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Katunga WSPA Groundwater Resource Assessment

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ABBREVIATIONS

| Abbreviation | Description |
|---------------------|---|
| A | Cross sectional area |
| b | Aquifer thickness |
| BGL | Below ground level |
| BOM | Bureau of Meteorology |
| CHM | Conceptual hydrogeological model |
| Cv | Conductance |
| DELWP | Department of Environment, Land, Water and Planning |
| DSE | Department of Sustainability and Environment |
| ET | Evapotranspiration |
| Fm | Formation |
| GMA | Groundwater Management Area |
| GMA016 | Lower Murray Alluvium GMA |
| GMP | Groundwater Management Plan |
| GMW | Goulburn-Murray Water |
| i | Hydraulic gradient |
| Kh | Horizontal hydraulic conductivity |
| Kv | Vertical hydraulic conductivity |
| LE | Loading efficiency |
| MDB | Murray Darling Basin |
| NOW | NSW Office of Water |
| S | Storativity |
| SA | Surface area |
| SAFE | Secure Allocations, Future Entitlements |
| Ss | Specific storage |
| SWL | Static water level |
| Sy | Specific yield |
| URS | URS Australia Pty Ltd |
| VAF | Victorian Aquifer Framework |
| WMIS | Water Management Information System |
| WSPA | Water Supply Protection Area |

EXECUTIVE SUMMARY

Introduction

Goulburn-Murray Water (GMW) manages groundwater extraction in the Katunga Water Supply Protection Area (WSPA) in northern Victoria. Groundwater pumping in this area is regulated by annual allocations and trade restrictions through the Katunga WSPA Groundwater Management Plan (GMP), which is currently being amended.

The main aquifer in the area is the Deep Lead, which is comprised of the Calivil Formation and the Renmark Group. For the past thirty years, the Deep Lead has been relied on as an important irrigation water supply. As a result water levels in the Deep Lead have declined over time.

The management objective of the GMP is to maintain a 5 year average spring (or annual maximum) recovery level at levels that ensures access to the groundwater without major cost impacts. Permanent restrictions to 70% of total allocation entitlement are in place, and there is an allowance to reduce that to 50% in any one year where the 5 year average usage exceeds 30,000 ML/year. This allocation methodology has been in place since 2006. However average spring recovery levels have dropped lower than 20 mBGL (the desired value nominated in the GMP) because the relationship between groundwater use and spring recovery level has not eventuated as predicted in 2006. Hence, a revised methodology is required.

URS Australia Pty Ltd was commissioned by GMW to undertake a probabilistic resource assessment of the Deep Lead aquifer in order to quantify inputs and outputs and identify the main controls on Deep Lead water levels. The primary objective of this assessment is to make recommendations for the revised GMP on the basis of the following criteria:

- Trigger levels for allocation restrictions;
- The scope for groundwater carryover, and;
- The impact of full use of entitlement on sustainability of the aquifer.

The Groundwater Resource Assessment

The main controls on Deep Lead groundwater levels within the Katunga WSPA are groundwater pumping, vertical flux from the overlying Shepparton Formation, lateral inflows and outflows, vertical flux from the underlying Basement, and mechanical loading from the watertable.

A probabilistic model was constructed to quantify each of these elements. The model inputs were probability distributions rather than single numbers, in order to quantify the uncertainty and variability in each input. The model outputs were frequency curves of expected annual water level change. The major advantage of a probabilistic model approach over a traditional water balance is the incorporation of uncertain and variable data inputs to applicable components of a water balance. The data uncertainty or variability is therefore reflected in the calculation outputs allowing managers to both see the output variability, where uncertainty lies, how it can be reduced and if required, findings can be selected appropriate to the level of management risk. The single value or simple range of values produced with a traditional water balance can be misleading. Various climate and pumping scenarios were run in the probabilistic model, in order to assess the effect of various environmental and management changes on Deep Lead water levels. The model was calibrated to pre-development and average Millennium Drought conditions.

The results show that direct pumping from the Deep Lead in Katunga WSPA has the greatest potential impact on predicted Deep Lead groundwater levels (scenarios 30,323 – 60,645 ML/year), followed closely by vertical flux from the Shepparton Formation (median estimates 14,493 – 20,137 ML/year). The latter also has the greatest uncertainty/variability of all model elements, largely due to the uncertainty in vertical hydraulic conductivity.

Median estimates for lateral inflows, lateral outflows and vertical flux from the Basement are 3,860 ML/year, 4,252 ML/year and 2,147 ML/year respectively. The Basement flux estimate is significant considering that it is often assumed to be impermeable. The influence of mechanical loading from the watertable was found to be negligible compared to the other controls on Deep Lead groundwater level.

The impacts of various climate and pumping scenarios on Deep Lead water levels were estimated. Average annual impacts for three scenarios are as follows:

- “Optimistic scenario” – 50% allocation usage, extreme dry climate, lower NSW pumping impact scenario – average annual water level change -1.0 m;
- “Likely” scenario – 50% allocation usage, dry climate (typified by the 2002-07 Deep Lead aquifer pressures), higher NSW pumping impact scenario – average annual water level change -1.4 m; and
- “Conservative” scenario – 70% allocation usage, wet climate, higher NSW pumping impact scenario – average annual water level change -3.6 m.

The cumulative impact of these scenarios was assessed assuming that the conditions under each scenario continue over a period of 10 years and that the annual water level change declines exponentially over this time to reach a new equilibrium. The cumulative 10 year impacts were added to the 2006 baseline average spring groundwater recovery level of 18 m. The estimated Deep Lead re-equilibrium spring recovery groundwater levels are as follows, in order from most likely to least likely (i.e. most conservative):

- 50th percentile (median) – 23 mBGL;
- 40th percentile (slightly conservative) – 25 mBGL;
- 30th percentile (moderately conservative) – 27 mBGL; and
- 20th percentile (very conservative) – 31 mBGL.

If an alternative to the current 20 m rolling average spring recovery water level objective was to be considered, URS would therefore suggest adopting the slightly or moderately conservative estimates above (i.e. 25 or 27 mBGL).

Under a 100% allocation use scenario, the estimates of cumulative 10 year impact increase to 39 m (median) to 59 m (very conservative). These values are close to or exceeding the average pump depth in the Katunga WSPA of 41.2 mBGL (GMW, 2012). Therefore, use of 100% allocation in the Katunga WSPA would likely restrict the ability to access groundwater without lowering pumps in many bores, and may result in increased capital costs and annual operating costs.

Outcomes

Impact of Full Use of Entitlement

The impact of full use of entitlement in the Katunga WSPA (60,645 ML/year) has been investigated using the 100% usage scenario in the model.

In the short term (one year), a groundwater level decline of 6.5 m/year has the potential to have significant impact on the sustainability of the aquifer with regards to groundwater users, particularly those with shallow bores and/or shallow pump depths.

In the longer term, use of full entitlement may result in Deep Lead water levels reaching a new equilibrium spring recovery level of around 39 mBGL (median estimate) to 59 mBGL (20th percentile conservative estimate). This would significantly restrict the ability to access groundwater in the Katunga WSPA.

These impacts would need to be addressed if an allocation of 100% entitlement was considered.

Groundwater Carryover

Groundwater carryover is a management tool available to be implemented in groundwater management units in Victoria. URS understands that carryover of 20% may be considered in the Katunga WSPA.

The typical annual entitlement usage rates are around 50% during years of 70% allocation. Therefore, the impact of carryover has been investigated using the difference in Deep Lead groundwater level decline between the 50% and 70% usage scenarios. The predicted water level decline is 1.8 m (Year 1) in addition to the decline expected from 50% usage, assuming the median climate scenario.

The introduction of groundwater carryover has the potential to impact on Deep Lead groundwater levels. However, the magnitude of this impact will depend on the realised usage rates. This impact can be adaptively managed using a groundwater level trigger. However, it may result in a higher likelihood of GMW needing to reduce allocations from 70% to 50% in any one year.

Further work should be undertaken to assess the desire for and potential impacts of carryover on groundwater levels.

Trigger Levels and Allocations

In line with the Katunga WSPA GMP objective, the adopted trigger level should enable access to groundwater to be maintained by current groundwater users without major cost impacts.

Therefore it is recommended that:

- The current 5 year rolling average spring recovery groundwater level **objective** of 20 mBGL be increased to 25 mBGL, in line with the “likely, slightly conservative” cumulative water level impact scenario estimate (Section 6.5.5); and
- A 5 year rolling average spring recovery groundwater level **trigger** of 25 mBGL be adopted, in line with the “likely, moderately conservative” cumulative water level impact scenario estimate (Section 6.5.5).

If this trigger was exceeded, allocation would be reduced from 70% to 50% in the subsequent year. The 2 m difference in the trigger level and the objective level allows for time lags in the response of the groundwater system, as well as uncertainties in NSW pumping regime.

The estimates contained here are subject to the uncertainties and limitations described throughout this report, and therefore it is recommended that any objective and trigger levels adopted for the Katunga WSPA be subject to regular review.

1 INTRODUCTION

1.1 Background

Goulburn-Murray Water (GMW) manages groundwater in the Katunga Water Supply Protection Area (WSPA) in northern Victoria under authority delegated by the Minister for Water (the Minister). Licensed groundwater pumping is regulated by annual allocations and trade restrictions through the *Katunga WSPA Groundwater Management Plan (GMP)*, which was prepared by a Consultative Committee appointed by the Minister under the *Water Act (1989)*. The GMP was approved by the Minister in 2006 and reviewed by GMW in 2012.

Groundwater pumping in the Katunga WSPA occurs mostly from the Deep Lead aquifer, which comprises the Calivil Formation and the Renmark Group sedimentary deposits. Over time, pumping has resulted in long term decline in spring (or maximum annual) groundwater recovery levels. One of the key management objectives for the Katunga WSPA is to “prevent groundwater levels measured in spring from declining below recent recovery levels and to maintain them at levels that ensure access to groundwater without major cost impacts” (Katunga WSPA Consultative Committee, 2006). A key finding of the review (GMW, 2012) was that the existing allocation methodology, which uses a basic groundwater usage versus groundwater level relationship, has not met this objective.

It was noted in the GMP review that further technical work was required to understand the components of the water balance and the impact of pumping both in Victoria and NSW. This work is required for the preparation of an amended GMP. URS Australia Pty Ltd (URS) was commissioned by GMW to undertake the groundwater resource assessment described in this report in order to improve the understanding of the water balance.

1.2 Objectives

The aim of this project is to investigate the elements of the water balance for the Deep Lead aquifer in the Katunga WSPA, in order to provide recommendations on:

- Future trigger levels for allocation restrictions;
- The potential for groundwater carryover (i.e. transfer of unused entitlement to the following year); and
- The impact of full use of entitlement on groundwater levels.

1.3 Scope

The scope of works is described in the proposal *Katunga Water Supply Protection Area, Water Resource (Groundwater) Assessment*, dated 13 February 2015, and summarised below:

1. Collation and review of relevant hydrogeological data and literature, as summarised in Section 2.2;
2. Development of a conceptual hydrogeological model (CHM) for the Deep Lead aquifer in the Katunga WSPA, with a particular focus on the controls on Deep Lead groundwater levels;
3. Development of a simple analytical, probabilistic “water balance” model for the Deep Lead aquifer using the software Oracle® Crystal Ball, including the following tasks:

- a) Conceptualising the model elements based on the CHM described above;
 - b) Compilation of hydraulic parameters and assigning input distributions for the model;
 - c) Evaluation of the model elements and a simple model calibration;
 - d) Evaluation of pumping and climate scenarios to determine the relative effect on groundwater levels in the Deep Lead aquifer.
4. Provide recommendations on the following to inform the upcoming GMP amendment:
- a) Trigger levels for future allocation restrictions;
 - b) Impact of use of full entitlement on water levels and sustainability of the aquifer; and
 - c) The scope for groundwater carryover in the WSPA.

A meeting was held between URS and GMW on Friday 20 March 2015 in order to discuss and agree the following:

- The Deep Lead aquifer CHM; and
- Conceptualisation of the probabilistic model, the main input parameters, and the proposed scenarios.

This meeting was the agreed Holdpoint #1 as stipulated in the proposal. Issuing of this Draft Report constitutes Holdpoint #2.

1.4 Limitations

This groundwater resource assessment is restricted to the Deep Lead aquifer (Calivil Formation and Renmark Group) in the Katunga WSPA. It is designed to be a simple analytical assessment of inputs and outputs to the Deep Lead aquifer, averaged over the entire WSPA. It is recognised that a spatially distributed transient numerical groundwater model designed to answer the questions described in Section 1.2 would provide superior results at a local, pumping site scale. However, as this project is considering a whole-of-region scale, numerical modelling is beyond the scope of this project.

2 METHODOLOGY

2.1 Project Approach

2.1.1 *Issues with the Traditional Water Balance*

The concept of a “water balance” where inputs and outputs are calibrated to result in either a net zero balance (stable system) or some imbalance (for a system not in equilibrium) is difficult to apply to groundwater due to the different timescales of groundwater response to stressors such as pumping and changes to storage. Furthermore, there is a large variability, and sometimes significant uncertainty, in some input parameters in a groundwater balance. The uncertainty in some inputs can be greater than the magnitude of the change being investigated. The method of dealing with uncertainty and variability in a traditional water balance approach is typically quite basic, and reporting of a single number or a simple sensitivity analysis range can give a false impression of confidence in the value.

2.1.2 *Probabilistic Assessment Methodology*

A probabilistic model is one where the inputs are entered as probability distributions rather than single numbers, and thus the outputs are presented as frequency curves. All of the variability and uncertainty in all of the input parameters is thus reflected in the output frequency curve. These outputs are a good tool for discussion purposes.

Setting the input parameter probability distributions involves deciding on a distribution type (e.g. normal, log normal, triangular, uniform, exponential), and setting the location variables (e.g. mean, 95th percentile). These can be decided using literature ranges, site specific data, and professional judgement.

The software used to perform this assessment is Oracle[®] Crystal Ball, an add-in for Microsoft Excel. This software runs thousands of calculations for every simulation, choosing values out of the input distributions at random, and compiling the frequency curve for the outputs.

All of the elements of the model are entered as annual volumes (inter-year variability is included in the input distribution), and the resulting imbalance in Deep Lead volume is converted from a change in elastic storage to a change in groundwater pressure. Various scenarios can then be run to simulate changes in pumping volumes and changes in climate. This is described further in Section 6.1.

2.2 Data and Information Sources

2.2.1 *Supplied to URS*

The following information was supplied to URS for use in this project:

- The following reports (full citations in Chapter 8): NOLAN-ITU (2002), Katunga Technical Working Group (2005), Holland and Rendell (2006), Katunga WSPA Consultative Committee (2006), NSW Office of Water (2010), Ellis (2010), GMW (2012), Beverly and Hocking (2014), GMW (2014a), GMW (2014b);
- A spreadsheet of licence entitlements and annual metered usage from 1999/00 to 2013/14 for the Katunga WSPA: “Licenced entitlement and usage.xlsx”;

- Spatial point data showing licenced bores and stock and domestic bores within the Katunga WSPA;
- Three powerpoint slides showing water balance estimates for time periods between 1992 and 2003, entitled "DEEP LEAD DIAGRAM.xlsx";
- A map showing change in average groundwater level between 1992/93 and 1999/00, prepared by SKM, entitled "Katunga Plan Figure 3.pdf";
- A map showing metered use intensity in the Katunga WSPA for 2002/03, prepared by SKM, entitled "TATDOC-#1725481-v2-PUMPING_INTENSITY_IN_KATUNGA_WSPA_2002_03.pdf";
- A spreadsheet with results from a traditional water balance calculation for the Calivil and Shepparton Formation for selected periods between 1953 and 2004. Unknown author. Spreadsheet entitled "TATDOC-#1630281-v5-KATUNGA_-_ESTIMATED_GROUNDWATER_BALANCE_-_OCTOBER_2005.xls";
- A spreadsheet containing an extract of results from the GMW pumping test database for the Deep Lead aquifer in the Katunga and Mid-Goulburn Groundwater Management Units (GMUs), entitled "pump test data base - katunga and mid goulburn.xlsx"; and
- Model files for the Katunga WSPA numerical groundwater model "KAT9B", dated September 2009. Prepared by NOLAN-ITU Pty Ltd.

2.2.2 Other Sources

Background information has been collated from a range of sources as cited throughout the report and listed in Chapter 8. Additional key datasets used in this project are described below.

2.2.2.1 Statewide 3D Aquifer Surfaces

Aquifer top and bottom layers have been generated for the whole of Victoria based on 15 hydrostratigraphic units as described in the Victorian Aquifer Framework (VAF; SKM, 2011). This work was conducted as part of the Secure Allocations, Future Entitlements (SAFE) Project conducted by the Department of Sustainability and Environment (DSE), now the Department of Environment, Land, Water and Planning (DELWP). The project is described further in GHD (2012).

2.2.2.2 Groundwater Data - Victoria

Groundwater monitoring bore data for Victoria was obtained from the DELWP Water Management Information System (WMIS)¹. This data includes location coordinates, construction information, lithological logs, and historic water level data.

Screened aquifer information for each monitoring bore was obtained from GMW (2012) for bores within the Katunga WSPA and from GMW (2014b) for bores in the Mid Goulburn Groundwater Management Area (GMA) and surrounds.

¹ Downloaded 10 March 2015 from <http://data.water.vic.gov.au/monitoring.htm>

2.2.2.3 *Groundwater Data - NSW*

Groundwater monitoring bore data was obtained from the NSW Office of Water (NOW) Continuous Water Monitoring Network² for use in this project. This data includes monitoring bore location coordinates, construction records, and historic water levels.

Screened aquifer information was obtained from NOW monitoring reports for the Lower Murray Alluvium GMA (NOW, 2011; NOW, 2014).

Licensed bore information for NSW was obtained from the NSW "PINNEENA" Groundwater Works Database, Version 3.2.

2.3 **Spatial Data Calculations**

Estimates of aquifer thickness, surface area and volumes were made using the Spatial Analyst extension in ArcGIS, based on the Statewide 3D Aquifer Surface rasters as described above.

Cross sectional areas were calculated using the 3D Analyst extension in ArcGIS to create section profiles that were exported to Excel and integrated to estimate the section area of the Deep Lead aquifer.

Potentiometric surfaces were interpolated from monitoring bore point data via kriging, using the Spatial Analyst extension in ArcGIS.

² NOW Continuous Water Monitoring Network "All Groundwater Data", available at <http://allwaterdata.water.nsw.gov.au/water.stm>

3 SITE SETTING

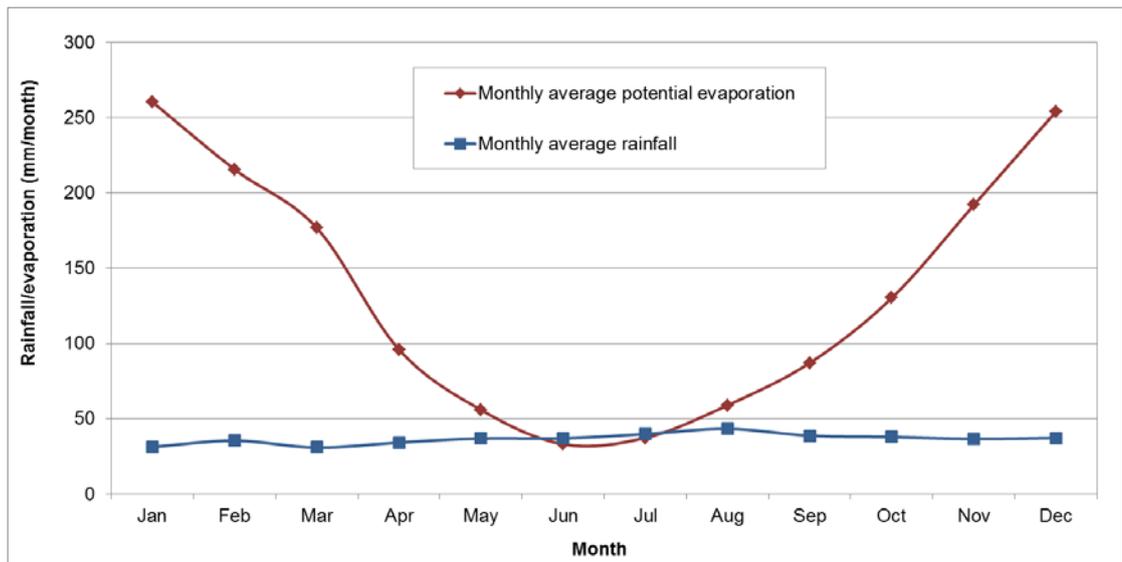
3.1 Location

The Katunga WSPA covers an area of around 2,100 km² in the Murray-Darling Basin (MDB) in northern Victoria (Figure A-1). The area is located in the Murray Valley within the Goulburn-Broken groundwater catchment, approximately 30 km north of Tatura. The main towns in the area are Numurkah and Cobram.

3.2 Climate

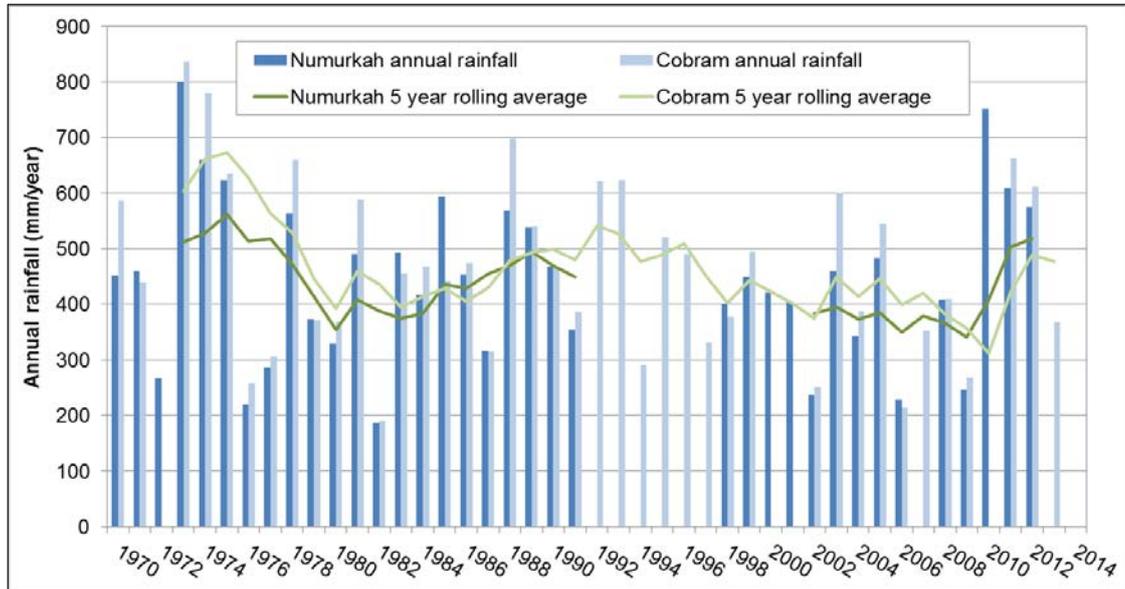
The Katunga WSPA is semi-arid with a high potential evaporation rate relative to rainfall. The average monthly rainfall and potential evaporation recorded at the Numurkah Bureau of Meteorology (BOM) monitoring station (station #080101) is shown in Chart 3-1. For most months throughout the year, potential evaporation exceeds rainfall significantly, except in June and July when average rainfall and evaporation are similar. Rainfall has been recorded at this station since 1968 and potential evaporation was recorded from 1968 to 1992.

Chart 3-1 Average Monthly Rainfall and Evaporation at Numurkah



Yearly rainfall totals from the Numurkah and Cobram (station #080109) BOM monitoring stations over the period 1970 to 2014 are shown in Chart 3-2. Annual rainfall is highly variable. Over this period, rainfall has ranged from 186 to 837 mm/year, with an average of 443 mm/year at Numurkah and 467 mm/year at Cobram.

Chart 3-2 Annual Rainfall at Numurkah and Cobram



3.3 Land Use

Most of the Katunga WSPA is within the Murray Valley Irrigation Area where irrigation occurs via a network of supply channels. Limited horticultural production occurs in the northeast of the area using a mix of flood, drop and micro-spray irrigation (Katunga WSPA Consultative Committee, 2006). Most of the remaining area uses flood irrigation to grow pasture for dairy production (Katunga WSPA Consultative Committee, 2006).

3.4 Hydrology

The Katunga WSPA is located on the floodplain of the Murray River and tributaries, and is bordered by the Murray River to the north. Broken Creek runs approximately parallel to the Murray River close to the southern border of the WSPA. Both rivers flow towards the west. The Murray River is classed as gaining to losing and the Broken Creek is classed as variable to losing (DSE, 2012). As noted above, there is also an extensive network of irrigation supply channels across the WSPA.

3.5 Geology

The study area is situated in the Murray sedimentary basin within the Tabberabbera structural zone of the Lachlan Fold Belt. This zone is bounded by the Governor Fault (Figure A-3c) to the west and the Kancoona Fault to the east. The key stratigraphic units in the area in order from youngest to oldest are described below.

3.5.1 Coonambidgal Formation

This unit consists of alluvial clays, silts, sands and gravels deposited by present day streams and their recent ancestors. The Coonambidgal Formation forms the alluvial terraces along the course of present day streams, including the Murray River in this area (Figure A-2). According to the DSE Statewide 3D Aquifer Surfaces (GHD, 2012), the Coonambidgal Formation is up to 10 m thick in this area.

The Coonambidgal Formation could be considered as just the latest phase of deposition of the Shepparton Formation (Tickell, 1991). In fact, Tickell (1978) could not distinguish between this unit and the underlying Shepparton Formation in this area. The age of the conformable boundary between the units has been estimated as 20,000 years using radiocarbon dating (Tickell, 1991).

3.5.2 Shepparton Formation

The Shepparton Formation consists of fluviatile sediments, including clays, silts, sands and gravels. It was deposited during the late Tertiary to Quaternary (late Pliocene to Pleistocene) and is 50 to 120 m thick in the study area. The unit outcrops across most of the study area away from the present day floodplain (Figure A-2).

The unit is mostly clay and silty clay, with irregularly shaped sand beds ranging from clean sand to sandy clay. The sand beds tend to be sinuous and narrow, and are usually 2-5 m thick, although they can be up to 10 m thick (Tickell, 1991). The location and abundance of sand beds depends on the location, form and energy of the river in which the sediments were deposited (Tickell, 1991). There tends to be more sand beds in the lower portion of the formation in this area.

3.5.3 Calivil Formation (Deep Lead)

The Calivil Formation is a Late Miocene to Early Pliocene coarse grained alluvial deposit. In the headwaters of the MDB it was deposited in valleys deeply incised into the pre-Tertiary bedrock, however in this area it mostly forms a sheet-like unit across the plain.

The Calivil Formation consists of fine to coarse grained quartz sand, reef quartz and metasediment gravel (Geoscience Australia, 2012). These sediments were deposited by streams of significantly higher energy than exist today. Minor beds of kaolinitic clay in the formation were likely deposited in lake environments. The unit overlies the Renmark Group where it exists, and elsewhere the pre-Tertiary Basement. The Calivil Formation does not outcrop in the study area.

3.5.4 Renmark Group (Deep Lead)

The Renmark Group is a fluvial sequence of interbedded fine to coarse grained sand, gravel, brown coal, and carbonaceous silt and clay. It consists of two sub-units, the upper Olney Formation (siltstone, claystone lignite and sand) and the lower Warina Sand (carbonaceous and micaceous sand). These sediments were deposited by high energy streams from the Middle Eocene to the Early Miocene. Coarse grained units were deposited in the alluvial valleys as the rivers meandered across the floodplain, and fine grained carbonaceous sediments were deposited in the low energy swamps and lakes between streams. The sand and gravel units are usually 2-20 m thick and the clay beds are usually less than 10 m thick (Tickell, 1991). This unit does not outcrop in the study area.

3.5.5 ***Urana Formation***

The Urana Formation is a Late Carboniferous to Early Permian glacio-marine and fluvial sedimentary unit that overlies the Ordovician bedrock across the western portion of the study area. It consists of sandstone, mudstone, conglomerate and tillite (Geoscience Australia, 2012). The Tertiary-Quaternary sediments of the Murray Basin, as described above, unconformably overlie this unit.

There is a mapped outcrop of this formation in the southeast of the study area (Figure A-2).

3.5.6 ***Adaminaby Group***

The bedrock unit in the study area is the Pinnak Sandstone of the Adaminaby Group, which is of Early Ordovician age. This unit consists of marine turbidic sandstone, siltstone, mudstone, minor thinly bedded chert, and minor black siliceous shale (Geoscience Australia, 2012). It was deposited as an extensive submarine fan. The unit outcrops to the south of the Murray River, south of Yarrawonga (Figure A-2).

4 THE KATUNGA WSPA GROUNDWATER MANAGEMENT PLAN

4.1 Introduction

The Katunga WSPA was declared in January 1999 in response to high rates of groundwater extraction and declining groundwater pressures in the lower Shepparton Formation and the Deep Lead. A GMP for the area was subsequently developed, and was approved in July 2006. The plan applies only to groundwater sourced from aquifers at depths of greater than 25 mBGL. Shallow groundwater (<25 mBGL) is managed separately.

The objective of the GMP is to ensure that “the water resources of the area are managed in an equitable manner so as to ensure the long-term sustainability of those resources” (Katunga WSPA Consultative Committee, 2006). This objective is fulfilled primarily through the application of annual allocations for groundwater pumping that are designed to ensure that groundwater levels do not fall below an acceptable level.

Three zones have been defined in the Katunga WSPA Groundwater Management Plan, in order to manage groundwater use through the implementation of different licence trading rules. The zones are as follows:

- North Western Dryland Zone [1061];
- Numurkah-Nathalia Zone [1062]; and
- Cobram Zone [1063].

The borders of these zones are shown in Figure A-1.

4.2 Allocation Methodology

On the basis of technical work completed prior to the plan implementation (Katunga Technical Working Group, 2005), a methodology was adopted for deriving annual allocation percentage restrictions. The objective of the allocation methodology is to maintain 5-year rolling average spring groundwater recovery levels at ≤ 20 mBGL. Prior to significant development in the Deep Lead aquifers (Calivil Formation and Renmark Group), average spring (or maximum annual) recovery level was approximately 12 mBGL. The value of 20 mBGL was adopted by the Katunga WSPA Consultative Committee (2006) as the average 5-year groundwater recovery level to aim for in order to maintain acceptable and equitable access for users without increasing pumping costs.

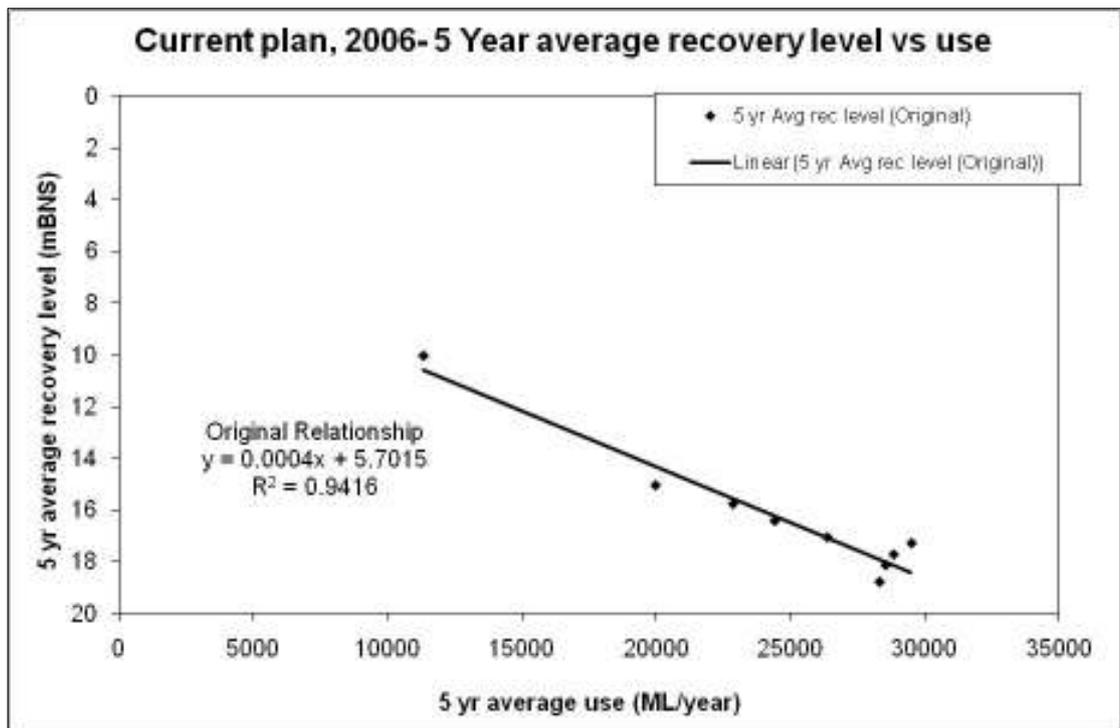
A 5-year average spring recovery level is used because the level in any one year is very sensitive to the timing of the start of the irrigation season and because there is a lag in groundwater response following years of high pumping.

A regression analysis of historical groundwater extraction versus spring recovery level (both as 5-year rolling averages) since the late 1980s suggested that:

- At extractions of less than around 10,000 ML/year, pre-development average recovery levels (12 mBGL) are maintained (i.e. there is no relationship between extraction and recovery level);
- Recovery levels decline with increasing extraction above 10,000 ML/year, and the target average recovery level of 20 mBGL equates to an extraction of approximately 30,000 ML/year (note that the average recovery level is 18 mBGL; this was rounded to 20 mBGL by GMW); and
- By extrapolation, if the annual extraction was to be as high as 40,000 ML, the average recovery level would be expected to be approximately 23 to 25 mBGL.

This relationship is shown in Chart 4-1.

Chart 4-1 Average Spring Recovery Level vs Average Extraction (GMW, 2012)



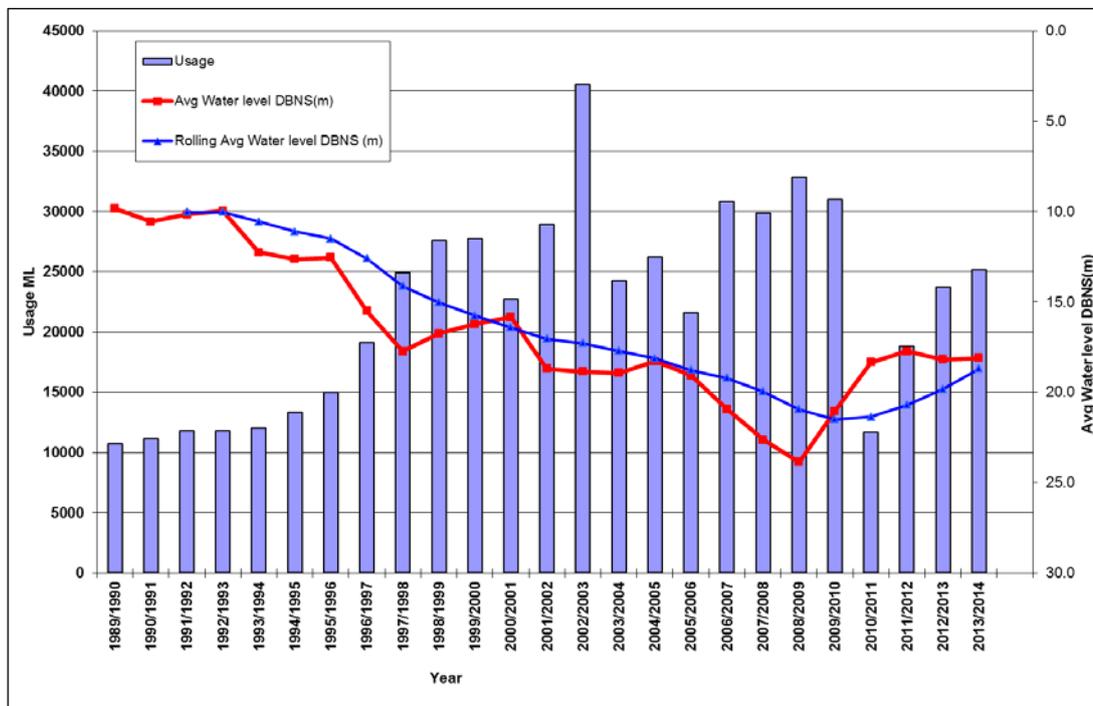
On the basis of a full entitlement of 60,000 ML/year, a permanent restriction to 70% of entitlement (42,000 ML) was implemented, with an option in any year to reduce the allocation to 50% (30,000 ML) if the 5 year rolling average extraction exceeded 30,000 ML.

It should be noted that the average spring recovery level is calculated by GMW using the 8 monitoring bores listed in Schedule 2 of the GMP (see bore locations in Figure A-2 and hydrographs for these bores in Appendix B-1. One of these bores is defective and is no longer monitored (109680; GMW, 2012).

4.3 The 2012 GMP Review

The GMP requires a review be undertaken every five years to assess its performance and any opportunities for improvement (GMW, 2012). The review found that the allocation methodology adopted in the GMP had not met the objective of maintaining the nominated average spring recovery level of ≤ 20 mBGL and that the relationship between groundwater level and usage was less significant than originally understood. From 2006 to 2010, the 5-year average extraction was maintained at less than 30,000 ML/year, however the 5 year average spring recovery level has been 1-3 m lower than the objective of 20 mBGL. This is illustrated in Chart 4-2.

Chart 4-2 Groundwater Extraction and Spring Recovery Levels



Two recommendations were made in the review that this report aims to address:

- That a groundwater level based trigger be adopted in place of a usage trigger; and
- That a water balance be prepared, including vertical flux through the Shepparton Formation and throughflow in the Deep Lead, in order to inform groundwater management and ensure resilience for future changes in climate and pumping scenarios.

As stated in the review, adoption of a groundwater level trigger of 20 mBGL (as the 5 year rolling average) would have resulted in restriction to 50% allocation in the years 2008/09 and 2009/10 (Chart 4-2). Based on the existing usage trigger, 70% allocations remained in place for those two years.

5 CONCEPTUAL HYDROGEOLOGICAL MODEL

5.1 Introduction

The purpose of this chapter is to summarise the conceptual model for groundwater in the Katunga WSPA, with a particular emphasis on the Deep Lead aquifer systems. The description of controls on Deep Lead aquifer groundwater pressure contained in Section 5.5 will be used as the basis for the probabilistic resource assessment in Chapter 6.

5.2 Hydrostratigraphy

The hydrostratigraphy in the study area is summarised in Table 5-1, along with the corresponding terminology and aquifer codes from the Victorian Aquifer Framework (SKM, 2011). Top of aquifer surfaces from the Statewide 3D Aquifer Surfaces dataset (GHD, 2012) are presented in Figure A-3a to Figure A-3c.

Table 5-1 Summary of Key Hydrogeological Units

| GEOLOGICAL UNIT NAME | VAF AQUIFER NAME | VAF AQUIFER CODE | VAF AQUIFER LETTER | HYDROGEOLOGICAL UNIT NAME IN THIS REPORT |
|------------------------|---------------------------------------|------------------|--------------------|--|
| Coonambidgal Formation | Quaternary Aquifer | 100 | QA | Shepparton Formation* |
| Shepparton Formation | Upper Tertiary/ Quaternary Aquifer | 102 | UTQA | |
| Calivil Formation | Upper Tertiary Aquifer (fluvial) | 105 | UTAF | Deep Lead |
| Renmark Group | Lower Tertiary Aquifer | 111 | LTA | |
| Urana Formation | Cretaceous and Permian Sediments | 113 | CPS | Basement |
| Adaminably Group | Mesozoic and Palaeozoic Bedrock | 114 | BSE | |

* Further divided into 'upper', 'mid' and 'lower' Shepparton Formation (Section 5.2.1).

5.2.1 Shepparton Formation

The Shepparton Formation is a layered aquifer/leaky aquitard unit of silts and clays with shoestring beds of sand and minor gravel. It ranges from unconfined to semi-confined, depending on the depth and overlying lithology. The significant layers of clays and silty clays act as leaky aquitards so that the connection from the upper to lower parts of the formation is muted. This unit is heterogeneous and anisotropic.

For the purposes of this study, the Coonambidgal Formation is treated as part of the Shepparton Formation. As stated in Section 3.5.1, the Coonambidgal Formation can be considered as just the latest depositional phase of the Shepparton Formation (Tickell, 1991) and has similar properties. It has been mapped on the floodplain of some present day streams in the area, including the Murray River, and is a maximum of 10 m thick.

The Shepparton Formation is sometimes classified into upper (<25 mBGL), mid (25-50 mBGL) and lower (>50 mBGL) units (Katunga Technical Working Group, 2005). The upper Shepparton Formation is managed separately due to salinity issues. The lower Shepparton Formation typically has a higher abundance of coarse grained material and is in strong hydraulic connection with the Deep Lead, as discussed in Section 5.3.1.

This aquifer extends across the entire Katunga WSPA (Figure A-3a). Based on volume estimates using the Statewide 3D Aquifer Surfaces, the average thickness of the Shepparton Formation across the Katunga WSPA is 99 m.

5.2.2 Deep Lead

The Deep Lead is the primary aquifer of interest in this study. The unit includes the Calivil Formation and the Renmark Group (Olney Formation and Warina Sand). Where one or more of these units are present, they are termed singularly or collectively, the Deep Lead because these units (usually the Calivil Formation) have been mined for gold historically in the headwaters of the basin.

The Deep Lead forms a mostly coarse grained, sheet-like sedimentary unit. Although the lower portion of the Deep Lead (the Renmark Group) contains significant thicknesses of fine grained material.

There are two main Deep Lead palaeovalleys running through Katunga, which join in the centre of the WSPA. The Murray palaeovalley enters from the west near Yarrowonga and the Goulburn palaeovalley enters from the south (Figure A-3b). There is also a small palaeovalley in the Broken Creek catchment to the southeast.

The area within the Katunga WSPA underlain by Deep Lead aquifer is 1873 km², which is equal to approximately 90% of the total WSPA area. Based on volume estimates using the Statewide 3D Aquifer Surfaces, the average thickness of this unit across its extent is 51 m. By volume, the Renmark Group forms 56% of the total Deep Lead aquifer.

5.2.3 Basement

The basement hydrostratigraphic unit encompasses all pre-Tertiary units in the study area, including the Ordovician Adaminably Group, the Devonian Granite, and the Carboniferous-Permian Urana Formation. This unit is likely to be highly faulted and deformed, with heterogeneous hydraulic properties. There is very little information available on the Basement hydraulic properties.

5.3 Groundwater Flow

5.3.1 Shepparton Formation

The Shepparton Formation is the watertable aquifer, and depth to water level is typically in the range 2-5 mBGL. The elevation of the watertable changes over time due to the change in the following processes: rainfall accessions, irrigation accessions, evapotranspiration (ET) losses, exchange with surface water features (gaining and losing), and shallow groundwater pumping.

As noted above, the Shepparton Formation is mostly fine grained with lenses of coarser grained material. Flow in the fine grained portions of the Shepparton Formation is mostly vertical, while in the sand lenses flow is mostly lateral due to the higher permeability. There is a significant head differential between the upper and lower Shepparton Formation. Groundwater in the sand units of the lower Shepparton Formation is very well hydraulically connected with the Deep Lead aquifer. Groundwater pumping also occurs in the coarse grained portion of the lower Shepparton Formation because yields are high (comparable to the Deep Lead). The hydraulic connection is evident in the nested hydrographs presented in Appendix B-2 (see bore locations in Figure A-7).

