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Uley Basin Groundwater Modelling Project Volume 2: Groundwater Flow Model

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Uley Basin Groundwater Modelling Project

Volume 2: Groundwater Flow Model

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Knowledge and Information
Department of Water, Land and Biodiversity Conservation

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FOREWORD

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

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

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

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

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EXECUTIVE SUMMARY

The Uley Basin, which consists of three fresh groundwater lenses — Uley South, Uley Wanilla and Uley East — forms part of the Southern Basins Prescribed Wells Area (PWA). Groundwater obtained from the basin provides the reticulated water supply system for Eyre Peninsula, and fulfils ~90% of current requirements.

A numerical groundwater flow model was developed by Department of Water, Land and Biodiversity Conservation (DWLBC) in conjunction with SA Water and the Eyre Peninsula Natural Resources Management Board (EPNRMB) to increase understanding of the groundwater system and assist in the long-term management of the Uley Basin. This model incorporates understanding of the groundwater flow system to date and is generally capable of simulating the regional aquifer system in the Uley Basin.

Groundwater in the Uley Basin predominantly occurs in rocks and sediments of three different geological environments within the Southern Basins — Quaternary Bridgewater Formation, Tertiary Wanilla Formation and a volcano–metasedimentary basement sequence. The Uley Wanilla, Uley East and Uley South groundwater lenses occur where Quaternary limestone is saturated. The Tertiary clay (TC) sediments form an aquitard between the Tertiary sand (TS) and the Quaternary limestone (QL) aquifer systems. Accordingly, the model consists of three layers, two aquifers and an aquitard, and accounts for the hydraulic interaction between these layers.

The model was calibrated by matching observed heads to simulated heads of both steady state and transient state modelling runs for the 1949–2005 period. The model also allows for 15 years of predictive modelling, simulating likely groundwater response to recharge scenarios until 2020.

The unconfined QL aquifer responds rapidly to changes in rainfall and the model is particularly sensitive to the recharge parameter. It also highlights a change in the recharge pattern since the early 1990s. In the last 15 years, rainfall contributed less to recharge by ~10% in Uley South and Uley East. In Uley Wanilla, this deficiency in recharge could be as high as 50%.

The QL and TS aquifers are hydraulically connected due to the leaky nature of the TC aquitard or its absence in parts of the study area. Connection between aquifers occurs through inter-aquifer leakage. The model outcomes for the QL aquifer are sensitive to the magnitude of this interaction. In addition, all three lenses are connected through the TS aquifer. In the southern extents of the Uley East and Uley Wanilla lenses, significant discharge from the QL aquifer occurs, contributing major inflow to the TS aquifer. Beneath Uley South, a large portion of the received groundwater inflow will be returned to the QL aquifer through upward leakage.

Three groundwater extraction regime scenarios were tested, with Uley Wanilla extractions kept constant at the current level of 300 ML/y and Uley South extractions varied between 7500–10 000 ML/y. Three different recharge options were tested under each scenario.

Predictive modelling results show that cones of depression in Uley South in each scenario would start developing in the central part of the lens, and would spread in a north to south-easterly direction. The dry cells would start appearing near the central-eastern boundary of Uley South, due to high basement and thinner saturated limestone. The drawdowns would be least prominent along the coastal boundary of the model. The maximum summer drawdowns in this lens would be 0.6–1.6 m.

Similarly, drawdowns in Uley Wanilla would start developing around production wells in the centre of the northern extent of the lens, and it would increase to almost the whole northern part of the lens under extremely low recharge conditions. The maximum summer drawdowns would be in order of 0.8–1.4 m, depending on the scenario.

In Uley East, summer drawdowns through natural discharge processes would be greatest in the central and southern part of the lens and would vary between 0.2 and 3.0 m, with the northern extent of the lens least affected by extreme conditions.

Water levels across the region would fully recover in winter under most favourable recharge conditions. However, in the worst-case scenario with 50% of the last 15 years rainfall repeated, permanent drawdown for 2020 will be between 1.2–1.4 m, which may be unsustainable.

An increase in extraction of ~10% or 1000 ML/y should not be of a great concern and it should not have detrimental impact on the groundwater resource in Uley South. However, it would cause a 2–3 m drawdown in Uley East, which in turn might affect current users and limit future development in this lens. The results should be used with caution, because the model is not able to predict impacts of increased extraction to the seawater–groundwater interface for the modelled scenarios. In addition, it is impossible to predict the future rainfall, and therefore accurately estimate potential recharge, which is a driving mechanism of this groundwater system.

1. INTRODUCTION

The Uley Basin consists of three fresh groundwater lenses — Uley South, Uley East and Uley Wanilla — which form part of the Southern Basins Prescribed Wells Area (Fig. 1). Groundwater obtained from the basin provides the reticulated water supply system for Eyre Peninsula, and the Uley South lens alone contributes 70% to the total reticulated water needs for Eyre Peninsula.

The quality and quantity of groundwater from the lenses are at risk of degradation should the extractions become greater than sustainable yield. The current understanding of these groundwater resources is that the extractions are close to or at their sustainable yield. The high dependence of sustainable yields on climatic conditions due to the unconfined nature and limited storage is of a particular concern. The recharge rates and sustainable yields are dependent on steady winter rainfall and it is largely unknown how the resource would respond to accumulated effects of long-term below average rainfall and increasing demands.

In order to gain better understanding of the groundwater resource in the Uley Basin and estimate the impacts increasing water demands might have on the resource, SA Water and EPNRMB, in partnership with DWLBC, initiated the Uley Basin groundwater modelling project in September 2005.

This model was developed based on integrated hydrogeological concepts of a number of authors, as presented in Volume 1 of Uley Basin Groundwater Modelling Project. Even though significant investigations have been carried out in the past, they were limited to the Quaternary aquifer and did not adequately address hydraulic connection between Quaternary and Tertiary sediments. Therefore, the developed model is based on a number of assumptions, which are in turn limitations and impediments to this model.

Nevertheless, this is another stage in developing a scientific tool for assessing the response of Uley Basin groundwater response to various climatic and hydrogeological conditions and enable more robust management practices.

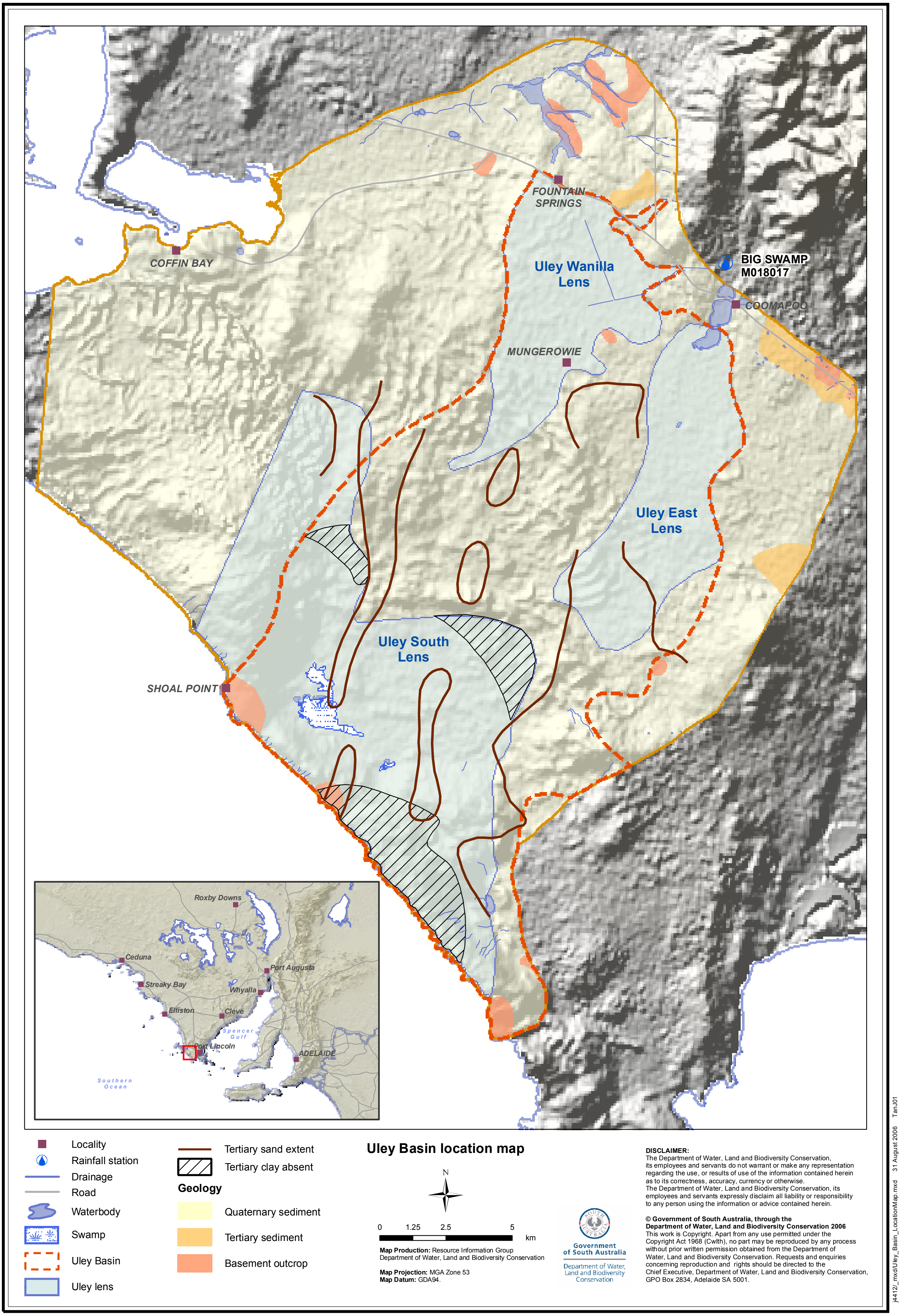

Figure 1. Uley Basin location map

2. AIM AND OBJECTIVES

The objectives of the project are to develop a numerical groundwater model flow that will help to:

- Determine sustainable yields from the Uley Basin aquifers.
- Predict the response of the aquifer system to potential groundwater use scenarios to provide a more robust declared annual water allocation based on percentage shares of the resource capacity.
- Predict the response of the aquifer system climatic variability, risk of over extraction and impact on the available yield.

3. ULEY BASIN HYDROGEOLOGY

Groundwater in the Uley Basin predominantly occurs in rocks and sediments of three different geological environments within the Southern Basins — Quaternary Bridgewater Formation, Tertiary Wanilla Formation and a volcano–metasedimentary basement sequence (Table 1). The buried surface of the basement sequence is a series of north–south-trending ridges and valleys. The Quaternary limestone (QL) and Tertiary sand (TS) and clay deposits form a thin veneer over the basement highs, with relatively thick accumulations within the basement troughs (Fig. 2). Where the QL is saturated, the Uley Wanilla, Uley East and Uley South groundwater lenses occur. The Tertiary clay (TC) sediments form an aquitard between the TS and QL aquifer systems.

Surface watercourses are scarce in the Uley Basin. Where present, they are tens to hundreds of metres long and terminate abruptly at sinkholes within surface depressions. There are no surface water outflows from the Uley Basin, with all surface watercourses draining to closed basins.

Big Swamp, an annually inundated surface water body located in the northeastern portion of the basin, acts as an endpoint for surface drainage systems to the northeast of the Uley Basin and consists of three sections. The northerly two sections directly overlie the TC and receive wet season dominated surface runoff. The third, southerly section of Big Swamp fills infrequently during the wet season from the second section (~2 in every 5 years). This section overlies the QL and hence provides recharge to this aquifer during wet years, occasionally overflowing and draining south into the Uley East lens area, then west into the Uley Wanilla area ~1 year in 20, where the surface water is believed to infiltrate into the limestone. Measurements of the free water line in the third basin during 1941–56 showed that this portion of Big Swamp filled on average every second year.

3.1 HYDROGEOLOGICAL UNITS

The aquifers and confining units in the study area are the basement rock, TS and TC, QL and coastal sand dunes (Table 1). The current understanding (Evans 1997) of the configuration of the aquifers, confining units and groundwater flow mechanisms are shown schematically in Figure 2. The configuration of the aquifers and confining units forms an important factor controlling the overall groundwater flow in the study area.

3.1.1 BASEMENT AQUIFER

Limited information exists on the basement units of the Uley Basin[1], but they are believed to consist of both weathered and unweathered Archaean quartz–feldspar gneiss and feldspathic quartzite. Groundwater resources have not been investigated but are understood to exhibit irregular occurrences, salinities and yields. The basement system is also believed to have negligible interaction with the Quaternary aquifer system, although its structure has a significant control over younger aquifer thicknesses and geometries.

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[1] The term 'Uley Basin' was first used by Evans (1997), who also defined the boundary of the basin.

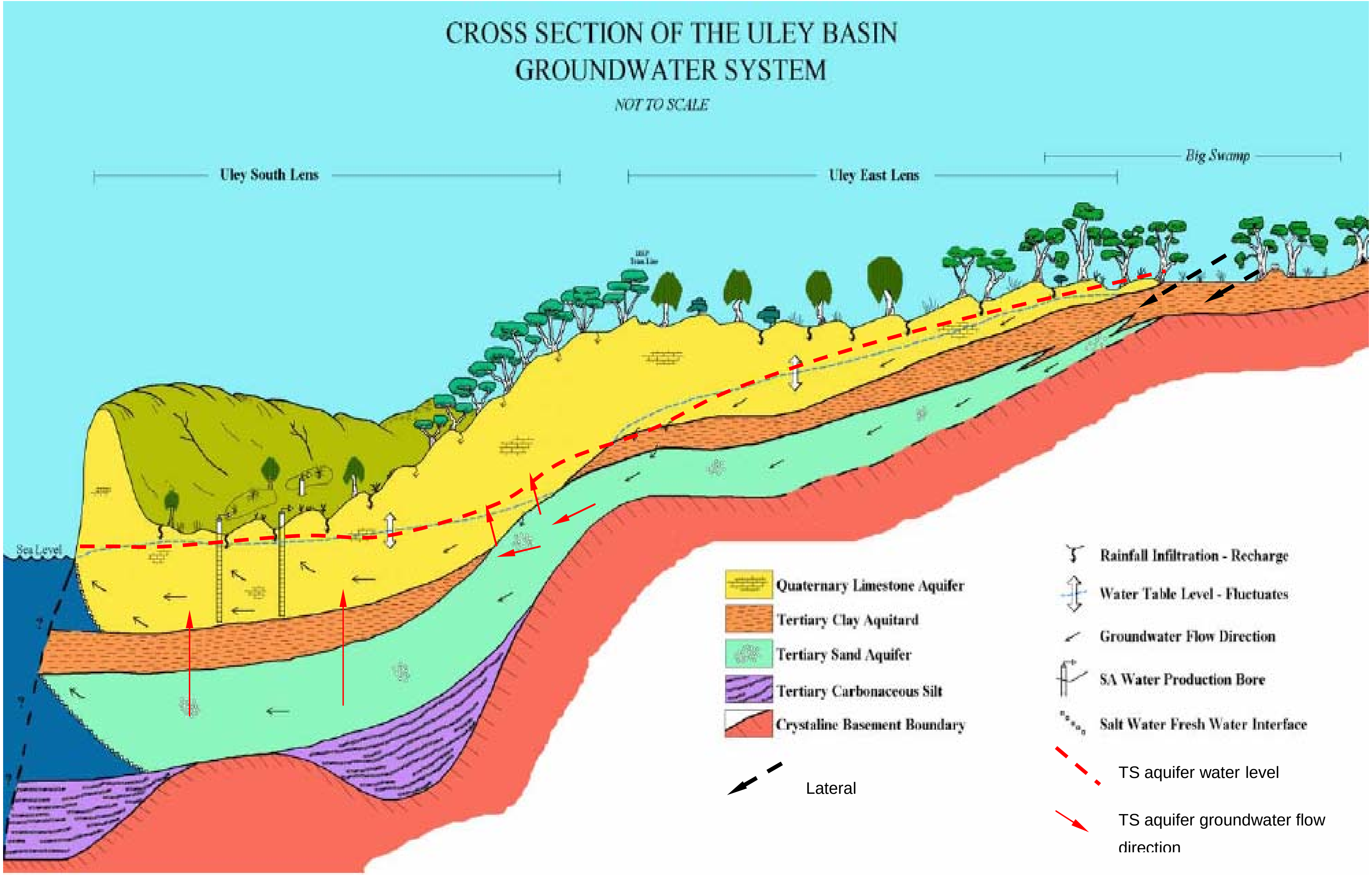

Figure 2. Schematic cross-section of the Uley Basin (adapted from Evans 2002)

