Arckaringa Basin Numerical Groundwater Model 2014

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Foreword

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

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

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

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES
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- Mark Keppel
- Graham Green

This report has been reviewed by Lloyd Sampson (Principal Hydrogeologist, DEWNR), Juliette Woods (Principal Groundwater Modeller, DEWNR) and Russell Crosbie (Bioregional Assessment Programme, Groundwater Modelling Discipline Lead, CSIRO).
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Summary

In recognition of the coal mining development potential, data scarcity and water resource significance, the Australian Government through the Department of Environment provided funding to the Government of South Australia’s Department of Environment, Water and Natural Resources to undertake a groundwater assessment of the Arckaringa Basin. Stage 1 of the project, now complete, involved a comprehensive desktop assessment; collating existing hydrogeological and geological data sets, compiling and reinterpreting basin architecture and development of a conceptual model for the Arckaringa Basin. Stage 2 involves detailed desktop and field studies to address key data and knowledge gaps, and development of a numerical groundwater model for the Arckaringa Basin.

The aims of the numerical groundwater modelling exercise were to: aid in understanding the hydrogeological system, estimate the regional scale water balance, test and improve the current understanding and conceptual model, conduct sensitivity testing, and define data and knowledge gaps. A steady state regional scale MODFLOW model has been developed for the Arckaringa Basin that simulates the long term average conditions using available data and current information, and is defined as Class 1 (Barnett et al., 2012). A Class 1 model is defined, as per the Australian Groundwater Modelling Guidelines (Barnett et al., 2012), as a low confidence level model that may have limited data available and as a result calibration of the model may show unacceptable levels of error, or potentially cannot be calibrated. A Class 1 model is considered suitable to be used as a starting point to develop higher classification models or to assess impacts in low value resources.

A steady state model was developed that simulates a long term average condition. The steady state model result for water level has been used as the initial conditions to run a transient model, which simulates the potential impacts of dewatering of a hypothetical mine in the north of the Arckaringa Basin.

A number of simplifications and assumptions have been made to improve numerical stability, due to the complicated geological structure of the basin. Model limitations are closely associated with assumptions, simplifications and availability of the data. It is recommended that the numerical stability is further investigated in future works, however the model is still considered fit for purpose.

A model calibration and confirmation process was conducted to ensure the model simulates the system behaviour and provides water level and flow directions similar to those observed. The model confirms the current conceptual understanding of the basin, indicating that modern-day recharge to the basin may primarily occur via lateral regional inflow through the Great Artesian Basin (GAB) aquifer and basement, and that discharge is mostly via lateral outflow through the GAB aquifer and basement.

A series of sensitivity tests were undertaken to assess the importance of aquifer hydraulic conductivity. The tests provided better understanding of which components drive the system. The results show that model outputs are most sensitive to the hydraulic conductivity of the GAB and Basement aquifer.

A hypothetical mine dewatering scenario was considered. The estimated impact of drawdown is regionally widespread and is related to the horizontal and vertical connectivity between the modelled aquifers. More robust sensitivity testing to support the model is recommended for future works.

The outcome of the modelling exercise is a compiled existing data, information and knowledge package that will be useful for future modelling and investigation projects. It is recommended that the model be upgraded as more data is obtained. The modelling exercise proved valuable in verifying and identifying key knowledge and data gaps, and providing a basis for the planning of future field investigations or activities. Recommendations have been provided in the report for future modelling.
1 Introduction

In 2012, the Australian Government established an Independent Expert Scientific Committee (IESC) on Coal Seam Gas (CSG) and Large Coal Mining (LCM) developments to provide independent, expert scientific advice on the future impact these activities may have on water resources. The IESC is a statutory body under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) which provides scientific advice to the Australian Government on the water-related impacts of coal seam gas and large coal mining development proposals. Under the EPBC Act, the IESC has several legislative functions to:

- Provide scientific advice to the Commonwealth Environment Minister and relevant state ministers on the water-related impacts of proposed CSG or LCM developments
- Provide scientific advice to the Commonwealth Environment Minister on:
  - Bioregional assessments being undertaken by the Australian Government, and
  - Research priorities and projects commissioned by the Commonwealth Environment Minister
- Publish and disseminate scientific information about the impacts of CSG and LCM activities on water resources.

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated on potential water-related impacts of coal seam gas and large coal mining developments. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale. For more information on bioregional assessments, visit <http://www.bioregionalassessments.gov.au>.

The South Australian Department of Environment, Water and Natural Resources (DEWNR), was commissioned by the Australian Government through the Department of the Environment to collate and ground-truth baseline groundwater, surface water and ecology information to inform the Bioregional Assessment Programme in the Lake Eyre Basin. The Lake Eyre Basin (LEB) bioregion (Figure 1.1) has been identified as one of six priority areas for a bioregional assessment across Australia. This report is part of a series of studies forming part of the Arckaringa Basin and Pedirka Basin Groundwater Assessment project. The Arckaringa Basin and Pedirka Basin Groundwater Assessment project is one of three water knowledge projects undertaken by DEWNR in the western Lake Eyre Basin bioregion, including the:

- LEB Rivers Monitoring project
- Arckaringa Basin and Pedirka Basin Groundwater Assessment project
- LEB Springs project.

This report documents the development of a numerical groundwater model for the Arckaringa Basin and forms a key component of the Arckaringa Basin and Pedirka Basin Groundwater Assessment.

1.1 Objectives of the modelling exercise

The development of a groundwater model for the Arckaringa Basin will improve our understanding the hydrogeological system through confirmation of the validity of the current conceptual model, sensitivity testing, and estimation of the regional scale water balance.

The modelling exercise identifies key knowledge and data gaps, which may direct planning of future field investigations or modelling activities. The outcome of the modelling exercise is a package of existing data, information and knowledge that can be considered for future modelling/investigation projects.
Based on project scope, timing, and data availability constraints, the model will not incorporate the small scale level of detail that is required to undertake scenario modelling for purposes of risk assessment, or to predict the impacts of mining activities. However, the model can form a basis for potential improvements and refinements to suit future purposes.

The design of a groundwater model for the Arckaringa Basin is impacted by data availability and data and knowledge gaps. According to The Australian Groundwater Modelling Guidelines (Barnett et al., 2012), the groundwater model developed for Arckaringa Basin is considered a regional scale, elementary model of low complexity, defined as Class 1.

1.2 Review of existing models

A review was undertaken to investigate previous conceptualisation and modelling approaches for simulation of groundwater flow within the Arckaringa Basin and the Western Great Artesian Basin (GAB).

1.2.1 Existing models of Arckaringa Basin aquifers

There are two models that simulate groundwater flow within the aquifers of the Arckaringa Basin. These are the Prominent Hill Mine Groundwater Model (SKM, 2010) and an unpublished numerical groundwater model (AWE).

1.2.1.1 Prominent Hill Mine Groundwater Model (SKM, 2010)

A numerical groundwater model was developed by Aquaterra in 2008 to simulate the impact of activities relating to the Prominent Hill copper-gold mine (Aquaterra, 2008). The model was updated between 2008 and 2010 as new data became available and conceptual understanding was improved. The latest version of the model (PH5) was reported in SKM (2010) and is described below.

The model simulates flow in the south east corner of the basin, in the vicinity of the Billa Kalina sub-basin. The purpose of the model was to simulate the impact of open cut mining (dewatering) and groundwater extraction from the Aries and Virgo water supply borefields, which are located approximately 30 to 60 km south-east of the Prominent Hill mine. Groundwater is extracted from the Boorthanna Formation for water supply to the mine.

Model results suggest that the current configuration of the Aries borefield is capable of meeting a water demand of 26 ML/d for the life of the mine. Model predictions indicate no significant difference in simulated GAB spring flow between pre-development, end of mining, and 100 years post mining (SKM, 2010).

The modelled flux laterally discharging to the general head boundary in the southeast in steady state is used to design boundary conditions for the Stuart Shelf Regional Groundwater Flow Model (SWS, 2010) and represents discharge from the Arckaringa Basin to the Andamooka Limestone of the Stuart Shelf.

1.2.1.2 Unnamed Groundwater Model (AWE)

A groundwater model for the Arckaringa Basin has been developed by Australian Water Environments (AWE). A report describing the development of this model has not yet been published therefore the model cannot be comprehensively reviewed.

1.2.2 Existing models of GAB aquifers

Groundwater modelling of the Great Artesian Basin (GAB) has undergone significant evolution over recent decades (1978 to present). Four models have been developed that simulate groundwater flow across the entire GAB. These models include GABSIM (Ungemach, 1975), GABHYD (Seidel, 1978), GABFLOW (Welsh, 2000) and GABtran (Welsh, 2006). The GABtran model is the only contemporary groundwater model. A brief summary of these models is given below.

1.2.2.1 GABSIM (Ungemach, 1975)

The GABSIM model was developed in 1971 and was the first groundwater model developed to simulate the entire GAB (Ungemach, 1975). It was a two dimensional model with a cell size of 25 km x 25 km and included a simulation period from...
1880 to 1970. The model could not be successfully calibrated as the numerical model was considered an oversimplification of the conceptual model. The model grid was too coarse to realistically represent major recharge processes and the model was over-constrained by boundary conditions.

### 1.2.2.2 GABHYD (Siedel, 1978)

The GABHYD model was developed in 1978 (Siedel, 1978). It sought to improve upon the GABSIM model by updating key input datasets such as aquifer transmissivity. A reasonable calibration could not be achieved in all aquifers. Fundamentally this model suffered from the same problems as GABSIM.

### 1.2.2.3 GABFLOW (Welsh, 2000)

In 2000, a steady state groundwater flow model, GABFLOW, was developed for the entire GAB. GABFLOW was originally developed for the GAB Sustainability Initiative (GABSI). The purpose of the model was to predict changes in artesian pressures in response to rehabilitation of bores and removal of bore drains in the GAB.

GABFLOW was based upon the Habermahl (1980) conceptualisation of the GAB, which considered the GAB aquifer as laterally continuous across the entire GAB. A MODFLOW model was developed that simulated groundwater flow in a single layer representing the main aquifer (Cadna-owie Formation, Algebuckina Sandstone and equivalents), with interaction between overlying and underlying GAB aquifers modelled as vertical leakage. Model cell size was 5 km x 5 km and the horizontal hydraulic conductivity of the aquifer ranged between 0.001 m/d and 40 m/d.

GABFLOW simulated the hydrodynamics of the basin as it was in 1960 and predicted the pressure head distribution after the system has reached equilibrium, but did not indicate how long this may take. The model was calibrated with Root Mean Square (RMS) error of 4.5 m. The horizontal hydraulic conductivity of the aquifer was demonstrated as the most sensitive of the model parameters. The model predicted the water saved and head recoveries for a number of scenarios related to the impact of GABSI.

### 1.2.2.4 GABTran (Welsh, 2006)

GABFLOW model was upgraded into a transient groundwater model, GABTran (Welsh, 2006). Model layering remained unchanged from GABFLOW, however refinements were made to aquifer hydraulic parameters and boundary conditions. The calibrated horizontal hydraulic conductivity of the aquifer ranged between 0.1 m/d and 20 m/d. Modelled recharge rates were approximately halved which was in agreement with more recent recharge estimations.

The single layer model was calibrated to groundwater levels between 1 January 1965 to 31 December 1999, with Scaled Root Mean Square (SRMS) error of 2.8%. The model results suggested that discharge was greater than recharge and the system was not in equilibrium. Scenarios were carried out to test the impact of GABSI.

GABTran has recently been used to estimate the impact of climate and groundwater development on groundwater levels in the GAB, as part of the Great Artesian Basin Water Resource Assessment (Welsh et al., 2012).

GABtran is regarded as the only contemporary model for the GAB. It simulates flow within the Cadna-owie Formation/Algebuckina sandstone of the GAB but does not simulate interaction with older and deeper aquifers that can exist in underlying basins, such as the Arckaringa Basin.

### 1.2.2.5 Other models incorporating the GAB

There are three groundwater models that have been developed to simulate flow within the western Eromanga Basin. These include the Prominent Hill model (SKM, 2009), the Olympic Dam borefield model (Berry, 2005) and the Olympic Dam dewatering model (BHPB, 2009). The Olympic Dam models have not been reviewed for this report, as they do not overlap the Arckaringa bioregion. A review of these groundwater models can be found in Smith and Welsh (2011).
1.3 Project scope

The outcomes of this project were:

1. a compilation of the current data for the Arckaringa Basin into a model
2. to use the model to test the understanding of the conceptualisation of the basin.

To achieve these outcomes the project can be broadly split into the following tasks:

1. compile existing data
2. identify knowledge and data gaps
3. use existing data to construct a groundwater model
4. using available monitoring data, calibrate the model to a standard consistent with a Class 1 model
5. confirm the model simulates the known flow processes consistent with the conceptualisation
6. perform a series of sensitivity tests on the model to test the sensitivity of the model to changes in parameter values
7. identify areas for future work that will improve the model and decrease uncertainty.
2 Hydrogeology and hydrology of the Arckaringa Basin

The report developed at the conclusion of Stage One summarises and evaluates available data and current conceptual understanding for the Arckaringa Basin (Wohling et al., 2013). This section summarises key aspects of the hydrogeology and hydrology and includes new information gathered since the completion of Stage 1 for the modelling exercise.

