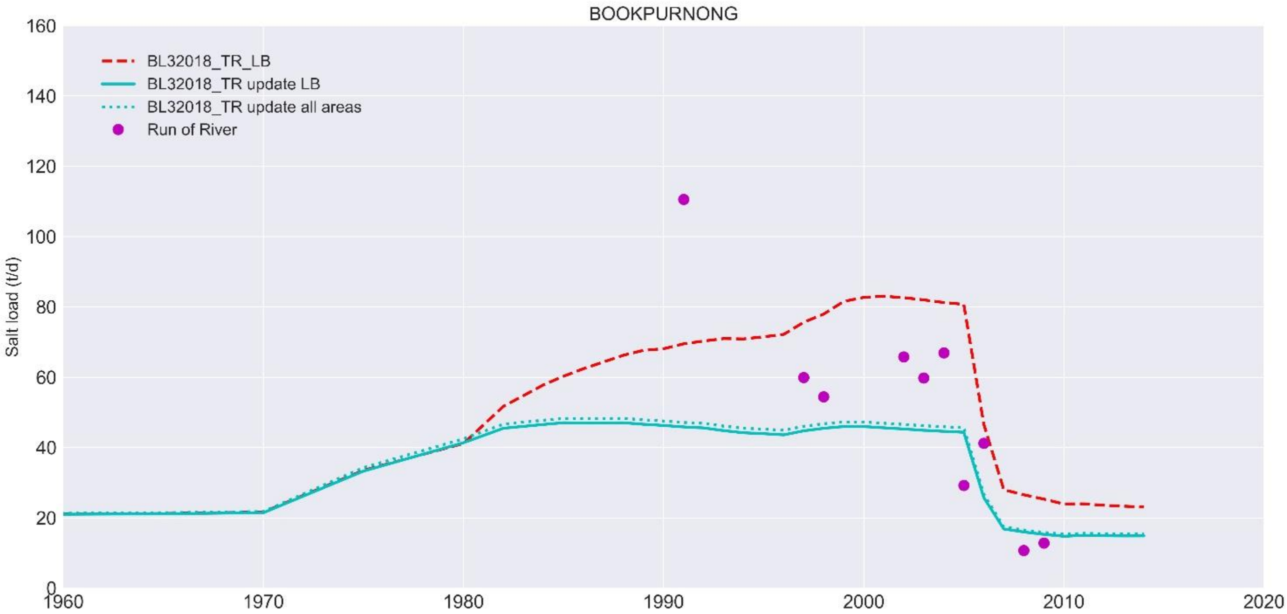

Figure 5.5 Bookpurnong salt load results between accredited models and 2018 updated irrigation footprints

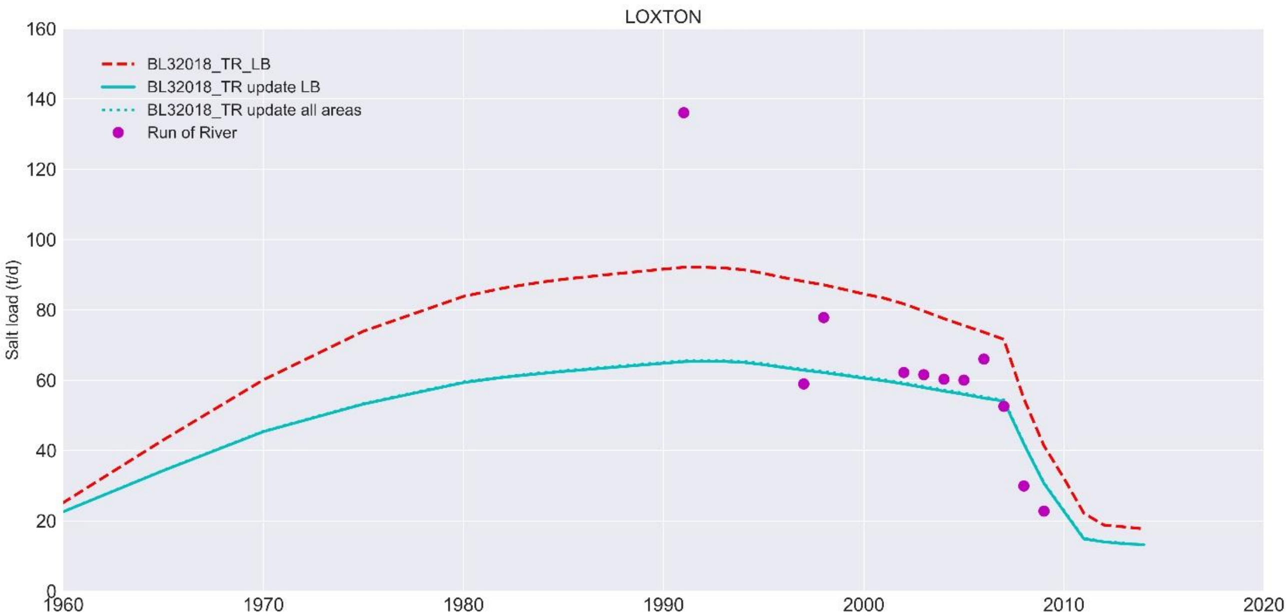

Figure 5.6 Loxton salt load results between accredited models and 2018 updated irrigation footprints

