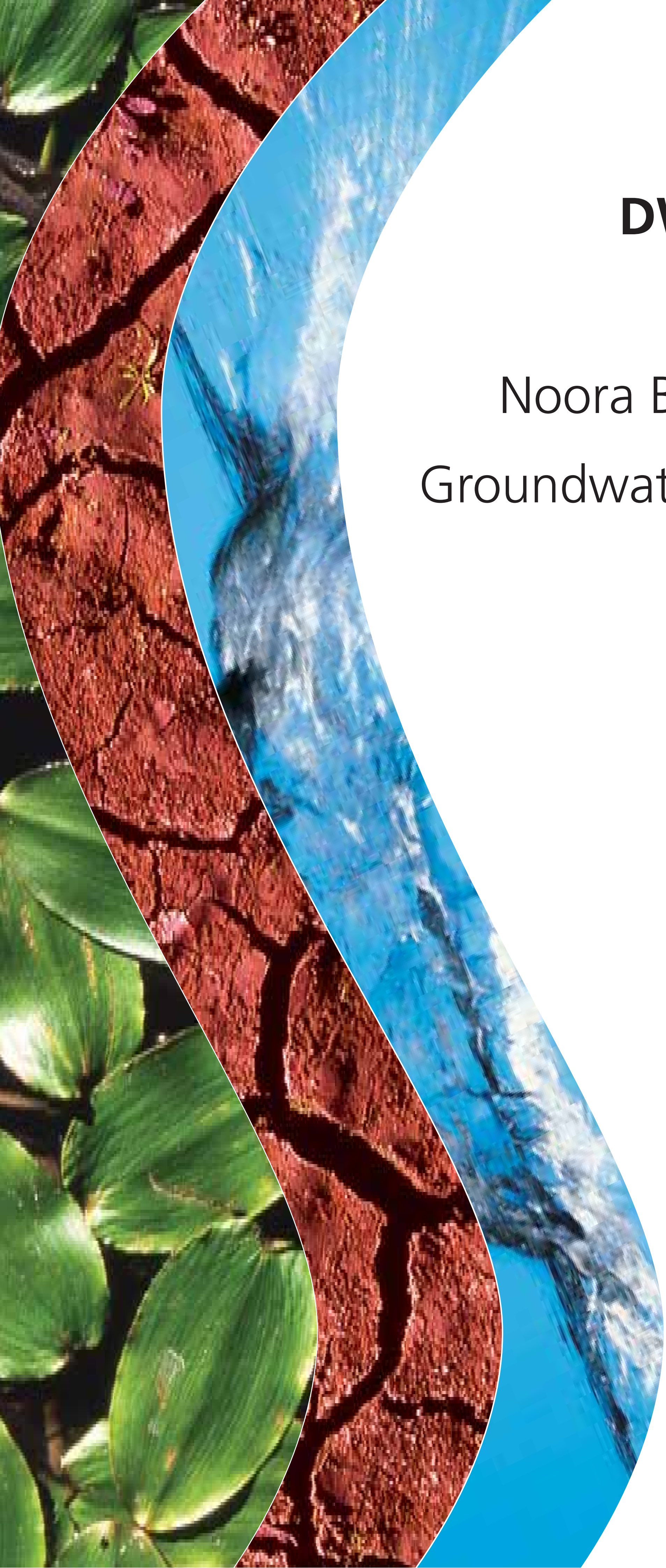

DWLBC REPORT

Noora Basin Numerical Groundwater Model 2007

2007/25

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Noora Basin Numerical Groundwater Model 2007

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Report DWLBC 2007/25

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the state. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continue to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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EXECUTIVE SUMMARY

The Knowledge and Information Division of the Department of Water, Land and Biodiversity Conservation (DWLBC) have teamed with Resource & Environmental Management Pty Ltd (REM) to estimate the changes to groundwater levels within the aquifer systems beneath and surrounding Noora Basin due (only) to basin inundation for several disposal (operating) scenarios. Changes to groundwater levels have been estimated using a calibrated numerical groundwater flow model. The modelling has been carried out to support the Murtho Salt Interception Scheme Approval Submission currently before the Murray–Darling Basin Commission, and to support other investigations into the potential impacts of basin operation upon surrounding land-use and vegetation.

The modelling has been performed with Visual MODFLOW (Version 4.1) software and has been undertaken on an existing regional model used by DWLBC in previous hydrogeological studies of the Mallee region. Model calibration of the immediate Noora Basin area has been refined using historical groundwater levels and basin operating data, as well as use of local and regional digital elevation model (DEM) data.

Three different basin operating scenarios have been modelled:

- Scenario 1 – Irrigation Drainage + Bookpurnong SIS + Loxton SIS + Murtho SIS.
- Scenario 2 – Irrigation Drainage + Bookpurnong SIS + Loxton SIS + Murtho SIS + Pike SIS.
- Scenario 3 – Basin water level maintained at 19.0 m AHD.

Scenario 1 and 2 attempt to simulate the planned and likely use of Noora Basin, whilst Scenario 3 was carried out to estimate the impacts of operating the basin at a maximum level of 19 m AHD. Some of the key inputs to the groundwater modelling have been derived as outputs from the recent surface water modelling of the basin operation by DWLBC (Heneker, 2007) and comprise areas of basin inundation, basin water levels and basin water salinity. Importantly, both the surface water and groundwater models use an adopted average value of leakage beneath the basin of 0.2 mm/d which is consistent with all previous Noora Basin studies.

Key findings of the modelling work comprise:

- The expansion of basin inundation for any of the model scenarios is not likely to have any significant effect on groundwater levels within the deeper confined Murray Group Limestone Aquifer, but will be limited to the regional watertable aquifer occurring in the Loxton Sands.
- Only a relatively limited watertable mound can develop around Noora Basin for either prediction scenario given the limited depth to groundwater and low regional hydraulic gradients. The shape of the watertable mounds are estimated to be similar for each scenario, although the extent and magnitude of the mound will vary slightly; increasing from Scenario 1 to Scenario 3 as more basin area is inundated to higher operating levels.
- Watertable rises will be limited in down-gradient directions (west and north-west) due to the presence of existing and larger irrigation-induced watertable mounds.

- Changes to watertable levels up gradient of Noora Basin will be influenced by the evaporative discharge of groundwater from shallow watertables in two major north-west trending topographic depressions that cross the South Australian – Victorian border (but typically slope gradually downwards to the north-west).
- For Scenario 2 (which represents the most likely future 'use' of Noora Basin and incorporates SIS at Bookpurnong, Loxton, Murtho and Pike) the estimated watertable rises in key areas (and their associated 'error' margins) comprise:
  - near the government-owned land boundary at Noora, long-term watertable rises are predicted to typically range between 1–2 m with an error margin of about +/- 0.5 m
  - the maximum watertable rise predicted at the South Australian – Victorian border is about 0.25 m and has an error margin of about +/- 0.1 m. This maximum rise occurs in an elevated area where the watertable depth is typically 5–30 m
  - in the low-lying depression to the south-east of Noora, the base case predicted watertable rise at the border is about 0.05 m, but ranges from zero (best case) to about 0.15 m (worst case).
- The low-lying areas within several kilometres of the government-owned Noora land boundary will act as a significant evaporation 'buffer' zone that will dampen and diminish the flux of groundwater and extent of watertable rise towards and inside other regional low-lying areas to the south-east, east and north-east of Noora.
- The regional groundwater level rise beyond about 5 km from the basin is typically less than about 0.3 m. Such a rise is not considered to be a significant change to the groundwater system in areas where the existing watertable depth is in excess of 5–10 m. Rises of this magnitude may be difficult to distinguish from natural background fluctuations, as indicated by monitoring wells near Noora Basin, which appear to show non-basin related fluctuations to groundwater levels of up to 0.2 m over several years.

Regular monitoring of groundwater levels will map the actual development of the watertable mound. Given the relatively slow response of the aquifer system to the gradual discharge increases planned for Noora Basin, monitoring will provide an effective tool for the longer-term management of the basin's impact on the surrounding landscape. Whilst the existing Noora Obswell monitoring well network (and other regional wells) is considered suffice for mapping the basin-related changes to groundwater levels, several more regional wells to the south-east, east, and north-east of Noora Basin could be installed to provide a greater coverage for monitoring regional background groundwater conditions and trends.

1. INTRODUCTION

1.1 BACKGROUND

The Noora Basin occupies an extensive low-lying groundwater discharge area about 20 km east of Loxton in the Riverland (Fig. 1) and is one of two major schemes used by South Australia (SA) to dispose of water from irrigation drainage and salt interception schemes. The basin was first used in 1982 when excess irrigation drainage water from the Berri and Disher Creek basins was pumped to Noora. Groundwater from the Bookpurnong Salt Interception Scheme (SIS) was first pumped to Noora Basin in late 2005 and more SIS discharge is scheduled from the Loxton SIS currently under construction.

The recent preparation of the SA Regional Disposal Strategy (RDS) and Murtho SIS Approval Submission has triggered a need to understand the long-term storage capacity of Noora Basin and the potential impacts on surrounding land and groundwater resources. In mid-2006, the Infrastructure and Business Division (IBD) of the Department of Water, Land and Biodiversity Conservation (DWLBC) initiated modelling work to help address these issues. This work was completed by the Knowledge and Information Division (KID) of DWLBC in September 2006 and showed that the 100-year capacity of the basin equated to an average inflow rate of about 370 L/s and that groundwater level rises were typically less than 0.2 m beyond several kilometres from the perimeter of the basin. These results were presented to the Murray-Darling Basin Commission (MDBC) and the partner governments in September and October 2006 as part of the Murtho SIS Approval Submission process.

Following consideration of the Murtho (and Noora) submission, the MDBC Technical Working Group noted that 'the scheme appears to be technically viable and should be adopted as a Shared Work provided that' several criteria could be met, which included one that stated '(e) The regional groundwater and surface water model for the Noora Basin be independently reviewed and agreed fit for purpose'.

In November 2006, IBD commissioned KID and Resource & Environmental Management Pty Ltd (REM) to undertake further basin and groundwater modelling to achieve acceptance by the MDBC of the two models as fit for purpose. This work has been undertaken between December 2006 and July 2007 and has been documented in two separate reports:

- DWLBC Report Book 2007/17 Noora Basin: Surface Water Investigation.
- DWLBC Report Book 2007/25 Noora Basin Numerical Groundwater Model 2007.

This report documents the groundwater modelling work undertaken by DWLBC, but also provides some background to the surface water modelling in Section 1.2 and previous modelling in Appendix A.

1.2 PURPOSE OF MODELLING

The main driver for the modelling work has been the need to support the Murtho SIS Approval Submission. However, the work has also been undertaken to assist in the preparation of the SA RDS and also to inform the longer-term design, operation and management of Noora Basin.

The objectives or purpose of the modelling work, against which an independent technical review can determine if the model is 'fit for purpose' or not, has been defined as:

Surface Water Modelling — to predict the maximum basin storage capacity (in terms of the average disposal inflow rate) over a 100-year period for a maximum operating level of 19.0 m AHD) and to predict the inundated areas and operating levels over a 100-year period for two disposal scenarios. Additionally, outputs from the surface water modelling (the inundated basin extent, pond levels and basin water salinity) are required to provide key inputs to the groundwater modelling.

Ground Water Modelling — to predict the changes to groundwater levels within the aquifer systems beneath and surrounding the basin due only to the operation of Noora Basin under several disposal (operating) scenarios.

Outputs from both models will be used by DWLBC to support past and current risk assessments of the potential impacts from the expanded Noora Basin operation on surrounding vegetation and land use and to develop suitable management and monitoring plans.

1.3 SCOPE OF WORK

The scope of work for the groundwater modelling exercise comprised:

- clarification of the basin disposal scenarios to model
- summarising previous basin modelling
- review and use of past basin operating data to improve calibration of the 2006 groundwater model in the immediate vicinity of the basin
- incorporating local and regional ground surface digital elevation models (DEMs) into the groundwater model and validation of the DEM accuracy against discrete survey point data
- incorporate regional groundwater well data and information to update the conceptual hydrogeological model of the Noora Basin and surrounding area
- run 100-year model predictions for each disposal scenario and undertake sensitivity analyses of key model parameters
- provide recommendations for groundwater monitoring.

The groundwater monitoring recommended in Section 8 is effectively just an introduction to a detailed monitoring framework and monitoring plan that is currently being developed by DWLBC, Rural Solutions and REM.

2. BACKGROUND

2.1 PREVIOUS MODELLING

Modelling of the Noora Basin was undertaken during development of the RDS. This work included modelling the surface water balance of the basin to assist the design of the basin, and also groundwater modelling to estimate the impacts of basin operation on the surrounding groundwater system and the River Murray. This work is summarised in Appendix A to highlight where and how some of the current modelling inputs have been derived. The work summarised comprises:

- Sinclair, Knight and Mertz (SKM) modelling, 2003–05
- Kellogg Brown and Root (KBR) review of SKM modelling, 2005
- Australian Water Environments (AWE)/SA water modelling 2005
- DWLBC, 2006.

2.2 CLIMATE

The Noora Basin is located within a semi-arid climate region with low (winter-dominant) rainfall and high evaporation. The annual average rainfall is 270 mm/y, whilst pan evaporation averages about 2100 mm/y. Table 1 shows the long-term average monthly rainfall for the Renmark (Taldra) rain gauging station.

Table 1. Long-term average monthly rainfall for Taldra rain gauging station (mm)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16	18	15	17	26	26	26	25	27	27	20	18

As most of the summer rainfall is lost by evaporation before it has a chance to percolate down to the watertable, only winter rainfall (April–October) is considered to be effective in contributing to the water balance (Barnett and Marsden, 2003).

Figure 2 displays the long-term monthly rainfall data recorded at the Renmark (Taldra) rain gauging station as well as the cumulative deviation from mean rainfall, which measures the difference between the actual rainfall and the long-term average. Upward trends in the cumulative deviation indicate above-average rainfall, whilst downward trends represent periods of below-average rainfall. The rainfall data shows that below-average rainfall has occurred in the region since Noora Basin was first commissioned as a drainage disposal basin in 1982, apart from periods in 1992–93, 1999 and 2004.

2.3 REGIONAL HYDROGEOLOGY

The Noora region occurs within the Murray Basin, a Tertiary sequence of marine and non-marine sediments which have been deposited over the last 65 million years to form three main aquifer systems, namely the:

- unconfined Loxton Sands Aquifer (shallowest)
- Murray Group Limestone (MGL) Aquifer
- Renmark Group Aquifer (deepest).

These aquifers are separated by marine clay and marl deposits that form effective confining layers. Previous work (Barnett, 1992) has summarised the stratigraphy of the Noora region as shown in Table 2 in order of increasing depth.

Table 2. Stratigraphy of the Noora Region (after Barnett, 1992)

Unit	Age	Description
Yamba Formation	Quaternary	Gypsiferous clays and silts deposited in lower lying areas in the Noora Basin.
Woorinen	Quaternary	Quartz rich loamy sand, can be associated with the Bakara Calcrete and Ripon Calcrete
Blanchetown Clay	Tertiary	Lacustrine clays and silts, low permeability unit causing perched watertables.
Loxton Sands (Pliocene Sands)	Tertiary	Fine to coarse sand, in areas can contain fractions of silt and clay, local watertable aquifer for Noora.
Bookpurnong Beds	Tertiary	Marine silts and clay, confining bed between Parilla/Loxton Sands and Murray Group Limestone.
Murray Group Limestone	Tertiary	Grey off-white fossiliferous limestone, confined aquifer.
Ettrick Formation	Tertiary	Grey-green glauconitic marl, confining layer.
Renmark Group	Tertiary	Brown and grey clays with fine to medium sand interlayers, some siltstone and lignite.

The Noora Basin occurs within an extensive groundwater discharge area where watertable depths are generally less than 2 m. This discharge area lies within one of the lowest parts of the Murray Basin (outside the floodplain) at ~18 m AHD, where evaporative discharge of groundwater from the shallow watertable in the Loxton Sands Aquifer has occurred for thousands of years (Barnett and Marsden, 2003).

The influence of evaporative discharge can be seen in Figure 3, which shows recent groundwater elevations within the unconfined aquifer. Within the Noora area, evaporation has lowered the watertable level and flattened the regional gradient to the east. The regional groundwater flow is from the east to the west and north-west (i.e. from Victoria towards the River Murray).

2.4 HYDROGEOLOGICAL UNITS

2.4.1 YAMBA FORMATION

This unit comprises thin gypsiferous clays and silts deposited in lower lying areas in the Noora Basin and other low-lying salinas of the Mallee region. The formation reflects a seasonal interplay between aeolian, pluvial and groundwater conditions (Brown and Stephenson, 1991).

Within Noora Basin, the unit is unlikely to be thicker than 1–2 m (Barnett, 1992).

2.4.2 WOORINEN FORMATION

The Woorinen Formation forms a thin capping of Aeolian quaternary silt and loamy sands up to about 5 m thick across much of the project area and can contain multiple hard calcrete horizons. However, the unit is typically not present within low-lying highland areas such as the Noora Basin.

This formation can host a perched aquifer in areas where excess drainage from irrigation is inhibited from recharging the true watertable by the presence of relatively thick or clayey sections of underlying Blanchetown Clay.

2.4.3 BLANCHETOWN CLAY

The Blanchetown Clay occurs sporadically throughout the Riverland region and was deposited under low-energy lacustrine conditions. It has a variable lithology and can grade from silty soft clay with poor plasticity and low density, to hard dense clay with high plasticity (Yan et al. 2006).

It is typically thickest in elevated highland areas and is thin or absent in low-lying discharge areas such as Noora Basin.

The Yamba Formation, Woorinen Formation and Blanchetown Clay are unsaturated (apart from local perching in the Woorinen Formation) and consequently are not represented in the numeric groundwater model.

2.4.4 LOXTON SANDS

The Loxton Sands have been eroded across the floodplain but are present throughout the highland areas, often exposed in cliff faces. The Loxton Sands form the regional watertable aquifer, which has also been described in other hydrogeological reports of the Mallee region as the Loxton-Parilla, Parilla Sands or Pliocene Sands aquifer.

In the Loxton and Pike regions of SA, the Loxton Sands generally comprise three main lithofacies: (1) an Upper Loxton Sand facies dominated by pale yellow/grey medium- to coarse-grained sand; (2) a Lower Loxton Sand facies dominated by greyish coarse-grained sand and gravel; and (3) a Lower Loxton Shells facies dominated by remnant fossiliferous shell beds (Yan et al. 2006).

In the Noora Basin area, geological logging of recently installed monitoring wells indicate that the shallowest sections of the Loxton Sands typically comprise pale yellow to orange to grey, poorly sorted (fine- to coarse-grained) quartz sands with minor and variable levels of silt and clay.

2.4.5 BOOKPURNONG BEDS

The Lower Loxton Clay and the Bookpurnong Beds, whilst recognised as discrete stratigraphic units, form a major confining bed throughout the region that separates the MGL and Loxton Sands aquifers.

In the Riverland region of SA, the Bookpurnong Beds consist of a dark green (glauconitic) sequence of fossiliferous marls and silts about 15–20 m thick. The unit typically dips gently to the north-east.

2.4.6 MURRAY GROUP LIMESTONE

The MGL typically comprises a grey/off white consolidated, fine- to coarse-grained bioclastic limestone. Within the Noora region, it represents a confined aquifer about 100 m thick.

Groundwater flow within the aquifer in the Noora region is generally to the west and north-west under fairly low gradients from recharge areas in south-west Victoria (Fig. 4). In the region surrounding Noora Basin, groundwater levels in the MGL Aquifer are typically several metres higher than the Loxton Sands Aquifer, which indicates a potential for upward leakage. However, work by Barnett (1992) indicates that the formation of dense saline water in the watertable aquifer from evaporation has created the potential for downwards leakage in the immediate Noora Basin area, and led to the formation of a saline groundwater plume within the MGL Aquifer over thousands of years by localised density-driven flow.

2.4.7 ETTRICK FORMATION

The Ettrick Formation is a low permeability marine deposit (confining layer) between the MGL and underlying confined aquifers, consisting of glauconitic and fossiliferous marl varying between 10–25 m in thickness.

2.4.8 RENMARK GROUP

The Renmark Group aquifer is a confined aquifer system underlying the whole region. It comprises unconsolidated carbonaceous sands, silt and clay up to 150 m thick, which directly overlie basement rocks.

2.5 GROUNDWATER SALINITY

Groundwater salinity values in the Loxton Sands Aquifer within and surrounding the Noora Basin typically fall within the range from 30 000–60 000 mg/L, although higher values up to about 100 000 mg/L have been recorded (Fig. 5). Increased groundwater salinity is closely linked to the degree of evaporative discharge; previous work by Barnett (1992) has found that values of over 35 000 mg/L are associated with the subdued topography below 40 m AHD.

A review of groundwater impacts following 20 years of basin operation (Barnett and Marsden, 2003) showed two common salinity trends within Obswells – a broad rising trend caused by evaporative concentration of groundwater (GDN 11, 14 and 24), and a ‘bell’ shaped curve (GDN 15, 16 and 21), probably caused by dilution by recharge from ponded surface runoff during wet years.

2.6 GROUNDWATER MONITORING

Two aquifers are monitored in the Noora area: the unconfined Loxton Sands Aquifer and the confined MGL Aquifer, with most monitoring wells completed within the shallow sections of the Loxton Sands. The current Noora Obswell network contains 56 wells and is displayed in Figure 6.

Monitoring of groundwater levels has occurred on a fairly regular basis (typically six-monthly) since the basin was commissioned in 1982, with DWLBC (and its predecessors) undertaking most of the groundwater monitoring. Data is stored on the DWLBC Obswell database and is freely available at https://info.pir.sa.gov.au/obswell/new/obsWell/MainMenu/menu. SA Water has recently taken over the groundwater monitoring as part of their role in operating and maintaining salt interception schemes within SA.

An assessment of groundwater impacts from the first 20 years of basin operation was conducted by DWLBC (Barnett and Marsden) in 2003. This review identified:

- Initial disposal rates to the basin were up to 6000 ML/y before falling to less than 2000 ML/y in response to irrigation efficiency improvements.
- The maximum watertable rise was 2 m beneath the northern sub-basin, with the level of rise decreasing with distance away from the basin to about 4–5 km.
- The maximum watertable level was reached by about 1988–90 and has since declined slightly in response to lower discharge rates.
- Regional watertable rise trends beneath higher ground of about 3 cm/y due to native vegetation clearance.
- Groundwater level rises of about 2 cm/y in the deep confined (MGL) aquifer groundwater levels were due to hydrostatic loading.

In late 2005 and early 2006, the Noora Obswell network was expanded by the installation of an additional 11 monitoring wells within the Loxton Sands Aquifer to provide additional monitoring coverage of the basin. This expansion was in response to further inundation of the basin expected from the commissioning of several new SIS. The new wells are shown in Figure 6 and were sited to augment the existing network and to form transects with existing wells to monitor areas at risk of rising groundwater levels.

2.7 CONCEPTUAL HYDROGEOLOGICAL MODEL

Figure 7 shows the location of two regional cross-sections (Figs 8 and 9) that have been created to help visualise the conceptual hydrogeological model of the Noora Basin region. These sections highlight that:

- The basin represents a major groundwater discharge feature within the unconfined Loxton Sands Aquifer, with significant volumes of water lost to evaporation from shallow watertables.
- The evaporative concentration effects of Noora Basin on regional groundwater causes groundwater salinities to increase to as high as 100 000 mg/L, which forms a regional plume of highly saline groundwater that travels through the watertable aquifer (Loxton Sands) to the north-west and west where it ultimately discharges into the River Murray (or its associated floodplain).

- Regionally, there is an upward vertical head gradient from the deeper confined MGL Aquifer to the Loxton Sands Aquifer, however, locally at least, the density effects from evapoconcentration has reversed this gradient and caused minor amounts of downwards leakage of hypersaline groundwater into the MGL Aquifer.
- Upgradient from Noora Basin, groundwater levels are slightly higher but as the ground surface is typically higher, there is less evaporative discharge in these areas compared to the Noora region within SA (Fig. 9).
- Aligned parallel to the Noora Basin low-lying trough, but located about 10–15 km to the north-east, is another low-lying depression where significant groundwater discharge by evaporation is likely to occur.

3. MODEL CONSTRUCTION

3.1 INTRODUCTION

A numerical groundwater model previously developed by DWLBC for the Mallee region was chosen for the current modelling work, as it covers a wide area within SA and Victoria and is considered suitable for assessing the regional impacts of the basin operation. The model covers the whole Murray Basin area in SA and extends 43 km from the border into Victoria. It is a five-layer model which includes the three major regional aquifer systems, however, the shallowest (Loxton Sands) aquifer was the main focus of the model improvements and predictions.

Modelling was undertaken with MODFLOW using Visual MODFLOW Version 4.1 for both pre- and post-processing of MODFLOW data. MODFLOW is a three-dimensional finite difference mathematical code that was developed by the US Geological Survey (McDonald and Harbaugh, 1988).

3.2 MODEL STRUCTURE

3.2.1 MODEL DOMAIN AND GRID

The model domain is shown in Figure 10 and simulates an area 200 km (east-west) by 200 km (north-south). The bounding coordinates of the model domain are 340 000 mE/ 6 060 000 mN (south-west) and 540 000 mE/6 260 000 mN (north-east).

The extensive model domain surrounding the smaller project area is consistent with good modelling practice, so that the model domain boundaries do not erroneously influence the behaviour of the aquifer system in the study area.

The model grid was divided into 459 rows and 475 columns. The minimum grid size is 125 x 125 m in the Noora Basin area with a maximum grid size of 500 x 500 m in the outer parts of the model domain (Fig. 11).

3.2.2 MODEL LAYERS

The regional groundwater system has been represented in a five-layer model with four aquifer layers and one aquitard layer, which are shown in Figure 12 and summarised in Table 3.

The model grid was applied to the five layers resulting in 1 090 125 finite difference cells.

Table 3. Model layer summary

Layer no.	Hydrogeological unit	Aquifer/aquitard	MODFLOW layer
1	Loxton Sands, Monoman Formation	Unconfined aquifer	Type-1
2	Lower Loxton Clay and Bookpurnong Formation	Aquitard	Type-3
3	Murray Group Limestone	Unconfined/confined aquifer	Type-3
	Ettrick Formation	Aquitard	Simulated as leakage
4	Upper Renmark Group	Confined aquifer	Type-0
5	Lower Renmark Group	Confined aquifer	Type-0

Layer-1: Loxton Sands Aquifer

Layer 1 simulates the regional watertable aquifer, which in highland areas occurs within the Loxton Sands and within the Monoman Formation inside the River Murray valley. These two units are assumed to be in direct hydraulic connection with each other, with regional groundwater flow entering the Monoman Formation from the Loxton Sands before discharging to the river or its anabranches, or being discharged as evaporation. The floodplain regions of the model are not of great significance to the modelling of the Noora Basin area.

The top of Layer 1 is the natural ground surface and has been represented in the groundwater model by the raster dataset shown in Figure 13. The ground surface raster was created by merging two different DEMs:

- A regional DEM provided to DWLBC by the MDBC, which was originally compiled by AGRECON Pty Ltd in 2005 for use in a study of hillside farm dams within the Murray Darling Basin.
- A local Noora Basin DEM, which was created by SKM in around 2004 as part of the RDS Stage 3 project work. This DEM was created after digitising a set of 1.0 m elevation contours of the Noora Basin, as plotted onto 24 separate 1:2000 scale plans. These contour plans were originally produced in the late 1970s from point data and photogrammetric analyses as part of the preparations for initial discharge to Noora Basin. Figure 13 highlights where the boundary of this 'local' DEM fits in with the regional DEM.

The incorporation of the natural ground surface DEM into the model represents one of the major changes compared with the 2006 modelling performed by DWLBC. As outlined in Appendix A, the previous modelling did not simulate the natural ground surface, but rather modelled evaporative losses from shallow watertables by approximating low-lying areas as drainage cells.

The modelled ground surface (or DEM values) has been compared at several locations in the Noora region with point survey data from the Noora Obswell network. The locations of the Obswells used in the comparison are shown in Figure 14 and the x-y plots of Obswell versus DEM ground levels are shown Figure 15. These data show a good alignment along the x=y trendline plotted, although some individual points show a scatter of up to several metres, which is also expected given that the DEM ground surface represents an average value over a fairly large model cell area (up to 500 x 500 m).

Layer-2: Lower Loxton Clay and Shells, Bookpurnong Formation

Layer-2 simulates the regional aquitard formed by the Lower Loxton Clay and Shells, and Bookpurnong Beds, which separates the watertable aquifer and the deeper confined MGL Aquifer. Contours of the top of this layer (or the base of Layer 1) are displayed in Figure 16, which highlight the gentle regional stratigraphic dip of the unit towards the north-east. These contours are based on those produced as part of the regional hydrogeologic mapping undertaken by the Bureau of Mineral Resources in the early 1990s (Barnett, 1991).

Within the Noora Basin area, Layer 2 has a modelled thickness of about 25 m.

Layer-3: Murray Group Limestone Aquifer

The MGL Aquifer generally occurs as an unconfined aquifer in the western half of the model area and is confined over the remainder of the model area, notably within the Noora project area.

The top of the layer shows a gentle dip towards the north-east (Fig. 17), as defined by the contouring of Barnett (1991). The layer is of the order of 100 m thickness in the Noora region.

Layer-4: Upper Renmark Group Aquifer

The Upper Renmark Group Aquifer is a confined aquifer underlying the regional aquitard formed by the Ettrick Formation. The aquitard is simulated within the model by setting very low vertical hydraulic conductivity (Kv) values.

The aquifer comprises unconsolidated carbonaceous sands, silt and clay with regional groundwater flow from south-east to the west and north-west, but does not form a significant part of the Noora Basin modelling.

Layer-5: Lower Renmark Group Aquifer

The Lower Renmark Group Aquifer is a confined aquifer immediately underlying the Upper Renmark layer. The unit is similar to Layer 4, but is relatively more permeable, and does not have significant influence on the assessment of Noora Basin operation upon regional groundwater systems.

3.3 MODEL HYDRAULIC PARAMETERS

The adopted aquifer and aquitard hydraulic parameters used in the model to represent the Noora Basin area are presented in Table 4.

Table 4. Aquifer and aquitard hydraulic parameters in the Noora Basin area

Aquifer/aquitard	Layer	Hydraulic conductivity		Storage	
		Kh (m/d)	**Kv** (m/d)	**Sy** (-)	**Ss** (/m)
Loxton Sands	**1**	5	0.5	0.01-0.1	–
Monoman Formation	**1**	15	1.5	0.1	–
Lower Loxton Clay and Shells, Bookpurnong Formation	**2**	0.0001	0.0001	0.001	$1x10^{-6}$
Murray Group Limestone	**3**	0.5-1	0.05-0.1	0.05	$1x10^{-6}$
Ettrick Formation	Vertical leakance*	–	$1e\text{-}10^{-6}$	–	–
Upper Renmark Group	**4**	1	0.1	–	$1x10^{-6}$
Lower Renmark Group	**5**	5	0.5	–	$1x10^{-6}$

* Vertical leakance calculated by the model package for each cell using Kv and thickness of the layer

Key points to note regarding the adopted parameters include:

- Specific yield value for Layer 1 of 0.1 was adjusted as part of the transient calibration to a lower value of 0.01 in the Noora Basin area, suggesting a semi-confined aquifer conditions within the Loxton Sands (Fig. 18). These conditions may be a result of the thin layer of fine-grained sediments of the Yamba Formation present in low-lying salinas such as Noora Basin.
- Horizontal hydraulic conductivity of 5 m/d was set for the Loxton Sands to be consistent with values previously used by AWE (2005) or those recommended by KBR (2005) (refer to App. A).
- A vertical:horizontal ratio of K for the Loxton sands was assumed to be 0.1.
- Values for layers 2 to 5 are unchanged from the values used when the model was originally developed.

3.4 MODEL BOUNDARIES

The five-layer model is complex, and different boundary conditions in the project area were applied to simulate the aquifer system, River Murray, and their hydraulic connections.

3.4.1 LAYER 1: LOXTON SANDS AND MONOMAN FORMATION

The regional groundwater flow is from east to west within the model domain with groundwater flux eventually entering the River Murray or being discharged as evaporation. Where the aquifers are laterally adjacent, groundwater flows from the Loxton Sands into the Monoman Formation. The following boundary conditions were applied to Layer 1 and are also shown in Figures 19 and 20:

- No-flow boundaries where groundwater flow is parallel to the model edge.
- General head boundaries and constant head boundaries to simulate groundwater flow on the model edges where flow occurs into and out of the model.
- River cells to simulate the hydraulic connection between inundated parts of Noora Basin with the underlying watertable aquifer. The conductance values were set at various levels to ensure that the overall flux of water from the river cells to the watertable (i.e.

basin leakage) was maintained at an assigned value of 0.2 mm/d, which was set as a 'base-case' value based on previous groundwater modelling by SKM (2005) and AWE (2005) that derived basin leakage estimates as a model output.

- Evapotranspiration rates ranging from 120–400 mm/y with extinction depths of 1.2–2.0 m were applied in the Noora Basin area and surrounding low-lying areas and were determined as part of the calibration process. Throughout the remainder of the model domain, evapotranspiration was fixed at 250 mm/y with an extinction depth of 1.5 m, which is consistent with values used in other floodplain groundwater models developed previously by DWLBC and CSIRO.
- Constant head boundary cells to simulate the River Murray (river stage):
  a. 22.3 m AHD upstream Lock-7,
  b. 19.25 m AHD upstream Lock-6,
  c. 16.30 m AHD upstream Lock-5,
  d. 13.2 m AHD Lock-5 to Lock-4,
  e. 9.8 m AHD Lock-4 to Lock-3.
- River cells to simulate major anabranch creeks on the floodplain.
- Fixed head cells used to simulate the existing irrigation-induced watertable mounds present under the Loxton, Bookpurnong, Lyrup and Simarloo areas.

3.4.2 LAYER 2: LOWER LOXTON CLAY AND SHELLS AND BOOKPURNONG FORMATION

Very small volumes of water move laterally into and out of this model layer due to its low permeability. The following boundary conditions were applied to Layer 2:

- No-flow boundaries were used at the model edges.
- Some river cell boundaries were used along the River Murray in areas where the river is in hydraulic communication with the Pata Formation.
- River cells were used to simulate Lake Bonney.

These boundary conditions no significant effect on the predictions of watertable changes in Layer 1.

3.4.3 LAYER 3: MURRAY GROUP LIMESTONE

Regional groundwater flow is from the south-east to north-west within the Noora Basin area of the model domain. The following boundary conditions were applied to Layer 3 and are shown in Figure 21:

- No-flow boundaries where groundwater flow is parallel to the model edge.
- General head boundaries were used at the model edges to simulate groundwater flow into and out of the model.
- Constant head cells were used in the western area of the model where the River Murray is in direct hydraulic connection with the MGL.

- Constant head cells simulate the River Murray (river stage):
  a. 6.1 m AHD upstream Lock-2,
  b. 3.3 m AHD upstream Lock-1,
  c. 0.7 m AHD downstream Lock-1.

3.4.4 LAYER 4: UPPER RENMARK GROUP

Regional groundwater flow is from the south-east to north-west within the model domain. The following boundary conditions were applied to Layer 4.

- No-flow boundaries where groundwater flow is parallel to the model edge.
- General head boundaries were used at the model edges to simulate groundwater flow into and out of the layer.

These boundary conditions, like those of Layer 5, are not considered significant to the model results generated for Layer 1.

3.4.5 LAYER 5: LOWER RENMARK GROUP

Regional groundwater flow is from the south-east to north-west within the model domain. The following boundary conditions were applied to Layer 5.

1. No-flow boundaries where groundwater flow is parallel to the model edge.
2. General head boundaries were used at the model edges to simulate groundwater flow into and out of the layer.

3.5 MODEL RECHARGE

The Noora Basin area has a semi-arid climate with hot dry summers and some rainfall during winter months. The average rainfall is 270 mm/y and Pan A evaporation is between 2000–2200 mm/y.

Prior to clearance of the native vegetation on the highland, vertical recharge to the watertable aquifer in the Mallee region resulting from rainfall infiltration is believed to have been as low as 0.1 mm/y (Allison et al. 1990). Following clearance of native Mallee vegetation for dryland agriculture, rainfall recharge rates in the Mallee region of SA have increased. Work by CSIRO (Cook, Leaney and Miles 2004) and the Department of Environment and Heritage (DEH) indicates that rainfall recharge has increased to up to about 11 mm/y in Mallee clearance areas.

For this modelling project, both during the calibration and prediction periods, recharge has been assigned as 0.1 mm/y in all highland areas, apart from beneath the inundated parts of the basin (which had a recharge value effectively set by controlling river cell conductance to match adopted leakage rates). This approach was used to ensure that potential groundwater levels rises due **only** to basin inundation were predicted, and not the additional changes expected from Mallee clearing.

3.6 MODEL STRESS PERIOD

A total of 110 stress periods were assigned during the calibration period. The time intervals of these stress periods are somewhat variable and were selected to minimise the overall number of stress periods without comprising the accuracy and variability of the historical record of Noora Basin water levels and Obswell groundwater levels.

One year stress periods were used for prediction modelling for 100 years.

4. MODEL CALIBRATION

4.1 STEADY STATE MODEL CALIBRATION

A steady state model run was undertaken to generate suitable initial groundwater levels for the subsequent transient calibration period that commenced in 1980. The steady state calibration assumed that the groundwater system was close to equilibrium conditions, with insignificant changes of storage within the Noora project area.

The groundwater levels derived from the steady state calibration for Layers 1 and 3 were compared to historical groundwater levels and contours available for the period near 1980 and found to have a reasonable fit.

4.2 TRANSIENT MODEL CALIBRATION

The transient model calibration period is from 1980–2006 and was chosen to allow calibration of model parameters in the local Noora Basin area using historical basin operating data and groundwater levels from the surrounding Noora Obswell network after the commissioning of Noora Basin in 1982.

Basin water levels have been historically measured at several locations on an approximate fortnightly schedule. This dataset was represented in the model as a transient set of river cells that are constrained by the minimum and maximum pool levels (17.5–18.8 m AHD) and areas of historical inundation (Fig. 19).

The transient calibration involved adjustment to parameters only within the Loxton Sands Aquifer (Layer 1) as it is the major aquifer affected by basin discharge and evaporation and because a suitable historic record only exists for this aquifer. The transient calibration was undertaken on an iterative basis by adjusting specific yield, evapotranspiration rates, and boundary conditions until a satisfactory match with observed data was obtained. Each time a change to the boundary conditions and aquifer hydraulic parameters was made in the transient model, the steady state model was altered and rerun, with the output being used as the starting point for the transient model.

Following calibration to the observed groundwater levels, the fluxes out of the river cells used to model the inundated areas of Noora Basin were checked. The total flux corresponded to an average leakage rate of about 0.2 mm/d, which is reasonably consistent with estimates of leakage made by previous groundwater models during predictive model runs (SKM, 2005 and AWE, 2005).

4.3 QUALITATIVE COMPARISON OF GROUNDWATER LEVELS (CONTOURS)

A qualitative evaluation of the transient model calibration result was undertaken by comparing contours of the modelled groundwater levels around Noora Basin area with contours derived from observed data.

Figure 22 shows a comparison of modelled watertable levels with those provided by Aquaterra that show observed contours through Victoria in 2003 (from the Eastern Mallee Ground Water Model project). In a regional sense the two sets of contours show a good match. In the immediate vicinity of Noora Basin, Figure 23 shows a comparison between modelled and observed watertable levels as at April 2006. Whilst not contoured, these two datasets are very similar, with the difference between modelled and observed levels typically being less than 10 cm.

Figure 24 shows the transient model contours for the MGL Aquifer against the observed 1991 contours generated by Barnett (1991). Regionally, and within the Noora area, these two sets of contours show a good fit.

4.4 QUALITATIVE COMPARISON OF GROUNDWATER LEVELS (HYDROGRAPHS)

Twenty six (26) Noora Obswell monitoring wells within the Loxton Sands Aquifer have been used during the transient calibration. The locations of these wells are displayed in Figure 25, whilst Figures 26 (a) to (z) show the time record of modelled versus observed groundwater levels for each of these wells.

In general terms, the hydrographs display a very good fit between modelled and observed and show some features that are dependent on their general location with respect to the location of basin inundation during the period from 1982–2006:

- In south-eastern and eastern areas, the modelled hydrographs (e.g. BKP006) match the flat observed trends very well, including the initial level. The model does not match the irregular pattern of sinuous groundwater levels (with maximum amplitudes of about 0.2 m), which may reflect significant climate-related variations in recharge and discharge from nearby low-lying areas.
- In south-western areas the modelled hydrograph for BKP011 reflects the influence of the (relatively) nearby Loxton irrigation mound and matches the observed trend quite well.
- In western, north-western and northern areas, the modelled hydrographs simulate the trends of observed watertable rises (of about 0.2–0.6 m) that have been observed and attributed largely to basin inundation since 1982. Some of these hydrographs do not fit as well in recent times compared to earlier periods of basin operation. Small fluctuations as described above are also superimposed on the observed watertable rises in these areas.
- In north-eastern areas, some of the modelled hydrographs do not match the relatively large-scale observed fluctuations observed in the first eight years of basin operation, but do show a good trend match in subsequent years.

4.5 QUANTITATIVE COMPARISON OF GROUNDWATER LEVELS (ITERATION RESIDUAL ERROR)

The iteration residual error between modelled and observed groundwater levels for the Loxton Sands Aquifer around the Noora Basin area was calculated using all Obswells used in the transient calibration process for several years (1981, 1985, 1990, 1995, 2003 and 2006).

The calculations are shown in Figures 27 (a) to (f) and indicate a normalised root mean square (RMS) value for:

- 1980 — 5.4%
- 1985 — 5.5%
- 1990 — 6.3%
- 1995 — 6.1%
- 2003 — 6.7%
- 2006 — 7.1%.

All these RMS values are within the 5–10% range recommended by the Groundwater Flow Modelling Guideline (MDBC 2001) and indicate a good fit between modelled and observed data over the full calibration time period from 1980–2006.

5. MODEL SCENARIOS AND PREDICTIONS

Following satisfactory calibration, the transient model can be used for estimating the potential effects upon the regional aquifer system(s) due to the expanded operation of Noora Basin in accordance with the different basin operating scenarios outlined below.

Three different basin operating scenarios have been modelled:

- Scenario 1 — Irrigation drainage + Bookpurnong SIS + Loxton SIS + Murtho SIS.
- Scenario 2 — Irrigation drainage + Bookpurnong SIS + Loxton SIS + Murtho SIS + Pike SIS.
- Scenario 3 — Basin water level maintained at 19.0 m AHD.

Key inputs to the groundwater modelling relate to the different areas of inundation, basin water levels and basin water salinity associated with each scenario. These input parameters to the groundwater model are outputs from the surface water modelling (DWLBC, 2007), which completed salt and water balance modelling according to the fixed discharge schedules of Scenarios 1 and 2. For Scenario 3, the surface water modelling worked in 'reverse' and determined the maximum pumping rate (averaged over 100 years) that could be achieved by using 19.0 m AHD as a maximum pond water level.

An important point to note in the assessment of model results is that both the surface water model and the groundwater model used the same 'base case' value for basin leakage (infiltration to the watertable) of 0.2 mm/d. This level of leakage is consistent with previous modelling by AWE (2005) and SKM (2005), which derived leakage estimates as a model output.

5.1 SCENARIO 1

5.1.1 SCENARIO 1 CONDITIONS

Table 5 presents the discharge schedule used in the surface water modelling for Scenario 1 and highlights how the Bookpurnong and Loxton SISs produce a relatively constant discharge compared to the Murtho SIS, which gradually increases over the 100-year timeframe.

Inputs to the Scenario 1 predictive groundwater modelling are based on the results of the Scenario 1 surface water modelling displayed in Figure 28 and comprise:

- The inundated basin area in the groundwater model is represented by river cells and is assumed to be constant over 100 years and equivalent to the 2106 area predicted by the surface water model.
- Potentiometric head levels in the river cells were derived by applying a density correction (from McCutcheon, Martin and Barnwell 1993) to the salinity difference between the predicted basin water salinities and an adopted regional groundwater salinity of 44 000 mg/L. For the western basin, a maximum predicted basin water level of 18.6 m AHD was adjusted to 20.89 m AHD (final basin salinity of 230 000 mg/L). In the eastern basin, a maximum predicted basin water level of 18.45 m AHD was adjusted to 21.17 m AHD (final basin salinity of 260 000 mg/L).

Table 5. Scenario 1 discharge schedule

Year	Average discharge rate (L/s)				Total (L/s)
	Irrigation drainage	*Bookpurnong SIS*	*Loxton SIS*	*Murtho SIS*	
2006	40	86	0	0	126
2008	40	47	123	0	210
2010	40	39	79	50	208
2012	40	36	68	48	193
2014	40	39	64	48	192
2020	40	48	59	50	196
2030	40	54	57	58	209
2040	40	57	57	69	223
2050	40	59	58	75	233
2060	40	60	59	81	240
2070	40	61	60	92	253
2080	40	61	61	107	269
2090	40	61	62	116	280
2100	40	62	63	125	289
2106	40	62	63	128	293

- Conductance values of the river cells representing the inundated basin were adjusted to ensure that an average leakage rate of 0.2 mm/d was maintained.

5.1.2 SCENARIO 1 RESULTS

Figure 29 shows a raster-based derivation of the current-day depth to the watertable which highlights areas where shallow watertables occur in the Noora Basin and surrounding areas, to provide a baseline image for comparison with changes to watertable depths predicted by groundwater modelling.

The results of Scenario 1 modelling focuses on changes to watertable levels in the Loxton Sands Aquifer, which are shown in Figure 30 that displays:

- contours of the change to watertable levels after 100 years
- depths to the watertable after 100 years in areas where the watertable is less than 5 m
- a predicted hydrograph in the vicinity of Obswell BKP008.

Figure 30 highlights that:

- The watertable is predicted to eventually rise by the order of 0.5–1.0 m in areas adjacent to government-owned land.
- Maximum watertable rises of about 0.15 m are predicted near the South Australian – Victorian border to the east-north-east of Noora Basin in areas where the watertable is greater than 5 m depth. In lower-lying areas near the border, watertable rises of typically 0.1 m are predicted.

- The shape of the shallow watertable mound formed is influenced by regional factors. The mound is limited in the down-gradient direction as a result of the larger irrigation-induced watertable mounds already present in the Loxton, Bookpurnong and Lyrup areas. To the south-east of Noora Basin, the continuation of low-lying areas provides for significant levels of groundwater discharge by evaporation.
- Watertable levels are likely to rise to near steady-state levels after about 40 years of expanded basin operation.

Groundwater levels within the deeper confined MGL Aquifer are not predicted to change significantly as a result of the expanded inundation of Noora Basin.

5.2 SCENARIO 2

5.2.1 SCENARIO 2 CONDITIONS

Scenario 2 is similar to Scenario 1 but includes additional discharge to Noora Basin based on the assumed commissioning of the planned Pike SIS in 2012 (Table 6).

Table 6. Scenario 2 discharge schedule

Year	**Average discharge rate** (L/s)					**Total** (L/s)
	Irrigation drainage	*Bookpurnong SIS*	*Loxton SIS*	*Murtho SIS*	*Pike SIS*	
2006	40	86	0	0	0	126
2008	40	47	123	0	0	210
2010	40	39	79	50	0	208
2012	40	36	68	48	61	254
2014	40	39	64	48	56	248
2020	40	48	59	50	56	252
2030	40	54	57	58	63	272
2040	40	57	57	69	60	284
2050	40	59	58	75	70	303
2060	40	60	59	81	79	319
2070	40	61	60	92	84	336
2080	40	61	61	107	88	356
2090	40	61	62	116	91	370
2100	40	62	63	125	93	382
2106	40	62	63	128	94	387

Similar to Scenario 1, inputs to the Scenario 2 predictive groundwater modelling are based on the results of the Scenario 2 surface water modelling displayed in Figure 31 and comprise:

- The inundated basin area in the groundwater model is represented by river cells and is assumed to be constant over 100 years and equivalent to the 2106 area predicted by the surface water model.

- Head levels in the river cells were derived by applying a density correction (from McCutcheon, Martin and Barnwell 1993) to the salinity difference between the predicted basin water salinities and an adopted regional groundwater salinity of 44 000 mg/L. For the western basin, a maximum predicted basin water level of 18.79 m AHD was adjusted to 20.44 m AHD (final basin salinity of 180 000 mg/L). In the eastern basin, a maximum predicted basin water level of 18.79 m AHD was adjusted to 21.39 m AHD (final basin salinity of 260 000 mg/L).
- Conductance values of the river cells representing the inundated basin were adjusted to ensure that an average leakage rate of 0.2 mm/d was maintained.

5.2.2 SCENARIO 2 RESULTS

Figure 32 summarises the predicted watertable level changes after 100 years and highlights that:

- The watertable is predicted to rise to slightly higher levels (0.5–1.5 m) in areas adjacent to government-owned land compared with Scenario 1.
- Maximum watertable rises of about 0.25 m are predicted near the South Australian–Victorian border to the east-north-east of Noora Basin in areas where the watertable is greater than 5 m depth. In lower-lying areas near the border, watertable rises of 0.1–0.15 m are predicted.
- The shape of the shallow watertable mound is similar to Scenario 1 but extends to greater distances from Noora Basin, which reflects the increased volume of leakage from the basin within the same set of aquifer parameters.
- As in Scenario 1, most of the predicted watertable rise occurs within the first 40 years of expanded basin operation, with the rate of rise very small after this period.

The Scenario 2 predictions do not result in any significant change to groundwater levels within the MGL Aquifer.