Table 1. Hydrogeology and stratigraphy of Eyre Peninsula (Evans 2002)

Age			Stratigraphy	Aquifer, aquitard	Salinity range (mg/L)
Cainozoic	Recent	Holocene	*Coastal dunes:* Fine-grained aeolianites, unconsolidated, mobile. Grains comprise calcite and shell fragments.	***Unconfined aquifer**:* seasonal, small yielding, thin, low salinity supplies located at the base of the mobile sand dune systems.	NA
	Quaternary	Pleistocene	*Bridgewater Formation:* Aeolianites, fine to medium-grained, cross-bedded, weakly to moderately cemented, grains are calcite and shell fragments, mainly 0.1–1.5 mm. Generally calcrete at surface. Coastal dunes.	***Unconfined aquifer**:* generally low salinity. Permeability ranges from low to very high. Transmissivity ranges from 2.0 to 8.0 x 10^3 m^3/d/m. The usual target aquifer for large water supplies on Eyre Peninsula.	<1000
	Tertiary	Eocene	*Uley Formation:* Sandstone, clayey to orange-brown quartz, well sorted and rounded, minor lateritic and non-lateritic gravel.	***Aquitard**:* generally a confining layer beneath the Quaternary aquifer. Where it is permeable can hold the watertable or allow infiltration to the underlying sediments.	NA
			Wanilla Formation: Clay, sand (quartz) and gravel with thin lignite layers. Sand is generally fine-grained, less than 0.5 mm, uncemented or weakly cemented.	***Semi-confined to confined aquifer**:* low to moderate permeability but with marked variations vertically and laterally.	500–5500
Proterozoic	Neoproterozoic		*Precambrian basement:* Schist, gneiss and quartzite intruded by granite and basic rocks. Deeply weathered in places.	***Semi-confined to confined aquifers**:* groundwater occurs in the weathered profile or within the fracture spaces of these rocks.	>7000

3.1.2 TERTIARY SAND

Directly overlying the basement rocks, and known to be over 60 m thick in the basement trough that forms the western part of the Uley South lens, are the Tertiary sediments, consisting of fluvial sand, clay and grit with some lignitic lenses. TS is the main aquifer in this sequence, comprising sand and gravel but silty and carbonaceous at its base. Groundwater flow in the TS aquifer is generally from northeast to southwest, similar to that in the QL aquifer system, following the slope of the underlying basement structure. The TS aquifer is believed to occur mainly in the Uley South region, and monitoring is predominantly limited to this portion of the study area, where it lies mostly below sea level.

3.1.3 TERTIARY CLAY

The upper Tertiary unit consists of a 5–25 m thick clayey laterite palaeosol horizon. The TC forms an aquitard between the TS and the QL aquifer systems, with vertical hydraulic conductivity (K_v) estimated in the Uley South region to be 6.8 x 10^{-4} m/d (Morton & Steel 1968). Again, due to the fluvial depositional environment of the Tertiary sediments, the TC is not expected to have spatially uniform hydraulic properties and is described by Morton and Steel (1970) as consisting of clay and silty clay.

The clay is considered to be a relatively effective aquitard due to the fact that hydraulic heads in the underlying TS aquifer are generally above the base of the clay. However, Morton and Steel (1968) considered it to be a leaky aquitard, and the lack of field information on the layer means that there may be a number of unidentified areas where effective connection between the QL and TS aquifers occurs through the clay.

The clay is not continuous across the entire study area, with a number of areas identified in which QL is in direct contact with TS (Evans 1997). Examples of such areas include the northwestern, southeastern and northeastern portions of the Uley South lens area (Fig. 2). In some other areas, TC has been identified but its thickness is not known. These occur below the northern portion of the Uley Wanilla lens, below most of the Uley East lens and below the western part of the Uley South lens.

3.1.4 QUATERNARY LIMESTONE

QL (Bridgewater Formation) forms the uppermost aquifer system in the study area. This unit forms a thin covering over the basement-controlled structure in the east and northwest of the study area, and is over 130 m thick in the Uley South region. The unit consists of aeolian sediments, mainly fine sand-sized shell fragments that are generally unconsolidated or loosely aggregated. However, the QL can be more consolidated in some parts, as near-vertical cliff occurrences along the Southern Ocean coastline suggests. It is known to be laterally variable in composition, being marly and of a relatively low permeability in some areas and hard and cavernous in others, for example in the central Uley South lens area (Morton & Steel 1970). Secondary porosity is known to occur within the unit, along with secondary cementation in the form of a calcrete horizon at the evaporation front. Groundwater in the QL occurs in lenses, namely Uley East, Uley Wanilla and Uley South, forming potable water supplies with high yields and low salinity (<1000 mg/L). Groundwater flow in the Uley South lens is generally from the northeast to the southwest along the axes of basement troughs. Groundwater in the Uley Wanilla lens flows along an initially gradual and then a steep hydraulic gradient towards the southwest. There is also a northerly flow which historically discharges in the Fountain Springs area. The watertable ranges from 103 m AHD to 40 m AHD across the lens. Similarly to the Uley Wanilla lens, groundwater in the Uley East lens flows towards the southwest. The watertable elevation ranges between ~100 m AHD and 30 m AHD across the lens.

3.2 GROUNDWATER FLOW SYSTEM

The conceptual model for groundwater flow in the study area is based on the concept described in Section 4.4, Volume 1 of this report. The conceptual model is a simplified representation of the hydrogeological features, which govern groundwater flow in the study area. The hydrologic component of the groundwater flow system that affects the water balance in the study area are — the hydrostratigraphic layers; distribution and volume of natural and non-natural groundwater recharge and discharge; inter-aquifer flow; lateral inflow and outflow across the model boundaries; hydraulic conductivity values of the hydrostratigraphic layers; water levels; and hydrochemistry (salinity). This information, together with the configuration of the aquifers and confining unit, was used to conceptualise groundwater movement and model calibration. Figure 2 depicts the conceptual hydrogeological model of the groundwater flow in the Uley Basin under pre-development conditions. The conceptual model distinguishes four hydrostratigraphic layers in the study area — QL, TC, TS and basement rock. In addition to identifying the hydrostratigraphic layers of the aquifer, the conceptual model also defines the mechanisms of recharge and discharge as well as groundwater flow through the aquifer.

The primary source of recharge across the study area is from direct rainfall infiltration. The distribution and quantification of recharge have been evaluated using empirical and chloride balance methods (Barnett 1978; Evans 1997; Harrington et al. 2006). Inter-formational flow between the hydrostratigraphic layers has led to redistribution of groundwater that is recharged into different aquifer layers as a result of variation in hydraulic properties, hydraulic heads and topography.

Water level elevations measured in September 1942 (Uley Wanilla and Uley East) and September 1963 (Uley South) were contoured to show the configuration of the potentiometric surface and determined the directions of groundwater flow in the study area (Fig. 3). Based on the water level contours developed from 1940 and 1963 water level data, areas of potential lateral groundwater inflow and outflow along the model boundary were defined for pre-development conditions. The hydraulic gradients determined from 1942 and 1963 potentiometric surface maps indicate that, in general, the direction of groundwater flow in the study area is from the northeast to the southwest towards the ocean. The flow of water to and from the QL aquifers is presented below.

The inflow component to the QL aquifers include:

- Inflow to the Uley South lens is believed to be local rainfall and surface runoff and subsurface flow from topographically high regions of the surface drainage catchment (Evans 1997).
- Regular recharge contribution from Big Swamp to the Uley East lens, when the third section of Big Swamp is filled with water and overflows (Evans 1997).
- Recharge contribution from Big Swamp to Uley Wanilla is likely but negligible, with surface inflow to the lens occurring through a narrow interface only once in every 10–15 years (Evans 1997).
- It is known that the confining TC unit is semi-permeable (Morton & Steel 1970), and that groundwater in the TS aquifer is under pressure in the Uley South lens region, implying that there is the possibility of upward flow from the TS aquifer to the QL aquifers in regions where the hydraulic gradient between the TS and QL aquifers is upward.

The outflow component of the QL aquifer include:

- Natural outflow from the Uley South lens via groundwater discharge to the ocean.
- Another discharge zone is believed to be towards sand dunes in a southwesterly to westerly direction; this option is instigated from the pre-pumping water level contour maps (1963) and is supported by this modelling exercise.
- Natural groundwater outflow along the southern boundaries of the Uley Wanilla and Uley East lenses through a process of vertical downward leakage through the TC aquitard into the TS aquifer.
- Natural discharge from the Uley Wanilla lens at Fountain Springs in the north, where groundwater historically discharged to the land surface. Currently, the artificial lowering of groundwater levels in the aquifer prevents this natural discharge occurring.

The flow of water to and from the TS aquifer include:

- Recharge through the outcropping Tertiary clayey sediments in the northern portion of the study area (Fig. 2).

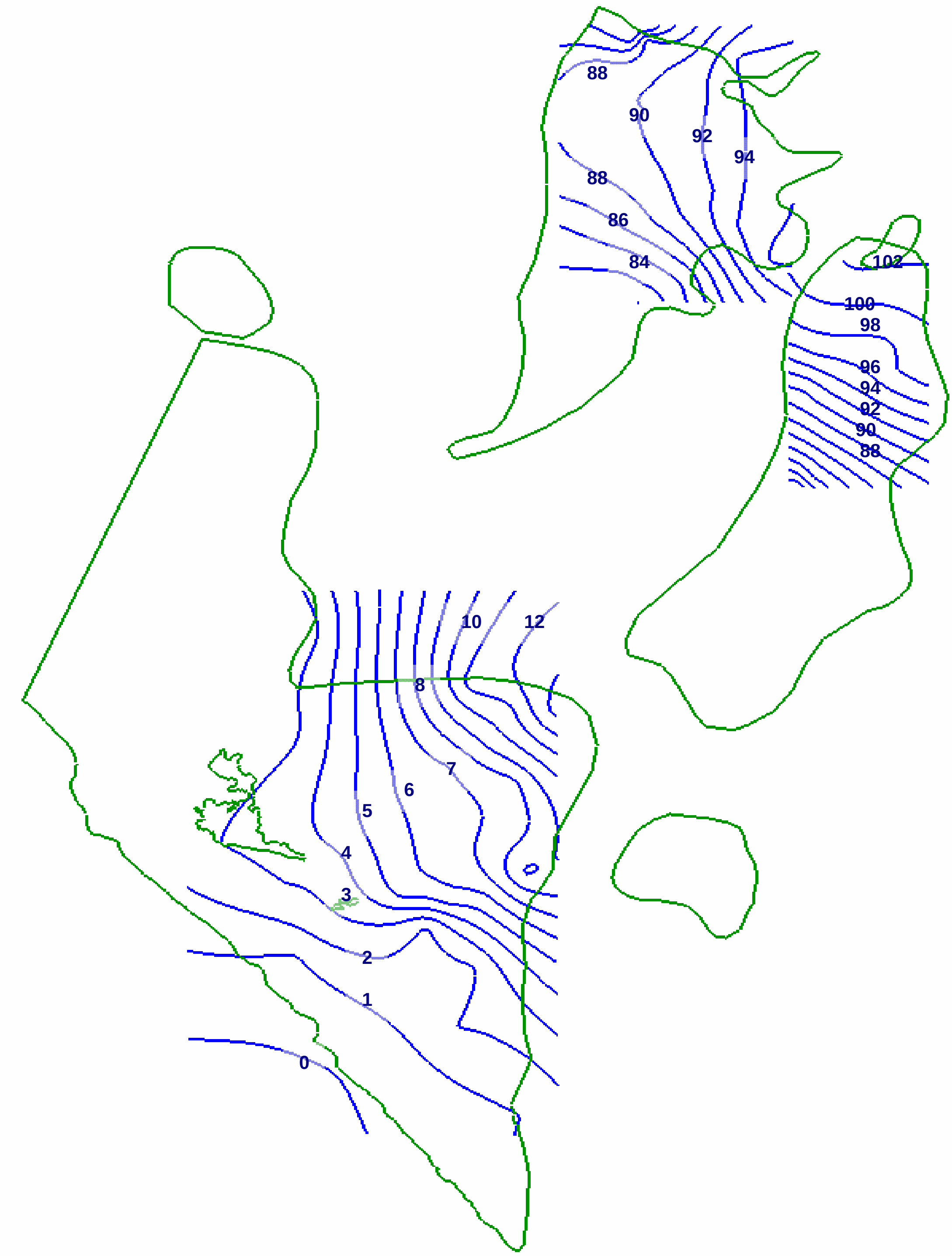

Figure 3. Potentiometric surface map, September 1942 (Uley Wanilla and Uley East) and September 1963 (Uley South)

- Direct recharge to the TS aquifer in the central portion of the study area where the QL aquifer is dry and the aquitard is absent.
- Leakage from the QL aquifer through the TC aquitard, or in areas where the aquitard is absent.
- Downward leakage to the basement units (this is likely to represent an insignificant portion of the water budget).
- Upward leakage to the QL aquifer.
- The TS aquifer discharges to the Southern Ocean at the southwestern boundary of the Uley Basin, and this is thought to be the only groundwater discharge for that aquifer. At the coast, the TS aquifer may lie greater than 30 m below sea level and discharge would be influenced by density effects at the seawater interface.

3.2.1 HYDRAULIC PROPERTIES

The TS aquifer has a large storage capacity, but poor to moderate yields. Lateral variation in the permeability of this aquifer can be expected due to the fluviatile nature of its deposition (Morton & Steel 1970). However, information on the hydraulic properties of the TS aquifer is currently limited to observations from one well (PT1), and it is estimated to have a transmissivity of 682 m^2/d and a storativity of 0.007 (Morton & Steel 1970).

Groundwater use

The Uley Basin forms part of the Southern Basins Prescribed Wells Area (PWA). Groundwater in the basin is fully allocated, primarily meeting the demand of the reticulated water supply for Eyre Peninsula. The Uley South lens alone currently provides more than 70% of the total reticulated water use for Eyre Peninsula. Groundwater production from the Uley Wanilla lens began in 1949, ranging between ~300 and 2800 ML/y. Groundwater extractions from Uley South exceeding 4000 ML/y commenced in 1976. The current extractions from Uley South are ~7500 ML/y.

Groundwater salinity

Groundwater salinities (Total Dissolved Solids) observed during the initial drilling programs are discussed by Evans (1997) and were generally <600 mg/L in the Uley South lens. The salinity distribution did not change significantly for the 1993–94 sampling event reported by Evans (1997), suggesting that groundwater extraction had not had a noticeable effect on groundwater salinities in this lens.

Quaternary aquifer groundwater salinity maps from the Uley East lens presented by Evans (1997) for both the initial drilling programs (1930s to 1960s) and the 1993–94 sampling program show a plume of comparatively high salinity groundwater of 600–900 mg/L along the western half of the lens, while groundwater in the eastern half of the lens has low salinities of 300–450 mg/L.

During the initial 1930s to 1960s drilling programs, groundwater salinity across the Uley Wanilla lens was below 1000 mg/L, with a zone in the centre of the lens having salinities >500 mg/L (600–700 mg/L). Between the initial drilling programs and the 1993–94 sampling, the higher salinity zone expanded from a small area to most of the northern part of the Uley Wanilla lens, suggesting a reduction in groundwater recharge between these two sampling events. Below the Uley South lens, the pattern of Tertiary groundwater salinities reflects those in the overlying QL aquifer, but are generally at least 100–200 mg/L higher, ranging from 540 to ~1200 mg/L (Evans 1997). The salinities are similar to those in the southern parts of the Quaternary Uley Wanilla and Uley East lenses, possibly supporting the theory of inflow from these lenses.

4. MODEL SET-UP

4.1 GENERAL

The groundwater modelling software MODFLOW-2000 (Harbaugh et al. 2000) was utilised to simulate the saturated groundwater flow conditions in the study area. MODFLOW is a three-dimensional finite difference mathematical code that is generally accepted as the industry standard for groundwater flow modelling.