5.2.4 Pyap to Kingston sub-model

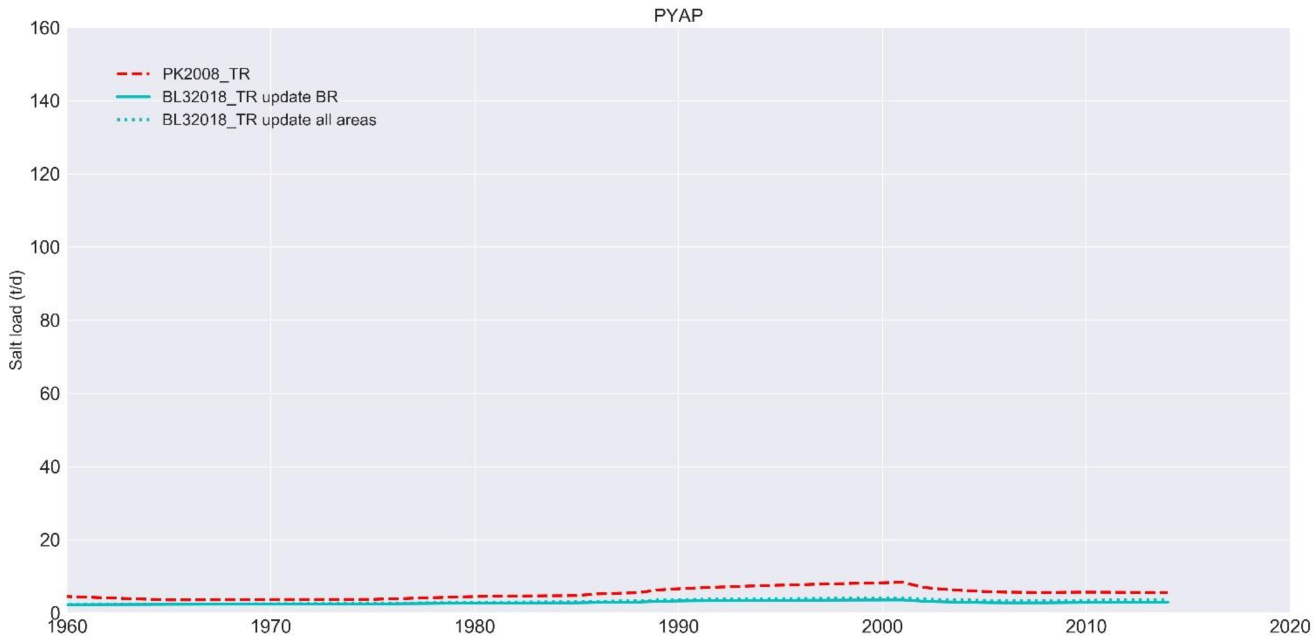

Figure 5.7 Pyap salt load results between accredited models and 2018 updated irrigation footprints

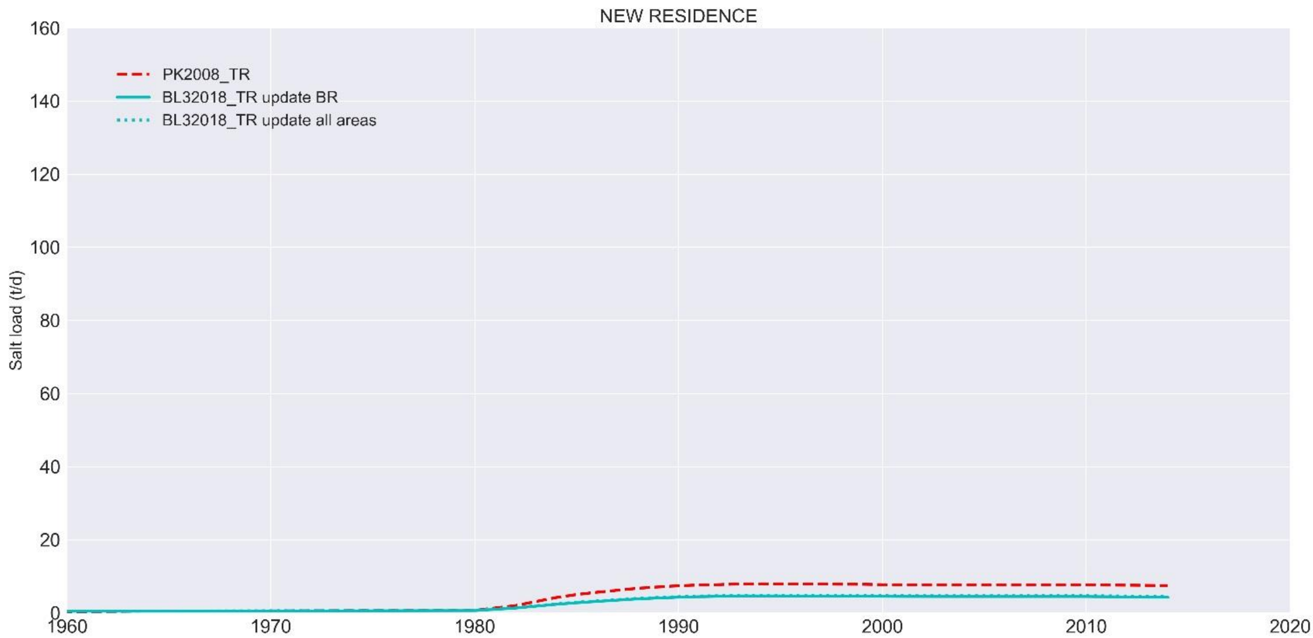

Figure 5.8 New Residence salt load results between accredited models and 2018 updated irrigation footprints

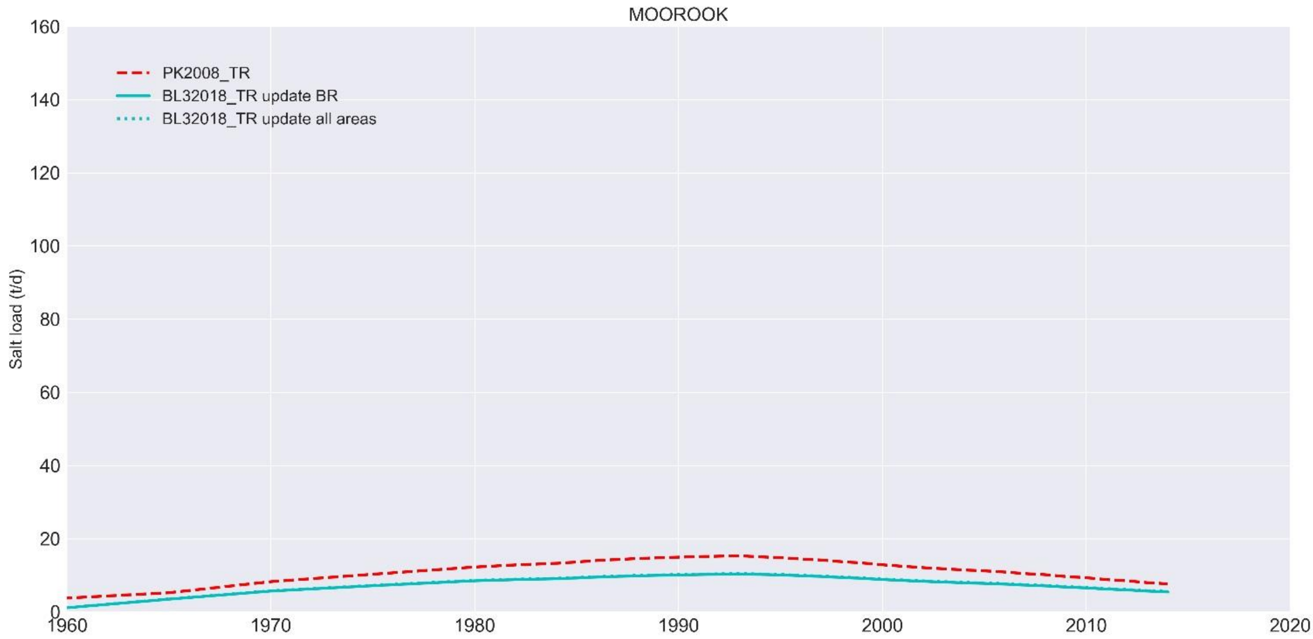

Figure 5.9 Moorook salt load results between accredited models and 2018 updated irrigation footprints