2.1 Location and topography

The Arckaringa Basin is located in the far north region of South Australia approximately 600 km north to north-west of Adelaide and approximately 400 km south of Alice Springs (Figure 2.1). The spatial extent of the Arckaringa Basin covers an area of approximately 100 000 km². The topography of the study region is largely flat-lying or controlled by dune field development. The dominant landscape features of the Arckaringa Basin are gravelly (“gibber”) plains and tablelands. Elevation ranges between 20 and 380 m AHD, with a mean elevation of approximately 180 m AHD.

2.2 Climate

The climate of central Australia has been described by Allan (1990) and McMahon et al. (2005) as arid; while Stern et al. (2000) describes the region as ‘desert’. Average maximum peak-summer monthly temperatures range between 36.1°C and 39.5°C, although daily maximums are regularly above 40°C. In contrast, the minimum peak-winter monthly temperatures range from 4.9°C and 6.4°C, although daily minimums may reach below 0°C.

Pan evaporation range between 2500 mm/y and 3000 mm/y. Generally, southern-derived winter rainfall is the dominant source of precipitation in the Arckaringa Basin. A distinctive rainfall gradient occurs across the basin with average annual rainfall generally decreasing from 200 mm/y in the north–north-west to 150 mm/y in the east–south-east (Figure 2.2).
NOTE: Outlier extents have not been incorporated into the groundwater model and are not shown in subsequent figures in the report.
Figure 2.2  Arckaringa Basin average annual rainfall
2.3 Regional geology and hydrogeology

The Arckaringa Basin is a sedimentary basin comprising Carboniferous to Permian sediments, the majority of which are subcropping. The basin unconformably overlies the Warburton and Officer Basins and Proterozoic basement rock. The Arckaringa Basin unconformably underlies the Mesozoic Eromanga Basin, synonymous with the Great Artesian Basin within the study extent. Relations between the Arckaringa Basin and other sub-geological basins are given in Figure 2.3.

The western portion of the Arckaringa Basin is thin, geologically simple and only moderately faulted whereas the eastern portion of the basin is more geologically complex, with structure influenced by faulting and glacial scouring (Figure 2.4). The Arckaringa Basin is bound to the east by the Peake and Denison Inlier (Davenport Range), to the south by the Gawler Ranges and Stuart Shelf and to the north and west by the Officer Basin.

There are a number of depocentres in the west of the basin that are located around basement highs (Figure 2.4). The deepest areas of the basin are within the Boorthanna Trough, Billa Kalina sub-basin, Penrhyrn Trough, Phillipson Trough, Willira Trough and West Trough.

There are three major recognised hydrogeological formations within the Arckaringa Basin: Mount Toondina Formation, Stuart Range Formation and the underlying Boorthanna Formation. Drilling investigations have focused on the eastern portion of the basin and very little is known about the hydrogeological characteristics of the western portion of the basin. Coal seams have been encountered within the upper Mount Toondina Formation during drilling in the northern Arckaringa Basin.

Table 2.1 provides a summary of the hydrogeological formations encountered with depth within the Arckaringa Basin study extent (from Keppel et al., 2013 and Wohling et al., 2013). A detailed description of the major geological and hydrogeological formations in the Arckaringa Basin are presented in Section 2.4.
Figure 2.3 Adjoining geological basins
Figure 2.4  Arckaringa Basin physiography
### Table 2.1 Description of geological and hydrogeological formations within the study extent (Keppel et al., 2013 and Wohling et al., 2013)

<table>
<thead>
<tr>
<th>Geological Basin</th>
<th>Hydrostratigraphy</th>
<th>Geological Unit(s)</th>
<th>Age</th>
<th>Depositional Environment</th>
<th>Description of Lithology</th>
<th>Hydrogeological Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billa Kalina</td>
<td>Cainozoic</td>
<td>Tertiary to Quaternary</td>
<td></td>
<td>Fluvial and lucastrine</td>
<td>-</td>
<td>Discrete aquifers can occur</td>
</tr>
<tr>
<td>Great Artesian Basin</td>
<td>-</td>
<td>Bulldog Shale</td>
<td>Cretaceous to Jurassic</td>
<td>Low energy marine</td>
<td>Marine shaley mudstone and silt</td>
<td>Aquitard</td>
</tr>
<tr>
<td></td>
<td>J-K aquifer</td>
<td>Cadna-owie Formation</td>
<td>Mid-Cretaceous to Jurassic</td>
<td>Marine transitional and terrestrial</td>
<td>Fine to coarse grained sandstone and siltstone</td>
<td>Aquifer</td>
</tr>
<tr>
<td>Arckaringa Basin</td>
<td>-</td>
<td>Mount Toondina Formation</td>
<td>Permian (195 – 290.1 Ma)</td>
<td>Non-marine lagoons and swamps with intermittent fluvial</td>
<td>Carbonaceous shale, coal and interbedded sandstones and siltstone</td>
<td>Potential aquifers and aquitards within the one formation</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Stuart Range Formation</td>
<td>Permian (298.9 – 290.1 Ma)</td>
<td>Brackish restricted marine with periods of anoxic, bottom water conditions</td>
<td>Marine mudstones, siltstones and shales</td>
<td>Potential aquitard</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Boorthanna Formation</td>
<td>Permian (298.9 – 295.0 Ma)</td>
<td>Marine and glacial</td>
<td>Upper unit a marine conglomerate and sandstone ; lower unit is boulder clays (diamictite)</td>
<td>Potential aquifers and aquitards within the one formation</td>
</tr>
<tr>
<td>Warburton Basin</td>
<td>Basement</td>
<td>Finke Group</td>
<td>Cambrian to Devonian</td>
<td>Epeiric to marine</td>
<td>Sedimentary basin; poorly understood</td>
<td>Poorly understood</td>
</tr>
<tr>
<td>Officer Basin</td>
<td>Basement</td>
<td>Murnaroo Formation</td>
<td>Cambrian to Ordovician</td>
<td>?</td>
<td>Sandstone</td>
<td>Poorly understood</td>
</tr>
<tr>
<td></td>
<td>Basement</td>
<td>Relief Sandstone</td>
<td>Cambrian to Ordovician</td>
<td>Sandstone</td>
<td>Sandstone</td>
<td>Poorly understood</td>
</tr>
<tr>
<td></td>
<td>Basement</td>
<td>Trainor Hill Sandstone</td>
<td>Cambrian to Ordovician</td>
<td>Sandstone</td>
<td>Sandstone</td>
<td>Poorly understood</td>
</tr>
<tr>
<td></td>
<td>Basement</td>
<td>Mt Chandler Sandstone</td>
<td>Cambrian to Ordovician</td>
<td>Sandstone</td>
<td>Sandstone</td>
<td>Poorly understood</td>
</tr>
<tr>
<td></td>
<td>Basement</td>
<td>Proterozoic and Archaean</td>
<td>Cambrian to Ordovician</td>
<td>Sandstone</td>
<td>Sandstone</td>
<td>Poorly understood</td>
</tr>
</tbody>
</table>
2.4 Basin geology and hydrogeology

In the Arckaringa subregion, the following seven major geological and hydrogeological units were considered in the modelling project:

- Cainozoic
- Eromanga Basin (Bulldog Shale and J-K aquifer)
- Arckaringa Basin (Mount Toondina Formation, Stuart Range Formation and Boorthanna Formation)
- Basement.

Basin cross-sections which demonstrate the major hydrogeological units are shown in Figure 2.5.

2.4.1 Cainozoic

The most recent phases of sedimentation are predominantly composed of braided fluvial and lacustrine sediments. Cainozoic sedimentation may be divided into two depositional episodes; sedimentation that occurred during the Paleogene and Neogene prior to up-warping at 15 to 5 Ma and those associated with the current hydrological system; both phases may provide discrete aquifers. Two sedimentary basins of Paleogene and Neogene age occur in the vicinity of the Arckaringa subregion, namely the Billa Kalina Basin and Lake Eyre (geological) Basin.

The Billa Kalina Basin is a small terrestrial basin composed of fluvial and lacustrine-derived sandstone, clay and dolomite that partly overlies the south-eastern Arckaringa Basin. Sediments associated with the Lake Eyre (geological) Basin largely occur to the east of the Arckaringa subregion. These were primarily deposited in three phases of braided fluvial and lacustrine sedimentation.

2.4.2 Eromanga Basin

The Great Artesian Basin encompasses a number of smaller sedimentary basins, however in South Australia it is synonymous with the Eromanga Basin. Geologically, the GAB describes a terrestrial to marine Cretaceous–Jurassic hydrogeological super-basin that covers much of eastern and central Australia.

GAB sediments conformably overlie the majority of the Arckaringa Basin, except along the west and south-west margin. In the vicinity of the Arckaringa Basin, hydrogeological units of primary importance are the Bulldog Shale and Cadna-owie Formation and Algebuckina Sandstone (J-K aquifer).

2.4.2.1 Bulldog Shale

The Bulldog Shale is considered the main confining unit of the GAB within the study area. The Bulldog Shale may be absent or thin along the west, south-east and south-west margins of the Arckaringa Basin (Keppel et al., 2013). Areas where the Bulldog Shale is absent may be important when determining recharge to the J-K aquifer or Permian aquifers of the Arckaringa Basin.

Little information is available regarding the hydraulic properties of the Bulldog Shale. Estimates of vertical hydraulic conductivity range between $3.46 \times 10^{-9} \text{ m/d}$ and $8.64 \times 10^{-9} \text{ m/d}$ (Keppel et al., 2013). Estimated rates of diffuse discharge may range between $3 \times 10^{-4} \text{ mm/y}$ and $5 \times 10^{-4} \text{ mm/y}$, but can be orders of magnitude higher where preferential flow paths occur along fractures and faults (Love et al., 2013b).

2.4.2.2 J-K aquifer

The Cadna-owie Formation and Algebuckina Sandstone are considered a single aquifer, named the J-K aquifer, within the study extent.

In the vicinity of the non-artesian, south-eastern margin of the GAB, typical yields vary between 0.1 L/s to 6.0 L/s, although larger yields of up to 130 L/s have been reported Olympic Dam Wellfield B. The hydraulic conductivity of the J-K aquifer along the western margin of the GAB ranges from a typical lower value of between 0.1 m/d and 1.6 m/d to a typical higher value of...
between 7 m/d and 20 m/d (Keppel et al., 2013). Storage coefficient ranges between $7 \times 10^{-6}$ to $7 \times 10^{-3}$ for the whole basin, with a mean value of $2.5 \times 10^{-4}$ (Keppel et al., 2013).

A potentiometric surface for the J–K aquifer is given in Figure 2.6 (after Keppel et al., 2013). Inferred direction of regional groundwater flow is from the west and north-west along the margin of the Eromanga Basin toward the location of the springs in the east and south-east. The steep hydraulic gradient in the north-west is coincident with a thinning and elevated position of the GAB sediments along the margins of the aquifer and potential increase in upward leakage from the deeper units.

The J–K aquifer is unsaturated along the western extent of the Arckaringa Basin and close to areas of basement outcropping such as the Davenport Ranges. Within the Billa Kalina sub-basin, in the south east of the Arckaringa Basin, the J–K aquifer is thin and either unsaturated or sub-artesian. There are limited measurements available for the J–K aquifer western half of the Arckaringa Basin.

### 2.4.3 Permian aquifers and aquitards

Permian sediments deposited within the Arckaringa Basin are hydrogeologically defined as the Mount Toondina Formation, the Stuart Range Formation and the Boorthanna Formation. These formations can possess significant heterogeneity and discrete aquifers and aquitards may exist within each of these formations. Drilling investigations in the past have focused on the main depocentres in the eastern portion of the basin. There is limited knowledge of the hydrogeology in the western half of the basin.

#### 2.4.3.1 Mount Toondina Formation

The Mount Toondina Formation disconformably underlies the J–K aquifer as well as palaeochannels that occur in the north of the basin. The Mount Toondina Formation overlies the Stuart Range Formation where present and may directly overly the Boorthanna Formation where the Stuart Range Formation is absent.

Figure 2.4 provides the extent of formations within the Arckaringa sub region.

The Mount Toondina is divided into upper and lower units based on sedimentary characteristics. The Upper Mount Toondina Formation consists of grey carbonaceous shales, coals and interbedded sandstones, siltstones and sandy shales. The Lower Mount Toondina Formation is less carbonaceous and slightly sandier with clay and shales present. The Lower Mount Toondina Formation may have similar sedimentary properties to the underlying Stuart Range Formation.

Estimates of porosity for sandstone units within the Mount Toondina Formation range between 4% and 36.6%. Packer tests undertaken in the Upper Mount Toondina Formation by Coffey and Partners (1983) indicate that the hydraulic conductivity of the coal seams may be higher than that of the sedimentary interbeds. The hydraulic conductivity of the coal seams is estimated as being low to moderate (0.9 m/d to 0.009 m/d) whereas the interbedded sediments were found to have very low to low hydraulic conductivity ($9 \times 10^{-5}$ m/d to $9 \times 10^{-4}$ m/d). This field testing indicates that discrete aquifers and aquitards may exist within the Upper Mount Toondina Formation. There are no hydraulic conductivity estimates available for the Lower Mount Toondina Formation.