5.3 SCENARIO 3

5.3.1 SCENARIO 3 CONDITIONS

Groundwater modelling for Scenario 3 assumes that the basin is filled instantly to 19.0 m AHD and maintained at this level for 100 years. River cell head corrections were applied from day one based on the final basin salinities. In the western basin, river cell heads were adjusted to 19.0 m AHD based on a basin salinity of 40 000 mg/L, whilst in the eastern basin, river cell heads were corrected to 21.62 m AHD for a basin water salinity of 260 000 mg/L.

5.3.2 SCENARIO 3 RESULTS

Figure 33 displays the predicted watertable level changes after 100 years and in comparison with Scenarios 1 and 3, shows an increased watertable mound magnitude and extent due to the higher volumes of leakage from increased areas of basin inundation. The figure also highlights that:

- The watertable is predicted to rise to slightly higher levels (1.5–2 m) in areas adjacent to government-owned land.
- Maximum watertable rises of about 0.3 m are predicted near the South Australian–Victorian border to the east-north-east of Noora Basin in areas where the watertable is greater than 5 m depth. In lower-lying areas near the border, watertable rises of 0.1–0.25 m are predicted.
- The shape of the shallow watertable mound is similar to Scenario 1 but extends to greater distances from Noora Basin, which reflects the increased volume of leakage from the basin within the same set of aquifer parameters.
- Watertable levels rise relatively quickly in the first 20 years (based on the somewhat unrealistic assumption that 435 L/s of water would be discharged to Noora Basin from Year 1) and reach near steady-state levels after about 60 years.

As with other scenarios, Scenario 3 does not cause any significant changes to groundwater levels within the MGL Aquifer.

6. MODEL SENSITIVITY ANALYSES

6.1 SENSITIVITY ANALYSES

Sensitivity analyses are done to identify the key drivers of the system and are conducted by undertaking multiple model runs with incremental variations to aquifer hydraulic parameters or model stresses.

Based on previous hydrogeological investigations and groundwater modelling of the Noora area, the basin leakage rate and hydraulic conductivity (horizontal) and specific yield of Layer 1 (watertable aquifer) were already identified as key model parameters. The sensitivity analyses completed for this project (for each prediction scenario) was undertaken by combining a pragmatic and credible set of best case and worst case values to produce a set of groundwater levels after 100 years to compare with the base case results presented in Section 5.

The definition of best case relates to the combination of parameters that would result in the minimum amount or extent of watertable mounding, which includes the minimum leakage rate from beneath the inundated basin, the maximum specific yield (which maximises the near-basin storage of basin leakage) and the minimum horizontal hydraulic conductivity (which restricts the rate and extent of lateral mound development). The values chosen for the best case sensitivity analyses are based on previous work completed by AWE (2005) and SKM (2005), and also SIS investigations and modelling completed by DWLBC in the Riverland region between Loxton and Murtho.

The worst case sensitivity is based on adopting likely values that would combine to produce the maximum amount and extent of watertable mounding. The values shown in Table 7 are consistent with the worst case values adopted in previous studies.

Table 7. Sensitivity parameters

	Leakage Rate (mm/d)	**Sy**	**Kh** (m/d)
Base case	0.2	0.1	5
Best case	0.1	0.2	3
Worst case	0.4	0.05	6

6.2 SENSITIVITY RESULTS

6.2.1 SCENARIO 1

Figure 34 shows the base case and worst case contours of watertable change after 100 years of basin operation. This scenario incorporates inflows from irrigation drainage and the Bookpurnong, Loxton and Murtho SISs. Figure 35 shows the base case and best case contours. These figures indicate that:

- The worst case contours show the watertable mounding, as defined by the 0.05 m contour, extends a further 4–10 km to the south, east and north directions.
- In low-lying areas where significant capacity exists for discharge of groundwater by evaporation, the difference between base case and worst case groundwater levels is not as large as in elevated areas.
- In areas adjacent to the government-owned land, the watertable may rise by about 1–2 m.
- Under best case conditions, watertable mounding is effectively limited to SA and that watertable rises near the government–owned land boundary at Noora may be as low as 0.5–1 m.

6.2.2 SCENARIO 2

Figure 36 shows the base case and worst case contours of watertable change after 100 years of basin operation which incorporates inflows from irrigation drainage and the Bookpurnong, Loxton, Murtho and Pike SISs, whilst Figure 37 shows the base case and best case contours. These figures indicate that:

- The worst case contours show the watertable mounding, as defined by the 5 cm contour, extending significantly further to the south, east and north directions (by about 8–16 km) when compared to the base case.
- Little change occurs to the extent of the watertable west of the Basin, which reflects the barrier effect of the much larger irrigation watertable rounds near the River Murray.
- In low-lying areas where significant capacity exists for discharge of groundwater by evaporation, the difference between base case and worst case groundwater levels is not as large as in elevated areas.
- In areas adjacent to the government-owned land, the watertable may rise by about 1.5–2 m.
- Under best case conditions, there is limited watertable mounding within Victoria, with a predicted watertable rise of about 0.1 m near the border in elevated areas and about 0.05 m in low-lying areas.

6.2.3 SCENARIO 3

Figure 38 shows the base case and worst case contours of watertable change after 100 years of basin operation, which assumes that the basin is filled to and maintained at 19.0 m AHD from Year 1. Figure 39 shows the best case and base case contours.

Both these figures show similar patterns to the Scenario 2 sensitivity results, except that the extent and magnitude of the watertable is slightly increased. For the worst case conditions, the maximum predicted watertable rise near the Victorian border is about 0.4 m in elevated areas and more typically about 0.15–0.25 m in low-lying areas. For best case conditions, watertable rises are predicted to be significantly lower and range from about 0.15 m in elevated areas to less than about 0.07 m in low-lying areas.

7. DISCUSSION

7.1 MODEL RESULTS

The results of each model scenario display some similarities as a result of the similarity in the applied model stresses and include:

- Only a limited-height watertable mound can develop beneath Noora Basin due to the pre-existing shallow depth of groundwater and the shallow regional hydraulic gradient.
- The development of the watertable mound is restricted in the down-gradient (west) direction due to the presence of pre-existing and larger irrigation-induced watertable mounds.
- The watertable mound will develop to greater distances up gradient of the basin.
- Significant groundwater discharge by evaporation will occur in low-lying areas in the immediate vicinity of Noora Basin, both along the north-west trending margin of the government-owned land and in the major depression to the south-east of the main basin area (this area has been referred to as Noora South and is shown in Fig. 29). This process will have a strong control on the distribution of watertable level changes.
- Most of the groundwater level rises for Scenarios 1 and 2 occur gradually within the first 40 years of expanded basin operation, with only very small rates of rise after this period.

Increased groundwater discharge by evaporation from shallow watertables would cause increases in groundwater and soil salinity that may have adverse effects on vegetation and land use. Figure 40 highlights areas surrounding the government-owned land at Noora where the watertable is currently less than 2 m below ground or is predicted to become less than 2 m after 100 years of expanded basin inundation. While the 2 m level is somewhat arbitrary in terms of its significance on land use or vegetation, it helps focus on areas where the impacts of increased groundwater levels and evaporation may be the most significant. It shows that the margins of low-lying areas in the main Noora topographic depression will gradually become affected and that an area near the South Australian – Victorian border in the topographic depression to the north-east of Noora is at risk of watertables becoming shallower than 2 m.

To quantify the predicted changes to evaporative fluxes, three budget zones were created over the main low-lying areas. These are displayed in Figure 40 and were defined to capture low-lying areas within Victoria most likely to be affected by Noora Basin (Zone 18), low-lying areas near Noora Basin in SA (Zone 16) and low-lying areas in SA to the north-east of Noora (Zone 17). The area to the south-west of Noora Basin was not captured as a budget zone as there are relatively few zones of shallow watertables in this region. Table 8 presents the daily evaporation fluxes (m^3/d) for these budget zones at different times.

Table 8. Evaporative Fluxes (m^3/d)

Time	Zone 16	Zone 17	Zone 18
Current day	767	157	358
Scenario 1			
20 years	1307	166	346
100 years	1405	212	361
Scenario 2			
20 years	1995	195	355
100 years	2147	271	380
Scenario 3			
20 years	2322	211	361
100 years	2484	302	390

The data in Table 8 is useful in highlighting that, as a result of Noora Basin:

- no significant increases to existing evaporation fluxes are expected within Victoria (Zone 18)
- only minor increases to evaporative fluxes are expected in Zone 17
- the most significant increases will occur closest to Noora Basin, where the flux will eventually increase by about 100% for Scenario 1 or about 350% for Scenario 3.

Notwithstanding the impacts within Zone 16, this area forms an evaporation 'buffer' zone that will dampen and diminish the flux of groundwater and extent of watertable rise towards and inside other regional low-lying areas (Zones 7 and 18). For Scenario 3, the additional groundwater flux lost to evaporation in Zone 16 as a result of basin inundation is about 1720 m^3/d (20 L/s), which represents 40% of the total flux 'generated' from basin leakage (about 50 L/s based on 2100 Ha at 0.2 mm/d).

The impacts of expanded basin operation on regional groundwater levels will take several decades to be fully realised. Figures 41 and 42 highlight the slow growth of the watertable mound by plotting watertable level change contours in 2011 and 2021 for Scenario 1. Importantly, these figures show that for at least the next 15 years, the predicted changes to watertable levels for Scenario 1 will be confined to within SA and also within the limits of the existing Obswell groundwater monitoring network.

7.2 MODEL LIMITATIONS AND UNCERTAINTY

The accuracy of groundwater models is rightly questioned but not usually readily answered. Good calibrations do not necessarily make for good predictions due to the non-uniqueness of model solutions, and future reconciliations of model predictions rely on assumptions about conditions (model stresses) being actually realised.

This numeric groundwater model has its limitations and uncertainties , which comprise:

- The predicted watertable changes are considered to be slightly overestimated (by about 10%) due to the density-corrected potentiometric heads applied to the model river cells that represent the inundated basin area. This would only be significant in areas close to the basin where the watertable rises are greatest and specific yields are lowest. In regional areas, 10% of a 5 or 10 cm watertable rise (i.e. 0.5–1 cm) is not significant.

- The model attempts to simulate the effects of **only** the basin inundation upon regional groundwater levels (although it does incorporate the regional effect of the large irrigation-induced watertable mounds to the west and north-west of Noora). The model has not attempted to estimate the impact of other factors that may change groundwater levels, such as climate-change and resultant natural recharge variations, increased recharge due to mallee clearing, nor local variations to watertable recharge and discharge that may result from ponding of surface runoff from large rainfall events. The combination of these factors will make any future review and reconciliation of groundwater levels difficult to apportion the effect of Noora Basin, especially in regional areas where the watertable change is small.
- The question of model accuracy is partly addressed by the sensitivity analyses undertaken. For Scenario 2 (which represents the most likely future ‘use’ of Noora Basin and incorporates Bookpurnong, Loxton, Murtho and Pike SISs) the estimated watertable rises in key areas (and their associated ‘error’ margins) comprise:
    - near the government-owned land boundary at Noora, long-term watertable rises are predicted to typically range between 1–2 m with an error margin of about +/- 0.5 m
    - the maximum watertable rise predicted at the South Australian – Victorian border is about 0.25 m and has an error margin of about +/- 50% (i.e. estimates range from 0.12–0.37 m). This maximum rise occurs in an elevated area where the watertable depth is typically 5–30 m
    - in the low-lying depression to the south-east of Noora, the base case predicted watertable rise at the border is about 0.05 m, but ranges from zero (best case) to about 0.15 m (worst case).
- The potential effect of the fine-grained sediments of the Yamba Formation or (future) precipitated salt layers on the floor of Noora Basin on leakage rates has not been modelled because of uncertainty about their significance. It is considered unlikely that either of these materials would prevent significant leakage and to provide ‘conservatism’ to the model predictions, these have been ignored.

8. GROUNDWATER MONITORING

The monitoring of groundwater levels beneath and surrounding Noora Basin will ultimately provide confirmation of the extent and magnitude of the actual watertable mound and support assessments of actual impacts. From an environmental management perspective, groundwater monitoring does not always provide a useful ‘preventative’ type tool, as groundwater impacts may be realised relatively quickly once an action or landscape change is committed to. However, in the case of Noora Basin, groundwater monitoring can serve as a proactive tool in the future operation of the basin and management of any impacts as the inundation of Noora Basin is relatively slow and gradual, as will be the aquifer responses.

Figures 40 and 41 display the predicted basin inundation areas and watertable level changes after five and 15 years of expanded operation for Scenario 1 (irrigation drainage, Bookpurnong, Loxton and Murtho SISs). The figures also display the location of existing Noora Obswell monitoring wells, which would be suffice for ‘mapping’ the mound development for many years, as there are numerous wells beyond the zone of predicted influence which would provide background data and/or provide additional sites should the mound develop further than predicted.

Six-monthly groundwater level monitoring of all Noora Obswells is considered sufficient and could be supported in the future with infrequent measurements of groundwater salinity in wells closest to the inundated areas. This level of monitoring in the long term would support any groundwater model refinements, basin capacity reviews, or assessments of impacts on vegetation and land use. As part of the overall management of Noora Basin, DWLBC’s Infrastructure and Business Division is coordinating the development of a Noora Basin Monitoring Framework and Monitoring Plan. The plan will provide full details of the purpose and nature of the various monitoring for Noora, which includes surface water, groundwater, vegetation, fauna and socio-economic components. These documents are still being drafted and are due for completion in September 2007.

In terms of future reviews of groundwater monitoring data, it is unlikely that they will be needed at less than five-yearly frequencies. However, groundwater monitoring data may be used more frequently to support other monitoring (e.g. vegetation health) reviews. When groundwater monitoring reviews are undertaken, they should access groundwater data from neighbouring SA Obswell networks and also from monitoring wells located in far western Victoria (Fig. 7). These additional data will help provide assessment of background conditions and the effects of aquifer stresses from sources other than Noora Basin. There are many monitoring wells within SA to serve this purpose but relatively few in Victoria (as based on a data extraction from the public domain Water Resources Data Warehouse). To improve the assessment of background conditions in regional areas east of Noora Basin, it should be established if there are actually more wells installed than indicated by the data warehouse and if there are not, then consideration should be given to installing several more wells. Possible locations for such wells are displayed in Figure 42.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

Key conclusions following the completion of model calibration and predictions comprise:

- The model in its current state is considered suitable for a broad assessment of changes to regional groundwater levels due **only** to the operation of Noora Basin, which meets the intended purpose of the work completed. The model remains a regional assessment tool despite the model changes made by improving model calibration to historic groundwater levels in the immediate vicinity of Noora Basin and also by simulating the natural ground surface with the best available DEM data.
- The expansion of basin inundation for any of the model scenarios is not likely to have any significant effect on groundwater levels within the deeper confined MGL Aquifer, but will be limited to the regional watertable aquifer occurring within the Loxton (Pliocene) Sands.
- Only a relatively limited watertable mound can develop around Noora Basin for either prediction scenario given the limited depths to groundwater and low regional hydraulic gradients. The shape of the watertable mounds will be similar for each scenario, although the extent and magnitude of the mound will vary slightly, increasing from Scenario 1 to Scenario 3 as more basin area is inundated and to higher water levels.
- Watertable rises will be limited in down-gradient directions (west and north-west) due to the presence of pre-existing and larger irrigation-induced watertable mounds.
- Changes to watertable levels up gradient of Noora Basin will be influenced by the evaporative discharge of groundwater from shallow watertables in two major north-west trending topographic features that cross the South Australian – Victorian border (but typically slope gradually downwards to the north-west).
- For Scenario 2 (which represents the most likely future ‘use’ of Noora Basin and incorporates Bookpurnong, Loxton, Murtho and Pike SISs) the estimated watertable rises in key areas (and their associated ‘error’ margins comprise:
    - Near the government-owned land boundary at Noora, long-term watertable rises can be considered as ranging between 1–2 m with an error margin of about +/- 0.5 m.
    - The maximum watertable rise predicted at the South Australian – Victorian border is about 0.25 m and has an error margin of about +/- 50% (i.e. estimates range from 0.12–0.37 m). This maximum rise occurs in an elevated area with deep watertables such that any of the predicted rises are unlikely to have adverse consequences.
    - In the low-lying depression to the south-east of Noora, the base case predicted watertable rise at the border is about 0.05 m, but ranges from zero (best case) to about 0.15 m (worst case).
- The low-lying areas within several kilometres of the government-owned Noora land boundary will act as a significant evaporation ‘buffer’ zone that will dampen and diminish the flux of groundwater and extent of watertable rise towards and inside other regional low-lying areas. Scenario 3 modelling indicates that up to 40% of the total additional groundwater flux ‘generated’ from basin leakage would be discharged as evaporation from these areas. While this buffer zone may limit adverse impacts further to the south-east, east and north-east, watertable rises and associated groundwater and soil salinity impacts may have adverse impacts within the zone.

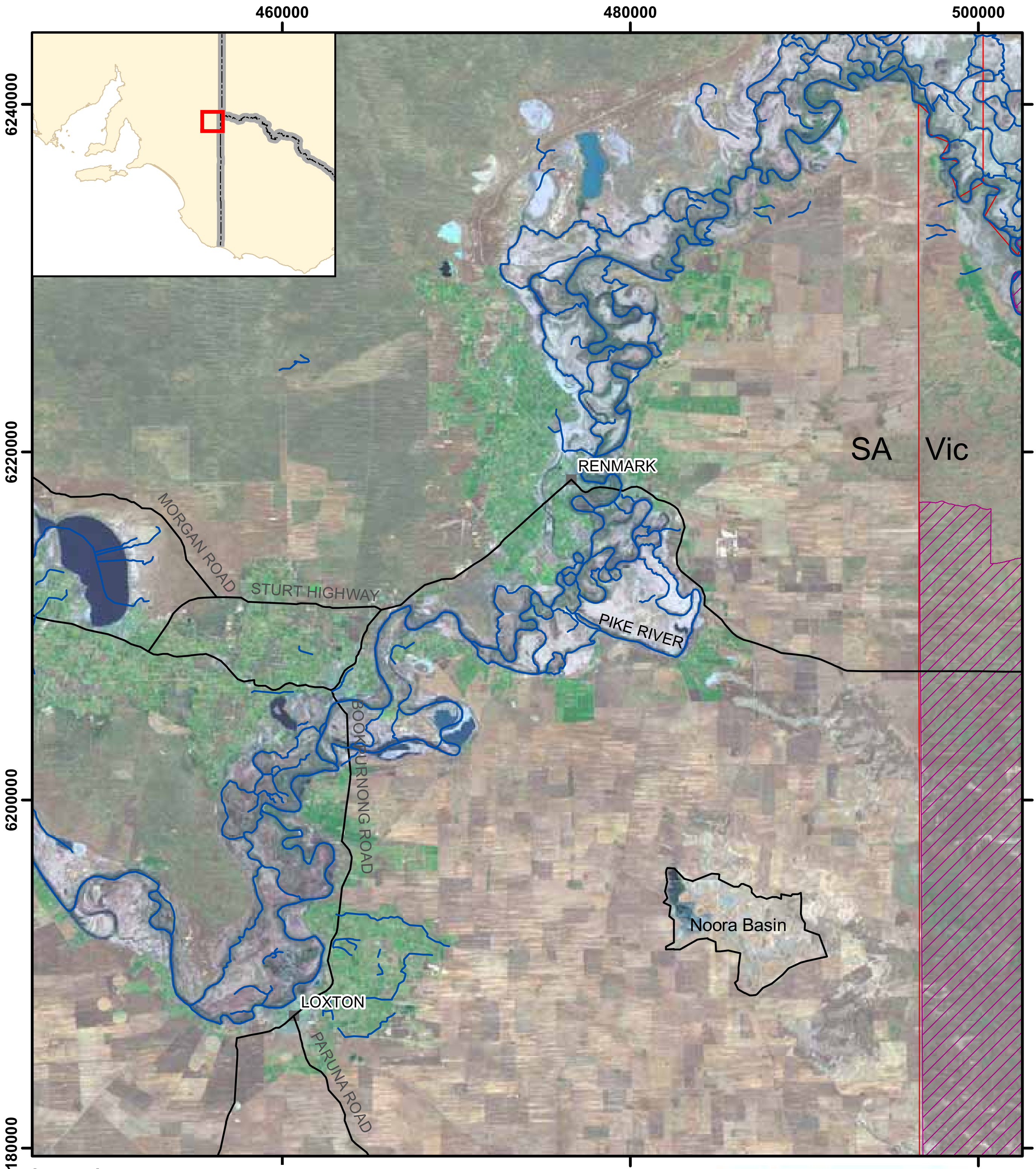
- The regional groundwater level rise beyond a few kilometres from the basin is typically less than about 0.3 m for any scenario or sensitivity run. Such a rise is not considered to be a significant change to the groundwater system in areas where the existing watertable depth is in excess of 5–10 m. From monitoring wells near Noora Basin, there appears to be a natural (background) fluctuation to groundwater levels of up to 0.2 m over periods of one or several years.
- Regular monitoring of groundwater levels will map the ultimate development of any associated watertable mound. Given the relatively slow response of the aquifer system to the gradual discharge increases planned for Noora Basin, monitoring will provide an effective ‘early-warning’ tool for the longer-term management of the basin impacts on the surrounding landscape.
- The existing Noora Obswell network, in conjunction with other surrounding monitoring wells in SA and Victoria, provides an adequate coverage to monitor the regional impacts of Noora Basin for many years to come.

9.2 RECOMMENDATIONS

The following recommendations are made in light of the findings of this modelling project and also from the development of an overall Noora Monitoring Framework and Plan currently being coordinated by DWLBC:

- Monitor groundwater levels from all the Noora Obswell monitoring wells on a six-monthly basis.
- Determine if there are any other monitoring wells in the Victorian section of the study area besides those indicated by the Water Resources Data Warehouse website. If there are none, consider drilling several more regional monitoring wells to provide a greater coverage of background groundwater conditions and trends to the south-east, east and north-east of Noora Basin.
- Undertake brief reviews of groundwater level trends no more frequently than at five year intervals for reconciling predicted changes with observed groundwater change.

FIGURES



Legend

- Noora Basin Government Owned Land
- SA/Vic Border
- Murray Sunset National Park Boundary
- Major Roads
- River Murray
- Towns

0 2 4 8 Kilometres

Datum: GDA94
Map Projection: MGA Zone 54

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Figure 1. Project Area

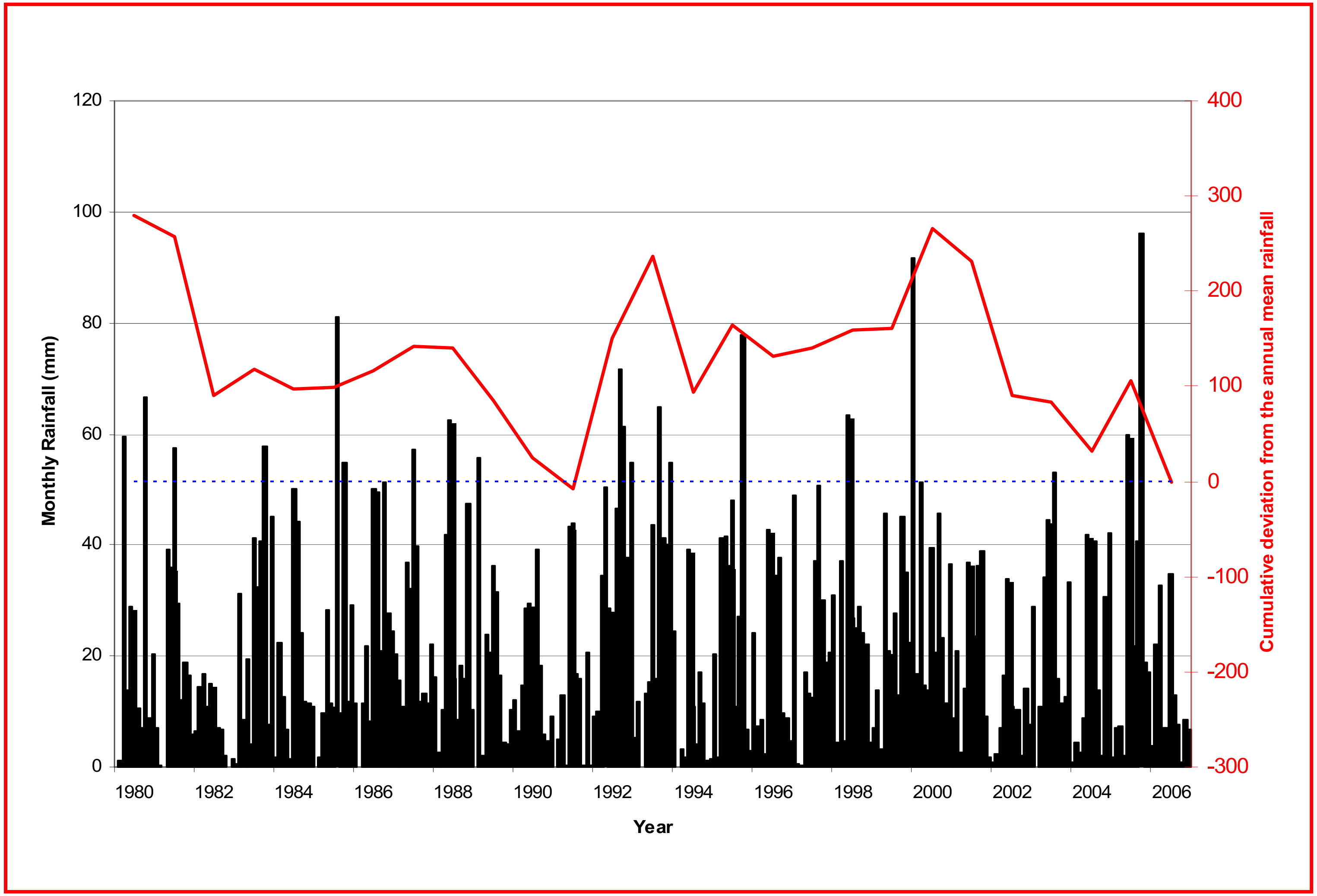
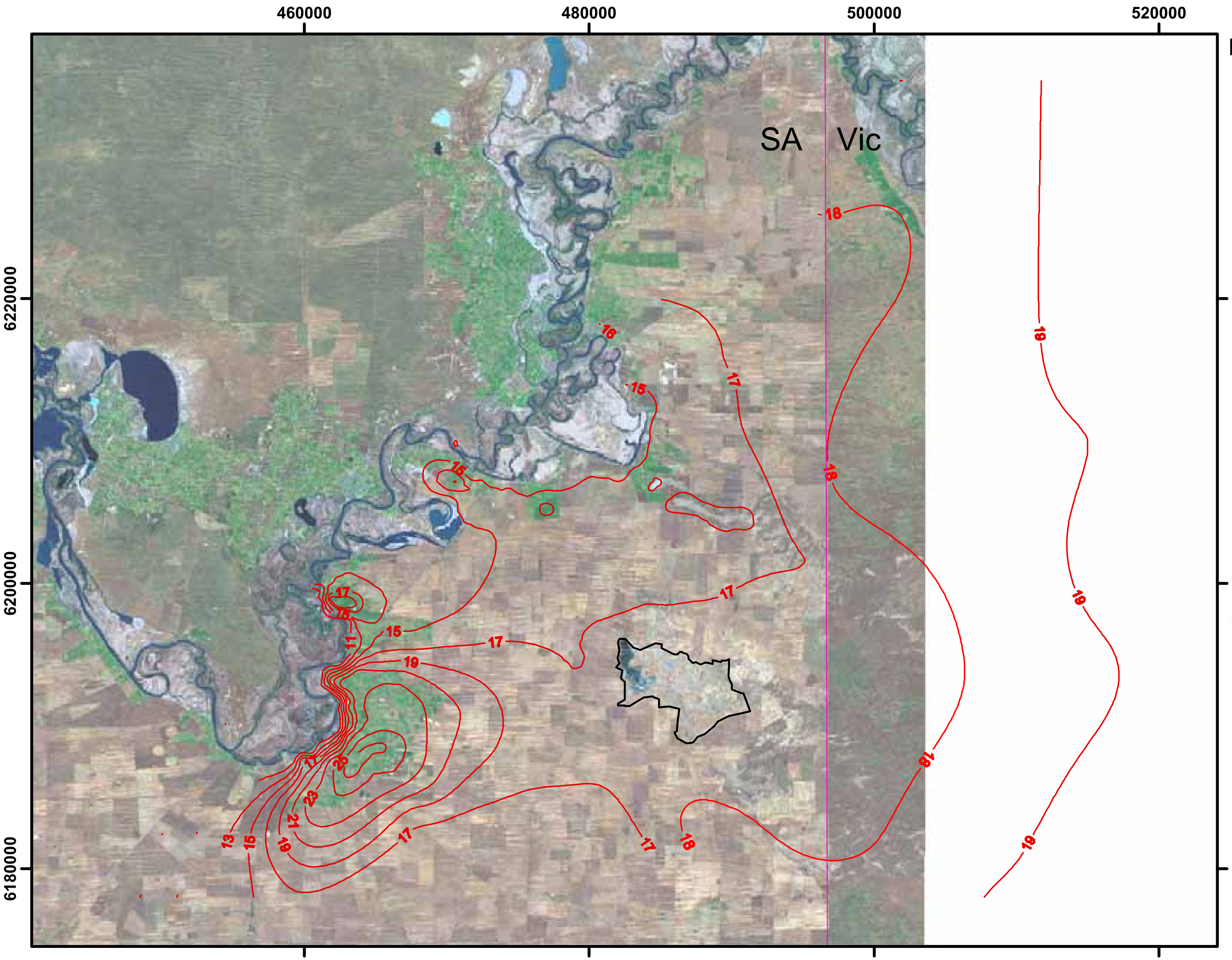


Figure 2 Monthly rainfall for Renmark (Taldra)



Legend

Regional Watertable Contours Jan06 (m AHD)
Major Roads
Towns
Noora Basin Government Owned Land
SA/Vic Border

0 3 6 12 Kilometres

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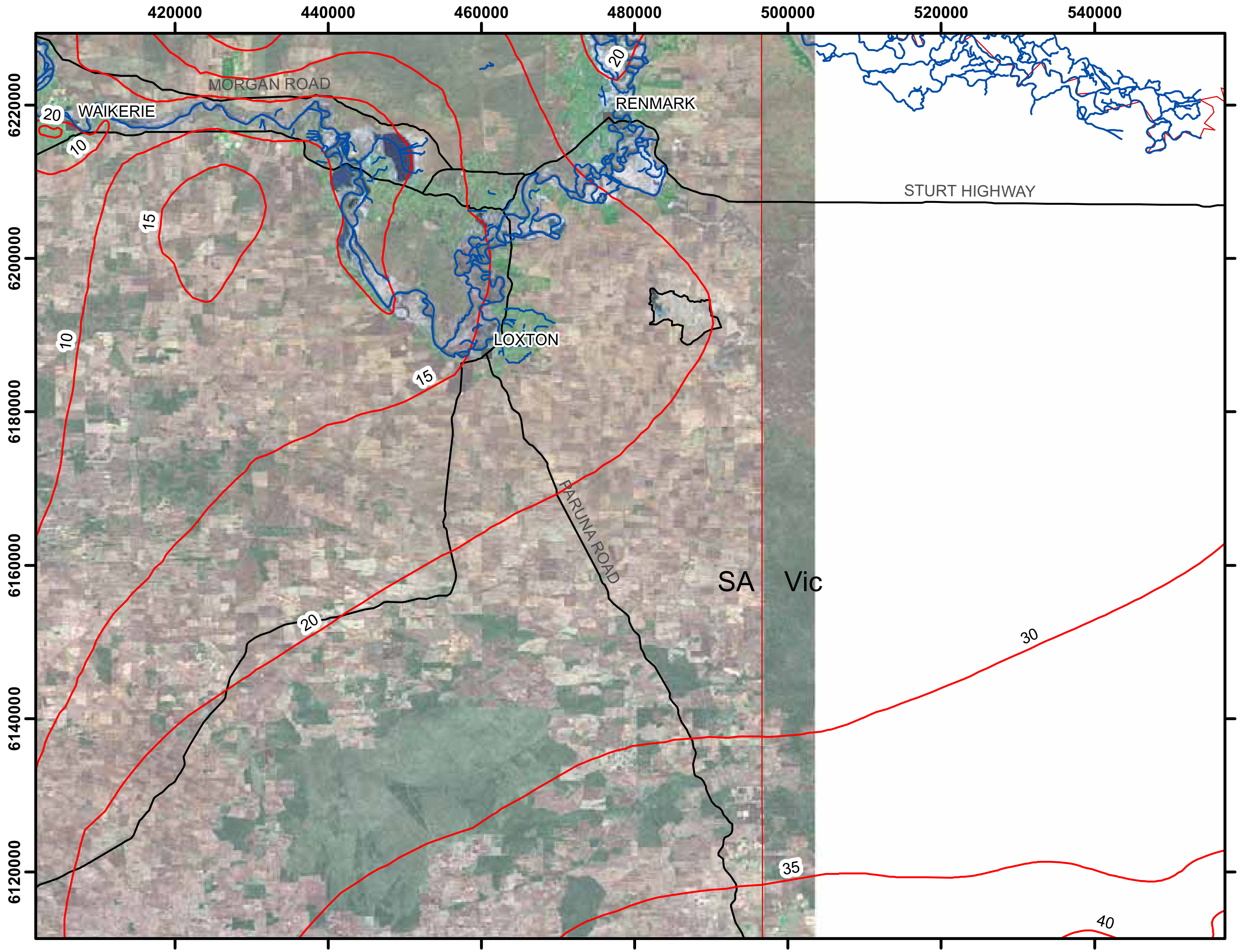
Figure 3 Regional Watertable Contours (m AHD) January 2006

N W E S
Datum: GDA94
Map Projection: MGA Zone 54



Legend

- Potentiometric Surface Contours Murray Group Limestone (m AHD)
- Noora Basin Government Owned Land
- SA/Vic Border
- River Murray and channels
- Major Roads
- Towns

0 4.5 9 18 27 Kilometres

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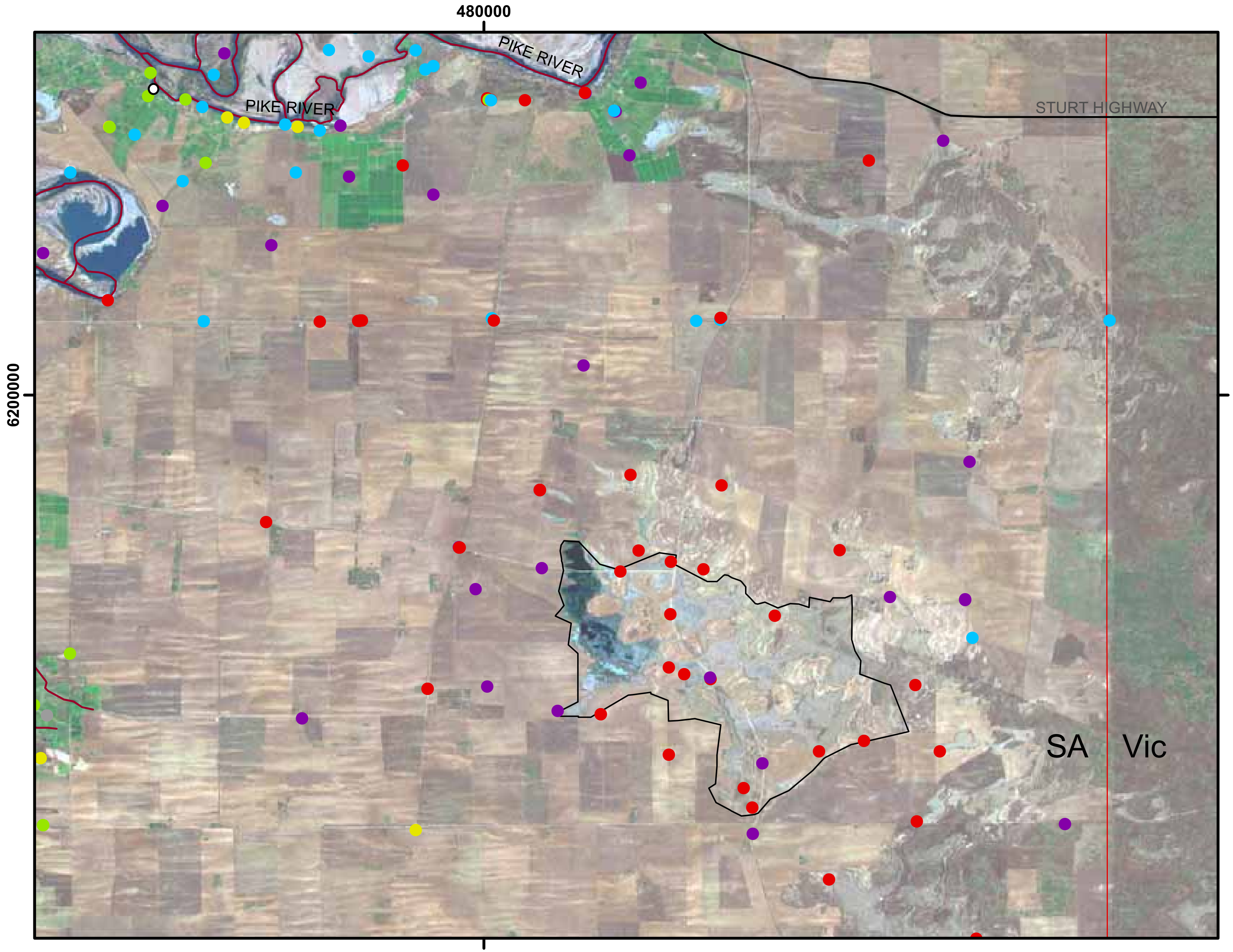
Figure 4 Potentiometric Surface Contours (m AHD) Murray Group Limestone Aquifer 1991 (after Barnett, 1991).

N
W E
S

Datum: GDA94
Map Projection: MGA Zone 54



Legend

Regional Salinity (mg/L)

TDS

- < 1500
- 1500 - 3000
- 3000 - 10000
- 10000 - 20000
- 20000 - 35000
- 35000 - 50000
- > 50000
- Noora Basin Government Owned Land
- Major Roads
- Towns
- SA/Vic Border

0 1.5 3 6 Kilometres

Figure 5 Regional Watertable Salinity

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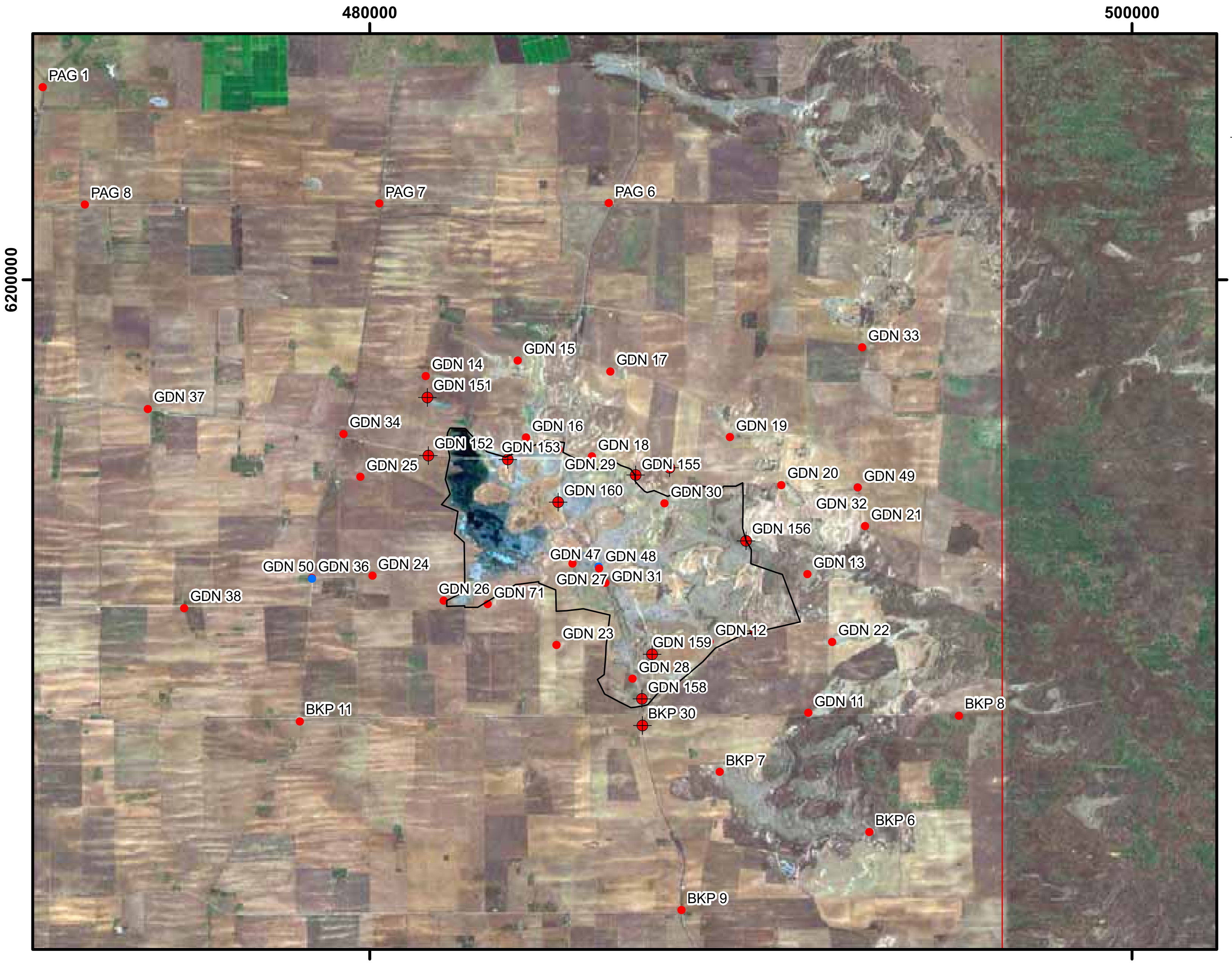
N W E S

Datum: GDA94
Map Projection: MGA Zone 54



Legend

Noora Basin Government Owned Land

Latest Wells Drilled Feb 2006

Noora Obswell Network Wells - Loxton Sands Aquifer

Noora Obswell Network Wells - MGL Aquifer

Major Roads

Towns

SA/Vic Border

0 1.25 2.5 5 Kilometres

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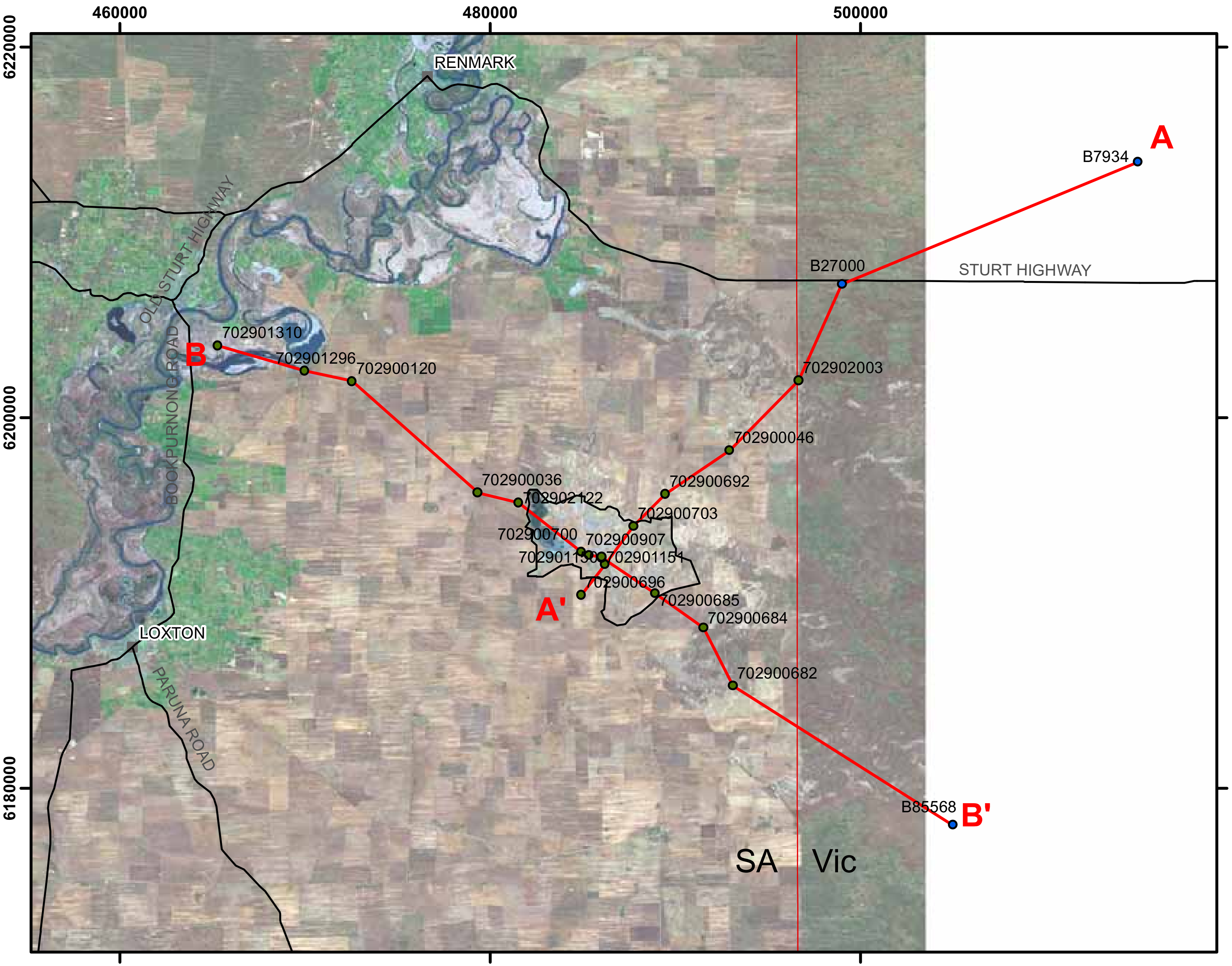
Figure 6 Current Noora Obswell Groundwater Monitoring Network

N W E S

Datum: GDA94
Map Projection: MGA Zone 54



Legend

- Noora Basin Government Owned Land
- Transect
- South Australian Wells
- Victorian Wells
- Major Roads
- Towns
- SA/Vic Border

0 2 4 8 Kilometres

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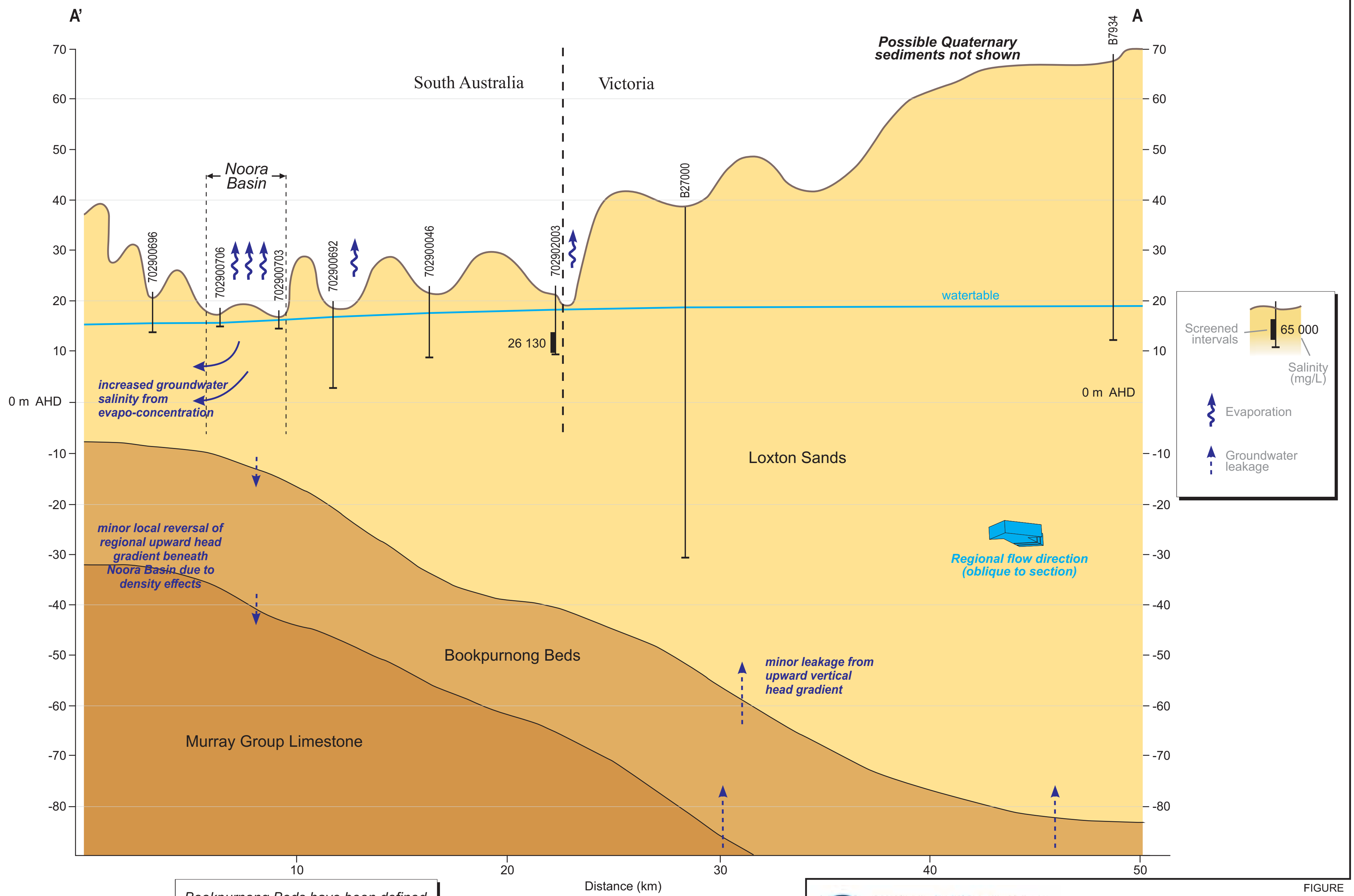
Figure 7 Locations of Hydrogeologic Cross Sections