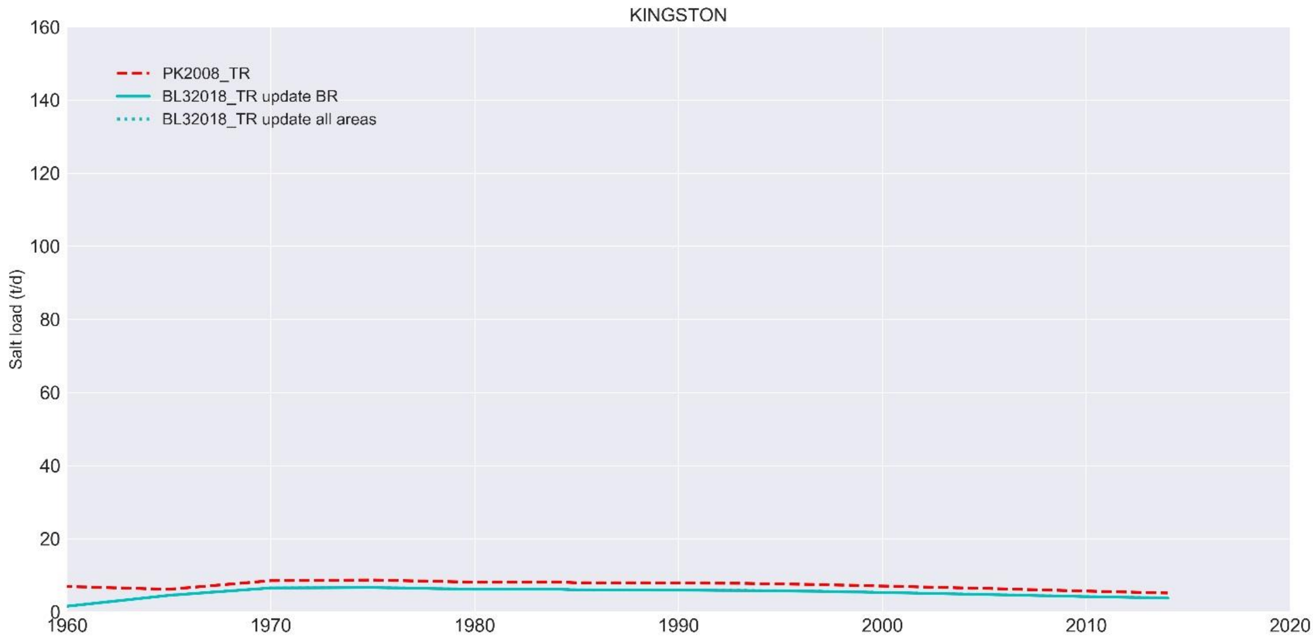

Figure 5.10 Kingston salt load results between accredited models and 2018 updated irrigation footprints

6 Recharge rate assumptions

6.1 Overview

Groundwater flux to the river is mainly driven by irrigation-derived recharge. There is reasonable confidence in the recharge rates and areas used in the transient historical models. There is less confidence in model recharge rates used in the predictive modelling. It is likely that there will be changes in irrigation practices, efficiencies and crop types.

Estimates of future impacts are sensitive to assumptions made about current and future recharge rates. Model recharge rates and irrigation areas in the future are considered to be a key contribution to model uncertainty.

6.2 Method

In this study, an uncertainty test is performed to gauge the impact of recharge rate assumptions on SA's standard Scenario 4 which simulates current irrigation without SIS for a hundred years into the future.

In third generation models, the recharge rate for current irrigation areas into the future is assumed to be 100 mm/y. In second generation models, recharge rates lower than 100 mm/y were assumed on the floodplain, e.g. in the Berri-Renmark region, the majority of irrigation area is located on the floodplain with a recharge rate ranging from 37-85 mm/y.

Based on the updated irrigation model of Section 5, two future scenarios were developed to predict salt loads to the river, which differ by recharge rate assumption (Table 6.1). All irrigation areas within the Border to Lock 3 model domain are simulated. The additional stress periods are a year in length.

Table 6.1 Uncertainty scenarios

Groundwater Vistas model	Simulation period	Number of stress periods	Irrigation area	Future recharge rate assumption (2014-2114)
BL32018_ S4_100mm/y	1880-2114	152	All; based on 2018 update	100 mm/y
BL32018_ S4_120mm/y	1880-2114	152	All; based on 2018 update	120 mm/y

Future irrigation rates are assumed to be 100 mm/y and 120 mm/y. Rates are held constant and do not vary by current crop type or by irrigation method. If irrigation is new to a location, the closest zone lag time are applied. The recharge rate of 100 mm/y has been used for the 'future development' prediction in the Register Entry and accredited models (Yan et al., 2011, Yan et al., 2012, Woods et al., 2013 and Woods et al., 2014). 120 mm/y is another plausible value. In the SIMRAT model (Fargher et al., 2003), water use efficiency was assumed to result in 120 mm/year recharge to the watertable at 2003 (Middlemis et al., 2005, Yan et al., 2007, and Yan et al., 2008).

6.3 Results

This section presents salt load results from the uncertainty tests compared with the modelled salt load from Scenario 4 in the accredited Salinity Register Border to Lock 3 sub-models. Table 6.2 provides scenarios used in salt load comparison.

Table 6.2 Scenarios used to compare salt load results

Visual MODLFOW	S4 Irrigation area	Groundwater Vistas Uncertainty Test 1	Groundwater Vistas Uncertainty Test 2
PM2014_S4	Pike-Murtho	BL32018_S4_ 100mm/y	BL32018_S4 _120mm/y
BR2007_S4	Berri-Renmark	BL32018_S4 _100mm/y	BL32018_S4 _120mm/y
LB2011_S4	Loxton-Bookpurnong	BL32018_S4 _100mm/y	BL32018_S4 _120mm/y
PK2008_S4	Pyap to Kingston	BL32018_S4 _100mm/y	BL32018_S4 _120mm/y

The uncertainty test results of salt load due to using different recharge rates are shown in Figure 6.1 to Figure 6.10. These figures also compare the results with salt loads from the accredited models, which use unrevised estimates of irrigation area. The maximum salt load differences between the accredited models and the uncertainty test simulations are provide in Table 6.3.

Unsurprisingly, in all cases the 120 mm/y assumption leads to higher salt loads than the 100 mm/y assumption.

When comparing the uncertainty scenarios with the accredited models, we are comparing the combined impact of model platform update (Section 2), the simulation of all sub-model areas simultaneously (Section 3), revised irrigation area (Section 4) and the irrigation recharge rate for current irrigation. The aim is to see how the accredited model salt loads may change once the models are updated. However, the updated models have not been recalibrated, so these will not be the final salt load estimates.

