TECHNICAL REPORT

LOXTON–BOOKPURNONG NUMERICAL GROUNDWATER MODEL 2011

VOLUME 1: REPORT AND FIGURES

2011/22

Government of South Australia
Department for Water

LOXTON–BOOKPURNONG NUMERICAL GROUNDWATER MODEL 2011

VOLUME 1: REPORT AND FIGURES

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Science, Monitoring and Information Division
Department for Water

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Technical Report DFW 2011/22

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FOREWORD

South Australia's Department for Water leads the management of our most valuable resource — water.

Water is fundamental to our health, our way of life and our environment. It underpins growth in population and our economy — and these are critical to South Australia's future prosperity.

High-quality science and monitoring of our State's natural water resources are central to the work that we do. This will ensure that we have a better understanding of our surface and groundwater resources so that there is sustainable allocation of water among communities, industry and the environment.

Department for Water scientific and technical staff continue to expand their knowledge of our water resources through undertaking investigations, technical reviews and resource modelling.

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT FOR WATER

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Linda Vears of the Department for Water advised on policy, assisted with irrigation data gathering and coordinated The 5 Year Review Modelling Registers Project Team.

The scenarios were refined with input and approval from The 5 Year Review Modelling Registers Project Team for Loxton–Bookpurnong:

- Chris Wright, Linda Vears, Wei Yan and (on secondment) Juliette Woods of the Department for Water
- Phil Pfeiffer and Asitha Katupitiya of the Murray-Darling Basin Authority
- Peter Forward of SA Water.

The report was peer reviewed by Don Armstrong (Lisdon Associates) as an expert hydrogeologist, geologist and groundwater modeller, Bob Newman as an expert in Murray-Darling Basin salinity management and policy and Steve Barnett as Principal Hydrogeologist in Department for Water.

The report was also reviewed on behalf of the MDBA by two experts in groundwater modelling, Hugh Middlemis of RPS Aquaterra and Ray Evans of Sinclair Knight Mertz.

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SUMMARY

The Loxton and Bookpurnong irrigation areas are adjacent to the River Murray in the north-eastern region of the South Australian part of the Murray Basin, close to Lock 4. The underlying regional groundwater is highly saline. The region had previously been cleared for dryland farming. Land clearance and irrigation have mobilised salt from groundwater towards the River Murray and its floodplain in a process involving long lag times. Instream flow and salinity observations provide a long-term understanding of salt accessions from Lock 5 to Lock 4 and Lock 3. According to measured salt load entering the River Murray by Run of River (RoR) in 1997, 78 t/d of salt entered the river in the Loxton area (river kilometres 487 to 502) and 67 t/d of salt entered the river in the Bookpurnong area (river kilometres 503 to 521). Subsequent actions including salt interception and improved irrigation practices have mitigated or offset these impacts. Groundwater models are used to quantify these impacts.

To meet obligations under the Murray-Darling Basin Authority's (MDBA) Basin Salinity Management Strategy (BSMS), South Australia is developing a suite of accredited MODFLOW groundwater models to bring entries forward to the BSMS Salinity Registers. This work is undertaken by the Science, Monitoring and Information Division [(Department for Water (DFW)] under the broad direction of the Policy Division of DFW, in liaison with the MDBA. Through the groundwater modelling process, scenarios are established to assist in determining the origin and volume of salt entering the River Murray from groundwater sources.

DFW has developed a MODFLOW numerical groundwater flow model (Border to Lock 3 Model) from the South Australia–Victoria border to the Woolpunda area in South Australia (Yan & Stadter 2008). This model covers most of the Riverland area, including the Loxton–Bookpurnong project area. The objectives of the modelling project were to develop a model capable of simulating the regional aquifer system in the Riverland area which could be used to:

- improve the understanding of the hydrogeology of the regional aquifer system and processes in the model area
- provide estimated salt loads entering the River Murray under different accountable development and management actions (100 year predictions from current year) for use as Salinity Register entries
- assist with broad-scale planning for groundwater management schemes (e.g. salt interception schemes — SIS) that help to control the flux of saline groundwater and therefore salt load, entering the River Murray.

The fundamental objective of the modelling work undertaken has been to improve confidence in the model parameters and results to the level that will enable and assist:

- accreditation of the model by the MDBA
- use of modelled salt loads as Salinity Register entries.

The model was developed in 2004 and accredited for the design of the Loxton and Bookpurnong SIS in 2005. The design SIS is the scheme as designed, prior to changes made during construction. For the five-year review process, the model was updated in 2011 based on new data and improvements in hydrogeological understanding. The model was recalibrated to head observations, including new data from constructed SIS bores on the floodplain and its results confirmed through comparison to RoR salt load observations, NanoTEM data on gaining stream reaches and new estimates of accession volumes in irrigation areas. The model is satisfactorily calibrated.

The calibrated historical model estimates the pre-development base salt load entering the river to be 2.9 and 22.2 t/d in Loxton and Bookpurnong, respectively. In the model, salt load peaks at 93.2 t/d in

1990 and 1991 for Loxton and 85.2 t/d in 2000 for Bookpurnong. This additional salt load results from an increased flux of saline groundwater due to the development of groundwater mounds induced by irrigation drainage. Salt loads have since decreased, due to improvements in irrigation practices (including rehabilitation of infrastructure), water restrictions and the construction of SIS. The model estimates that 19.3 and 25.7 t/d of salt enter the river in 2010 in the Loxton and Bookpurnong areas, respectively.

After calibration, the transient model was used to run scenarios under the conditions required for the Salinity Register entries. The scenarios estimate groundwater fluxes and resultant salt load entering the River Murray due to accountable irrigation and management actions in the Loxton and Bookpurnong areas.

This report documents the numerical groundwater flow model, including comprehensive information on the model design, model inputs and estimated annual salt loads for different scenarios. The results of the model scenario runs are summarised in Tables S-1 and S-2.

This report delivers the technical information about the model and model results for the accreditation process. For Salinity Register entry, the estimated salt loads will be provided to the MDBA for conversion to credits and debits for the BSMS Salinity Register following accreditation of the model. The entries will then be submitted through the Basin Salinity Management Advisory Panel for approval prior to being entered onto the Salinity Registers.

Table S-1 Loxton area — Summary of predicted salt load (t/d) entering the River Murray

Loxton					Year/Salt load (t/d)						
Scenario	**Name**	**Irrigation development area**	**IIP[1] & RH[2]**	**SIS[3]**	**1920**	**1988**	**2000**	**2010**	**2015**	**2050**	**2110**
Calibrated model	Historical irrigation, RH, IIP & SIS	Irrigation history	Yes	Yes	3	92	84	19	–	–	–
Scenario-1	Natural System (Steady State since 1920)	None	–	–	3	3	3	3	3	3	3
Scenario-2	Mallee Clearance	None	–	–	3	3	3	4	4	5	8
Scenario-3a	Irrigation Pre-1988, no IIP, no RH	Pre-1988	No	No	3	92	100	105	107	112	115
Scenario-3c	Irrigation Pre-1988, with IIP & RH	Pre-1988	Yes	No	3	92	84	72	68	60	60
Scenario-4	Current irrigation (business as usual)	Pre-1988 + Post-1988	Yes	No	3	92	84	73	70	72	79
Scenario-5	Current plus future irrigation	Pre-1988 + Post-1988 + Future development	Yes	No	3	92	84	73	70	78	86
Scenario-8a	Current irrigation plus constructed SIS	Pre-1988 + Post-1988	Yes	Yes	3	92	84	21	17	17	18
Scenario-8b	Pre-1988, with IIP & RH plus constructed SIS	Pre-1988	Yes	Yes	3	92	84	21	17	14	14
Scenario-8c	Current plus future irrigation plus constructed SIS	Pre-1988 + Post-1988 + Future development	Yes	Yes	3	92	84	21	17	18	20

IIP[1]: Improved irrigation practices RH[2]: Rehabilitation SIS[3]: Salt interception schemes

See Glossary for definitions

Table S-2 Bookpurnong area — Summary of predicted salt load (t/d) entering the River Murray

Bookpurnong					Year/Salt load (t/d)						
Scenario	**Name**	**Irrigation development area**	**IIP[1] & RH[2]**	**SIS[3]**	**1920**	**1988**	**2000**	**2010**	**2015**	**2050**	**2110**
Calibrated model	Historical irrigation, RH, IIP & SIS	Irrigation history	Yes	Yes	22	70	85	26	-	-	-
Scenario-1	Natural System (Steady State since 1920)	None	–	–	22	22	22	22	22	22	22
Scenario-2	Mallee Clearance	None	–	–	22	22	22	22	23	23	26
Scenario-3a	Irrigation Pre-1988, no IIP, no RH	Pre-1988	No	No	22	70	99	109	111	117	121
Scenario-3c	Irrigation Pre-1988, with IIP & RH	Pre-1988	Yes	No	22	70	85	79	79	81	82
Scenario-4	Current irrigation (business as usual)	Pre-1988 + Post-1988	Yes	No	22	70	85	84	91	128	137
Scenario-5	Current plus future irrigation	Pre-1988 + Post-1988 + Future development	Yes	No	22	70	85	84	92	133	144
Scenario-8a	Current irrigation plus constructed SIS	Pre-1988 + Post-1988	Yes	Yes	22	70	85	20	21	28	30
Scenario-8b	Pre-1988, with IIP & RH plus constructed SIS	Pre-1988	Yes	Yes	22	70	85	19	19	19	19
Scenario-8c	Current plus future irrigation plus constructed SIS	Pre-1988 + Post-1988 + Future development	Yes	Yes	22	70	85	20	21	29	31

IIP[1]: Improved irrigation practices RH[2]: Rehabilitation SIS[3]: Salt interception schemes

See Glossary for definitions

1. INTRODUCTION

River salinity levels are 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 from landscape. Agricultural practices can mobilise additional salt from groundwater to the river. This affects the water quality of the River Murray for industrial, agricultural and potable use, including the water supply for metropolitan Adelaide. Increases in River Murray salinity can also lead to degradation of floodplain vegetation health.

Due to its ecological and economic impacts, Federal and State initiatives have been developed to manage River Murray salinity. Many of these rely on numerical groundwater models to estimate the salinity impacts of management strategies on the River Murray.

The Loxton and Bookpurnong irrigation areas of South Australia are two of the agricultural areas that affect the salinity of the River Murray. Their salinity impact has been assessed using the Border to Lock 3 numerical groundwater model, which was originally developed by the Department for Water, Land and Biodiversity Conservation (DWLBC) in 2005 (Yan et al. 2005). Since the model was developed, further hydrogeological studies have improved the understanding of the region’s aquifer systems.

The aim of this project is to upgrade the existing Border to Lock 3 model in the Loxton–Bookpurnong area and to evaluate salt loads resulting from local, accountable actions such as land clearance, irrigation area development, changes in irrigation practice and the construction of SIS. After the model has been reviewed by groundwater modelling experts and accredited by the Murray-Darling Basin Authority (MDBA), the model results may be used to calculate Salinity Register entries.

This report extensively documents the groundwater flow model in a format that will assist completion of the MDBA review and accreditation process. It includes comprehensive information on model inputs and details of calculated salt loads for different scenarios. The report has two volumes:

- Volume 1 — Report and Figures, which contains the report and key figures depicting the project area, model structure, parameters and model results
- Volume 2 — Appendices, which contains detailed model inputs (recharge zones and rates), outputs of groundwater flux and salt loads for the various scenarios modelled and data for sensitivity and uncertainty analyses.

This report delivers the technical information about the model and model results for the accreditation process. For Salinity Register entry, the estimated salt loads will be provided to the MDBA for conversion to credits and debits for the BSMS Salinity Register following accreditation of the model. The entries will then be submitted through the Basin Salinity Management Advisory Panel for approval prior to being entered onto the Salinity Registers.

1.1. POLICY BACKGROUND

1.1.1. FEDERAL INITIATIVES

Schedule B of the Murray-Darling Basin Agreement 2008 (the Agreement) provides the legislative framework to manage and reduce the impacts of salinity in the MDB and the Basin Salt Management Strategy (BSMS) 2001–2015 provides the strategic policy framework. These initiatives followed the adoption of the Ministerial Council’s Salinity and Drainage Strategy in 1988 (S&DS).

The BSMS aims to:

- maintain the water quality of the shared water resources of the Murray and Darling Rivers for all beneficial uses — agricultural, environmental, urban, industrial and recreational
- control the rise in salt loads in all tributary rivers of the MDB and, through that control, protect their water resources and aquatic ecosystems at agreed levels
- control land degradation and protect important terrestrial ecosystems, productive farm land, cultural heritage and built infrastructure at agreed levels basin-wide
- maximise net benefits from salinity control across the MDB.

A key feature of the strategy is the adoption of salinity targets for each tributary valley and a basin target at Morgan in South Australia. The Basin Salinity Target is an average daily salinity at Morgan at a simulated level of less than 800 EC for at least 95% of the time, under the hydrological conditions of the benchmark period. The benchmark period is an agreed climatic/hydrologic sequence, from 1 May 1975 to 30 April 2000, which is chosen as representative.

The salinity targets are supported by a system of salinity credits and debits, recorded and reported on the Salinity Registers, where a credit corresponds to an action that decreases salinity and a debit relates to an action that increases salinity. The Salinity Registers track all actions that are assessed to have a significant effect on salinity, defined as a change in average daily salinity at Morgan which will be at least ±0.1 EC within 100 years. A significant effect can result from a change in the magnitude or timing of salt loads or water flows. Actions that can increase salinity include the clearance of native vegetation and the introduction of irrigation. Actions that can decrease salinity include improved irrigation practice, rehabilitation of water delivery methods and construction of SIS. The BSMS allows for any action resulting in an increase in river salinity, such as new irrigation developments, to occur provided that salinity credits gained by contributing to the funding of SIS or other measures are available to offset any salinity debits arising from these accountable actions.

The S&DS and later salinity agreements adopt a baseline date from which any subsequent actions that affect the River Murray are the responsibility of the State in which the action occurred. The baseline date for New South Wales, South Australia and Victoria is 1 January 1988; the baseline date for Queensland is 1 January 2000. Hence the Registers distinguish between ‘legacy of history’ and ‘future actions’ that affect salinity: Register B records the salinity impact of ‘legacy of history’ actions that occurred prior to the baseline date but which continue to affect river salinity, while Register A records the salinity impact of actions occurring after the baseline date.

The impact of actions is typically assessed using a numerical groundwater flow model. Since the BSMS was agreed, South Australia has developed a series of four numerical groundwater models that have been accredited to estimate salinity debits and credits for the Registers. They cover the following reaches of the River Murray: (i) the Chowilla floodplain including areas in New South Wales, South Australia and Victoria, (ii) the SA Border to Lock 3, (iii) Lock 3 to Morgan and (iv) Morgan to Wellington. These models have been used to assess impacts of native vegetation clearance, irrigation, improvements in irrigation practice and infrastructure and the SIS.

The BSMS commits the partner governments to an investment program of salinity mitigation works and measures implemented across the MDB to deliver 61 EC credits to the river and to offset the States’ accountable actions. South Australia proposed a credit allocation and cost-sharing methodology on the basis of the model results of the various accountable actions occurring before and after the baseline date, which in South Australia are typically referred to as ‘Pre-1988’ and ‘Post-1988’ actions. The assessment of those impacts must be consistent with the reporting requirements of both Schedule C of the Murray-Darling Basin Agreement 1992 and the Basin Salinity Management Strategy Operational Protocols 2005.

One of the main kinds of salinity mitigation works under the BSMS is the construction of SIS, which are built to reduce river salinity. When an SIS is first proposed, the salinity impact of the Concept Design is estimated as part of the approval process for the MDBA, using a suitable model that is not necessarily one accredited for use for the Registers. If further SIS investigations are approved, the SIS design is likely to be refined as new information becomes available and the salinity impact of the resulting Revised Design is also estimated for the MDBA prior to construction of the scheme. Once constructed, the salinity impact must be included on the Salinity Registers. The MDBA currently requires that the salinity impact of each scheme be reviewed and possibly revised for the Registers as part of the periodic Five Year Reviews of the schemes.

1.1.2. STATE INITIATIVES

South Australia has a number of State initiatives linked to the BSMS objectives:

- the SA Salinity Zoning Policy specifies that new irrigation developments along the River Murray are limited to areas of low salinity impact, in accordance with the Water Allocation Plan (WAP) for the River Murray Prescribed Water Course.
- Target 3.11 of South Australia's Strategic Plan is that 'South Australia maintains a positive balance on the Murray-Darling Basin Commission salinity register'.
- South Australia's River Murray Salinity Strategy (SARMSS) also establishes the Basin Salinity Target as a State objective. In addition, under SARMSS, South Australia undertakes monitoring at a number of sites and this may give an ongoing indicator of likely performance against the Basin Salinity Target.

Strategies to achieve these include:

- the construction and maintenance of infrastructure such as SIS to reduce salt loads to the river
- forming partnerships with communities to reduce the salinity impacts of irrigation
- the development and implementation of salinity management policies
- undertaking transparent and accurate assessment of South Australia's salinity accountability.

These strategies have proved successful and South Australia is currently removing more salt than it is putting into the River Murray and the MDBA's Basin Salinity Management Strategy (BSMS) Salinity Registers currently assess South Australia as having a strong positive balance. Productive agricultural areas have been able to expand (the recent drought notwithstanding) while significant reductions in river salinity have been achieved, at least above Lock 1.

There remain some salinity management issues in South Australia that have not yet been thoroughly addressed. For example, the potential salt impacts from flooding are currently being estimated. There is also a need to develop salinity targets for the section of river below Morgan, from which Adelaide draws much of its water supply.

Numerical groundwater models assist with many of these South Australian policy goals. They are used to estimate salinity impacts of management options, for example in the design and optimisation of SIS works.

1.2. THE LOXTON–BOOKPURNONG AREA

Loxton and Bookpurnong are two adjacent irrigation areas within the Riverland region of South Australia. Both are reliant on water pumped from the River Murray. Root zone drainage, from rainfall and irrigation, recharges the groundwater table and has developed groundwater mounds in both areas. These mounds have significantly increased the flux of saline groundwater and therefore salt load, entering the River Murray.

To reduce the salt from groundwater that enters the River Murray, improvements have been made to irrigation practices and SIS have been constructed at Loxton and Bookpurnong. Both of the SIS use extraction bores to lower groundwater gradients to the river. The Loxton scheme also includes a Horizontal Drainage Well and a Cliff Toe Drain.

The Federal and State strategies outlined in Section 1.1 require that the future salinity impacts of land clearance, the irrigation areas and their SIS be estimated. The Border to Lock 3 numerical groundwater model is used to estimate river salinity impacts for the Loxton and Bookpurnong reaches.

1.3. DEVELOPMENT OF THE BORDER TO LOCK 3 MODEL

The Border to Lock 3 numerical groundwater model has been developed and revised in a number of stages.

The model was initially based on work undertaken by Australian Water Environments (AWE). AWE developed a MODFLOW numerical model of the Loxton–Bookpurnong area in 1999 for a Land and Water Management Plan, investigating the utility of proposed SIS; this work culminated in a submission to the Murray-Darling Basin Commission (MDBC) High Level Inter-Jurisdictional Working Group on Salt Interception in February 2003 (DWLBC 2003). AWE developed a more complex model in early 2003 (AWE 2003).

DWLBC commenced further hydrogeological investigations in the Loxton area from mid-2003. One component of these investigations was modelling and in late 2003 DWLBC took over the development of the AWE (2003) model. The model assisted the construction-ready design of SIS in the Loxton area.

DWLBC then further developed the Border to Lock 3 model, which covers a large area that includes the Loxton–Bookpurnong area. The model domain is designed to cover the entire Riverland area for use with various projects and also to avoid potential model boundary effects interfering with model results within the project area. The major irrigation districts included are Loxton, Bookpurnong, Pike, Murtho, Berri, Renmark, Pyap, New Residence, Moorook and Kingston. The model is an impact assessment model of moderate complexity, capable of simulating the regional aquifer system. An initial version had eight layers (Yan, Howles & Hill 2005) but a subsequent revision reduced this to five layers, modelling the lower aquitards implicitly via vertical hydraulic conductivity (Yan et al. 2005).

The model was used by DWLBC for SIS investigations in the Loxton–Bookpurnong and Pike–Murtho areas (Yan et al. 2006). The model and results for the Loxton area were reviewed and accredited for Register use by the MDBC in 2004, for Bookpurnong in 2005 and for Pike–Murtho in 2006 (Salient Solutions 2006).

The Berri–Renmark region of the model was revised in 2006 by Aquaterra in partnership with Resource and Environmental Management (REM) and AWE (Aquaterra, REM & AWE 2006). The model for the Berri–Renmark region was independently reviewed by Lisdon Associates. The review recommended that the model not be used for Register entries unless the calibration was improved. Since mid-2006, DWLBC and Aquaterra have improved the calibration and have addressed issues raised by Lisdon Associates

(Yan et al. 2007). The final report was reviewed by Salient Solutions (2009a) based on the MDBC (2001) Guideline and the requirements for the MDBC Salinity Register entries.

The model was revised further in 2007 in the Pyap–Kingston region only (Yan & Stadter 2008). The model was again reviewed by Lisdon Associates and Salient Solutions (2009b).

In 2008, the MDBC was disbanded and its functions were subsumed by the Murray-Darling Basin Authority (MDBA). The DWLBC Unit that developed the model became part of the Department for Water (DFW) upon its establishment in 2010.

Since the development of the Border to Lock 3 model, field investigations have refined the understanding of both the Loxton and Bookpurnong areas and additional data have been collected from the SIS. A comprehensive report (AWE 2011a) summarising the hydrogeology of the region will be published shortly, including an atlas covering both regions (AWE 2011b).

1.4. CURRENT MODELLING EXERCISE

The first Five Year Review of the Loxton and Bookpurnong SIS and the Salinity Register entries is in progress. As part of the review, AWE has summarised the available hydrogeological data into a report and atlas (AWE 2011a,b). DFW has updated the accredited 2005 model documented in Yan et al. (2005) and Yan & Stadter (2008). No major improvements were requested in the reviews of Yan et al. (2005), so the model upgrades are based on additional data obtained since the development of the model.

The revisions include the following changes to the conceptual model and its numerical representation:

- updated model layer structural contours, particularly for the Loxton Clay – Bookpurnong Formation aquitard
- the representation of the River Murray using the MODFLOW river package instead of constant head cells
- revised evapotranspiration (ET) rates
- input pumping rate data from constructed SIS bores
- updated recharge zones and rates consistent with a detailed review of irrigation data (e.g. application volumes and irrigation efficiencies over time)
- revised model salinity zones and groundwater salinity values.

Further data were collected for comparison to model results during calibration and confirmation:

- a detailed review of irrigation history, conducted by Laroona Environmetrics, included as Appendix C-1
- a detailed SUTRA modelling report from Lisdon Associates about lag times for irrigation drainage to reach the watertable, included as Appendix C-2
- updated potentiometric head time series data from OBSWELL
- updated potentiometric head time series data at the midpoint SIS bores
- RoR salt loads as analysed using the new Burnell method
- NanoTEM surveys of riverbed resistivity
- recent CSIRO research on actual ET value.

Revisions have also been made to the conceptualisation of scenarios, as agreed by a committee of MDBA, DFW and SA Water representatives. The scenario definitions are included in Appendix A-2.

INTRODUCTION

The aim of this project is to upgrade the numerical groundwater model as a predictive management tool for determining salt loads entering the River Murray from the Loxton–Bookpurnong area. The revised model provides quantitative estimates of salt loads entering the River Murray under a range of past and future land and water use conditions that are required by MDBA Salinity Register entries.

2. HYDROGEOLOGY AND HYDROLOGY OF THE LOXTON–BOOKPURNONG AREA

The hydrogeology of the Loxton–Bookpurnong area is detailed in a report (AWE 2011a) and an atlas (AWE 2011b). Yan et al. (2005) provided a description of the hydrogeology as understood at the time of the previous model's development; this has not changed substantially, but information gathered in subsequent years has provided more detailed information in some areas, particularly in the floodplain. Barnett (1991) summarised regional hydrogeological data as part of the Murray Basin Hydrogeological Map Series.

Section 2 summarises key aspects of the hydrogeology and hydrology based on these documents. It concentrates on aspects that will be included in the conceptual and numerical model, but also notes hydrogeological features that are omitted from the present model but could be included in later versions.

2.1. LOCATION AND TOPOGRAPHY

The Loxton and Bookpurnong irrigation areas are located adjacent to the River Murray in the north-eastern region of the South Australian part of the Murray Basin (Fig. 2.1).

The Loxton–Bookpurnong project area extends from river kilometres 486.7 to 520.6 and occupies an area of ~23 000 ha. The project area is based on the Land and Water Management Plan boundary and is bounded by the River Murray on the western side. Water bodies and irrigation areas are distinguishable using aerial photography as shown in Figure 2.2.

The topography is divided into 'highland' and floodplain regions. The highland regions are at an elevation of ~30 to 50 m AHD, through which the River Murray has carved a floodplain valley with a ground elevation between 9 and 18 m AHD. LIDAR data of 2 m horizontal resolution is available for the floodplain elevation. Highland elevation data are from Shuttle Radar mapping, which has a lower horizontal resolution of 72 m (National Geospatial-Intelligence Agency 2011).

2.2. CLIMATE

The climate is characterised by hot dry summers and cool winters. At Loxton weather station 025034, the average annual rainfall is ~300 mm with a potential ET of ~2000 mm/y (Bureau of Meteorology 2006; Table 2.1). Rainfall is higher in the winter months.

The potential ET exceeds rainfall, especially in the summer months, suggesting that aquifer recharge from rainfall is likely to be minimal (see Section 2.4.3).

Table 2.1 Average monthly rainfall and potential evapotranspiration at Loxton

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Rainfall (mm)	15	17	17	21	27	26	35	33	33	32	26	22	304
Potential ET (mm)	313	263	214	129	74	48	59	84	120	177	234	295	2009

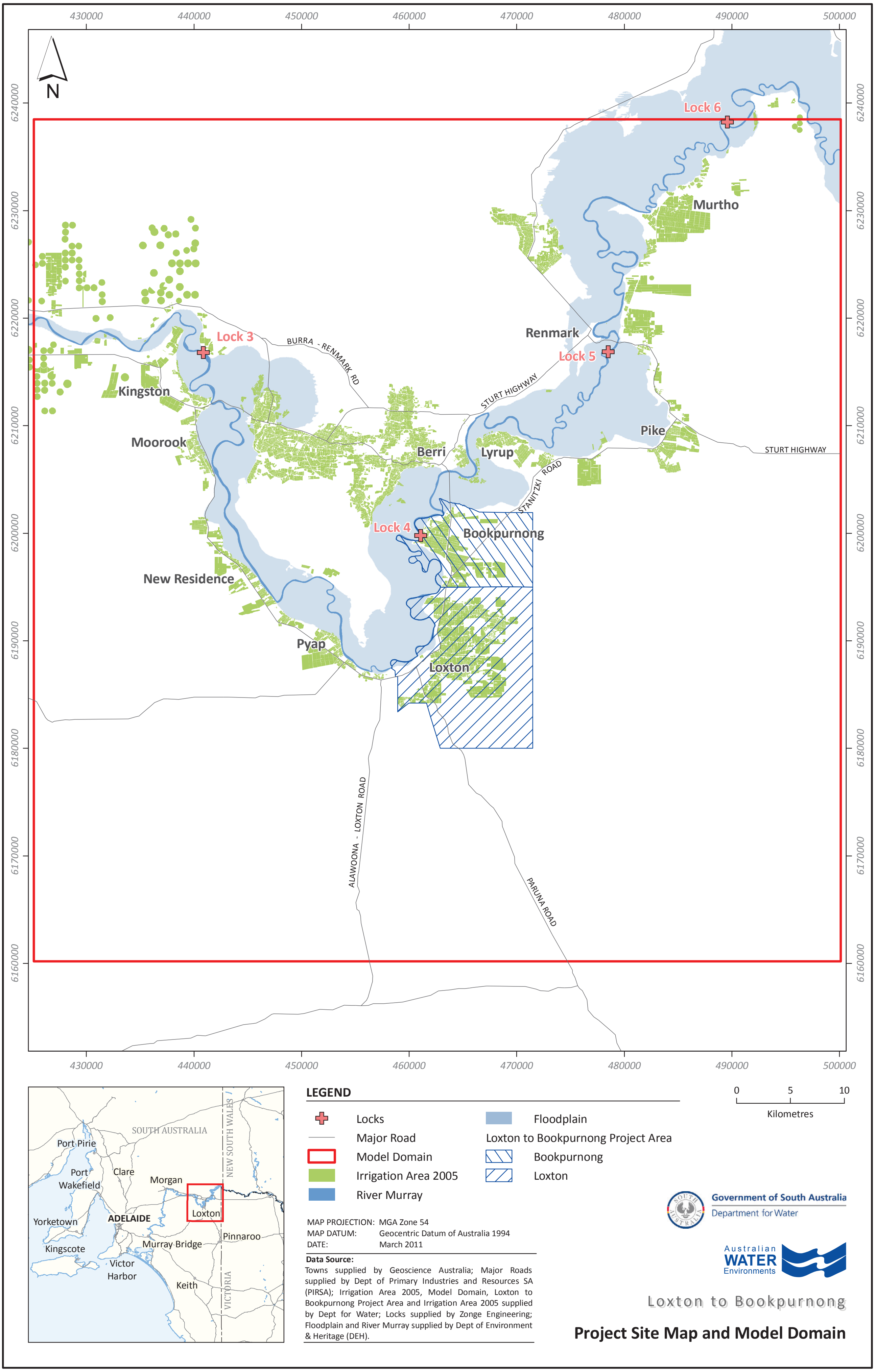

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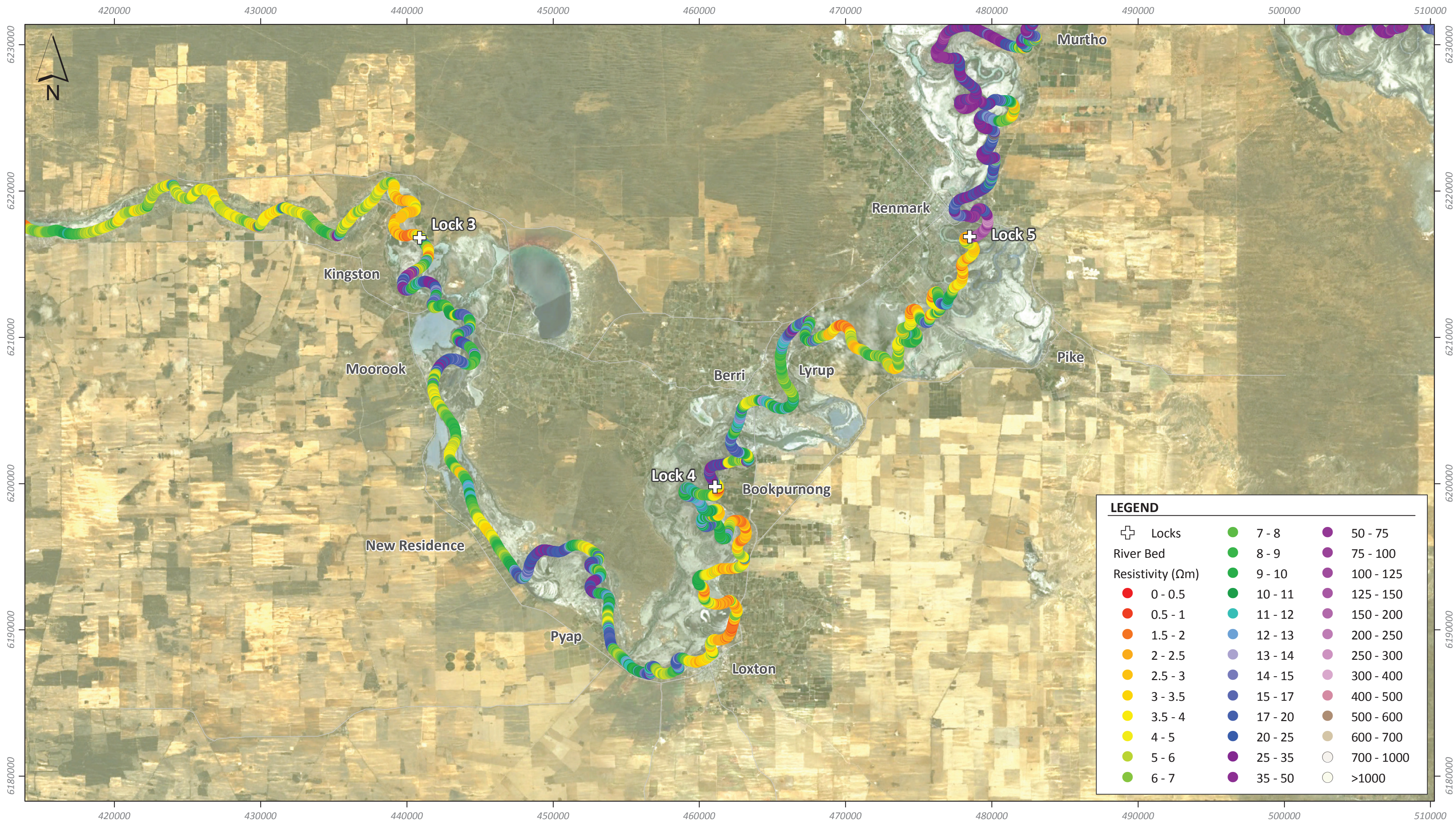
Figure 2.1



Government of South Australia
Department for Water

Australian WATER Environments

Data Source:
Aerial Photography obtained from Google Earth; Locks supplied by Zonge Engineering; Roads supplied by Dept of Primary Industries and Resources SA (PIRSA); Towns supplied by Geoscience Australia; River Bed Resistivity (NanoTEM 2004) supplied by Australian Water Environments (AWE).

MAP PROJECTION: MGA Zone 54
MAP DATUM: Geocentric Datum of Australia 1994
DATE: March 2011

Loxton to Bookpurnong

Aerial Photography and NanoTEM (2004): Lock 6 to Lock 3

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Figure 2.2

2.3. HYDROGEOLOGY

2.3.1. REGIONAL SETTING

The MDB is a closed groundwater basin consisting of Cainozoic unconsolidated sediments and sedimentary rock (Evans & Kellet 1989). It is wide but shallow, extending up to 900 km east–west and averaging 200 m thick, with a maximum thickness of 600 m (Brown 1989). It includes a number of regional aquifer systems. Its surface waters and groundwater are connected to the sea only at the Murray Mouth. Salt from rainfall, surface water and groundwater has accumulated within the basin over the past half a million years (Brown 1989).

The Loxton–Bookpurnong area lies in the Renmark Trough, a transitional zone between the thicker sediments of the Western Central Depocentre to the east, where sediments are greater than 500 m thick and the basement high lying west of the Hamley Fault, where sediments are less than 200 m thick (AWE 2011a). This change of sediment thickness forces groundwater upwards. The groundwater is highly saline and contributes significant quantities of salt when it flows into the River Murray.

The hydrogeological units of the Loxton–Bookpurnong area of the MDB are given in Figure 2.3. Within the study area, the key aquifer systems are (i) the watertable aquifers within the Loxton Sands and Monoman Formation, (ii) the Murray Group aquifer system and (iii) the Renmark Group aquifer system (Barnett 1991; Yan et al. 2005; AWE 2011a).

The characteristics of each hydrogeological unit in the project area are discussed briefly in order of elevation, deeper sediments first, in this section. Figure 2.3 provides a sample cross-section.

Table 2.2 summarises aquifer and aquitard properties. It is based on Yan et al. (2005) and AWE (2011a,b). The ranges of hydraulic parameters omit extreme values from aquifer tests which are either due to using non-suitable analytical method or not considered regionally representative of the Monoman Sands and Loxton Sands aquifers; for example, hydraulic conductivities of up to 202 m/d have been estimated for the Monoman Formation near Clark's Floodplain in Bookpurnong which may be due to using non-suitable analytical method and up to 78 m/d for the Loxton Sands near the horizontal drainage well in Loxton which may only reflect localised condition (horizontal and vertical).

2.3.2. RENMARK GROUP AND ETTRICK FORMATION

The Renmark Group aquifer overlies basement rock. The base of the group lies at approximately -450 to -400 m AHD in the Loxton–Bookpurnong area (Barnett 1991). The sediments are ~250 m thick (Barnett 1991) and of Eocene origin (AWE 2011a). Geochemical investigations suggest that the Renmark Group was last recharged 30 000 years ago (Harrington, James-Smith & Love 2006).

In the Loxton–Bookpurnong area, the Tertiary clay Ettrick Formation acts as an effective confining aquitard between the Renmark Group and aquifer units of the Murray Group. There is a vertical gradient in the potentiometric head of 10–15 m between the Renmark and Murray Group aquifers (Barnett 1991). Few observations have been made of the Renmark Group aquifer in the Loxton–Bookpurnong area, so it is not possible to characterise it in detail. The Renmark Group is omitted from the model, as it is anticipated that impacts to the River Murray are insignificant.

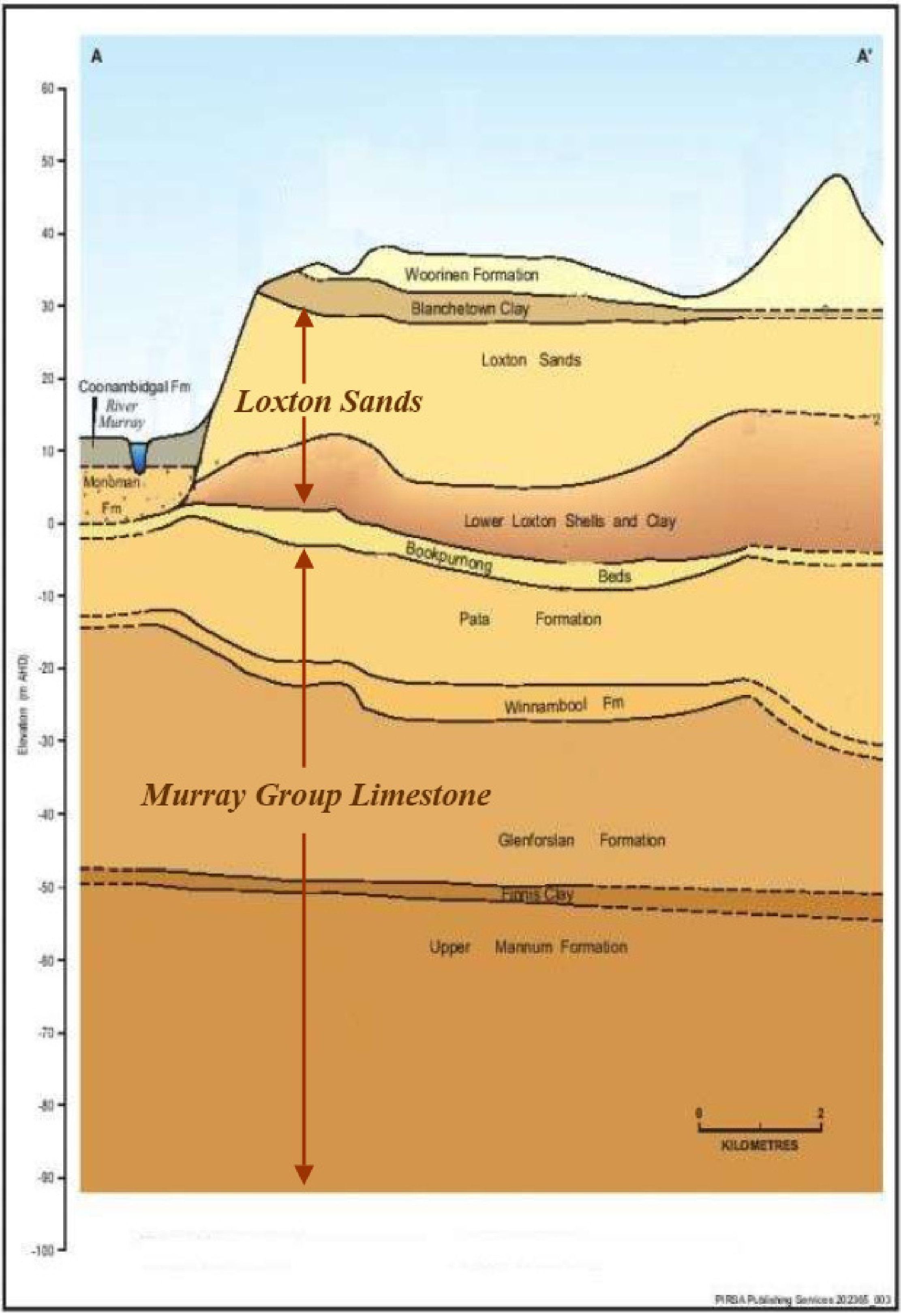


Figure 2.3 Hydrogeological cross-section (See Figure 2.1 for line of section)

Table 2.2 Hydrogeological units and calculated parameters from aquifer tests in the Loxton–Bookpurnong area

Hydrogeological Unit		Aquifer/ Aquitard	Salinity (mg/L)	K_h or K_v (m/d)	T (m^2/d)	S_s (/m) or S_y (-)
Coonambidgal Formation		Aquitard	NA	NA	NA	NA
Monoman Formation		Aquifer: unconfined to semi-confined	1300 to 46 000	K_h: 4.1 to 67	30 to 1010	7.2×10^{-6} to 6.5×10^{-2}
Loxton Sands		Aquifer: unconfined to possibly semi-confined	2000 to 64 000	K_h: 2.6 to 23	42 to 450	0.01 to 0.24
Lower Loxton Clay and Shells		Aquitard	NA	NA	NA	NA
Bookpurnong Formation		Aquitard	NA	K_v: 1×10^{-3} to 5×10^{-3}	NA	NA
Murray Group Limestone	Pata Formation	Aquifer: semi-confined	5000 to 32 000	K_h: 0.09 to 0.42	1 to 4	3.1×10^{-5} to 4.9×10^{-4}
	Winnambool Formation	Aquitard	NA	K_v: 1×10^{-5} to 1×10^{-3}	NA	NA
	Glenforslan Formation	Aquifer: semi-confined	3000 to 27 000	K_h: 0.14 to 0.55	3 to 9	1.8×10^{-4} to 2.0×10^{-4}
	Finniss Formation	Aquitard	NA	K_v: 1×10^{-5} to 1×10^{-4}	NA	NA
	Upper Mannum Formation	Aquifer: confined	2000 to 25 000	K_h: 1.3 to 2.3	62 to 112	2.1×10^{-4} to 2.8×10^{-4}
	Lower Mannum Formation	Aquifer: confined	NA	NA	NA	NA
Ettrick Formation		Aquitard	NA	NA	NA	NA
Renmark Group		Aquifer: confined	NA	NA	NA	NA

2.3.3. MURRAY GROUP FORMATIONS

The Murray Group is a Tertiary Oglio-Miocene sequence of limestone aquifers and marl aquitards (AWE 2011a). On a regional scale, the Murray Group may be considered as a single aquifer, but in areas such as the South Australian Riverland, the characteristics of its separate units have a local impact on the hydrogeology. The Murray Group units include the Upper and Lower Mannum Formations, the Glenforslan Formation, the Winnambool Formation and the Pata Formation (Lukasik & James 1998).

In the Loxton–Bookpurnong area, Murray Group units dip towards the north-east and are therefore deepest north of Bookpurnong and reach their highest elevations south-east of Pyap, near river kilometre 583 (AWE 2011b). In this high-elevation area south of the floodplain, the Pata Formation aquifer is unconfined, but all other Murray Group aquifers are confined in the study area. Each unit is described below.

2.3.3.1. The Upper and Lower Mannum Formations

The Mannum Formation is a limestone aquifer that is confined in the Loxton–Bookpurnong area but is unconfined in other Riverland regions to the west, such as Woolpunda (Barnett 1991).

The Lower Mannum Formation is up to 75 m thick at Bookpurnong. This unit comprises hard, well-compacted and moderately to well-cemented grey limestone with some evidence of recrystallisation. There is an increase of fine carbonate sand towards the top of the unit (Yan et al. 2005).

The Upper Mannum Formation aquifer comprises highly fossiliferous calcarenitic and sandy limestone. This unit is ~25 m thick at Bookpurnong and dips to the north-east, but it is difficult to separate from the underlying Lower Mannum Formation in the Loxton region (Yan et al. 2005). The top of the Mannum Formation is highest south-east of Pyap, where it lies at -35 m AHD.

The total thickness of the Upper and Lower Mannum Formations combined varies from 83 to 101 m in the region, with a median of 86 m, but this is based on only three measurements (AWE 2011a).

Four aquifer tests have been conducted in the Upper Mannum Formation within the Loxton–Bookpurnong area. Hydraulic conductivity ranged from 1.2 to 2.6 m/d and storage coefficient from $1.5x10^{-4}$ to $2.8x10^{-4}$ (AWE 2011a).

Potentiometric maps of the Upper Mannum Formation have been constructed (e.g. AWE 2011a), but there are few bores screened in this aquifer, so there is little detail. The horizontal head gradient is ~$5x10^{-4}$ near Loxton, trending from south-east to north-west (AWE 2011a,b). Hydrographs show stable to gently declining heads since 2003 (AWE 2011a).

The vertical gradient from below, i.e. the Renmark Group aquifer, indicates upward leakage into the Mannum Formation aquifer. The vertical gradient between the Mannum Formation aquifer and the Glenforslan Formation above varies by location: examples in AWE (2011a) trend downwards in highland areas and upwards under the floodplain. There is insufficient information to determine whether the irrigation mounds of the upper aquifers have impacted on heads in the Mannum Formation (Yan et al. 2005).

Groundwater salinity observations in the Upper Mannum Formation range from 2000 mg/L south of Katarapko Island to 25 000 mg/L at Rilli's Floodplain adjacent to the northern Loxton irrigation area, but few values are available (Yan et al. 2005; AWE 2011b).

2.3.3.2. Finniss Formation

The Finniss Formation aquitard is a thin but persistent grey to dark grey clay with thin sand layers and hard bands separating the Glenforslan Formation and Upper Mannum Formation (Yan et al. 2005). The Finniss Formation is between 2 and 14 m thick, with a median thickness of 2.8 m (AWE 2011a). At some locations there is a steep vertical gradient for potentiometric head through the Finniss Formation of more than 0.2 m/m, indicating that the Finniss aquitard must have a low vertical hydraulic conductivity, given that it is a thin unit (AWE 2011a).

2.3.3.3. Glenforslan Formation

The Glenforslan Formation semi-confined aquifer is a grey sandy limestone closely resembling the Pata Formation, with the exception that it contains occasional fine-grained hard bands (Yan et al. 2005). It varies in thickness from 16 to 30 m, with a median thickness of 26 m (AWE 2011a).

Similar to other Murray Group units, the Glenforslan Formation dips to the north-east (Yan et al. 2005). In the Loxton–Bookpurnong area, its upper surface lies between -42 m AHD north-east of Bookpurnong and 2 m AHD south of Pyap (AWE 2011b).

Yan et al. (2005) plotted the potentiometric surface for the Glenforslan Formation for May 2004 and AWE (2011b) provided the potentiometric surface for early 2010. The Loxton groundwater mound can be clearly observed within the Glenforslan aquifer. As of 2010, the maximum observed head under the Loxton irrigation area is 19.4 m AHD. There is only a single head value available for the Bookpurnong area, so it is not clear whether a groundwater mound has developed there within the Glenforslan aquifer. There are few observations west of the River Murray, but those available show a small horizontal gradient to the west-northwest (AWE 2011a). Hydrographs show stable to gently declining heads since 2003 (AWE 2011a).

The direction of vertical flux between the Glenforslan Formation aquifer and the overlying Pata Formation aquifer varies by location (Yan et al. 2005). For example, in the centre of the Loxton mound, there was a downwards-driving head difference of ~4 m in 2010 (AWE 2011b). Near the centre of Katarapko Island in the floodplain, the vertical head difference was 5 m in 2010, driving upwards (AWE 2011b).

Groundwater salinity in the Glenforslan Formation ranges from 3000 mg/L south-east of Pyap to 27 000 mg/L west of Loxton. No salinity data since 2002 are available for Bookpurnong. Trends are similar to those observed in the Upper Mannum Formation (AWE 2011b). The highest salinity values, greater than 20 000 mg/L, are observed in the northern Loxton floodplains, intermediate values are observed in a band running east–west through central Loxton to north of Pyap and values below 10 000 mg/L are found east of Pyap and south of Loxton.

Only two aquifer tests have been conducted in the Glenforslan aquifer at Loxton. Hydraulic conductivity ranged from 0.14 to 0.56 m/d and storage coefficient from 1.6×10^{-4} to 2×10^{-4} (AWE 2011a).

2.3.3.4. Winnambool Formation

The Winnambool Formation aquitard comprises grey to pale green calcareous clay (marl) and silty clay (Yan et al. 2005). This unit dips to the north-east, consistent with the regional tilt of the Murray Group. To the south-west of Loxton this formation occurs at approximately -3 m AHD, deepening to as much as -34 m AHD north-east of Bookpurnong (AWE 2011b). This unit has a median thickness of

7 m and varies from 2 to 14 m (AWE 2011a). The Winnambool Formation provides an effective aquitard between the Pata and Glenforslan Formations.

2.3.3.5. Pata Formation

The Pata Formation semi-confined aquifer is a poorly consolidated bryozoal limestone with interbedded friable sand layers that occurs throughout the Loxton–Bookpurnong area (Yan et al. 2005). This unit crops out to the south of Loxton where it is exposed at river pool level downstream from the Loxton Caravan Park, river kilometre 486 (Yan et al. 2005) and is absent within an area of the floodplain adjacent to river kilometre 483 (AWE 2011b). The Pata Formation aquifer dips to the north-east from a depth of ~19 m AHD south-east of Pyap to 70 m below ground (-26 m AHD) at Bookpurnong (Yan et al. 2005; AWE 2011b). In the Loxton area this unit commonly occurs 35 to 40 m below ground surface on the highland, but can occur as shallow as 10 m beneath the surface on the floodplains. The Pata Formation is typically in the range of 10 to 15 m in thickness (Yan et al. 2005; AWE 2011a).

Although described as a limestone, the unit is a poor aquifer due to the presence of marl. Pumping tests conducted by DFW at both floodplain and highland sites have returned yields of ~0.5 to 1 L/s (Yan et al. 2005). Aquifer tests in the area give hydraulic conductivity values between 0.1 and 0.7 m/d and storage coefficient values of 3.1×10^{-5} to 4.9×10^{-4} (AWE 2011b).

The potentiometric surface for the Pata Formation for January–February 2010 is given in Figure 2.4. Similar to the other Murray Group aquifers, the regional flow is from south-east to north-west. The Loxton groundwater mound is clearly visible, with the head peaking at 23.3 m AHD in 2010 (AWE 2011b). There are not enough observations in the Bookpurnong area to determine whether the local irrigation mound has affected heads in the Pata Formation aquifer (AWE 2011b).

Hydrographs indicate stable conditions beneath the floodplain near Pyap and north of Bookpurnong (AWE 2011a). Pata head is declining west of Loxton and under the Loxton groundwater mound by up to 0.25 m/y (AWE 2011a). Heads at Bookpurnong are still increasing by up to 0.09 m/y (AWE 2011a).

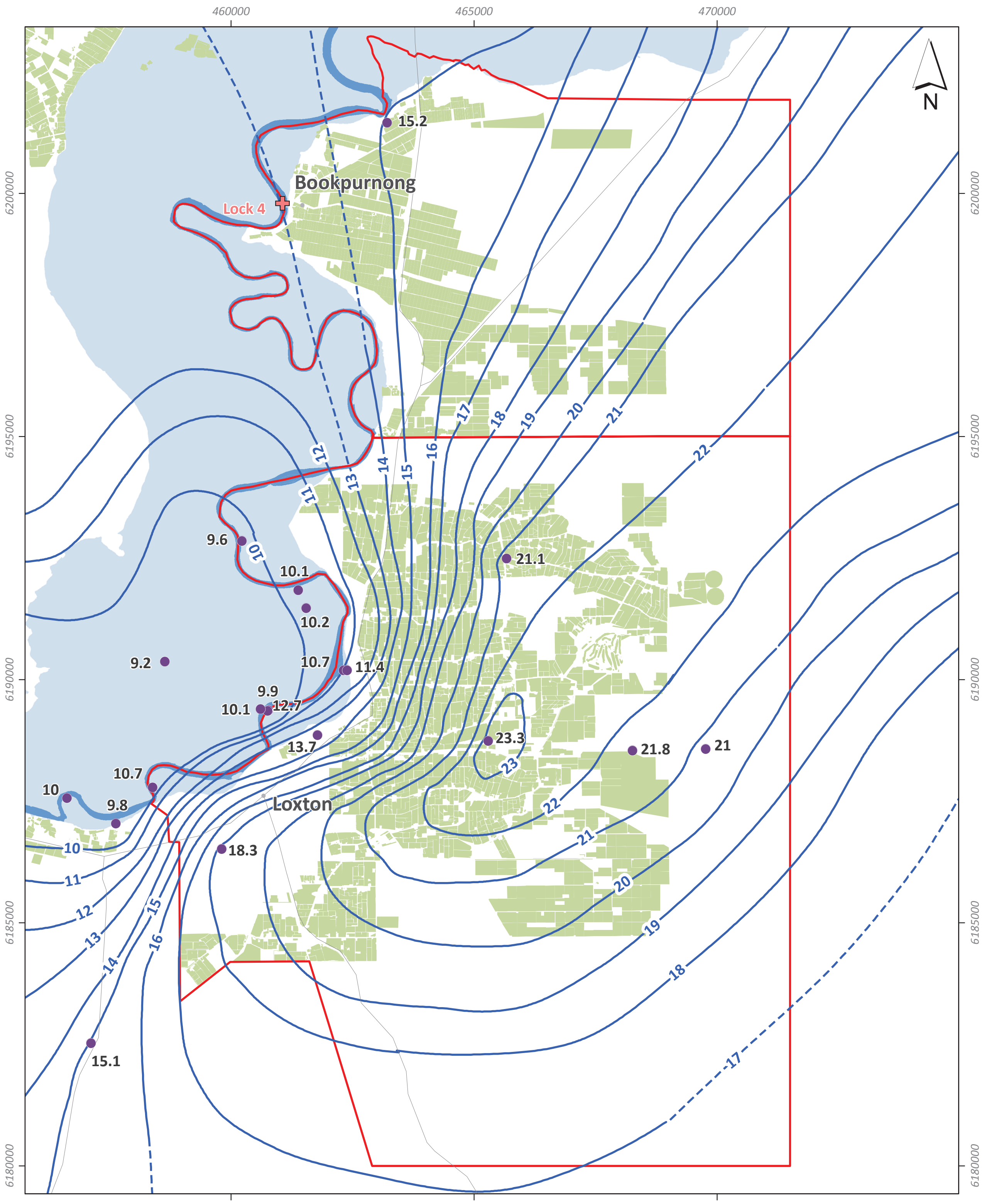
When the heads of the Pata Formation aquifer are compared to the heads in the overlying Loxton Sands and Monoman Formation aquifers, heads are higher in the Loxton Sands within the Loxton irrigation area but are lower or equal in the Monoman Formation aquifer. That is, vertical leakage is downwards in the mound and upwards or absent in the floodplain. At Bookpurnong, there is only one observation location, which shows an upward-driving gradient near Nitschke Road (AWE 2011b).

Groundwater salinities in the Pata Formation are between 8000 and 32 000 mg/L in the Loxton and Bookpurnong areas, but 5000 to 8600 mg/L near Pyap (AWE 2011b).

2.3.4. LOXTON CLAY, LOXTON SHELLS AND THE BOOKPURNONG FORMATION

Between the Murray Group and the overlying Loxton Sands aquifer is an aquitard consisting of the Bookpurnong Formation, the Loxton Clay and Loxton Shells. The Bookpurnong Formation consists of poorly consolidated plastic silts and shelly clays that are differentiated from the Lower Loxton Clays and Shells (grey in colour) on the basis of colour (light to dark khaki) and increased plasticity (Yan et al. 2005).

The Loxton–Bookpurnong aquitard dips and thickens to the north-east (AWE 2011a,b). South of Katarapko Island, its surface reaches 24 m AHD while north-east of Bookpurnong it deepens to -18 m AHD (AWE 2011b). It is absent in a large area west of Loxton (AWE 2011b), more likely as a consequence of erosion, but possibly as a result of depositional thinning (Yan et al. 2005).



LEGEND

- Locks
- Pata Formation RSWL (mAHD)
- Potentiometric Surface Contours (mAHD)
  - Index or Intermediate
  - Approximate
- Major Road
- Irrigation Area 2005
- River Murray
- Floodplain
- Loxton to Bookpurnong Project Area

0 2 4
Kilometres

MAP PROJECTION: MGA Zone 54
MAP DATUM: Geocentric Datum of Australia 1994

Government of South Australia
Department for Water

Australian WATER Environments

Data Source:
Towns supplied by Geoscience Australia; Major Roads supplied by Dept of Primary Industries and Resources SA (PIRSA); Irrigation Area 2005, Model Domain, Loxton to Bookpurnong Project Area and Irrigation Area 2005 supplied by Dept for Water; Locks supplied by Zonge Engineering; Floodplain and River Murray supplied by Dept of Environment & Heritage (DEH); Pata Formation Potentiometric Surface Contours 2010 created by Australian Water Environments (AWE); Pata Formation Bores with RSWL obtained by AWE from Drillhole Enquiry System (DES) and OBSWELL, PIRSA.

Loxton to Bookpurnong

Pata Formation Potentiometric Surface 2010

Job No. 11072 - 004
110304

Figure 2.4

The combined thickness of the Loxton Clay, Loxton Shells and Bookpurnong Formation forming the aquitard varies from 0 m (i.e. absent) to 25 m, with a median of 9 m (AWE 2011a).

2.3.5. LOXTON SANDS

The Loxton Sands, a highly heterogeneous unconfined aquifer, is the uppermost aquifer in the highland area of Loxton–Bookpurnong. In the Murray valley, most of this unit has been eroded and the Monoman Formation deposited in its stead (Yan et al. 2005).

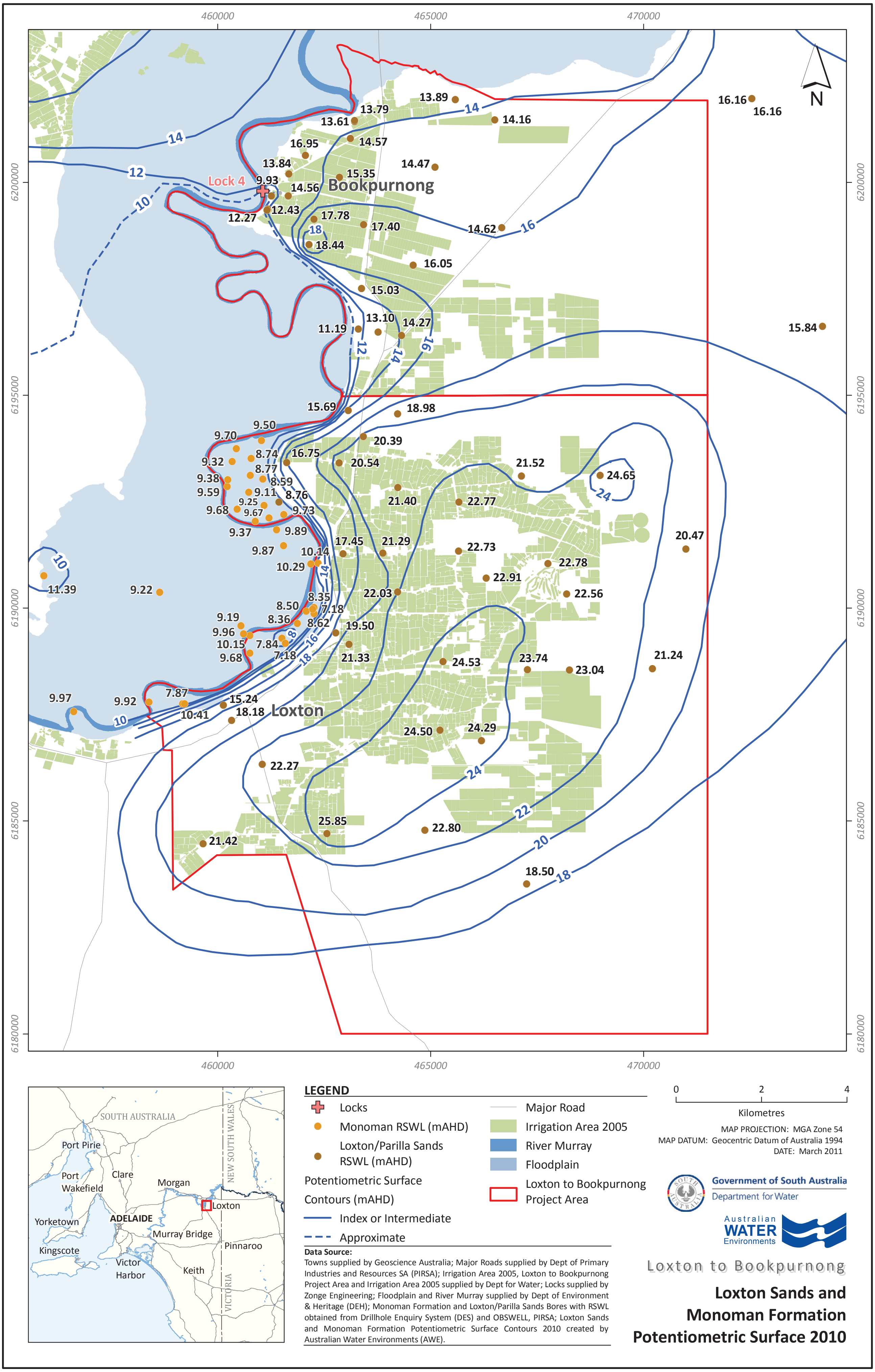
In broad terms, the Loxton Sands has its most permeable coarse-grained and frequently unsaturated sands occurring at the top of the sequence and the least permeable fine sands (and occasional shell hash) at the base of the succession. These sands grade to a low permeability silty clay and shell facies towards the Lower Loxton Clay and Shells (Yan et al. 2005).

Its surface occurs at 16 to 42 m AHD in the Loxton–Bookpurnong area. Unlike the units below it, there is no consistent and obvious dip.

While the Loxton Sands has a median thickness of 19 m (AWE 2011a), the permeable basal shell hash and coarse sand unit that occurs at the base of the succession in the Loxton area is only 2 to 3 m thick (Yan et al. 2005). The thickness of the Loxton Sands varies from 4 to 38 m (AWE 2011a). Yields up to 1.5 L/s have been observed in production wells completed in the basal shell hash facies. Elsewhere, yields vary from <0.5 L/s in fine-grained sands up to 5 L/s in coarse-grained facies in the area targeted for highland interception in the Bookpurnong area (Yan et al. 2005). Aquifer tests have given hydraulic conductivity values, of which 80% lie in the range between 4 and 37 m/d, with a median of 18 m/d and storage values (storage coefficient and/or specific yield) between 0.009 and 0.16.

The potentiometric surface for the Loxton Sands and Monoman Formation for May 2004 is given in Yan et al. (2005). The potentiometric surface for January–February 2010 is given in AWE (2011b) and is reproduced as Figure 2.5. A prominent groundwater mound trending north-east to south-west occurs in the Loxton Sands in the Loxton irrigation area with a maximum height of 25.9 m AHD and a relatively smaller mound occurs in the Bookpurnong area, peaking at 18.4 m AHD. The aquifer is considered to be unconfined, but some aquifer tests have recorded storage values that suggest it may be locally semi-confined (AWE 2011a). A comparison of potentiometric head and aquifer base elevation maps from AWE (2011b) shows that the saturated thickness may be less than 2 m west of Gurra Gurra Lake, rising to 13 m near the centre of the Loxton mound and possibly higher at Bookpurnong.

Loxton Sands hydrographs (see Section 4) show the development of the groundwater mounds over time. Many observation bores in the Loxton irrigation mound peaked near the year 2000, although others peaked earlier (e.g. GDN61). Potentiometric head in the Loxton mound has declined steeply since then everywhere except at bore GDN38. Hydrographs from Bookpurnong show that trends vary there by location. Heads are declining in the north-west, are stable in the north and east, but are continuing to rise in the south. This correlates with the commencement of irrigation, with established areas showing declining heads and newer areas showing increasing heads.



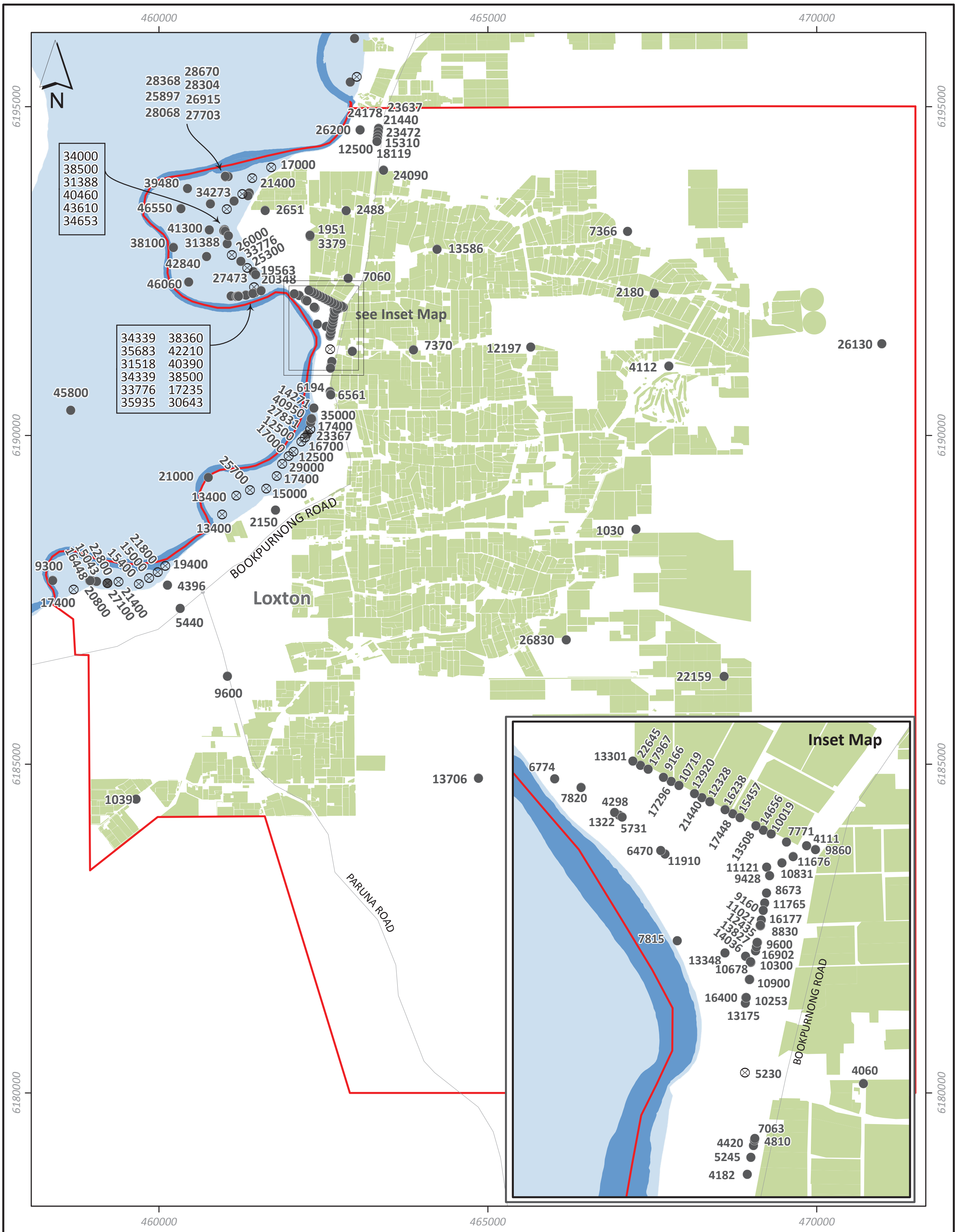
Job No. 11072 - 003
110304

Figure 2.5

Figures 2.6 and 2.7 show the salinity in the Loxton Sands and Monoman Formation aquifers in the Bookpurnong and Loxton areas, respectively. The salinity information is from two sources: those given in the legend as 'Latest available' are from the Drillhole Enquiry System (DES) or OBSWELL databases, while those labelled 'Representative' are derived from monitored SIS bores. Determining groundwater salinity in these aquifers is complicated by the fact that the salinity may vary with depth in the aquifer and over time. In the highland areas, salinity may vary with monitoring depth due to fresher irrigation water mounding on top of saline regional groundwater. Values recorded for a particular bore may therefore depend on depth of bore screen. Salinity in many SIS bores has also changed significantly over time (AWE 2011b) due to disturbances during construction and operation, the fact that the most accessible water will be pumped first which may not reflect regional salinities and mixing with fresher waters such as irrigation returns and river water. At some locations, the SIS pumps have been run at high flow rates which have induced flow from the river into the groundwater (P Forward, SA Water, pers. comm., 2011). Due to these complications, a methodology has been developed to select a single salinity value for each location that would be 'representative' of the groundwater. After discussion with the Five Year Review Modelling for Salinity Registers Project Team, the following principles have been adopted for the selection of groundwater salinity values for SIS and Salinity Register purposes:

- the representative salinity should reflect the model purpose — to estimate salt load impact to the River Murray for the Salinity Registers. The salt load from groundwater entering the Murray depends on the salinity of the regional groundwater adjacent to the river which is displaced into the river by the irrigation mound. The consistent assumption is that the salt load impact is from the regional groundwater next to the river, not a mixture of regional water with irrigation water on top of the watertable mound.
- for highland bores, higher and/or deeper values are selected as the representative salinity as this will better reflect regional saline groundwater rather than the fresher irrigation-derived water
- for floodplain SIS bores, a value from approximately a year after pumping commences is selected as the representative salinity. Salinities observed at earlier times may reflect local, not regional conditions. Salinities observed at later times may be impacted by mixing with river water as the SIS have been over-pumped.
- for conversion from recorded EC to mg/L, use the Australian Water Quality Centre's conversion table (App. C-4).

Groundwater salinity values in the Loxton Sands vary dramatically across the Loxton–Bookpurnong area, reflecting the impact of low salinity irrigation recharge and river water on the saline native groundwater. Salinities at Bookpurnong vary from 11 460 to 64 000 mg/L and are typically from 30 000 to 40 000 mg/L. Salinities may be much lower within the Loxton irrigation mound due to mixing with irrigation returns: salinity varies by more than an order of magnitude from 1900 to 27 000 mg/L.



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Department for Water

Australian WATER Environments

Data Source:
Towns supplied by Geoscience Australia; Major Roads supplied by Dept of Primary Industries and Resources SA (PIRSA); Irrigation Area 2005, Loxton to Bookpurnong Project Area and Irrigation Area 2005 supplied by Dept for Water; Locks supplied by Zonge Engineering; Floodplain and River Murray supplied by Dept of Environment & Heritage (DEH); Latest available and Representative Groundwater Salinity in the Upper Loxton Sands/Monoman Formation obtained by AWE via Drillhole Enquiry System (DES) and OBSWELL, PIRSA and SA Water.