Vertical flux from the Shepparton Formation to the Deep Lead is driven by the head differential between the upper Shepparton Formation (controlled by the surface processes described above) and the Deep Lead. This head differential has increased over time largely due to declines in Deep Lead pressure from pumping. The maximum head differential occurred around February 2009; this head differential is presented in Figure A-5d for nested upper Shepparton Formation – Deep Lead sites. The flux from the Shepparton Formation to the Deep Lead is quantified in the analytical model described in Chapter 6.

5.3.2 Deep Lead

Flow in the Deep Lead aquifer is primarily horizontal. Recharge occurs via throughflow from the Murray Valley Deep Lead in the east, throughflow from the Goulburn Valley Deep Lead in the south, vertical flux from the Shepparton Formation, and vertical flux from the Basement. Discharge occurs via throughflow towards the northwest into NSW and via direct pumping from the Deep Lead in the Katunga WSPA.

The regional context of the Deep Lead aquifer is illustrated in Figure A-4, which includes the boundaries of the neighbouring Mid Goulburn GMA in Victoria and the Lower Murray Alluvium GMA in NSW. This map shows that the Katunga WSPA is situated at the confluence of a number of palaeovalley systems, where the sedimentary deposits change from valley type deposits to sheet-like alluvial plain deposits.

Potentiometric surfaces for the Deep Lead aquifer have been generated for the following periods:

- August/September 1993 (pre development) – Figure A-5a;
- February 2009 (greatest pumping-induced drawdown on record) – Figure A-5b; and
- September 2009 (spring recovery level after greatest pumping induced drawdown season) – Figure A-5c.

These figures show that flow was largely east to west prior to significant pumping induced changes in flow direction (Figure A-5a). Pumping has resulted in lower Deep Lead pressures overall, higher lateral gradients in both inflow areas (Murray and Goulburn palaeovalleys), and a change in outflow direction from westerly to northerly (Figure A-5b). This northerly flow direction is largely due to the very high pumping rates in NSW just north/northwest of Katunga WSPA where the groundwater depression is over 20 m below pre-pumping levels. This is discussed further in Section 5.4.3.

Interestingly, there is a groundwater divide at the confluence of the Broken Creek palaeovalley with the Murray and Goulburn palaeovalleys, so that groundwater flow was back towards the southeast within the Broken Creek system prior to development (Figure A-5a). This was also noted by Tickell and Humphrys (1987) based on groundwater levels in 1981. The cause of this groundwater divide is not known. Pumping in the Katunga WSPA has resulted in a flatter potentiometric surface, however the flow direction is still towards the southeast in this system (Figure A-5c). Based on the inferred position of the groundwater divide, it is assumed that there is no lateral flow between the Broken Creek system and the Deep Lead in the Katunga WSPA.

5.3.3 Basement

There is very little hydraulic information on the Basement aquifer because there are very few bores drilled in this unit, and no monitoring bores screened in this unit within the Katunga WSPA. Due to the lack of information on this unit, it is often assumed to be impermeable and modelled as a no flow boundary. However it is not likely to be impermeable. In fact, the vertical hydraulic conductivity (K_v) estimated from a pumping test in Campaspe West was in the same order of magnitude as the K_v of the lower Shepparton Formation (0.1-0.3 mm/day and 0.06-0.42 mm/day respectively; SKM, 1997a).

It could be plausibly assumed that groundwater pressure in the Basement aquifer was in equilibrium with the Deep Lead prior to pumping-induced pressure declines in the Deep Lead. If this is true, there would now be a significant head differential between the Deep Lead and Basement, with potential for significant pumping-induced upwards flux. This is quantified in the analytical model in Chapter 6.

5.4 Groundwater Pumping

Groundwater pumping is a key focus of this study. The discussion below includes historical extraction and potential future use patterns (where possible) for both the Katunga WSPA and adjoining management areas, as the latter influence the hydraulic gradients that control throughflow rates in the Deep Lead aquifer. The adjoining management areas of interest are the Mid Goulburn GMA up hydraulic gradient of the study area, and the Lower Murray Alluvium GMA (GMA016) down hydraulic gradient of the study area. The locations of these management areas are shown on Figure A-4.

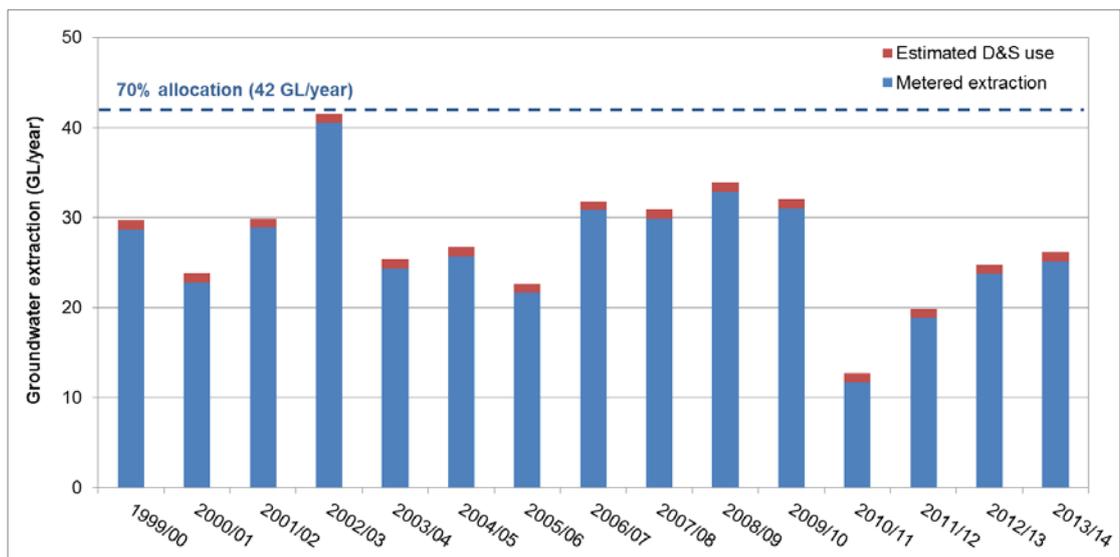
5.4.1 Katunga WSPA

The total licensed entitlement for groundwater extraction from the Deep Lead aquifer from 246 licences in the Katunga WSPA is 60,645 ML/year (GMW, 2012). Since the GMP was implemented in 2006 there has been a moratorium on new entitlement and a permanent allocation restriction to 70% of entitlement, with an option to reduce that to 50% in any one year where the 5 year rolling average usage exceeds 30,000 ML (Section 4.2). The reduction to 50% has never been triggered.

Groundwater usage has been metered since 1999/00 and this data is shown in Chart 5-1. During the Millennium Drought years (~1998-2010), usage averaged 28,800 ML/year with a maximum of 40,470 ML in 2002/03. Usage decreased significantly following the heavy rainfall in 2010-2011 because surface water allocation increased and the ready availability of rainfall through the year. Average usage since the end of the drought is 19,800 ML/year.

Domestic and stock use has been estimated assuming 2 ML/year usage from each bore with a total depth less than 25 mBGL, and assuming that bores installed more than 30 years ago are no longer operational (RMCG, 2011). Based on the spatial data provided by GMW, there are 516 bores stock and domestic bores in the Katunga WSPA fitting these criteria. This equates to an estimated use of 1,032 ML/year, as shown on Chart 5-1. The locations of licenced extraction bores and stock and domestic bores are shown in Figure A-6.

Chart 5-1 Historical Groundwater Extraction in the Katunga WSPA

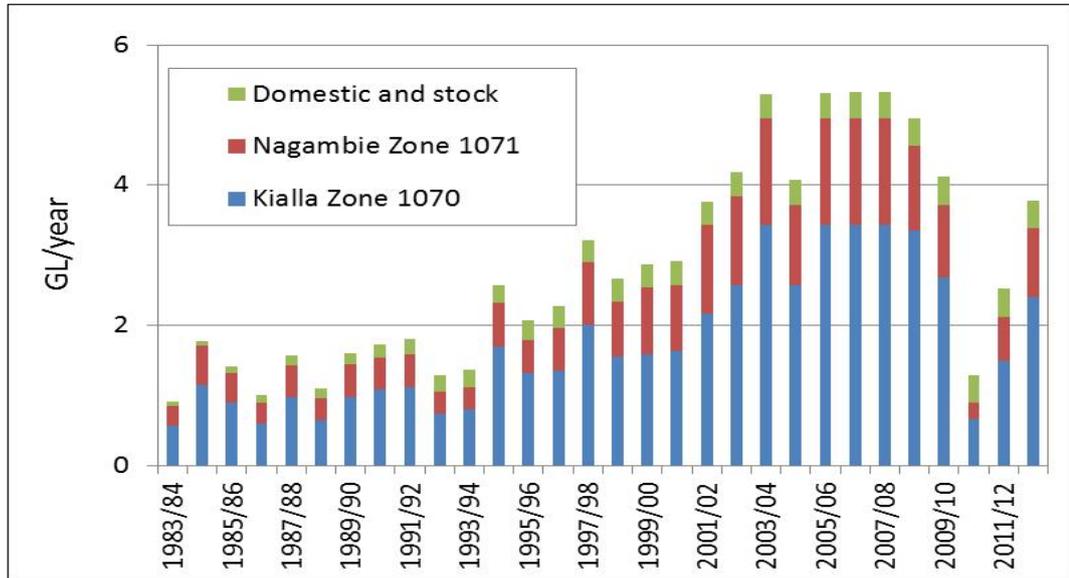


5.4.2 Mid Goulburn GMA

By comparison, the total licence entitlement for groundwater extraction from the Deep Lead aquifer in the Mid Goulburn GMA is 12,465 ML/year, of which 8,189 ML/year is held in the north management zone of the GMA, the Kialla Zone. The boundary of the GMA and its management zones are shown in Figure A-4.

Historical usage has generally been below around 5,000 ML/year for the GMA (Chart 5-2). The estimated domestic and stock use is 404 ML/year in total, of which 156 ML/year is from the Kialla Zone (GMW, 2014).

Chart 5-2 Historical Groundwater Extraction in the Mid Goulburn GMA (GMW, 2014)*



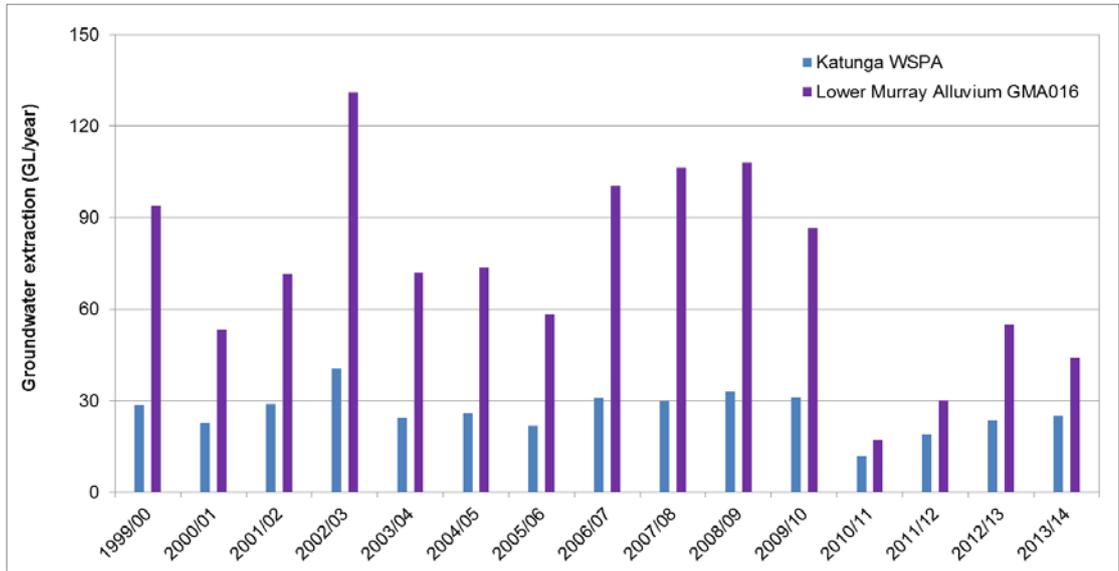
*Note: metering began in 2008/09. Usage prior to this has been estimated based on the date licensed bores were installed; their licence volume; and climate.

5.4.3 Lower Murray Alluvium GMA016

Across the Murray River in southern New South Wales, the licence entitlement for the Lower Murray Alluvium groundwater management area (GMA016) is 84,388 ML/year (84.4 GL/year) plus a supplementary volume of 47.8 GL/year (total ~132 GL; NSW, 2011). The supplementary volume is currently being phased out because it is recognised that the Deep Lead aquifer in this GMA is over-allocated; it is due to be zero by the final year of the plan (2015/16; NSW, 2014).

Historic metered usage is shown in Chart 5-3 along with Katunga usage for comparison purposes. Extraction rates in GMA016 are significantly higher. Groundwater use peaked at 131,000 ML in 2002/03, and has dropped off significantly since the end of the Millennium Drought.

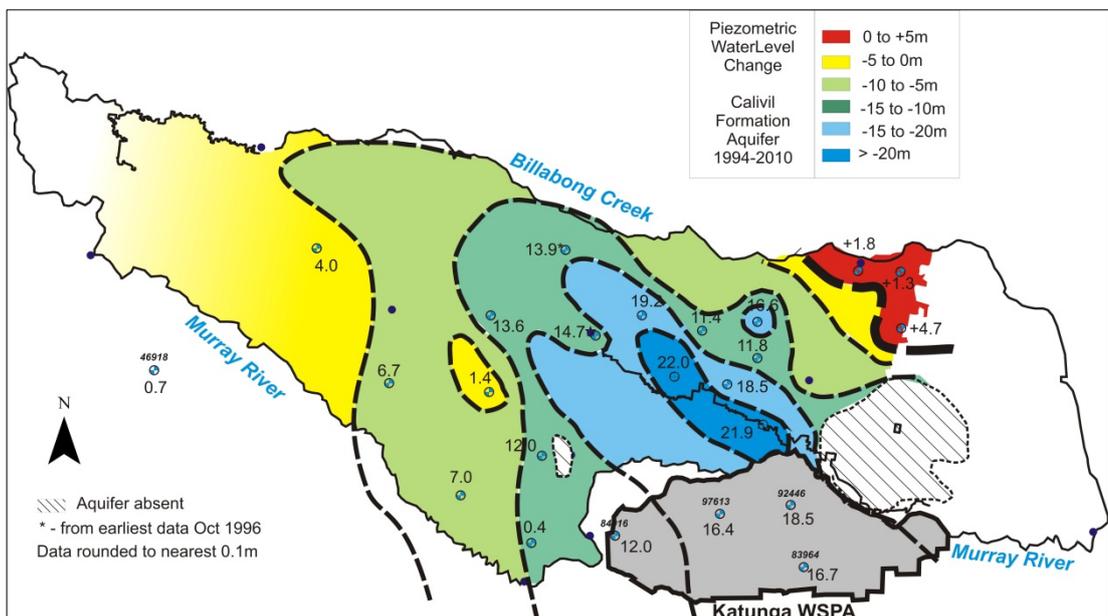
Chart 5-3 Historical Groundwater Extraction in GMA016



Groundwater usage in this GMA is strongly linked to the availability of surface water through the surface water allocation process. The very high groundwater usage in GMA016 during 2002/03 was triggered by a regulated surface water allocation of only 10% that year (NSW, 2011).

Selected hydrographs for bores screened in the Deep Lead in this GMA are shown in Appendix B-3 (see bore locations in Figure A-7). The seasonal and long term changes in Deep Lead groundwater levels are similar to that seen in the Katunga WSPA. However the declines are significantly greater, particularly in the region just north/northwest of the Katunga WSPA where pumping is greatest. This is illustrated in Figure 5-1, which shows that the pumping-induced depression over the period 1994 to 2010 is over 20 m just north of the Katunga WSPA.

Figure 5-1 NSW Deep Lead Potentiometric Surface Decline 1994-2010 (modified after URS, 2014b)



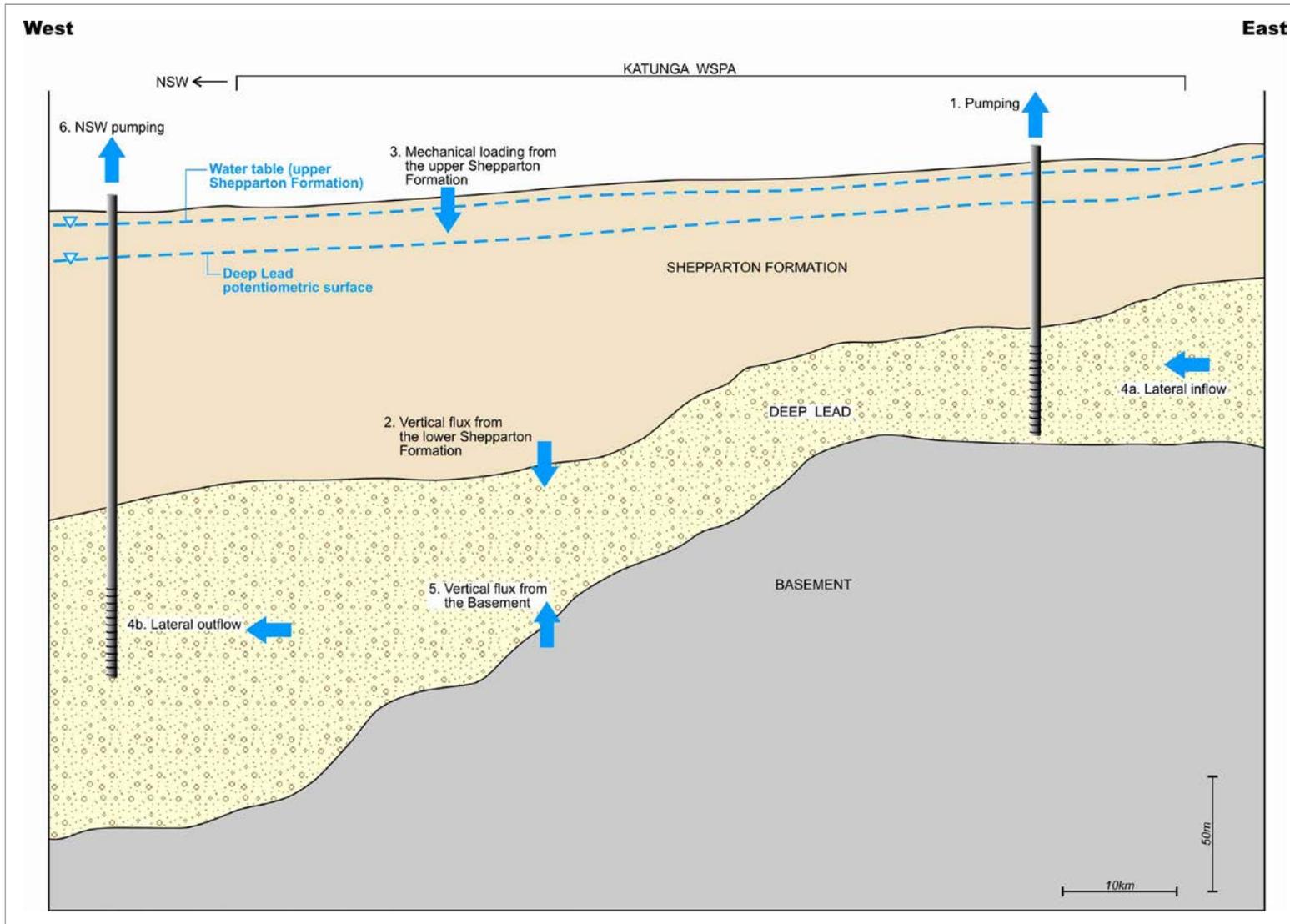
5.5 Conceptual Hydrogeological Model Summary: Controls on Deep Lead Groundwater Pressure

The key physical processes that control average groundwater levels in the Deep Lead aquifer in the Katunga WSPA are as follows:

1. **Direct pumping from the Deep Lead within Katunga WSPA.**
2. **Vertical flux from the lower Shepparton Formation** – dependent on changes to the vertical head differential between the lower Shepparton Formation and the Deep Lead.
3. **Mechanical loading from the upper Shepparton Formation** –The vertical pressure exerted through the pore-space of the saturated soil/water columns from the surface as water table levels change, propagate elastic pressure changes to the groundwater in the Deep Lead aquifer. This therefore represents a mechanical pressure loading, with a consequential change in potentiometric pressure in confined aquifers, rather than an actual flux of water, and is therefore dependent on and sensitive to changes in the watertable elevation.
4. **Lateral flux to/from upgradient and downgradient portions of the Deep Lead** – dependent on the water balance in Katunga and adjoining areas (including pumping in upgradient and downgradient areas).
5. **Vertical flux from the Basement** – dependent on changes to the vertical head differential between the Deep Lead and the Basement.
6. **NSW pumping** – dependent on changes in pumping rates in NSW, which is in turn influenced by annual surface allocations and management changes (e.g. phasing out of supplementary licences).

These processes are illustrated in Figure 5-2.

Figure 5-2 Conceptual Hydrogeological Model schematic: Controls on Deep Lead Groundwater Pressure in the Katunga WSPA



6 GROUNDWATER RESOURCE ASSESSMENT – PROBABILISTIC MODEL

6.1 Approach and Objective

The methodology for this probabilistic groundwater resource assessment is outlined in Section 2.1.2. Each of the six key processes that influence Deep Lead groundwater levels (Figure 5-2) are entered into the model as an annual volume. Inter-year variability is included in the input probability distributions rather than by running the model at annual time steps. The model output is a change in elastic storage (as a volume), which is converted to a change in head.

The aim of the model is to:

- Quantify each of the processes controlling Deep Lead groundwater levels (items 1-6 in Figure 5-2) to improve the understanding of the relative importance of each process;
- Investigate the impact of various Katunga pumping rates and climate scenarios on Deep Lead groundwater levels;
- Investigate the impact of pumping in NSW on Deep Lead groundwater levels in Katunga; and
- Use these results to make recommendations on future trigger levels for allocation restrictions, the scope for groundwater carryover, and the impact of full use of entitlement on the sustainability of the Deep Lead aquifer.

6.2 Input Data and Equations

Inputs into the model include hydraulic conductivities (lateral and vertical), storativities (confined and unconfined), head differentials, gradients (lateral and vertical), cross sectional areas, surface areas, thicknesses, and others. The probability distribution and location parameters for each input variable have been assigned based primarily on a review of published reports and analysis of site-specific data. Descriptions of all of the input variable derivations are provided in Appendix C. The model probability input distributions (termed “assumptions” in Crystal Ball software) are provided in Appendix E-1.

Table 6-1 Summary of Equations used for Monte Carlo Simulations

| MODEL ELEMENT* | DESCRIPTION | EQUATION |
|----------------|--------------------------------------|--|
| 1 | Direct pumping from Katunga | $Q = \text{annual pumping rate}^\#$ |
| 2 | Vertical flux from the Shepparton Fm | $Q = C_v \times \Delta H \times SA$ $C_v = \text{conductance} = K_v/b'$ – $\Delta H = \text{head differential (upper Shep Fm to Deep Lead)}^\#$ – $SA = \text{surface area of Shep Fm/Deep Lead contact}$ – $K_v = \text{vertical hydraulic conductivity (Shep Fm)}$ – $b' = \text{thickness of aquitard portion of Shep Fm (total thickness x proportion of fine grained material)}$ |
| 3 | Mechanical loading [^] | $Q = \Delta SWL \times S_y \times LE \times SA \times S$ – $\Delta SWL = \text{change in SWL (upper Shep Fm)}^\#$ – $S_y = \text{specific yield (Shep Fm)}$ – $LE = \text{loading efficiency (Deep Lead)}$ – $SA = \text{surface area of Shep Fm/Deep Lead contact}$ – $S = \text{storativity (Deep Lead)} = S_{sb} = \text{specific storage x aquifer thickness}$ |
| 4a | Lateral inflow | $Q = K_h \times i \times A$ (summed for two inflow areas) – $K_h = \text{lateral hydraulic conductivity (Deep Lead)}$ – $i = \text{lateral hydraulic gradient (Deep Lead)}^\#$ – $A = \text{cross sectional area (Deep Lead)}$ |
| 4b | Lateral outflow | $Q = K_h \times i \times A$ – $K_h = \text{lateral hydraulic conductivity (Deep Lead)}$ – $i = \text{lateral hydraulic gradient (Deep Lead)}^\#$ – $A = \text{cross sectional area (Deep Lead)}$ |
| 5 | Vertical flux from the Basement | $Q = K_v \times i \times SA$ – $K_v = \text{vertical hydraulic conductivity (Basement)}$ – $i = \text{vertical hydraulic gradient (Basement to Deep Lead)}$ – $SA = \text{surface area of Basement/Deep Lead contact}$ |
| 6 | NSW pumping | Approximated using a semi-log distance-drawdown relationship as outlined in Section 6.3.3. |

* See Figure 5-2.

= entered into model as scenarios (see Section 6.3).

[^] This is converted to an annual change in elastic storage volume in the model in order to carry out the resource assessment. However as noted in Section 5.5 this is not an actual flux of water, but rather a change in pressure.

Q = volumetric flow rate

6.3 Scenarios

6.3.1 Climate Scenarios

The purpose of running “climate” scenarios is to investigate the impact of changes in the Shepparton Formation – Deep Lead head differential on model elements 2 and 3 (vertical flux and mechanical loading). Climate and pumping rates are intrinsically linked, and furthermore, the head differential in any one year is a result of cumulative climate/pumping regimes in previous years. Four situations have been selected from the historical record in order to simulate these regimes; these are summarised in Table 6-2 below. Essentially, the head differential is greatest in the “Dry (extreme)” scenario and lowest in the “Wet pre development” scenario. This can be seen in the nested hydrographs in Appendix B-2.

Using this historical range of head differentials gives some idea of the variability that could be expected in the future. However it is recognised that future climate/pumping regimes could fall outside of the historical range (e.g. longer drought period with more intense pumping). The ranges built into the input distributions for each of these head differentials in the model (Table C-1, Appendix C) account for some of this uncertainty.

Table 6-2 Summary of Climate Scenarios adopted for Monte Carlo Simulations

| SCENARIO CATEGORY | SCENARIO ID | DESCRIPTION | COMMENT |
|-------------------|-------------|----------------------|--|
| Climate | C1* | Wet pre development | Pre-1994 conditions |
| | C2 | Dry | Average during the middle of the Millennium Drought (2002-2007) |
| | C3 | Dry (extreme) | The most extreme year during the Millennium Drought in terms of water level decline (2009) |
| | C4 | Wet post development | The average during the wet post-drought period (2011-2014) |

* Scenario C1 is for the purposes of calibration only (Section 6.4).

6.3.2 Katunga WSPA Deep Lead Aquifer Pumping Scenarios

Three pumping scenarios are used in the model in order to understand the impact of usage on the predicted change in Deep Lead water level. Scenarios P1 and P2 (50 and 70% of allocation; Table 6-3) were selected because these are the allocations currently allowed for in the GMP. Scenario P3 (100% of allocation) was selected to assess the impact of full use of entitlement on Deep Lead groundwater levels and the sustainability of the aquifer.

It is noted that historically in years of 70% allocation, actual usage has been closer to 50% of entitlement (Section 5.4.1). Comparison of model results between the 50% and 70% scenarios will address the project objective of investigating the impact of implementing groundwater carryover in Katunga.

Table 6-3 Summary of Katunga WSPA Deep Lead aquifer groundwater pumping scenarios adopted for Monte Carlo Simulations

| SCENARIO CATEGORY | SCENARIO ID | % OF ENTITLEMENT | COMMENT |
|--------------------------------|-------------|------------------|----------------|
| Katunga WSPA Deep Lead Pumping | P1 | 50% | 30,323 ML/year |
| | P2 | 70% | 42,451 ML/year |
| | P3 | 100% | 60,645 ML/year |

6.3.3 NSW Deep Lead Aquifer Pumping Scenarios

The impact of pumping from the Deep Lead aquifer in southern NSW on water levels in the Katunga WSPA is difficult to estimate due to interference effects, i.e. some of the drawdown observed at wells in NSW is due to Deep Lead aquifer pumping from the Katunga WSPA, and vice versa. This would best be approximated with a spatially distributed numerical groundwater model. However for the purposes of this assessment, potential impact has been estimated using a distance-drawdown relationship (Cooper and Jacob, 1946).

Drawdown over the period 1993/94 (pre-development) to 2009/10 (maximum drawdown) has been estimated at observation wells screened within the Deep Lead in southern NSW. Observation well GW036743 is reportedly closest to the centre of maximum pumping-induced drawdown (NOW, 2011), and drawdown should then decrease with distance from this assumed centre.

The estimated drawdown for selected NSW observation bores is shown in Figure A-8. A range of wells were used at different orientations from the assumed centre of pumping in order to help quantify the uncertainty in the input parameter distributions. Two scenarios were generated, both of which assumed that 50% of the drawdown at all observation wells (except that closest to the centre of pumping) was due to pumping in Katunga. This assumption results in a steeper distance drawdown relationship, and thus a lower estimate of NSW impact (considered a “conservative” estimate). The second scenario (N2) differs to first in that some of the drawdown at the closest well was assumed to be due to pumping in Katunga (20%; Table 6-4) in order to investigate the sensitivity of the model to this assumption.

For both scenarios, a semi-log regression line was fitted through the centre of the data and also through the maximum and minimum points in order to help quantify the uncertainty. The impact in the Katunga WSPA was then estimated using the distance to the northern, the centre, and the southern borders of the WSPA. The total drawdown over the period 1993/94 to 2009/10 was converted to an average change in m/year for the presentation of model results. The relationships, calculations, and assumptions are presented in Appendix D.

Table 6-4 Summary of NSW Deep Lead Pumping Scenarios Adopted for Monte Carlo Simulations

| SCENARIO CATEGORY | SCENARIO ID | DESCRIPTION | COMMENT |
|-------------------------------|-------------|-------------------|---|
| NSW Deep Lead Aquifer Pumping | N1 | Most Conservative | Assuming 50% of drawdown at NSW observation wells is due to pumping in Katunga, but 0% at the closest well to the centre of pumping in NSW* |
| | N2 | Conservative | Assuming 50% of drawdown at NSW observation wells is due to pumping in Katunga, but 20% at the closest well to the centre of pumping in NSW |

*Note: this assumption results in steeper distance-drawdown relationship, and hence a lower estimate of impact in Katunga. Conservative here refers to assuming less impact from NSW.

6.4 Calibration

An approximate model calibration was performed using the following two calibration targets:

1. Average water level change in the “wet pre development” period (i.e. pre 1994; scenario C1) on the order of 0 to -0.4 m/year, based on historic changes from the early 1980s to 1994 in Katunga Schedule 2 bores, with the following assumptions:
 - The “wet pre development” climate scenario (C1);
 - Inflow and outflow gradients and areas based on 1993 calculated values;
 - No Basement flux into the Deep lead because Basement and Deep Lead heads assumed to be in equilibrium; and
 - Approximate “pre development” usage of 10,000 ML/year.
2. Average annual predicted water level change in the order of -1.1 m/year for the “Dry” climate scenario (C2), under the 50% usage scenario (P1). This is based on estimates of actual historical drawdown in Katunga over the period 1993/94 to 2009/10 using the 8 Schedule 2 bores. The drawdown estimates ranged from 14 to 23 m with an average of 17 m. This equates to -0.9 to -1.4 m/year with an average of -1.1 m/year.

The model was most sensitive to the following parameters: Shepparton Formation Kv, Basement Kv, and Deep Lead specific storage. Therefore, these parameters were used to calibrate the model within acceptable ranges as defined by the compilation of input values presented in Table C-1 (Appendix C).

The results of the model calibration are presented in Table 6-5.

Table 6-5 Model Calibration Results

| CALIBRATION TARGET* | TARGET RESULT | CALIBRATED RESULT | COMMENT |
|---------------------|------------------|-------------------|-------------------|
| 1 | 0 to -0.4 m/year | -0.35 m/year | Result acceptable |
| 2 | -1.1 m/year | -1.12 m/year | Result acceptable |

* Calibration target numbers as listed above.

6.5 Results

The key results from the probability model are discussed below. The Crystal Ball model frequency distribution output report (forecasts), containing all model results in graphical format and as percentiles, is presented in Appendix E-2.

The model outputs are converted from a volumetric change in elastic storage to a change in head using the following equation:

$$\Delta\text{Head} = \Delta\text{Volume} / (\text{Ss} \times \text{b} \times \text{SA})$$

Where SA = surface area (Deep Lead)
 Ss = specific storage (Deep Lead)
 b = aquifer thickness (Deep Lead)

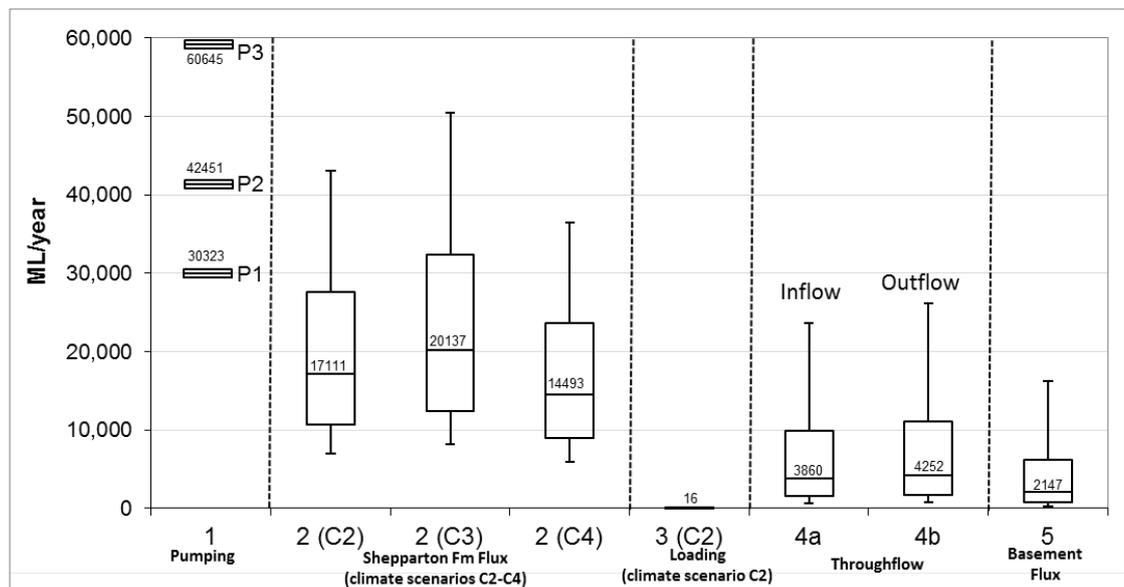
6.5.1 Relative Importance of Each Model Element

Direct pumping from Katunga has the greatest impact on the predicted Deep Lead groundwater pressure, followed by vertical flux from the Shepparton Formation. Loading from the Shepparton Formation has negligible influence on Deep Lead pressure. This is illustrated in the boxplot in Chart 6-1. Lateral inflows, lateral outflows, and vertical flux from the Basement have a similar range of influence on Deep Lead pressure. Basement flux is often assumed to be zero in this area, however even with conservative estimates of the vertical hydraulic conductivity, this model element could be significant.

The extent of the “whiskers” in Chart 6-1 are defined as the 10th and 90th percentiles in this case, and show the magnitude of the uncertainty and variability in each physical process. The parameter with the most associated uncertainty and variability is vertical flux from the Shepparton Formation.

Estimates of Shepparton Formation flux, lateral inflows, and lateral outflows are broadly consistent with estimates previously made by GMW (Table 6-6).

Chart 6-1 Boxplot Showing Relative Magnitude and Variability in Model Elements 1 to 5*



*See Section 6.3 for a description of scenarios P1-P3 and C2-C4.

*The limits of the “box” are Q1 (25th percentile) and Q3 (75th percentile). The minimum and maximum limits of the “whiskers” are the 10th and 90th percentiles respectively. The median (50th percentile) is represented by the line inside the box (Q2).

*Model element #1 results are shown as boxes to improve visibility.

Chart 6-2 Boxplot Showing Relative Magnitude and Variability of Deep Lead Inflow Estimates

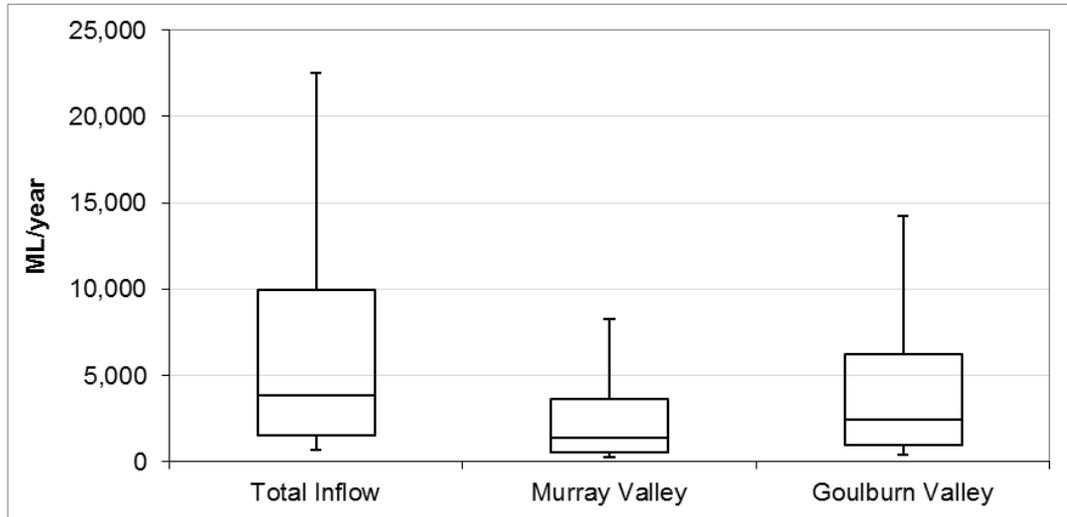


Table 6-6 Comparison with existing GMW water balance element estimates

| MODEL ELEMENT | PROBABILITY MODEL ESTIMATES (Q1-Q3) ML/year | GMW ESTIMATES (min-max) ML/year |
|---------------------------------|---|---|
| 2 – Flux from the Shepparton Fm | 10,620 – 27,610 (C2) | 18,215 – 35,000* |
| | 12,390 – 32,386 (C3) | |
| | 8,945 – 23,586 (C4) | |
| 4a – Inflow | 1,501 – 9,917 (total) | 7,000 – 8,500* (total) |
| | 516 – 3,607 (Murray Valley) | None available |
| | 944 – 6,254 (Goulburn Valley) | 4,100 – 13,200 (Goulburn Valley) [^] |
| 4b – Outflow | 1,672 – 11,124 | 5,000 – 15,000* |
| 5 – Flux from the Basement | 731 – 6,192 | None available |

* Based on GMW annual estimates from 1999/00 to 2003/04 (TATDOC-#1630281-v5; supplied 13 March 2015; Section 2.2.1).

[^] GMW (2014a).

Chart 6-3 Boxplot Showing Estimates of the Relative Magnitude of Groundwater in Storage vs Annual Use in the Katunga WSPA Deep Lead Aquifer

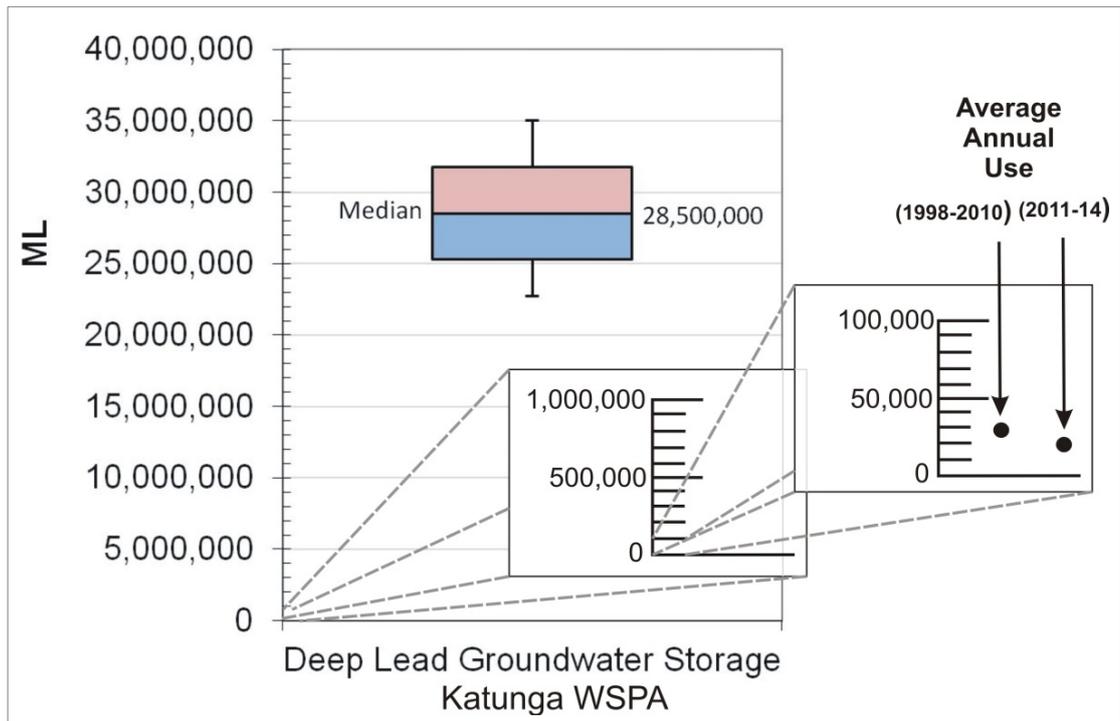


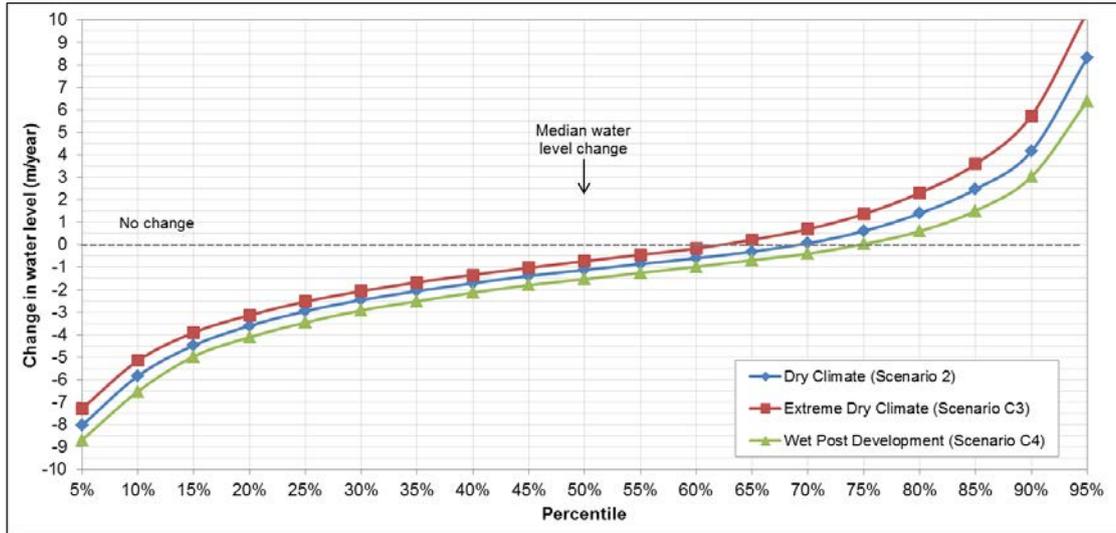
Chart 6-3 above shows the Monte Carlo estimates of total groundwater in storage in the Deep Lead aquifer within the Katunga WSPA boundary compared to average annual use. At the P50 (median) level of confidence, the volume of groundwater held in elastic storage (storage from water compression within the aquifer that leads to artesian head) accounts for around 8% of the total volume of groundwater in storage (28,500,000 ML at P50), the bulk of the water is held in the pores between the sands and gravels that makes up the Deep Lead aquifer. These figures are included to put into context, the 20,000-30,000 ML of groundwater pumped from the aquifer in the Katunga WSPA each year.