Salt loads in the uncertainty simulations are higher than those of the accredited Pike-Murtho and Berri-Renmark sub-models. In contrast, the uncertainty simulation salt load is less than those of the accredited Loxton-Bookpurnong and Pyap to Kingston sub-models. For Loxton-Bookpurnong, this is because the updated irrigation area is significantly smaller. For Pyap to Kingston, it is due to changing from constant head cells to river cells for river representation. Therefore, maximum salt load difference in Loxton-Bookpurnong and Pyap to Kingston for 120 mm/y recharge rate is less than 100 mm/y recharge rate when compared to accredited model salt loads (Table 6.3).

Table 6.3 Maximum salt load difference from varying recharge rates

Visual MODLFOW Register Entry models	Groundwater Vistas Uncertainty Test 1	Maximum salt load difference (t/d)
PM2014_S4	BL32018_S4_ 100mm/y	33
BR2007_S4	BL32018_S4 _100mm/y	80
LB2011_S4	BL32018_S4 _100mm/y	76
PK2008_S4	BL32018_S4 _100mm/y	15
	Uncertainty Test 2	
PM2014_S4	BL32018_S4 _120mm/y	93
BR2007_S4	BL32018_S4 _120mm/y	97
LB2011_S4	BL32018_S4 _120mm/y	62
PK2008_S4	BL32018_S4 _120mm/y	13