LEGEND

Loxton Sands\Monoman: Salinity

- Latest available TDS (mg/L)
- Representative TDS (mg/L)
- Locks
- Major Road
- Loxton Project Area
- Irrigation Area 2005
- River Murray
- Floodplain

0 1.5 3
Kilometres

MAP PROJECTION: MGA Zone 54
MAP DATUM: Geocentric Datum of Australia 1994
DATE: March 2011

Loxton to Bookpurnong

Groundwater Salinity in the Upper Loxton Sands/Monoman Formation: Loxton

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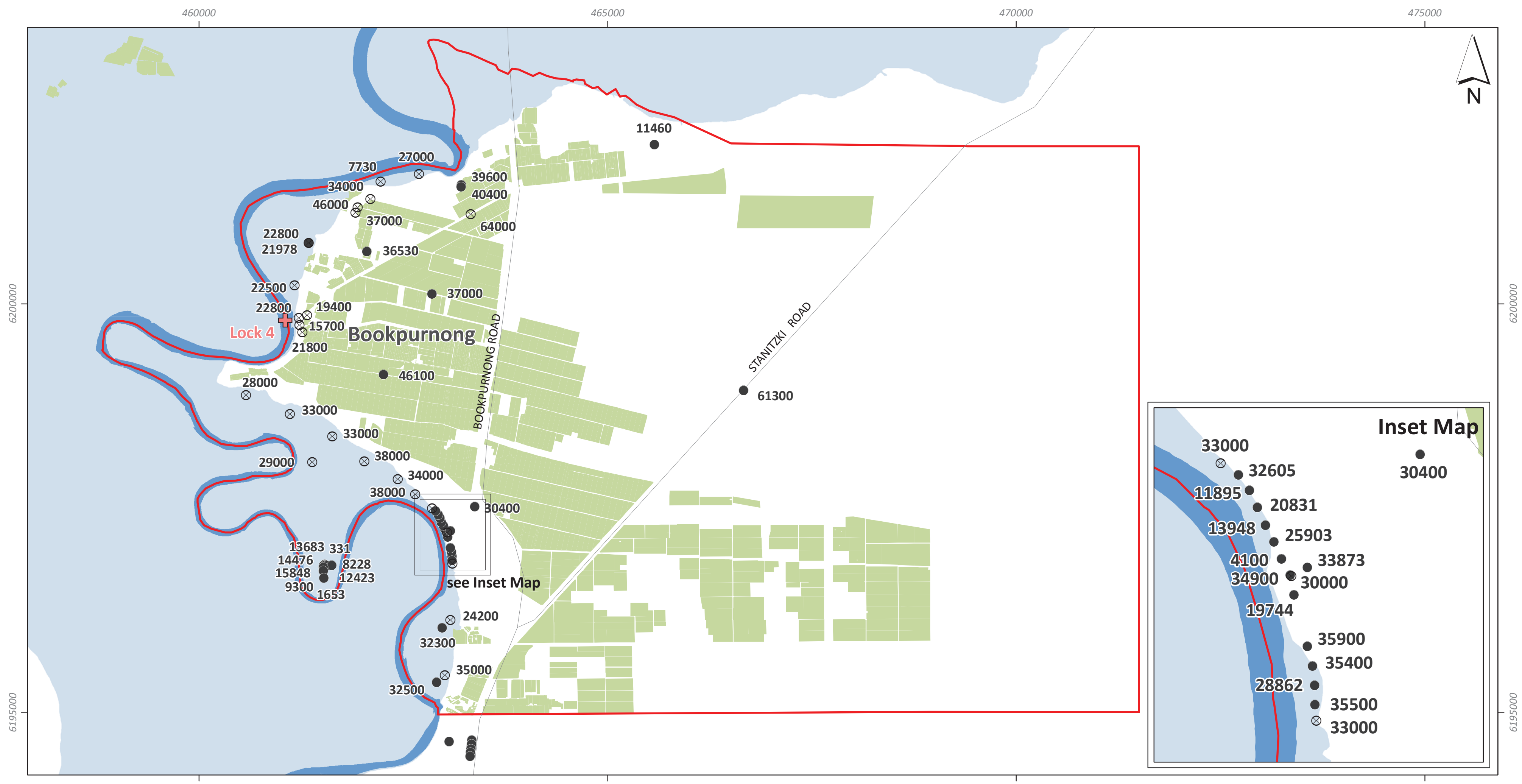
110308

Figure 2.6



MAP PROJECTION: MGA Zone 54
MAP DATUM: Geocentric Datum of Australia 1994
DATE: March 2011

Government of South Australia
Department for Water

Australian WATER Environments

Data Source:

Towns supplied by Geoscience Australia; Major Roads supplied by Dept of Primary Industries and Resources SA (PIRSA); Irrigation Area 2005, Bookpurnong Project Area and Irrigation Area 2005 supplied by Dept for Water; Locks supplied by Zonge Engineering; Floodplain and River Murray supplied by Dept of Environment & Heritage (DEH); Latest available and Representative Groundwater Salinity in the Upper Loxton Sands/Monoman Formation obtained by AWE via Drillhole Enquiry System (DES) and OBSWELL, PIRSA and SA Water.

LEGEND

Loxton Sands\Monoman: Salinity
- Latest available TDS (mg/L)
- Representative TDS (mg/L)
- Locks
- Major Road
- Bookpurnong Project Area
- Irrigation Area 2005
- River Murray
- Floodplain

0 1.5 3
Kilometres

Loxton to Bookpurnong

Groundwater Salinity in the Upper Loxton Sands/Monoman Formation: Bookpurnong

Job No. 11072 - 010
110308

Figure 2.7

2.3.6. MONOMAN FORMATION

The Monoman Formation consists of relatively clean, fine to coarse-grained, fluvial sands deposited as point bar sands within a wide floodplain. This unit occasionally includes minor clay and silt layers and occasional lignite bands towards the base of section (Yan et al. 2005). As a consequence of the depositional environment, the Monoman Formation is a highly variable aquifer with yields ranging from 0.5 to 10 L/s. This variability makes it difficult to predict likely yields across the floodplain, even at a scale of tens of metres (Yan et al. 2005). Aquifer tests show a high variance in hydraulic conductivity. Of interpreted hydraulic parameters for the Monoman Formation, 80% of the hydraulic conductivity values are within 16 to 136 m/d, with a median of 47 m/d, while 80% of the storage coefficient vales are between $7x10^{-7}$ to $6.5x10^{-2}$, with a mean of $2.6x10^{-3}$ (AWE 2011a).

The base of the Monoman Formation lies between -4 and -10 m AHD and its top surface lies between 3 and 13 m AHD (AWE 2011b). It is difficult to discern clear trends in the elevation and knowledge is limited west of the River Murray as there are few data points from the floodplains apart from Katarapko Island. The median thickness is 6 m (AWE 2011a). It is thin to absent at the break in slope. However, it can be up to 25 m thick in deeply incised channels within the meander belt (Yan et al. 2005).

The potentiometric surface for the Monoman Formation is merged with that of the Loxton Sands aquifer, as the aquifers are considered to be in direct hydraulic connection. The surface for May 2004 is given in Yan et al. (2005) and the potentiometric surface for January–February 2010 is given in AWE (2011b) and reproduced here as Figure 2.5. Potentiometric heads are up to 2 m above the river pool level of 9.8 m AHD at the break of slope where the Loxton Sands and Monoman Formation meet on the eastern side of the River Murray. On the western side of the river, potentiometric heads are either close to or below river pool level, with the exception of a slightly elevated potentiometric head (~10 m AHD) in the area of the Katarapko Island Disposal Basin to which irrigation drainage water from the Comprehensive Drainage System (CDS) network is pumped. A comparison of potentiometric head and surface elevation shows that the Monoman Formation aquifer is semi-confined by the Coonambidgal Formation.

Monoman hydrographs (see Section 4) show that potentiometric head in the aquifer responds strongly to River Murray levels and SIS pumping. Head levels have declined since SIS commenced pumping, but levels have risen again at some SIS observation bores in the past few months due to higher river levels and, in some locations, the temporary cessation of SIS pumping.

Since the 2005 model was constructed, much more salinity data has become available for the Monoman Formation aquifer, due to the construction and monitoring of SIS bores. Figures 2.6 and 2.7 show the salinity in the Loxton Sands and Monoman Formation aquifers in the Loxton and Bookpurnong areas, respectively; see Section 2.3.5 for details on how representative salinity values were chosen for each location. The salinity is highly variable, due to ET and the mixing of freshwater and groundwater. The Total Dissolved Solids (TDS) range from ~1300 to 46 000 mg/L (Figs 2.6 and 2.7). The lower salinity value is effectively an outlier value at river water salinity, as this value was obtained from a bore close to the river during an aquifer test.

2.3.7. COONAMBIDGAL FORMATION

The Coonambidgal Formation clay layer occurs across the floodplain and comprises clay and silt deposited during periods of episodic flooding (Yan et al. 2005). It is the confining bed overlying the Monoman Formation aquifer. This unit is commonly 4 to 5 m thick in the middle of the respective floodplains, but can vary in thickness from 1 to 11 m, with the greater thicknesses observed at the break in slope between the floodplain and highland (Yan et al. 2005). This unit has been reworked in part by the meanders of the River Murray and the reworked sediments may be more permeable (AWE 2011a). The hydraulic conductivity of the formation is not known but is likely to vary spatially.

2.3.8. BLANCHETOWN CLAY

The discontinuous Blanchetown Clay underlies the surface deposits of the Woorinen Formation and overlies the Loxton Sands. It is a Quaternary lacustrine unit, consisting of poorly consolidated greenish grey and red-brown laminated clay, which may be locally silty and sandy (Barnett 1991). Regionally, it is within the unsaturated zone.

Perched aquifers have formed above the Blanchetown Clay in the region. At Bookpurnong, drainage bores were constructed to reduce waterlogging from the perched aquifer. The extent of the perched aquifers over time is not definitively known. The existence of the perched aquifers may mean that the irrigation footprint is not the same as the recharge footprint, as root zone drainage water spreads laterally over the Blanchetown Clay. It will also retard the recharge rate and increase the time taken for water to move from the root zone to the watertable aquifer, known as the ‘lag time’.

The Blanchetown Clay is not included in the model because it is not in contact with the river and it is located in the unsaturated zone which the current MODFLOW model does not simulate.

2.3.9. WOORINEN FORMATION

The Woorinen Formation consists of Quaternary unconsolidated red-brown silty sand and clay (Barnett 1991). This is an aeolian dune formation and part of the unsaturated zone which is not simulated in the model.

2.4. SURFACE WATER FEATURES IMPACTING GROUNDWATER

This section describes the data and information available on features within the Loxton–Bookpurnong area that interact with groundwater flow. These include the River Murray, areal recharge, ET and SIS pumping.

2.4.1. THE RIVER MURRAY

Most of the Loxton–Bookpurnong reach lies between Lock 4 and Lock 3, where the river pool level is 9.8 m AHD. Northern Bookpurnong is adjacent to Lock 4, above which the river pool level is 13.2 m AHD. The locks were constructed in the late 1920s and early 1930s.

River levels have changed over time in periods of flood and drought, which will alter the gradient between the River Murray and the groundwater and hence the flux. However, changes in gradient due to changes in river level will be minimal when compared to the very steep gradient from the irrigation-induced groundwater mounds, which may be up to 15 m of head difference from highland to floodplain.

Backwaters may also influence groundwater and river salinity by adding saline surface water during flood recessions.

2.4.1.1. NanoTEM

NanoTEM surveys estimate the resistivity of sediments below the riverbed. Low resistivity corresponds to high salinities (or proportion of clay) and suggests a gaining stream reach, where high-salinity groundwater flows into the Murray. High resistivity corresponds to low salinities or clay proportion, suggesting a losing stream reach where low-salinity river water flows into the aquifer.

Figure 2.2 shows NanoTEM data collected in 2004 for sediments just below the riverbed. The NanoTEM suggests that most of the Loxton reach is gaining. The Murray is gaining in Bookpurnong wherever the river lies close to the highland, i.e. near cliffs, which agrees with steep groundwater gradients in these areas. Where there is a wide floodplain between the river and the highland, the NanoTEM suggests that the river is a losing stream. This is consistent with heads in the floodplain, which may be below river pool level.

The area adjacent to river kilometres 492–493, west of the Loxton Horizontal Drainage Well shows low resistivity, indicating high-salinity water in the riverbed (AWE 2011a). The NanoTEM data suggest freshwater residing in the riverbed downstream of river kilometre 481; based on hydrogeological, structural, salinity and isotopic data, low salinity and deep groundwater may also discharge upwards to the floodplain Monoman Formation in this area (AWE 2011a).

2.4.1.2. Run of River

AWE (2011a) reviewed and analysed in-stream salinity data, including the annual RoR surveys and the continuous daily EC records at fixed stations along the reach. This provides further information on the interaction between the River Murray and the groundwater system (Monoman Formation and Loxton Sands aquifers).

The RoR results are presented as a cumulative salt inflow from Lock 5 downstream to Lock 3. The 10 surveys are shown in Figure 2.8, as reproduced from AWE (2011a). To assist in locating where salt inflows are estimated to enter the river, the figure also shows the extent of the Bookpurnong and Loxton SIS and other key physical features. Older surveys are in red, newer surveys in blue. The line thickness also decreases towards the late surveys. The numbered arrows represent the chronological sequence. Initial high salt inflow conditions have reduced over time.

Steep changes in cumulative salt inflow can be due to salt from surface water or from groundwater. The sharp increase at river kilometre 541 is attributed to Pike River (AWE 2011a). The increase in salt load downstream section of the Loxton SIS, between river kilometres 495 and 487, is attributed to groundwater.

The overall salt inflow has decreased significantly from an average of 264 t/d prior to 2003 to ~100 t/d in 2008 and 2009, due primarily to changes in irrigation practice and infrastructure and construction of the SIS (AWE 2011a).

The RoR results are presented in Table 2.3 on a reach by reach basis. The salt inflow in reaches impacted by the Bookpurnong and Loxton SIS has decreased to ~30% of the pre-scheme values.

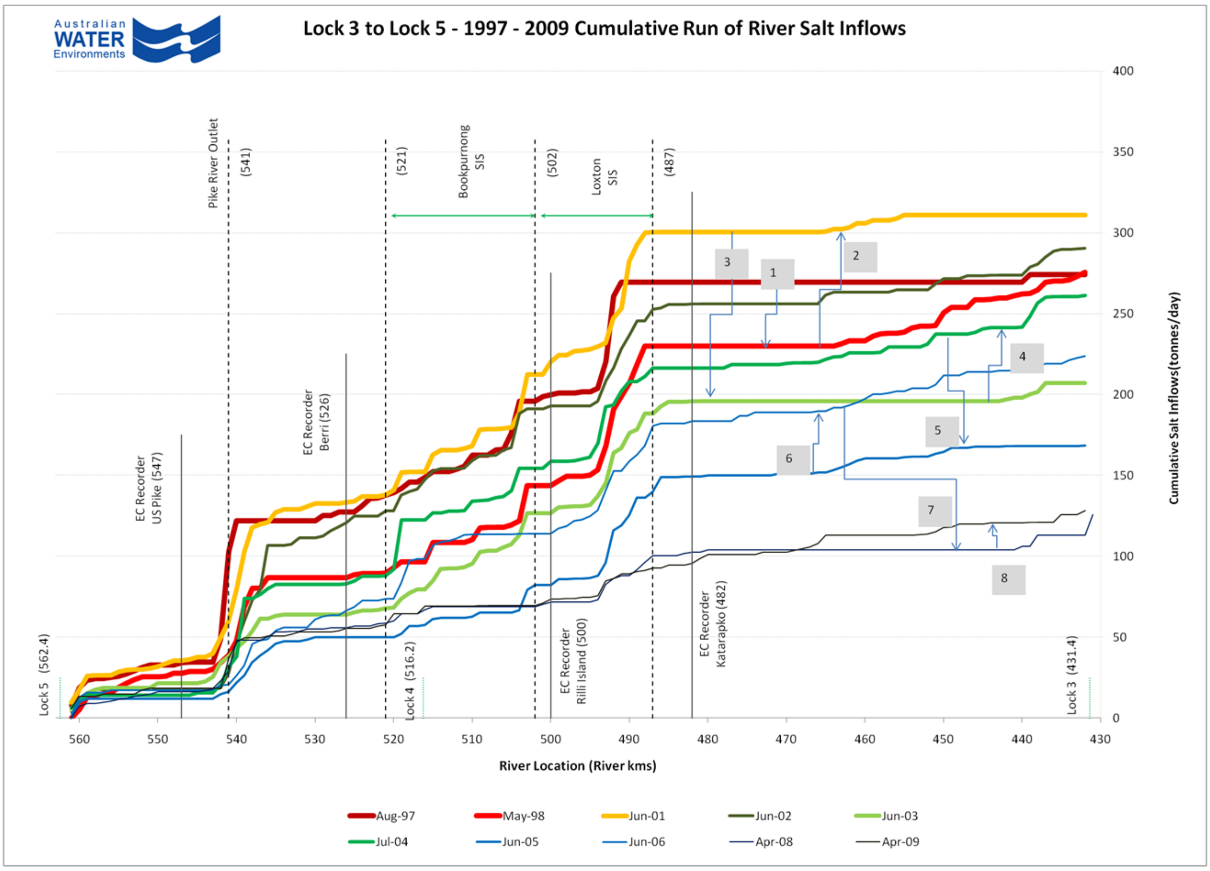


Figure 2.8 Lock 3 to Lock 5 – 1997–2009 Cumulative Run of River Salt Inflows

Table 2.3 RoR Inflow by Reach (t/d)

Date	Location	
	Bookpurnong	Loxton
	River km 525 to 500	River km 499 to 482
Aug-97	72	70
May-98	57	86
Jun-01	87	80
Jun-02	72	63
Jun-03	63	69
Jul-04	76	57
Jun-05	32	67
Jun-06	47	70
Apr-08	16	29
Apr-09	18	22
Average	***54***	***61***
08 & 09 / Pre-2006 as %	27%	36%

2.4.1.3. Toroidal Coil

DFW has installed several permanent EC toroidal coil recording stations in the reaches from Lock 5 to the downstream end of Loxton SIS. Detailed analysis of data (AWE 2011a) from five stations is presented below. These five stations allow segmentation of the saline inflows into four reaches, two of which are impacted by the SIS schemes. Using a 90-day rolling average, as shown in Figure 2.9, allows ready assessment of the trends in each plot. This figure also includes analysis of the overall reach from Lock 5 to Katarapko, which is the sum of the four sub-reaches. The RoR survey results are also shown for the respective reaches and provide a good correlation with the EC coil analysis, especially over the longer reaches.

EC data analysis for the Bookpurnong reach indicates that the saline inflow was an average of 72 t/d between April 2001 and July 2005. The variability does not appear to correlate with a seasonal cycle. Pumping of the SIS commenced in August 2005 with most of the scheme commissioned by mid-2006. Average inflows decreased from mid-2005, to be virtually eliminated by the end of 2007. Since mid-2008, inflows show a small increasing trend. These observations indicate that effective interception was achieved by mid-2008, however salt inflows may have increased marginally since mid-2008 in the upstream section of the Bookpurnong SIS, presumably due to lowered pump rates in that area (AWE 2011a).

EC data in the Loxton reach indicate that saline inflow was an average of 70 t/d from April 2001 to July 2007. The variability in the plot seems to correlate with seasonal evaporation. The Loxton SIS bores were constructed from late 2007 to 2010. The analysis shows that saline inflows have gradually decreased over this period but still remain at ~20 t/d, while the relative impact of seasonal fluctuations also reduced. The critical saline inflow zones for the Loxton SIS include the two sections where the river is immediately adjacent to the cliff at Thiele's Highland (river kilometres 494 to 492) and near the Cliff Toe Drain (between river kilometres 489 and 490).

2.4.2. RECHARGE

Areal recharge to groundwater in this report is derived from rainfall and irrigation root zone drainage.

2.4.2.1. Dryland recharge

Prior to the clearance of native mallee vegetation on the highland, vertical recharge to the watertable aquifer resulting from rainfall infiltration is believed to have been as low as 0.07 to 0.1 mm/y (Allison et al. 1990). This is due to the dry climate and deep-rooted native vegetation.

Cook, Leaney & Miles (2004) estimated recharge at cleared mallee sites in South Australia to be one or two orders of magnitude greater than uncleared sites, up to 11 mm/y. The recharge rate depends on soil properties, vegetation and climate. Zones and rates of estimated recharge in dryland areas including Loxton–Bookpurnong are given in Cook, Leaney & Miles (2004).

2.4.2.2. Irrigation development

Laroona Environmetrics was engaged by DFW to collate, summarise and verify irrigation data for Loxton and Bookpurnong, including changes in irrigation area over time (where the Department of Environment and Natural Resources (DENR) provided spatial data on irrigation areas as shown in Figure 2.10) and volume of water applied to crops. The Laroona Environmetrics (2011) report is included as Appendix C-1 to this report. A brief summary is provided below.

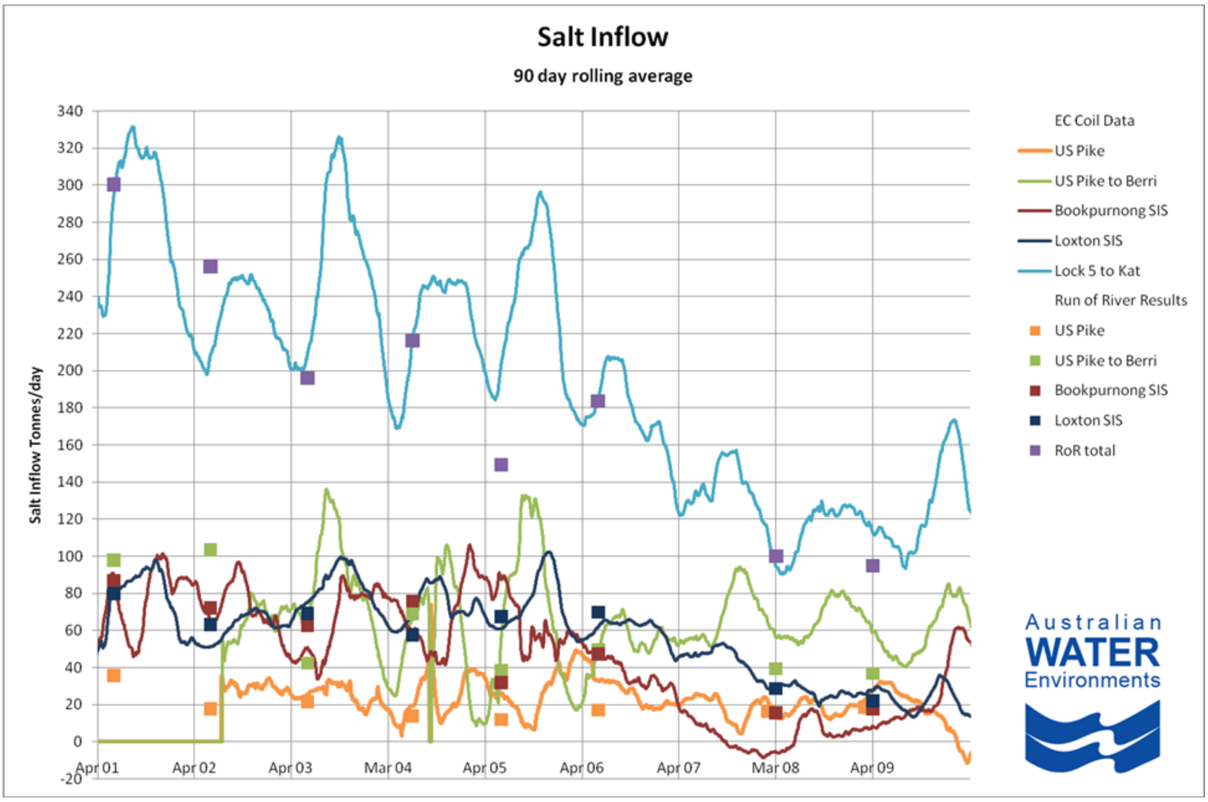
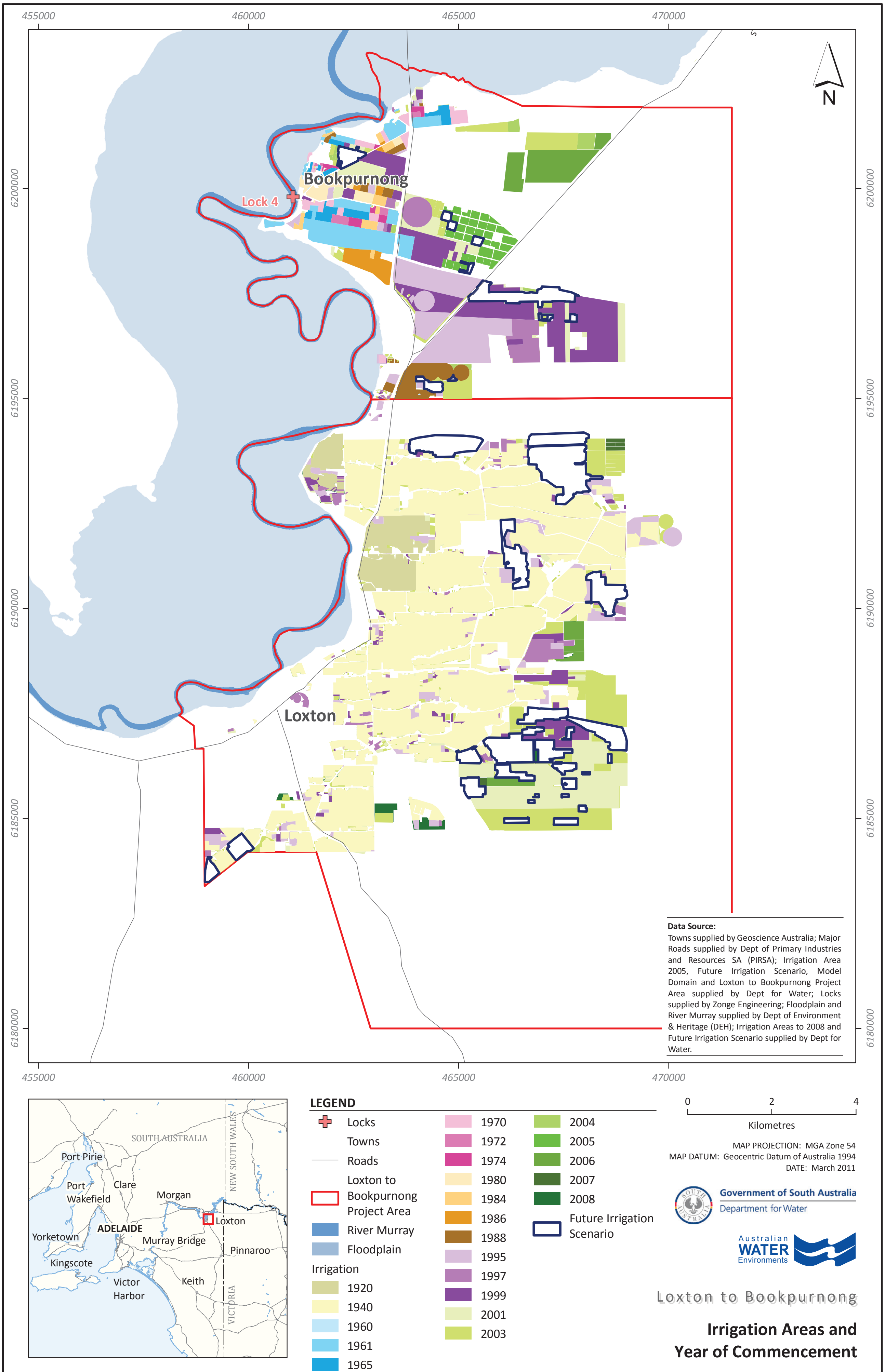


Figure 2.9 Salt inflow – 90 day rolling average

While irrigation began at Loxton as early as 1920, the majority of the current development was irrigated in the late 1940s as the Loxton Irrigation Trust Area (LITA). Soon after the LITA was developed, perched watertables were observed above the Blanchetown Clay. A CDS was constructed in the mid-1950s to intercept a proportion of the root zone drainage and the drainage water was pumped to a disposal basin on Katarapko Island.

Major irrigation development at Bookpurnong commenced in 1960. Pipes were used to transport irrigation water from the river, minimising water loss. Drainage bores were also built in the Bookpurnong area, at undocumented dates, which have been used to dispose of drainage water into the Loxton Sands aquifer.

Irrigation practices in the South Australian Riverland have changed over time. Generally speaking, older irrigation sites used flood irrigation, on a four or two-week schedule. As irrigators could not know what the rainfall would be like over the weeks until the next watering, large volumes were used to ensure that crops had sufficient water. Later there was a shift from flood irrigation to sprinklers, then drip systems. Many irrigators now use soil moisture monitors to target water application. These changes in irrigation practices have reduced irrigation application volumes and hence the volume of root zone drainage and irrigation-derived aquifer recharge. Figure 2.11 shows a typical irrigation practice history for the Riverland (Vears 2010, adapted from Adams & Meissner 2009).



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Loxton to Bookpurnong

Irrigation Areas and Year of Commencement

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Figure 2.10

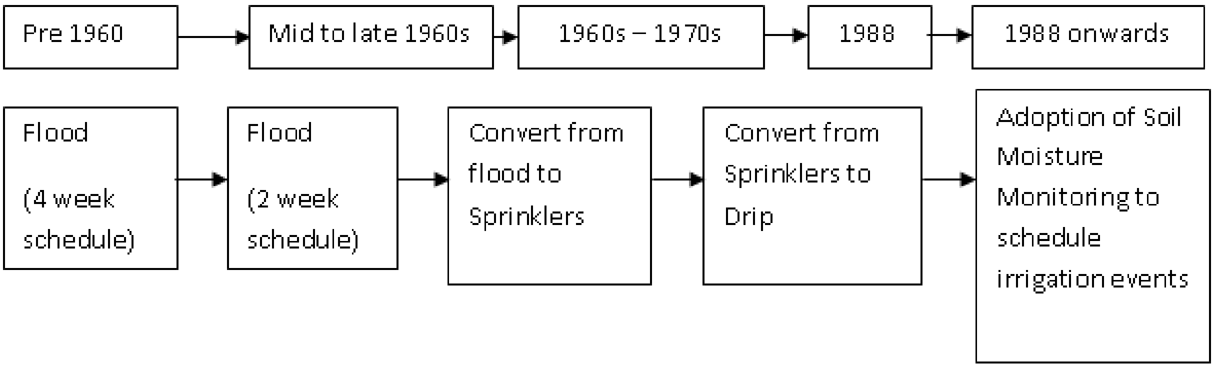


Figure 2.11 Irrigation history (Vears 2010)

Irrigation-derived aquifer recharge has also reduced over time due to other improvements in irrigation infrastructure, for example, when channels are replaced by pipes. This is referred to as 'Rehabilitation' in Salinity Register reports.

Unfortunately, it is very difficult to measure irrigation-derived recharge rates directly in the field. A CSIRO study took some measurements at Bookpurnong, all indicating very low rates (~90 mm/y), but it is not clear how representative these values are for the irrigation areas (F. Leaney, CSIRO, pers. comm., 2008).

Root zone drainage volumes can be estimated based on water balance calculation which includes rainfall and irrigation application volumes. The latest estimates of root zone drainage for the Loxton and Bookpurnong irrigation areas are given in Appendix C-1 from Laroona Environmetrics (2011).

The drainage water percolates into the unsaturated sediments and a proportion will remain in the unsaturated zone within the pore spaces. If there is a low-conductivity layer in the unsaturated zone, such as the Blanchetown Clay, a perched aquifer will form. Some of the drainage water will then remain in the perched aquifer, or will flow laterally across the surface of the clay before seeping down towards saturated sediments. Due to these unsaturated zone processes, the root zone drainage rates and footprint may differ from the nominal recharge rates and footprint.

Drainage water takes time to percolate through the unsaturated zone to reach the watertable — the 'lag-time'. Initially, the lag time (initial lag time) under a new irrigation area is several years or more, as the unsaturated sediments become wetter and perched aquifers form (Fuller et al. 2005; AWE 2011c). Once an irrigation area is established, the unsaturated sediments below are wetter and the lag time (late lag time) is reduced or even becomes negligible. This is due in part to the relationship between hydraulic conductivity and saturation. The lag-time mechanism has been demonstrated using the SUTRA model code in the saturated/unsaturated model (Lisdon Associates 2010 in App. C-1).

2.4.3. EVAPOTRANSPIRATION

ET combines two processes — evaporation of water from groundwater lying close to the ground surface and transpiration from plants that use groundwater. ET varies with rainfall, humidity, temperature, soil type, vegetation type and groundwater salinity (as plants preferentially use low-salinity sources of water). In this report, ET means groundwater losses through evaporation and transpiration that occurred only on the floodplain, as elsewhere the groundwater is too far below the ground surface.

Doody et al. (2009) conducted a study at a Bookpurnong floodplain. ET was estimated from 208±135 mm near the river to 32±30 mm further from the river over 241 days, giving an actual ET range of 48 to 315 mm/y, although the confidence interval is large when compared to the values.

An unpublished study measured an actual ET of 196 mm/y for the fringing river woodland of River Red Gum, Black Box and River Cooba. In the Loxton–Bookpurnong floodplain areas, the woodland generally covers 30–40% of the total floodplain, suggesting an overall floodplain average ET of ~60 to 80 mm/y (K Holland, CSIRO, pers. comm., 2011).

2.4.4. THE SALT INTERCEPTION SCHEMES

Two SIS have been built to control salt loads from the groundwater system entering the River Murray in the Loxton–Bookpurnong reach (Figs 2.12 and 2.13). Groundwater is pumped from the Monoman Formation and Loxton Sands aquifers.

The Bookpurnong SIS was constructed from June 2005 to July 2006. It has 15 floodplain production bores and seven highland production bores, with a total nominal flow rate of 50 L/s (AWE 2011a), pumping saline groundwater away from the River Murray for disposal into the Noora Disposal Basin to the south-east. The intercepted salt load increases over time as root zone drainage from newer irrigation areas has not yet reached the watertable. Aluminium clogging of bores in the northernmost part of the scheme near Nitschke Road has prevented that section from intercepting its planned volumes.

The Loxton SIS includes a Horizontal Drainage Well, floodplain bores, a Cliff Toe Drain and highland bores that divert groundwater to the Noora Disposal Basin. It was constructed in stages from 2005 to 2010. The Horizontal Drainage Well was commissioned in November 2005 and currently diverts groundwater at an average rate of 3.2 L/s. There were 28 floodplain bores commissioned between June 2007 and June 2008, with a nominal flow of 50 L/s. The Cliff Toe Drain was commissioned in May 2008 and currently intercepts 1.4 L/s. There were 22 bores added to the scheme at Thiele’s Highland in September 2010, intercepting 25 L/s. Most recently, there were five bores constructed at Rilli’s Highland to intercept 2.0 L/s (AWE 2011a).

The aim of most of the production bores on the floodplain is to achieve a potentiometric head of around 9.8 m AHD at the midpoint observation bores. Close to Lock 4, the target head is ~13.2 m AHD to minimise the loss of upstream river water into the groundwater. The Horizontal Drainage Well is located at 13 m AHD (AWE 2011a) which is very close to the base of the Loxton Sands aquifer and the Cliff Toe Drain at Loxton is located at 9.8 m AHD.

2.5. CONCEPTUAL MODEL

2.5.1. OVERVIEW

There are three main aquifer systems in contact with the River Murray in the Loxton–Bookpurnong area — the semi-confined Monoman Formation and Loxton Sands aquifers and the aquifer sub-units of the Murray Group. The sediments of the upper two aquifer systems trend from deeper in the north-east to higher in the south-west and the upper sediments have also been eroded away in a small area south-east of Pyap. In addition to the main aquifer systems, there are also local perched aquifers (above the Blanchetown Clay) in the main irrigation areas.

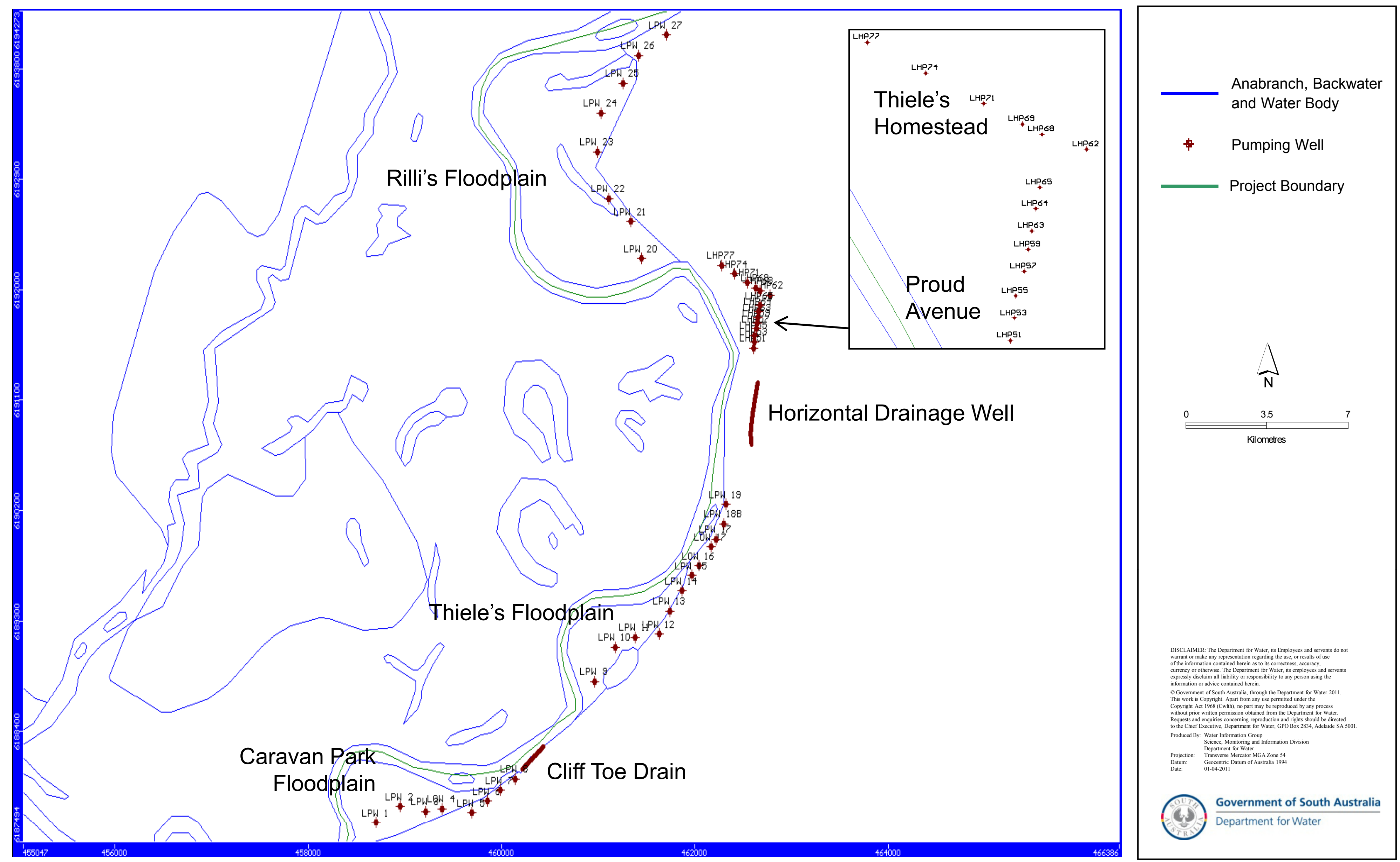


Figure 2.12 Location of pumping wells in the Loxton project area

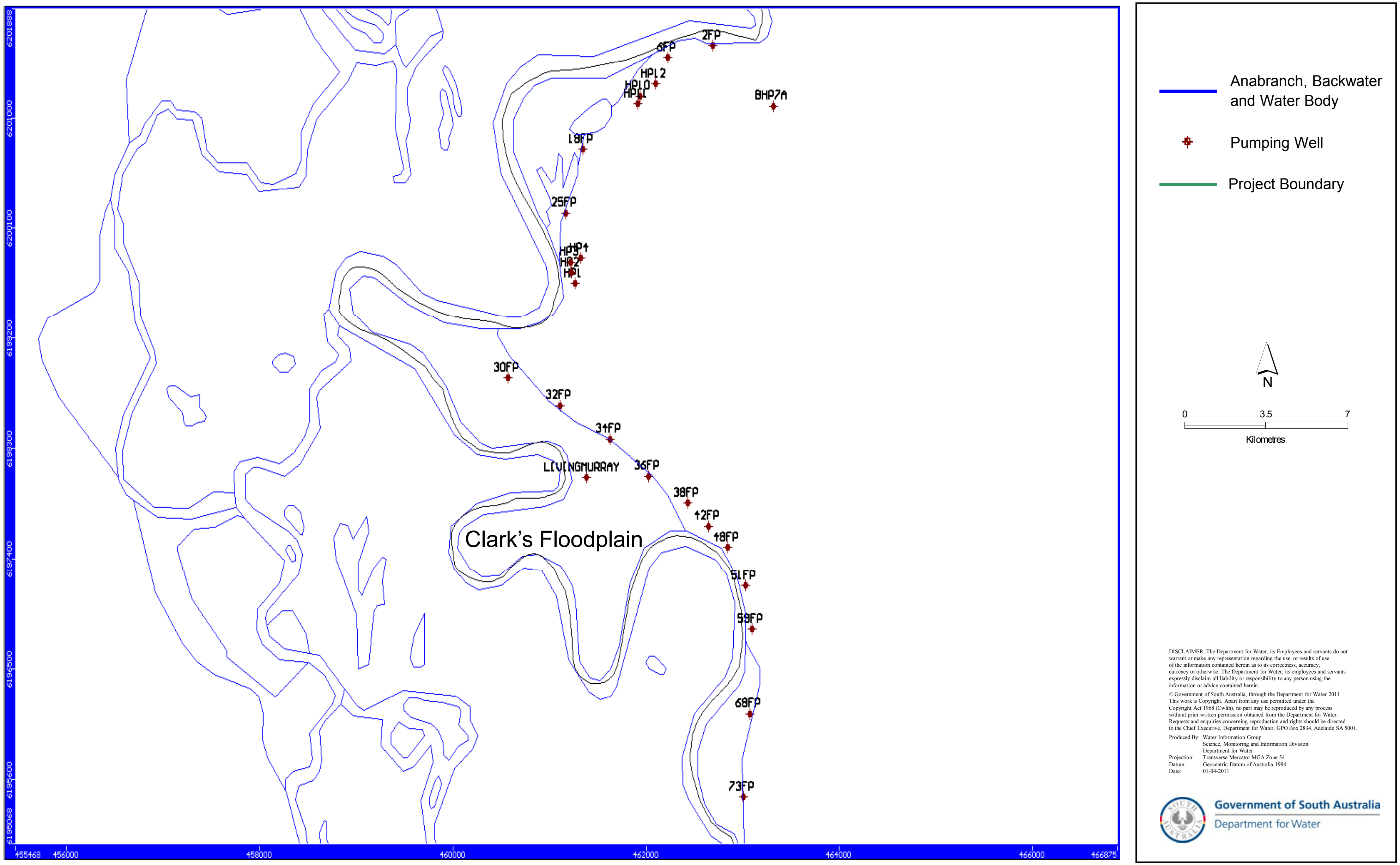


Figure 2.13 Location of pumping wells in the Bookpurnong project area

The dominant regional lateral flow is from east to west, ultimately driven by distant recharge sources. There is also a regional trend of upflow from the deeper aquifers due to the thinning of Murray Basin sediments in the Loxton–Bookpurnong area when compared to thicker deposits to the east.

The River Murray has carved a valley through the landscape, into which the Monoman Formation has been deposited. The river strongly influences the regional groundwater levels. Regional heads in the aquifers of the Monoman Formation, Loxton Sands and Murray Group reflect long-term river levels. The head in the Monoman Formation aquifer may respond to short-term fluctuations in river level and its backwaters. Due to the shallow watertable in the floodplain, the Monoman Formation aquifer is also influenced by ET from groundwater, which may lower heads to below river level in some areas. There is some upward leakage from the Murray Group aquifers into the Monoman aquifer in wide floodplain areas.

Recharge to the watertable aquifers is derived from rainfall and irrigation drainage on highland areas. The dry climate and deep-rooted native vegetation cause very low recharge rates under natural conditions. Recharge rates under cleared dryland are one or two orders of magnitude greater and recharge under irrigation areas is even greater. Recharge from irrigation at Loxton and Bookpurnong has led to the development of perched aquifers and also groundwater mounds within the Loxton Sands aquifer and the upper aquifer sub-units of the Murray Group. Recharge rates have changed over time due to unsaturated zone processes (e.g. 'wetting up' of sediments, lateral movement within perched aquifers), changes in irrigation area, construction and later decommissioning of drainage bores, construction of a CDS at Loxton, improvements in irrigation practice and rehabilitation of irrigation infrastructure.

The groundwater mounds have induced pressure to push regional groundwater discharge into the River Murray and localised downwards vertical flow from the Loxton Sands into the Murray Group aquifer system. Cliff seepage also occurs where the Loxton Sands abut the River Murray valley.

The irrigation drainage induced groundwater mounds have substantially increased groundwater flow into the River Murray. As the regional groundwater salinity is very high, this has resulted in high salt loads to the river. To mitigate this, SIS have been built at both Loxton and Bookpurnong irrigation areas in the last decade. Production bores, a Horizontal Drainage Well and a Cliff Toe Drain divert saline groundwater from the Monoman and Loxton Sands aquifers to the Noora Disposal Basin, which is located in at a natural groundwater discharge area to the south-east. The SIS have sharply reduced the potentiometric head in the pumped aquifers.

There are no other pumping bores in the area, as the groundwater is too saline for crop, stock or human use. Groundwater salinities in the top part of the Loxton Sands aquifer are declining in some areas due to mixing with irrigation drainage water. In some floodplain areas, SIS pumping has induced lateral recharge of the Monoman Formation by river water.

The current trends in watertable hydrographs show that the mound height is declining in Loxton and the more established irrigation areas of Bookpurnong, while rising in the more recently developed irrigation areas of Bookpurnong.

A schematic diagram of the conceptual hydrogeological model for the Loxton–Bookpurnong area is given in Figure 2.14. The figure details the conceptual model of groundwater flow between the aquifers, the broader regional groundwater flow system, inter-aquifer flow and local recharge mechanisms.

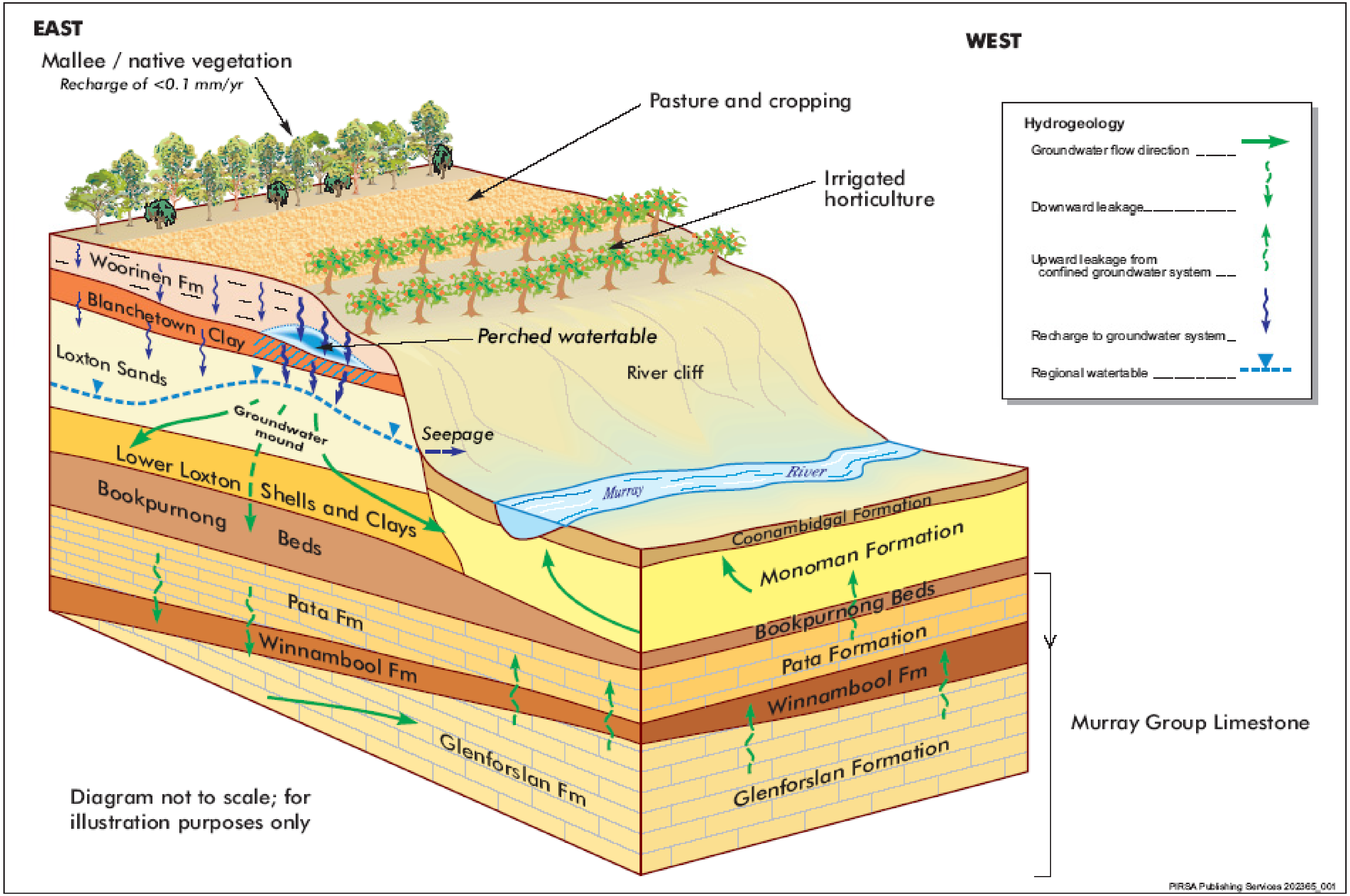


Figure 2.14 Elementary conceptual hydrogeological model

Section 3 describes the numerical groundwater model which is a simplified representation of this conceptual model, as constrained by data availability and computational efficiency.

2.5.2. PATHWAYS FOR SALT TO THE RIVER MURRAY

The purpose of the numerical model is to estimate salt loads to the River Murray for Salinity Register entry.

Under natural conditions before river regulation and irrigation, there would have been a small flux from the Monoman Formation to the River Murray, driven by lateral and vertical head gradients. In areas where the head in the floodplain was below river level due to ET, small flux would have been from the River Murray into the Monoman Formation.

Locks and weirs were constructed on the River Murray in the 1920s and 1930s to regulate the flow. These would have changed the river level and hence local groundwater gradients and fluxes to and from the river.

Large-scale irrigation began at Loxton in the 1940s and at Bookpurnong in the 1960s, altering the local interaction between groundwater and the River Murray as groundwater mounds developed in the Loxton Sands aquifer.

Saline groundwater now enters the River Murray by the following mechanisms in the Loxton–Bookpurnong area (Yan et al. 2005):

- direct inflow or via seepage from exposed Loxton Sands at or near the base of cliffs adjacent to the River Murray
- discharge from the Monoman Formation that acts as a conduit for lateral flow from the Loxton Sands
- discharge from the Monoman Formation that acts as a conduit for upward leakage from the underlying confined Murray Group aquifer system. Yan et al. (2005) estimated that this was a relatively small contribution to the River Murray of only 1 to 3 t/d in the Loxton area and 0.5 to 2 t/d in the Bookpurnong area; this conceptual model was confirmed by Harrington, James-Smith & Love (2006).
- discharge from the Murray Group aquifer where there is direct communication with the River Murray due to erosion of the Lower Loxton Clay and Shells and Bookpurnong Formation
- discharge during and after periods of flood from the Monoman Formation, localised hypersaline lakes (salinas) and mobilised salt from the unsaturated zone.

Yan et al. (2005) considered two floodplain areas at Loxton:

- on Rilli's Floodplain (a wider floodplain in the northern part of Loxton), groundwater flows from the highland into the Monoman Formation, which acts as a conduit for lateral flow from the Loxton Sands to the River Murray. ET results in the concentration and storage of salt in the floodplain. This salt is mobilised and flushed by flood events, which may induce an influx of highly saline groundwater to the river, but a recent study (AWE 2011c) indicated that this additional mobilised salt may increase river salinity only slightly.

- on Thiele's Floodplain (a narrow floodplain in the southern part of Loxton) where ET is of less significance, a small hydraulic gradient results in the discharge of groundwater to the River Murray from the Monoman aquifer.

3. MODEL CONSTRUCTION

The model presented here is a revision of the Border to Lock 3 model, which covers a large region that includes the Loxton–Bookpurnong study area. The model domain is designed to cover the entire Riverland, including the major irrigation districts of Loxton, Bookpurnong, Pike, Murtho, Berri, Renmark, Pyap, New Residence, Moorook and Kingston.

The Border to Lock 3 model was first developed in 2005 (Yan, Howles & Hill 2005; Yan et al. 2005). Since then it has been used for a number of projects and revised each time in the region of project interest — at Loxton–Bookpurnong and Pike–Murtho (Yan et al. 2006), Berri–Renmark (Aquaterra, REM & AWE 2006; Yan et al. 2007) and Pyap–Kingston (Yan & Stadter 2008). Section 1.3 provides a detailed model history. It is an impact assessment model of moderate complexity, capable of simulating the regional aquifer system. The model and results for the Loxton area were reviewed and accredited for Register use by the MDBC in 2004, for Bookpurnong in 2005 and for Pike–Murtho in 2006.

The revised model is based on the most recent prior revision, that of Pyap–Kingston (Yan & Stadter 2008), but the hydrogeology of the Loxton and Bookpurnong areas has been refined. The principal revisions are listed in Section 1.4 and include updated structural contours, revised boundary conditions and more detailed salinity zones. Further data were also collected for comparison with model results during calibration and confirmation (Section 4). Revisions have also been made to the conceptualisation of scenarios (see Section 5 and App. A-2).

The figures presented in Section 3 show the full extent of the Border to Lock 3 model, its parameters and boundary conditions. However, the text concentrates on the Loxton–Bookpurnong study area. Detailed discussions of parameter and boundary condition choices in other areas are given in the prior model reports (Yan et al. 2005, 2006, 2007; Yan & Stadter 2008).

The purpose of this model is to provide a predictive management tool for determining salt loads entering the River Murray from the Loxton–Bookpurnong area for the Salinity Registers (see Section 1.1 for the policy background).

The revised model provides quantitative estimates of salt loads entering the River Murray under a range of past and future irrigation conditions and SIS for the Loxton–Bookpurnong area. The model upgrading, calibration and predictions were undertaken within the project area only, also referred to as the regional model "sub-zone". This "sub-zone by sub-zone" approach is appropriate in South Australia as there are minimal impacts from land use changes in neighbouring irrigation districts, due to the hydrogeological separation from the project area by hydraulic boundaries such as the River Valley, large floodplain, creek systems and groundwater dividing lines.

The future impact of accountable irrigation actions and benefit from schemes need be clearly distinguished. The estimation of future impacts due to climate sequence, such as changes in river level due to flood events, are not required for the Salinity Register.

3.1. MODFLOW AND VISUAL MODFLOW

MODFLOW-2000 was selected as the numerical code for the Border to Lock 3 model. It was chosen for reasons of reliability and consistency, as it is the industry standard groundwater flow code and the other South Australian models for the Salinity Register are also MODFLOW-2000 models. It is a three-dimensional finite difference code that was developed by the US Geological Survey (McDonald & Harbaugh 1988).

MODFLOW-2000 is used to simulate saturated groundwater flow only. Salt load is calculated based on groundwater fluxes output from the model, multiplied by groundwater salinity values specified along river reaches. This is a simplification of the hydrogeological conceptual model, as it omits the direct simulation of perched aquifers and groundwater salinity changes due to mixing of irrigation and surface waters with groundwater. It is currently judged that the substantial additional effort required to simulate the omitted processes would result in only a minor improvement in model accuracy.

MODFLOW's PCG2 solver is used for all steady-state and transient modelling runs. The convergence criteria are set to 0.1 m for the maximum absolute change in head (HCLOSE) and 0.1 m^3/d for the maximum absolute change in residual. This proved to be computationally efficient whilst retaining sufficient accuracy (i.e. percentage discrepancy was close to zero for all times).

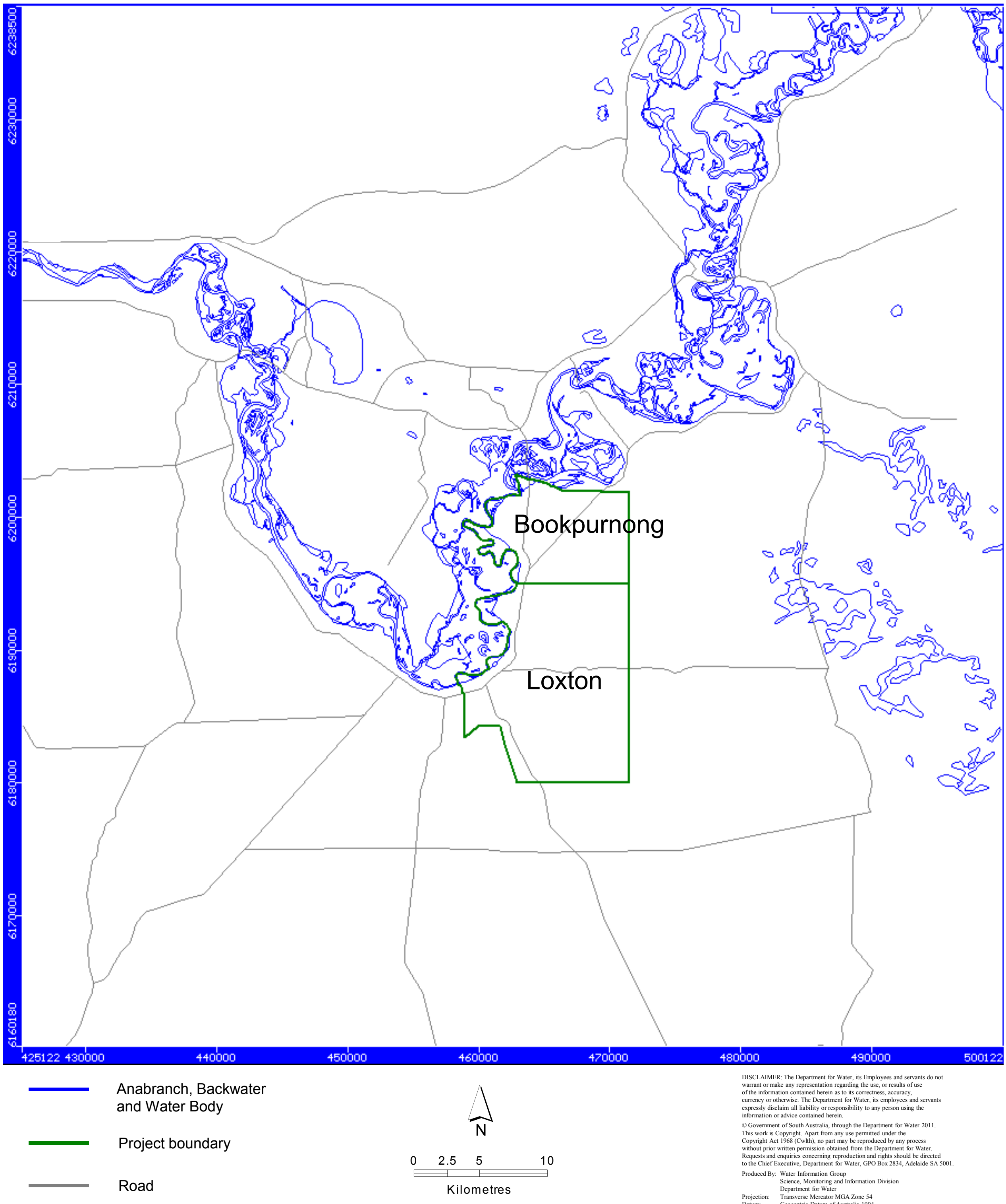
Visual MODFLOW Version 2010 was selected as a pre- and post-processor platform for quick generation of data files for MODFLOW, distributed by Schlumberger Water Services. It was used to generate MODFLOW model grids, boundary conditions, observation well data and zones for aquifer hydraulic parameters. The software was also used to set model options, to run the model and to obtain output results.

3.2. MODEL DOMAIN AND GRID

The model domain simulates an area 75 km east–west by 78.3 km north–south. The bounding GDA 1994 coordinates of the model domain are E425122 N6160180 in the south-west and E500122 N6238500 in the north-east (Figs 3.1 and 3.2). The grid is orientated north–south.

As the model was developed to simulate a number of adjacent Riverland regions for various projects, the model domain is much larger than the present Loxton–Bookpurnong study area. The selection of a large model domain that incorporates the smaller study area is consistent with good modelling practice, as the model domain boundaries are set at a sufficient distance so that they should not be influenced by the behaviour of the aquifer system in the study area over the modelled time period. One drawback of the large model extent is that computing times are greater than those of a model simulating a smaller area with the same grid resolution. The large model extent also means that the model design must reflect the hydrogeology of a large region, rather than detailing local conditions: for example, different hydrogeological units are important in different model regions, which could affect layer choice.

The rectangular model grid is divided into 491 columns and 472 rows. The minimum grid size is 125x125 m in the Loxton–Bookpurnong area and other irrigation areas (Berri–Renmark, Pike–Murtho and Pyap to Kingston). The remaining model area has a coarser grid size. The maximum row height and column width are 500 and 375 m, respectively. A cross-section of the model grid is shown in Figure 3.3.



Produced By: Water Information Group
Science, Monitoring and Information Division
Department for Water
Projection: Transverse Mercator MGA Zone 54
Datum: Geocentric Datum of Australia 1994
Date: 01-04-2011

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Figure 3.1 Regional model domain and project area

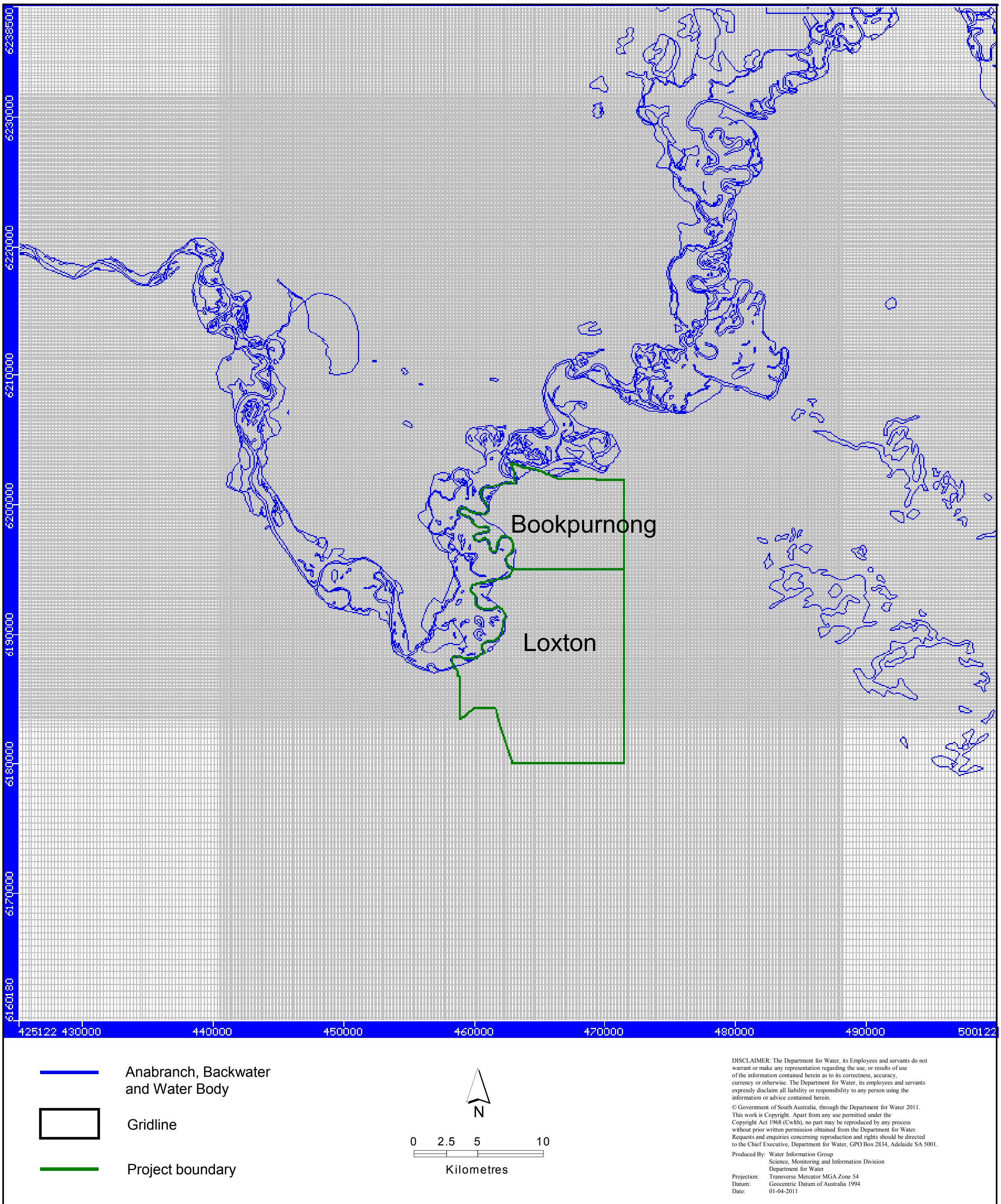

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Figure 3.2 Model grid

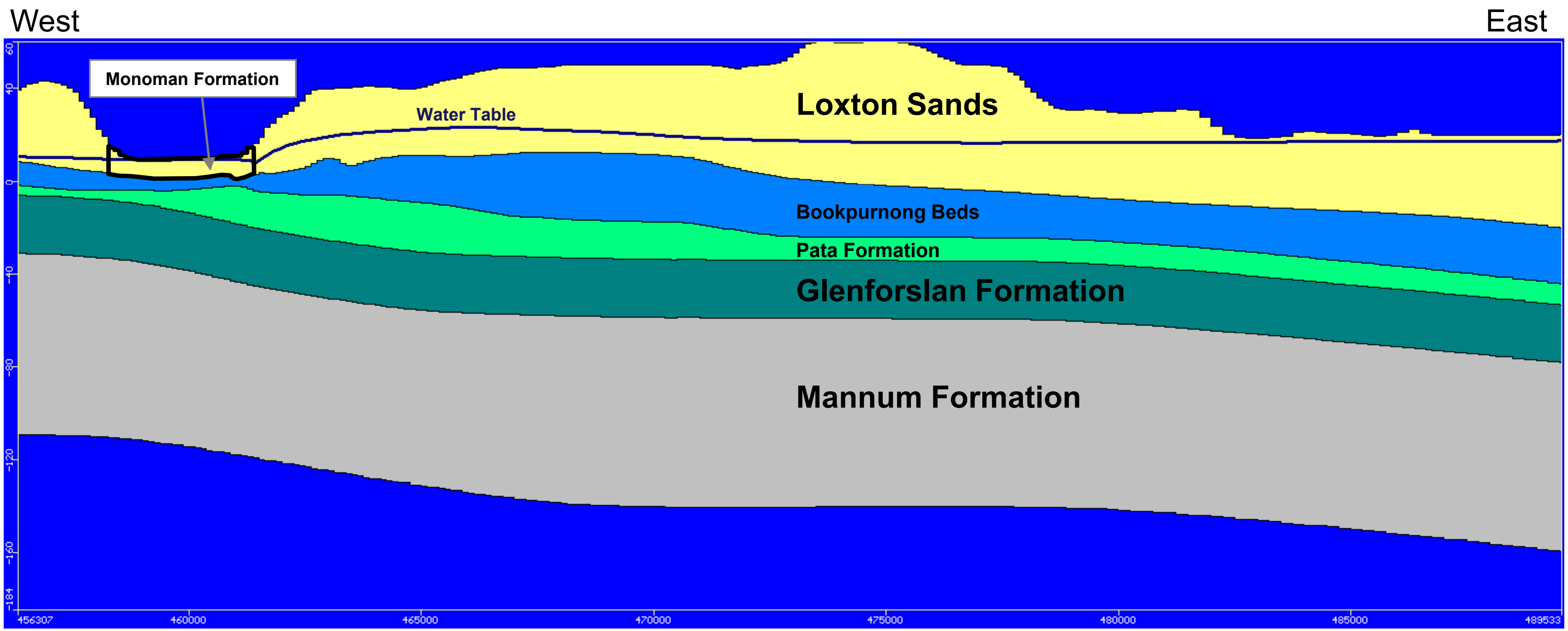


Figure 3.3 Model layers (Cross section through model row 340, approx N6193900)

3.3. MODEL STRESS PERIODS

The steady-state model represents the pre-irrigation development and post-regulation period.

Two transient models are used to simulate the historical period and future predictions, as below:

- Calibrated model — the historical transient model simulates 1920 to 2010
- Prediction model — the calibrated transient model was then used to develop the scenario modelling for predictions. All prediction models run from 1920 to 2110 but the changes of the input for scenario models only occur during the period between1988 to 2110 as required by Salinity Register purposes.

The stress periods are one year in length, as annual salt loads from 1988 to 2110 are required by the MDBA for the Salinity Register and the simulation of seasonal changes is not desired. All transient models have a time step multiplier of 1.2 and 10 time steps per stress period.

3.4. MODEL LAYERS IN THE LOXTON–BOOKPURNONG AREA

The Border to Lock 3 model represents key hydrogeological units within five layers, including four aquifer layers and one aquitard layer (Fig. 3.3, Table 3.1). The model grid, applied to five layers, results in a total of 1 158 760 finite difference cells. MODFLOW layer options are given in Table 3.2.

The Monoman, Loxton Sands, Pata, Glenforslan and Mannum Formation aquifers are simulated. The Upper and Lower Mannum Formation aquifers are treated as a single unit, as the head difference between the two is very small in the project area (Yan et al. 2005) and this reduces computational time with a negligible impact on accuracy.

The combined aquitard of the Lower Loxton Clay and Shells plus the Bookpurnong Formation is represented explicitly by a layer in the model, while the Finniss Formation and Winnambool Formation aquitards are implicitly modelled via vertical conductance. Aquitards can be simulated as vertical leakage between aquifers without an actual layer in the model, provided that storage in the aquitard is not important (McDonald & Harbaugh 1988), for example, where the aquitard layers are relatively thin and fairly uniformly distributed. This approach reduces the number of model layers and the input dataset requirements and speeds up the model calculation process. In the model area, the Winnambool Formation aquitard is ~7 m thick and the Finniss Formation aquitard is generally less than 5 m in thickness. These aquitards have been merged into the underlying/overlying aquifers and the vertical hydraulic conductivity values of those aquifer layers modified to control the vertical leakage between the aquifers.

Perched aquifers and the unsaturated zone are not simulated directly. The Coonambidgal Formation is not simulated. This means that the Monoman aquifer is modelled as unconfined, whereas it is actually semi-confined.

The Renmark Group aquifer is not simulated as it is anticipated that impact to the River Murray is insignificant and changes in the interaction between the Renmark Group and the upper aquifers occur over longer timescales than those simulated in the current study.

Where possible, a hydrogeological unit is represented by a single model layer. There are two main exceptions in this model. The first is that the Murray Valley has cut through the Loxton Sands, so layer 1 represents the Loxton Sands aquifer regionally and the Monoman Formation aquifer within the valley and there is a small area of Monoman Formation within layer 2. Secondly, as the Murray Group dips in the region, there is an area south-west of Loxton where the Pata Formation aquifer lies close to the surface and is unsaturated; this is represented in the model as zones in layers 1 and 2 with Pata properties.

Table 3.1 Model layer aquifers and aquitards

Layer number	Hydrogeological unit	Aquifer/ aquitard	MODFLOW layer
1	Loxton Sands regionally, Monoman Formation in the river valley, very small area represent Pata Formation in south-west of Loxton township area	Aquifers	Type-1
2	Lower Loxton Clay and Shells, Bookpurnong Formation/ Pata Formation south-west of Loxton, Monoman Formation	Aquitard/ Aquifers	Type-3
3	Pata Formation	Aquifer	Type-3
–	Winnambool Formation	Aquitard	Simulated as vertical leakage
4	Glenforslan Formation	Aquifer	Type-0
–	Finniss Formation	Aquitard	Simulated as vertical leakage
5	Mannum Formation	Aquifer	Type-0

Table 3.2 MODFLOW layer types

Layer type	Aquifer type	Aquifer hydraulic parameters
Type-0	Confined	Transmissivity and storage coefficient (specific storage, SS) are constant in each cell.
Type-1	Unconfined	Transmissivity varies and is calculated from saturated thickness and hydraulic conductivity of each cell. The storage coefficient (specific yield, S_Y) is constant. Type-1 is only valid for the uppermost layer of a model.
Type-2	Confined/unconfined	Transmissivity is constant — the storage coefficient may alternate between values applicable to the confined (S_S) or unconfined (S_Y) states.
Type-3	Confined/unconfined	Transmissivity varies and is calculated from the saturated thickness and hydraulic conductivity of each cell. The storage coefficient may alternate between values applicable to the confined (S_S) or unconfined (S_Y) state.