Datum: GDA94
Map Projection: MGA Zone 54



Bookpurnong Beds have been defined by both available lithological logs and the model layers

P:\DWLBC (AL)\09 - Noora\deliverables\Report Figs\figure8.cdr

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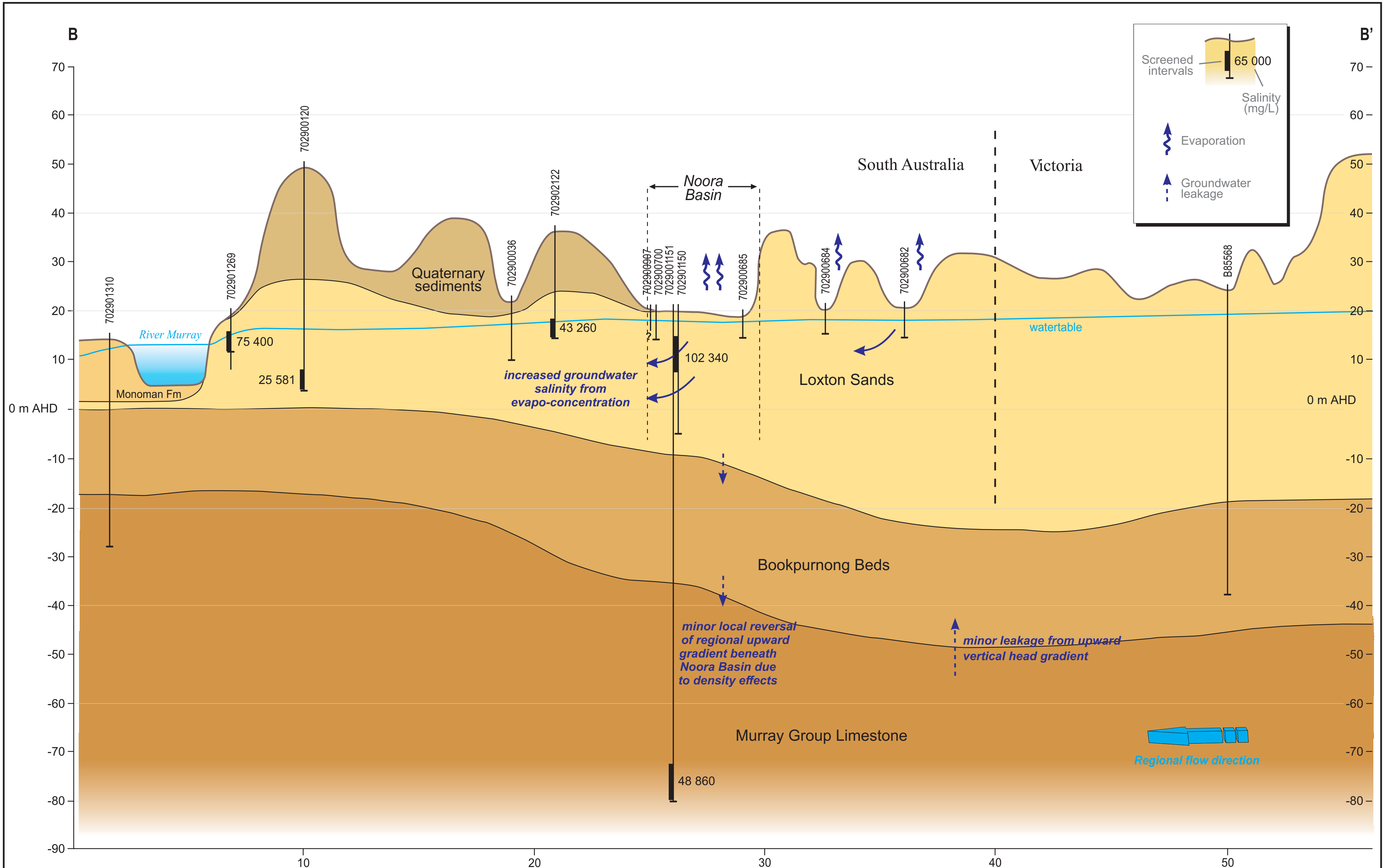
Conceptual Hydrogeologic Section A–A'

FIGURE 8



Bookpurnong Beds have been defined by both available lithological logs and the model layers

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FIGURE 9

Conceptual Hydrogeologic Section B–B'

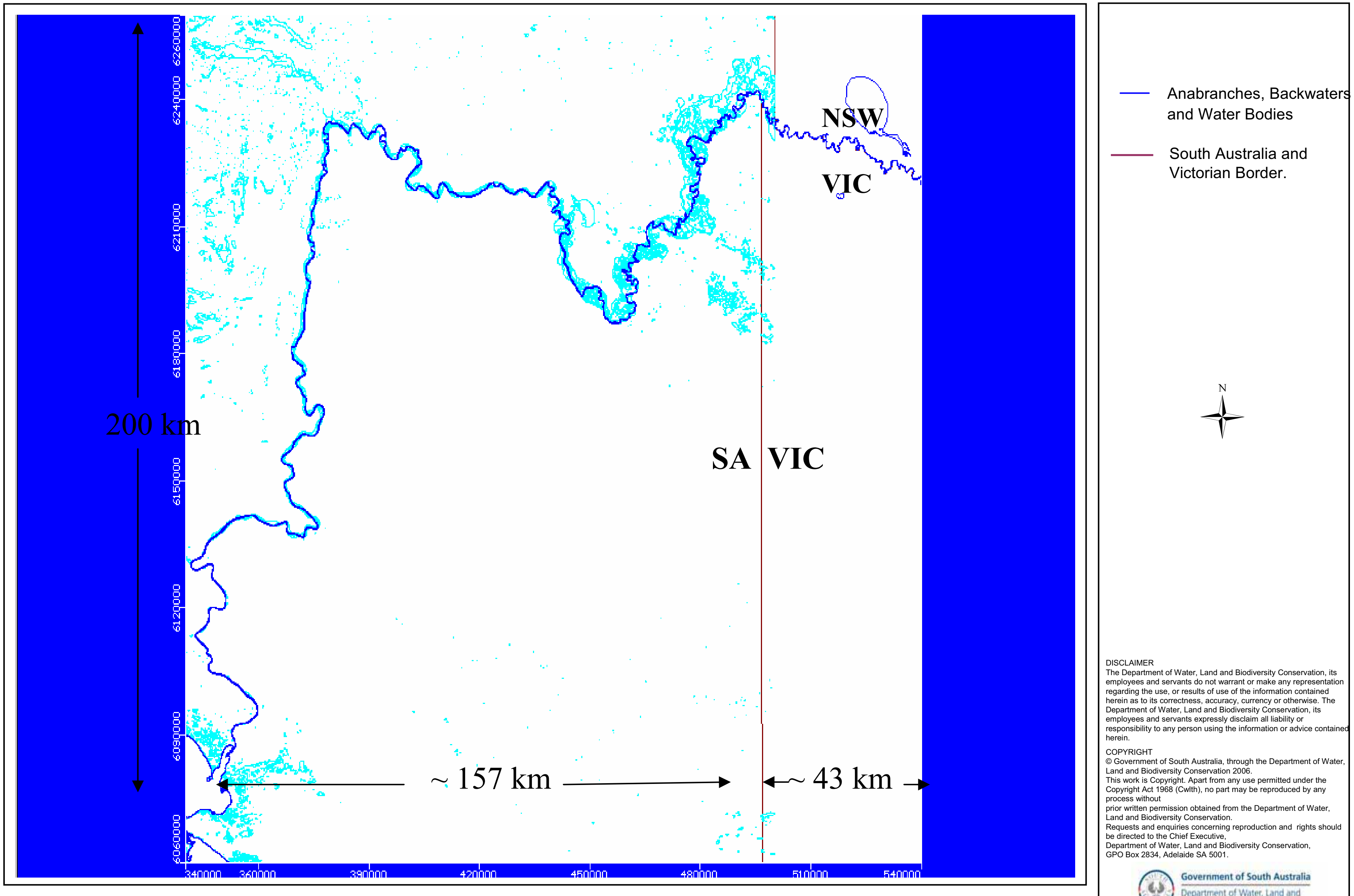
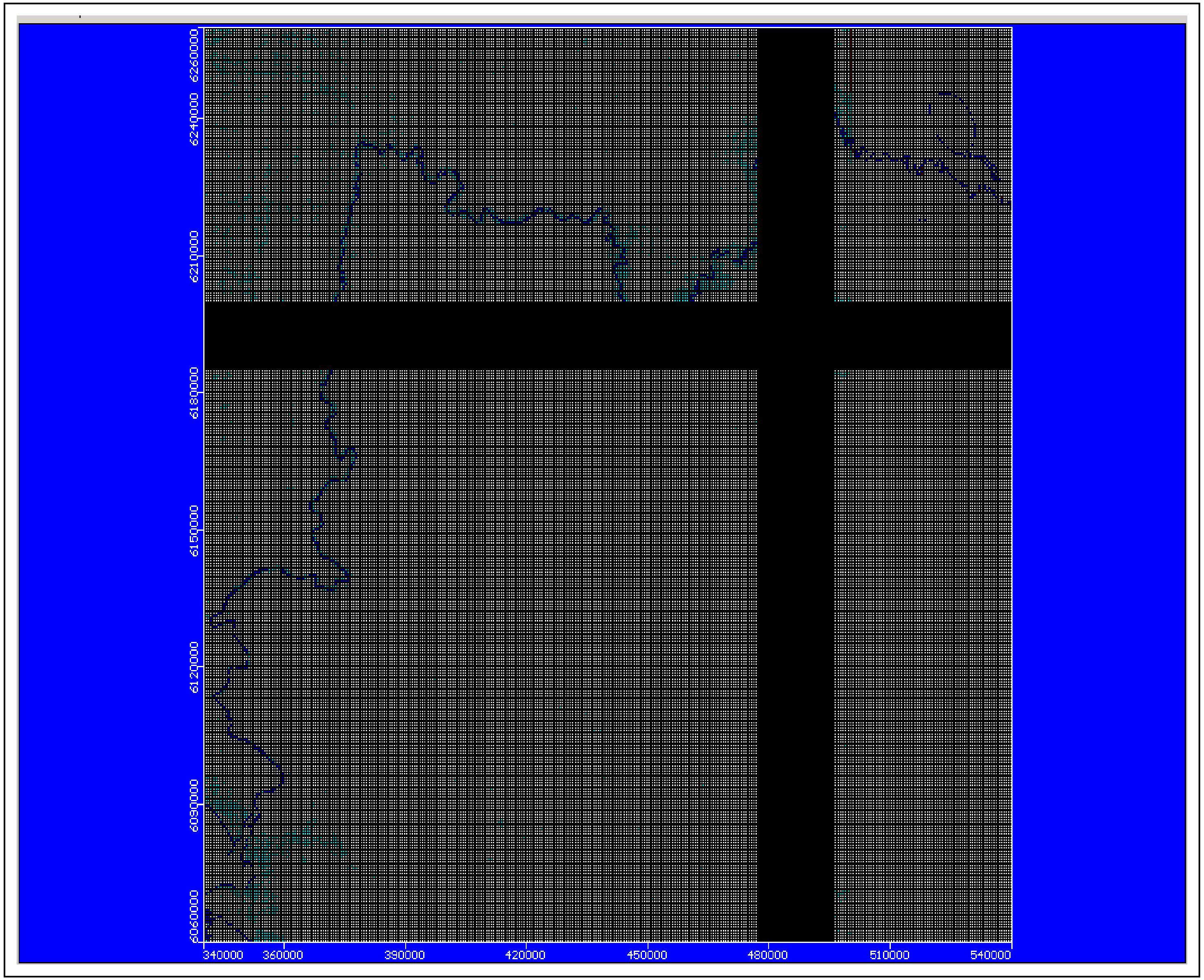


Figure 10 Model Domain



Anabranches, Backwaters and Water Bodies

Grid Size 125 X 125m

Grid Size 500 X 500m

N

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Figure 11 Model Grid

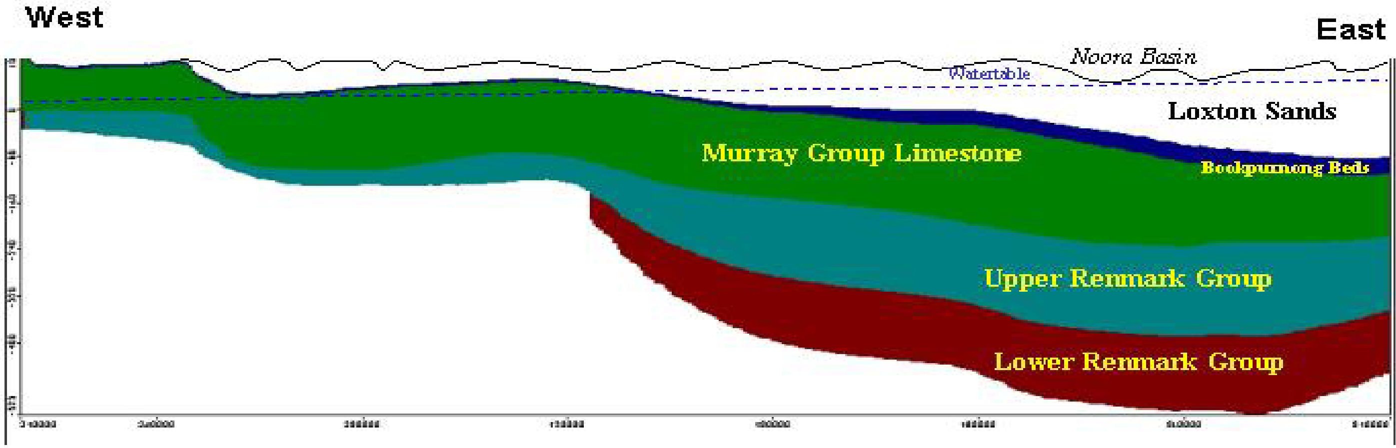

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Figure 12 Model Layers – East-West Section

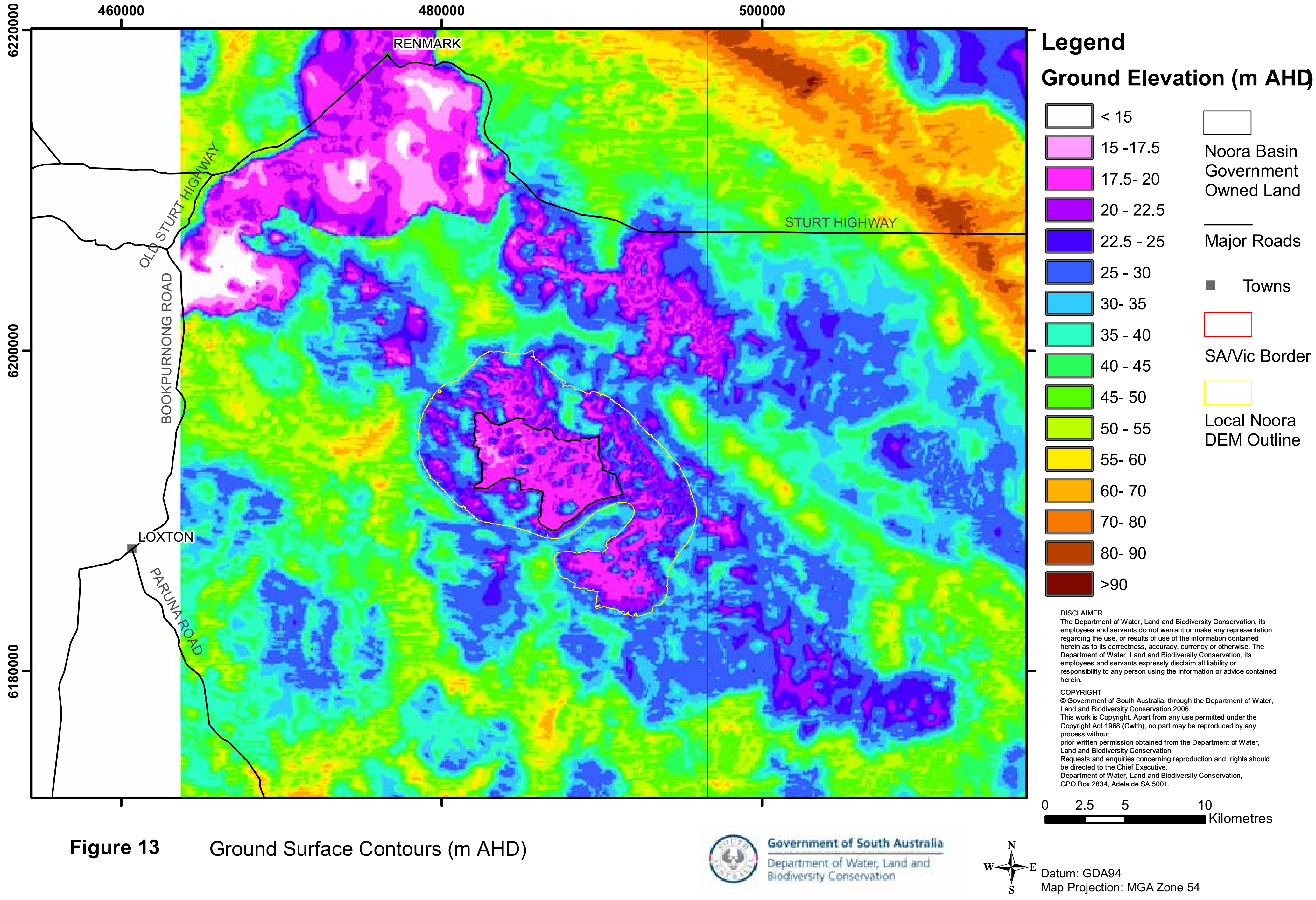

Figure 13 Ground Surface Contours (m AHD)

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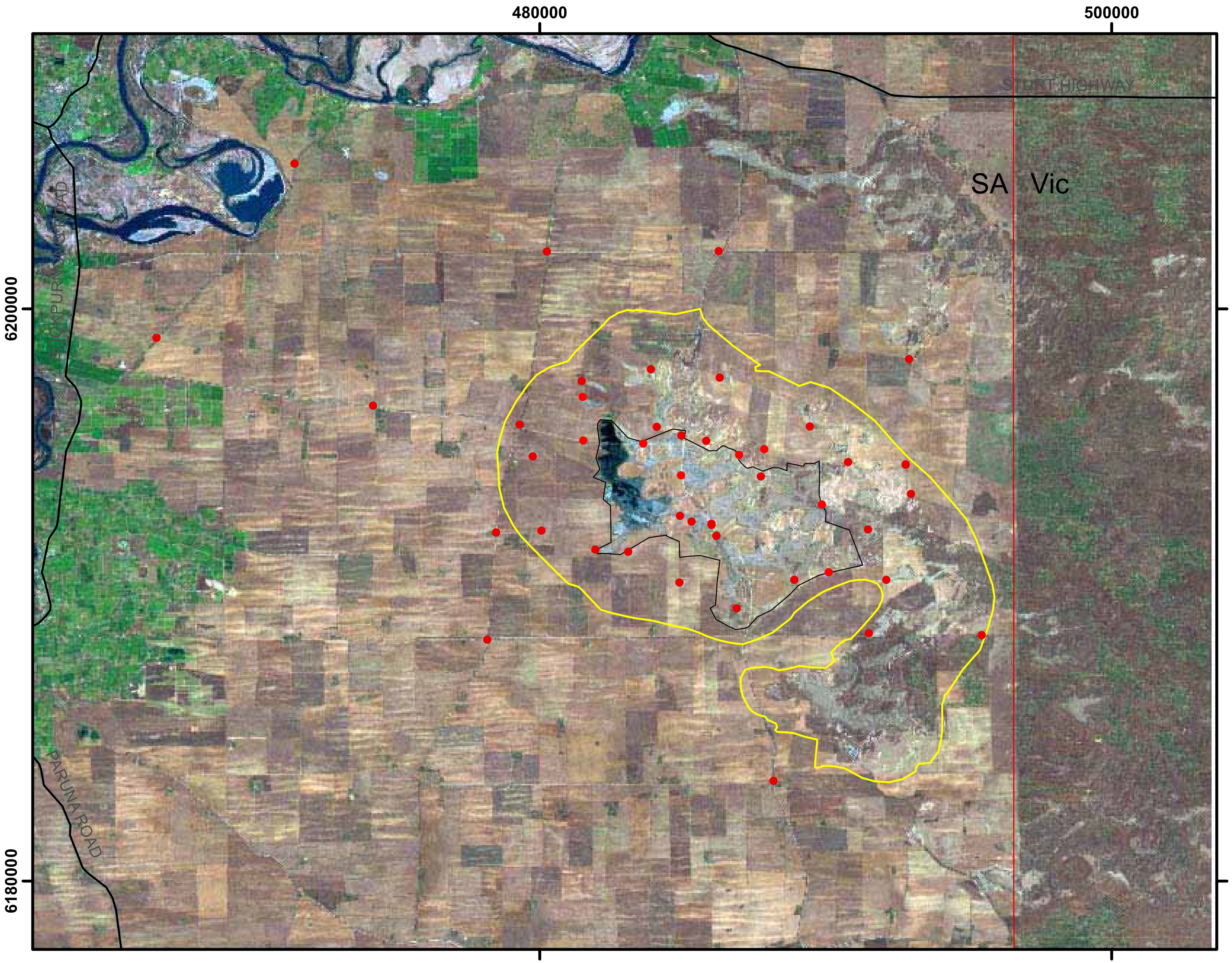

Legend

- Elevation Comparison Sites
- Noora Basin Government Owned Land
- Major Roads
- Towns
- SA/Vic Border
- Local Noora DEM Outline

0 1.5 3 6 Kilometres

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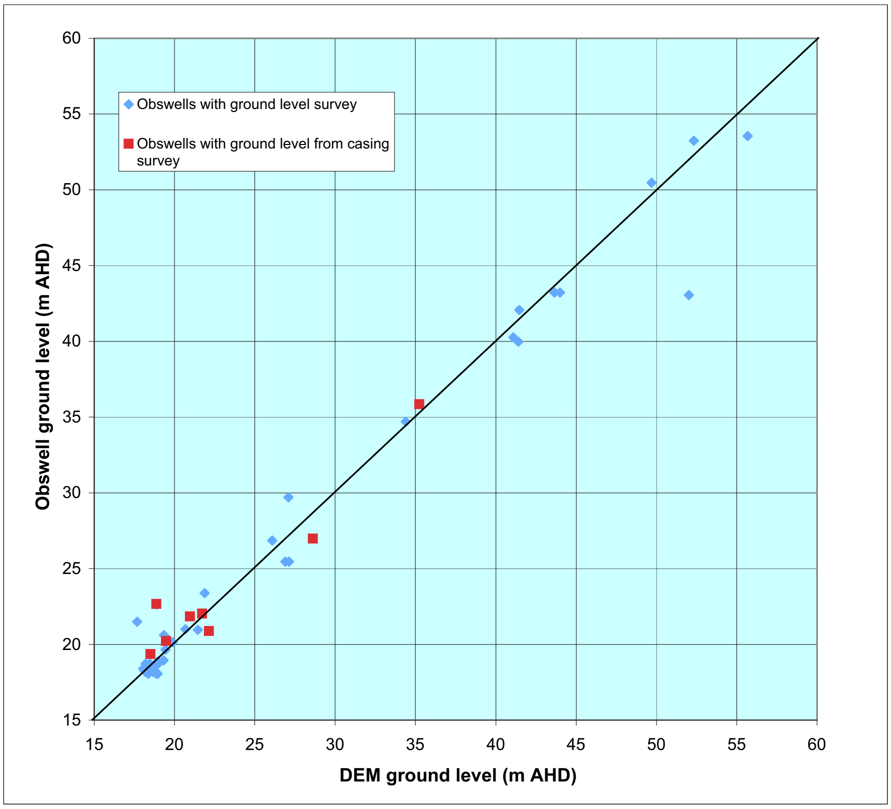
Figure 14 Obswell Sites Used for Elevation Comparison

N
W E
S

Datum: GDA94
Map Projection: MGA Zone 54



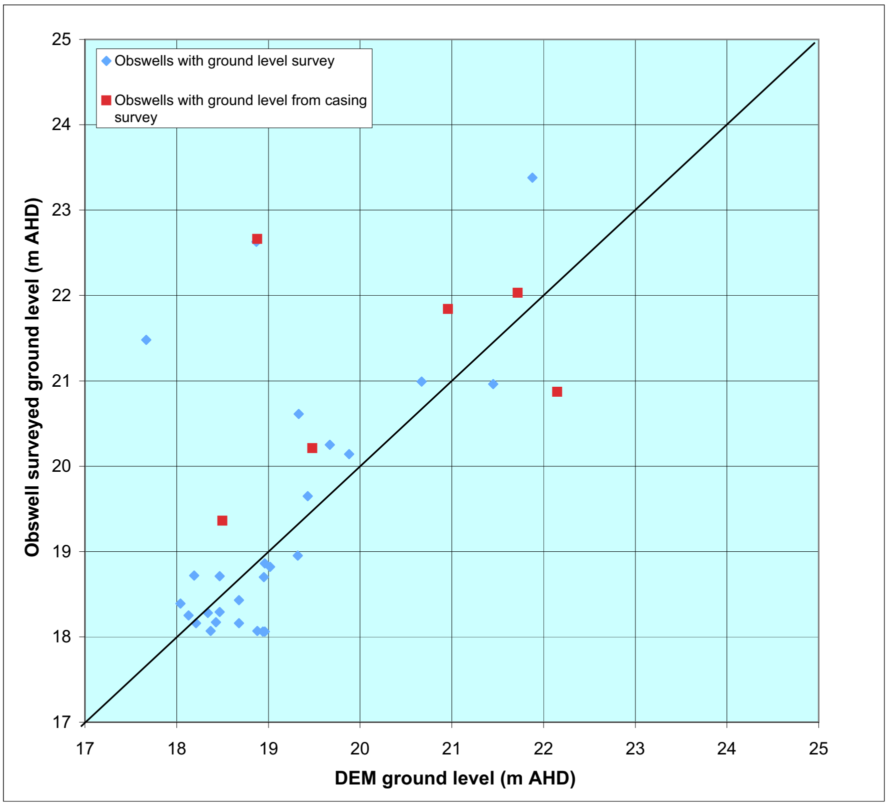
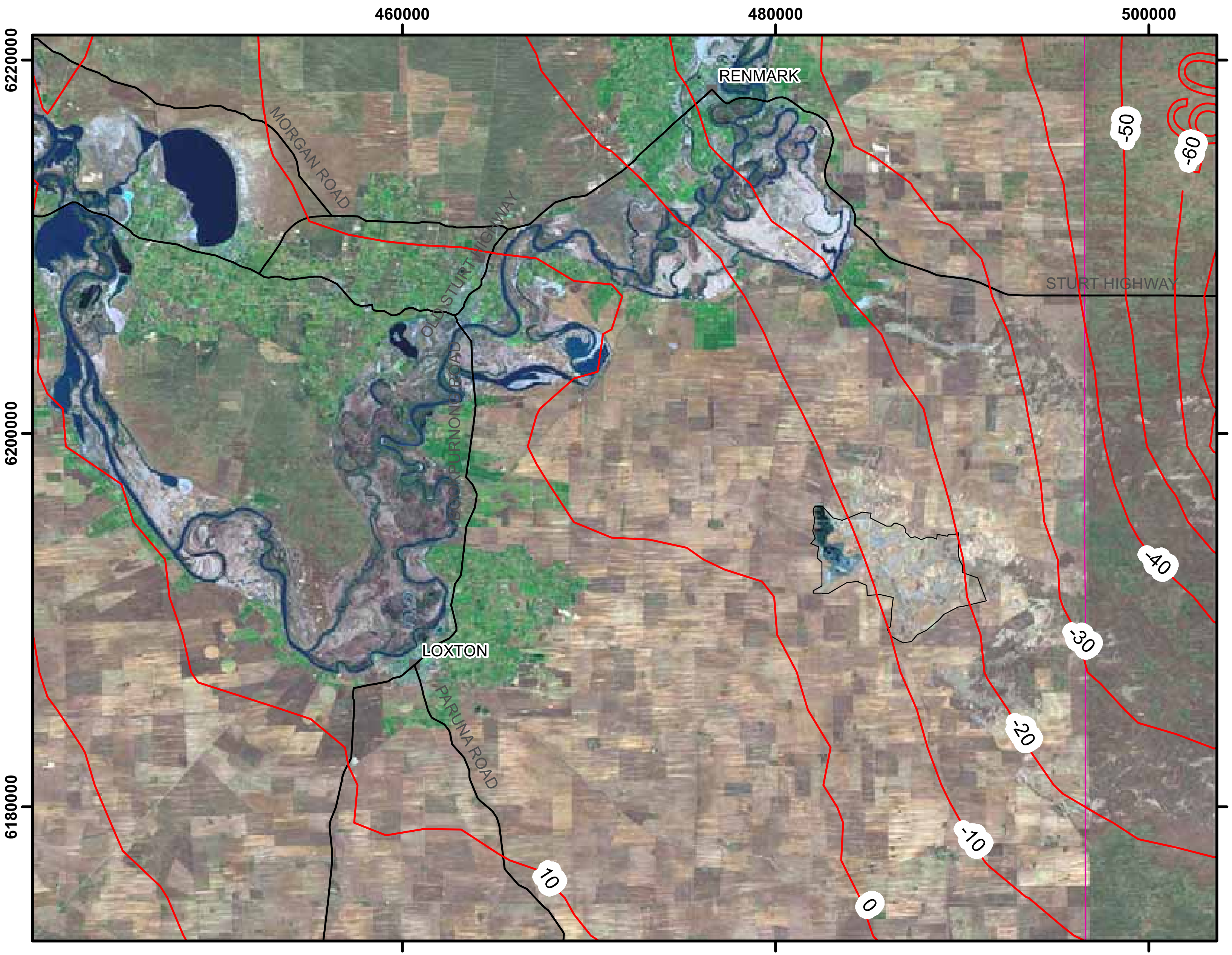


Figure 15 X-Y Plots of Obswell vs DEM Ground Levels



Legend

Top of Layer 2 (Bookpurnong Aquitard)

Noora Basin Government Owned Land

SA/Vic Border

Major Roads

Towns

0 2.5 5 10 Kilometres

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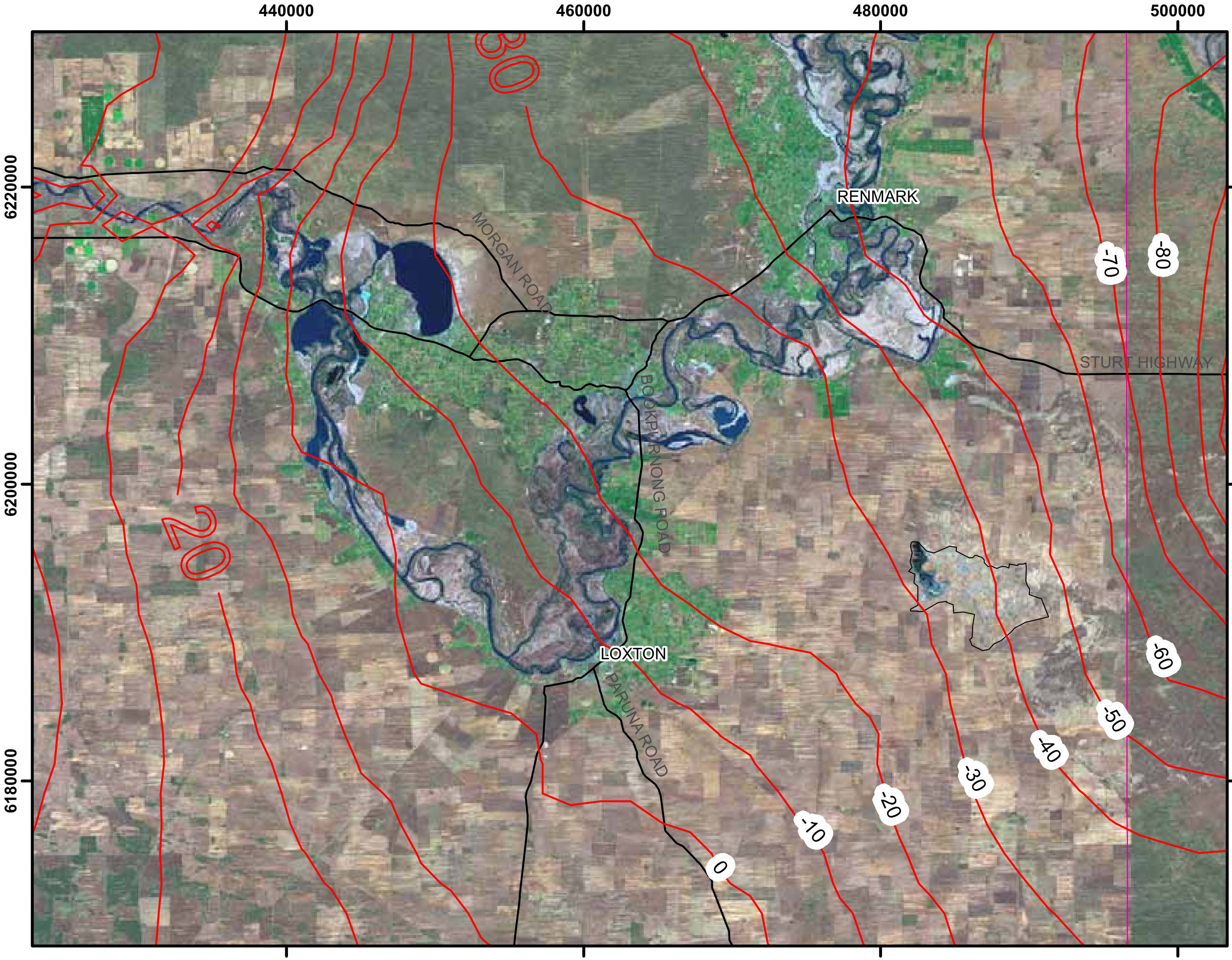
Figure 16 Top of Layer 2 Contours (m AHD)

N
W E
S
Datum: GDA94
Map Projection: MGA Zone 54



Legend

Top of layer 3 - (Murray Group Limestone Aquifer).

Noora Basin Government Owned Land

Major Roads

Towns

SA/Vic Border

0 3.5 7 14 Kilometres

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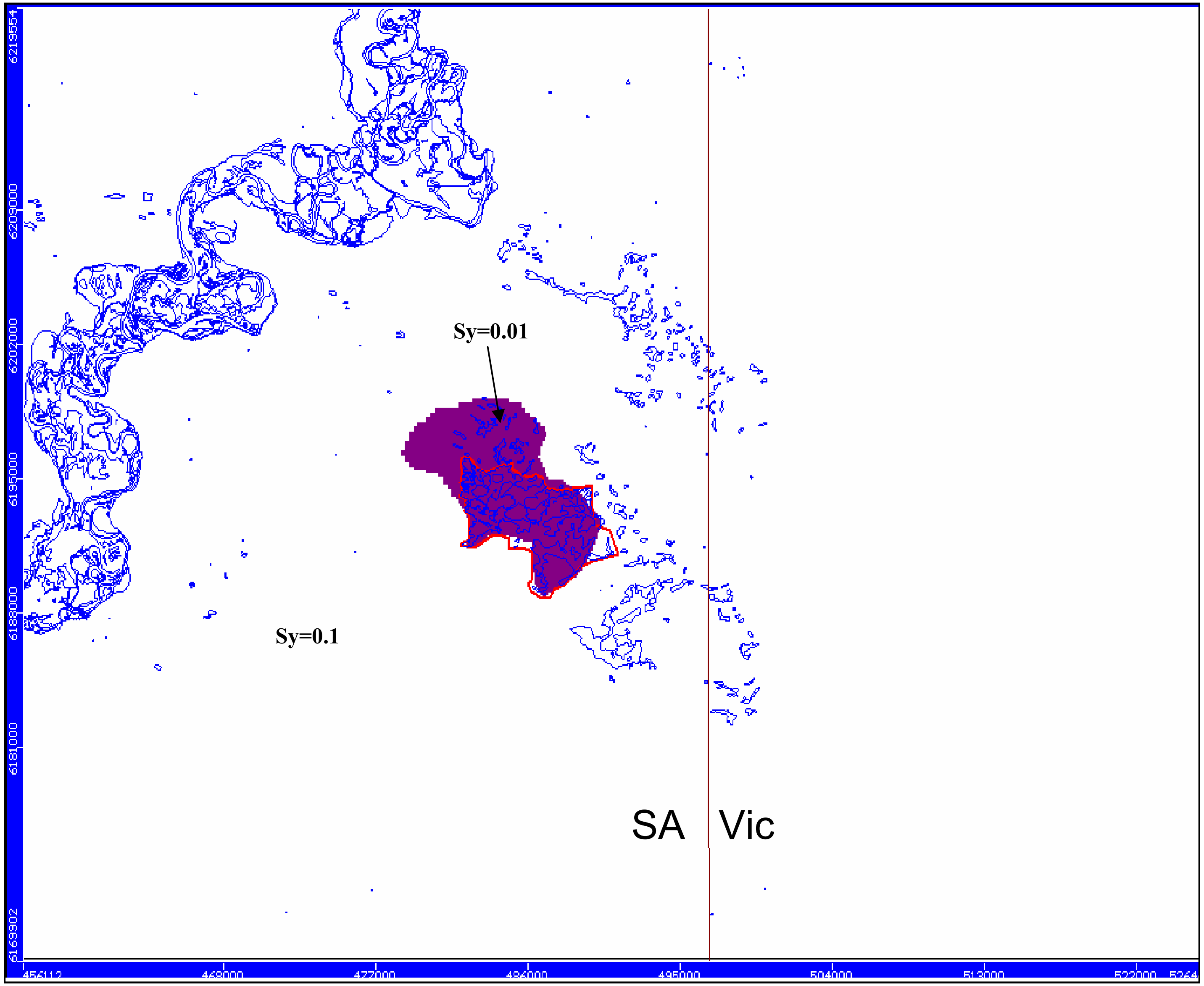
Figure 17 Top of Layer 3 Contours (m AHD)

N
W E
S

Datum: GDA94
Map Projection: MGA Zone 54



Anabranches, Backwaters and Water Bodies

South Australia and Victorian Border.

Noora Government Owned Land Boundary

Sy = 0.01

N

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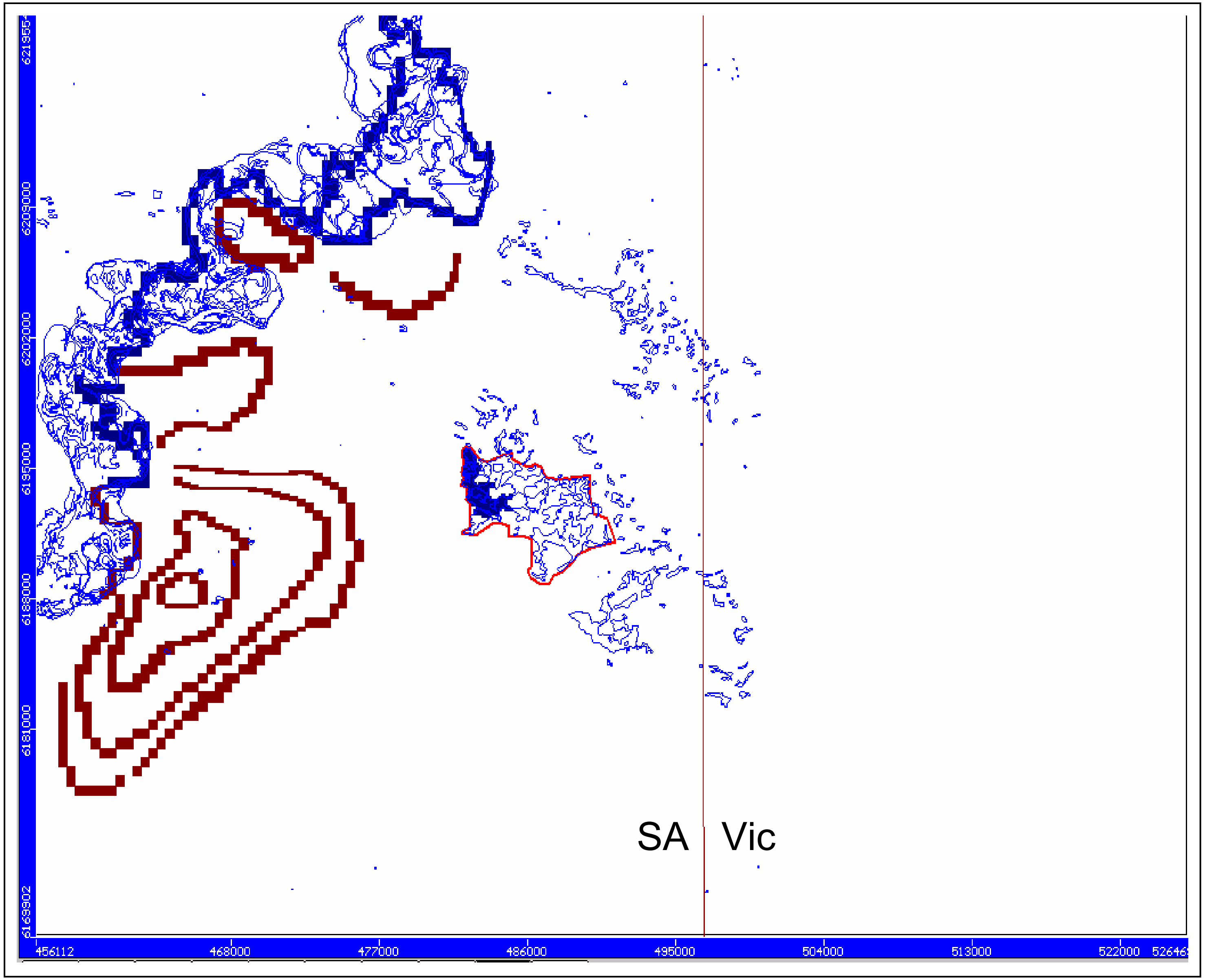
Department of Water, Land and Biodiversity Conservation

Figure 18 Layer 1 Specific Yields



Anabranches, Backwaters and Water Bodies

South Australia and Victorian Border.

Noora Government Owned Land Boundary

Model River Cells

Fixed or Change Head cells

N

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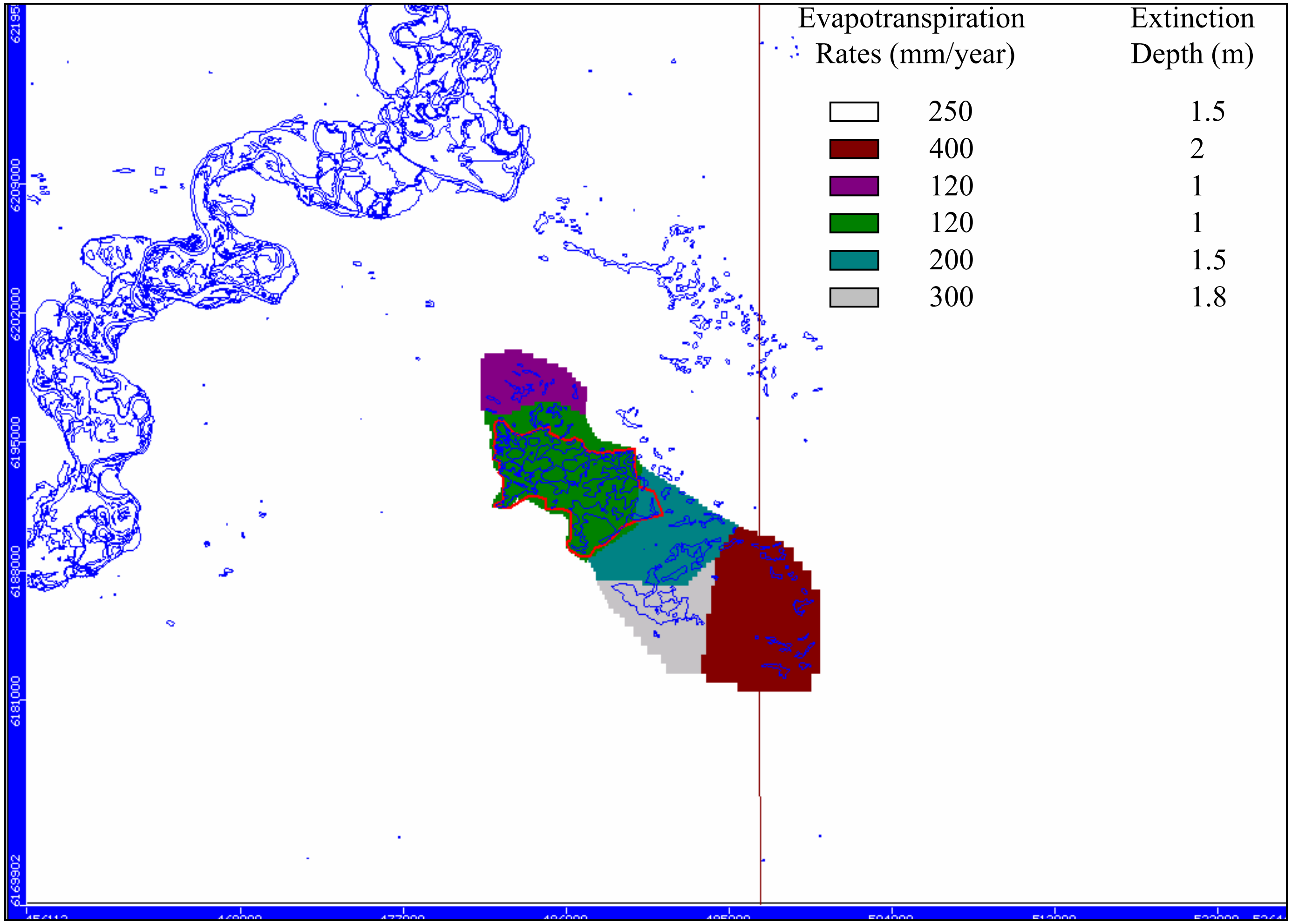
Department of Water, Land and Biodiversity Conservation

Figure 19 Layer 1 Boundary Conditions



Anabranches, Backwaters and Water Bodies

South Australia and Victorian Border.

Noora Government Owned Land Boundary

N

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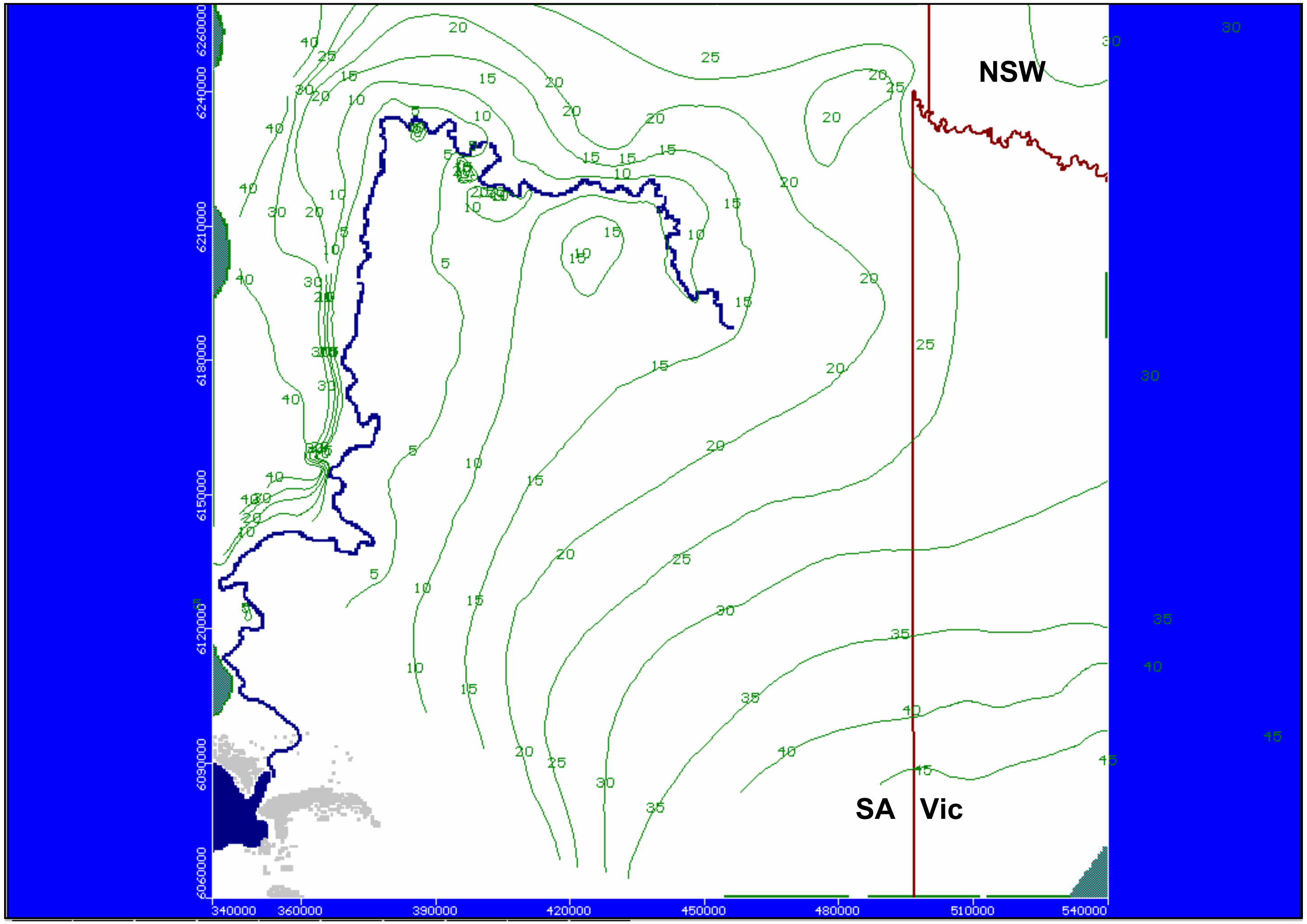
Figure 20 Evapotranspiration Zones



Anabranches, Backwaters and Water Bodies

South Australia and Victorian Border.