The Groundwater Modeling System (GMS) Version 6 (Environmental Modeling Research Laboratory 2005) was used pre- and post-processing of data.

Two sets of models were developed — steady state model that represents pre-development hydrologic conditions and transient models that simulate the dynamic changes in the hydrologic conditions in response to time-varying recharge and pumping stresses. The steady state model operates on the assumption of constant recharge stress over time and represents long-term average hydrologic conditions in the aquifer before significant pumping started. The transient model was developed from the final steady state model by incorporating time-varying recharge and pumping stresses.

The Preconditioned Conjugate Gradient solver package (PCG2) was used for steady state simulations. PCG2 was set up with a maximum head change criterion between iterations of 0.01. The Geometric Multigrid (GMG) solver package was used for transient simulations.

4.2 MODEL DOMAIN AND SPATIAL DISCRETISATION

The model domain simulates an area 24 km (east–west) by 33.75 km (north–south). The bounding AMG coordinates of the model domain are southwest 542840mE 6139140mN and northeast 566980mE 6172890mN (Fig. 4).

The model extends vertically from the ground surface to the top of the basement rock. The model is vertically discretised into three layers, which are defined to represent the QL, TC and TS hydrostratigraphic units (Table 2; Fig. 5). The model layers were divided into a 123 row and 83 column finite-difference grid. The grid spacing was set to ~500 x 500 initially, with finer discretisation in some areas (115 x 125 m) as shown in Figure 4.

Table 2. Model layer aquifers and aquitard, Uley Basin

Layer No.	Hydrogeological unit	Stratigraphic unit	MODFLOW layer
1	QL aquifer	Bridgewater Formation, coastal dunes	convertible
2	TC aquitard	Uley Formation	confined
3	TS aquifer	Wanilla Formation	convertible

The top of the model is ground surface elevation and the bottom of the model is the no-flow boundary representing the contact between the TS aquifer and impermeable bedrock. The Layer Property Flow Package was used to simulate the model layers to allow for both confined and watertable conditions. The model layers 1 and 3 were simulated as convertible from unconfined to confined conditions (Harbaugh et al. 2000). That is, active cells in layers 1 and 3 in which the simulated head is below the designated layer top were simulated under watertable conditions, and cells in which the simulated hydraulic head is above the designated layer top were simulated under confined conditions. Layer 2 was modelled as a confined layer.

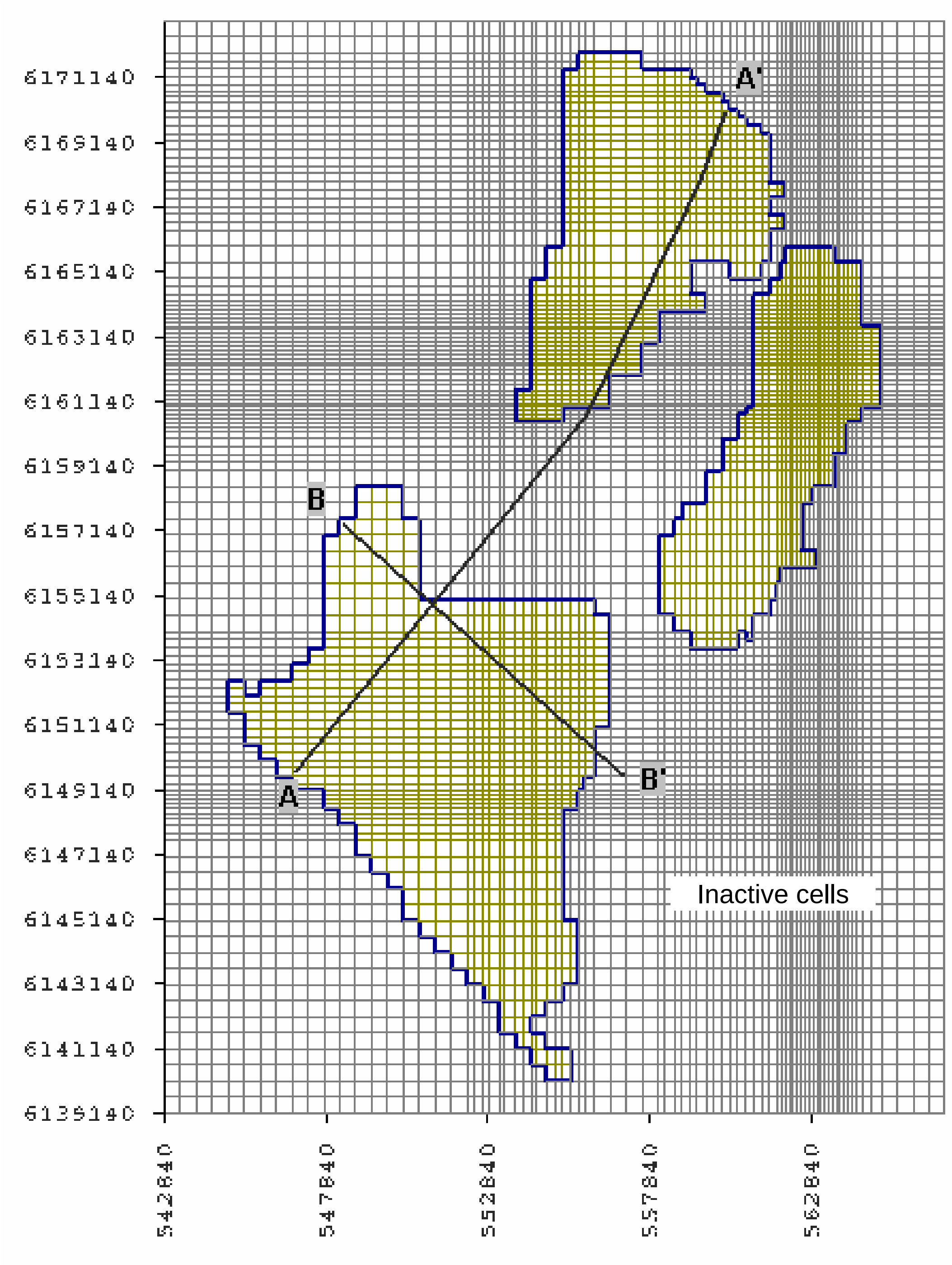

Figure 4. Model grid and domain of the Uley Basin from MODFLOW

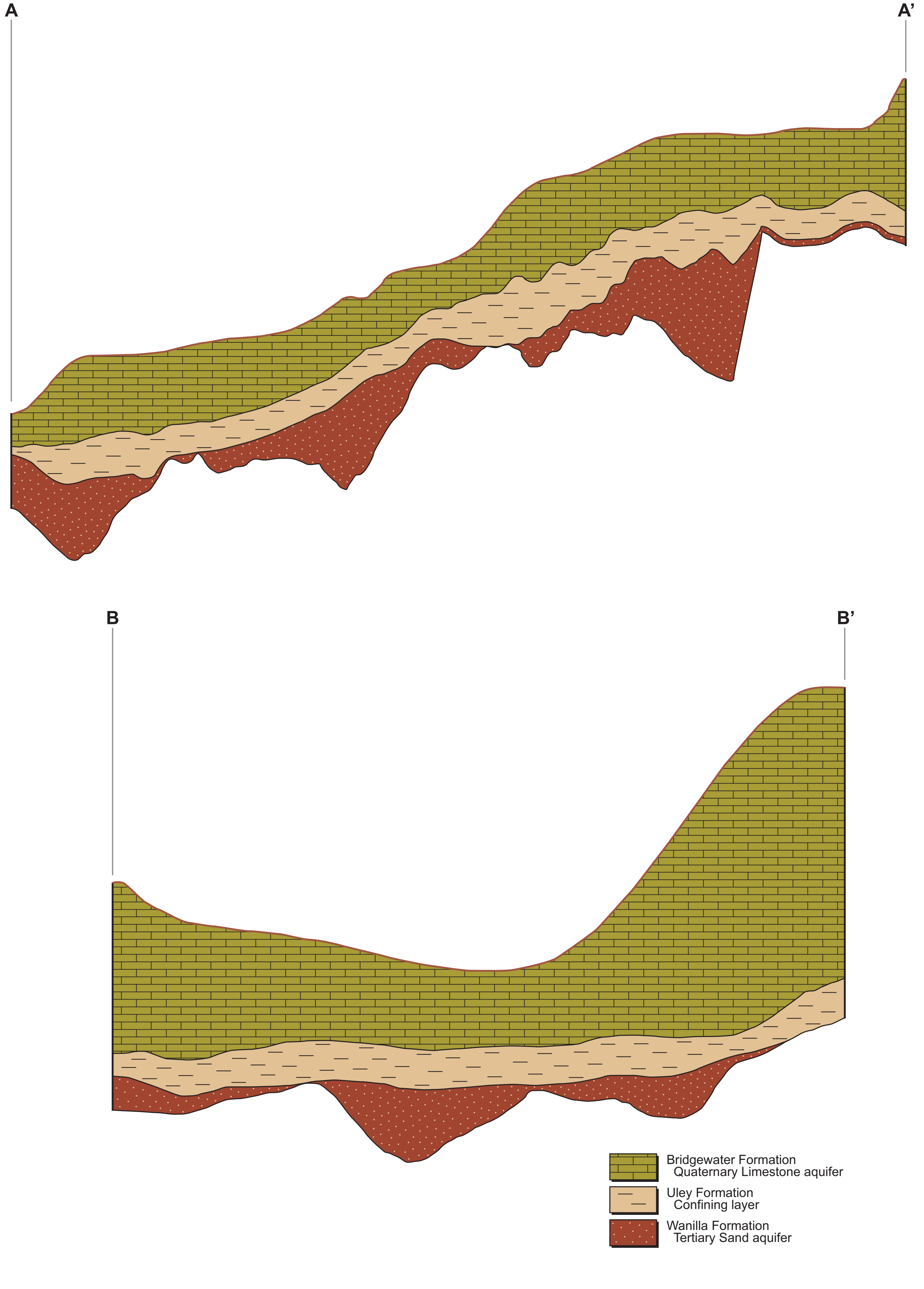

Figure 5. Uley Basin cross-sections showing model layers (from model)

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4.2.1 MODEL LAYERS

The model was constructed using elevations interpolated from available topographic maps, geological maps, geological logs and drillers logs.

4.2.1.1 Ground surface elevations

The ground surface elevation was interpolated from regional ground surface elevation data obtained from GIS land topography coverage (DEM_250) using the GMS software by the Kriging technique (AUSLIG 2001). The density of the source data points used to create the DEM and the horizontal resolution of the final DEM warrant that the DEM be considered as having a scale of ~1:250 000. Elevation accuracy of the coverage depends on slope, with higher errors in steep and complex terrains (errors are within the 7.5–20.0 m range).

4.2.1.2 Layer 1: Quaternary Limestone aquifer

Layer 1, the top model layer, represents the unconfined QL aquifer (Table 2). The elevation of the Uley South lens ranges from below 20 m AHD in the central portion, up to 140 m AHD at the west, north and east boundaries. The Uley Wanilla and Uley East areas rise from 60–70 m AHD in the south to a flat to undulating plateau at ~100 m AHD in the north. Specific information includes:

- Over most of the area, the unconfined aquifer is represented by the QL. The elevation of the top of Layer 1 was set equal to the elevation of the land surface. The base of Layer 1 is the base of the QL (Bridgewater Formation).
- The coastal dunes are present only in the southwestern portion in the Uley South lens.
- Groundwater in the QL occurs as lenses, namely Uley East, Uley Wanilla and Uley South. These lenses are separated by areas of high topographic elevation in which the QL aquifer is dry or marginally saturated.
- Base elevations at well sites were determined from geological and drillers logs (interpreted by S. Evans, DWLBC) and extrapolated across the study area. The elevation of the base of Layer 1 (top of Layer 2) occurs between -33 and 136 m AHD (Fig. 6).

4.2.1.3 Layer 2: Tertiary Clay aquitard

Layer 2 represents the TC aquitard (Uley Formation; Table 2). Specific information includes:

- Base elevations at well sites were determined from geological and drillers logs (interpreted by S. Evans, DWLBC) and extrapolated across the study area. The elevation of the base of Layer 2 (top of Layer 3) occurs between -33 and 88 m AHD (Fig. 7).
- The clay is not continuous across the entire study area, with a number of areas identified in which the clay is absent (Evans 1997). Examples of such areas include the northwestern, southeastern and northeastern portions of the Uley South lens area.
- In the northern portion of the Uley Wanilla lens, most of the Uley East lens, and western part of the Uley South lens, the TC has been identified but its thickness is not known. A range of approximate thickness values of 10–20 m was assigned to Layer 2 in these areas. This value was based on the average thickness of the TC located in south of the study area.