6.5.2 Impact of Climate Scenarios

As discussed in Section 6.3.1, the “climate scenarios” are essentially head differential scenarios between the Shepparton Formation and the Deep Lead. During drier climates, water levels drop in both aquifers. In the Deep Lead this is largely due to increased pumping, and in the Shepparton Formation this is largely due to a change in the rainfall-ET balance, along with the other key surface processes (Section 5.3.1). However, the decline in Deep Lead groundwater level is greater in magnitude than the decline in the Shepparton Formation aquifer, and hence the head differential increases during dry climatic conditions (see hydrographs in Appendix B). This results in an increase in the flux of water into the Deep Lead. This is illustrated in Chart 6-4. The median change in water level for the “extreme dry”, “dry” and “wet post development” scenarios (under 50% usage) is -0.7, -1.1, and -1.5 m/year respectively.

Although it may seem counter-intuitive for the modelled Deep Lead groundwater level to increase in drier climates, it should be remembered that all scenarios shown in Chart 6-4 are for simplicity at 50% entitlement (30,000 ML/year). During dry climatic conditions, the increase in direct pumping from the Katunga WSPA dominates the impact of the change in groundwater levels, as discussed in the following section.

Chart 6-4 Impact of Climate Scenarios on Predicted Annual Water Level Change (assuming 50% usage; Scenario P1)



6.5.3 Impact of Katunga Pumping Scenarios

Usage has the greatest impact on Deep Lead groundwater level. The vertical head differential between the Shepparton Formation and the Deep Lead has a lesser impact, as illustrated in Chart 6-5. The median predicted annual water level change for each pumping scenario is presented in Table 6-7 below.

Table 6-7 Predicted water level change under each pumping scenario (assuming C2 Scenario)

| SCENARIO ID | % OF ENTITLEMENT | MEDIAN PREDICTED WATER LEVEL CHANGE |
|-------------|------------------|-------------------------------------|
| P1 | 50% | -1.1 m/year |
| P2 | 70% | -2.9 m/year |
| P3 | 100% | -6.5 m/year |

These values were derived under the C2 head differential scenario (a “dry” climate). This climate scenario has been adopted for the pumping scenario evaluation because it is in the middle of the range of climate scenarios (Chart 6-4).

It should be noted that historical usage during periods of 70% allocations has been closer to 50%. The difference in water level decline between the 50% and 70% usage scenarios may give some indication of the impact of implementing groundwater carryover of up to 20% in a dry year. The simulations report an additional 1.8 m decline in water level (at the median level of confidence).

The maximum usage ever recorded was 40,470 ML in 2002/03, which is approximately 70% of allocation. One objective of this model was to estimate the impact of full use of entitlement (i.e. 100% allocation; 60,645 ML/year) on the sustainability of the aquifer. The simulations report a median drop in water level of 5.4 m in addition to the 1.1 m decline resulting from 50% usage.

Chart 6-5 Impact of Entitlement Allocation Scenarios on Annual Water Level Change (assuming a “Dry” climate; Scenario C2)

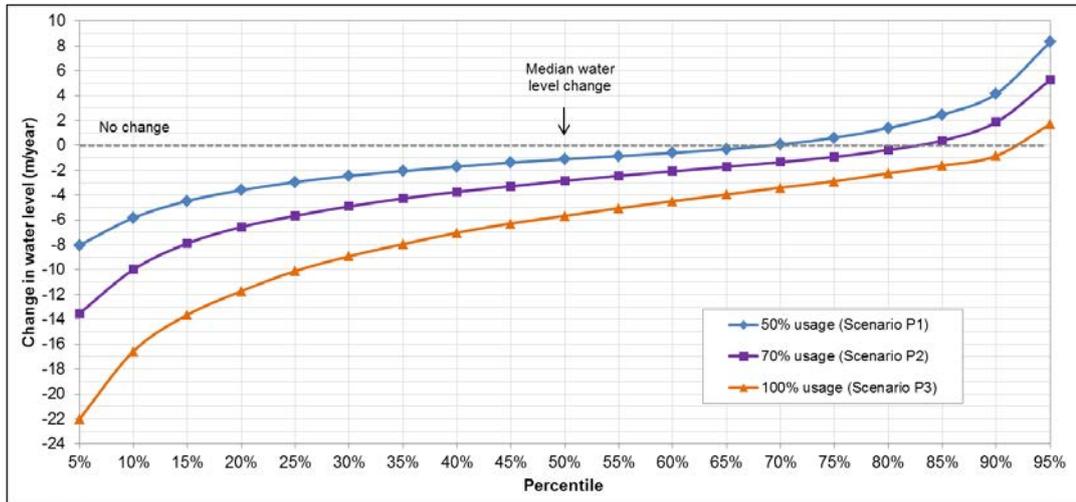


Chart 6-6 Impact of Entitlement Allocation Scenarios on Annual Water Level Change (assuming an “Extreme Dry” climate; Scenario C3)

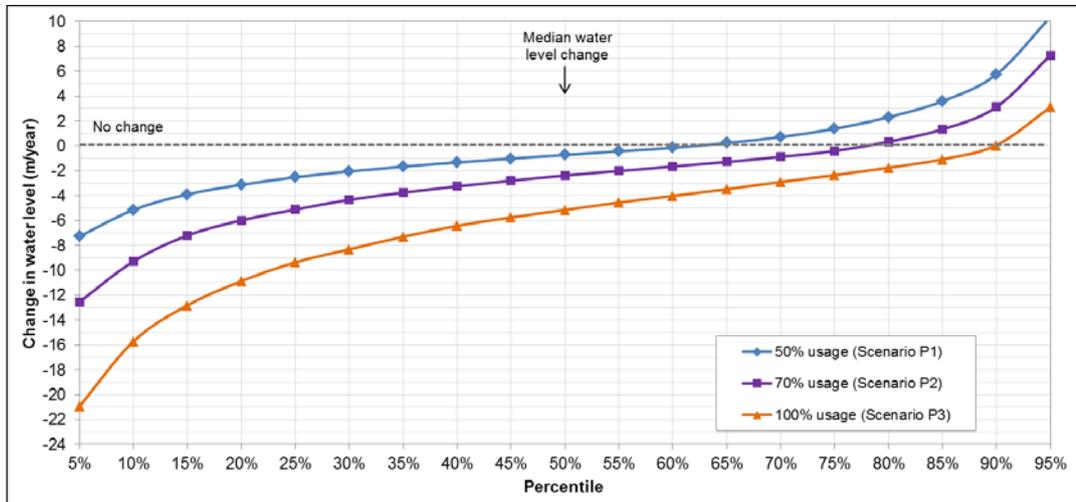
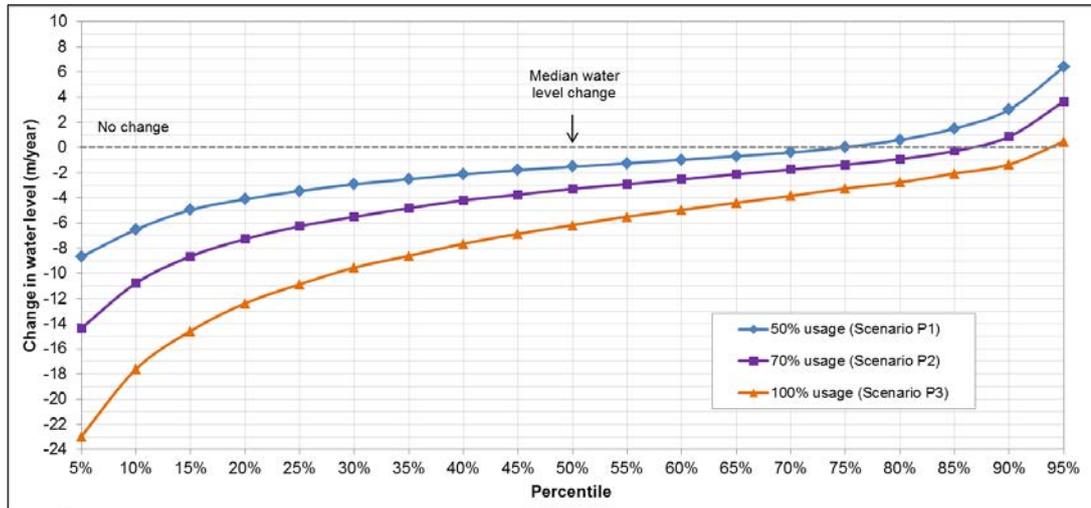


Chart 6-7 Impact of Entitlement Allocation Scenarios on Annual Water Level Change (assuming a “Wet” climate; Scenario C4)



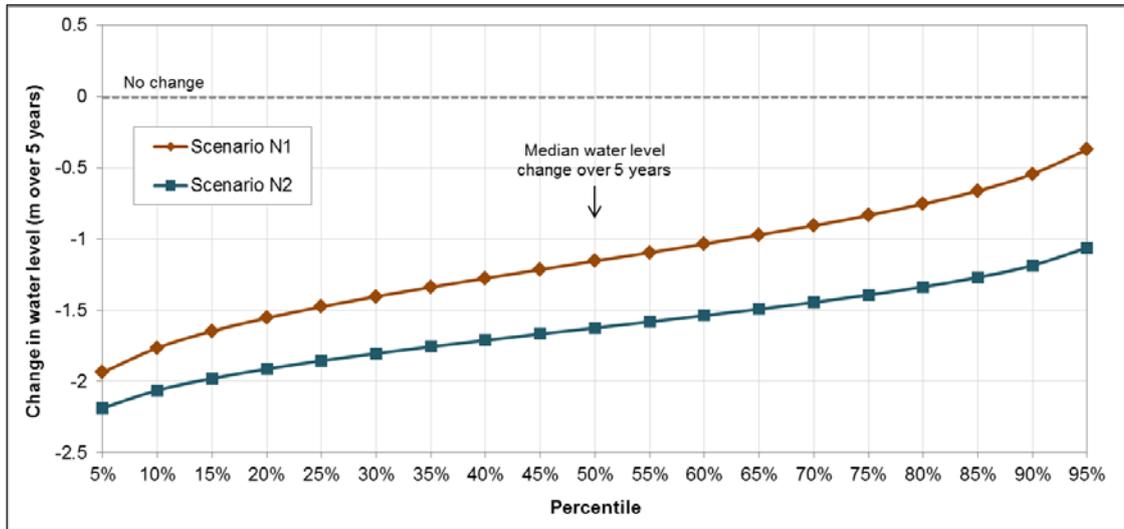
6.5.4 Impact of NSW Pumping

The estimated impact of NSW pumping on Deep Lead pressure over a period of 5 years is shown in Chart 6-8. The median impact is -1.2 m and -1.6 m for scenario N1 and N2 respectively. Using the middle 50% of data (25th to 75th percentile), the range of estimates for the two scenarios is -0.8 to -1.9 m over 5 years. This is considered a conservative estimate due to the assumption that 50% of drawdown in NSW observation wells is due to pumping in the Katunga WSPA Deep Lead aquifer, as described in Section 6.3.3 and Appendix D-3.

This impact could be partially responsible for the discrepancy between the Katunga WSPA usage-level relationship predicted in 2006 (Katunga WSPA Consultative Committee, 2006) and the actual usage-level data reviewed in 2012 (GMW, 2012). Implementing a groundwater level based trigger rather than a usage based trigger would resolve this issue because the management decisions would be taking this impact into account, along with all of the other variables that impact on Deep Lead aquifer pressures.

As discussed in Section 5.4.3, NSW is in the process of phasing out supplementary access licences. As of next season, the total entitlement in GMA016 will be approximately 84 GL/year. This should result in a lower usage than experienced during the period used for these calculations (1993/94 to 2009/10), where usage ranged from 53 to 131 GL/year with an average of 87 GL/year. Actual usage volumes in NSW into the future will likely depend largely on surface water allocations.

Chart 6-8 Estimated Impact of NSW (GMA016: Deep Lead) Pumping on Katunga WSPA Deep Lead Aquifer Water Levels



6.5.5 Cumulative Impacts

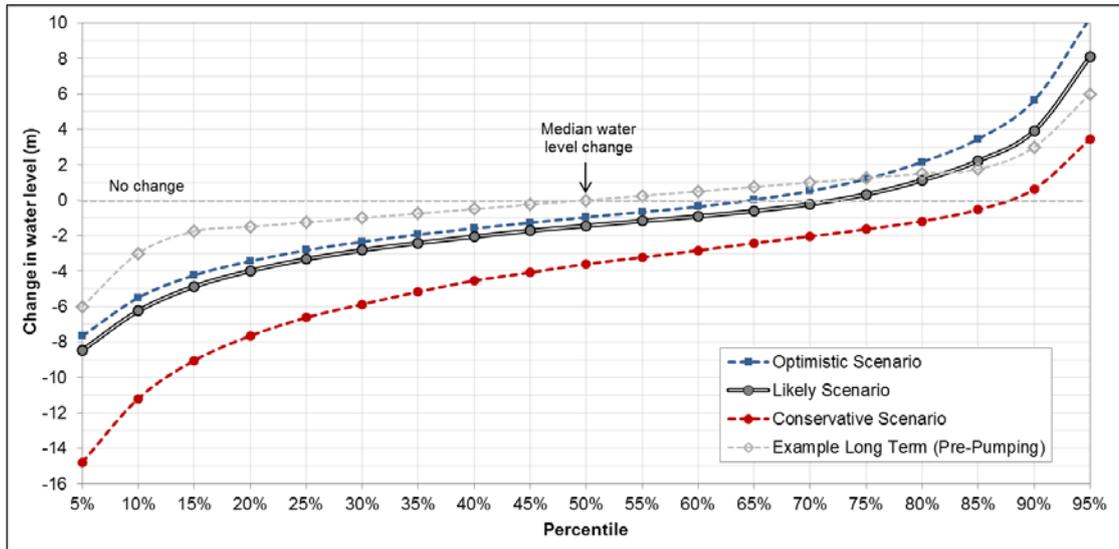
6.5.5.1 Monte Carlo Year 1 Outputs

The combined impacts of climate, usage and NSW impacts are presented in Chart 6-9 below as three usage scenarios. The Monte Carlo outcomes of the scenarios illustrated in the chart are as follows:

- Optimistic scenario – 50% allocation usage, extreme dry climate, lower NSW impact scenario;
- Likely scenario – 50% allocation usage, dry climate (typified by the 2002-07 Deep Lead aquifer pressures), higher NSW impact scenario; and
- Conservative scenario – 70% allocation usage, wet climate, higher NSW impact scenario.

These scenarios have been selected using professional judgement. The median (P50) annual water level changes for the Optimistic and Conservative scenarios are -1.0 and -3.6 m respectively. The median (P50) annual water level change that could be expected under the Likely scenario across the whole Katunga WSPA (averaged over the whole area) is -1.4 m.

Chart 6-9 Estimated Cumulative Impacts of Climate, Katunga Pumping and NSW Pumping Scenarios on Katunga Deep Lead Aquifer Water Levels (Year 1 Level Change)



6.5.5.2 Exponential Decline of Water Level Change over Time

The estimated water level changes are reported in isolation for any given year where the relevant scenario conditions (climate, pumping and NSW impacts) are met. The likelihood of experiencing successive years where the exact scenario conditions are met is in itself unlikely. Chart 6-9 above merely highlights the relative differences in outcomes between the three pumping/climate scenarios, given the variability and uncertainty of the input data under those scenarios.

All three scenario plots (above) show that for any year under any scenario, there is a greater likelihood of a decrease in groundwater level (and therefore Deep Lead aquifer storage) across the Katunga WSPA, rather than an increase. This does not imply that groundwater levels would decline every year in succession, but that a decline is more likely. Furthermore, the likelihood of decline is greater the more conservative the scenario.

Prior to any Deep Lead groundwater pumping, the long term Deep Lead aquifer groundwater level frequency curve would have yielded a median (P50) water level change of 0 m (see Chart 6-9). Long term historical pre-pumping Deep Lead water levels (not available) may have naturally fluctuated within a range of +/- several metres around the median level. Incorporating Deep Lead pumping, there is 35% likelihood of no change or water level increase under the Optimistic scenario, compared to 30% likelihood under the Likely scenario and only 13% likelihood under the Conservative scenario. Therefore, there is a general shift towards the Deep Lead aquifer pressure being lower more often than not under the influence of the variables that are acting on aquifer pressures.

Hydrographs from the Katunga WSPA show that Deep Lead aquifer water levels do not achieve their equilibrium, pre-pumping levels each year (at least since the mid-1990s). This is due to the irrigation (pumping) season being longer than the non-pumping season. Water levels are usually still recovering from the previous irrigation season when pumping from the next season commences. Each time this occurs additional drawdown is induced purely as the result of lost available drawdown. In this case, with all conditions being equal and consistent (which rarely occurs in reality), over time a new drawdown and recovery equilibrium (re-equilibrium) will eventually be achieved.

The cumulative impacts of groundwater pumping over successive years under an equilibrium re-establishment phase is not linear but exponential, with change becoming exponentially smaller over time. This non-linear relationship must be taken into consideration when estimating potential impact over successive years, in light of the Monte Carlo calculations made under this assessment.

The Monte Carlo simulation values reported are based on outcomes on an annual basis. Therefore, if the reported values represent Year 1 and the conditions represented under each scenario happen, by chance, to be identical for successive years, the impact on water level change will decrease exponentially. The time taken for the system to reach a new equilibrium is unknown. However, in order to estimate cumulative drawdown over time, it has been assumed that this will take 10 years.

6.5.5.3 *Impact Estimates under Exponential Decline*

Four Monte Carlo output ranges have been selected representing different degrees of conservatism, as follows:

- 50th percentile (P50 – Median);
- 40th percentile (P40 – Slightly Conservative);
- 30th percentile (P30 – Moderately Conservative); and
- 20th percentile (P20 – Very Conservative).

Chart 6-10 to Chart 6-12 below show the estimated exponential changes in Deep Lead water levels during a 10 year re-equilibrium phase under the Optimistic, Likely and Conservative pumping scenarios respectively, across the four confidence output levels. The Monte Carlo outputs, at the percentiles nominated above and shown in Chart 6-9 are used as the basis of this projection.

Chart 6-10 Optimistic Scenario – Exponential Water Level Declines from P20-P50 over a 10 Year Re-Equilibrium Period with the Cumulative Declines Nominated

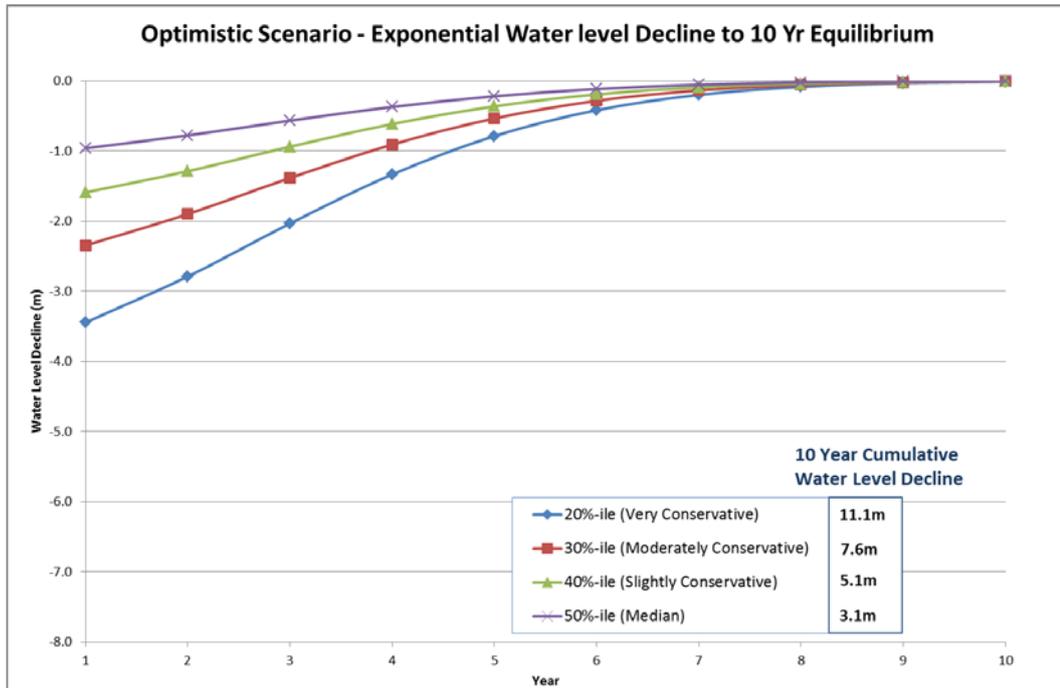


Chart 6-11 Likely Scenario – Exponential Water Level Declines from P20-P50 over a 10 Year Re-Equilibrium Period with the Cumulative Declines Nominated

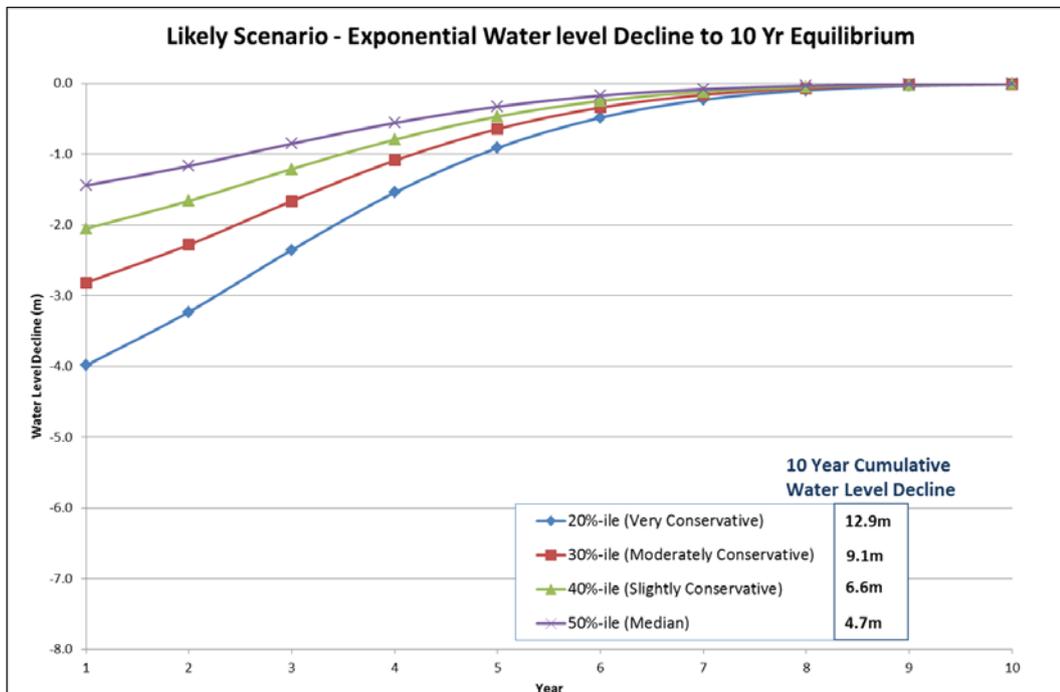
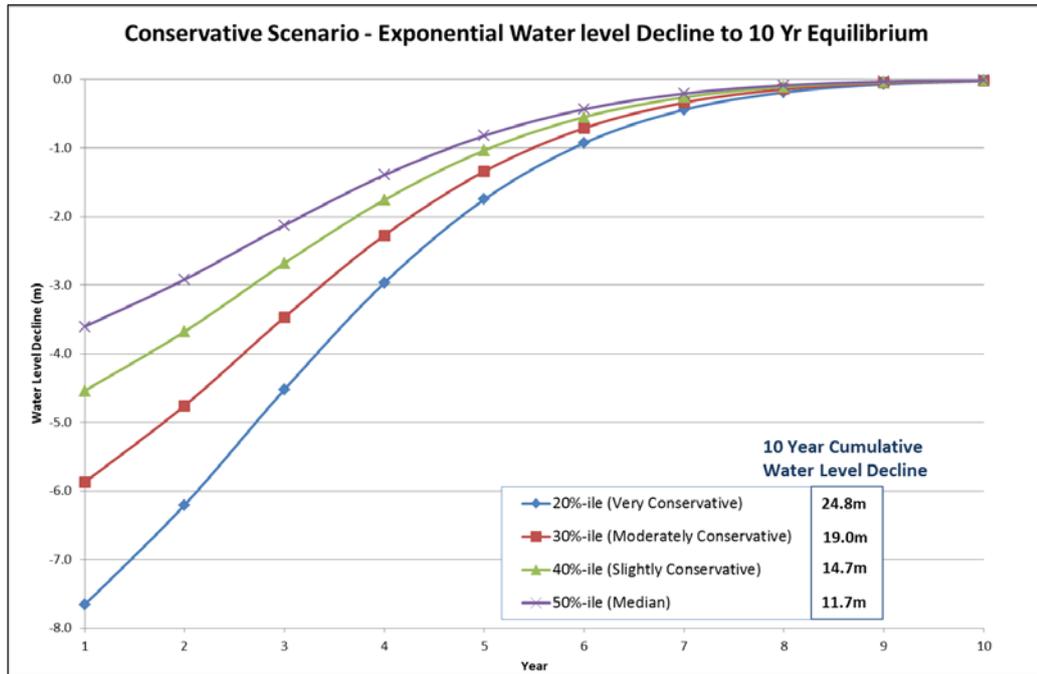


Chart 6-12 Conservative Scenario – Exponential Water Level Declines from P20-P50 over a 10 Year Re-Equilibrium Period with the Cumulative Declines Nominated.



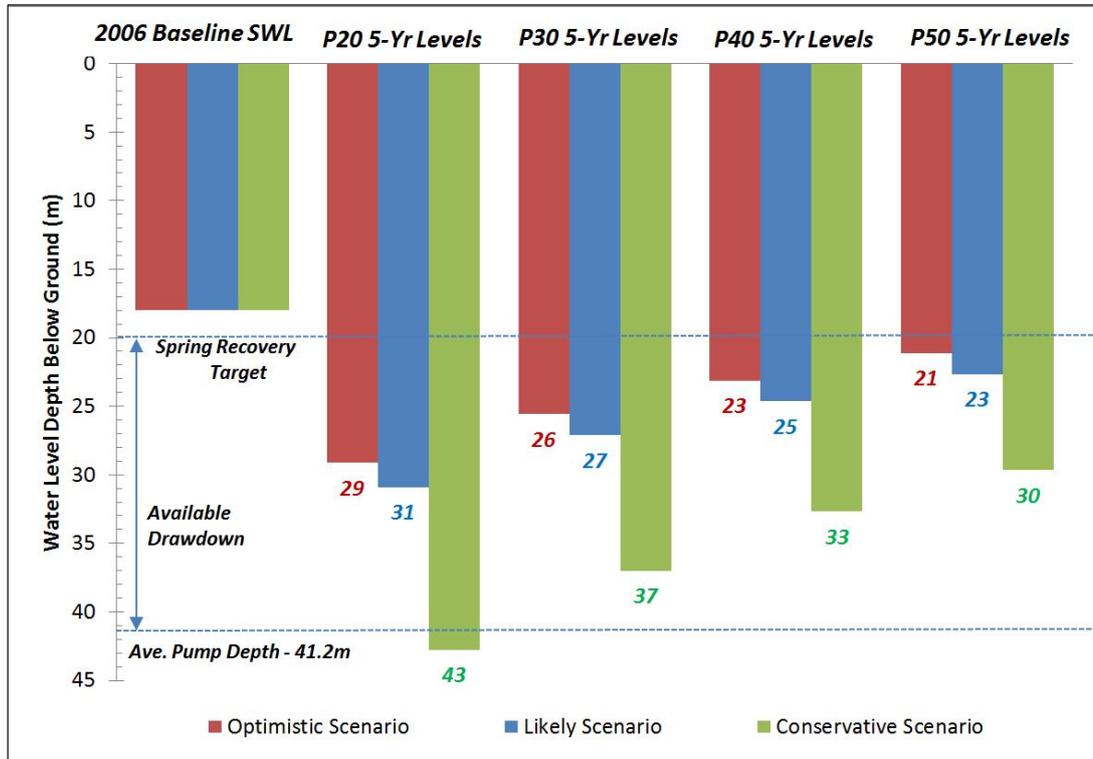
6.5.5.4 *Impacts Added to Baseline Water Level*

The charts above show the relative magnitude of cumulative water level changes over the 10 year water level re-equilibrium timeframe. However, these changes need to be assessed in the context of a baseline standing water level for the Deep Lead aquifer.

The Deep Lead average spring groundwater level was at around 12 m below ground level in the early 1980s before widespread pumping of the aquifer began. However by the time the Katunga WSPA was approved as a statutory management document, this level was around 18 m below ground level. The 18 m depth below ground level is therefore taken as the baseline standing water level upon which all the water level change outputs must be added to.

Chart 6-13 below shows the 10 year re-equilibrium period spring recovery water levels both in the context of the baseline standing water level (18 m below ground surface) and the current spring target recovery level (20 m below ground surface). The three pumping/climate scenarios are reported relative to each other and four levels of conservatism. The chart also shows the average depth of pumps in Deep Lead production bores in the Katunga WSPA (around 41.2 m below ground level; GMW, 2012).

Chart 6-13 Cumulative Water Levels Added to the 2006 Baseline Standing Water Level of 18 m for the Three Pumping/Climate Scenarios



These results suggest that over a 10 year re-equilibrium period, water levels are estimated to exceed the target 20 m average spring recovery level under all pumping scenarios and all levels of conservatism. It is noted that the median (P50) output of the Optimistic scenario is approximately equal to the current average spring recovery level.

If an alternative to the current 20 m rolling average spring recovery water level objective was to be considered, URS would therefore suggest adopting an objective based on the “Likely” pumping scenario (allocation usage at 30,000 ML/year under a dry climate with high NSW pumping impacts) under a slightly (P40) or moderately (P30) conservative level of confidence. These levels therefore equate to around 25 m and 27 m below ground level spring recovery levels respectively.

6.5.5.5 Impact of 100% Allocation Use

The above rationale when applied to the extreme 100% usage pumping scenario would yield the results shown in Chart 6-14 and Chart 6-15.

Chart 6-14 100% usage Scenario 10-Year Re-Equilibrium Period Water Level Decline

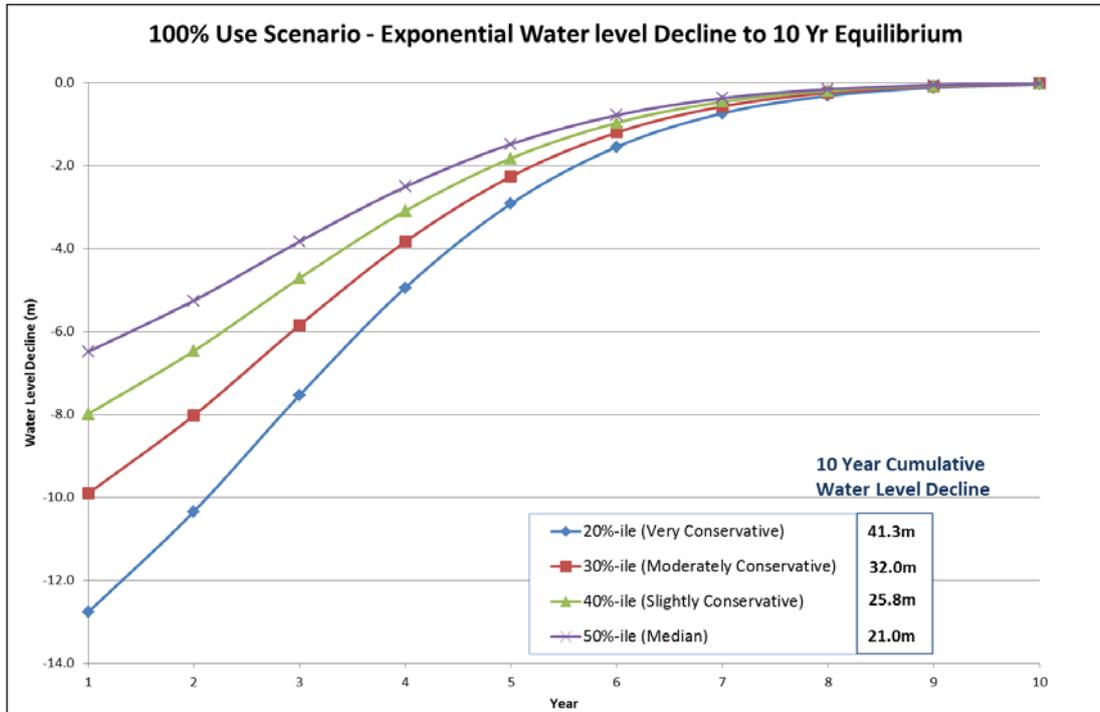
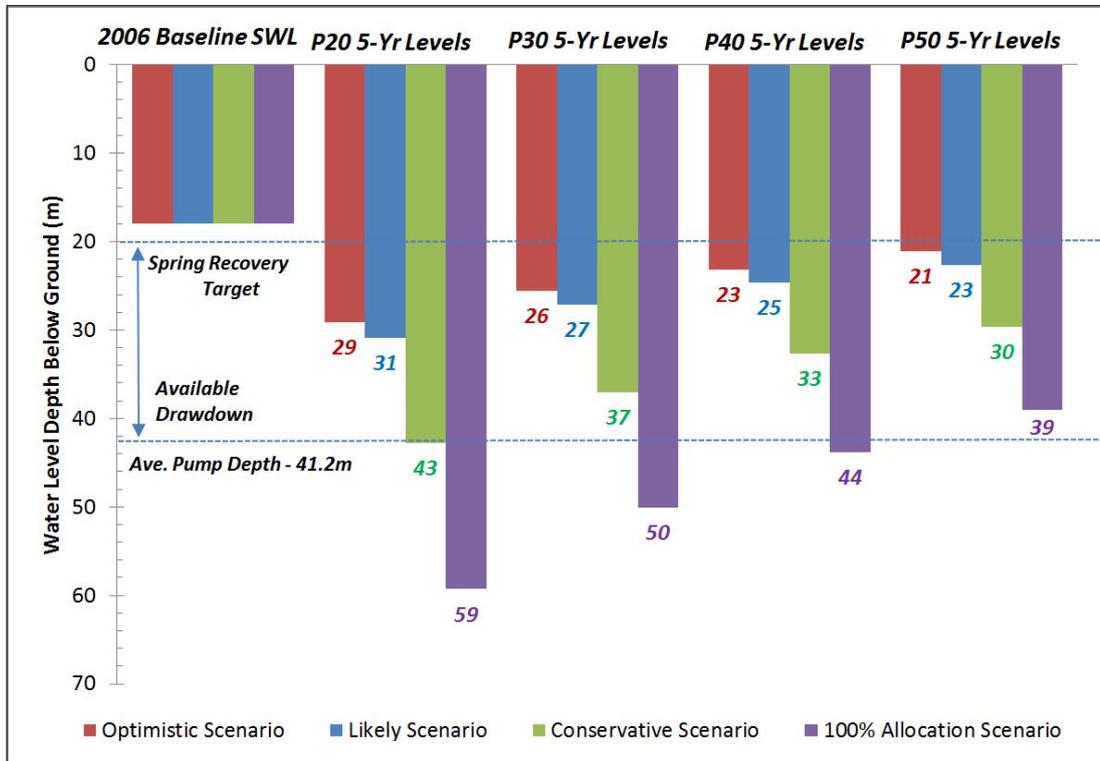


Chart 6-15 Cumulative Water Levels Added to the 2006 Baseline Standing Water Level of 18m including 100% usage Scenario



The chart above shows that under a 100% usage scenario, the potential water level after a 10 year re-equilibrium period is 40 m at the median level of confidence (P50), taking into account the adopted 2006 baseline average spring recovery level of 18 m. At the slightly (P40) to very conservative (P20) levels of confidence the 10 year water level depth could decrease to levels deeper than the average pump setting depth (Chart 6-15).

Therefore, use of 100% allocation in the Katunga WSPA would likely restrict the ability to access groundwater without lowering pumps in many bores. This would impact on annual operating costs and on capital costs for bores where pumps could be lowered.

6.6 Limitations

The key limitation of this model is that it is a relatively simple attempt to represent a dynamic, complex groundwater system where different parts of the system change at different rates to various stressors. A transient, spatially distributed numerical groundwater model would partly address this issue, however this type of modelling does not adequately account for data uncertainty. The probabilistic assessment methodology was selected because it does account for uncertainty, as described in Section 2.2.

Other key limitations of this model are summarised below:

- A simple calibration was achieved to pre-development and 50% usage conditions. Higher pumping scenarios could not be calibrated because they have not occurred in the past, or at least not for sufficient time to allow reliable calibration.
- The model approach does not allow the impact of climate to be separated from the impact of pumping regime changes (that are strongly related to climate). This approach was preferred over attempting to quantify the watertable inputs and outputs because this would be subject to a very high degree of error, based on uncertainty in ET estimates alone.
- Uncertainty in input parameters has been partially accounted for by using probability distributions. However it is still possible that some uncertainty (or variability) in input parameters has not been captured.
- The 10 year period for exponential decline of water level impacts has been assumed in order to estimate cumulative impacts under a re-equilibrium situation. It is recognised that this assumption is subject to significant uncertainty.

Limitations of the NSW Deep Lead aquifer pumping impact assessment were discussed in Section 6.5.4 and Appendix D-3.

6.7 Summary

A probabilistic groundwater resource assessment of the Deep Lead aquifer in the Katunga WSPA has been carried out, taking into account lateral inflows and outflows, vertical flux from the Shepparton Formation and the Basement, mechanical loading from the watertable, and pumping from the Deep Lead. The model was calibrated to pre-development and 50% usage scenarios (the average usage during the Millennium Drought).

The results show that direct pumping from the Deep Lead in Katunga WSPA has the greatest potential impact on predicted Deep Lead groundwater levels (scenarios 30,323 – 60,645 ML/year) , followed closely by vertical flux from the Shepparton Formation (median estimates 14,493 – 20,137 ML/year). The latter also has the greatest uncertainty/variability of all model elements, largely due to the uncertainty in vertical hydraulic conductivity.

Median (P50) estimates for lateral inflows, lateral outflows and vertical flux from the Basement are 3,860 ML/year, 4,252 ML/year and 2,147 ML/year respectively. The Basement flux estimate is significant considering that it is often assumed to be impermeable. The influence of mechanical loading from the watertable was found to be negligible compared to the other controls on Deep Lead groundwater level.

The impacts of various climate and pumping scenarios on Deep Lead water levels were estimated. Average annual impacts for three scenarios are as follows:

- “Optimistic scenario” – 50% allocation usage, extreme dry climate, lower NSW pumping impact scenario – average annual water level change -1.0 m;
- “Likely” scenario – 50% allocation usage, dry climate (typified by the 2002-07 Deep Lead aquifer pressures), higher NSW pumping impact scenario – average annual water level change -1.4 m; and
- “Conservative” scenario – 70% allocation usage, wet climate, higher NSW pumping impact scenario – average annual water level change -3.6 m.

The cumulative impact of these scenarios was assessed assuming that the conditions under each scenario continue over a period of 10 years and that the annual water level change declines exponentially over this time to reach a new equilibrium. The cumulative 10 year impacts were added to the 2006 baseline average spring groundwater recovery level of 18 m. The estimated Deep Lead re-equilibrium spring recovery groundwater levels are as follows, in order from most likely to least likely (i.e. most conservative):

- 50th percentile (median) – 23 mBGL;
- 40th percentile (slightly conservative) – 25 mBGL;
- 30th percentile (moderately conservative) – 27 mBGL; and
- 20th percentile (very conservative) – 31 mBGL.

If an alternative to the current 20 m rolling average spring recovery water level objective was to be considered, URS would therefore suggest adopting the slightly or moderately conservative estimates above (25 or 27 mBGL).

Under a 100% allocation use scenario, the estimates of cumulative 10 year impact increase to 39 m (median) to 59 m (very conservative). These values are close to or exceeding the average pump depth in the Katunga WSPA of 41.2 mBGL (GMW, 2012). Therefore, use of 100% allocation in the Katunga WSPA would likely restrict the ability to access groundwater without lowering pumps in many bores, and may result in increased capital costs and annual operating costs.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Impact of Full Use of Entitlement

The impact of full use of entitlement in the Katunga WSPA (60,645 ML/year) has been investigated using the 100% usage scenario in the model. It should be remembered that this estimate is outside of the limits of model calibration as 100% usage has never occurred in the Katunga WSPA.

Monte Carlo simulations show a median annual water level decline of 6.5 m (Year 1) under a 100% usage scenario, assuming a dry climate. In the short term (one year), a groundwater level decline of 6.5 m/year has the potential to have significant impact on the sustainability of the aquifer with regards to groundwater users, particularly those with shallow bores and/or shallow pump depths.

In the longer term, use of full entitlement may result in Deep Lead water levels reaching a new equilibrium spring recovery level of around 39 mBGL (median estimate) to 59 mBGL (20th percentile conservative estimate). This would significantly restrict the ability to access groundwater in the Katunga WSPA.

These impacts would need to be addressed if an allocation of 100% entitlement was considered.

7.2 Groundwater Carryover

Groundwater carryover is a management tool available to be implemented in groundwater management units in Victoria. URS understands that carryover of 20% may be considered in the Katunga WSPA.

The typical annual entitlement usage rates are around 50% during years of 70% allocation. Therefore, the impact of carryover has been investigated using the difference in Deep Lead groundwater level decline between the 50% and 70% usage scenarios. The predicted water level decline is 1.8 m/year in addition to the decline expected from 50% usage (assuming the median climate scenario).

The introduction of groundwater carryover has the potential to impact on Deep Lead groundwater levels. However, the magnitude of this impact will depend on the realised usage rates. This impact can be adaptively managed using a groundwater level trigger. However, it may result in a higher likelihood of GMW needing to reduce allocations from 70% to 50% in any one year.

Further work should be undertaken to assess the desire for and potential impacts of carryover on groundwater levels.

7.3 Trigger Levels and Allocations

As discussed in Section 4.3, the current usage-based trigger level is no longer considered appropriate for the Katunga WSPA. The results of the groundwater resource assessment described here show that the system response to usage is complex, and furthermore part of the water level decline observed in the Katunga WSPA is a result of pumping rates in NSW. Implementing a groundwater level based trigger would allow this risk to be more effectively managed.

In line with the Katunga WSPA GMP objective, the adopted trigger level should enable access to groundwater to be maintained by current groundwater users without major cost impacts.

Therefore it is recommended that:

- The current 5 year rolling average spring recovery groundwater level **objective** of 20 mBGL be increased to 25 mBGL, in line with the “likely, slightly conservative” cumulative water level impact scenario estimate (Section 6.5.5); and
- A 5 year rolling average spring recovery groundwater level **trigger** of 25 mBGL be adopted, in line with the “likely, moderately conservative” cumulative water level impact scenario estimate (Section 6.5.5).

If this trigger was exceeded, allocation would be reduced from 70% to 50% in the subsequent year. The 2 m difference in the trigger level and the objective level allows for time lags in the response of the groundwater system, as well as uncertainties in NSW pumping regime.

The estimates contained here are subject to the uncertainties and limitations described throughout this report, and therefore it is recommended that any objective and trigger levels adopted for the Katunga WSPA be subject to regular review.