6.3.1 Pike-Murtho sub-model

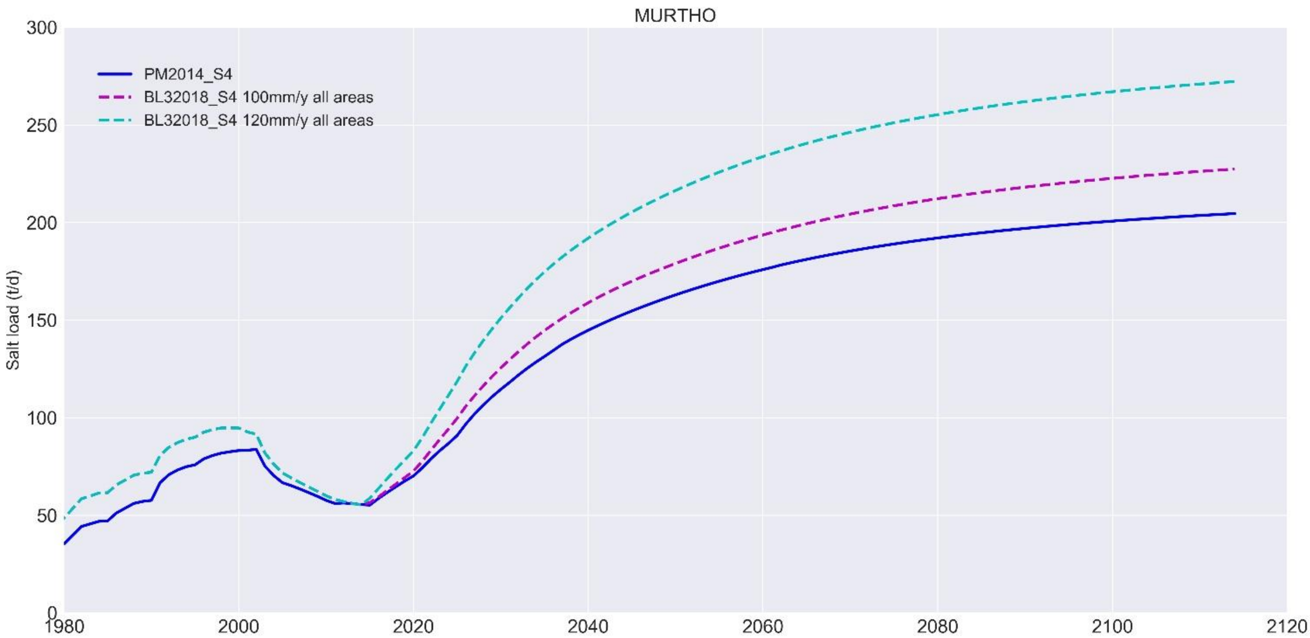

Figure 6.1 Murtho salt load results between recharge rates 100 mm/y and 120 mm/y

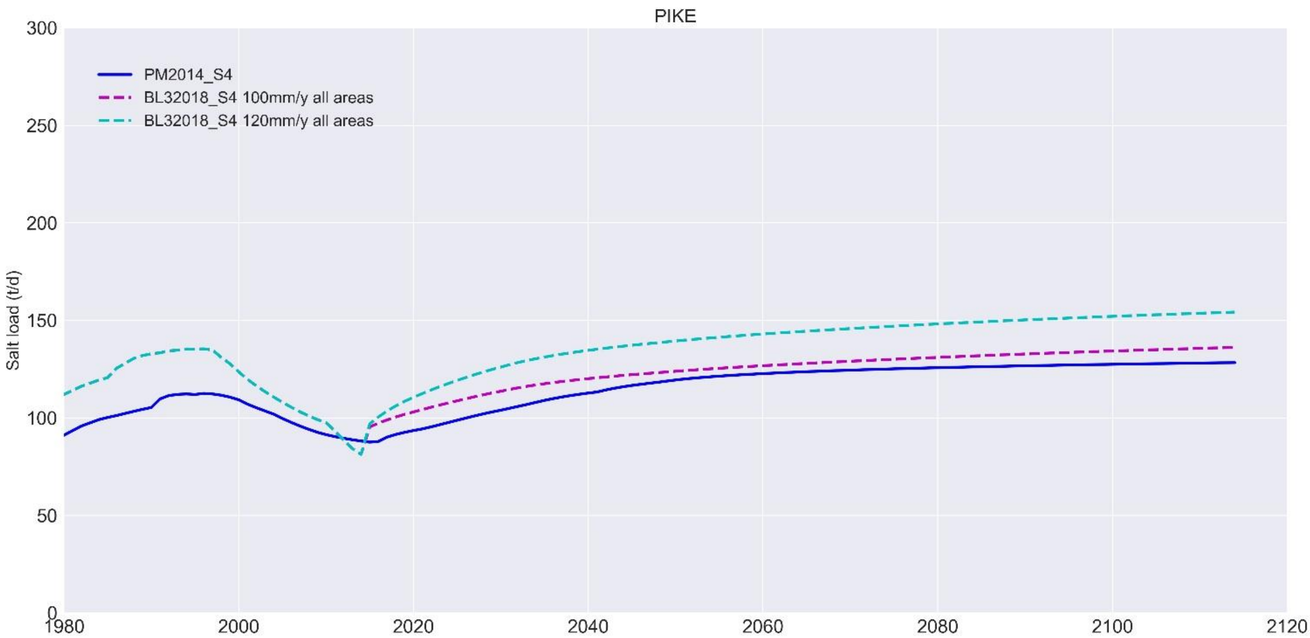

Figure 6.2 Pike salt load results between recharge rates 100 mm/y and 120 mm/y

6.3.2 Berri-Renmark sub-model

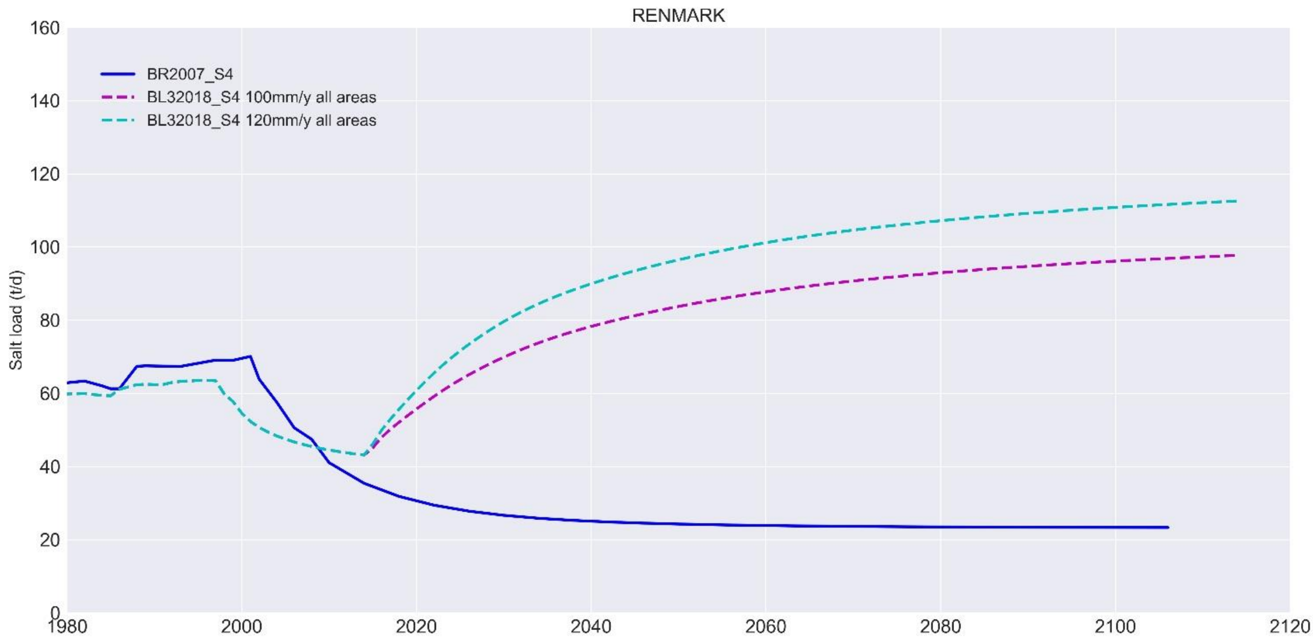

Figure 6.3 Renmark salt load results between recharge rates 100 mm/y and 120 mm/y