The top and bottom of each model layer is based on elevation data, borehole data and estimated structural contours, as described in detail in the following sections.

The layer elevations have been revised from those of Yan et al. (2008) within the Loxton–Bookpurnong area for the Loxton Sands, Lower Loxton Clays and Bookpurnong Formation. The revised elevations are based on preliminary work conducted by AWE in developing the Bookpurnong–Loxton Atlas (AWE 2011b). Work on the model calibration had to commence prior to completion of the atlas, so the final structure contour maps in the atlas may differ in small ways from the structure contours used in the model.

The bases of layers 1 and 2 were revised by AWE within a rectangular region which includes the Loxton–Bookpurnong study area but not any adjacent study areas. Data were obtained and interpreted from geological and geophysical logs for this region. Structure contours were hand-drawn to reflect both the data and other structural information, such as the location of faults and the edge of the Murray Valley. Both the bore data and structure contours were used to interpolate values. In some areas where there were minimal data, the initial interpolations had to be adjusted, for example, if they led to negative thicknesses in areas where the unit was known to exist.

The new interpolated values within the rectangular region were inset within the larger model domain and boundaries between the two datasets were smoothed across a kilometre overlap to form a merged whole. Areas outside the rectangle retain the same elevations they had in the previous version of the model (Yan & Stadter 2008).

3.4.1. LAYER 1: LOXTON SANDS AQUIFER, MONOMAN FORMATION AQUIFER AND PART PATA FORMATION AQUIFER

Layer 1 represents the Loxton Sands unconfined/semi-unconfined aquifer on the highland, the Monoman Formation semi-unconfined/semi-confined aquifer in the floodplain and part of the Pata Formation where it is unconfined downstream of Loxton and upstream of Pyap (Yan et al. 2005).

Ground elevation is adopted as the top of layer 1. This is reasonable wherever the Loxton Sands, Monoman and Pata aquifers are unconfined and is a simplification elsewhere. DENR provided the regional elevation data for the groundwater model. Ground surface elevation is given in Figure 3.4. The elevation of the floodplain is ~9 to 18 m AHD and the elevation of the highland is ~30 to 60 m AHD in the Loxton–Bookpurnong area.

The elevation of the base of layer 1 (top of layer 2) occurs from between -14 and 14 m AHD in the project area (Fig. 3.5).

In the study area, the base of layer 1 represents the top of the aquitard formed by the Loxton Clay and Shells and the Bookpurnong Formation, except where this is absent in the south-west of the model, where the base is defined to be 1 m above the top of the Pata Formation. The initial interpolation smoothed the transition at the edge of the eroded river valley too much, so a constraining contour of 3 m AHD was added. The initial interpolation also led to the aquitard being absent in small areas where it is known or presumed to occur and this was addressed by setting a minimum aquitard thickness of 1 m.

3.4.2. LAYER 2: LOWER LOXTON CLAY AND SHELLS AND BOOKPURNONG FORMATION AQUITARDS AND PART PATA FORMATION AQUIFER

Layer 2 represents the Lower Loxton Clay and Shells and Bookpurnong Formation aquitards and part of the Pata Formation semi-confined aquifer. Note also that there is a region within the river valley just west of the study area where layer 2 represents to the Monoman Formation.

The base of layer 2 is the top of the Pata Formation. It occurs between -27 and 3 m AHD in the project area (Fig. 3.6). The base was revised by AWE in the Loxton–Bookpurnong area as described in Section 3.4.1 above.

3.4.3. LAYER 3: PATA FORMATION AQUIFER

Layer 3 represents the regionally-distributed Pata Formation, which is modelled as a semi-confined low permeability aquifer. The base elevation of layer 3 was interpreted from geological and geophysical logs and extrapolation of these values and by examination of the cross-section given in Figure 2.3. Layer 3 has a thickness of 4 to 22 m. The base elevation of layer 3 (top of layer 4) occurs between -36 and -8 m AHD in the project area (Fig. 3.7).

3.4.4. WINNAMBOOL FORMATION AQUITARD

The Winnambool Formation vertical hydraulic conductivity was applied to the Pata Formation (layer 3) and the upper part of the Glenforslan Formation (layer 4) to allow calculation of the leakage between these aquifers. This modelling method simulates the effect of the Winnambool Formation.

3.4.5. LAYER 4: GLENFORSLAN FORMATION AQUIFER

Layer 4 represents the regionally distributed Glenforslan Formation, which is a semi-confined, low permeability aquifer. The thickness of layer 4 (~25 m) was taken from AWE (2003). The base elevation of layer 4 (top of layer 5) occurs between -61 and -33 m AHD in the project area (Fig. 3.8).

3.4.6. FINNISS FORMATION AQUITARD

The Finniss Formation vertical hydraulic conductivity was applied to the Glenforslan Formation (layer 4) and is combined with the specified vertical hydraulic conductivity of the Mannum Formation (layer 5) to allow the calculation of vertical leakage between these aquifers. This modelling method simulates the effect of mainly vertical flow through the Finniss Formation.

3.4.7. LAYER 5: MANNUM FORMATION AQUIFER

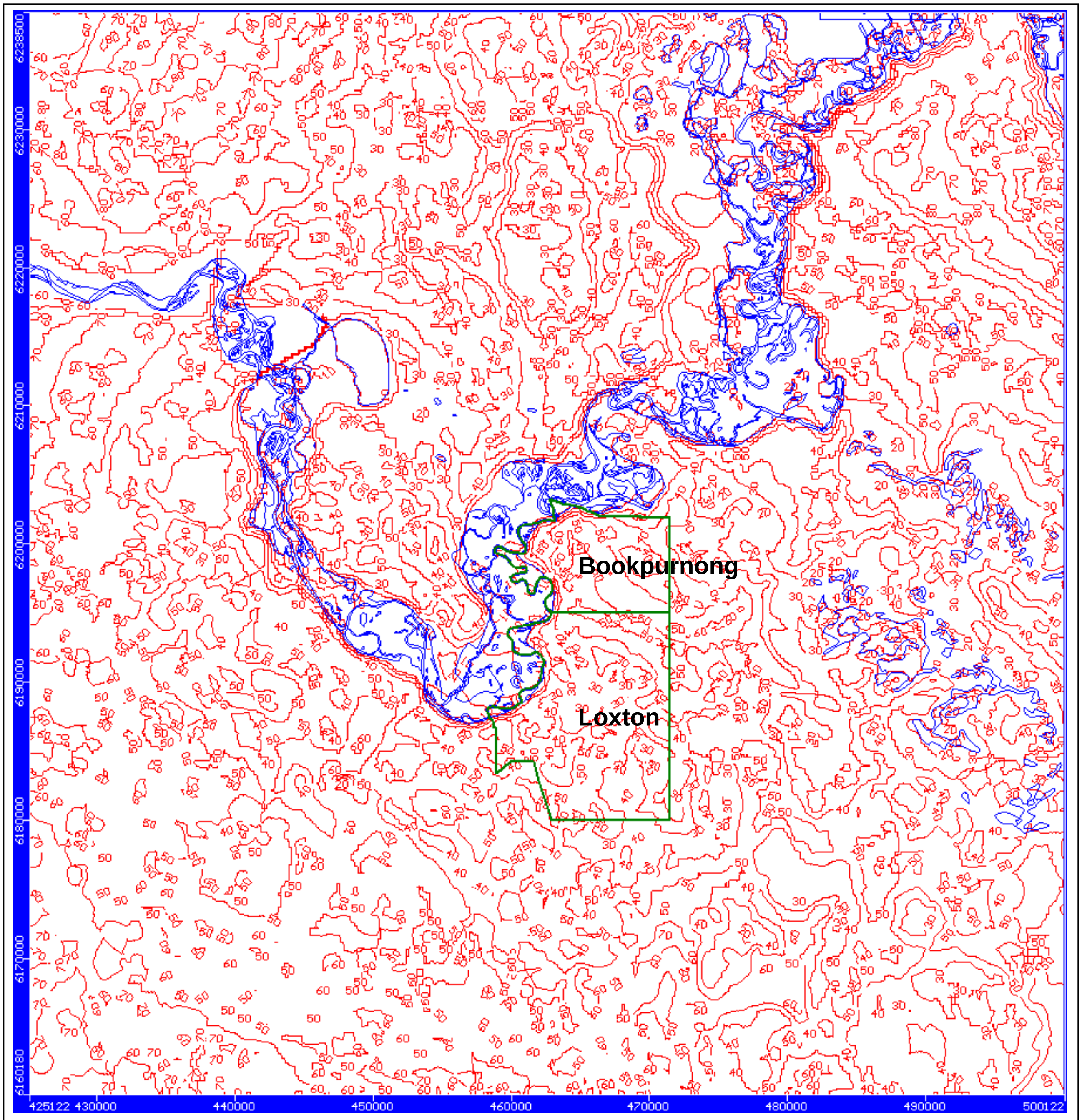
Layer 5 represents the regionally distributed Mannum Formation, which is a confined, moderate permeability aquifer. Layer 5 has a thickness of 80 m, taken from AWE (2003). The base elevation of layer 5 occurs around -130 m AHD in the project area (Fig. 3.9).

3.5. MODEL HYDRAULIC PARAMETERS

In order to constrain the model calibration, a physically realistic range of aquifer and aquitard hydraulic parameters were derived from previous reports and new data (Table 2.2). Hydraulic parameter zones and values from Yan & Stadter (2008) were adopted for initial runs of the model and then varied in the project area during calibration (see Section 4 for further details). The adopted aquifer and aquitard hydraulic parameters are given in Table 3.3, with their spatial distribution within each layer shown in Figures 3.10 to 3.16. Due to the representation of the Monoman Formation in the model as an unconfined aquifer, confined storage coefficient values determined from pumping tests are not applicable.

The adopted parameters are generally within the ranges given in Table 2.2. Three small zones within the Loxton Sands have horizontal hydraulic conductivities of 0.5 or 1 m/d, less than the observed minimum of 2 m/d, but this is within reasonable value given the heterogeneity of the sediments. The Pata Formation is given a small zone of comparatively high vertical hydraulic conductivity (1 m/d) under the Loxton irrigation mound to simulate the ready movement of groundwater via drainage bores. Transmissivities in the model range from 3 to 550 m^2/d for the Loxton Sands and range from 28 to 300 m^2/d for the Monoman Formation, showing a good agreement with the range of transmissivities values from pumping test analyses in the area (Table 2.2, Fig. 3.17) (Appendix C-5 shows selected values).

The Winnambool Formation aquifer is modelled as vertical leakance rather than as a layer. The effective vertical hydraulic conductivity of the Winnambool is close to the lower value of the vertical hydraulic conductivities adopted for layers 3 and 4, i.e. 5x10-5 to 2×10^{-4} m/d. Similarly, the effective vertical hydraulic conductivity of the Finniss Formation is 5×10^{-6} to 2×10^{-4} m/d in the study area. These values agree well with observed ranges.



Anabranch, Backwater and Water Body

Elevation Contour (m AHD)

Project Area

N

0 2.5 5 10

Kilometres

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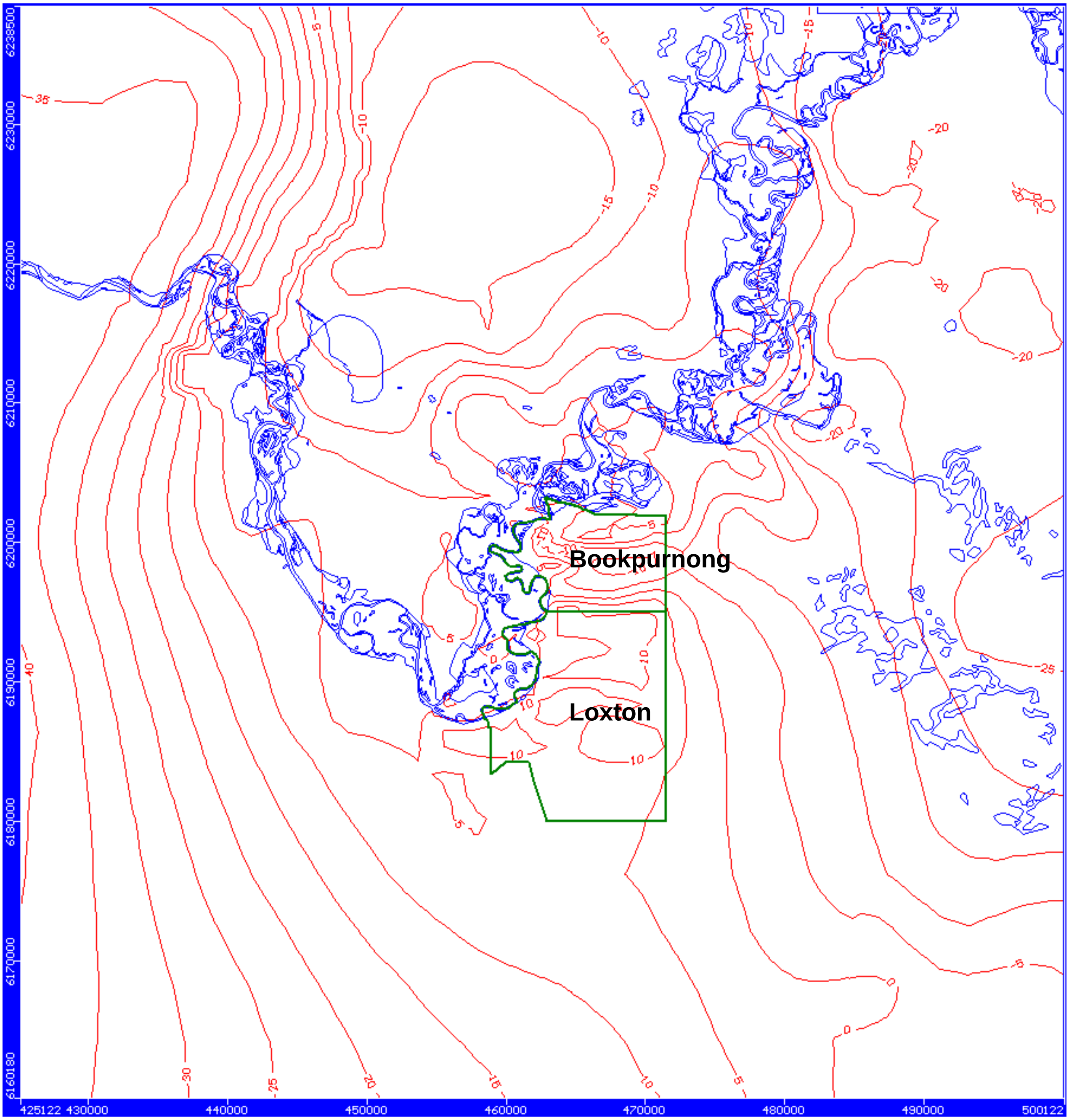
Figure 3.4 Ground surface elevation contours (m AHD)



Anabranch, Backwater and Water Body

Elevation Contour (m AHD)

Project Area

N

0 2.5 5 10

Kilometres

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Figure 3.5 Top of model layer 2 elevation contours (m AHD)

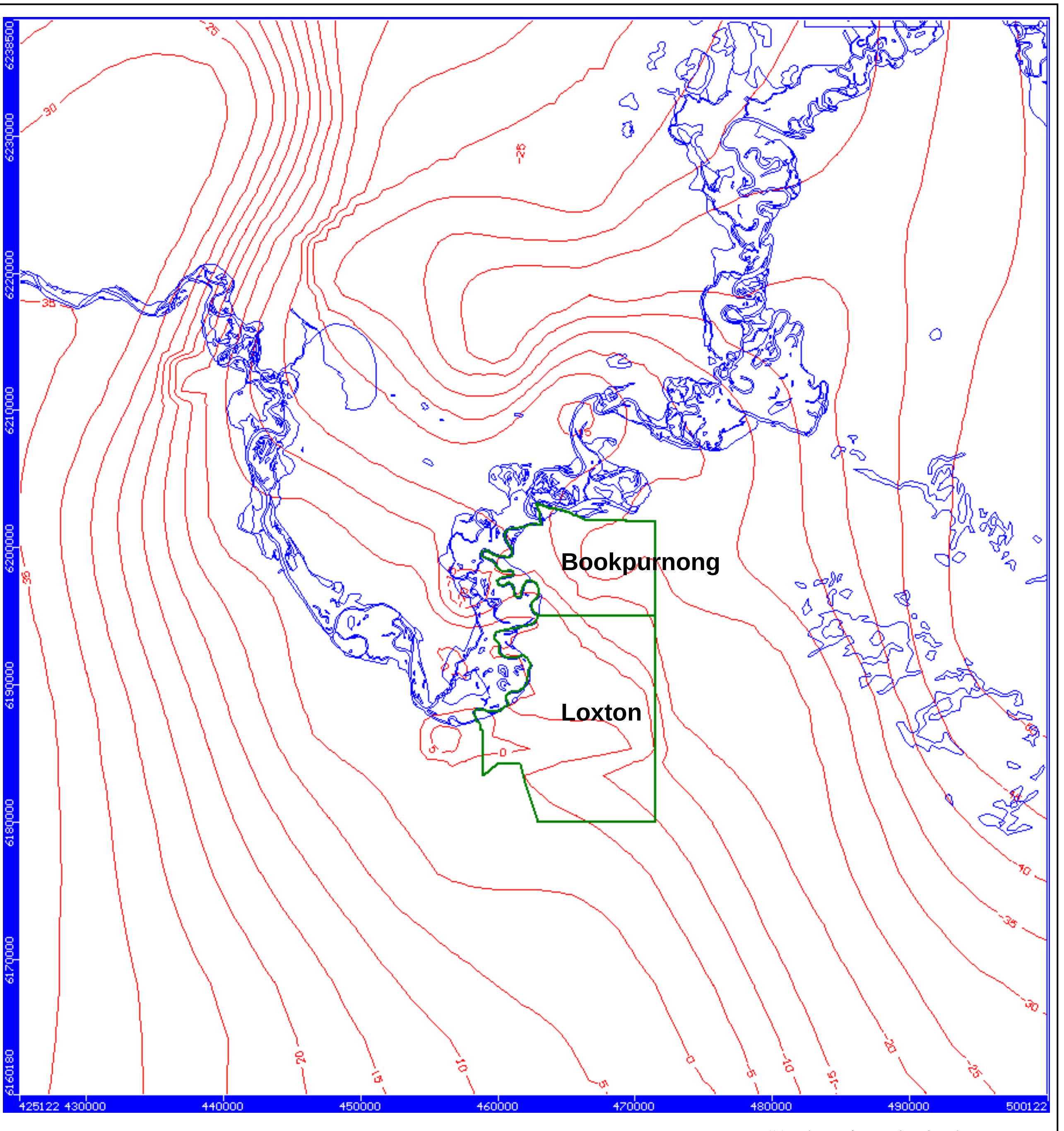

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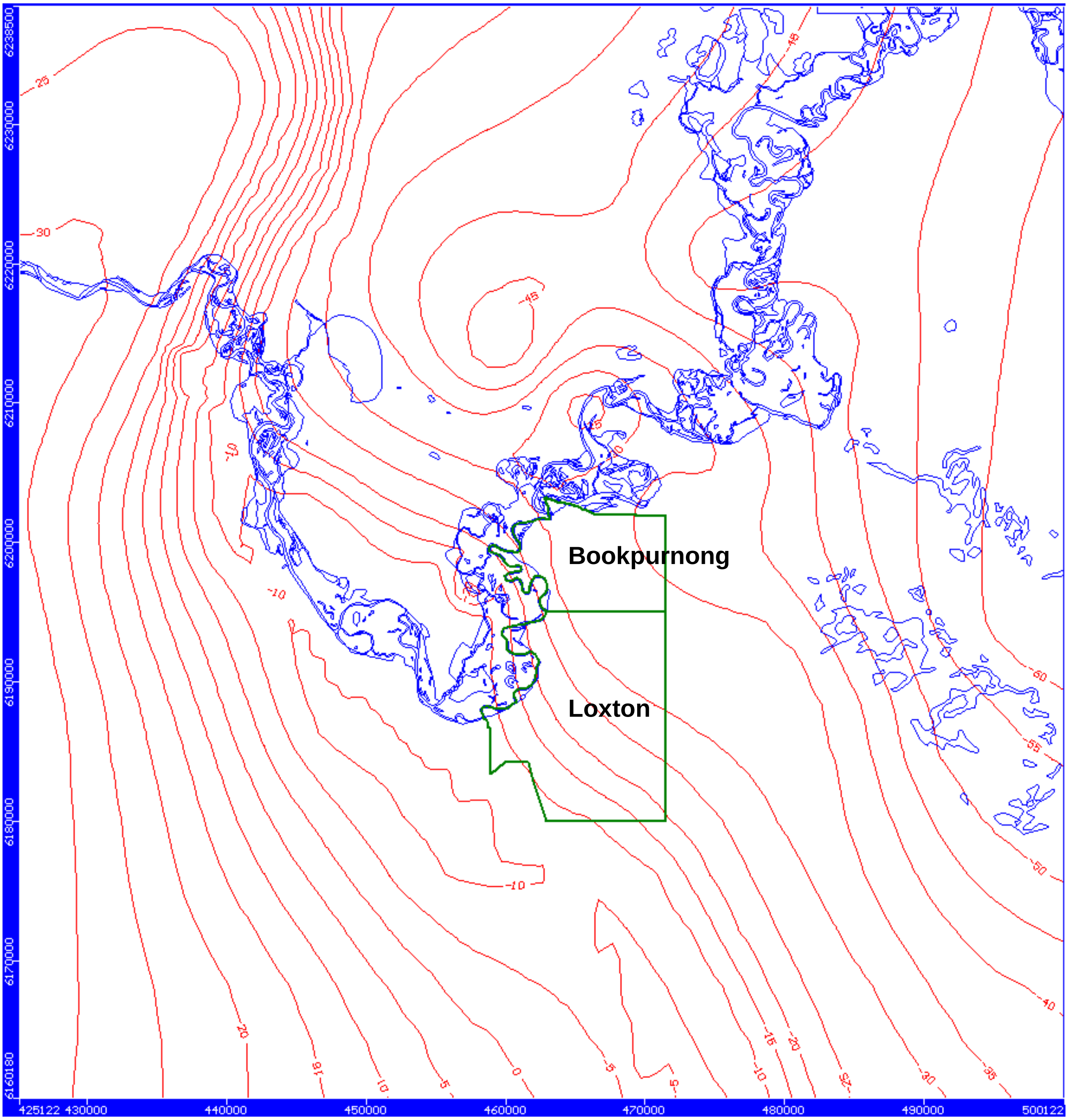
Figure 3.6 Top of model layer 3 elevation contours (m AHD)



Anabranch, Backwater and Water Body

Elevation Contour (m AHD)

Project Area

N

0 2.5 5 10

Kilometres

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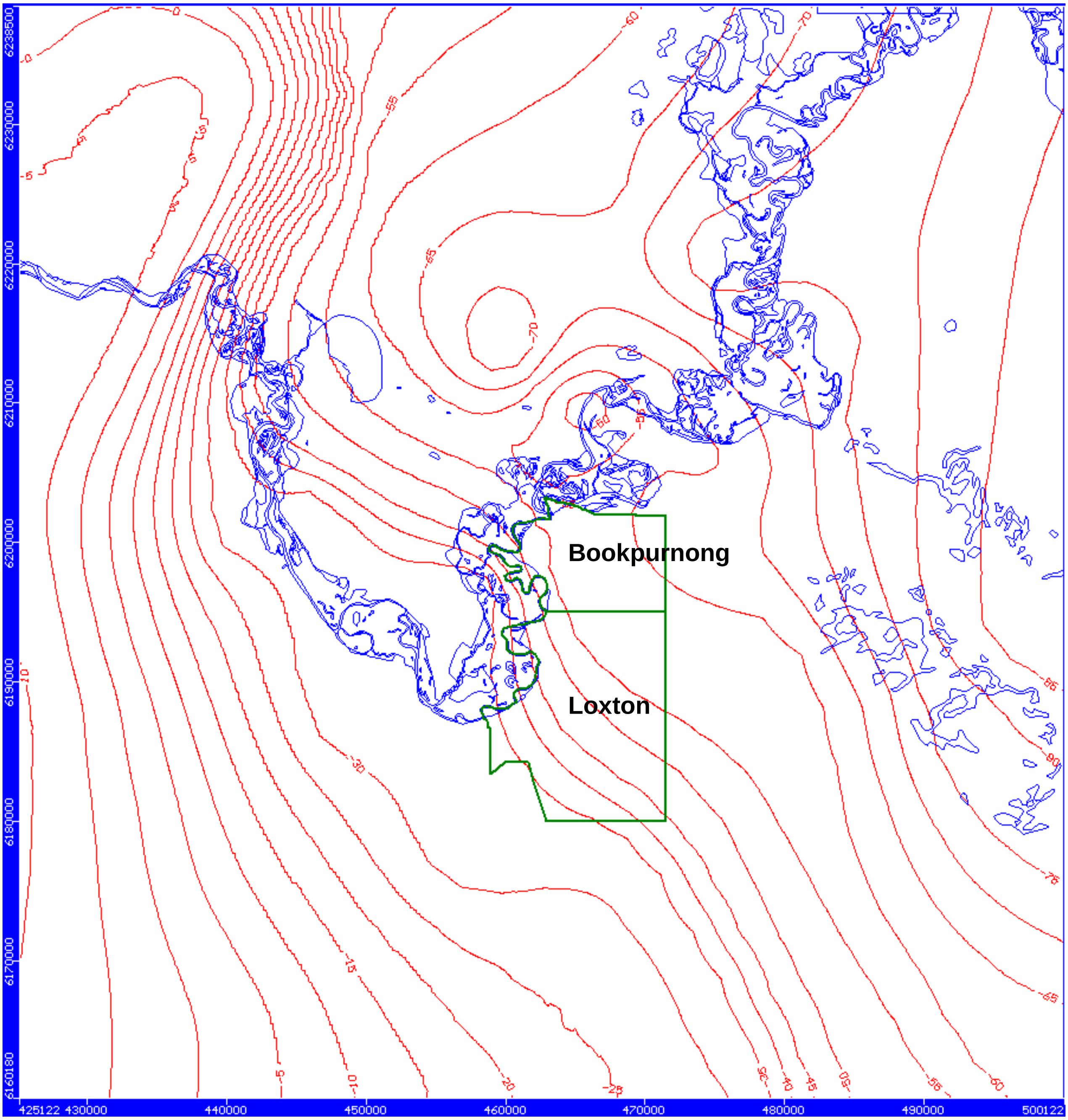
Figure 3.7 Top of model layer 4 elevation contours (m AHD)



Anabranch, Backwater and Water Body

Elevation Contour (m AHD)

Project Area

N

0 2.5 5 10

Kilometres

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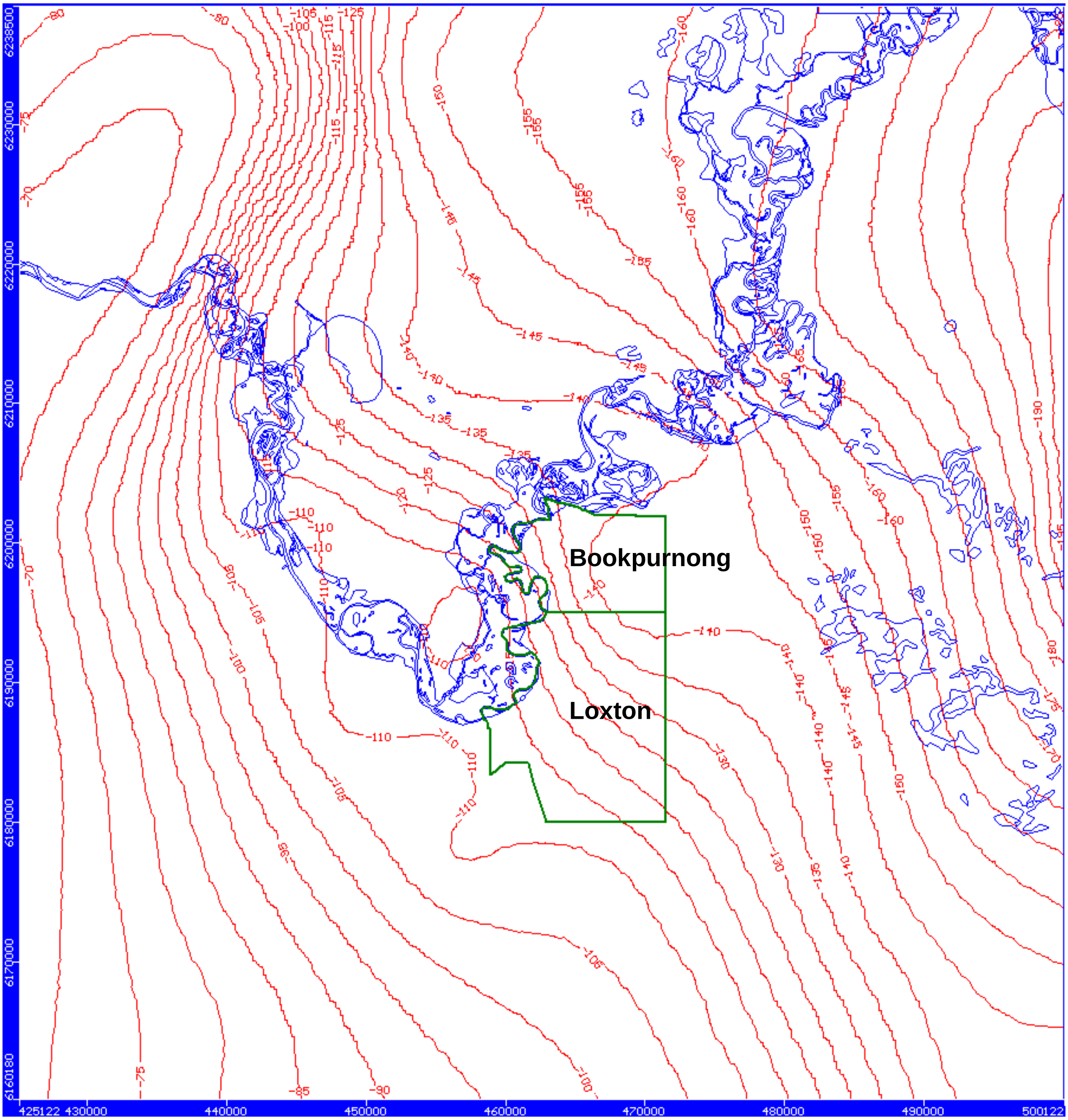
Figure 3.8 Top of model layer 5 elevation contours (m AHD)



Anabranch, Backwater and Water Body

Elevation Contour (m AHD)

Project Area

N

0 2.5 5 10

Kilometres

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Figure 3.9 Base of model layer 5 elevation contours (m AHD)

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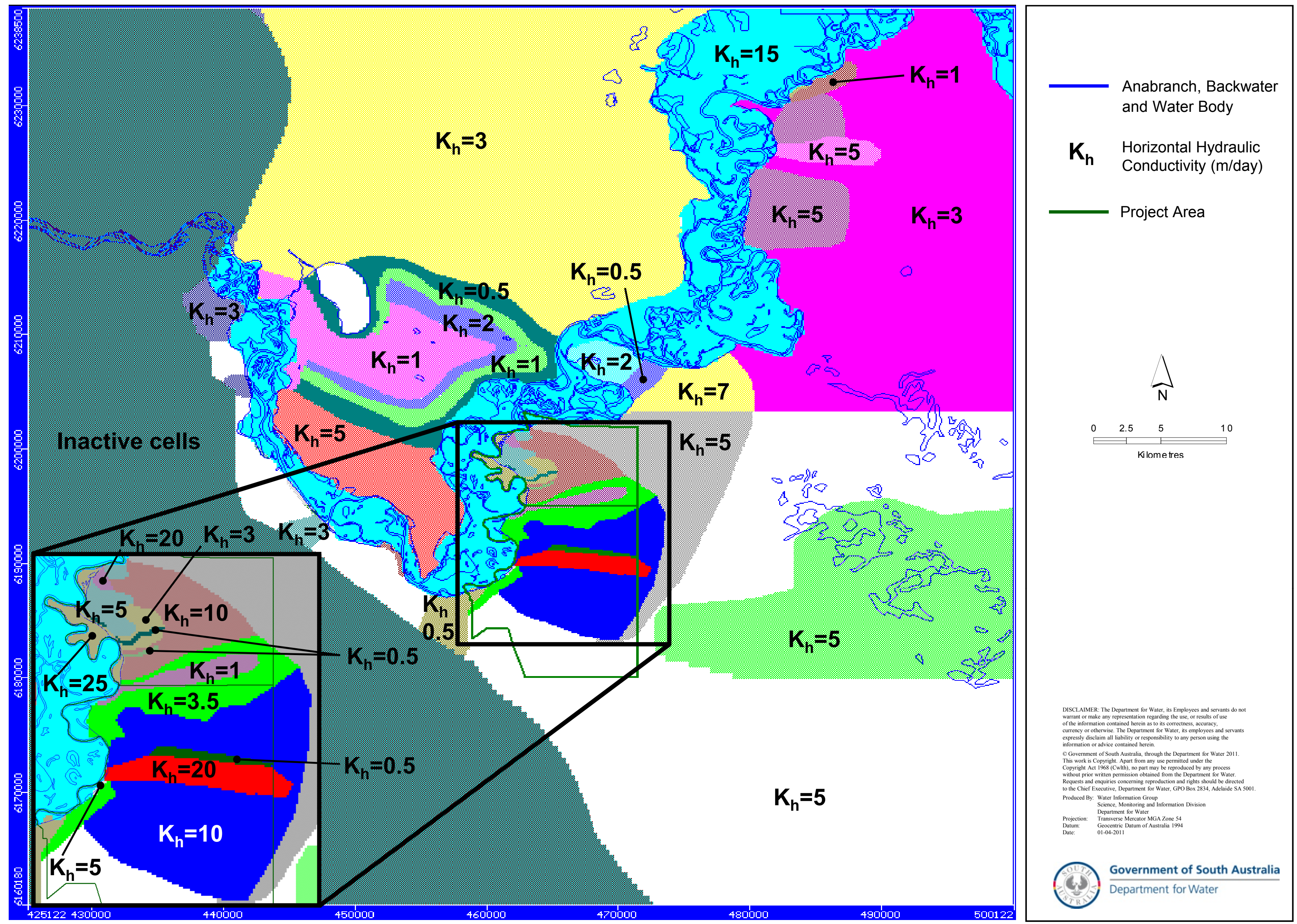

Figure 3.10 Model horizontal hydraulic conductivity zones and values (layer 1)

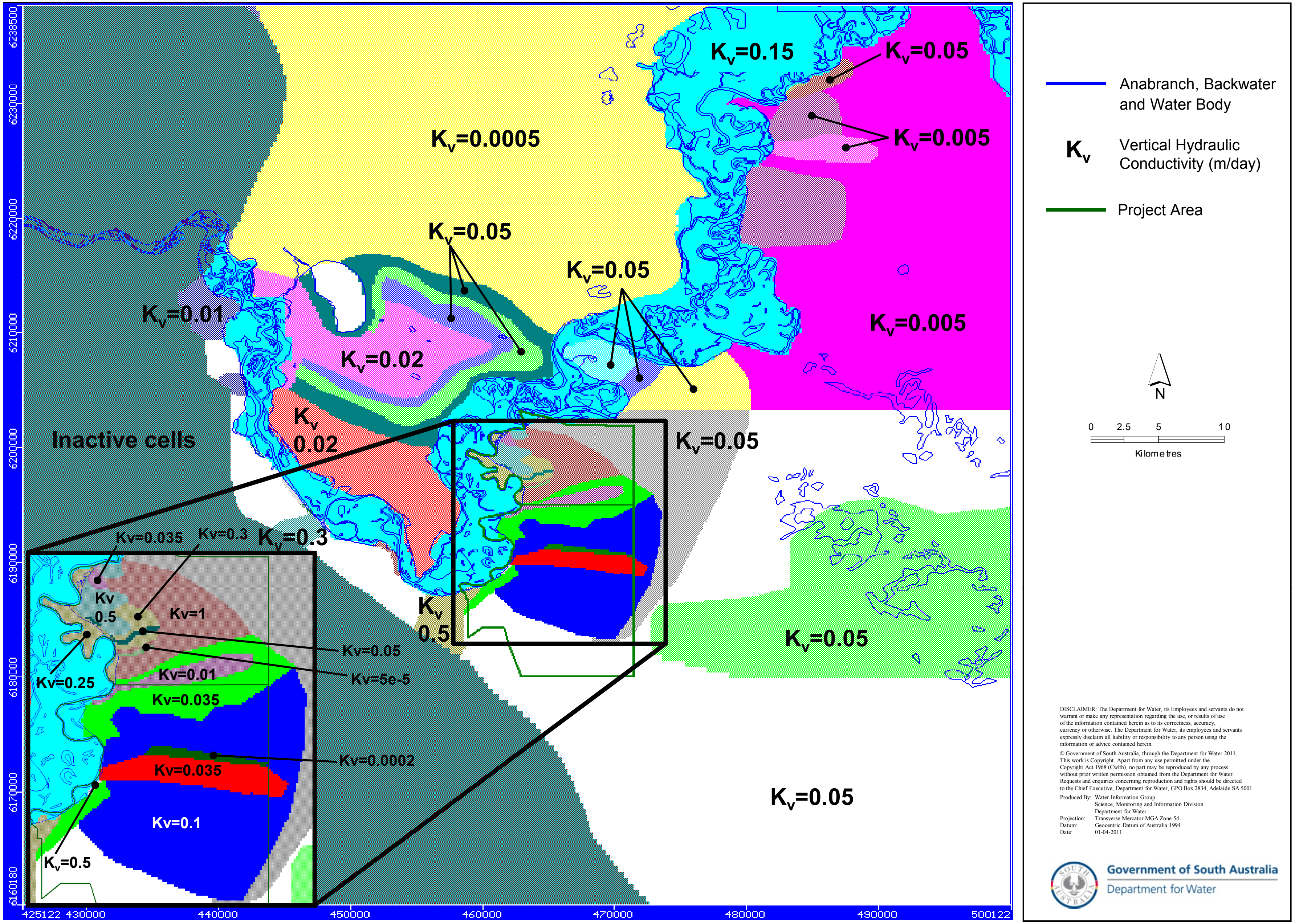

Figure 3.11 Model vertical hydraulic conductivity zones and values (layer 1)

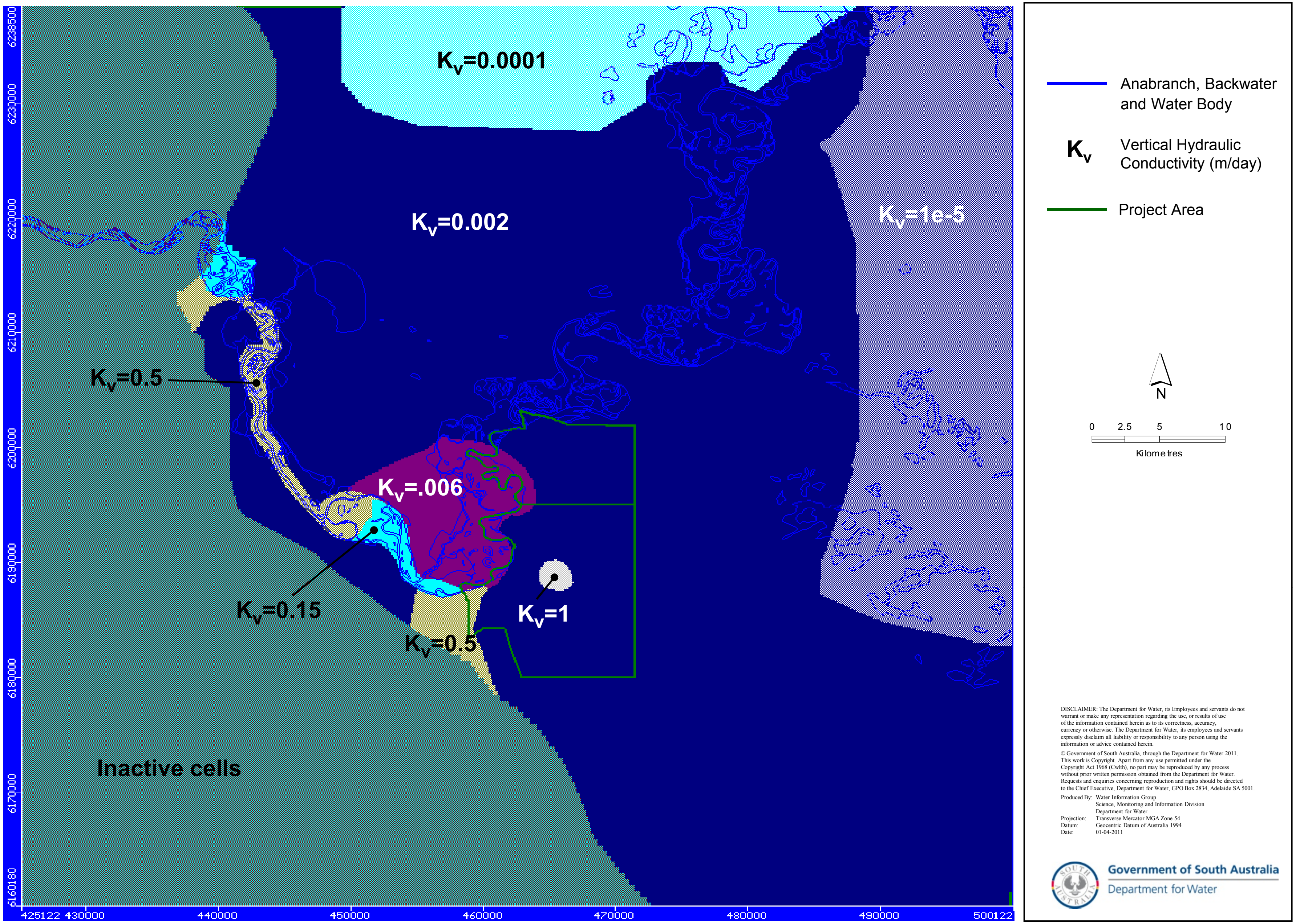

Figure 3.12 Model vertical hydraulic conductivity zones and values (layer 2)

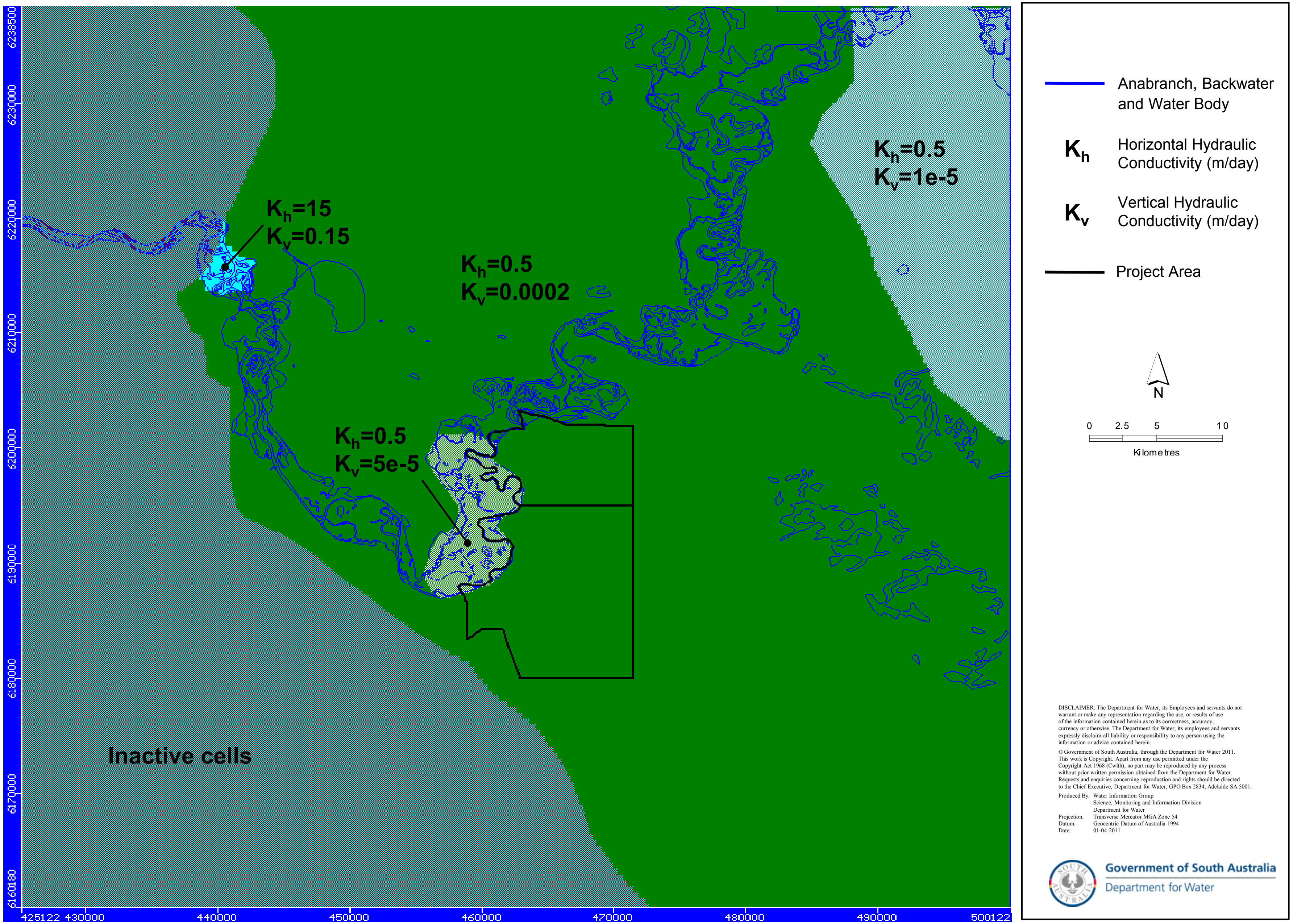

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Figure 3.13 Model horizontal and vertical hydraulic conductivity zones and values (layer 3)

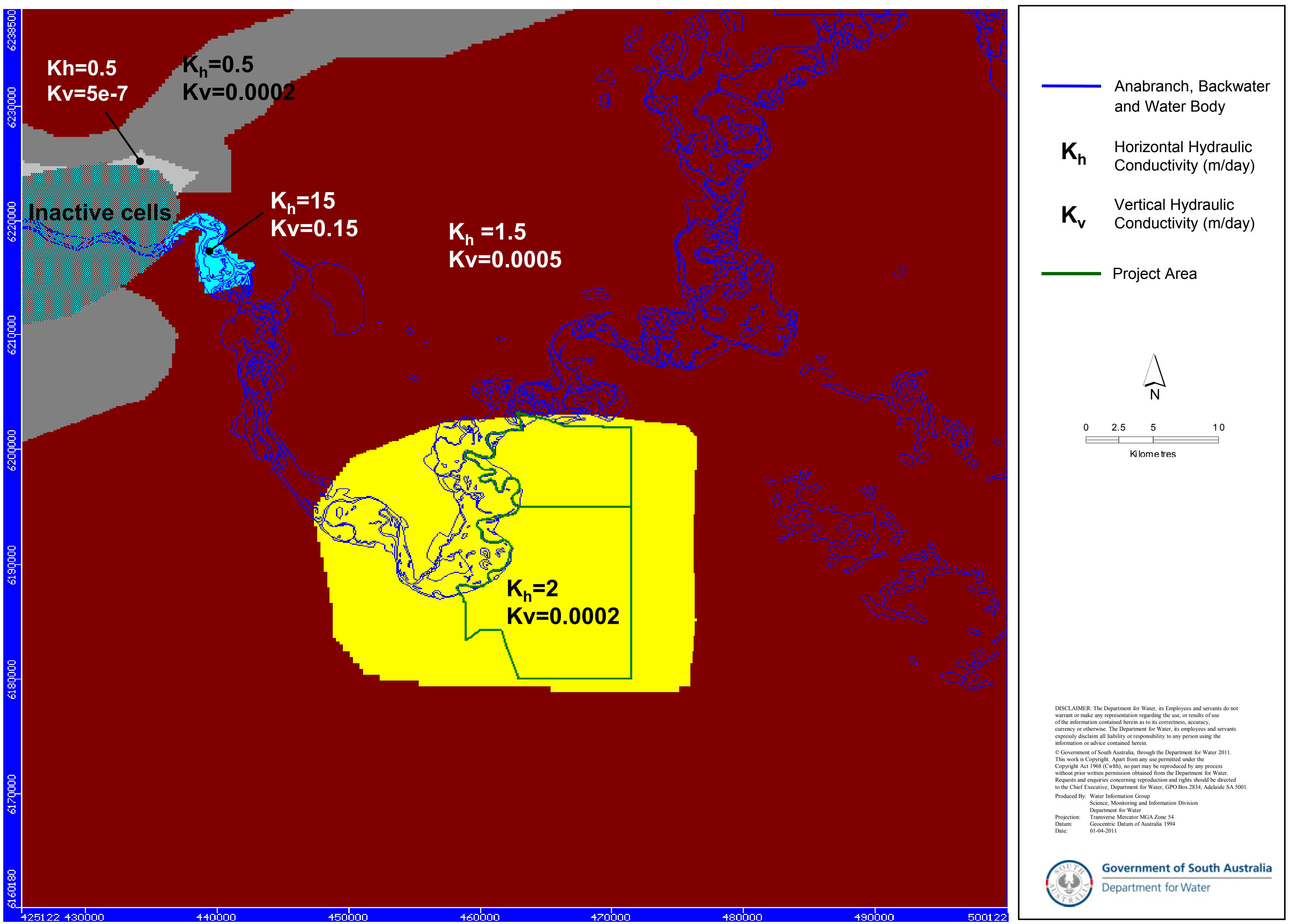


Figure 3.14 Model horizontal and vertical hydraulic conductivity zones and values (layer 4)

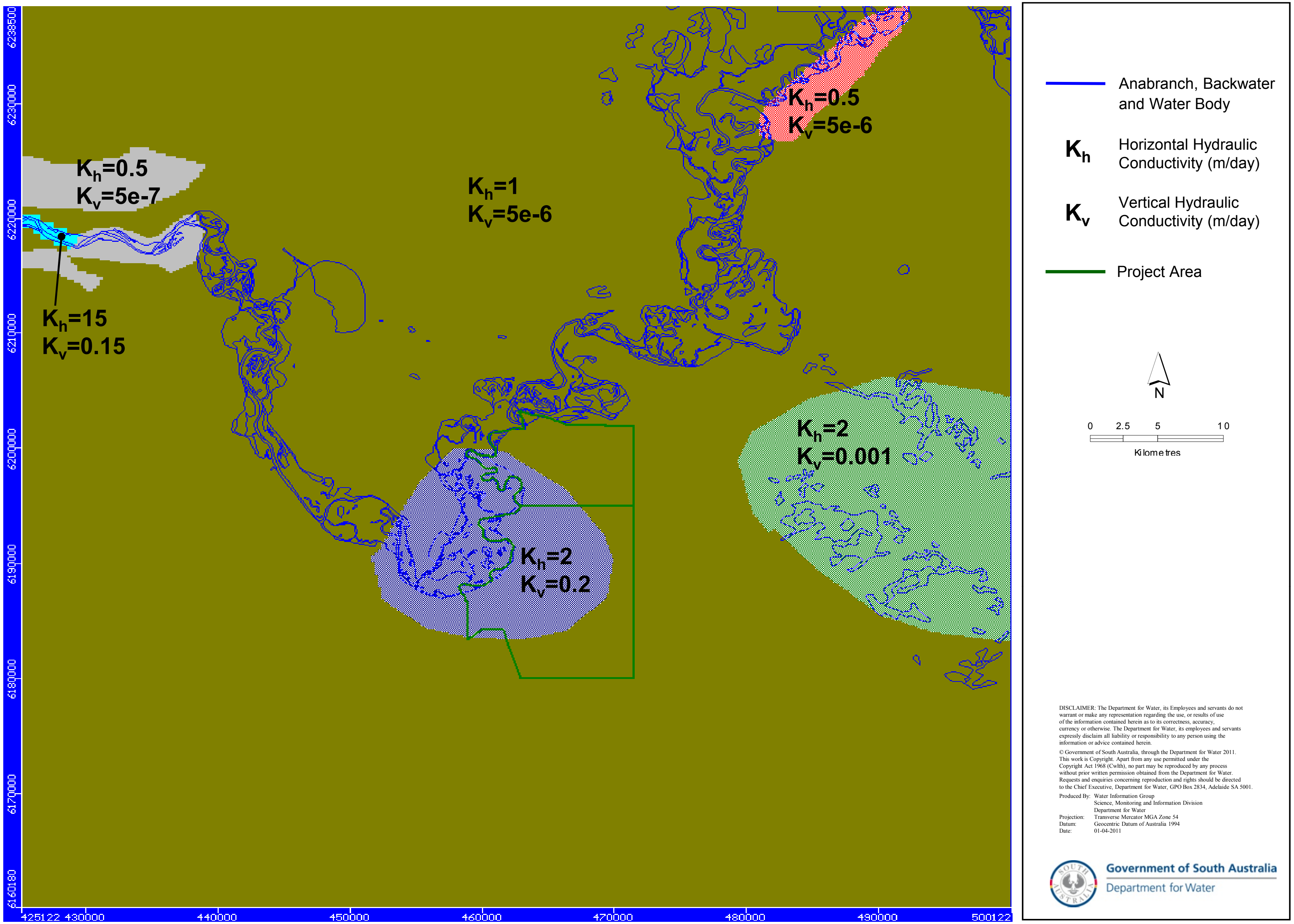
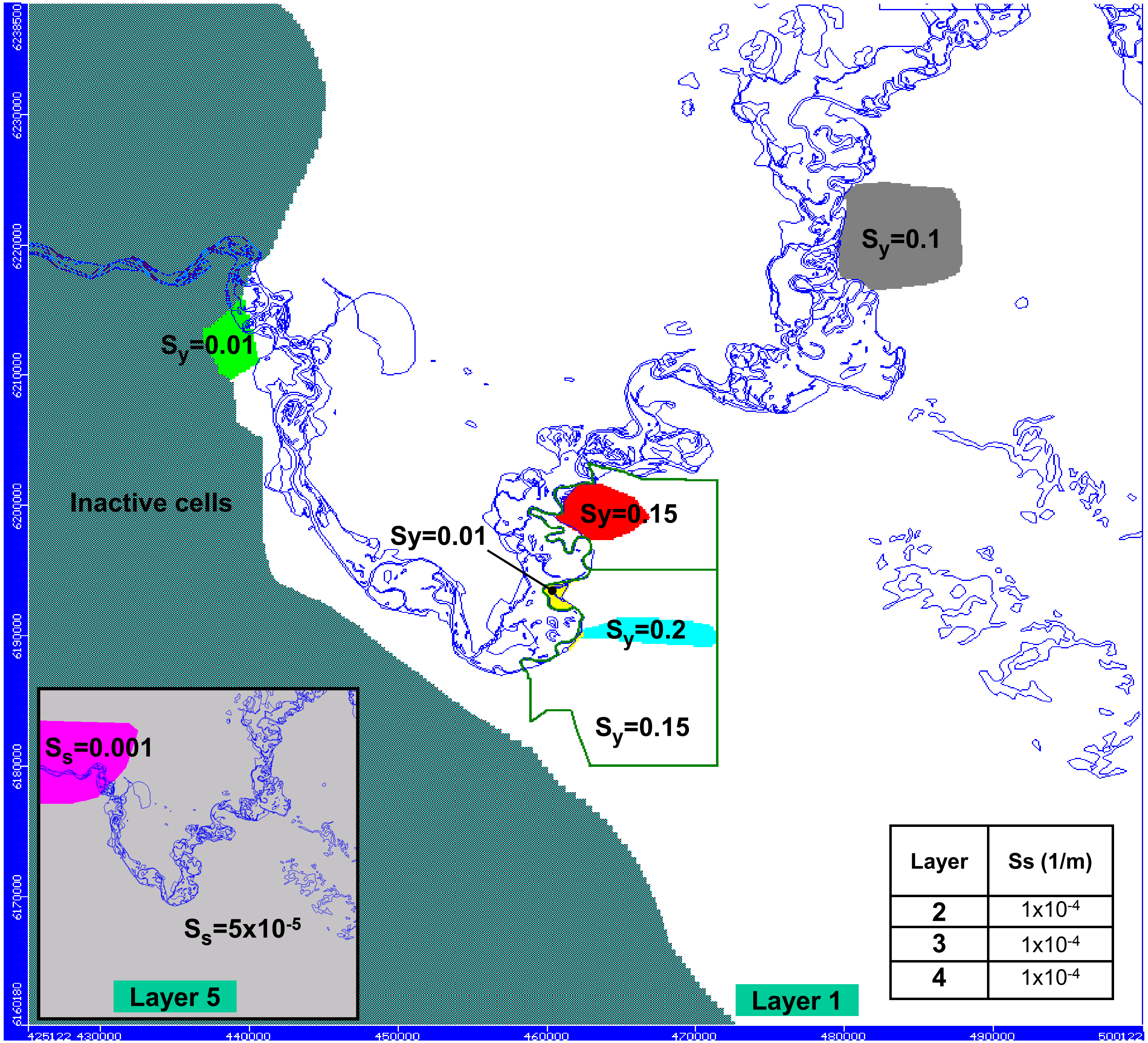


Figure 3.15 Model horizontal and vertical hydraulic conductivity zones and values (layer 5)



Layer	Ss (1/m)
2	1x10^{-4}
3	1x10^{-4}
4	1x10^{-4}

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Figure 3.16 Model Sy and Ss zones and values in Layer 1 (main map) and in Layer 5 (insert map) (Table shows Specific Storage [Ss] in other layers)

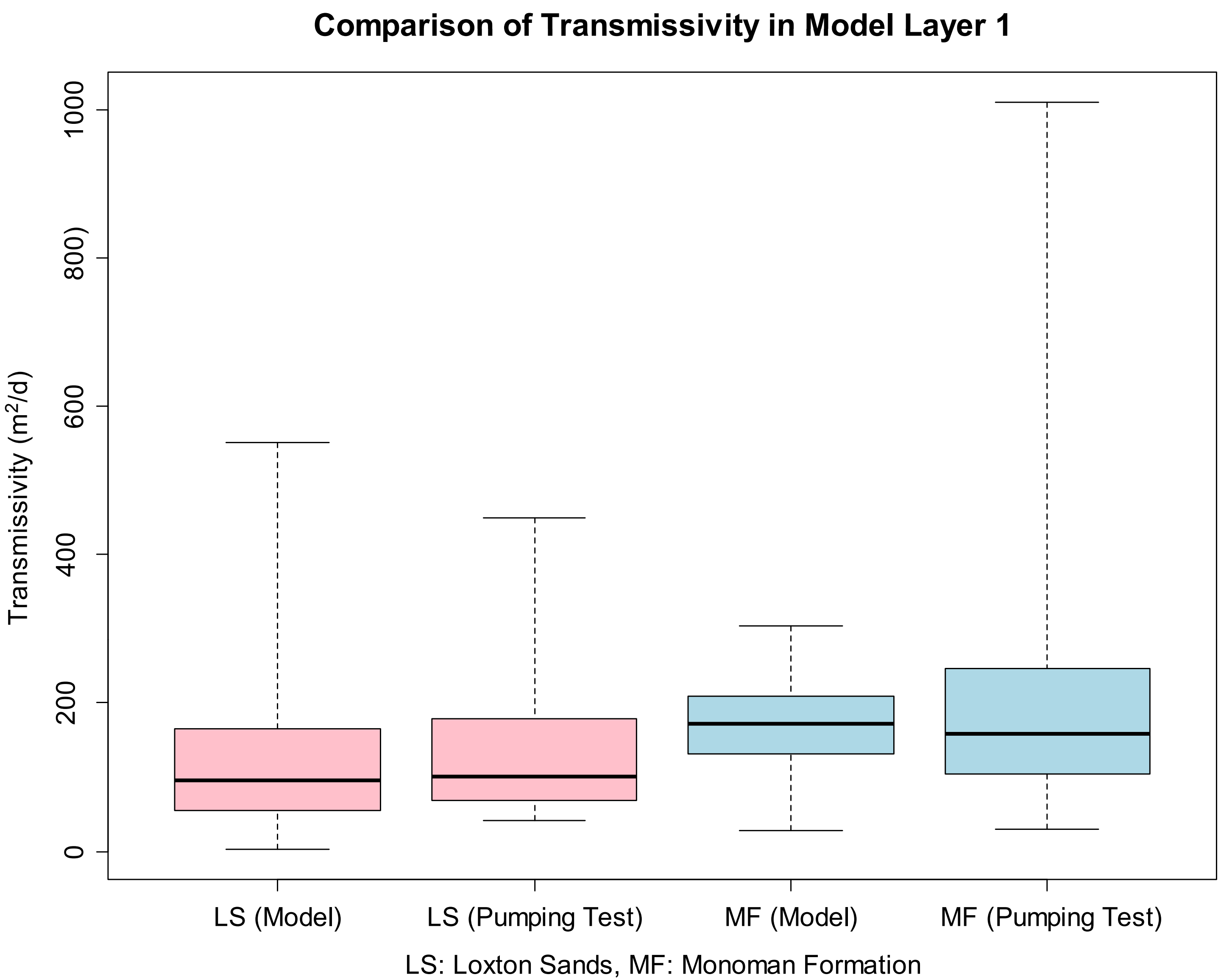


Figure 3.17 **Comparison of transmissivity between pumping test and modelled values within the project area in model layer 1**

Table 3.3 Adopted aquifer and aquitard hydraulic parameters in the Loxton–Bookpurnong area

Aquifer/aquitard	Layer	Hydraulic Conductivity		Storage	
		Kh (m/d)	Kv (m/d)	Sy (-)	Ss (/m)
Monoman Formation	1	15–25	0.15–0.25	0.01–0.15	
Loxton Sands[1]	1	0.5–20	$5x10^{-5}$–1	0.15–0.2	
Pata Formation	1	0.5	0.5	0.15	
Lower Loxton Clay and Shells/ Bookpurnong Formation	2	0.05–0.006	0.002–0.006		$1x10^{-4}$
Pata Formation	2	0.5	0.5		$1x10^{-4}$
Pata Formation	3	0.5	$5x10^{-5}$–$2x10^{-4}$		$1x10^{-4}$
Winnambool Formation			*		
Glenforslan Formation	4	2	$2x10^{-4}$		$1x10^{-4}$
Finniss Formation			*		
Mannum Formation	5	1–2	$5x10^{-6}$–0.2		$5x10^{-5}$

1 Loxton Sands Aquifer Parameters for the Loxton–Bookpurnong area only (east side of the river).

* Vertical leakance calculated by the model for each cell.

3.6. MODEL BOUNDARIES

The model boundary conditions are summarised for each layer in Figures 3.18 to 3.22. Areas that are expected to be dry for all scenarios are represented as inactive cells.

This section describes (i) the regional boundary conditions, (ii) the River Murray and (iii) surface and other local features within or near the Loxton–Bookpurnong study area. For details on other locations, see previous model reports (Yan et al. 2005, 2006, 2007; Yan & Stadter 2008). Recharge is described separately in Section 3.7.

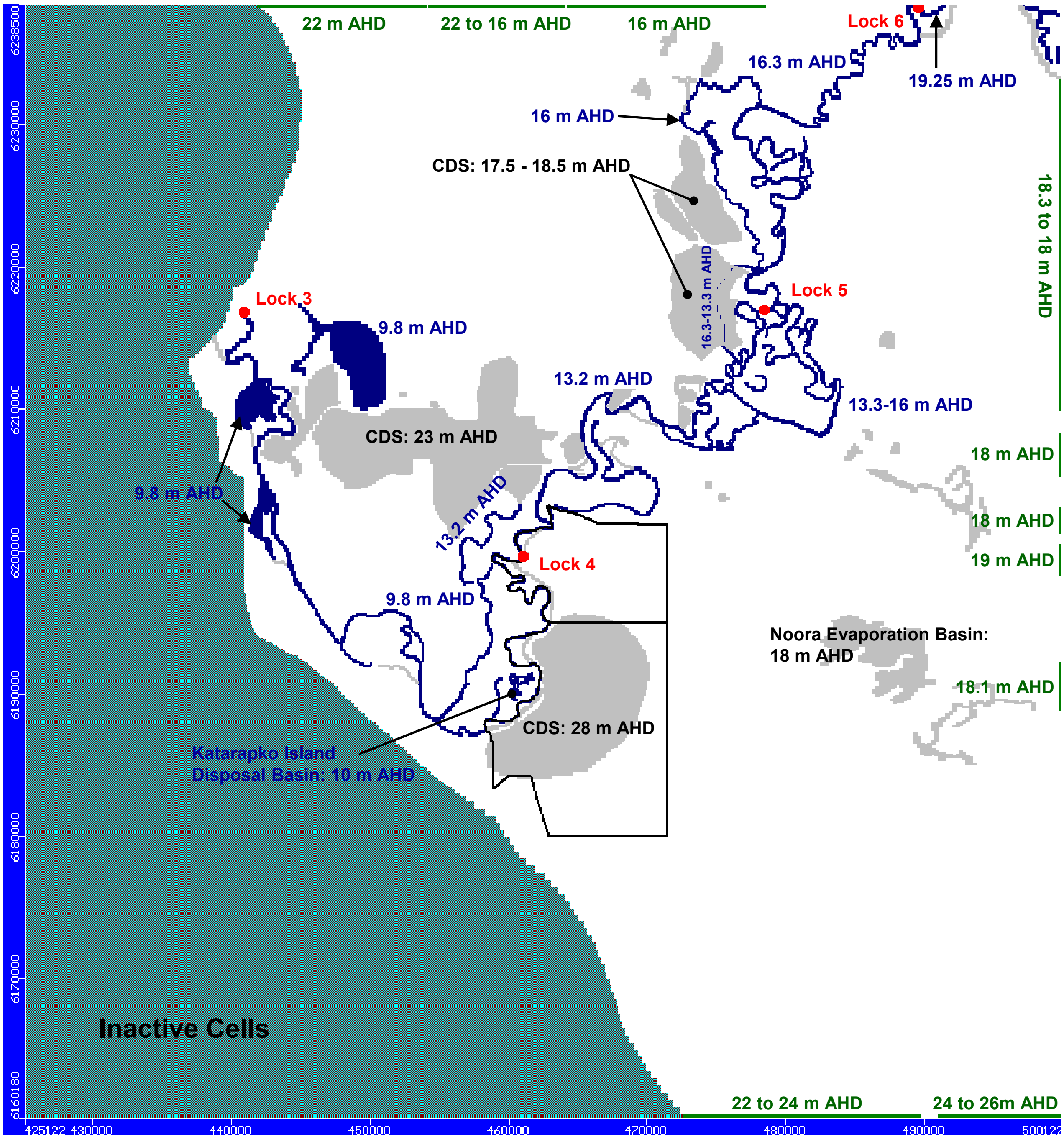
3.6.1. REGIONAL FLOW

The regional groundwater flow in the Loxton–Bookpurnong area is generally from east to west. This is simulated using general head boundary (head-dependent flow) cells along the edges of the model domain. The assigned head values for the general head boundary (Figs 3.18 – 3.22) are based on observed heads, e.g. from Barnett (1991). Note that the heads at a location are constant with depth (i.e. extend through all aquifer layers) except where upper layers are dry (i.e. have inactive cells); the one exception is a western section of the northern boundary.

The conductance was varied during calibration until a good match to observed heads was achieved regionally. The conductance is 100 m^2/d, except as follows:

- along the southern boundary in all layers, the 24 to 26 m AHD boundary has a conductance of 20 m^2/d
- along the northern boundary in layer 3, the 22 m AHD boundary and the 20 m AHD boundary have a conductance of 50 to 100 m^2/d
- along the northern boundary in layers 4 and 5, the 18 to 22 m AHD boundary has a conductance of 10 to 100 m^2/d
- along the inactive cell boundary to the west in layers 2 and 3, where the conductance of the 10.7 m AHD boundary is 1000 m^2/d.

Where the groundwater flow is parallel to the model edge, a no-flow boundary is implicit.