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Allocation methodology – the method by which the annual proportion of entitlement is determined.

Anisotropic aquifer – an aquifer in which the lateral vs horizontal hydraulic conductivities vary at a point of measurement within the aquifer.

Aquifer – a water bearing bed of strata, either by virtue of its porosity or because it is pervious.

Aquitard – A stratum that impedes the movement of water between on aquifer and another.

Groundwater level management objective – the 5 year rolling average spring recovery level (as measured in Schedule 2 bores) that is not to be exceeded (in terms of depth below ground surface) in any one year.

Groundwater trigger level for allocation – the 5 year rolling average spring recovery level (as measured in Schedule 2 bores) at which a reduced allocation percentage will be enacted.

Heterogeneous aquifer – an aquifer in which the hydraulic conductivity varies between points of measurement within the aquifer.

Homogeneous aquifer - an aquifer in which the hydraulic conductivity are equal between points of measurement within the aquifer.

Hydraulic conductivity – the rate of flow of water through a unit cross-sectional area under a unit hydraulic gradient.

Hydraulic gradient – the rate of change in height over a unit of distance in the direction of flow.

Isotropic aquifer – an aquifer in which the lateral vs horizontal hydraulic conductivities are equal at a point of measurement within the aquifer.

Location parameters – the values that define a distribution (e.g. for a normal distribution, this could be the mean and 95th percentile).

Percentile – the value below which a certain percentage of observations in a group of observations fall.

Probability distribution – a description of all of the possible values, and likelihoods of these values, that a parameter can take.

Average spring recovery level – the 5 year rolling average of maximum annual (generally observed in spring) level that groundwater in the Katunga WSPA recovers to (as measured in Schedule 2 bores).

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Goulburn-Murray Water and only those third parties who have been authorised in writing by URS to rely on the report.

It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the proposal dated 13 February 2015.

The methodology adopted and sources of information used by URS are outlined in this the Report.

Where this report indicates that information has been provided to URS by third parties, URS has made no independent verification of this information unless required as part of the agreed scope of work. URS assumes no liability for any inaccuracies in or omissions to that information.

This Report was prepared between February and July 2015. The information in this report is considered to be accurate at the date of issue and is in accordance with conditions at the site at the dates sampled. Opinions and recommendations presented herein apply to the site existing at the time of our investigation and cannot necessarily apply to site changes of which URS is not aware and has not had the opportunity to evaluate. This document and the information contained herein should only be regarded as validly representing the site conditions at the time of the investigation unless otherwise explicitly stated in a preceding section of this report. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

This report contains information obtained by inspection, sampling, testing or other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. The borehole logs indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the uniformity of conditions and on the frequency and method of sampling as constrained by the project budget limitations. The behaviour of groundwater and some aspects of contaminants in soil and groundwater are complex. Our conclusions are based upon the analytical data presented in this report and our experience. Future advances in regard to the understanding of chemicals and their behaviour, and changes in regulations affecting their management, could impact on our conclusions and recommendations regarding their potential presence on this site.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, URS must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time.

Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

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Any estimates of potential costs which have been provided are presented as estimates only as at the date of the Report. Any cost estimates that have been provided may therefore vary from actual costs at the time of expenditure.

APPENDIX A FIGURES

Figure A-1 Location

Figure A-2 Geology

Figure A-3a Top of Shepparton Formation

Figure A-3b Top of Deep Lead

Figure A-3c Top of Basement

Figure A-4 Regional Deep Lead Surface and GMAs

Figure A-5a Deep Lead Potentiometric Surface – Aug/Sep 1993

Figure A-5b Deep Lead Potentiometric Surface – Feb 2009

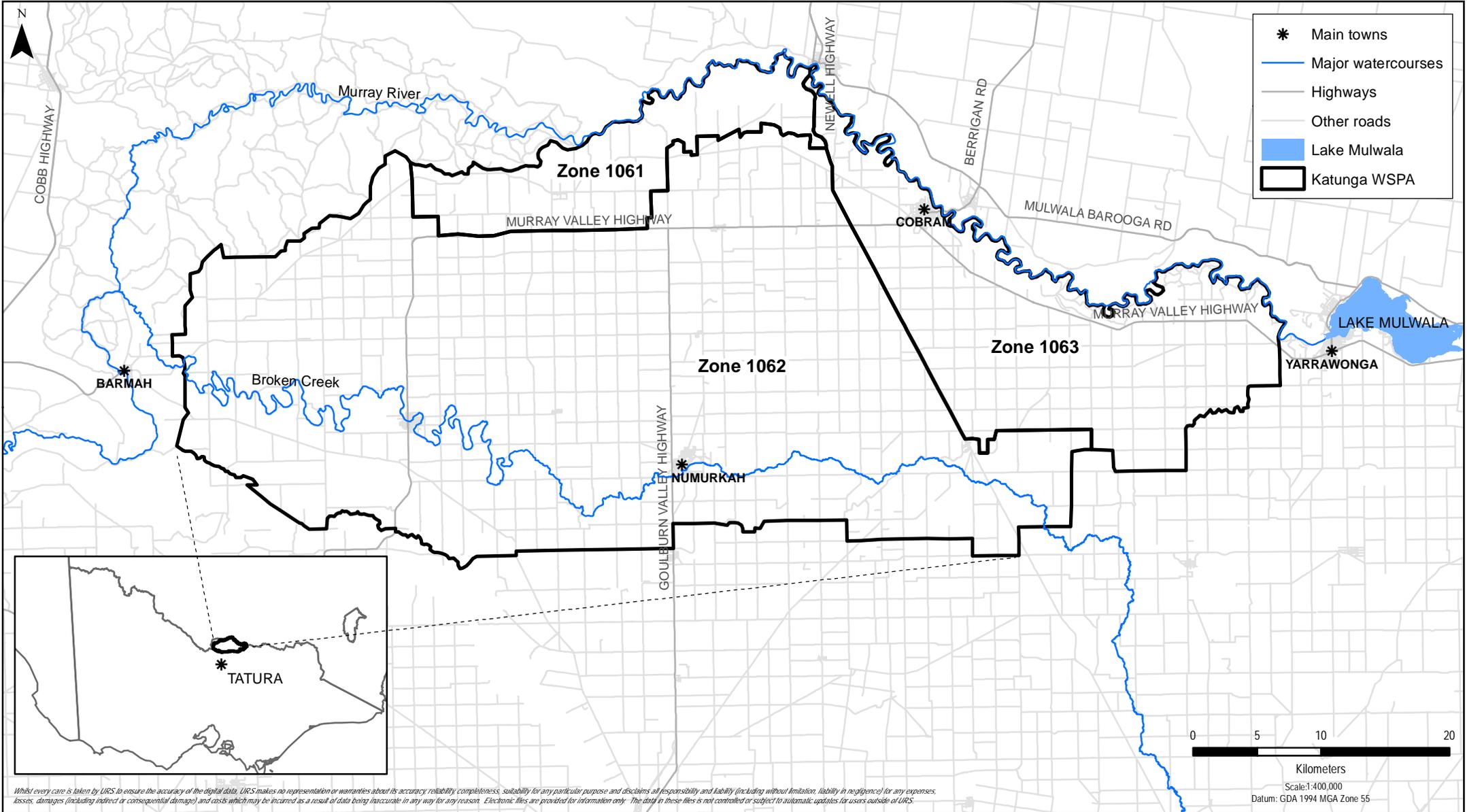
Figure A-5c Deep Lead Potentiometric Surface – Sep 2009

Figure A-5d Head Differential – Deep Lead / Shepparton Fm – Feb 2009

Figure A-6 Groundwater Users

Figure A-7 Hydrograph Bore Locations

Figure A-8 NSW Drawdown 1993/94 to 2009/10



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0 5 10 20
Kilometers
Scale: 1:400,000
Datum: GDA 1994 MGA Zone 55



KATUNGA WSPA GROUNDWATER RESOURCE ASSESSMENT

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LOCATION

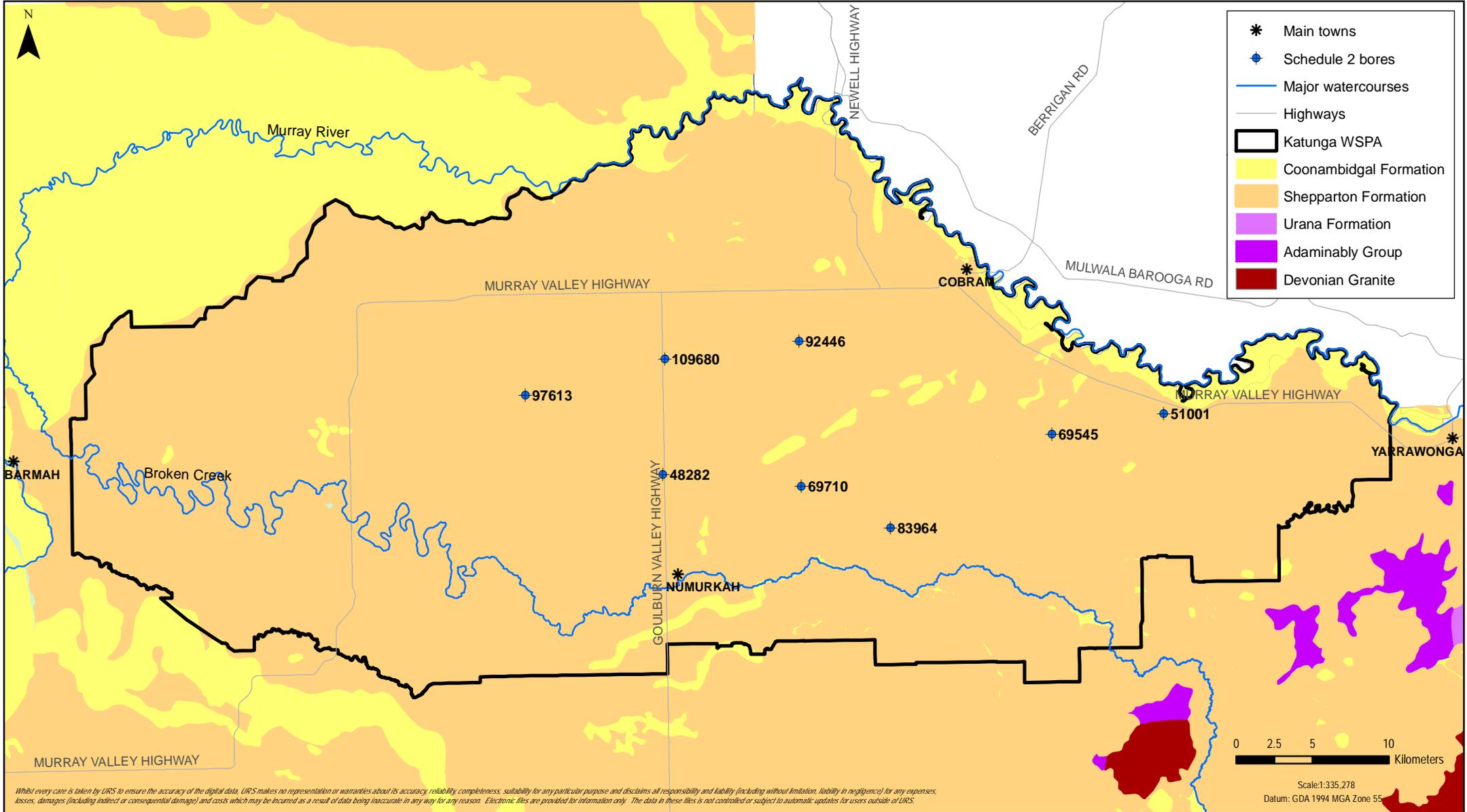


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Figure: **A-1**
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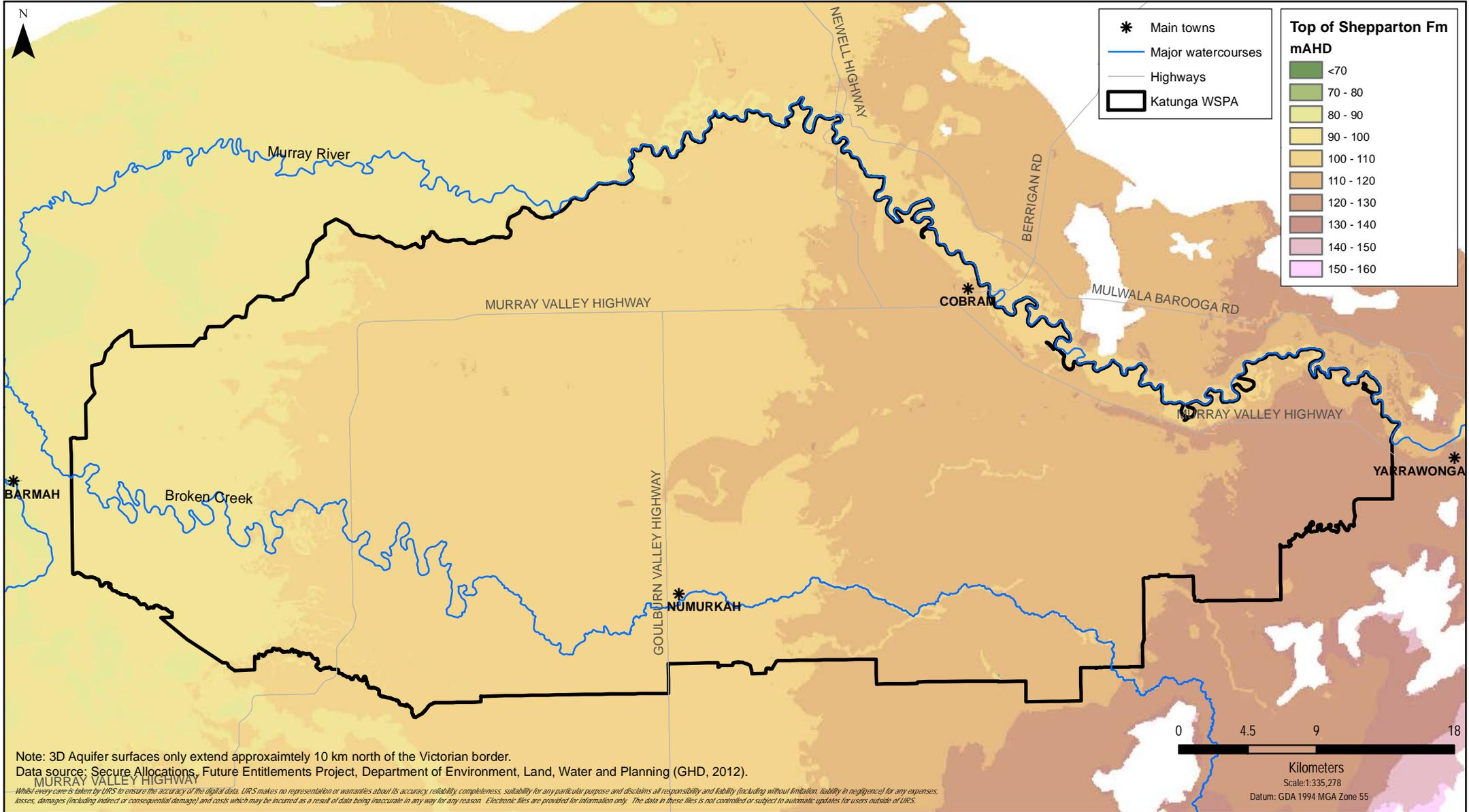
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TOP OF SHEPPARTON FORMATION
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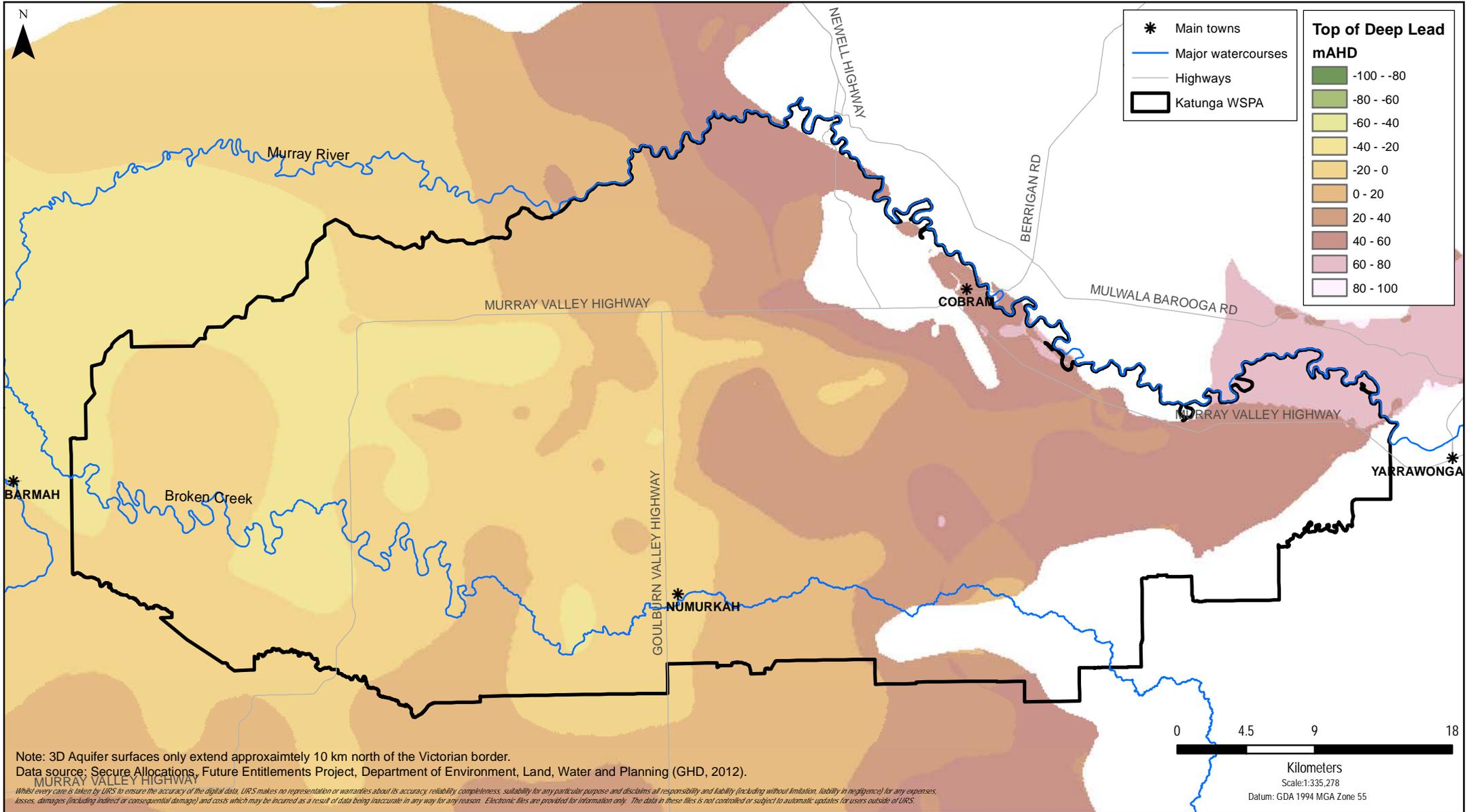
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TOP OF DEEP LEAD



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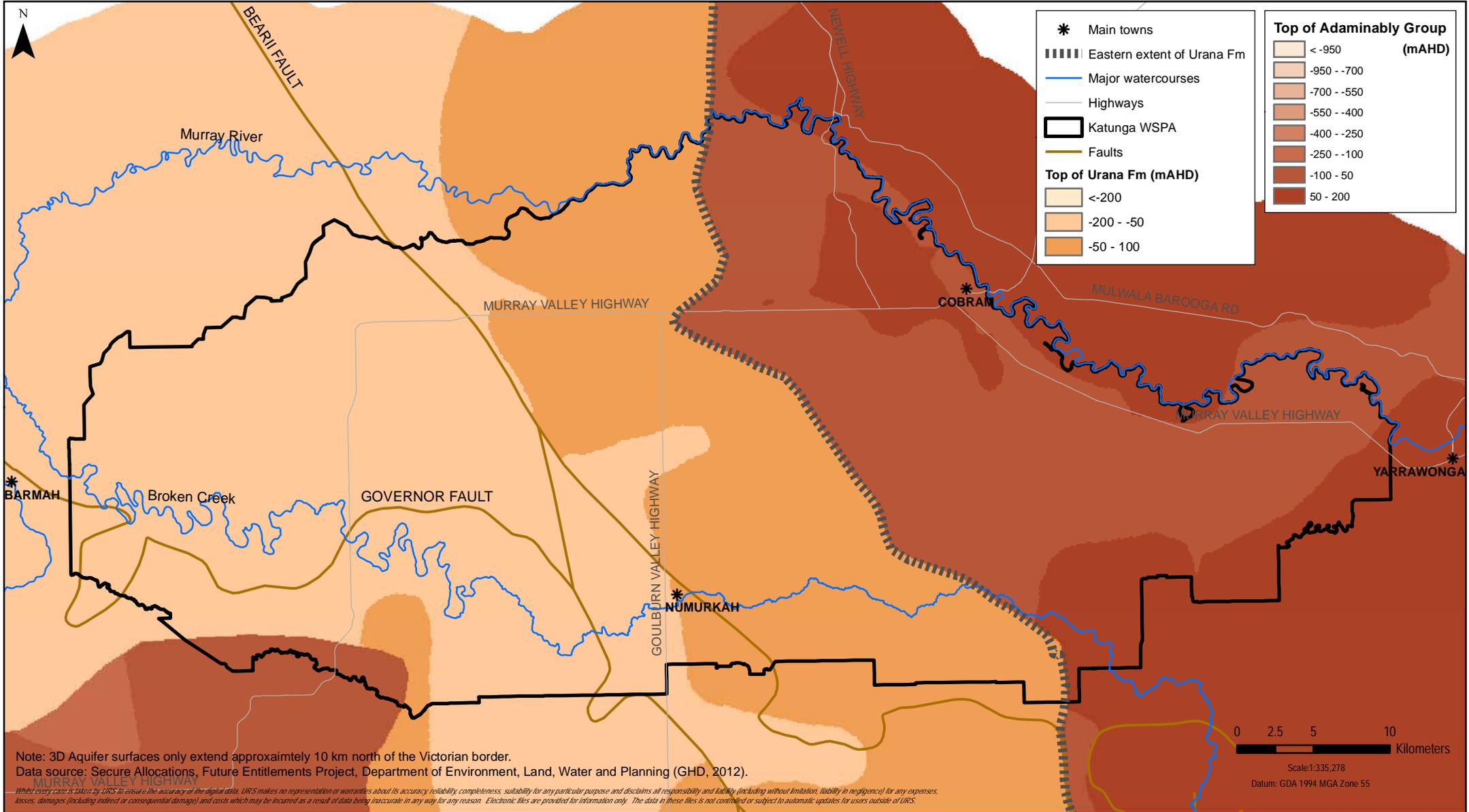
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 TOP OF BASEMENT



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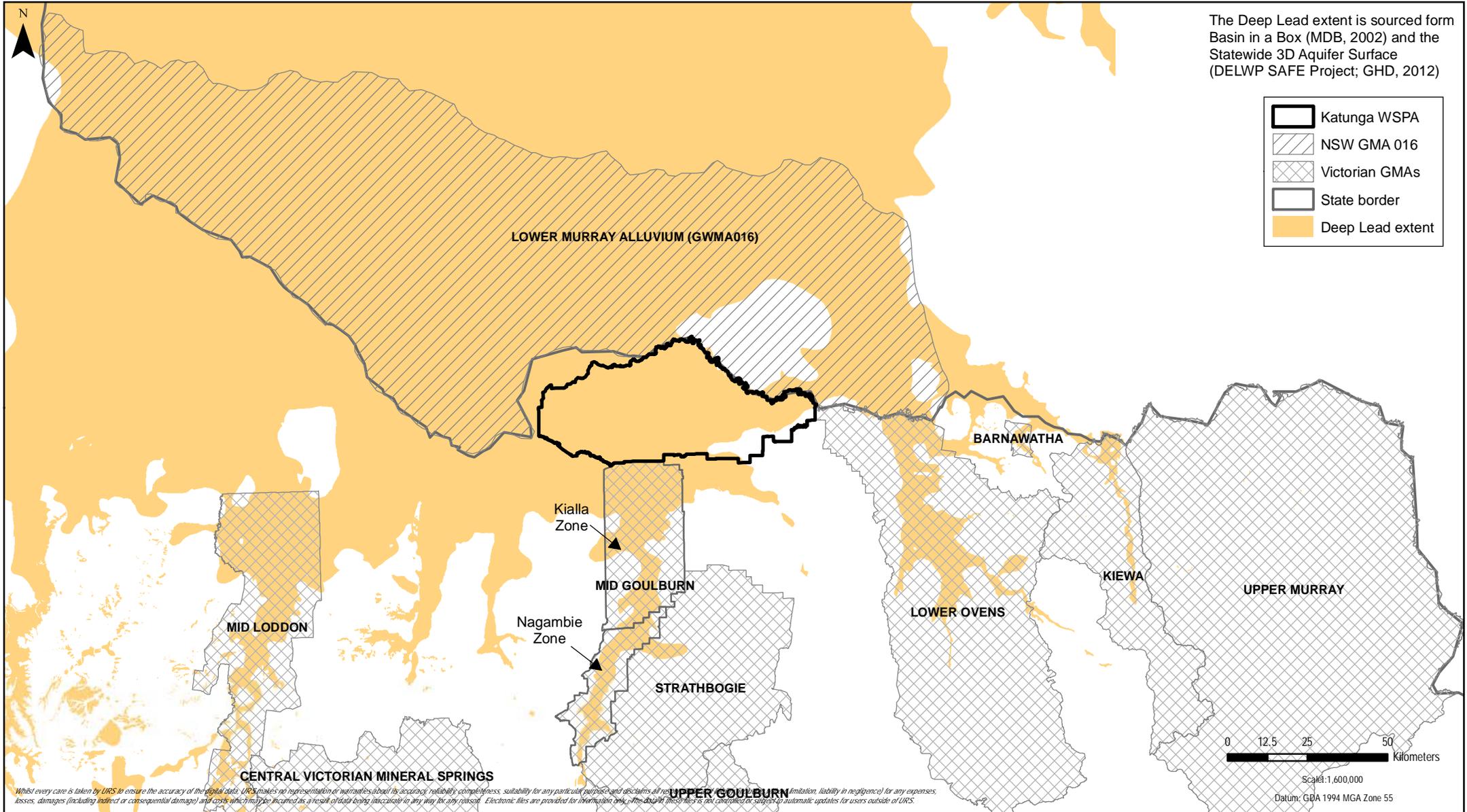
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Figure: A-3c

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REGIONAL DEEP LEAD SURFACE AND GMA BOUNDARIES



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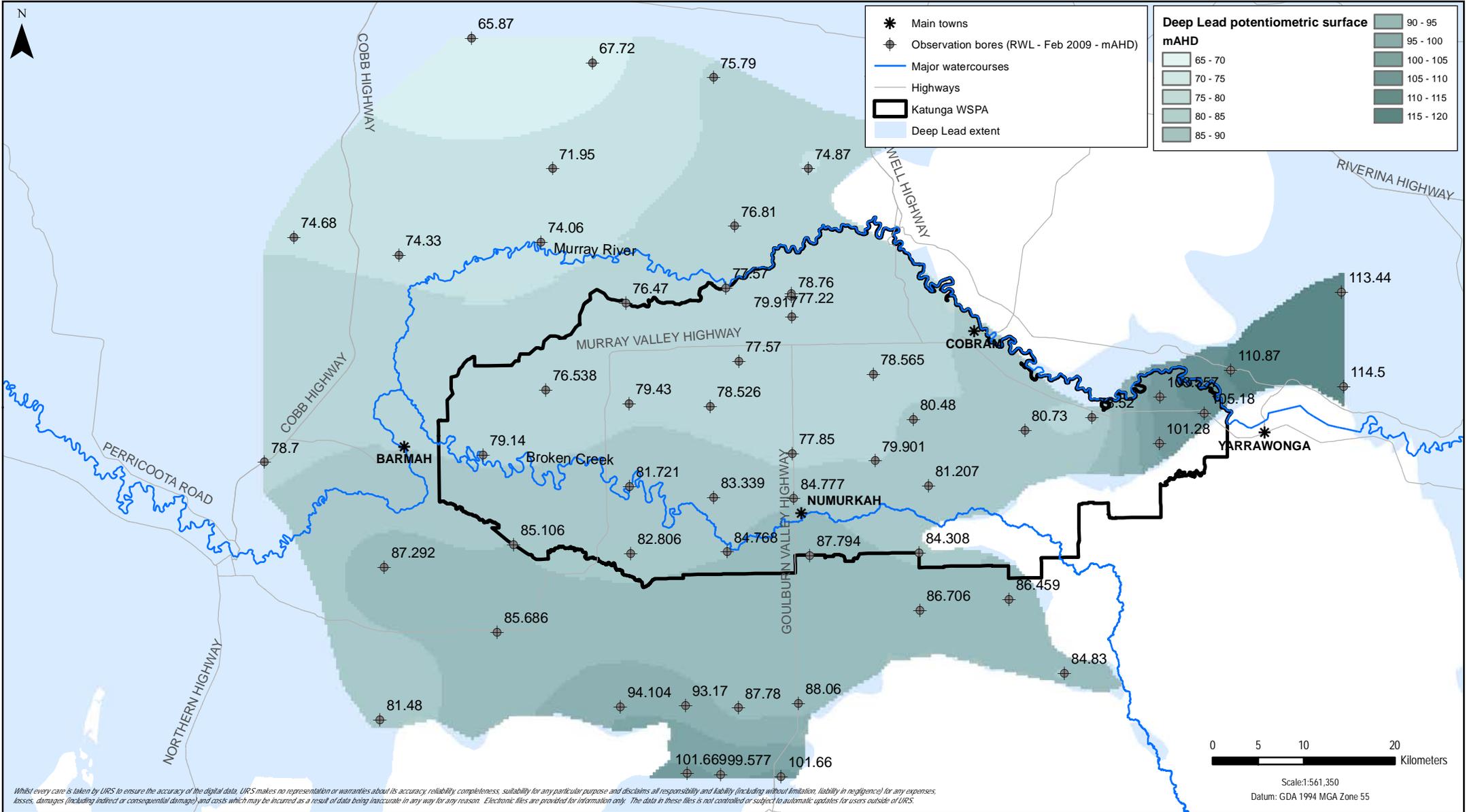
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KATUNGA WSPA GROUNDWATER RESOURCE ASSESSMENT

DEEP LEAD POTENTIOMETRIC SURFACE - FEB 2009



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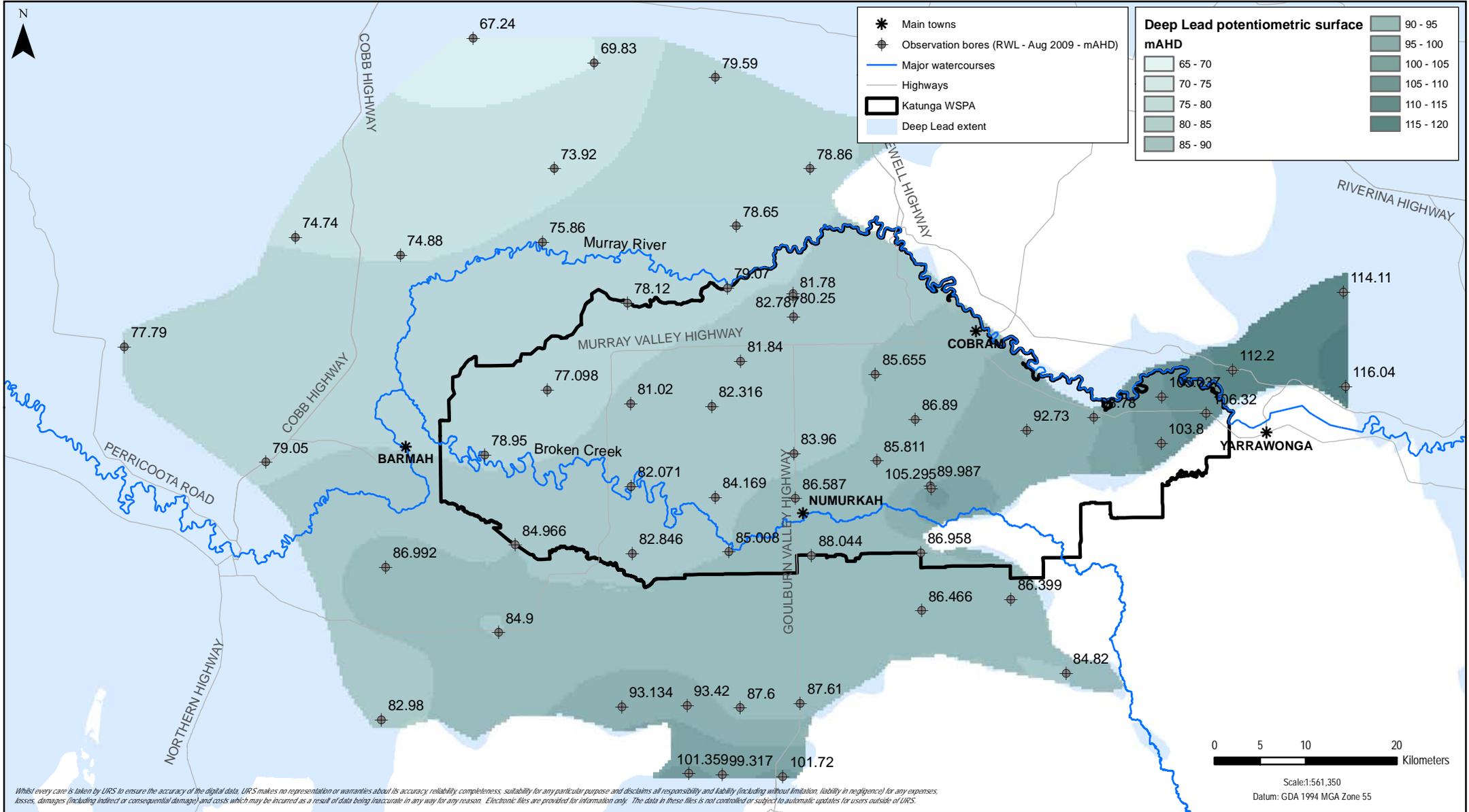
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KATUNGA WSPA GROUNDWATER RESOURCE ASSESSMENT

DEEP LEAD POTENTIOMETRIC SURFACE - AUG 2009



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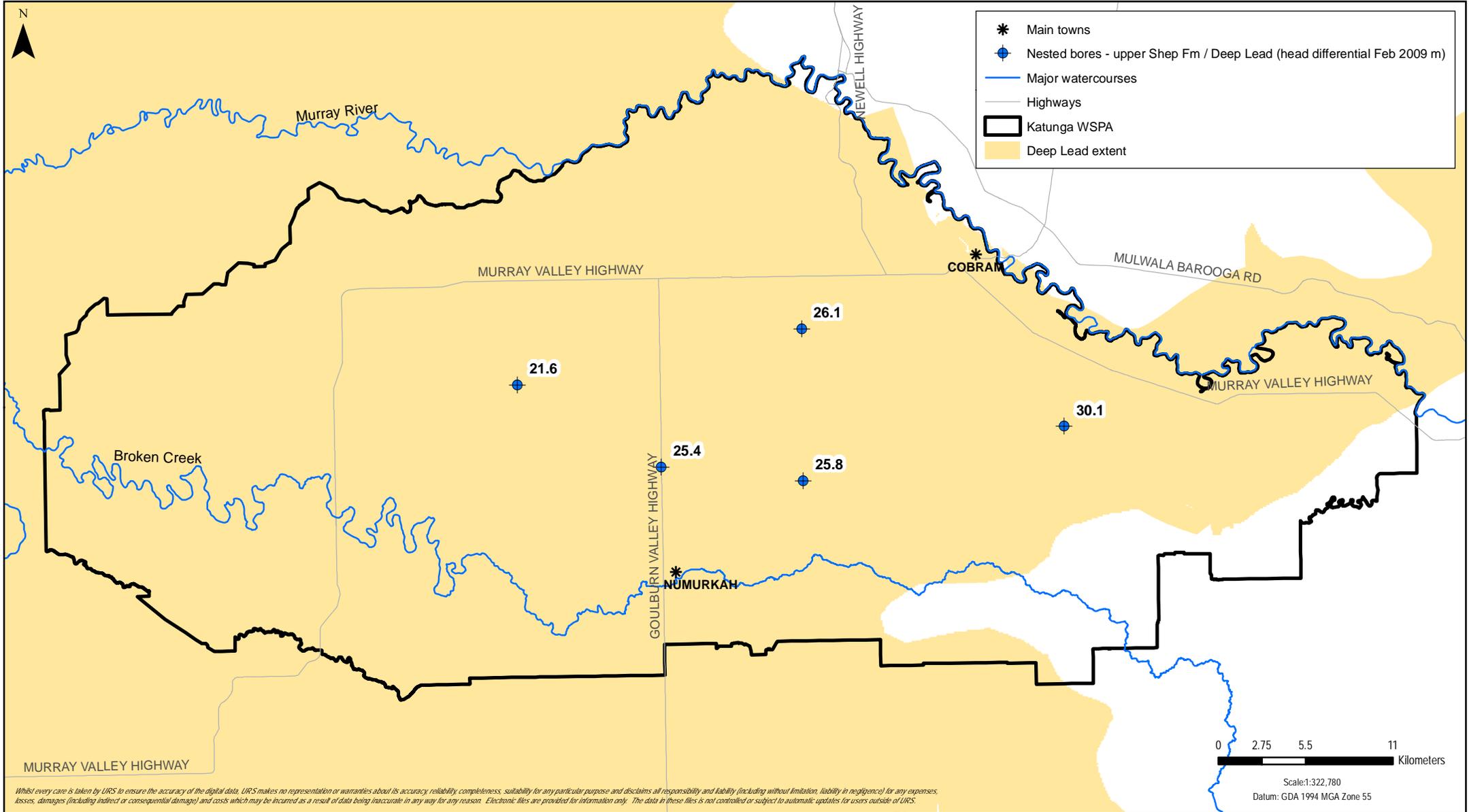
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KATUNGA WSPA GROUNDWATER RESOURCE ASSESSMENT

HEAD DIFFERENTIAL - DEEP LEAD / SHEPPARTON FM - FEB 2009



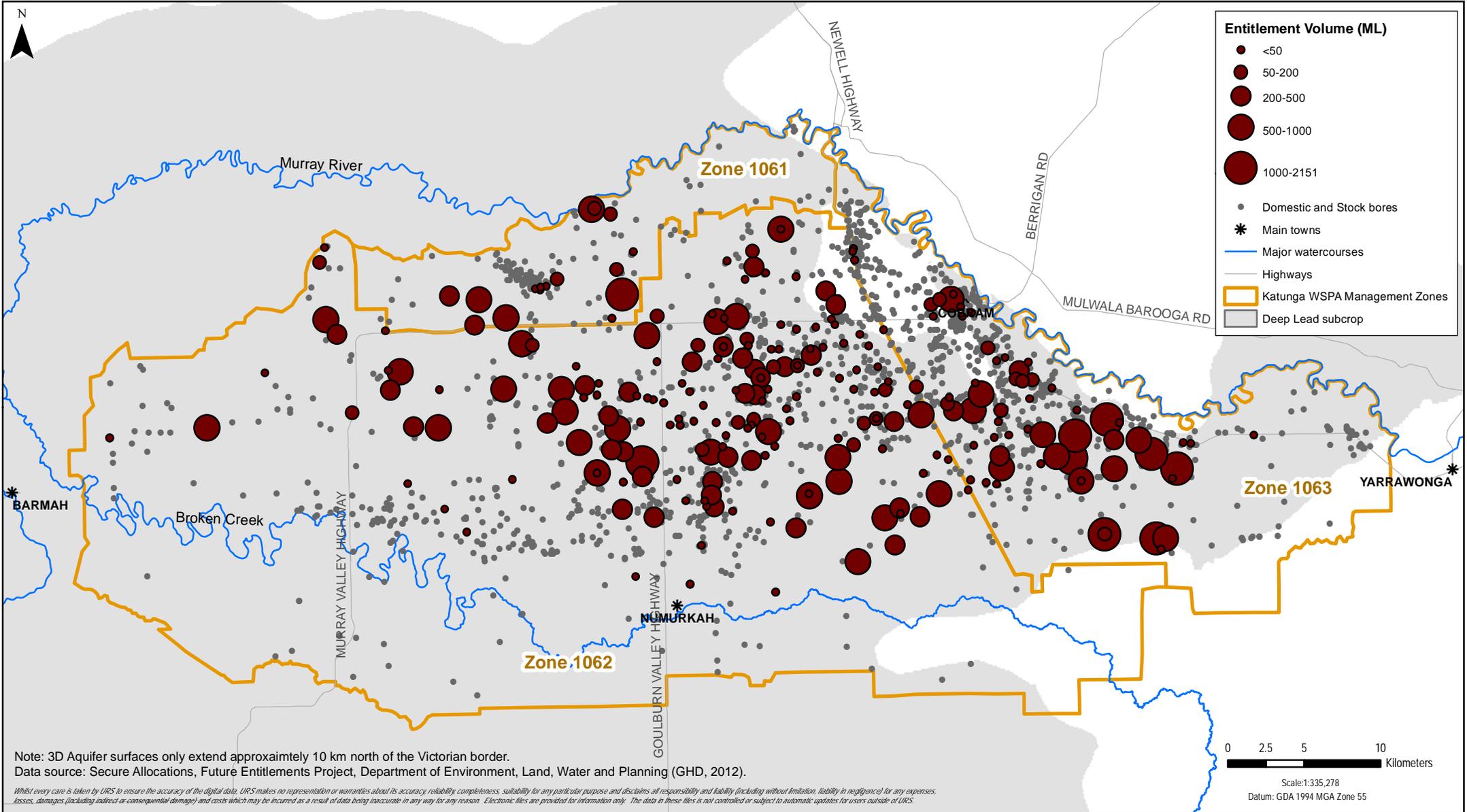
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Figure: **A-5d**