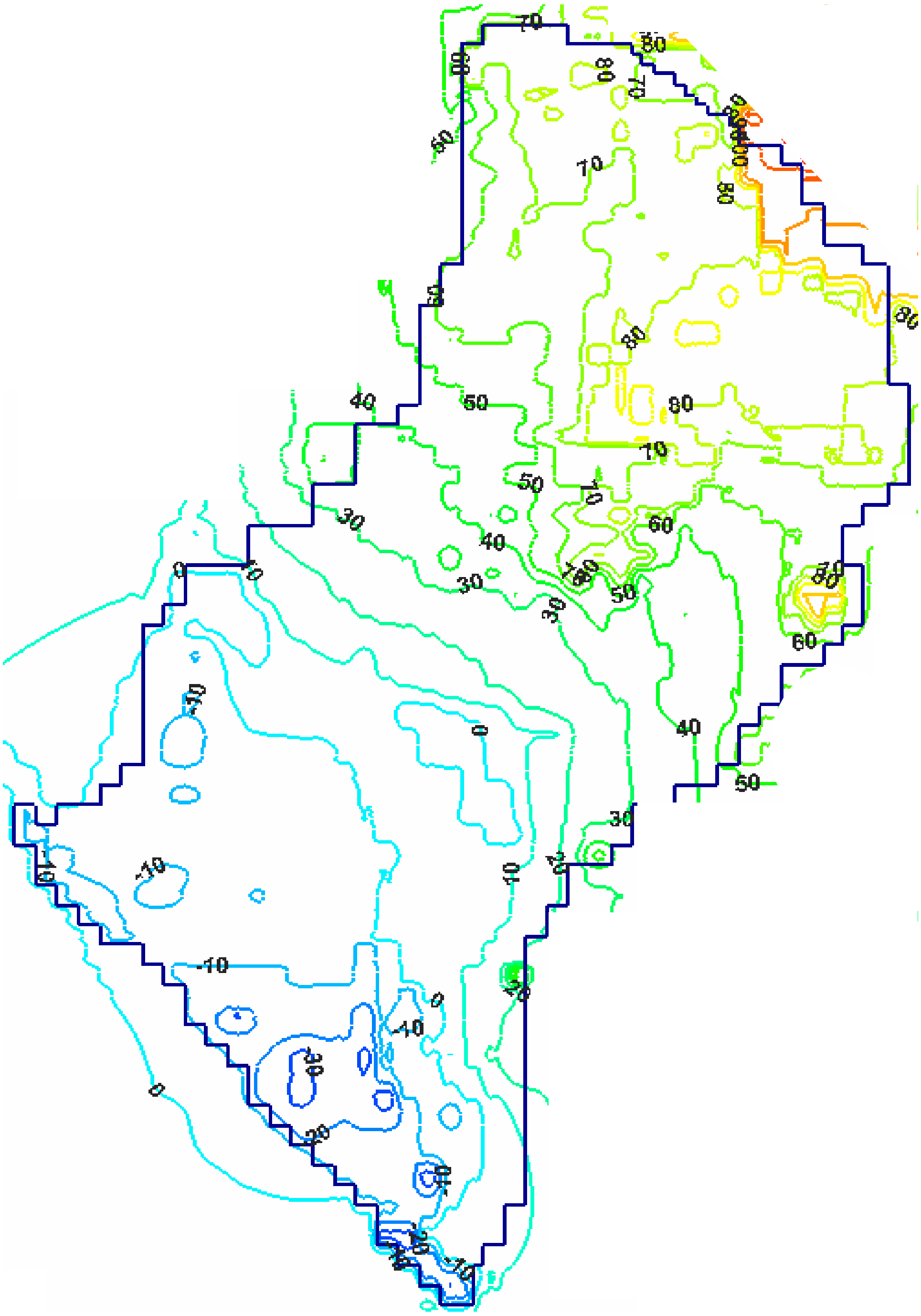


Figure 6. Bottom elevations (m AHD), QL aquifer, Uley Basin

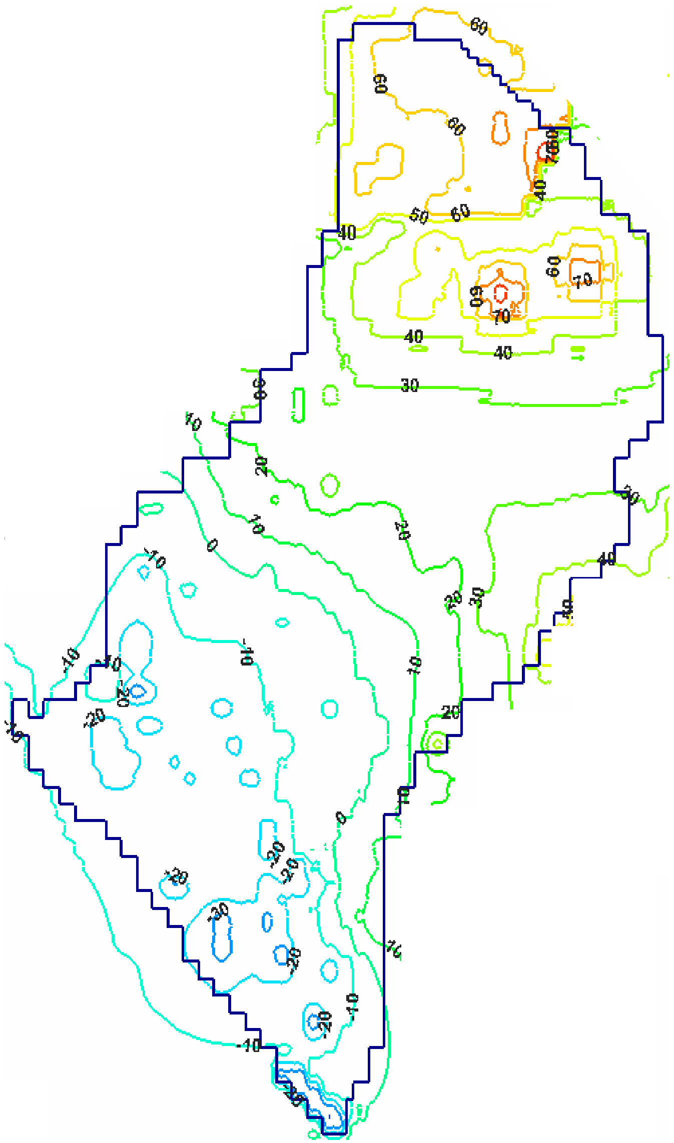


Figure 7. Bottom elevations (m AHD), TC aquitard, Uley Basin

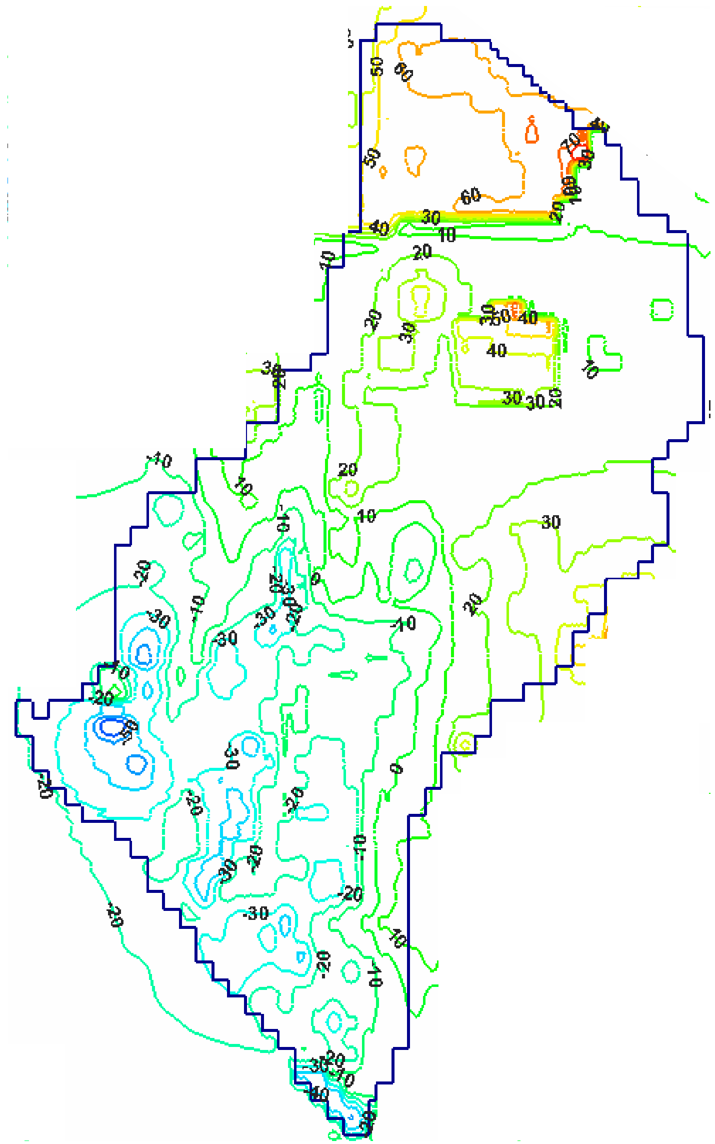


Figure 8. Bottom elevations (m AHD), TS aquifer, Uley Basin

4.2.1.4 Layer 3: Tertiary Sand aquifer

Layer 3 represents the confined–unconfined TS aquifer (Wanilla Formation). In areas where the TC is absent, the TS aquifer is in direct contact with the QL aquifer and is unconfined. In the rest of the area, this aquifer is considered to be confined. Specific information includes:

- Base elevations at well sites were determined from geological and drillers logs (interpreted by S. Evans, DWLBC) and extrapolated across the study area. The elevation of the base of Layer 3 occurs between -64 and 86 m AHD (Fig. 8).
- The sand layer is not continuous across the entire study area, with a number of areas identified in which it is absent (Evans 1997). In order to satisfy the model layer continuity requirement of MODFLOW, a model layer thickness of 0.01 m was assigned in areas where the TS is absent.
- The lateral extent and thickness of the TS aquifer in the north of the Uley Basin is not well known. The TS layer was modelled as a constant thickness in this area, with thickness based on that in the south of the study area.

4.3 TIME DISCRETISATION

The groundwater flow in the study area was simulated from September 1949 (pre-development period) to September 2005. The historic 56 year simulation period enabled calibration of 56 years of observed historical records from Uley Wanilla and Uley East, and 45 years from Uley South. Steady state conditions assumed to exist prior to 1949 were simulated before the transient simulation of the 1949–2005 historic period.

All years of the simulation are assumed to be 365.25 days long. Each year was divided into two stress periods representing winter and summer seasons. The winter stress periods represent average stresses for the months of May–September, and summer stress periods represent average stresses for the months of October–April. This is based on Evans' (1997) proposal that for there to be a net rise in groundwater level in the QL aquifer during the year, there needs to be at least 10 days of rainfall greater than 10 mm during the May to September period. These periods also coincide with the groundwater pumping intensity, which is significantly reduced during winter periods. The summer and winter stress periods were 210 and 155 days in length, respectively. The summer stress period was divided into seven equal time steps, each 30 days in length, and the winter stress period was divided into five equal time steps, each about 31 days in length.

The model also allows for 15 years of predictive modelling, from 2005–20.

4.4 MODEL HYDRAULIC PARAMETERS

Estimates of QL aquifer transmissivities in the Uley South region are an order of magnitude greater than in the Uley Wanilla region and highly variable, ranging between 680–13 000 m^2/d. Specific yields for Uley South were estimated using watertable recovery curves by Evans (1997) to range between 0.03 and 0.17. Painter (1969) estimated specific yields to be in the order of 0.3.

Estimated hydraulic conductivities of the QL aquifer in the Uley Wanilla lens range between 11–52 m/d. Specific yields for the Uley Wanilla and Uley East lenses were estimated from watertable recovery curves by Evans (1997) to be in the range of 0.01–0.12 and 0.03–0.1, respectively. There is currently no QL aquifer transmissivity data available for the Uley East lens.

Ranges of hydraulic parameters derived from previous reports are presented in Table 3. The hydraulic properties for all hydrostratigraphic units based on the values presented in the table were initially allocated to the model layers (refer to Map 5, Volume 1 of the report for test sites details).

Table 3. Calculated hydraulic properties, Uley Basin

Lens	Aquifer, aquitard	Hydraulic conductivity		Storage		Reference
		K_h (m/d)	K_v (m/d)	S_y tests	S_y rainfall	
US	QL	150–1370		0.03–0.7		Painter (1971); Selby (1974); Barnett (1978)
US	QL				0.11–0.17	Evans (1997)
US	TS	22		0.007		Morton & Steel (1970)
US	TC		6.8×10^{-4}			Morton & Steel (1968)
UW	QL	10–65		0.02–0.35		Painter (1971); Barnett (1978)
UW	QL				0.05–0.12	Evans (1997)
UE	QL				0.07–0.10	Evans (1997)

The final hydraulic parameter ranges are given in Table 4; the spatial distribution of each layer is given in Figures 9–11. The horizontal hydraulic conductivities in the Quaternary deposit simulated in Layer 1 ranged from 5–1400 m/d. The horizontal hydraulic conductivity values in the Tertiary deposits simulated in Layers 2 and 3 ranged from 0.0048 to 150 m/d. Vertical hydraulic conductivity for the entire model is simulated as a constant factor of one-tenth of horizontal hydraulic conductivity at each cell grid.

Some of the initial hydraulic conductivity and storage coefficient values were modified within appropriate ranges during both steady state and transient model calibration in order to achieve the best-fit models. On the basis of general groundwater flow pattern, lithological description and limited aquifer test data, the domain was subdivided into zones, each having a different hydraulic conductivity and storage coefficient. The hydraulic conductivity of each zone was assumed to be isotropic (i.e. K_x=K_y). In some zones, the hydraulic conductivity values had to be chosen carefully. For example, highly conductive zones A, B, C and D (Fig. 10) in Layer 2 required high hydraulic conductivity values so that sufficient inter-aquifer flow could be simulated, given that the lithology at these zones is sand. It is believed that these zones provide a conduit for sufficient inter-aquifer flow. Zones marked ABS in Figure 11 were zones where the TS aquifer was absent, and were subsequently considered as inactive cells.

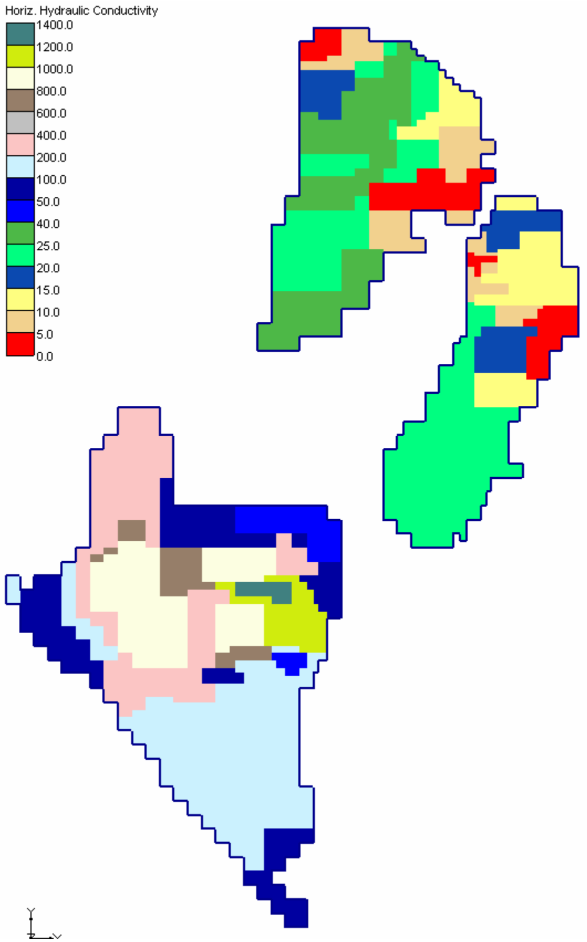


Figure 9. K_h **spatial distribution, QL aquifer, Uley Basin**

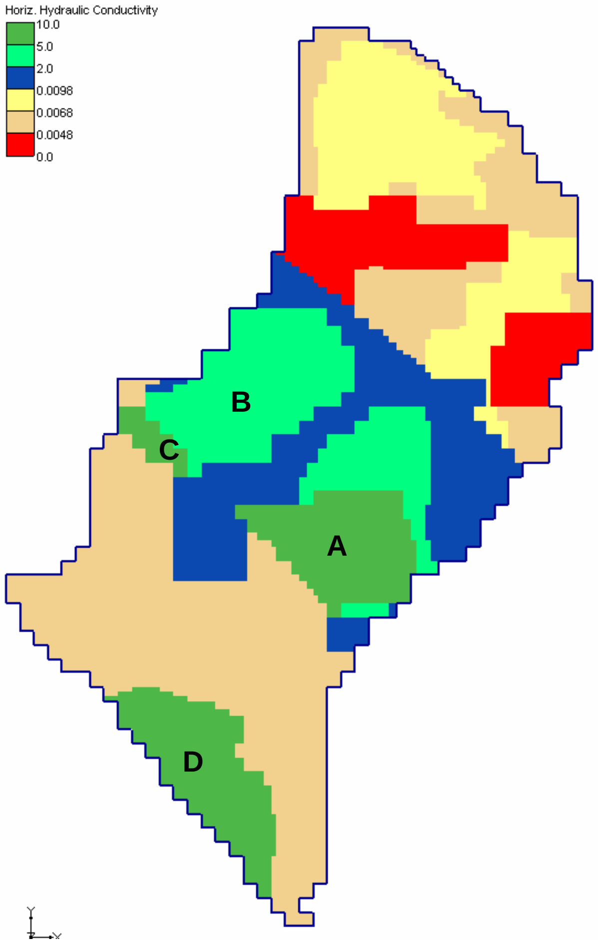


Figure 10. K_h **spatial distribution, TC aquitard, Uley Basin**

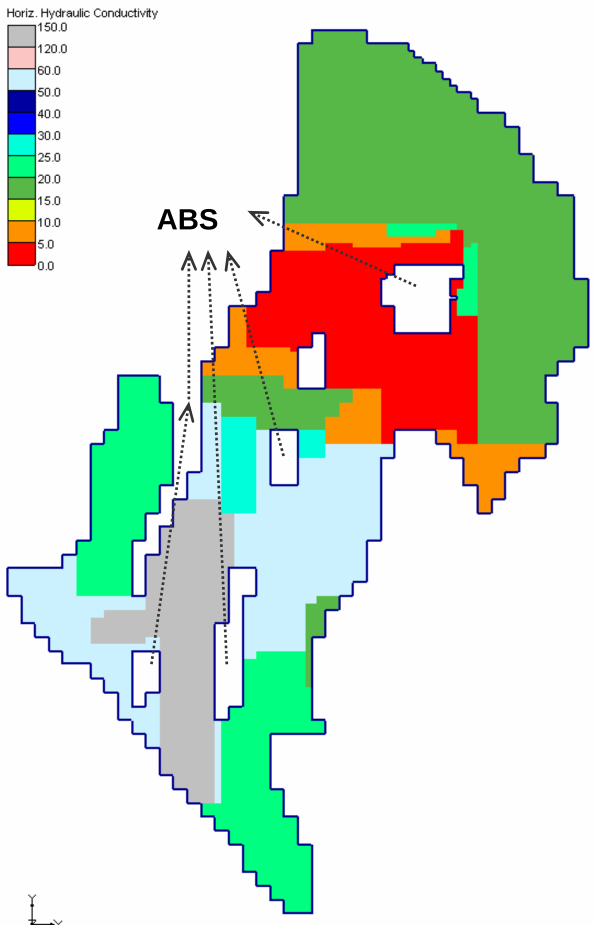


Figure 11. K_h **spatial distribution, TS aquifer, Uley Basin**

Table 4. Model hydraulic properties, Uley Basin

Aquifer, aquitard	Layer	Hydraulic conductivity		Storage	
		K_h (m/d)	K_v (m/d)	Sy	Ss
QL	1	5–1400	0.5–140	0.1–0.3	
TC	2	0.0048–10	0.00048–5		0.0001–0.001
TS	3	5–150	0.5–15	0.15	0.0001

4.5 RECHARGE

Eyre Peninsula is a semi-arid area that experiences cold, wet winters and hot, dry summers. The average rainfall is 560–570 mm/y and pan evaporation is 1130–1610 mm/y.