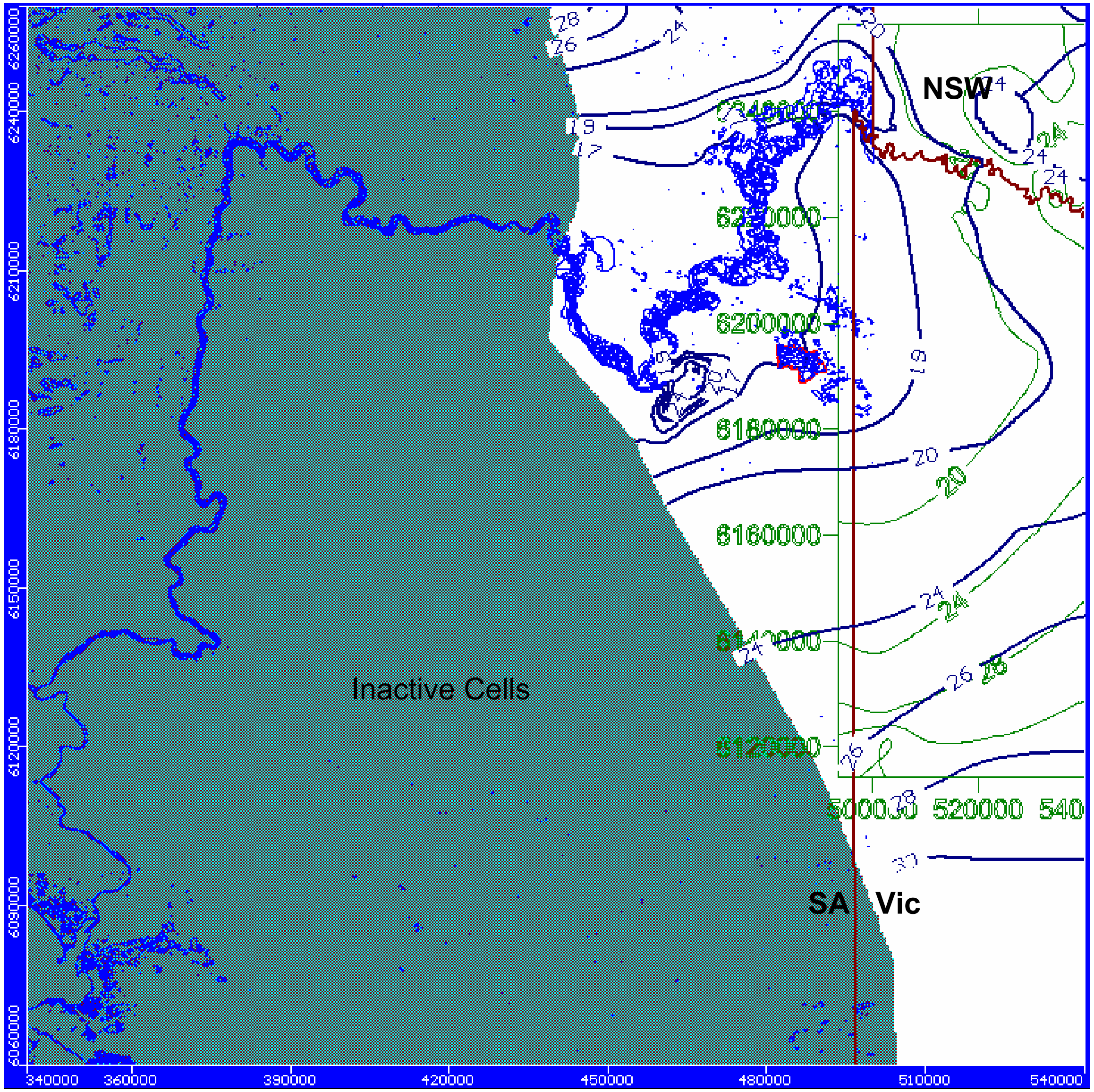
Potentiometric Surface Contours Surface layer 3 Murray Group Limestone

General Head

No-flow

N

Figure 21 Layer 3 Boundary Conditions



Anabranches, Backwaters and Water Bodies

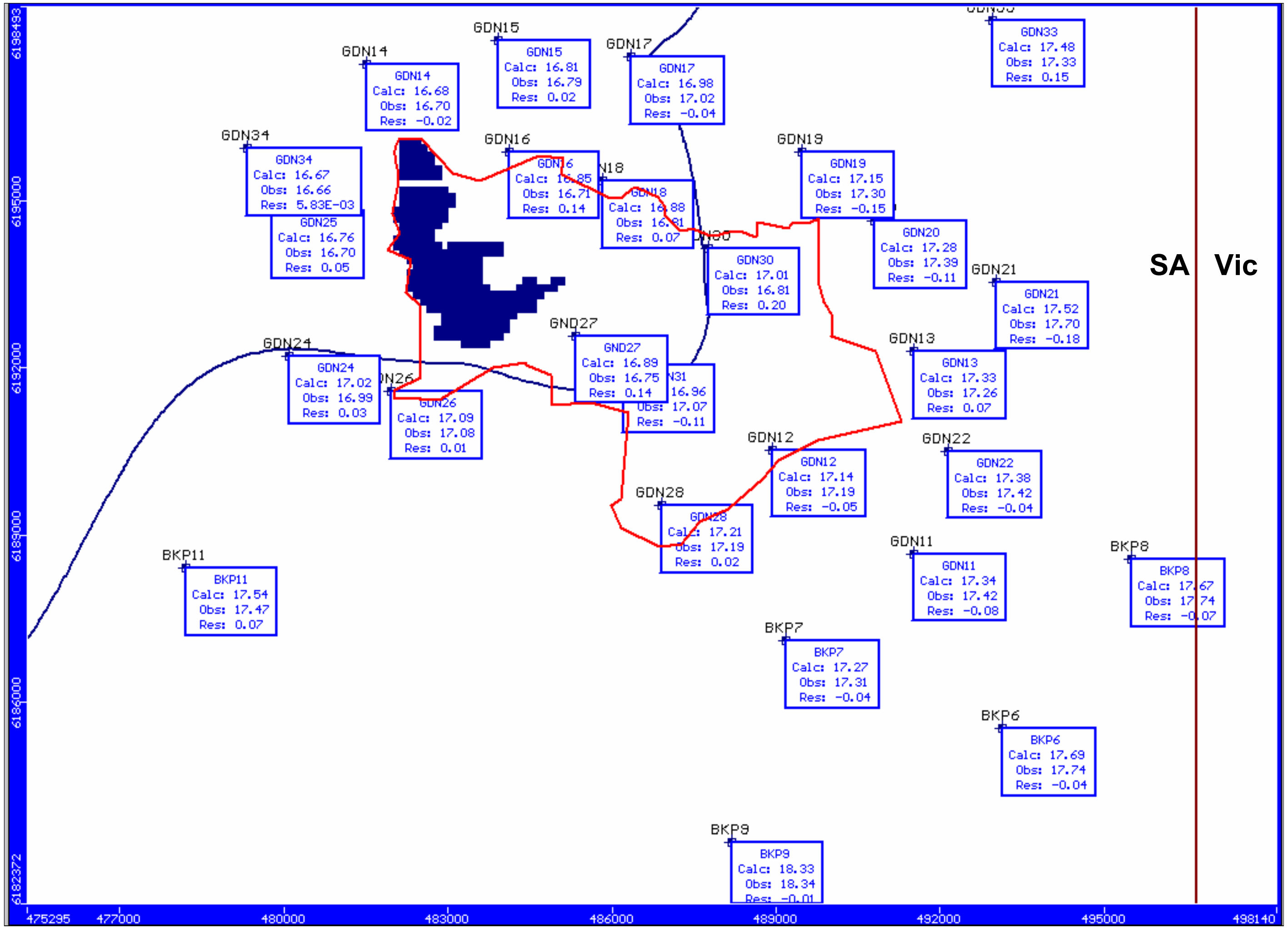
South Australia and Victorian Border.

Water table Surface layer 1 Loxton Sands

Modeled water table contours.

N

Figure 22 Comparison of Measured and Modelled Watertable Contours in Victoria – 2003



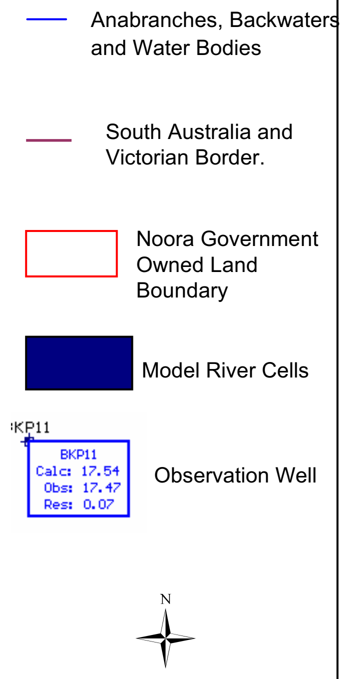


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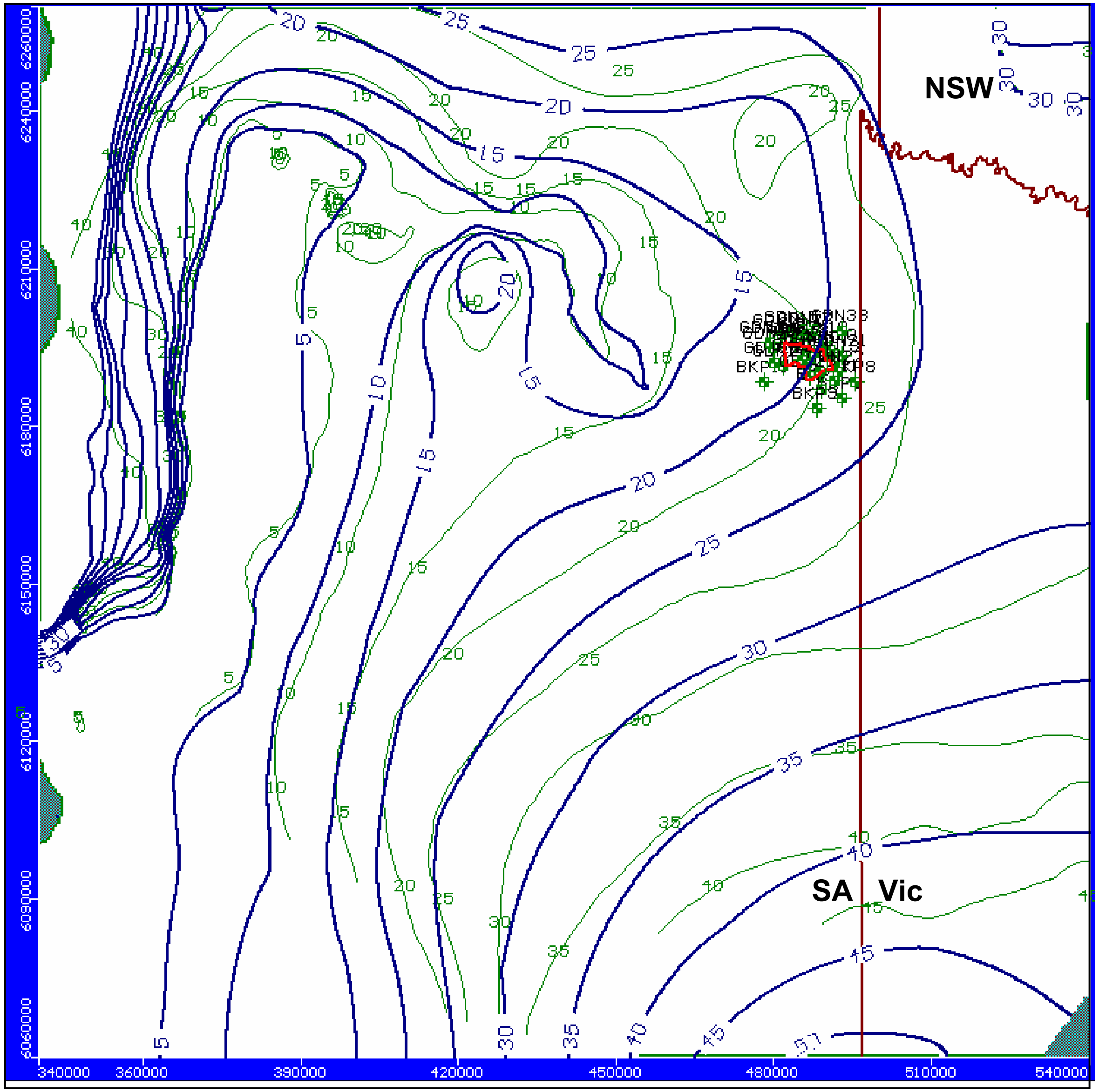
Figure 23 Comparison of Measured and Modelled Watertable Contours, Noora Area April 2006



Anabranches, Backwaters and Water Bodies

South Australia and Victorian Border.

Murray Group Limestone From S.R. Barnett, 1991

Modeled potentiometric surface contours.

Noora Government Owned Land Boundary

BKP11 Observation Well

N

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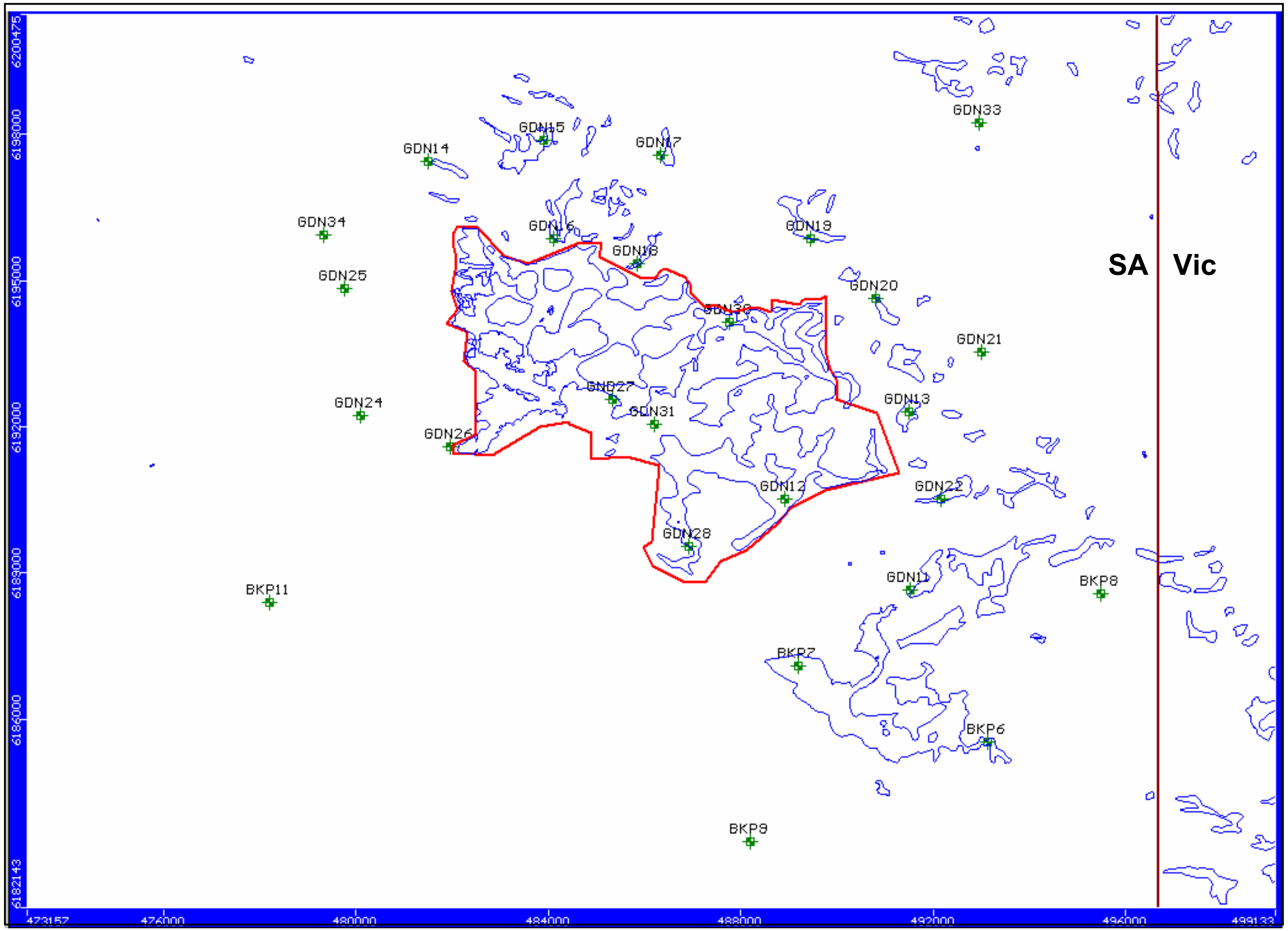
Figure 24 Comparison of Measured and Modeled Potentiometric Surface Contours, Murray Group Limestone Aquifer 1991



Anabranches, Backwaters and Water Bodies

South Australia and Victorian Border.

Noora Government Owned Land Boundary

Low lying area

BKP11 Observation Well

N

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Figure 25 Calibration Observation Well Locations (Loxton Sands Aquifer)

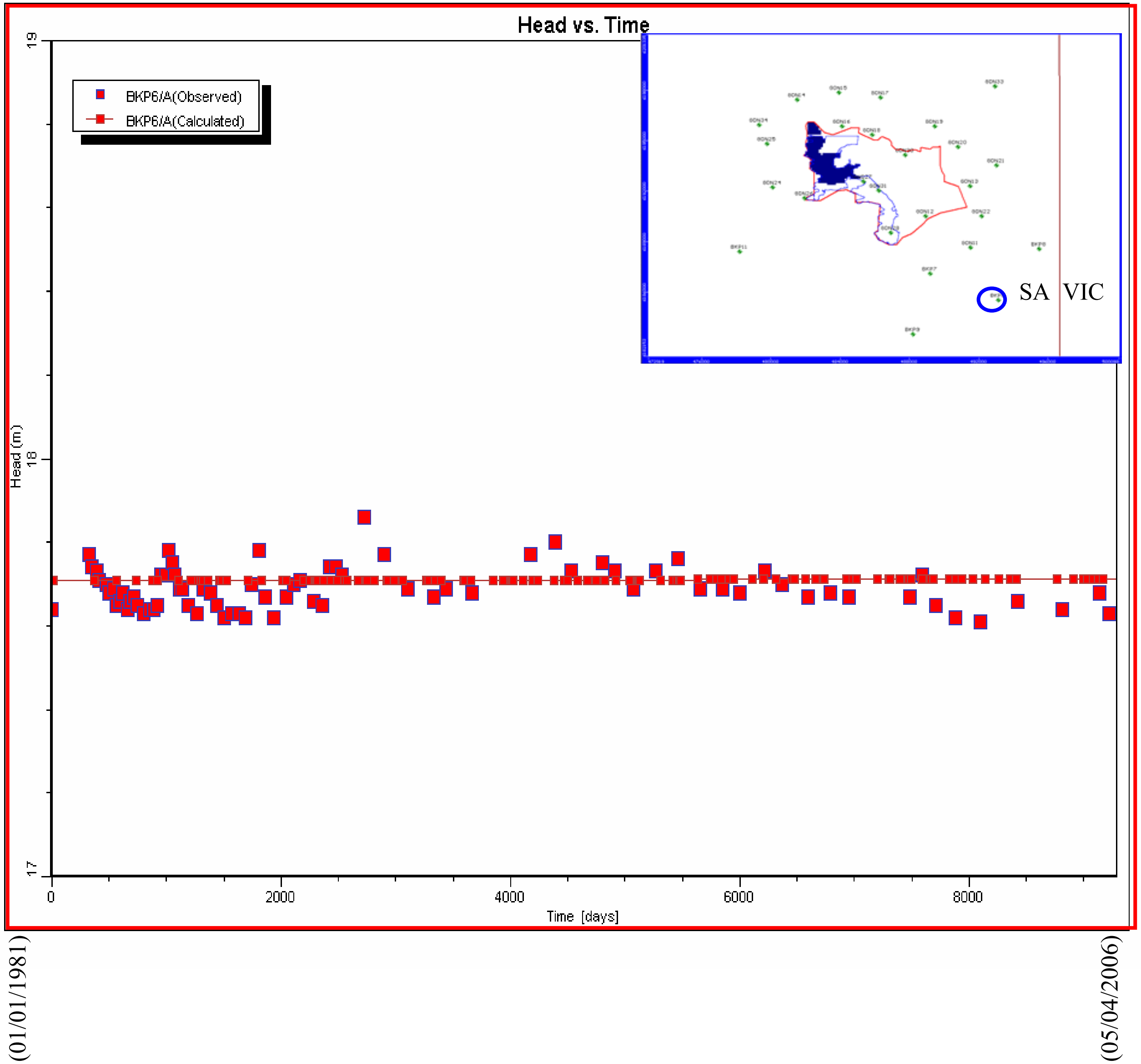
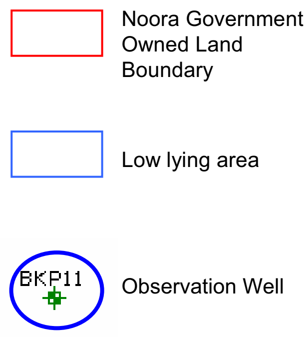


Figure 26a Calibration Observation Well Hydrograph BKP006



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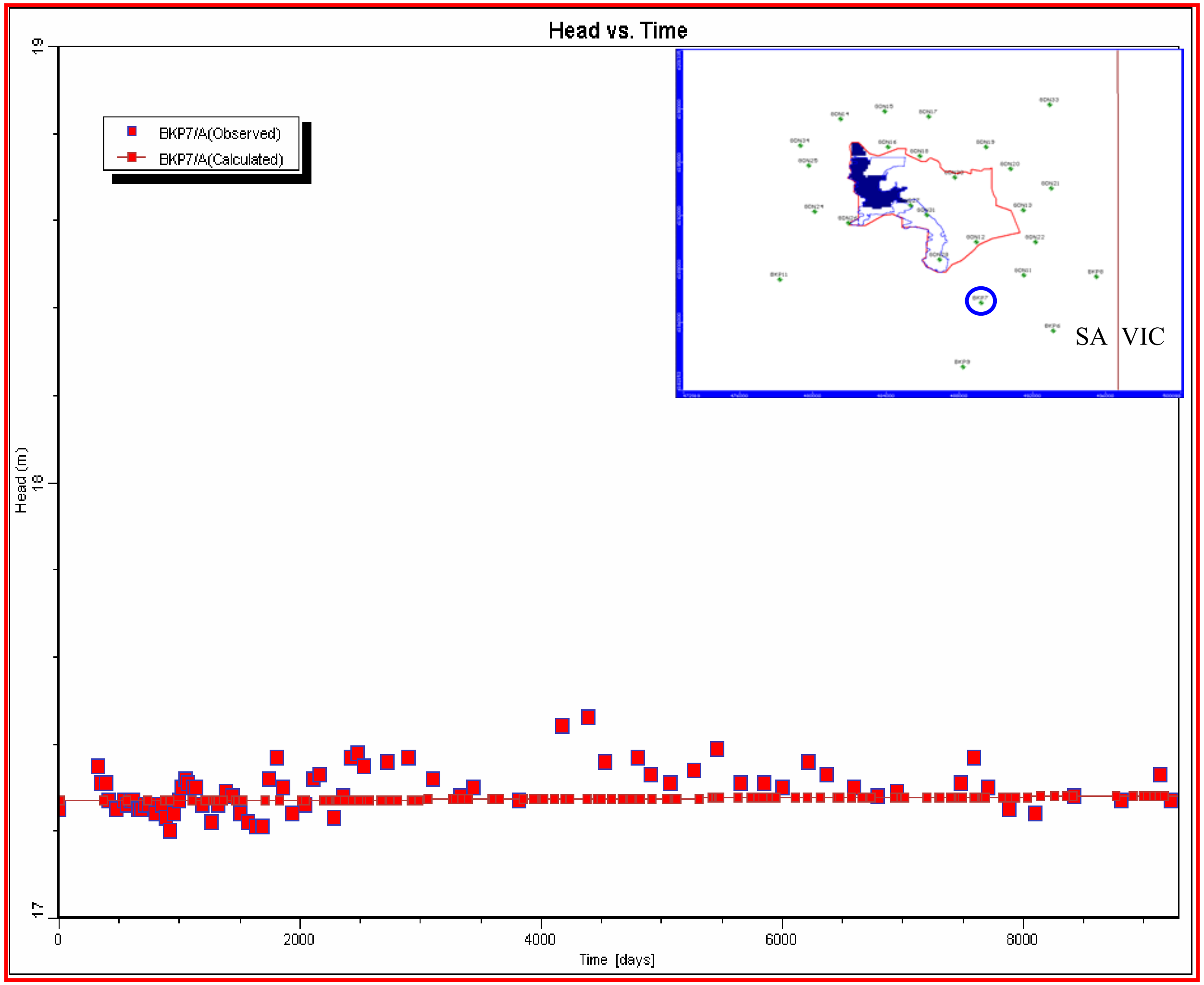

(01/01/1981)

(05/04/2006)

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

N

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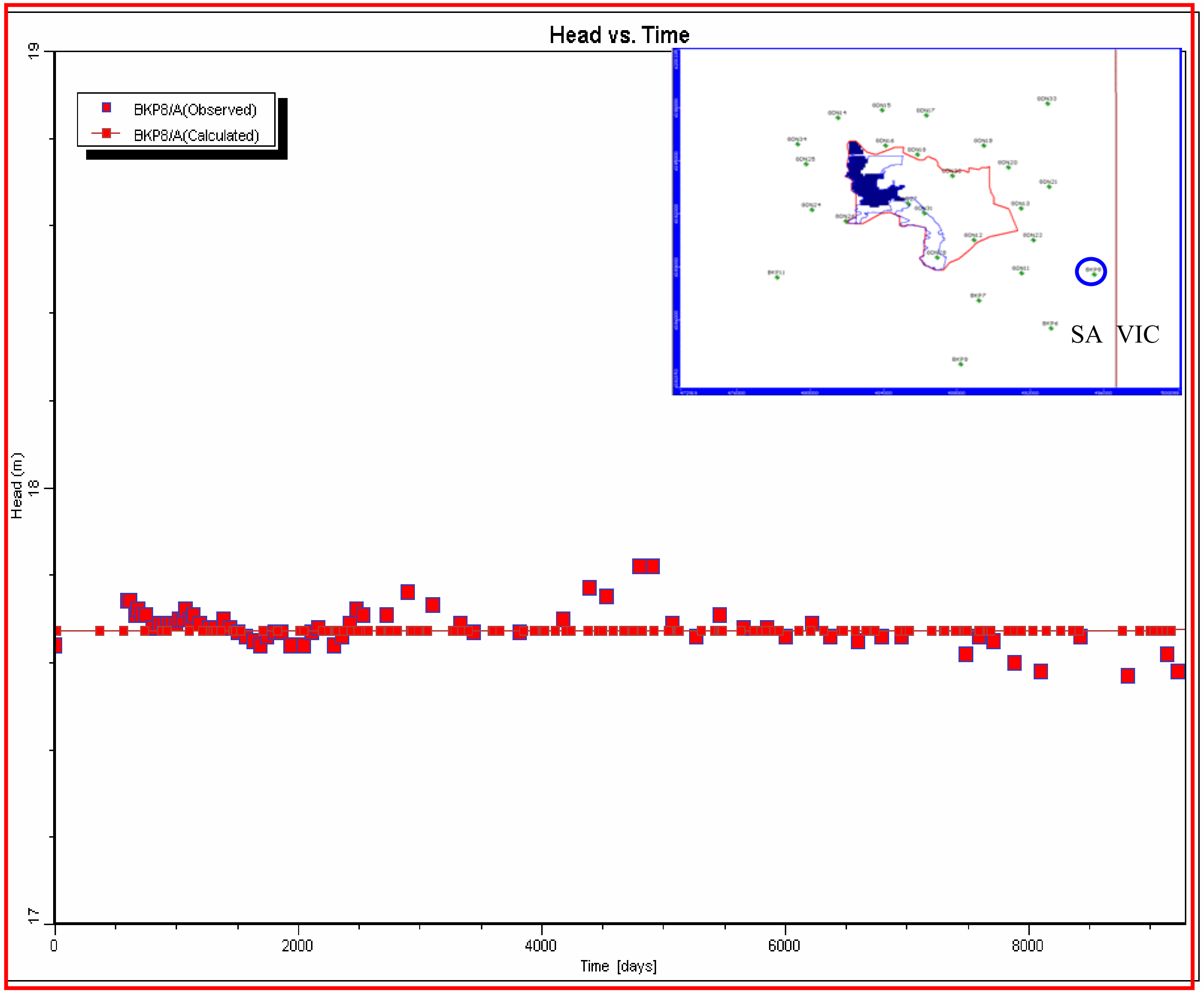
Department of Water, Land and Biodiversity Conservation

Figure 26b Calibration Observation Well Hydrograph BKP007



(01/01/1981)

(05/04/2006)

Noora Government Owned Land Boundary

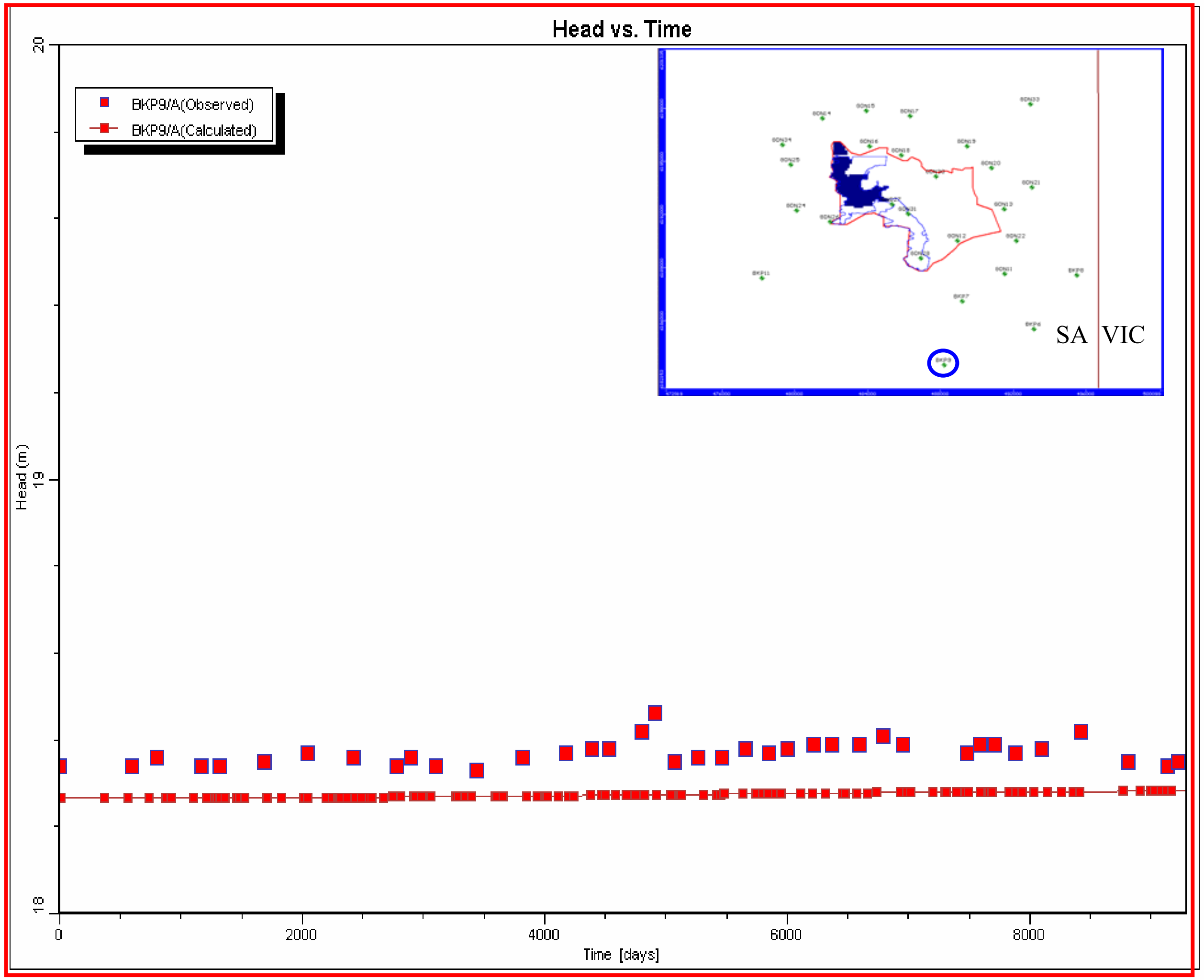
Low lying area

BKP11 Observation Well

N

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Figure 26c Calibration Observation Well Hydrograph BKP008



(01/01/1981) (05/04/2006)

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

N

Figure 26d Calibration Observation Well Hydrograph BKP009

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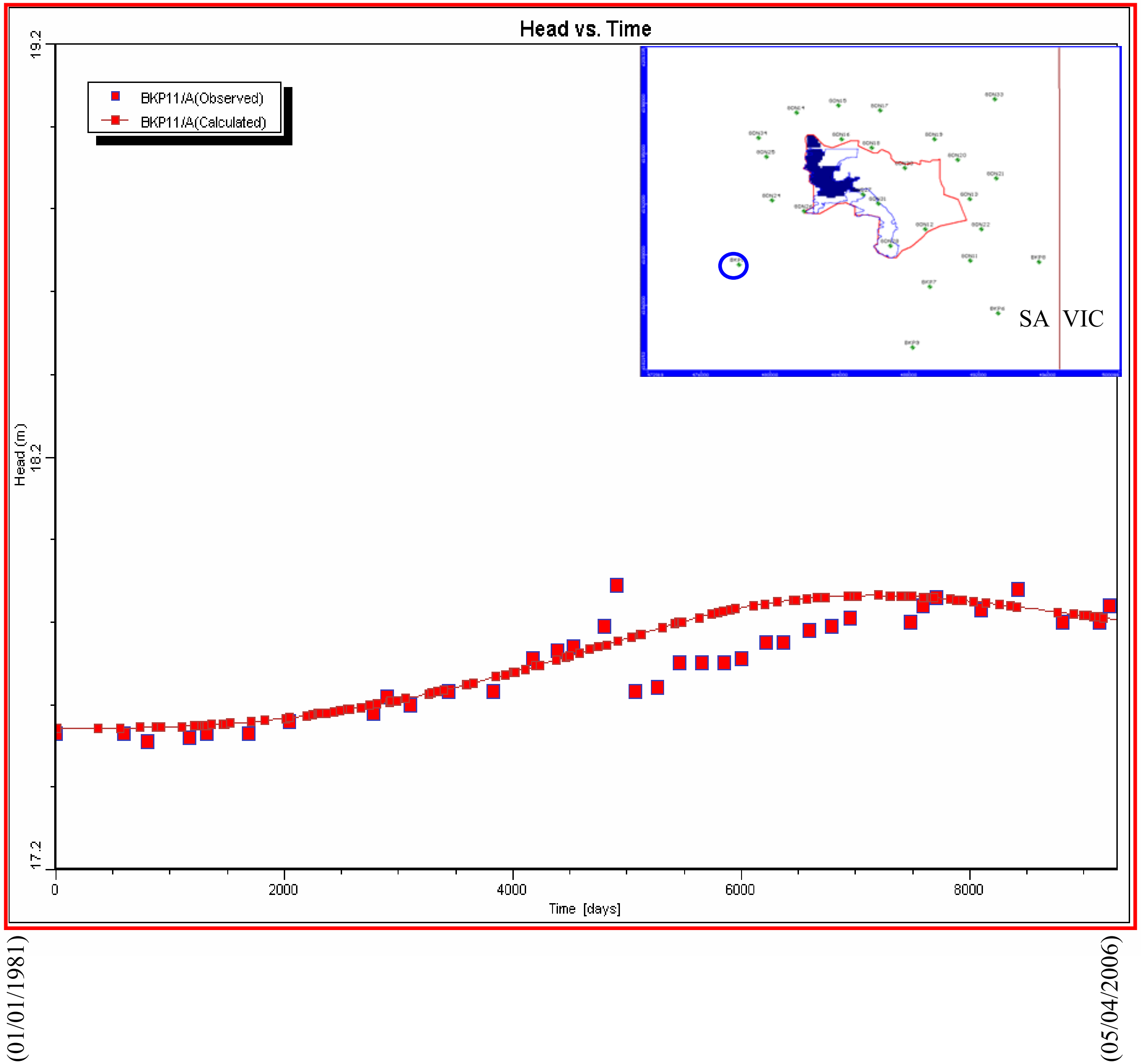
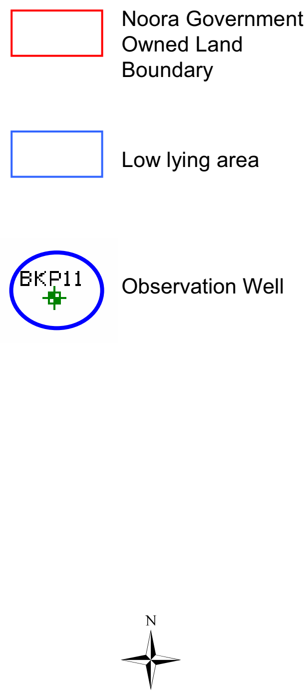


Figure 26e Calibration Observation Well Hydrograph BKP011



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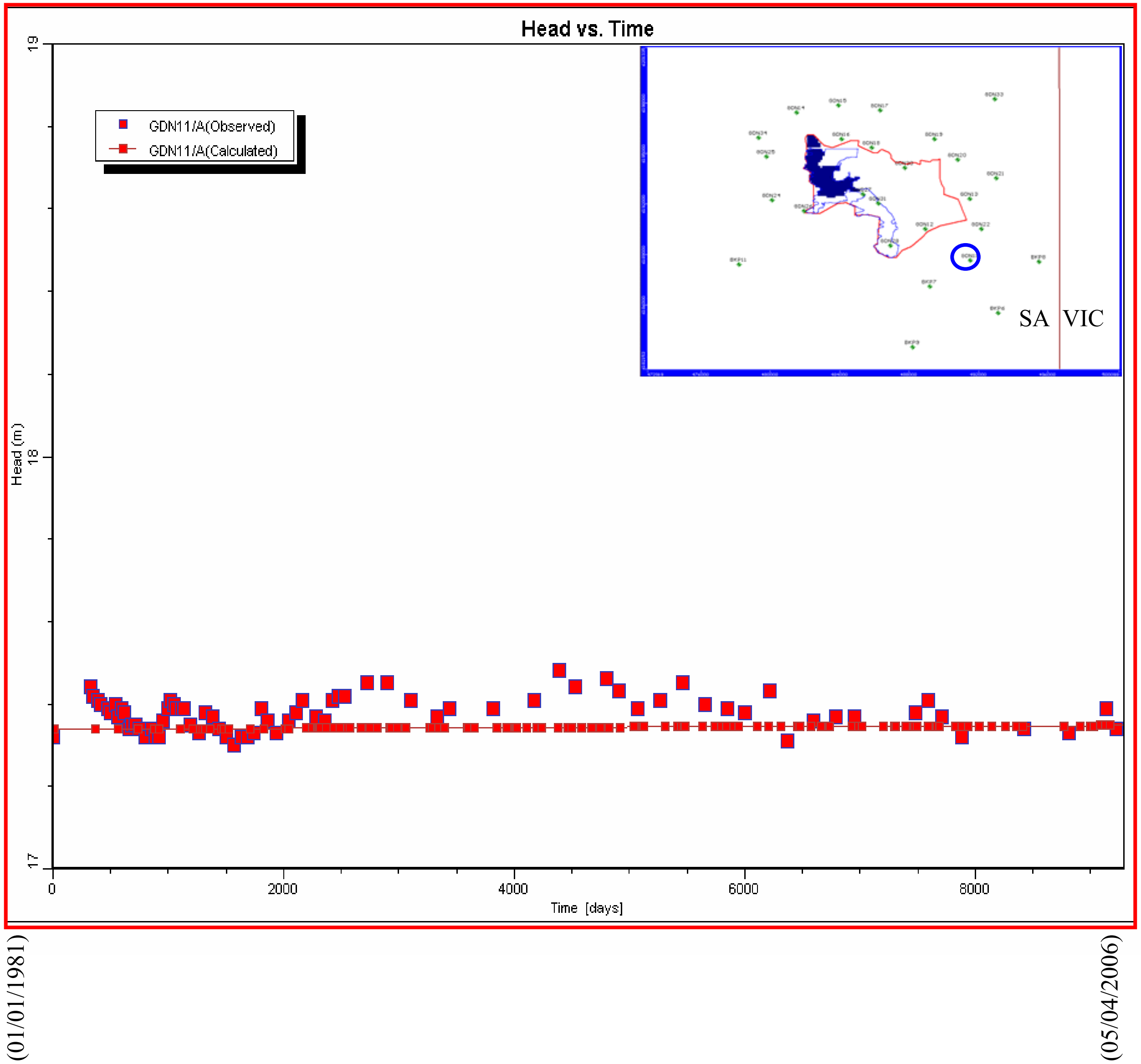

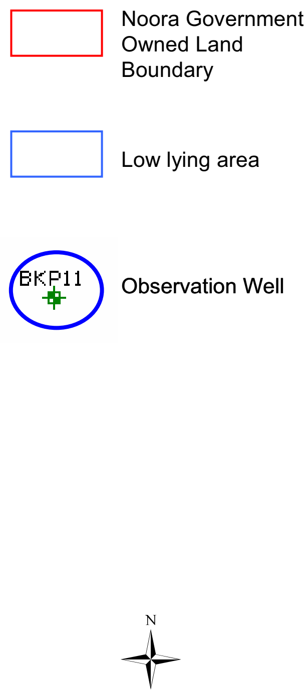

Figure 26f Calibration Observation Well Hydrograph GDN011

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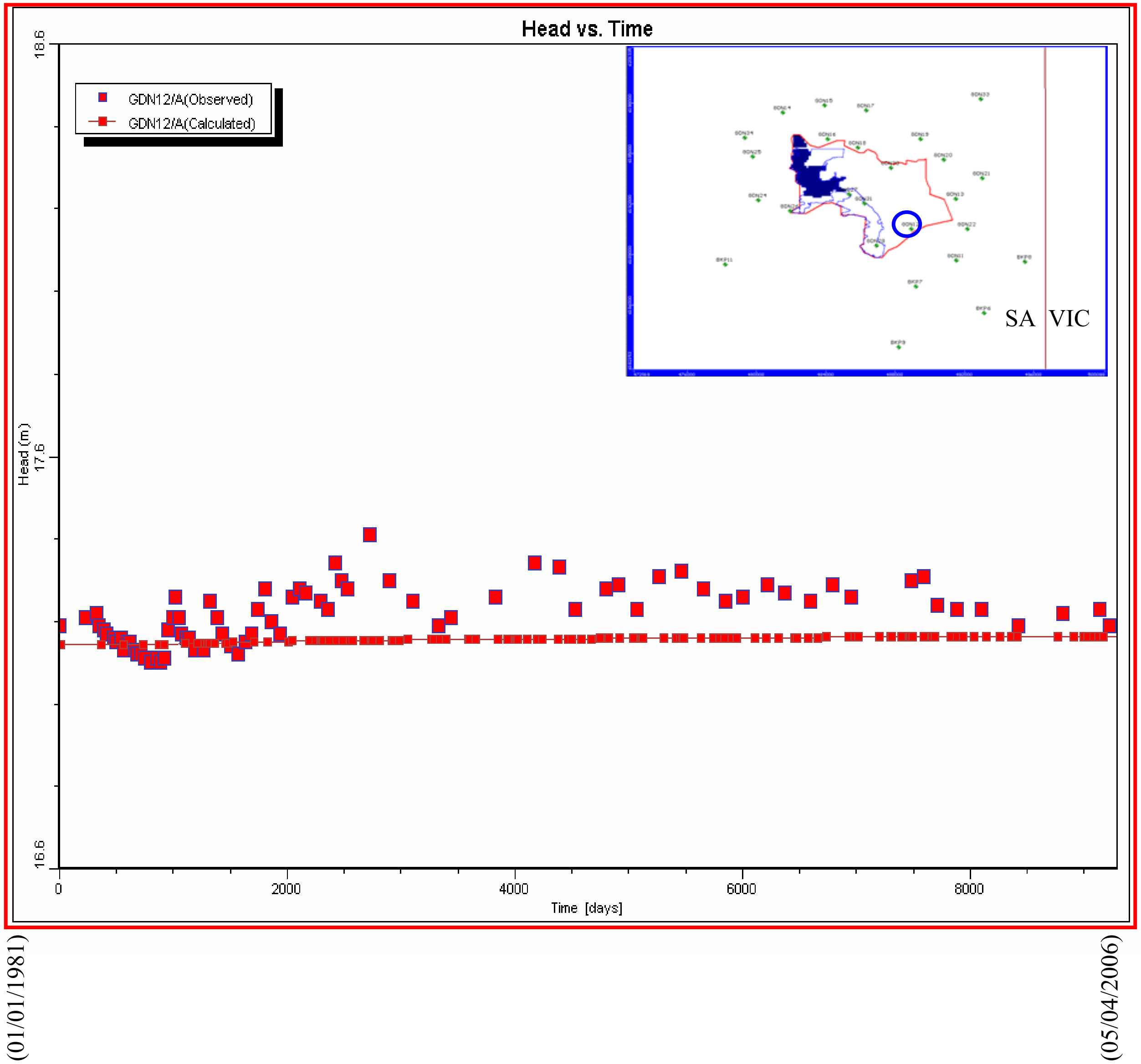

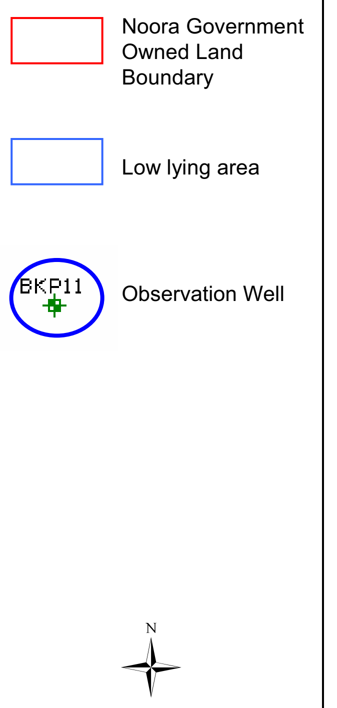

Figure 26g Calibration Observation Well Hydrograph GDN012

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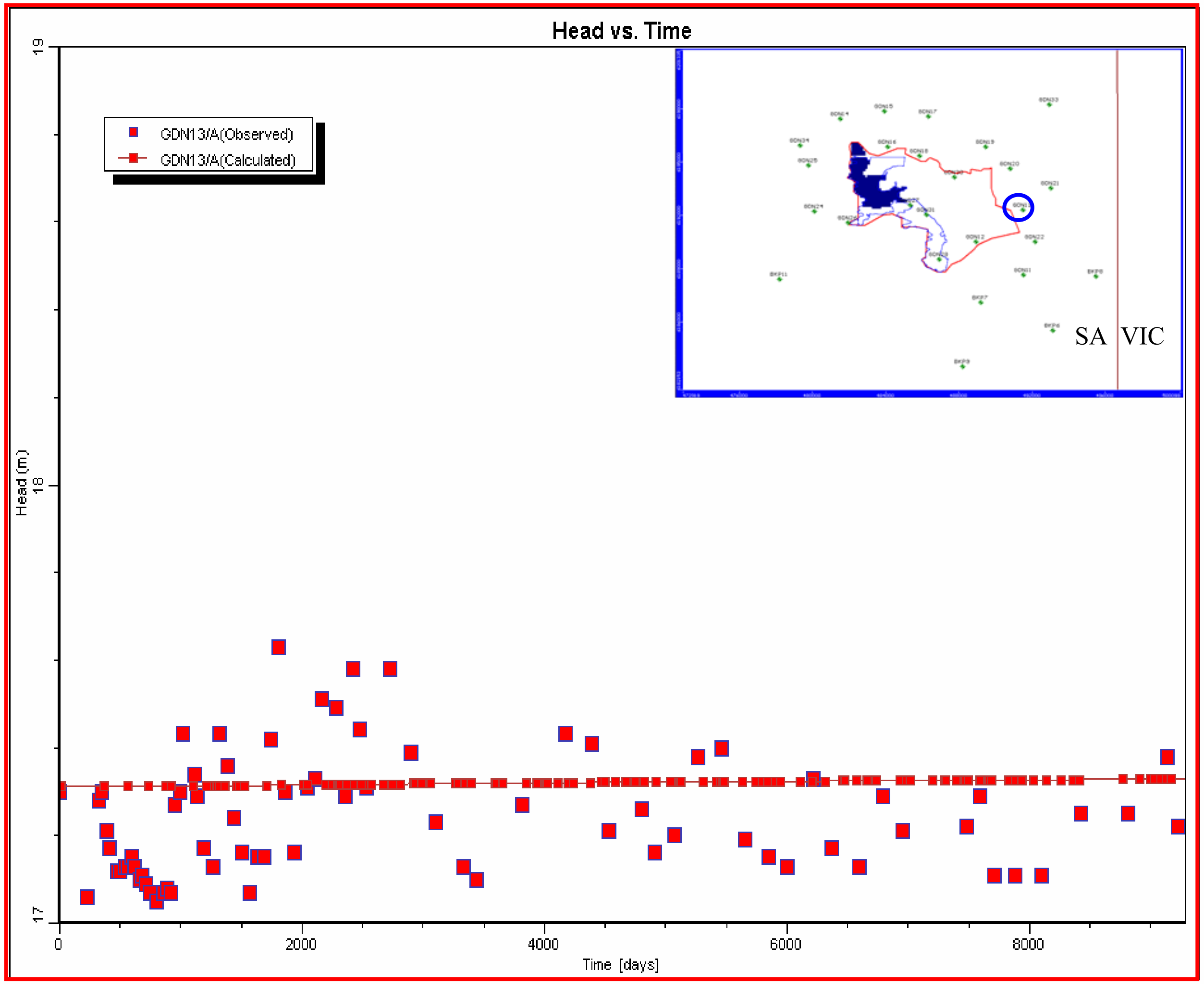