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KATUNGA WSPA GROUNDWATER RESOURCE ASSESSMENT

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 GROUNDWATER USERS

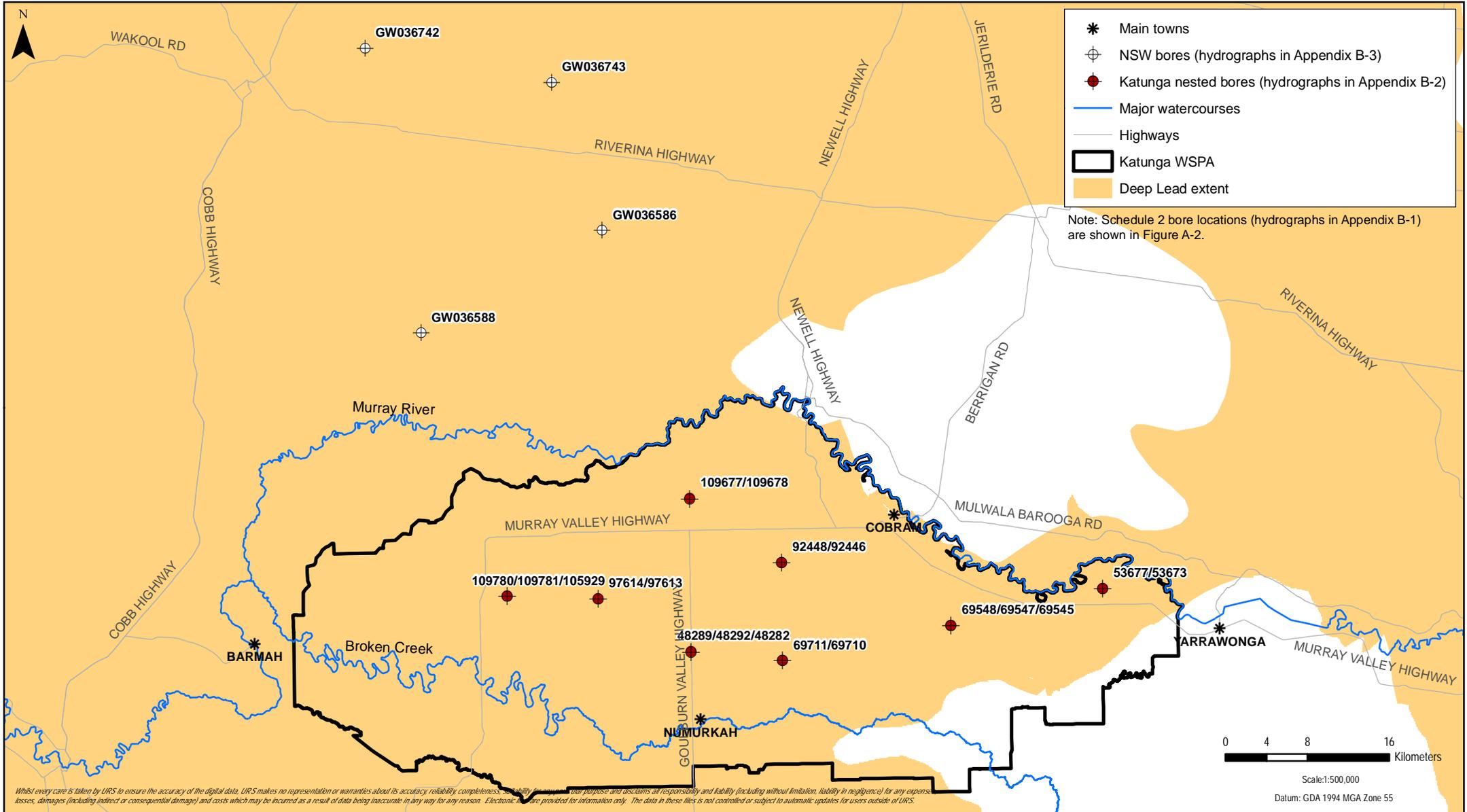


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Figure: **A-6**

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KATUNGA WSPA GROUNDWATER RESOURCE ASSESSMENT

HYDROGRAPH BORE LOCATIONS



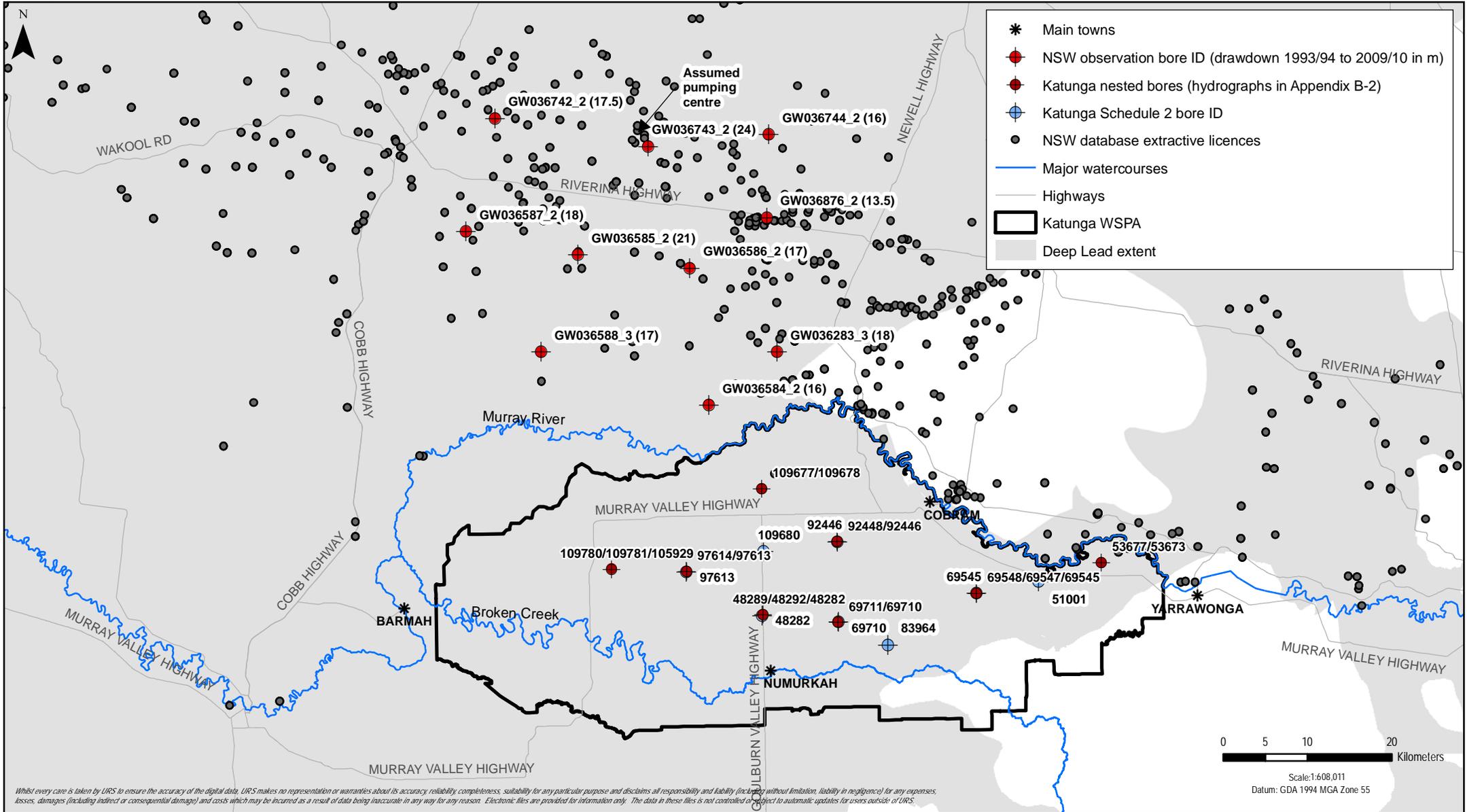
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Figure: **A-7**

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KATUNGA WSPA GROUNDWATER RESOURCE ASSESSMENT

**NSW DRAWDOWN
1993/94 TO 2009/10**



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File No: NSW Drawdown.mxd

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Figure: **A-8**

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B.1 Katunga WSPA Schedule 2 Bores

All bores in this section are screened in the Deep Lead Aquifer within the Katunga WSPA. The screened intervals are shown in chart legends.

Chart-B-1 Hydrograph for bores 48282 and 51001

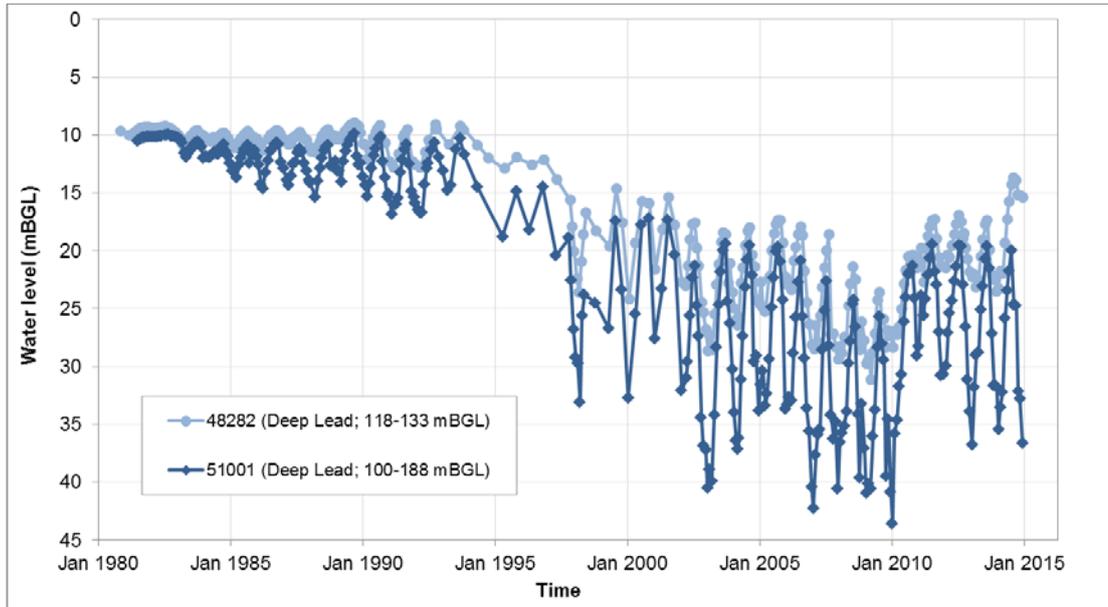


Chart-B-2 Hydrograph for bores 69710 and 92446

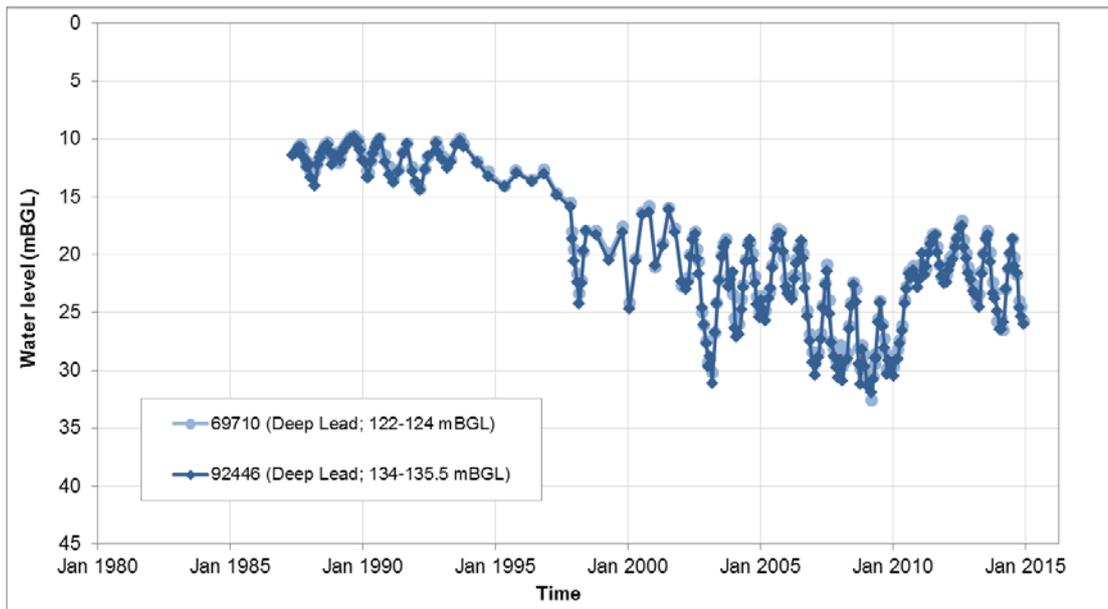


Chart-B-3 Hydrograph for bores 97613 and 69545

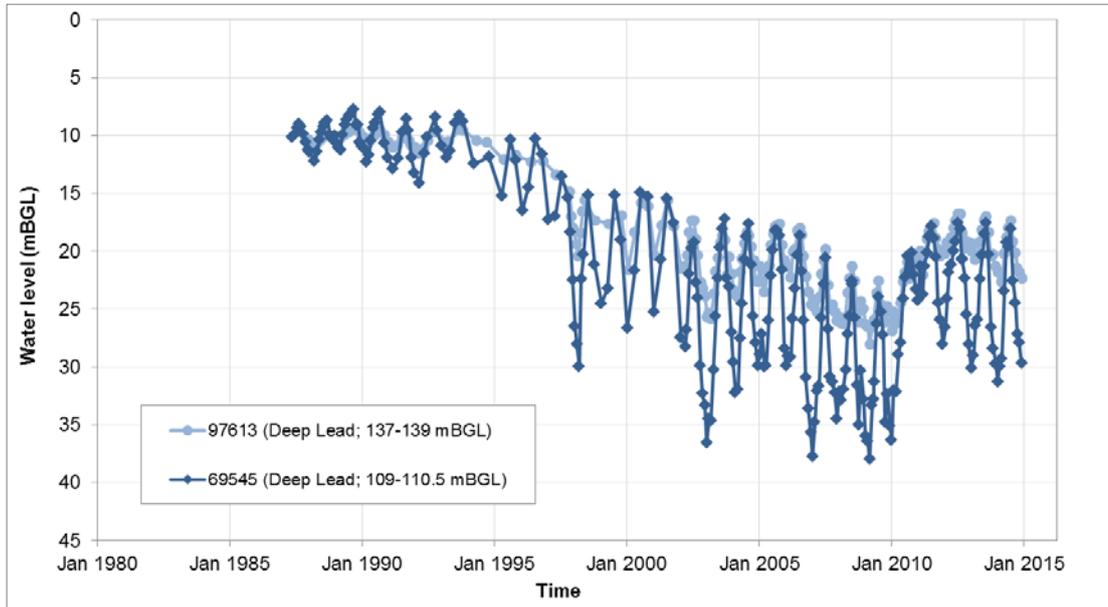
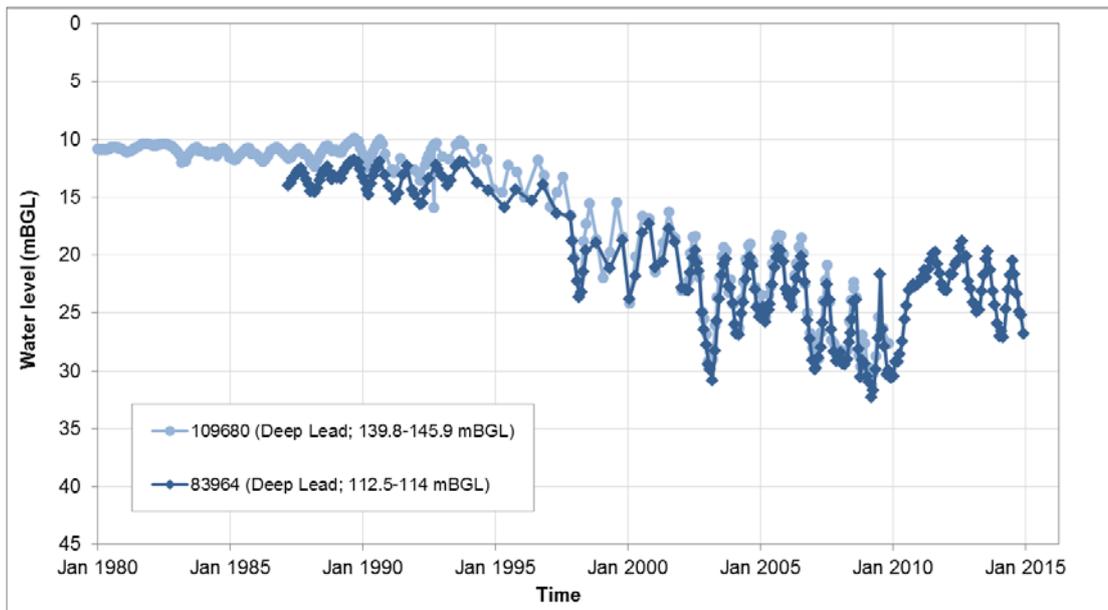


Chart-B-4 Hydrograph for bores 109680* and 83964



* Bore 109680 is no longer listed under Schedule 2 because it is defective and has not been monitored since 2009.

B.2 Nested Shepparton Formation / Deep Lead Bores

All bores shown in this section are located within the Katunga WSPA (see locations in **Figure A-7**). The colour key for charts in this section is as follows:

- Upper Shepparton Formation – red or pink;
- Mid Shepparton Formation – orange;
- Lower Shepparton Formation – green; and
- Deep Lead – blue.

Screened intervals are shown in chart legends.

Chart-B-5 Nested hydrograph: 48289/48292/48282

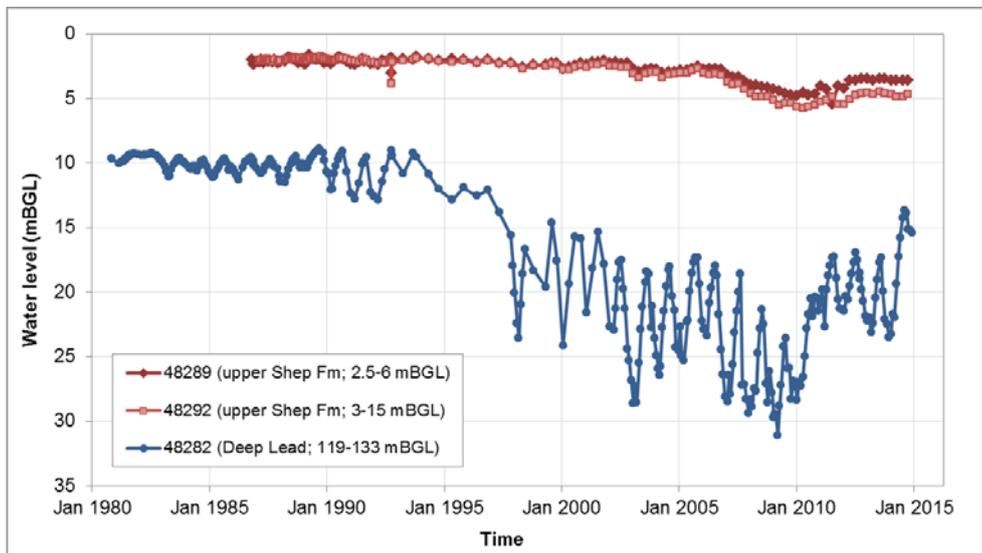


Chart-B-6 Nested hydrograph: 69548/69547/69545

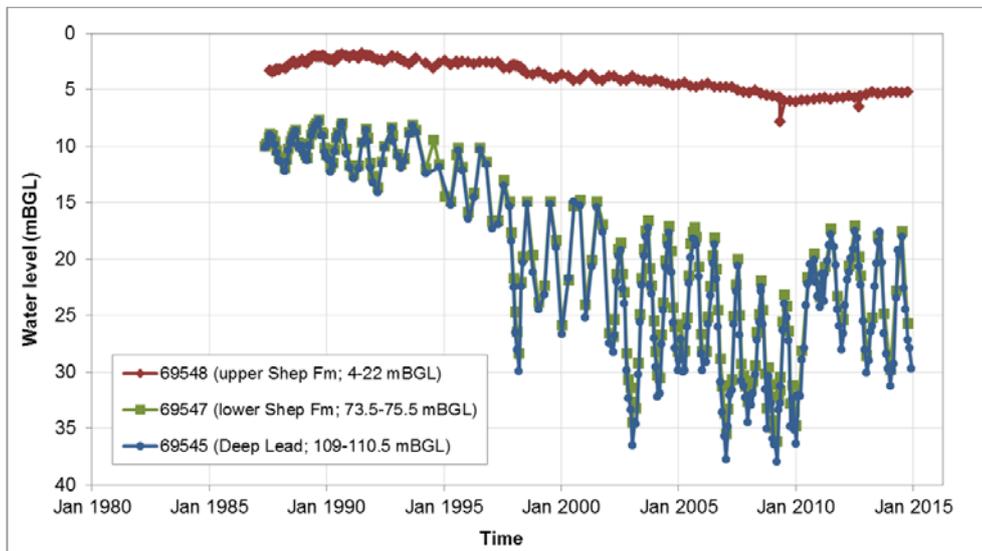


Chart-B-7 Nested hydrograph: 69711/69710

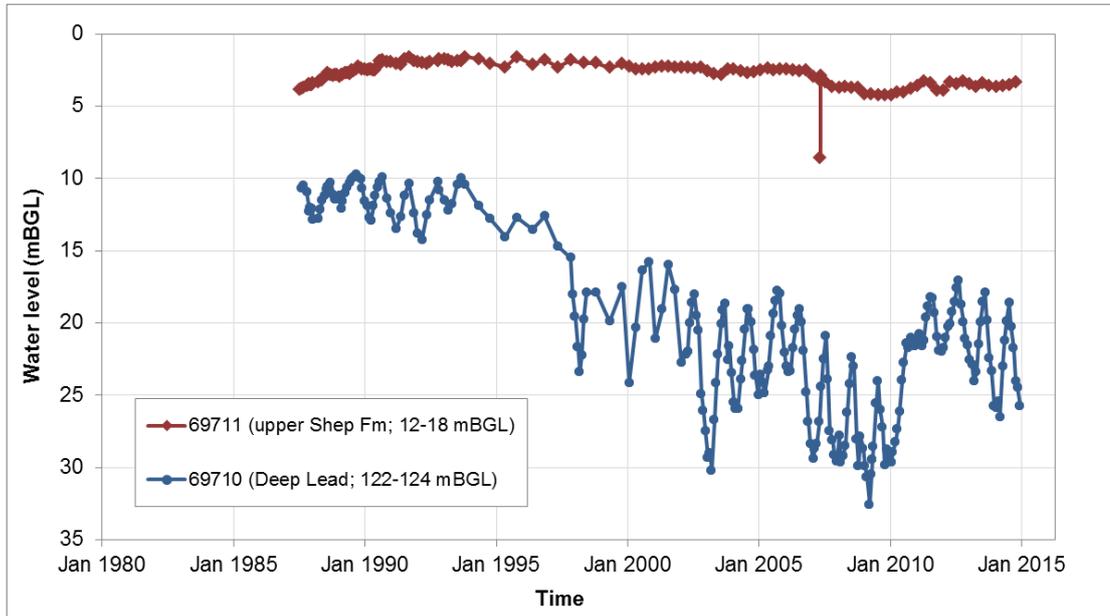


Chart-B-8 Nested hydrograph: 92448/92446

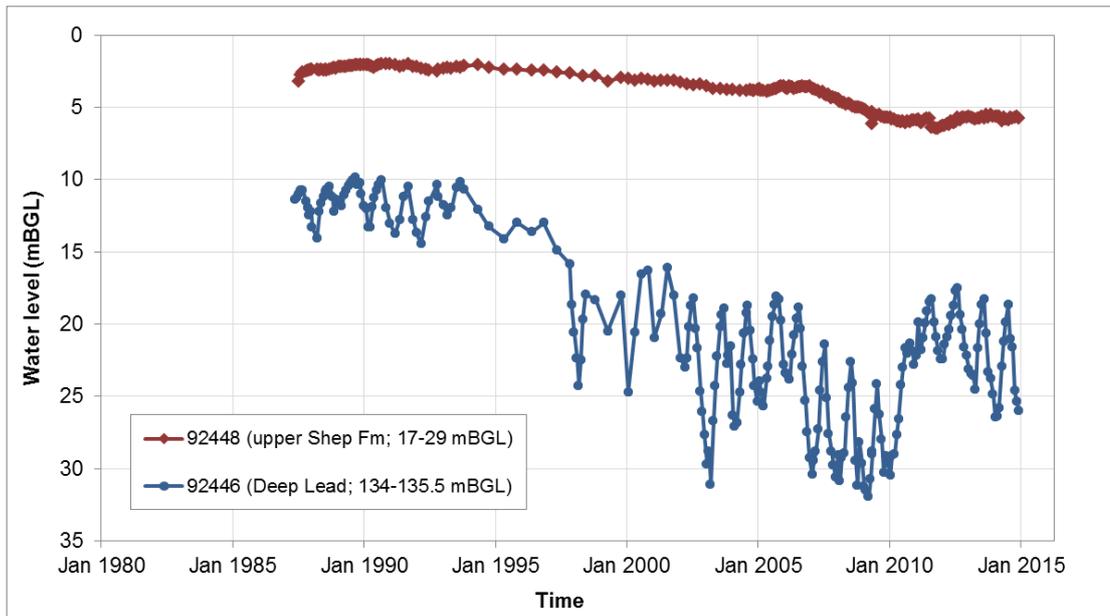


Chart-B-9 Nested hydrograph: 97614/97613

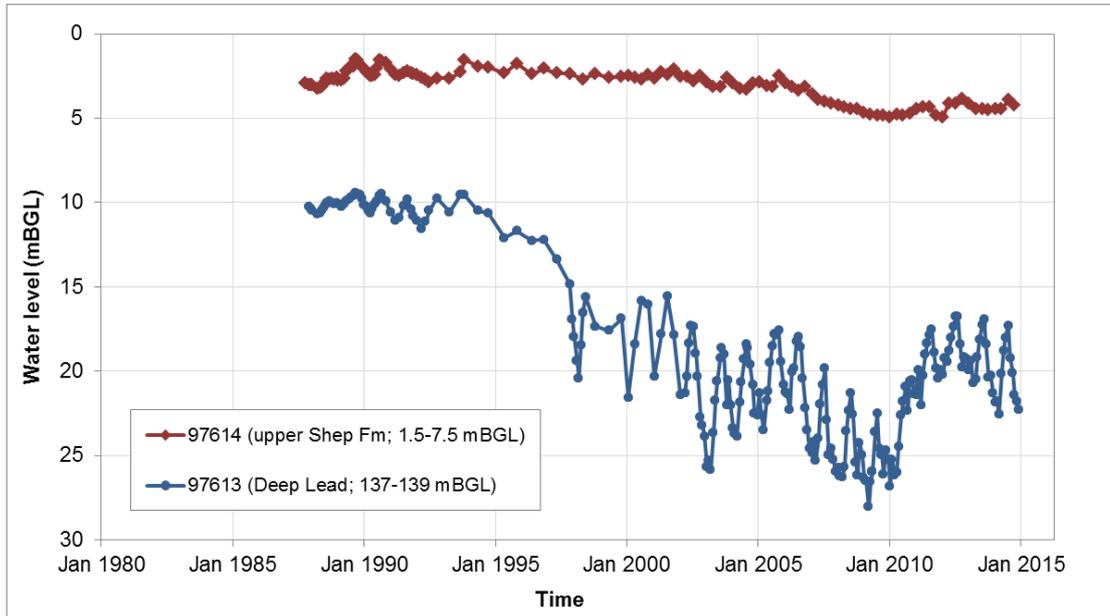


Chart-B-10 Nested hydrograph: 109780/109781/105929

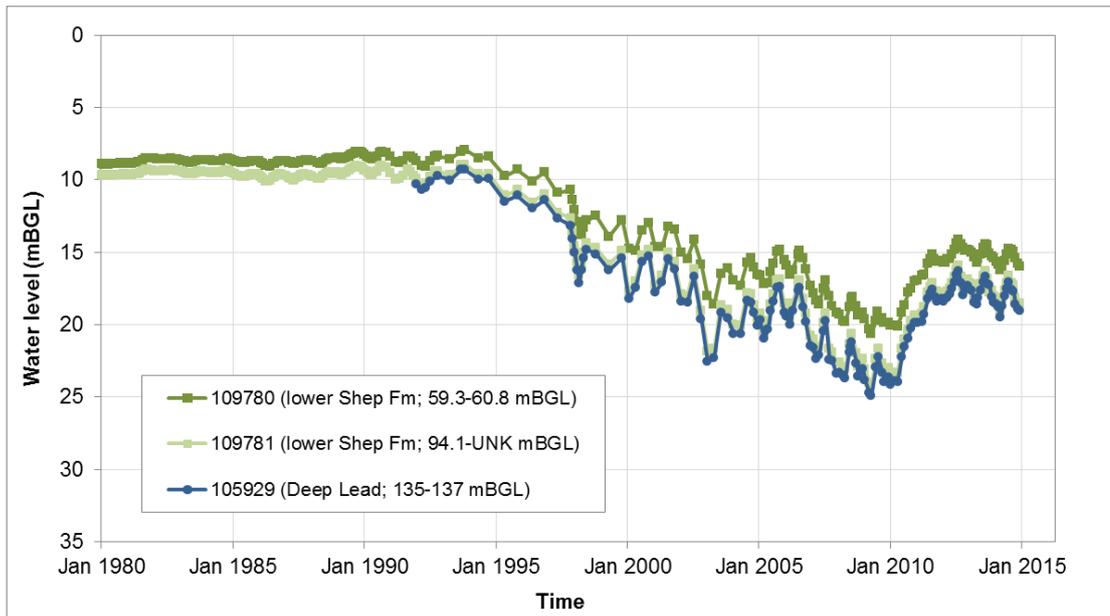


Chart-B-11 Nested hydrograph: 109677/109678

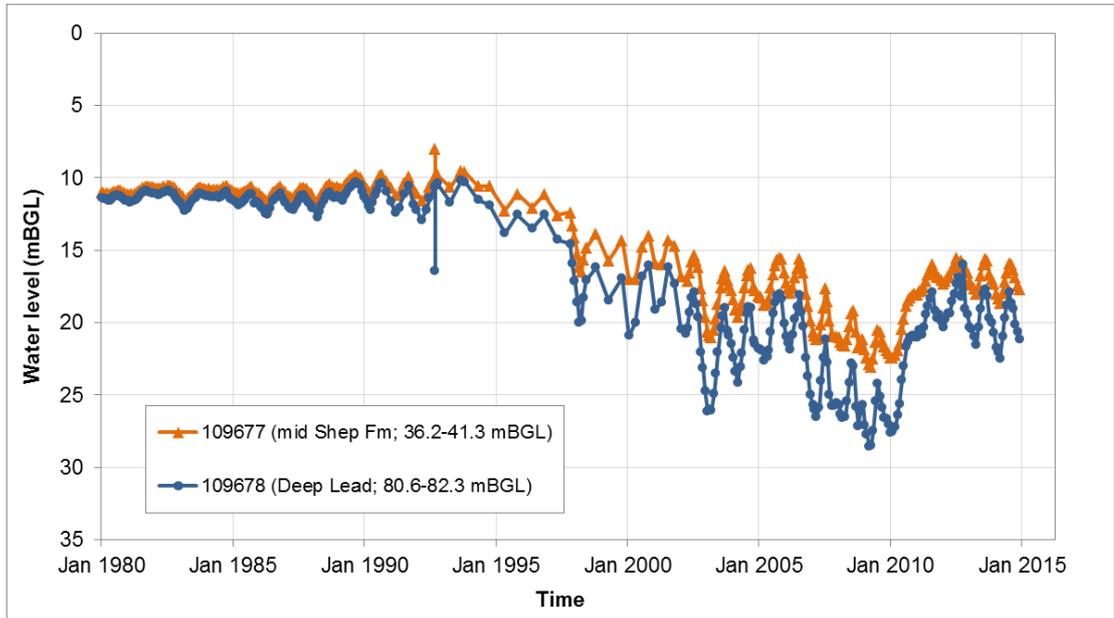
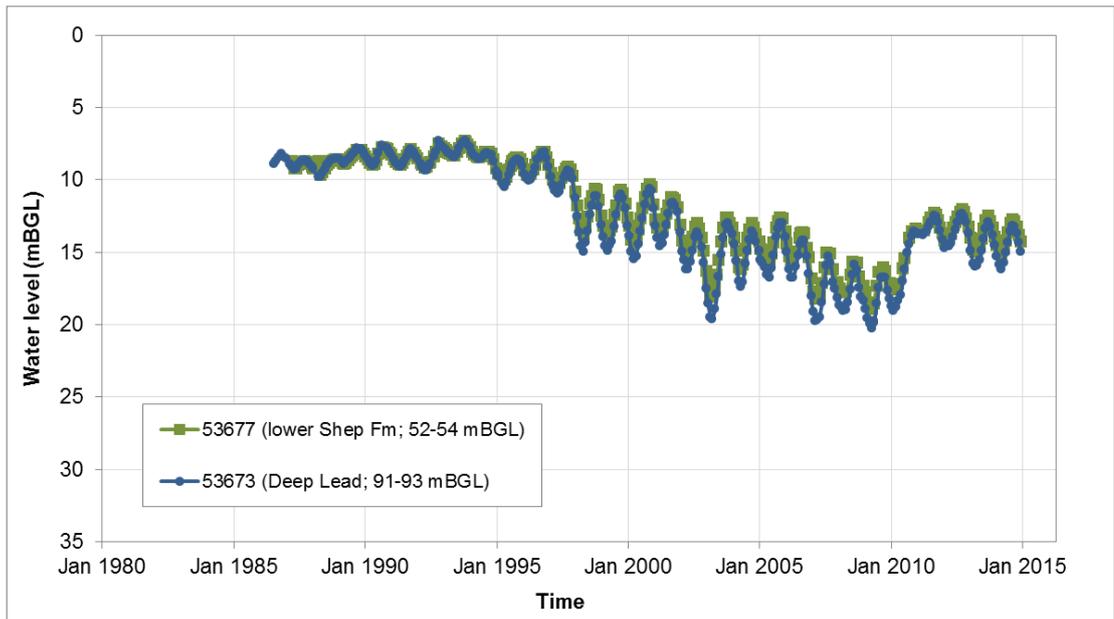


Chart-B-12 Nested hydrograph: 53677/53673



B.3 Selected GMA016 Bores

Please note: all charts in this section are sourced from NOW (2014). All bores are screened in the Deep Lead aquifer with screened depth as shown in chart legends.

Chart-B-13 Hydrograph for bore GW036743 (NSW Office of Water, 2014)

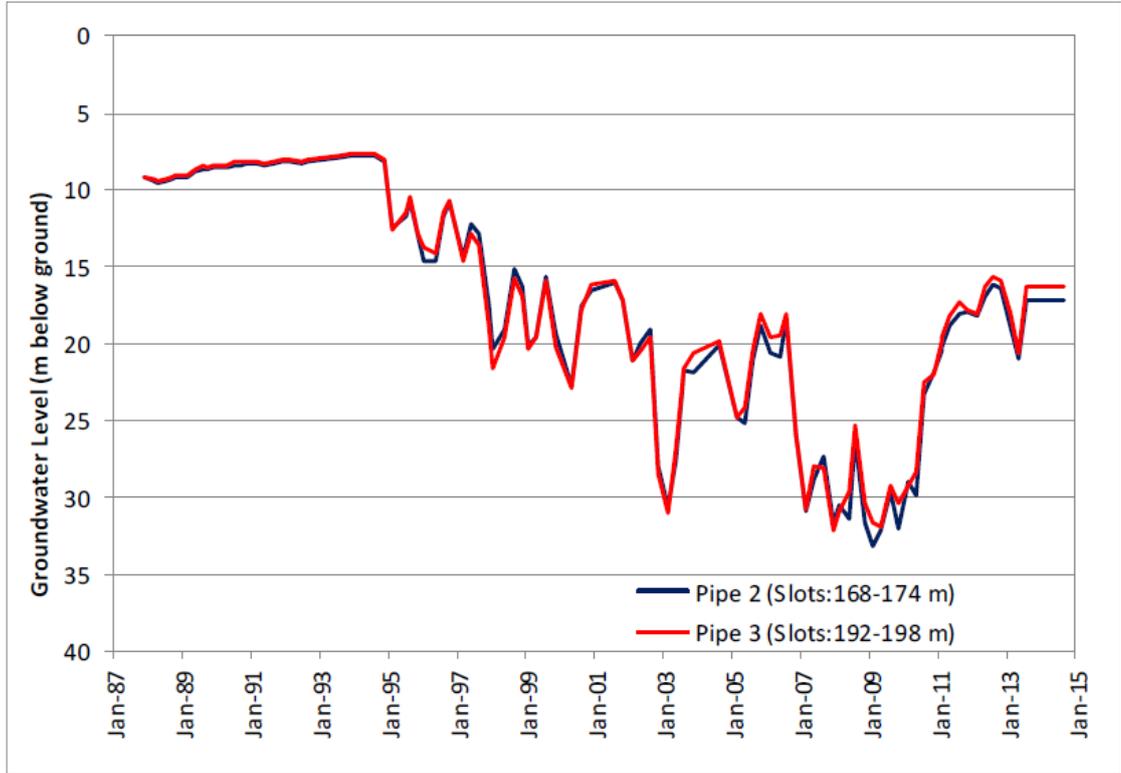


Chart-B-14 Hydrograph for bore GW036742 (NSW Office of Water, 2014)

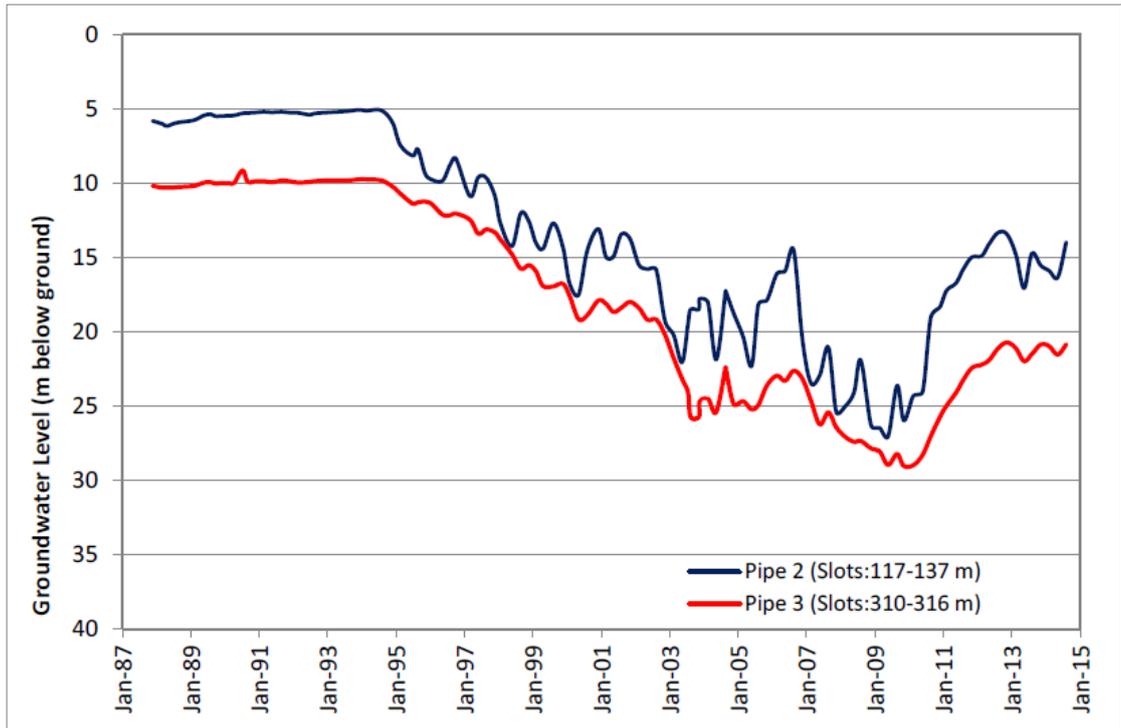


Chart-B-15 Hydrograph for bore GW036586 (NSW Office of Water, 2014)

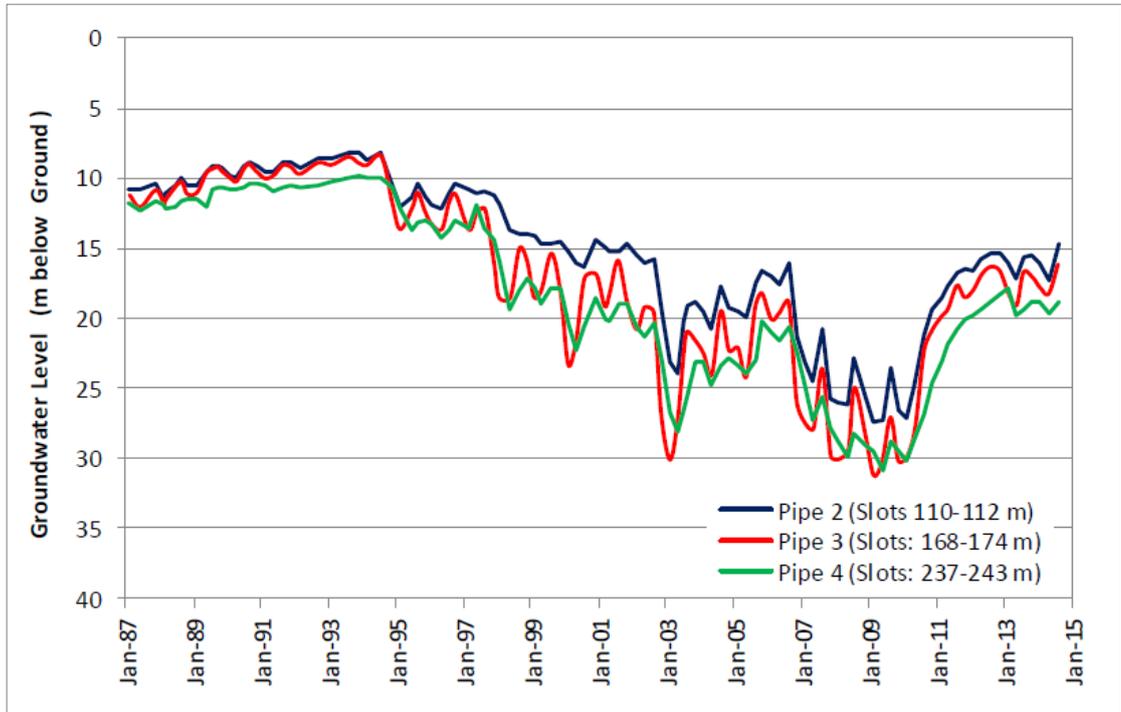


Chart-B-16 Hydrograph for bore GW036588 (NSW Office of Water, 2014)