Since the early 1940s, numerous studies have been undertaken to determine recharge rates, with application of different recharge estimation techniques. Estimated recharge values varied from 40–350 mm, with the most recent values determined to be between 50–160 mm (Evans 1997).

The majority of rainfall recharge estimates give an indication of average annual recharge rates, but the large variability in annual rainfall and rapid response indicate that average annual recharge rates cannot be used in water balance calculations to match hydrograph responses or predict future groundwater levels under various management and climatic scenarios. Due to a generally good agreement with the methods of Evans (1997), it is considered that the limiting winter rainfall recharge estimation method of Barnett (1978) was the most appropriate in provision of estimates of recharge rates.

Recharge rates also vary spatially between 0.15–100 mm, and are dependent on soil type, topography and land cover. The initial recharge rates used in the steady state model as well as the zones were obtained from Evans (1997) and are shown in Figure 12. Recharge was applied to the top active layer at each cell, and during pre-development was simulated as the long-term average recharge. Recharge of 0.15 mm was applied to all areas of unsaturated limestone outside the lenses except in an area north from Uley Wanilla and Uley East.

For a given time step, areal recharge was modelled as essentially constant over each recharge zone; through time, however, the recharge was varied in order to represent the portion of rainfall infiltrating the groundwater system for the given stress period (App. A). Hence, for simulating temporal variation in recharge from rainfall, recharge rates were estimated as the difference between winter or effective rainfall (May–October) and a specified base winter rainfall; in this case a value of 250 mm was adopted. The annual rainfall and annual winter rainfall were obtained from the Bureau of Meteorology (BoM) SILO website (BoM 1997–2006).

This method allowed the model to account for seasonal variations in infiltration rate and resulting rise and fall (decline) of water levels in observation wells. The approach produced very good results for years of average rainfall; extremely wet years had to be modified by increasing the recharge up to 80%. More details are provided in Chapter 5.3 (Transient model calibration).

It is assumed that summer rainfall does not contribute to the recharge.

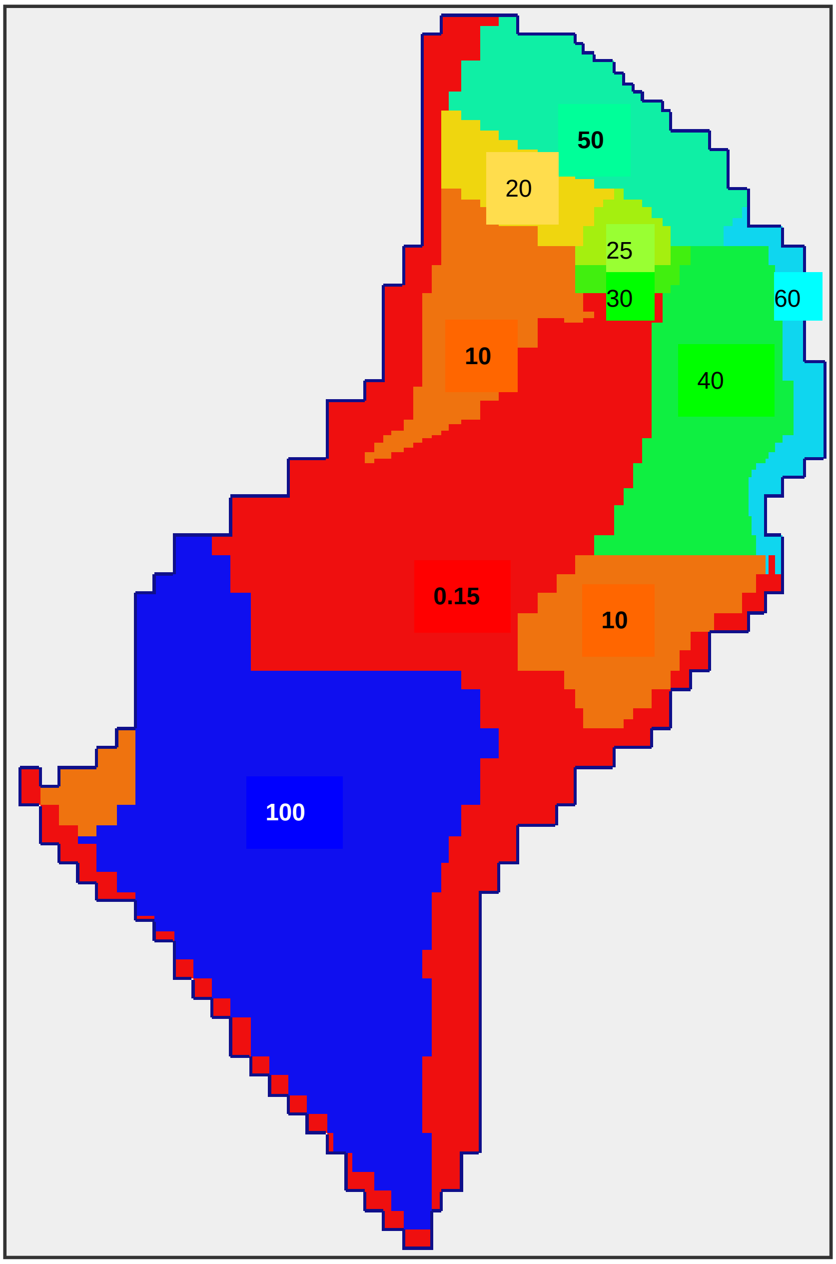


Figure 12. Recharge zones and values (mm/y), Uley Basin

4.6 GROUNDWATER EXTRACTIONS

SA Water supplied extraction data for the 28 town water supply wells, 11 of which are located in Uley Wanilla and 17 are located within three bore fields in Uley South (Fig. 13).

The provided data for periods 1949–2005 for Uley Wanilla and 1976–2005 for Uley South were given as monthly totals for all wells in each lens (Fig. 14). Total average yearly extraction from Uley Wanilla is ~1200 ML. Total average yearly extraction from Uley South was 5000 ML until 1999, when the wellfield was augmented to allow up to 8000 ML average annual extraction. The maximum extractions from Uley Wanilla were 2800 ML in 1961 and 7900 ML from Uley South in 2000.

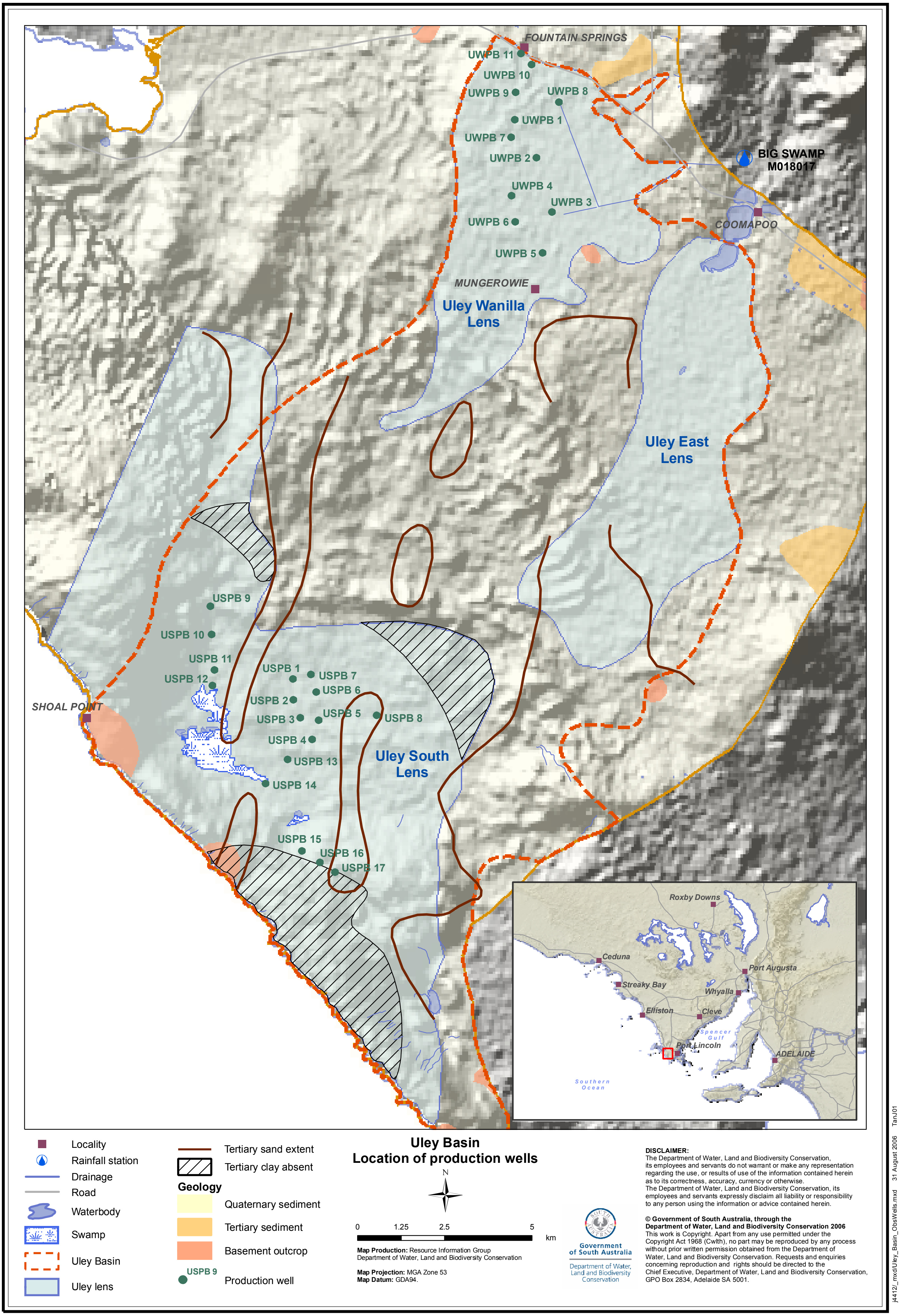


Figure 13. Location of production wells, Uley Basin

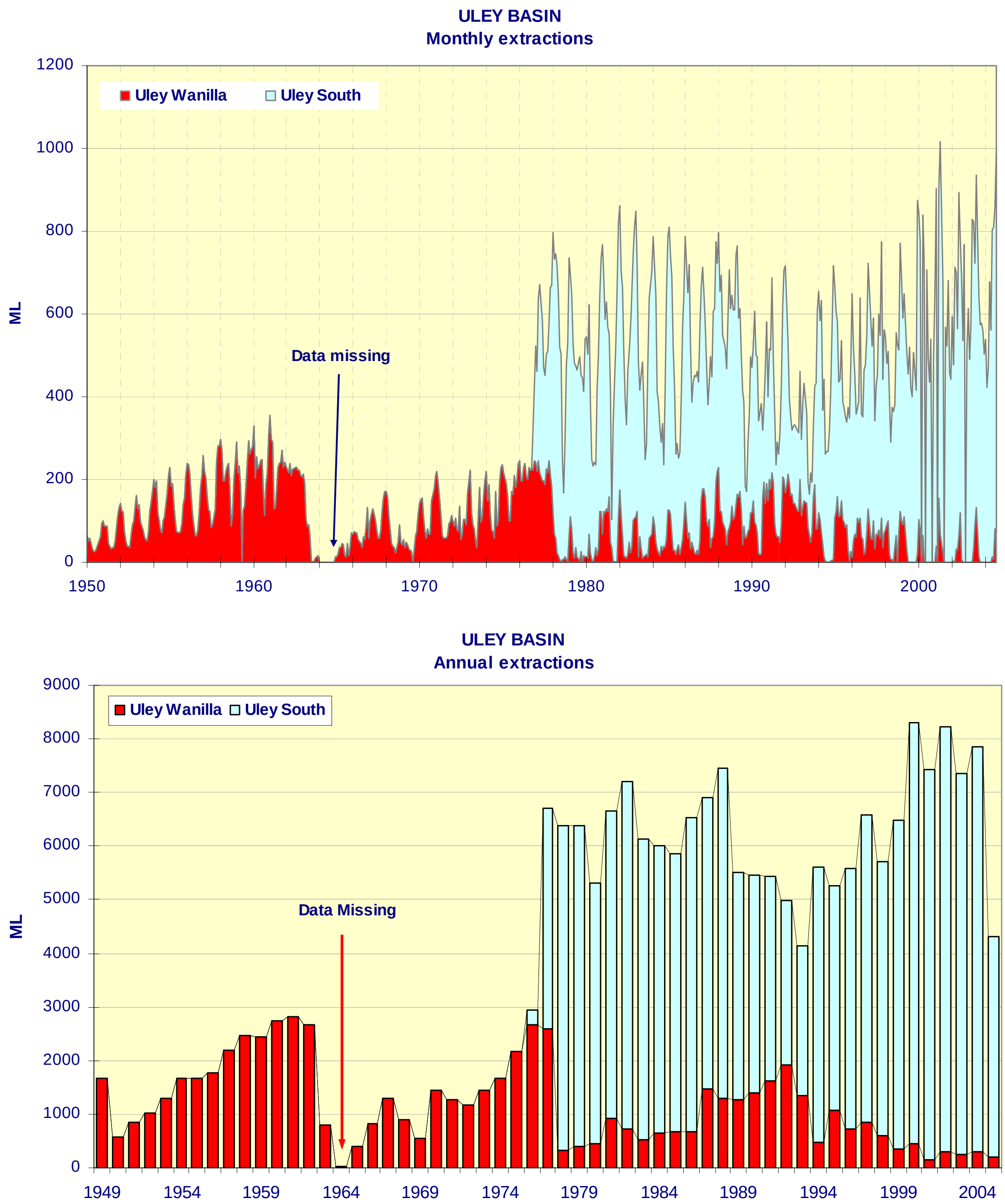


Figure 14. Annual and monthly groundwater extractions, Uley Basin

However, during 1998, 1999 and 2001, sporadic monthly extraction data were used to estimate long-term extraction percentage for each well and was extrapolated back for the whole modelling period. This resulted in:

- estimations of specific (unique) extraction amounts for each well
- distinctively different summer and winter extraction rates for both lenses.

The extrapolated data are presented in Appendix B.

4.7 EVAPOTRANSPIRATION

There have been no studies of evapotranspiration in the Uley Basin and, given the dense vegetative cover across the basin, this is likely to be a large part of the water balance for the basin. A swampy area of ~0.85 km^2 occurs just inland of the coastal cliffs in the Uley South lens and is known to be inundated during periods of intensive rainfall. Although evapotranspiration may be a significant process there, the area itself is relatively small in relation to the whole basin area, with irregular inundations occurring only during winter. The magnitude of evapotranspiration from this swamp region is negligible.

4.8 MODEL BOUNDARIES

The boundary conditions described how water enters or leaves the simulated aquifer system. Four different boundary conditions:

- no-flow boundary
- specified flow boundary
- general head boundary (GHB)
- constant head boundary (CHB)

were applied to simulate two aquifer systems and their hydraulic connectivity. Boundary conditions for all layers are presented in Figure 15.

Monitoring of water levels began in the early 1940s in Uley Wanilla and Uley East, and in 1962 in Uley South. The general groundwater flow direction and gradient determined from September 1940 and September 1963 measurements were used to estimate the water level for the constant head, while the general head boundaries were determined through model calibration.

The model incorporates the surface water interaction of the Big Swamp by using specified flow boundary conditions (injection wells) to represent intermittent recharge into the QL aquifer. The topmost active cells were simulated as “free surface”, allowing water to enter the system by way of recharge from rainfall.