(01/01/1981)

(05/04/2006)

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

N

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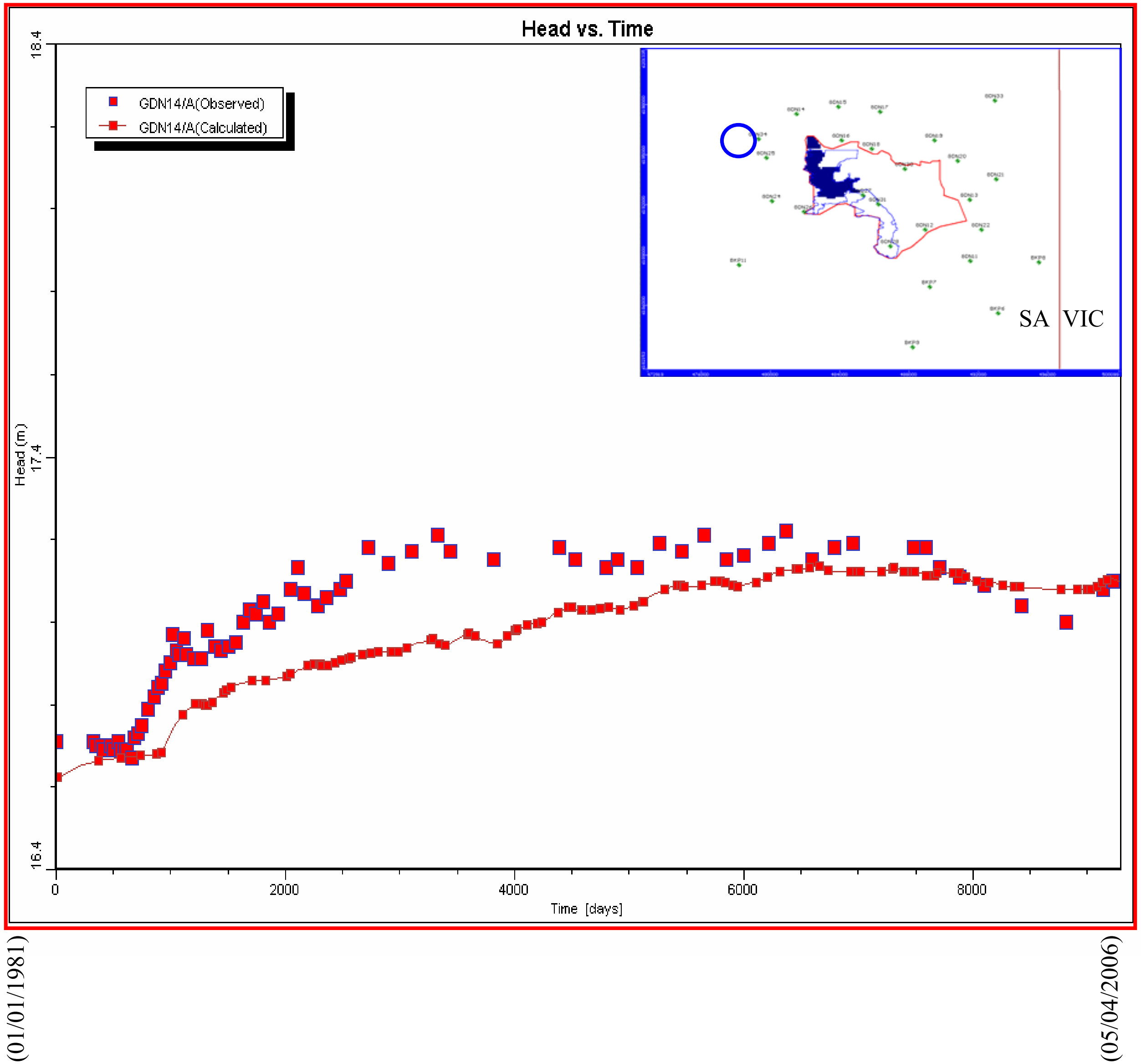
Figure 26h Calibration Observation Well Hydrograph GDN013



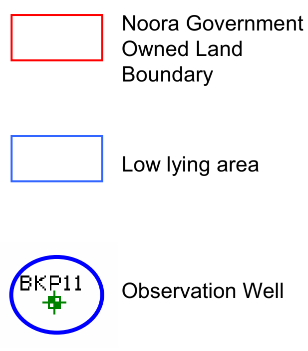


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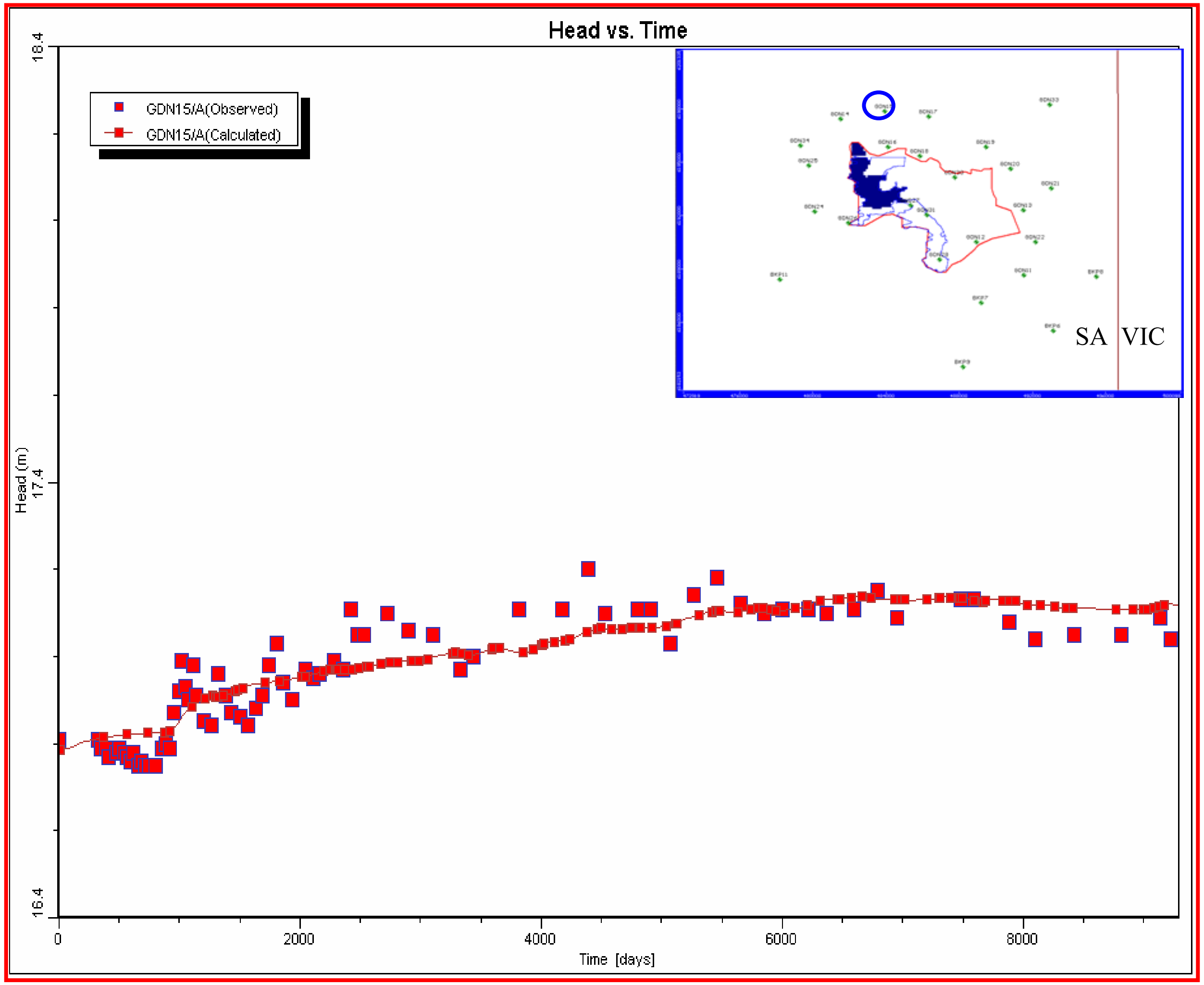
Figure 26i Calibration Observation Well Hydrograph GDN014



(01/01/1981)

(05/04/2006)

Figure 26j Calibration Observation Well Hydrograph GDN015

Noora Government Owned Land Boundary

Low lying area

BKP11 Observation Well

N

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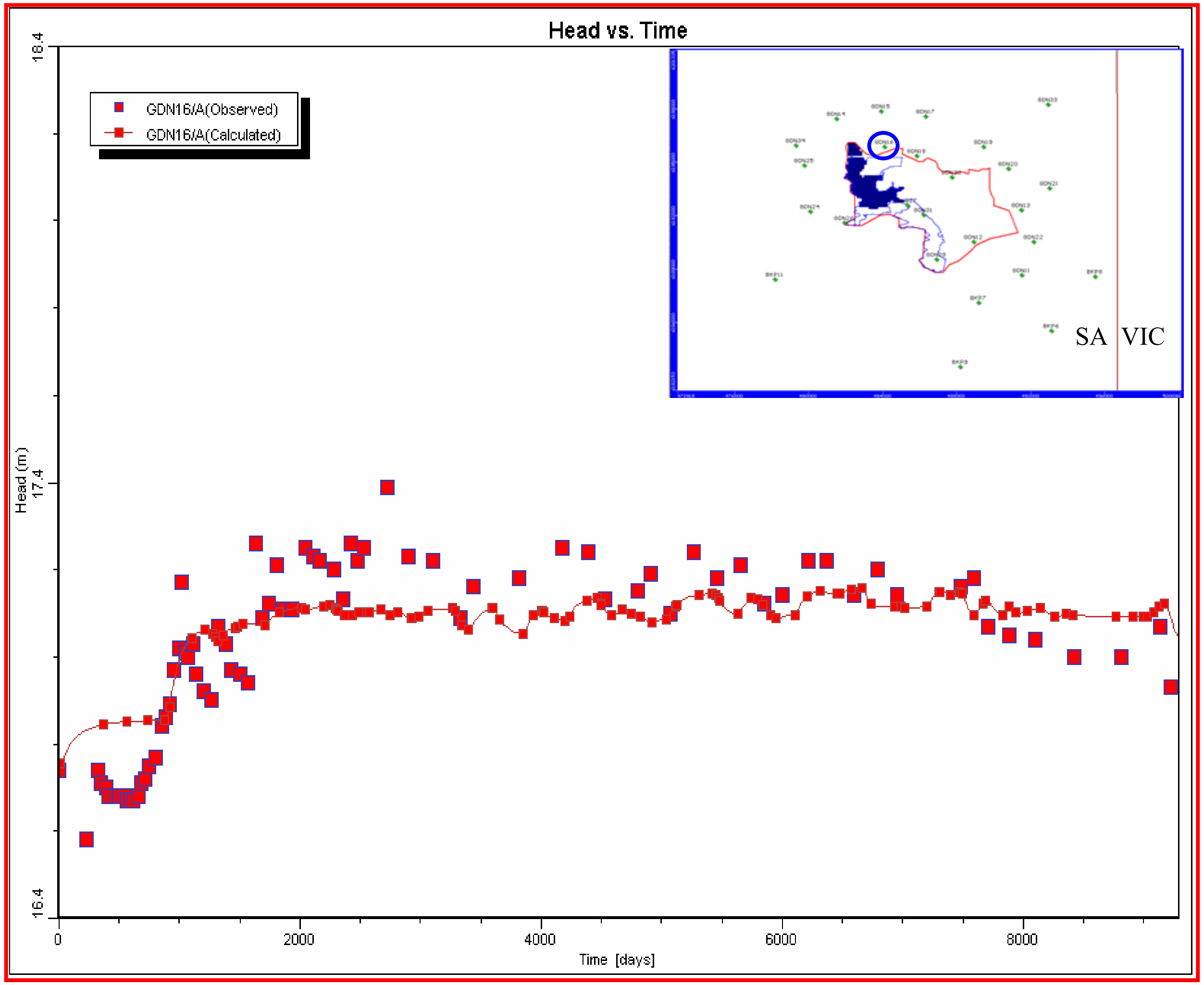


(01/01/1981)

(05/04/2006)

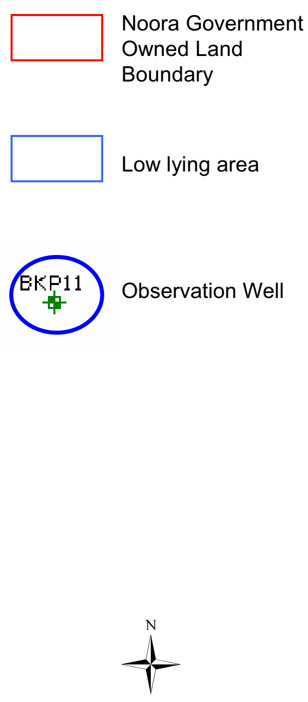
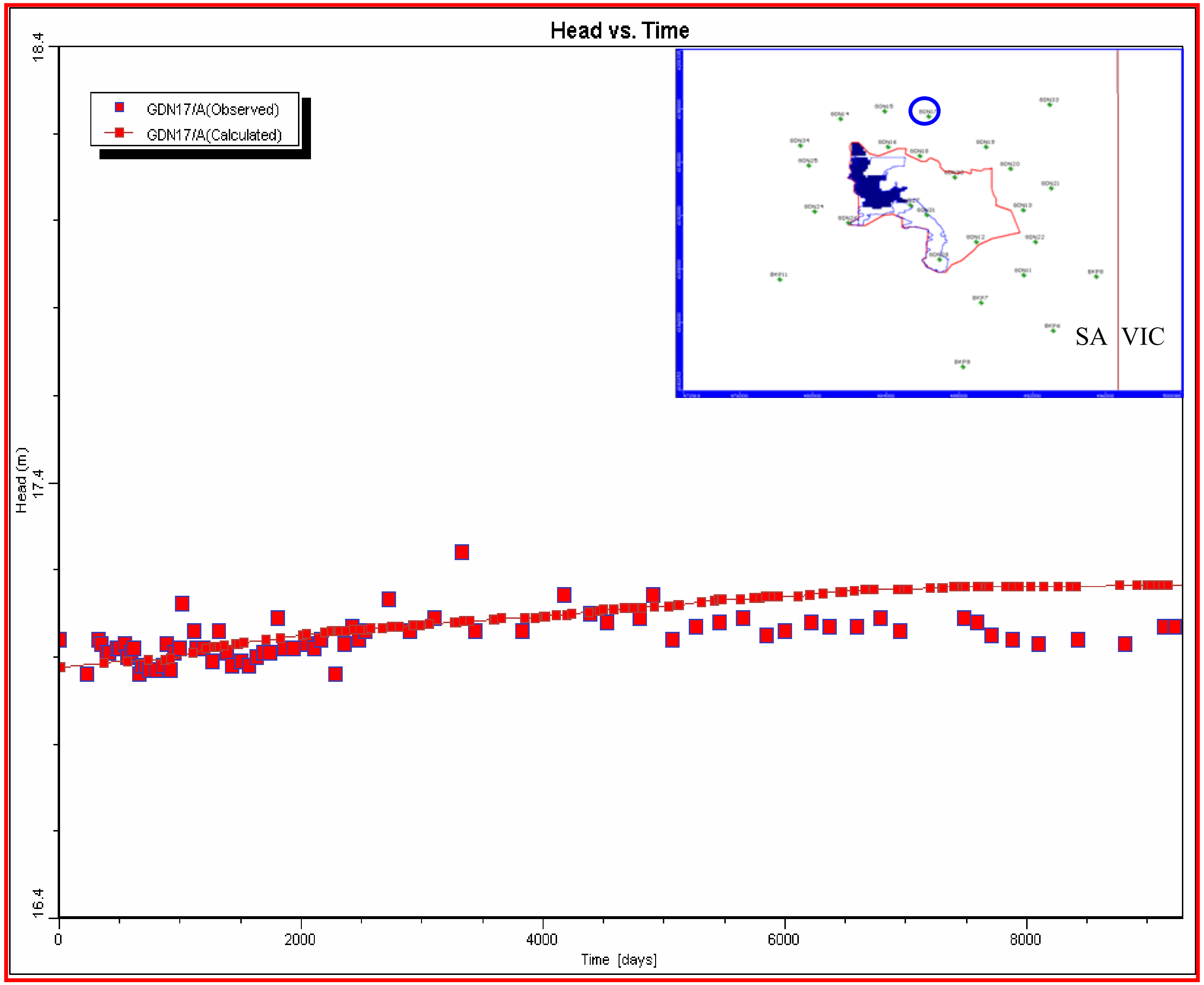


Figure 26k Calibration Observation Well Hydrograph GDN016



(01/01/1981)

(05/04/2006)

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

N

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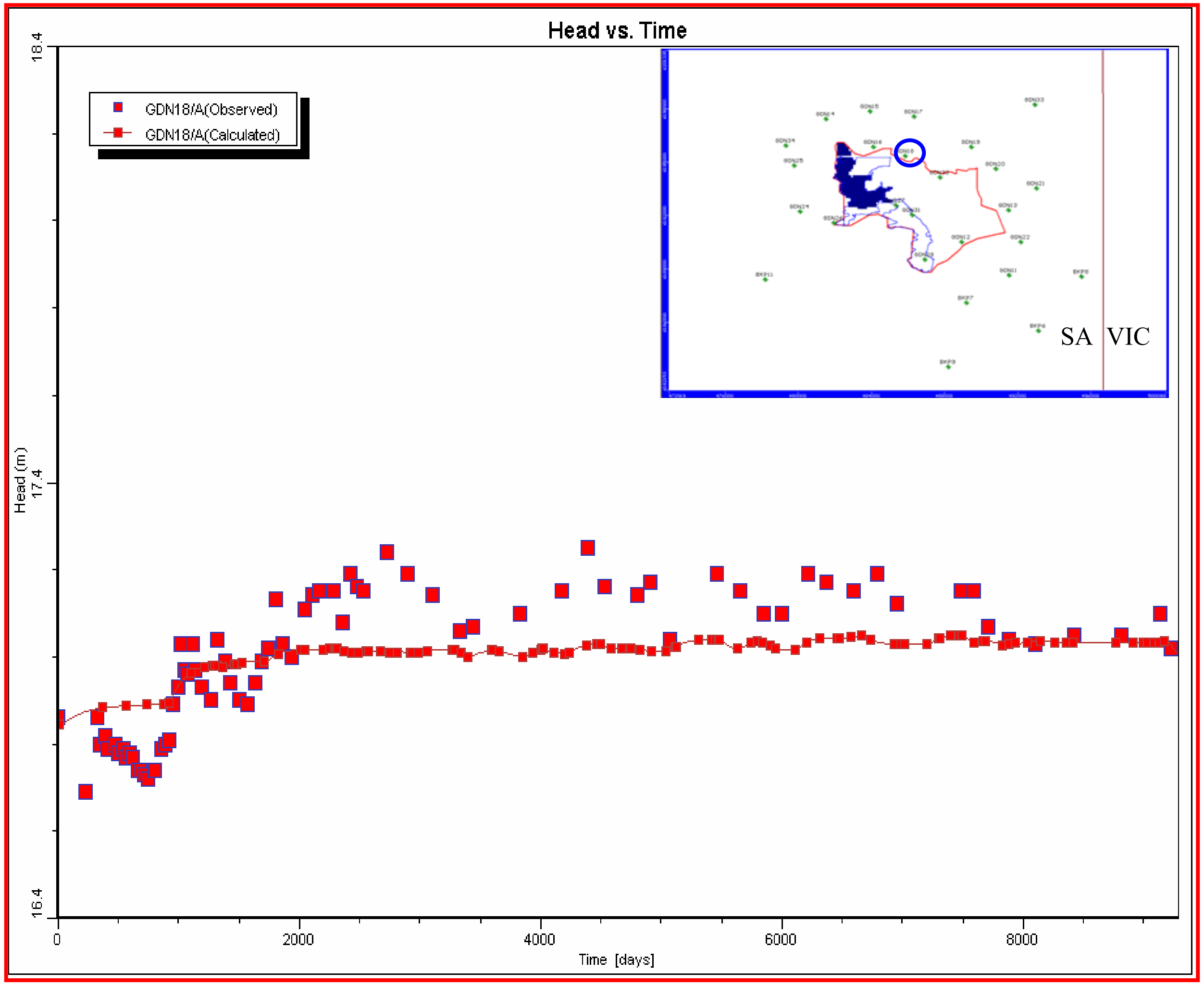
Department of Water, Land and Biodiversity Conservation

Figure 26l Calibration Observation Well Hydrograph GDN017



(01/01/1981)

(05/04/2006)

Figure 26m Calibration Observation Well Hydrograph GDN018

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

N

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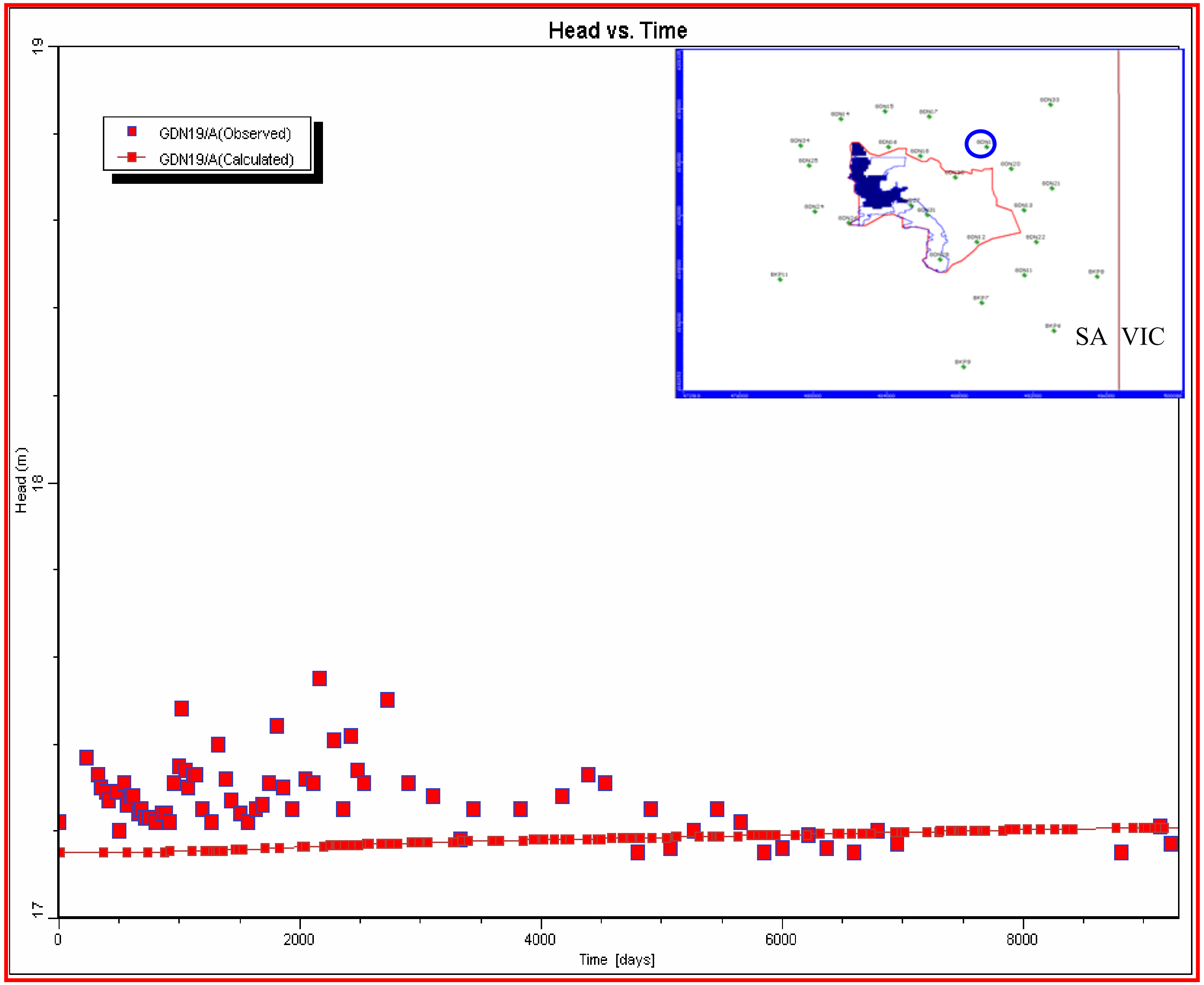
(01/01/1981)



(05/04/2006)

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

N

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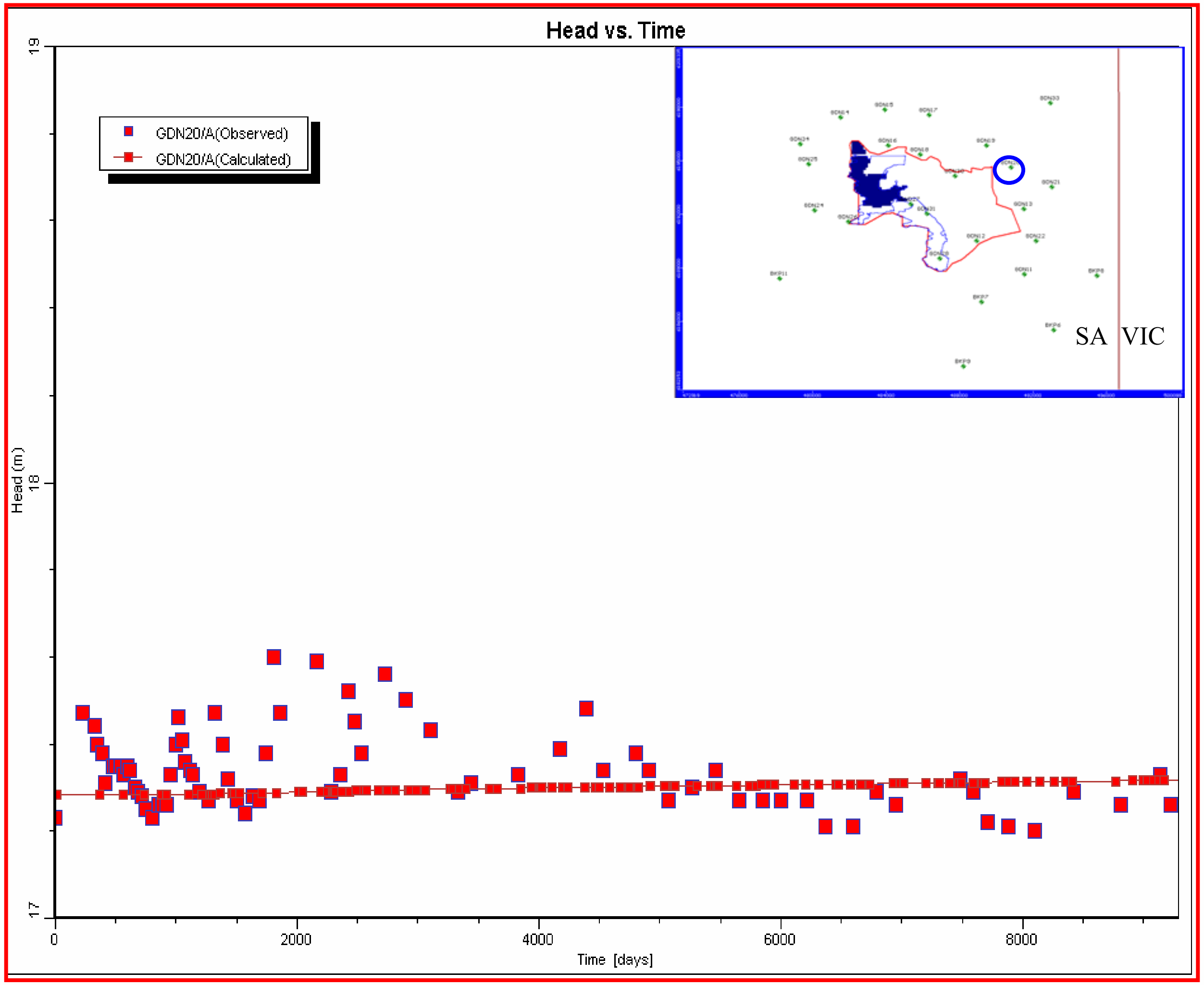
Figure 26n Calibration Observation Well Hydrograph GDN019



(01/01/1981)

(05/04/2006)

Figure 26o Calibration Observation Well Hydrograph GDN020

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

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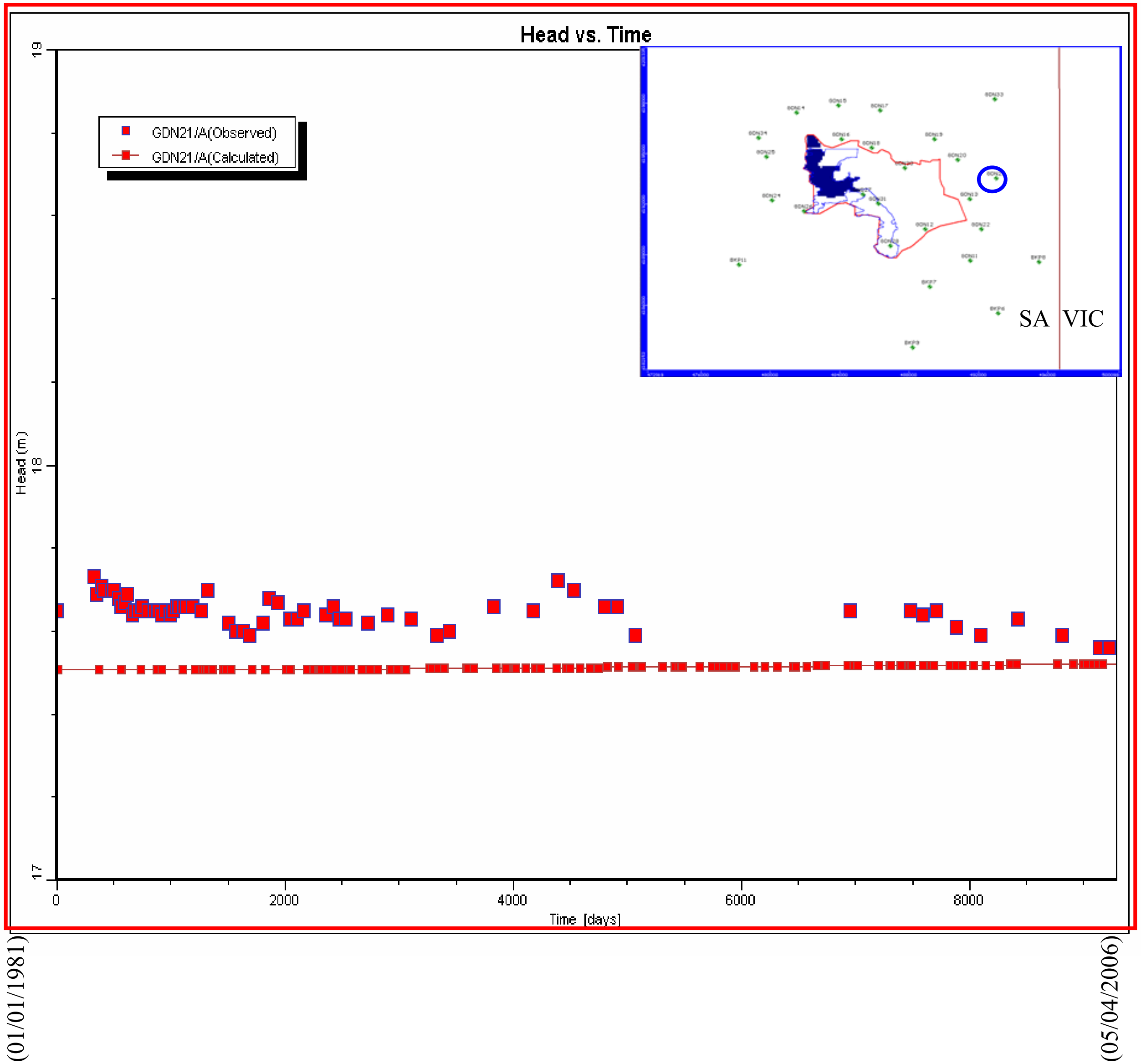

Noora Government Owned Land Boundary

Low lying area

BKP11 Observation Well

N

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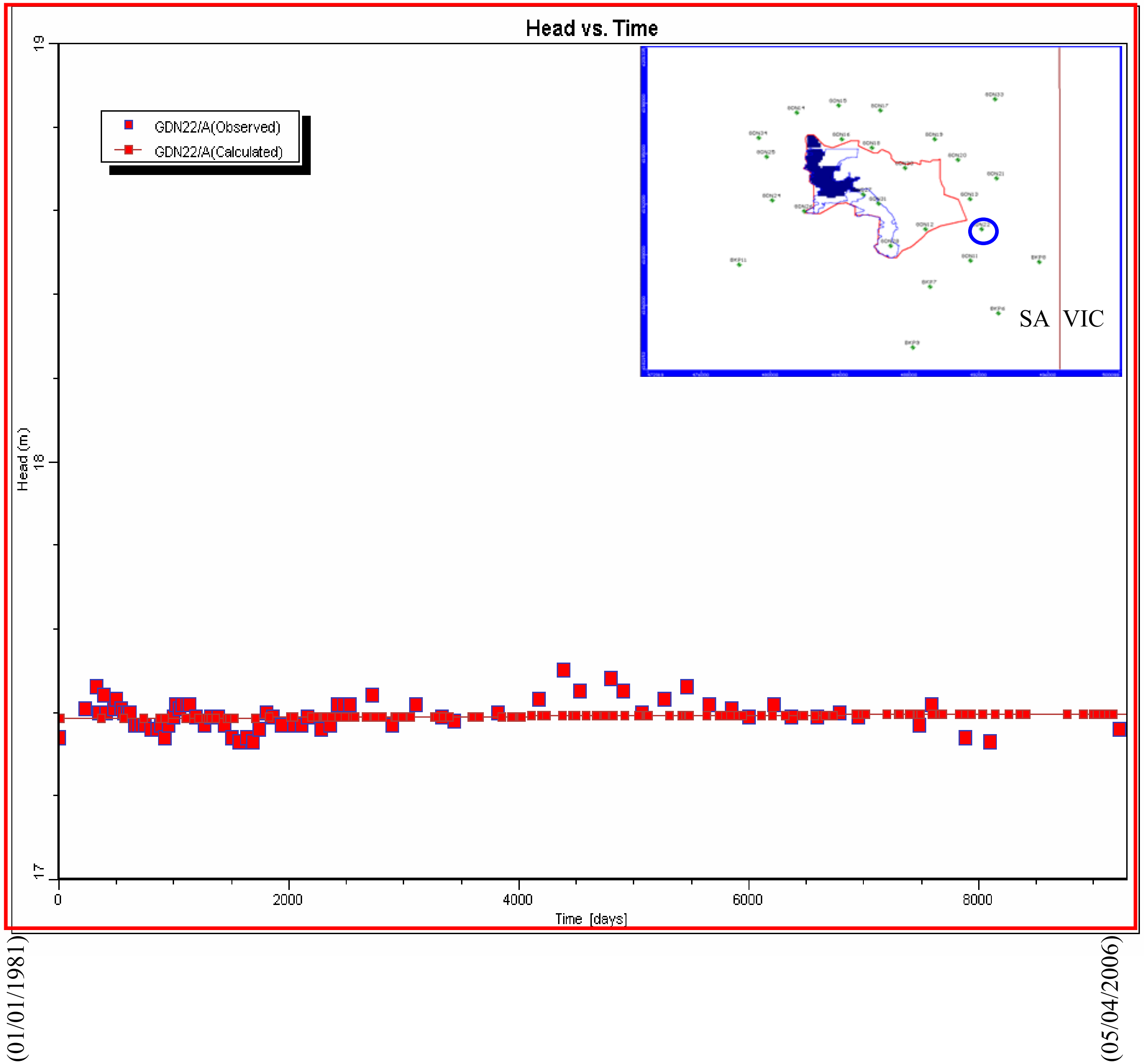
Figure 26p Calibration Observation Well Hydrograph GDN021



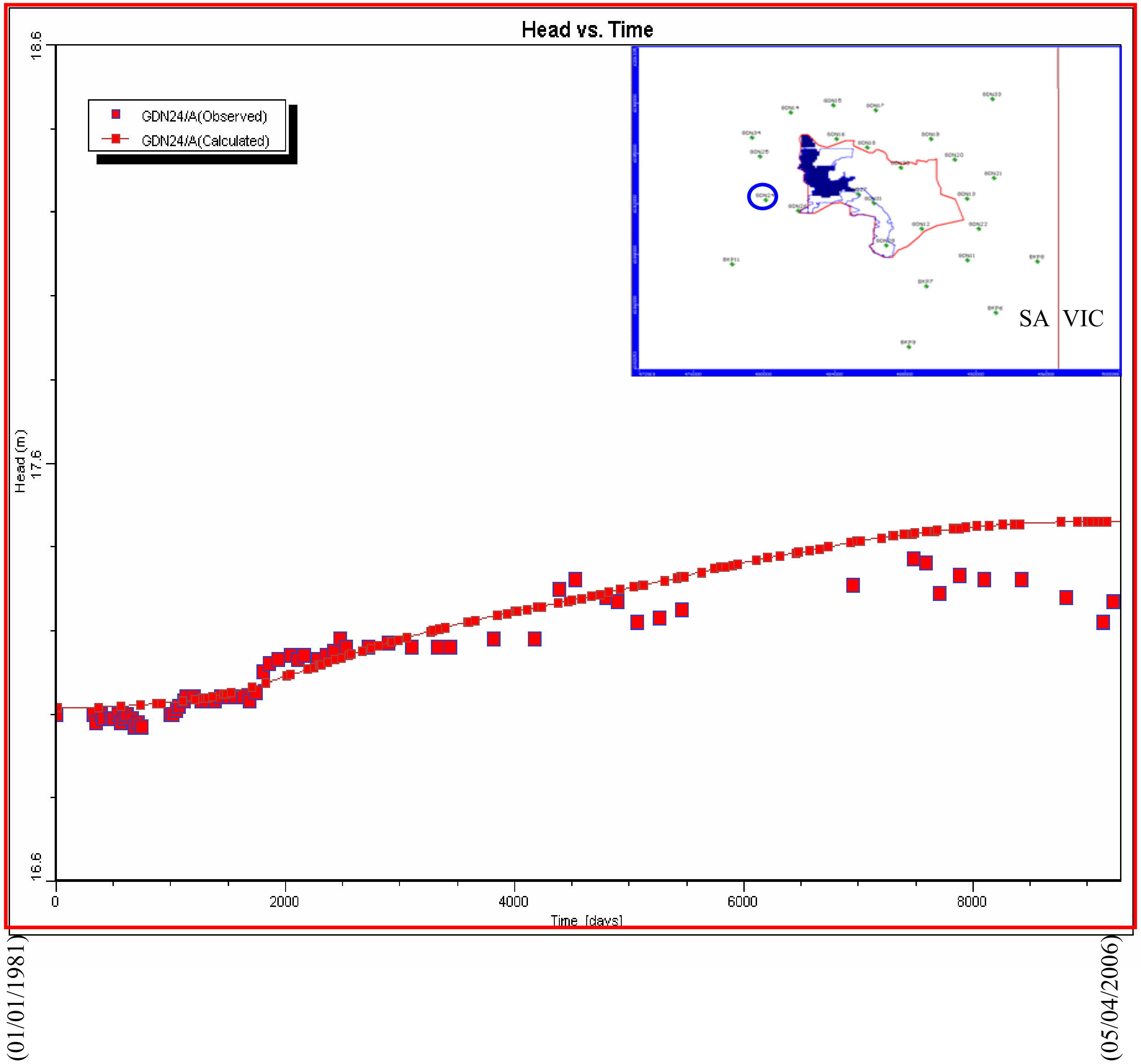
Noora Government Owned Land Boundary

Low lying area

Observation Well

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Figure 26q Calibration Observation Well Hydrograph GDN022



Noora Government Owned Land Boundary

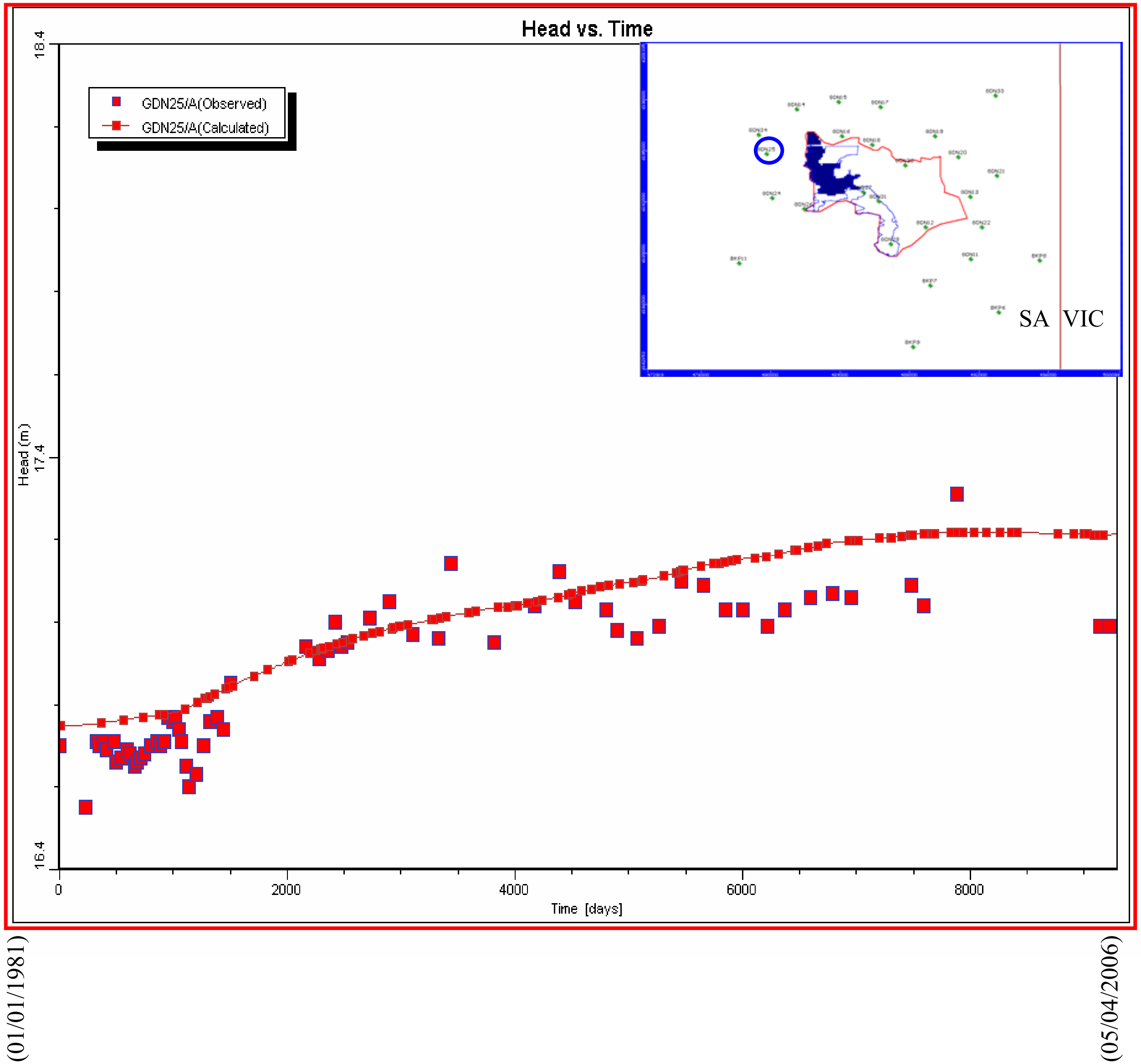
Low lying area

BKP11 Observation Well

N

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Figure 26r Calibration Observation Well Hydrograph GDN024



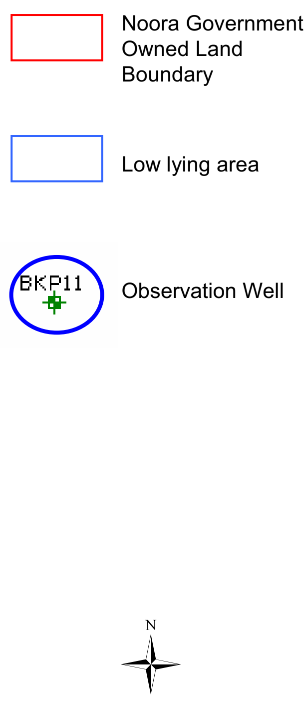


Figure 26s Calibration Observation Well Hydrograph GDN025

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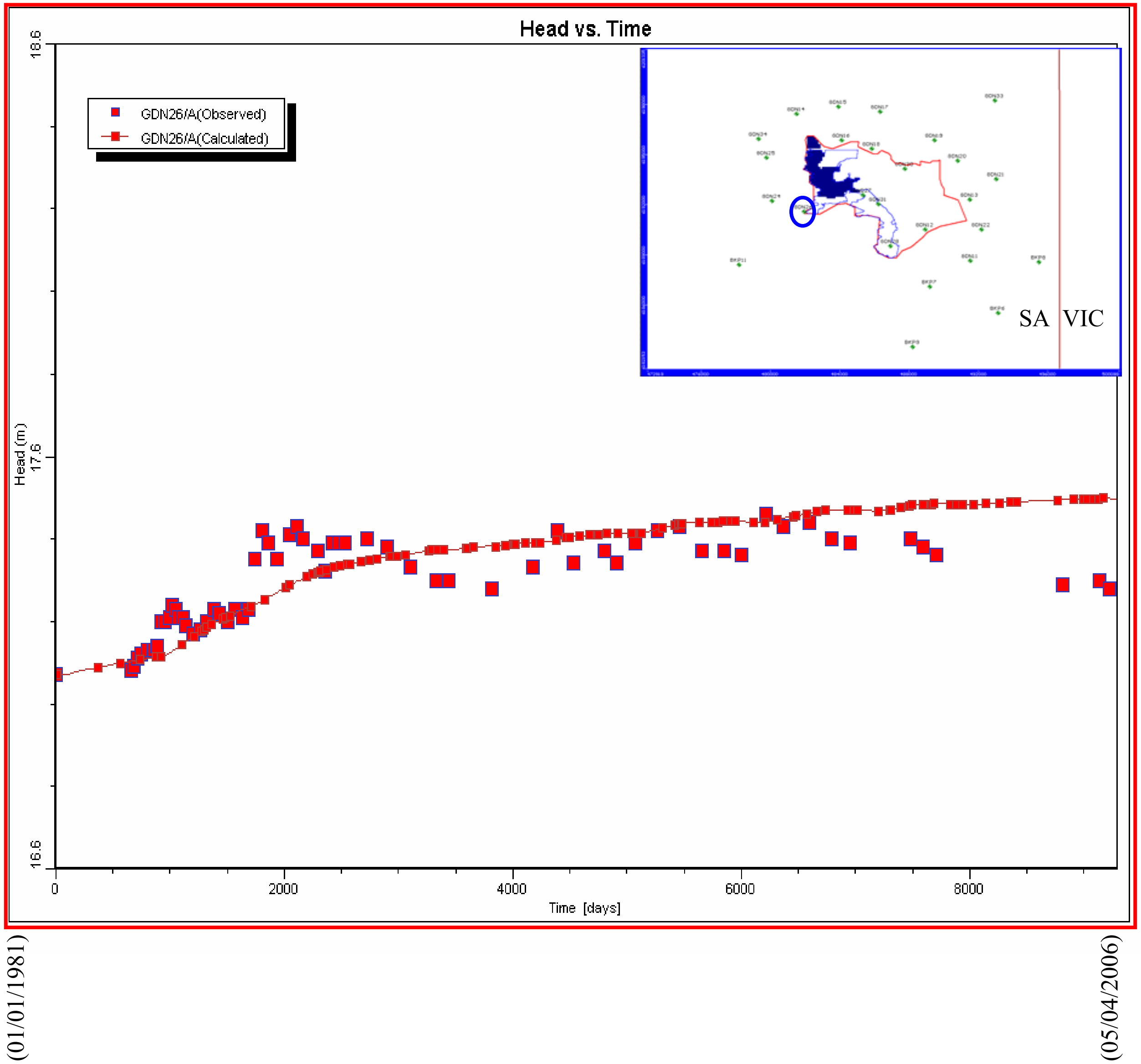