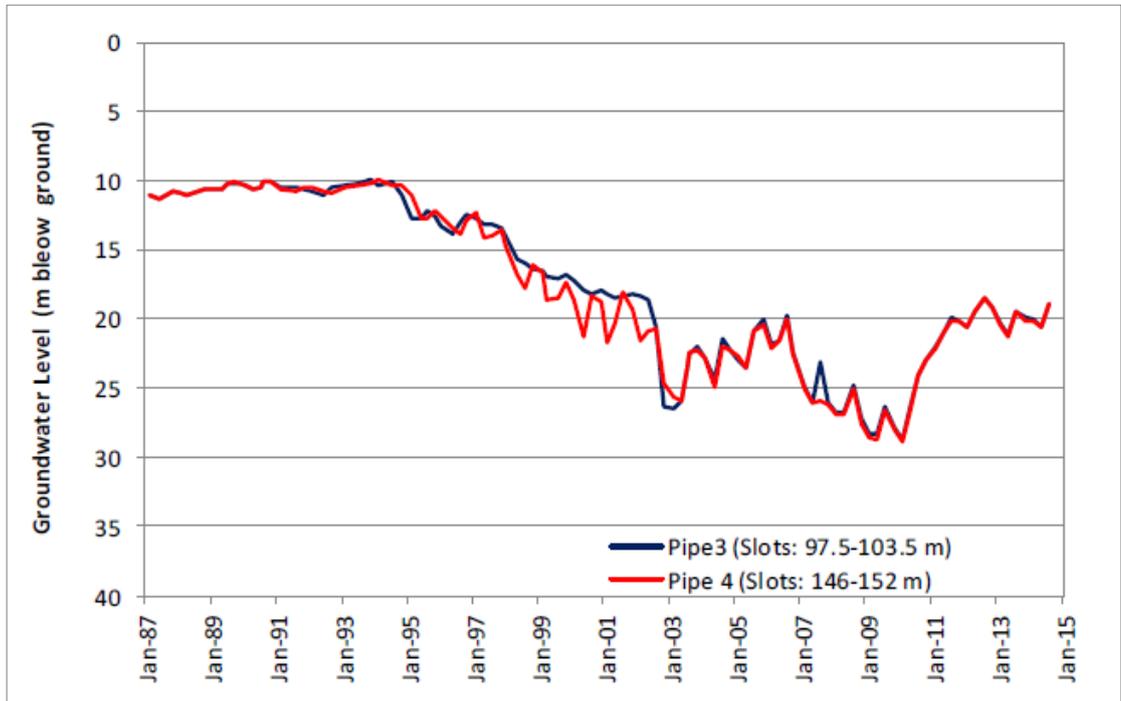


Table-C-1 Input data - compilation of values and selected model distributions

| COMPILATION OF VALUES | | | | MODEL INPUTS | | | |
|-------------------------------|---------------------------------|---|--|--------------------------|--|--|--|
| Parameter | Value | Data Source | Description | Probability Distribution | Values to define distribution | Log transformed values | Comment |
| Hydraulic Conductivity | | | | | | | |
| Kh (Deep Lead) m/day | 41 to 230 m/day | Tickell and Humphrys (1986) | Based on pumping test data from 4 bores in Katunga WSPA - see data in Appendix 3 (p.188). Data as follows (K in m/day, parish name in brackets): 41 (Katunga), 42 (Baulkamaugh), 230 (Strathmerton), <184 (Katamatite). Whole range for Deep Lead in Victorian Riverine Province is 11 to 230 m/day (p.44). | Normal (log transformed) | Mean = 20 m/day, 95th percentile = 200 m/day (therefore 5th percentile = 2 m/day). | Mean = 1.3, 95th percentile = 2.3, 5th percentile = 0.3. | Sources given most weight as follows: Tickell and Humphrys (1986), Cartwright and Weaver (2005), SKM (1997a, 1997b), and Lawrence (1975). Mean (20 m/day) is geometric mean of these ranges. GMW pump test database used to validate mean. Note: higher values from pumping tests in 1970s and 1980s considered more accurate (freshly drilled boreholes, good tests). NVic model values (Beverly and Hocking 2014) are considered too low because based on whole region - this area has higher K. However this is taken into account in setting range. Generic literature values used as a basic reality check. |
| | 7 to 60 m/day | Cartwright and Weaver (2005) cited in Cartwright et al (2008) | Based on 14C ages in the Calivil-Renmark Formation in the Goulburn palaeovalley (including the Katunga WSPA). | | | | |
| | 4.4 to 4.7 m/day | SKM, 1997a; SKM, 1997b | Based on the Murray Valley Pumping Test as described above (SKM 1997a, SKM 1997b). The Deep Lead properties were derived from test data prior to significant leakage effects (30-400 minutes into test). A T of 177-189 m ² /day is reported; this has been converted to K using an average Deep Lead thickness of 40 m in this area (based on SAFE 3D aquifer surfaces). | | | | |
| | 0.4 to 39 m/day | GMW pumping test database (K.Joy, pers. comm., 20 March 2015) | GMW pumping test database - for bores within Katunga as follows: WRK015889 (39 m/day), Katunga 1 (16 m/day), and Katunga 11 (0.4 m/day). | | | | |
| | 2 to 15 m/day, median 12 m/day | Beverly and Hocking (2014) | Values assigned to Model Layer 5 (Calivil Formation) - see references p.44 | | | | |
| | 0.5 to 10 m/day, median 2 m/day | Beverly and Hocking (2014) | Values assigned to Model Layer 9 (Renmark Formation) - see references p.44 | | | | |
| | 50 | SKM (2006) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 6.3 to 50 | GMW Pump test database DM#2788159 cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 8 to 50, median 45 | GHD (2010) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 16 m/day | Lawrence (1975) cited in Ellis (2010) | Cited as within or close to Katunga WSPA (p.35). | | | | |
| | 0.02 to 500 m/day (approx) | Domenico and Schwartz (1998) | Literature range for fine to coarse sand. | | | | |
| | 2.5 to 450 m/day | Todd and Mays (2005) | Literature range for fine sand to fine gravel. | | | | |
| 0.01 to 900 m/day (approx) | Freeze and Cherry (1979) | Literature range for silty sand to clean sand. | | | | | |

| COMPILATION OF VALUES | | | | MODEL INPUTS | | | |
|----------------------------------|--------------------------------------|---|--|--------------------------|---|--|--|
| Parameter | Value | Data Source | Description | Probability Distribution | Values to define distribution | Log transformed values | Comment |
| Hydraulic Conductivity | | | | | | | |
| Kv (lower Shep Fm) mm/day | 0.06 to 0.42 mm/day (lower Shep Fm) | SKM, 1997a; SKM, 1997b | Based on the Murray Valley Pumping Test - a 30 day pumping test 5 km north of Numurkah using a pumping bore screened at 124 to 136 mBGL. Kv estimated from drawdown at a lower Shep Fm bore screened at 88 to 91 mBGL. Estimate is based on a decrease in rate of drawdown around 8-22 hours after test initiation (assumed to be leakage from Shep Fm). | Normal (log transformed) | Mean = 0.1 mm/day. 95th percentile = 0.3 mm/day (therefore 5th percentile = 0.03 mm/day). | Units in m/day (log transformed): Mean = 4, 95th percentile = 3.5, 5th percentile = 4.5. | Original mean value (0.4 mm/day) based on: geometric mean of SKM range (1997a, 1997b), Tickell and Humphrys area weighted average (1987), geometric mean of Cartwright and Weaver (2005) 14C range. However this value was used to calibrate the model. The calibrated value was 0.1 mm/day, which is well within expected ranges. |
| | 0.01 to 10 mm/day (upper Shep Fm) | SKM, 1997a; SKM, 1997b | Based on the Murray Valley pumping test as described above, but using drawdown observed in an upper Shep Fm bore screened at 4-7 mBGL. This estimate was highly uncertain and little confidence is placed in this value range. | | | | |
| | 0.03 to 7 mm/day, average 0.5 mm/day | Tickell and Humphrys (1987) | Whole Victorian Riverine Province area weighted average (p.65). | | | | |
| | 0.31 mm/day | Al-Hosni (2007) cited in Ellis (2010) | Cited as within or close to Katunga WSPA (p.35). | | | | |
| | 0.03 to 0.2 mm/day | Tickell and Humphrys (1987) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 0.3 to 5 mm/day | SKM (1998a) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 0.01 – 10 mm/day | SKM (1998b) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 0.01 to 100 mm/day | Tickell and Humphrys (1987) and Cartwright and Weaver (2005) as cited in Cartwright et al. (2008) | The Cartwright and Weaver (2005) data is based on 14C ages in the Goulburn palaeovalley (including in the Katunga WSPA). | | | | |
| | 0.000864 to 1728 mm/day | Domenico and Schwartz (1998) | Literature range for silt and clay. | | | | |
| 0.2 to 80 mm/day | Todd and Mays (2005) | Literature range for silt and clay. | | | | | |
| Kv (Basement) mm/day | 0.1 to 0.3 mm/day | SKM (1997a) | Estimated from Campaspe West pumping test data. | Normal (log transformed) | Mean = 0.03 mm/day, 95th percentile = 0.1 mm/day (therefore 5th percentile = 0.01 mm/day approx). | Units in m/day (log transformed): Mean = 4.5, 95th percentile = 4, 5th percentile = -5. | Original mean chosen as middle of reported Campaspe West pumping test. However model calibrated value was lower (0.03 mm/day), which is within an order of magnitude of the one estimate available, and deemed to be plausible. |
| Storativity | | | | | | | |
| Sy (Deep Lead) | 0.05 | TATDOC-#1630281 spreadsheet | Assumed in GMA Katunga water balance spreadsheet | Triangular | "Expected" value = 0.15, Min = 0.02, Max = 0.3. | N/A | NVic model values (Beverly and Hocking, 2014) and TATDOC-#1630281 spreadsheet values considered to be low. Chosen range takes literature values for sand and gravel into account. |
| | 0.03 to 0.07, median 0.05 | Beverly and Hocking (2014) | Values assigned to Model Layer 5 (Calivil Formation) - see references p.42 | | | | |
| | 0.02 to 0.08, median 0.04 | Beverly and Hocking (2014) | Values assigned to Model Layer 9 (Renmark Formation) - see references p.42 | | | | |
| | 0.21 to 0.33 | Weight and Sonderegger (2001) | Literature range for fine sand to coarse gravel. Note that this is based on the range in arithmetic means for each sediment category: full range for all categories is 0.01 to 0.46. | | | | |
| | 0.005 to 0.1 | Domenico and Schwartz (1998) | Literature range for sandstone (unconsolidated sediment range not available from this reference). | | | | |

| COMPILATION OF VALUES | | | | MODEL INPUTS | | | |
|--|--|---|--|-----------------------------------|--|--|--|
| Parameter | Value | Data Source | Description | Probability Distribution | Values to define distribution | Log transformed values | Comment |
| Storativity | | | | | | | |
| S (Deep Lead) = Ssb | 0.00021 to 0.00034 | SKM, 1997a; SKM, 1997b | Same pumping test as described above (SKM 1997a, SKM 1997b) - Deep Lead properties derived from test data prior to significant leakage effects (30-400 minutes into test). | Normal (log transformed) | Mean = 0.003. 95th percentile = 0.01 (therefore 5th percentile = 0.003). | Mean = -2.5, 95th percentile = -2, 5th percentile = -3 | Original mean value (0.001) selected as geometric mean of NVic model median value (Beverly and Hocking 2014), SKM pumping tests, and Tickell and Humphrys local pumping tests. This parameter was used to calibrated the model - the calibrated value is 0.003, which is well within published ranges. The 95th percentile is equal to the median of 0.01 from Beverly and Hocking (2014). |
| | 0.005 to 0.05, median 0.01 | Beverly and Hocking (2014) | Values assigned to Model Layers 5 and 9 (Calivil and Renmark Formation) - see references p.43. | | | | |
| | 0.00039 to 0.00072 | Tickell and Humphrys (1987) | Katunga WSPA only - based on pumping test data for 2 bores (see Appendix 3 p.188). | | | | |
| | 0.00005 – 0.04 mean 0.0009 | Tickell and Humphrys (1987) | Whole Victorian Riverine Province. | | | | |
| | 0.00001 – 0.0053 | GHD (2010) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 0.0014 | GMW pump test database DM#2788159 cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 0.001 | SKM (2006) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| Sy (upper Shep Fm) | 0.01 to 0.1, median 0.08 | Beverly and Hocking (2014) | Values assigned to Model Layer 2 (upper Shep Fm) - see references p.42 | Triangular | "Expected" value = 0.08, Min = 0.01, Max = 0.1 | N/A | Primarily based on NVic model values (Beverly and Hocking, 2014) |
| | 0.02 – 0.00003 | Tickell and Humphrys (1987) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 0.00003 – 0.1, median 0.009 | GHD (2010) cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 0.00003 – 0.02 | GMW Pump test database DM#2788159 cited in GMW (2014) | Cited in the Mid Goulburn Water Balance report. | | | | |
| | 0.15 | SKM (2006) cited in GMW (2014) | Specific to upper Shep Fm | | | | |
| | 0.06 to 0.33 | Weight and Sonderegger (2001) | Literature ranges for clay silt and fine sand. Note that this is based on the range in arithmetic means for each sediment category: full range for all categories is 0.01 to 0.46. | | | | |
| Hydraulic Gradients/Head Differentials | | | | | | | |
| Lateral gradient – inflow 1* | 2.87x10 ⁻⁴ (1993) 8.95x10 ⁻⁴ (2009) | Water level data | Based on potentiometric surfaces generated from water level data for Vic and NSW for each time period. | N/A (see "gradient x area" below) | N/A | N/A | N/A |
| Lateral gradient – inflow 2* | 1.82x10 ⁻⁴ (1993) 3.01x10 ⁻⁴ (2009) | Water level data | Based on potentiometric surfaces generated from water level data for Vic and NSW for each time period. | N/A (see "gradient x area" below) | N/A | N/A | N/A |
| Lateral gradient – outflow | 1.27x10 ⁻⁴ (1993) 2.03x10 ⁻⁴ (2009) | Water level data | Based on potentiometric surfaces generated from water level data for Vic and NSW for each time period. | N/A (see "gradient x area" below) | N/A | N/A | N/A |
| Vertical gradient – Basement to Deep Lead | 10 ⁻¹ | Professional judgement | There is no water level data available for the Basement aquifer. In order to estimate this in the model, it was assumed that the head in this aquifer would have been in equilibrium with the head in the Deep Lead prior to pumping. Hence there might now be a head differential of ~11 m (average drop in head in the Deep Lead). A nominal flux distance of 100 m in the Basement was assumed. Since these values are subject to significant uncertainty, the range was set at an order of magnitude variation between the mean and the 95th/5th percentile. | Normal (log transformed) | Mean = 0.1. 95th percentile = 1. 5th percentile = 0.01. | Mean = -1, 95th percentile = 0, 5th percentile = -2 | Range is one order of magnitude either side of expected value, to reflect high degree of uncertainty. |

| COMPILATION OF VALUES | | | | MODEL INPUTS | | | |
|--|----------------|------------------|--|--------------------------|---|------------------------|--|
| Parameter | Value | Data Source | Description | Probability Distribution | Values to define distribution | Log transformed values | Comment |
| Hydraulic Gradients/Head Differentials | | | | | | | |
| Vertical head differential – upper Shep Fm to Deep Lead - SCENARIO C1 | 8.4 m | Water level data | The head differential for each climate scenario C1-C4 is based on historic water level data for 5 nested wells sites (48289/48282; 69548/69545; 69711/69710; 92448/92446; 97614/97613) with a bore screened in the upper Shepparton Formation and a bore in the Deep Lead. The expected or mean value is the arithmetic mean for the 5 nested sites. | Normal | Mean = 8.4. 95th percentile = 9.5. 5th percentile = 7.3 | N/A | The mean is the arithmetic mean of the 5 nested well pairs and the 95th percentile is the maximum value from the dataset. |
| Vertical head differential – upper Shep Fm to Deep Lead - SCENARIO C2 | 19 m | Water level data | The head differential for each climate scenario C1-C4 is based on historic water level data for 5 nested wells sites (48289/48282; 69548/69545; 69711/69710; 92448/92446; 97614/97613) with a bore screened in the upper Shepparton Formation and a bore in the Deep Lead. The expected or mean value is the arithmetic mean for the 5 nested sites. | Normal | Mean = 19. 95th percentile = 20.5. 5th percentile = 17.5. | N/A | The mean is the arithmetic mean of the 5 nested well pairs and the 95th percentile is the maximum value from the dataset. |
| Vertical head differential – upper Shep Fm to Deep Lead - SCENARIO C3 | 22.2 m | Water level data | The head differential for each climate scenario C1-C4 is based on historic water level data for 5 nested wells sites (48289/48282; 69548/69545; 69711/69710; 92448/92446; 97614/97613) with a bore screened in the upper Shepparton Formation and a bore in the Deep Lead. The expected or mean value is the arithmetic mean for the 5 nested sites. | Normal | Mean = 22.2. 95th percentile = 24. 5th percentile = 20.4 | N/A | The mean is the arithmetic mean of the 5 nested well pairs and the 95th percentile is the maximum value from the dataset. |
| Vertical head differential – upper Shep Fm to Deep Lead - SCENARIO C4 | 16.1 m | Water level data | The head differential for each climate scenario C1-C4 is based on historic water level data for 5 nested wells sites (48289/48282; 69548/69545; 69711/69710; 92448/92446; 97614/97613) with a bore screened in the upper Shepparton Formation and a bore in the Deep Lead. The expected or mean value is the arithmetic mean for the 5 nested sites. | Normal | Mean = 16.1. 95th percentile = 18. 5th percentile = 14.2. | N/A | The mean is the arithmetic mean of the 5 nested well pairs and the 95th percentile is the maximum value from the dataset. |
| Change in upper Shep Fm head - SCENARIO C1 | 0 m/year | Water level data | Average annual change in average upper Shepparton formation water level relative to pre-1994 levels. Based on the same hydrographs from nested sites described above. Value is zero by definition. | N/A | N/A | N/A | Not going into the model as a distribution because the value is 0 by definition (see description of climate scenarios). |
| Change in upper Shep Fm head - SCENARIO C2 | (-)0.1 m/year | Water level data | Average annual change in average upper Shepparton formation water level relative to pre-1994 levels. Based on the same hydrographs from nested sites described above. Note: this is a negative because it represents a water level drop. | Normal | Mean = 0.1. 95th percentile = 0.17. 5th percentile = 0.03. | N/A | Mean is based on arithmetic mean from the 5 nested well sites. 95th percentile is set as the highest value of the dataset. |
| Change in upper Shep Fm head - SCENARIO C3 | (-)0.8 m/year | Water level data | Average annual change in average upper Shepparton formation water level relative to pre-1994 levels. Based on the same hydrographs from nested sites described above. Note: this is a negative because it represents a water level drop. | Normal | Mean = 0.8. 95th percentile = 1.0. 5th percentile = 0.6. | N/A | Mean is based on arithmetic mean from the 5 nested well sites. 95th percentile is set as the highest value of the dataset. |
| Change in upper Shep Fm head - SCENARIO C4 | (+)0.17 m/year | Water level data | Average annual change in average upper Shepparton formation water level relative to pre-1994 levels. Based on the same hydrographs from nested sites described above. Note: this is a positive because it represents a water level rise. | Normal | Mean = 0.17. 95th percentile = 0.29. 5th percentile = 0.05. | N/A | Mean is based on arithmetic mean from the 5 nested well sites. 95th percentile is set as the highest value of the dataset. |

| COMPILATION OF VALUES | | | | MODEL INPUTS | | | |
|---|--|--|---|-----------------------------------|--|------------------------|---|
| Parameter | Value | Data Source | Description | Probability Distribution | Values to define distribution | Log transformed values | Comment |
| Areas/Lengths | | | | | | | |
| Cross sectional area – inflow 1* | 338,600 m2 (1993) 338,600 m2 (2009) | GIS calculation | Cross sectional areas calculated using GIS, based on the statewide aquifer surfaces. The location of the sections was drawn for each year (1993 and 2009) based on the groundwater flow directions inferred from the potentiometric surfaces. | N/A (see "gradient x area" below) | N/A | N/A | N/A |
| Cross sectional area – inflow 2* | 1,835,726 m2 (1993) 1,104,422 m2 (2009) | GIS calculation | Cross sectional areas calculated using GIS, based on the statewide aquifer surfaces. The location of the sections was drawn for each year (1993 and 2009) based on the groundwater flow directions inferred from the potentiometric surfaces. | N/A (see "gradient x area" below) | N/A | N/A | N/A |
| Cross sectional area – outflow | 3,608,972 m2 (1993) 3,591,795 m2 (2009) | GIS calculation | Cross sectional areas calculated using GIS, based on the statewide aquifer surfaces. The location of the sections was drawn for each year (1993 and 2009) based on the groundwater flow directions inferred from the potentiometric surfaces. | N/A (see "gradient x area" below) | N/A | N/A | N/A |
| Deep Lead surface area | 1,852,000,000 m2 | GIS calculation | Surface area of Deep Lead extent within Katunga WSPA based on the statewide aquifer surfaces. Note that the surface area of the Shepparton Fm and Basement extend across the whole Katunga WSPA. | Triangular | Expected = 1852 km2. Min = 1667 km2. Max = 2037 km2. | N/A | Range is +-10% of expected value (relatively low variability due to data source and calculation method). |
| Thickness | | | | | | | |
| Average Shepparton Formation thickness | 99 m | GIS calculation | The average thickness of the Shepparton Formation across the area of Deep Lead extent only, based on the statewide aquifer surfaces. | Triangular | "Expected" = 100 m. Min = 90 m. Max = 110 m. | N/A | Range is +-10% of expected value (relatively low variability due to data source and calculation method). |
| Average percentage of Shep Fm that is fine grained % | 75% | URS (2014) | Estimates based on lithological log interpretation as described in URS (2014). This estimate is based on logs for bores within 10 km of Murray River, however it is considered that this is a reasonable estimate for the whole area. | Triangular | "Expected" value = 75%, Min = 60%. Max = 90% | N/A | Range is +-20% of expected value. Based on the range in logs and also professional judgement. |
| Gradient x Area | | | | | | | |
| i x A - Inflow 1 | 97.18 (Aug 1993) 303.05 (Aug 2009) | Based on lateral gradients and cross sectional areas above | N/A - see above | Normal | Mean = 200. 95th percentile = 303. 5th percentile = 97. | N/A | Mean is arithmetic mean of two calculated values. 95th and 5th percentile is the two values. |
| i x A - Inflow 2 | 334.10 (Aug 1993) 332.43 (Aug 2009) | Based on lateral gradients and cross sectional areas above | N/A - see above | Normal | Mean = 333. 95th percentile = 334. 5th percentile = 332. | N/A | Mean is arithmetic mean of two calculated values. 95th and 5th percentile is the two values. |
| i x A - Outflow | 458.34 (Aug 1993) 729.13 (Aug 2009) | Based on lateral gradients and cross sectional areas above | N/A - see above | Normal | Mean = 594. 95th percentile = 729. 5th percentile = 458. | N/A | Mean is arithmetic mean of two calculated values. 95th and 5th percentile is the two values. |
| Other | | | | | | | |
| Loading efficiency (Deep Lead) | 0.1 to 0.8 | Harrington and Cook (2011) | Full range of "typical" values - all types of aquifers. However note that more rigid aquifers (sand/gravel) have lower values. | Triangular | "Expected" value = 0.6. Min = 0.1. Max = 0.8. | N/A | Expected value chosen as median between the mean from Hagerty (2013) and the value from Harrington and Cook (2011) - because the aquifer is probably more rigid than the TCSA. Min and max chosen from full range for all aquifers to reflect the high degree of uncertainty in this parameter. |
| | 0.77 | Harrington and Cook (2011) | Deep Tertiary Confined Sand Aquifer (TCSA) in Otways Basin - one bore only. The TCSA is described as interbedded quartz sand, finer grained sediments and clay horizons. | | | | |
| | 0.15 to 0.57 (mean 0.40) | Hagerty (2013) | Based on barometric efficiency calculations from high temporal resolution water level and atmospheric pressure data in bores screening semi-confined unconsolidated silty sand in the MDB, upper Wimmera catchment - based on 3 bores only. | | | | |

Notes

Loading efficiency (LE) is the fraction of external load change that is borne by water in a confined aquifer due to a change in pressure. $LE + \text{barometric efficiency (BE)} = 1$. Higher LE values (closer to 1) occur in more elastic aquifers (i.e. clay), and lower Le values in more rigid aquifers (i.e. sand/gravel).

Literature values for Kv (Shep Fm) are based on clay and silt rather than sand because downwards flux through the lower Shep Fm will be limited by the flux through the fine grained portion.

References

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GMW Pump test database DM#2788159

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D.1

Scenario N1

Chart-D-1 Scenario N1 distance-drawdown relationship

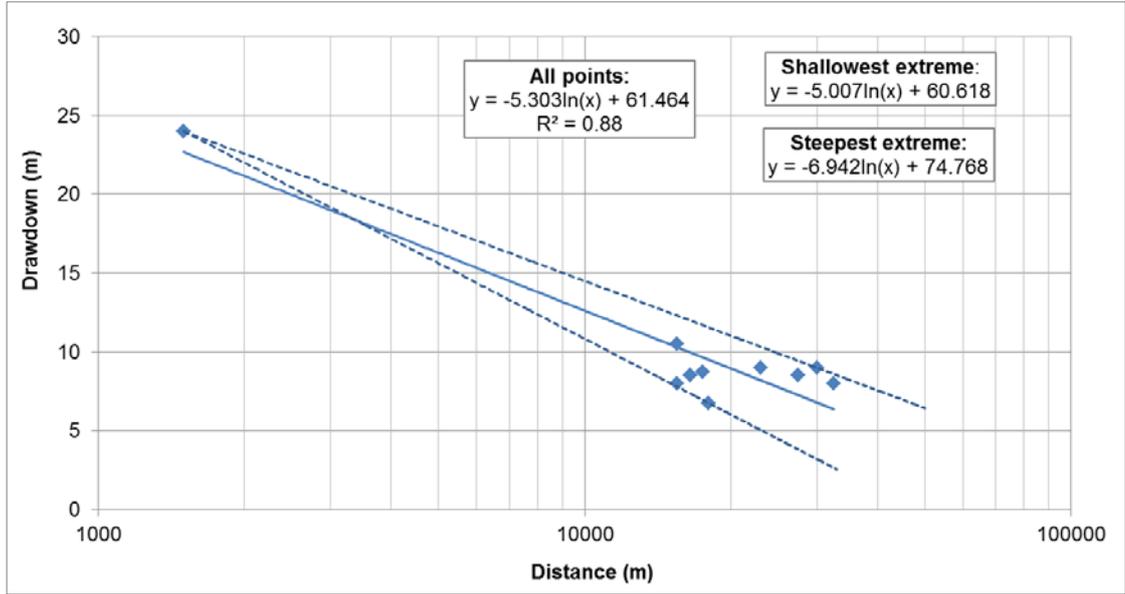


Table-D-1 Estimates of drawdown in the Katunga WSPA due to NSW pumping - Scenario N1

| ESTIMATE POINT IN KATUNGA WSPA | DISTANCE (km) | PREDICTED DRAWDOWN 1993/94 to 2009/10 (m) | | |
|--------------------------------|---------------|---|---------------------|-------------------|
| | | All points | Shallowest gradient | Steepest gradient |
| Northern border | 36 | 5.8 | 8.1 | 1.9 |
| Centre | 54 | 3.7 | 6.1 | 0.0 |
| Southern border | 70 | 2.3 | 4.8 | 0.0 |
| Geometric mean | | 3.7 | 6.2 | 0.1 |

D.2 Scenario N2

Chart-D-2 Scenario N2 distance-drawdown relationship

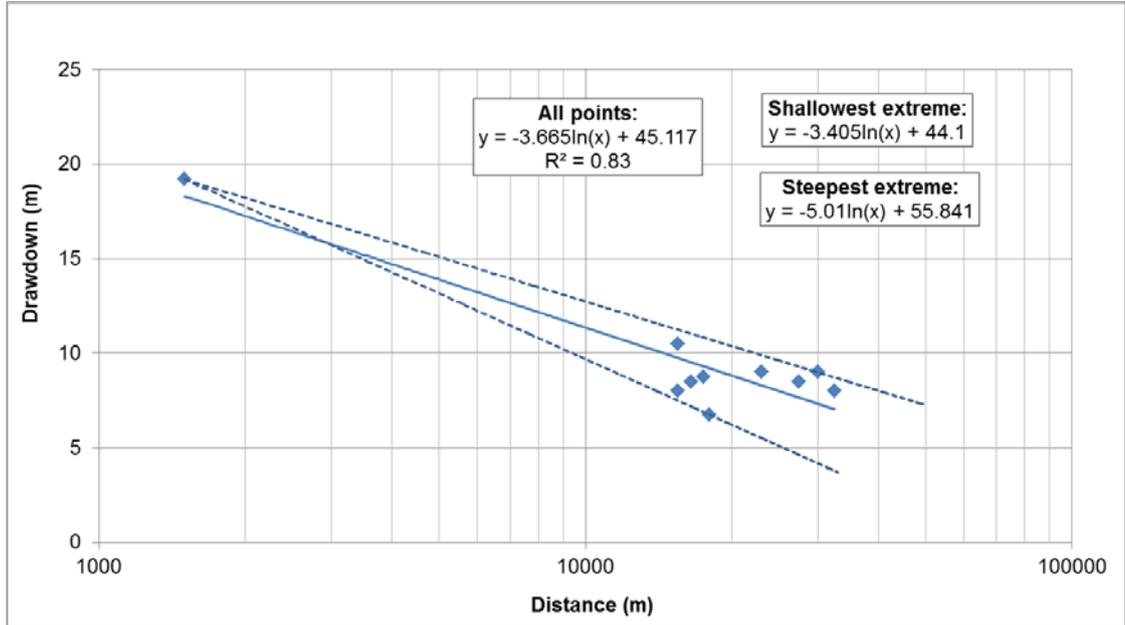


Table-D-2 Estimates of drawdown in the Katunga WSPA due to NSW pumping - Scenario N2

| ESTIMATE POINT IN KATUNGA WSPA | DISTANCE (km) | PREDICTED DRAWDOWN 1993/94 to 2009/10 (m) | | |
|--------------------------------|---------------|---|---------------------|-------------------|
| | | All points | Shallowest gradient | Steepest gradient |
| Northern border | 36 | 6.7 | 8.4 | 3.3 |
| Centre | 54 | 5.2 | 7.0 | 1.2 |
| Southern border | 70 | 4.1 | 6.0 | 0.0 |
| Geometric mean | | 5.2 | 7.0 | 0.3 |

D.3 Assumptions and Limitations

These estimates are based on the following assumptions:

- The aquifer is homogenous, isotropic, has a uniform thickness and is infinite in extent (i.e. no boundary effects in the data);
- There is a single centre of pumping in NSW, approximated as one well, and this is located approximately 1.5 km from bore GW036743 as shown in **Figure A-8**;
- The pumping rate from this point is constant;
- Prior to pumping, the horizontal hydraulic gradient over this area was flat;
- The pumping “well” fully penetrates the aquifer; and
- Around 50% of the drawdown in the NSW observation wells (excluding GW036743) shown in **Figure A-8** is due to the pumping from this location.

This is a very simplistic estimate of a complex phenomenon, and most of the assumptions listed above are violated in some way, some of which may have a significant effect on the result, and some of which would not have a significant effect. Some of this uncertainty has been captured by running different scenarios and by using variations of the distance-drawdown relationship derived from multiple observation wells. However, due to the uncertainties and assumptions, this is intended as an approximate “order of magnitude” assessment only.



APPENDIX E PROBABILITY ANALYSIS MODEL REPORTS

E.1 Model Inputs

The model assumptions report is generated by the software Crystal Ball. It is a record of all assumptions, or inputs, in the probabilistic model, including the name of each cell (listed as Assumption: NAME), the location variables that define the distribution (below the title), and an image showing the distribution shape. The assumption names are described in **Table-E-1** below.

Table-E-1 Explanation of terms in the model assumptions report

| “ASSUMPTION” NAME | DESCRIPTION | LOCATION VARIABLE UNITS |
|-------------------|---|--|
| D35 | Lateral gradient x cross sectional area –inflow areas 1 and 2 summed - 1993 value for calibration | m ² |
| D36 | Lateral gradient x cross sectional area –outflow area - 1993 value for calibration | m ² |
| dH(C1) | Vertical head differential – upper Shep Fm to Deep Lead - SCENARIO C1 | m |
| dH(C2) | Vertical head differential – upper Shep Fm to Deep Lead - SCENARIO C2 | m |
| dH(C3) | Vertical head differential – upper Shep Fm to Deep Lead - SCENARIO C3 | m |
| dH(C4) | Vertical head differential – upper Shep Fm to Deep Lead - SCENARIO C4 | m |
| dSWL(C2) | Change in upper Shep Fm head - SCENARIO C2 | m/year |
| dSWL(C3) | Change in upper Shep Fm head - SCENARIO C3 | m/year |
| dSWL(C4) | Change in upper Shep Fm head - SCENARIO C4 | m/year |
| fine(Shp) | Average proportion of Shep Fm that is fine grained | unitless |
| i(BSE) | Vertical gradient between Basement and Deep Lead aquifers | unitless (log ₁₀ transformed) |
| iA(inf1) | Lateral gradient x cross sectional area –inflow area 1 (Murray Valley) | m ² |
| iA(inf2) | Lateral gradient x cross sectional area –inflow area 2 (Goulburn Valley) | m ² |
| iA(outf) | Lateral gradient x cross sectional area –outflow | m ² |
| Kh(DL) | Deep Lead horizontal hydraulic conductivity | m/day (log ₁₀ transformed) |
| Kv(BSE) | Basement vertical hydraulic conductivity | m/day (log ₁₀ transformed) |

| "ASSUMPTION" NAME | DESCRIPTION | LOCATION VARIABLE UNITS |
|----------------------|--|---|
| Kv(Shp) | Shepparton Formation vertical hydraulic conductivity | m/day (log ₁₀ transformed) |
| I(Shp) | Average Shepparton Formation thickness | m |
| LE | Deep Lead loading efficiency | unitless |
| NSW_Impact_1 | Change in SWL 1993 to 2009 (m) - SCENARIO N1 | m |
| NSW_Impact_2 | Change in SWL 1993 to 2009 (m) - SCENARIO N2 | m |
| SA | Deep Lead surface area | km ² |
| Ssb(DL) | Deep Lead confined storativity | unitless (log ₁₀ transformed) |
| Sy(DL) | Deep Lead specific yield | unitless |
| Sy(Shp) | Shepparton Formation specific yield | unitless |

Crystal Ball Report - Assumptions

Worksheet: [Monte Carlo Calculations MASTER.xlsx]CALCULATIONS

Assumption: D35

Cell: D35

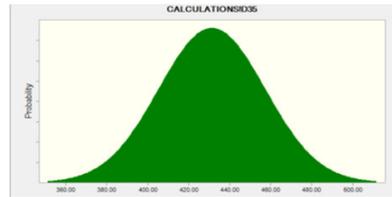
Normal distribution with parameters:

Mean

431.28

95%

474.00



Assumption: D36

Cell: D36

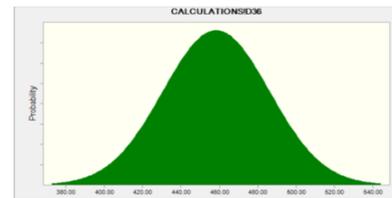
Normal distribution with parameters:

Mean

458.34

95%

504.00



Assumption: dH(C1)

Cell: D13

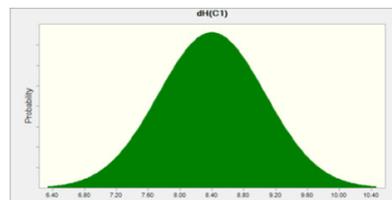
Normal distribution with parameters:

Mean

8.40

95%

9.50



Assumption: dH(C2)

Cell: D14

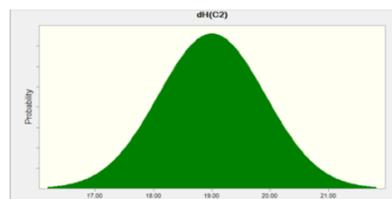
Normal distribution with parameters:

Mean

19.00

95%

20.50



Appendix E-1 Model Assumptions Report

Assumption: dH(C3)

Cell: D15

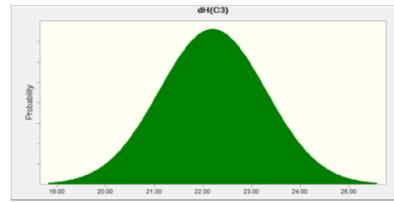
Normal distribution with parameters:

Mean

22.20

95%

24.00



Assumption: dH(C4)

Cell: D16

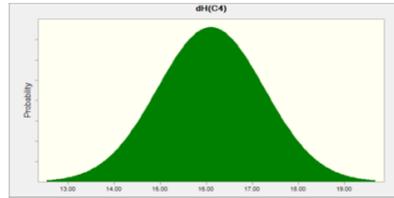
Normal distribution with parameters:

Mean

16.10

95%

18.00



Assumption: dSWL(C2)

Cell: D18

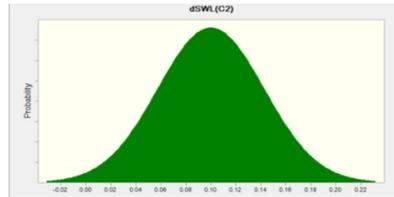
Normal distribution with parameters:

Mean

0.10

95%

0.17



Assumption: dSWL(C3)

Cell: D19

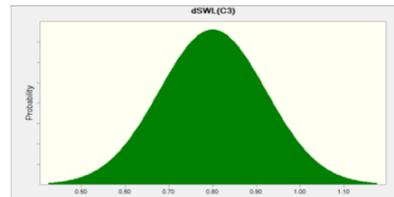
Normal distribution with parameters:

Mean

0.80

95%

1.00



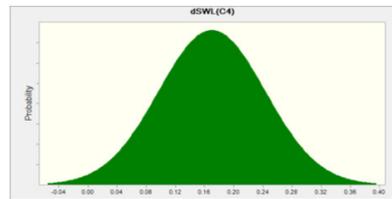
Appendix E-1 Model Assumptions Report

Assumption: dSWL(C4)

Cell: D20

Normal distribution with parameters:

Mean 0.17
95% 0.29

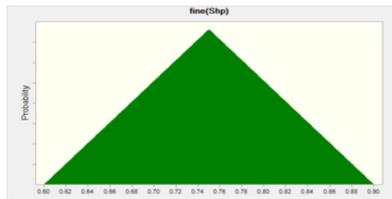


Assumption: fine(Shp)

Cell: D24

Triangular distribution with parameters:

Minimum 0.60
Likeliest 0.75
Maximum 0.90

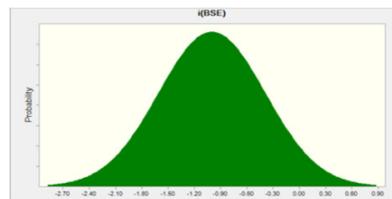


Assumption: i(BSE)

Cell: D12

Normal distribution with parameters:

Mean -1.00
95% 0.00

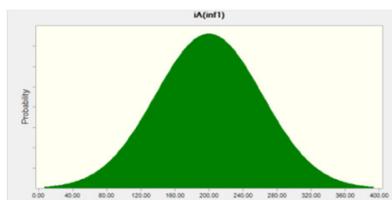


Assumption: iA(inf1)

Cell: D26

Normal distribution with parameters:

Mean 200.00
95% 303.00



Appendix E-1 Model Assumptions Report

Assumption: iA(inf2)

Cell: D27

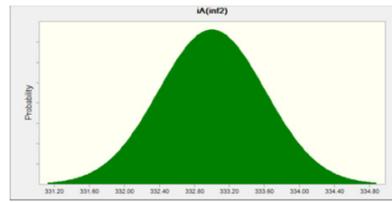
Normal distribution with parameters:

Mean

333.00

95%

334.00



Assumption: iA(outf)

Cell: D28

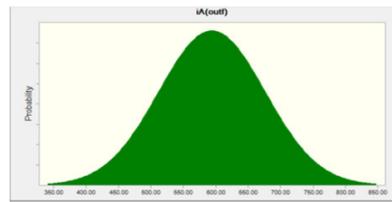
Normal distribution with parameters:

Mean

594.00

95%

729.00



Assumption: Kh(DL)

Cell: D4

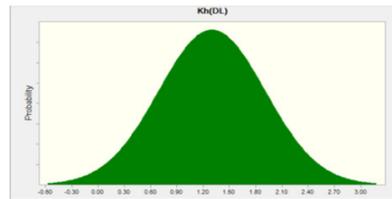
Normal distribution with parameters:

Mean

1.30

95%

2.30



Assumption: Kv(BSE)

Cell: D6

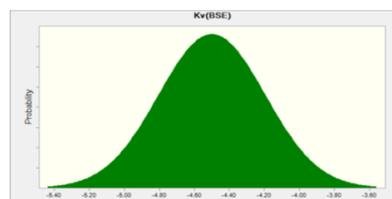
Normal distribution with parameters:

Mean

-4.50

95%

-4.00



Appendix E-1 Model Assumptions Report

Assumption: Kv(Shp)

Cell: D5

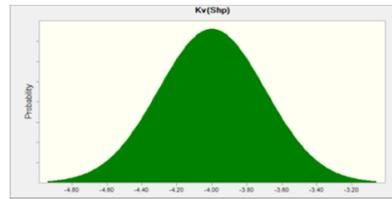
Normal distribution with parameters:

Mean

-4.00

95%

-3.50



Assumption: I(Shp)

Cell: D23

Triangular distribution with parameters:

Minimum

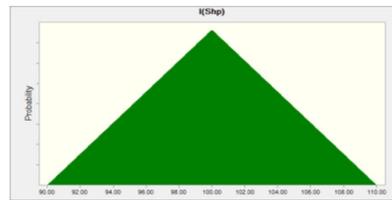
90.00

Likeliest

100.00

Maximum

110.00



Assumption: LE

Cell: D30

Triangular distribution with parameters:

Minimum

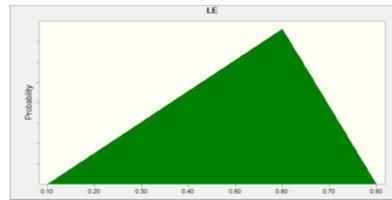
0.10

Likeliest

0.60

Maximum

0.80



Assumption: NSW_Impact_1

Cell: D32

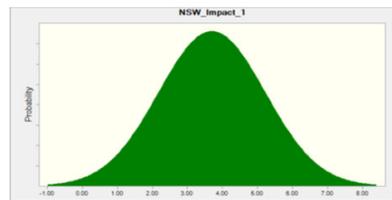
Normal distribution with parameters:

Mean

3.70

95%

6.20



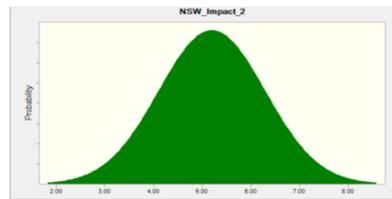
Appendix E-1 Model Assumptions Report

Assumption: NSW_Impact_2

Cell: D33

Normal distribution with parameters:

Mean 5.20
95% 7.00

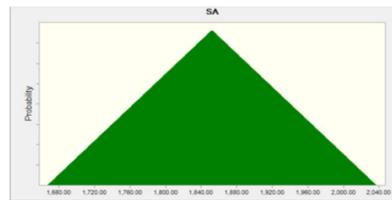


Assumption: SA

Cell: D22

Triangular distribution with parameters:

Minimum 1,667.00
Likeliest 1,852.00
Maximum 2,037.00

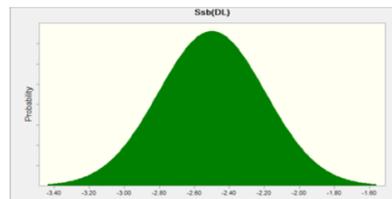


Assumption: Ssb(DL)

Cell: D9

Normal distribution with parameters:

Mean -2.50
95% -2.00

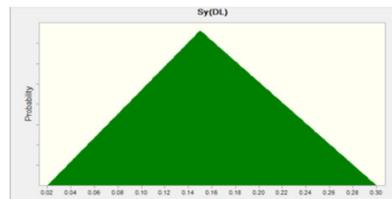


Assumption: Sy(DL)

Cell: D8

Triangular distribution with parameters:

Minimum 0.02
Likeliest 0.15
Maximum 0.30

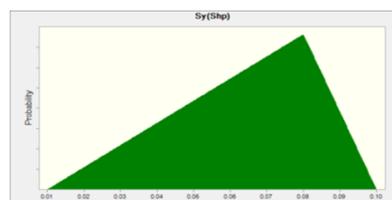


Assumption: Sy(Shp)

Cell: D10

Triangular distribution with parameters:

Minimum 0.01
Likeliest 0.08
Maximum 0.10



E.2 Model Outputs

The model forecasts report is also generated by the software Crystal Ball. It is a record of all the outputs of the probabilistic model. It includes the name of each output (under Forecasts: NAME), a histogram showing the results for that output, and the value for each percentile (i.e. the frequency curve). The latter is the key result of interest. A description of all forecasts, or outputs, is presented in **Table-E-1** below.