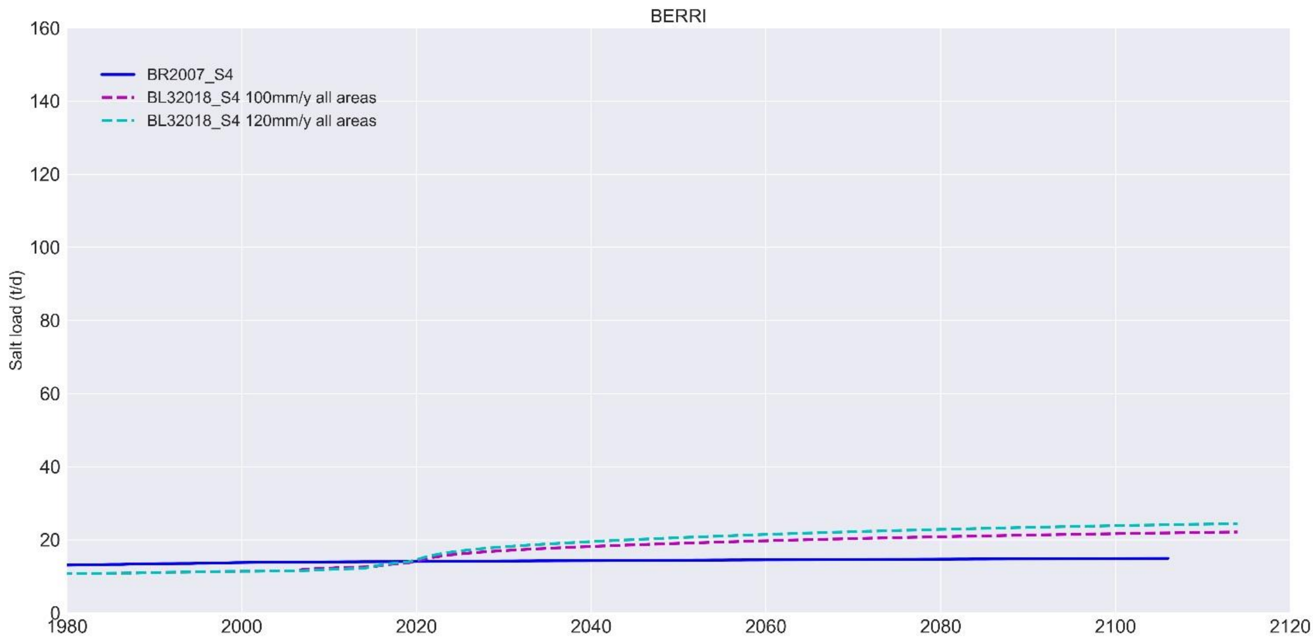

Figure 6.4 Berri salt load results between recharge rates 100 mm/y and 120 mm/y

6.3.3 Loxton-Bookpurnong sub-model

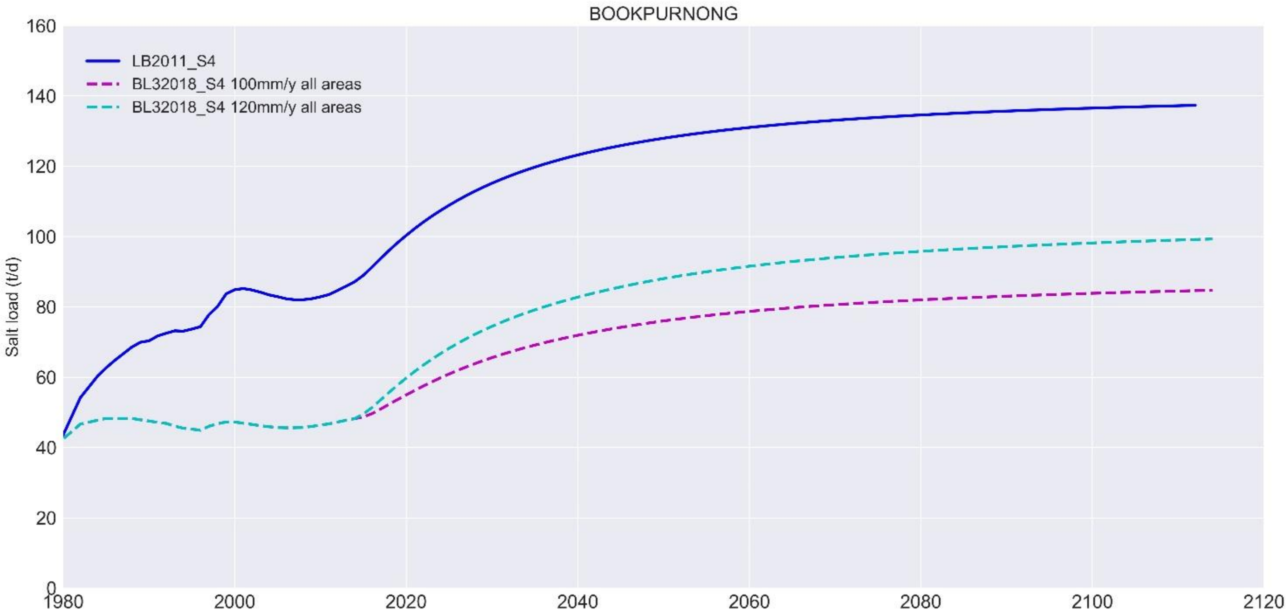

Figure 6.5 Bookpurnong salt load results between recharge rates 100 mm/y and 120 mm/y