4.8.1 LAYER 1: QUATERNARY LIMESTONE AQUIFER

The regional groundwater flow is from the northeast to the southwest where it discharges to the ocean. In Uley South, discharge occurs towards sand dunes in the west, while in Uley Wanilla discharge is towards the north, in the Fountain Springs area. Accordingly, Layer 1 was simulated using:

- No-flow boundaries on the perimeter of the model to simulate conceptualised groundwater flow parallel to groundwater flow paths from northeast to southwest.
- Constant head boundary to simulate groundwater outflow to the ocean in Uley South lens.
- General head boundaries to simulate conceptualised groundwater flow to and from the sand dunes located in the west of Uley South and in the Fountain Springs area in Uley Wanilla.
- Specified flow boundary (by the use of injection wells) to simulate conceptualised intermittent recharge from the Big Swamp in the Uley East lens.

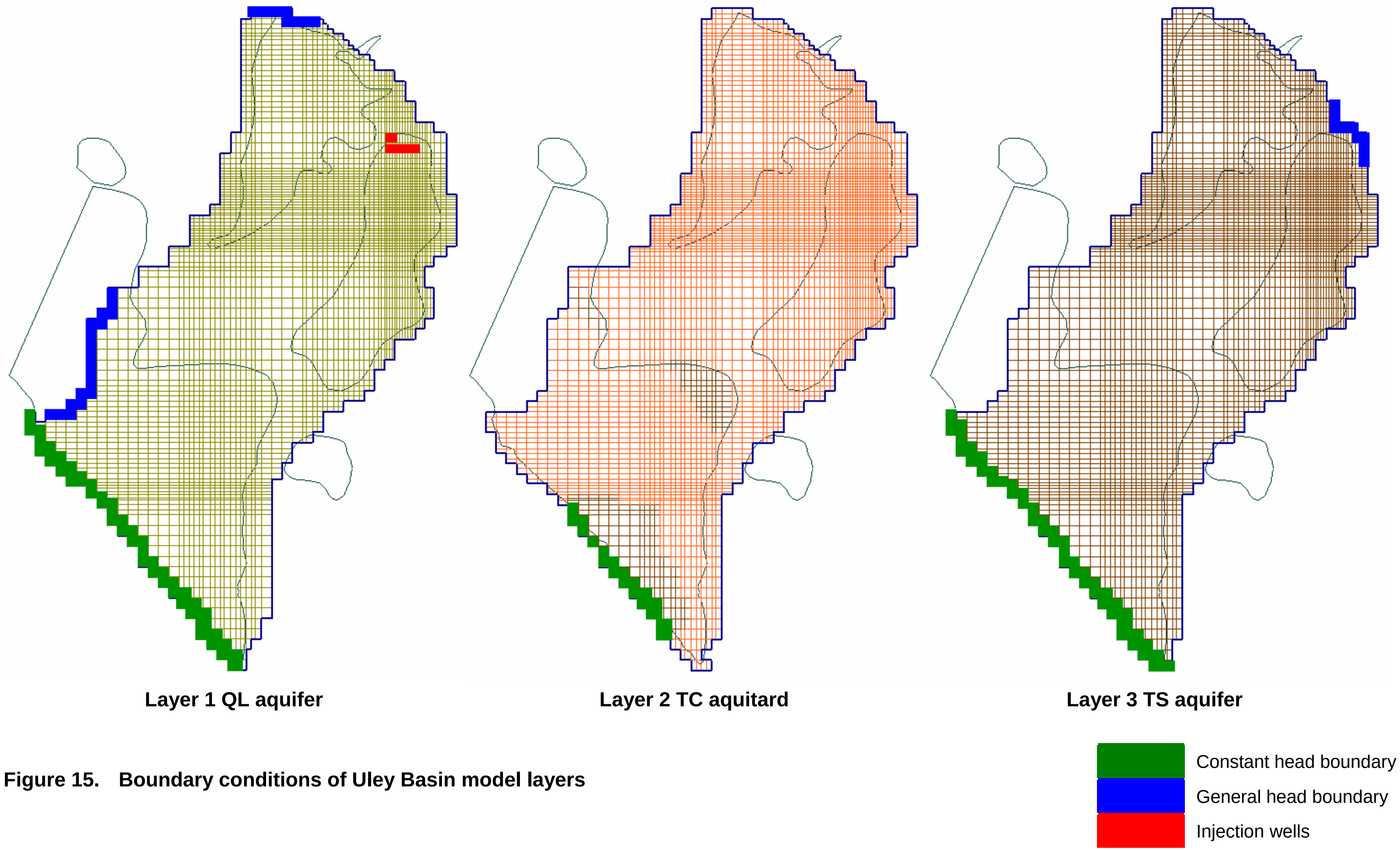


Figure 15. Boundary conditions of Uley Basin model layers

- Specified flux boundary to simulate conceptualised recharge due to infiltration from rainfall to the aquifer system by using the recharge package of MODFLOW-2000.
- Inactive grid cells in areas where the QL is unsaturated (or dry). The areas where this aquifer is unsaturated or dry are separated from the rest of the domain using no-flow boundary conditions.

4.8.2 LAYER 2: TERTIARY CLAY AQUITARD

It is assumed that very small volumes of water move laterally into and out of this layer due to its low permeability. Therefore, the lateral boundaries of Layer 2 were simulated as:

- No-flow boundary at the model edges except at the southern boundary where clay is absent.
- Constant head boundary was used to simulate conceptualised groundwater outflow to the ocean.

4.8.3 LAYER 3: TERTIARY SAND AQUIFER

The regional groundwater flow is similar to that in the QL aquifer, generally from the northeast to the southwest. The following boundaries are applied to Layer 3:

- No-flow boundary at the model edges where groundwater flow direction and path are conceptualised to be parallel to the model perimeter.
- Constant head boundary along the southern margins to simulate outflow to the ocean.
- General head boundary along portion of the northeastern boundary to simulate lateral flow to and from Layer 3.
- The bottom of Layer 3, the lowest simulated hydrogeological unit, was simulated as a no-flow boundary.

5. MODEL CALIBRATION

The groundwater flow models were calibrated by adjusting the value and distribution of model input parameters so that the resulting model output matched the measured water levels and other observed or determined hydrologic parameters within an acceptable level of accuracy.

Two stages of calibrations were carried out — steady state and transient. Observation data are available from the early 1940s for Uley Wanilla and Uley East, and from 1962 for the Uley South lens. During the calibration process, adjustments were made to the model parameters and boundary conditions to enable the models to approximate the observed pre-development and stressed conditions. Changes to the model hydrogeological parameter values were evaluated during the calibration process to assure that the changes were within the acceptable range of variability of the parameter as reported by previous investigators (Harrington et al. 2006; Evans 1997; Barnett 1978; Selby 1974; Morton & Steel 1968, 1970; Painter 1971); these are listed in Table 4. After each change in model parameter value, model output was generated and compared to the measured data to evaluate the effect of the selected parameter. The model's accuracy was calculated using the Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Mean Error (ME) comparison between the simulated and observed water levels. Each of these statistics was calculated within the GMS modelling environment.

The standard trial-and-error method was employed during calibration. The models were considered calibrated when the following criteria were satisfied:

- Incremental parameter changes in model input did not result in smaller RMSE for model Layers 1 and 3, and the ME was close to zero.
- The simulated groundwater head and flow directions in the model compared favourably to those determined from water level measurements and previously published potentiometric surface maps for the QL and TS aquifers.
- The simulated fluxes compared favourably to estimated values.
- The model calculated water budget compared favourably to estimated values.
- The simulated transient water levels and measured water levels during the transient calibration period react to the effects of variable stresses throughout time in a logical manner throughout the simulation.

5.1 STEADY STATE MODEL CALIBRATION

The steady state (pre-development) conditions for Uley East and Uley Wanilla regions were simulated using water levels measured in September 1942, while the steady state pre-development conditions for the Uley South region were simulated using water levels measured in September 1963. The potentiometric surface maps constructed using September 1942 water levels for the northern lenses, and water level records in September 1963 for Uley South to represent pre-development conditions, are shown in Figure 3.

The steady state model was calibrated by trial-and-error adjustment of hydraulic conductivity values (within reasonable limits) and boundary conditions until potentiometric heads matched pre-development water levels and observed heads. The model was initially simplified with uniform hydraulic conductivity for each model layer and a uniform constant recharge. As calibration proceeded, complexity was systematically integrated into the model to improve the model output and to better represent the actual conditions. This was achieved by increasing the variability of hydraulic conductivity and recharge, and adjusting other hydrogeological parameters of the model to the extent supported by available data and the conceptual model. The calibrated horizontal hydraulic conductivity values and zones used in the models are shown in Figures 9–11, and the calibrated steady state recharge values and zones are shown in Figure 12.

Initially, all the cells in the original active zones in the model were assumed wet throughout. However, some of the model original active cells became dry during the simulation and calibration. Dry cells in these areas represent a watertable surface that is below the bottom elevation of the cell. The extent of dry cells in the model active area was monitored during the calibration process. It is conceptually valid that some of the initially active cells in the model would become dry during the calibration due to small geological unit thicknesses and steep elevation changes at the affected cells.

There are 102 calibration sites (observation wells) throughout the model area; 16 observation wells monitor the TS aquifer and 86 observation wells monitor the QL aquifer (Fig. 16). Figure 17 shows comparison between observed and simulated September 1942 and September 1963 potentiometric surfaces representing the steady state pre-development conditions in Uley South, Uley East and Uley Wanilla.

The observed water levels and simulated hydraulic heads in the QL and TS aquifers prior to groundwater development are plotted along 1:1 correlation lines in Figure 18. The statistical comparison between the simulated and measured values for the steady state model was done by using water level data from the observation wells to quantitatively assess the steady state calibration match (App. C).

The distribution of ME, MAE and RMSE in the calibrated steady state model is shown in Table 5.

Table 5. Steady state calibration error summary, Uley Basin model

Model layer, aquifer	ME (m)	MAE (m)	RMSE (m)
QL overall	0.28–(0.08[1])	0.47–(0.28[1])	1.59–(0.39[1])
TS overall	-0.37–(0.02[2])	0.83–(0.5[2])	1.25–(0.63[2])
Lens			
Uley South	0.1	0.29	0.39
Uley Wanilla	0.6–(0.04[1])	0.88–(0.31[1])	2.94–(0.73[1])
Uley East	0.23	0.34	0.49

[1]without well ULE 171 [2]without wells ULE 198 and ULE 84

The RMSE for QL aquifer for all lenses is 1.59 with an ME of 0.28, but when well ULE 171 is not considered these values become 0.39 and 0.08, respectively. Similarly, RMSE for TS aquifer overall is 1.25 with an ME of -0.37. When wells ULE 198 and ULE 84 are excluded, both RMSE and ME reduce dramatically to 0.63 and 0.02, respectively. The negative value for ME indicates that the simulated heads were generally lower than measured heads.