It is recognised that the upper and lower units of the Mount Toondina Formation may have significantly different sedimentary properties and hydraulic characteristics. However in the absence of available hydrogeological data, we will consider the Mount Toondina as a single unit.

#### 2.4.3.2 Stuart Range Formation

The Stuart Range Formation underlies the Mount Toondina Formation where present, and disconformably underlies the J–K aquifer where the Mount Toondina Formation is absent in the southeast of the basin. The Stuart Range Formation overlies the Boorthanna Formation where present, and can overlie basement rock where the Boorthanna Formation is absent in the centre of the basin.

The Stuart Range Formation typically consists of marine mudstones with siltstones and shales. The extent of Stuart Range Formation may be important when determining area of recharge to the Boorthanna Formation.
The Stuart Range Formation is relatively homogenous and is considered a regional scale aquitard. The properties of the aquitard have been described as anywhere between effective (REM 2005; SKM 2009) to leaky (Kellett et al., 1999; Belperio 2005). Short term aquifer testing at the Prominent Hill borefield demonstrated a limited connectivity between the J–K aquifer and Boorthanna Formation which could indicate the effectiveness of the Stuart Range Formation as an aquitard. A single estimate of vertical hydraulic conductivity for the Stuart Range Formation is estimated at $1 \times 10^{-4}$ m/d from aquifer testing undertaken by Howe et al. (2008).

2.4.3.3 Boorthanna Formation

The Boorthanna Formation is comprised of sediments deposited during the late Carboniferous to early Permian age. The Boorthanna Formation underlies the Stuart Range Formation where present or the Mount Toondina Formation where the Stuart Range Formation is absent. The Boorthanna Formation may subcrop along basin margins such as in the east near the Davenport Ranges and in the southeast of at the margin of the Billa Kalina sub-basin. The Boorthanna Formation overlies sediments associated with the Warburton and Officer Basins, or overlies older basement rock. Seismic data infers that the Boorthanna Formation may be laterally disconnected north and south of the Boorthanna Fault. (Figure 2.5)

The Boorthanna Formation is divided into upper and lower units on the basis of sedimentary characteristics. The Upper Boorthanna Formation consists of interbedded marine clastics with grain size ranging from silt to boulders. The Lower Boorthanna Formation consists of glaciogene sandy to boulder claystone diamictite, and its deposition is limited to deeper areas of the basin.

Discrete aquifers and aquitards may exist within the Boorthanna Formation, with the possibility of aquifers existing as semi-discontinuous “pods” (SKM, 2009). Secondary porosity (fracturing) may be important for groundwater supply, with Kellet et al. (1999) observing well yields between <0.1 L/s to 5 L/s in the Boorthanna Formation in the south-east of the basin. The upper Boorthanna Formation is a recognised aquifer within the Billa Kalina sub-basin where groundwater is extracted to supply water to the Prominent Hill Mine. The estimated horizontal hydraulic conductivity of the Boorthanna Formation ranges between 0.2 m/d and 5 m/d.

2.4.3.4 Permian Aquifer Interactions

Significant heterogeneity can exist within the Mount Toondina Formation and Boorthanna Formation. In the absence of available hydrogeological data, the Mount Toondina Formation will be considered an aquifer, the Stuart Range Formation will be considered an aquitard and the Boorthanna Formation will be considered an aquifer. Permian sediments deposited south of the basin (such as Mulgathing Trough) are considered to be hydrogeologically separated from the main basin, and any groundwater occurring in these areas is disconnected from the groundwater system of the Arckaringa basin.

Most water level data is focused in the east and south-east of the basin, with few measurements in the west and north-west. The direction of regional groundwater flow is assumed to occur from recharge areas in the west and northwest (where the Bulldog Shale is absent and the J aquifer is unsaturated) toward the Stuart Shelf and GAB springs in the east and south-east. Depth to groundwater immediately west of the Davenport Ranges is at or near ground surface, which may be related to mountain system recharge (Love et al., 2013). Recharge to the Boorthanna Formation aquifer where it sub-crops may be responsible for the elevated groundwater levels along the southern basin margin.

For the purposes of this investigation, basement includes sedimentary deposits in the Warburton Basin, Officer Basin and Stuart Shelf, as well as Proterozoic and Achaean rock, which outcrops along the Davenport Ranges. The Warburton Basin is a
large pericratonic, epeiric to marine sedimentary basin that underlies the Arckaringa Basin in the north. Formation ages are primarily Cambrian to Ordovician, and the hydrogeological characteristics of formations within the Warburton Basin are poorly understood. The Officer Basin is a large sedimentary basin that has similar origins to that of the Warburton Basin and sediments are primarily Cambrian to Ordovician age. The Officer Basin borders and partly underlies the western margin of the Arckaringa Basin, and may be important to recharge processes within the Arckaringa Basin aquifers. The Stuart Shelf represents largely marine deposition within a pelagic and continental shelf environment and include limestone, sandstone, shale, quartzite, dolomite, tillite, conglomerate and volcanics; and occurs along south-east of the Arckaringa subregion.
Figure 2.5 Interpreted cross-sections based on surfaces from seismic and well data (Wohling et al., 2013)
Figure 2.6  Potentiometric surface for J-K aquifer (GAB) (Keppel et al., 2013)
Figure 2.7  Potentiometric surface for Mount Toondina aquifer
2.5 Hydrology

This section describes the surface water features within the Arckaringa Basin which may interact with groundwater. These include various rivers and creeks as potential sources of (direct or indirect) recharge to the basin, as well as evaporative discharge features such as salt pans in the vicinity of Margaret Creek. Springs occurring near the eastern margin of the basin are considered groundwater discharge features.

2.5.1 Creeks and river systems

The surface water system in the region is characterised by a network of ephemeral rivers and creeks that drain concentrically east towards Kati Thanda-Lake Eyre or one of the other large playas in the region (Figure 2.1). The majority of flow events are short lived, relatively small and occur on either an annual or bi-annual basis (Fulton, 2012).

There are a number of creek systems within the eastern half of the Arckaringa Basin. Where aquifers outcrop and intersect these creeks, aquifers may be recharged. Recharge to the Boorthanna Formation aquifer from Millers Creek may occur where the Boorthanna Formation is shallow and there is little or no Stuart Range Formation present (SKM, 2010). Groundwater salinity measurements in the Boorthanna Formation aquifer in the Billa Kalina sub-basin indicate a freshening of the groundwater system, in an easterly direction, coinciding with Millers Creek.

2.5.2 Salt pans at Margaret Creek

Previous hydrogeological investigations within the Billa Kalina sub-basin have highlighted the potential for groundwater occurring within the J-K aquifer to discharge to salt pans in the vicinity of Margaret Creek (SKM, 2010). Discharge from the Boorthanna Formation aquifer to the overlying J-K aquifer within this area may indirectly contribute to the evaporative discharge.

2.5.3 GAB springs

There are a number of significant spring wetland environments occurring along the eastern margin of the Arckaringa Basin and further east. These spring environments have cultural and spiritual significance for the indigenous people of the region, as well as supporting a number of rare and endemic ecosystems. These groundwater dependent ecosystems support a unique population of flora and fauna.

Hydrochemical and groundwater level data indicate that western GAB spring waters reflect mixing of western, northern and southern GAB flow paths with fluids sourced from horizontal flow paths as well as deeper (vertical) flow paths (Love et al., 2013). West of the Peake and Denison Inlier, discharge to the springs is most likely sourced from recharge areas along the west and northwest basin margins, with groundwater discharging primarily from the J-K aquifer, with minor but important contributions from Permian aquifers. Some groundwater flow to springs around the Peake and Denison Inlier are sourced from the mountain block area (Love et al., 2013). Hydrochemical evidence suggests that the groundwater system west of the Billa Kalina fault is not connected to the springs located east of the fault (SKM, 2010).

2.6 Diffuse recharge

Diffuse recharge is defined as recharge in response to rainfall infiltrating the soil surface and percolating through the unsaturated zone to the water table. Investigation of potential diffuse recharge occurring within the western GAB suggests that minimal diffuse recharge has occurred over the last 10 000 years and ephemeral river recharge may be the only source of modern day recharge to the GAB (Keppel et al., 2013).

Diffuse recharge to the Permian aquifer(s) may have occurred in the past, or is currently occurring (albeit at a slow rate), along the west and north-west margin of the Arckaringa Basin, occurring where the Bulldog Shale is absent or thin. The area over which diffuse recharge is occurring or has occurred in the past is not known with certainty. Diffuse recharge to the Permian aquifer(s) may occur in other areas of the basin where the aquifer subcrops and is shallow.
Mountain system recharge in the vicinity of the Peake and Denison Inlier may provide recharge to the Permian aquifer west of the Davenport Ranges, and to the J-K aquifer east of the Davenport Ranges. Similarly, mountain system recharge is thought to occur at the Musgrave Ranges, located on the north–west margin of the Arckaringa Basin. Mountain system recharge is likely to have occurred in the past and is still occurring (Love et al., 2013).

Modern day recharge is thought to be less than discharge, and the basin is in a state of long term pressure decline as a result of declining rainfall over the recent climate cycle (last 10 000 years or earlier). Diffuse recharge has been estimated from a chloride mass balance (CMB) approach at between 0.05 to 0.22 mm/y suggesting that modern diffuse recharge is negligible. Diffuse recharge is thought to have been declining at a rate of 1 mm/y every 1000 years. Outcomes from a numerical modelling exercise suggests that a change to hydraulic conditions in the GAB may take 50 000 to 60 000 years to stabilise (Keppel et al., 2013).

### 2.7 Groundwater pumping

Groundwater is extracted from the Boorthanna Formation aquifer within the vicinity of the Aries Borefield in the Billa Kalina sub-basin for supply to Prominent Hill mine. OZ Minerals, who own and operate the mine, have licence to extract 26 ML/d from the Boorthanna Formation aquifer. There is no other known users of groundwater extracted from the Permian aquifers.

There are a number of pastoral bores within the Arckaringa Basin that extract groundwater from the J-K aquifer. Volumes of groundwater extracted from the J-K aquifer within the study extent are not known with certainty.

### 2.8 Groundwater salinity

Groundwater salinity measured from bores targeting the Permian aquifers range from 625 to 25 024 mg/L. Observed salinities in the Mount Toondina and Boorthanna formations are shown in Figure 2.8. Salinities above 100 000 mg/L occur near the southern margin of the basin and are associated with groundwater extracted from coal bearing units within the Mount Toondina Formation. Fresher salinities are encountered in wells immediately west of the Davenport Ranges which may be associated with mountain system recharge.
Groundwater Salinity (mg/L)

<table>
<thead>
<tr>
<th>Mount Toondina Formation</th>
<th>Boorthanna Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 - 2000</td>
<td>10001 - 20000</td>
</tr>
<tr>
<td>2001 - 5000</td>
<td>&gt; 200000</td>
</tr>
<tr>
<td>5001 - 10000</td>
<td></td>
</tr>
<tr>
<td>&gt; 200000</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.8 Groundwater salinity for Permian aquifers
2.9 Conceptual model

The shape and structure of the basin is influenced by faults and glacial scouring. The most significant faults are the Boorthanna Fault and Billa Kalina Fault. Faulting may displace sediments and influence groundwater flow, however mapping indicates that in general faulting is minimal within the study area and that flow systems are largely unaffected.

2.9.1 Flow direction

Regional groundwater flow direction is generally occurring from the west and north-west along basin margins to the east and south-east. In the south-east portion of the Arckaringa Basin groundwater flow in the J–K aquifer is generally toward the east and is influenced by discharge to the springs, whereas groundwater flow in the Permian aquifer is generally toward the south-east and discharge is to the Stuart Shelf.

2.9.2 Aquifer interaction

Significant heterogeneity can exist within the Mount Toondina Formation and the Boorthanna Formation, with formations divided into sub-units based on lithology. These formations may contain discrete aquifers and aquitards. Aquifers within the Boorthanna Formation may exist as discrete “pods” that have limited lateral extent. The coal deposits within the upper Mount Toondina Formation may have significantly higher horizontal hydraulic conductivity than the sedimentary interbeds. The Stuart Range Formation is considered more homogenous and is an effective aquitard.

In the absence of available hydrogeological data, the Mount Toondina Formation will be considered an aquifer, the Stuart Range Formation will be considered an aquitard and the Boorthanna Formation will be considered an aquifer. Faulting and fracture zones may enable vertical connectivity between the J–K aquifer and Permian aquifers, particularly along the eastern margin of the basin, where previous research has demonstrated that deeper groundwater systems may contribute to spring discharge.

2.9.3 Recharge

It is postulated that diffuse recharge is currently occurring (albeit at very low rates), or has occurred in the past, along the west and northwest margin of the basin. Diffuse recharge to the Permian aquifer may also occur in other areas of the basin, including where the aquifer subcrops and is shallow, such as along basin margins. Water level and salinity data support the concept of recharge to the Permian aquifer due to mountain system recharge along the Davenport Ranges. It is presumed that diffuse recharge has been declining over the recent climate cycle (last 10 000 years or earlier) due to reduced rainfall. According to current information, modern diffuse recharge is low (less than 0.2 mm/y).