General Head

Drainage Cells

River Cells

Project Area

N

0 2.5 5 10

Kilometres

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Figure 3.18 Model boundary conditions (layer 1)

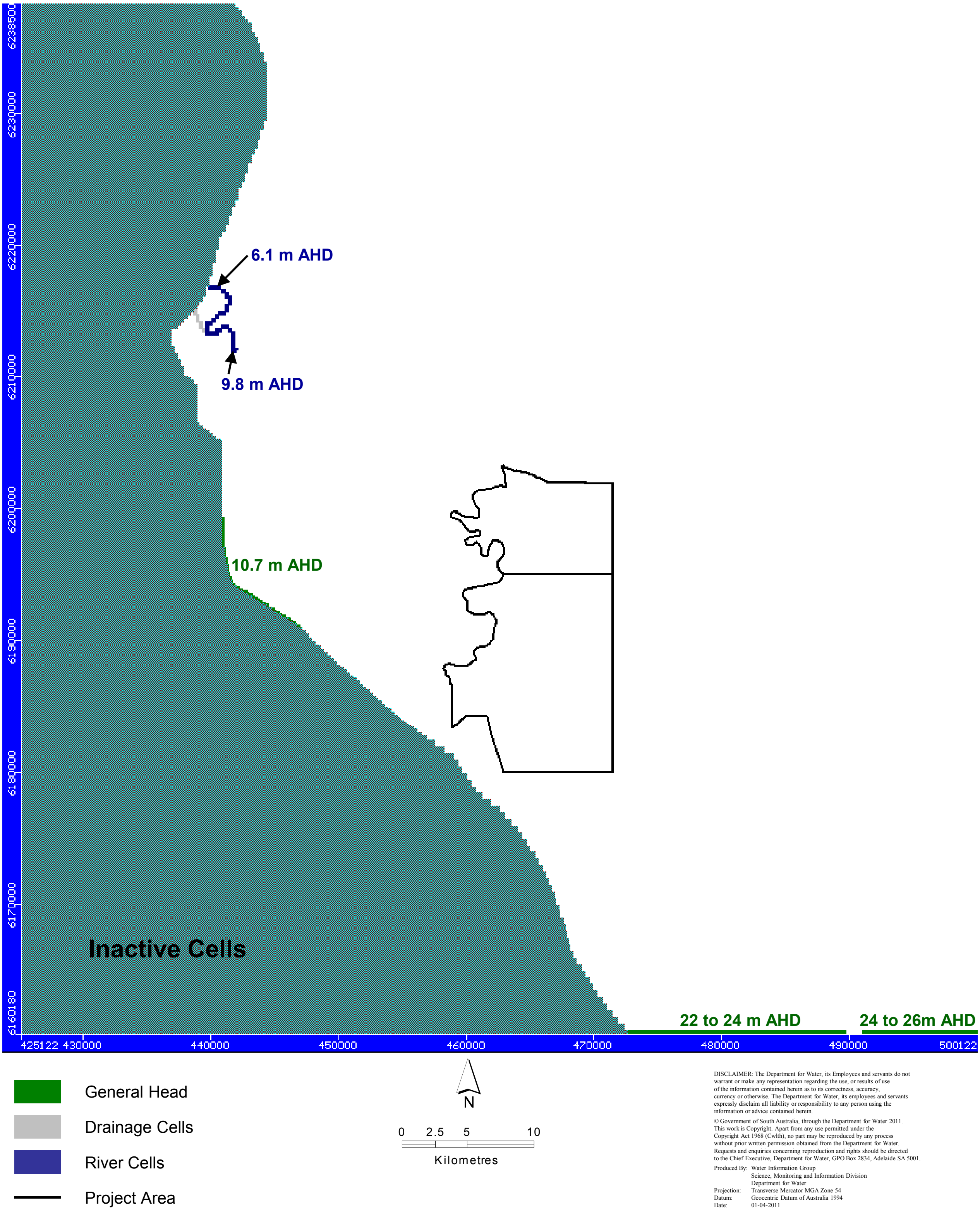

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Figure 3.19 Model boundary conditions (layer 2)

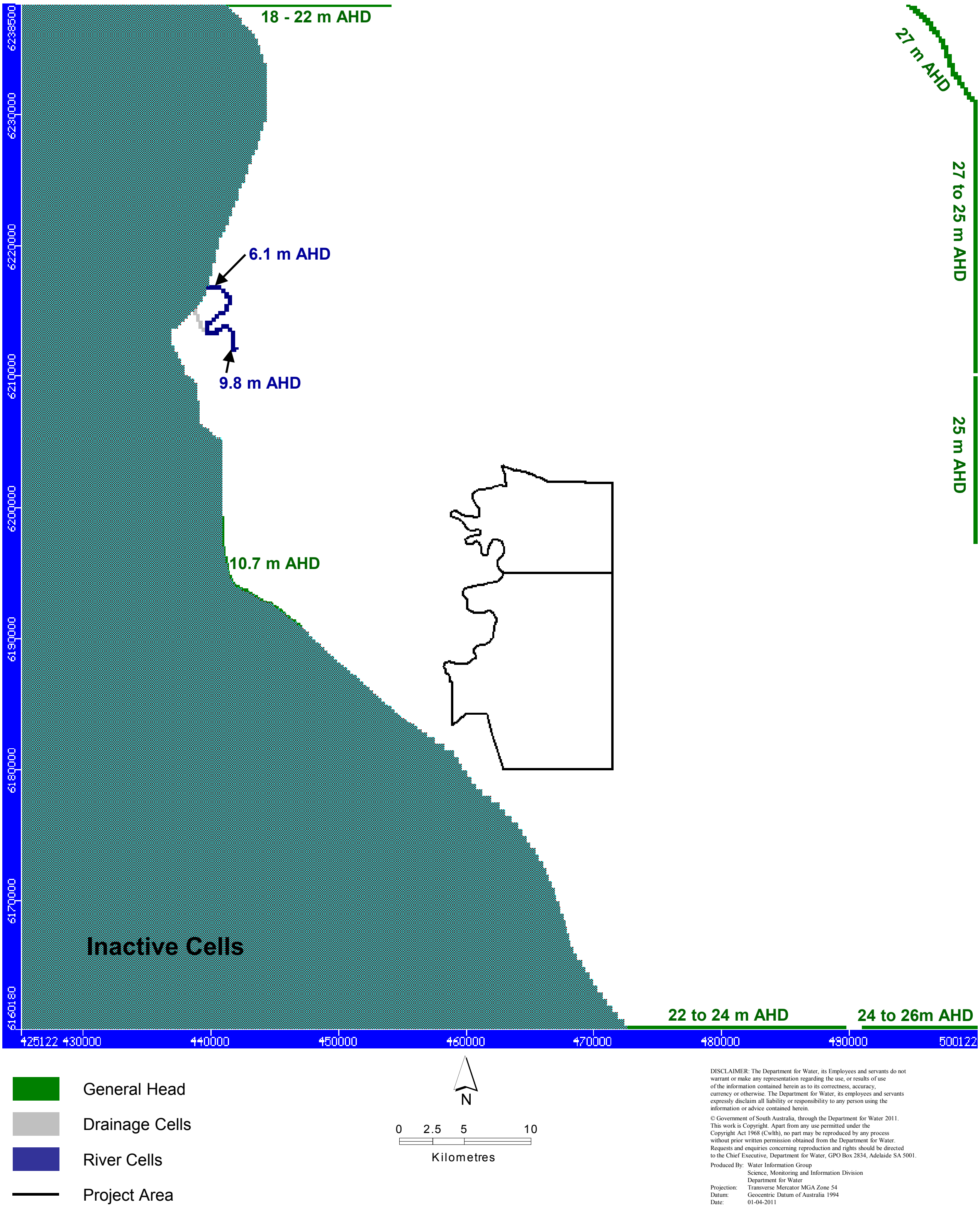

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Figure 3.20 Model boundary conditions (layer 3)

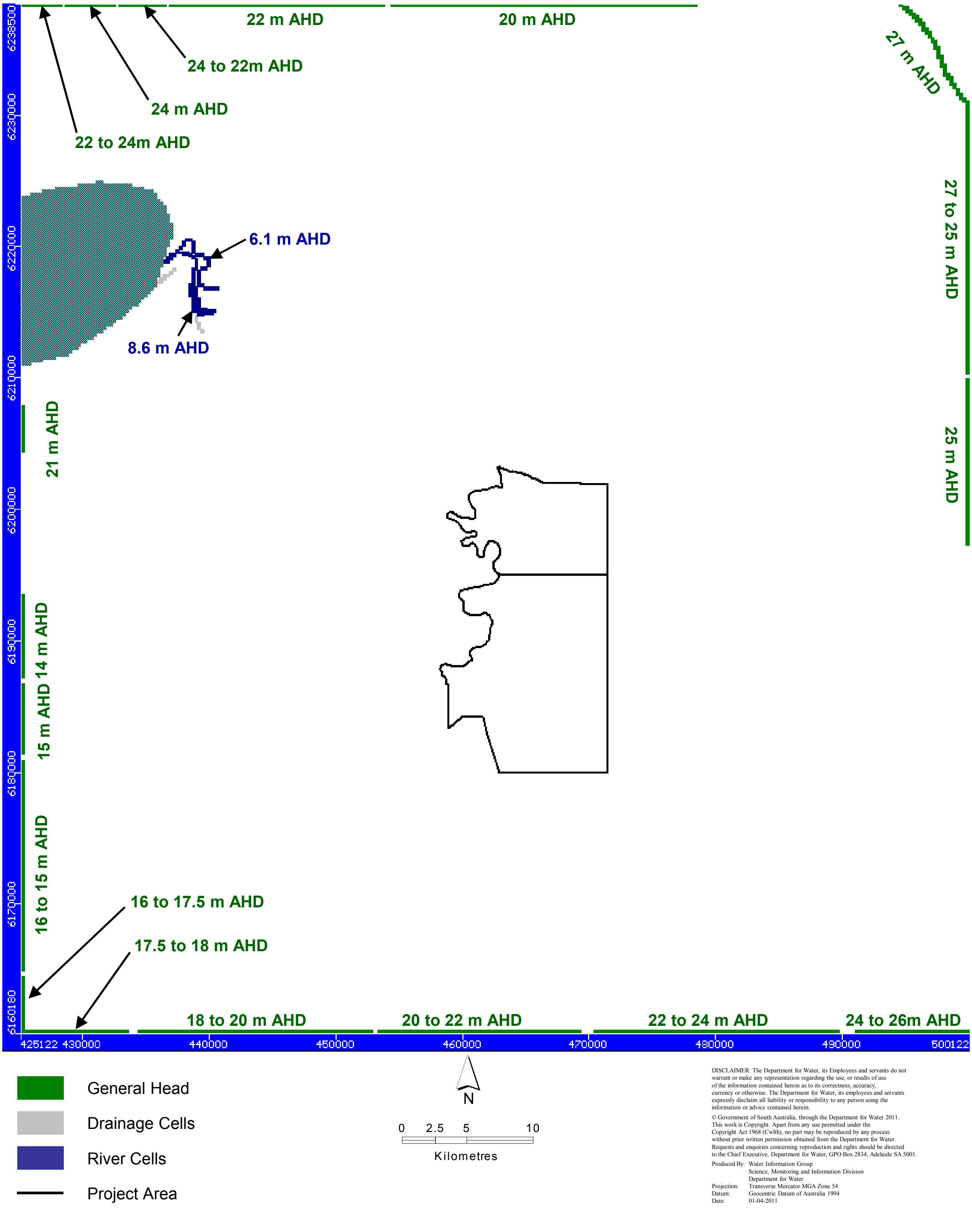

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Figure 3.21 Model boundary conditions (layer 4)

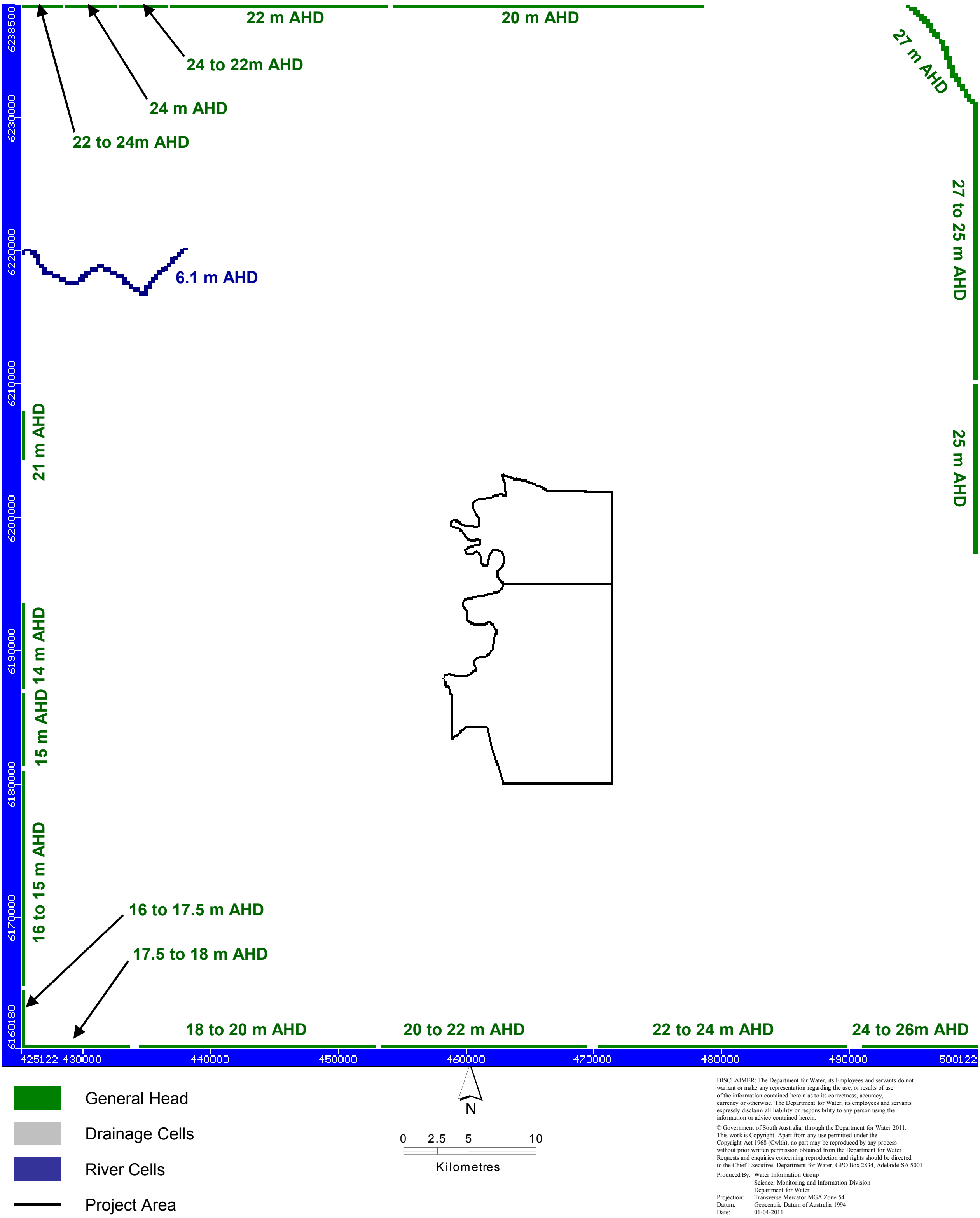

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Figure 3.22 Model boundary conditions (layer 5)

3.6.2. SURFACE WATER

The River Murray, including its anabranches, is simulated using MODFLOW river cells. In previous model versions, it was simulated using constant head cells. In terms of the conceptual model, river cells allow for flow in floodplain sediments under the River Murray (throughflow) and the groundwater head in the Monoman Formation may differ from the river stage in the same cell. This should provide a better approximation of the interaction between the River Murray and groundwater.

In the Loxton–Bookpurnong area, the River Murray occurs mainly in layer 1 and the riverbed elevation is based on bathymetry data, with a depth of 2 to 3 m. The river stage is held constant at pool level. This is a simplification of the real system dynamics which is consistent with the purpose of the Salinity Registers.

Note: The Salinity Registers compare the relative impacts of anthropogenic accountable actions, not including climate change. Other processes, such as changes in river level due to flood or drought, may alter River Murray salinity, but these are not simulated for the Salinity Register. If those processes were included in the model, numerous simulations would be required to distinguish the contribution to river salinity from those of accountable actions. Following instruction from MDBA, constant pool level at normal condition was adopted *in the calculation especially for Salinity Register purpose.*

The river stages for the River Murray are as follows:

- 19.25 m AHD upstream of Lock 6
- 16.3 m AHD between Lock 6 and Lock 5
- 13.2 m AHD between Lock 5 and Lock 4
- 9.8 m AHD between Lock 4 and Lock 3
- 6.1 m AHD below Lock 3.

Conductance for MODFLOW river cell was obtained during calibration. The main river channel has a conductance of 1500 m^2/d.

Katarapko Island Disposal Basin is also simulated using MODFLOW river cells, with a stage level of 10 m AHD, conductance of 1000 m^2/d and a riverbed elevation of 9.5 m AHD. It lies in layer 1.

The Noora Disposal Basin is represented by model drain cells in layer 1 with a drain elevation of 18 m AHD and a conductance of 1000 m^2/d. This presumes that, on a regional scale and under normal conditions, Noora predominantly acts as a groundwater discharge feature. The watertable at Noora is generally within two metres of the ground surface, discharging groundwater via evapotranspiration. Only a relatively small area has constantly held disposed water for the last 40 years. The current water level in the ponding area is the same as the watertable level, indicating that evapotranspiration acts strongly to control the water balance and that recharge is negligible.

3.6.3. CLIFF SEEPAGE

MODFLOW's drain cells are used to simulate groundwater seepage from the highland Loxton Sands to the floodplain in the Loxton–Bookpurnong area. The drain elevation is at 11 m AHD in Loxton and 12 m AHD in Bookpurnong, which is the average ground surface elevation of the floodplains. The conductance of MODFLOW drain cell is 10 m^2/d, as determined during calibration. These cells are represented in layer 1.

3.6.4. DRAINAGE SCHEMES AND BORES

MODFLOW drainage cells are used in the Loxton region throughout the area where the CDS controls the groundwater table if it rises to the elevation of the CDS. The drain elevation is 28 m AHD and the conductance is 100 m^2/d.

Actual drainage bores are represented in two different ways within the model. In the Bookpurnong area, drainage bores extend to the Loxton Sands and drainage water is simply included in recharge rates in small localised zones; little or no lag time is applied (rates and zones are discussed further in Section 1.6). In the Loxton irrigation area, drainage bores extend to the Pata Formation: recharge is increased to the Loxton Sands and a zone of higher vertical hydraulic conductivity is included in the layer 2 aquitard to facilitate the movement of drainage water to the Pata aquifer.

3.6.5. SALT INTERCEPTION SCHEMES SIMULATION IN THE CALIBRATED MODEL

MODFLOW's Well Package is used to simulate conventional production bores for both the Loxton and Bookpurnong SIS in the transient calibrated model (Figs 2.12 and 2.13). The pumping rates adopted in the model are the annual medians of the recorded pumping rates (App. A-4 and A-5). The SIS pumping bores at Rilli's Highland have only operated since late 2010, at the very end of the period simulated for the transient calibration and therefore are not included in the calibrated historical model.

The Cliff Toe Drain and the Horizontal Drainage Well in the Loxton area are simulated using MODFLOW's Drain Package. The Drain Package models the Cliff Toe Drain and the Horizontal Drainage Well efficiently but does not capture some features of operation. For example, the Cliff Toe Drain is constructed below river level but only intercepts lateral flow from the direction of the groundwater mound, as it is sealed on the bottom and on the side closer to the river. The Horizontal Drainage Well is constructed just above the confining beds. These conceptual limitations mean that it is difficult to include these features exactly as physically constructed. Instead, the Cliff Toe Drain and Horizontal Drainage Well are simulated using elevation and conductance values obtained during calibration which achieves a satisfactory match to observed heads and intercepted flux.

Table 3.4 summarises the conditions in the calibrated historical model to simulate SIS in the project area.

3.6.6. EVAPOTRANSPIRATION

ET is simulated using the ground surface as the ET surface. An ET rate of 250 mm/y and extinction depth of 1.5 m are used in the project area, based on Holland et al. (2001). The ET parameters were confirmed during calibration against actual ET rates observed in the field (Section 4). ET is most likely to occur on the floodplains and in some lowland areas where the watertable is shallow.

3.6.7. GROUNDWATER ALLOCATION AND USE

There is no allocation of groundwater or known groundwater use in the Loxton–Bookpurnong area.

Table 3.4 SIS setup in the calibrated model

SIS Section	Year of commencement	Observed pumping rates (L/s)	Modelled pumping rates (L/s)	Target Aquifer	Region
Caravan Park Floodplain	2008	0.5–2.1	0.5–2.0	Monoman Formation	Loxton
Cliff Toe Drain	2009	1.8–1.9	1.6	Loxton Sands	Loxton
Horizontal Drainage Well	2005	3.0–5.2	2.7–3.3	Loxton Sands	Loxton
Proud Avenue	2009	1.0–3.1	0.2–2.3	Loxton Sands	Loxton
Rilli’s Highland	October 2010	Not included		Loxton Sands	Loxton
Rilli's Floodplain	2007	1.0–5.0	0.9–2.8	Monoman Formation	Loxton
Thiele's Floodplain	2007	1.0–6.4	1.1–5.8	Monoman Formation	Loxton
Thiele's Homestead	July 2010	0.4–3.2	0.4–3.2	Loxton Sands	Loxton
Bookpurnong Highland	2006	0.5–3.8	0.5–2.8	Loxton Sands	Bookpurnong
Clark's Floodplain	2005	1.5–6.4	1.3–4.8	Monoman Formation	Bookpurnong

3.7. MODEL RECHARGE

Modelled recharge rates and areas simulate recharge due to rainfall, irrigation and drainage bores.

3.7.1. RECHARGE UNDER NATIVE VEGETATION

Areas covered by native vegetation are given a recharge rate of 0.1 mm/y (Allison et al. 1990). This rate is applied across the whole model domain for the steady-state simulation, which simulates the region prior to land clearance and irrigation.

In all transient simulations except Scenario 2 for Mallee Clearance, it is assumed that the recharge rate for non-irrigated areas is 0.1 mm/y. This neglects the impact of land clearance, which is presumed to have a much smaller impact on river salinity than irrigation. This simplification has been agreed to in discussion with the MDBA.

3.7.2. RECHARGE DUE TO MALLEE CLEARANCE

Scenario 2 (see Section 5) simulates the impact of mallee clearance on River Murray salt loads. The recharge zones and rates are specified by DENR and are based on studies by CSIRO (Cook, Leaney & Miles 2004) and DENR using SIMRAT and SIMPACT models. Lag time and recharge rates to the watertable aquifer are estimated using information on soil type, depth to groundwater and thickness of the Blanchetown Clay. The mallee clearance is assumed to have started in 1920. There are 42 recharge zones and rates vary from 0.1 to 11 mm/y. The details of recharge zones shown in Figure 3.23 and rates are given in Appendix A-1.

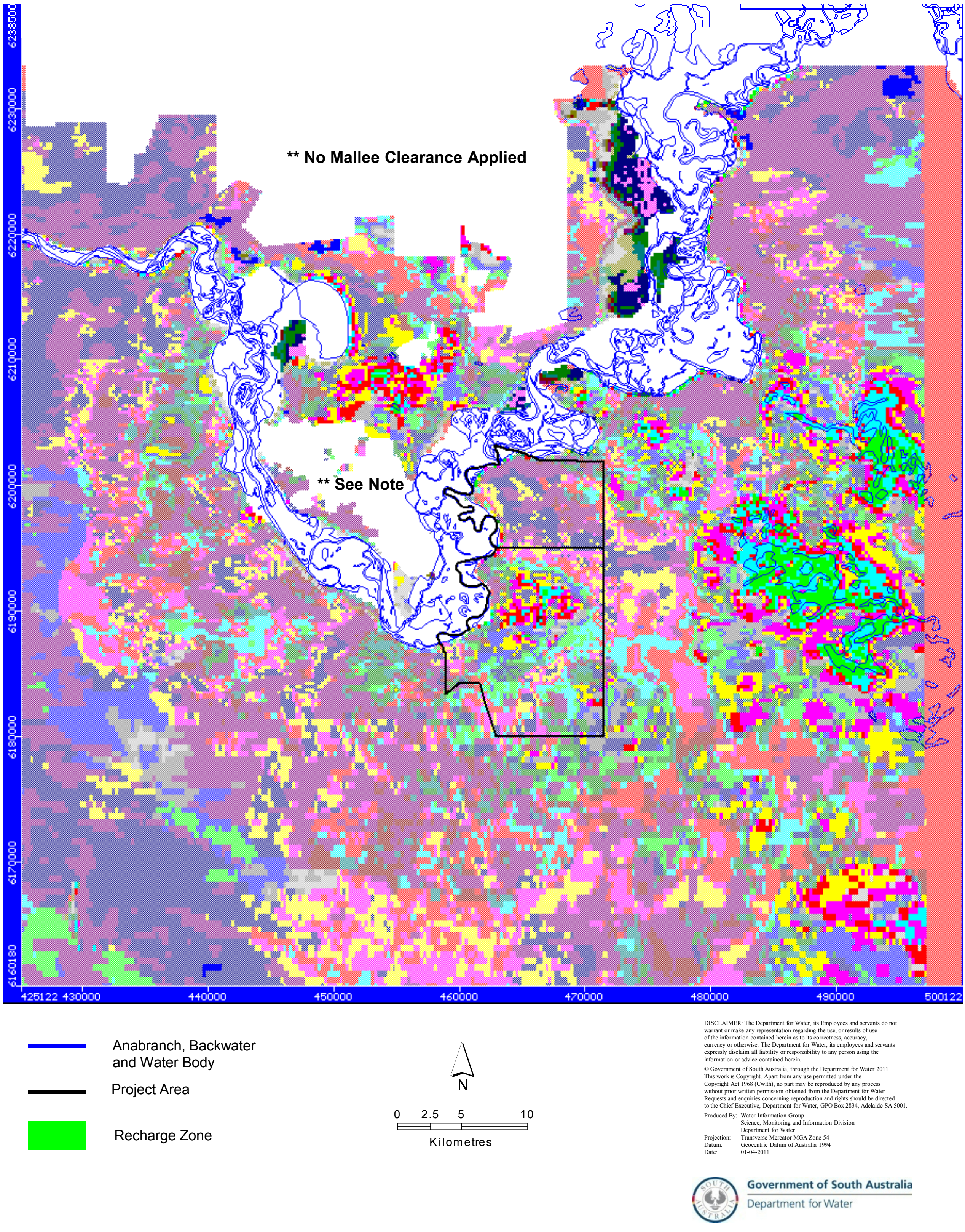


Figure 3.23 Mallee Clearance recharge zones (42 zones); Recharge rates given in Appendix A-1

3.7.3. OUTLINE OF APPROACH OF RECHARGE DUE TO IRRIGATION

It is not currently possible to accurately calculate recharge over time based on irrigation and hydrogeological information alone, owing to a lack of historical irrigation data, a lack of data of some key hydrogeological properties (some of which are not measured at all, while others are not sampled at the scale required to simulate the impact of local heterogeneity) and gaps in the scientific knowledge of unsaturated zone processes. Until these issues are addressed through research, for practical purposes recharge must be estimated by other methods. For the South Australia numerical groundwater models for the Salinity Register, the recharge is estimated from measured groundwater levels via inverse groundwater numerical modelling, as described below.

The total spatial extent of recharge for a given year is based on irrigation footprint and commencement year data from DENR. The irrigated areas are divided into zones based on irrigation commencement year, initial lag time and estimated recharge rates. During calibration, the recharge zones, initial lag time and recharge rates are adjusted within reasonable ranges until the modelled water level and trend consistently approximates the observed water level and trend.

The difficulty of this approach is non-uniqueness. That is, there may be more than one combination of input parameters that will provide a reasonable match to available data. In particular, modelled head levels depend on hydraulic conductivity and the recharge rate. As there is a degree of uncertainty about both aquifer hydraulic conductivity and the recharge rates, it is unlikely that the recharge estimates derived from inverse modelling are unique. However, a careful approach has been adopted to minimise the uncertainty and to improve the likelihood that recharge estimates are within acceptable known knowledge range of their true values.

The main aspects of the approach are:

- calibration begins with a numerical model incorporating the best available hydrogeological data and an up-to-date conceptual model, at scales appropriate for the project aims
- recharge zones are determined by recharge areas, rates and lag times that are based on the best available data and the latest scientific research, such as a variably-saturated groundwater flow model conducted by Lisdon Associates
- during calibration, the recharge rate of each zone is varied within a reasonable range appropriate for that time period’s irrigation practices. If this leads to a poor match to observed heads, the aquifer properties are also varied within reasonable ranges, provided that the hydrogeological data supports such changes.
- to confirm the validity of the model parameters, lag times, recharge estimates and salt load results are compared to available data sources, including:
    - a comparison of lag time estimates with results from a cross-sectional variable-saturation model by Lisdon Associates
    - a comparison of recharge estimates with known historical practices and an independent assessment of accession water by Laroona Environmetrics
    - a comparison of estimated salt loads with historical monitoring sites and RoR data.
- sensitivity and uncertainty analyses are performed to estimate model uncertainty.

To assist in the validation of key parameter ranges and numerical model outputs for the Loxton–Bookpurnong area, three studies were commissioned:

- a cross-sectional variable-saturation model to estimate the time taken for root zone drainage to reach the watertable under different conditions, conducted by Lisdon Associates (2010)
- an independent estimate of root zone drainage by Laroona Environmetrics (2011)
- a 3-D saturated groundwater flow model conducted by DFW (this report).

3.7.4. MODEL IRRIGATION RECHARGE SETTINGS AND ASSUMPTIONS

The process in developing modelled recharge is described below.

3.7.4.1. Recharge area

The areas of recharge in the model are assumed to be the same as the irrigation areas in the Loxton–Bookpurnong area.

The model recharge areas are based on the irrigation footprint GIS data provided by DENR. The spatial extent of irrigation development at specific milestones (1920, 1940, 1961, 1965, 1970, 1972, 1974, 1980, 1984, 1986, 1988, 1995, 1997, 1999, 2001 and 2003 to 2008 yearly data) was used to generate recharge areas over time. The location of irrigation areas and starting years as provided by DENR are indicated in Figure 2.10.

As the irrigation footprint data indicate that irrigation areas expand with time (Fig. 2.10), the GIS files were used to assign model recharge areas with different starting years. As irrigation continues to develop, more model irrigation recharge areas become active to simulate the irrigation area expanding. The year that an irrigation zone becomes active depends on the commencement year of irrigation and on the initial lag time, which is discussed later. The recharge zones and lag time used in the calibrated model for the Loxton and Bookpurnong areas are given in Figures 3.24 and 3.25.

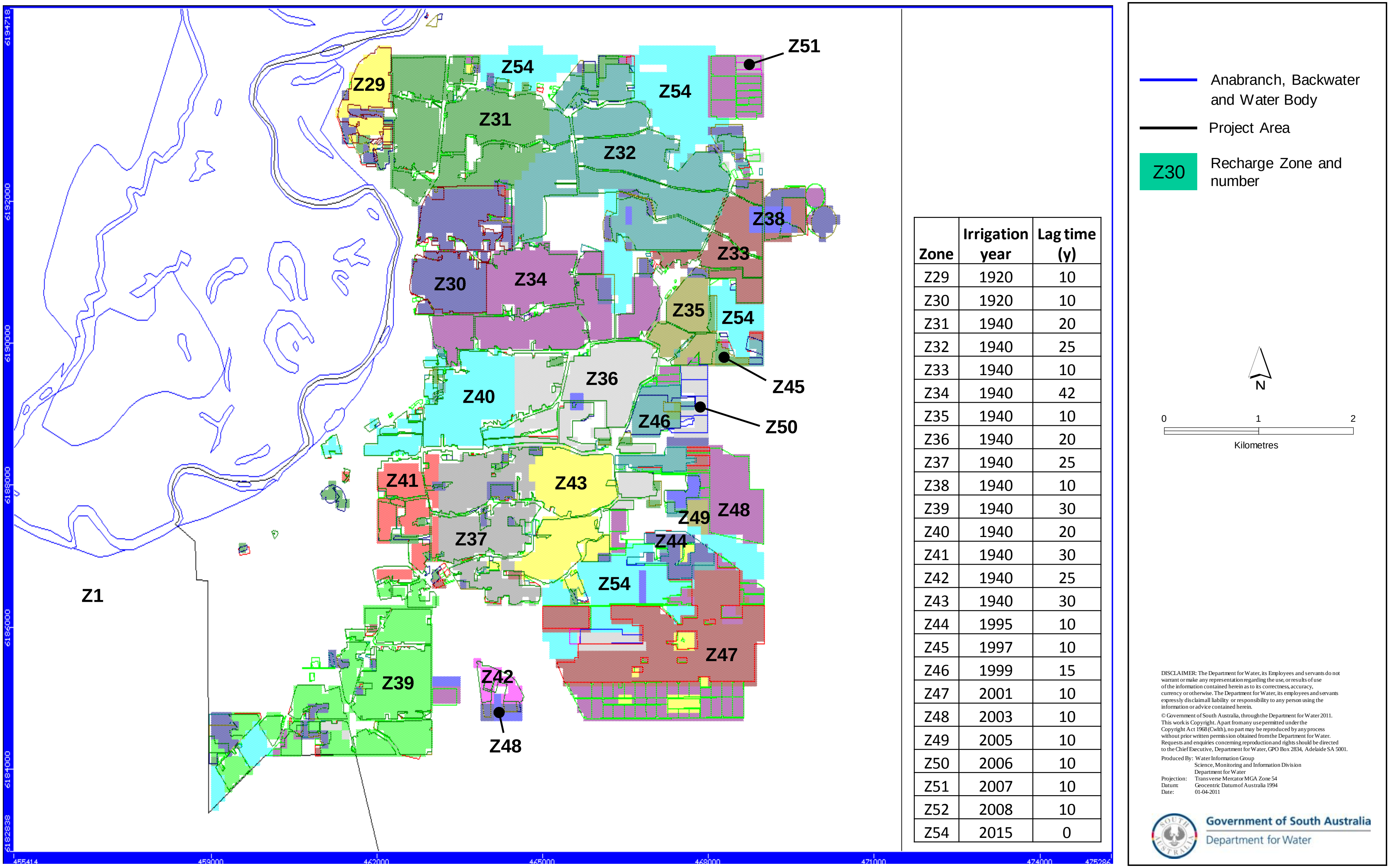
Within a recharge zone, there may be properties or paddocks that are irrigated in some years but not others. These small fluctuations in irrigation area within a zone are not simulated directly, but are represented as changes in recharge rate.

No major regional lateral movement in the unsaturated zone has been observed. Potential localised lateral movement of accession water from zone to zone is addressed indirectly by varying recharge during calibration.

3.7.4.2. Initial lag time

Initial lag time is the time taken for the irrigation water wetting front to pass from the root zone through the unsaturated zone to reach the groundwater table — this can be several decades to many decades, depending on key variables. It depends on local geological conditions in the unsaturated zone, hydrogeological conditions (e.g. depth to watertable), vegetation, soil conditions and irrigation accession rates and history.

The SIMRAT model was developed to provide quick impact assessment for future irrigation developments and estimates the initial lag time. SIMRAT makes a number of simplifying assumptions that do not apply to Loxton and Bookpurnong — for example, that the water moves vertically and not laterally and that the irrigation accession rate is 120 mm/y which is lower than estimated rates for early irrigation. The assumptions and input information in SIMRAT could lead to estimates that are significantly different to the true historical lag time.



Zone	Irrigation year	Lag time (y)
Z29	1920	10
Z30	1920	10
Z31	1940	20
Z32	1940	25
Z33	1940	10
Z34	1940	42
Z35	1940	10
Z36	1940	20
Z37	1940	25
Z38	1940	10
Z39	1940	30
Z40	1940	20
Z41	1940	30
Z42	1940	25
Z43	1940	30
Z44	1995	10
Z45	1997	10
Z46	1999	15
Z47	2001	10
Z48	2003	10
Z49	2005	10
Z50	2006	10
Z51	2007	10
Z52	2008	10
Z54	2015	0

Produced By: Water Information Group
Science, Monitoring and Information Division
Department for Water
Projection: Transverse Mercator MGA Zone 54
Datum: Geocentric Datum of Australia 1994
Date: 01-04-2011

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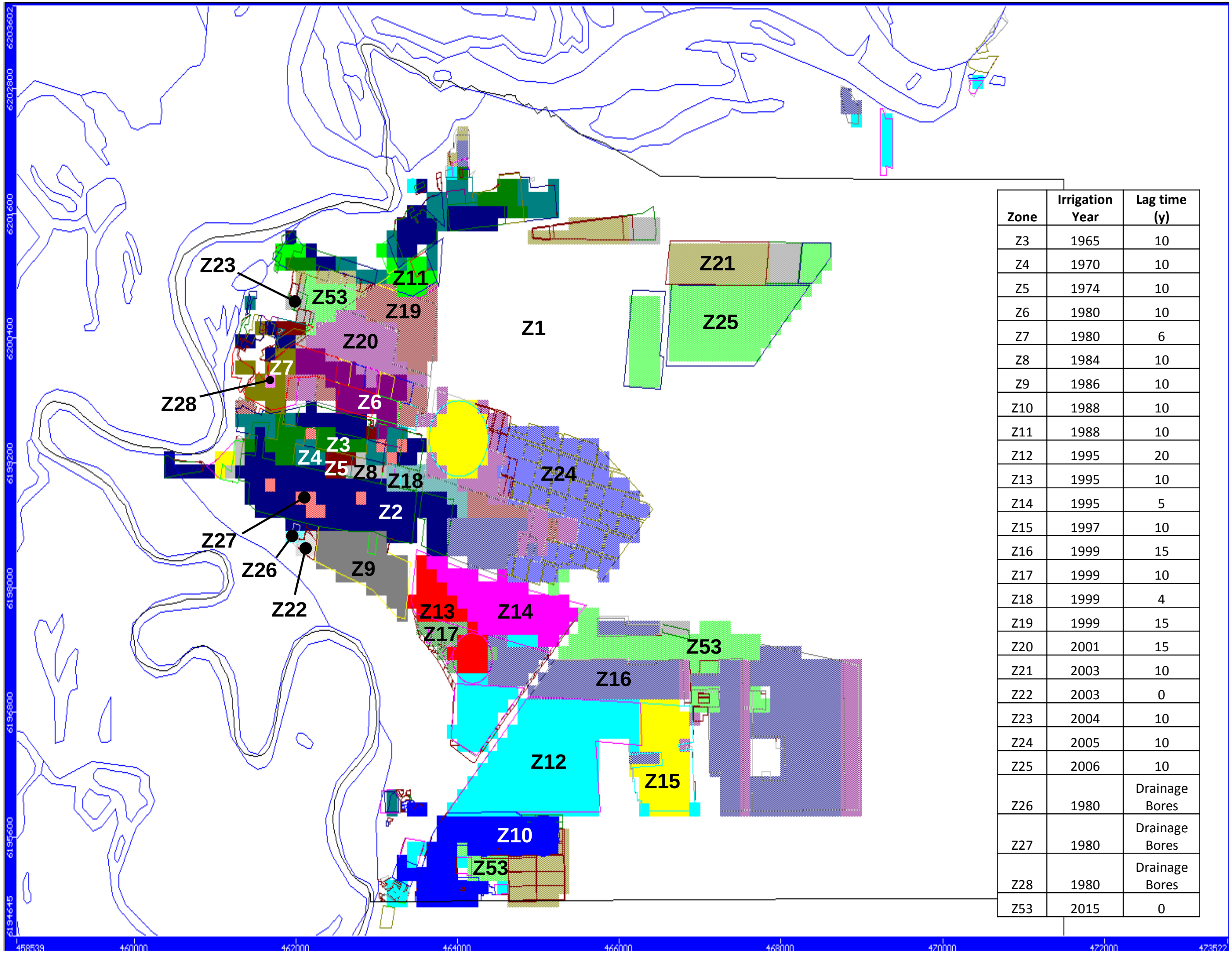
Figure 3.24 Model recharge zones in the Loxton area (recharge rates in each zone against time are listed in Appendix A-2)



Zone	Irrigation Year	Lag time (y)
Z3	1965	10
Z4	1970	10
Z5	1974	10
Z6	1980	10
Z7	1980	6
Z8	1984	10
Z9	1986	10
Z10	1988	10
Z11	1988	10
Z12	1995	20
Z13	1995	10
Z14	1995	5
Z15	1997	10
Z16	1999	15
Z17	1999	10
Z18	1999	4
Z19	1999	15
Z20	2001	15
Z21	2003	10
Z22	2003	0
Z23	2004	10
Z24	2005	10
Z25	2006	10
Z26	1980	Drainage Bores
Z27	1980	Drainage Bores
Z28	1980	Drainage Bores
Z53	2015	0

Produced By: Water Information Group
Science, Monitoring and Information Division
Department for Water
Projection: Transverse Mercator MGA Zone 54
Datum: Geocentric Datum of Australia 1994
Date: 01-04-2011

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Figure 3.25 Model recharge zones in the Bookpurnong area (recharge rates in each zone against time are listed in Appendix A-3)

The independent study by Lisdon Associates (2010) involved a variably-saturated cross-sectional model of Loxton that estimated both initial lag time and late lag time — the time taken for changes to root zone drainage volumes to alter recharge to the watertable. The simulations show that the initial lag time for accession water (220 mm/y) from a new irrigation area to reach the watertable is approximately 12 years. The initial lag times used in the final calibrated groundwater numerical model were around 10 to 15 years in the Loxton–Bookpurnong area. This is confirmed by Lisdon Associates' (2010) estimates but shorter than SIMRAT's estimations.

The Lisdon Associates (2010) lag times are shorter than SIMRAT's estimate of 20 to 30 years, but were found to be acceptable as the early (1950s) irrigation accession water could be up to 500 mm/y, implying that the actual initial lag time was in fact significantly shorter than SIMRAT's run which assumed 120 mm/y. Therefore, the initial lag time from SIMRAT was only considered as the starting point in model development and it was altered with other model input parameters to achieve the closest match to the best available evidence — observed hydrographs and other data.

3.7.4.3. Recharge zoning

The following factors were considered in defining the irrigation recharge zones:

- <u>Irrigation commencement year:</u> Model recharge areas were divided into a number of model recharge zones based on the commencement year of the irrigation. For instance, irrigation areas starting in 1920 and 1940 were simulated by two different model recharge zones.
- <u>Initial lag time:</u> Model recharge zones that may have different lag times were separated into different model recharge zones. For example, if the model recharge zone simulating the irrigation area starting in 1940 consisted of areas with three different lag time values, then that recharge zone was divided into three zones.
- <u>Recharge rate:</u> Recharge rate was the last aspect to be considered during the model recharge zoning process. If a recharge zone contained more than one observation bore, it was possible that the observation bores showed different groundwater level trends, hence the recharge rates needed to achieve calibration for those bores would be different. In this situation, the recharge zone was separated into smaller model recharge zones as each zone could only have one set of recharge rates.

3.7.4.4. Late lag time

Late lag time is the time taken for changes in root zone drainage to alter recharge to the watertable in an existing irrigation area where the irrigation water's wetting front has already reached the watertable. This will therefore apply to irrigation areas where an irrigation groundwater mound exists.

The independent study by Lisdon Associates (2010) utilised a variably-saturated cross-section model that also estimated the late lag time. The simulations show that after the wetting front has reached the watertable, the time taken for changes in irrigation practice to impact on the recharge to the watertable can be within a few months. This result is supported by observed responses in hydrographs following changes to the irrigation activities. This is an important outcome to assist in defining the recharge, particularly the appropriate recharge rates for scenario modelling to distinguish impacts from irrigation activities.

3.7.5. REFINEMENT OF RECHARGE DURING THE CALIBRATION PROCESS

For the simulation of groundwater mound development due to irrigation, the calibration was conducted based primarily on available long-term observation data (hydrographs) in highland areas where irrigation-induced groundwater mounds have developed.

The initial model run adopted the inputs as described in the previous section. The hydraulic parameters were first altered to achieve steady-state model calibration that provides the initial head for transient model calibration. The transient model calibration was then conducted, as described below, to achieve a good match between modelled outputs and available observations, particularly modelled heads and trends from hydrographs.

For a given recharge zone, or group of zones near observation bores, recharge rates and lag times were iteratively altered to better match observed head and trends. In some cases, zones were further subdivided to reflect varying rates to improve the match. The recharge rates were adjusted within predefined ranges based on knowledge of irrigation practices over time (P Cole, DWLBC, pers. comm., 2005; Adams & Meissner 2009; Vears 2010), as given in Table 3.5 below and further verified through the results of Laroona Environmetrics (2011).

Table 3.5 Modelled recharge and irrigation legacy*

Irrigation Time Period	Interpreted Irrigation Activities	Model Recharge Time Period	Model recharge rates (mm/y)	
			Loxton	Bookpurnong
1920–65	Flood irrigation (4 week schedule)	1930–65	300–400	–
Mid- to late-1960s	Flood irrigation (2 week schedule)	1965–70	250–400	–
1970s	Comprehensive Drainage System was developed in Loxton in late 1960s Convert from flood to sprinklers	1970–80	150–350	250–300
1980s to early 1990s	Convert from sprinklers to drip	1980–95	120–250	150–300
1995–2005	Adoption of Soil Moisture Monitoring to schedule irrigation events start from middle of 1990s	1995–2005	100–200	100–150
2006–09	Water restrictions from 2006 to 2010	2006–10	60–80	60–100

* Adams & Meissner 2009

If there was a poor match to observed heads in an area that could not be addressed by varying the recharge in the appropriate range, then the hydraulic conductivity zones were reconsidered. Where supported by the available hydrogeological knowledge and other potential evidence, the hydraulic conductivity of a zone was altered.

To achieve best calibration results with available information, more than 700 model runs were conducted. The result is a calibrated model that:

- is consistent with available regional-scale hydrogeological data
- has recharge rates within reasonable bounds
- matches observed hydrographs extremely well
- compares well with other datasets, as described in the next section.

It is important to note that irrigation recharge is the major factor that drives groundwater level change (trend) in the Loxton and Bookpurnong highland area. Hydraulic conductivities control the head level rather than the trend. Specific yield has little impact on the trend-matching process due to the relatively slow pace of irrigation-induced groundwater level change (month/years) in the highland area. Note that this is distinctly different to the rapid aquifer response from pumping activities such as salt interception schemes.

3.7.6. CONFIRMATION FOR IRRIGATION RECHARGE

The good match to groundwater trends indicates that the recharge rates estimated via inverse modelling (calibration) are consistent with available potentiometric head information. Model results are also compared against other datasets to confirm the recharge estimates.

To seek confirmation of recharge estimates, an independent estimate of accession water volumes was undertaken (Laroona Environmetrics 2011) and is included in Appendix C-1. The accession estimates are based on a review of irrigation and infrastructure information for both Loxton and Bookpurnong sourced from DFW and historical irrigation trust records. A water balance method was employed in the calculation.

The outputs of this work are compared in Section 4.4.3 to the total recharge applied in the calibrated model to confirm that the modelled recharge is within an appropriate range. The comparison provides confidence that the total recharge applied in the model is within the reasonable range and is consistent with accession estimates. It can be clearly seen that, once the initial lag time is considered, there is close alignment in the increase in calculated and modelled accession volumes. The early gap may indicate the initial losses through wetting front and lateral movement. After the wetting front reaches the watertable, the trends become similar for both the accession water and the total recharge. As expected, the total recharge volume is lower than the accession water. It is noted that accession water is not the same as the total recharge as in reality they may differ by volume, rate over time and footprint due to some of the accession water remaining in the pore spaces of the unsaturated zone and within perched aquifers; the remainder becomes watertable recharge. Additionally, the accession water rates differ from the recharge due to losses in the unsaturated zone due to lateral movement, especially when there is an intervening clay layer and there is an initial wetting front loss as the accession water percolates towards the watertable.

In Section 4.4, model outputs are also carefully checked against other key data, including:

- observation bore hydrographs
- RoR salt loads
- NanoTEM patterns of gaining and losing streams.

The confirmations provide confidence that the recharge rates applied in the model are a reasonable estimate of the true recharge rates and reproduce the observed impacts in the groundwater and the River Murray.

3.7.7. RECHARGE IN THE LOXTON–BOOKPURNONG AREA

3.7.7.1. Modelled recharge in the Loxton area

First irrigation commenced in 1920 with small areas near the river valley. Major irrigation commenced in the 1940s in the Loxton area. The calibrated recharge rates, given in Appendix A-2, indicate that recharge from irrigation first reached the watertable from 1950 to 1970, an initial lag time of 10 to 30 years between the onset of irrigation and modelled recharge, depending on location. The lower end of the range in initial lag time is due to the installation of numerous drainage wells during the 1950s. These wells directed irrigation drainage water to deeper aquifers (Loxton Sands and Pata Formation; DWLBC 2003). If these wells had not been constructed, recharge may not have reached the watertable for at least 20 years after the onset of irrigation.

The modelled recharge rates in the 1950s and 1960s are high (between 250 to 400 mm/y, as given in Appendix A-2), which is consistent with flood irrigation practices and the use of drainage wells delivering water directly to the Loxton Sands. The high total recharge is clearly indicated in Appendix A-2 and confirmed by Laroona Environmetrics's (2011) report in Appendix C-1.

Calibrated recharge rates decline from the 1970s. This is consistent with the findings of the Laroona Environmetrics (2011) report which identifies that irrigation practices and infrastructure became more efficient over time. The reductions in recharge are most likely due to the transfer of a portion of the accession water to the Katarapko Island Disposal Basin via the CDS. Further reductions in recharge occurred from the late 1990s due to the introduction of improved irrigation practices (i.e. soil moisture systems). In 2002, recharge was again reduced due to the impact of the Loxton headworks rehabilitation (i.e. upgraded distribution infrastructure). Recharge rates were further reduced in most areas to less than 100 mm/y, which may be due to severe drought and water restrictions. The reductions in total recharge are clearly indicated in Appendix A-2.

3.7.7.2. Modelled recharge in the Bookpurnong area

Irrigation commenced around 1960 in the Bookpurnong area. Appendix A-3 indicates that modelled recharge to the watertable begins in around 1970. The 10-year initial lag time between the onset of irrigation and modelled recharge is due to the installation of drainage wells during the 1960s, without which the lag time would be approximately 20 years in this area.

Drainage bores are simulated using recharge zones in the Bookpurnong area. These zones have relatively high initial recharge (injection) rates, which can either rise further or fall with time based on the nearby observed groundwater levels. The commencement year of the drainage bores was confirmed from SA-Geodata and the injection rates are around 0.5 to 2 L/s, confirmed by AWE (2011a).

Total recharge volumes increased steadily during the 1980s and 1990s in response to the expansion of irrigated area. Reductions in recharge rate occur from the late 1990s in all recharge zones, due to improved irrigation practices. Recharge rates were further reduced in some areas after 2005 to the range of less than 100 mm/y which may be due to severe drought and water restrictions.

Changes in total recharge are clearly indicated in Appendix A-3.

3.8. MODEL SALINITY ZONES

The River Murray is divided into a number of zones based on project area, groundwater salinity values, river kilometres and river conditions (e.g. losing/gaining stream conditions, cliff face and floodplain). The salinity value for each zone was selected for calculation of salt load based on the best judgement (see Section 2.3.5). Location, zone number and salinity values are shown in Figures 3.26 and 3.27.

3.9. MODEL SIMPLIFICATIONS

All numerical models are simplified representations of reality. The main simplifications adopted in this model are given below.

Simulated processes:

- The model does not estimate future impacts due to climate sequence, such as changes in river level, as these are not required for the Salinity Register. One consequence is that the modelled floodplain heads will not mimic fluctuations in observed head due to changes in river level.
- The model simulates irrigation recharge and salt interception schemes only for the Loxton–Bookpurnong area. Land use change and SIS construction in other irrigation districts are not simulated, as it is assumed that this will have negligible impact when compared to local factors, due to the hydrogeological separation from the project area by hydraulic boundaries such as the River Valley, large floodplain, creek systems and groundwater dividing lines.
- Perched aquifers and the unsaturated zone are not simulated directly; the impact on recharge rates is instead estimated during the calibration process
- The salt load is calculated by multiplying the groundwater flux by the appropriate salinity values for each reach. This conservative assumption ensures that the salt load is not underestimated but neglects salinity changes due to mixing of groundwater with river water and irrigation returns, which could in future years become an important factor in determining the salt flux to the river. This simplification is based on limited current knowledge of groundwater salinity changes due to irrigation, flood and SIS. The model can be used to conduct solute transport modelling to estimate the groundwater salinity changes when observation data and improved knowledge about the groundwater salinity changes in the aquifers are obtained.

Model layers:

- Due to the limited data available, the model layer elevations are necessarily approximate and will not reflect the full heterogeneity of the system (this limitation is true of all numerical models)
- The Monoman aquifer is modelled as if it was unconfined, rather than semi-confined, as the Coonambidgal Formation is not modelled and the ground surface is used as the top of layer 1
- The Finniss Formation and Winnambool Formation aquitards are modelled implicitly via aquifer leakage

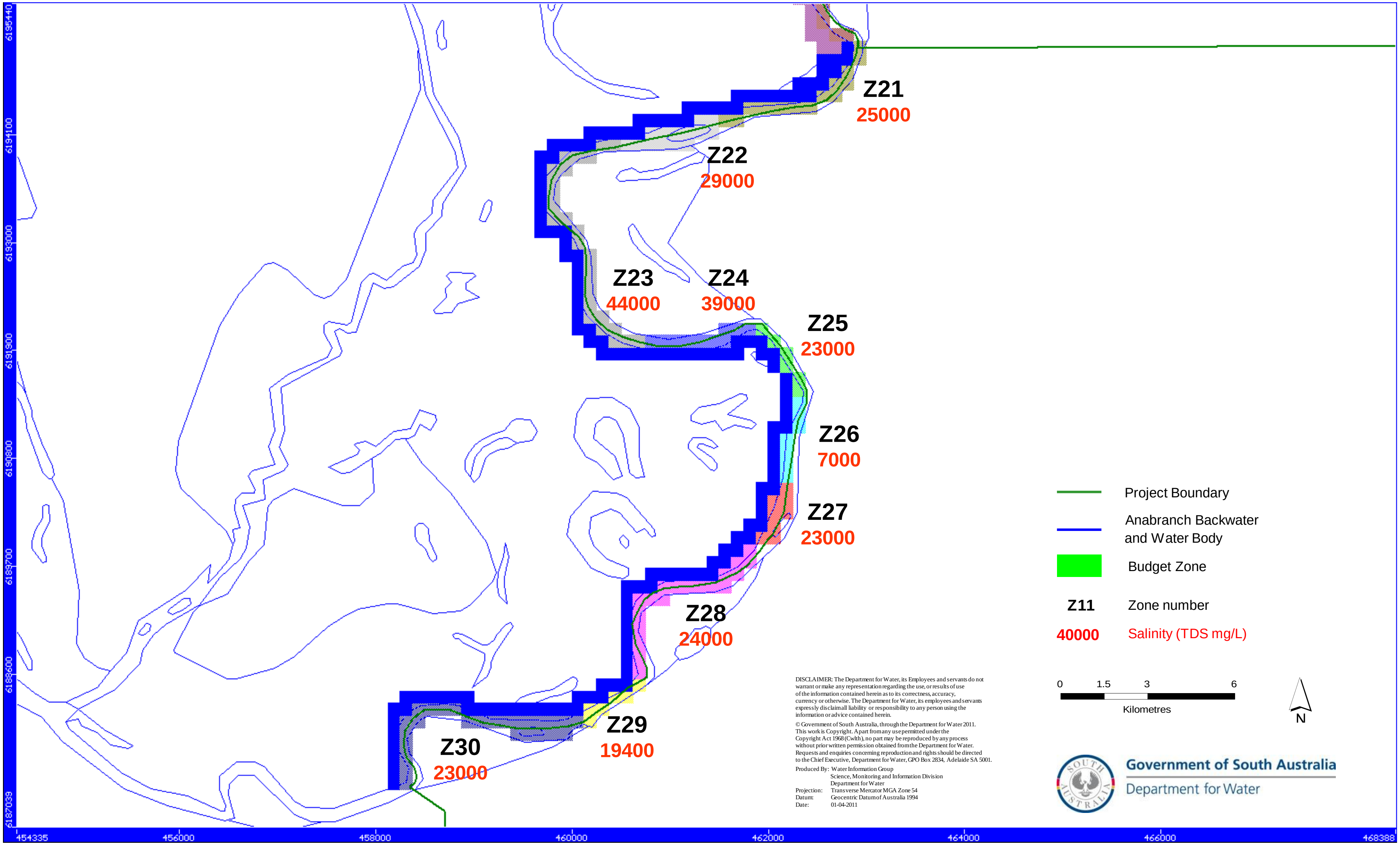


Figure 3.26 Flow budget zones (model layer 1) and groundwater salinity values (TDS mg/L) in the Loxton area

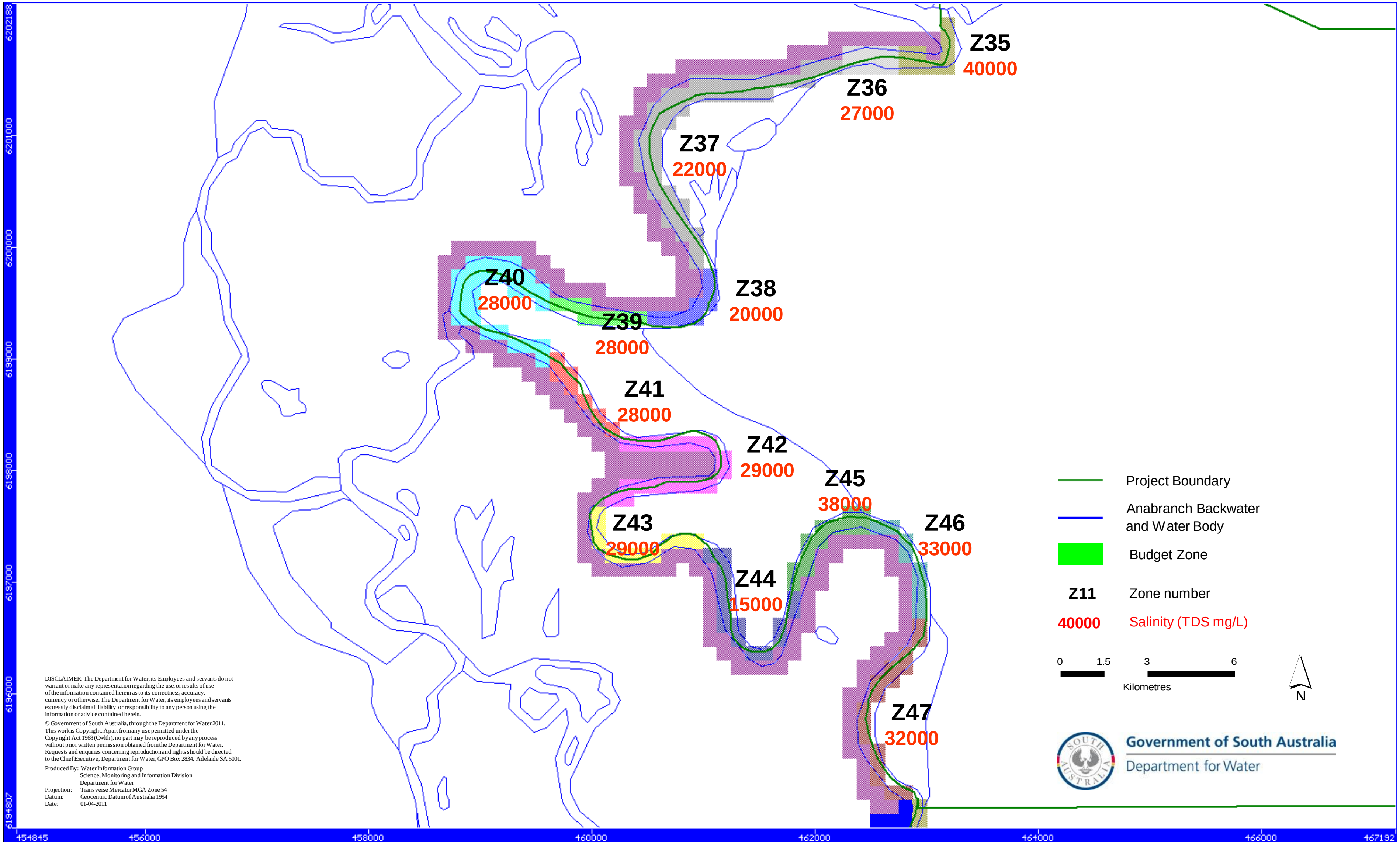


Figure 3.27 Flow budget zones (model layer 1) and groundwater salinity values (TDS mg/L) in the Bookpurnong area

- The Renmark Group aquifer is not simulated as it is anticipated that the impact to the River Murray is minimal and changes in the interaction between the Renmark Group and the upper aquifers occur over longer timescales than those simulated in the current study.

Stress periods:

- Each stress period is one year long and consequently seasonal changes and short-term changes in SIS pump rates are not included.

Model parameters:

- The fine detail of hydrogeological units is not included, for example the textural information available for the Loxton Sands, as this level of detail is not required for the Salinity Register
- The hydraulic conductivities of the Monoman Formation and Loxton Sands are generally lower than the median observed value but are within the observed range
- The Pata Formation is given a small zone of comparatively high vertical hydraulic conductivity (1 m/d) under the Loxton irrigation mound to simulate the ready movement of groundwater via drainage bores. An alternative is to estimate the drainage volume and simulate it as open-bottom injection wells.
- The heterogeneity within each hydrogeological unit is not fully known due to data limitations, but is estimated during calibration
- Groundwater salinities are assumed to remain constant when predicting future salt loads entering the river. However, groundwater salinity will most likely change in the future in response to accessions from brackish irrigation drainage.

Boundary conditions:

- Riverbed conductivity has not been estimated in the field, so the conductance of the river boundary was estimated during calibration
- The model assumes a constant ET rate and extinction depth. This may suit average conditions, but may be neglecting local variations in vegetation, soil type and groundwater salinity.
- In all transient simulations except Scenario 2, it is assumed that the recharge rate for non-irrigated areas is 0.1 mm/y. This neglects the impact of land clearance, which is presumed to have a much smaller impact on river salinity than irrigation.
- The model assumes that the recharge footprint is the same as the irrigation footprint. This is a reasonable assumption where there are no aquitards in the unsaturated zone, or where irrigation drainage bores extend through such aquitards. There may be places within the Loxton–Bookpurnong area where this assumption is not valid, but there is not enough data on the perched aquifers to locate the local structures.
- Recharge due to irrigation is complex to define because there is a considerable amount of uncertainty relating to the commencement time of irrigation flux to the surface and the time for the flux to reach the watertable (lag time). It is accepted that the values reported by DFW, AWE and DENR involve professional judgement in the derivation.

4. MODEL CALIBRATION

4.1. CALIBRATION APPROACH

Steady-state models are used to model equilibrium hydrologic conditions and/or conditions when changes in storage are insignificant. Transient models are used to model time-dependent stresses and/or conditions when water is released from or taken into storage.

Model calibration to historical data ('history matching') is done to improve confidence in predictive modelling. It demonstrates whether the model can replicate the behaviour of the aquifer system over a set of recorded historical conditions. Sensitivity analyses should also be undertaken to determine the relative importance of model parameters in achieving calibration. An uncertainty analysis should be performed to gauge the robustness of the calibrated model results (Section 6).

4.2. STEADY-STATE MODEL CALIBRATION

Steady-state calibration is undertaken to develop a broad-scale hydraulic conductivity distribution and basic boundary conditions. Dynamic stresses and storage effects are excluded from steady-state calibration by definition. Here the steady-state model simulates conditions after river regulation (i.e. after the locks were constructed) but before irrigation.

Hydraulic conductivities and model boundary conditions are varied within reasonable limits. Due to the absence of pre-irrigation head data, the results from the steady-state model are compared with the potentiometric surface developed in previous investigations which is believed to be the best available estimate of pre-development equilibrium hydraulic conditions in the project area.

There is a good match between the estimated and modelled potentiometric surfaces for the Loxton Sands and Monoman Formation aquifers in most areas (Fig. 4.1), but there are discrepancies in some other areas. It is not possible to determine whether the discrepancies are due to model limitations or to uncertainties in the estimation of the historic (pre-river regulation) surface.

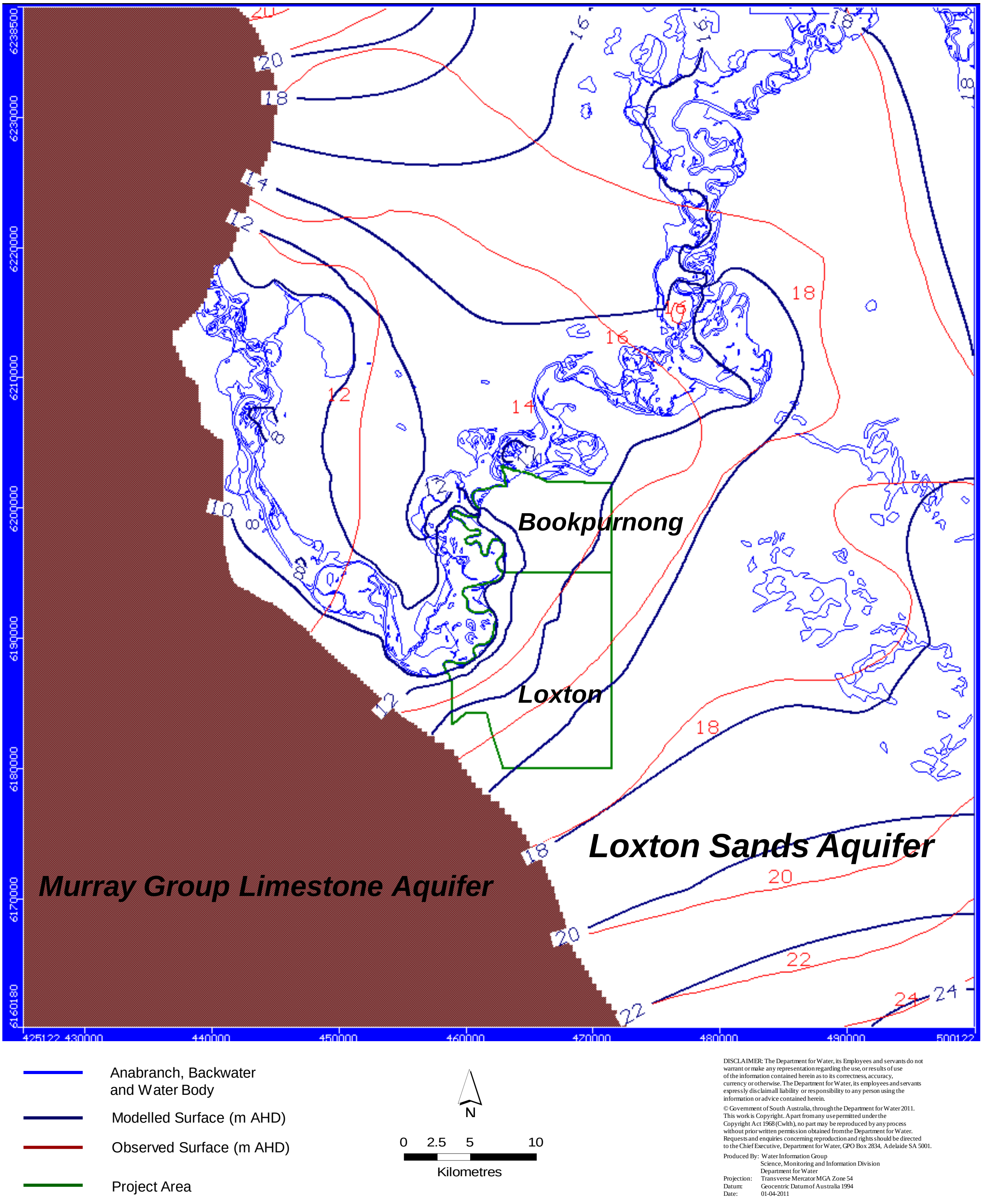
The steady-state model is incorporated into the transient model by simulating the first stress period of the transient model as steady state, which is standard practice for MODFLOW-2000. This approach has the advantage that any changes made to the transient model will be automatically applied to the steady-state model.

4.3. TRANSIENT MODEL CALIBRATION

Transient calibration is undertaken on an iterative basis by adjusting hydraulic parameters, recharge rates and boundary conditions until a satisfactory match with observed data is obtained. The output from a steady-state model with matching parameters and boundary conditions provides the initial conditions for transient model runs. The historical period from 1920 to 2010 was simulated.

Model calibration was achieved by the following actions, in accordance with the *Groundwater Flow Modelling Guideline* (MDBC 2001):

- qualitative comparison between modelled and observed potentiometric heads, both contours and hydrographs
- quantitative assessments of the iteration residual error (scaled RMS)
- quantitative confirmation that the water balance criteria is <1% for all times



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Department for Water
Projection: Transverse Mercator MGA Zone 54
Datum: Geocentric Datum of Australia 1994
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Figure 4.1 Comparison of interpreted and modelled potentiometric surface for model layer 1, steady-state condition (Yan et al. 2005)

- confirmation, as a water balance cross-check, by comparing model outcomes with:
    - total RoR salt load entering the River Murray
    - in-river NanoTEM
    - estimated recharge volumes
    - estimated floodplain ET values from CSIRO field studies.

In the Loxton–Bookpurnong project area, the majority of salt loads entering the River Murray are from lateral groundwater flux through the Loxton Sands and Monoman Formation as a result of irrigation water mounding. Matching observed water level trends in the Loxton Sands was therefore considered imperative during calibration. The head level in the Murray Group Limestone has also been considered in the calibration, due to the potential for upward leakage from the underlying aquifers driven by these heads and connection beneath the River Valley.

Section 3.7.5 provides further information on the calibration process, particularly in regard to recharge estimation.

4.3.1. CALIBRATION RESULTS — POTENTIOMETRIC HEAD CONTOURS

Modelled regional potentiometric head contours were compared with contours estimated from recorded head at observation bores. The most recent available estimated head contours, which are for 2010 (AWE 2011b), were used for the comparison. Both the head elevations and the flow directions should be evaluated.

4.3.1.1. Layer 1: Loxton Sands and Monoman Formation

Figure 4.2 shows modelled and estimated contours for the Loxton Sands and Monoman Formation aquifers in the Loxton–Bookpurnong area. The modelled surface closely matches the shape and form of the estimated surface of the Loxton groundwater mound, except for the 18 m AHD contour to the north-east.

In the Bookpurnong area, there are some discrepancies between the modelled and estimated surfaces in the highland area. Note, however, that the modelled surface is reasonably consistent with the observed heads.

Where data exist in the other areas, the modelled surface matches reasonably well.

4.3.1.2. Murray Group Limestone

Layer 3: Pata Formation

Due to the scarcity of observation points in the Pata Formation within the project area, the computed potentiometric surface is compared to the observed heads (Fig. 4.3) rather than estimated contours.

The observed values and modelled surfaces match well in the highland area in Loxton. However, the model appears to overestimate hydraulic heads in the floodplain area, perhaps because the vertical hydraulic conductivity of the layer 2 aquitard is too low.

Only a minimal comparison is possible for the Bookpurnong area as there is only one observation point, where the modelled head is a metre below the observed head.

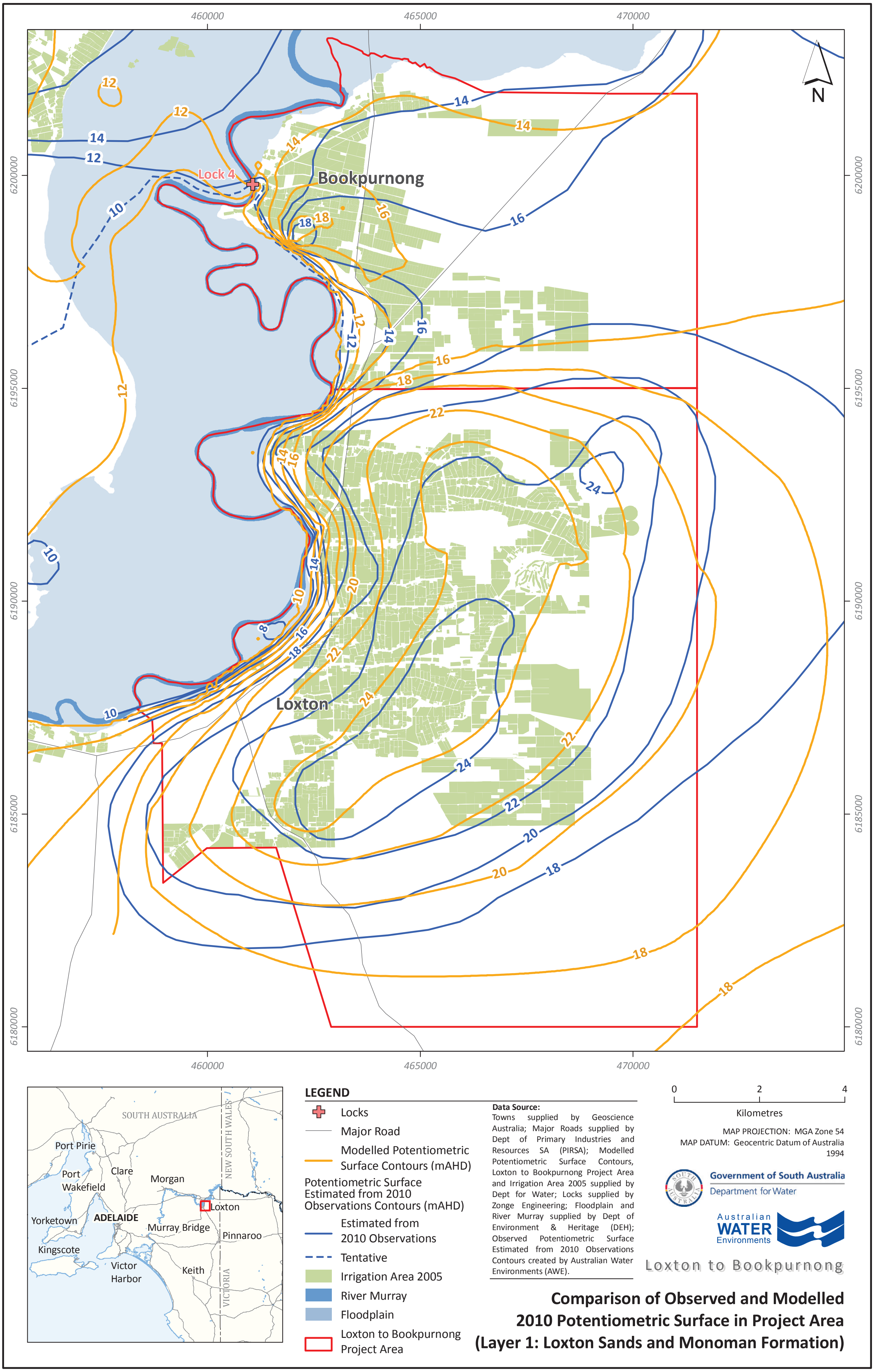

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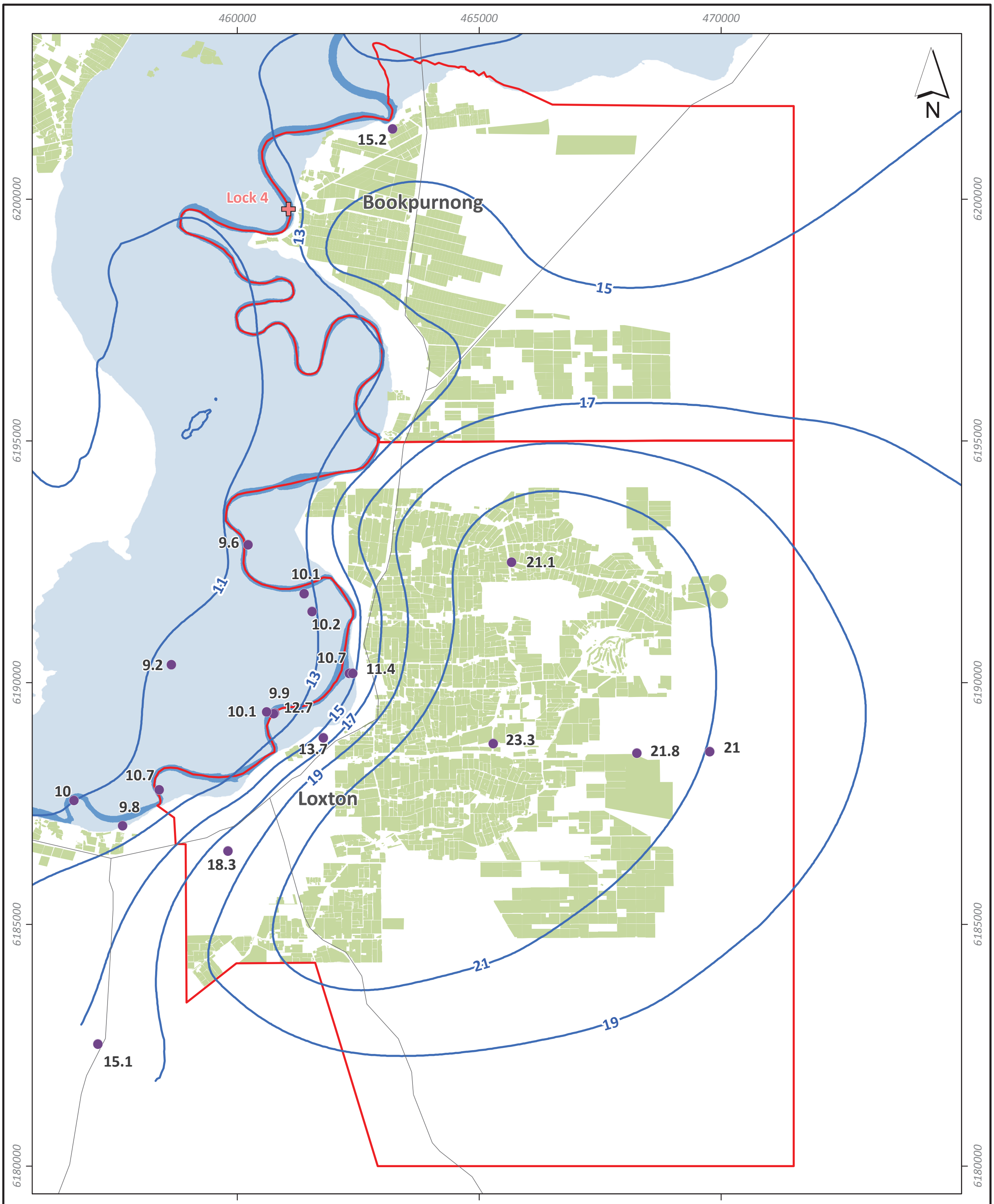
Figure 4.2



LEGEND

- Locks
- Pata Formation RSWL (mAHD)
- Major Road
- Modelled Potentiometric Surface Contours (mAHD)
- Irrigation Area 2005
- River Murray
- Floodplain
- Loxton to Bookpurnong Project Area

Data Source:
Towns supplied by Geoscience Australia; Major Roads supplied by Dept of Primary Industries and Resources SA (PIRSA); Modelled 2010 Potentiometric Surface Contours Mannum Formation, Loxton to Bookpurnong Project Area and Irrigation Area 2005 supplied by Dept for Water; Locks supplied by Zonge Engineering; Floodplain and River Murray supplied by Dept of Environment & Heritage (DEH); Mannum Formation Potentiometric Contours created by Australian Water Environments (AWE).