Noora Government Owned Land Boundary

Low lying area

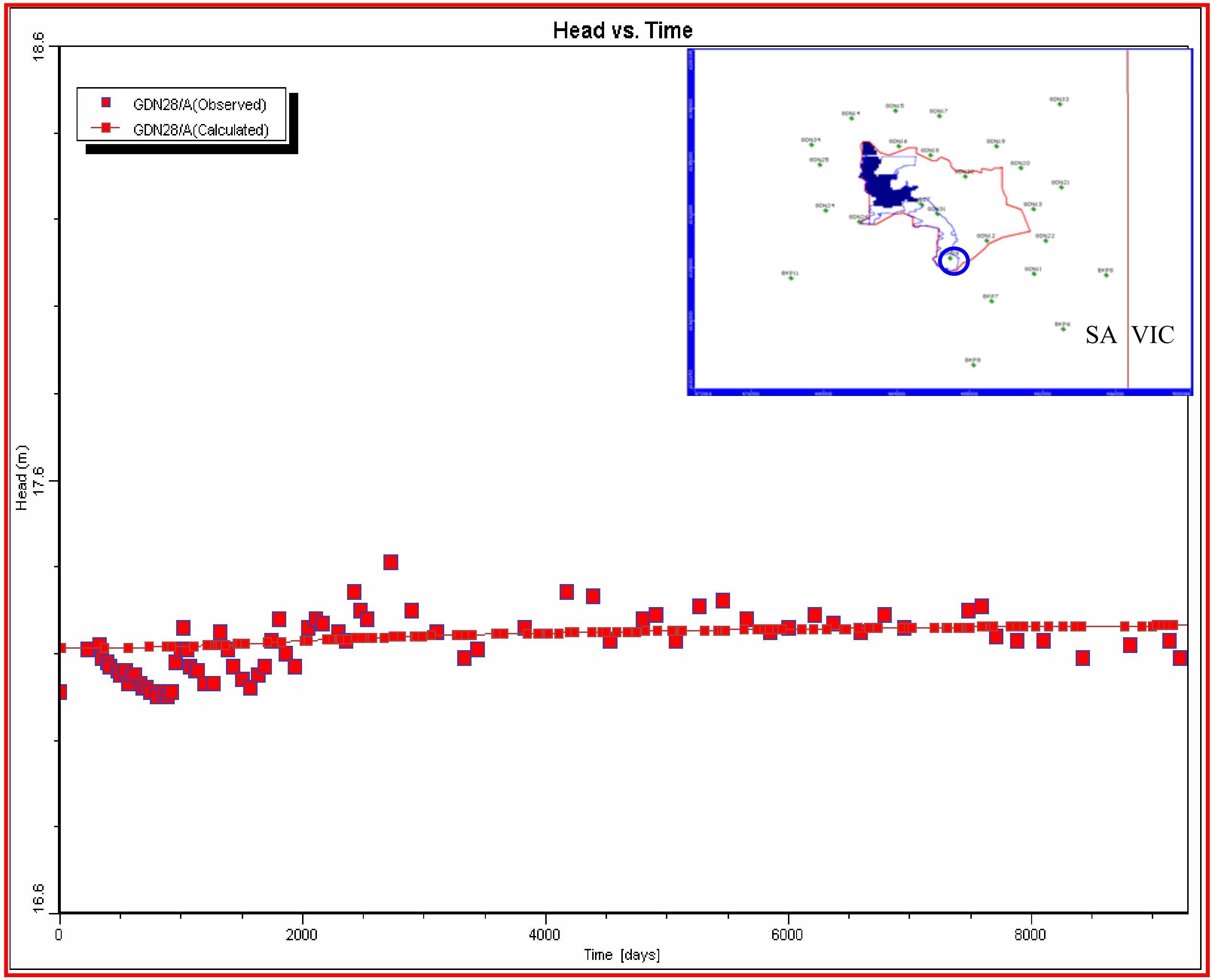
BKP11

Observation Well

N

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Figure 26t Calibration Observation Well Hydrograph GDN026



(01/01/1981)

(05/04/2006)

Figure 26u Calibration Observation Well Hydrograph GDN028

Noora Government Owned Land Boundary

Low lying area

BKP11 Observation Well

N

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Department of Water, Land and Biodiversity Conservation

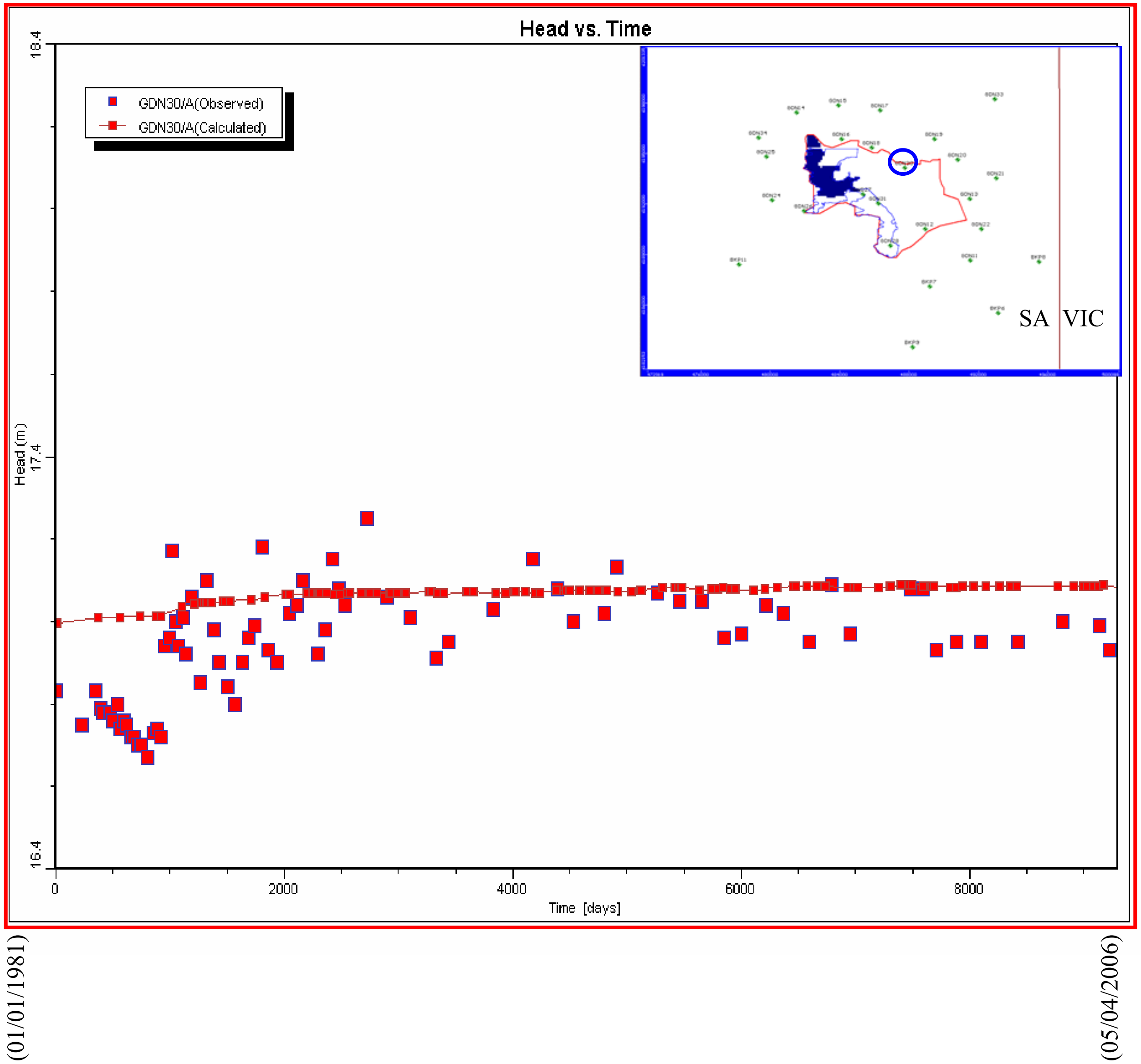
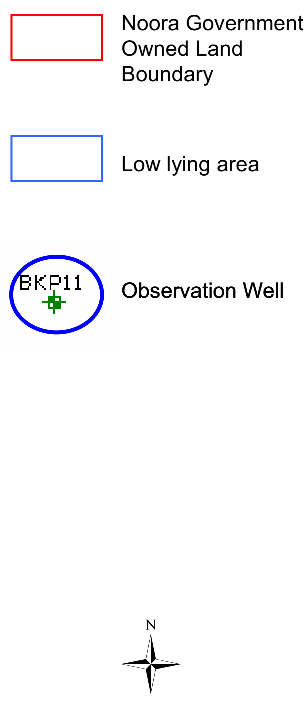


Figure 26v Calibration Observation Well Hydrograph GDN030



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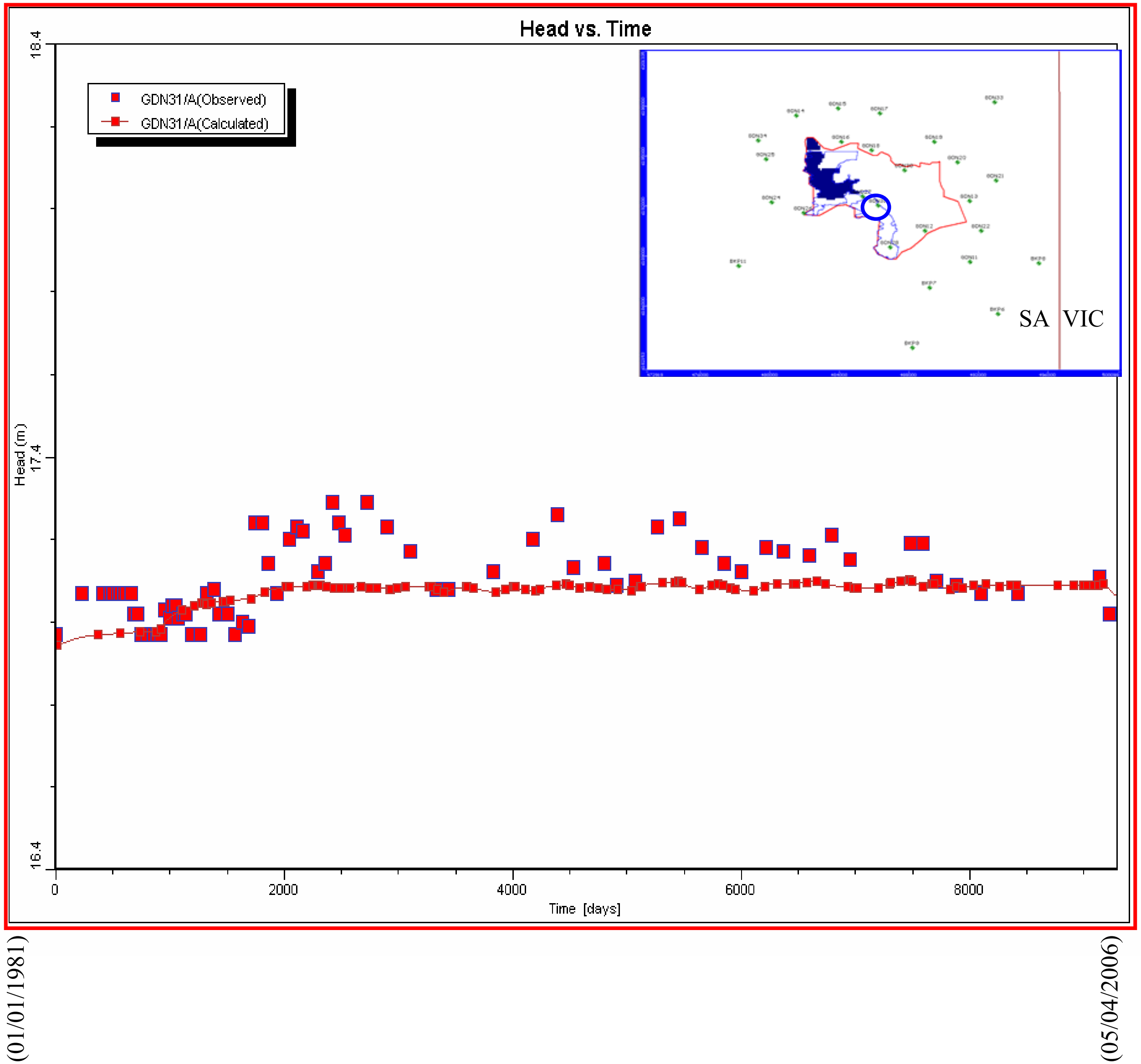

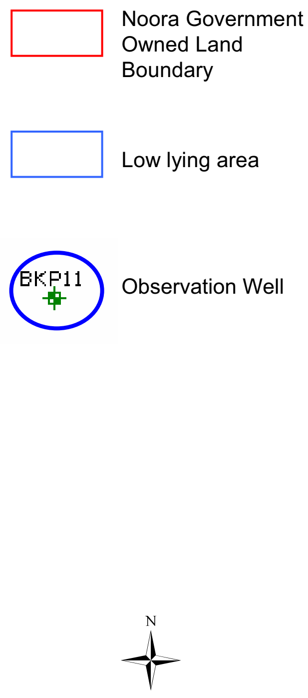

Figure 26w Calibration Observation Well Hydrograph GDN031

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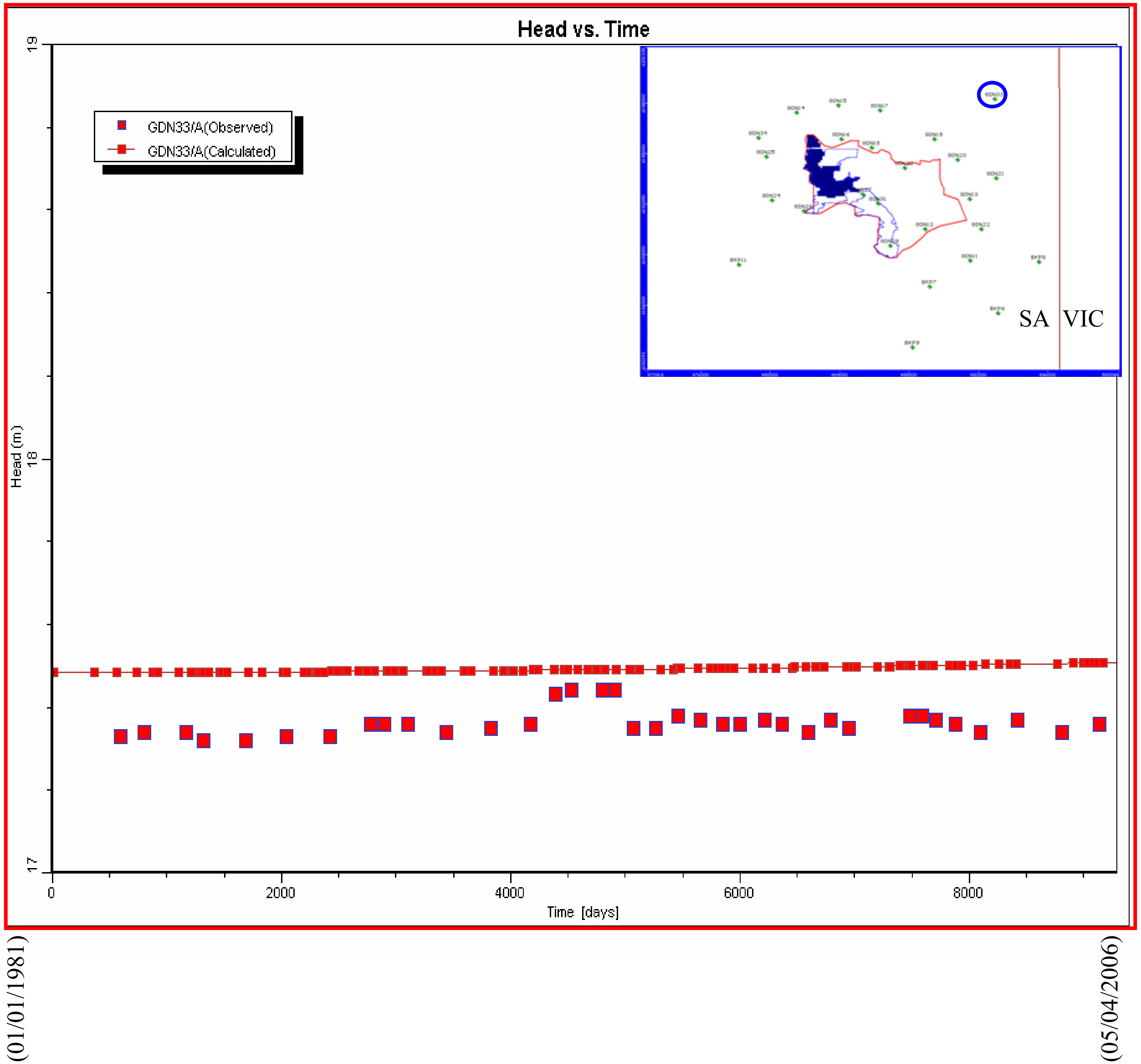

Noora Government Owned Land Boundary

Low lying area

BKP11 Observation Well

N

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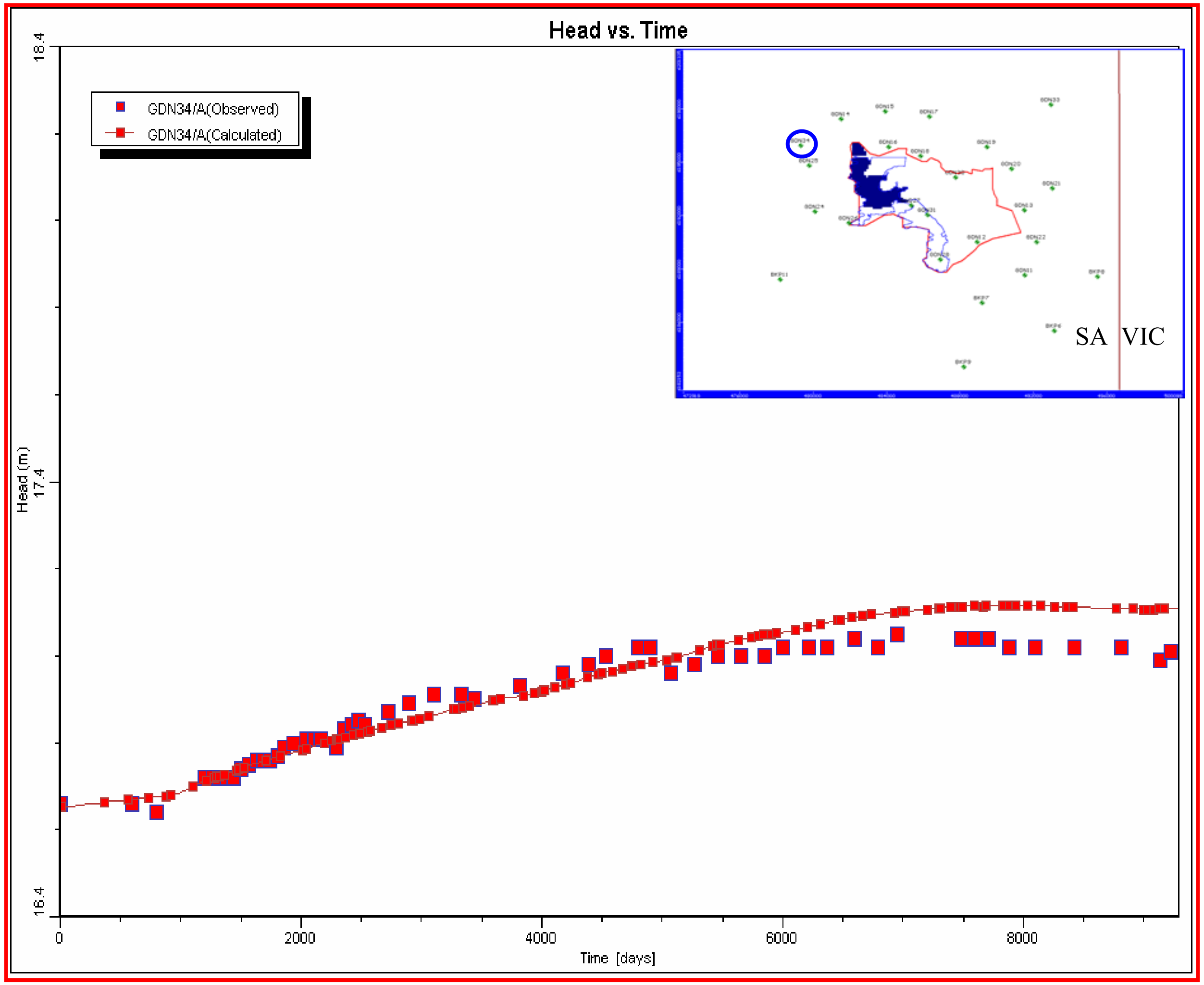
Figure 26x Calibration Observation Well Hydrograph GDN033



(01/01/1981)

(05/04/2006)

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

N

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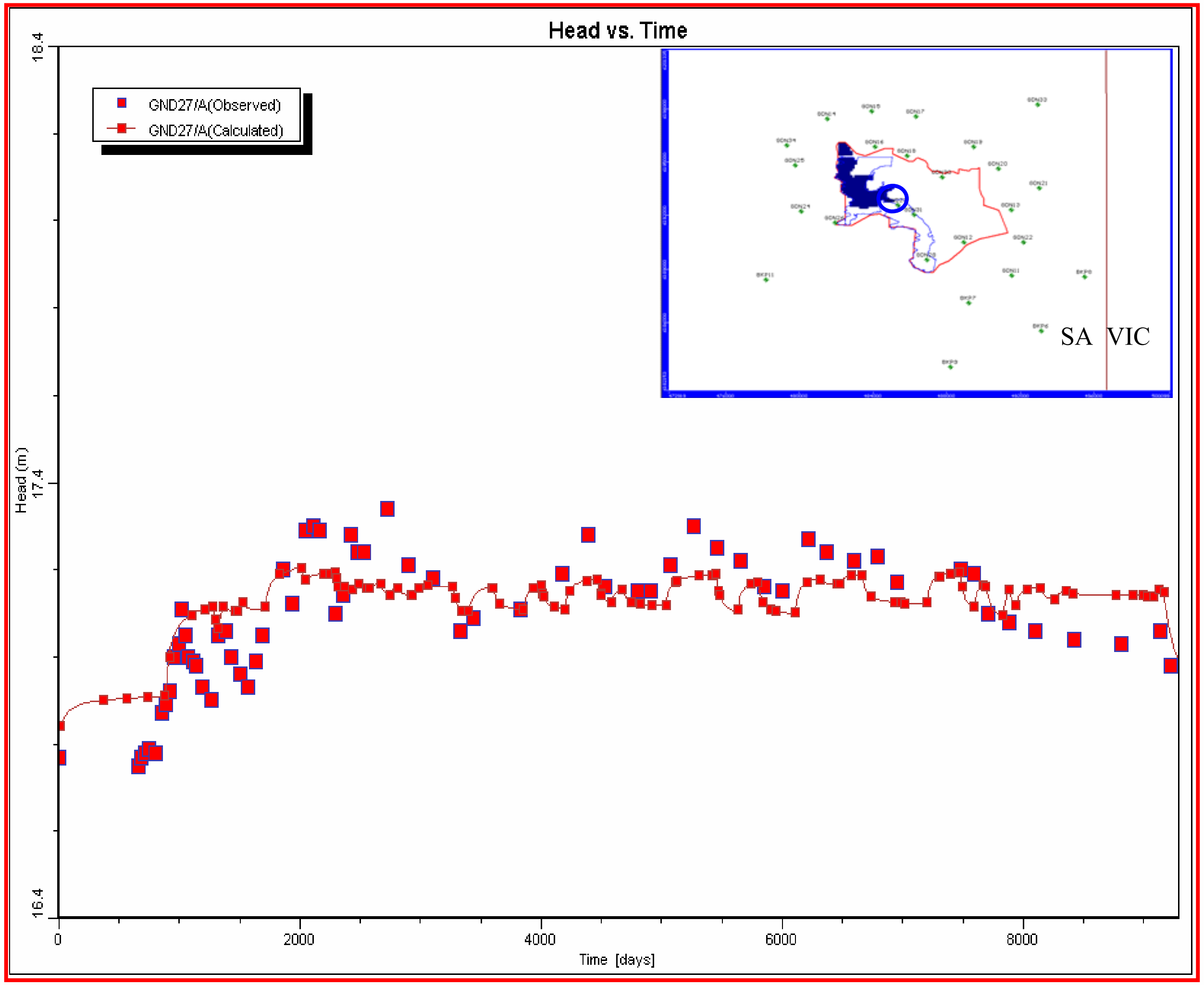
Department of Water, Land and Biodiversity Conservation

Figure 26y Calibration Observation Well Hydrograph GDN034



(01/01/1981)

(05/04/2006)

Figure 26z Calibration Observation Well Hydrograph GND027

Noora Government Owned Land Boundary

Low lying area

BKP11

Observation Well

N

Government of South Australia
Department of Water, Land and Biodiversity Conservation

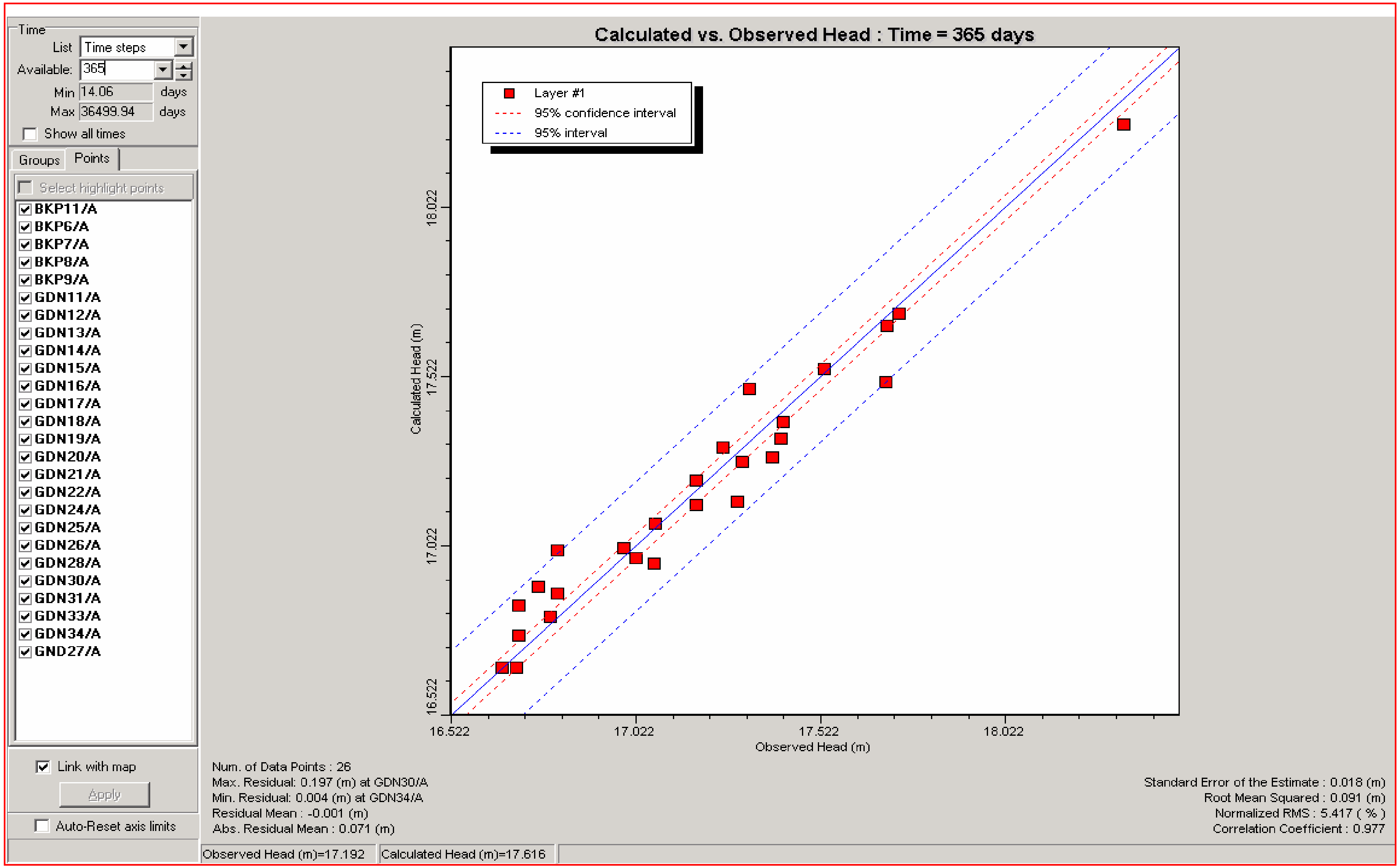


Figure 27a Calibration Results 1981

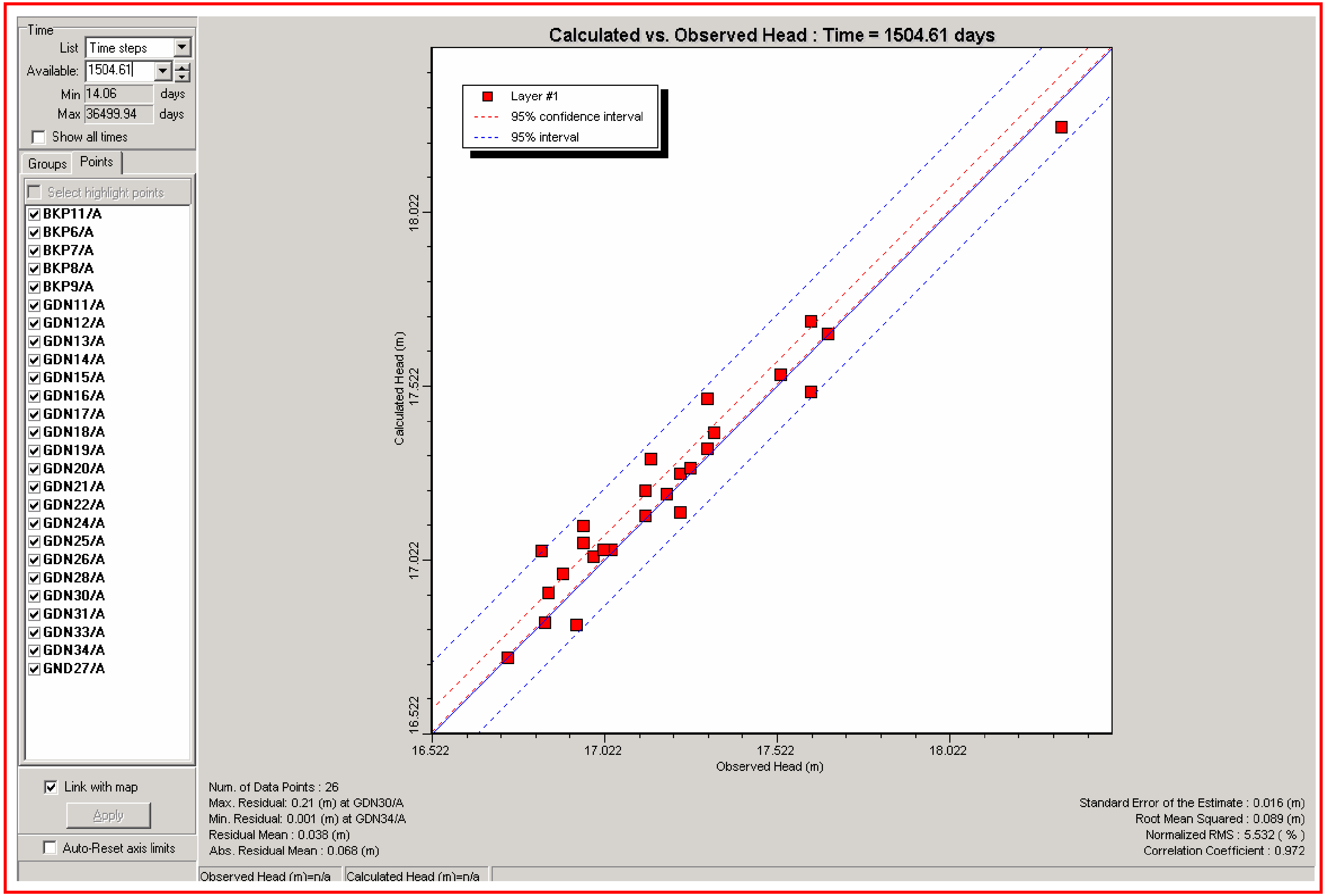


Figure 27b Calibration Results 1985

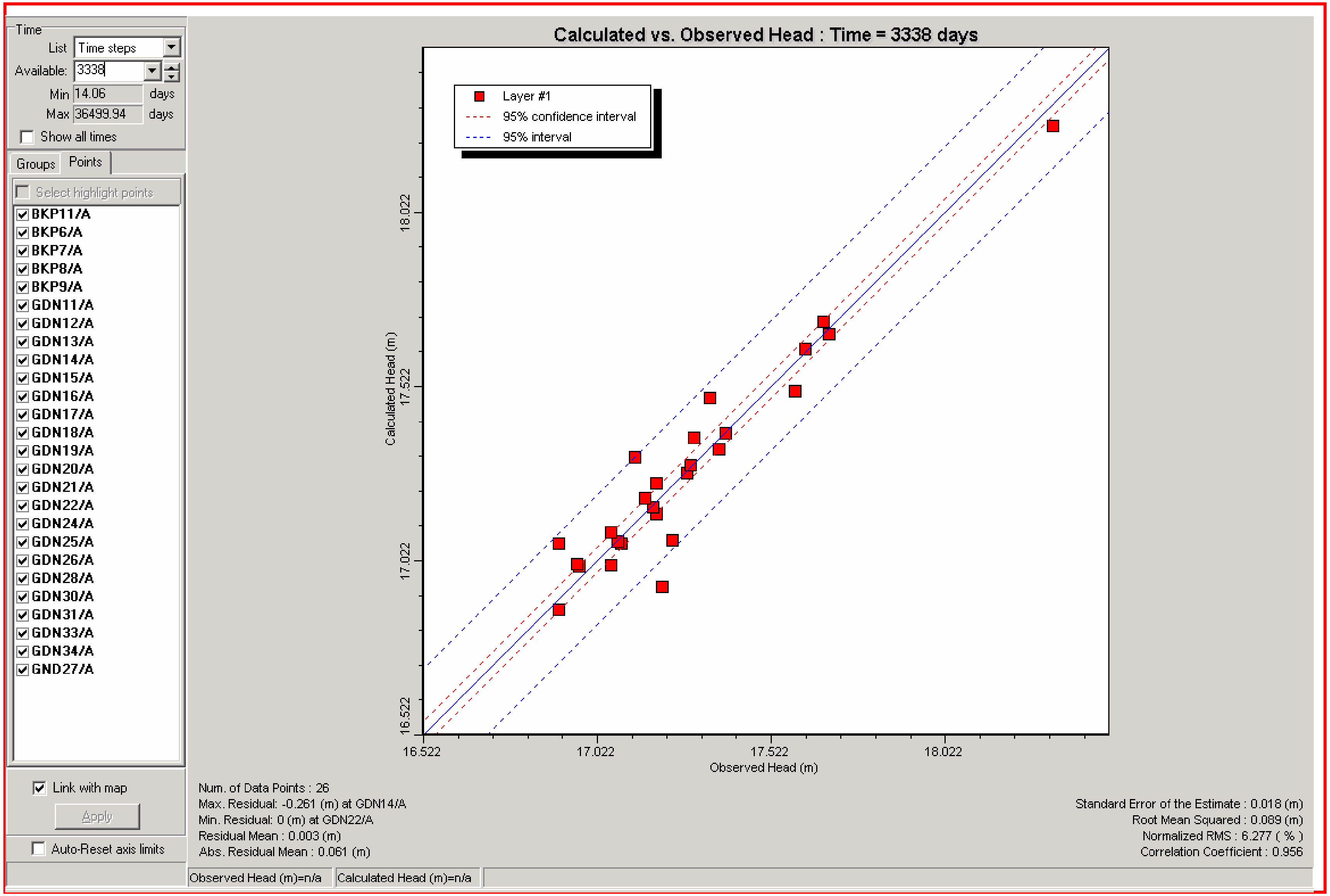


Figure 27c Calibration Results 1990

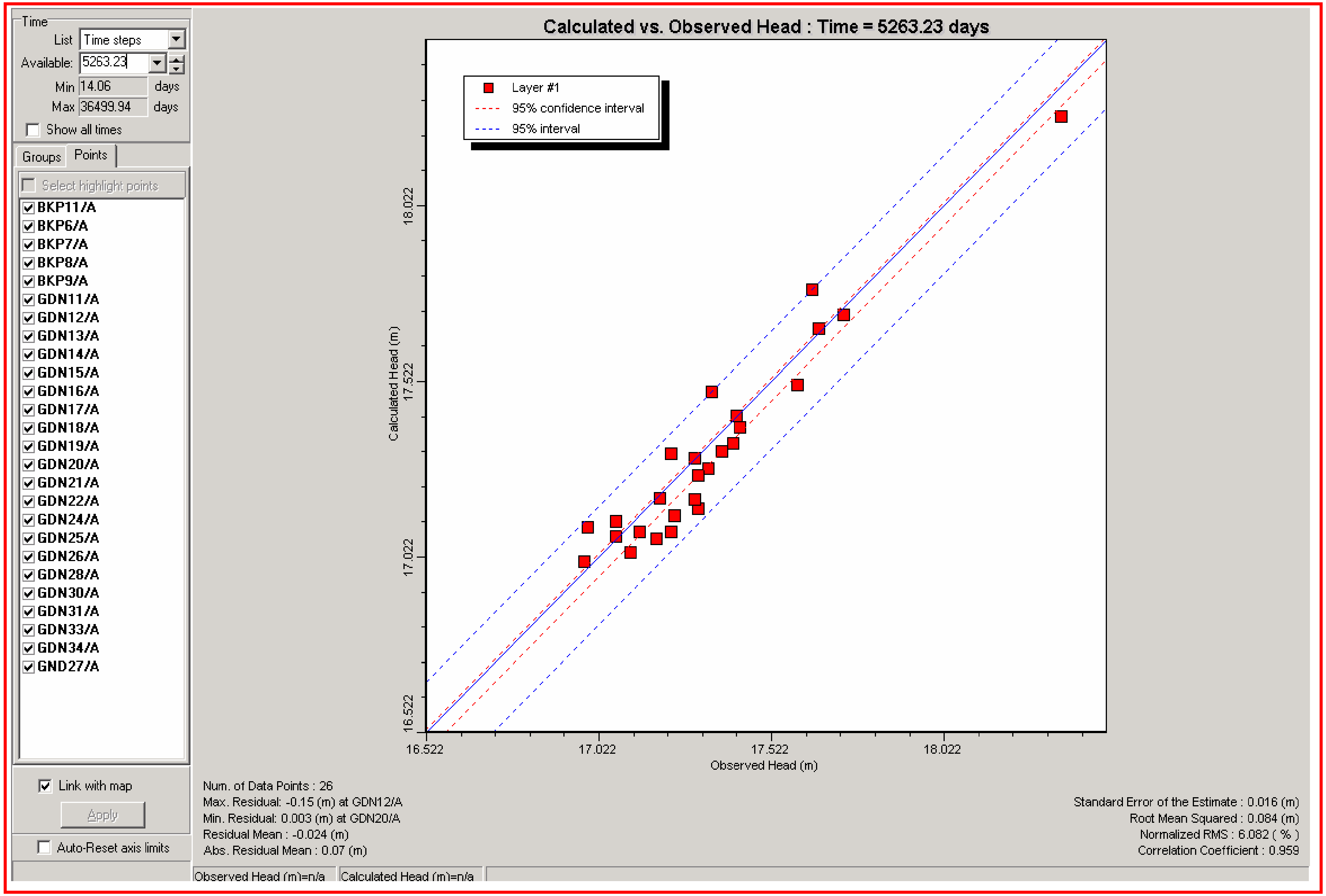


Figure 23d Calibration Results 1995

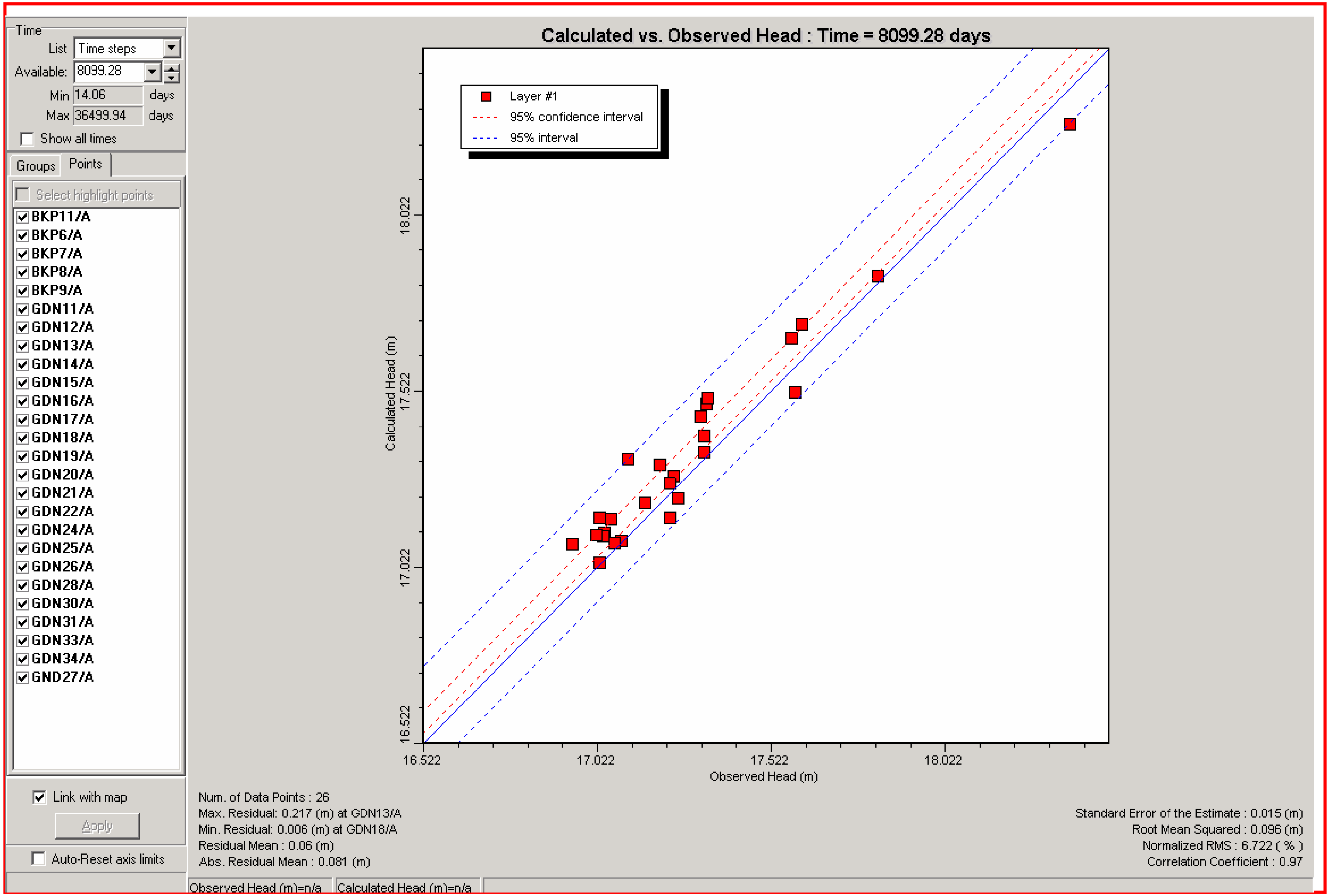


Figure 27e Calibration Results 2003

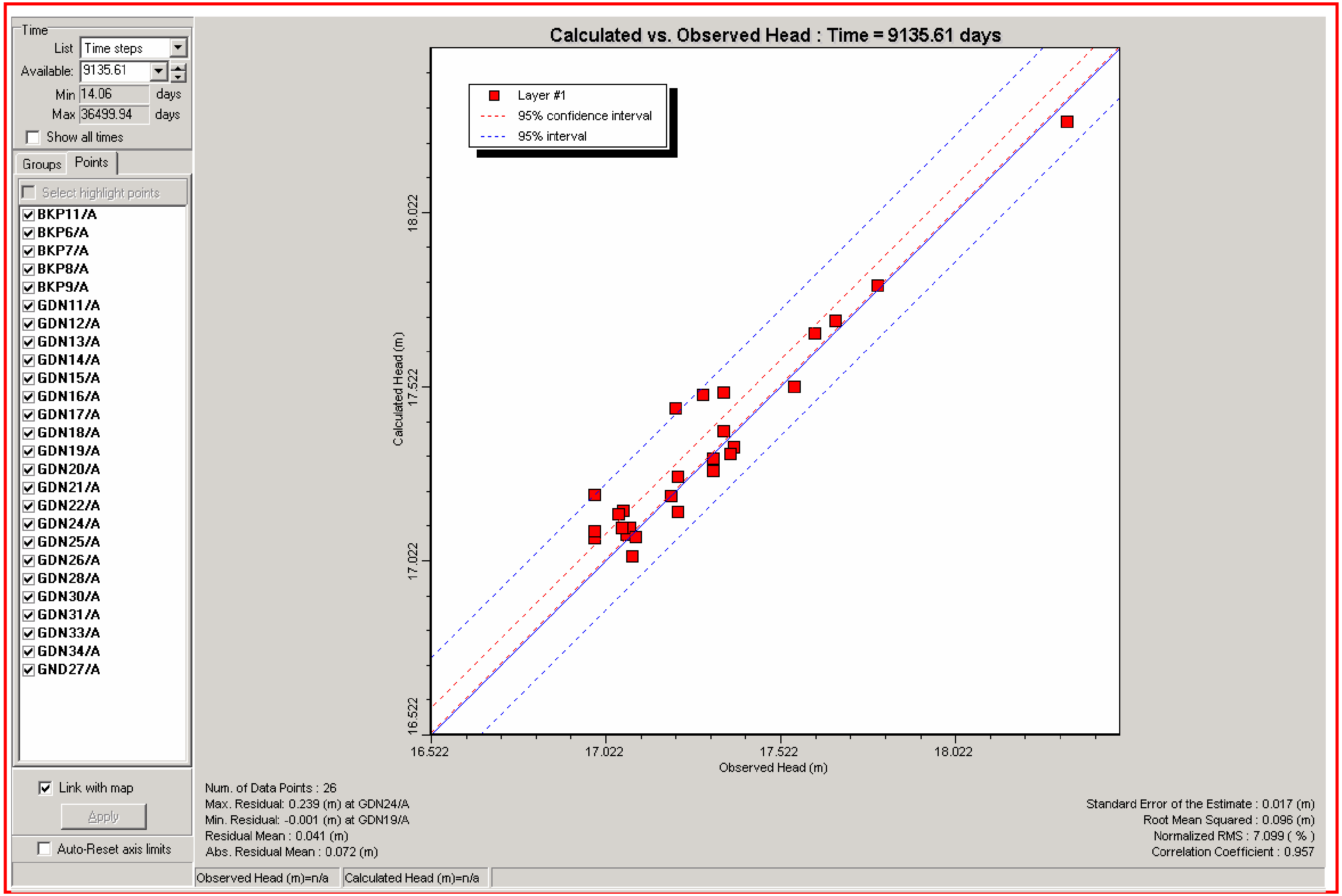
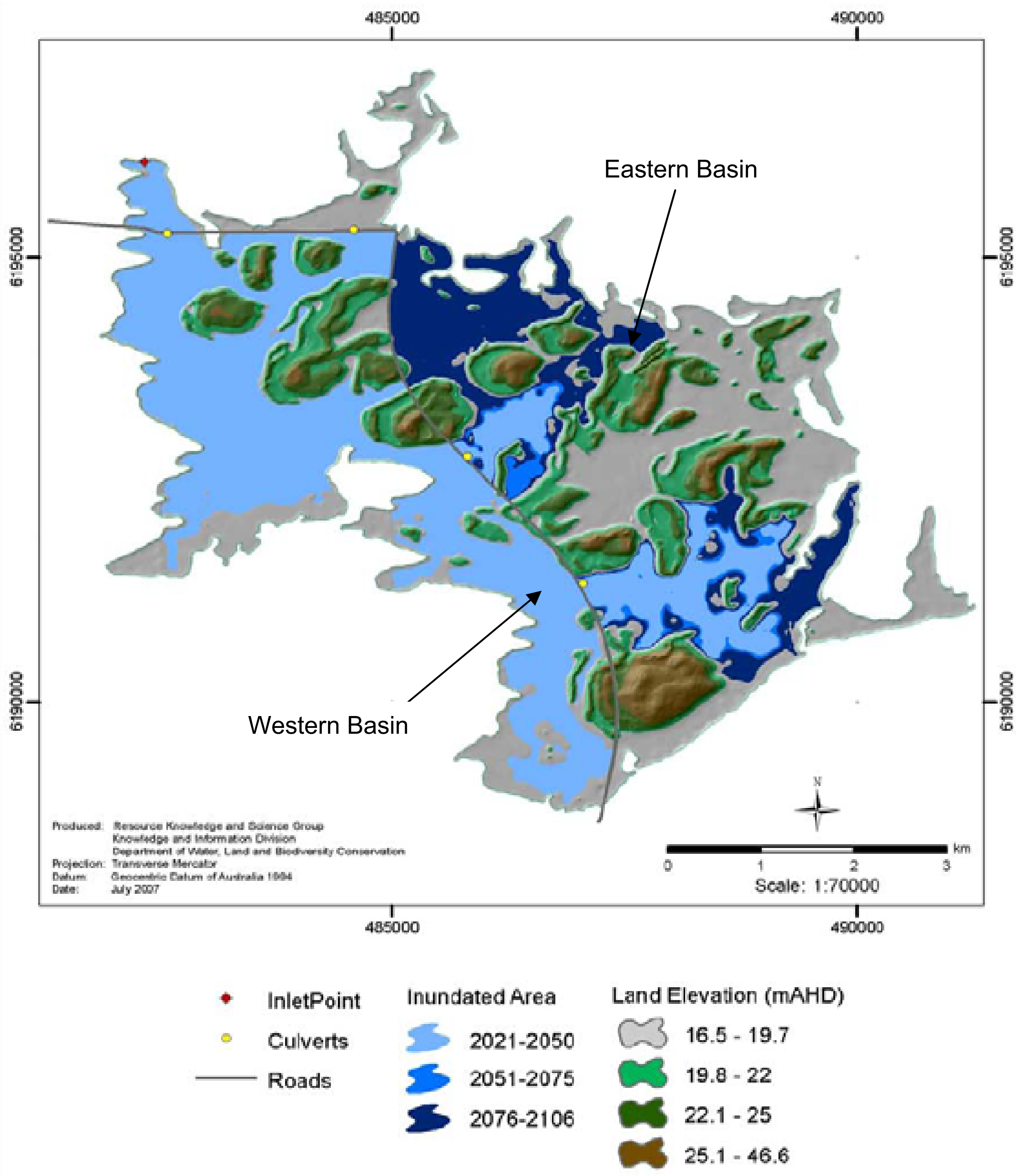


Figure 27f Calibration Results 2006



Maximum Water Levels, Stored Volume and Inundated Areas: Drainage and Loxton, Bookpumong and Murtho SIS (Scenario 1A)

Period	Maximum Water Level (mAHD)		Total Volume (ML)	Total Inundated Area (Ha)
	Western Basin	Eastern Basin		
2021-2050	18.60	18.01	6481	1205
2051-2075	18.60	18.20	7346	1433
2076-2106	18.60	18.47	9277	1694

Notes
Control Height between Western and Eastern Basins is 18.6 mAHD.