Other mechanisms for recharge include lateral inflow from the Officer Basin along the western margin of the basin and surface water recharge in the east of the basin. Surface water recharge may occur where outcropping aquifers intersect rivers and creeks, such as Millers Creek in the Billa Kalina sub-basin. This may be the primary mechanism for modern-day recharge to the basin.

2.9.4 Discharge

It is considered that groundwater within the J–K aquifer discharges to springs, salt pans, salinas and pumping wells and artesian wells. The Bulldog Shale controls the rate of vertical discharge from the J–K aquifer to shallower aquifers within the Cainozoic. Previous investigations suggest that rates of diffuse discharge through the Rolling Downs Group (Bulldog Shale) are low, although preferential flow can occur along fractures. There may also be (downward) vertical discharge to the Mount Toondina Formation.

Groundwater within the Permian aquifer(s) is considered to discharge to the J–K aquifer where the Stuart Range is thin or absent (i.e. Boorthanna Formation is in direct contact with the J–K aquifer), or where faulting and fracture zones may influence vertical connectivity. Previous research has highlighted the potential for some spring flow to be sourced from Permian aquifers. Most groundwater flow within the Permian aquifers is expected to discharge laterally to the Stuart Shelf. Discharge is known to occur through GAB springs to the east of the Arckaringa Basin, however, rates of discharge are uncertain.
3 Model construction

The aims of the modelling exercise is to test the validity of the current conceptual understanding of the Arckaringa Basin, estimate the regional scale water balance, confirm the current understanding of the hydrogeological system, and conduct sensitivity testing.

An existing data, knowledge and information package is compiled through the modelling process which can be used for future modelling projects. The modelling exercise was also a process to verify and identify key data and knowledge gaps, which can direct future planning of field investigations in the Arckaringa Basin.

The groundwater model developed for Arckaringa Basin is considered as a regional scale, elementary model, defined as Class 1 (Barnett et al., 2012).

3.1 Modelling reference group

A modelling reference group was formed at the commencement of the project. The purpose of the reference group was to fill in knowledge gaps where possible and provide feedback regarding conceptualisation of the groundwater flow system, modelling approach and model development.

The reference group acknowledged that the design of the groundwater model for the Arckaringa Basin was consistent with the aims of the modelling exercise, data and information available. Modelling assumptions, simplifications and approach were discussed and agreed to by the reference group, such as:

- Model layering
- Selection of aquifer and aquitard parameters and the modelling process
- Regional boundary conditions representing regional flow into and out of the model domain
- Declining diffuse recharge rate
- Approach to sensitivity testing and variation of parameters and stresses
- Non hydrogeologically continuous Permian units that exist outside the main extent of the Arckaringa Basin, along the southern boundary of the basin, have not been included in this model.

The reference group acknowledged that the groundwater model developed for the Arckaringa Basin was an adequate starting point, and that the model should be refined in the future as more data is gained to better constrain the model and improve the representation of the physical system.

3.2 Modelling package and user interface

MODFLOW was selected as the numerical code for groundwater flow modelling of the Arckaringa Basin. MODFLOW is a three-dimensional finite difference code developed by the US Geological Survey (McDonald and Harbaugh 1988) and it is the most used groundwater flow code worldwide. It was chosen for reasons of reliability, consistency, stability and to fit the purpose for this project.

The standard version of MODFLOW simulates flow exclusively within the saturated zone and no density impact is considered. Density effects due to groundwater temperature may influence flow in the aquifers of the Arckaringa Basin. It was considered that, due to the magnitude of uncertainty in key processes and measured parameters, the substantial additional effort required to simulate effects of density would not improve model accuracy.

The MODFLOW-SURFACT™ (Version 4; HydroGeoLogic, Inc. 2011) package, an extension of the standard MODFLOW package, has been used to simulate both saturated and unsaturated flow conditions using the pseudo-soil function. Modflow-Surfact is well suited to problems where there exists thin layers or dry cell issues which occur in the modelled region.
The numerical solver chosen was the PCG5 solver, with a head change criterion of 0.001 m. Newton-Raphson linearisation with backtracking has been implemented in the solver as a result of difficulties encountered with model convergence.

Groundwater Vistas (Version 6, Rumbaugh & Rumbaugh, 2000) was selected as a pre and post processor and the Visual MODFLOW package was used to assist in model testing and to develop figures and 3D visualisations for the report.

### 3.3 Model domain and grid

The model domain simulates an area 555 km east–west by 496 km north–south, and the GDA 1994 Lambert coordinates of the model origin are E695000 N2124000 (Figure 3.1). As common modelling practice, the model domain was designed larger than the basin. It includes regions situated outside of the Arckaringa Basin at a minimum distance of 7 km from the basin boundaries.

The rectangular model grid was divided into 1110 columns, 817 rows, and uniform model grid of 500 m × 500 m which was considered to be capable of representing the basin architecture at an acceptable resolution, while keeping the computational effort at a reasonable level.

Six model layers are included in the model (see Section 3.5), resulting in 5 441 220 finite difference cells. Two cross-sections of the model layers (west–east and north–south) are shown in Figure 3.2. Locations of these cross-sections are shown in Figure 3.1. Layers 3 to 5 are thickest in the location of the Boorthanna Trough (several hundreds of metres to kilometres thick), and thin toward the west. The basin uplifts toward the north and west, where there is potential for recharge to sub-cropping Permian sediments.
Figure 3.1  Model domain and project area
Figure 3.2 Model layers (cross-sections along 2390000N and 1050000E)
3.4 Model stress periods and initial conditions

Based on the objectives of the project, a steady state model has been developed, being independent of time and representing long term average conditions in the basin. It is thought that in the past there has been greater diffuse (rainfall) recharge to the basin, however current conditions have been considered as appropriate for this investigation. Initial water levels used as input for this steady state model are equal to topography.

In addition to the steady state calibrated model, a transient prediction model has been developed which uses the steady state modelled water levels as the initial conditions. This transient model has been used to investigate the impact of a hypothetical dewatering test in the north of the Arckaringa Basin over a period of 30 years. For this dewatering simulation, a single 30 year stress period has been used. This was considered to be appropriate since the stresses applied to the model do not vary with time.

3.5 Model layers

The groundwater model for the Arckaringa Basin represents six key hydrogeological units. Model layers representing these hydrogeological units are described in Figure 3.2 and Table 3.1. The layering chosen includes the major regional hydrogeological units to the best of current data, knowledge and information.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Primary Hydrogeological Group or Unit</th>
<th>Aquifer / Aquitard</th>
<th>MODFLOW-Surfact Layer Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bulldog Shale</td>
<td>Aquitard</td>
<td>Type 43 (confined/unconfined)</td>
</tr>
<tr>
<td>2</td>
<td>J–K Aquifer</td>
<td>Aquifer</td>
<td>Type 43 (confined/unconfined)</td>
</tr>
<tr>
<td>3</td>
<td>Mount Toondina Formation</td>
<td>Aquifer/Aquitard</td>
<td>Type 43 (confined/unconfined)</td>
</tr>
<tr>
<td>4</td>
<td>Stuart Range Formation</td>
<td>Aquitard</td>
<td>Type 43 (confined/unconfined)</td>
</tr>
<tr>
<td>5</td>
<td>Boorthanna Formation, Stuart Shelf</td>
<td>Aquifer</td>
<td>Type 43 (confined/unconfined)</td>
</tr>
<tr>
<td>6</td>
<td>Basement</td>
<td>Aquifer/Aquitard</td>
<td>Type 43 (confined/unconfined)</td>
</tr>
</tbody>
</table>

The structure of model layers consider topographic variation, drill hole data, seismic data and hydrogeological understanding of faulting and deposition (Wohling et al., 2013). Where necessary, model layer elevations have been modified to ensure that all layer thicknesses have a minimum thickness of 1 metre. The top of Layers 2–6 are assumed to be equal to the base of the layer above, unless otherwise noted.

Further explanation of each model layer is given in Sections 3.5.1 to 3.5.6.

3.5.1 Layer 1: Bulldog Shale

The top of Layer 1 has been defined by the topographic surface (shown in Figure 3.3), while the base of Layer 1 has been defined by the top of the J–K aquifer, discussed in Section 3.5.2. Where the Bulldog Shale sediments are absent the minimum layer thickness of 1 m has been assumed within the boundary of the Eromanga Basin. Outside of the Eromanga Basin, a nominal thickness of 1 m has been set for the upper most unit. Figure 3.3 and 3.4 show the elevations of the top and bottom of Layer 1, while Figure 3.5 shows the thickness of model Layer 1.
Figure 3.5  Layer 1 Thickness
3.5.2 Layer 2: J-K aquifer

The top of Layer 2 has been defined by the top of the J-K aquifer. The elevation for the base of Layer 2 has been defined by two datasets:

1) Top of the Permian units
2) Top of the Basement.

Where the J-K aquifer exists, and is underlain by Permian units, the base of Layer 2 was defined to be the top of the Permian units. Where the J-K aquifer exists and there is no underlying Permian units, the top of the basement was used to define the top of Layer 2. Where the J-K aquifer is absent (predominantly to the west and south of the model domain) the thickness of Layer 2 was defined as being 1 m.

The thickness of Layer 2 ranges from approximately 1000 m in the north-east of the model domain, to the defined minimum thickness of 1 m. Figure 3.6 shows the thickness of model Layer 2, while Figure 3.7 shows the elevation of the base of the layer.
3.5.3 Layer 3: Mount Toondina Formation

The base elevation of Layer 3 has been defined by the interpreted thickness of the Mount Toondina Formation, which ranges in thickness from approximately 800 m to less than 1 m. Where the Mount Toondina Formation is absent the layer is defined to have a thickness of 1 m. The thickness of Layer 3 is shown in Figure 3.8, while the elevation of the base of Layer 3 is shown in Figure 3.9.

The elevation of the top of Layer 3 is assumed to be equal to the base of Layer 2, discussed above.
Figure 3.8 Layer 3 Thickness
3.5.4 Layer 4: Stuart Range Formation

The base elevation of Layer 4 has been defined by the interpreted thickness of the Stuart Range Formation which ranges from approximately 500 m to less than 1 m. Where the Stuart Range Formation is absent, the layer is defined to have a thickness of 1 m. The thickness of Layer 4 is shown in Figure 3.10, while the elevation of the base of Layer 4 is shown in Figure 3.11.

The elevation of the top of Layer 4 has been defined as being equal to the top of Layer 3, discussed above.
Figure 3.11  Layer 4 Base
3.5.5 Layer 5: Boorthanna Formation and Stuart Shelf

As Layer 5 represents the Boorthanna Formation and Stuart Shelf, the layer elevations are defined so as to represent both of these units. Where the Boorthanna Formation exists, the base of Layer 5 is defined by the interpreted thickness of the Boorthanna Formation, which ranges between from approximately 1200 m to less than 1 m. Where the Stuart Shelf is present in the south-east corner of the model domain, the layer thickness was assumed to be 100 m. This is considered to be a reasonably representative thickness of the Andamooka Limestone in the region (BHP Billiton, 2008). Where neither of these units are present, the layer is defined as having a thickness of 1 m. Figure 3.12 shows the thickness of Layer 5 while Figure 3.13 shows the elevation of the base of the layer.

The elevation of the top of Layer 5 is defined as being equal to the base of Layer 4, discussed above.
Figure 3.12      Layer 5 Thickness
Arckaringa Basin

- Town
- Reduced Elevation (m AHD)
  - Major Rivers
  - Principle Roads
  - Lakes
  - Model Domain
  - Arckaringa Basin
  - Lake Eyre Basin

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Figure 3.13 Layer 5 Base
3.5.6 Layer 6: Basement

The base of Layer 6 has been defined as -3500 m AHD, resulting in a layer thickness ranging from 980 m to approximately 4130 m.

3.6 Model hydraulic parameters

Due to a limited set of published hydraulic parameters for the Arckaringa Basin, the model hydraulic parameters were based on the knowledge of values within the available published data from similar formations in other areas. The adopted aquifer and aquitard hydraulic parameters are summarised in Table 3.2 along with the range of estimates obtained from available data.

3.6.1 Layer 1 hydraulic parameter distribution

Layer 1 was primarily used to represent the overlying Bulldog Shale in the region. Where the Bulldog Shale is absent, Layer 1 represents the uppermost underlying unit (Stuart Range Formation, Boorthanna Formation and basement units). The spatial distribution of the Layer 1 hydraulic parameters are shown in Figure 3.14. The spatial distribution used to represent the Bulldog Shale in the model does not represent the spatial variability known to occur in the region due to insufficient data.

Where the Bulldog Shale is present, the hydraulic parameters representative of the Bulldog Shale were used. Outside of these areas where Bulldog Shale is absent, hydraulic parameters of the underlying units were used.