0 2 4
Kilometres

MAP PROJECTION: MGA Zone 54
MAP DATUM: Geocentric Datum of Australia 1994

Government of South Australia
Department for Water

Australian WATER Environments

Loxton to Bookpurnong

Comparison of Observed and Modelled 2010 Potentiometric Surface in Project Area (Layer 3: Pata Formation)

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Figure 4.3

Layers 4 and 5: Glenforslan Formation and Mannum Formation

Little observation data are available for the Glenforslan Formation and Mannum Formation aquifers in the study area. For this reason, head contours for the aquifers are compared with regional estimated head contours from a published hydrogeological map (Barnett 1991). The estimated head contours are for the combined units of the Murray Group, including the Pata, Glenforslan and Mannum Formations.

The estimated head contours of the Murray Group match well with modelled Pata contours west of Loxton and with modelled Mannum contours in the east. Figure 4.4 compares the modelled Mannum and observed Murray Group potentiometric contours. Where there are differences, the potentiometric head is likely to be measured in the different sub-units in the Murray Group.

4.3.2. CALIBRATION RESULTS — HYDROGRAPHS

As mentioned in Section 3.7.5, irrigation recharge is the major factor that drives groundwater level change (trends) in the Loxton and Bookpurnong highland areas. Hydraulic conductivities control the head level rather than the trend. Specific yield has little impact on the trend-matching process due to the relatively slow pace of irrigation-induced groundwater level change (month/years) in the highland area. Note that this is distinctly different to the rapid changes in head in response to pumping activities such as salt interception schemes.

There are many observation bores in the Loxton–Bookpurnong study area, so a subset was chosen. The selected bores either contain reliable long-term historical observation data or are SIS observation bores. The SIS bores were constructed in the last few years, but the observation data provide information on aquifer response to pumping. It is very useful that the SIS bores are located in an area where steep potentiometric gradients drive groundwater into the river, so a good match with the observations would suggest that the model simulates groundwater flux to the river adequately.

Most of the selected observation bores are in the Loxton Sands and Monoman Formation (layer 1), as these are the major aquifers that contribute salt load to the River Murray. A few bores lie within the Pata Formation. The location of the observation bores in Loxton and Bookpurnong are shown in Figures 4.5 and 4.6, respectively.

As discussed in Section 2.3.5, most hydrographs in the Loxton Sands show a rising trend as the irrigation mounds develop and a decline as changes in irrigation practice lower recharge rates. For the Monoman Formation floodplain hydrographs, water level changes are due to river level change and SIS pumping. In the Pata Formation, hydrographs indicate stable conditions beneath the floodplain near Pyap and north of Bookpurnong, but hydraulic head is declining west of Loxton and increasing at Bookpurnong (AWE 2011a).

Comparison between modelled and observed (historical) potentiometric heads indicates a close match in most bores (Figs 4.7–4.13) in terms of actual levels and trends. The match within the Loxton and Bookpurnong irrigation mounds is generally very good for both the Loxton Sands and the Pata Formation. Near or below the floodplain at Loxton, modelled head in the Pata is overestimated.

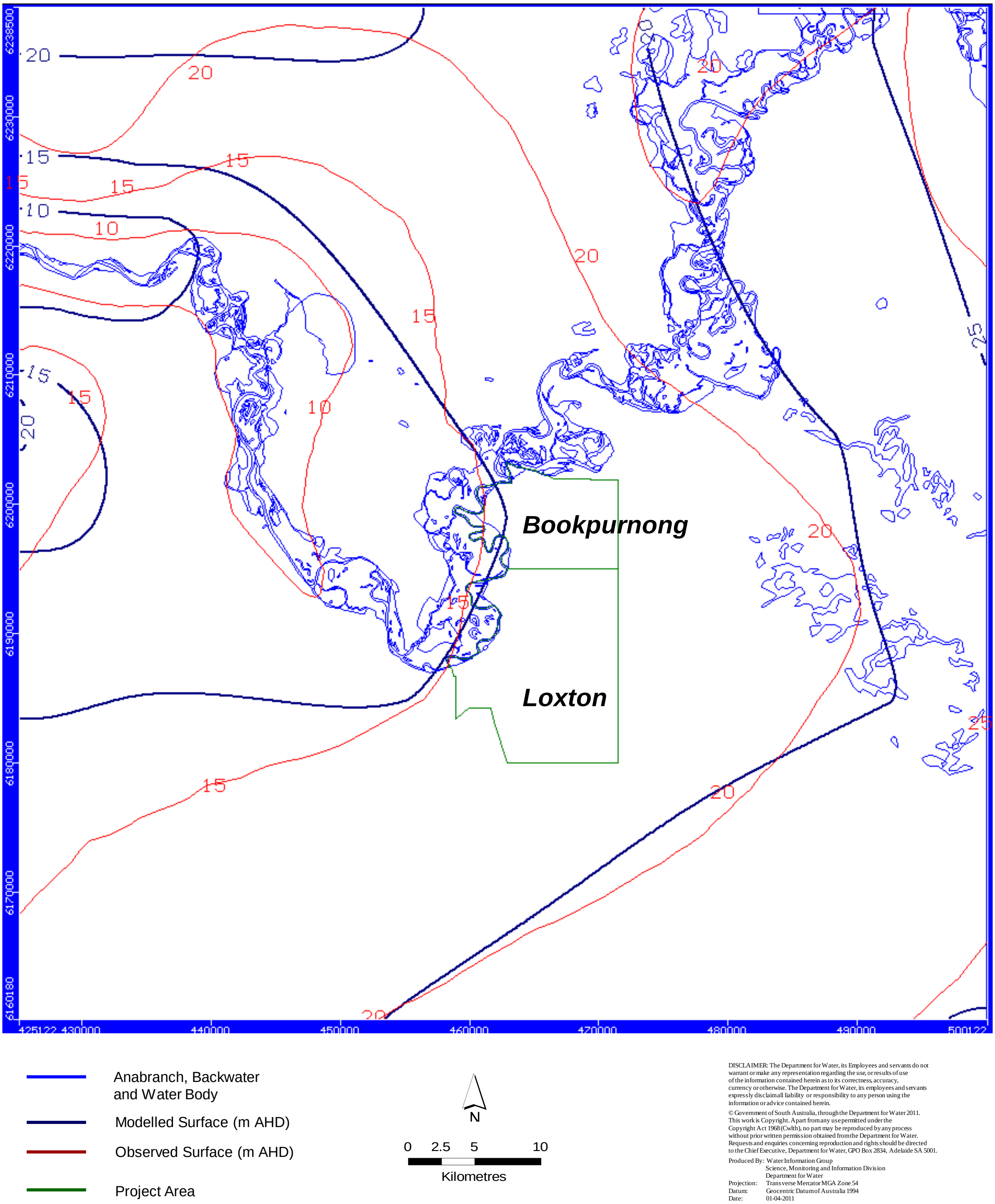

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Figure 4.4 Comparison of observed and modelled 2005 potentiometric surface in project area (Layer 5 Mannum Formation)

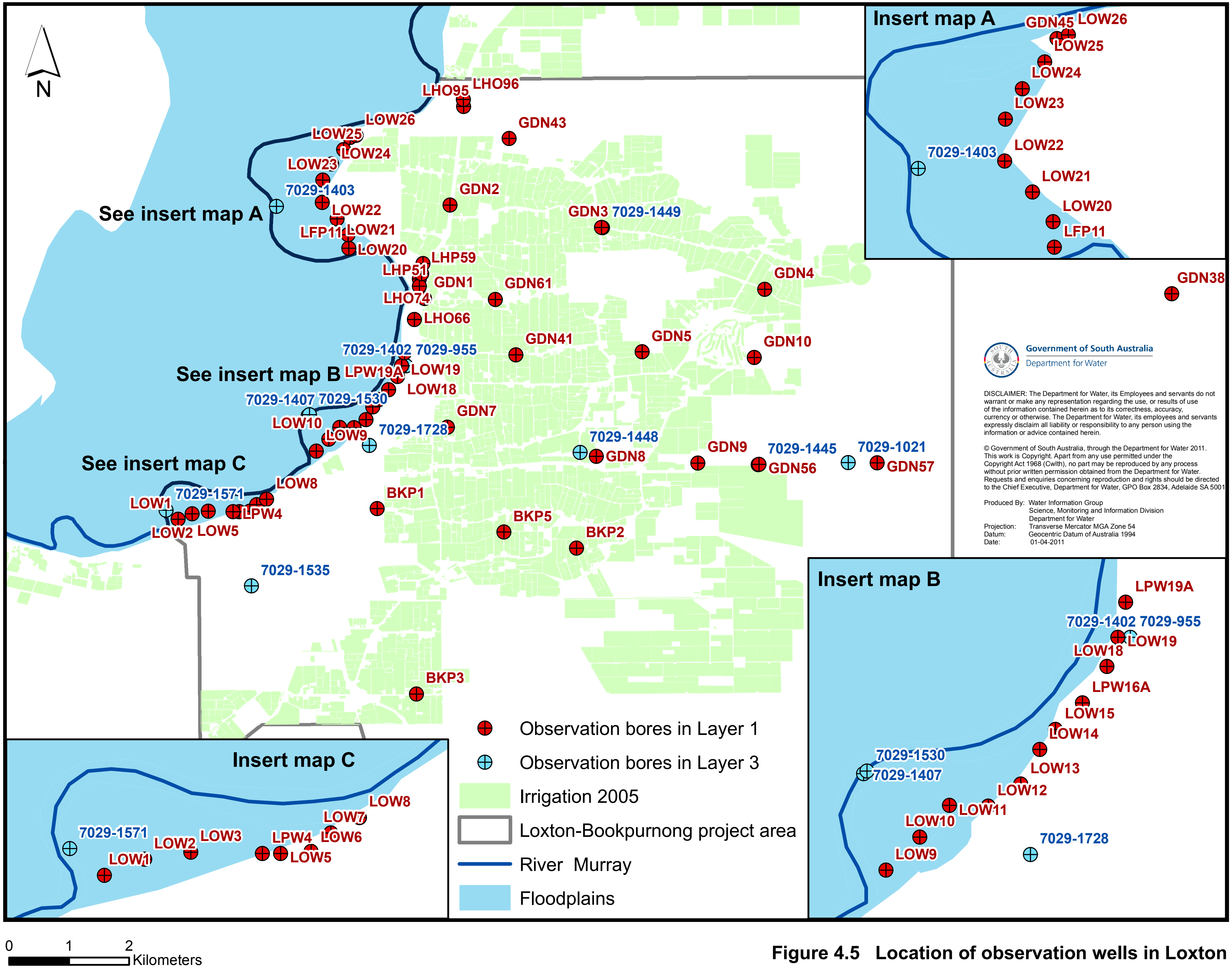


Figure 4.5 Location of observation wells in Loxton

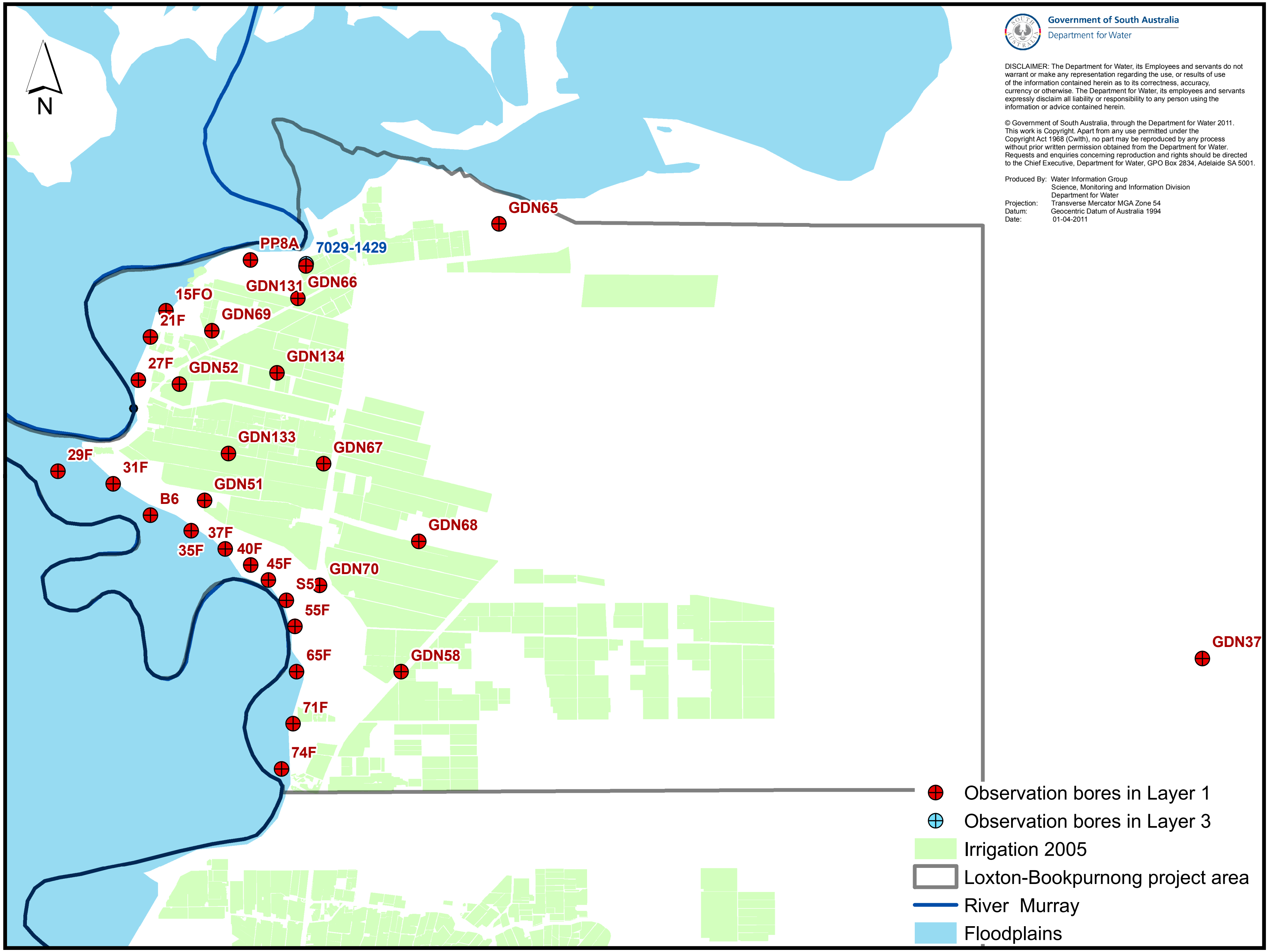


Figure 4.6 Location of observation wells in Bookpurnong

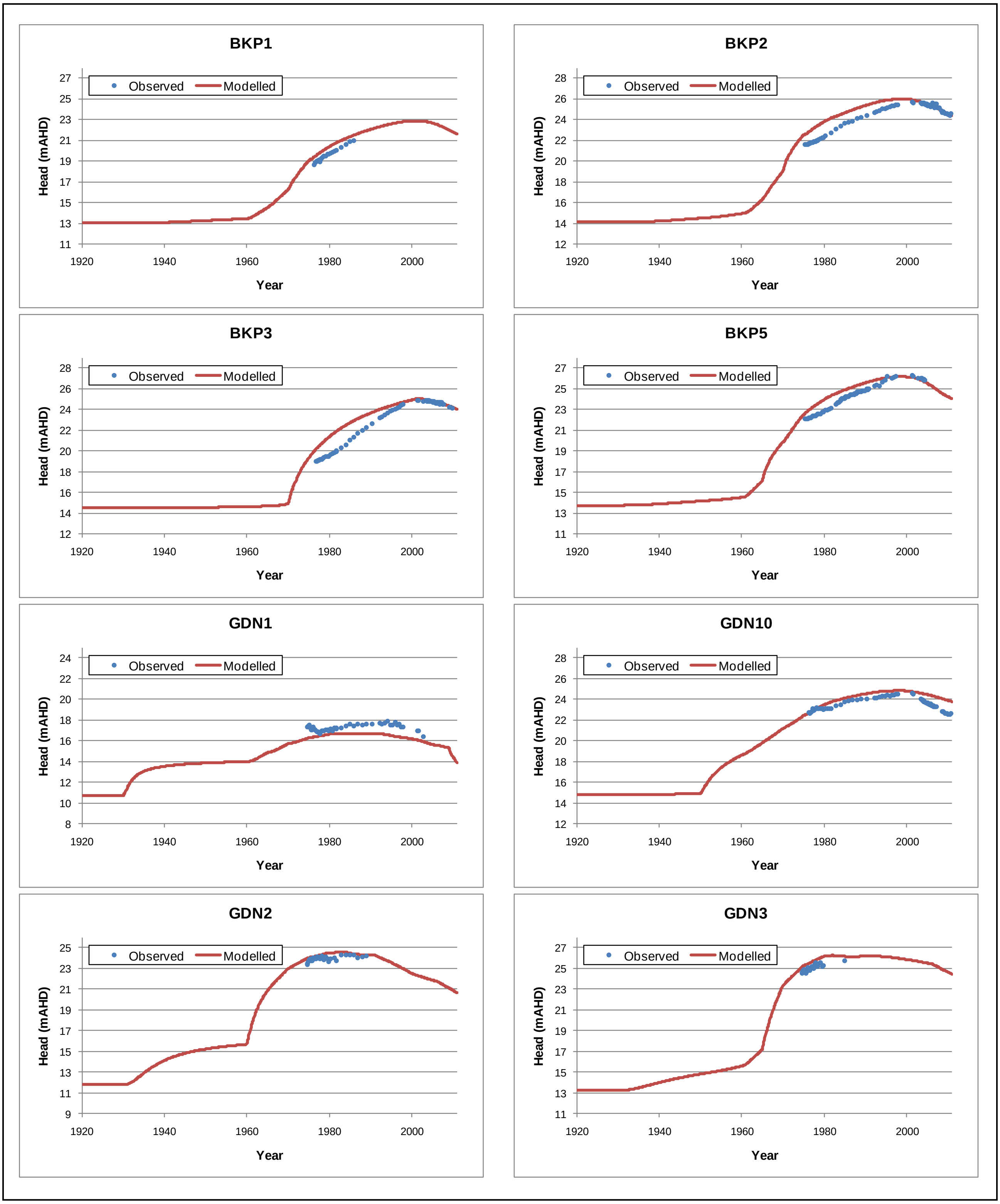


Figure 4.7a Loxton Highland calibration results – modelled and observed potentiometric heads

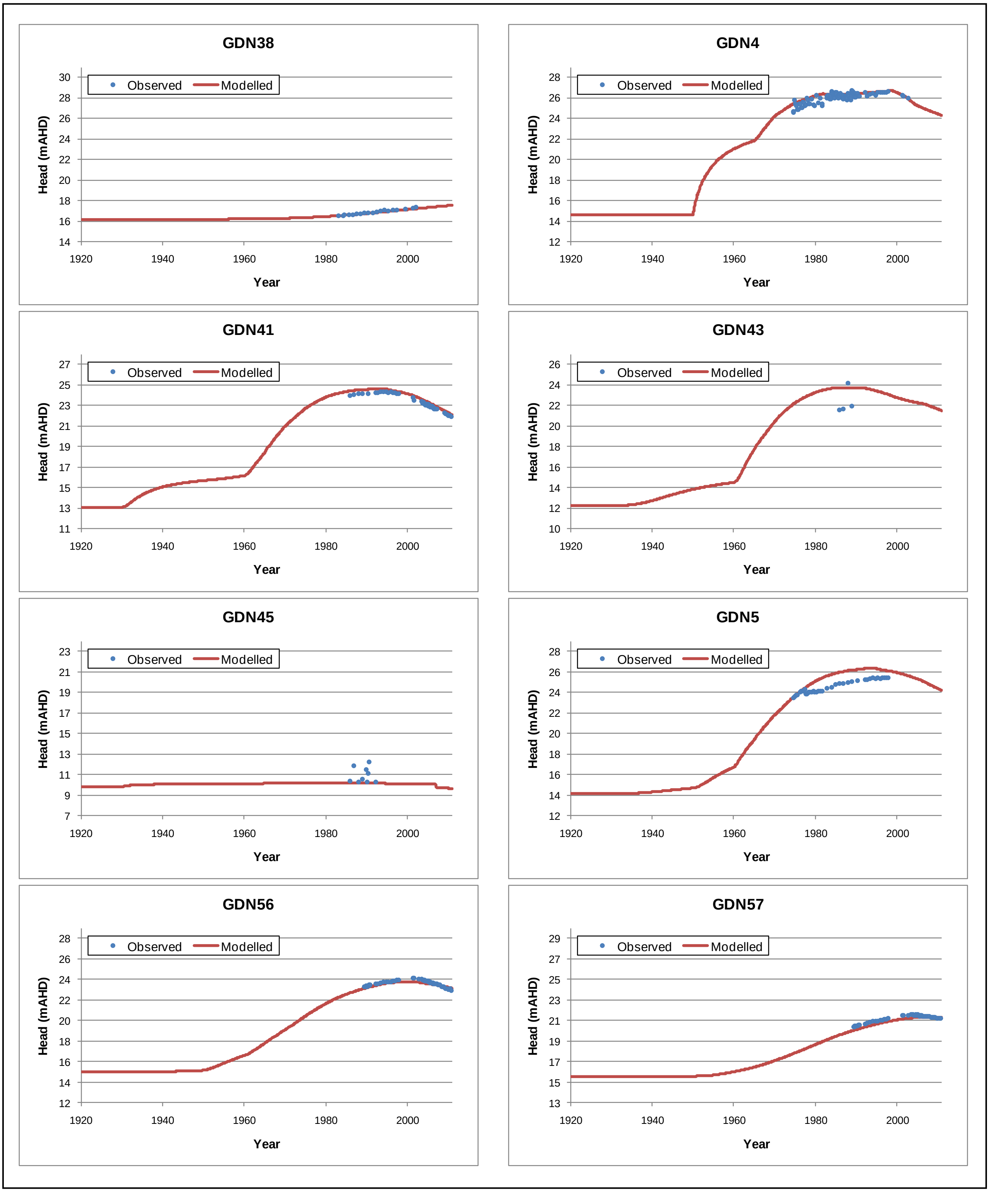


Figure 4.7b Loxton Highland calibration results – modelled and observed potentiometric heads

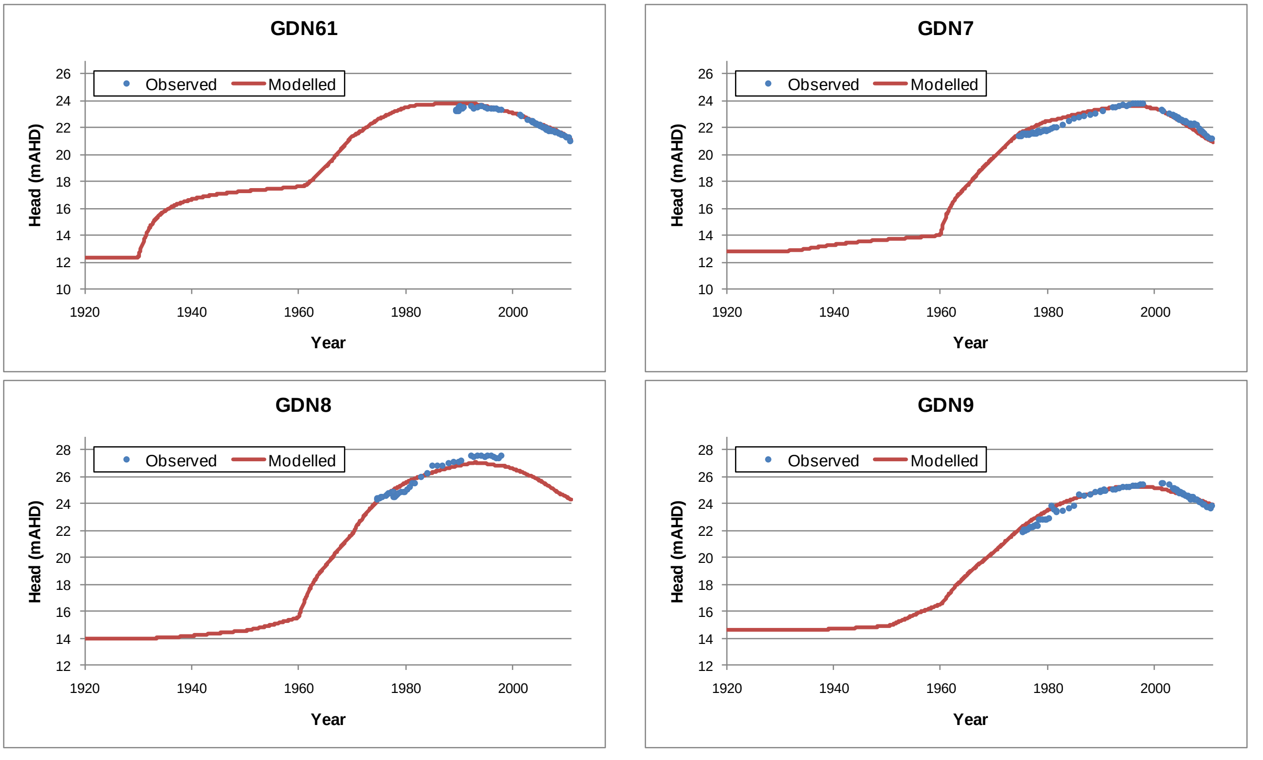


Figure 4.7c Loxton Highland calibration results – modelled and observed potentiometric heads

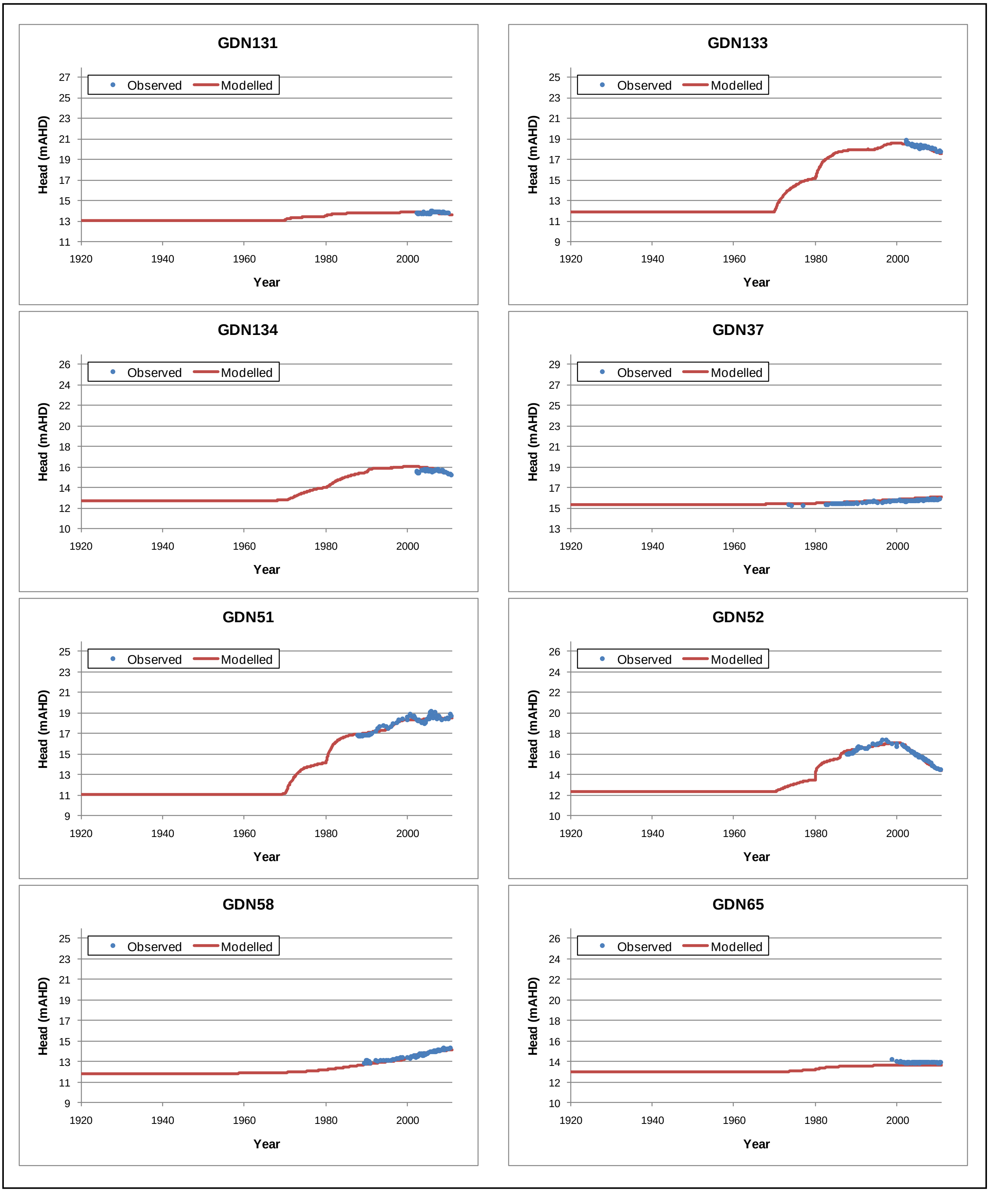


Figure 4.8a Bookpurnong Highland calibration results – modelled and observed potentiometric heads

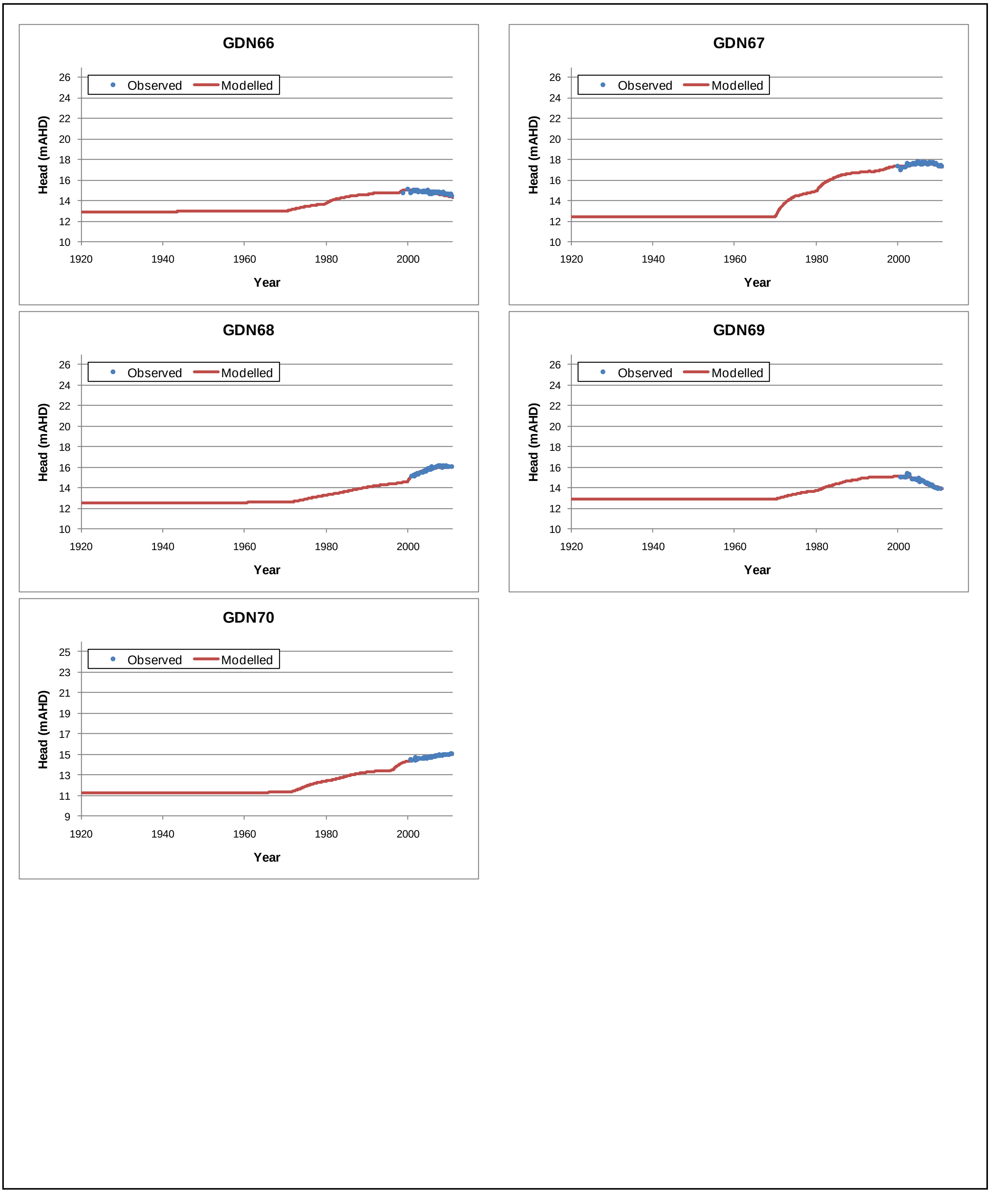


Figure 4.8b Bookpurnong Highland calibration results – modelled and observed potentiometric heads

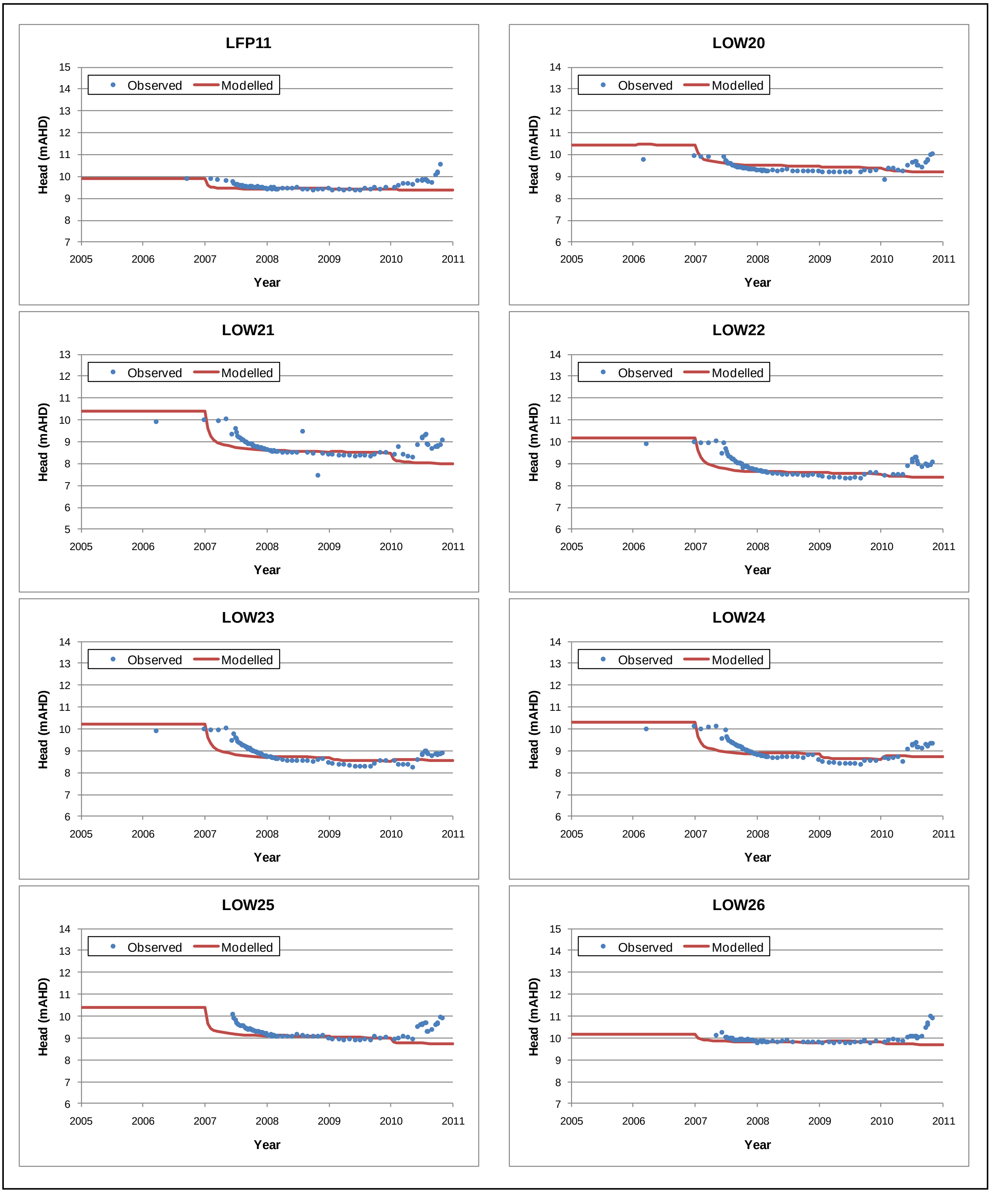


Figure 4.9 Rilli's Floodplain (Loxton) calibration results – modelled and observed potentiometric heads

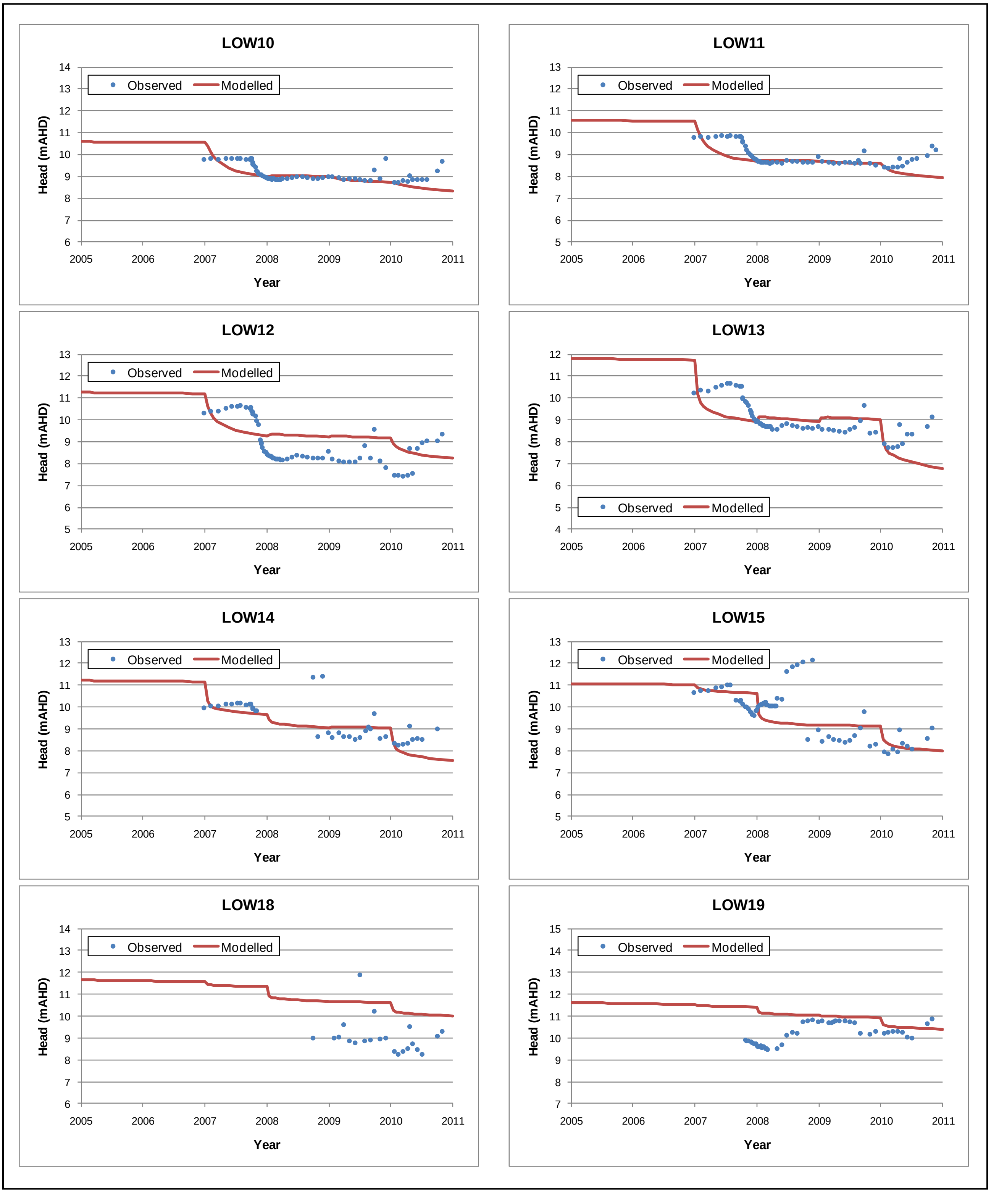


Figure 4.10a Thiele's Floodplain (Loxton) calibration results – modelled and observed potentiometric heads

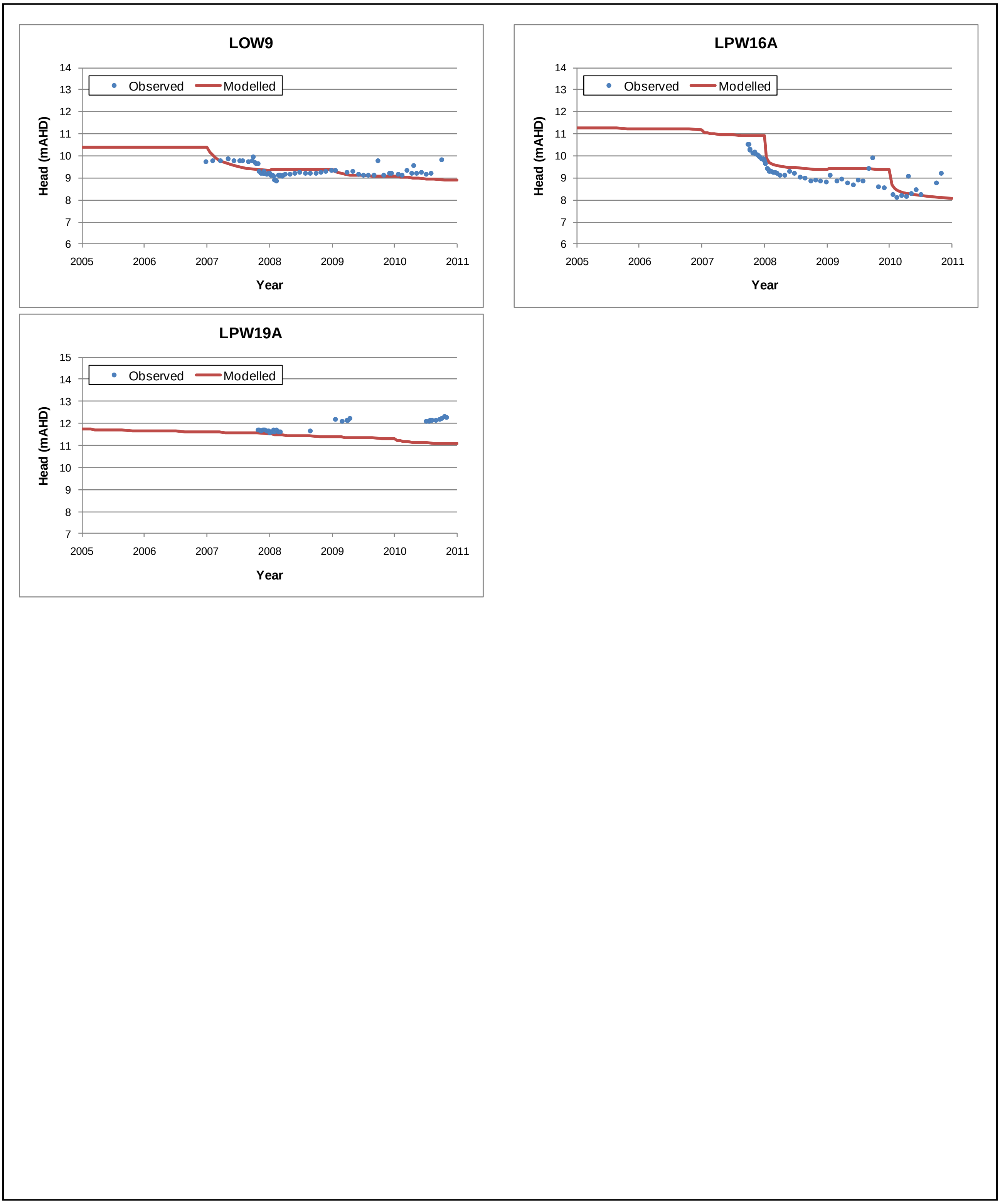


Figure 4.10b Thiele's Floodplain (Loxton) calibration results – modelled and observed potentiometric heads

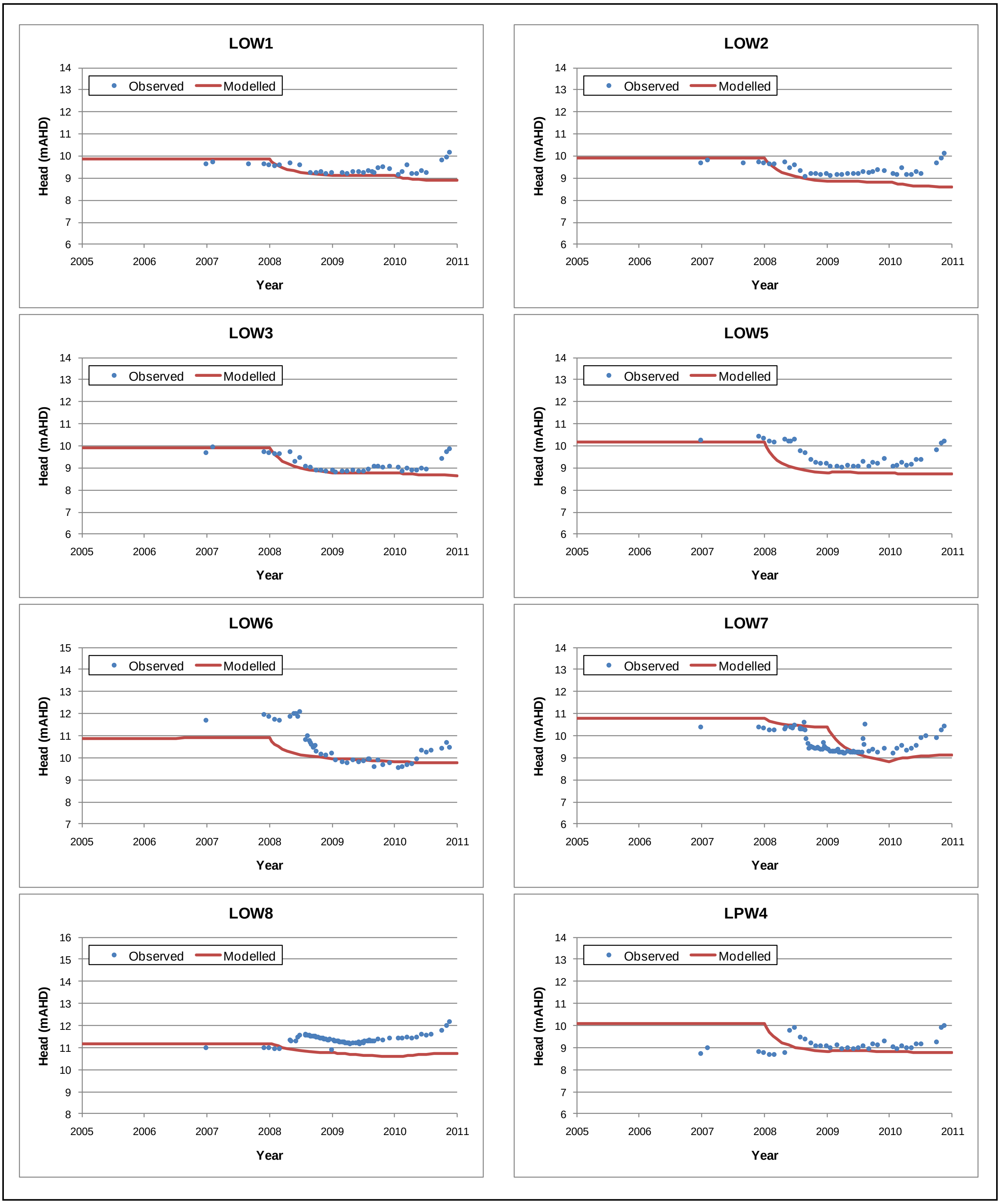


Figure 4.11 Caravan Park Floodplain (Loxton) calibration results – modelled and observed potentiometric heads

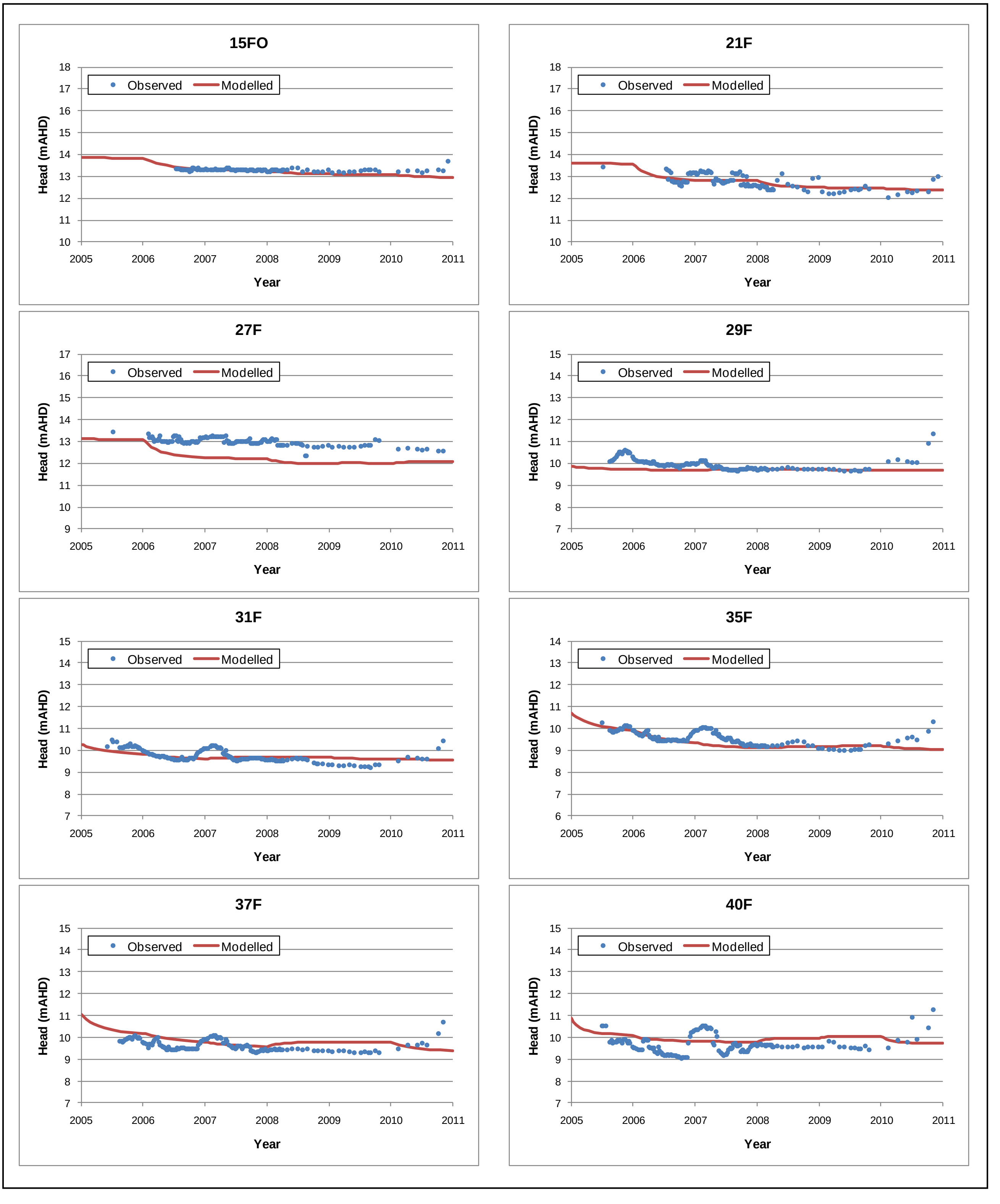


Figure 4.12a **Clark's Floodplain (Bookpurnong) calibration results – modelled and observed potentiometric heads**

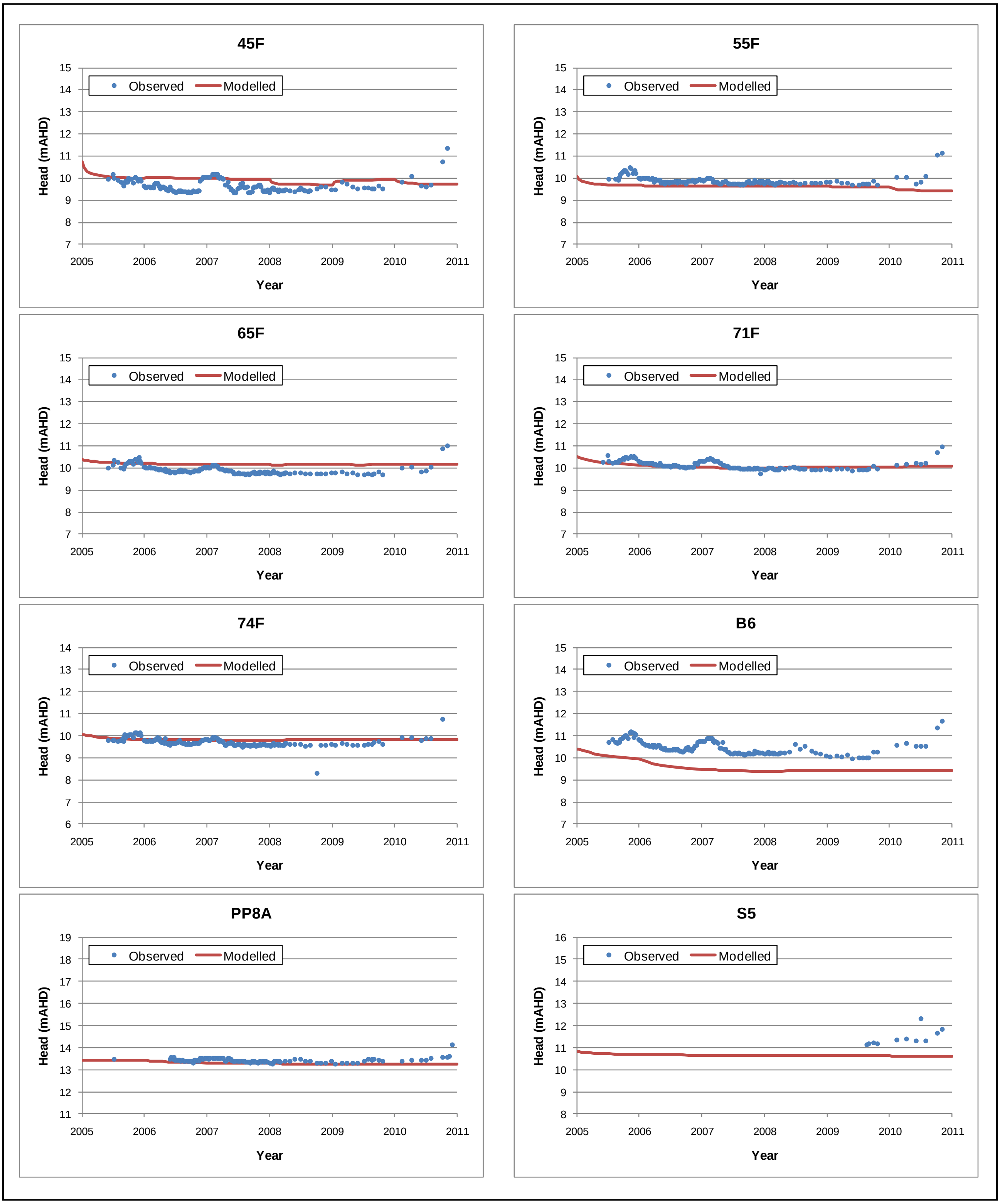


Figure 4.12b Clark's Floodplain (Bookpurnong) calibration results – modelled and observed potentiometric heads

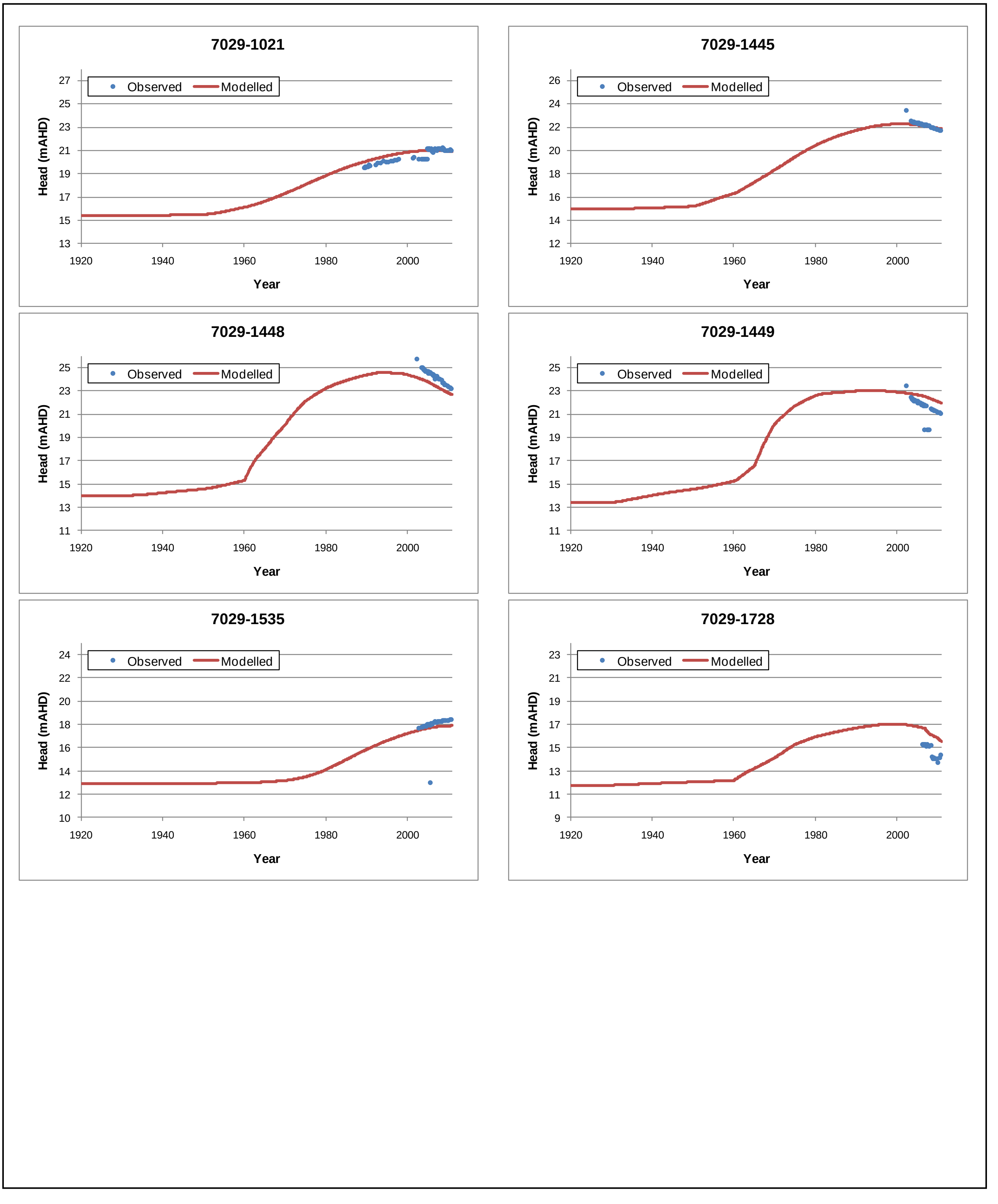


Figure 4.13a Pata Formation (Highland area) calibration results – modelled and observed potentiometric heads

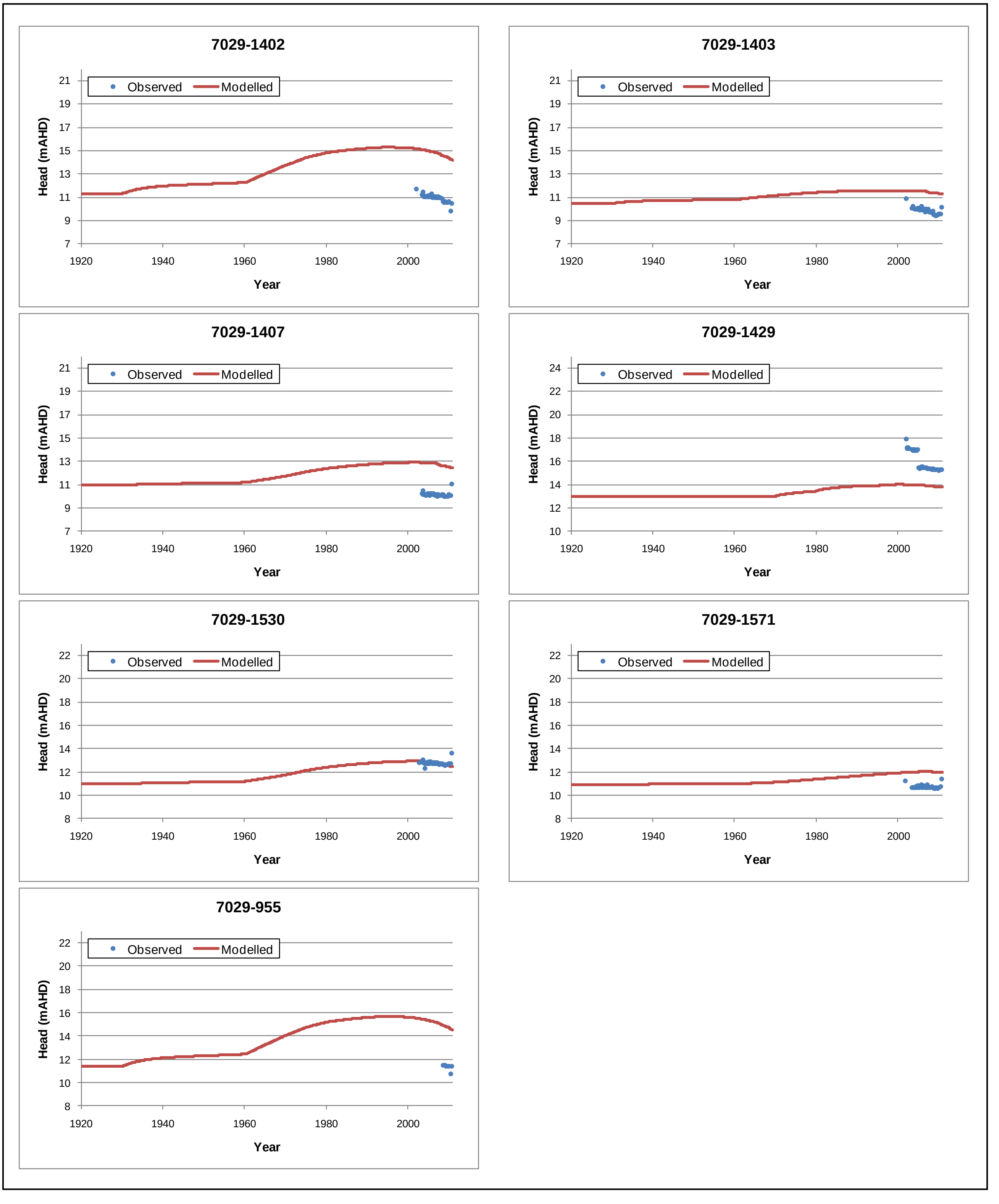


Figure 4.13b Pata Formation (Floodplain area) calibration results – modelled and observed potentiometric heads

The match for Monoman Sands floodplain bores is constrained by two model assumptions — the river level is held constant, so fluctuations in groundwater level due to changes in river stage are not simulated; and stress periods are one year in length, so fluctuations due to brief changes in SIS pumping rates are not simulated either. For example, consider LOW21. The modelled head lowers due to SIS pumping at the start of 2007 as this is the start of the stress period, while the observed head lowers in mid-2007 when the SIS pumping started in reality. However, the pre-pumping and post-pumping heads are not dissimilar. Higher heads are observed in the second half of 2010, presumably due to the raised river level or the temporary cessation of SIS pumping at that time, which the model does not simulate. Given those simplifications, modelled floodplain heads are a good match to observations for Rilli's Floodplain, the Caravan Park Floodplain and Clark's Floodplain. Observed heads in Thiele's Floodplain are more variable, e.g. LOW15 and it is not clear if the mismatch with observed heads is due to the two model assumptions mentioned here or some other process.

4.3.3. CALIBRATION RESULTS — ITERATION RESIDUAL ERROR

The iteration residual error between modelled and observed potentiometric heads of the Loxton Sands and Monoman Formation in the Loxton–Bookpurnong area is calculated using data from 1977, 1988, 2001 and 2009, which are the years with the most data. The calculations (Figs 4.14–4.17) indicate a scaled root mean squared value (SRMS) for the study area of:

- 6.0% in 1977
- 4.0% in 1988
- 2.2% in 2001
- 2.3% in 2009.

The 1988, 2001 and 2009 values are within the 5% SRMS range suggested by the *Groundwater Flow Modelling Guideline* (MDBC 2001) and indicate a good fit between modelled and observation data over the simulation period.

4.3.4. CALIBRATION RESULTS — WATER BALANCE ERROR

The model water balance error is less than 1% at all times. This is within the criteria defined in the *Groundwater Flow Modelling Guideline* (MDBC 2001).

4.4. MODEL CONFIRMATION

4.4.1. SALT LOADS

The salt load entering the River Murray is calculated using the modelled groundwater flux and groundwater salinity in each model flow budget zone. The resulting calculations of the salt load for 2004 and 2009 are given in Figures 4.18 – 4.21 and Appendices B-3 and B-4.

The results given in Table 4.1 indicate the modelled flux and salt load entering the River Murray in the Loxton–Bookpurnong area for the historical model.