Figure 28 Scenario 1 Surface Water Results (from Heneker, 2007)

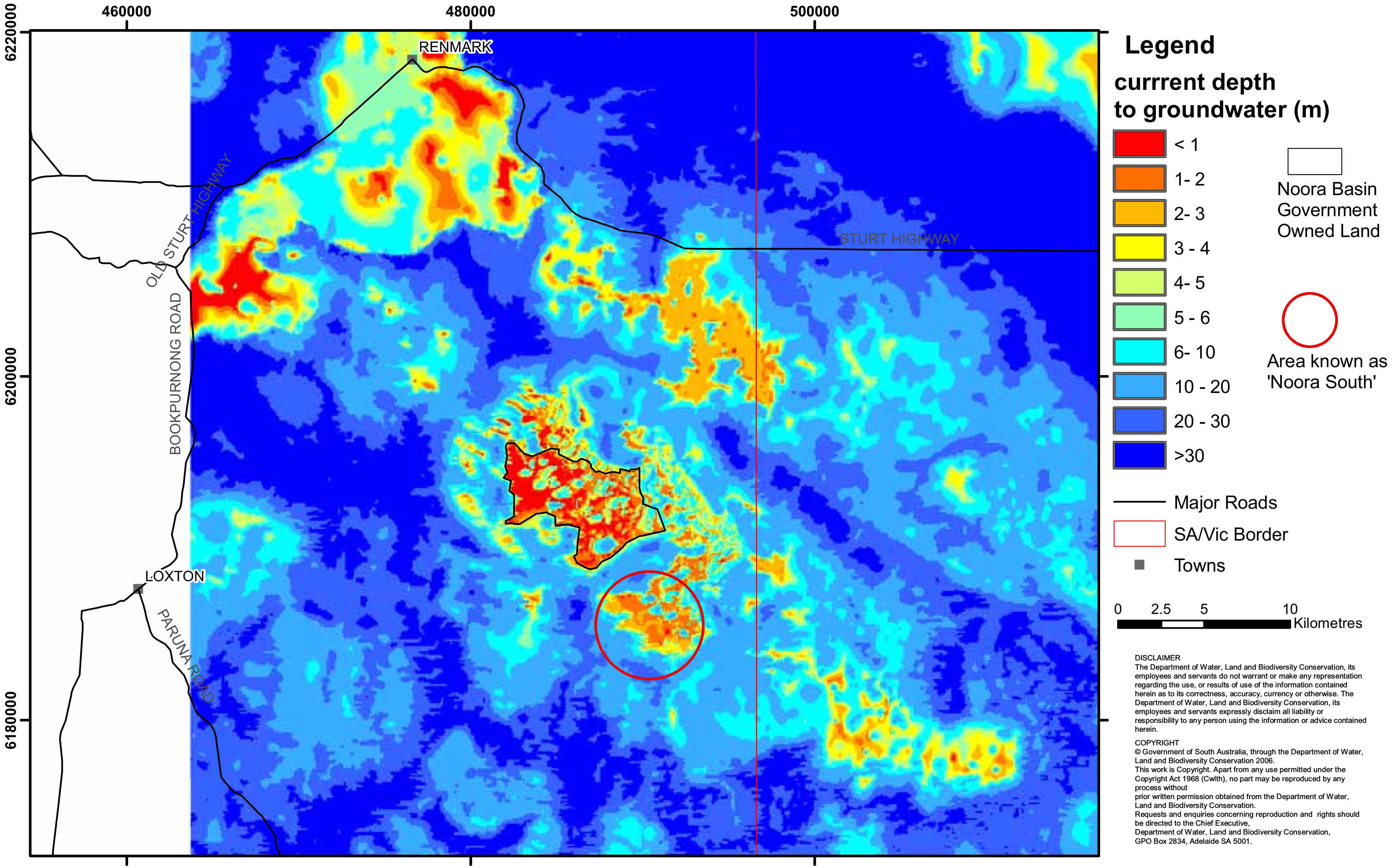
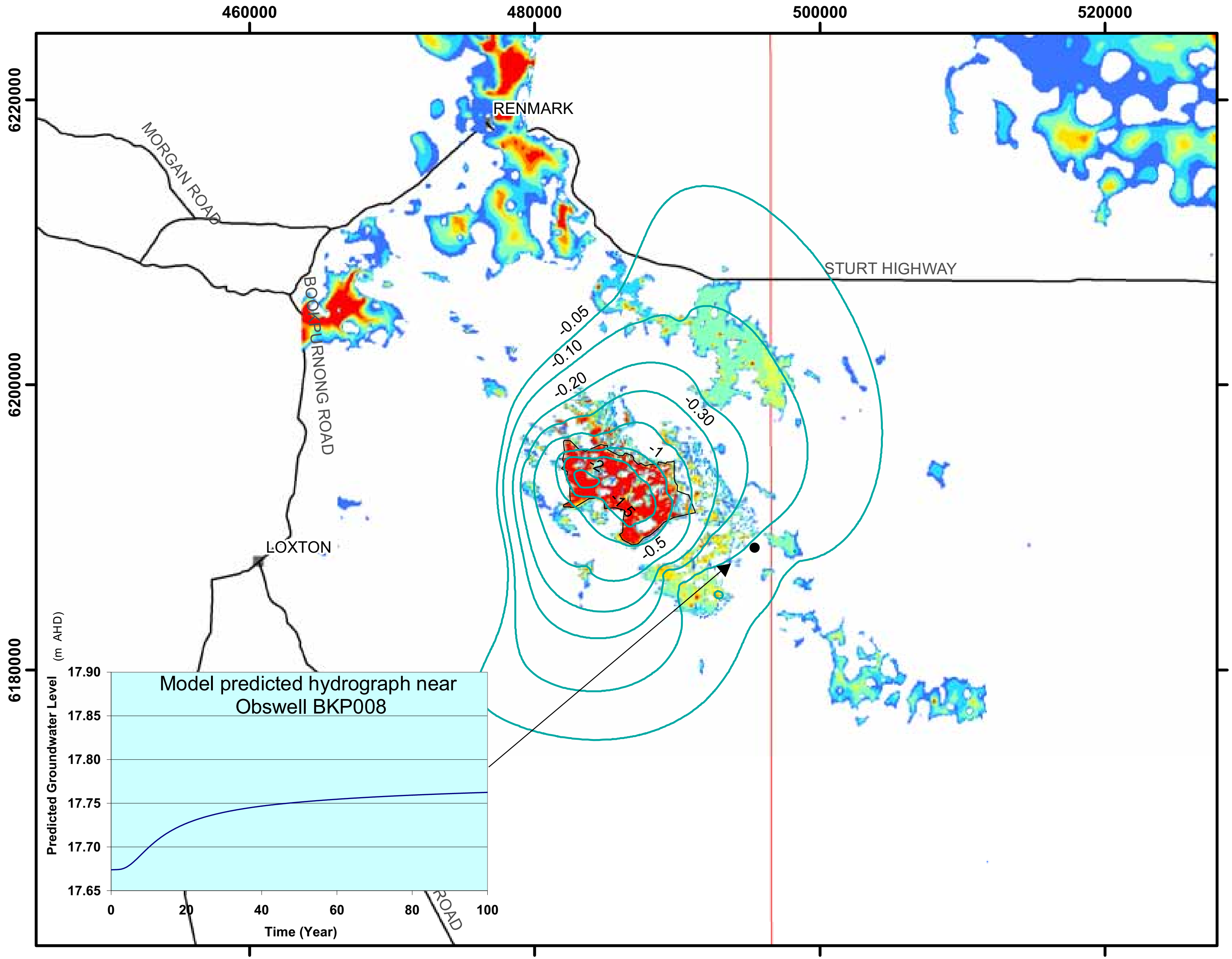


Figure 29 Current Depth to Watertable (m)



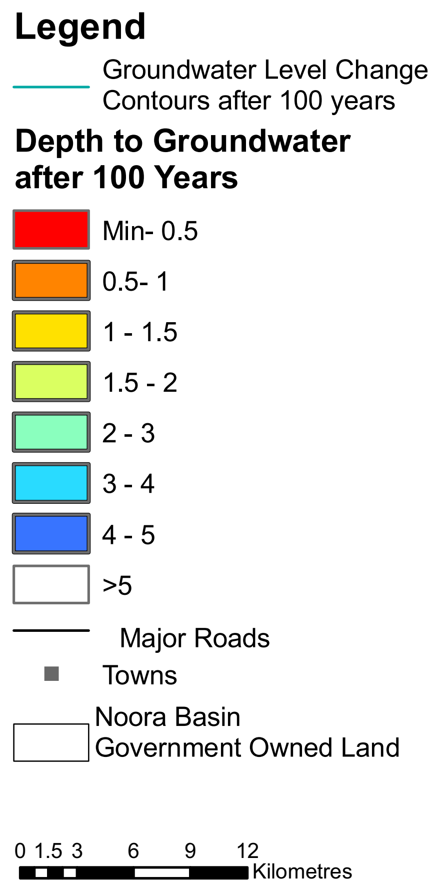


Figure 30 Scenario 1 Predicted Watertable Levels after 100 years.

Government of South Australia
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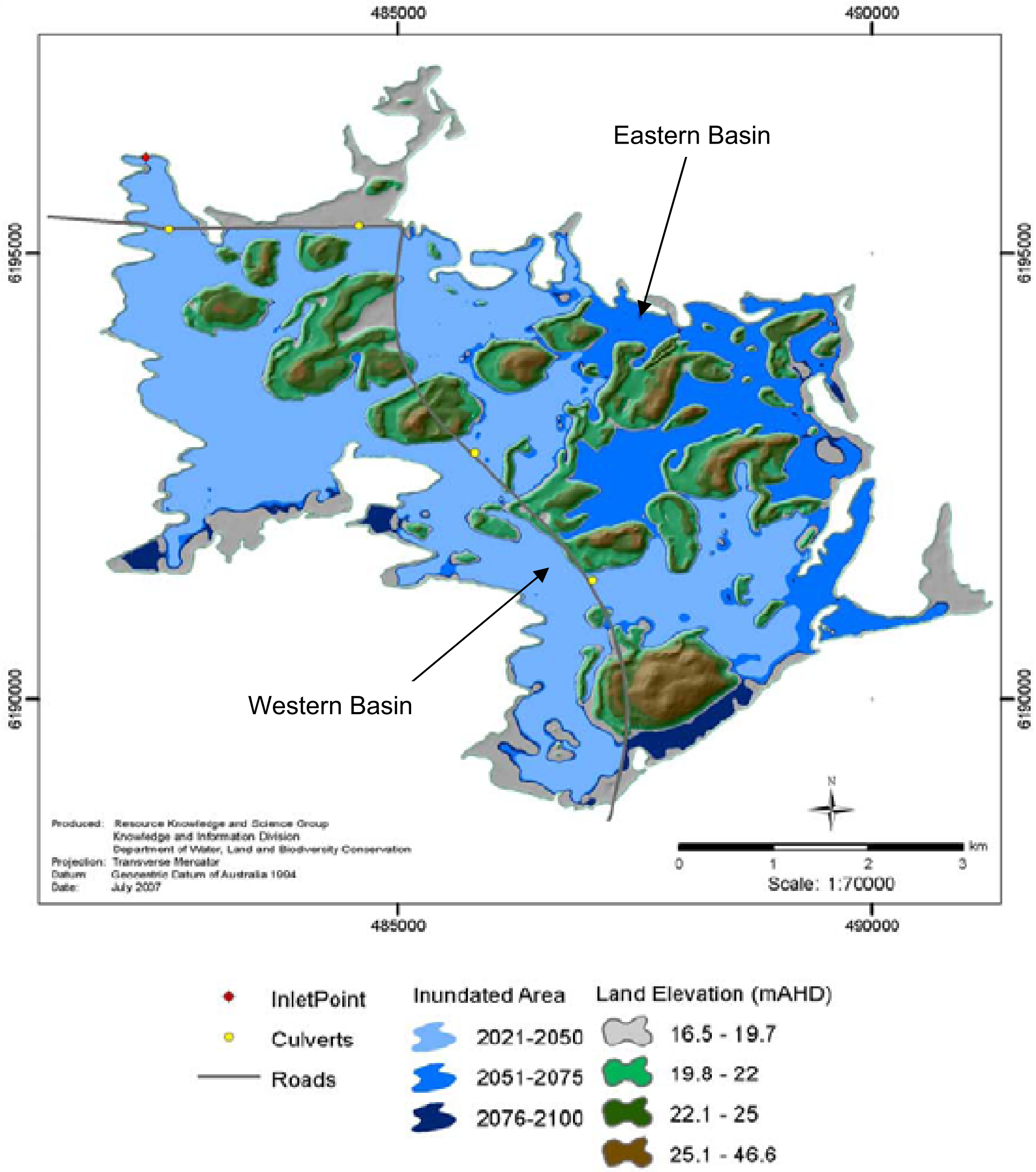
Datum: GDA94
Map Projection: MGA Zone 54



Maximum Water Levels, Stored Volume and Inundated Areas: Drainage and Loxton, Bookpumong, Murtho and Pike SIS (Scenario 2A)

Period	Maximum Water Level (mAHD)		Total Volume (ML)	Total Inundated Area (Ha)
	Western Basin	Eastern Basin		
2021-2050	18.60	18.38	8519	1615
2051-2075	18.62	18.62	10664	1782
2076-2106	18.79	18.79	14039	1965

Notes
Control Height between Western and Eastern Basins is 18.6 mAHD.

Figure 31 Scenario 2 Surface Water Results (from Heneker, 2007)

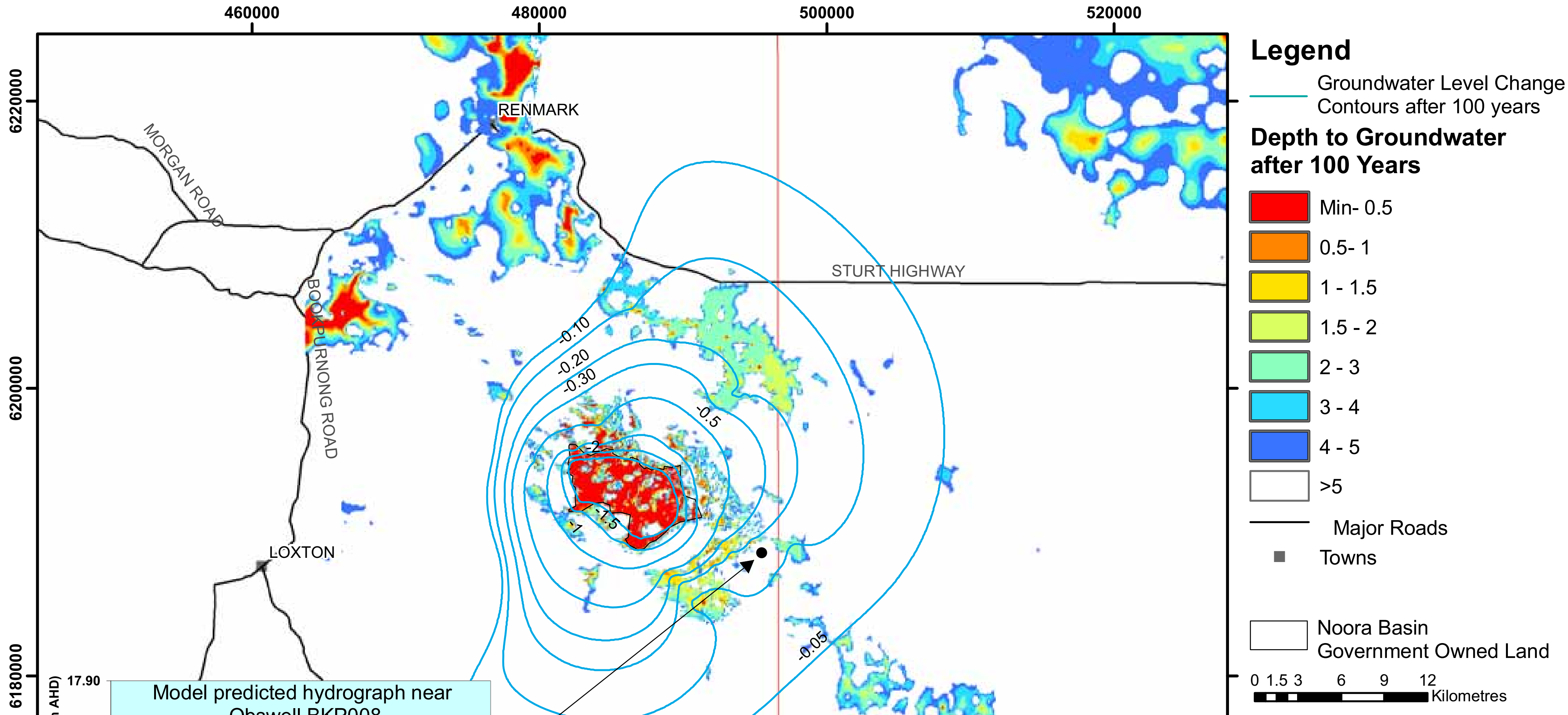


Figure 32 Scenario 2 Predicted Water table Levels after 100 years

Government of South Australia
Department of Water, Land and Biodiversity Conservation

N W E S

Datum: GDA94
Map Projection: MGA Zone 54

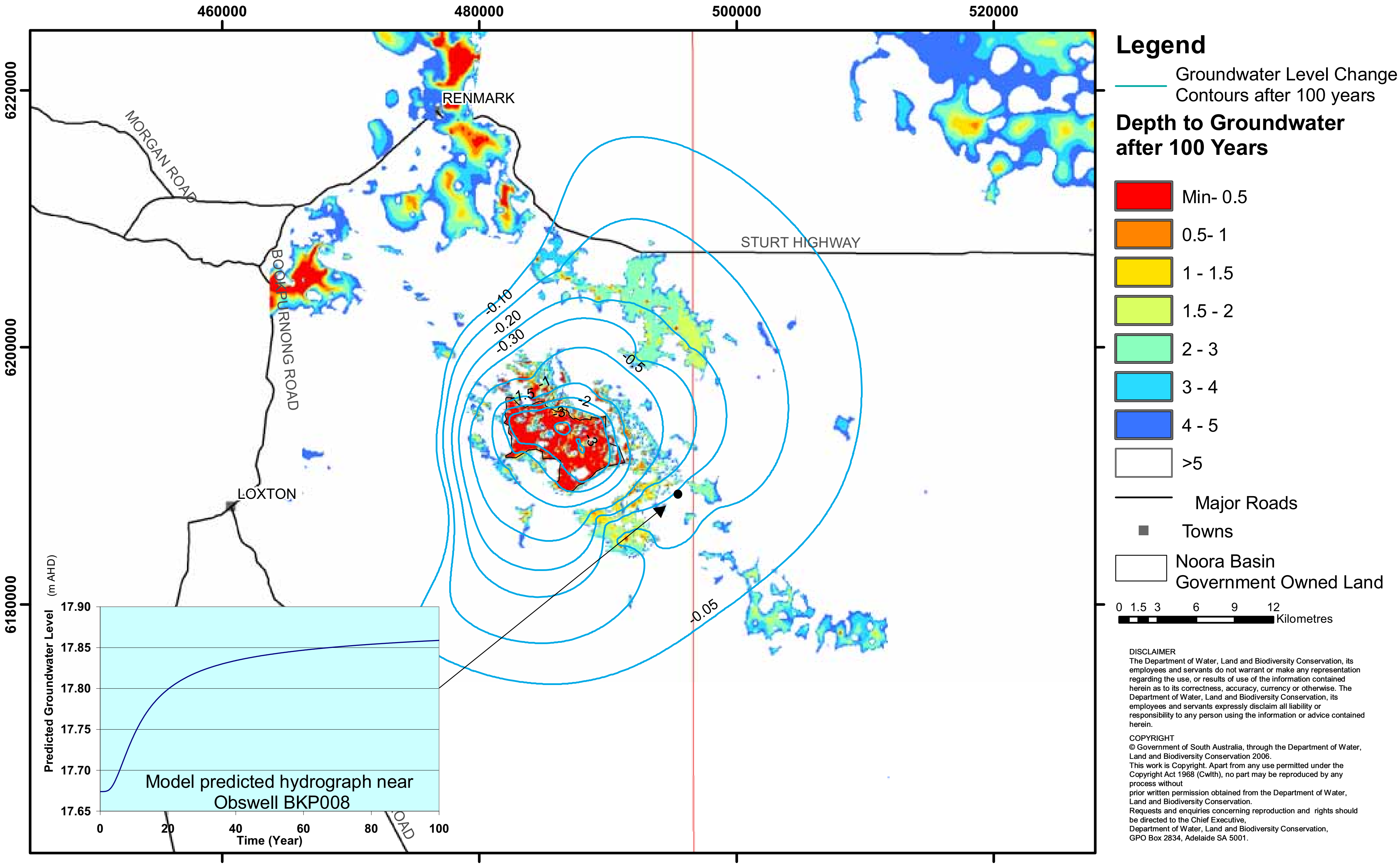


Figure 33 Scenario 3 Predicted Watertable levels after 100 years

Government of South Australia
Department of Water, Land and Biodiversity Conservation

N W E S

Datum: GDA94
Map Projection: MGA Zone 54

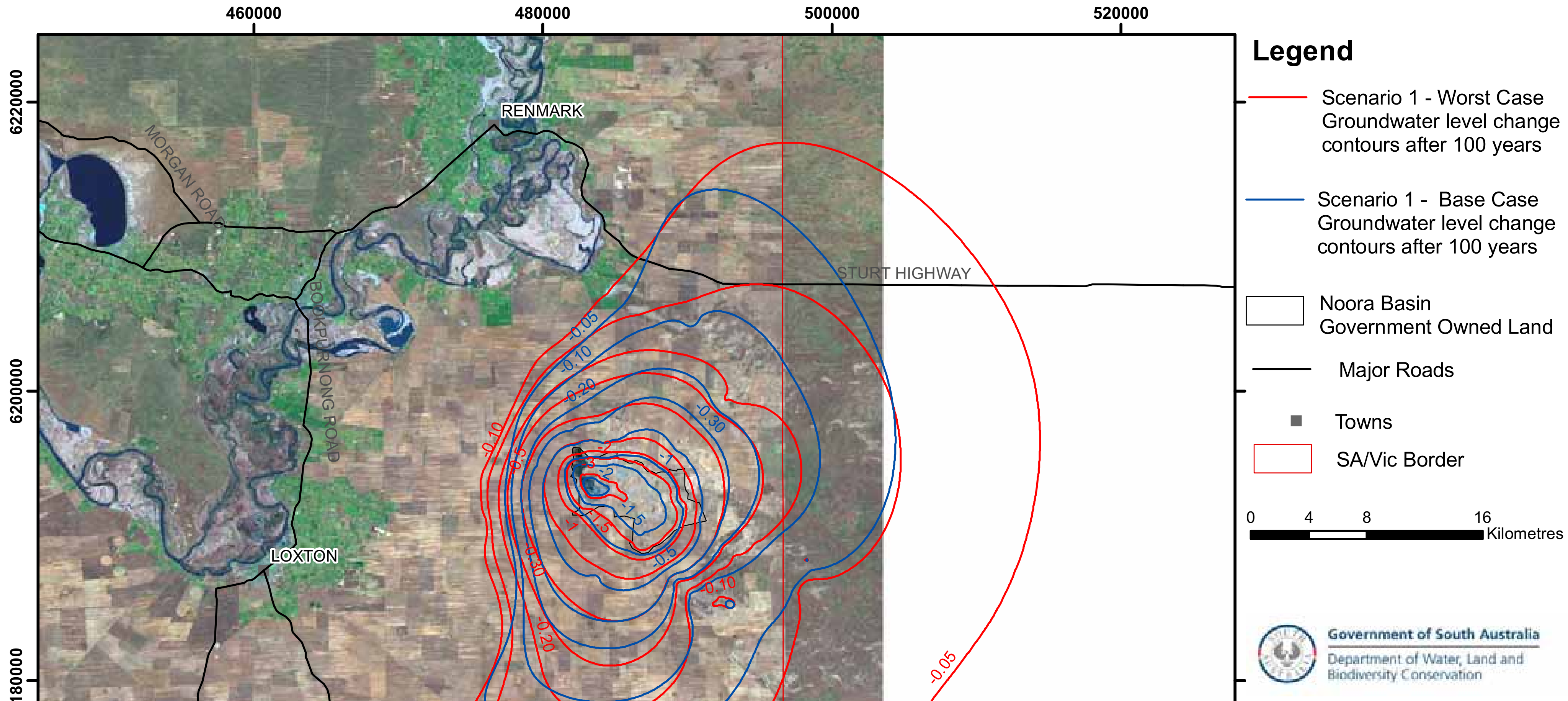
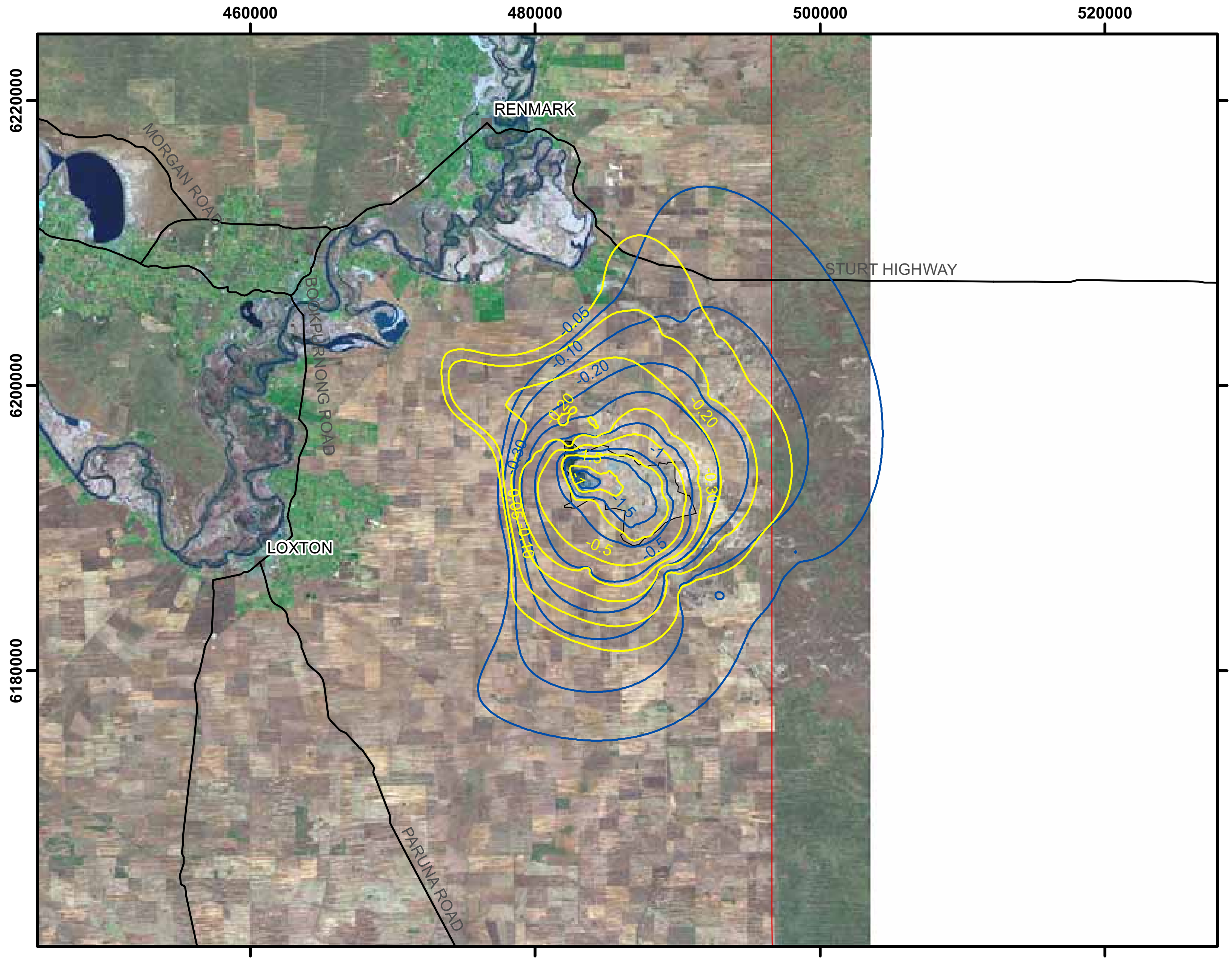


Figure 34 Scenario 1 Sensitivity Results
Predicted Base Case and Worst Case Groundwater Level Changes after 100 Years.

N E S W
Datum: GDA94
Map Projection: MGA Zone 54



Legend

Scenario 1 - Best Case Groundwater level change contours after 100 years

Scenario 1 - Base Case Groundwater level change contours after 100 years

Noora Basin Government Owned Land

Major Roads

Towns

SA/Vic Border

0 3.75 7.5 15 Kilometres

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Figure 35 Scenario 1 Sensitivity Results
Predicted Base Case and Best Case Groundwater Level Changes after 100 Years.

N E S W

Datum: GDA94
Map Projection: MGA Zone 54

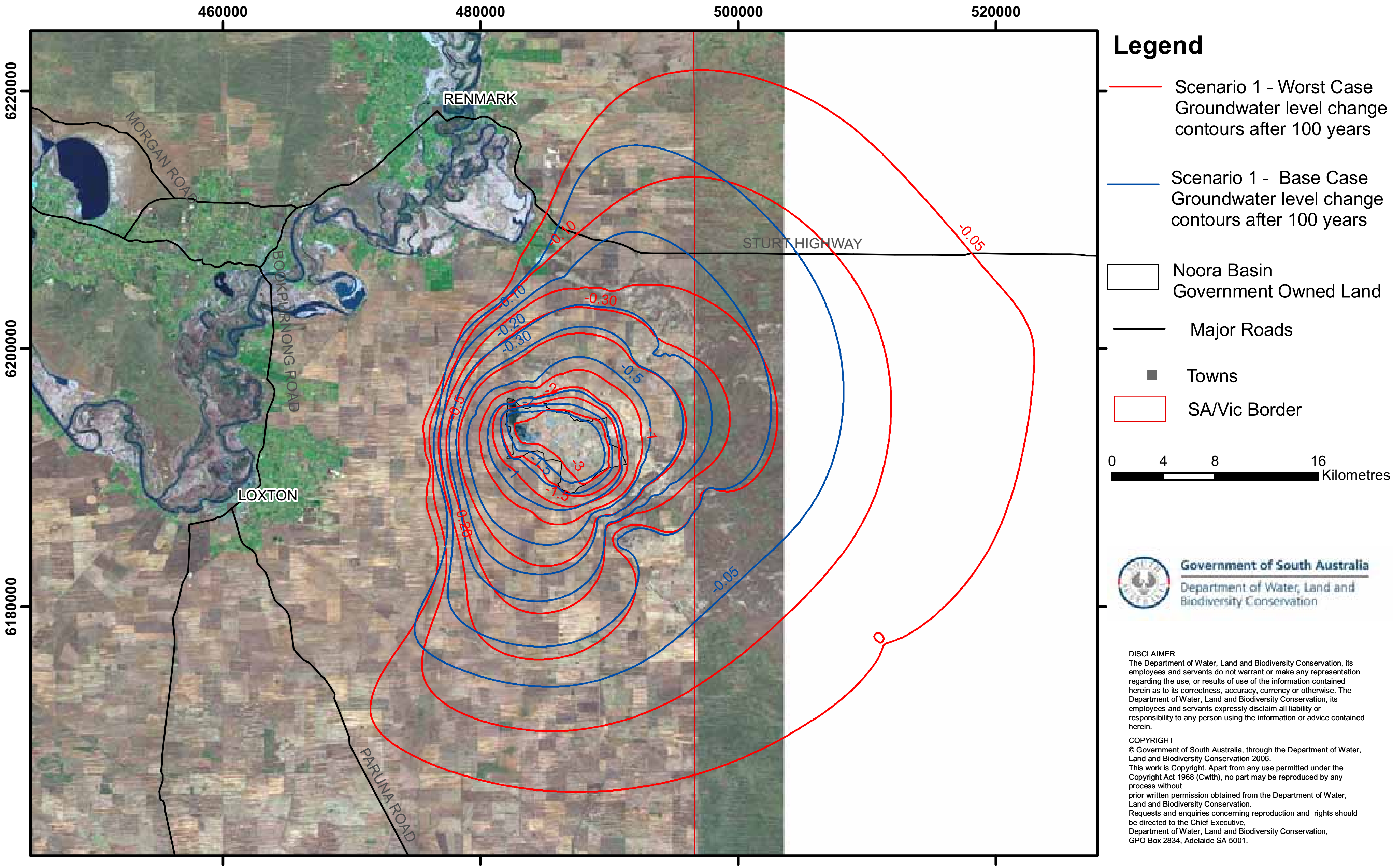


Figure 36 Scenario 2 Sensitivity Results
Predicted Base Case and Worst Case Groundwater Level Changes after 100 Years.

Datum: GDA94
Map Projection: MGA Zone 54

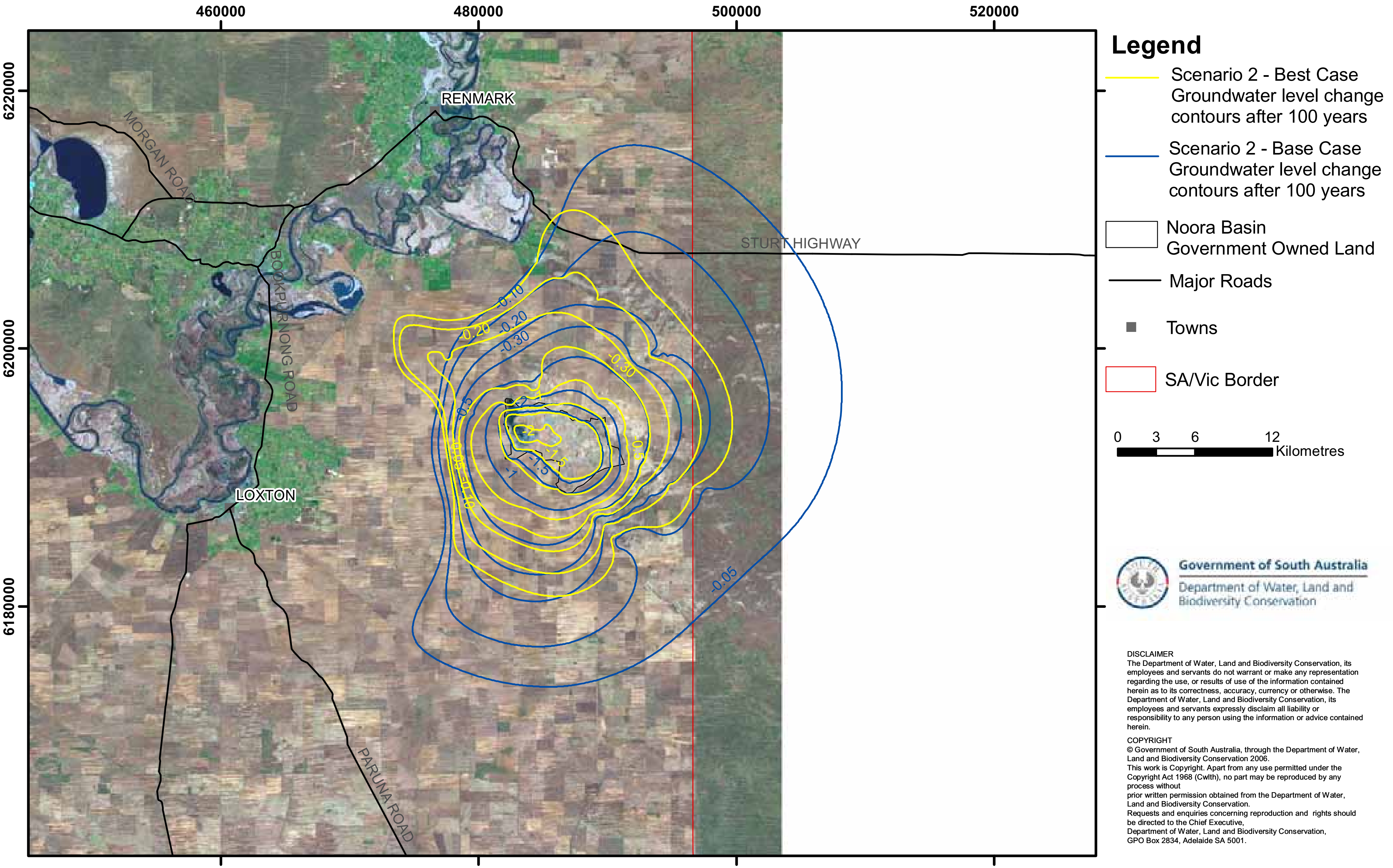


Figure 37 Scenario 2 Sensitivity Results
Predicted Base Case and Best Case Groundwater Level Changes after 100 Years.

Datum: GDA94
Map Projection: MGA Zone 54

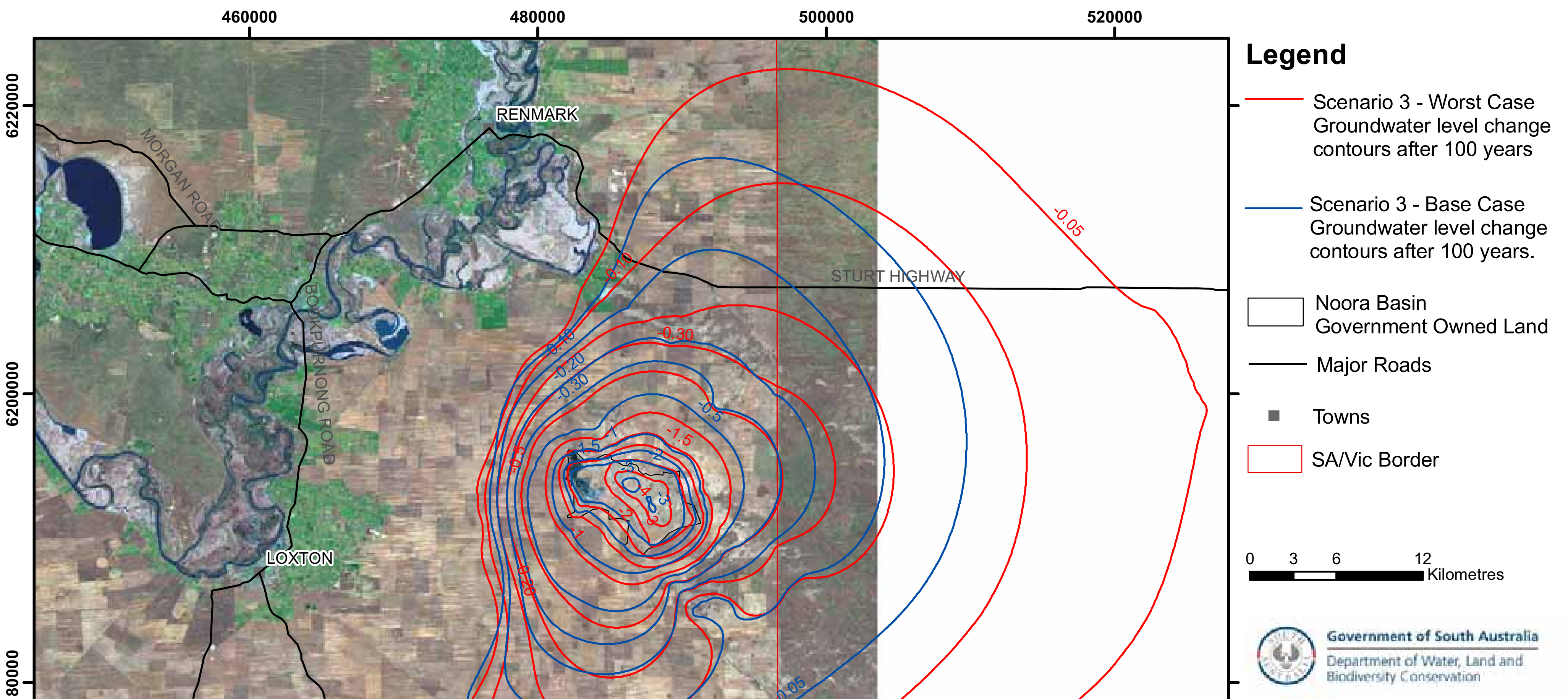
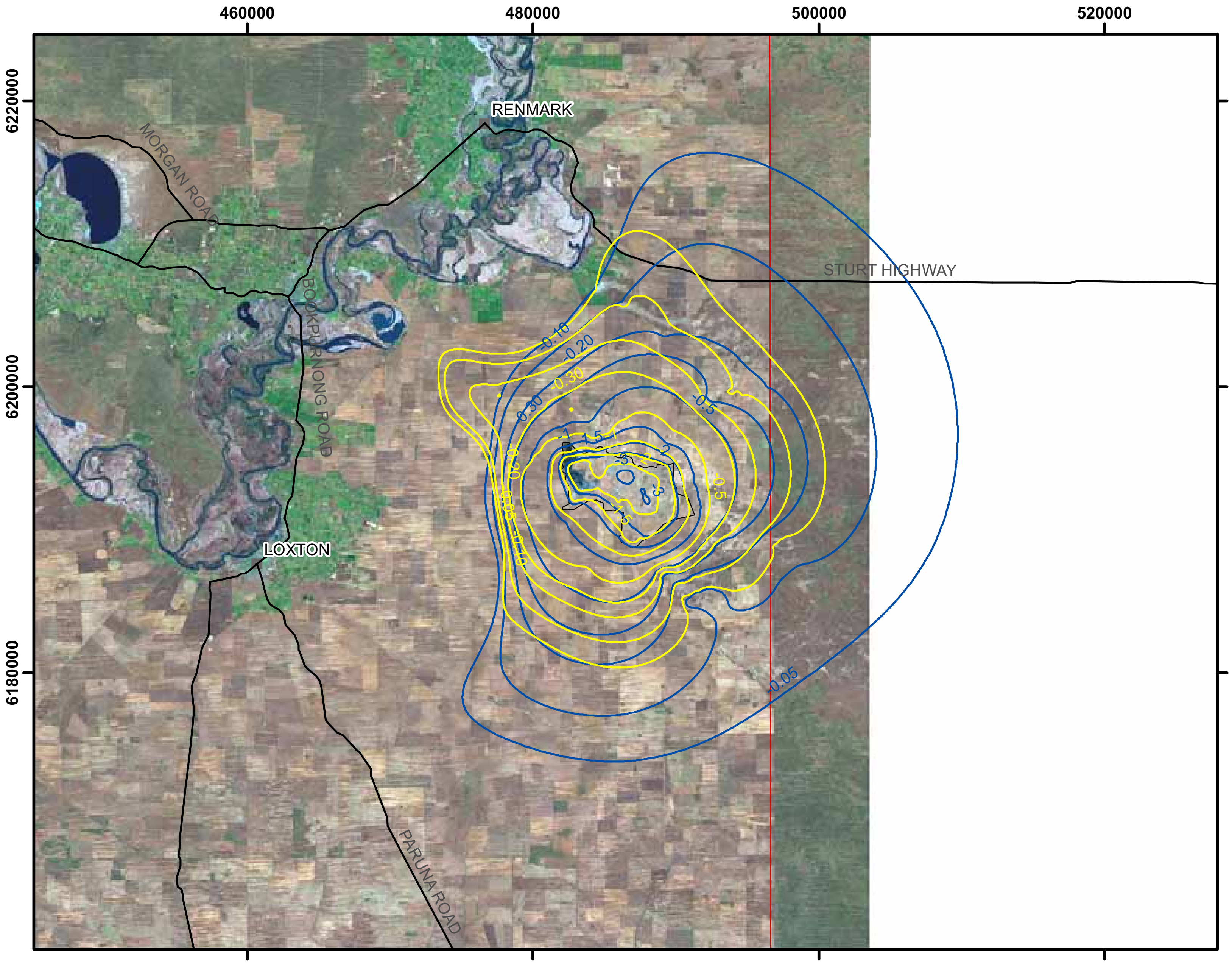


Figure 38 Scenario 3 Sensitivity Results
Predicted Base Case and Worst Case Groundwater Level Changes after 100 Years

N W E S

Datum: GDA94
Map Projection: MGA Zone 54



Legend

Scenario 3 - Best Case Groundwater level change contours after 100 years

Scenario 3 - Base Case Groundwater level change contours after 100 years

Noora Basin Government Owned Land

Major Roads

Towns

SA/Vic Border

0 3 6 12 Kilometres

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Figure 39 Scenario 3 Sensitivity Results
Predicted Base Case and Best Case Groundwater Level Changes after 100 Years.