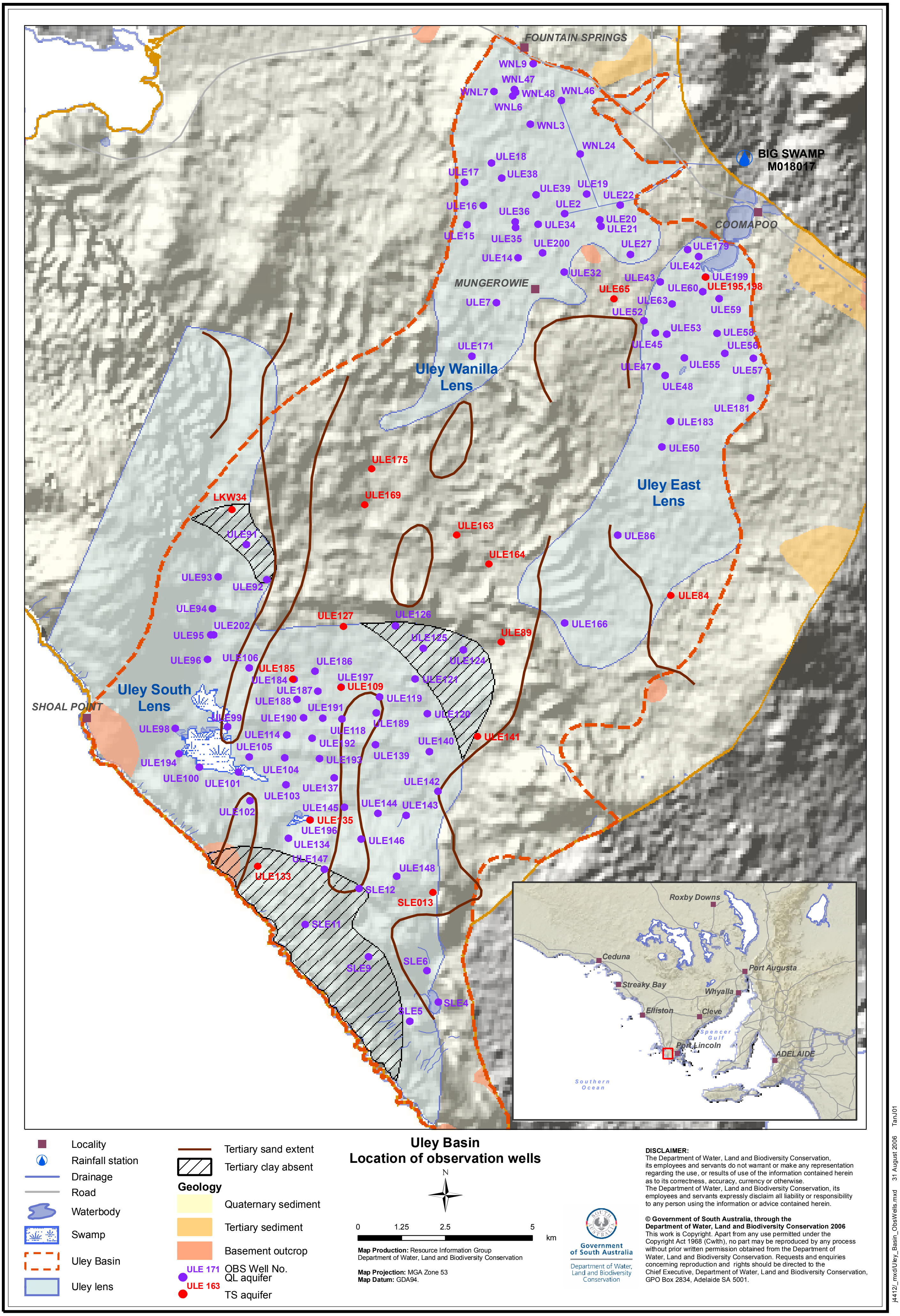


Figure 16. Location of observation wells, Uley Basin

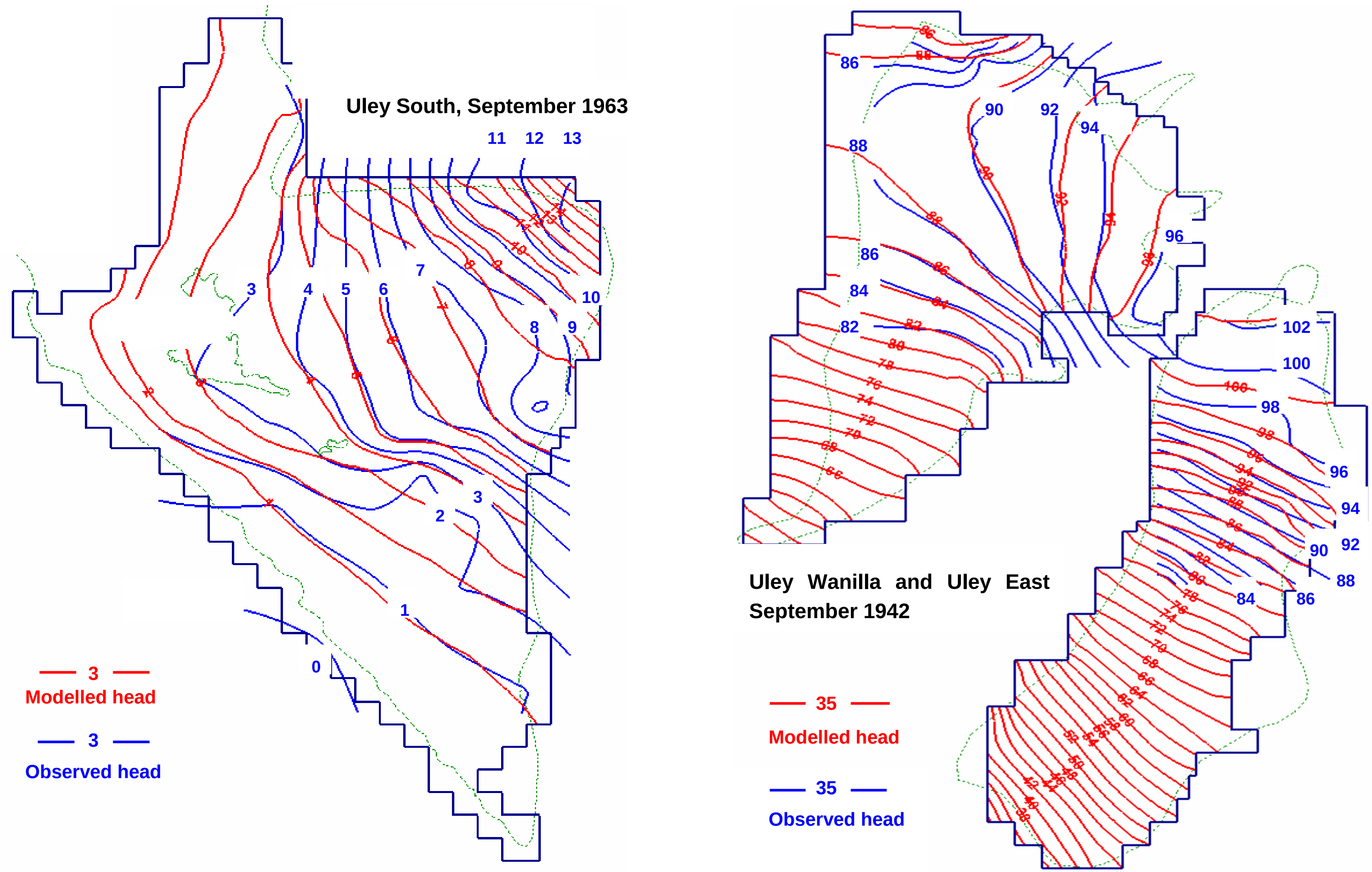
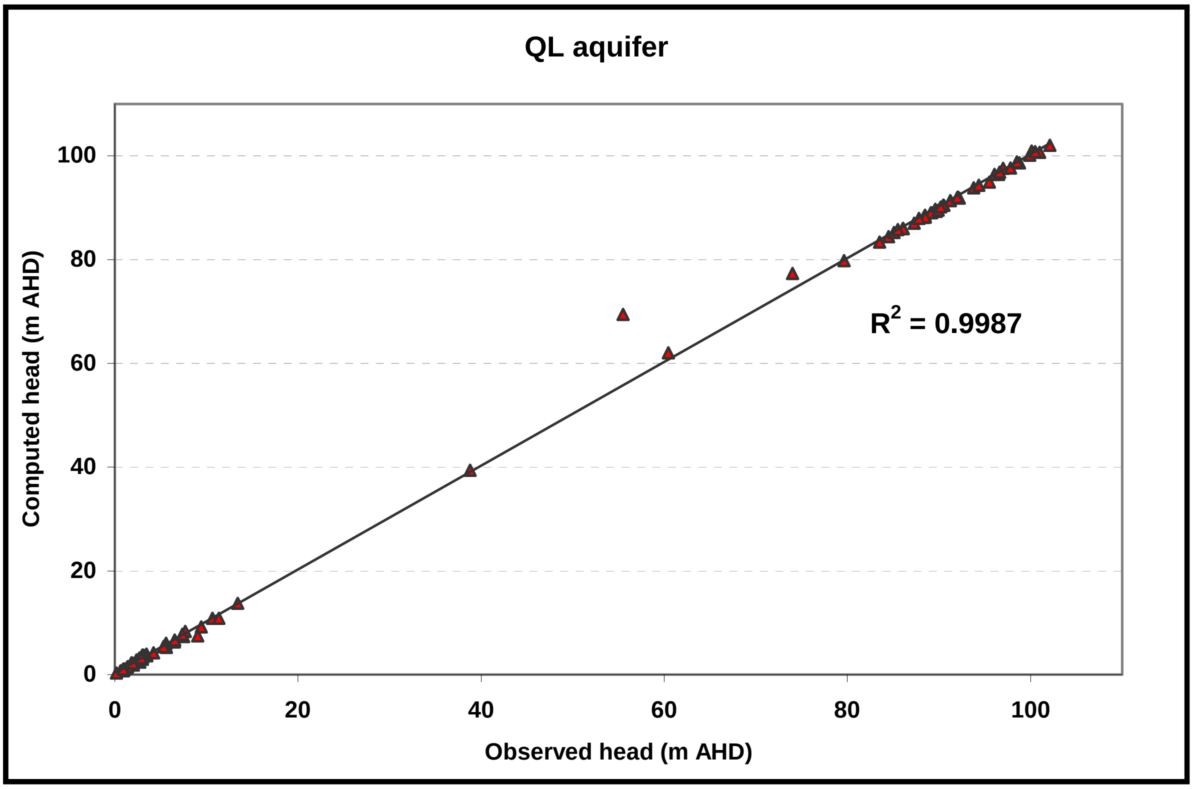


Figure 17. Calculated and observed potentiometric surface in the QL aquifer, Uley Basin



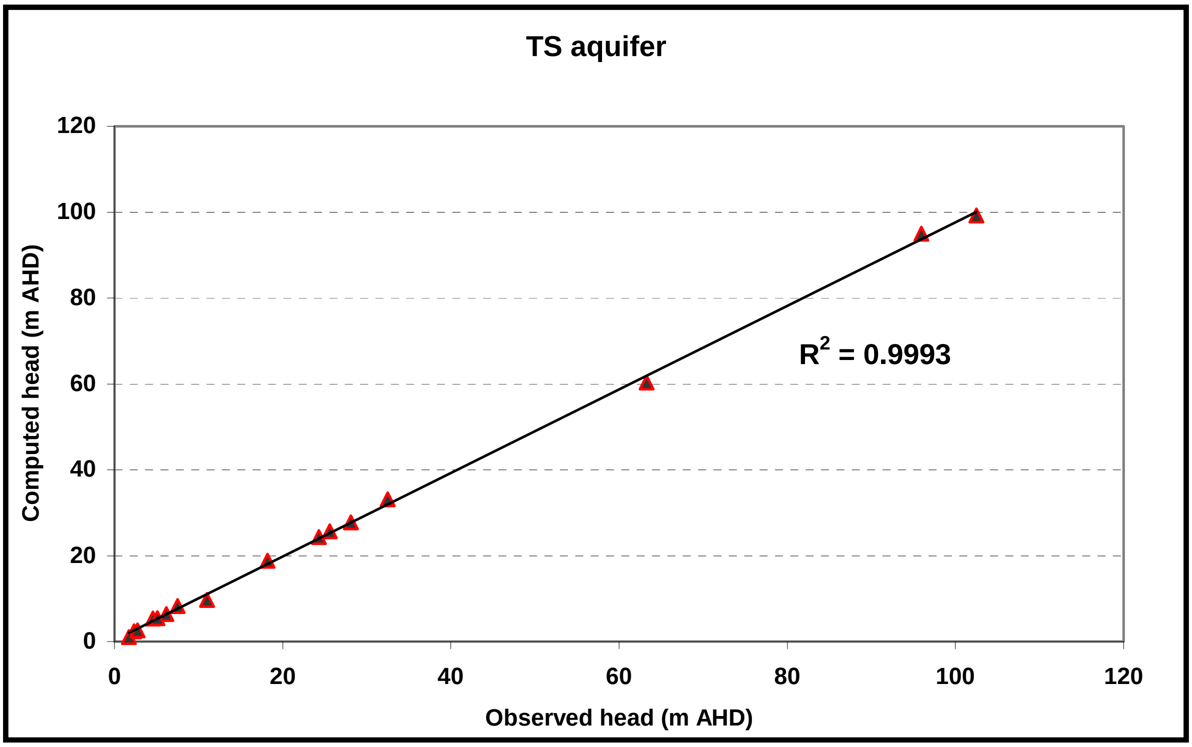


Figure 18. Steady state calibration results along 1:1 correlation line

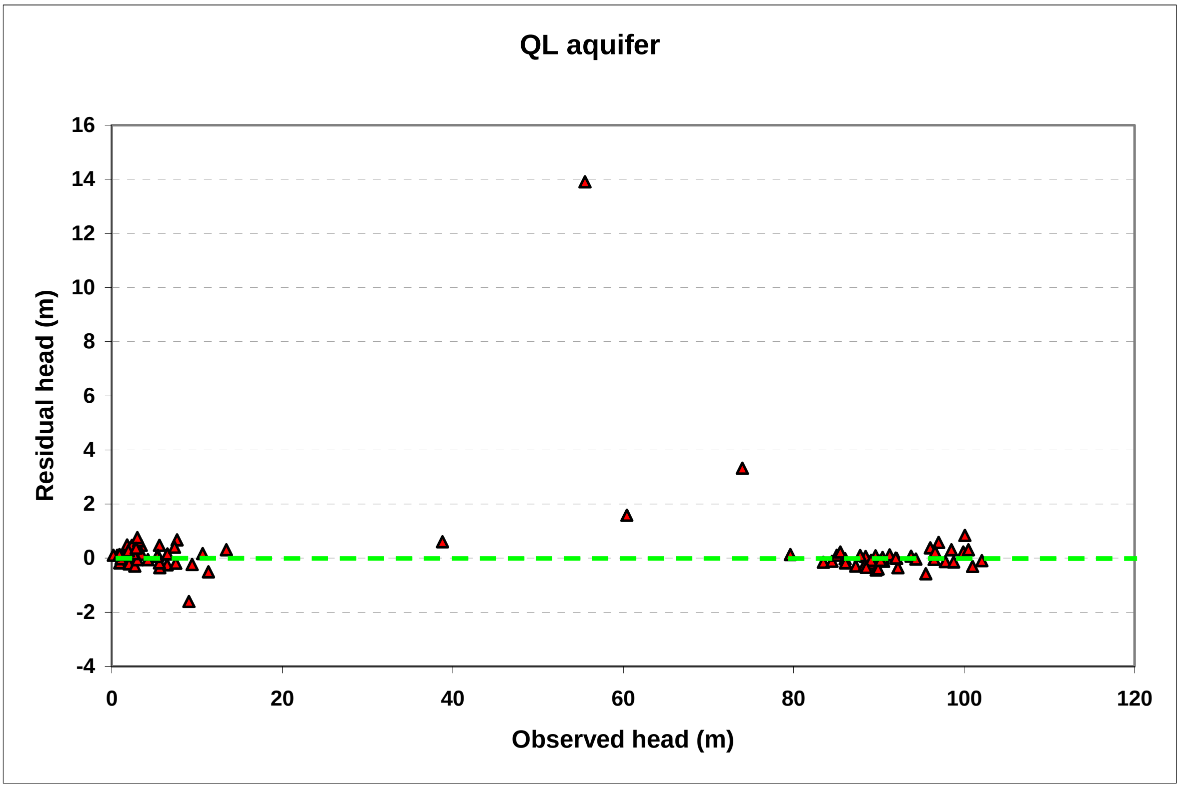
Since the level of available information and knowledge of hydraulic parameters and extent of each lens is different, it is more appropriate to analyse results separately for each lens, as presented in Table 10. After calibration, the simulated heads in Uley South were within 0.02 and 0.68 m of the observed (measured) water level, with RMSE of 0.39 and ME 0.1. The normalised root mean squared (RMS) value for the QL aquifer is 3.5% in Uley South, 0.75% in Uley East and 6.4% in Uley Wanilla, which are all less than or close to the 5% recommended by Middlemis (2000). The normalised RMSE for the TS aquifer is 1.25%.

The steady state model residuals are randomly distributed around zero, as shown in Figure 19. This indicates that the steady state model is generally unbiased. After calibration, the simulated heads in the QL aquifer were within 0.01 and 0.84 m of the observed water levels, with the exception of observation wells ULE 7 and ULE 171 in Uley Wanilla, ULE 86 in Uley East and ULE 142 in Uley South. ULE 142 is completed in the QL aquifer on the boundary of the Uley South lens where the TS aquifer is absent, and it seems that there is a local flow from the basement in the east. Other wells that could not achieve satisfactory calibration results are located in the southern parts of Uley Wanilla and Uley East where hydraulic properties of all layers are unknown and were estimated fairly roughly. The extent and thickness of the confining and TS layers were also based on a very broad assumption.

Calibration performance measures such as residual mean, residual standard deviation, minimum and maximum residual, sum of squares, head range and residual standard deviation/head range are the indicators if good calibration was achieved. The statistical values for both aquifers are presented in Table 6. It is accepted that good calibration is achieved when the residual mean is close to zero and the ratio of residual deviation to the overall range in head is <10%. The residual mean values are 0.28 and -0.37 for the QL and TS aquifers respectively, while the ratios are 1.54% for the QL aquifer and 1.22% for the TS aquifer.

Table 6. Calibration performance measures, Uley Basin model

Performance measures	QL aquifer	TS aquifer
Minimum residual	-1.60	-3.29
Maximum residual	13.91	0.77
Residual mean	0.28	-0.37
Sum of squared	217.33	24.99
Residual standard deviation	1.57	1.23
Head range	101.93	100.8
Residual standard deviation/head range ratio	0.015	0.012
Residual standard deviation/head range ratio (%)	1.54	1.22



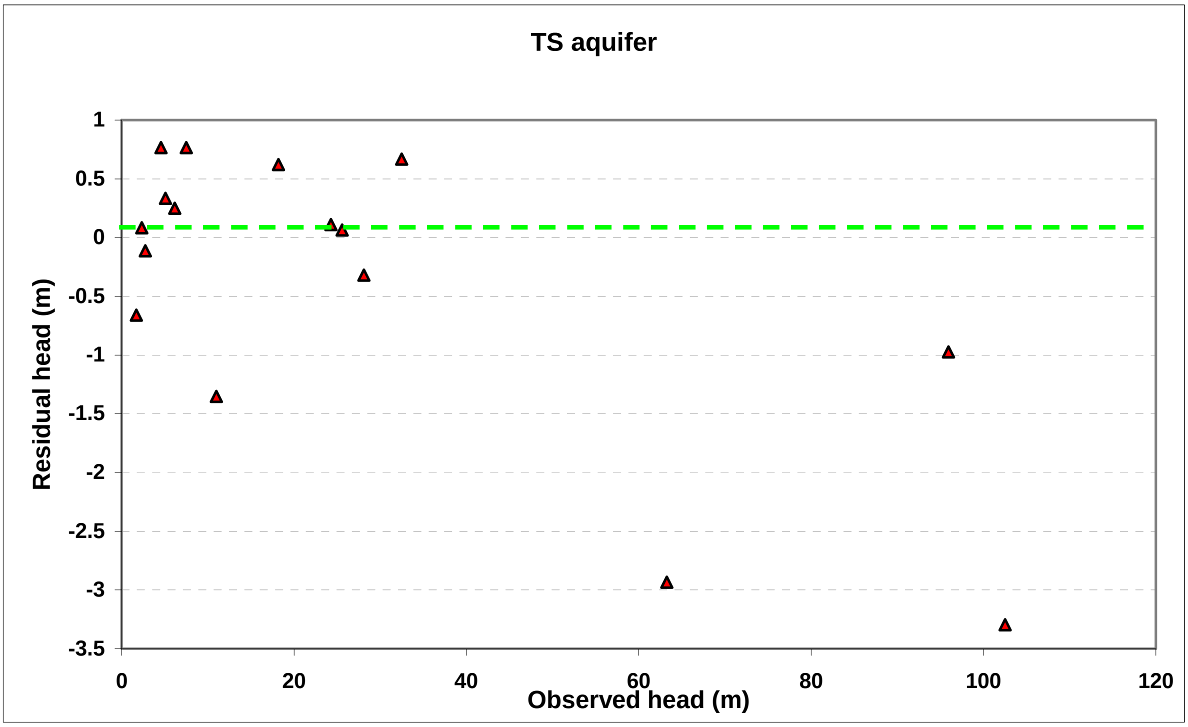


Figure 19. Steady state calibration results, residual versus observed heads

5.2 WATER BUDGET

Pre-pumping water balance steady state model outputs for the QL aquifer for each lens, as well as TS aquifer, provide an evaluation of all sources of supply and corresponding discharges in respect to aquifers and in comparison with previous water budget calculations.