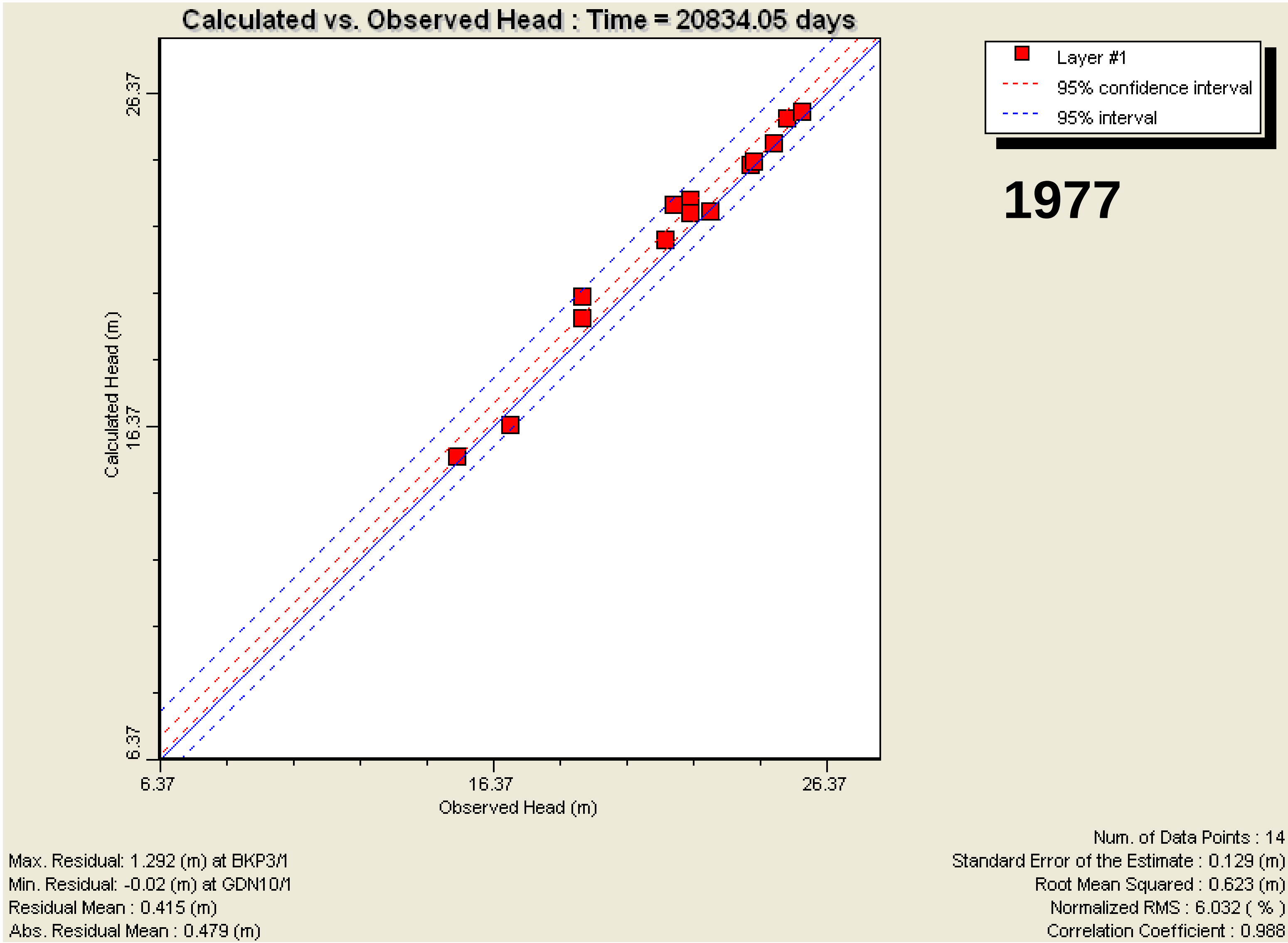


Figure 4.14 Loxton calibration results (1977)
(No Bookpurnong observations are available for this year)

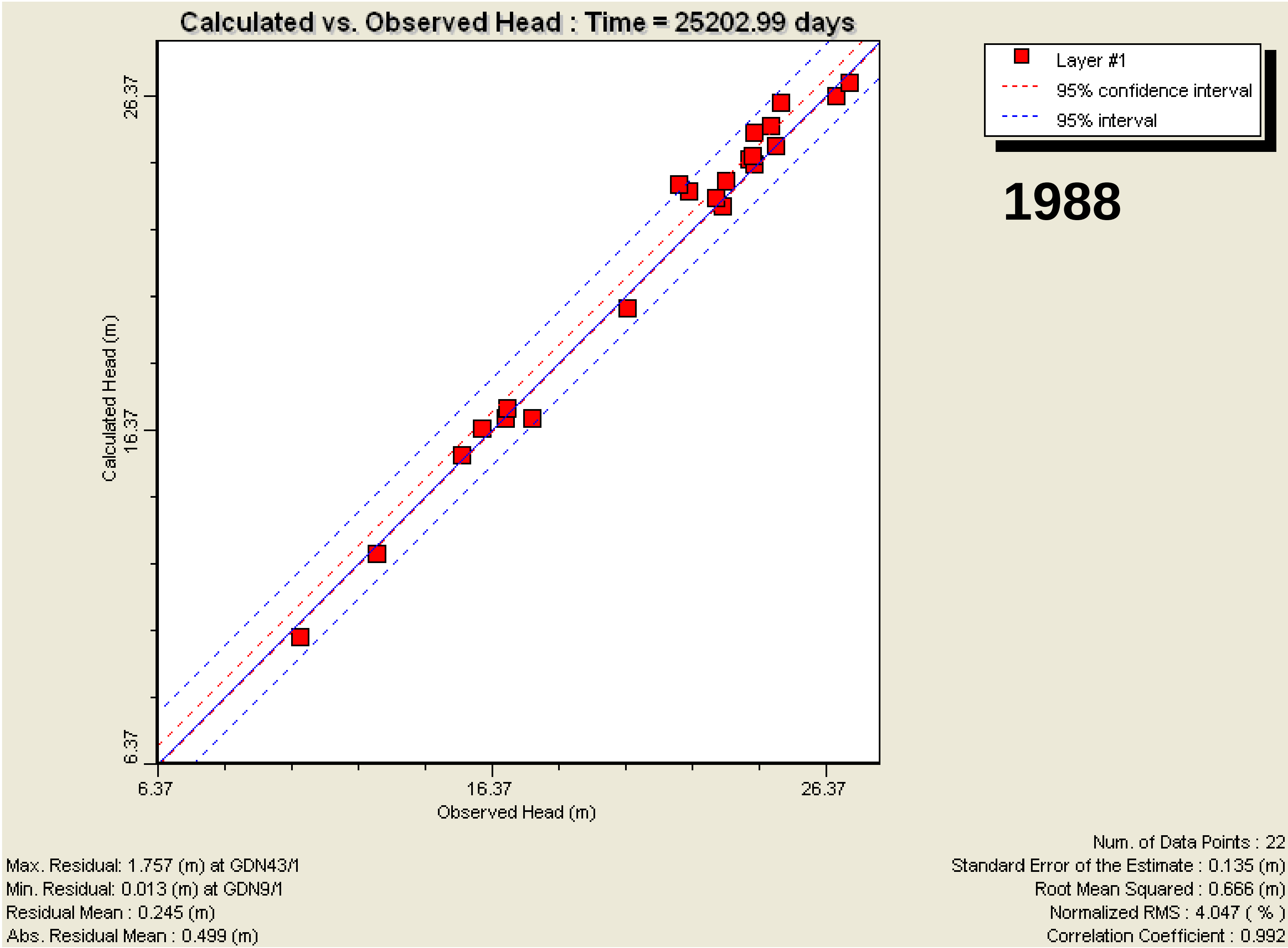


Figure 4.15 Loxton – Bookpurnong calibration results (1988)

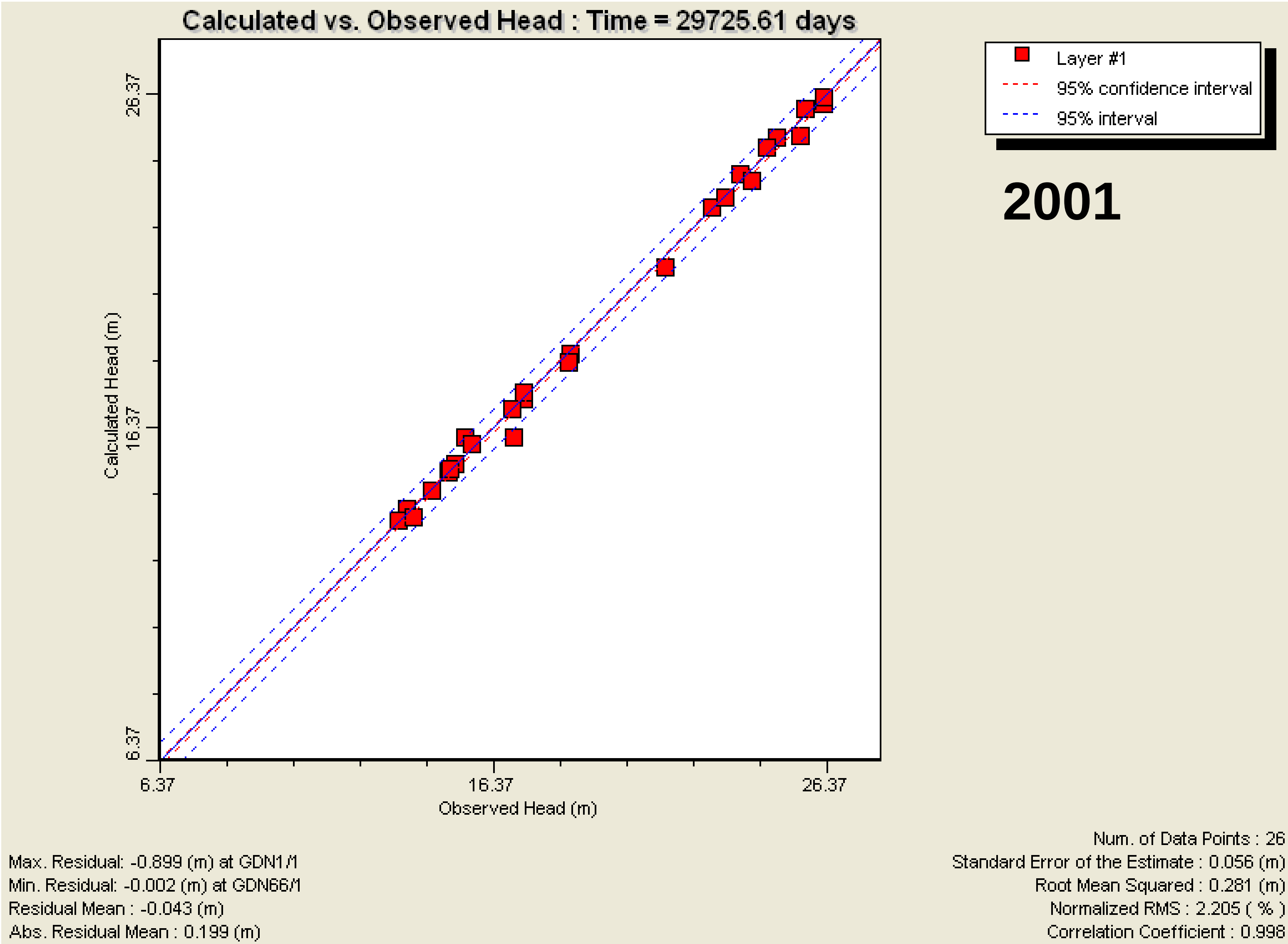


Figure 4.16 Loxton – Bookpurnong calibration results (2001)

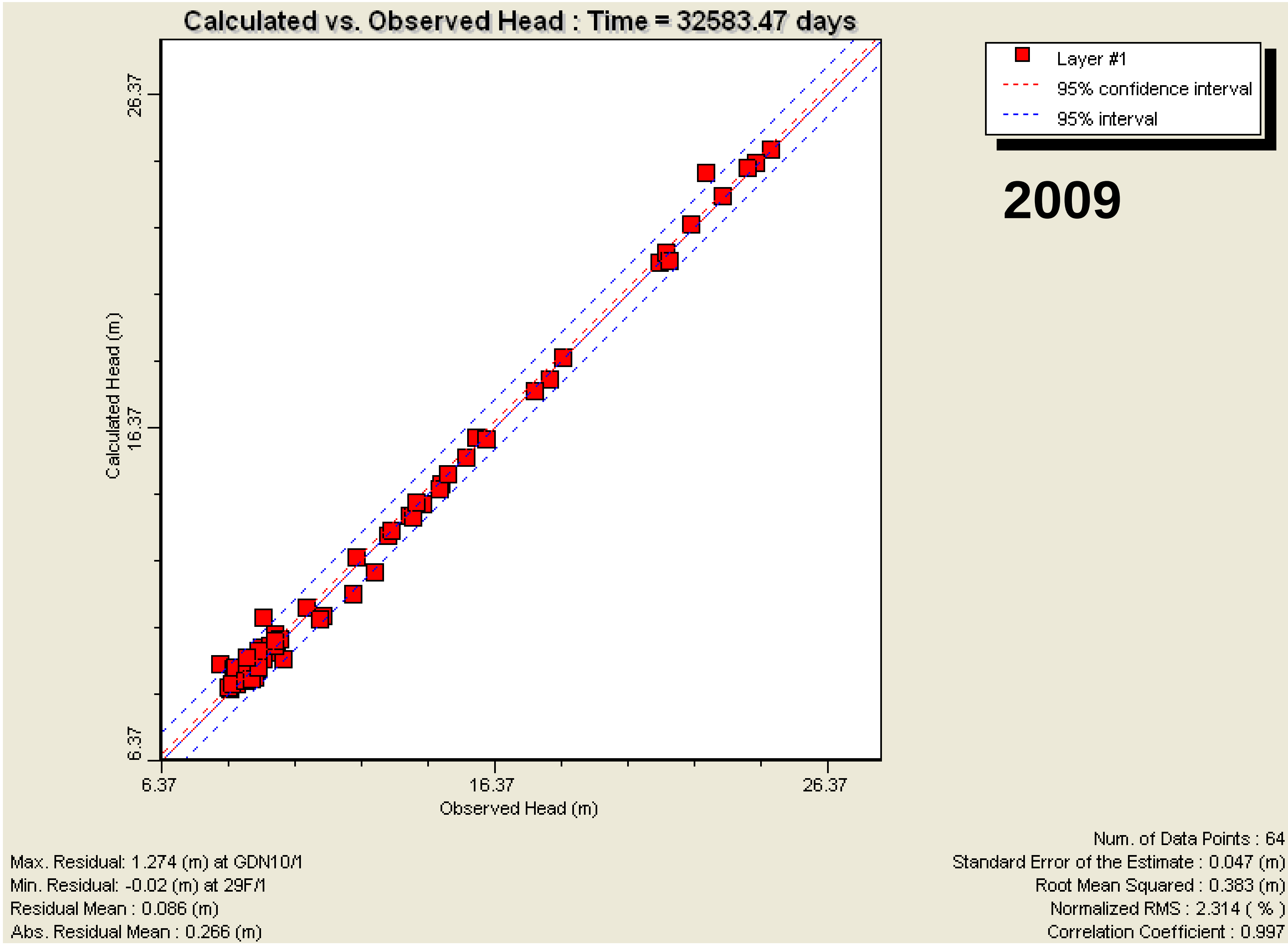


Figure 4.17 Loxton – Bookpurnong calibration results (2009)

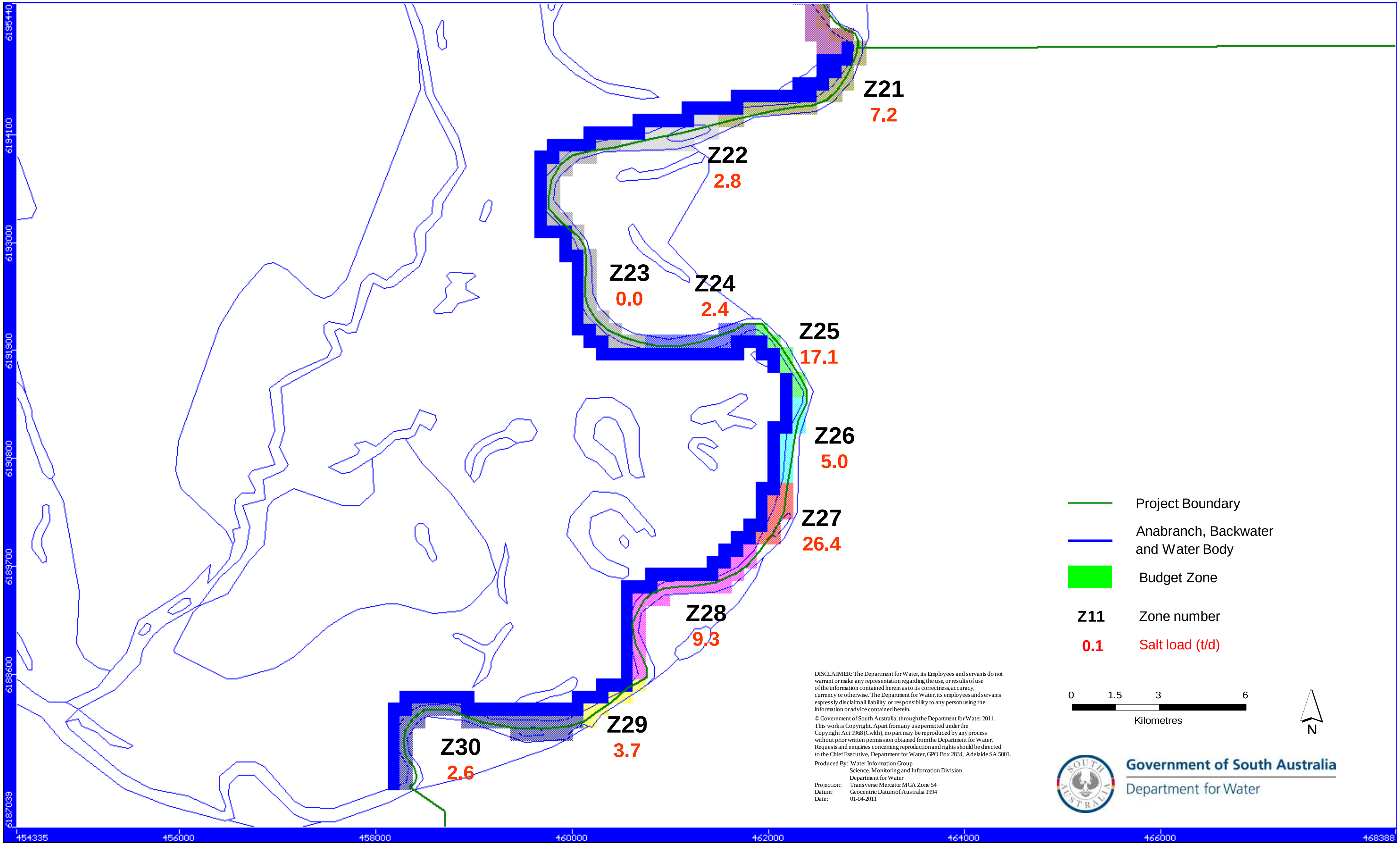


Figure 4.18 Model flow budget zones and modelled salt load at 2004 (t/d) in the Loxton area

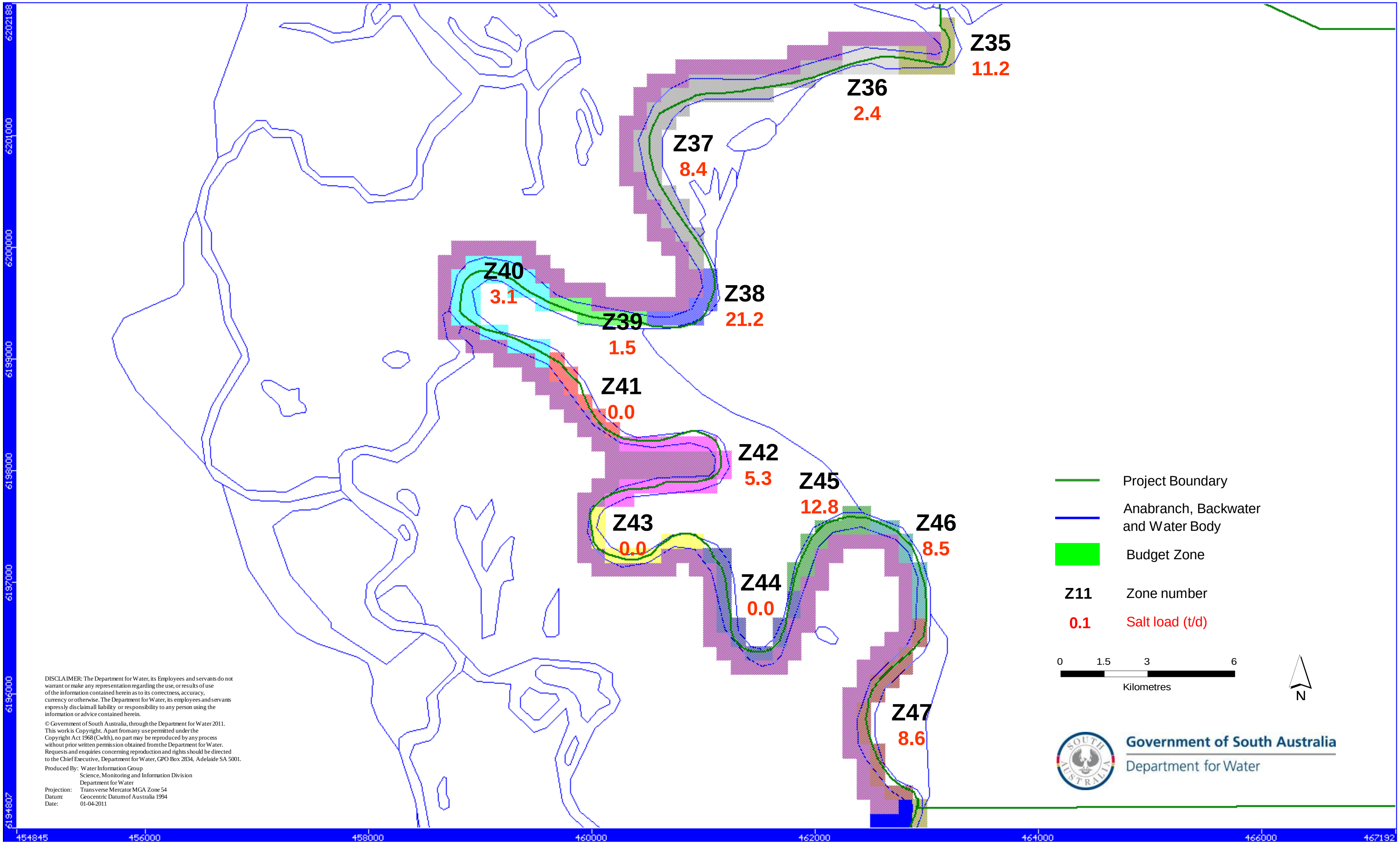


Figure 4.19 Model flow budget zones and modelled salt load at 2004 (t/d) in the Bookpurnong area

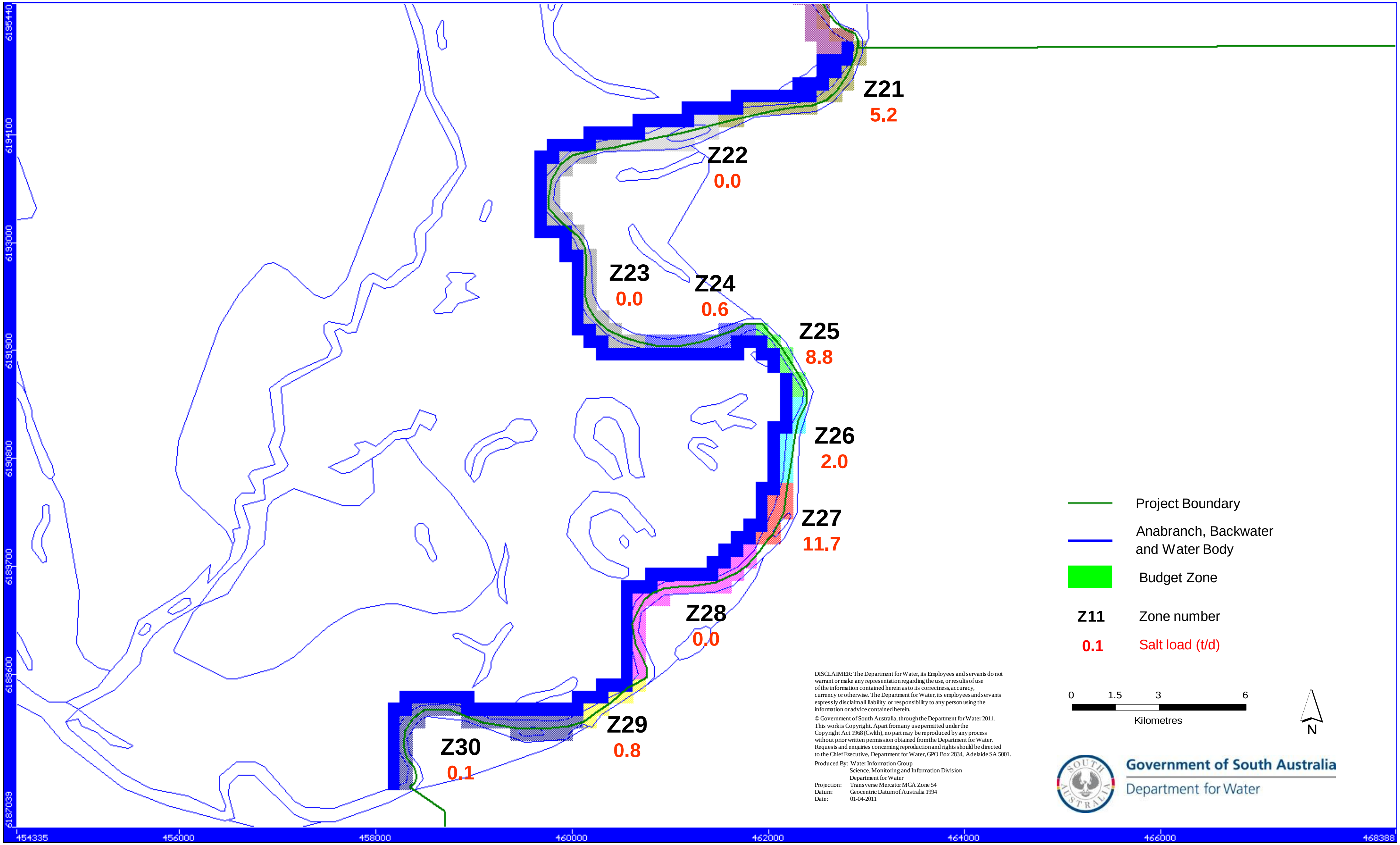


Figure 4.20 Model flow budget zones and modelled salt load at 2009 (t/d) in the Loxton area

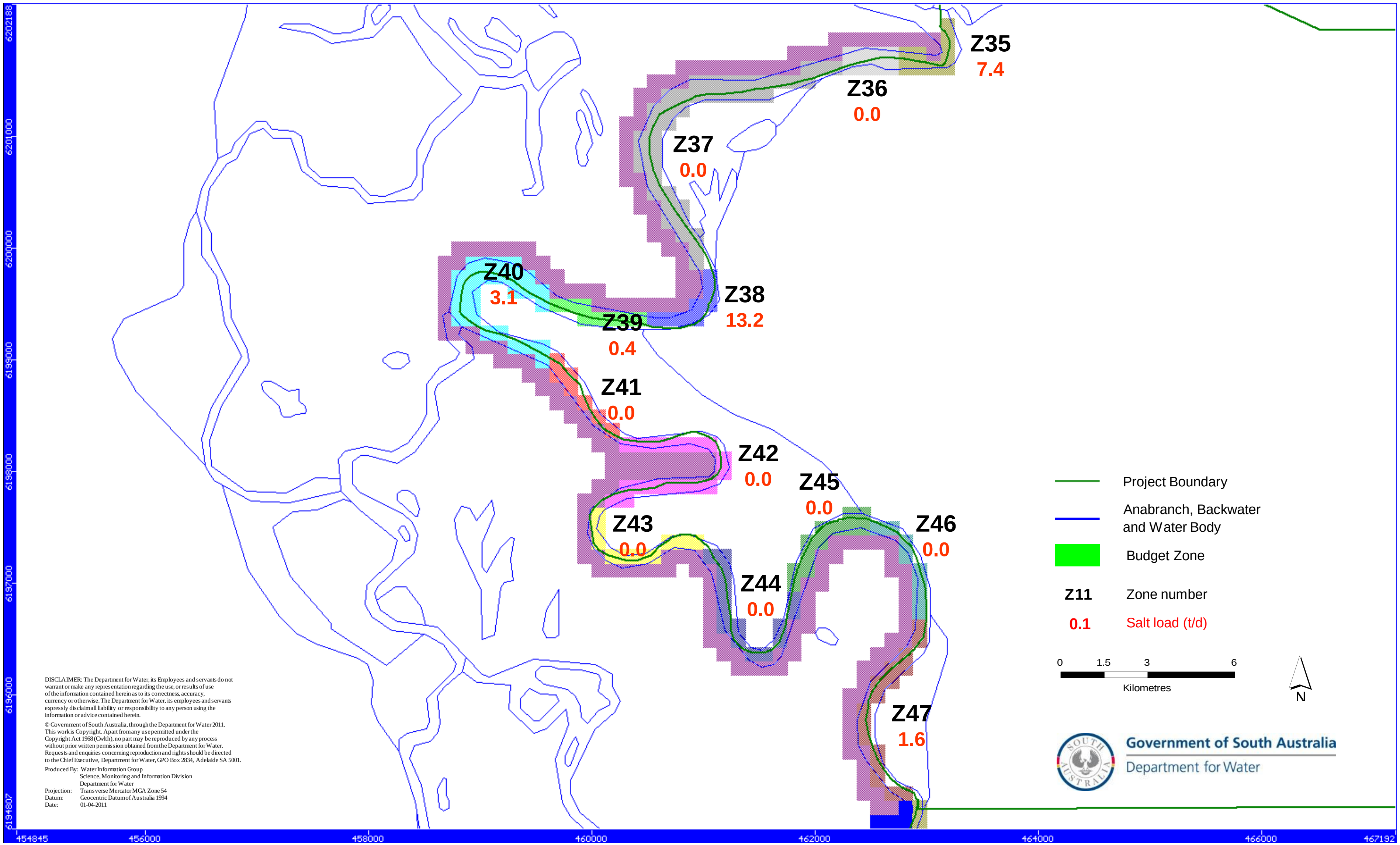


Figure 4.21 Model flow budget zones and modelled salt load at 2009 (t/d) in the Bookpurnong area

Table 4.1 Modelled groundwater flux and salt load in the Loxton–Bookpurnong area (calibrated model)

	Year		
	1988	**2000**	**2010**
Loxton area			
Flux (m^3/d)	4513	4148	975
Salt load (t/d)	92.2	84.4	19.3
Bookpurnong area			
Flux (m^3/d)	2633	3133	1034
Salt load (t/d)	70.0	85.2	25.7

Figure 4.22 compares the RoR salt loads with the modelled salt loads for Loxton and Bookpurnong respectively (river kilometres 487 to 502 and 503 to 521). The modelled salt loads for the Loxton and Bookpurnong reach follow the general trend of the RoR values, but are typically 10 to 20 t/d higher. The differences may be due to the fact that model values are being calculated based on average conditions, while most RoR values after 1991 were measured under low river flow conditions. The RoR measurement in 1991 is considerably higher than the modelled value for both Loxton and Bookpurnong, believed to be due to variations in river flow conditions which is an unknown factor in most River Murray salt load calculations.

Table 4.2 shows the total salt load from both the RoR surveys and the numerical model. The modelled salt loads for the Loxton and Bookpurnong reaches are within the RoR salt load range.

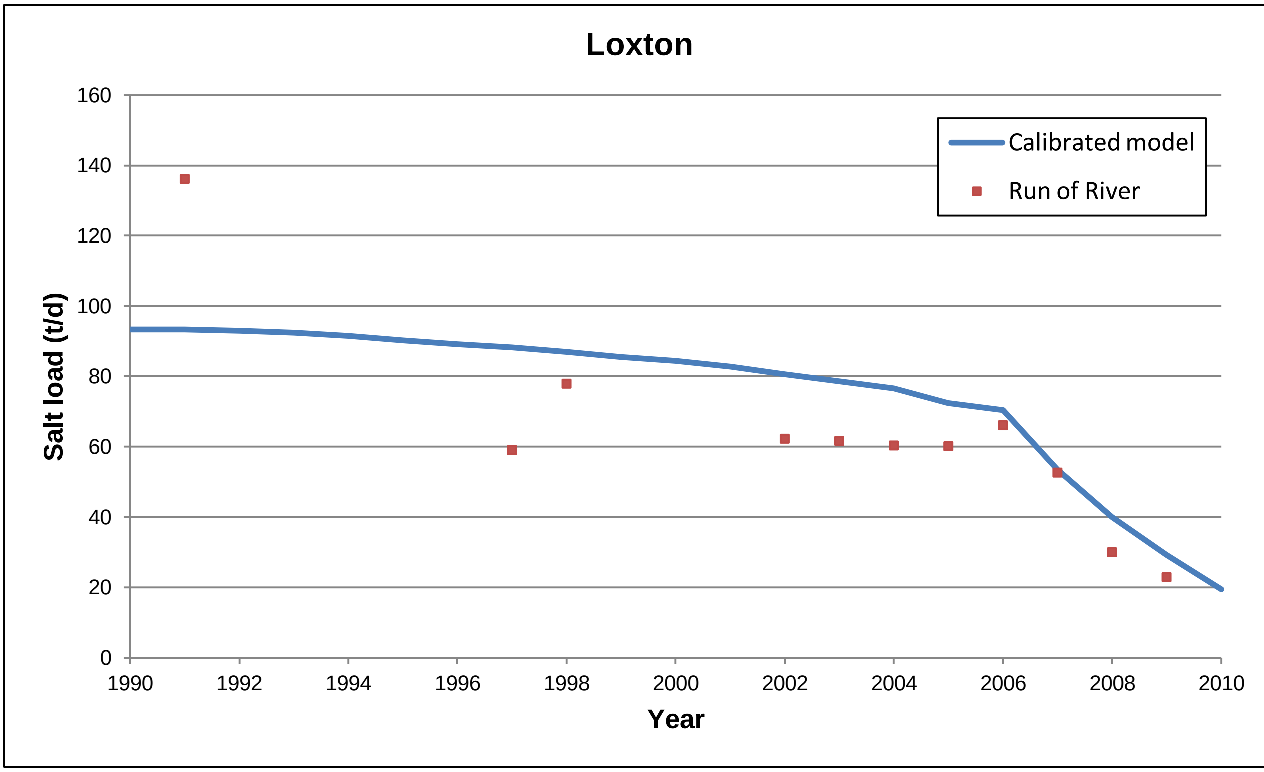
Table 4.2 Comparison between RoR results and modelled salt load in the Loxton–Bookpurnong area

	RoR salt load (t/d)	**Modelled salt load (t/d)**
Loxton	22.9–136.2	19.3–93.2
Bookpurnong	10.8–110.6	22.2–85.2

4.4.2. GAINING AND LOSING REACHES

The 2004 NanoTEM data (Fig. 2.2) show that the majority of salt load entering the River Murray comes from the river reach between Rilli’s Floodplain and Thiele’s Floodplain (river kilometres 492 to 495) in Loxton and from upstream (river kilometres 515 to 516) and downstream of Clark’s Floodplain (river kilometres 502 to 506) in Bookpurnong.

Figures 4.18 and 4.19 show the 2004 modelled salt load along the river reaches for Loxton and Bookpurnong, respectively. The location of the river reaches with high modelled salt load values coincides with NanoTEM data, hence increasing the confidence in the model results. The salt load is particularly high for zone 27 in Loxton (26.4 t/d), where the potentiometric gradients between the centre of the Loxton groundwater mound and the river are steepest and the groundwater salinity is high.



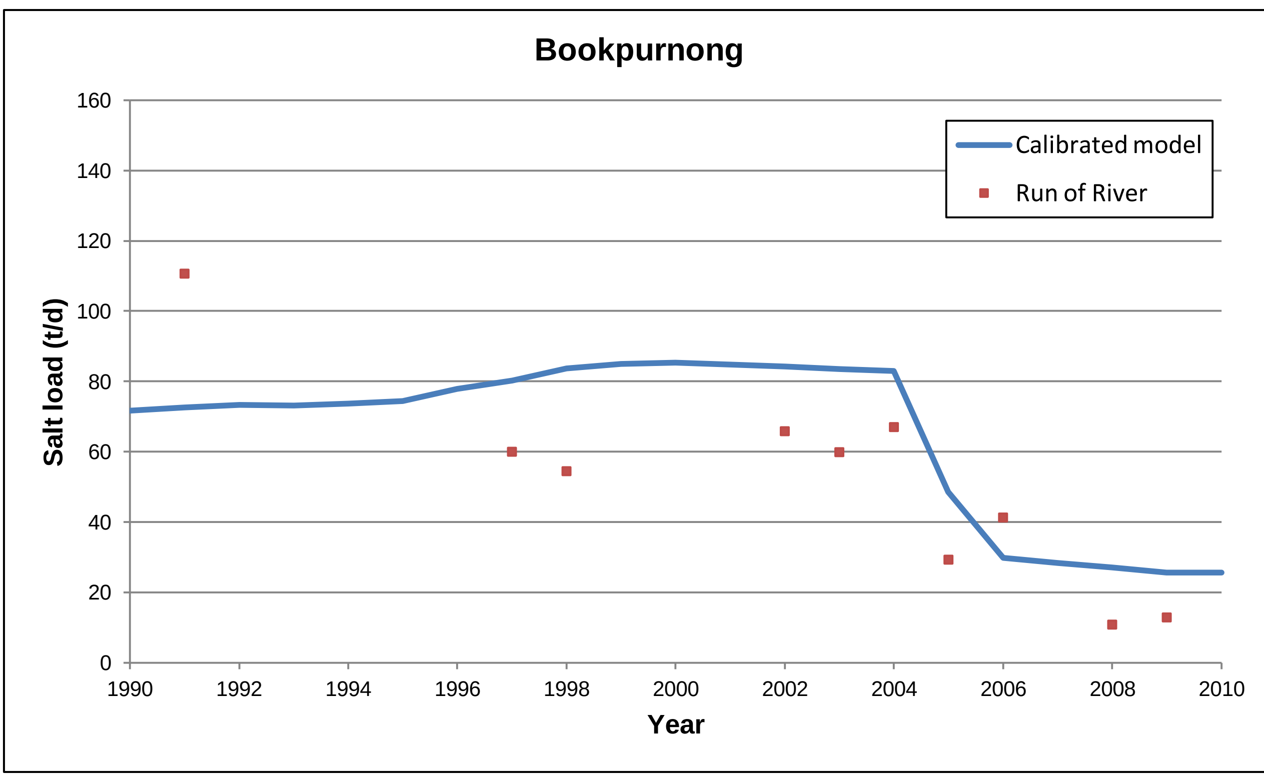


Figure 4.22 Comparison of salt loads between Run-of-River measurements and the calibrated model outputs

4.4.3. RECHARGE VOLUMES

The good match to groundwater trends indicates that the recharge rates estimated via inverse modelling (calibration) are consistent with available hydrogeological information. While this minimises uncertainty, confirmation through alternative evidence is also needed.

To seek confirmation of recharge estimates, an independent estimate of accession water volumes was undertaken (Laroona Environmetrics 2011, in App. C-1). The accession estimates are based on a review of irrigation and infrastructure information for both Loxton and Bookpurnong sourced from DFW and historical irrigation trust records. A water balance method was employed in the calculation and the details are shown in Appendix C-1. The outputs of this work were compared with the total recharge applied in the calibrated model to confirm that the modelled recharge was within appropriate range. This comparison provides confidence that the total recharge applied in the model is within the reasonable range and is consistent with accession estimates.

Figure 4.23 compares the accession water estimates of Laroona Environmetrics (2011) with the total recharge volume from the calibrated model. It can be clearly seen that once the initial lag time is considered there is close alignment in the increase in calculated and modelled accession volume. The early gap may indicate the initial losses through the wetting front and lateral movement.

After the wetting front reaches the watertable, the trends become similar in both accession water and total recharge. As expected, the total recharge volume is lower than the accession water. It is noted that accession water is not the same as the total recharge as in reality it may differ by volume, rate over time and footprint due to some of the accession water remaining in the pore spaces of the unsaturated zone and within perched aquifers; the remainder becomes watertable recharge. Additionally, the accession water rates differ from the recharge due to losses in the unsaturated zone through lateral movement, especially when there is an intervening clay layer and there is an initial wetting front loss as the accession water percolates towards the watertable.

The recharge volume over time for the current model was also compared with that of the previous Loxton–Bookpurnong model (Yan et al., 2005b) in Figure 4.24. From 1965 to 2005, the recharge volumes are very much similar value and same trend. Recharge volumes show differently for Loxton area prior to 1965, this is because the 2011 model includes detailed information on the early irrigation history of Loxton which was not available when the 2005 model was developed. The comparison otherwise indicates a consistency between the model versions.

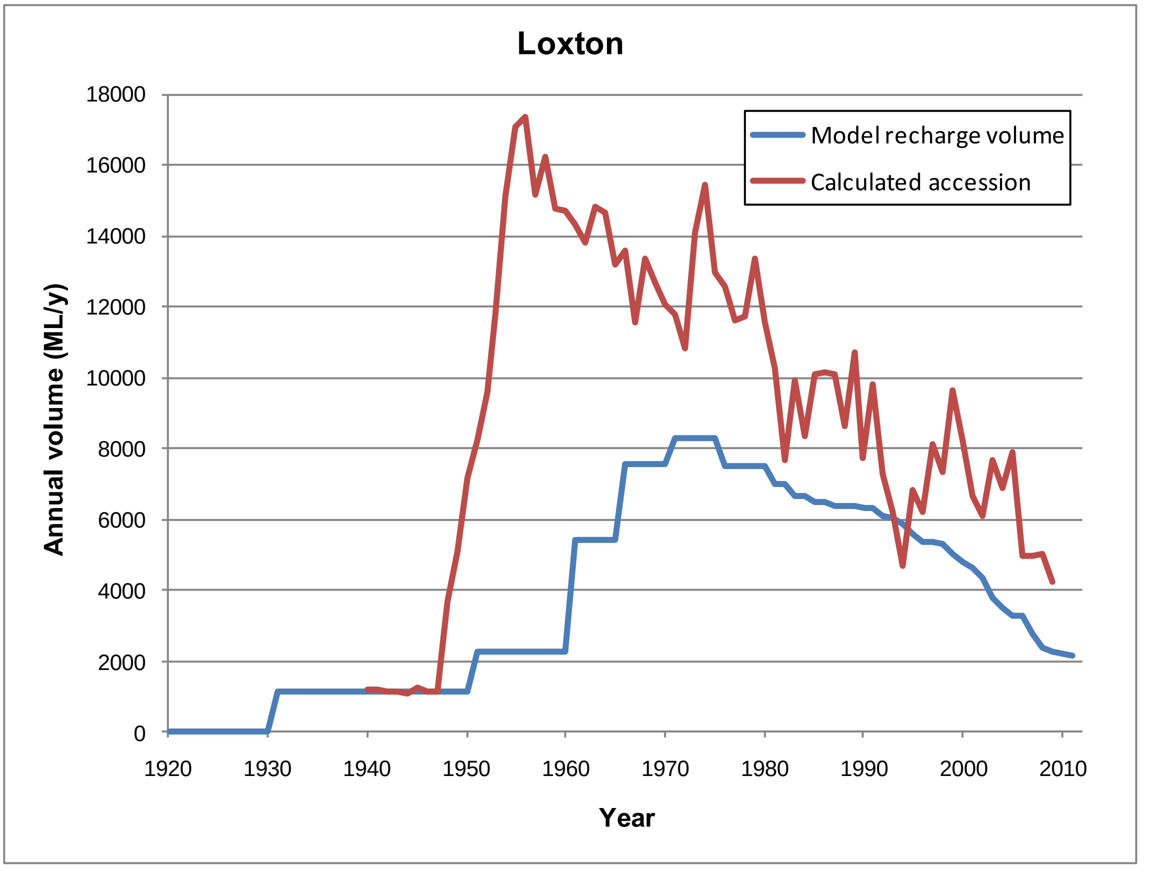
Model outputs were also carefully checked using available information and research outcomes, including:

- observation bore hydrographs
- RoR salt loads
- NanoTEM patterns of gaining and losing streams.

The confirmations provide confidence that the recharge applied in the model are a reasonable estimate of the true recharge rates and reproduce the observed impacts in the groundwater and the River Murray.

4.4.4. FLOODPLAIN EVAPOTRANSPIRATION

ET rates have been investigated in Loxton's Rilli's Floodplain and the Bookpurnong floodplain (Holland et al. 2001; Doody et al. 2009). The maximum potential ET rates were found to be ~250 mm/y with an extinction depth of roughly 2 m. An unpublished recent study indicates that average actual ET rates on floodplains may be in the range of 60–80 mm/y, assuming the woodland covers 30 to 40% of the floodplain (K Holland, CSIRO, pers. comm., 2011).



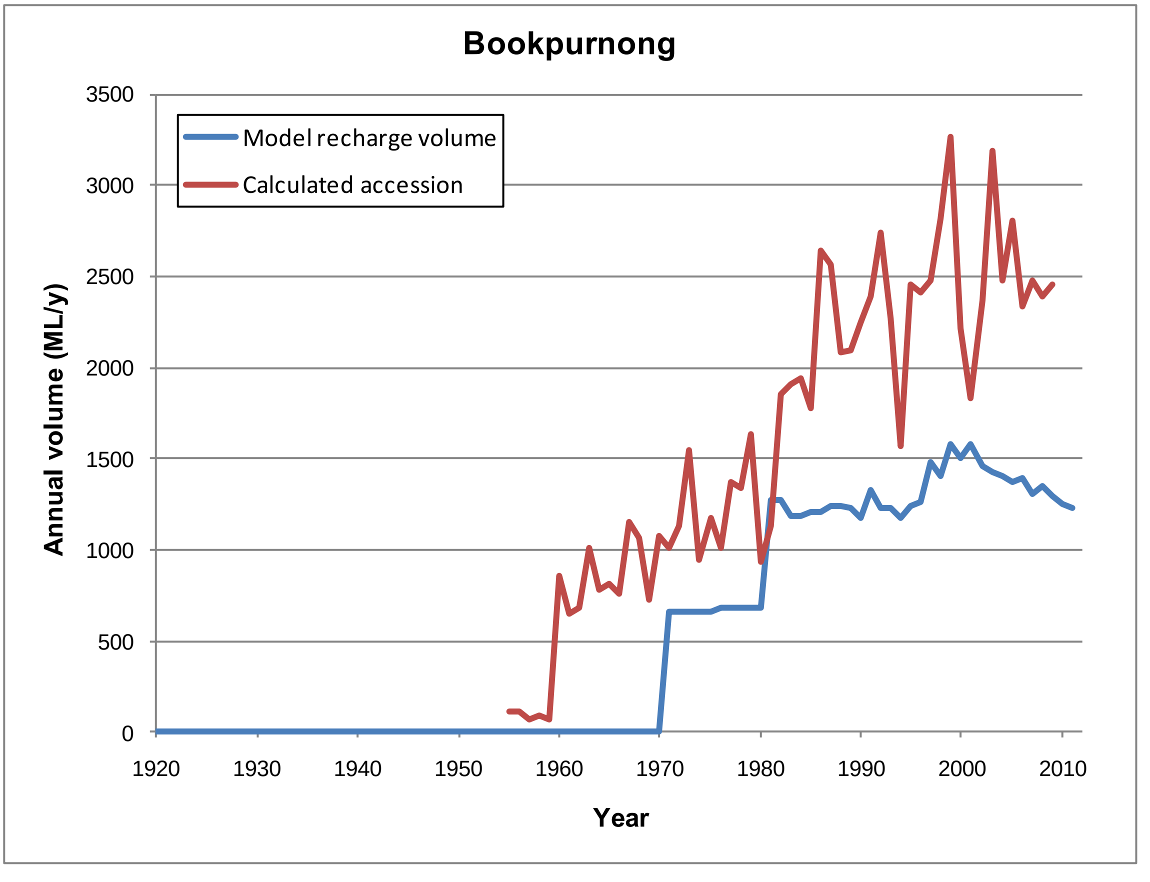
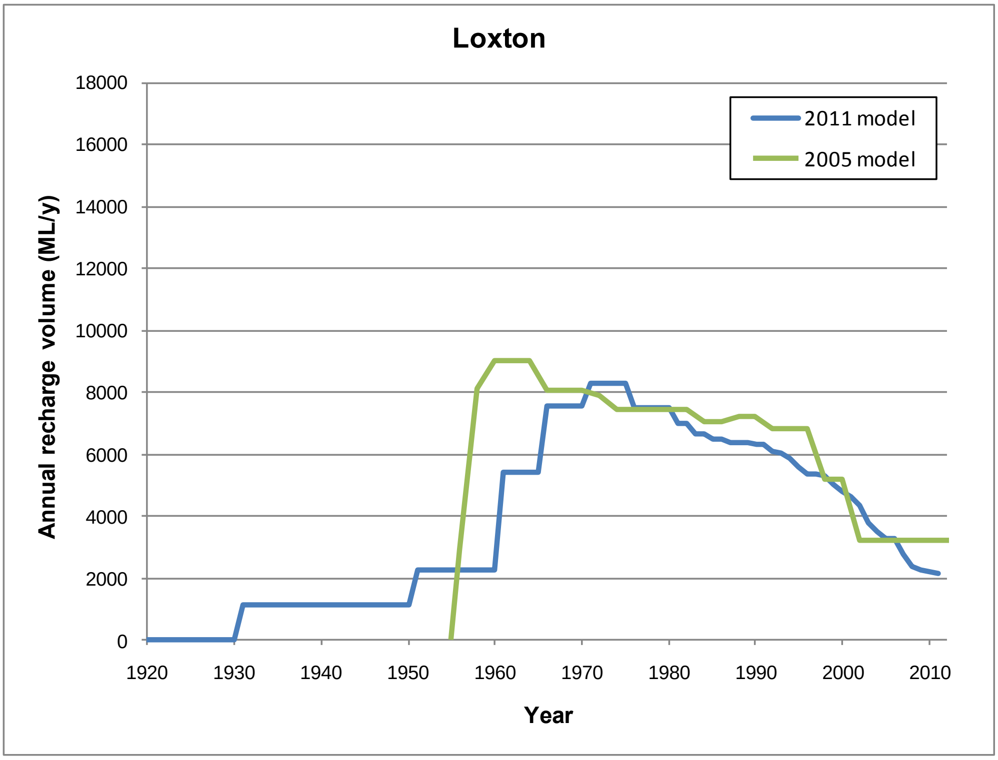


Figure 4.23 Comparison of the total recharge volumes in the calibrated model with the calculated accession from Laroona Environmetrics 2011 (Appendix C-1)



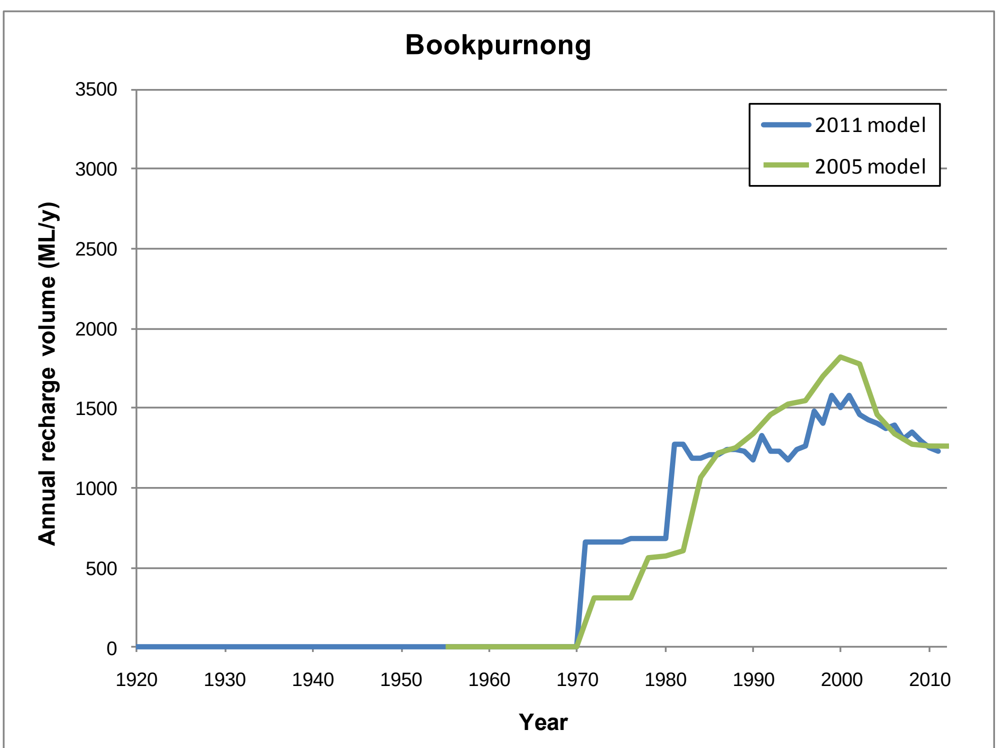


Figure 4.24 **Comparison of the total recharge volumes between the 2005 model (Yan et al. 2005) and 2011 model**

The calibrated model has a specified maximum (i.e. potential) ET rate of 250 mm/y and an extinction depth of 1.5 m. The model result shows that ~65 mm/y of groundwater is lost as ET (i.e. actual ET) in the floodplain within the project area, which matches well with the recent CSIRO estimates. This provides a higher confidence in the ET applied in the model.

4.5. MODEL WATER BALANCE

Table 4.3 reports the water balance for the Loxton–Bookpurnong project area in layer 1, i.e. the Monoman Sands and Loxton Sands aquifers which is in direct contact with the river valley or the River Murray. The details of flow are given for the steady-state period (prior to irrigation), the beginning of 2005 (typical irrigation conditions prior to SIS) and 2010 (with SIS and drought water restrictions).

Under the natural conditions of the steady-state model, most of the flows into the aquifers are from losing-stream reaches of the river (8.2 ML/d) which were mainly upstream of Lock 4 and side end of floodplain areas. Total regional flow is 1.8 ML/d, including 1.2 ML/d of lateral flow and 0.6 ML/d of vertical leakage from the Murray Group. The main outflows from the aquifers are lateral regional flow (5.7 ML/d), evapotranspiration (3.1 ML/d) and flow into gaining reaches of the River Murray (1.1 ML/d). Recharge from rainfall is negligible.

At the beginning of 2005, the conditions and water balance were different. Inflows to the aquifers have more than doubled, mostly due to increasing recharge from irrigation (12.7 ML/d). Flow from losing reaches of the Murray is still significant (6.2 ML/d) but has decreased by 2 ML/d due to the growing irrigation-water mound (higher watertable) which increases the gradient towards the river. The increase in inflows leads to an increase in flow to the River Murray's gaining reaches (6.8 ML/d), regional lateral flow (7.7 ML/d, an increase of 2 ML/d from steady-state), to the Murray Group via downward leakage (3.8 ML/d) and into storage where groundwater mounds are still growing (2.7 ML/d). There is a small increase in evapotranspiration.

By 2010, total recharge has declined due to SIS, irrigation efficiency improvement and water restriction during drought. The recharge has declined by 3.3 ML/d to 9.4 ML/d. The SIS have been commissioned from 2005 and the SIS extract 10 ML/d in 2010. The main impact is on the River Murray: groundwater flow from the River Murray (losing) increased by 5 ML/d (to 11.3 ML/d) and groundwater flow entering the River Murray (gaining) declines to 2.5 ML/d. Water is also released from aquifer storage. There is a small increase in evapotranspiration.

In summary, the natural water balance is dominated by the exchange of water between the River Murray and the watertable aquifers and regional lateral flow. In 2005, high recharge from irrigation induced increasing groundwater into the River Murray and small proportion downwards flow into the Murray Group. Since the SIS have commenced, groundwater flux entering the River Murray declines substantially, as designed. These model results are consistent with the hydrogeological understanding of the region.

Table 4.3 Water balance for the Loxton–Bookpurnong area

Water Balance Component INFLOW to the aquifer	Water volume (ML/d)		
	Steady-state	2005	2010
Withdrawal from storage	0.000	3.604	5.687
Recharge from irrigation and rainfall	0.065	12.697	9.420
River leakage (river losses to the aquifer)	8.195	6.226	11.278
Lateral flow (into the project area)	1.200	0.824	0.805
Vertical flow (Upward from MGL)	0.582	1.159	1.188
Total IN	**10.040**	**24.510**	**28.377**
Water Balance Component OUTFLOW from the aquifer	**Water volume (ML/d)**		
	Steady-state	**2005**	**2010**
Flow to storage	0.000	2.687	1.872
SIS Wells (include horizontal drainage well & cliff toe drain)	0.000	0.000	10.017
Cliff seepage (model drain cells)	0.000	0.192	0.043
ET	3.105	3.354	2.925
River leakage (discharge to the river)	1.109	6.767	2.469
Lateral flow (outward from the project area)	5.651	7.721	7.530
Vertical flow (downward to MGL)	0.175	3.789	3.522
Total OUT	**10.041**	**24.510**	**28.377**
Total IN - Total OUT	**-0.001**	**0.000**	**0.000**

5. MODEL SCENARIOS AND PREDICTIONS

The calibrated historical model is used as a basis for estimating past and future salt loads to the River Murray under a number of scenarios. Most of the model scenarios are those required for the MDBA's BSMS Salinity Register such as estimating how salt loads vary due to mallee clearance, irrigation and the SIS.

Scenarios 5 and 8c assist State decisions on salinity management.

The scenarios have been developed progressively in consultation with State (DFW) and MDBA staff. The aims are to:

1. evaluate the impact of various accountable actions, to be recorded on the MDBA Salinity Registers A and B, including:
    a. the impact of the various pre- and post-1988 actions on the groundwater flux and salt load entering the River Murray
    b. the impact of improved irrigation practices (IIP) and the rehabilitation (RH) of distribution systems
    c. the potential benefits from SIS.
2. determine the State and Federal responsibility for cost sharing
3. satisfy the reporting requirements of:
    a. Schedule C of the Murray-Darling Basin Agreement 1992
    b. the Basin Salinity Management Strategy Operational Protocols 2003.

The modelling scenarios are summarised in Table 5.1 and are discussed in detail in the following sections.

To prevent the over-estimation of salinity credits, future scenarios presume that recharge due to irrigation will be similar to 2005 rates, prior to the water restrictions imposed during the drought years of 2006 to 2010. The minimum recharge rate is set conservatively at 100 mm/y, unless the calibration model indicates a lower recharge rate prior to 2006. Meaning that the impacts of improved irrigation practices and rehabilitation are also not over-estimated. This is consistent with the MDBA approach that the Salinity Register entries should not include the impact of climate sequence.

To satisfy the Salinity Register requirements, the annual salt load (t/d) from 1988 up to CY100 (current year + 100 years) is reported in a summary section and detailed values are in Appendix B-1. The results will be input into MSM-BIGMOD to calculate the in-river EC impact at Morgan.

Table 5.2 provides definitions for some terms used for South Australian numerical models for Salinity Register estimates. There are some definitions included in the table that are not used in the current project.

All scenarios have the same discretisation, convergence criteria, parameters and boundary conditions as those adopted in the calibrated transient historical model described in Section 3, except as noted in Sections 5.2 to 5.10 below. The model results are compared in Section 5.11.

Table 5.1 Summary of modelled scenarios and conditions adopted for Loxton–Bookpurnong

Scenario and Number	Name	Simulated period	Irrigation development area	IIP & RH	SIS
Calibrated model	Historical	1920–2010	Foot print of irrigation history	Yes	Yes
Scenario–1	Natural system	Steady-state	None	–	–
Scenario–2	Mallee clearance	1988–2110*	None (but includes mallee clearance area)	–	–
Scenario–3a	Pre-1988, no IIP, no RH	1988–2110*	Pre-1988	No	–
Scenario–3c	Pre-1988, with IIP and with RH	1988–2110*	Pre-1988	Yes	No
Scenario–4	Current irrigation	1988–2110*	Pre-1988 + post-1988	Yes	No
Scenario–5	Current plus future irrigation	1988–2110*	Pre-1988 + post-1988 + future development	Yes	No
Scenario–8a	Current irrigation plus constructed SIS	1988–2110*	Pre-1988 + post-1988	Yes	Yes
Scenario–8b	Pre-1988, with IIP and with RH plus constructed SIS	1988–2110*	Pre-1988	Yes	Yes
Scenario–8c	Current plus future irrigation plus constructed SIS	1988–2110*	Pre-1988 + post-1988 + future development	Yes	Yes

*Simulation period represents the period for model outputs which is required for the Salinity Register entries. Conditions and input details are documented in a later section.

5.1. RECHARGE APPLIED IN IRRIGATION SCENARIOS

As a result of the model calibration described in the previous section, the following areas and rates are utilised in the scenarios intended to simulate the impact of accountable irrigation actions on groundwater salt loads to the River Murray:

- for pre-1988 irrigation: two scenarios, each using the irrigation area at 1988 to define the recharge area, with one scenario adopting the varying recharge rates as provided by calibration and the other maintaining the calibrated recharge rate at 1988 into the future (the 'do nothing' scenario). Comparison of these two scenarios will provide the benefit gained by reduction in recharge rates attributed to improved irrigation practices and rehabilitation.
- for post-1988 irrigation: the post-1988 irrigation areas will be used to define the recharge area and the calibrated recharge rates at 2005 are used to define the current average condition (representing average conditions prior to water restrictions).
- for future irrigation: no lag time is applied in areas where an irrigation water mound exists and an initial lag time is applied if the new developed area is located away from existing irrigation water mounds.

More detail is given in the descriptions of the individual scenarios which follow.

Table 5.2 Definitions of conditions for scenarios

Recharge	Irrigation drainage and/or rainfall infiltration reaching the groundwater table.
Initial lag time **(New irrigation development)**	Time (years) taken for recharge to reach the groundwater table. Lag time is affected by depth to groundwater table and the presence and properties of aquitards. As predicted by SIMRAT, initial lag time can be several decades.
Late lag time **(Existing irrigation area with water mound)**	Time (years) taken for recharge to reach the groundwater table in an existing irrigation area where the irrigation water wetting front has already reached the watertable. This will therefore apply to irrigation areas where an irrigation water mound exists. According to recent research, late lag time can be shorter than a couple of months.
Current year (CY)	e.g. 2010.
Current year + 100 (CY100)	100 years from the current year (e.g. if current year is 2010, then CY100 = 2110).
Pre-1988 irrigation	Irrigation development area and recharge rates that occurred prior to 01/01/1988.
Post-1988 irrigation	Irrigation development area and recharge that occurred between 01/01/1988 and the current year.
Future development	Future irrigation development area and recharge (assuming recharge of 100 mm/y) resulting from activation of already allocated water that is assumed to occur after the current year (i.e. 2015).
Mallee clearance	Clearance of natural vegetation commencing during the 1920s, resulting in increased recharge to the groundwater table in dry-land (non-irrigated) areas. No major clearing of native vegetation occurred after 1988.
Improved Irrigation Practices (IIP)	Irrigation efficiency improved over time as sprinkler and drip systems replaced flood irrigation via earth channels. In this report, IIP means the greatly improved technology, monitoring soil system and management of irrigation systems after 1988.
Rehabilitation (RH)	Replacement of leaky concrete water distribution channels with pipelines after 1988 (e.g. in the Loxton area rehabilitation commenced in 2002) resulted in reduced water transportation losses which are reflected by reduced recharge to the groundwater table. Rehabilitation in pre-1988 irrigation areas is explicitly omitted from Salinity Register scenarios.
Concept Design SIS	The Concept Design SIS designed to intercept the maximum groundwater flux and salt load resulting from all past, present and future irrigation development, or the naturally occurring groundwater flux where this is large and must be intercepted and

	used in the MDBC Approval Submission process to determine the: • cost-benefit ratio • sharing of costs between the State and the MDBC • total SIS wellfield flux for pipeline design. The Concept Design SIS may not be able to control 100% of the salt load due to technical or economic constraints. The modelled Concept Design SIS may not represent the actual numbers of production wells that are eventually constructed.
Revised Design SIS	During the investigation and construction phase of an SIS, expectations regarding the effectiveness of the SIS, or its extent, may be revised due to technical issues that arise, resulting in the Revised Design SIS. The Revised Design SIS represents the current view of what the final constructed and operating SIS is most likely to be. The Revised Design SIS may change, as issues that have arisen are resolved. The Revised Design SIS may not be able to control 100% of the salt load due to technical or economic constraints. The modelled Revised Design SIS may not represent the actual number of production wells that are eventually constructed.
As Constructed SIS	Model representation of the on-ground As Constructed SIS infrastructure using historical pumping rates and forward projections that may or may not be constrained by production well pumping capacity or pipeline capacity or disposal basin capacity. Significant differences to the Concept or Revised SIS may result in the need to recalibrate the model at the time of the 5-year review. The As Constructed SIS may not be able to control 100% of the salt load due to technical or economic constraints. The modelled As Constructed SIS may result in the need for model recalibration and re-accreditation, if the actual numbers of on-ground wells are different to those that have been applied in the Concept and Revised Design SIS.
Modelled result	Output from the calibrated model (e.g. potentiometric head distribution) that can be compared to observed data.
Predicted result	Output from the prediction model has been used to determine the future result of a particular scenario.

5.2. SCENARIO 1: NATURAL SYSTEM

Scenario 1 estimates the baseline groundwater flux and salt load entering the River Murray post-river regulation but prior to irrigation development.

The following conditions are applied to the model (LB2011_SS):

- the model is steady-state
- River Murray levels are post-regulator (i.e. the river locks are included)
- there is no land clearance
- there is no irrigation development
- recharge rates everywhere are 0.1 mm/y, based on CSIRO studies of uncleared mallee.

There are no SIS in this scenario. This scenario is identical to the steady-state model used during calibration to provide initial conditions for the transient historical model.

The salt load to the River Murray is 2.9 t/d in Loxton and 22.2 t/d in Bookpurnong. This is the baseline salt load for the study area. Salt loads are low in Loxton as the head gradient in the Loxton Sands adjacent to the floodplain is fairly flat (Fig. 4.1). The higher salt load at Bookpurnong is partly due to the very high natural salinity of the groundwater and the influence of Lock 4. Table 5.3 gives the modelled flux and salt load entering the River Murray in the Loxton–Bookpurnong area for Scenario 1.

Table 5.3 Modelled groundwater flux and salt load in the Loxton–Bookpurnong area (Scenario 1: Natural Condition)

	Loxton	**Bookpurnong**
Flux to river (m^3/d)	*132*	*977*
Salt load to river (t/d)	2.9	22.2

5.3. SCENARIO 2: MALLEE CLEARANCE

Scenario 2 simulates the clearance of the native mallee vegetation and subsequent increase in recharge rates. It estimates the resulting hydrological changes, groundwater flux and salt load entering the River Murray.

The following conditions are applied to the transient model (LB2011_S2):

- the simulated time period is 1920 to CY100
- land clearance prior to 1920 is assumed to have occurred in 1920
- recharge due to mallee clearance is represented by zones and rates estimated by CSIRO and provided by DENR (formerly the Department of Environment and Heritage), except where inconsistent with aerial photography. These recharge rates are greater than or equal to 0.1 mm/y, increasing in some areas to ~10 mm/y, with changes occurring every 10 years. The rates and zones are given in Appendix A-1.
- the vegetation outside the cleared zones is mallee, so a recharge rate of 0.1 mm/y is applied
- there is no irrigation development.

Table 5.4 summarises the predicted flux and salt load entering the River Murray in the Loxton–Bookpurnong area. Further results are given Appendix B-1. The starting values in 1920 are those given for Scenario 1 in Table 5.3. The salt load increases almost threefold at Loxton from 2.9 to 8.3 t/d from 1920 to 2110. The salt load increases from 22.2 to 25.6 t/d at Bookpurnong over the same period, a 15% increase. Mallee clearance impacts the Loxton reach more than the Bookpurnong reach, but overall salt loads are low when compared to other scenarios (see Section 5.11).

Table 5.4 Predicted groundwater flux and salt load (Scenario 2: Mallee clearance)

	Year					
	1988	**2000**	**2010**	**2015**	**2050**	**2110**
Loxton						
Flux to river (m^3/d)	*144*	*153*	*164*	*170*	*226*	*387*
Salt load to river (t/d)	3.2	3.4	3.6	3.7	4.9	8.3
Bookpurnong						
Flux to river (m^3/d)	*983*	*985*	*987*	*988*	*1007*	*1088*
Salt load to river (t/d)	22.4	22.4	22.5	22.5	23.1	25.6

5.4. SCENARIO 3A: PRE-1988 IRRIGATION WITHOUT IMPROVED IRRIGATION PRACTICES OR REHABILITATION

Scenario 3a simulates what would have happened if irrigation development and practices had remained unchanged from 1988. This scenario is used in conjunction with Scenario 3c to estimate the salinity benefits of improvements in irrigation practice and the rehabilitation of irrigation infrastructure after 1988. It estimates the resulting hydrological changes, groundwater flux and salt load entering the River Murray.

The following conditions are applied to the transient model (LB2011_S3a):

- the simulated time period is from 1920 to CY100
- the model is identical to the calibrated historical model until 1 January 1988
- the recharge zones for 1988 to CY100 are based on the 1988 irrigation development area
- recharge rates for 1988 to CY100 are assigned as follows and are given in Appendices A-2 and A-3:
  - in established irrigation areas, it is assumed that there is negligible lag time for recharge to pass from the irrigation drainage root zone to the groundwater table, so the recharge rates from 1988 in the historical model are applied
  - there are irrigation areas planted before 1988 where the lag time means that root zone drainage water has not yet reached the watertable by 1988. In those areas, recharge rates may still increase after 1988 to reflect the delay. Recharge becomes constant no more than lag time years after 1988.
  - in areas where irrigation did not exist in 1988, the mallee recharge rate of 0.1 mm/y is adopted
- the results for 1988 to CY100 are reported as required by the MDBA for the Salinity Register.

Table 5.5 summarises the predicted flux and salt load entering the River Murray in the Loxton–Bookpurnong area. Further results are given Appendix B-1. The starting values in 1920 are those given for Scenario 1 in Table 5.3. The salt load increases from 2.9 to 114.8 t/d from 1920 to 2110 at Loxton. The salt load increases from 22.2 to 120.6 t/d at Bookpurnong over the same period, almost a six-fold increase.

Table 5.5 Predicted groundwater flux and salt load (Scenario 3a: Pre-1988, no IIP, no RH)

	Year					
	1988	**2000**	**2010**	**2015**	**2050**	**2110**
Loxton						
Flux to river (m^3/d)	*4513*	*4872*	*5133*	*5222*	*5488*	*5600*
Salt load to river (t/d)	92.2	99.6	105.0	106.8	112.4	114.8
Bookpurnong						
Flux to river (m^3/d)	*2633*	*3583*	*3901*	*3967*	*4168*	*4277*
Salt load to river (t/d)	70.0	98.6	108.6	110.7	117.1	120.6

5.5. SCENARIO 3B: PRE-1988 IRRIGATION WITH IMPROVED IRRIGATION PRACTICES BUT NO REHABILITATION

Scenario 3b simulates what would have happened if irrigation development and infrastructure had remained unchanged from 1988 but improvements had been made in irrigation practices.

This scenario has been simulated in earlier reports so that the impact of improved irrigation practices could be estimated separately from the impact of rehabilitation. However, this scenario is not required for the Salinity Registers. Note also that there is no clear and established methodology to estimate the decline in recharge due to improved irrigation practices separately from rehabilitation. For these reasons, this scenario is not simulated in this study.

5.6. SCENARIO 3C: PRE-1988 IRRIGATION WITH IMPROVED IRRIGATION PRACTICES AND REHABILITATION

Scenario 3c simulates what would have happened if the irrigation development area had remained unchanged from 1988, but improvements in irrigation practice and rehabilitation of infrastructure had still occurred. This scenario is used in conjunction with Scenario 3a to estimate the salinity benefits of improvements in irrigation practice and the rehabilitation of irrigation infrastructure after 1988. It estimates the resulting hydrological changes, groundwater flux and salt load entering the River Murray.

The following conditions are applied to the transient model (LB2011_S3c):

- the simulated time period is from 1920 to CY100
- the model is identical to the calibrated historical model until 1 January 1988
- the recharge zones for 1988 to CY100 are based on the 1988 irrigation development area recharge rates for 1988 to CY100 are assigned as follows and are given in Appendices A-2 and A-3:
  - the rates from the calibrated model are used until 2006, to reflect best estimates of the impact of rehabilitation and improved irrigation practice
  - from 2006 until 2010 (CY), the calibrated rates from the historical model are adopted, except where these fall below 100 mm/y due to the drought restrictions of those years. This is because the Salinity Register scenarios should not include climate sequence impacts. In those zones, the recharge rates are instead held constant at 100 mm/y from 2006 to CY100.

   - zones with a calibrated recharge rate greater than or equal to 100 mm/y are assumed to benefit from improved irrigation practices from CY, when they are set to 100 mm/y
   - zones with a calibrated recharge rate less than 100 mm/y prior to the drought restriction period of 2006 to 2010 are fixed at the lower rate, where infrastructure such as a CDS are present, unless the lower rate is likely to be due to lag times in newer irrigation developments, in which case the recharge rate will rise to a maximum of 100 mm/y
   - in areas where irrigation did not exist in 1988, the mallee recharge rate of 0.1 mm/y is adopted
- the results for 1988 to CY100 are reported as required by the MDBA for the Salinity Register.

Table 5.6 summarises the predicted flux and salt load entering the River Murray in the Loxton–Bookpurnong area. Further results are given Appendix B-1. The starting values in 1920 are those given for Scenario 1 in Table 5.3. The salt load increases from 2.9 to 59.8 t/d from 1920 to 2110 at Loxton, which is half that estimated for Scenario 3a without improved irrigation practices and rehabilitation. The salt load increases from 22.2 to 82.1 t/d at Bookpurnong over the same period, which is less than the 120.6 t/d of Scenario 3a.