N E S W

Datum: GDA94
Map Projection: MGA Zone 54

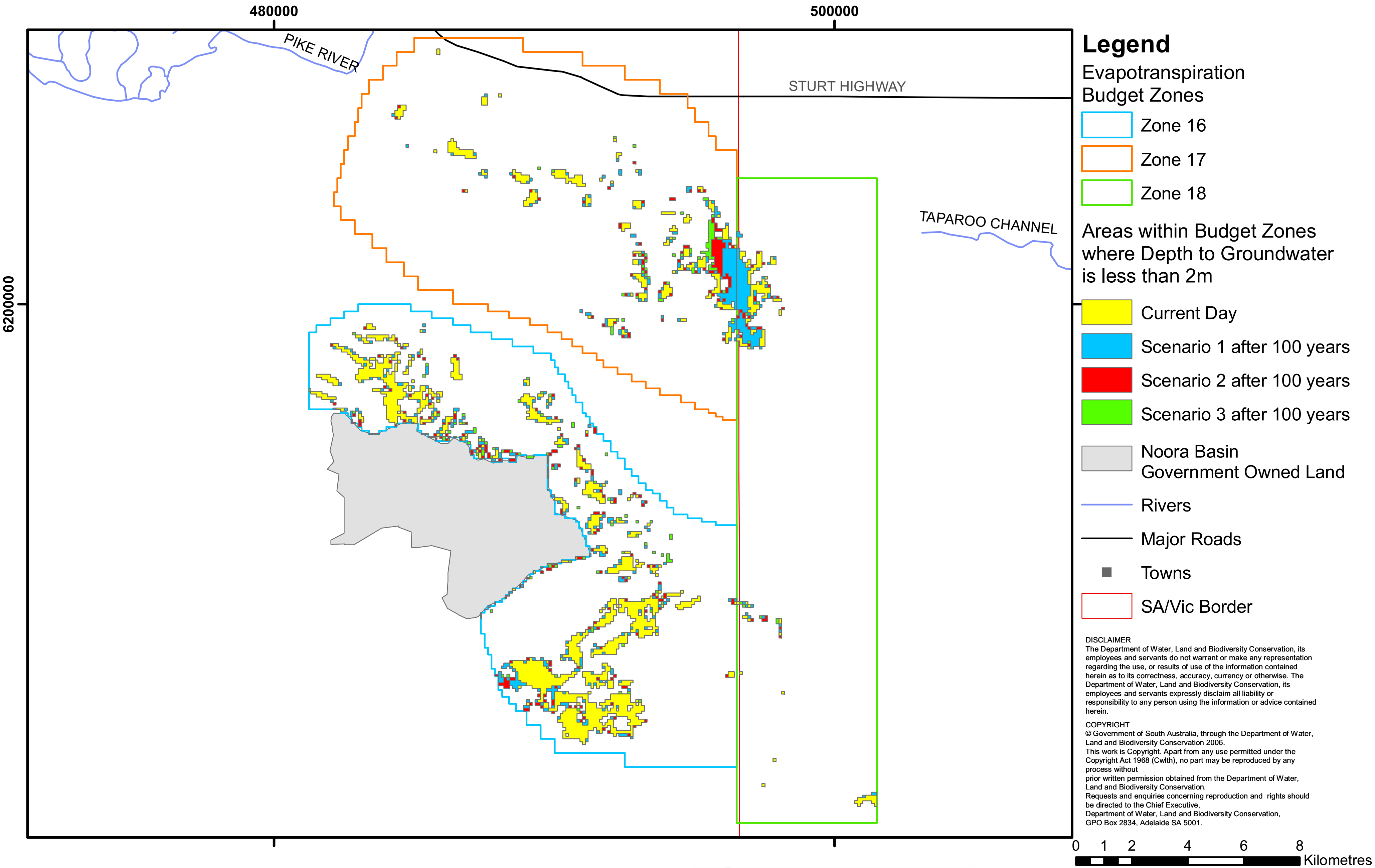


Figure 40 Areas where Watertable is Predicted to Rise to Less than 2m below ground

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Datum: GDA94
Map Projection: MGA Zone 54

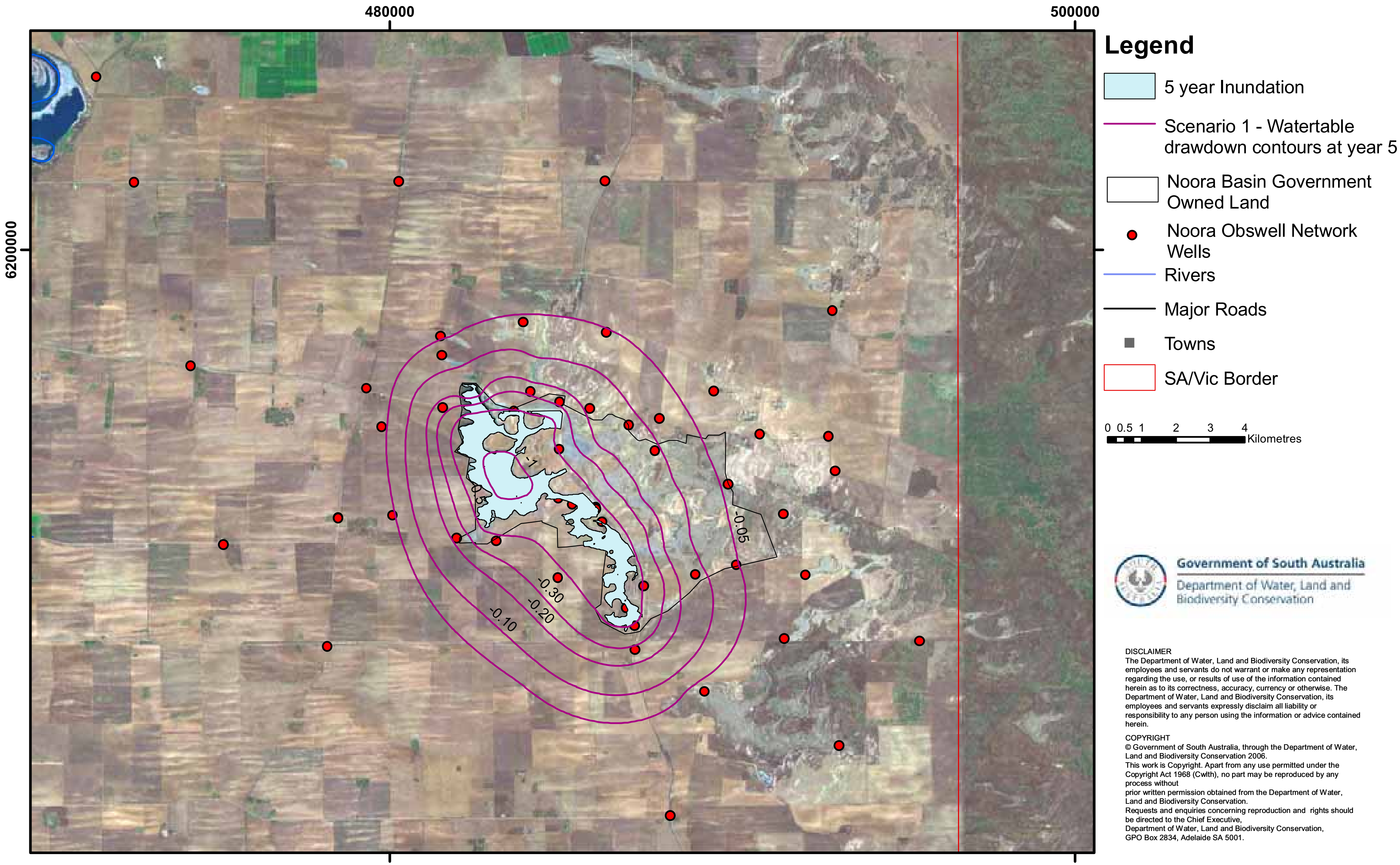
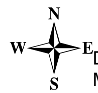
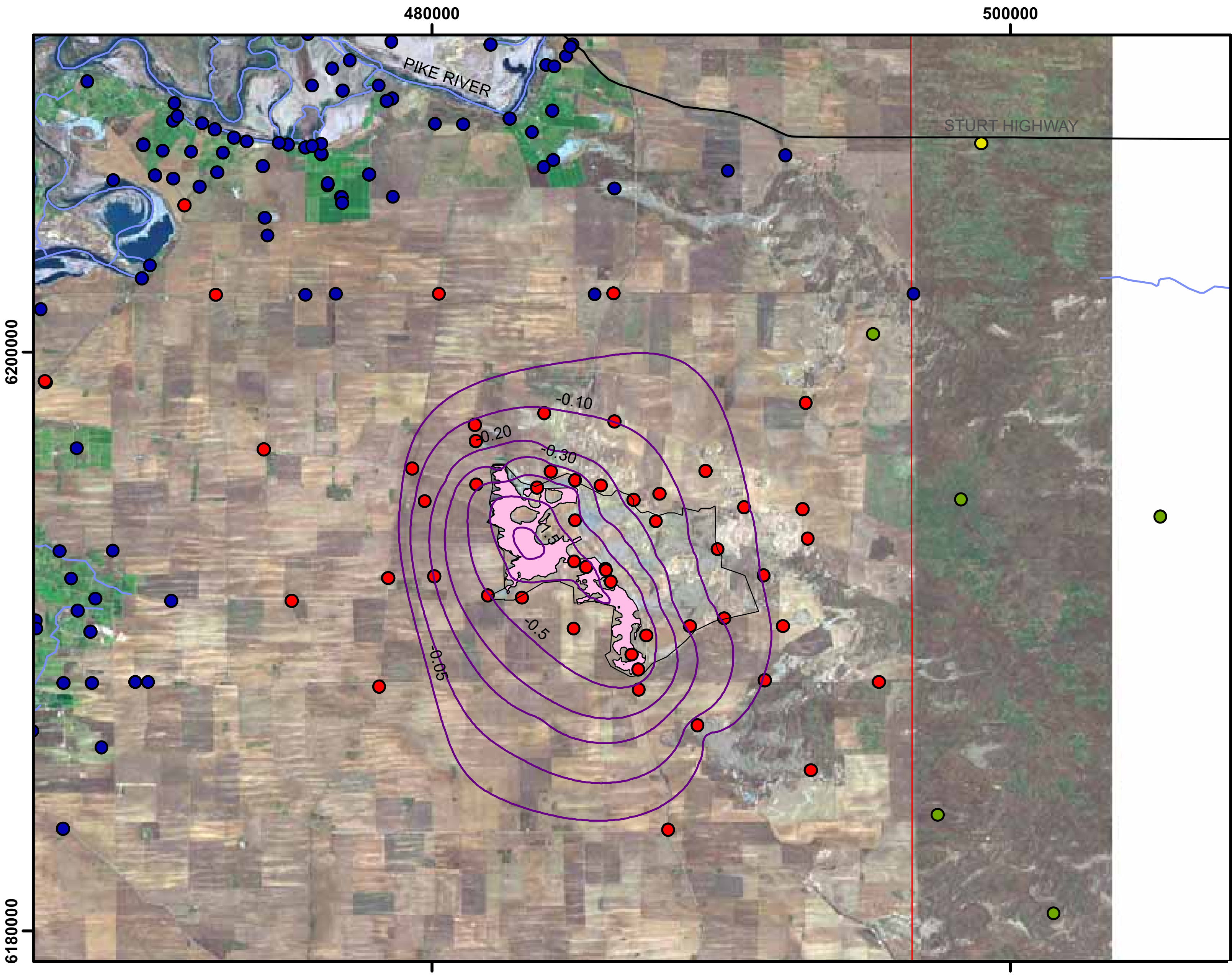


Figure 41 Scenario 1 Predicted Basin Inundate Area and Watertable Level Change Contours 2011



Datum: GDA94
Map Projection: MGA Zone 54



Legend

15 year Inundation

Scenario 1 - Watertable drawdown contours at year 15

Noora Basin Government Owned Land

Noora Network Wells

Potential New Regional Monitoring Wells

Other SA Obswells

Victorian Monitoring Wells

Rivers

Major Roads

Towns

SA/Vic Border

0 1 2 4 6 8 Kilometres

Government of South Australia
Department of Water, Land and Biodiversity Conservation

N W E S

Datum: GDA94
Map Projection: MGA Zone 54

Figure 42 Scenario 1 Predicted Basin Inundated Area and Watertable Level Change Contours, 2021

APPENDIX

A. PREVIOUS NOORA BASIN MODELLING

This section provides a summary of the groundwater and basin modelling done prior to this project. It focuses on the work performed by Sinclair Knight Merz (SKM) as part of the Regional Disposal Strategy (RDS) Stage 3 work program in 2003–05, the groundwater modelling done by AWE and SA Water in 2005 and the work completed by DWLBC in 2006. Earlier work, including that by AWE as part of the RDS Stage 1 and 2 work, is not summarised here.

A1 SKM MODELLING

Sinclair, Knight and Mertz (SKM) was commissioned by DWLBC in 2003 to undertake Stage 3 of the RDS. Stage 3 had the key objectives of quantifying the available disposal capacity of Noora and Stockyard Plain disposal basins and assessment of the potential for establishing new basins at Woolpunda South and Rufus River. At Noora, the work also included an assessment of the potential for expanding basin capacity and provision of preliminary costing.

A1.1 Groundwater modelling

SKM developed a conceptual hydrogeology model after consideration of previous work by Barnett (1991, 1992, and 1999), Barnett and Marsden (2003), Kinhill (1979), Howles (1987) and others. This led to the development in Visual MODFLOW (Ver. 2000) of a model that extended from 460 000–510 000 mE and 6 170 000–6 210 000 mN. Cell sizes ranged from 500 x 500 m near model margins to 100 x 100 m in the Noora area. The ground surface in the model was created by merging the local Noora DEM created by DWLBC using local spot height data with the regional nine second (~250 m cell size) DEM obtained from Geoscience Australia. The model was created with one layer to simulate the Loxton Sands Aquifer with a uniform base set at -5 m AHD.

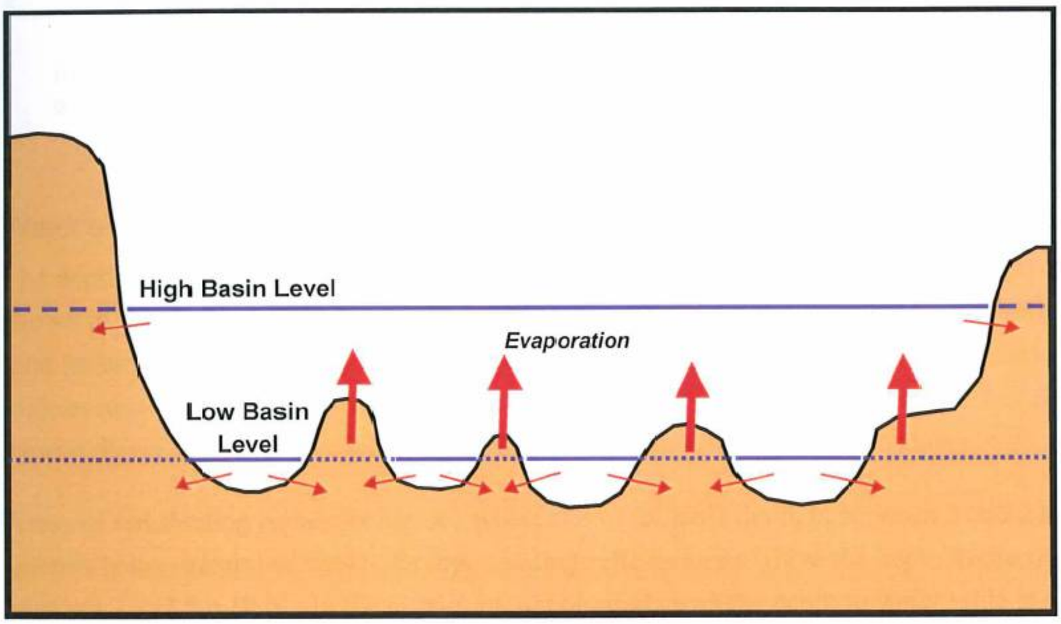
A hydraulic conductivity of 4 m/d was applied uniformly throughout the model. Recharge of 1 mm/y was applied to the model to simulate direct rainfall recharge, except in the irrigated areas of Loxton, Bookpurnong and Pike, where 100–150 mm/y was applied to represent irrigation drainage. A uniform evapotranspiration (ET) rate of 400 mm/y was applied throughout the model with an extinction depth of 1 m.

The model was run in steady state mode to match observed groundwater levels at about 1940. A 40-year transient model run was then performed to simulate the main period of watertable mound growth observed beneath the irrigated areas from 1942–82. A transient run from 1982–2003 was then run. It simulated the operation of Noora by applying an 18.5 m AHD constant head boundary (CHB) in the northern sub-basin and 17.8 m AHD in the southern sub-basin over ponded areas.

The modelled groundwater levels from the 1982-2003 run were compared with observed 2003 groundwater level contours (as produced by Surfer software) and contours produced by Barnett and Marsden (2003). The modelled levels showed a relatively poor fit with observed levels, producing a RMS of 25%.

Predictive model runs were then used to estimate the long-term leakage rates expected by applying pragmatic estimates of the inundated areas at different basin pool levels (19.0, 20.0, 21.0, 22.5 and 24.0 m AHD) as CHBs in the model over 100 years. The long-term leakage rate was calculated as the flux of water into the model from the basin CHB divided by the average inundated area. For the basin historical operating period from 1982–2003, SKM estimated a leakage rate of 39 mm/y. For the 100 year predictions, SKM estimated that leakage rates range from 39 mm/y (for 24 m AHD operating level) to 146 mm/y for 19 m AHD.

The decreasing leakage rates with increasing basin levels was somewhat unexpected, as greater head gradients normally result in increases to leakage fluxes. SKM explained the leakage rate/basin operating level relationship in terms of the shallow groundwater regime at Noora. The ability of the watertable aquifer to receive leakage from the basin is limited by the low regional hydraulic gradients and the relatively low transmissivity. Given these constraints on leakage to the regional groundwater system, SKM believe leakage rates beneath the basin will be strongly controlled by evaporation. At lower basin operating levels, there is a greater area of land subject to evaporation from the shallow watertable compared to higher levels. This relationship is represented from SKM (2005) in Figure A1.



- **Figure 8-2 Schematic cross section of Noora Basin at high and low basin levels. Note that evapotranspiration from the shallow water table is more dominant under the shallow basin level where there are areas of shallow water table. The basin surface is indicated by the black lines, the solid blue lines indicate the ponded surface, the dashed blue lines indicate the water table.**

Figure A1. Schematic cross section of Noora Basin at high and low basin levels (from SKM, 2005)

In terms of groundwater impacts, SKM concluded that operating levels above 20 m AHD in the eastern parts of Noora Basin are likely to cause rises in groundwater levels beneath the Murray-Sunset National Park (MSNP). Groundwater level rise contours are only presented by SKM at 0.5 m intervals, which suggest that rises of the order of 0.1 m beneath MSNP may result for operating levels of 19 m AHD. At an operating level of 24 m AHD, the modelling indicates rises beneath MSNP of up to 2 m. SKM also concluded that landowners adjacent to the government-owned property may be adversely affected by groundwater level rises caused by operating the basin at 19 m AHD.

In terms of basin design and disposal potential, SKM concluded that the groundwater modelling indicated that:

- Leakage rates from the basin were likely to be small (<1 mm/d) and not significant in the basin water balance.
- The low leakage rates would lead to accumulation of salt within the basin and the eventual precipitation of solid salt.

Notwithstanding the above, SKM also stated that if leakage rates were higher by a factor of two, the basin could change from precipitating to non-precipitating.

A1.2 Basin modelling

The basin design and capacity was modelled with Resource Allocation Model (REALM) using the same ground surface DEMs used in the groundwater model. Seventeen sub-basins were assigned based on variations in local topography, and the areas and volumes of each were calculated at 0.25 m increments.

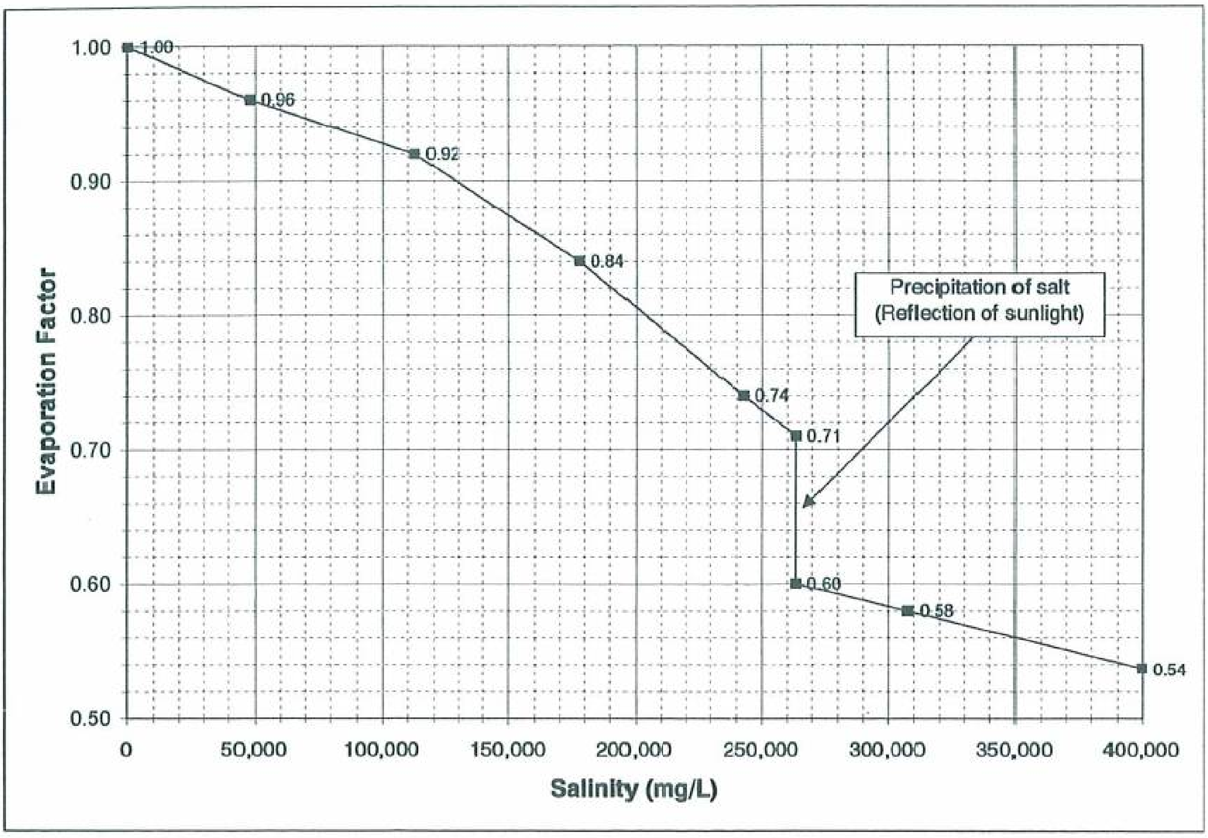
A1.2.1 Model inputs and development

Several model inputs were provided by DWLBC. Disposal rates varied in accordance with the estimated pumping rates and start dates from planned and possible SISs. A constant rate of 20 L/s from the shallow irrigation drainage network was assumed. Total disposal rates modelled ranged from 160 L/s in 2005 to 800 L/s beyond 2015. A constant salinity value of 30 000 mg/L total dissolved solids (TDS) was applied by SKM after discussion with DWLBC staff.

Rainfall for the basin model was assigned as 241 mm/y, which is the average of long-term records from the Renmark Irrigation (024003) and Renmark Taldra (024017) rainfall stations.

SKM carefully considered the evaporation rate to apply at Noora. The pan evaporation data from Lock 5 (1584 mm/y) was used and a pan factor of 0.75 applied to derive 1192 mm/y. SKM noted that pan evaporation data from other sites away from the River Murray was significantly higher (to over 2000 mm/y) but reasoned that the lower Lock 5 rates (associated with the higher humidity levels adjacent to a large water body) would be more representative of Noora Basin once inundated. They also noted that the Bureau of Meteorology determined an areal ET of about 972 mm/y in the Noora region using Morton's Complementary Method.

Evaporation rates decline with increasing water salinity, however, this relationship is typically only significant to water and salt balances for hypersaline water (above 100 000 mg/L TDS). Figure A2 shows the graphical relationship between salinity and evaporation factor used by SKM. The specific gravity of precipitated salt was assumed to be 1.25.



▪ **Figure 8-8 The relationship between salinity and evaporation factor.**

Figure A2. Salinity – Evaporation Relationship (from SKM, 2005)

A1.2.2 Model outputs and uncertainties

The maximum operating level applied by SKM for design work was 19 m AHD, 'which allows for sufficient disposal capacity without the requirement for significant embankment works and without the disposal water encroaching upon neighbouring properties'.

Assuming little or no leakage, SKM estimated the salinity of basin water will increase rapidly, reaching saturation (260 000 mg/L TDS) after 16 years. At this point, evaporation would have halved form the initial level of 9 ML/ha/y to 4.5 ML/ha/y. The initial modelling also indicated that the basin would be filled with precipitated salt after 79 years.

SKM assume that salt precipitation will 'form an impermeable layer on the bed of the lake' and that during the first 16 years before such an impermeable layer is formed, the significantly denser basin water 'could impose a head greater than 19 m AHD on the regional groundwater system' and 'could cause a significant rising of groundwater levels beneath the Murray Sunset National Park'. However, we are uncertain if a layer of precipitated salt beneath hypersaline basin water would form a significant aquitard. The additional head caused by denser basin water would not itself cause an actual rise in groundwater levels if the aquifer is truly unconfined, but would at least induce a greater horizontal flux of groundwater away from the basin.

The initial modelling results indicated that for Noora Basin to meet disposal requirements, it would be necessary to divide the basin into two ponds (Pond A and B). Pond A would be located on the eastern side and used as the working pond to evaporate water before transferring the hypersaline to Pond B, where salt would eventually precipitate and accumulate. Pond B is located on the western side of the basin to minimise the density effects of groundwater levels beneath MSNP. The optimised two-pond design is more than adequate to meet the Stage 1 design disposal requirements of 340 L/s over the first 10 years. The model results for Stage 2 (800 L/s) requirements are not summarised here.

SKM identified uncertainty associated with seepage as the most important effect upon basin design. At a leakage rate of 0.2 mm/d, SKM calculate that salinities of incoming water (30 000 mg/L TDS) would be expected to increase by 12-fold to 360 000 mg/L TDS (to match the net open-water evaporation rate of about 960 mm/y) and hence precipitation would occur. If the leakage rate was 0.4 mm/d then incoming water salinity would be expected to increase six-fold to 185 000 mg/L TDS, below the level of precipitation (260 000 mg/L TDS).

SKM also note significant uncertainty around the effects of increasing salinity upon seepage and evaporation, which relates to:

- Possible formation of an impermeable solid salt layer at the base of the basin (or by deposition of decomposed biological material).
- Uncertainty relating to the evaporation of bitterns (the magnesium rich hypersaline water remaining after sodium chloride is precipitated). Magnesium chloride is hygroscopic (it absorbs water) and its effect on evaporation is uncertain. In the Dead Sea, a harvesting pond rich in bitterns formed hard mushroom-shaped precipitates that spread across the water surface, restricting evaporation.
- The density effects of basin water upon the regional groundwater system. The additional heads may impose themselves in a uniform fashion, or ‘fingers’ of brine may ‘plunge’ vertically to the base of the aquifer and then spread laterally. Based on the work of Simmons and Narayan (1997), SKM believe that the latter is more likely.

SKM concluded that an interim design option (Stage 1T) should be adopted to investigate uncertainties around the seepage rate and resultant basin designs. The Stage 1T design involves using the north-south road as a levee to hold all disposed water to the west. A partitioning embankment would be required to create a north and south pond to enable the saline and hypersaline storage process.

As a critical component of the Stage 1T design, SKM advocated a rigorous monitoring and investigation program, which would comprise:

- monitoring of the incoming volume and its salinity
- weekly basin level and salinity readings at a number of points around the basin
- an annual grid survey across the basin to determine its salt load
- an annual salt balance to keep track of its seepage outflow rate
- extra groundwater monitoring close to the water’s edge to help interpret the initial filling up of the dry soil around the basin
- in Year 4, calibration of a groundwater model against the observed seepage (leakage), followed by use of the model to predict long-term steady state seepage.

A2 KBR MODEL REVIEW

Kellogg Brown and Root (KBR) was commissioned by River Murray Water in 2005 to review the assumptions, assessment techniques and disposal options used and identified by SKM for Noora Basin. The review was focused on:

- hydrogeological assessments of leakage rates
- assumptions used regarding evaporation of highly saline water
- predicted impacts on the regional watertable
- REALM modelling
- embankment design and costing.

A2.1 Groundwater modelling

A2.1.1 Model inputs and development

In general terms, KBR supported the conceptualisation and groundwater model development undertaken by SKM. KBR noted or recommended that:

- SKM's explanation that the higher modelled groundwater levels to the south-east of the basin compared with observed levels as a result of downwards leakage conflicts with the conceptualised upward gradients.
- The general head boundaries set by SKM are an appropriate way to model the specified boundaries but the relatively high conductance value ($8m^2/d$) assigned to these boundaries makes them act more like a CHB. However, KBR did not consider the high conductances to adversely effect the predictive simulations in the vicinity of Noora Basin.
- It is important to assign reasonable evapotranspiration values to the model given the significant influence they have on leakage rates according to SKM. KBR noted that previous regional groundwater models had adopted an extinction depth of 2 m (CSIRO, 2004). SKM adopted 1 m 'to account for the fact that the basin area is largely cleared of vegetation'. KBR believe the evapotranspiration rate of 400 mm/y adopted by SKM is conservatively low and note that no model sensitivity analyses were done for evapotranspiration and extinction depth, 'despite the high reliance of predicted leakage rates on evapotranspiration'.
- SKM adopted a hydraulic conductivity of 4 m/d for the Loxton Sands at the conclusion of calibration, which is near the upper range of values adopted by earlier work (Barnett, 1992).
- The calibration of groundwater levels appears to be reasonable in the north-west part of the basin area but KBR believe that modelled gradients across the model domain are overestimated. KBR also believe that a higher hydraulic conductivity of 5 m/d may improve calibration and confidence in the modelled leakage rates. KBR note that 'a flatter gradient in the model would tend to decrease the leakage from the ponds'. It should be noted that the regional gradients in the Noora Basin area are also influenced by evapotranspiration, not just hydraulic conductivity.
- The simulation of basin water levels in the groundwater model as constant head boundaries is the most appropriate way to assess leakage rates given that the model is a basic one layer model. This means that (long-term) basin leakage is only determined by hydraulic conductivity and hydraulic gradients. KBR believe that the SKM model

overestimates leakage rates as the calibrated hydraulic gradient is too high and there is no allowance for a layer of low permeability lake sediments.

- Consideration should be given to modelling the impacts of higher salinity-induced heads, even though SKM suggest that the likely salinity-density effect is density fingering, whereby fingers of brine plunge vertically through the underlying aquifer. KBR estimated a salinity head correction of +0.22 m and +0.82 m for salinities of 75 000 and 300 000 mg/L.

A2.1.2 Model outputs and uncertainties

In terms of the predictive outputs of the groundwater modelling by SKM, KBR noted or recommended that:

- Predictive runs were made over 100 years for basin operating levels of 19.0, 20.0, 21.0, 22.5 and 24.0 m AHD and leakage rates were calculated by dividing the flux through the CHB by the ponded area.
- Modelled leakage rates are largely driven by evapotranspiration, with greater leakage rates at lower basin operating levels when the area of shallow watertables (less than 1 m) is much greater than at higher basin operating levels. Evapotranspiration fluxes increase by about 25% per metre increase in operating level for low operating levels and diminishes to less than 10% for the higher operating levels simulated. However, KBR noted some discrepancies in the SKM work regarding this relationship and recommended that the role of evapotranspiration in the modelling be revisited and confirmation provided whether or not evapotranspiration occurs from the CHB cells. We can confirm that evapotranspiration flux 'losses' do not occur from CHB cells in MODFLOW as CHBs assume an infinite water supply is available to maintain the assigned level, so evapotranspiration is not relevant to the model validity.
- Given the initial purposes and objectives of the basic model, the model results produced by SKM are reasonable. Whilst more complex modelling could be undertaken to address some issues, KBR believe that more modelling would retain significant uncertainties to predictions as a result of the nature of basin bed sediments and effects of saline loading over time.
- Basin operating levels greater than 20 m AHD in the eastern part of the basin are likely to cause rises in groundwater levels beneath MSNP. KBR note that the groundwater model was not run for a split basin scenario and that a 20 m AHD operating level in the western parts of the basin may also cause a rise in groundwater levels beneath MSNP. KBR also not that for the Stage 1 option of basin operation, salinity-induced corrections to basin operating levels remain below 20 m AHD, therefore there should be no effect on groundwater levels beneath MSNP. As we noted earlier, in a true watertable aquifer the density corrections applied to the CHB-simulated basin water level do not cause the actual watertable level to rise. Instead, the increased pressure between groundwater of different salinity over a certain horizontal difference will increase the horizontal flux of groundwater.

KBR recommended additional groundwater model runs be undertaken to further investigate the impacts of groundwater levels beneath MSNP and the sensitivity of calculated leakage rates by:

- using a hydraulic conductivity of 5 m/d
- altering the general head boundaries
- simulating the split basin scenario for the Stage 2 configuration

- using a higher salinity-induced head.

A2.2 Basin modelling

A2.2.1 Model inputs and development

In terms of the model inputs and development KBR noted that:

- Initial basin modelling to determine capacity and concept design was done using the REALM model but final calculations were done manually.
- The concept design for the basin 'was primarily driven by both the capacity to store 100 years worth of salt and the capacity to receive the estimated volumes of disposal water for the various stages of the development of the contributing Salt Interception Schemes'.
- SKM concluded that leakage rates from the basin are likely to be small and not significant to the basin water balance, hence leakage was ignored for the concept design. KBR identified that this position conflicts with the statement by SKM that precipitation of salt from brine within the basin is highly sensitive to leakage rates.
- Leakage rates and evaporation rates are the most sensitive parameters in the basin salt and water balance. The specific gravity of salt is considered a low sensitivity for values ranging from 1.2–1.5.
- Refinements to the estimated disposal volumes and salinities would impact the basin concept design and that initially higher dewatering (disposal) rates need to be taken into account by the basin design.
- The use of evaporation data from Paringa Lock 5 to calculate Noora Basin evaporation rates is appropriate, as the higher moisture content near the River would be also realised at Noora Basin with the creation of a large water body.
- The pan factor of 0.75 applied to convert the pan evaporation to open water evaporation is valid, although earlier work applied a factor of 0.7.
- The salinity-evaporation relationship used by SKM is considered suitable in the absence of site specific data. KBR discuss the various factors affecting evaporation at increasing salinities and state that a high level of uncertainty occurs when estimating evaporation rates of hypersaline water bodies.

A2.2.2 Model outputs and uncertainties

In terms of the basin modelling outputs and impacts on basin design, KBR noted or recommended that:

- The primary controlling factor on the sizing of disposal capacity was found to be the ability to store 100 years worth of salt.
- The basin surface area required to meet the estimated disposal volumes is dependent on the evaporation volume, which has a high level of uncertainty at hypersaline salinities.
- The occurrence of salt precipitation is heavily dependent on the adopted leakage rate.
- Further REALM modelling should be undertaken following the implementation of the interim basin design (Stage1T) and associated monitoring.

Given the overall high levels of uncertainty in basin design, KBR agree with SKM that a staged basin design and monitoring approach is 'pragmatic, and in fact the only sensible approach to detailed Basin design'. KBR support the monitoring program recommended by SKM and made the following additional monitoring recommendations:

- Extra groundwater monitoring close to the water's edge to include soil moisture profiling using a neutron probe which would improve confidence in the local evapotranspiration extinction depths.
- A site evaporation pan should be established to determine local freshwater evaporation rates, which may also supplemented by research and development experiments on brine evaporation rates and analysis of brine composition.
- Monitor rainfall, solar energy, wind speed and relative humidity.

A3 AWE MODELLING

The main objective of the groundwater modelling undertaken by SA Water and Australian Water Environments (AWE) in 2005 was to test the sensitivity of the basin design in terms of the net salinity benefits by assessing the salinity benefit arising from disposal of saline water to the basin and the salinity impacts of basin operation upon the River Murray. Similar modelling work has been done for Stockyard Plain and is an important part of the 'fundamental design philosophy' considered by SA Water to be a critical step in basin area selection and design.

Both groundwater flux and solute transport was modelled using MODFLOW. The model is only considered as a basic model but fit for the purpose of evaluating the basins net salinity benefit. Evapotranspiration was not explicitly simulated in the model, nor were groundwater levels adjusted for salinity-density effects. Three scenarios were modelled:

- 300 L/s disposal at 19 m AHD basin operating level
- 600 L/s disposal at 21.5 m AHD basin operating level
- 1000 L/s disposal at 24 m AHD basin operating level.

A constant pond area of 3225 Ha was used for each scenario.

The sensitivity of the fundamental basin design was tested by adopting best and worst case values of hydraulic conductivity (2 and 5 m/d) and specific yield (0.2 and 0.05) from previous work. Both best and worst case modelling assumed:

- a regional groundwater salinity of 40 000 mg/L TDS
- a disposal water salinity of 30 000 mg/L TDS
- an infiltrating brine salinity of 100 000 mg/L TDS.

Leakage (infiltration) beneath the basin was one of the model outputs and was shown to be reasonably insensitive to variations in hydraulic conductivity and specific yield. Figure A3 displays the similarity in modelled leakage rates for the 300 L/s/19.0 m AHD scenario, whilst Figure A4 displays the modelled benefits and impacts for the same operational scenario.

For the 19 m AHD worst case scenarios, the average leakage over 100 years was predicted to be about 40 L/s for all disposal (inflow) rates, which equates to a leakage rate of about 0.1 mm/d for a basin area of 3225 Ha. For the 24 m AHD worst case scenarios, the average leakage over 100 years was predicted to be about 110 L/s for all disposal (inflow) rates, which equates to a leakage rate of about 0.3 mm/d for a basin area of 3225 Ha.

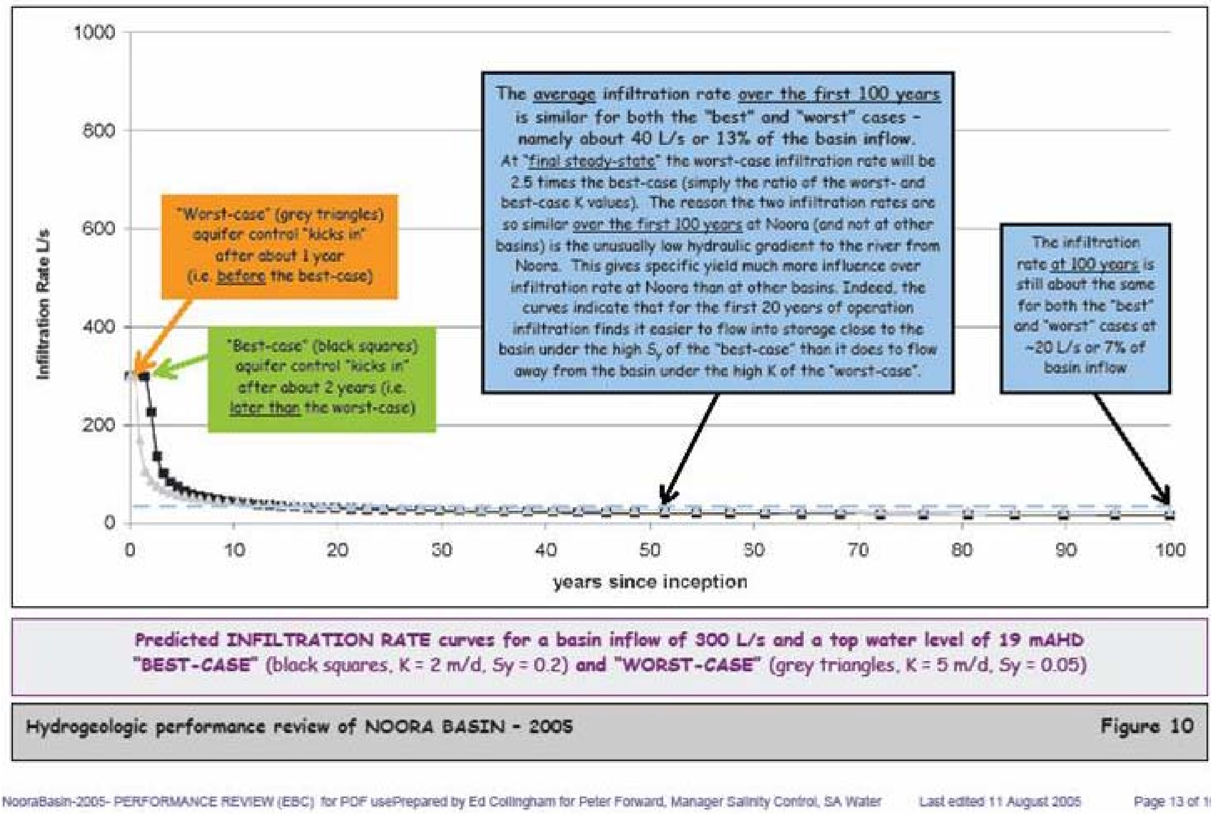


Figure A3. Predicted infiltration rates for 300 L/s and 19.0 m AHD scenario (from SA Water, 2005)

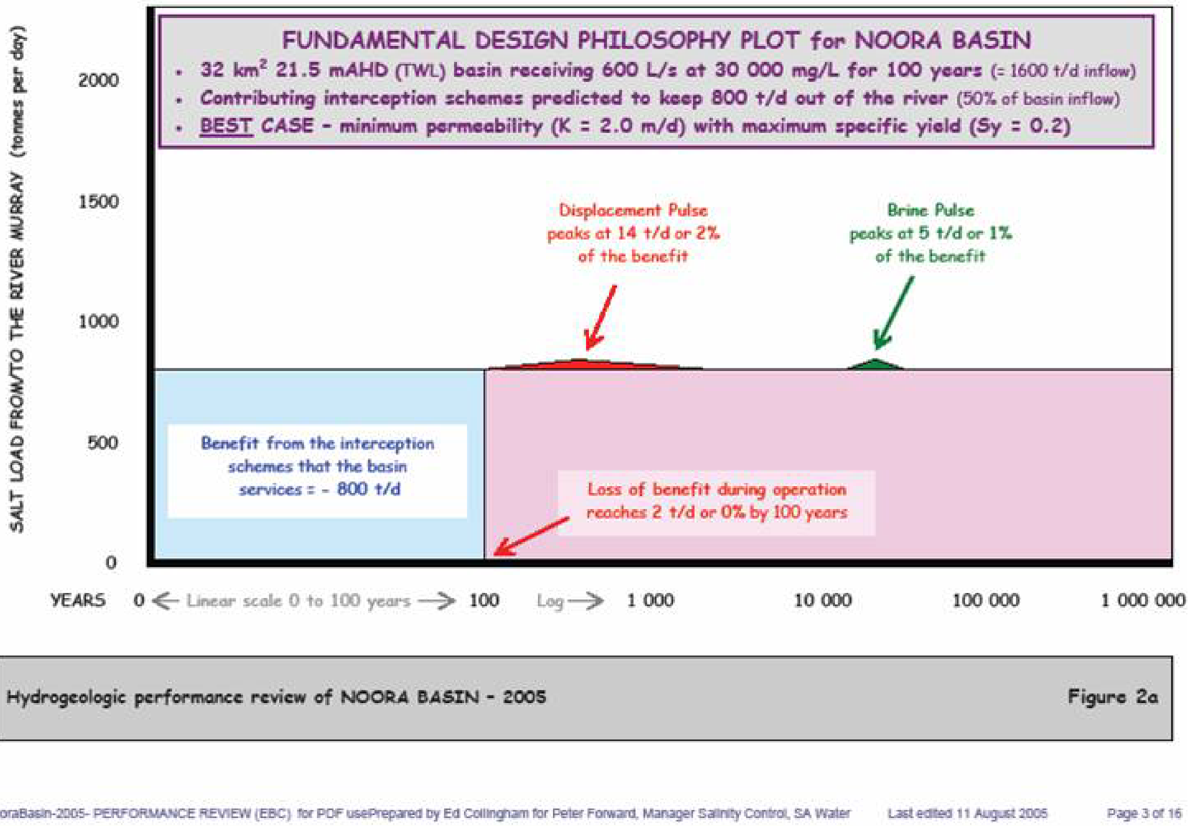


Figure A4. Fundamental design philosophy plot for 300 L/s 19.0 m AHD scenario (from SA Water, 2005)

A4 2006 DWLBC MODELLING

A4.1 Basin modelling

The model set up and methodology used in 2006 has not significantly changed in comparison to the recent 2007 basin modelling, so consequently it is not discussed here, but is provided in detail in DWLBC Report Book 2007/17

The key differences between the 2006 and 2007 basin modelling have been:

- the 2006 basin model used a leakage rate of 0.1 mm/d whereas the 2007 model used a leakage rate of 0.2 mm/d
- the 2006 model used different disposal flow rates to Noora Basin (they were revised slightly in early 2007)
- minor differences to the salinity of disposal water.

A4.2 Groundwater modelling

Details of the groundwater model used by KID in 2006 are provided in greater detail in this report in Section 3. The model used is based on the model developed by Barnett and Yan (2000) to simulate groundwater and salinity impacts from dryland clearing in the Mallee region of SA. Like the basin model of 2006, recent revisions have been made to the groundwater model and different disposal scenarios applied to further improve the prediction of basin operation and groundwater impacts, which forms the main content of this report.

The purpose of this summary section is to highlight differences between the KID groundwater model inputs and results between the 2006 and 2007 work projects.

The 2006 groundwater model applied a combination of model inputs that would tend to produce a conservative 'worst case' impact in terms of potential groundwater level rises as a result of basin operation. This combination comprised a relatively:

- high hydraulic conductivity of 5 m/d
- low specific yield of 0.05
- high leakage rate of 0.4 mm/d (146 mm/y).

These values were largely adopted from the 'worst case' inputs and outputs of the AWE modelling. In the 2006 DWLBC modelling, the leakage rate was made an input to the model rather than an output by simulating the inundated basin area as river cells and assigning a conductance value (8m^2/d) that effectively controlled the river cell flux out to match a leakage rate of 0.4 mm/d.

As the 2006 groundwater model does not simulate the natural ground surface, evapotranspiration was simulated in the model in key areas surrounding the Noora Basin and beneath MSNP by assigning drain cells to low-lying areas where shallow watertables were likely. Elevation values for the drainage cells were assigned after geographic information system based inspection of the same DEMs used by SKM. Figure A5 displays the outlines of the drainage and river cells applied in the groundwater model.

Density-salinity corrections were applied to the basin operating levels for each disposal scenario based on the formulae provided in McCutcheon, Martin and Barnwell (1993).

Predictive modelling was done over 100 years at one-year time steps. The maximum groundwater level rises predicted beneath Victoria ranged between 0.03–0.15 m depending on the disposal scenario modelled. No sensitivity analyses were required as part of the 2006 modelling.

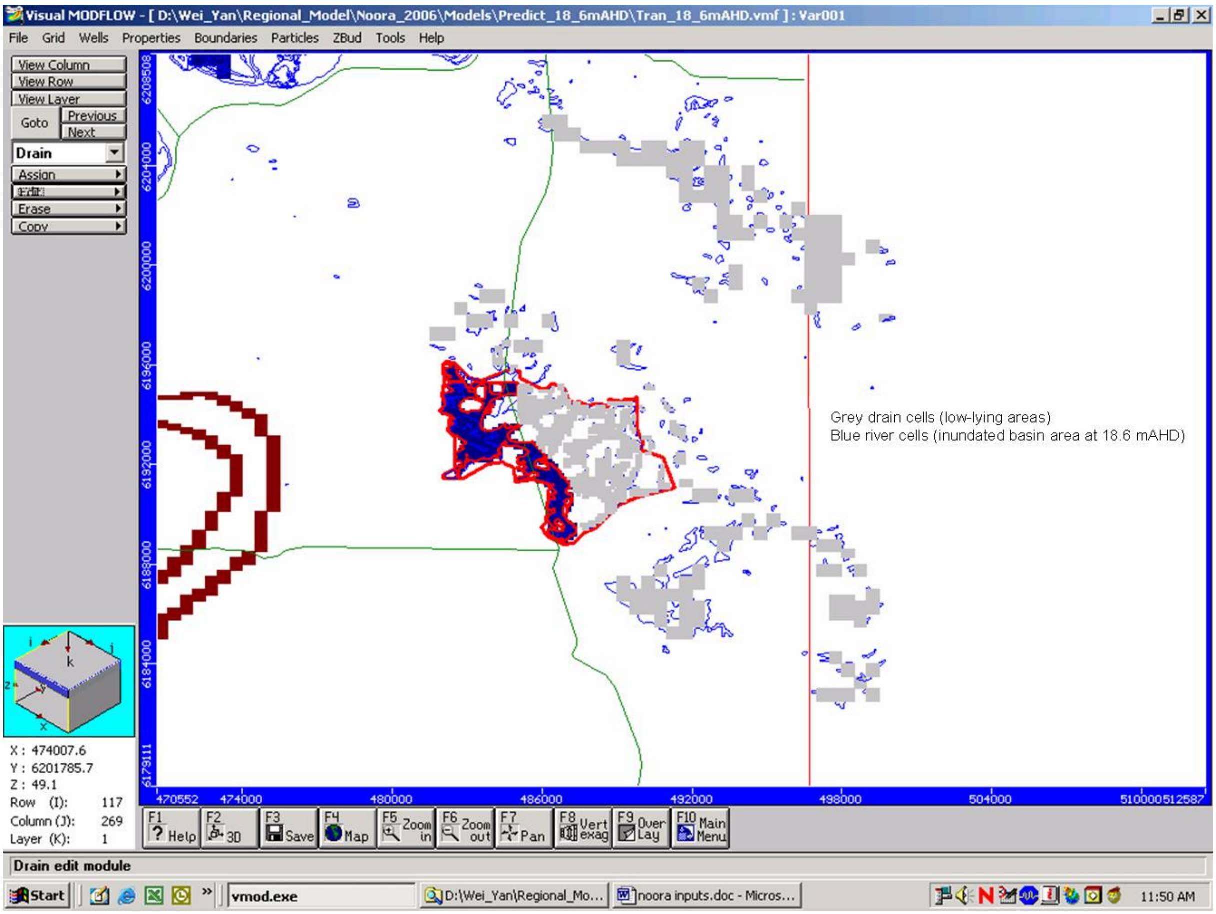


Figure A.5 Drain and river cell locations used in the 2006 DWLBC groundwater model

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

~	approximately equal to
δD	hydrogen isotope composition
$\delta^{18}O$	oxygen isotope composition
^{14}C	carbon-14 isotope (percent modern carbon)
CFC	chlorofluorocarbon (parts per trillion volume)
EC	electrical conductivity (μS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

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 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 resource 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.

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

Bore — *See well.*

CHB — Constant head boundary.

DEM — Digital elevation model.

DWLBC — Department of Water, Land and Biodiversity Conservation.

EC — Electrical conductivity**.** 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C. Commonly used to indicate the salinity of water.

ET — 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: (a) the floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under Part 7 of the *Water Resources Act 1997*; or (b) where paragraph (a) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development Act 1993*, or (c) where neither paragraph (a) nor paragraph (b) 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 the current year.

GL — Gigalitre. One thousand million litres (1 000 000 000).

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 — *See undergroundwater.*

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers. *(See 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 hydrogeology.)*

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

Kh — Horizontal hydraulic conductivity.

KID — Knowledge and Information Division.

Kv — Vertical hydraulic conductivity.

Lake — A natural lake, pond, lagoon, wetland or spring (whether modified or not) and 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.

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land.

Mallee clearance — Clearance of natural vegetation.

MDBC — Murray–Darling Basin Commission.

ML — Megalitre. One million litres (1 000 000).

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

MSNP — Murray Sunset National Park

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

Percentile — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard. The unit is m^2/d.

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

RDS — Regional Disposal Strategy.

REALM — Resource Allocation Model.

Recharge — Irrigation drainage and/or rainfall infiltration reaching the watertable.

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

REM — Resource & Environmental Management Pty Ltd.

RMS — Root mean square.

SKM — Sinclair, Knight and Mertz.

SIS — salt interception scheme designed to intercept the (maximum) groundwater flux and salt load resulting from the pre-1988, post-1988 and future irrigation development.

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir.

TDS — Total dissolved solids.

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

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse.

Well — (a) an opening in the ground excavated for the purpose of obtaining access to undergroundwater; (b) an opening in the ground excavated for some other purpose but that gives access to undergroundwater; (c) a natural opening in the ground that gives access to undergroundwater.

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