3.6.2 Layer 2 hydraulic parameter distribution

Layer 2 was primarily used to represent the J-K aquifer in the region, and hydraulic parameters representative of the J-K aquifer were applied to this area. Where the J-K aquifer is absent, hydraulic parameters of the underlying units were assumed as displayed in Figure 3.15. A single representative value of hydraulic conductivity has been used to represent the J-K aquifer, which is considered appropriate for a regional scale model of Class 1.

3.6.3 Layer 3 hydraulic parameter distribution

Layer 3 was primarily used to represent the Mount Toondina Formation in the model. Outside of the Mount Toondina Formation, Layer 3 represents the Boorthanna Formation, Stuart Range Formation and basement units.

Where the Mount Toondina Formation is present, the hydraulic parameters representative of the Mount Toondina Formation were used. Outside these areas, where the Mount Toondina is thought to be absent, hydraulic parameters of the underlying units are used. The spatial distribution of the parameters in Layer 3 is shown in Figure 3.16.

3.6.4 Layer 4 hydraulic parameter distribution

Layer 4 was primarily used to represent the Stuart Range Formation in the model. Outside of the Stuart Range Formation, Layer 4 represents the Boorthanna Formation and basement units.

Where the Stuart Range Formation exists, hydraulic parameters representative of the Stuart Range formation have been used. Outside of these areas where the Stuart Range Formation is absent, the hydraulic parameters of the underlying units were used. The spatial distribution of the parameters in Layer 4 is shown in Figure 3.17.

3.6.5 Layer 5 hydraulic parameter distribution

Layer 5 was primarily used to represent the Boorthanna Formation in the model. In the south-east portion of the model domain, Layer 5 was used to represent the Stuart Shelf. Outside of these regions, Layer 5 represents basement hydrogeological units.

Where the Boorthanna Formation exists, the hydraulic parameters representative of the Boorthanna Formation were used. Similarly, where the Stuart Shelf exists, parameters representative of the Stuart Shelf were used.
Outside of the areas where the Boorthanna Formation and Stuart Shelf are present, hydraulic parameters of the underlying basement unit were used. The spatial distribution of the parameters in Layer 5 is shown in Figure 3.18.

3.6.6 Layer 6 hydraulic parameter distribution

Layer 6 consists entirely of the basement unit. As a result the entire layer is defined as having basement hydraulic properties.

Table 3.2 Adopted hydraulic parameter summary table

<table>
<thead>
<tr>
<th>Hydro-geological unit</th>
<th>Model Layer</th>
<th>Modelled hydraulic parameters</th>
<th>Field Estimates of hydraulic parameters</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kh (m/d)</td>
<td>Kv (m/d)</td>
<td>Ss (-/m)</td>
</tr>
<tr>
<td>Bulldog Shale</td>
<td>1</td>
<td>0.5</td>
<td>1×10^{-6}</td>
<td>1×10^{-5}</td>
</tr>
<tr>
<td>J–K aquifer</td>
<td>2</td>
<td>20</td>
<td>2</td>
<td>1×10^{-3}</td>
</tr>
<tr>
<td>Mount Toondina Formation</td>
<td>3</td>
<td>5</td>
<td>1×10^{-3}</td>
<td>1×10^{-5}</td>
</tr>
<tr>
<td>Stuart Range</td>
<td>4</td>
<td>1×10^{-4}</td>
<td>1×10^{-4}</td>
<td>1×10^{-5}</td>
</tr>
<tr>
<td>Boorthanna Formation</td>
<td>5</td>
<td>1.25</td>
<td>0.125</td>
<td>1×10^{-5}</td>
</tr>
<tr>
<td>Stuart Shelf</td>
<td>5</td>
<td>5</td>
<td>1×10^{-4}</td>
<td>1×10^{-5}</td>
</tr>
<tr>
<td>Basement</td>
<td>6</td>
<td>0.3</td>
<td>5×10^{-4}</td>
<td>1×10^{-5}</td>
</tr>
</tbody>
</table>

Note 1: Field estimates for Mount Toondina Formation based on limited data sets
Note 2: Modelled hydraulic parameter Kh/Kv ratios determined during model calibration
Figure 3.14 Layer 1 Hydraulic Conductivity Distribution
Figure 3.15   Layer 2 Hydraulic Conductivity Distribution
Figure 3.16  Layer 3 Hydraulic Conductivity Distribution
Figure 3.18  Layer 5 Hydraulic Conductivity Distribution
3.7 Model boundary conditions

This sub-section describes boundary conditions representing recharge and discharge features in the model. Groundwater extraction has been excluded from the model as the model represents long term average (pre development) conditions.

3.7.1 Surface drainage

The surface drainage network has been defined in the model using the MODFLOW River package. All surface drainage is defined in Layer 1 of the model (Figure 3.19). The base of the river cells have been set equal to the topography. The majority of the rivers in the region are ephemeral, and so may recharge the system during high rainfall events. However, as the model is considering the long term average conditions of the basin, it has been assumed that the rivers in this region act as discharge, rather than recharge features. As such, it was assumed that the river stage is zero metres (i.e. river height is equal to the river base).

3.7.2 Springs

Springs to the east of the Arckaringa Basin have been implemented into the model as MODFLOW drain cells in Layer 1 of the model. The water level in the drain cells was set equal to topography, while the conductance was defined as 1000 m$^2$/d so as not to limit discharge from the model. The location of the modelled springs is shown in Figure 3.19.

3.7.3 Regional flow

Regional lateral inflow and outflow of the modelled region was simulated using general head boundary (GHB) (head-dependent flow) cells along the edges of the model domain where the aquifer was saturated and groundwater flow direction was inferred from water level contours. Areas where water level contours were approximately perpendicular to the boundary were assigned as no-flow boundaries.

The GHBs were defined to match measured water levels and replicate the regional in and out flow across the model domain. Conductance for these boundary conditions have been assigned as 500 m$^2$/d to permit regional flow into and out of the model domain. Regional in and out flow may be refined via changes to boundary conductance in these GHBs should supporting data become available.

Locations and assigned water levels for boundary conditions representing regional flow in Layers 2–4 are shown in Figure 3.20, and similarly the locations and assigned water levels for boundary conditions representing regional flow in Layers 5–6 are shown in Figure 3.21. GHBs have been defined in layers where the assigned water level is above the layer base. Assigned water levels have been linearly interpolated between the water levels specified in the figures.
Figure 3.19 Boundary Conditions – Layer 1
Figure 3.21  Boundary Conditions – Layers 5 – 6

Arckaringa Basin

- Town
- Major Rivers
- Principle Roads
- Lakes
- Model Domain
- Arckaringa Basin
- Lake Eyre Basin
- General Head Boundary

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3.8 Model evapotranspiration

Evapotranspiration has been assigned to the model based on the mean annual point potential evapotranspiration for the Arckaringa subregion (Miles et al. 2015). The evapotranspiration surface was assumed to be equal to topography, with an extinction depth of five metres assigned as an initial estimate. Maximum evapotranspiration rate for the model domain varies spatially, as shown in Figure 3.22. The actual rate of evapotranspiration varies linearly with depth, ranging from the maximum evapotranspiration rate when water levels are at the land surface to zero when water levels are greater than five metres below topography.
Figure 3.22  Model Evapotranspiration Distribution
3.9 Model recharge

Mechanisms for recharge to the basin include diffuse (rainfall) recharge and recharge from surface water features such as rivers and creeks. Diffuse recharge features are represented in the model using the MODFLOW Recharge (RCH) Package. Recharge was applied to the highest active model layer.

3.9.1 Diffuse recharge

Recharge to the basin is thought to occur where the Bulldog Shale is absent (or thin). For the purposes of this study, thin is considered to be in areas where Layer 1 representing the Bulldog Shale is 1 metre thick.

As a result, recharge was applied to the model where:

1) Bulldog Shale was absent or thin

2) J-K aquifer, Mount Toondina Formation, Stuart Range Formation or Boorthanna Formation are present (i.e. no recharge to basement)

Recharge to the basin is low, currently estimated to be 0.16 ± 0.08 mm/y (Love et al., 2000). Reflecting this, the recharge rate to the water table has been defined as being 0.075 % of the observed annual average rainfall. Figure 3.23 shows the recharge distribution applied to the model.
Figure 3.23  Modelled Recharge Distribution – Steady State Model

Arckaringa Basin

- Town
- Major Rivers
- Principle Roads
- Lakes
- Model Domain
- Extent of GAB Aquifer
- Arckaringa Basin
- Lake Eyre Basin

Modelled Recharge Distribution

- 0.145 mm/y
- 0.135 mm/y
- 0.125 mm/y
- 0.115 mm/y
- 0.105 mm/y
- 0 mm/y

Kilometres

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Map Preparation: Alinta Consulting

Date: 13 February 2015

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Lake Eyre Basin
3.9.2 Recharge from surface water features

There are a number of surface water features located within the model domain, as shown in Figure 2.1. These surface water features are considered to be ephemeral (Wohling et al., 2014), flowing only during high rainfall events, and as a result are considered to contribute minimal recharge to the aquifer. As described in Section 3.7.1, surface water features may remove water from the system, but not contribute to it.
4 Model calibration and confirmation

4.1 Model calibration

Detailed calibration was not conducted because of spatially limited monitoring data (data tended to be clustered in specific regions and often only for single points in time) and aquifer parameters to constrain the model. Where possible (and appropriate), modelled water levels have been compared to these observed water levels to allow assessment of model calibration performance. Based on existing data (both quantity and distribution), and objectives of the modelling exercise, the model was developed as a regional scale, elementary Class 1 model (Barnett et al., 2012) and was considered fit for purpose.

Model confirmation was conducted to test whether the model simulates the groundwater system as per the current conceptual model and modelled results are similar to the measured data.

Modelled steady state water levels for Layers 2 (J-K aquifer) and 3 (Mount Toondina Formation) are shown in Figure 4.1 and 4.2. The general flow pattern in these layers is a reasonable match to those shown in Figure 2.6 and 2.7 in the east. However, the modelled water level gradients in the west are less steep than those observed. Residuals have been calculated (Layers 3 and 5) for the steady state model and are shown in Figure 4.3. The SRMS for this steady state calibration is 13.1%, which is considered acceptable for a Class 1 model. In general, the modelled water levels are higher than the observed levels (negative residuals). This is particularly true in the south-east corner of the model domain. It is known that there has been recent groundwater extraction occurring in this area which has not been simulated in this model since the extraction would not be consistent with the long term average conditions of the region.

Table 4.1 shows water balance of the model with respect to the in and out flows of each modelled unit.

The higher than expected outflow from the J–K aquifer to the general head boundaries was due to the uncertainty around the regional water levels on the eastern extent of the model. Inflow to the J–K aquifer occurs in the north – east of the model. A large proportion of these inflows are removed from the model further south. The water level contours shown in Figure 4.1 show that the modelled flow in the J–K aquifer is toward the boundary in the middle of the eastern model boundary.

Outflow to springs (represented as drain cells) in the region was zero as evapotranspiration maintained the water level below the level of the drains (set equal to topography). Therefore, the evapotranspiration term may be considered to incorporate the spring flows of the region. Modelled evapotranspiration is shown in Figure 4.4 and can be seen to occur in areas where spring flow is known to occur.
### Table 4.1 Model water balance (m³/d)

<table>
<thead>
<tr>
<th></th>
<th>To Basement</th>
<th>To Bulldog Shale</th>
<th>To J-K aquifer</th>
<th>To Mount Toondina</th>
<th>To Stuart Range</th>
<th>To Boorthanna</th>
<th>To Stuart Shelf</th>
<th>Evaporation</th>
<th>General Head Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement</td>
<td>0</td>
<td>25 284</td>
<td>78 337</td>
<td>5635</td>
<td>19 194</td>
<td>119 569</td>
<td>16 399</td>
<td>76 705</td>
<td>89 664</td>
</tr>
<tr>
<td>Bulldog Shale</td>
<td>73</td>
<td>0</td>
<td>6309</td>
<td>31</td>
<td>93</td>
<td>128</td>
<td>0</td>
<td>241 030</td>
<td>0</td>
</tr>
<tr>
<td>J-K aquifer</td>
<td>131 996</td>
<td>215 817</td>
<td>0</td>
<td>47 114</td>
<td>3415</td>
<td>18 680</td>
<td>0</td>
<td>0</td>
<td>118 676</td>
</tr>
<tr>
<td>Mount Toondina</td>
<td>3475</td>
<td>1052</td>
<td>134 684</td>
<td>0</td>
<td>2618</td>
<td>5725</td>
<td>0</td>
<td>452</td>
<td>0</td>
</tr>
<tr>
<td>Stuart Range</td>
<td>2386</td>
<td>1797</td>
<td>10 814</td>
<td>55 560</td>
<td>0</td>
<td>5008</td>
<td>0</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Boorthanna</td>
<td>13 392</td>
<td>0</td>
<td>37 432</td>
<td>39 658</td>
<td>50 201</td>
<td>0</td>
<td>196</td>
<td>10 351</td>
<td>0</td>
</tr>
<tr>
<td>Stuart Shelf</td>
<td>15 666</td>
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<td>268 111</td>
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</table>
Figure 4.1 Modelled Steady State Water Levels – Layer 2 (J-Aquifer)
Figure 4.2 Modelled Steady State Water Levels – Layer 3 (Mount Toondina Formation)
Figure 4.4  Modelled Evapotranspiration
4.2 Model confirmation

Modelled water level contours were compared to existing water level data for the J-K aquifer, Mount Toondina Formation and Boorthanna Formation, considering both point values, interpreted water level contours and flow patterns. Modelled water levels were a reasonable match against the available observed data and broadly replicate the flow patterns in this observed data. Figure 4.5 shows that GAB saturated extent is broadly consistent with the extent of saturated model cells in Layer 2.