Table 5.6 Predicted groundwater flux and salt load (Scenario 3c: Pre-1988, with IIP and with RH)

	Year					
	1988	**2000**	**2010**	**2015**	**2050**	**2110**
Loxton						
Flux to river (m^3/d)	*4513*	*4147*	*3538*	*3355*	*2955*	*2936*
Salt load to river (t/d)	92.2	84.4	71.9	68.2	60.1	59.8
Bookpurnong						
Flux to river (m^3/d)	*2633*	*3132*	*2876*	*2882*	*2938*	*2971*
Salt load to river (t/d)	70.0	85.2	79.0	79.2	81.1	82.1

5.7. SCENARIO 4: CURRENT IRRIGATION

Scenario 4 simulates what would have happened if the current irrigation development and practices had continued indefinitely without the construction of the SIS. In conjunction with Scenario 8a, it can be used to estimate SIS benefits. It estimates the resulting hydrological changes, groundwater flux and salt load entering the River Murray. As the Salinity Register entries should not include the impact of climate sequence, the model does not simulate the contraction of irrigation area and reduction in recharge rates due to drought restrictions from 2006 to 2010. The irrigation areas and rates for future years are based on those of 2005 rather than 2010, as 2010 is presumed to be anomalous.

The following conditions are applied to the transient model (LB2011_S4):

- the simulated time period is from 1920 to CY100
- the model is identical to the calibrated historical model until 1 January 2006
- the recharge zones for 2006 to CY100 are based on the 2005 irrigation development area
- recharge rates for 2006 to CY100 are assigned as follows and are given in Appendices A-2 and A-3:
   - from 2006 until 2010 (CY), the calibrated rates from the historical model are adopted, except where these fall below 100 mm/y due to the drought restrictions of those years.

In those zones, the recharge rates are instead held constant at 100 mm/y from 2006 to CY100.
    - zones with a calibrated recharge rate greater than or equal to 100 mm/y are assumed to benefit from improved irrigation practices from CY, when they are set to 100 mm/y
    - zones with a calibrated recharge rate less than 100 mm/y prior to the drought restriction period of 2006 to 2010 are fixed at the lower rate, where infrastructure such as a CDS are present, unless the lower rate is likely to be due to lag times in newer irrigation developments, in which case the recharge rate will rise to a maximum of 100 mm/y
    - an initial lag time of 10 years and recharge rates of 100 mm/y were applied in irrigation areas developed after 2000
    - in areas where irrigation did not exist in 2005, the mallee recharge rate of 0.1 mm/y is adopted
- the results for 1988 to CY100 are reported as required by the MDBA for the Salinity Register.

Table 5.7 summarises the predicted flux and salt load entering the River Murray in the Loxton–Bookpurnong area. Further results of the predicted flux of saline groundwater and salt load are given in Appendix B-1. The results are discussed further in Section 5.11.

Table 5.7 Predicted groundwater flux and salt load (Scenario 4: Current irrigation)

	Year					
	1988	**2000**	**2010**	**2015**	**2050**	**2110**
Loxton						
Flux to river (m^3/d)	*4513*	*4148*	*3593*	*3452*	*3542*	*3891*
Salt load to river (t/d)	92.2	84.4	73.2	70.5	72.4	79.5
Bookpurnong						
Flux to river (m^3/d)	*2633*	*3133*	*3019*	*3279*	*4442*	*4722*
Salt load to river (t/d)	70.0	85.2	83.6	91.3	128.4	137.3

5.8. SCENARIO 5: CURRENT PLUS FUTURE EXPANSION OF IRRIGATION

Scenario 5 simulates what would have happened if the SIS had not been constructed but irrigation development continued after 2010. It is identical to Scenario 4 except that irrigation development continues after 2010, so it is used to estimate the salinity impact of future (post-2010) irrigation development. It estimates the resulting hydrological changes, groundwater flux and salt load entering the River Murray. Note that this scenario is not required by the MDBA for the Salinity Registers but informs State policy.

The following conditions are applied to the transient model (LB2011_S5):
- the simulated time period is from 1920 to CY100
- the model is identical to the Scenario 4 model until 1 January 2015
- the recharge zones and rates for 2015 to CY100 are identical to Scenario 4 except that additional irrigation recharge zones are included, based on potential new development areas estimated by DFW and the PIRSA Policy and Planning Group (Fig. 2.10). A recharge rate of 100 mm/y is applied in the new zones. No lag time is included as the new irrigation areas are located in or immediately adjacent to existing irrigation areas.

- the recharge rates are given in Appendices A-2 and A-3
- the results for 1988 to CY100 are reported as required by the MDBA for the Salinity Register.

Table 5.8 summarises the predicted flux and salt load entering the River Murray in the Loxton–Bookpurnong area. Further results of the predicted flux of saline groundwater and salt load are given in Appendix B-1. The results are discussed further in Section 5.11.

Table 5.8 Predicted groundwater flux and salt load (Scenario 5: Current plus future irrigation)

	Year					
	1988	**2000**	**2010**	**2015**	**2050**	**2110**
Loxton						
Flux to river (m^3/d)	4513	4148	3593	3452	3794	4230
Salt load to river (t/d)	92.2	84.4	73.2	70.5	77.5	86.4
Bookpurnong						
Flux to river (m^3/d)	*2633*	*3133*	*3019*	*3296*	*4604*	*4929*
Salt load to river (t/d)	70.0	85.2	83.6	91.8	133.3	143.7

5.9. SCENARIO 8A: CURRENT IRRIGATION WITH AS-CONSTRUCTED SIS

Scenario 8a simulates what will happen if the current irrigation development and practices continue indefinitely and the SIS continue to operate as currently constructed. It is identical to Scenario 4 except that it includes the SIS, so the two scenarios can be compared to estimate SIS benefits. It estimates the resulting hydrological changes, groundwater flux and salt load entering the River Murray. As with Scenario 4, Scenario 8a does not simulate the impact of the 2006 to 2010 drought restrictions and the irrigation areas and rates for future years are based on those of 2005 rather than 2010, as 2010 is presumed to be anomalous.

The following conditions are applied to the transient model (LB2011_S8a):

- the simulated time period is from 1920 to CY100
- the model is identical to the Scenario 4 model except that SIS are included
- the SIS are represented as follows:
  - the Cliff Toe Drain and the Horizontal Drainage Well are simulated using the MODFLOW Drain Package as in the calibrated historical model (see Section 3.6.5)
  - the production bores are simulated using the Drain Package (note that the calibrated historical model employed the Well Package). Drain cells are used rather than fixed pump rates, as the SIS operators will vary pump rates over time to achieve target heads at the midpoint observation bores. Different drain elevation and conductance values were trialled until the model achieved the target heads. Where this resulted in pumping rates greater than SIS design limits, the conductance was lowered until the pumping rates were within design limits. To achieve the middle point level equal to or slightly lower than the river level and pumping rates within the actual recorded pumping rates, the adopted drain elevations in the model are around 9.5 m AHD below Lock 4 and around 12.9 m AHD above Lock 4 and the conductance is between 45 and 1000 m^2/d. Appendices A-6 and A-7 provide further detail.
- the results for 1988 to CY100 are reported as required by the MDBA for the Salinity Register.

Table 5.9 summarises the predicted flux and salt load entering the River Murray in the Loxton–

Bookpurnong area. Further results of the predicted flux of saline groundwater and salt load are given in Appendix B-1. The salt loads are significantly lower than those of Scenario 4, as discussed in Section 5.11.

Table 5.9 Predicted groundwater flux and salt load (Scenario 8a: Current irrigation plus SIS)

	Year					
	1988	**2000**	**2010**	**2015**	**2050**	**2110**
Loxton						
Flux to river (m^3/d)	*4513*	*4148*	*1092*	*917*	*894*	*966*
Salt load to river (t/d)	92.2	84.4	21.3	17.4	16.9	18.2
Bookpurnong						
Flux to river (m^3/d)	*2633*	*3133*	*755*	*796*	*978*	*1023*
Salt load to river (t/d)	70.0	85.2	19.6	21.2	28.5	30.3

5.10. SCENARIO 8B: PRE-1988 IRRIGATION WITH AS-CONSTRUCTED SIS

Scenario 8b simulates what would have happened if the irrigation development area had remained unchanged from 1988, but improvements in irrigation practice and rehabilitation of infrastructure had still occurred and the SIS had been constructed. It is identical to Scenario 3c except that it includes the SIS, so the two scenarios can be compared to estimate SIS benefits for cost-sharing calculations. It estimates the resulting hydrological changes, groundwater flux and salt load entering the River Murray.

The following conditions are applied to the transient model (LB2011_S8b):

- the simulated time period is from 1920 to CY100
- the model is identical to the Scenario 3c model except that SIS are included
- the SIS are simulated using the same methodology as Scenario 8a. Appendices A-6 and A-7 provide further detail.
- the results for 1988 to CY100 are reported as required by the MDBA for the Salinity Register.

The results given in Table 5.10 summarise the predicted flux and salt load entering the River Murray in the Loxton–Bookpurnong area. Further results of the predicted flux of saline groundwater and salt load are given in Appendix B-1.

Table 5.10 Predicted groundwater flux and salt load (Scenario 8b: Pre-1988 irrigation plus SIS)

	Year					
	1988	**2000**	**2010**	**2015**	**2050**	**2110**
Loxton						
Flux to river (m^3/d)	*4513*	*4147*	*1074*	*891*	*752*	*743*
Salt load to river (t/d)	92.2	84.4	20.8	16.9	14.2	14.0
Bookpurnong						
Flux to river (m^3/d)	*2633*	*3132*	*743*	*731*	*733*	*738*
Salt load to river (t/d)	70.0	85.2	19.1	18.7	18.8	19.0

5.11. SCENARIO 8C: FUTURE IRRIGATION WITH AS-CONSTRUCTED SIS

Scenario 8c simulates what will happen if irrigation development continues after 2010 and the SIS continue to operate as constructed. It is identical to Scenario 5 except that it includes the SIS, so the two scenarios can be compared to estimate SIS benefits. It estimates the resulting hydrological changes, groundwater flux and salt load entering the River Murray. Note that this scenario is not required by the MDBA for the Salinity Registers but informs State policy.

The following conditions are applied to the transient model (LB2011_S8c):

- the simulated time period is from 1920 to CY100
- the model is identical to the Scenario 5 model except that SIS are included
- the SIS are simulated using the same methodology as Scenario 8a. Appendices A-6 and A-7 provide further detail.
- the results for 1988 to CY100 are reported as required by the MDBA for the EC calculation.

The results given in Table 5.11 summarise the predicted flux and salt load entering the River Murray in the Loxton–Bookpurnong area. Further results of the predicted flux of saline groundwater and salt load are given in Appendix B-1.

Table 5.11 Predicted groundwater flux and salt load (Scenario 8c: Future irrigation plus SIS)

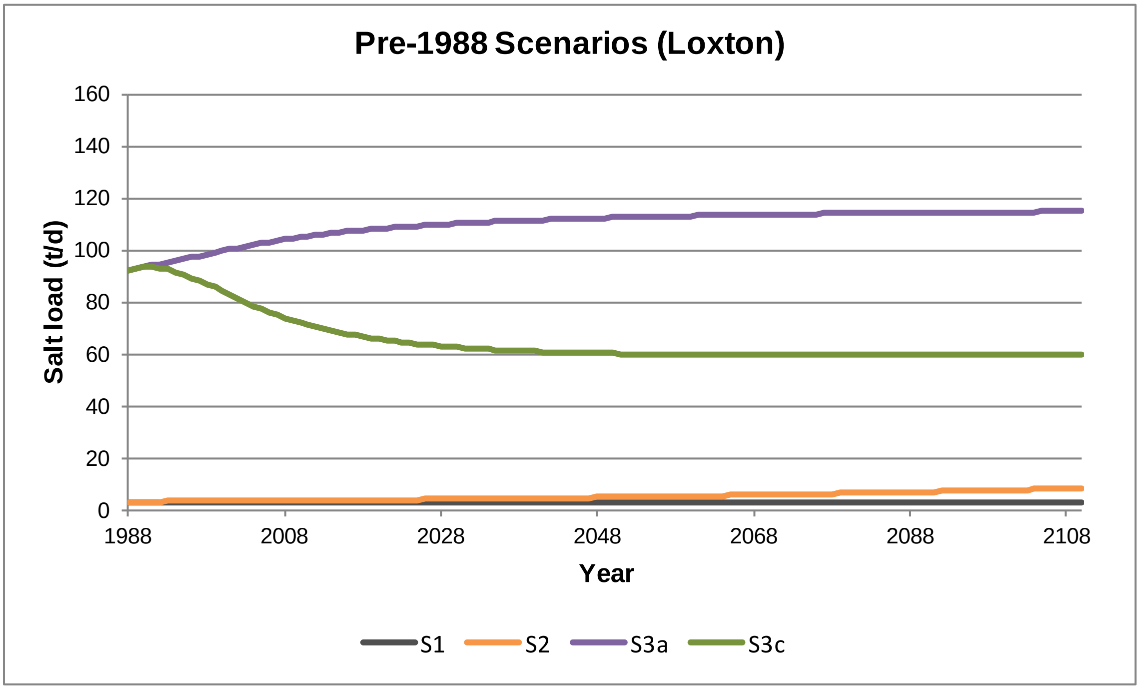
	Year					
	1988	**2000**	**2010**	**2015**	**2050**	**2110**
Loxton						
Flux to river (m^3/d)	*4513*	*4148*	*1092*	*917*	*954*	*1049*
Salt load to river (t/d)	92.2	84.4	21.3	17.4	18.1	19.8
Bookpurnong						
Flux to river (m^3/d)	*2633*	*3133*	*755*	*797*	*995*	*1049*
Salt load to river (t/d)	70.0	85.2	19.6	21.3	29.2	31.3

5.12. COMPARISON OF SCENARIO SALT LOADS TO THE RIVER MURRAY

The model-predicted salt loads entering the River Murray over time for the scenarios are shown in Figures 5.1–5.4. Details of model results (flux and salt load) for all scenarios are given in Appendix B-1.

5.12.1. LOXTON REACH

The first graph in Figure 5.1 compares the Loxton salt loads of scenarios in which (i) irrigation development either never occurred or it ceased in 1988 and (ii) no SIS were built. The baseline salt load of Scenario 1 is a low 3 t/d. Scenario 2 shows the slow rise of salt load due to increased recharge from land clearance; by 2110 it has increased to 8 t/d. Scenario 3a assumes that irrigation development and practices were constant after 1988 and the salt load rises from 92 t/d at 1988 to an equilibrium value of 115 t/d by CY100. The salt load rises after 1988 as the impact of irrigation is not immediate: there is the vertical lag time between accession and recharge and there is also the time taken for a change in recharge to lead to increased flux to the river. Scenario 3c shows how the salt load of Scenario 3a is reduced by post-1988 improvements in irrigation practice and rehabilitation. The equilibrium salt load is 60 t/d, so IIP and RH reduce the salt load by almost half.



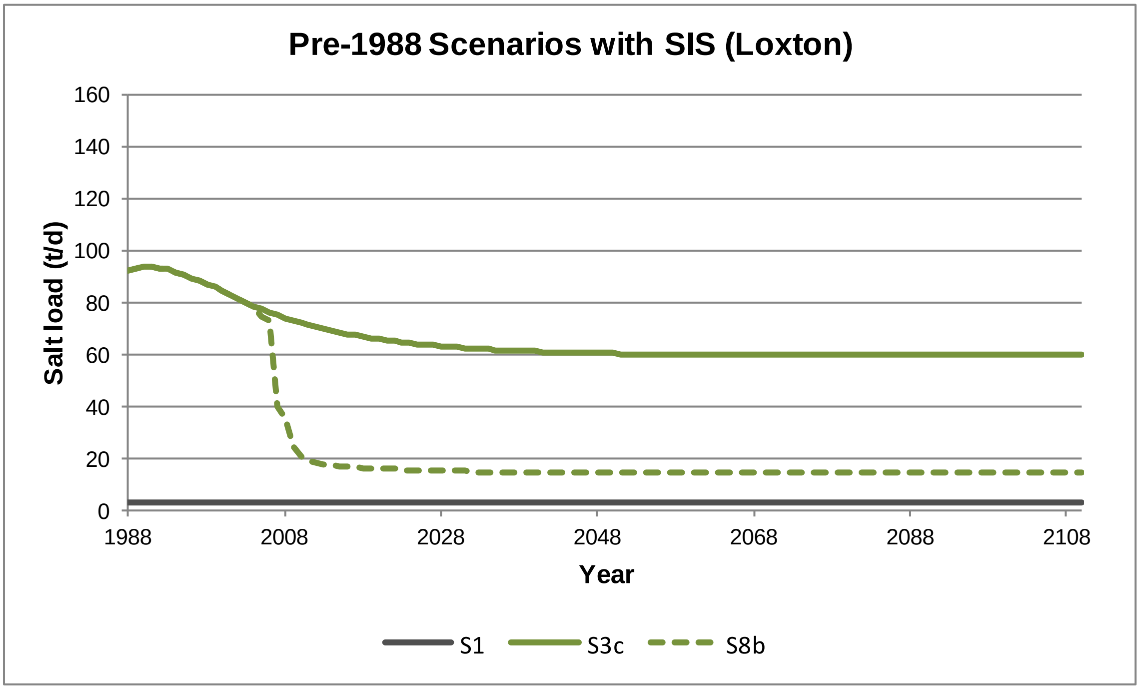
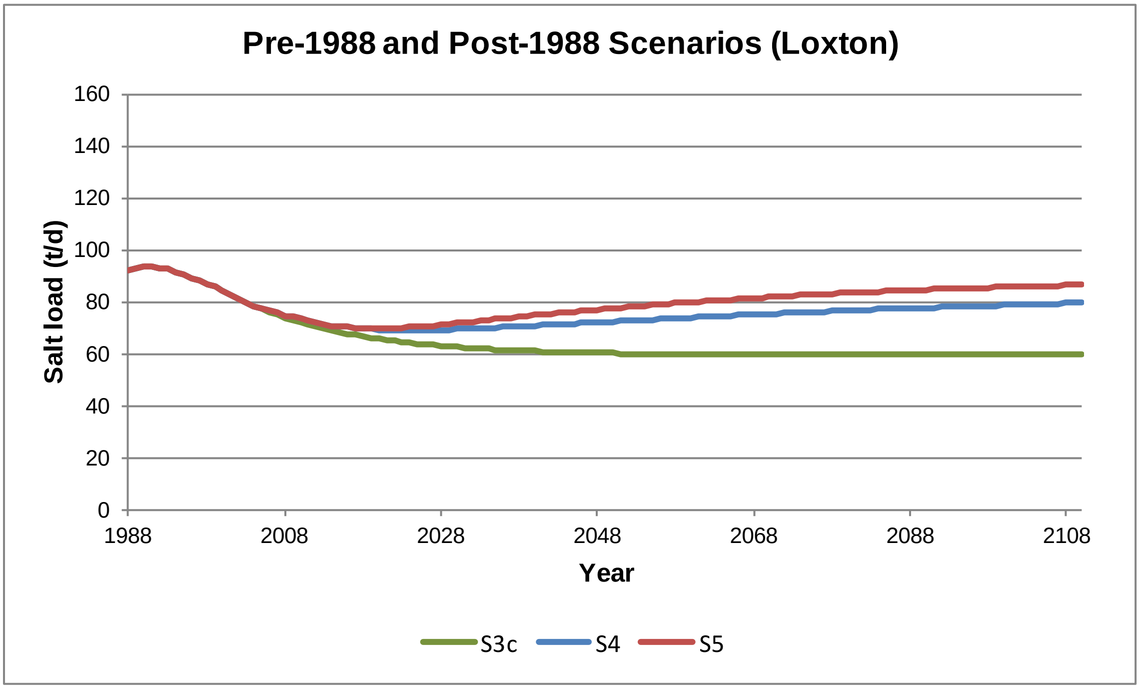


Figure 5.1 Predicted total salt loads entering the River Murray from Loxton for Pre-1988 scenarios



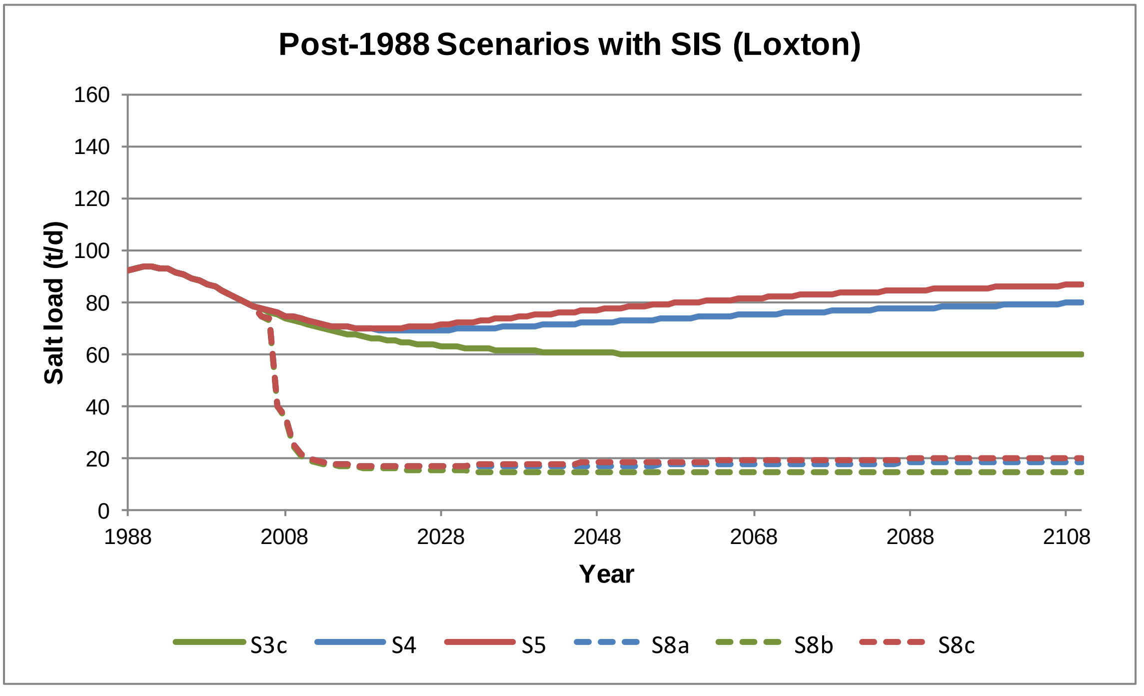
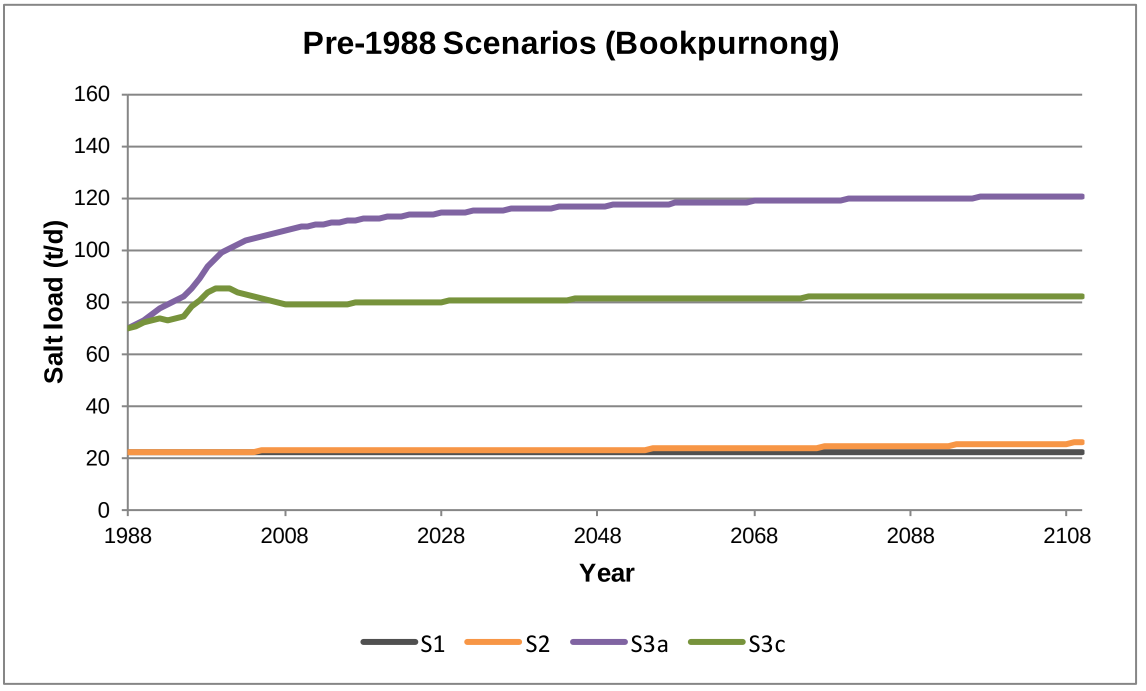


Figure 5.2 Predicted total salt loads entering the River Murray from Loxton for Pre-1988 and Post-1988 scenarios



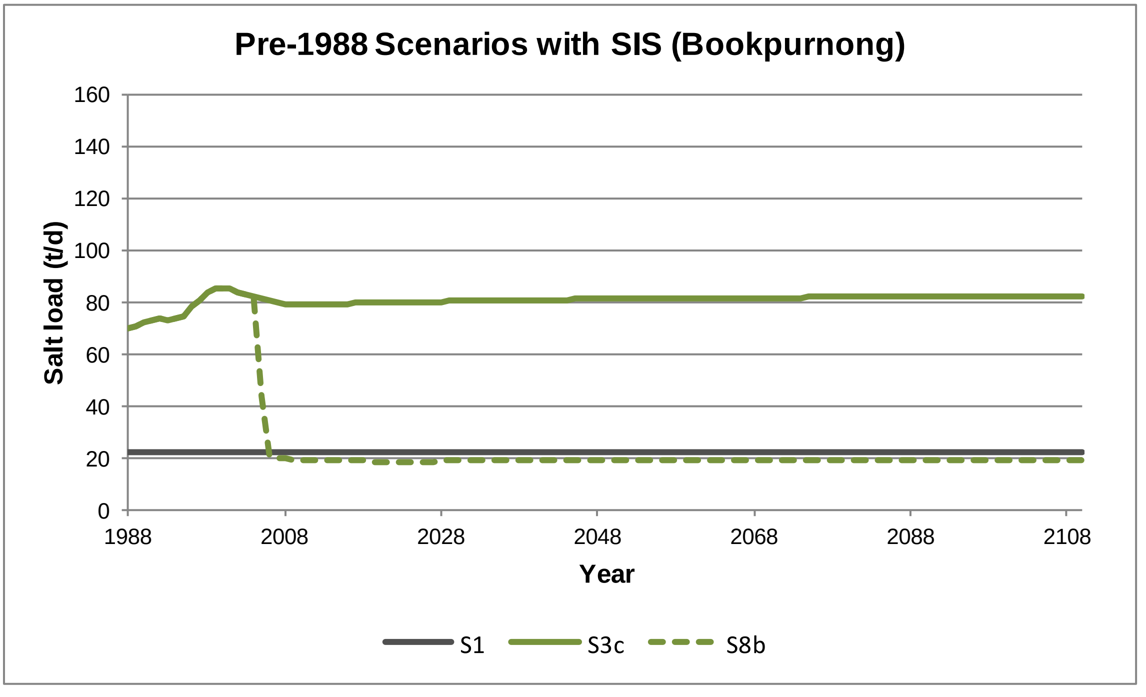
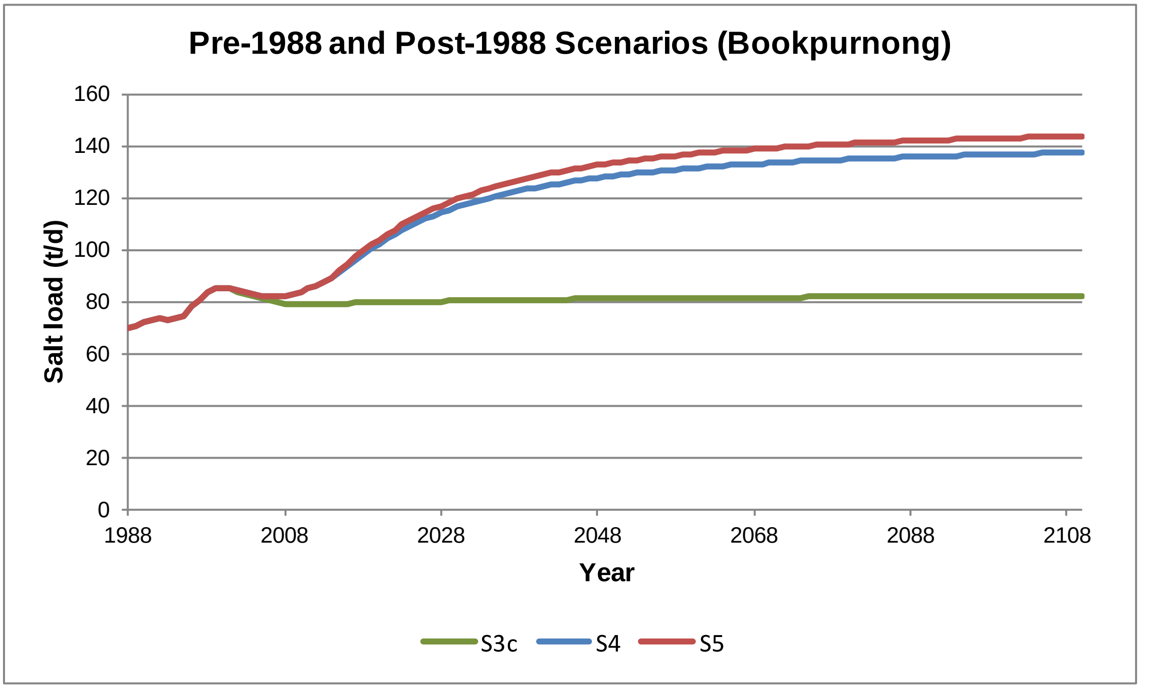


Figure 5.3 Predicted total salt loads entering the River Murray from Bookpurnong for Pre-1988 scenarios



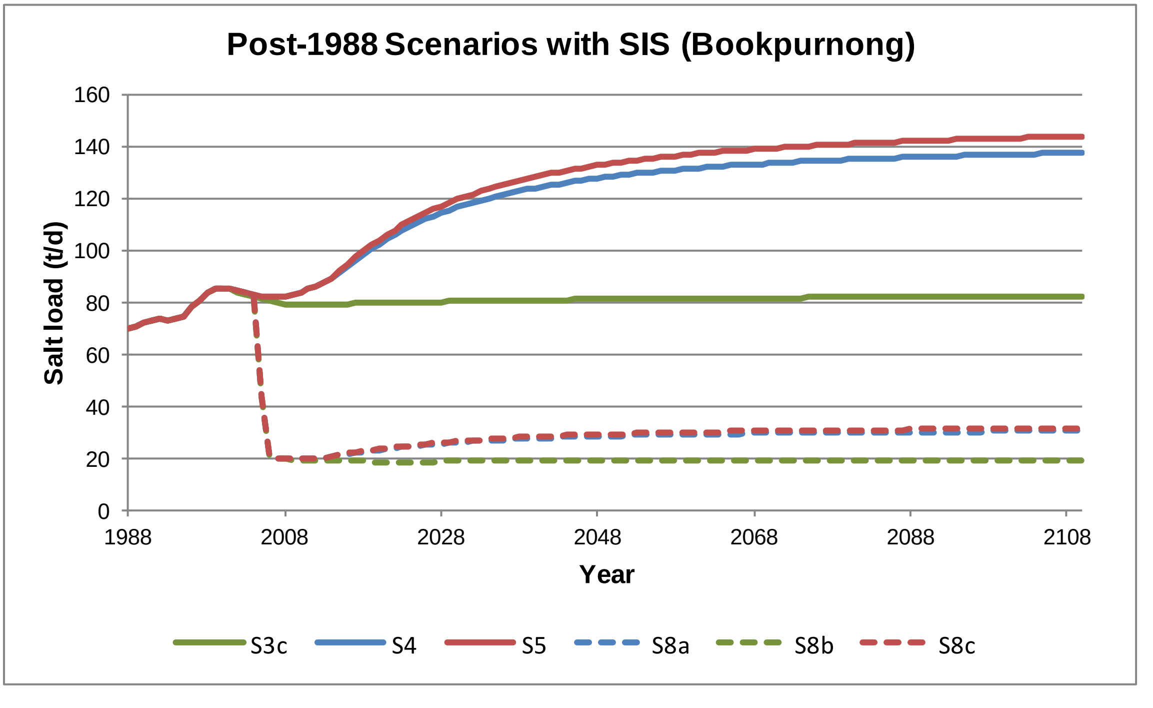


Figure 5.4 Predicted total salt loads entering the River Murray from Bookpurnong for Pre-1988 and Post-1988 scenarios

The second graph in Figure 5.1 shows the salinity benefits of the Loxton SIS for the case when irrigation development ceased in 1988 but improvements were made in irrigation practice and in rehabilitation after 1988. Scenario 8b is identical to Scenario 3c except that it includes the as-constructed SIS. The salt load for Scenario 8b declines sharply as the SIS is constructed in stages from 2005 to 2009. The CY100 salt load is 14 t/d with SIS, a reduction of 46 t/d.

The first graph in Figure 5.2 compares the Loxton salt loads for three irrigation scenarios without SIS. Scenarios 3c, 4 and 5 have similar assumptions for changes in recharge rate over time, due to improved irrigation practices and rehabilitation, but differ in the size of the irrigated area. Scenario 3c has an irrigation area fixed from 1988, Scenario 4 has an irrigation area fixed from 2005 and Scenario 5 includes the 2005 irrigation area and adds some future irrigation areas. Changes in irrigation area from 1988 to 2005 increase the 2110 salt load from 60 to 80 t/d. The estimated future irrigation areas increase the salt loads to 86 t/d by 2110. Note that the Scenario 4 and 5 salt loads are still trending upwards after 2110 due to time taken for changes in irrigation to increase river salt loads.

The second graph in Figure 5.2 shows the salinity benefits of the Loxton SIS for scenarios in which irrigation development continued after 1988. Scenarios 4 and 8a assume current (2005) irrigation area and rates: the SIS reduces the salt load from 80 to 18 t/d by 2110. Scenarios 5 and 8c assume current (2005) and future irrigation area and rates: the SIS reduces the salt load from 86 to 20 t/d by 2110. The salt load for Scenario 8b (1988 irrigation area with IIP and RH and SIS) is included for comparison, showing that the SIS intercept almost all of the additional salt load due to irrigation expansion since 1988. Again, the salt loads are still slowly trending upwards at 2110 due the delayed impact of irrigation on river salt loads.

5.12.2. BOOKPURNONG REACH

The first graph in Figure 5.3 compares the Bookpurnong salt loads of scenarios in which (i) irrigation development either never occurred or it ceased in 1988 and (ii) no SIS were built. The baseline salt load of Scenario 1 is 22 t/d, presumably due to the high groundwater salinity and the influence of Lock 4. Scenario 2 shows the slow rise of salt load due to increased recharge from land clearance; by 2110 it has increased only a little to 26 t/d. Scenario 3a assumes that irrigation development and practices were constant after 1988 and the salt load rises from 70 t/d at 1988 to an equilibrium value of 121 t/d by CY100. Similar to the Loxton reach, the salt load rises after 1988 as the impact of irrigation is not immediate: there is the vertical lag time between accession and recharge and there is also the time taken for a change in recharge to lead to increased flux to the river. Scenario 3c shows how the salt load of Scenario 3a is reduced by post-1988 improvements in irrigation practice and rehabilitation. The equilibrium salt load is 82 t/d, so IIP and RH reduce the salt load by 39 t/d, a less dramatic reduction than the Loxton reach. The salt load in Scenario 3a rises before it falls, presumably due to delayed impacts from newer irrigation areas.

The second graph in Figure 5.3 shows the salinity benefits of the Bookpurnong SIS for the case when irrigation development ceased in 1988 but improvements were made in irrigation practice and in rehabilitation after 1988. Scenario 8b is identical to Scenario 3c except that it includes the as-constructed SIS. The salt load for Scenario 8b declines very sharply after the SIS becomes operational in 2006. The CY100 salt load is 19 t/d with SIS, a reduction of 63 t/d. This is 3 t/d lower than the baseline salt load (Scenario 1).

The first graph in Figure 5.4 compares the Bookpurnong salt loads for three irrigation scenarios without SIS. Scenarios 3c, 4 and 5 have similar assumptions for changes in recharge rate over time, due to IIP and RH, but differ in the size of the irrigated area. Scenario 3c has an irrigation area fixed from 1988, Scenario 4 has an irrigation area fixed from 2005 and Scenario 5 includes the 2005 irrigation area and adds some future irrigation areas. Changes in irrigation area from 1988 to 2005 increase the 2110 salt load from 82 to 137 t/d, as a significant fraction of the Bookpurnong irrigation area commenced after 1988. The estimated future irrigation areas increase the salt loads to 144 t/d by 2110. Note that the Scenario 4 and 5 salt loads are still trending upwards after 2110 due to time taken for changes in irrigation to increase river salt loads.

The second graph in Figure 5.4 shows the salinity benefits of the Bookpurnong SIS for scenarios in which irrigation development continued after 1988. Scenarios 4 and 8a assume current (2005) irrigation area and rates: the SIS reduces the salt load from 137 to 30 t/d by 2110, just slightly above the baseline salt load of Scenario 1. Scenarios 5 and 8c assume current (2005) and future irrigation area and rates: the SIS reduces the salt load from 144 to 31 t/d by 2110. Again, the salt loads are still trending upwards at 2110 due the delayed impact of irrigation on river salt loads.

6. SENSITIVITY AND UNCERTAINTY ANALYSES

Sensitivity analysis is a procedure for quantifying the impact of an incremental variation in aquifer hydraulic parameters or stresses on modelled responses (MDBC 2001). For a given calibrated model, it identifies whether small changes in model inputs lead to large changes in modelled outputs. As model outputs are a function of model inputs, sensitivity analysis provides an estimate of the local gradient of the model output function with respect to a given model input.

Uncertainty analysis is a broader term, encompassing the estimation of uncertainty in model results due to poorly known parameter distributions, observation errors and simplified model assumptions such as omitted processes. Within Australian groundwater modelling there is no industry-wide agreed approach to uncertainty analysis. The *Groundwater Flow Modelling Guideline* (MDBC 2001) outlines some options, such as worst-case scenario modelling, Monte Carlo simulations and predictive analysis. More recent handbooks such as that of Hill & Tiedeman (2007) are yet to be adopted for widespread Australian use.

The key output of the Loxton–Bookpurnong model is the salt load to the River Murray at Loxton and Bookpurnong. Following the MDBC Guideline (2001), the approach used in this project is to conduct a sensitivity analysis with changes of 15% in calibrated hydraulic parameters that may impact model results. The following parameters were chosen for the analysis:

- the aquifer parameters horizontal conductivity K_h and specific yield S_y of the Loxton Sands, which control horizontal flux to the floodplain
- the vertical hydraulic conductivity K_v of the Bookpurnong Formation, which controls the vertical flux to and from the Murray Group aquifers to the watertable aquifer.

The uncertainty analysis is based on changing model inputs that most likely impact on the model results but may not change the calibrated model significantly. The key inputs include:

- ET parameters (maximum potential rate in the model), which strongly influence heads and the water balance in the floodplain sediments
- typical river conditions, including river level and riverbed sediment conductance
- groundwater salinity adjacent to the River Murray
- recharge over time induced by irrigation drainage.

Other model inputs are important, but their values are more easily and reliably observed, e.g. SIS pump rates, or are expected to be less heterogeneous and therefore robustly interpolated from observations, e.g. potentiometric heads along model boundaries.

6.1. SENSITIVITY ANALYSES

The sensitivity of the model to the parameters of the Loxton Sands and Bookpurnong Formation was examined in the previous Loxton–Bookpurnong modelling report (Yan et al. 2005). As the model has not changed substantially in its representation of these units, presented here are the results of the 2005 sensitivity analysis. This evaluates the impact of variations in the following aquifer hydraulic parameters by ±15% from the calibrated values:

- STest 1 — Loxton Sands hydraulic conductivity
- STest 2 — Loxton Sands specific yield

- STest 3 — Vertical hydraulic conductivity (K_v) for the Bookpurnong Formation.

The *Groundwater Flow Modelling Guideline* (MDBC 2001) notes that this type of test is more often used for a model that has low confidence due to lack of observed data and long-term monitoring data to complete the calibration. Even though the model has been very well calibrated, the sensitivity tests were conducted to follow MDBA requirements and make sure potential changes are reported.

The worst irrigation impact scenario, Scenario 5, was used as base case for the sensitivity simulations. Table 6.1 gives the maximum salt load differences at 2110, compared to the 2005 model's base case actual salt load of 95 t/d in Loxton and 137 t/d in the Bookpurnong area. The results indicate that the salt load entering the River Murray is most sensitive to horizontal hydraulic conductivity and less sensitive to specific yield in the Loxton Sands and Monoman Formation aquifers. It is only slightly sensitive to changes in vertical hydraulic conductivity. In all cases, a change of 15% in the input parameter leads to a change in salt load of less than 8%.

Table 6.1 Sensitivity test results (Salt load difference t/d) at 2110

	STest 1 K_h in Loxton Sands 0.5–20 (m/d)		STest 2 S_y in Loxton Sands 0.01 –0.2		STest 3 K_v Bookpurnong Formation ~0.0020 (m/d)	
Parameters change	**-15%**	**+15%**	**-15%**	**+15%**	**-15%**	**+15%**
Loxton: **Salt load difference (t/d)**	-7.3	5.6	4.0	- 4.3	0.5	-0.3
Bookpurnong: **Salt load difference (t/d)**	-6.0	5.7	1.1	-1.3	0.5	-0.2

6.2. UNCERTAINTY ANALYSIS

The approach for uncertainty analysis is to select input parameters that are poorly known and/or highly heterogeneous. The parameters are varied within reasonable bounds, based on available data and current knowledge. Model results are compared with the observed head (calculating the SRMS) and measured RoR salt load to identify the likelihood of occurrence for each case. The test results are then discussed.

The following input parameters were varied in the uncertainty analysis to determine the impact on salt load to the River Murray in the Loxton and Bookpurnong reaches:

- UTest 1 — ET in the floodplain
- UTest 2 — Representative river pool levels
- UTest 3 — Riverbed sediment conductance
- UTest 4 — Groundwater salinity
- UTest 5 — Irrigation recharge.

6.2.1. UNCERTAINTY TESTS 1 TO 3

The first three pairs of uncertainty tests consider the impact of changes in time-invariant input parameters which alter groundwater flux.

UTest 1: The potential (i.e. maximum) ET rate is a model input parameter that influences head and hence gradients in the floodplain sediments, altering groundwater flux to the River Murray. Representative regional values of potential ET are difficult to measure in the field. In order to obtain a reasonable range of potential ET values for the uncertainty analysis, observations of actual ET are used; the potential ET rate is varied until the target actual ET is obtained on the floodplain. Estimates of actual ET rates for floodplains vary from 5 mm/y, based on prior models (AWE 2010), to 80 mm/y, based on recent CSIRO research (K Holland, CSIRO, pers. comm., 2011). The modelled actual ET over the floodplain is 65 mm/y in the calibrated model. A potential ET rate of 15 mm/y is required in the model to obtain a 5 mm/y actual ET rate and 350 mm/y is required to obtain an 80 mm/y actual ET rate on the floodplain area. In all cases, an extinction depth of 1.5 m is assumed.

UTest 2: For the purposes of the Salinity Register calculations, the river level is fixed for each reach so that the impact of accountable actions can be clearly estimated, regardless of climate sequence factors such as changes in river level over time. The calibrated model assumes that the appropriate, representative river level is normal pool level, which is 9.8 m AHD in most of the Loxton–Bookpurnong area. In the UTest 2 simulations, the river level is held constant at higher levels, 10 m AHD or 10.5 m AHD, to determine the impact on salt loads. The higher river levels were selected based on the most frequently observed records from Loxton, river kilometre 493.9.

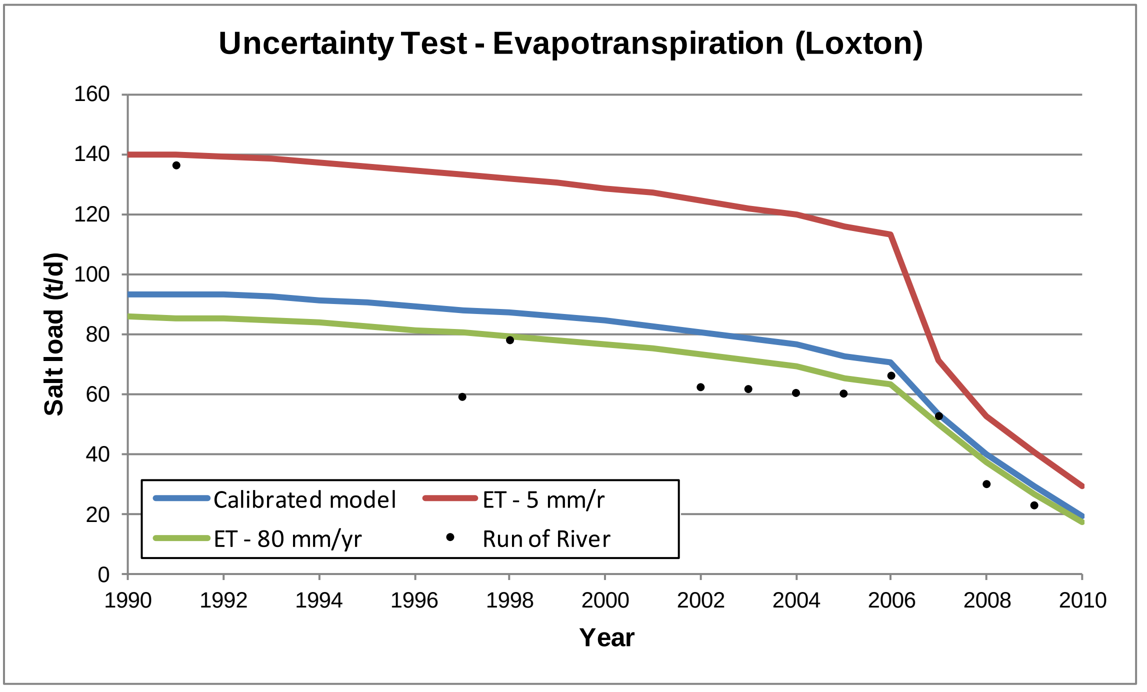
UTest 3: No field observations have been made of riverbed sediment conductance. The uncertainty in this property can be reduced during calibration by matching modelled heads to observations from floodplain bores, but there is little available long-term data to calibrate to, as most of the floodplain bores were built in the last decade. The calibrated model assumes a conductance of 1500 m^2/d. As the conductance has not been directly measured, UTest 3 varies the conductance within a reasonable range of 500 to 4500 m^2/d. For riverbed sediments of 1 m thickness, this conductance implies a conductivity of 0.032 to 0.288 m/d.

For each uncertainty simulation, a single input parameter is changed and the model is not recalibrated. To give an indication of whether the model is still a good fit to observations, Table 6.2 lists Scaled RMS (%) in the Loxton–Bookpurnong area for each test and Figures 6.1 to 6.3 compare modelled salt loads with RoR values. The SRMS includes all head observations in the Loxton and Bookpurnong areas, but the chosen parameters mostly alter heads in or near the floodplain. For this reason, a small change in SRMS may represent large changes in floodplain heads and salt loads.

The 5 mm/y actual ET model has a worse SRMS and a substantially poorer match to RoR salt loads (Fig. 6.1), suggesting that this condition probably does not occur. The 10.5 m AHD river level matches reasonably well to RoR salt loads (Fig. 6.2), but the SRMS is higher, particularly for 2009, so this condition is also considered to be less likely than the calibrated model conditions.

Table 6.2 and Figures 6.1 to 6.3 show that the other test simulations change the SRMS and modelled salt loads only slightly. Those models still demonstrate a good overall fit to observations.

Tables 6.3 and 6.4 give the salt load difference between the calibrated model and uncertainty test models.



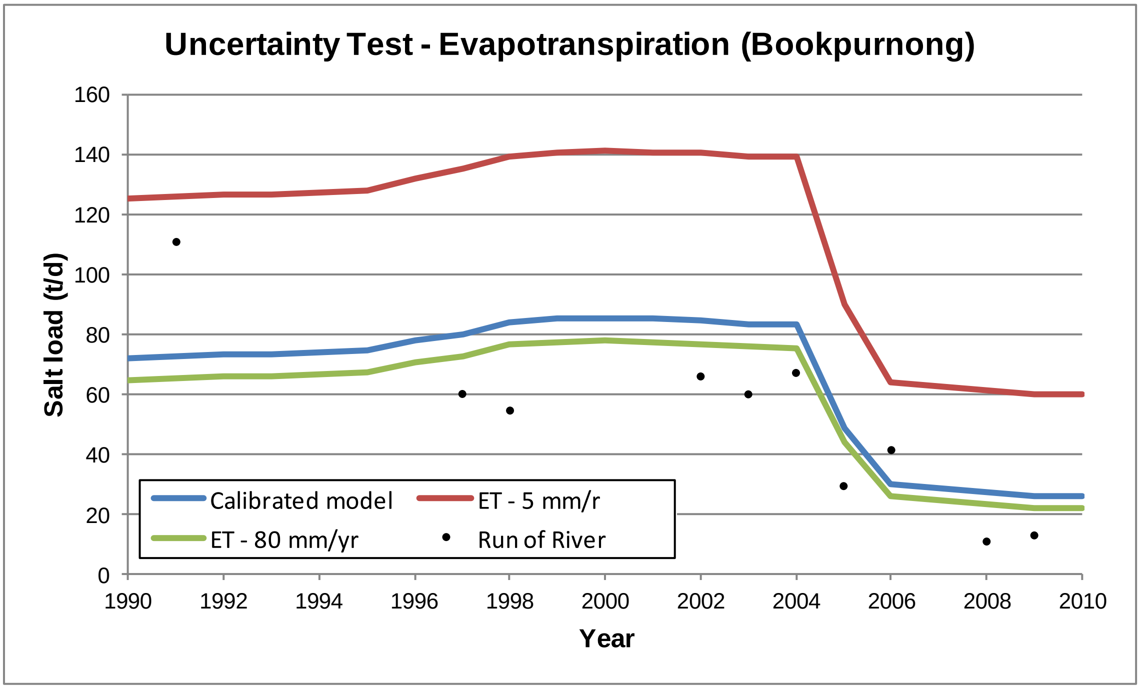
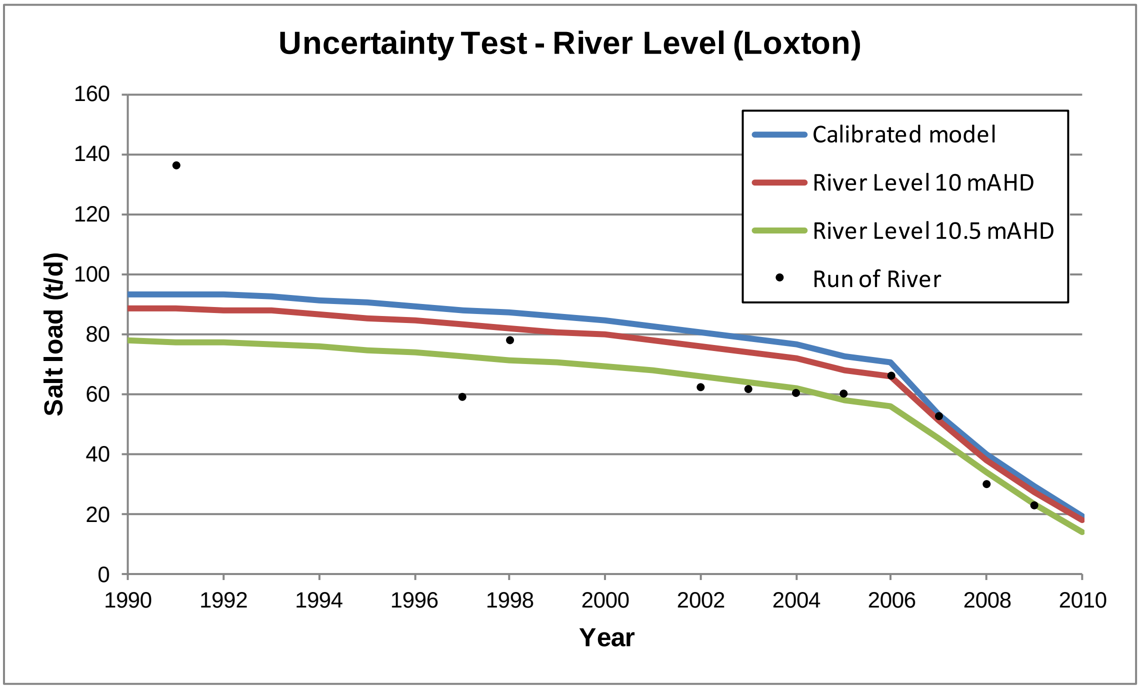


Figure 6.1 Model uncertainty to evapotranspiration



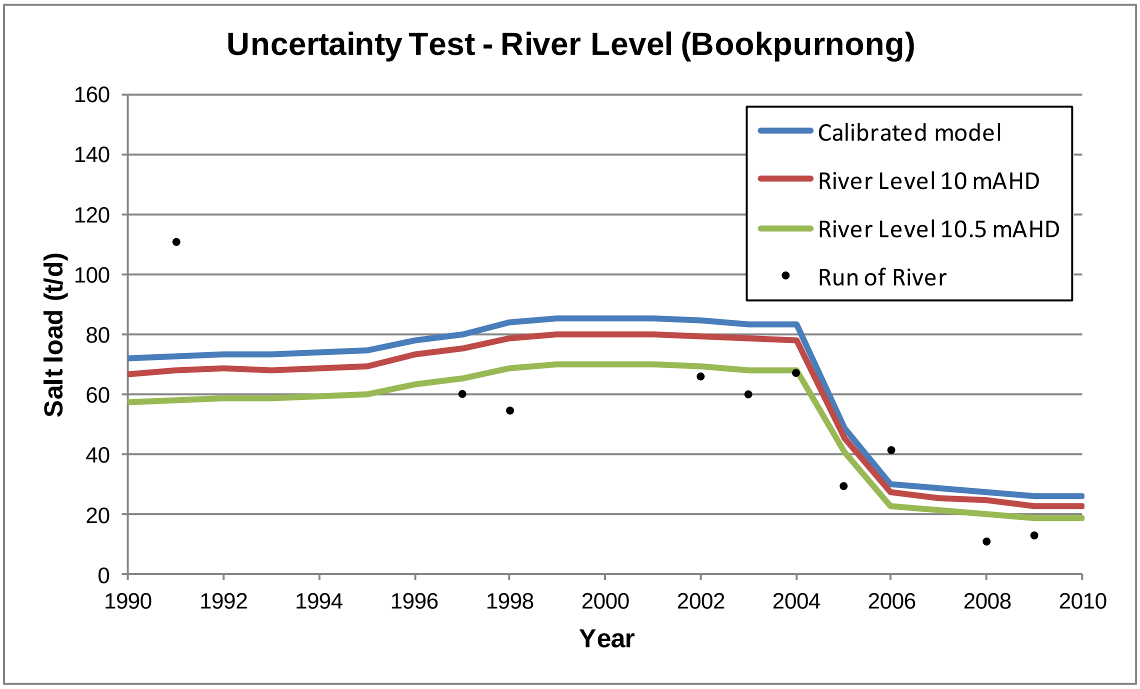
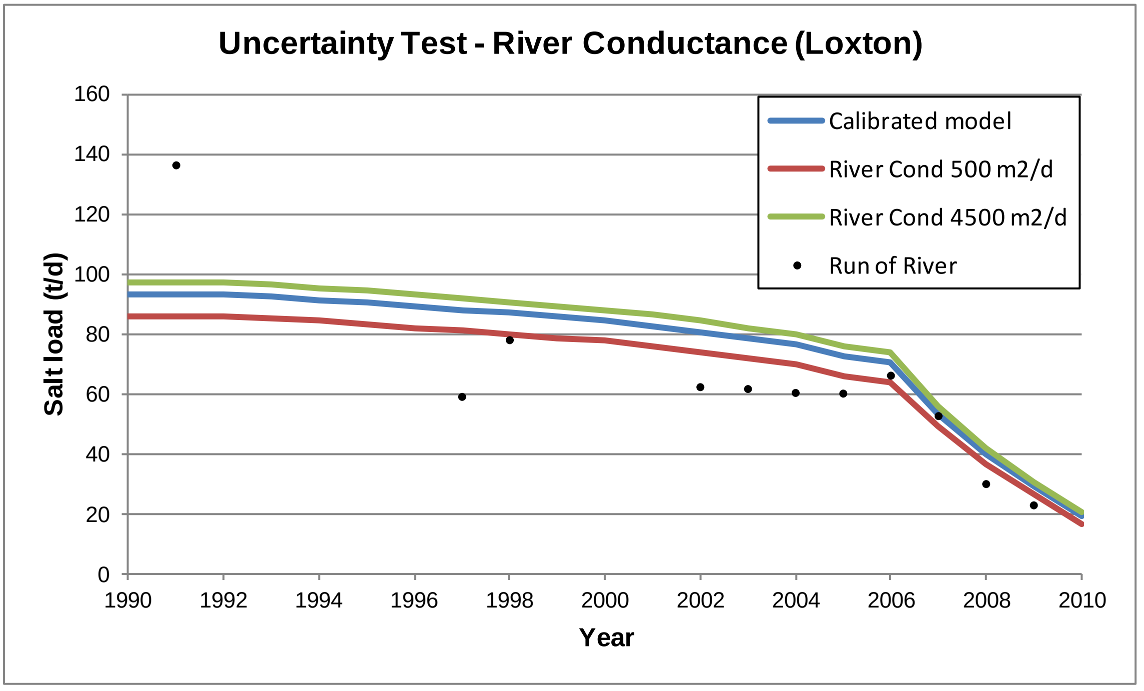


Figure 6.2 Model uncertainty to river pool level



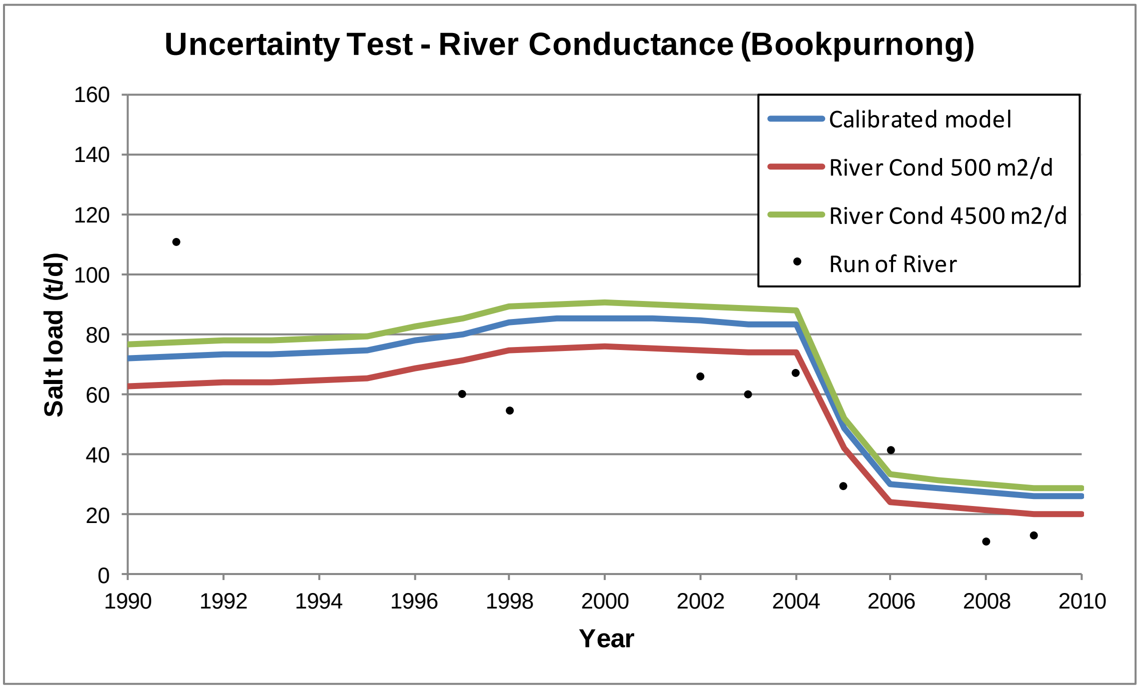


Figure 6.3 Model uncertainty to river conductance

Table 6.2 Uncertainty Tests 1 to 3: Scaled RMS (%) for Loxton and Bookpurnong areas

	Calibrated model: 60 mm/y, 9.8 m AHD, 1500 m^2/d	UTest 1 Actual ET		UTest 2 River Pool Level		UTest 3 River Conductance	
Year	**SRMS %**	**5 mm/y**	**80 mm/y**	**10 m AHD**	**10.5 m AHD**	**500 m^2/d**	**4500 m^2/d**
1977	6.03	7.17	5.82	6.28	6.99	6.02	6.04
1988	4.05	4.43	3.99	4.10	4.37	4.04	4.05
2001	2.21	2.31	2.25	2.13	2.17	2.15	2.23
2009	2.31	2.51	2.28	2.69	4.35	2.33	2.32

Table 6.3 Uncertainty Tests 1 to 3: Salt load difference (t/d) in the Loxton area

Loxton	Calibrated model: 60 mm/y, 9.8 m AHD, 1500 m^2/d	UTest 1 Actual ET Salt Load Difference (t/d)		UTest 2 River Pool Level Salt Load Difference (t/d)		UTest 3 River Conductance Salt Load Difference (t/d)	
Year	**Salt Load (t/d)**	**5 mm/y**	**80 mm/y**	**10 m AHD**	**10.5 m AHD**	**500 m^2/d**	**4500 m^2/d**
1977	**81.2**	43.3	-6.8	-4.2	-13.8	-6.9	3.9
1988	**92.2**	46.0	-7.6	-4.8	-15.5	-7.4	4.0
2001	**82.7**	44.1	-7.5	-4.8	-15.1	-6.7	3.7
2009	**29.3**	11.5	-2.7	-1.9	-6.2	-2.8	1.5

Table 6.4 Uncertainty Tests 1 to 3: Salt load difference (t/d) in the Bookpurnong area

Bookpurnong	Calibrated model: 60 mm/y, 9.8 m AHD, 1500 m^2/d	UTest 1 Actual ET Salt Load Difference (t/d)		UTest 2 River Pool Level Salt Load Difference (t/d)		UTest 3 River Conductance Salt Load Difference (t/d)	
Year	**Salt Load (t/d)**	**5 mm/y**	**80 mm/y**	**10 m AHD**	**10.5 m AHD**	**500 m^2/d**	**4500 m^2/d**
1977	**41.1**	47.3	-6.3	-4.5	-12.2	-7.0	3.4
1988	**70.0**	52.7	-7.2	-4.9	-14.4	-8.9	4.6
2001	**84.8**	55.9	-7.6	-5.2	-15.3	-9.5	5.2
2009	**25.6**	34.1	-3.6	-2.8	-7.1	-5.4	2.9

UTest 1 indicates that low actual ET (5 mm/y) results in a significant increase in the salt load. This is because lower ET results in higher floodplain heads and hence steeper groundwater gradients and greater fluxes to the river. However, the SMRS and RoR results suggest that this low ET case is unlikely to occur in the Loxton or Bookpurnong areas. Higher actual ET decreases the salt load entering the River Murray. An actual ET rate of 80 mm/y results in 3 to 8 t/d less salt load than the calibrated model in the Loxton and Bookpurnong areas. The reduction is generally less than 9% reduction in the Loxton area and 9 to 15% in the Bookpurnong area.

The results of UTest 2 indicate that higher river levels reduce the salt load entering the River Murray. This is because the gradient from the aquifer to the river is lowered. A pool level of 10 m AHD reduces salt loads by 2 to 5 t/d from the calibrated model in the Loxton and Bookpurnong areas. The results show around 5% reduction in the Loxton area and 6 to 11% reduction in the Bookpurnong area.

Results from UTest 3 indicate that lower riverbed conductance decreases the salt load and higher river conductance increases salt load, as expected. A lower river conductance of 500 m^2/d reduces salt load by 3 to 10 t/d less than the salt load from the calibrated model in the Loxton and Bookpurnong areas, with a reduction of about 9% in Loxton and 11–21% in the Bookpurnong area. Increasing river conductance to 4500 m^2/d increases salt loads by 2 to 5 t/d than the calibrated model, increasing the salt load by around 5% in the Loxton area and 6–11% in the Bookpurnong area.

6.2.2. UNCERTAINTY TEST 4: GROUNDWATER SALINITY

While much groundwater salinity data are available, salinity in a given aquifer may vary spatially, with location and depth and also over time. There is uncertainty as to what salinity value may be typical of groundwater adjacent to a river reach. Section 2.3.5 explains how 'representative' salinity values were obtained for each near-river bore in the Loxton Sands and Monoman Formation aquifers. The representative values were then used to estimate a single salinity value for each salinity zone, as described in Section 3.8.

The model calculates groundwater flow but does not simulate groundwater salinity changes using solute transport modelling. The salt loads for each reach are estimated externally to the MODFLOW model, by multiplying the modelled flux value by the salinity zone value. For the purposes of the Salinity Register, it assumed that groundwater salinity is constant over time as the irrigation-derived groundwater mounds push regional groundwater into the river. This conservative assumption is adopted as the salt load impacts of accountable actions for the Registers should not include impacts such as the possible freshening of groundwater due to SIS pumping or other management actions.

An analysis of salinity data in the region is detailed in Appendix C-3. The representative salinity values within 3 km east of the River Murray from the Loxton Sands and Monoman Formation for each model flow budget zone were analysed. The values of maximum, minimum, mean minus standard deviation, mean plus standard deviation, mean and median salinity values were determined for each flow budget zone. Note that the calculation of the standard deviation relies on a normal distribution of salinity, but many of the zoned samples did not have a normal distribution. As a result, the mean minus one standard deviation may be less than the minimum observed salinity, or the mean plus one standard deviation may be greater than the observed maximum.

UTest 4 varies the salinity values adopted for the reaches and consists of applying three different salinities to each of the designated zones:

- Low salinity case: the minimum observed value
- High salinity case: the maximum observed value
- Applied salinity case: values presented in the calibrated model.

The salinity values for each case are given in Appendix C-3.

The various salt loads derived through applying the 'low salinity case', 'high salinity case' and 'calibrated model case' are presented in Table 6.5 and are compared with RoR data in Figure 6.4.

Table 6.5 Uncertainty Test 4: Salt load difference (t/d) for Loxton and Bookpurnong

Year	Calibrated model Actual Salt Load (t/d)		Low Salinity Case Salt Load Difference (t/d)		High Salinity Case Salt Load Difference (t/d)	
	Loxton	Bookpurnong	Loxton	Bookpurnong	Loxton	Bookpurnong
1977	**81.2**	**41.1**	-50.1	-8.9	22.7	8.4
1988	**92.2**	**70.0**	-56.3	-16.3	26.7	20.3
2001	**82.7**	**84.8**	-50.3	-21.5	25.7	24.2
2009	**29.3**	**25.6**	-17.5	-3.3	9.4	6.4

If the 'low salinity case' values are used in the Loxton area, the salt load is reduced by up to 56 t/d, which is highly significant, but RoR data show that this case matches poorly to observations, indicating that this is not a likely possibility (Fig 6.4). In the Bookpurnong area, the salt load is reduced by up to 22 t/d, about 25%.

If the 'high salinity case' values are used in Loxton area, the salt load increases by up to 27 t/d, around 30%. In the Bookpurnong area, the salt load increases by up to 24 t/d, ~28%.

The salinity values selected for the calibrated model are deliberately chosen to reflect the higher regional salinity values, rather than localised and recent mixing with surface waters and/or irrigation-derived recharge. It is therefore expected that the difference between the results of the high-salinity and calibrated models would be less than the difference between the low-salinity and calibrated models. The 'low salinity case' will underestimate salt load impacts, particularly at Loxton and results should therefore be treated with caution.

6.2.3. UNCERTAINTY TEST 5: IRRIGATION RECHARGE

Recharge over time forms a critical suite of input parameters to the model. Groundwater flux to the river is driven by the groundwater mounds formed by irrigation-derived recharge.

Recharge is difficult to measure in the field. Section 2.4.2 summarises known relevant data, but there remains a great deal of uncertainty about recharge rates over time.

The model scenarios of Section 5 explore the impact of different recharge areas and rates over time, with and without SIS. These pairs of scenarios can be treated as uncertainty tests for recharge:

- Scenarios 3a and 3c have identical recharge areas but differ by recharge rate after 1988. By 2009, Scenario 3a recharge rates generally range between 120 and 400 mm/y while Scenario 3c recharge rates have mostly decreased to 100 mm/y.

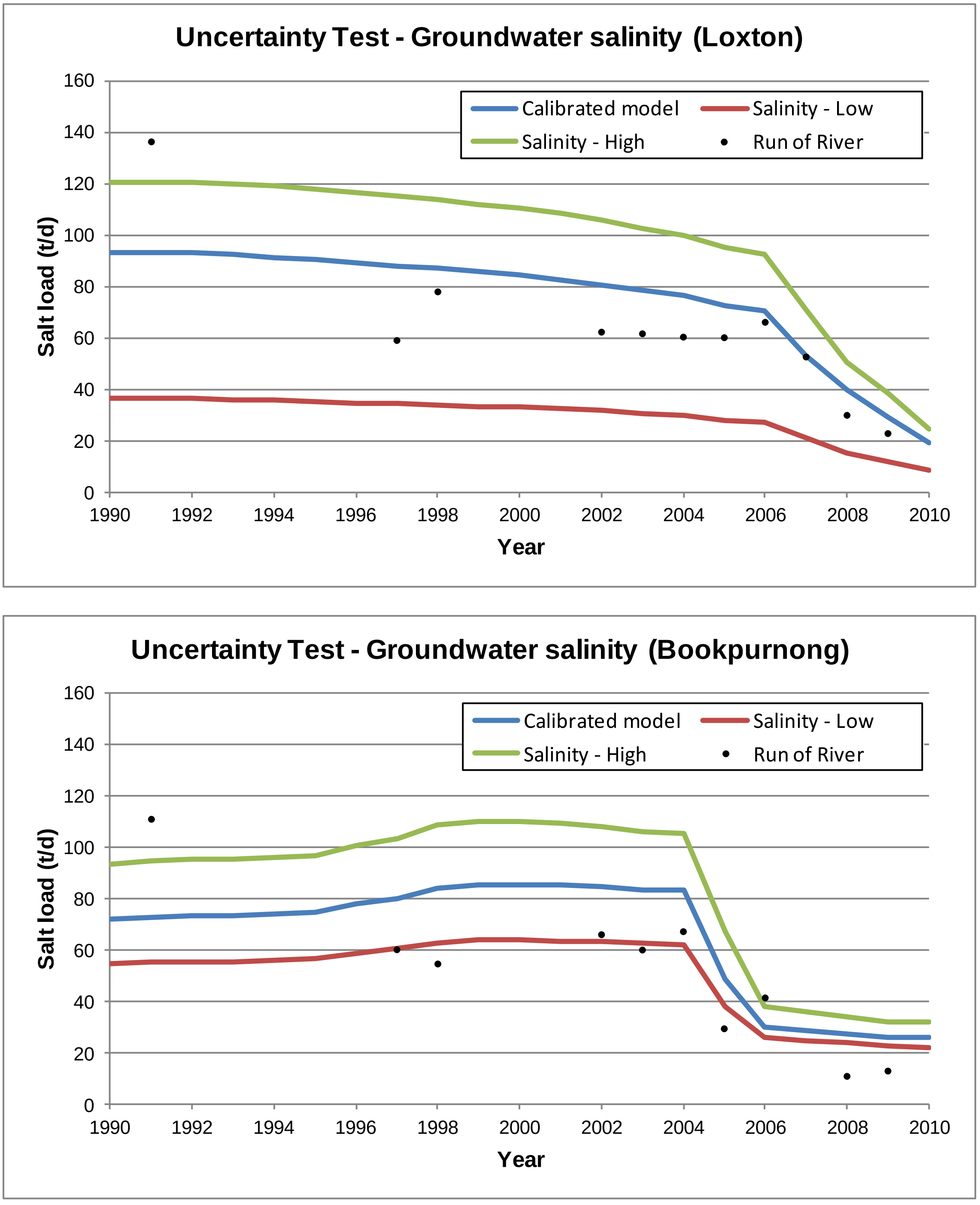


Figure 6.4 Model uncertainty to groundwater salinity

- Scenarios 3c and 4 have identical recharge rates but differ by recharge area.