Table-E-1 Explanation of terms in the model forecasts report

| "FORECAST" NAME | TYPE OF OUTPUT AND UNITS | DESCRIPTION | |
|------------------|---|---|---|
| 2_C1 | Estimated total volume of each model element, under each relevant scenario (m ³ /year) | Volumetric flux from the Shepparton Fm - SCENARIO C1 | |
| 2_C2 | | Volumetric flux from the Shepparton Fm - SCENARIO C2 | |
| 2_C3 | | Volumetric flux from the Shepparton Fm - SCENARIO C3 | |
| 2_C4 | | Volumetric flux from the Shepparton Fm - SCENARIO C4 | |
| 3_C1 | | Equivalent volumetric change in the Deep Lead due to mechanical loading at the watertable - SCENARIO C1 | |
| 3_C2 | | Equivalent volumetric change in the Deep Lead due to mechanical loading at the watertable - SCENARIO C2 | |
| 3_C3 | | Equivalent volumetric change in the Deep Lead due to mechanical loading at the watertable - SCENARIO C3 | |
| 3_C4 | | Equivalent volumetric change in the Deep Lead due to mechanical loading at the watertable - SCENARIO C4 | |
| 4a | | Lateral inflow into the Deep Lead (summed from Murray Valley and Goulburn Valley) | |
| 4b | | Lateral outflow from the Deep Lead | |
| 5 | | Volumetric flux from the Basement aquifer | |
| 6_N1 | | Estimated change in head under each NSW pumping impact scenario (m/year) | Average head change due to NSW pumping (1993 to 2009) - SCENARIO N1 |
| 6_N2 | | | Average head change due to NSW pumping (1993 to 2009) - SCENARIO N2 |
| HEAD_Calibration | Water balance result as a change in head (m/year) | Predicted head under pre-development conditions (as described in Section 6.4) | |
| HEAD_Dry_100 | | Predicted change in head – SCENARIO C2, P3 | |
| HEAD_Dry_50 | | Predicted change in head – SCENARIO C2, P1 | |
| HEAD_Dry_70 | | Predicted change in head – SCENARIO C2, P2 | |
| HEAD_ExtDry_100 | | Predicted change in head – SCENARIO C3, P3 | |

| "FORECAST" NAME | TYPE OF OUTPUT AND UNITS | DESCRIPTION |
|--------------------|--|---|
| HEAD_ExtDry_50 | | Predicted change in head – SCENARIO C3, P1 |
| HEAD_ExtDry_70 | | Predicted change in head – SCENARIO C3, P2 |
| HEAD_Wet_100 | | Predicted change in head – SCENARIO C4, P3 |
| HEAD_Wet_50 | | Predicted change in head – SCENARIO C4, P1 |
| HEAD_Wet_70 | | Predicted change in head – SCENARIO C4, P2 |
| VOL_Dry_100 | | Water balance result as a change in volume (m3/year) |
| VOL_Dry_50 | Predicted change in volume – SCENARIO C2, P1 | |
| VOL_Dry_70 | Predicted change in volume – SCENARIO C2, P2 | |
| VOL_ExtDry_100 | Predicted change in volume – SCENARIO C3, P3 | |
| VOL_ExtDry_50 | Predicted change in volume – SCENARIO C3, P1 | |
| VOL_ExtDry_70 | Predicted change in volume – SCENARIO C3, P2 | |
| VOL_Wet_100 | Predicted change in volume – SCENARIO C4, P3 | |
| VOL_Wet_50 | Predicted change in volume – SCENARIO C4, P1 | |
| VOL_Wet_70 | Predicted change in volume – SCENARIO C4, P2 | |

Appendix E-2 Model Forecasts Report

Crystal Ball Report - Forecasts

Simulation started on 7/04/2015 at 11:09 AM

Simulation stopped on 7/04/2015 at 11:09 AM

Run preferences:

| | |
|------------------------|--------|
| Number of trials run | 5,000 |
| Latin Hypercube (size) | 500 |
| Random seed | |
| Precision control on | |
| Confidence level | 95.00% |

Run statistics:

| | |
|--------------------------|--------|
| Total running time (sec) | 3.25 |
| Trials/second (average) | 1,537 |
| Random numbers per sec | 38,434 |

Crystal Ball data:

| | |
|----------------------|----|
| Assumptions | 25 |
| Correlations | 0 |
| Correlation matrices | 0 |
| Decision variables | 0 |
| Forecasts | 32 |

Forecasts

Worksheet: [Monte Carlo Calculations MASTER.xlsx]CALCULATIONS

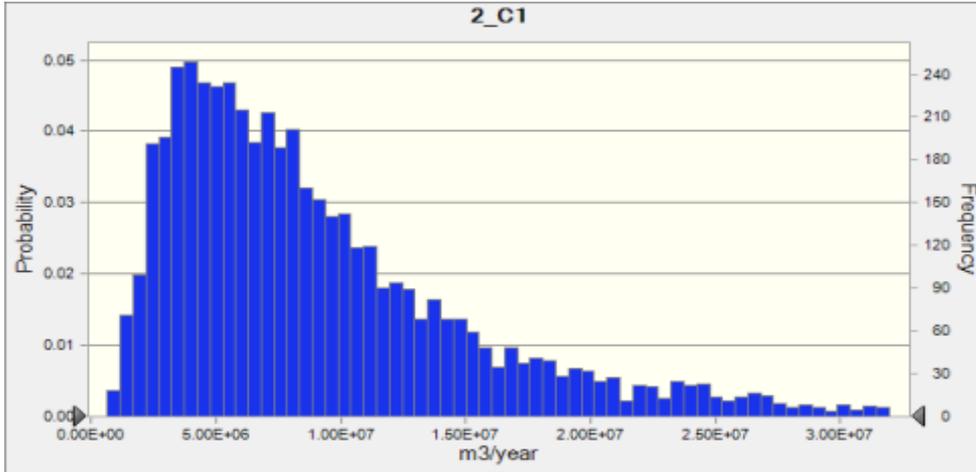
Appendix E-2 Model Forecasts Report

Forecast: 2_C1

Cell: G9

Summary:

Entire range is from 6.59E+05 to 8.77E+07
 Base case is 7.58E+06
 After 5,000 trials, the std. error of the mean is 1.12E+05



Statistics:

Forecast values

| | |
|---------------------|----------|
| Trials | 5,000 |
| Base Case | 7.58E+06 |
| Mean | 9.78E+06 |
| Median | 7.59E+06 |
| Mode | --- |
| Standard Deviation | 7.91E+06 |
| Variance | 6.26E+13 |
| Skewness | 2.62 |
| Kurtosis | 14.45 |
| Coeff. of Variation | 0.8093 |
| Minimum | 6.59E+05 |
| Maximum | 8.77E+07 |
| Range Width | 8.71E+07 |
| Mean Std. Error | 1.12E+05 |

Forecast: 2_C1 (cont'd)

Cell: G9

Percentiles:

Forecast values

| | |
|------|----------|
| 0% | 6.59E+05 |
| 10% | 3.03E+06 |
| 20% | 4.11E+06 |
| 30% | 5.19E+06 |
| 40% | 6.33E+06 |
| 50% | 7.59E+06 |
| 60% | 9.09E+06 |
| 70% | 1.09E+07 |
| 80% | 1.38E+07 |
| 90% | 1.90E+07 |
| 100% | 8.77E+07 |

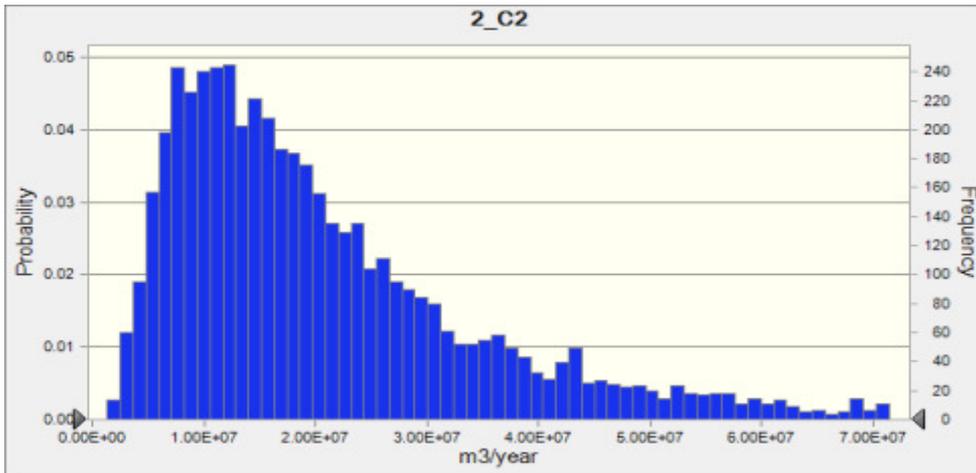
Appendix E-2 Model Forecasts Report

Forecast: 2_C2

Cell: G10

Summary:

Entire range is from 1.36E+06 to 2.01E+08
 Base case is 1.71E+07
 After 5,000 trials, the std. error of the mean is 2.49E+05



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | 1.71E+07 |
| Mean | 2.21E+07 |
| Median | 1.71E+07 |
| Mode | --- |
| Standard Deviation | 1.76E+07 |
| Variance | 3.10E+14 |
| Skewness | 2.59 |
| Kurtosis | 14.48 |
| Coeff. of Variation | 0.7987 |
| Minimum | 1.36E+06 |
| Maximum | 2.01E+08 |
| Range Width | 2.00E+08 |
| Mean Std. Error | 2.49E+05 |

Forecast: 2_C2 (cont'd)

Cell: G10

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | 1.36E+06 |
| 10% | 6.96E+06 |
| 20% | 9.46E+06 |
| 30% | 1.18E+07 |
| 40% | 1.43E+07 |
| 50% | 1.71E+07 |
| 60% | 2.05E+07 |
| 70% | 2.48E+07 |
| 80% | 3.09E+07 |
| 90% | 4.31E+07 |
| 100% | 2.01E+08 |

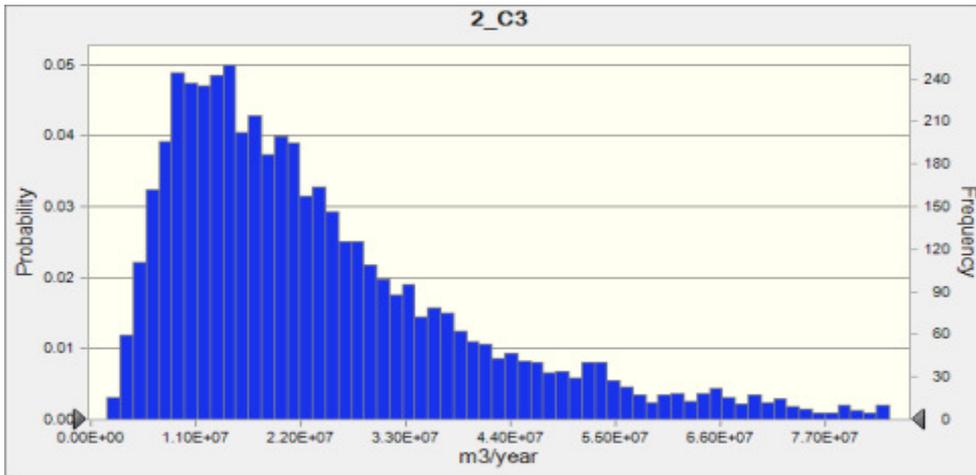
Appendix E-2 Model Forecasts Report

Forecast: 2_C3

Cell: G11

Summary:

Entire range is from 1.70E+06 to 2.36E+08
 Base case is 2.00E+07
 After 5,000 trials, the std. error of the mean is 2.92E+05



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | 2.00E+07 |
| Mean | 2.58E+07 |
| Median | 2.01E+07 |
| Mode | --- |
| Standard Deviation | 2.07E+07 |
| Variance | 4.27E+14 |
| Skewness | 2.60 |
| Kurtosis | 14.36 |
| Coeff. of Variation | 0.8012 |
| Minimum | 1.70E+06 |
| Maximum | 2.36E+08 |
| Range Width | 2.35E+08 |
| Mean Std. Error | 2.92E+05 |

Forecast: 2_C3 (cont'd)

Cell: G11

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | 1.70E+06 |
| 10% | 8.16E+06 |
| 20% | 1.10E+07 |
| 30% | 1.38E+07 |
| 40% | 1.68E+07 |
| 50% | 2.01E+07 |
| 60% | 2.40E+07 |
| 70% | 2.90E+07 |
| 80% | 3.65E+07 |
| 90% | 5.05E+07 |
| 100% | 2.36E+08 |

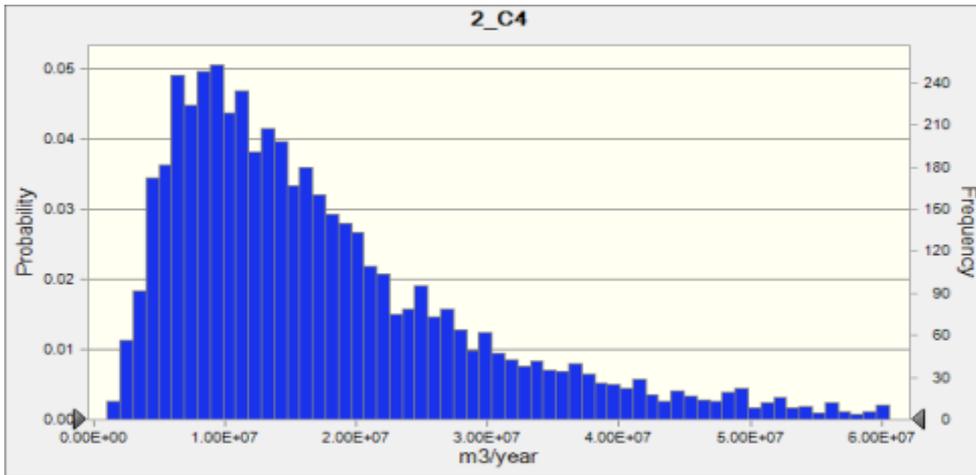
Appendix E-2 Model Forecasts Report

Forecast: 2_C4

Cell: G12

Summary:

Entire range is from 1.09E+06 to 1.83E+08
 Base case is 1.45E+07
 After 5,000 trials, the std. error of the mean is 2.11E+05



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | 1.45E+07 |
| Mean | 1.87E+07 |
| Median | 1.45E+07 |
| Mode | --- |
| Standard Deviation | 1.49E+07 |
| Variance | 2.23E+14 |
| Skewness | 2.57 |
| Kurtosis | 14.47 |
| Coeff. of Variation | 0.7991 |
| Minimum | 1.09E+06 |
| Maximum | 1.83E+08 |
| Range Width | 1.82E+08 |
| Mean Std. Error | 2.11E+05 |

Forecast: 2_C4 (cont'd)

Cell: G12

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | 1.09E+06 |
| 10% | 5.92E+06 |
| 20% | 7.97E+06 |
| 30% | 9.93E+06 |
| 40% | 1.21E+07 |
| 50% | 1.45E+07 |
| 60% | 1.74E+07 |
| 70% | 2.09E+07 |
| 80% | 2.65E+07 |
| 90% | 3.65E+07 |
| 100% | 1.83E+08 |

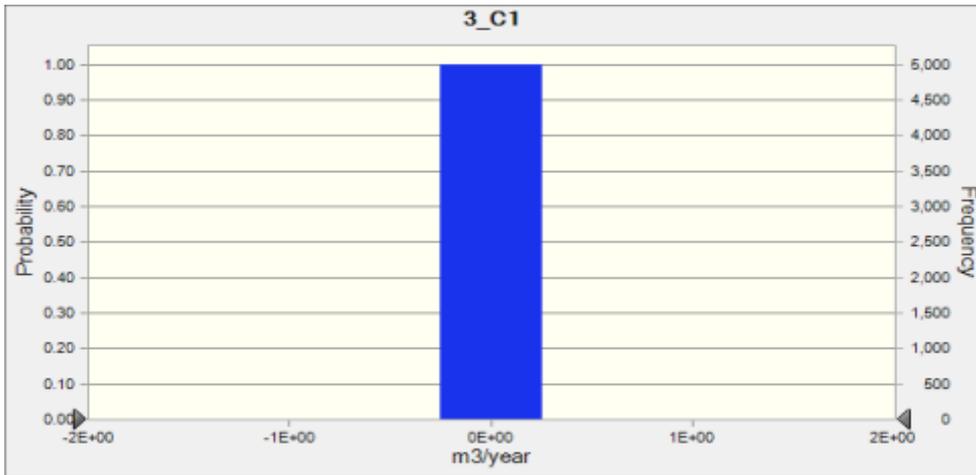
Appendix E-2 Model Forecasts Report

Forecast: 3_C1

Cell: G15

Summary:

Entire range is from 0.00E+00 to 0.00E+00
 Base case is 0.00E+00
 After 5,000 trials, the std. error of the mean is 0.00E+00



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | 0.00E+00 |
| Mean | 0.00E+00 |
| Median | 0.00E+00 |
| Mode | 0.00E+00 |
| Standard Deviation | 0.00E+00 |
| Variance | 0.00E+00 |
| Skewness | --- |
| Kurtosis | --- |
| Coeff. of Variation | --- |
| Minimum | 0.00E+00 |
| Maximum | 0.00E+00 |
| Range Width | 0.00E+00 |
| Mean Std. Error | 0.00E+00 |

Forecast: 3_C1 (cont'd)

Cell: G15

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | 0.00E+00 |
| 10% | 0.00E+00 |
| 20% | 0.00E+00 |
| 30% | 0.00E+00 |
| 40% | 0.00E+00 |
| 50% | 0.00E+00 |
| 60% | 0.00E+00 |
| 70% | 0.00E+00 |
| 80% | 0.00E+00 |
| 90% | 0.00E+00 |
| 100% | 0.00E+00 |

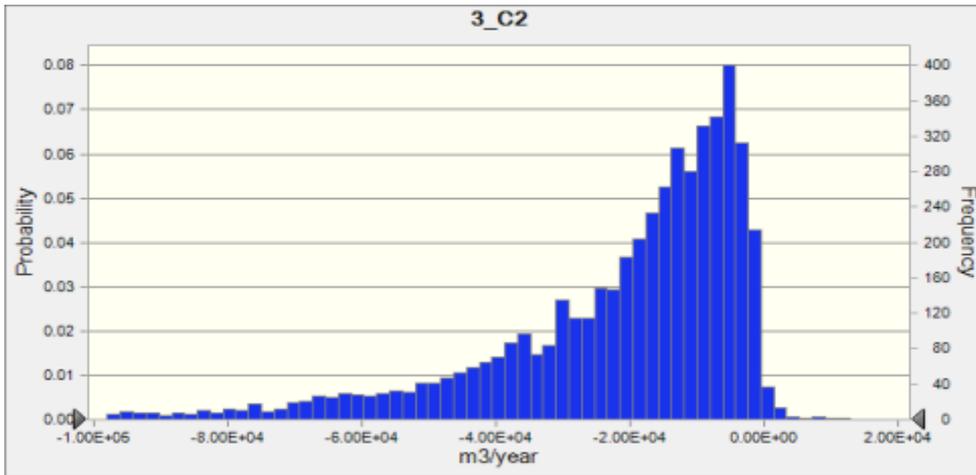
Appendix E-2 Model Forecasts Report

Forecast: 3_C2

Cell: G16

Summary:

Entire range is from -3.47E+05 to 1.87E+04
 Base case is -2.81E+04
 After 5,000 trials, the std. error of the mean is 3.75E+02



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | -2.81E+04 |
| Mean | -2.37E+04 |
| Median | -1.56E+04 |
| Mode | --- |
| Standard Deviation | 2.65E+04 |
| Variance | 7.02E+08 |
| Skewness | -3.43 |
| Kurtosis | 22.67 |
| Coeff. of Variation | -1.12 |
| Minimum | -3.47E+05 |
| Maximum | 1.87E+04 |
| Range Width | 3.66E+05 |
| Mean Std. Error | 3.75E+02 |

Forecast: 3_C2 (cont'd)

Cell: G16

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -3.47E+05 |
| 10% | -5.19E+04 |
| 20% | -3.59E+04 |
| 30% | -2.66E+04 |
| 40% | -2.02E+04 |
| 50% | -1.57E+04 |
| 60% | -1.23E+04 |
| 70% | -9.10E+03 |
| 80% | -6.25E+03 |
| 90% | -3.80E+03 |
| 100% | 1.87E+04 |

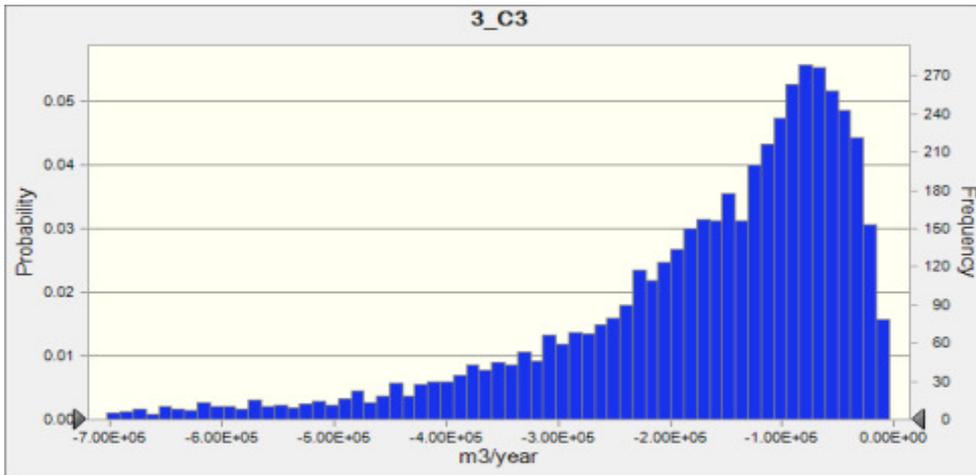
Appendix E-2 Model Forecasts Report

Forecast: 3_C3

Cell: G17

Summary:

Entire range is from -2.37E+06 to -4.98E+03
 Base case is -2.25E+05
 After 5,000 trials, the std. error of the mean is 2.59E+03



Statistics:

Forecast values

| | |
|---------------------|-----------|
| Trials | 5,000 |
| Base Case | -2.25E+05 |
| Mean | -1.89E+05 |
| Median | -1.36E+05 |
| Mode | --- |
| Standard Deviation | 1.83E+05 |
| Variance | 3.36E+10 |
| Skewness | -3.14 |
| Kurtosis | 20.37 |
| Coeff. of Variation | -0.9701 |
| Minimum | -2.37E+06 |
| Maximum | -4.98E+03 |
| Range Width | 2.37E+06 |
| Mean Std. Error | 2.59E+03 |

Forecast: 3_C3 (cont'd)

Cell: G17

Percentiles:

Forecast values

| | |
|------|-----------|
| 0% | -2.37E+06 |
| 10% | -3.88E+05 |
| 20% | -2.77E+05 |
| 30% | -2.12E+05 |
| 40% | -1.71E+05 |
| 50% | -1.36E+05 |
| 60% | -1.07E+05 |
| 70% | -8.43E+04 |
| 80% | -6.37E+04 |
| 90% | -4.14E+04 |
| 100% | -4.98E+03 |

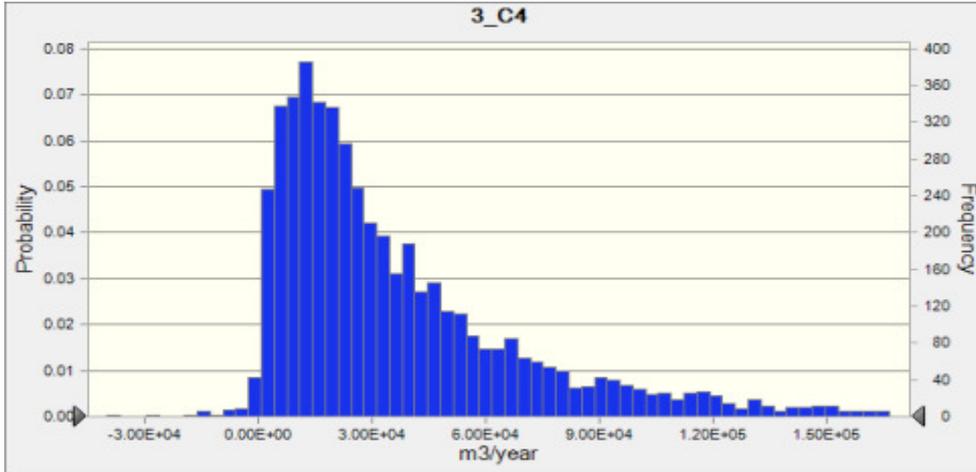
Appendix E-2 Model Forecasts Report

Forecast: 3_C4

Cell: G18

Summary:

Entire range is from $-3.97E+04$ to $5.51E+05$
 Base case is $4.78E+04$
 After 5,000 trials, the std. error of the mean is $6.36E+02$



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | $4.78E+04$ |
| Mean | $4.03E+04$ |
| Median | $2.63E+04$ |
| Mode | --- |
| Standard Deviation | $4.50E+04$ |
| Variance | $2.02E+09$ |
| Skewness | 3.48 |
| Kurtosis | 24.81 |
| Coeff. of Variation | 1.12 |
| Minimum | $-3.97E+04$ |
| Maximum | $5.51E+05$ |
| Range Width | $5.91E+05$ |
| Mean Std. Error | $6.36E+02$ |

Forecast: 3_C4 (cont'd)

Cell: G18

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | $-3.97E+04$ |
| 10% | $6.28E+03$ |
| 20% | $1.10E+04$ |
| 30% | $1.54E+04$ |
| 40% | $2.05E+04$ |
| 50% | $2.63E+04$ |
| 60% | $3.43E+04$ |
| 70% | $4.51E+04$ |
| 80% | $6.02E+04$ |
| 90% | $9.08E+04$ |
| 100% | $5.51E+05$ |

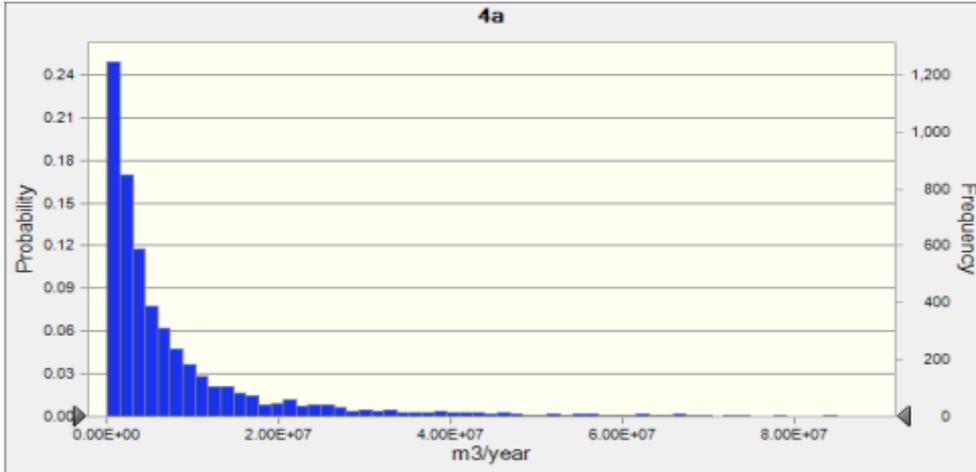
Appendix E-2 Model Forecasts Report

Forecast: 4a

Cell: G21

Summary:

Entire range is from 2.18E+04 to 1.10E+09
 Base case is 3.88E+06
 After 5,000 trials, the std. error of the mean is 3.98E+05



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | 3.88E+06 |
| Mean | 1.05E+07 |
| Median | 3.86E+06 |
| Mode | --- |
| Standard Deviation | 2.82E+07 |
| Variance | 7.94E+14 |
| Skewness | 17.24 |
| Kurtosis | 523.19 |
| Coeff. of Variation | 2.69 |
| Minimum | 2.18E+04 |
| Maximum | 1.10E+09 |
| Range Width | 1.10E+09 |
| Mean Std. Error | 3.98E+05 |

Forecast: 4a (cont'd)

Cell: G21

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | 2.18E+04 |
| 10% | 6.43E+05 |
| 20% | 1.18E+06 |
| 30% | 1.87E+06 |
| 40% | 2.75E+06 |
| 50% | 3.86E+06 |
| 60% | 5.58E+06 |
| 70% | 8.05E+06 |
| 80% | 1.25E+07 |
| 90% | 2.36E+07 |
| 100% | 1.10E+09 |

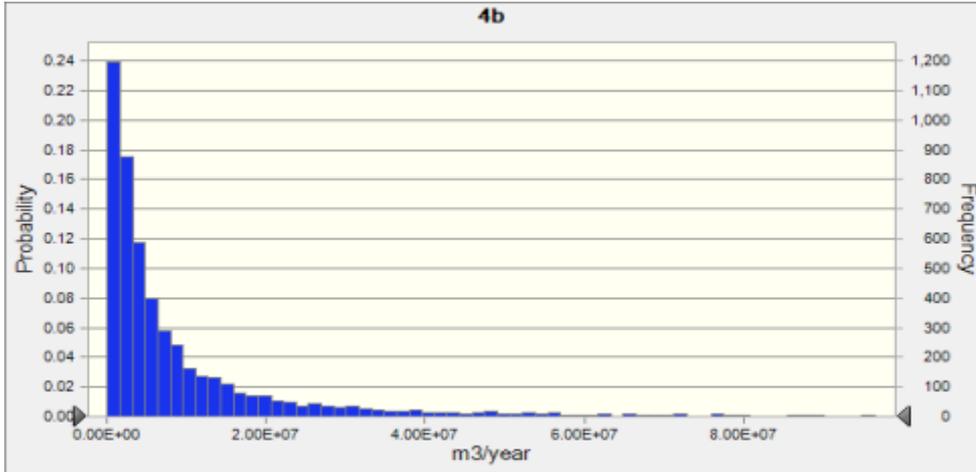
Appendix E-2 Model Forecasts Report

Forecast: 4b

Cell: G25

Summary:

Entire range is from 2.78E+04 to 1.16E+09
 Base case is 4.33E+06
 After 5,000 trials, the std. error of the mean is 4.28E+05



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | 4.33E+06 |
| Mean | 1.16E+07 |
| Median | 4.25E+06 |
| Mode | --- |
| Standard Deviation | 3.03E+07 |
| Variance | 9.18E+14 |
| Skewness | 16.10 |
| Kurtosis | 476.27 |
| Coeff. of Variation | 2.60 |
| Minimum | 2.78E+04 |
| Maximum | 1.16E+09 |
| Range Width | 1.16E+09 |
| Mean Std. Error | 4.28E+05 |

Forecast: 4b (cont'd)

Cell: G25

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | 2.78E+04 |
| 10% | 7.06E+05 |
| 20% | 1.31E+06 |
| 30% | 2.09E+06 |
| 40% | 2.99E+06 |
| 50% | 4.25E+06 |
| 60% | 6.05E+06 |
| 70% | 8.96E+06 |
| 80% | 1.41E+07 |
| 90% | 2.61E+07 |
| 100% | 1.16E+09 |

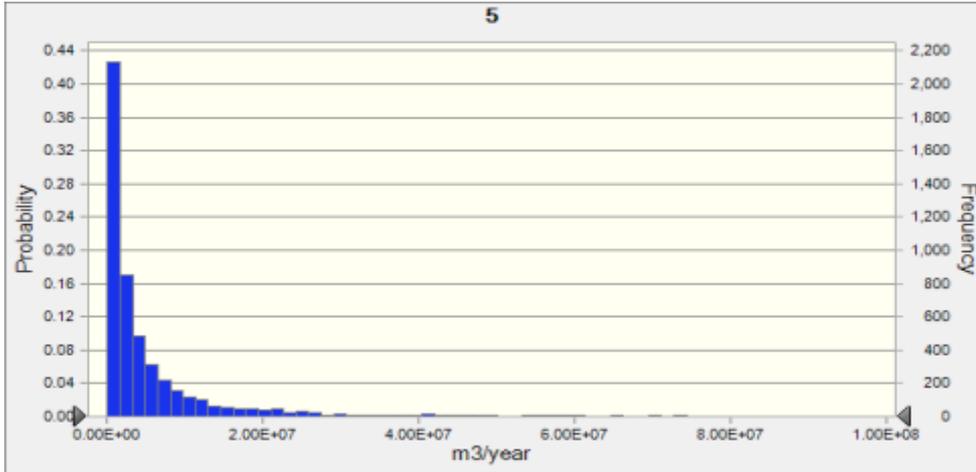
Appendix E-2 Model Forecasts Report

Forecast: 5

Cell: G29

Summary:

Entire range is from 7.15E+03 to 1.47E+09
 Base case is 2.14E+06
 After 5,000 trials, the std. error of the mean is 4.59E+05



Statistics:

Trials
 Base Case
 Mean
 Median
 Mode
 Standard Deviation
 Variance
 Skewness
 Kurtosis
 Coeff. of Variation
 Minimum
 Maximum
 Range Width
 Mean Std. Error

Forecast values

5,000
 2.14E+06
 7.64E+06
 2.15E+06

 3.24E+07
 1.05E+15
 27.15
 1,013.41
 4.24
 7.15E+03
 1.47E+09
 1.47E+09
 4.59E+05

Forecast: 5 (cont'd)

Cell: G29

Percentiles:

0%
 10%
 20%
 30%
 40%
 50%
 60%
 70%
 80%
 90%
 100%

Forecast values

7.15E+03
 2.75E+05
 5.58E+05
 9.20E+05
 1.43E+06
 2.15E+06
 3.27E+06
 4.93E+06
 8.04E+06
 1.62E+07
 1.47E+09

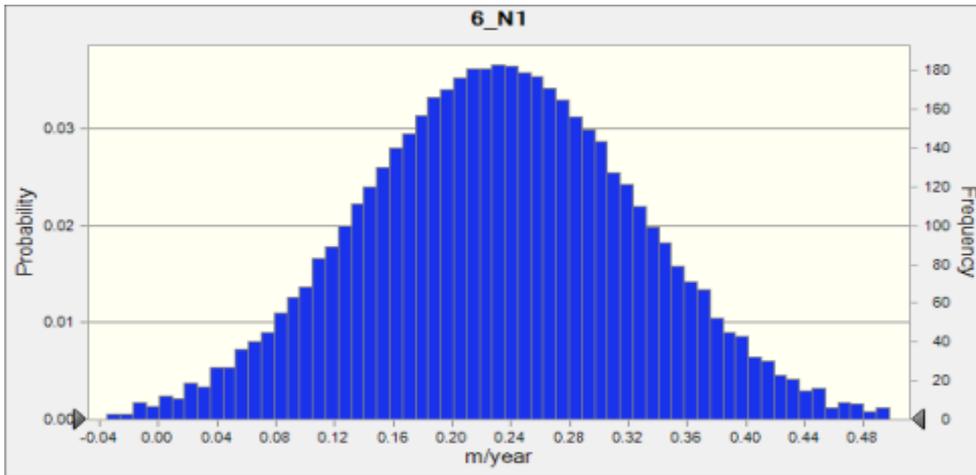
Appendix E-2 Model Forecasts Report

Forecast: 6_N1

Cell: G32

Summary:

Entire range is from -0.09 to 0.58
 Base case is 0.23
 After 5,000 trials, the std. error of the mean is 0.00



Statistics:

Forecast values

| | |
|---------------------|--------|
| Trials | 5,000 |
| Base Case | 0.23 |
| Mean | 0.23 |
| Median | 0.23 |
| Mode | --- |
| Standard Deviation | 0.09 |
| Variance | 0.01 |
| Skewness | 0.0012 |
| Kurtosis | 2.96 |
| Coeff. of Variation | 0.4104 |
| Minimum | -0.09 |
| Maximum | 0.58 |
| Range Width | 0.67 |
| Mean Std. Error | 0.00 |

Forecast: 6_N1 (cont'd)

Cell: G32

Percentiles:

Forecast values

| | |
|------|-------|
| 0% | -0.09 |
| 10% | 0.11 |
| 20% | 0.15 |
| 30% | 0.18 |
| 40% | 0.21 |
| 50% | 0.23 |
| 60% | 0.26 |
| 70% | 0.28 |
| 80% | 0.31 |
| 90% | 0.35 |
| 100% | 0.58 |

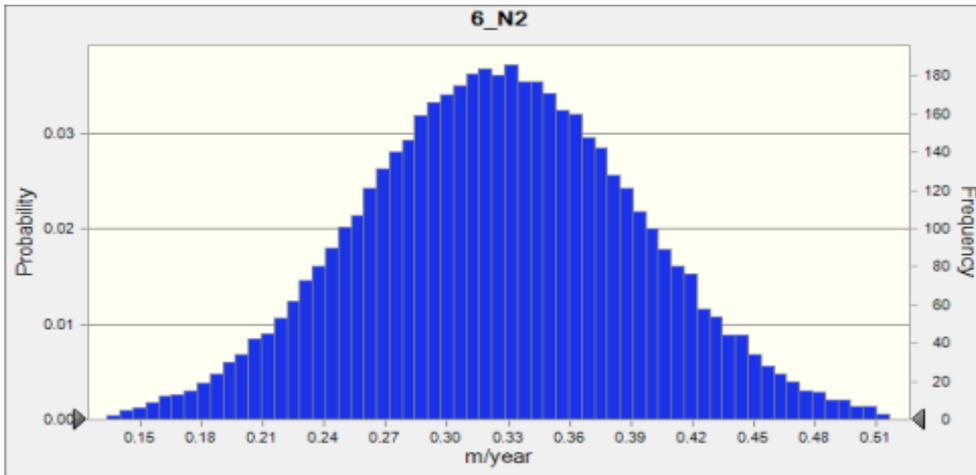
Appendix E-2 Model Forecasts Report

Forecast: 6_N2

Cell: G33

Summary:

Entire range is from 0.09 to 0.56
 Base case is 0.33
 After 5,000 trials, the std. error of the mean is 0.00



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | 0.33 |
| Mean | 0.32 |
| Median | 0.33 |
| Mode | --- |
| Standard Deviation | 0.07 |
| Variance | 0.00 |
| Skewness | -0.0023 |
| Kurtosis | 2.97 |
| Coeff. of Variation | 0.2104 |
| Minimum | 0.09 |
| Maximum | 0.56 |
| Range Width | 0.47 |
| Mean Std. Error | 0.00 |

Forecast: 6_N2 (cont'd)

Cell: G33

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | 0.09 |
| 10% | 0.24 |
| 20% | 0.27 |
| 30% | 0.29 |
| 40% | 0.31 |
| 50% | 0.32 |
| 60% | 0.34 |
| 70% | 0.36 |
| 80% | 0.38 |
| 90% | 0.41 |
| 100% | 0.56 |

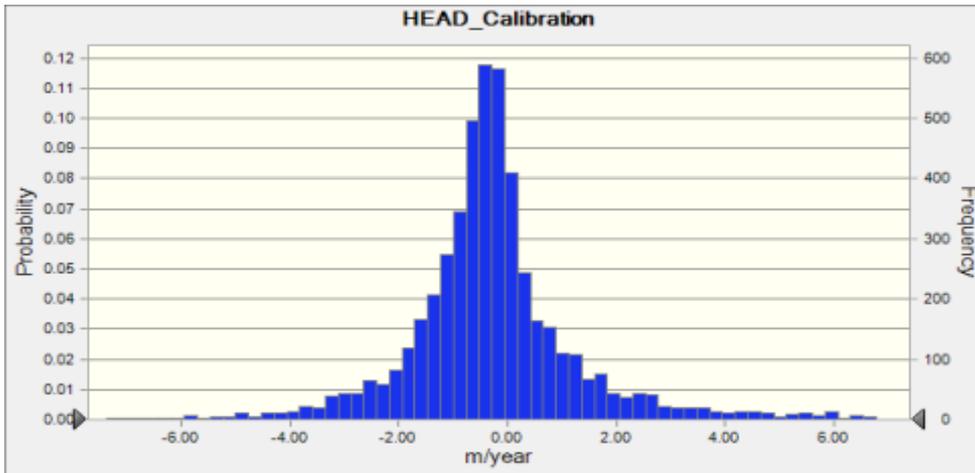
Appendix E-2 Model Forecasts Report

Forecast: HEAD_Calibration

Cell: I38

Summary:

Entire range is from -73.54 to 37.90
 Base case is -0.45
 After 5,000 trials, the std. error of the mean is 0.04



Statistics:

Forecast values

| | |
|---------------------|--------|
| Trials | 5,000 |
| Base Case | -0.45 |
| Mean | -0.18 |
| Median | -0.35 |
| Mode | --- |
| Standard Deviation | 2.56 |
| Variance | 6.57 |
| Skewness | -1.78 |
| Kurtosis | 173.24 |
| Coeff. of Variation | -14.54 |
| Minimum | -73.54 |
| Maximum | 37.90 |
| Range Width | 111.44 |
| Mean Std. Error | 0.04 |

Forecast: HEAD_Calibration (cont'd)

Cell: I38

Percentiles:

Forecast values

| | |
|------|--------|
| 0% | -73.54 |
| 10% | -1.88 |
| 20% | -1.19 |
| 30% | -0.80 |
| 40% | -0.56 |
| 50% | -0.35 |
| 60% | -0.16 |
| 70% | 0.08 |
| 80% | 0.55 |
| 90% | 1.60 |
| 100% | 37.90 |

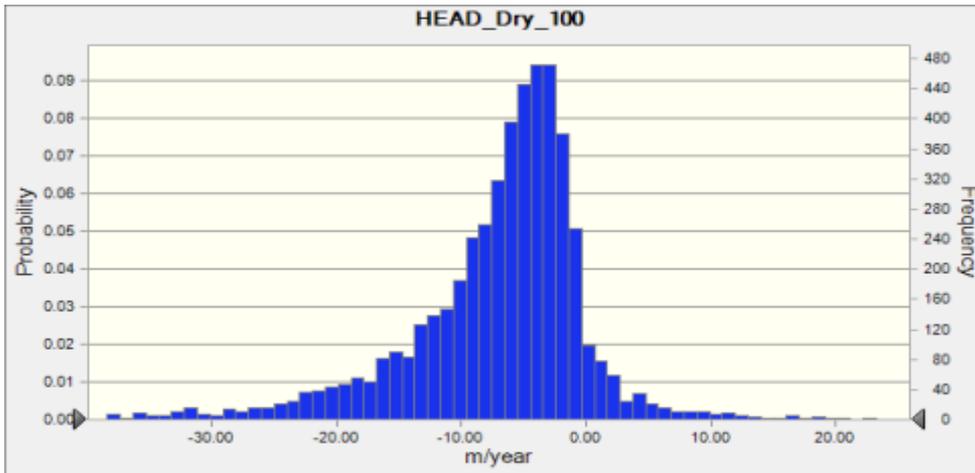
Appendix E-2 Model Forecasts Report

Forecast: HEAD_Dry_100

Cell: I44

Summary:

Entire range is from -89.44 to 311.45
 Base case is -7.14
 After 5,000 trials, the std. error of the mean is 0.16



Statistics:

Forecast values

| | |
|---------------------|--------|
| Trials | 5,000 |
| Base Case | -7.14 |
| Mean | -7.07 |
| Median | -5.67 |
| Mode | --- |
| Standard Deviation | 11.19 |
| Variance | 125.23 |
| Skewness | 6.77 |
| Kurtosis | 178.49 |
| Coeff. of Variation | -1.58 |
| Minimum | -89.44 |
| Maximum | 311.45 |
| Range Width | 400.89 |
| Mean Std. Error | 0.16 |

Forecast: HEAD_Dry_100 (cont'd)

Cell: I44

Percentiles:

Forecast values

| | |
|------|--------|
| 0% | -89.44 |
| 10% | -16.57 |
| 20% | -11.73 |
| 30% | -8.92 |
| 40% | -7.03 |
| 50% | -5.67 |
| 60% | -4.49 |
| 70% | -3.40 |
| 80% | -2.24 |
| 90% | -0.85 |
| 100% | 311.45 |