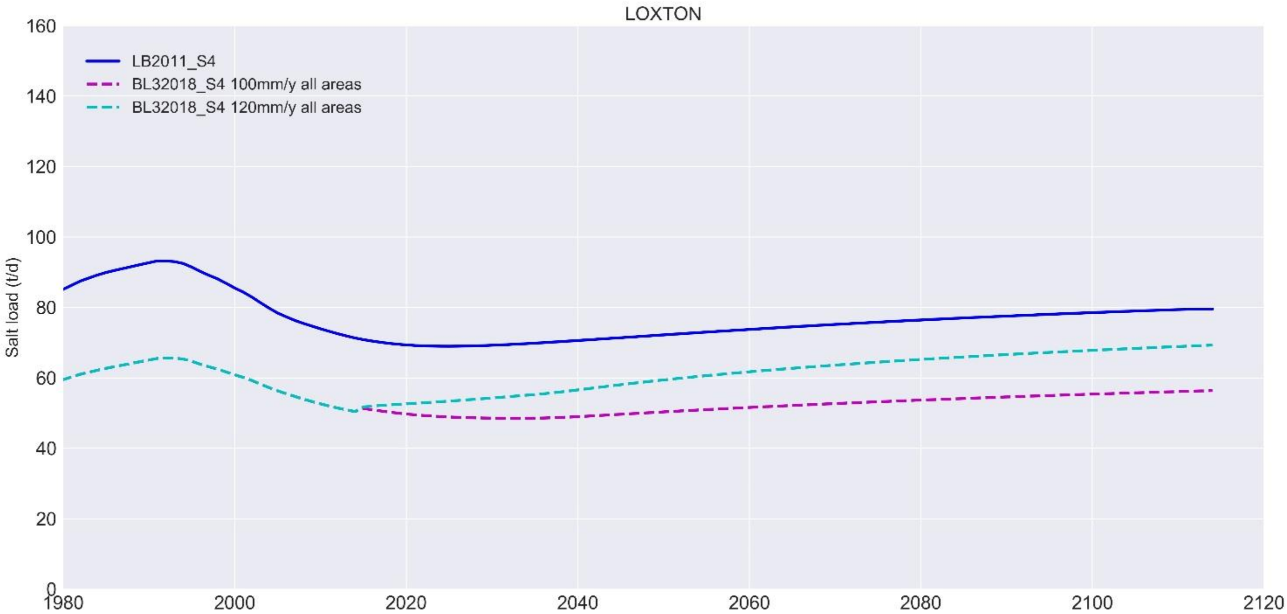

Figure 6.6 Loxton salt load results between recharge rates 100 mm/y and 120 mm/y

6.3.4 Pyap to Kingston sub-model

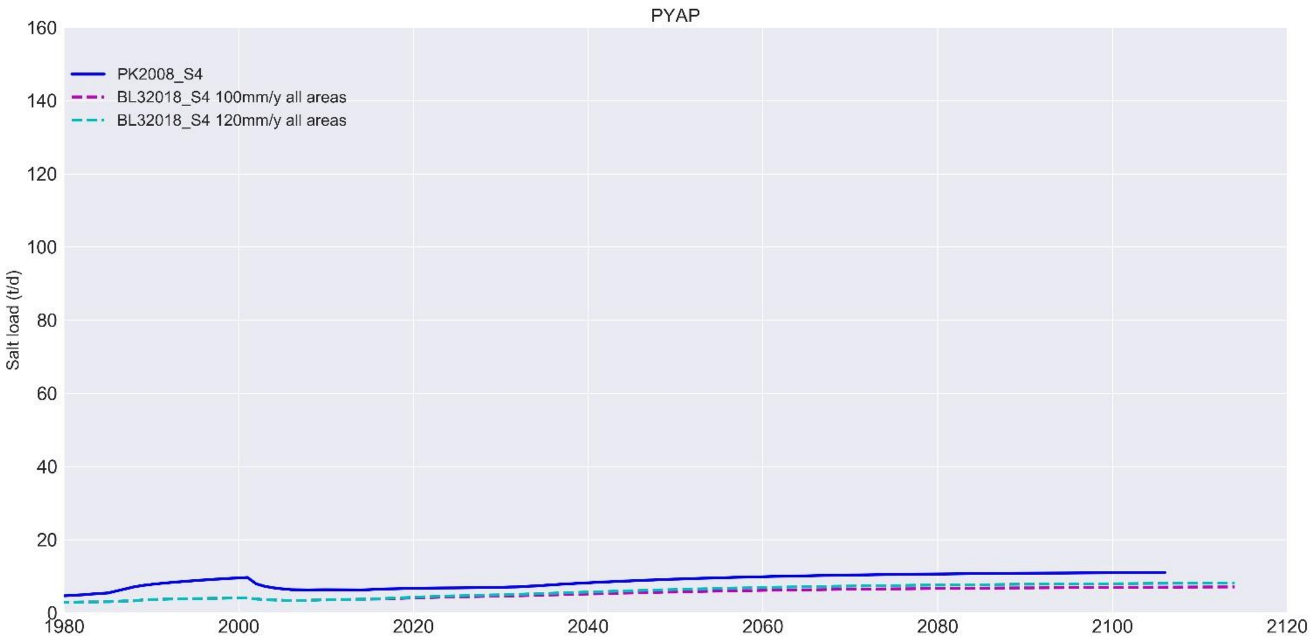

Figure 6.7 Pyap salt load results between recharge rates 100 mm/y and 120 mm/y

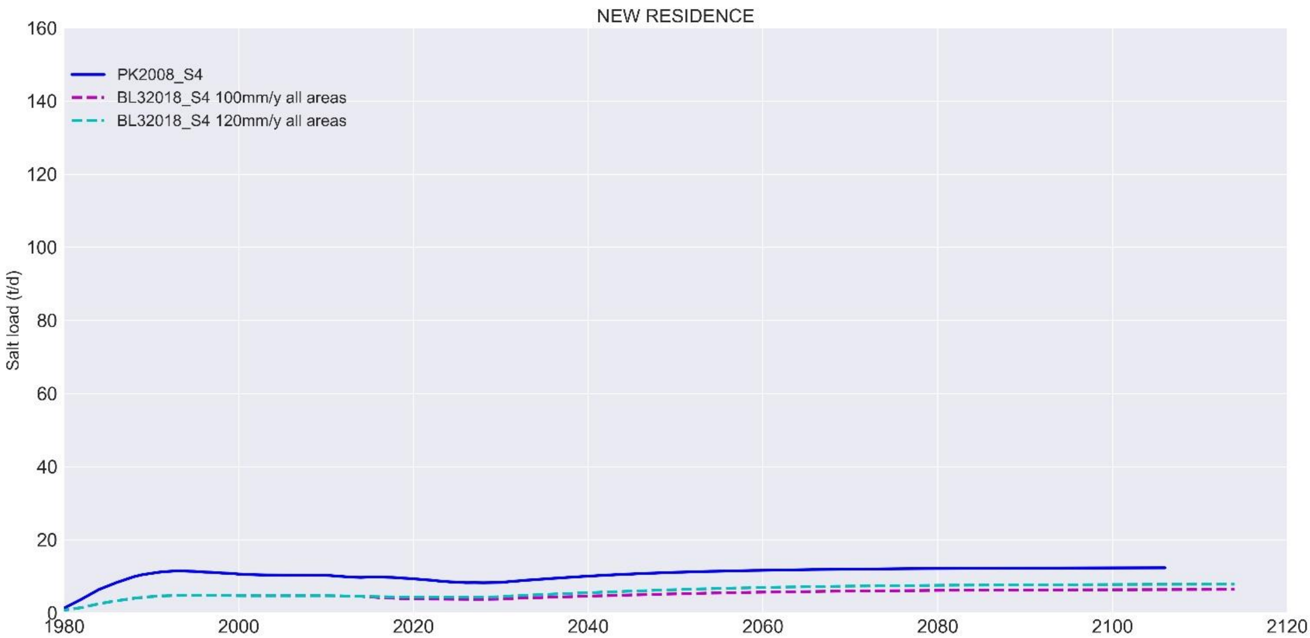

Figure 6.8 New Residence salt load results recharge rates 100 mm/y and 120 mm/y

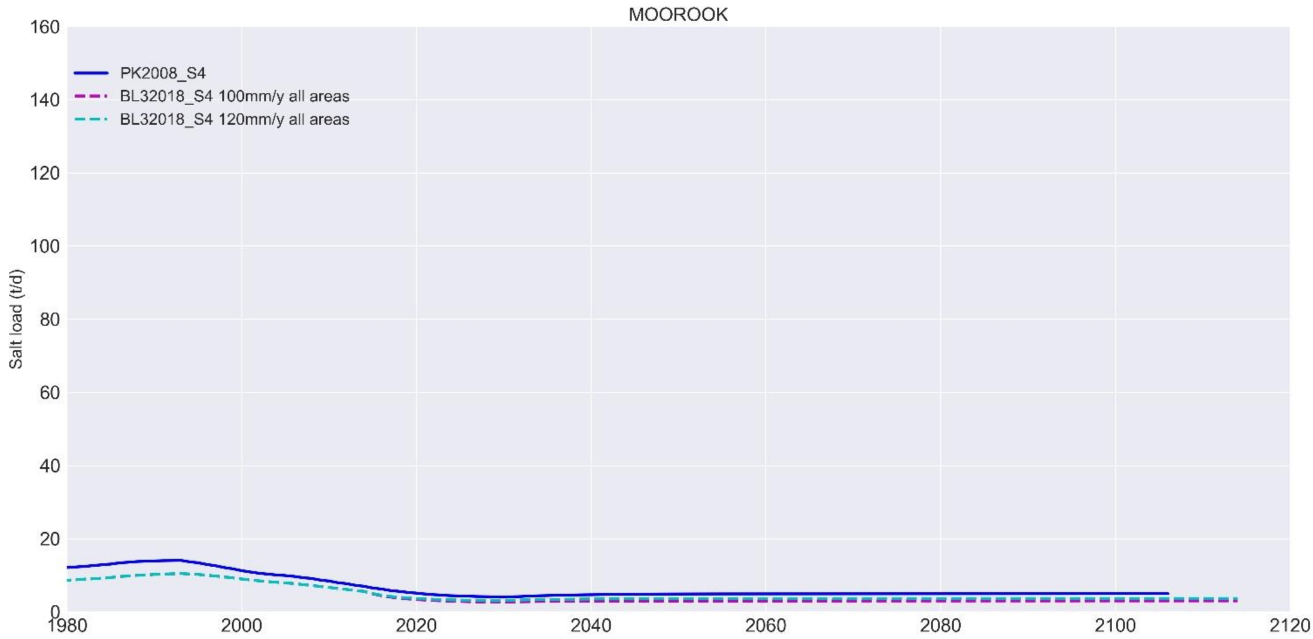

Figure 6.9 Moorook salt load results between recharge rates 100 mm/y and 120 mm/y