Table 6.6 shows how the salt loads differ between base case and scenarios.

Table 6.6 Uncertainty Test 5: Salt load difference (t/d) at 2009

	Base case S3c		Different Recharge Rate Case S3a		Different Recharge Area Case S4	
	Loxton	**Bookpurnong**	**Loxton**	**Bookpurnong**	**Loxton**	**Bookpurnong**
Total recharge volume (ML)	3219	1185	6365	1852	3562	1462
			98%	56%	11%	23%
Total irrigation area (ha)	3516	641	3516	641	3859	914
			0%	0%	10%	43%
Salt load (t/d)	72.8	79.0	104.5	108.1	74.0	82.9
Salt load difference (t/d)	–	–	31.7	29.1	1.2	3.9
			44%	37%	2%	5%

Note that a given percentage change in recharge does not lead to the same percentage change in salt load at 2009. This is because the salt load impact also depends on the location of the recharge, the time since the recharge changed and aquifer parameters (Knight, Gilfedder & Walker 2005).

6.3. DISCUSSION

There are uncertainties associated with ET, river pool level, river conductance, groundwater salinity and irrigation recharge.

6.3.1. FLOODPLAIN PROCESSES

The hydrogeology of the highland areas is considered to be reasonably well understood and simulated in the model but the floodplains are, due to the limitations imposed by the requirements of producing data for the Salinity Registers, simulated in what is a very generalised approximation of their true hydrogeological behaviour which omits the impacts of changes in river level and flooding as a stage in the salt cycle.

The groundwater flux through floodplain to the River Murray is partly controlled by ET and the river conditions (i.e. pool level and conductance). The uncertainty tests of Section 6.2.1 indicate that changes in these floodplain inputs change salt load by no more than 25%.

Small-scale and transient features of floodplain processes are not simulated. This is because climate-driven changes are not to be included in Salinity Register calculations, other processes are poorly understood and there is limited data on, for example, heterogeneity of riverbed sediments. The salt load results should be considered to be representative, average-condition values and are not precise over small spatial and time scales.

6.3.2. GROUNDWATER SALINITY

The groundwater salinity values and the zones that have been applied in the calculation of salt load, represent the best current understanding of the groundwater salinity distribution derived from the analysis of all existing available data and understanding of the local groundwater system (see Section 2.6).

All available observed salinity values from a zone extending ~3 km to the east of the River Murray in the Loxton–Bookpurnong reach were analysed. Low-salinity and high-salinity cases were calculated for each model flux budget zone and details are given in Appendix C-3.

The uncertainty tests of Section 6.2.2 indicate that the high-salinity case increases salt load by less than 35%. The salt load is reduced by up to 65% in the low-salinity case, but the low-salinity case is likely to heavily underestimate salt loads, as the lower salinity values will reflect irrigation and surface waters more than regional groundwater which is the main source of salt pushed into the River Murray in most irrigation areas.

6.3.3. RECHARGE DUE TO IRRIGATION

There is reasonably high confidence in the recharge rates used for the historical modelling. The recharge rates applied took account of calculated accession volumes (i.e. based on district diversion) but were adjusted to achieve improved calibrations of observed hydrographs. Given the available information and range of knowledge, it is considered that the irrigation recharge applied in the model is appropriate. It is acknowledged that the methodology used to estimate recharge rates has limitations, but given the constraints of data availability, the state of scientific knowledge and the project budget and deadlines, every attempt has been made to provide a robust and defensible result.

Model recharge rates and irrigation areas in the future are considered to be key contributors to model uncertainty. There is less confidence in the recharge values used in the predictive modelling beyond 2010. The recharge rate of 100 mm/y is used for the 'future development' predictions in the highland areas at Loxton and Bookpurnong. It is highly likely that there will be changes in irrigation efficiency (that will affect recharge accession) and irrigated area and therefore deviations from the assumed development sequence in the future.

7. MODEL LIMITATIONS

The *MDBC Groundwater Modelling Guideline* 2001 states that: *It is important to recognise that there is no such thing as a perfect model and all models should be regarded as works in progress of continuous improvement as hydrogeological understanding and data availability improve. By definition, model limitations comprise relatively negative statements and they should not necessarily be viewed as serious flaws that affect the fitness for purpose of the model, but rather as a guide to where improvements should be made during work.*

Section 3.9 details model simplifications in representing the conceptual model. Section 6.3 describes the key model uncertainties due to uncertainties in key input parameters, which may serve as a guide for where improvements could be made in the future with the availability of additional data or with the improvement of hydrogeological understanding.

The model has limitations due to the current knowledge, existing information and special requirements of estimating salt loads for the Salinity Register. Some hydrogeological and hydrological features are simplified to reflect the needs of the Register. If the model were to be adapted for other purposes, the assumptions below may require alteration:

1. Fine detail of hydrogeological units is not included, for example textural information available for the Loxton Sands, as this level of detail is not required for the Salinity Register and cannot be included in a regional numerical model.

2. As the Salinity Register salt loads should not include climate sequence impacts, river pool level fluctuations are not simulated, so salt loads in effect assume average conditions in future predictions. Short-term changes in groundwater level and salt load are not simulated.

3. Groundwater salinities are assumed to remain constant when predicting future salt loads entering the river. However, groundwater salinity will most likely change in the future in response to accessions from brackish irrigation drainage. This limitation is related to the current knowledge, existing information and current techniques for monitoring of groundwater salinity changes. The model can be used to run a solute transport model when the groundwater salinity changes under irrigation area and floodplain area are fully understood and the observed data are available.

4. Model recharge zones and rates are based on the best available information, but are likely to be different in reality and differ in the future to those used in predictive modelling.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. MODEL IMPROVEMENTS

The Border to Lock 3 numerical groundwater flow model has been upgraded in the Loxton–Bookpurnong area as part of the review of the SIS and Salinity Register entries. The model was upgraded based on new information from hydrogeological investigations, particularly SIS construction and SIS operations after 2005. Following the MDBC Guideline (2001), the modified model was recalibrated using long-term observed (historical) potentiometric heads and newer data from SIS observation bores. Its results have been confirmed using RoR data, irrigation accession estimates and other information. The model was used to estimate salt loads to the River Murray for different scenarios required for the Salinity Register and cost-sharing. As specified by the Guideline (MDBC 2001), sensitivity and uncertainty tests were undertaken to aid risk assessment in management and policy decisions.

8.2. MODELLING RESULTS

The model is an 'impact assessment model of high complexity' in the terminology of the MDBC Guideline (MDBC 2001). The modelling work has resulted in an improved understanding of the hydrogeology of the aquifer system in the Loxton–Bookpurnong area. The upgraded model was used to predict the flux of saline groundwater (salt load) entering the River Murray under different irrigation practices and development scenarios. Comparison of scenario modelling results (salt loads) can be seen in Figures 5.1–5.4 and in Tables 8.1 and 8.2. The annual salt loads for each scenario are given in Figures 8.1 – 8.4.

Table 8.1 Summary of predicted salt load (t/d) entering the River Murray—Loxton area

Loxton area	Years simulated	Salt Load required by Salinity Register						
		1988	2000	2010	2015	2050	2100	2110
Calibrated historical model	1920–2010	92.2	84.4	22.6	NA	NA	NA	NA
Scenario–1	Steady-state	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Scenario–2	1920–2110	3.2	3.4	3.6	3.7	4.9	7.6	8.3
Scenario–3a	1988–2110	92.2	99.6	105.0	106.8	112.4	114.6	114.8
Scenario–3c	1988–2110	92.2	84.4	71.9	68.2	60.1	59.6	59.8
Scenario–4	1988–2110	92.2	84.4	73.2	70.5	72.4	78.6	79.5
Scenario–5	1988–2110	92.2	84.4	73.2	70.5	77.5	85.7	86.4
Scenario–8a	1988–2110	92.2	84.4	21.3	17.4	16.9	18.1	18.2
Scenario–8b	1988–2110	92.2	84.4	20.8	16.9	14.2	14.0	14.0
Scenario–8c	1988–2110	92.2	84.4	21.3	17.4	18.1	19.6	19.8

Table 8.2 Summary of predicted salt load (t/d) entering the River Murray—Bookpurnong Area

Bookpurnong area	Years simulated	Salt Load required by Salinity Register						
		1988	2000	2010	2015	2050	2100	2110
Calibrated historical model	**1920–2010**	70.0	85.2	25.7	NA	NA	NA	NA
Scenario–1	**Steady-state**	22.2	22.2	22.2	22.2	22.2	22.2	22.2
Scenario–2	**1920–2110**	22.4	22.4	22.5	22.5	23.1	25.1	25.6
Scenario–3a	**1988–2110**	70.0	98.6	108.6	110.7	117.1	120.2	120.6
Scenario–3c	**1988–2110**	70.0	85.2	79.0	79.2	81.1	82.0	82.1
Scenario–4	**1988–2110**	70.0	85.2	83.6	91.3	128.4	136.6	137.3
Scenario–5	**1988–2110**	70.0	85.2	83.6	91.8	133.3	142.9	143.7
Scenario–8a	**1988–2110**	70.0	85.2	19.6	21.2	28.5	30.2	30.3
Scenario–8b	**1988–2110**	70.0	85.2	19.1	18.7	18.8	18.9	19.0
Scenario–8c	**1988–2110**	70.0	85.2	19.6	21.3	29.2	31.1	31.3

8.3. RECOMMENDATIONS FOR FUTURE WORK

The numerical model is required by Schedule B to be reviewed at intervals of not more than seven years. The Register entries derived from the model are to be reviewed every five years. The model review process considers new information, knowledge, and landscape-scale changes. The following recommendations are made so that the quality of each aspect of the model is maintained or improved over time.

8.3.1. MONITORING AND DATA COLLECTIONS

The following recommendations are for monitoring, field work and data collection:

- collection of irrigation data should continue. Application volumes, irrigation area and crop type should be recorded and collated to provide estimates of root zone drainage over time. This information provides higher confidence on model recharge.
- the current monitoring of potentiometric head and salinity at OBSWELL and SIS bores should continue for model validation in the next Five Year Review
- RoR surveys should continue as they are used for model confirmation which increases model output confidence
- additional observation bores in the Loxton Sands aquifer would add additional value by providing groundwater level and salinity information in the eastern Bookpurnong area
- additional monitoring bores in the Pata Formation would assist by providing groundwater-level information in the Bookpurnong irrigation area (where there is currently only one monitored bore) and south of Loxton. Further potentiometric-head observations will help to improve the accuracy of future models in simulating the groundwater mounds in the Loxton Sands and Pata Formation.
- monitoring groundwater salinity over time may improve salt load calculations.

8.3.2. ADDITIONAL MODEL FEATURES AND PROCESSES

It is recommended that the following numerical model improvements be considered during the next Five Year Review. The usefulness and feasibility of each item listed below will depend on the future requirements and assumptions of the Salinity Registers, the state of scientific knowledge and data availability.

Features requiring additional model development:

- refining stress-period lengths to better simulate the impact of changing SIS pump rates;
- improving calibration in the Pata Formation
- improving reporting of recharge rates in irrigation areas
- improving simulation of evapotranspiration from groundwater, if more information becomes available
- possibly improving calibration in the floodplain area against flood events, such as fluctuations in river level over time, when data becomes available (e.g. detailed pool level and inundation area).

8.3.3. POTENTIAL WORK FOR FUTURE

The following works will improve the quality of the numerical model results but may not be necessary for the next Five Year Review process:

- investigation of riverbed conductivity
- AEM data will improve salt load calculations. These data will be useful if solute transport modelling is included in future models
- consideration of groundwater salinity changes over time in salt load calculations when valid information becomes available. This will affect salt loads and calculation of salt loads by either:
  - multiplying groundwater flux to the river by salinity that varies with time for each reach, or
  - full solute transport simulation.

Time	S-1	S-2	S-3a	S-3c	S-4	S-5	S-8a	S-8b	S-8c
(y)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)
1988	2.9	3.2	92.2	92.2	92.2	92.2	92.2	92.2	92.2
1989	2.9	3.2	92.8	92.7	92.7	92.7	92.7	92.7	92.7
1990	2.9	3.2	93.3	93.2	93.2	93.2	93.2	93.2	93.2
1991	2.9	3.2	94.0	93.2	93.2	93.2	93.2	93.2	93.2
1992	2.9	3.2	94.6	93.0	93.0	93.0	93.0	93.0	93.0
1993	2.9	3.2	95.2	92.5	92.5	92.5	92.5	92.5	92.5
1994	2.9	3.2	95.8	91.5	91.5	91.5	91.5	91.5	91.5
1995	2.9	3.3	96.4	90.2	90.2	90.2	90.2	90.2	90.2
1996	2.9	3.3	97.1	89.1	89.1	89.1	89.1	89.1	89.1
1997	2.9	3.3	97.7	88.1	88.1	88.1	88.1	88.1	88.1
1998	2.9	3.3	98.3	86.9	86.9	86.9	86.9	86.9	86.9
1999	2.9	3.3	98.9	85.5	85.5	85.5	85.5	85.5	85.5
2000	2.9	3.4	99.6	84.4	84.4	84.4	84.4	84.4	84.4
2001	2.9	3.4	100.2	83.0	83.0	83.0	83.0	83.0	83.0
2002	2.9	3.4	100.8	81.4	81.4	81.4	81.4	81.4	81.4
2003	2.9	3.4	101.4	79.8	79.8	79.8	79.8	79.8	79.8
2004	2.9	3.4	102.0	78.4	78.4	78.4	78.4	78.4	78.4
2005	2.9	3.5	102.5	77.2	77.4	77.4	74.5	74.3	74.5
2006	2.9	3.5	103.1	76.0	76.3	76.3	73.5	73.1	73.5
2007	2.9	3.5	103.6	74.8	75.5	75.5	39.9	39.5	39.9
2008	2.9	3.5	104.1	73.8	74.7	74.7	35.6	35.2	35.6
2009	2.9	3.5	104.5	72.8	74.0	74.0	24.9	24.4	24.9
2010	2.9	3.6	105.0	71.9	73.2	73.2	21.3	20.8	21.3
2011	2.9	3.6	105.4	71.0	72.6	72.6	19.8	19.3	19.8
2012	2.9	3.6	105.8	70.2	71.9	71.9	18.7	18.3	18.7
2013	2.9	3.6	106.1	69.5	71.4	71.4	18.1	17.6	18.1
2014	2.9	3.7	106.5	68.8	70.9	70.9	17.7	17.2	17.7
2015	2.9	3.7	106.8	68.2	70.5	70.5	17.4	16.9	17.4
2016	2.9	3.7	107.1	67.6	70.1	70.1	17.2	16.6	17.2
2017	2.9	3.7	107.4	67.1	69.8	69.9	17.0	16.3	17.1
2018	2.9	3.8	107.7	66.6	69.6	69.7	16.9	16.1	16.9
2019	2.9	3.8	107.9	66.1	69.4	69.6	16.8	16.0	16.8
2020	2.9	3.8	108.2	65.7	69.2	69.6	16.7	15.8	16.8
2021	2.9	3.8	108.4	65.2	69.1	69.7	16.6	15.7	16.7
2022	2.9	3.9	108.7	64.9	69.0	69.8	16.5	15.5	16.7
2023	2.9	3.9	108.9	64.5	69.0	69.9	16.5	15.4	16.7
2024	2.9	3.9	109.1	64.2	69.0	70.1	16.5	15.3	16.8
2025	2.9	4.0	109.3	63.9	69.0	70.3	16.4	15.2	16.8
2026	2.9	4.0	109.5	63.6	69.0	70.6	16.4	15.1	16.8
2027	2.9	4.0	109.6	63.3	69.1	70.9	16.4	15.1	16.8
2028	2.9	4.1	109.8	63.0	69.2	71.1	16.4	15.0	16.9
2029	2.9	4.1	110.0	62.8	69.3	71.4	16.4	14.9	16.9
2030	2.9	4.1	110.1	62.6	69.4	71.7	16.4	14.9	17.0
2031	2.9	4.1	110.3	62.4	69.5	72.0	16.4	14.8	17.0
2032	2.9	4.2	110.4	62.2	69.6	72.3	16.5	14.7	17.1
2033	2.9	4.2	110.6	62.0	69.7	72.6	16.5	14.7	17.1
2034	2.9	4.3	110.7	61.8	69.9	72.9	16.5	14.6	17.2
2035	2.9	4.3	110.9	61.6	70.0	73.2	16.5	14.6	17.3
2036	2.9	4.3	111.0	61.5	70.2	73.5	16.5	14.6	17.3
2037	2.9	4.4	111.1	61.3	70.3	73.9	16.6	14.5	17.4
2038	2.9	4.4	111.2	61.2	70.5	74.2	16.6	14.5	17.4
2039	2.9	4.4	111.3	61.1	70.6	74.5	16.6	14.5	17.5
2040	2.9	4.5	111.5	61.0	70.8	74.7	16.6	14.4	17.5
2041	2.9	4.5	111.6	60.9	70.9	75.0	16.7	14.4	17.6
2042	2.9	4.5	111.7	60.7	71.1	75.3	16.7	14.4	17.6
2043	2.9	4.6	111.8	60.7	71.3	75.6	16.7	14.3	17.7
2044	2.9	4.6	111.9	60.6	71.4	75.9	16.7	14.3	17.8
2045	2.9	4.7	112.0	60.5	71.6	76.2	16.8	14.3	17.8
2046	2.9	4.7	112.1	60.4	71.7	76.5	16.8	14.3	17.9
2047	2.9	4.7	112.2	60.3	71.9	76.7	16.8	14.3	17.9
2048	2.9	4.8	112.3	60.3	72.1	77.0	16.9	14.2	18.0
2049	2.9	4.8	112.3	60.2	72.2	77.3	16.9	14.2	18.0
2050	2.9	4.9	112.4	60.1	72.4	77.5	16.9	14.2	18.1
2051	2.9	4.9	112.5	60.1	72.5	77.8	16.9	14.2	18.1
2052	2.9	5.0	112.6	60.0	72.7	78.0	17.0	14.2	18.1
2053	2.9	5.0	112.7	60.0	72.9	78.3	17.0	14.2	18.2
2054	2.9	5.1	112.7	59.9	73.0	78.5	17.0	14.1	18.2
2055	2.9	5.1	112.8	59.9	73.2	78.7	17.1	14.1	18.3
2056	2.9	5.1	112.9	59.8	73.3	78.9	17.1	14.1	18.3
2057	2.9	5.2	112.9	59.8	73.5	79.2	17.1	14.1	18.4
2058	2.9	5.2	113.0	59.8	73.6	79.4	17.1	14.1	18.4
2059	2.9	5.3	113.1	59.7	73.8	79.6	17.2	14.1	18.4
2060	2.9	5.3	113.1	59.7	73.9	79.8	17.2	14.1	18.5
2061	2.9	5.4	113.2	59.7	74.1	80.0	17.2	14.1	18.5
2062	2.9	5.4	113.3	59.7	74.2	80.2	17.3	14.1	18.6
2063	2.9	5.5	113.3	59.6	74.4	80.4	17.3	14.1	18.6
2064	2.9	5.5	113.4	59.6	74.5	80.6	17.3	14.1	18.6
2065	2.9	5.6	113.4	59.6	74.6	80.8	17.3	14.0	18.7
2066	2.9	5.6	113.5	59.6	74.8	81.0	17.4	14.0	18.7
2067	2.9	5.7	113.5	59.6	74.9	81.2	17.4	14.0	18.8
2068	2.9	5.7	113.6	59.6	75.1	81.4	17.4	14.0	18.8
2069	2.9	5.8	113.6	59.5	75.2	81.6	17.4	14.0	18.8
2070	2.9	5.8	113.7	59.5	75.3	81.8	17.5	14.0	18.9
2071	2.9	5.9	113.7	59.5	75.5	81.9	17.5	14.0	18.9
2072	2.9	5.9	113.7	59.5	75.6	82.1	17.5	14.0	18.9
2073	2.9	6.0	113.8	59.5	75.7	82.3	17.5	14.0	19.0
2074	2.9	6.1	113.8	59.5	75.8	82.4	17.6	14.0	19.0
2075	2.9	6.1	113.9	59.5	76.0	82.6	17.6	14.0	19.0
2076	2.9	6.2	113.9	59.5	76.1	82.8	17.6	14.0	19.1
2077	2.9	6.2	113.9	59.5	76.2	82.9	17.6	14.0	19.1
2078	2.9	6.3	114.0	59.5	76.3	83.1	17.6	14.0	19.1
2079	2.9	6.3	114.0	59.5	76.5	83.2	17.7	14.0	19.1
2080	2.9	6.4	114.0	59.5	76.6	83.4	17.7	14.0	19.2
2081	2.9	6.4	114.1	59.5	76.7	83.5	17.7	14.0	19.2
2082	2.9	6.5	114.1	59.5	76.8	83.7	17.7	14.0	19.2
2083	2.9	6.6	114.1	59.5	76.9	83.8	17.8	14.0	19.3
2084	2.9	6.6	114.2	59.5	77.0	83.9	17.8	14.0	19.3
2085	2.9	6.7	114.2	59.5	77.1	84.1	17.8	14.0	19.3
2086	2.9	6.7	114.2	59.5	77.2	84.2	17.8	14.0	19.3
2087	2.9	6.8	114.3	59.5	77.4	84.3	17.8	14.0	19.4
2088	2.9	6.8	114.3	59.5	77.5	84.4	17.9	14.0	19.4
2089	2.9	6.9	114.3	59.5	77.6	84.5	17.9	14.0	19.4
2090	2.9	7.0	114.4	59.5	77.7	84.7	17.9	14.0	19.4
2091	2.9	7.0	114.4	59.6	77.8	84.8	17.9	14.0	19.5
2092	2.9	7.1	114.4	59.6	77.9	84.9	17.9	14.0	19.5
2093	2.9	7.1	114.4	59.6	78.0	85.0	17.9	14.0	19.5
2094	2.9	7.2	114.5	59.6	78.1	85.1	18.0	14.0	19.5
2095	2.9	7.3	114.5	59.6	78.2	85.2	18.0	14.0	19.5
2096	2.9	7.3	114.5	59.6	78.3	85.3	18.0	14.0	19.6
2097	2.9	7.4	114.5	59.6	78.4	85.4	18.0	14.0	19.6
2098	2.9	7.5	114.6	59.6	78.5	85.5	18.0	14.0	19.6
2099	2.9	7.5	114.6	59.6	78.5	85.6	18.1	14.0	19.6
2100	2.9	7.6	114.6	59.6	78.6	85.7	18.1	14.0	19.6
2101	2.9	7.6	114.6	59.7	78.7	85.7	18.1	14.0	19.7
2102	2.9	7.7	114.7	59.7	78.8	85.8	18.1	14.0	19.7
2103	2.9	7.8	114.7	59.7	78.9	85.9	18.1	14.0	19.7
2104	2.9	7.8	114.7	59.7	79.0	86.0	18.1	14.0	19.7
2105	2.9	7.9	114.7	59.7	79.1	86.1	18.2	14.0	19.7
2106	2.9	8.0	114.7	59.7	79.2	86.1	18.2	14.0	19.7
2107	2.9	8.1	114.8	59.7	79.3	86.2	18.2	14.0	19.8
2108	2.9	8.1	114.8	59.7	79.3	86.3	18.2	14.0	19.8
2109	2.9	8.2	114.8	59.8	79.4	86.3	18.2	14.0	19.8
2110	2.9	8.3	114.8	59.8	79.5	86.4	18.2	14.0	19.8

Scenario	Name	Model Run	Irrigation development area	IIP and RH	SIS
S-1	Natural System (Steady State since 1920)	Steady State	None	No	No
S-2	Mallee Clearance	1920 - CY100	None	No	No
S-3a	Irrigation Pre-1988, no IIP, no RH	1988 – CY100	Pre-1988	No	No
S-3c	Irrigation Pre-1988, with IIP & RH	1988 – CY100	Pre-1988	Yes	No
S-4	Current irrigation (business as usual)	CY – CY100	Pre-1988 + Post-1988	Yes	No
S-5	Current plus future irrigation	CY – CY100	Pre-1988 + Post-1988 + Future development	Yes	No
S-8a	Current irrigation plus constructed SIS	CY – CY100	Pre-1988 + Post-1988	Yes	Yes
S-8b	Pre-1988, with IIP & RH plus constructed SIS	CY – CY100	Pre-1988	Yes	Yes
S-8c	Current plus future irrigation plus constructed SIS	CY – CY100	Pre-1988 + Post-1988 + Future development	Yes	Yes

IIP = improved irrigation practices   RH = Rehabilitation of irrigation distribution networks   SIS = Saltl interception scheme
CY = current year   CY100 = 100 yrs from the current year

The tables below are designed to assist MDBC in deciding the correct inputs for BIGMOD and to show the impact of each of the individual accountable actions.

Year	Accountable action - Debits			
	Mallee Clearance S2 - S1	Pre-1988 S3C - S1	1988-Current Irrigation S4 - S3C	Future Irrigation S5 - S4
2000	*0.5*	*81.5*	*0.0*	*0.0*
2005	0.6	74.3	0.2	0.0
2006	0.6	73.1	0.4	0.0
2007	0.6	71.9	0.7	0.0
2008	0.6	70.9	1.0	0.0
2009	0.6	69.9	1.2	0.0
2010	0.7	69.0	1.4	0.0
2011	0.7	68.1	1.6	0.0
2012	0.7	67.3	1.7	0.0
2013	0.7	66.6	1.8	0.0
2014	0.8	65.9	2.0	0.0
2015	*0.8*	*65.3*	*2.3*	*0.0*
2016	0.8	64.7	2.5	0.0
2017	0.8	64.2	2.8	0.1
2018	0.9	63.7	3.0	0.1
2019	0.9	63.2	3.3	0.2
2020	0.9	62.8	3.6	0.4
2021	1.0	62.3	3.9	0.6
2022	1.0	62.0	4.2	0.7
2023	1.0	61.6	4.5	0.9
2024	1.0	61.3	4.8	1.1
2025	1.1	61.0	5.2	1.3
2026	1.1	60.7	5.5	1.5
2027	1.1	60.4	5.8	1.7
2028	1.2	60.1	6.2	1.9
2029	1.2	59.9	6.5	2.1
2030	1.2	59.7	6.8	2.3
2031	1.3	59.5	7.1	2.5
2032	1.3	59.3	7.5	2.7
2033	1.3	59.1	7.8	2.9
2034	1.4	58.9	8.1	3.1
2035	1.4	58.7	8.4	3.2
2050	*2.0*	*57.2*	*12.3*	*5.1*
2100	*4.7*	*56.7*	*19.0*	*7.0*

Accountable action - Credits	
	IIP & RH
Year	S3A - S3C
2000	*15.2*
2005	25.4
2006	27.1
2007	28.7
2008	30.3
2009	31.8
2010	33.1
2011	34.4
2012	35.5
2013	36.6
2014	37.6
2015	38.6
2016	39.5
2017	40.3
2018	41.1
2019	41.8
2020	42.5
2021	43.2
2022	43.8
2023	44.4
2024	44.9
2025	45.4
2026	45.9
2027	46.4
2028	46.8
2029	47.2
2030	47.6
2031	47.9
2032	48.3
2033	48.6
2034	48.9
2035	49.2
2050	52.3
2100	55.0

Figure 8.1 Accountable debits and credits for the Loxton reach (t/d)

Time	S-1	S-2	S-3a	S-3c	S-4	S-5	S-8a	S-8b	S-8c
(y)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)	(t/d)
1988	22.2	22.4	70.0	70.0	70.0	70.0	70.0	70.0	70.0
1989	22.2	22.4	71.2	70.4	70.4	70.4	70.4	70.4	70.4
1990	22.2	22.4	73.0	71.8	71.8	71.8	71.8	71.8	71.8
1991	22.2	22.4	75.3	72.5	72.5	72.5	72.5	72.5	72.5
1992	22.2	22.4	77.1	73.2	73.2	73.2	73.2	73.2	73.2
1993	22.2	22.4	78.7	73.1	73.1	73.1	73.1	73.1	73.1
1994	22.2	22.4	80.4	73.7	73.7	73.7	73.7	73.7	73.7
1995	22.2	22.4	81.7	74.4	74.4	74.4	74.4	74.4	74.4
1996	22.2	22.4	85.4	77.8	77.8	77.8	77.8	77.8	77.8
1997	22.2	22.4	88.7	80.2	80.2	80.2	80.2	80.2	80.2
1998	22.2	22.4	93.3	83.7	83.7	83.7	83.7	83.7	83.7
1999	22.2	22.4	96.3	84.9	84.9	84.9	84.9	84.9	84.9
2000	22.2	22.4	98.6	85.2	85.2	85.2	85.2	85.2	85.2
2001	22.2	22.4	100.5	84.7	84.8	84.8	84.8	84.7	84.8
2002	22.2	22.4	102.0	83.9	84.2	84.2	84.2	83.9	84.2
2003	22.2	22.4	103.3	82.9	83.5	83.5	83.5	82.9	83.5
2004	22.2	22.4	104.4	82.1	82.9	82.9	82.9	82.1	82.9
2005	22.2	22.4	105.3	81.1	82.4	82.4	43.8	43.6	43.8
2006	22.2	22.4	106.1	80.2	82.1	82.1	20.6	20.5	20.6
2007	22.2	22.5	106.9	79.5	82.1	82.1	20.1	19.9	20.1
2008	22.2	22.5	107.5	79.1	82.4	82.4	19.9	19.6	19.9
2009	22.2	22.5	108.1	79.0	82.9	82.9	19.7	19.3	19.7
2010	22.2	22.5	108.6	79.0	83.6	83.6	19.6	19.1	19.6
2011	22.2	22.5	109.1	79.1	84.7	84.7	19.7	19.0	19.7
2012	22.2	22.5	109.5	79.1	85.9	85.9	19.9	18.9	19.9
2013	22.2	22.5	110.0	79.1	87.2	87.2	20.1	18.8	20.1
2014	22.2	22.5	110.3	79.2	89.0	89.0	20.6	18.7	20.6
2015	22.2	22.5	110.7	79.2	91.3	91.8	21.2	18.7	21.3
2016	22.2	22.5	111.0	79.3	93.8	94.5	21.7	18.7	21.7
2017	22.2	22.5	111.4	79.4	96.1	97.1	22.0	18.6	22.2
2018	22.2	22.5	111.7	79.4	98.3	99.5	22.4	18.6	22.6
2019	22.2	22.5	112.0	79.5	100.4	101.7	22.8	18.6	23.0
2020	22.2	22.6	112.2	79.6	102.3	103.9	23.2	18.6	23.3
2021	22.2	22.6	112.5	79.6	104.2	105.9	23.5	18.6	23.7
2022	22.2	22.6	112.7	79.7	105.9	107.8	23.8	18.6	24.1
2023	22.2	22.6	113.0	79.8	107.5	109.5	24.2	18.6	24.4
2024	22.2	22.6	113.2	79.8	109.0	111.2	24.5	18.6	24.7
2025	22.2	22.6	113.4	79.9	110.4	112.8	24.7	18.6	25.0
2026	22.2	22.6	113.6	80.0	111.7	114.3	25.0	18.6	25.3
2027	22.2	22.6	113.8	80.0	112.9	115.7	25.3	18.6	25.6
2028	22.2	22.7	114.0	80.1	114.1	117.0	25.5	18.6	25.9
2029	22.2	22.7	114.2	80.1	115.2	118.2	25.7	18.6	26.1
2030	22.2	22.7	114.4	80.2	116.2	119.4	26.0	18.6	26.4
2031	22.2	22.7	114.6	80.3	117.2	120.5	26.2	18.6	26.6
2032	22.2	22.7	114.8	80.3	118.1	121.5	26.3	18.6	26.8
2033	22.2	22.7	114.9	80.4	119.0	122.5	26.5	18.6	27.0
2034	22.2	22.8	115.1	80.4	119.8	123.4	26.7	18.6	27.2
2035	22.2	22.8	115.2	80.5	120.6	124.3	26.9	18.7	27.4
2036	22.2	22.8	115.4	80.5	121.3	125.1	27.0	18.7	27.5
2037	22.2	22.8	115.5	80.6	122.0	125.9	27.2	18.7	27.7
2038	22.2	22.8	115.7	80.6	122.6	126.7	27.3	18.7	27.8
2039	22.2	22.8	115.8	80.7	123.2	127.4	27.4	18.7	28.0
2040	22.2	22.9	115.9	80.7	123.8	128.0	27.5	18.7	28.1
2041	22.2	22.9	116.1	80.7	124.4	128.7	27.7	18.7	28.3
2042	22.2	22.9	116.2	80.8	124.9	129.3	27.8	18.7	28.4
2043	22.2	22.9	116.3	80.8	125.4	129.9	27.9	18.7	28.5
2044	22.2	22.9	116.4	80.9	125.9	130.5	28.0	18.7	28.6
2045	22.2	23.0	116.6	80.9	126.4	131.0	28.1	18.7	28.7
2046	22.2	23.0	116.7	80.9	126.8	131.5	28.2	18.7	28.8
2047	22.2	23.0	116.8	81.0	127.2	132.0	28.3	18.7	28.9
2048	22.2	23.0	116.9	81.0	127.6	132.4	28.3	18.7	29.0
2049	22.2	23.0	117.0	81.0	128.0	132.9	28.4	18.8	29.1
2050	22.2	23.1	117.1	81.1	128.4	133.3	28.5	18.8	29.2
2051	22.2	23.1	117.2	81.1	128.7	133.7	28.6	18.8	29.3
2052	22.2	23.1	117.3	81.1	129.1	134.1	28.6	18.8	29.4
2053	22.2	23.2	117.4	81.1	129.4	134.5	28.7	18.8	29.4
2054	22.2	23.2	117.5	81.2	129.7	134.9	28.8	18.8	29.5
2055	22.2	23.2	117.6	81.2	130.0	135.2	28.8	18.8	29.6
2056	22.2	23.2	117.7	81.2	130.3	135.5	28.9	18.8	29.6
2057	22.2	23.3	117.8	81.3	130.5	135.8	28.9	18.8	29.7
2058	22.2	23.3	117.8	81.3	130.8	136.1	29.0	18.8	29.8
2059	22.2	23.3	117.9	81.3	131.1	136.4	29.0	18.8	29.8
2060	22.2	23.3	118.0	81.3	131.3	136.7	29.1	18.8	29.9
2061	22.2	23.4	118.1	81.4	131.5	137.0	29.1	18.8	29.9
2062	22.2	23.4	118.2	81.4	131.8	137.3	29.2	18.8	30.0
2063	22.2	23.5	118.2	81.4	132.0	137.5	29.2	18.8	30.0
2064	22.2	23.5	118.3	81.4	132.2	137.8	29.3	18.8	30.1
2065	22.2	23.5	118.4	81.4	132.4	138.0	29.3	18.8	30.1
2066	22.2	23.6	118.5	81.5	132.6	138.2	29.4	18.8	30.2
2067	22.2	23.6	118.5	81.5	132.8	138.5	29.4	18.8	30.2
2068	22.2	23.6	118.6	81.5	133.0	138.7	29.4	18.8	30.3
2069	22.2	23.6	118.7	81.5	133.1	138.9	29.5	18.8	30.3
2070	22.2	23.7	118.7	81.6	133.3	139.1	29.5	18.9	30.4
2071	22.2	23.7	118.8	81.6	133.5	139.3	29.5	18.9	30.4
2072	22.2	23.8	118.9	81.6	133.6	139.5	29.6	18.9	30.4
2073	22.2	23.8	118.9	81.6	133.8	139.6	29.6	18.9	30.5
2074	22.2	23.9	119.0	81.6	133.9	139.8	29.6	18.9	30.5
2075	22.2	23.9	119.0	81.6	134.1	140.0	29.7	18.9	30.5
2076	22.2	23.9	119.1	81.7	134.2	140.1	29.7	18.9	30.6
2077	22.2	24.0	119.2	81.7	134.4	140.3	29.7	18.9	30.6
2078	22.2	24.0	119.2	81.7	134.5	140.5	29.7	18.9	30.6
2079	22.2	24.1	119.3	81.7	134.6	140.6	29.8	18.9	30.7
2080	22.2	24.1	119.3	81.7	134.7	140.7	29.8	18.9	30.7
2081	22.2	24.2	119.4	81.7	134.9	140.9	29.8	18.9	30.7
2082	22.2	24.2	119.4	81.8	135.0	141.0	29.8	18.9	30.8
2083	22.2	24.3	119.5	81.8	135.1	141.2	29.9	18.9	30.8
2084	22.2	24.3	119.5	81.8	135.2	141.3	29.9	18.9	30.8
2085	22.2	24.4	119.6	81.8	135.3	141.4	29.9	18.9	30.8
2086	22.2	24.4	119.6	81.8	135.4	141.5	29.9	18.9	30.9
2087	22.2	24.4	119.7	81.8	135.5	141.7	29.9	18.9	30.9
2088	22.2	24.5	119.7	81.8	135.6	141.8	30.0	18.9	30.9
2089	22.2	24.5	119.8	81.9	135.7	141.9	30.0	18.9	30.9
2090	22.2	24.6	119.8	81.9	135.8	142.0	30.0	18.9	31.0
2091	22.2	24.6	119.9	81.9	135.9	142.1	30.0	18.9	31.0
2092	22.2	24.7	119.9	81.9	136.0	142.2	30.0	18.9	31.0
2093	22.2	24.7	119.9	81.9	136.1	142.3	30.1	18.9	31.0
2094	22.2	24.8	120.0	81.9	136.2	142.4	30.1	18.9	31.0
2095	22.2	24.8	120.0	81.9	136.3	142.5	30.1	18.9	31.1
2096	22.2	24.9	120.1	82.0	136.3	142.6	30.1	18.9	31.1
2097	22.2	24.9	120.1	82.0	136.4	142.7	30.1	18.9	31.1
2098	22.2	25.0	120.1	82.0	136.5	142.8	30.1	18.9	31.1
2099	22.2	25.0	120.2	82.0	136.6	142.9	30.2	18.9	31.1
2100	22.2	25.1	120.2	82.0	136.6	142.9	30.2	18.9	31.1
2101	22.2	25.1	120.3	82.0	136.7	143.0	30.2	18.9	31.2
2102	22.2	25.2	120.3	82.0	136.8	143.1	30.2	18.9	31.2
2103	22.2	25.3	120.3	82.0	136.9	143.2	30.2	18.9	31.2
2104	22.2	25.3	120.4	82.1	136.9	143.3	30.2	18.9	31.2
2105	22.2	25.4	120.4	82.1	137.0	143.3	30.2	18.9	31.2
2106	22.2	25.4	120.4	82.1	137.1	143.4	30.3	18.9	31.2
2107	22.2	25.5	120.5	82.1	137.1	143.5	30.3	18.9	31.3
2108	22.2	25.5	120.5	82.1	137.2	143.6	30.3	18.9	31.3
2109	22.2	25.6	120.5	82.1	137.2	143.6	30.3	18.9	31.3
2110	22.2	25.6	120.6	82.1	137.3	143.7	30.3	19.0	31.3

Scenario	Name	Model Run	Irrigation development area	IIP and RH	SIS
S-1	Natural System (Steady State since 1920)	Steady State	None	No	No
S-2	Mallee Clearance	1920 - CY100	None	No	No
S-3a	Irrigation Pre-1988, no IIP, no RH	1988 – CY100	Pre-1988	No	No
S-3c	Irrigation Pre-1988, with IIP & RH	1988 – CY100	Pre-1988	Yes	No
S-4	Current irrigation (business as usual)	CY – CY100	Pre-1988 + Post-1988	Yes	No
S-5	Current plus future irrigation	CY – CY100	Pre-1988 + Post-1988 + Future development	Yes	No
S-8a	Current irrigation plus constructed SIS	CY – CY100	Pre-1988 + Post-1988	Yes	Yes
S-8b	Pre-1988, with IIP & RH plus constructed SIS	CY – CY100	Pre-1988	Yes	Yes
S-8c	Current plus future irrigation plus constructed SIS	CY – CY100	Pre-1988 + Post-1988 + Future development	Yes	Yes

IIP = improved irrigation practices RH = Rehabilitation of irrigation distribution networks SIS = Saltl interception scheme
CY = current year CY100 = 100 yrs from the current year

The tables below are designed to assist MDBC in deciding the correct inputs for BIGMOD and to show the impact of each of the individual accountable actions.

Year	Accountable action - Debits			
	Mallee Clearance S2 - S1	Pre-1988 S3C - S1	1988-Current Irrigation S4 - S3C	Future Irrigation S5 - S4
2000	*0.2*	*63.0*	*0.0*	*0.0*
2005	0.2	58.9	1.3	0.0
2006	0.2	58.0	1.8	0.0
2007	0.2	57.3	2.6	0.0
2008	0.2	56.9	3.2	0.0
2009	0.2	56.8	3.9	0.0
2010	0.3	56.8	4.5	0.0
2011	0.3	56.8	5.7	0.0
2012	0.3	56.9	6.8	0.0
2013	0.3	56.9	8.1	0.0
2014	0.3	57.0	9.8	0.0
2015	*0.3*	*57.0*	*12.1*	*0.4*
2016	0.3	57.1	14.5	0.7
2017	0.3	57.1	16.7	1.0
2018	0.3	57.2	18.9	1.1
2019	0.3	57.3	20.9	1.4
2020	0.4	57.3	22.8	1.5
2021	0.4	57.4	24.5	1.7
2022	0.4	57.5	26.2	1.9
2023	0.4	57.5	27.7	2.1
2024	0.4	57.6	29.1	2.3
2025	0.4	57.7	30.5	2.4
2026	0.4	57.7	31.7	2.6
2027	0.4	57.8	32.9	2.7
2028	0.4	57.9	34.0	2.8
2029	0.4	57.9	35.1	3.0
2030	0.5	58.0	36.0	3.1
2031	0.5	58.0	37.0	3.3
2032	0.5	58.1	37.8	3.4
2033	0.5	58.1	38.6	3.5
2034	0.5	58.2	39.4	3.6
2035	0.6	58.2	40.1	3.7
2050	*0.9*	*58.8*	*47.3*	*4.9*
2100	*2.9*	*59.8*	*54.6*	*6.3*

Accountable action - Credits	
Year	IIP & RH S3A - S3C
2000	*13.4*
2005	24.2
2006	25.9
2007	27.4
2008	28.4
2009	29.1
2010	29.6
2011	30.0
2012	30.5
2013	30.8
2014	31.1
2015	31.5
2016	31.7
2017	32.0
2018	32.2
2019	32.5
2020	32.7
2021	32.9
2022	33.0
2023	33.2
2024	33.4
2025	33.5
2026	33.7
2027	33.8
2028	34.0
2029	34.1
2030	34.2
2031	34.3
2032	34.4
2033	34.6
2034	34.7
2035	34.8
2050	*36.0*
2100	*38.2*

Figure 8.2 Accountable debits and credits for the Bookpurnong reach (t/d)

Time	S-1	S-2	S-3a	S-3c	S-4	S-5	S-8a	S-8b	S-8c
(y)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)
1988	132	144	4513	4513	4513	4513	4513	4513	4513
1989	132	144	4541	4539	4539	4539	4539	4539	4539
1990	132	145	4569	4564	4564	4564	4564	4564	4564
1991	132	146	4599	4563	4563	4563	4563	4563	4563
1992	132	147	4628	4554	4554	4554	4554	4554	4554
1993	132	148	4659	4530	4530	4530	4530	4530	4530
1994	132	148	4689	4479	4479	4479	4479	4479	4479
1995	132	149	4720	4423	4423	4423	4423	4423	4423
1996	132	150	4751	4372	4372	4372	4372	4372	4372
1997	132	151	4780	4326	4326	4326	4326	4326	4326
1998	132	152	4811	4267	4267	4267	4267	4267	4267
1999	132	152	4842	4204	4204	4204	4204	4204	4204
2000	132	153	4872	4147	4148	4148	4148	4147	4148
2001	132	154	4901	4081	4082	4082	4082	4081	4082
2002	132	155	4930	4006	4007	4007	4007	4006	4007
2003	132	156	4959	3933	3933	3933	3933	3933	3933
2004	132	157	4988	3864	3865	3865	3865	3864	3865
2005	132	158	5014	3802	3809	3809	3492	3485	3492
2006	132	159	5041	3743	3756	3756	3445	3432	3445
2007	132	160	5066	3686	3710	3710	2019	2007	2019
2008	132	161	5090	3633	3669	3669	1821	1803	1821
2009	132	162	5112	3583	3629	3629	1256	1237	1256
2010	132	164	5133	3538	3593	3593	1092	1074	1092
2011	132	165	5153	3495	3558	3558	1025	1007	1025
2012	132	166	5172	3456	3526	3526	978	959	978
2013	132	167	5190	3421	3497	3497	950	929	950
2014	132	168	5206	3387	3472	3472	931	908	931
2015	132	170	5222	3355	3452	3452	917	891	917
2016	132	171	5236	3326	3434	3435	906	877	906
2017	132	172	5251	3300	3419	3421	897	865	898
2018	132	173	5263	3274	3406	3413	890	855	891
2019	132	174	5276	3251	3396	3408	884	846	887
2020	132	176	5288	3229	3387	3407	879	838	884
2021	132	177	5299	3208	3382	3409	875	830	883
2022	132	179	5310	3189	3378	3415	872	824	882
2023	132	180	5320	3172	3376	3422	870	818	882
2024	132	182	5330	3155	3376	3432	869	812	883
2025	132	183	5339	3140	3376	3442	868	807	885
2026	132	184	5348	3125	3378	3455	867	803	886
2027	132	186	5357	3111	3381	3467	867	799	889
2028	132	187	5365	3099	3385	3481	867	795	891
2029	132	189	5373	3087	3389	3495	867	791	894
2030	132	190	5380	3076	3394	3510	867	788	896
2031	132	192	5387	3065	3400	3525	868	785	899
2032	132	193	5394	3055	3406	3540	869	782	902
2033	132	195	5401	3046	3412	3555	870	779	905
2034	132	197	5408	3038	3419	3570	871	776	908
2035	132	198	5414	3030	3426	3585	872	774	911
2036	132	200	5420	3022	3433	3600	873	772	914
2037	132	201	5426	3015	3440	3615	874	770	917
2038	132	203	5432	3008	3448	3630	876	768	920
2039	132	205	5437	3002	3456	3645	877	766	923
2040	132	207	5443	2996	3463	3659	878	764	926
2041	132	209	5448	2991	3471	3673	880	763	929
2042	132	210	5453	2986	3479	3688	881	761	932
2043	132	212	5457	2981	3487	3702	883	760	935
2044	132	214	5462	2976	3495	3716	885	759	938
2045	132	216	5467	2972	3503	3730	886	757	941
2046	132	218	5471	2968	3511	3743	888	756	943
2047	132	220	5476	2965	3519	3756	889	755	946
2048	132	222	5480	2961	3527	3769	891	754	949
2049	132	224	5484	2958	3534	3782	892	753	952
2050	132	226	5488	2955	3542	3794	894	752	954
2051	132	228	5492	2952	3550	3807	895	751	957
2052	132	230	5495	2950	3558	3818	897	751	959
2053	132	233	5499	2947	3565	3831	899	750	962
2054	132	235	5503	2945	3573	3842	900	749	964
2055	132	237	5506	2943	3581	3853	902	749	966
2056	132	239	5509	2941	3588	3865	903	748	969
2057	132	241	5512	2939	3595	3876	905	747	971
2058	132	243	5515	2937	3603	3886	906	747	973
2059	132	245	5518	2936	3610	3897	908	746	975
2060	132	248	5521	2934	3617	3908	909	746	978
2061	132	250	5524	2933	3625	3918	911	746	980
2062	132	253	5527	2932	3632	3928	912	745	982
2063	132	255	5529	2931	3639	3938	914	745	984
2064	132	257	5532	2930	3646	3947	915	744	986
2065	132	260	5534	2929	3653	3957	916	744	988
2066	132	262	5537	2928	3660	3966	918	744	990
2067	132	264	5539	2927	3666	3975	919	744	992
2068	132	267	5541	2927	3673	3984	921	743	994
2069	132	269	5543	2926	3680	3993	922	743	996
2070	132	272	5545	2926	3686	4002	923	743	998
2071	132	274	5547	2925	3692	4011	925	743	999
2072	132	277	5549	2925	3699	4019	926	742	1001
2073	132	280	5551	2924	3705	4028	927	742	1003
2074	132	282	5553	2924	3711	4036	928	742	1005
2075	132	285	5555	2924	3718	4044	930	742	1006
2076	132	287	5557	2924	3724	4052	931	742	1008
2077	132	290	5559	2924	3730	4059	932	742	1010
2078	132	292	5560	2924	3736	4067	933	742	1011
2079	132	295	5562	2924	3741	4074	935	742	1013
2080	132	298	5564	2924	3747	4081	936	742	1015
2081	132	301	5565	2924	3753	4088	937	741	1016
2082	132	303	5567	2924	3759	4095	938	741	1018
2083	132	306	5568	2924	3764	4102	939	741	1019
2084	132	309	5570	2924	3770	4109	940	741	1021
2085	132	311	5571	2924	3775	4115	941	741	1022
2086	132	314	5573	2924	3780	4121	943	741	1023
2087	132	317	5574	2925	3786	4127	944	741	1025
2088	132	320	5576	2925	3791	4133	945	741	1026
2089	132	322	5577	2925	3796	4139	946	741	1027
2090	132	325	5578	2926	3801	4145	947	741	1029
2091	132	328	5580	2926	3806	4150	948	741	1030
2092	132	331	5581	2926	3811	4155	949	741	1031
2093	132	334	5582	2927	3816	4161	950	741	1032
2094	132	337	5583	2927	3821	4166	951	741	1034
2095	132	340	5585	2928	3826	4171	952	741	1035
2096	132	343	5586	2928	3830	4175	953	741	1036
2097	132	346	5587	2929	3835	4180	954	742	1037
2098	132	349	5588	2929	3840	4184	955	742	1038
2099	132	352	5589	2930	3844	4189	956	742	1039
2100	132	355	5590	2930	3849	4193	957	742	1040
2101	132	358	5591	2931	3853	4197	958	742	1041
2102	132	361	5592	2931	3857	4201	959	742	1042
2103	132	364	5593	2932	3862	4205	960	742	1043
2104	132	368	5594	2933	3866	4209	960	742	1044
2105	132	371	5595	2933	3870	4213	961	742	1045
2106	132	374	5596	2934	3875	4216	962	742	1045
2107	132	377	5597	2934	3879	4220	963	742	1046
2108	132	381	5598	2935	3883	4223	964	742	1047
2109	132	384	5599	2936	3887	4227	965	743	1048
2110	132	387	5600	2936	3891	4230	966	743	1049

Scenario	Name	Model Run	Irrigation development area	IIP and RH	SIS
S-1	Natural System (Steady State since 1920)	Steady State	None	No	No
S-2	Mallee Clearance	1920 - CY100	None	No	No
S-3a	Irrigation Pre-1988, no IIP, no RH	1988 – CY100	Pre-1988	No	No
S-3c	Irrigation Pre-1988, with IIP & RH	1988 – CY100	Pre-1988	Yes	No
S-4	Current irrigation (business as usual)	CY – CY100	Pre-1988 + Post-1988	Yes	No
S-5	Current plus future irrigation	CY – CY100	Pre-1988 + Post-1988 + Future development	Yes	No
S-8a	Current irrigation plus constructed SIS	CY – CY100	Pre-1988 + Post-1988	Yes	Yes
S-8b	Pre-1988, with IIP & RH plus constructed SIS	CY – CY100	Pre-1988	Yes	Yes
S-8c	Current plus future irrigation plus constructed SIS	CY – CY100	Pre-1988 + Post-1988 + Future development	Yes	Yes

IIP = improved irrigation practices; RH = Rehabilitation of irrigation distribution networks; SIS = Saltl interception scheme
CY = current year; CY100 = 100 yrs from the current year

Figure 8.3 Modelled flux (m^3/d) entering the River Murray in the Loxton Reach

Time (y)	S-1 (m^3/d)	S-2 (m^3/d)	S-3a (m^3/d)	S-3c (m^3/d)	S-4 (m^3/d)	S-5 (m^3/d)	S-8a (m^3/d)	S-8b (m^3/d)	S-8c (m^3/d)
1988	977	983	2633	2633	2633	2633	2633	2633	2633
1989	977	983	2676	2648	2648	2648	2648	2648	2648
1990	977	983	2745	2700	2700	2700	2700	2700	2700
1991	977	983	2827	2730	2730	2730	2730	2730	2730
1992	977	983	2891	2754	2754	2754	2754	2754	2754
1993	977	984	2949	2752	2752	2752	2752	2752	2752
1994	977	984	3010	2776	2776	2776	2776	2776	2776
1995	977	984	3056	2799	2799	2799	2799	2799	2799
1996	977	984	3167	2900	2900	2900	2900	2900	2900
1997	977	984	3264	2970	2970	2970	2970	2970	2970
1998	977	984	3413	3088	3088	3088	3088	3088	3088
1999	977	984	3509	3124	3124	3124	3124	3124	3124
2000	977	985	3583	3132	3133	3133	3133	3132	3133
2001	977	985	3642	3110	3113	3113	3114	3110	3114
2002	977	985	3690	3074	3083	3083	3083	3074	3083
2003	977	985	3731	3031	3047	3047	3047	3031	3047
2004	977	985	3767	2993	3019	3019	3019	2993	3019
2005	977	986	3796	2951	2989	2989	1805	1798	1805
2006	977	986	3823	2919	2975	2975	781	777	781
2007	977	986	3846	2895	2976	2976	768	763	768
2008	977	986	3866	2883	2985	2985	761	754	761
2009	977	986	3885	2878	3000	3000	757	747	757
2010	977	987	3901	2876	3019	3019	755	743	755
2011	977	987	3916	2876	3059	3059	757	739	757
2012	977	988	3931	2878	3100	3100	761	736	761
2013	977	988	3944	2879	3143	3143	767	734	767
2014	977	988	3956	2880	3204	3204	780	733	780
2015	977	988	3967	2882	3279	3296	796	731	797
2016	977	988	3978	2884	3357	3385	806	731	808
2017	977	989	3988	2885	3431	3467	816	730	819
2018	977	989	3997	2888	3501	3543	825	729	829
2019	977	989	4007	2890	3565	3615	835	729	839
2020	977	990	4015	2892	3627	3682	844	729	849
2021	977	990	4023	2894	3684	3745	853	729	858
2022	977	991	4031	2896	3738	3804	861	729	867
2023	977	991	4039	2898	3787	3859	869	729	875
2024	977	992	4046	2900	3834	3912	876	729	884
2025	977	992	4053	2902	3878	3961	884	729	891
2026	977	992	4059	2904	3920	4008	890	729	899
2027	977	992	4066	2906	3959	4051	897	729	906
2028	977	993	4072	2908	3996	4092	903	729	912
2029	977	993	4078	2910	4030	4131	909	729	918
2030	977	994	4084	2912	4062	4167	914	730	924
2031	977	995	4089	2913	4093	4202	919	730	930
2032	977	995	4094	2915	4121	4234	924	730	935
2033	977	996	4100	2917	4148	4265	928	730	940
2034	977	996	4105	2918	4173	4294	933	730	945
2035	977	997	4110	2920	4198	4321	937	731	949
2036	977	997	4114	2921	4220	4347	941	731	953
2037	977	998	4119	2923	4242	4372	944	731	958
2038	977	998	4123	2924	4262	4395	948	731	961
2039	977	998	4128	2926	4281	4418	951	731	965
2040	977	999	4132	2927	4300	4439	954	732	968
2041	977	1000	4136	2928	4317	4459	957	732	972
2042	977	1001	4140	2929	4334	4478	960	732	975
2043	977	1002	4144	2931	4350	4497	962	732	978
2044	977	1002	4148	2932	4365	4514	965	732	981
2045	977	1003	4151	2933	4379	4531	967	732	983
2046	977	1004	4155	2934	4393	4547	970	733	986
2047	977	1004	4158	2935	4406	4562	972	733	989
2048	977	1005	4162	2936	4419	4577	974	733	991
2049	977	1005	4165	2937	4430	4590	976	733	993
2050	977	1007	4168	2938	4442	4604	978	733	995
2051	977	1008	4171	2939	4453	4617	980	733	997
2052	977	1009	4174	2940	4463	4629	981	734	999
2053	977	1010	4177	2941	4473	4641	983	734	1001
2054	977	1010	4180	2942	4483	4652	985	734	1003
2055	977	1011	4183	2943	4492	4663	986	734	1005
2056	977	1012	4186	2944	4501	4673	988	734	1007
2057	977	1013	4189	2944	4510	4683	989	734	1008
2058	977	1014	4191	2945	4518	4693	990	734	1010
2059	977	1014	4194	2946	4526	4702	992	734	1011
2060	977	1016	4197	2947	4534	4711	993	735	1013
2061	977	1017	4199	2948	4541	4719	994	735	1014
2062	977	1018	4202	2948	4548	4728	995	735	1016
2063	977	1019	4204	2949	4555	4736	996	735	1017
2064	977	1020	4206	2950	4561	4743	998	735	1018
2065	977	1021	4209	2950	4568	4751	999	735	1019
2066	977	1022	4211	2951	4574	4758	1000	735	1020
2067	977	1023	4213	2952	4580	4765	1001	735	1022
2068	977	1024	4215	2952	4586	4771	1001	735	1023
2069	977	1025	4217	2953	4591	4778	1002	735	1024
2070	977	1027	4219	2954	4596	4784	1003	736	1025
2071	977	1028	4221	2954	4602	4790	1004	736	1026
2072	977	1030	4223	2955	4607	4796	1005	736	1027
2073	977	1031	4225	2955	4611	4802	1006	736	1028
2074	977	1032	4227	2956	4616	4807	1006	736	1029
2075	977	1034	4229	2956	4621	4813	1007	736	1029
2076	977	1035	4231	2957	4625	4818	1008	736	1030
2077	977	1036	4233	2958	4629	4823	1009	736	1031
2078	977	1037	4235	2958	4634	4827	1009	736	1032
2079	977	1038	4236	2959	4638	4832	1010	736	1033
2080	977	1040	4238	2959	4642	4837	1011	736	1033
2081	977	1042	4240	2960	4645	4841	1011	736	1034
2082	977	1043	4241	2960	4649	4845	1012	736	1035
2083	977	1045	4243	2961	4653	4850	1012	737	1036
2084	977	1046	4244	2961	4656	4854	1013	737	1036
2085	977	1048	4246	2962	4659	4858	1013	737	1037
2086	977	1049	4247	2962	4663	4861	1014	737	1037
2087	977	1051	4249	2963	4666	4865	1014	737	1038
2088	977	1052	4250	2963	4669	4869	1015	737	1039
2089	977	1053	4252	2963	4672	4872	1015	737	1039
2090	977	1055	4253	2964	4675	4876	1016	737	1040
2091	977	1057	4255	2964	4678	4879	1016	737	1040
2092	977	1058	4256	2965	4681	4882	1017	737	1041
2093	977	1060	4257	2965	4684	4885	1017	737	1041
2094	977	1062	4259	2965	4686	4888	1018	737	1042
2095	977	1063	4260	2966	4689	4891	1018	737	1042
2096	977	1065	4261	2966	4692	4894	1019	737	1043
2097	977	1066	4262	2967	4694	4897	1019	737	1043
2098	977	1068	4264	2967	4697	4900	1019	737	1044
2099	977	1069	4265	2967	4699	4903	1020	738	1044
2100	977	1071	4266	2968	4701	4905	1020	738	1045
2101	977	1073	4267	2968	4704	4908	1020	738	1045
2102	977	1074	4268	2969	4706	4911	1021	738	1046
2103	977	1076	4270	2969	4708	4913	1021	738	1046
2104	977	1078	4271	2969	4710	4915	1022	738	1046
2105	977	1080	4272	2970	4712	4918	1022	738	1047
2106	977	1081	4273	2970	4714	4920	1022	738	1047
2107	977	1083	4274	2970	4716	4922	1023	738	1048
2108	977	1084	4275	2971	4718	4925	1023	738	1048
2109	977	1086	4276	2971	4720	4927	1023	738	1048
2110	977	1088	4277	2971	4722	4929	1023	738	1049

Scenario	Name	Model Run	Irrigation development area	IIP and RH	SIS
S-1	Natural System (Steady State since 1920)	Steady State	None	No	No
S-2	Mallee Clearance	1920 - CY100	None	No	No
S-3a	Irrigation Pre-1988, no IIP, no RH	1988 – CY100	Pre-1988	No	No
S-3c	Irrigation Pre-1988, with IIP & RH	1988 – CY100	Pre-1988	Yes	No
S-4	Current irrigation (business as usual)	CY – CY100	Pre-1988 + Post-1988	Yes	No
S-5	Current plus future irrigation	CY – CY100	Pre-1988 + Post-1988 + Future development	Yes	No
S-8a	Current irrigation plus constructed SIS	CY – CY100	Pre-1988 + Post-1988	Yes	Yes
S-8b	Pre-1988, with IIP & RH plus constructed SIS	CY – CY100	Pre-1988	Yes	Yes
S-8c	Current plus future irrigation plus constructed SIS	CY – CY100	Pre-1988 + Post-1988 + Future development	Yes	Yes

IIP = improved irrigation practices RH = Rehabilitation of irrigation distribution networks SIS = Saltl interception scheme
CY = current year CY100 = 100 yrs from the current year

Figure 8.4 Modelled flux (m^3/d) entering the River Murray in the Bookpurnong Reach

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

Shortened forms

~ approximately equal to

bgs below ground surface

EC electrical conductivity (µS/cm)

K hydraulic conductivity (m/d)

pH acidity

pMC percent of modern carbon

ppb parts per billion

ppm parts per million

ppt parts per trillion

w/v weight in volume

w/w weight in weight

GLOSSARY

Anabranch — A branch of a river that leaves the main channel

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells and to more accurately estimate the sustainable use of the water resources available for development from the well

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

AWE — Australian Water Environments Pty Ltd

Basin — The area drained by a major river and its tributaries

Benchmark condition — Points of reference from which change can be measured

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

BoM — Bureau of Meteorology, Australia

Bore — See 'well'

BSMS — Basin Salinity Management Strategy developed by Murray-Darling Basin Authority

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge; continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

CSIRO — Commonwealth Scientific and Industrial Research Organisation

DENR — Department for Environment and Natural Resources (Government of South Australia)

DES — Drillhole Enquiry System; a database of groundwater wells in South Australia, compiled by the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC)

DFW — Department for Water (Government of South Australia)

Dryland salinity — The process whereby salts stored below the surface of the ground are brought close to the surface by the rising watertable. The accumulation of salt degrades the upper soil profile, with impacts on agriculture, infrastructure and the environment.

GLOSSARY

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia)

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land and surface water bodies

Floodplain — Of a watercourse means: (1) floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under the Act; or (2) where (1) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development (SA) Act 1993*; or (3) where neither (1) nor (2) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse

Future irrigation development — Future irrigation development area and recharge (assuming recharge of 100 mm/y) resulting from activation of already allocated water that is assumed to occur after current year

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes and the properties of aquifers; see also 'hydrology'

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

IAG-Salinity — Independent Audit Group for Salinity

Improved Irrigation Practices (IIP) — Commencing in the mid 1990s when flood irrigation via earth channels was replaced by sprinkler and drip irrigation systems, thus increasing irrigation efficiency (70% - 85%) and reducing recharge to the groundwater table

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment

Irrigation — Watering land by any means for the purpose of growing plants

Irrigation season — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May

Lag time — Time (in years) taken for recharge to reach the water table. Lag time is affected by depth to water table and the presence and properties of aquitards

Lake — A natural lake, pond, lagoon, wetland or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

MDBA — Murray-Darling Basin Authority

MDBC — Murray-Darling Basin Commission

GLOSSARY

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change

Modelled results — Output from the calibrated model (e.g. potentiometric head distribution) that can be compared to observed data

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

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc). See also recharge area, artificial recharge

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Obswell — Observation Well Network

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m^2/d

PIRSA — Primary Industries and Resources South Australia (Government of South Australia)

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

Production well — The pumped well in an aquifer test, as opposed to observation wells; a wide-hole well, fully developed and screened for water supply, drilled on the basis of previous exploration wells

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. See also artificial recharge, natural recharge

Rehabilitation (RH) — Replacement of leaky concrete water distribution channels with pipelines resulting in reduced transportation losses, which are reflected by reduced recharge to the water table

Salt interception scheme (SIS) — Interception of saline groundwater flux and salt load which would otherwise enter the River Murray

SA Water — South Australian Water Corporation (Government of South Australia)

Specific storage (S_s) — Specific storativity; the amount of stored water realised from a unit volume of aquifer per unit decline in head; it has dimensions of 1/length

Specific yield (S_y) — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless

Storativity/Storage coefficient (S) — The volume of groundwater released or taken into storage per unit plan area of aquifer per unit change of head; it is dimensionless

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

Tertiary aquifer — A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago)

Transmissivity (T) — A parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m^2/d

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

USGS — United States Geological Survey

Watertable — The saturated – unsaturated interface within the ground

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

REFERENCES

Adams, T & Meissner, T 2009, *How efficient are we? Draft report of project findings*, prepared for SAMDBNRMB and DWLBC, August 2009.

Allison, GB, Cook, PG, Barnett, SR, Walker, GR, Jolly, ID & Hughes, MW 1990, 'Land clearance and river salinisation in the western Murray Basin, Australia', *Journal of Hydrology*, 119, pp. 1-20.

Aquaterra, REM & AWE 2006, *Hydrogeological Investigations of Irrigation Trust Areas at Renmark, Chaffey, Berri and Cobdogla*, prepared by Aquaterra, Resource and Environmental Management and Australian Water Environments for DWLBC, May 2006.

AWE 2003, *Loxton and Bookpurnong Salt Interception Schemes Groundwater Model*, October 2002–February 2003 (Not Published).

AWE 2010, *Murtho SIS Stage 3 Borefield Optimisation and Climate Sequence Modelling,* prepared for SA Water.

AWE 2011a, *Loxton–Bookpurnong SIS 5 Year Review Hydrogeology Report*, prepared for SA Water.

AWE 2011b, *Loxton–Bookpurnong SIS Figure Atlas*, prepared for SA Water.

AWE 2011c, *River Murray Floodplain Salt Mobilisation and Salinity Exceedances at Morgan : Final Report to the MDBA Project Flood Recession Salt Mobilisation from Floodplain of the River Murray*, prepared for the MDBA, in review.

Barnett, S, SA Department of Mines and Energy, 1991, Renmark Hydrogeological Map (1:250 000 scale) Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

Brown, CM 1989, 'Structural and Stratigraphic Framework of Groundwater Occurrence and Surface Discharge in the Murray basin, Southeastern Australia, *BMR Journal of Geology and Geophysics*, 11, pp. 127-146.

Bureau of Meteorology 2006, Commonwealth of Australia, viewed 02 November 2010, <http://www.bom.gov.au>.

Cook, PG, Leaney, FW & Miles, M 2004, *Groundwater Recharge in the North-East Mallee Region, South Australia*, CSRIO Land and Water Technical Report No 25/04, South Australia.

Doody, TM, Holland, KL, Benyon, RG & Jolly, ID 2009, 'Effect of groundwater freshening on riparian vegetation water balance', *Hydrological Processes*, 23(24): 3485-3499.

DWLBC 2003, Bookpurnong and Loxton Salt Interception Schemes, Joint Works/State Action Approval Submission to the Murray-Darling Basin Commission High Inter-Jurisdictional Working Group on Salt Interception, prepared by Department for Water, Land and Biodiversity Conservation, February 2003.

Evans, WR & Kellet, JR 1989, 'The hydrogeology of the Murray Basin, southeastern Australia', *BMR Journal of Australian Geology and Geophysics*, 11, pp. 147–166.

Fuller, D, Watkins, N, Woods, J, Hoxley, G & Miles, M 2005, *SIMRAT v2.0.1 summary report*, prepared for the Murray-Darling Basin Commission, May 2005.

Harrington, N, James-Smith, J & Love, A 2006, *Environmental tracers to constrain conceptual hydraulic models in the Loxton - Bookpurnong region, South Australia*, DWLBC Report 2005/25, Department of Water, Land and Biodiversity Conservation, Adelaide.

REFERENCES

Hill, MC & Tiedeman, CR 2007, *Effective Groundwater Model Calibration*, Wiley Inter-Science, United States.

Holland, K, Jolly, ID, Tyerman, S, Mensforth, L, Telfer, A & Walker, GR 2001, Interception of groundwater discharge by floodplain in the lower River Murray: Implications for river salinity, 8th Murray-Darling Basin Groundwater Workshop 2001.

Knight, JH, Gilfedder, M & Walker, GR 2005, 'Impact of Irrigation and dryland development on groundwater discharge to rivers: A unit response approach to cumulative impacts analysis', *Journal of Hydrology*, 303, pp. 79-91.

Laroona Environmetrics 2011, *Estimation of accession for Loxton and Bookpurnong irrigation areas*, prepared for the Department for Water.

Lisdon Associates 2010, *Lag-Time Study — SUTRA model based on Loxton Hydrogeological Profile*, prepared for DWLBC, May 2010.

Lukasik, JJ & James, NP 1998, 'Lithostratigraphic revision and correlation of the Oligo-Miocene Murray Supergroup, western Murray Basin, South Australia', *Australian Journal of Earth Sciences*, 45, pp. 889–902.

McDonald, MG & Harbaugh, AW 1988, A modular three-dimensional finite-difference groundwater flow model, Techniques of Water-Resources Investigations of the United State Geological Survey, Modelling Techniques Book 6.

MDBC 2001, *Groundwater Flow Modelling Guideline*, August 2001.

National Geospatial-Intelligence Agency 2011, *Shuttle Radar Topography Mission DTED Level 1 (3-arc second) Data (DTED-1)*, National Aeronautics and Space Administration, viewed 13 May 2011 <http://gcmd.nasa.gov/records/GCMD_DMA_DTED.html>.

REM-Aquaterra 2005a, *Salt Interception Scheme Concept Design Murtho and Pike River, Hydrogeology and Proposed Groundwater Modelling Approach*, Prepared by Resource and Environmental Management - Aquaterra for Department of Water, Land and Biodiversity Conservation, August 2005.

REM-Aquaterra 2005b, *Salt Interception Scheme Concept Design Murtho and Pike River, Groundwater Modelling and Salt Interception Scheme Concept Design Report*, Prepared by Resource and Environmental Management - Aquaterra for Department of Water, Land and Biodiversity Conservation, September 2005.

Salient Solutions 2006, *Review of Three South Australian Groundwater Models, Morgan to Lock3, South Australian Dryland Clearing and Pike-Murtho*, prepared for the Murray-Darling Basin Commission.

Salient Solutions 2009a, Berri–Renmark numerical groundwater model peer review MD1146, prepared for the Murray-Darling Basin Authority, February 2009.

Salient Solutions 2009b, Pyap to Kingston Numerical Groundwater Model Peer Review MD1146, prepared for the Murray-Darling Basin Authority, February 2009.

Vears, L 2010, Draft SA/MDBA Groundwater Modelling Meeting 9am-1pm, Thursday 21 January, 2010. Meeting minutes prepared by Department for Water.

Yan, W, Georgiou, J, Howe, B, Armstrong, D & Barnett, S 2007, *Berri-Renmark Numerical Groundwater Model 2007*, DWLBC Report 2007/30, Department of Water, Land and Biodiversity Conservation, Adelaide.

Yan, W, Howe, B, Hodgkin, T & Stadter, M 2006, *Pike–Murtho Numerical Groundwater Model 2006*, DWLBC Report 2006/26, Department of Water, Land and Biodiversity Conservation, Adelaide.

Yan, W, Howles, S & Hill, T 2005, *Loxton Numerical Groundwater Model 2004*, DWLBC Report 2005/16, Department of Water, Land and Biodiversity Conservation, Adelaide.

Yan, W, Howles, S, Howe, B & Hill, T 2005, *Loxton–Bookpurnong Numerical Groundwater Model 2005*, DWLBC Report 2005/17, Department of Water, Land and Biodiversity Conservation, Adelaide.

Yan, W & Stadter, M 2008, *Pyap to Kingston Numerical Groundwater Model 2008*, DWLBC Report 2008/19, Department of Water, Land and Biodiversity Conservation, Adelaide.