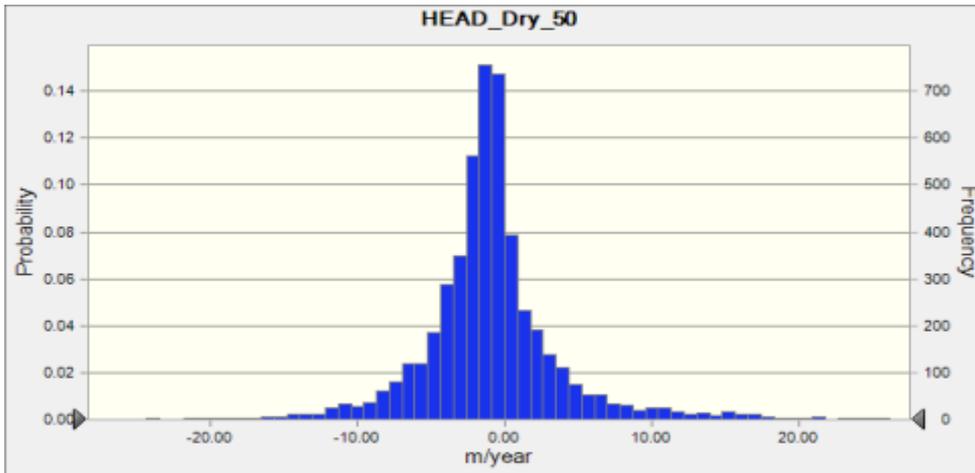
Appendix E-2 Model Forecasts Report

Forecast: HEAD_Dry_50

Cell: I42

Summary:

Entire range is from -57.76 to 322.49
 Base case is -1.97
 After 5,000 trials, the std. error of the mean is 0.13



Statistics:

Forecast values

| | |
|---------------------|--------|
| Trials | 5,000 |
| Base Case | -1.97 |
| Mean | -0.45 |
| Median | -1.12 |
| Mode | --- |
| Standard Deviation | 9.48 |
| Variance | 89.96 |
| Skewness | 13.78 |
| Kurtosis | 360.05 |
| Coeff. of Variation | -21.07 |
| Minimum | -57.76 |
| Maximum | 322.49 |
| Range Width | 380.25 |
| Mean Std. Error | 0.13 |

Forecast: HEAD_Dry_50 (cont'd)

Cell: I42

Percentiles:

Forecast values

| | |
|------|--------|
| 0% | -57.76 |
| 10% | -5.84 |
| 20% | -3.61 |
| 30% | -2.46 |
| 40% | -1.71 |
| 50% | -1.12 |
| 60% | -0.60 |
| 70% | 0.07 |
| 80% | 1.39 |
| 90% | 4.15 |
| 100% | 322.49 |

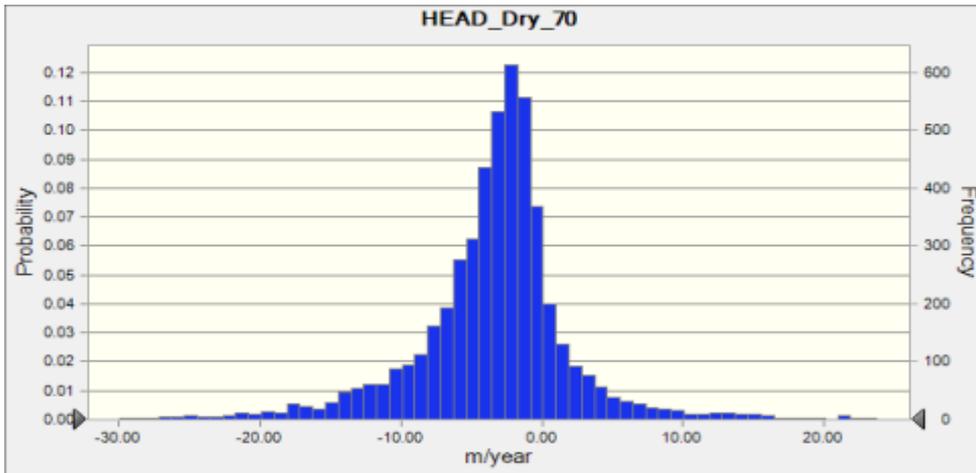
Appendix E-2 Model Forecasts Report

Forecast: HEAD_Dry_70

Cell: I43

Summary:

Entire range is from -67.57 to 318.07
 Base case is -4.04
 After 5,000 trials, the std. error of the mean is 0.14



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | -4.04 |
| Mean | -3.10 |
| Median | -2.85 |
| Mode | --- |
| Standard Deviation | 9.88 |
| Variance | 97.55 |
| Skewness | 11.46 |
| Kurtosis | 299.27 |
| Coeff. of Variation | -3.19 |
| Minimum | -67.57 |
| Maximum | 318.07 |
| Range Width | 385.64 |
| Mean Std. Error | 0.14 |

Forecast: HEAD_Dry_70 (cont'd)

Cell: I43

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -67.57 |
| 10% | -10.00 |
| 20% | -6.57 |
| 30% | -4.91 |
| 40% | -3.75 |
| 50% | -2.85 |
| 60% | -2.09 |
| 70% | -1.35 |
| 80% | -0.36 |
| 90% | 1.86 |
| 100% | 318.07 |

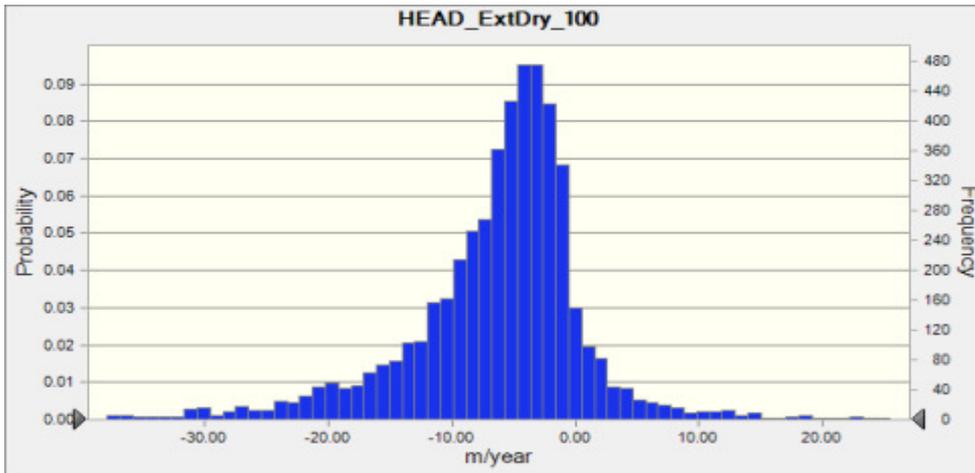
Appendix E-2 Model Forecasts Report

Forecast: HEAD_ExtDry_100

Cell: I47

Summary:

Entire range is from -80.94 to 316.51
 Base case is -6.69
 After 5,000 trials, the std. error of the mean is 0.16



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | -6.69 |
| Mean | -6.27 |
| Median | -5.16 |
| Mode | --- |
| Standard Deviation | 11.29 |
| Variance | 127.50 |
| Skewness | 7.14 |
| Kurtosis | 181.08 |
| Coeff. of Variation | -1.80 |
| Minimum | -80.94 |
| Maximum | 316.51 |
| Range Width | 397.45 |
| Mean Std. Error | 0.16 |

Forecast: HEAD_ExtDry_100 (cont'd)

Cell: I47

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -80.94 |
| 10% | -15.73 |
| 20% | -10.88 |
| 30% | -8.33 |
| 40% | -6.44 |
| 50% | -5.16 |
| 60% | -4.03 |
| 70% | -2.91 |
| 80% | -1.76 |
| 90% | 0.05 |
| 100% | 316.51 |

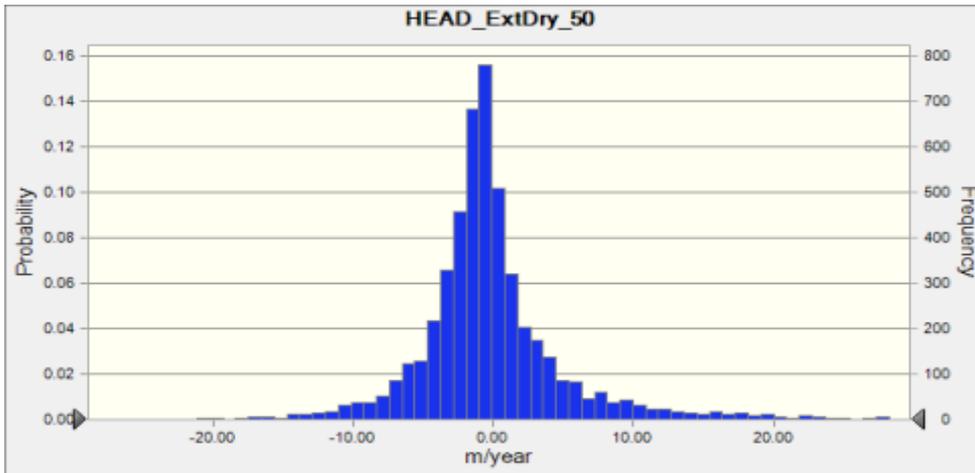
Appendix E-2 Model Forecasts Report

Forecast: HEAD_ExtDry_50

Cell: I45

Summary:

Entire range is from -53.76 to 327.55
 Base case is -1.51
 After 5,000 trials, the std. error of the mean is 0.14



Statistics:

Forecast values

| | |
|---------------------|--------|
| Trials | 5,000 |
| Base Case | -1.51 |
| Mean | 0.35 |
| Median | -0.73 |
| Mode | --- |
| Standard Deviation | 9.95 |
| Variance | 98.92 |
| Skewness | 12.81 |
| Kurtosis | 316.20 |
| Coeff. of Variation | 28.51 |
| Minimum | -53.76 |
| Maximum | 327.55 |
| Range Width | 381.32 |
| Mean Std. Error | 0.14 |

Forecast: HEAD_ExtDry_50 (cont'd)

Cell: I45

Percentiles:

Forecast values

| | |
|------|--------|
| 0% | -53.76 |
| 10% | -5.15 |
| 20% | -3.13 |
| 30% | -2.06 |
| 40% | -1.34 |
| 50% | -0.73 |
| 60% | -0.17 |
| 70% | 0.70 |
| 80% | 2.31 |
| 90% | 5.74 |
| 100% | 327.55 |

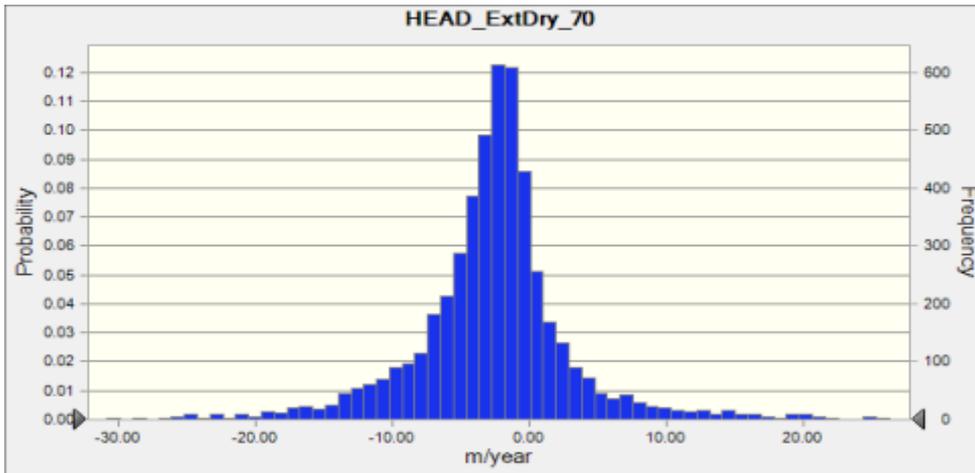
Appendix E-2 Model Forecasts Report

Forecast: HEAD_ExtDry_70

Cell: I46

Summary:

Entire range is from -63.57 to 323.14
 Base case is -3.58
 After 5,000 trials, the std. error of the mean is 0.14



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | -3.58 |
| Mean | -2.30 |
| Median | -2.38 |
| Mode | --- |
| Standard Deviation | 10.19 |
| Variance | 103.83 |
| Skewness | 11.19 |
| Kurtosis | 279.60 |
| Coeff. of Variation | -4.43 |
| Minimum | -63.57 |
| Maximum | 323.14 |
| Range Width | 386.71 |
| Mean Std. Error | 0.14 |

Forecast: HEAD_ExtDry_70 (cont'd)

Cell: I46

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -63.57 |
| 10% | -9.30 |
| 20% | -5.99 |
| 30% | -4.34 |
| 40% | -3.27 |
| 50% | -2.38 |
| 60% | -1.66 |
| 70% | -0.88 |
| 80% | 0.33 |
| 90% | 3.12 |
| 100% | 323.14 |

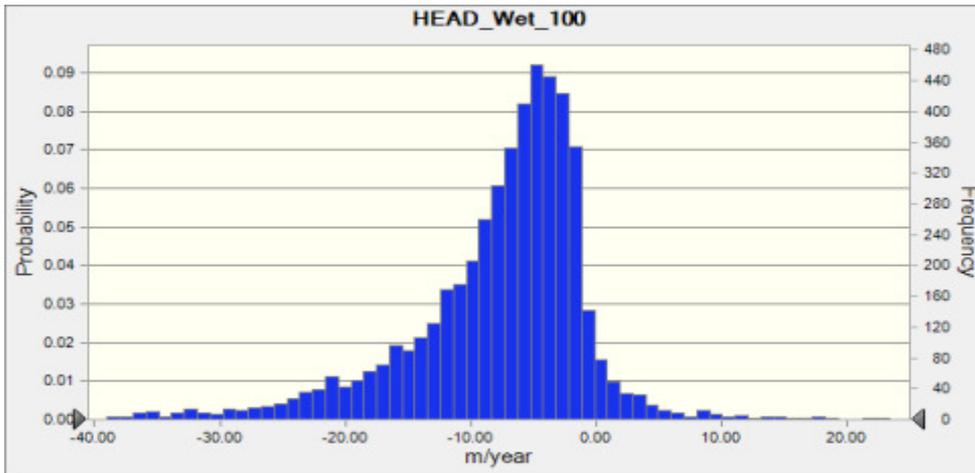
Appendix E-2 Model Forecasts Report

Forecast: HEAD_Wet_100

Cell: I41

Summary:

Entire range is from -88.00 to 310.32
 Base case is -7.58
 After 5,000 trials, the std. error of the mean is 0.16



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | -7.58 |
| Mean | -7.80 |
| Median | -6.16 |
| Mode | --- |
| Standard Deviation | 11.13 |
| Variance | 123.88 |
| Skewness | 6.50 |
| Kurtosis | 178.75 |
| Coeff. of Variation | -1.43 |
| Minimum | -88.00 |
| Maximum | 310.32 |
| Range Width | 398.31 |
| Mean Std. Error | 0.16 |

Forecast: HEAD_Wet_100 (cont'd)

Cell: I41

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -88.00 |
| 10% | -17.62 |
| 20% | -12.39 |
| 30% | -9.55 |
| 40% | -7.65 |
| 50% | -6.17 |
| 60% | -4.95 |
| 70% | -3.84 |
| 80% | -2.76 |
| 90% | -1.34 |
| 100% | 310.32 |

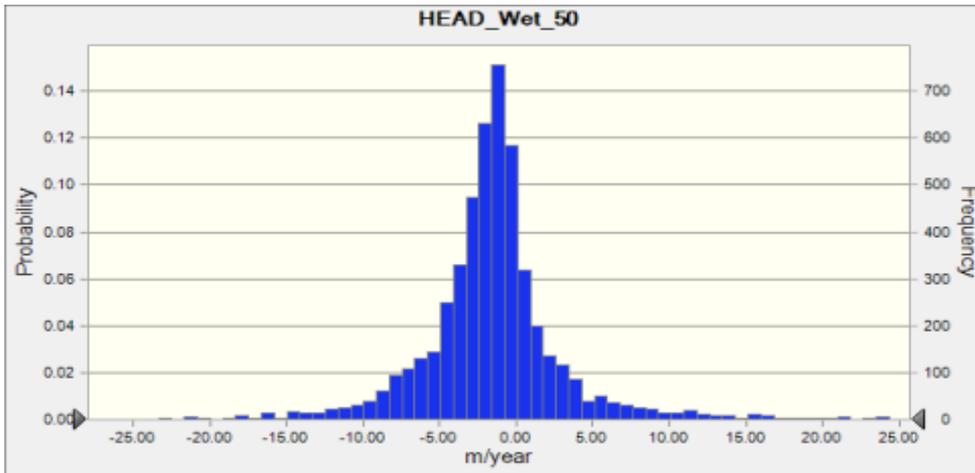
Appendix E-2 Model Forecasts Report

Forecast: HEAD_Wet_50

Cell: I39

Summary:

Entire range is from -57.91 to 321.36
 Base case is -2.40
 After 5,000 trials, the std. error of the mean is 0.13



| Statistics: | Forecast values |
|---------------------|-----------------|
| Trials | 5,000 |
| Base Case | -2.40 |
| Mean | -1.18 |
| Median | -1.53 |
| Mode | --- |
| Standard Deviation | 9.11 |
| Variance | 82.94 |
| Skewness | 14.78 |
| Kurtosis | 411.38 |
| Coeff. of Variation | -7.73 |
| Minimum | -57.91 |
| Maximum | 321.36 |
| Range Width | 379.26 |
| Mean Std. Error | 0.13 |

Forecast: HEAD_Wet_50 (cont'd)

Cell: I39

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -57.91 |
| 10% | -6.52 |
| 20% | -4.11 |
| 30% | -2.92 |
| 40% | -2.13 |
| 50% | -1.53 |
| 60% | -0.98 |
| 70% | -0.40 |
| 80% | 0.60 |
| 90% | 3.02 |
| 100% | 321.36 |

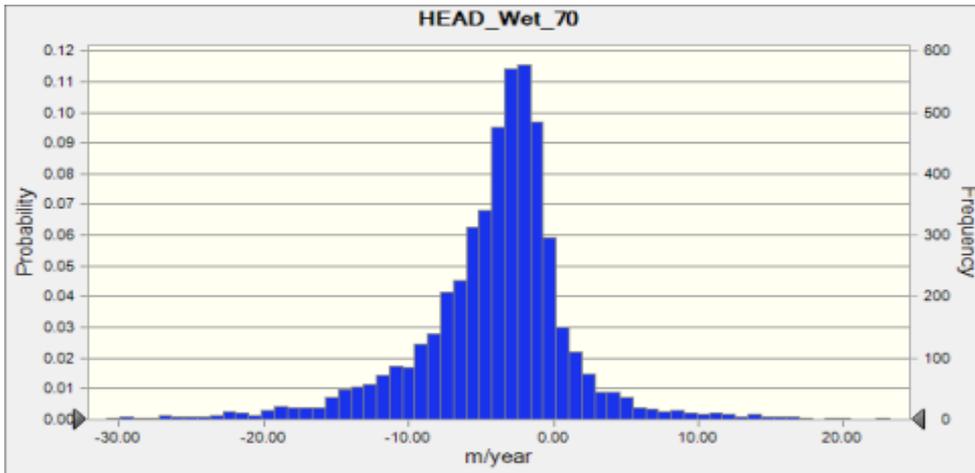
Appendix E-2 Model Forecasts Report

Forecast: HEAD_Wet_70

Cell: I40

Summary:

Entire range is from -67.71 to 316.94
 Base case is -4.47
 After 5,000 trials, the std. error of the mean is 0.14



Statistics:

Forecast values

| | |
|---------------------|--------|
| Trials | 5,000 |
| Base Case | -4.47 |
| Mean | -3.83 |
| Median | -3.28 |
| Mode | --- |
| Standard Deviation | 9.63 |
| Variance | 92.80 |
| Skewness | 11.75 |
| Kurtosis | 322.24 |
| Coeff. of Variation | -2.52 |
| Minimum | -67.71 |
| Maximum | 316.94 |
| Range Width | 384.65 |
| Mean Std. Error | 0.14 |

Forecast: HEAD_Wet_70 (cont'd)

Cell: I40

Percentiles:

Forecast values

| | |
|------|--------|
| 0% | -67.71 |
| 10% | -10.79 |
| 20% | -7.28 |
| 30% | -5.51 |
| 40% | -4.20 |
| 50% | -3.28 |
| 60% | -2.53 |
| 70% | -1.75 |
| 80% | -0.92 |
| 90% | 0.86 |
| 100% | 316.94 |

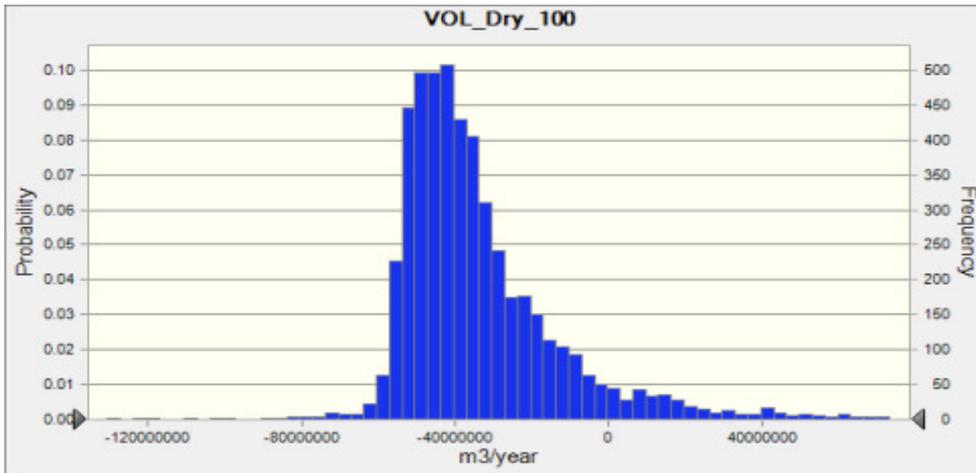
Appendix E-2 Model Forecasts Report

Forecast: VOL_Dry_100

Cell: G44

Summary:

Entire range is from -130612986 to 1450587876
 Base case is -41842004
 After 5,000 trials, the std. error of the mean is 530967



| Statistics: | Forecast values |
|---------------------|------------------|
| Trials | 5,000 |
| Base Case | -41842004 |
| Mean | -32149820 |
| Median | -39002560 |
| Mode | --- |
| Standard Deviation | 37545039 |
| Variance | 1409629981103180 |
| Skewness | 18.38 |
| Kurtosis | 598.11 |
| Coeff. of Variation | -1.17 |
| Minimum | -130612986 |
| Maximum | 1450587876 |
| Range Width | 1581200862 |
| Mean Std. Error | 530967 |

Forecast: VOL_Dry_100 (cont'd)

Cell: G44

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -130612986 |
| 10% | -52590128 |
| 20% | -49081202 |
| 30% | -45805299 |
| 40% | -42475986 |
| 50% | -39008423 |
| 60% | -35051686 |
| 70% | -29749562 |
| 80% | -21185664 |
| 90% | -7155945 |
| 100% | 1450587876 |

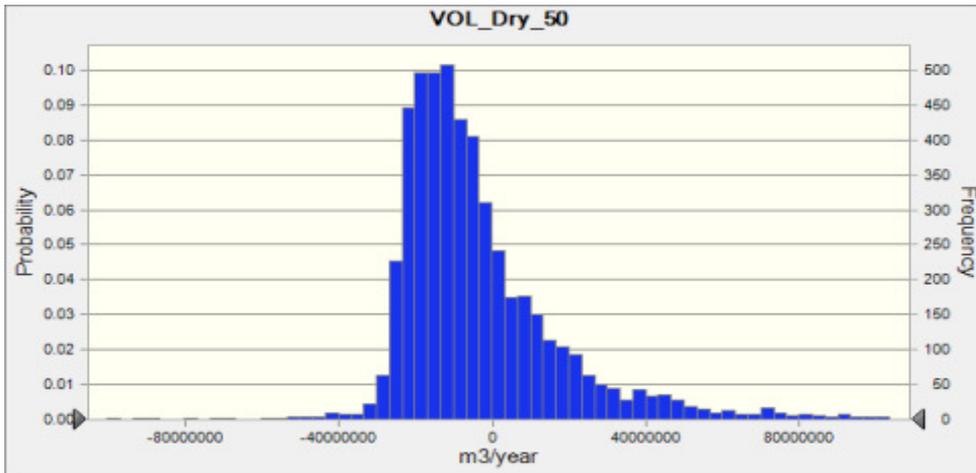
Appendix E-2 Model Forecasts Report

Forecast: VOL_Dry_50

Cell: G42

Summary:

Entire range is from -100290486 to 1480910376
 Base case is -11519504
 After 5,000 trials, the std. error of the mean is 530967



| Statistics: | Forecast values |
|---------------------|------------------|
| Trials | 5,000 |
| Base Case | -11519504 |
| Mean | -1827320 |
| Median | -8680060 |
| Mode | --- |
| Standard Deviation | 37545039 |
| Variance | 1409629981103180 |
| Skewness | 18.38 |
| Kurtosis | 598.11 |
| Coeff. of Variation | -20.55 |
| Minimum | -100290486 |
| Maximum | 1480910376 |
| Range Width | 1581200862 |
| Mean Std. Error | 530967 |

Forecast: VOL_Dry_50 (cont'd)

Cell: G42

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -100290486 |
| 10% | -22267628 |
| 20% | -18758702 |
| 30% | -15482799 |
| 40% | -12153486 |
| 50% | -8685923 |
| 60% | -4729186 |
| 70% | 572938 |
| 80% | 9136836 |
| 90% | 23166555 |
| 100% | 1480910376 |

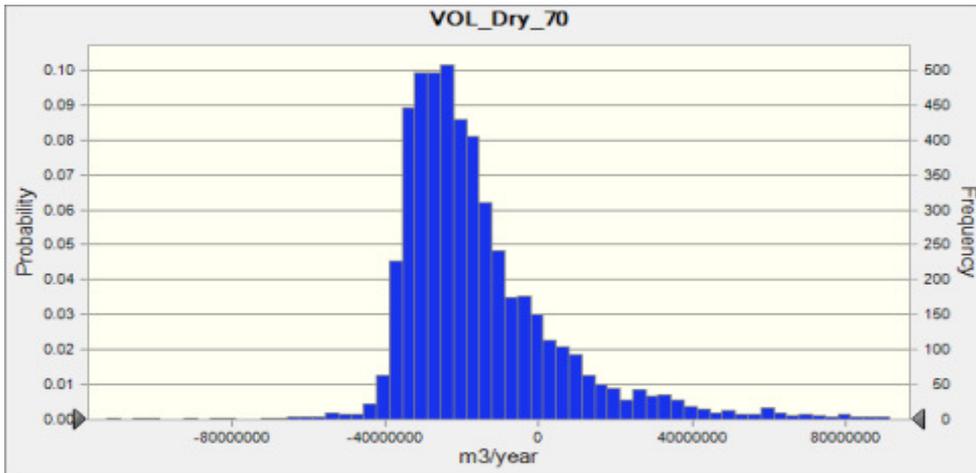
Appendix E-2 Model Forecasts Report

Forecast: VOL_Dry_70

Cell: G43

Summary:

Entire range is from -112419486 to 1468781376
 Base case is -23648504
 After 5,000 trials, the std. error of the mean is 530967



| Statistics: | Forecast values |
|---------------------|------------------|
| Trials | 5,000 |
| Base Case | -23648504 |
| Mean | -13956320 |
| Median | -20809060 |
| Mode | --- |
| Standard Deviation | 37545039 |
| Variance | 1409629981103180 |
| Skewness | 18.38 |
| Kurtosis | 598.11 |
| Coeff. of Variation | -2.69 |
| Minimum | -112419486 |
| Maximum | 1468781376 |
| Range Width | 1581200862 |
| Mean Std. Error | 530967 |

Forecast: VOL_Dry_70 (cont'd)

Cell: G43

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -112419486 |
| 10% | -34396628 |
| 20% | -30887702 |
| 30% | -27611799 |
| 40% | -24282486 |
| 50% | -20814923 |
| 60% | -16858186 |
| 70% | -11556062 |
| 80% | -2992164 |
| 90% | 11037555 |
| 100% | 1468781376 |

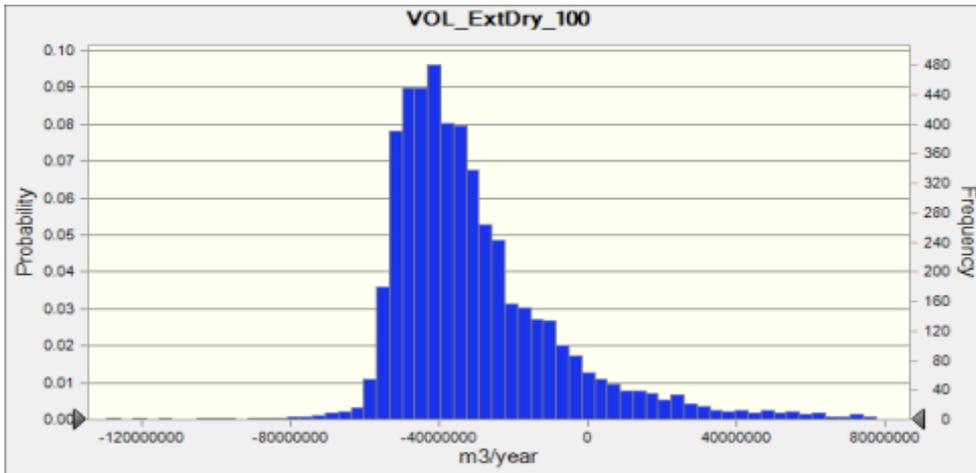
Appendix E-2 Model Forecasts Report

Forecast: VOL_ExtDry_100

Cell: G47

Summary:

Entire range is from -129445159 to 1455648859
 Base case is -39152627
 After 5,000 trials, the std. error of the mean is 553473



| | |
|---------------------|------------------|
| Statistics: | Forecast values |
| Trials | 5,000 |
| Base Case | -39152627 |
| Mean | -28571740 |
| Median | -36026763 |
| Mode | --- |
| Standard Deviation | 39136455 |
| Variance | 1531662095392500 |
| Skewness | 16.47 |
| Kurtosis | 511.07 |
| Coeff. of Variation | -1.37 |
| Minimum | -129445159 |
| Maximum | 1455648859 |
| Range Width | 1585094018 |
| Mean Std. Error | 553473 |

Forecast: VOL_ExtDry_100 (cont'd)

Cell: G47

| | |
|--------------|-----------------|
| Percentiles: | Forecast values |
| 0% | -129445159 |
| 10% | -51505110 |
| 20% | -47532772 |
| 30% | -43856197 |
| 40% | -40176124 |
| 50% | -36029234 |
| 60% | -31547913 |
| 70% | -25416691 |
| 80% | -15805577 |
| 90% | 301483 |
| 100% | 1455648859 |

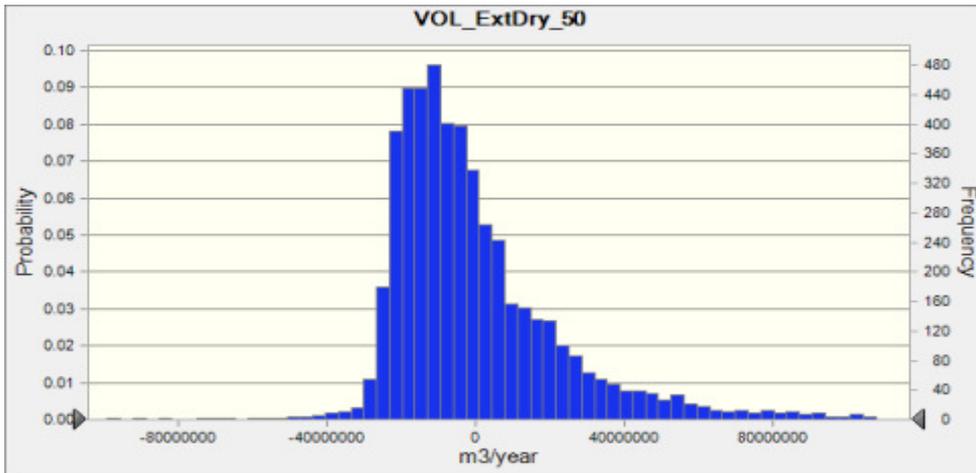
Appendix E-2 Model Forecasts Report

Forecast: VOL_ExtDry_50

Cell: G45

Summary:

Entire range is from -99122659 to 1485971359
 Base case is -8830127
 After 5,000 trials, the std. error of the mean is 553473



| Statistics: | Forecast values |
|---------------------|------------------|
| Trials | 5,000 |
| Base Case | -8830127 |
| Mean | 1750760 |
| Median | -5704263 |
| Mode | --- |
| Standard Deviation | 39136455 |
| Variance | 1531662095392500 |
| Skewness | 16.47 |
| Kurtosis | 511.07 |
| Coeff. of Variation | 22.35 |
| Minimum | -99122659 |
| Maximum | 1485971359 |
| Range Width | 1585094018 |
| Mean Std. Error | 553473 |

Forecast: VOL_ExtDry_50 (cont'd)

Cell: G45

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -99122659 |
| 10% | -21182610 |
| 20% | -17210272 |
| 30% | -13533697 |
| 40% | -9853624 |
| 50% | -5706734 |
| 60% | -1225413 |
| 70% | 4905809 |
| 80% | 14516923 |
| 90% | 30623983 |
| 100% | 1485971359 |

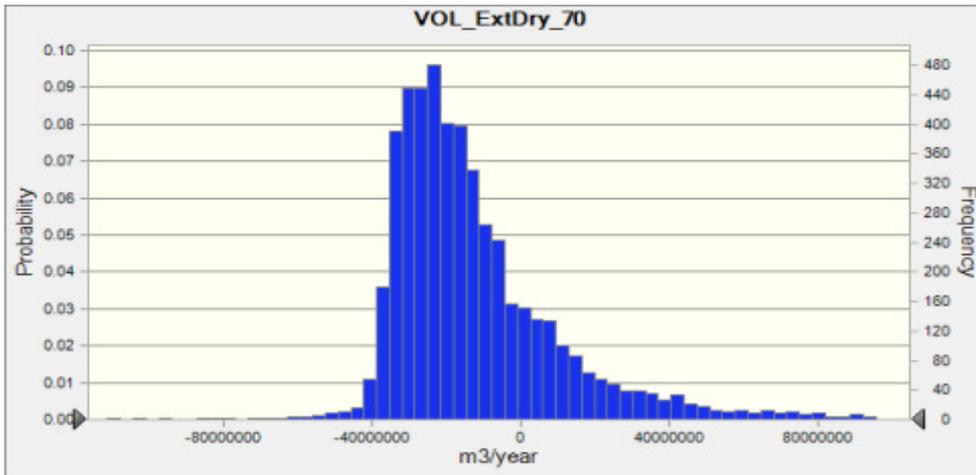
Appendix E-2 Model Forecasts Report

Forecast: VOL_ExtDry_70

Cell: G46

Summary:

Entire range is from -111251659 to 1473842359
 Base case is -20959127
 After 5,000 trials, the std. error of the mean is 553473



| Statistics: | Forecast values |
|---------------------|------------------|
| Trials | 5,000 |
| Base Case | -20959127 |
| Mean | -10378240 |
| Median | -17833263 |
| Mode | --- |
| Standard Deviation | 39136455 |
| Variance | 1531662095392500 |
| Skewness | 16.47 |
| Kurtosis | 511.07 |
| Coeff. of Variation | -3.77 |
| Minimum | -111251659 |
| Maximum | 1473842359 |
| Range Width | 1585094018 |
| Mean Std. Error | 553473 |

Forecast: VOL_ExtDry_70 (cont'd)

Cell: G46

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -111251659 |
| 10% | -33311610 |
| 20% | -29339272 |
| 30% | -25662697 |
| 40% | -21982624 |
| 50% | -17835734 |
| 60% | -13354413 |
| 70% | -7223191 |
| 80% | 2387923 |
| 90% | 18494983 |
| 100% | 1473842359 |

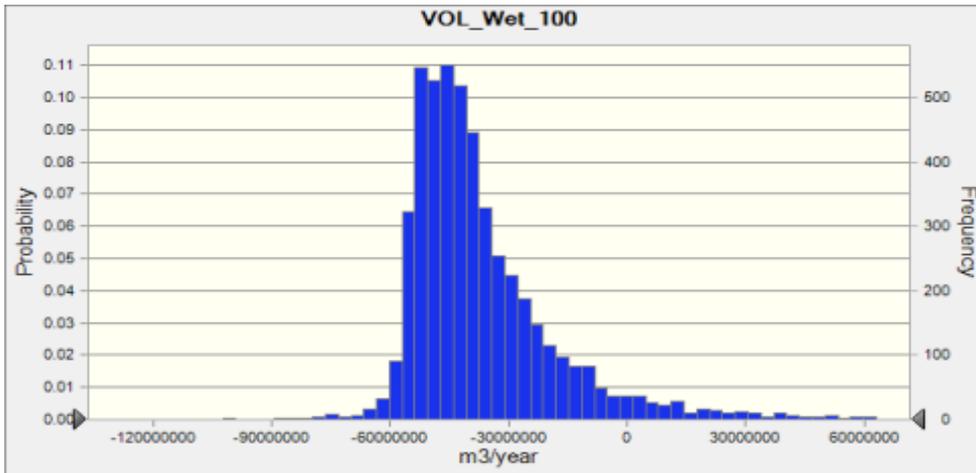
Appendix E-2 Model Forecasts Report

Forecast: VOL_Wet_100

Cell: G41

Summary:

Entire range is from -131589522 to 1441082911
 Base case is -44381683
 After 5,000 trials, the std. error of the mean is 513464



| Statistics: | Forecast values |
|---------------------|------------------|
| Trials | 5,000 |
| Base Case | -44381683 |
| Mean | -35445958 |
| Median | -41749372 |
| Mode | --- |
| Standard Deviation | 36307353 |
| Variance | 1318223848195120 |
| Skewness | 20.05 |
| Kurtosis | 674.59 |
| Coeff. of Variation | -1.02 |
| Minimum | -131589522 |
| Maximum | 1441082911 |
| Range Width | 1572672433 |
| Mean Std. Error | 513464 |

Forecast: VOL_Wet_100 (cont'd)

Cell: G41

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -131589522 |
| 10% | -53777646 |
| 20% | -50772820 |
| 30% | -47829038 |
| 40% | -44780226 |
| 50% | -41755362 |
| 60% | -38283164 |
| 70% | -33441730 |
| 80% | -26191519 |
| 90% | -12565842 |
| 100% | 1441082911 |

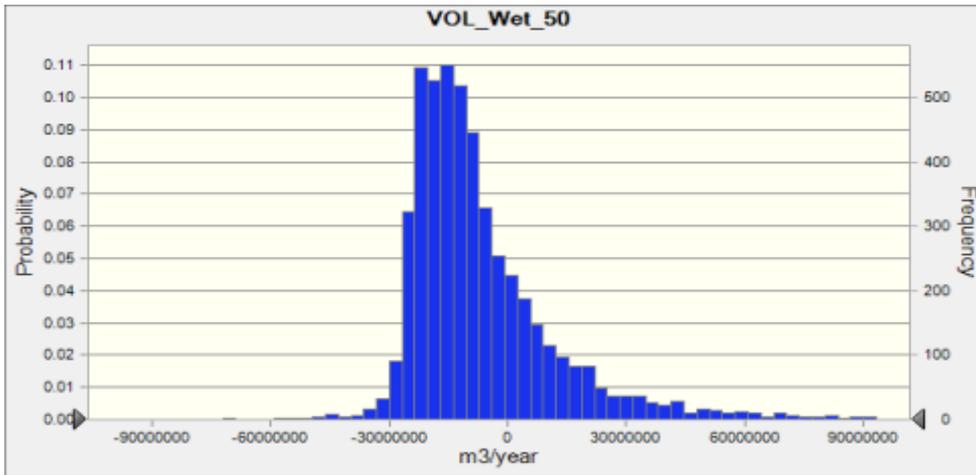
Appendix E-2 Model Forecasts Report

Forecast: VOL_Wet_50

Cell: G39

Summary:

Entire range is from -101267022 to 1471405411
 Base case is -14059183
 After 5,000 trials, the std. error of the mean is 513464



| Statistics: | Forecast values |
|---------------------|------------------|
| Trials | 5,000 |
| Base Case | -14059183 |
| Mean | -5123458 |
| Median | -11426872 |
| Mode | --- |
| Standard Deviation | 36307353 |
| Variance | 1318223848195120 |
| Skewness | 20.05 |
| Kurtosis | 674.59 |
| Coeff. of Variation | -7.09 |
| Minimum | -101267022 |
| Maximum | 1471405411 |
| Range Width | 1572672433 |
| Mean Std. Error | 513464 |

Forecast: VOL_Wet_50 (cont'd)

Cell: G39

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -101267022 |
| 10% | -23455146 |
| 20% | -20450320 |
| 30% | -17506538 |
| 40% | -14457726 |
| 50% | -11432862 |
| 60% | -7960664 |
| 70% | -3119230 |
| 80% | 4130981 |
| 90% | 17756658 |
| 100% | 1471405411 |

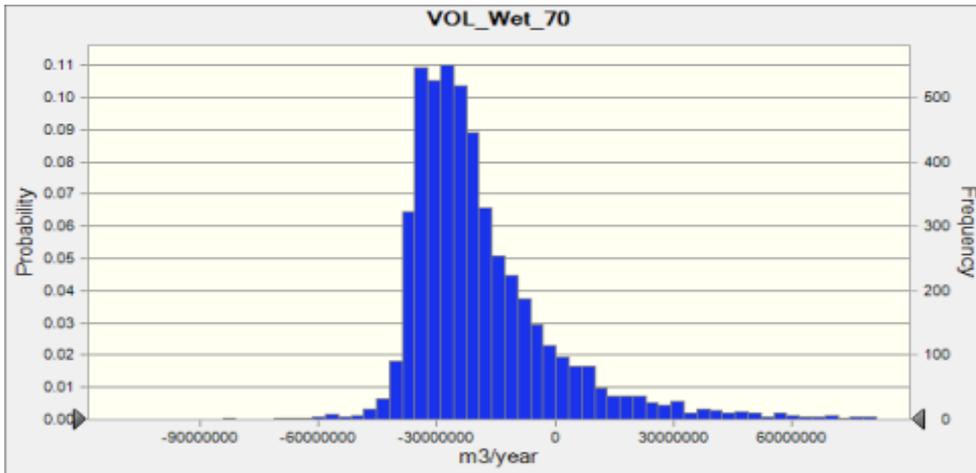
Appendix E-2 Model Forecasts Report

Forecast: VOL_Wet_70

Cell: G40

Summary:

Entire range is from -113396022 to 1459276411
 Base case is -26188183
 After 5,000 trials, the std. error of the mean is 513464



| Statistics: | Forecast values |
|---------------------|------------------|
| Trials | 5,000 |
| Base Case | -26188183 |
| Mean | -17252458 |
| Median | -23555872 |
| Mode | --- |
| Standard Deviation | 36307353 |
| Variance | 1318223848195120 |
| Skewness | 20.05 |
| Kurtosis | 674.59 |
| Coeff. of Variation | -2.10 |
| Minimum | -113396022 |
| Maximum | 1459276411 |
| Range Width | 1572672433 |
| Mean Std. Error | 513464 |

Forecast: VOL_Wet_70 (cont'd)

Cell: G40

| Percentiles: | Forecast values |
|--------------|-----------------|
| 0% | -113396022 |
| 10% | -35584146 |
| 20% | -32579320 |
| 30% | -29635538 |
| 40% | -26586726 |
| 50% | -23561862 |
| 60% | -20089664 |
| 70% | -15248230 |
| 80% | -7998019 |
| 90% | 5627658 |
| 100% | 1459276411 |



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