Modelled flow from the Boorthanna Formation into the Stuart Shelf has been compared to previous modelling of the Stuart Shelf (BHP Billiton, 2008). Modelled estimates of flow are consistent with previous studies, which provides a level of validation of our conceptual understanding of flow processes in the south east of the model domain. Further on ground works are required to confirm the conceptualisation and volumes.

Spatially restricted data has limited the extent of the model calibration process, however the results are considered to be an acceptable representation of the flow processes present in the Arckaringa Basin.
Figure 4.5  Layer 2 Modelled Water Levels Compared to Extent of Saturated GAB Aquifer
5 Sensitivity and uncertainty analysis

Sensitivity analysis is a procedure for quantifying the impact of an incremental variation in aquifer hydraulic parameters or stresses on modelled responses (Middlemis et al., 2000). A manual sensitivity analysis was performed. This required changing a single model parameter, re-running the model to obtain a new set of predicted heads and fluxes and observing the effect of the change. The emphasis is on determining how sensitive the model is to each parameter (Barnett et al., 2012).

There was considerable uncertainty in a number of key parameters due to the paucity of field estimates. The aim of this analysis was to evaluate the sensitivity of the model to several key parameters, only varying these parameters within reasonable limits on the basis of hydrogeological knowledge. The sensitivity results are presented in terms of head, model water balance and modelled evapotranspiration.

Sensitivity testing has been conducted on seven model parameters (hydraulic conductivity of each hydrogeologic unit) by varying each by an order of magnitude.

A summary of the sensitivity tests, comparing the calculated SRMS of each test with the SRMS of the calibration model is shown in Figure 5.1. It should be noted that in this context a lower SRMS does not necessarily indicate an improved calibration as the observation data is likely to be skewed by the spatially clustered data reflecting groundwater extraction in the vicinity of the Prominent Hill mine site which are not representative of historical long term trends.

Figure 5.1 Sensitivity analysis summary - comparison of model SRMS with calibration model
5.1 Sensitivity test results

5.1.1 Bulldog Shale hydraulic conductivity

As the Bulldog Shale was thought to have significantly lower hydraulic conductivity in some areas, one sensitivity run has been performed on the Bulldog Shale to investigate the impact of a decreased conductivity. Hydraulic conductivity (both horizontal and vertical) has been reduced by one order of magnitude. Results for this sensitivity test is given below in terms of an overall water balance, water level, and evapotranspiration map.

In general, a decrease in hydraulic conductivity has resulted in a reduced flow to the Bulldog Shale from underlying units. With the reduced volume of water available in the Bulldog Shale, evapotranspiration is reduced from the Bulldog Shale, but marginally increased from the outcropping basement. A summary of the modelled water balance for this sensitivity test is shown in Table 5.1.

Water levels (shown in Figure 5.2) within the basin were generally higher (approximately 5 m) in the centre of the basin when compared to the calibrated model. This was thought to be a function of the reduced vertical conductivity, rather than the reduced horizontal conductivity, in this test. By reducing the vertical conductivity, less water was available to be taken out of the system via evapotranspiration (shown spatially in Figure 5.3) and so remains in the lower units. The increase in volume in the lower layers was demonstrated via the increase in outflow from the J–K aquifer, basement and Stuart Shelf units in this test.

Table 5.1  Bulldog Shale K decreased - water balance (m³/d) – difference from calibration model

<table>
<thead>
<tr>
<th></th>
<th>To Basement</th>
<th>To Bulldog Shale</th>
<th>To J-K aquifer</th>
<th>To Mount Toondina</th>
<th>To Stuart Range</th>
<th>To Boorhanna</th>
<th>To Stuart Shelf</th>
<th>Evaporation</th>
<th>General Head Boundary</th>
</tr>
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</table>
Note: positive value indicates sensitivity test model value is higher than calibration value

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Figure 5.3  Bulldog Shale K decreased - Evapotranspiration
5.1.2 J-K aquifer hydraulic conductivity

Two sensitivity tests were performed to investigate the impact of varying the hydraulic conductivity of the J-K aquifer. The hydraulic conductivity (horizontal and vertical) for the J-K aquifer has been decreased and increased by an order of magnitude. A summary of results for these sensitivity tests are given below in terms of an overall water balance, water level, and evapotranspiration map.

The tests indicate that changes in conductivity for the J-K aquifer have a significant impact on the flow into and out of the modelled region through the general head boundaries in the J-K aquifer and basement. An increase in conductivity in the J-K aquifer induced five times the flow into and out of the J-K aquifer though the general head boundaries when compared to the calibration model. In addition to increased through flow in the J-K aquifer, regional inflow to the basement doubled and regional outflow from the basement tripled. Summaries of the modelled water balance for each test is given in Table 5.2 and 5.3.

Changes in conductivity in the J-K aquifer impact the flow through the basin, with increased in conductivity leading to improved connection between the Bulldog Shale above and the Stuart Range and Boorthanna units below. This improved connection results in an increased in evapotranspiration from the Bulldog Shale. Modelled evapotranspiration for these sensitivity runs are shown in Figure 5.5 and 5.7.

Water levels in these tests (shown in Figure 5.4 and 5.6) demonstrate that the modelled water levels within the Arckaringa Basin respond proportionally to the variations in hydraulic conductivity of the J-K aquifer when compared to the calibrated model. An increase in conductivity (by an order of magnitude) resulted in a decrease in water level of approximately 10 m near the centre of the basin. Conversely, a decrease in hydraulic conductivity (by an order of magnitude) resulted in an increase in modelled water levels in the centre of the basin by approximately 5 m.

| Table 5.2 J-K aquifer K increased - water balance (m³/d) – difference from calibration model |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                | To Basement     | To Bulldog     | To J-K aquifer  | To Mount Toondina | To Stuart Range | To Boorthanna | To Stuart Shelf | Evaporation | General Head Boundary |
| Basement                       | 0              | 8695           | 222 333         | 2502            | 7526           | 24 182         | 2072           | 31 799        | 184 145          |
| Bulldog Shale                 | 41             | 0              | -72             | 20              | -17            | -1             | 0              | 474 347        | 0               |
| J-K aquifer                   | 241 355        | 536 971        | 0               | -6280           | 2312           | 16 793         | 0              | 0              | 472 862          |
| Mount Toondina                | -1763          | 174            | 33 410          | 0               | -1509          | 625            | 0              | 409            | 0               |
| Stuart Range                  | -905           | 2457           | 655             | 23 391          | 0              | 1621           | 0              | -7             | 0               |
| Boorthanna                    | -1256          | 1              | 13 239          | 11 374          | 18 896         | 0              | 78             | 1106           | 0               |
| Stuart Shelf                  | 1905           | 0              | 0               | 0               | 27             | 0              | 0              | 0              | 227             |
| Recharge                      | 0              | -1             | 0               | 0               | 0              | 0              | 0              | -              | -               |
| General Head Boundary         | 241 653        | 0              | 988 835         | 0               | 0              | 0              | 0              | -              | -               |

Note: positive value indicates sensitivity test model value is higher than calibration value
Figure 5.4  J-K Aquifer K increased – Water Level
Figure 5.5  J–K Aquifer K increased - Evapotranspiration
### Table 5.3  J-K aquifer K decreased - water balance (m³/d) – difference from calibration model.

<table>
<thead>
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<th>To Basement</th>
<th>To Bulldog Shale</th>
<th>To J-K aquifer</th>
<th>To Mount Toondina</th>
<th>To Stuart Range</th>
<th>To Boorthanna</th>
<th>To Stuart Shelf</th>
<th>Evaporation</th>
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Note: positive value indicates sensitivity test model value is higher than calibration value.
Figure 5.6  J-K Aquifer K Decreased – Water Level
Figure 5.7  J-K Aquifer K Decreased - Evapotranspiration
5.1.3 Mount Toondina hydraulic conductivity

Two sensitivity tests have been performed to investigate the impact of varying the hydraulic conductivity of the Mount Toondina Formation. The hydraulic conductivity (horizontal and vertical) for the Mount Toondina Formation was increased and decreased by an order of magnitude. A summary of results for these sensitivity tests are given below in terms of an overall water balance, water level, and evapotranspiration map.

In general, changes to the Mount Toondina Formation conductivity had little impact on the modelled system water balance under steady state conditions. Increased conductivity provided a slightly improved connection between the units above and below (J-K aquifer and Bulldog Shale) which was expressed as an increased in evapotranspiration from the Bulldog Shale, shown in Figure 5.9 and 5.11.

Within the Arckaringa Basin extent, conductivity increases in the Mount Toondina Formation resulted in increased flow into the Mount Toondina Formation from both the J-K aquifer and Boorthanna units. Summaries of the modelled water balance for each of the Mount Toondina sensitivity runs are shown in Table 5.4 and 5.5.

The modelled water levels (shown in Figure 5.8 and 5.10) in these tests demonstrate that the system was more sensitive to increases in hydraulic conductivity in the Mount Toondina Formation rather than decreases. An increase in hydraulic conductivity (by an order of magnitude) resulted in a decrease of approximately 20 m in water level in the centre of the basin when compared to the calibrated model. Conversely, a decrease in hydraulic conductivity (by an order of magnitude) resulted in an increase of approximately 4 m in water level in the centre of the basin.

Table 5.4 Mount Toondina increased K - water balance (m³/d) – difference from calibration model

<table>
<thead>
<tr>
<th></th>
<th>To Basement</th>
<th>To Bulldog Shale</th>
<th>To J-K aquifer</th>
<th>To Mount Toondina</th>
<th>To Stuart Range</th>
<th>To Boorthanna</th>
<th>To Stuart Shelf</th>
<th>Evaporation</th>
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Note: positive value indicates sensitivity test model value is higher than calibration value
Figure 5.8 Mount Toondina increased K – Water Level
Figure 5.9  Mount Toondina increased K - Evapotranspiration
Table 5.5  Mount Toondina decreased K - water balance (m$^3$/d) – difference from calibration model

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Note: positive value indicates sensitivity test model value is higher than calibration value
Figure 5.10 Mount Toondina decreased K – Water Level
Figure 5.11  Mount Toondina decreased K- Evapotranspiration
5.1.4 Stuart Range hydraulic conductivity

Two sensitivity tests were performed to investigate the impact of varying the hydraulic conductivity of the Stuart Range Formation. The hydraulic conductivity (horizontal and vertical) for the Stuart Range Formation was increased and decreased by an order of magnitude. A summary of results for these sensitivity tests are given below in terms of an overall water balance, water level, and evapotranspiration map.

In general, an increase in conductivity in the Stuart Range Formation increased the flow to and from the Boorthanna, Mount Toondina and J-K aquifer units. In terms of the overall water balance the volume increase is small and so changes to conductivity in the Stuart Range Formation are not considered to have a significant impact on the modelled system. Summaries of each of these sensitivity tests are given in Table 5.6 and 5.7, while Figure 5.13 and 5.15 show the modelled evapotranspiration.

Modelled water levels (shown in Figure 5.12 and 5.14) in the Arckaringa Basin do not change significantly as a result of varying hydraulic conductivity of the Stuart Range Formation. An increase in hydraulic conductivity (by an order of magnitude) resulted in no significant change to the water levels in the centre of the basin, when compared to the calibrated model. Similarly, a decrease in hydraulic conductivity (by an order of magnitude) resulted in an increase in water level, when compared to the calibrated model, of 3 m.

Table 5.6 Stuart Range increased K - water balance (m$^3$/d) – difference from calibration model

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<th></th>
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<th>To Mount Toondina</th>
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<th>To Stuart Shelf</th>
<th>Evaporation</th>
<th>General Head Boundary</th>
</tr>
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Note: positive value indicates sensitivity test model value is higher than calibration value.
Figure 5.12 Stuart Range increased K – Water Level
Figure 5.13  Stuart Range increased K – Evapotranspiration
Table 5.7  Stuart Range decreased K - water balance (m³/d) – difference from calibration model

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<th>To Basement</th>
<th>To Bulldog Shale</th>
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<th>To Mount Toondina</th>
<th>To Stuart Range</th>
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Note: positive value indicates sensitivity test model value is higher than calibration value.
Figure 5.13: Stuart Range Sensitivity Test 2 - Water Level (Layer 3)

Figure 5.14: Stuart Range decreased K – Water Level
Figure 5.15  Stuart Range decreased K - Evapotranspiration
5.1.5 Boorthanna hydraulic conductivity

Three sensitivity test were performed to investigate the impact of varying the hydraulic conductivity of the on the Boorthanna Formation. As with previous sensitivity tests described above, the first two tests involved increasing and decreasing the hydraulic conductivity (horizontal and vertical) by an order of magnitude. The third test involved setting the vertical conductivity equal to hydraulic conductivity. A summary of results for these sensitivity tests are given below in terms of an overall water balance, water level, and evapotranspiration map.