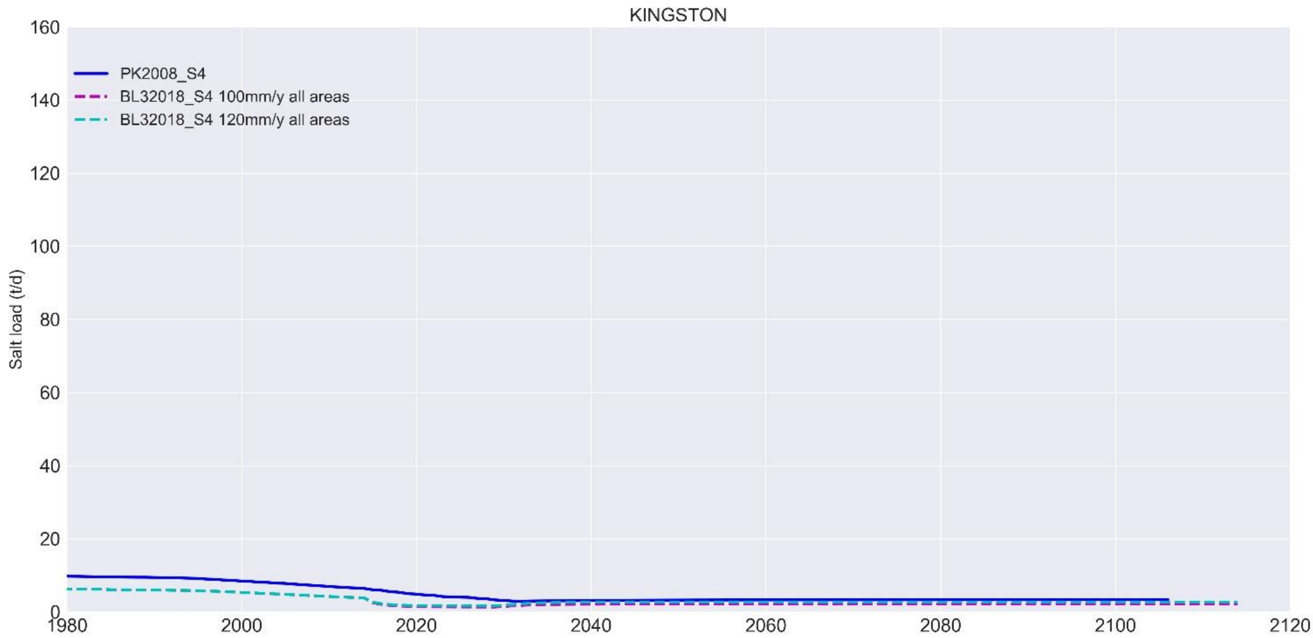

Figure 6.10 Kingston salt load results between recharge rates 100 mm/y and 120 mm/y

7 Conclusions, limitations, and recommendations

7.1 Conclusions

The ongoing River Murray Groundwater Salinity Modelling and Hydrogeological Advice Project maintains models to support SA accountable actions on the Basin Salinity Management 2030 (BSM2030) Salinity Register. In this study, several options for future Salinity Register model upgrades were trialled by modifying the Border to Lock 3 model.

The sub-models of the Border to Lock 3 model were transferred from the Visual MODFLOW platform to Groundwater Vistas. This is a preliminary step for the upgrade of the Pike-Murtho, Berri-Renmark, Loxton-Bookpurnong, and Pyap to Kingston sub-models. The Groundwater Vistas platform will enable the models to simulate reductions in irrigation area over time, and to simulate all irrigation regions simultaneously.

Transferring model platforms resulted in minimal salt load change in most irrigation districts, with the exception of Renmark. A number of assumptions have changed within the Border to Lock 3 model since the Berri-Renmark sub-model was developed, which cause the difference in salt load. Further investigation is recommended as part of the future model upgrade of the Berri-Renmark sub-model, scheduled in 2020-21.

The sub-model approach was tested, i.e. the assumption that irrigation recharge and SIS pumping within one project area will not substantially impact the potentiometric head in another project area. A simulation was run which included all irrigation areas and SISs simultaneously. Salt load results confirm the general validity of the sub-model approach. The exception is the Pike-Murtho region, which shows significant impact from adjacent irrigation, as salt load is significantly increased in both Pike and Murtho.

A revised irrigation area was developed by cross-checking between multiple datasets (MSA Crop Data 2013-2014 (MSA), Google Earth Pro imagery dated 2015 (Google Inc.), ArcGIS imagery dated 2014 (ESRI) and SA Land Cover epoch 2010-2015 (DEW)). In general, the updated irrigation area is smaller than previous estimates, including those used in the accredited and Register Entry models.

The Border to Lock 3 model was run with the revised irrigation area in the transient historical scenario in order to gauge the potential impact to the Salinity Register entries. Overall, accredited Salinity Register models had a larger irrigation recharge area and hence larger salt load impact than the revised simulations. In most areas, salt load results are decreased as the irrigation areas decreased. A significant change can be seen in Pike-Murtho and Loxton-Bookpurnong sub-model results.

The impact of revised irrigation areas on Salinity Register calculations will depend on the time period simulated. The sub-models in this report have not yet been recalibrated. During calibration, the recharge volume for historical periods is estimated through inverse modelling, matching observed potentiometric heads, and it is likely that previous overestimates of irrigation area will have been compensated for by underestimating recharge rates. Hence the changes to historical salt load presented in this report are likely to diminish once the sub-models have been recalibrated. However, salt loads impacts in future years are strongly dependent on irrigation area, as the recharge rate is fixed at 100 mm/y.

Uncertainty scenarios explore the impact of different irrigation recharge rate assumptions in a future scenario, SA "Scenario 4" with irrigation but without SIS for the next 100 years. Rates of 100 mm/y and 120 mm/y were considered. Higher recharge rates resulted in higher salt load to the river, particularly for the Pike-Murtho and Berri-Renmark sub-models. The combined impact of revised irrigation area and higher irrigation recharge rate led to minimal change in salt loads for the Loxton-Bookpurnong and Pyap to Kingston sub-models.

7.2 Limitations

This modelling study has limitations, which require consideration when the models are reviewed and upgraded:

- The coarse salinity zones of the second generation models have not been refined. Updating salinity zones and salinity values will likely have significant impact on salt load estimates.
- Only the transient historical and Scenario 4 were considered in this study. Other scenarios will be updated as part of the scheduled reviews.
- Many factors influence recharge rates, hence future recharge rates are a simplification, e.g. they do not take into account variability relating to crop type, irrigation practice, and the time for the recharge flux to reach the watertable.

Despite these limitations, the current exercise of changing groundwater model platform and updating irrigation area provide important findings and recommendations for the scheduled model reviews and updates.

7.3 Recommendations

1. All SA Salinity Register models should be transferred to the Groundwater Vistas platform as part of their scheduled reviews. This enables the models to simulate reductions in irrigation area over time, and to simulate all irrigation regions simultaneously.
2. The sub-model approach should no longer be used for the Pike-Murtho and Berri-Renmark study areas.
3. The irrigation area from below Lock 3 to Wellington should be updated using the approach outlined in this document (Section 2.3) to complete the irrigation area review within the SAMDB.
4. The SA Salinity Register models should be updated with the revised irrigation areas as part of their scheduled reviews.
5. The inactive zone within the Border to Lock 3 model should be revised to accommodate the expanding irrigation areas from Pyap to Kingston and in the Berri irrigation district.

   The recharge rates assumed for current irrigation into the future need to be discussed and agreed between the MDBA and basin jurisdictions.

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