Hydraulic conductivity in the Boorthanna Formation effects the modelled evapotranspiration that is taken from the Boorthanna unit. An order of magnitude increase in hydraulic conductivity results in a doubling of evapotranspiration from the Boorthanna Formation. Conversely, reducing the hydraulic conductivity of the Boorthanna Formation halved the evapotranspiration from the Boorthanna unit, and generally reduced the flow to the Boorthanna Formation from adjacent units. The modelled evapotranspiration distribution for each of these tests is given in Figure 5.19, 5.17 and 5.21.

Setting the vertical hydraulic conductivity equal to the horizontal hydraulic conductivity showed no significant change in water balance when compared to the calibrated model, indicating that the system appears to be more sensitive to changes in horizontal conductivity in the Boorthanna Formation than vertical.

Summaries of the modelled water balance for each of these sensitivity runs is shown in Table 5.8, 5.9 and 5.10.

Modelled water levels (shown in Figure 5.16, 5.18 and 5.20) for these tests indicate that variations in hydraulic conductivity for the Boorthanna unit do not significantly impact the modelled basin system. An increase in hydraulic conductivity (by an order of magnitude) has resulted in a decrease in modelled water level of three metres in the centre of the basin when compared to the calibrated model. Decreasing the hydraulic conductivity of the Boorthanna unit had no significant effect of water levels in the basin when compared to the calibrated model. The third test investigating the effect of increasing only the vertical hydraulic conductivity showed no significant change in water levels in the basin when compared to the calibrated model.

| Table 5.8 Boorthanna increased K - water balance (m³/d) – difference from calibration model |
| Basement | To Basement | To Bulldog Shale | To J-K aquifer | To Mount Toondina | To Stuart Range | To Boorthanna | To Stuart Shelf | Evaporation | General Head Boundary |
| Basement | 0 | 263 | 9176 | 1022 | -1702 | 34894 | -401 | -4351 | -179 |
| Bulldog Shale | -1 | 0 | -12 | -4 | -11 | 0 | 0 | 12095 | 0 |
| J-K aquifer | 7461 | 9981 | 0 | -2733 | -126 | 12322 | 0 | 0 | -98 |
| Mount Toondina | 35 | -42 | -2236 | 0 | 3413 | 4230 | 0 | -99 | 0 |
| Stuart Range | 1270 | 1783 | -1836 | 2908 | 0 | 2918 | 0 | -7 | 0 |
| Boorthanna | 13792 | 0 | 19357 | 4101 | 5461 | 0 | 533 | 11332 | 0 |
| Stuart Shelf | -3 | 0 | 0 | 0 | 0 | 147 | 0 | 0 | -12 |
| Recharge | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | - |
| General Head Boundary | 16142 | 0 | 2344 | 0 | 0 | 0 | 0 | - | - |

Note: positive value indicates sensitivity test model value is higher than calibration value
Figure 5.16  Boorthanna increased K – Water Level
Figure 5.17  Boorthanna increased K - Evapotranspiration
Table 5.9 Boorthanna decreased K - water balance (m$^3$/d) – difference from calibration model

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<th>To Stuart Range</th>
<th>To Boorthanna</th>
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Note: positive value indicates sensitivity test model value is higher than calibration value
Figure 5.18 Boorthanna decreased K – Water Level
Figure 5.19  Boorthanna decreased K - Evapotranspiration
Table 5.10  Boorthanna $K_s$ equal to $K_h$ - water balance (m$^3$/d) – difference from calibration model

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Note: positive value indicates sensitivity test model value is higher than calibration value
Figure 5.20 Boorthanna Kz equal to Kh – Water Level
Figure 5.21  Boorthanna Kz equal to Kh - Evapotranspiration
5.1.6 Stuart Shelf hydraulic conductivity

Two sensitivity tests were performed to investigate the impact of varying the hydraulic conductivity of the Stuart Shelf. The hydraulic conductivity (horizontal and vertical) for the Stuart Shelf was increased and decreased by an order of magnitude. A summary of results for these sensitivity tests are given below in terms of an overall water balance, water level and evapotranspiration map.

Variations in hydraulic conductivity for the Stuart Shelf primarily influence the interaction between the basement surrounding the Stuart Shelf (horizontally and vertically) and the interface between the Boorthanna Formation and Stuart Shelf. Increased hydraulic conductivity provided increased flow into and out of the Stuart Shelf via surrounding units. Vertical flow was increased and subsequently increased evapotranspiration from within the Lake Torrens area intercepts much of the regional outflow which previously reported to the general head boundary to the east of Lake Torrens in the calibration model.

Conversely, a reduction in hydraulic conductivity decreases the flow into and out of the Stuart Shelf from surrounding units. Regional outflow in the vicinity of Lake Torrens is largely unaffected. Summaries of the modelled water balances for these sensitivity runs are shown in Table 5.11 and 5.12, while the spatial distribution of modelled evapotranspiration is shown in Figure 5.23 and 5.25.

Changes to the Stuart Shelf hydraulic conductivity, as expected, primarily affected water levels in the vicinity of the Stuart Shelf region. Modelled water levels (shown in Figure 5.22 and 5.24) in the Stuart Shelf region had greatest change when hydraulic conductivity was increased by an order of magnitude. In this test water levels decreased by approximately 20 m when compared to the calibrated model. Significantly, this decrease in water level in the Stuart Shelf region reversed flow (from outflow to inflow) across the general head boundary near Lake Torrens in the south east of the model domain. Reducing the hydraulic conductivity of the Stuart Shelf resulted in modelled water levels local to the Stuart Shelf increasing by approximately 10 m.

Table 5.11 Stuart Shelf increased $K$ - water balance ($m^3/d$) – difference from calibration model

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Note: positive value indicates sensitivity test model value is higher than calibration value.
Arckaringa Basin

- Town
- Major Rivers
- Lakes
- Model Domain
- Arckaringa Basin
- Lake Eyre Basin

Stuart Shelf Sensitivity Test 1

Dry Cells

Modelled Water Level (m AHD) (Layer 3)

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Produced by: Science, Monitoring and Knowledge Branch

Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: February 2015

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

Figure 5.22 Stuart Shelf increased K – Water Level
Figure 5.23  Stuart Shelf increased K - Evapotranspiration
Table 5.12  Stuart Shelf decreased K - water balance (m³/d) – difference from calibration model

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Note: positive value indicates sensitivity test model value is higher than calibration value.
Figure 5.25 Stuart Shelf decreased K - Evapotranspiration
5.1.7 Basement hydraulic conductivity

Three sensitivity tests were performed to investigate the impact of varying the hydraulic conductivity of basement units. For the first two sensitivity tests the basement hydraulic conductivity (horizontal and vertical) was increased and decreased by an order of magnitude. For the third sensitivity test the vertical conductivity was set equal to the horizontal conductivity. A summary of results for these sensitivity tests are given below in terms of an overall water balance, water level, and evapotranspiration map.

Changes in basement conductivity had the most significant impact on the modelled system both in terms of flow into and out of the system, and flow between modelled units.

An increase in basement conductivity resulted in a significant increase in flow into the system via general head boundaries, while conversely, a decrease in conductivity resulted in a reduction of flow into the system. Similarly, an increase in basement conductivity resulted in a significant increase in outflow from the system via evapotranspiration from both the outcropping basement unit and the Bulldog Shale.

These sensitivity tests indicate that the conductivity of the basement controls the volume of through flow in the modelled region resulting in a greater volume of water entering the Arckaringa Basin via interaction with the basement unit. For example, increased basement conductivity resulted in nearly a four times the flow from the basement to the overlying Boorthanna Formation. Similar results are noted for each of the other modelled hydrogeological units.

The third sensitivity run tests the impact of an increased vertical conductivity, while leaving horizontal conductivity unchanged from the calibrated model. An increased vertical conductivity resulted in a significant increase in outflow via evapotranspiration from the outcropping basement unit while simultaneously decreasing the evapotranspiration from the Bulldog Shale unit.

Summaries of each of the sensitivity tests are shown in Table 5.13, 5.14 and 5.15, while the spatial distribution of modelled evapotranspiration is shown in Figure 5.27, 5.29 and 5.31.

The modelled water levels (shown in Figure 5.26, 5.28 and 5.30) demonstrated the greatest change when the hydraulic conductivity of the basement was increased by an order of magnitude. Under this test, modelled water levels in the centre of the basin increased by approximately 30 m. This was in response to increased regional flow from the boundaries. Conversely, a decrease in basement hydraulic conductivity (by an order of magnitude) decreased modelled water levels in the centre of the basin by 13 m. Modelled water level decreases of up to 30 m were observed on the western extents of the modelled Arckaringa Basin. Varying only the vertical conductivity (set equal to the horizontal conductivity) showed a decrease in modelled water level in the centre of the basin of approximately 10 m, when compared to the calibrated model. Water levels elsewhere in the modelled basin show less variation from the calibrated model.
Table 5.13  Basement increased K - water balance (m$^3$/d) – difference from calibration model

<table>
<thead>
<tr>
<th></th>
<th>To Basement</th>
<th>To Bulldog Shale</th>
<th>To J-K aquifer</th>
<th>To Mount Toondina</th>
<th>To Stuart Range</th>
<th>To Boorthanna</th>
<th>To Stuart Shelf</th>
<th>Evaporation</th>
<th>General Head Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement</td>
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<td>321 451</td>
<td>28 624</td>
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<tr>
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<tr>
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<td>77 430</td>
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Note: positive value indicates sensitivity test model value is higher than calibration value.
Figure 5.26  Basement increased K – Water Level
Figure 5.27  Basement increased K - Evapotranspiration
<table>
<thead>
<tr>
<th></th>
<th>To Basement</th>
<th>To Bulldog Shale</th>
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<th>To Mount Toondina</th>
<th>To Stuart Range</th>
<th>To Boorthanna</th>
<th>To Stuart Shelf</th>
<th>Evaporation</th>
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Note: Positive value indicates sensitivity test model value is higher than calibration value.
Figure 5.29  Basement decreased K – Evapotranspiration
Table 5.15  Basement $K_z$ equal to $K_h$ - water balance (m$^3$/d) – difference from calibration model

<table>
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<tr>
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<th>To Basement</th>
<th>To Bulldog Shale</th>
<th>To J-K aquifer</th>
<th>To Mount Toondina</th>
<th>To Stuart Range</th>
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<th>To Stuart Shelf</th>
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Note: positive value indicates sensitivity test model value is higher than calibration value
Figure 5.30  Basement Kz equal to Kh – Water Level
Figure 5.31  Basement Kz equal to Kh - Evapotranspiration
6 Prediction scenarios – mine dewatering

Two dewatering scenarios were performed using a transient (uncalibrated) version of the model. Both scenarios were centred at the location of a hypothetical coal mine in the north-east of the Arckaringa Basin. The first test shows the impact of a single dewatering bore placed in the Mount Toondina Formation (model layer 3) extracting 300 ML/d for 30 years, while the second test investigates the dewatering requirement to reduce the water level to approximately 200 mbgl.

As the transient model is uncalibrated, these results are indicative of the processes only. Further work would be necessary before the model can be used confidently to assess mining impacts.

6.1 Mine dewatering scenario 1

A single dewatering bore was placed in the Mount Toondina Formation (Layer 3) at the coordinate (973025E, 2449253N) and extraction set to 300 ML/d for a period of 30 years. Figure 6.1 shows the drawdown in Layer 3, after 1, 5, 10 and 30 years of extraction.

The predicted drawdown after 30 years extends approximately 135 km to the south of the mine site, while the total area impacted by the dewatering operations (drawdown greater than 1 m is approximately 41 000 km²).
Figure 6.1 Dewatering Scenario 1 – Layer 3 drawdown
6.2 Mine dewatering scenario 2

Dewatering was simulated in this test using a series of drain cells in model Layers 1, 2 and 3. The water level for each drain cell has been defined as -100 m AHD (approximately 200 mbgl) and the conductance set high (1 ×10^5 m^2/d) to minimise the resistance to flow into the drain feature.

After 30 years of dewatering, drawdown in Layer 3 (Mount Toondina Formation) is predicted to extend 146 km to the south of the dewatering point, while the total area impacted by drawdown in excess of 1 m is approximately 48 500 km^2. Figure 6.2 shows the drawdown in Layer 3 for this scenario after 1, 5, 10 and 30 years.

The dewatering rate required to achieve and maintain a water level 200 m below ground level was initially predicted to be 870 ML/d, decreasing to approximately 540 ML/d by the end of mining. Figure 6.3 shows the predicted dewatering rate for the 30 years of simulated mining.
Figure 6.2  Dewatering Scenario 2 – Layer 3 drawdown
6.3 Uncertainty analysis

A single uncertainty run has been performed on the transient dewatering model presented in Section 6.2. Based on the results of the sensitivity analysis, which showed that the model was most sensitive to changes in basement hydraulic conductivity, the conductivity of the basement has been increased in the dewatering model by an order of magnitude and rerun.

The predicted draw down is shown in Figure 6.4 after 1, 5, 10 and 30 years of dewatering. It was noted that the extent of the drawdown was much reduced, compared to those seen in Figure 6.2. This was a result of the basement effectively recharging the Arckaringa Basin in response to the dewatering. The dewatering rate required in this case is initially similar to those seen in Section 6.2, however the long term dewatering rate is more than 50 ML/d higher. The time series dewatering rate is shown in Figure 6.5.

It should be noted that there was drawdown shown at the western boundary, which was in response to the change in basement hydraulic conductivity, rather than the dewatering simulation.
Figure 6.4 Uncertainty Test 1 - Layer 3 Drawdown
Figure 6.5  Predicted dewatering rate - mine dewatering with Basement K increased
7 Alternative conceptualisation

The model runs reported in the previous sections reflect a conceptualisation where the Arckaringa Basin was recharged via regional flow, rather than diffuse recharge. The model has been constructed with a thick basement layer (ranging from 980 m to 4130 m) which represents all units below the Boorthanna Formation. The assumption that there is a thick basement unit was tested in this conceptualisation by restricting the thickness of the basement layer, and adding a further, less conductive, basement layer.

The model described in this section was compared to the calibration model with respect to the modelled water levels and water balance. The model described in this section has not been subject to a calibration procedure, and should be considered as the basis for future work.

7.1 Model setup

The basement layer in the calibration model was reduced in thickness to 300 m, and a sub-basement layer added, also 300 m thick. Boundary conditions used in the basement layer have been transferred to the sub-basement model layer. This model setup effectively limits regional flow to a 600 m thick unit.

The hydraulic conductivity of the sub-basement layer was set to be an order of magnitude less than the basement layer, with $K_h = 3 \times 10^{-2}$ and $K_v = 5 \times 10^{-5}$

7.2 Model results

Model results from this uncalibrated model have been produced consistent with the adopted calibration model shown in Table 7.1 shows the water balance for the alternative conceptualisation discussed above. The most significant changes from the adopted calibration model is the decrease in regional flow through the basement unit (including the sub-basement) and the reduction in evapotranspiration. This reduced regional inflow has reduced the upward flow from basement to the overlying layers, resulting in lower generally water levels throughout the modelled Arckaringa Basin region. Figure 7.1 and 7.2 show the modelled water levels in Layers 2 and 3 respectively. These can be compared to Figure 4.1 and 4.2. Modelled evapotranspiration is shown in Figure 7.3, which can be compared with the modelled evapotranspiration for the calibration model, shown in Figure 4.4. Evapotranspiration is significantly reduced in extent and rate due to the decrease in water levels.

7.3 Summary

The model presented in this section was used to demonstrate the impact of a reduction in thickness of the basement layer, a fundamental component of the adopted conceptualisation shown in the calibration model. The adopted conceptualisation used in the calibration model was such that the Arckaringa Basin was recharged from below via regional flow. The conceptualisation modelled in this section restricted the regional inflow and demonstrated the impact of this change in the model, when compared to the current calibrated model. As this model is uncalibrated, further work would be required to fully explore this conceptualisation. It is suggested that the decrease in regional flow to the Arckaringa Basin may be balanced by an increase in recharge on the western and eastern extents of the basin, simulating the historic recharge that is thought to have occurred in the past.
### Table 7.1 Alternative conceptualisation - water balance (m$^3$/d)

<table>
<thead>
<tr>
<th></th>
<th>To Basement</th>
<th>To Bulldog Shale</th>
<th>To J-K aquifer</th>
<th>To Mount Toondina</th>
<th>To Stuart Range</th>
<th>To Boorthanna</th>
<th>To Stuart Shelf</th>
<th>Evaporation</th>
<th>General Head Boundary</th>
</tr>
</thead>
<tbody>
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Figure 7.1  Alternative Conceptualisation - Modelled Water Levels – Layer 2 (J–K Aquifer)
Figure 7.2  Alternative Conceptualisation - Modelled Water Levels – Layer 3 (Mount Toondina Formation)
Figure 7.3  Alternative Conceptualisation - Modelled Evapotranspiration
8 Model limitations and capabilities

As a Class 1 model it was acknowledged that the model will have major limitations. These were generally related to a lack of understanding of the physical system or limited observation data. The objective of this model was to provide a platform for further development and to highlight areas to prioritise for further work and investigations.

8.1 Model limitations

8.1.1 Western boundary of Arckaringa Basin.

Water levels in the west of the Arckaringa Basin are much higher than elsewhere in the basin. It is unknown whether these water levels are due to high regional water levels from outside of the basin, or whether there is a groundwater mound due to historical diffuse recharge on the western extent of the basin. This model assumes the former, with boundary water levels applied to suit. In future model refinement, the western boundary could be redefined to match that of the Arckaringa Basin western boundary to limit the uncertainty to the west of the model domain. Further investigations may determine the source of the water level mounding on this boundary which can be implemented into the model. It is acknowledged that the model calibration was poor in this area, suggesting that the conceptual understanding requires improvement.

8.1.2 Regional flow processes

There was uncertainty surrounding the flow processes relating the regional flow to those within the Arckaringa Basin. Based on the available data, this modelling showed that the regional flow was a significant flow process in the context of the Arckaringa Basin. Quantifying the regional flow into and out of the Arckaringa Basin would provide additional constraints on the model which would benefit the calibration of the model and representation of the flow processes within the Arckaringa Basin.

8.1.3 Lake Torrens ET artifacts

Evapotranspiration maps shown in the previous section show spatially the rate of evapotranspiration removed from the model. In the south-east of the model domain, approximately along the centre line of Lake Torrens are some model artifacts expressing themselves as a high evapotranspiration (linear) feature. This was due to a depression in the topography (Lake Torrens) coupled with an underlying high conductivity zone (Stuart Shelf) within 5 m of the topographic surface (i.e. within the ET extinction depth). Additional investigation may be required to investigate the interaction and relationship of the Stuart Shelf with the overlying units.

8.1.4 Bulldog Shale conductivity

The Bulldog Shale was considered to be effectively impermeable, which limits direct rainfall recharge to the basin, and restricts the availability of water to be removed via evaporation. In this modelling study, the Bulldog Shale vertical hydraulic conductivity has been defined as being low ($1 \times 10^{-6}$ m/d). Field studies indicate that the hydraulic conductivity may be significantly lower ($1 \times 10^{-9}$ m/d) in some areas.

Section 5.1.1 demonstrated the effect of lowering the hydraulic conductivity of the Bulldog Shale, specifically the decrease in evaporation and the increase in water levels in the underlying layers due to the Bulldog Shale acting as a confining unit. Further sensitivity runs have been attempted to investigate the effect of further decreases in hydraulic conductivity, however these resulted in model instability.

Conceptually, it was thought that the Bulldog Shale hydraulic conductivity may range in value from near impermeable in some areas, to relatively permeable where the unit is thin. In the latter case, diffuse recharge enters the system via these more permeable areas. Modelling the Bulldog Shale as a single hydraulic conductivity value may be an over simplification that will require some additional work in the future.
8.1.5 Surface water recharge

Surface water features have been modelled as discharge zones, rather than sources of recharge, consistent with the long term average conditions in the region. During high rainfall events however, these surface water features may act as areas of recharge. Further investigations may be required to characterise the interaction between groundwater and surface water in these areas under these conditions.

8.1.6 Spring flow

Spring flow in the modelled area was estimated to be approximately 5 ML/d (source). The modelled springs (represented using the MODFLOW DRAIN (DRN) package) suggests that spring flow was not occurring (contradicting on ground observations). As the model is currently set up, drain cells are ineffective as modelled evapotranspiration intercepts any shallow flows prior to reaching the drain cells. Future updates of this model may require re-conceptualisation of spring features to align with outcomes of the Lake Eyre Basin Springs projects’ hydrogeological baseline characterisation of springs sub-project.

8.1.7 Definition of the basement units

The adopted calibration model assumed a thick basement unit extending to -3500 m AHD. The results of the sensitivity analysis performed in Section 5 and the alternate conceptualisation in Section 7 showed that the model is sensitive to parameters which decrease the transmissivity of the modelled basement. Currently the thickness of the basement unit in this area is considered an unknown. Improved understanding of the basement unit, (for example, unit thickness or hydraulic parameters) may help to refine the conceptualisation and subsequently the model results.

8.1.8 No spatial variation in hydraulic conductivity

Due to the scarcity of data, each modelled unit has a single representative value of hydraulic conductivity assumed. It is likely that there are variations in hydraulic properties, both spatially and with depth, throughout the modelled region, which may be significant with respect to the flow regime.

8.2 Model capabilities

The primary purpose of the Arckaringa groundwater model was to test the validity of the current conceptualisation of the Arckaringa Basin, by incorporating the latest data and knowledge within the model.

The Class 1 model, as developed, broadly simulates the flow regime of the Arckaringa Basin, including the interaction between hydrogeologic units contained within the basin. The model simulates the interaction between the Arckaringa Basin and the overlying J–K aquifer (GAB), the adjacent Stuart Shelf and the regional flow system.

The model provides a platform for future development. The model is capable of being upgraded to include updated data or be used as an investigative tool to test refined conceptualisations of the basin.

The model, extended to a transient model, provides indicative or preliminary results for mine dewatering impacts within the modelled region. However, these results should be used with caution as the transient model has not been calibrated due to spatially insufficient long term data.

During the modelling process, uncertainties in the conceptualisation, or gaps in data have been noted. These knowledge gaps may be used to guide future field work programs to help refine our understanding of the basin and its interaction with surrounding basins.
9 Conclusions and recommendations

The key findings in relation to the specific project objectives are:

**Objective:** Develop a Class 1 groundwater model of the Arckaringa Basin.

The Arckaringa Basin groundwater model has been developed using the latest data and conceptual understanding of the processes within the basin. The model assumes the long term average climatic conditions in the basin, including diffuse recharge and evapotranspiration. The model is intended as a platform to be used as a starting point to develop higher classification models by incorporating additional knowledge as it becomes available which meets the definition of a Class 1 model according to the Australian Groundwater Modelling Guidelines.

**Objective:** Test the validity of the current conceptual model.

The model successfully simulates the regional scale flow processes in the basin including water levels and flow direction. The model validates much of the current conceptual understanding of flow processes within the basin. Knowledge gaps identified during the development of the model have suggested alternative conceptual models which have been tested using the model.

**Objective:** Identify key knowledge and data gaps, which may direct planning of future field investigations or modelling activities.

A number of knowledge and data gaps have been identified throughout the development of the model. These knowledge and data gaps form the basis of the recommendations for future development of the model. Recommendations for future development of the model are:

1. Incremental updates to the model as updated data becomes available through future field programs
2. Gain further understanding of the recharge mechanisms within the basin, including the role of surface water interaction with groundwater systems and basement contribution. Modelled recharge should be subject to sensitivity analysis.
3. Characterise the distribution of low and high conductivity areas within the Bulldog Shale. This is likely to inform where diffuse recharge is occurring.
4. Investigate and quantify the interaction between the Arckaringa Basin and regional basement unit. Flow to and from the regional basement unit has been identified in this modelling exercise as having a significant influence on the flow regime of the Arckaringa Basin. Validation (or otherwise) of this would be beneficial for further development of the model and refining the conceptual model. A sensitivity analysis should be performed on the height and conductance values used in the general head boundaries used to represent regional flow.
5. Investigate and quantify the interaction between the Arckaringa Basin and overlying J-K aquifer
6. Refine the implementation of springs within the model. Spring flow could be used as a secondary calibration target in future model revisions.
7. Investigate the role of evapotranspiration within the system, particularly in the vicinity of the springs. A sensitivity analysis should be performed on the evapotranspiration parameters used in the model.
8. Implement groundwater extraction. Currently all groundwater extraction is omitted from the model, however where there exists sufficient data (e.g. Prominent Hill mine site), inclusion of this data is likely to improve the model calibration significantly.

In addition to the objectives stated above, a transient (uncalibrated) version of the model has been used to test potential regional scale impacts of a hypothetical mine dewatering. The hypothetical mine dewatering scenario suggested that the estimated impact of drawdown would be regionally widespread. Further work, including sensitivity and uncertainty testing, would be required to provide additional confidence in these modelled impacts.
10 Units of measurement

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

<table>
<thead>
<tr>
<th>Name of unit</th>
<th>Symbol</th>
<th>Definition in terms of other metric units</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>day</td>
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<td>24 h</td>
<td>time interval</td>
</tr>
<tr>
<td>gigalitre</td>
<td>GL</td>
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<td>volume</td>
</tr>
<tr>
<td>gram</td>
<td>g</td>
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<td>mass</td>
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<tr>
<td>hectare</td>
<td>ha</td>
<td>$10^4 \text{ m}^2$</td>
<td>area</td>
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<tr>
<td>hour</td>
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<td>$10^{-3} \text{ m}^3$</td>
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<td>year</td>
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<td>time interval</td>
</tr>
</tbody>
</table>

10.2 Shortened forms

~ approximately equal to
bgl below ground level
K hydraulic conductivity (m/d)
11 References


SWS (2010). Updates to Stuart Shelf Regional Groundwater Flow Model. Prepared for BHP Billiton by Schlumberger Water Services Australia Pty Ltd.