The water budget for the calibrated steady state model was used to evaluate the model and determined if the model results were consistent with the conceptual model. The average annual water budget for the groundwater flow system for individual aquifers in the study area as calculated by the steady state model is given in Tables 7–10.

Table 7 shows the water budget for the QL aquifer in Uley South. The modelled outflow to the ocean is 18 658 ML/y for the entire coastal boundary. Evans (1997) estimated that 10 700 ML/y of groundwater was flowing from within the 1997 zone of influence of the Uley South QL aquifer wellfield into the ocean. From the same section used by Evans to estimate this outflow, the model predicts a total outflow of 9300 ML/y. A significant component of the inflow for the QL aquifer in Uley South is shown to be upward leakage, particularly in zones where the TC aquitard is absent. The model suggests that beneath this lens there is no downward leakage to the TS aquifer. The primary sources of inflow to the modelled Uley South lens are rainfall recharge (81.8%) and upward leakage from TS aquifer (18.2%). Model-calculated outflow from the Uley South lens consists of 66.7% to the ocean and 33.3% to the sand dunes southwest of the Uley South region.

Table 7. Flow budget for Uley South (ML/y)

INFLOW		OUTFLOW		
Flow source	**Model-calculated inflow**	**Flow source**	**Model-calculated outflow**	**Evans (1997)**
Recharge	22 886	Outflow to ocean	18 658	10 700*
Upward leakage	5 101	Outflow to the southwest (sand dunes)	9 329	
Total IN	**27 987**	**Total OUT**	**27 987**	**10 700***
IN–OUT	**0**			

*Outflow to the ocean between no-flow boundaries

The water budget summary for the QL aquifer for Uley East is presented in Table 8. The modelling exercise supports the assumption that the QL aquifer discharges at the southern extent of the lens, and indicates that there is upward leakage of ~474 ML/y in the northern portion of the lens. Rainfall recharge constitutes 81.9% of the total inflow to the Uley East lens, upward leakage from TS is 14.9% of total inflow, and inflow from Big Swamp is 3.2% of total inflow. Outflow consisted mainly of downward leakage of 3167 ML/y to model Layer 3 (TS aquifer).

Table 8. Flow budget for Uley East (ML/y)

INFLOW			OUTFLOW		
Flow source	**Model-calculated inflow**	**Evans (1997)**	**Flow source**	**Model-calculated outflow**	**Evans (1997)**
Big Swamp inflow	100	118			
Recharge	2 590	4 375*			1 410
Upward leakage	474		Downward leakage	3 163	
Total IN	**3 164**		**Total OUT**	**3 163**	
IN–OUT	**1**	**0.017%**			

*Harrington (2006)

Similarly, the QL aquifer in Uley Wanilla receives 555 ML/y inflow from upward leakage (or 17.7% of total inflow) at the northern extent of the lens, while the discharge immediately beneath the lens at the southern extent is estimated to be 2075 ML/y (66.2% of total outflow), as shown in Table 9. Rainfall recharge constitutes 82.3% of the total inflow to this lens. The discharge to Fountain Springs is 294 ML/y or 9.4%.

Table 9. Flow budget for Uley Wanilla (ML/y)

INFLOW			OUTFLOW		
Flow source	**Model-calculated inflow**	**Harrington et al. (2006)**	**Flow source**	**Model-calculated outflow**	**Evans (1997)**
Recharge	2 580	2 785	Fountain Springs (FS)	294	312
			Outflow at FS area	766	
Upward leakage	555		Downward leakage	2 075	2 790
Total IN	**3 135**	**2 785**	**Total OUT**	**3 135**	**3 102**
IN–OUT	**0**				

The conceptual model was based on an assumption that the TS aquifer discharges into the ocean. This outflow is calculated to be 2390 ML/y while the lateral inflow from the north is 2165 ML/y (Table 10). If recharge is derived from infiltration of rainfall in the Big Swamp catchment, with an area of ~40 km^2, this equates to a recharge rate of 50 mm/y.

Table 10. Flow budget for TS aquifer (ML/y)

INFLOW		OUTFLOW	
Flow source	**Model-calculated inflow**	**Flow source**	**Model-calculated outflow**
Lateral inflow	2 165	Flow to ocean	2 390
Recharge through limestone outside lenses	5 129	Upward leakage US (clay absent)	3 740
Downward leakage US	0	Upward leakage US	963
Downward leakage UE south	689	Upward leakage UE north	533
Downward leakage UW south	419	Upward leakage UW north	782
Total IN	**8 402**	**Total OUT**	**8 408**
IN–OUT	**-6**	**0.07%**	

5.3 TRANSIENT MODEL CALIBRATION

Transient calibration of the groundwater flow model to hydrologic conditions measured from 1949–2005 was completed by comparing the change in simulated water levels to the change in measured water levels at the observation sites. The model-calculated steady state heads were used as initial heads for the transient model runs. During the transient calibrations, adjustments were made to the model boundary conditions and hydraulic conductivity values and zones. Each time changes were made to the transient model, the steady state model was updated to reflect the latest parameter changes and re-run with the latest output being used as the starting point for the transient model. These adjustments improved both the steady state and transient simulation.

The transient model is similar to the final steady state model in that the model grid, aquifer geometry, boundary conditions (other than recharge) and hydraulic properties (with the addition of aquifer storage properties) are the same. Stresses, however, vary with time. The transient model was calibrated primarily by varying the annual recharge rates and the storage properties within ranges of realistic values to obtain a reasonable match between simulated and observed water levels from 1949–2005. Recharge from rainfall was altered for individual stress periods to account for extremely wet years or years when floods occurred by increasing the recharge between 40–80%.

Recharge from Big Swamp was simulated in two-year cycles, during which recharge from Big Swamp was specified in the winter stress period of the second year. This scheme is considered to represent the average flow cycle from Big Swamp.

The model-calibrated specific yield and storage values are show in Figure 20. Specific yield values ranging from 0.1 to 0.3 were used for the QL aquifer, while a value of 0.15 was used uniformly across the model area for the TS aquifer. Specific storages ranging from 0.001 to 0.0001 1/m were used for the TC aquitard and TS aquifer.

5.3.1 QUALITATIVE COMPARISON OF POTENTIOMETRIC HEADS

The modelled and observed potentiometric heads from 2002 were compared to determine the accuracy of the calibration for the QL aquifer (Fig. 20). May 2002 watertable contours for Uley Wanilla and Uley South used for comparison were generated by Evans (2002), while a new watertable contour map was generated for Uley East. The data set used to generate the watertable map for Uley East did not include observation well ULE 182 because it is not clear that this well is completed in the QL or TS aquifer.

Qualitative comparison between model-calculated and observed potentiometric heads of the QL aquifer indicates that, in general:

- Model-calculated potentiometric head in the QL aquifers adequately represents the shape and form of the observed potentiometric head (Fig. 21).
- Model-calculated water level fluctuations correspond fairly well with the observed seasonal high and low water levels (App. D).

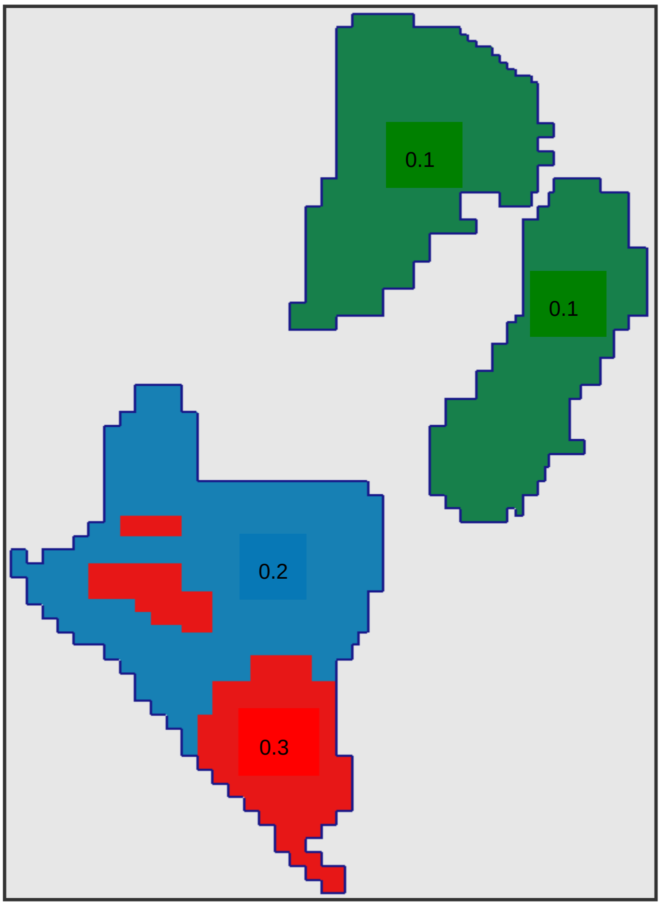


Figure 20. Calibrated values of specific yield for the QL aquifer, Uley Basin

In those zones where this representation is less adequate, it can be attributed to sparse aquifer and aquitard hydraulic parameter information, which were applied over larger areas than actually tested.

Qualitative comparison was not attempted for the TS aquifer due to lack of monitoring data in Uley Wanilla and Uley East. Several monitoring wells completed in the TS aquifer exist in the Uley South area but, because of their uneven distribution over the whole region, they cannot adequately represent groundwater flow mechanisms in this aquifer.

5.3.2 QUANTITATIVE COMPARISON OF POTENTIOMETRIC HEADS

Quantitative calibration was conducted on both QL and TS aquifers, with emphasis on the target QL aquifer. The lack of observation data for the TS aquifer and poor spatial distribution across the model area limit quantitative calibration for this layer. The location of all observation wells is presented in Figure 16.

Quantitative comparison of the modelled and observed historical potentiometric heads in the QL aquifer overall indicates satisfactory match (App. D). Specifically, very good match was achieved in Uley South (ULE 96, 99, 101–103, 194, 192) and northern section of Uley East (ULE 42, 59, 60, 179, 199).

The TS aquifer exhibits different types of trends in different areas, and in some areas such as Uley South, the match between observed and modelled heads is quite satisfactory (ULE 127, 185, 133, 109, SLE 13).

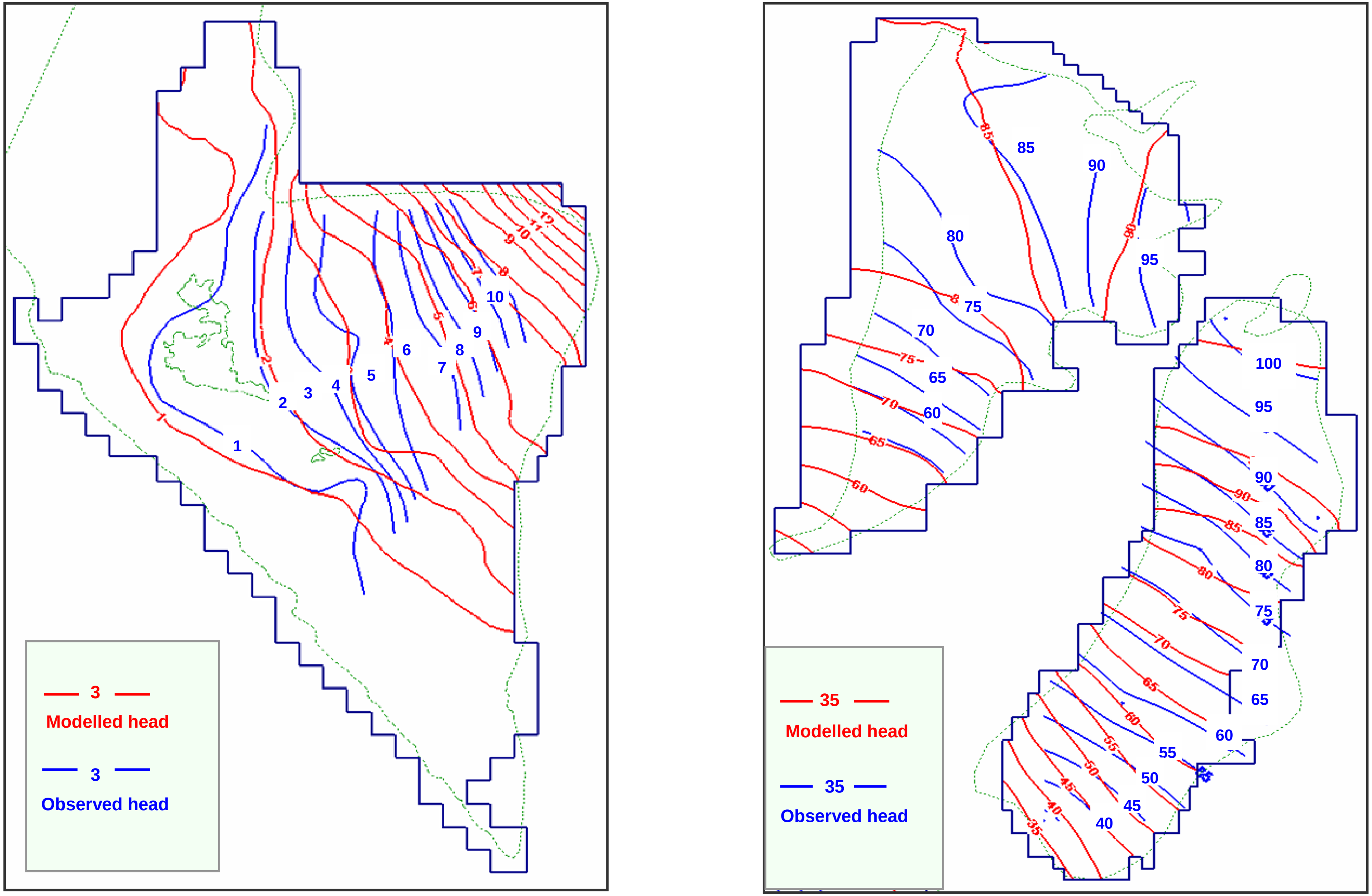


Figure 21. Observed and modelled potentiometric surface (m AHD) for QL aquifer, Uley Basin, May 2002

To be able to satisfactorily match observed hydrograph peaks, recharge had to be increased by 40–80% (Table 11) for individual stress periods across the whole model area. This is typical of extremely high rainfall – recharge years during the early model stage, with frequent occurrence between the early 1950s and 1971. Years of the average winter rainfall match hydrographs trends very well, but the recharge pattern has changed since 1990. It seems that in the last 15 years rainfall contributed less to recharge by ~10% in Uley South and Uley East. In Uley Wanilla, this change in recharge is much more dramatic.

Table 11. Rate and periods of increased recharge, Uley Basin

Year	Stress period	Rate of increase (%)
1954	10	40
1956	14	60
1957	16	50
1958	18	50
1963	28	50
1964	30	50
1968	38	80
1969	40	40
1971	44	50
1986	74	50

Reducing the recharge in the Uley Wanilla region by 50% even resulted in over-estimation of heads for this period (ULE 36). This implies that there has been a significant reduction in recharge in the Uley Wanilla region in the past 15 years.

This confirms an assumption based on results of salinity sampling between two sampling events. The studies revealed an expansion of the high salinity zone from a small area to most of the northern part of the Uley Wanilla lens, suggesting a reduction in groundwater recharge.

There could be several reasons for the decline of water levels in the Uley Wanilla region, including changes in climatic conditions, rainfall pattern and distribution, vegetation cover and pumping intensity. However, despite extraction being reduced in the past 10 years, with a drastic reduction since 2000, continuous decline in water levels has been observed over most of the Uley Wanilla area since 1990. There has not been a significant seasonal recovery in water levels since the mid-1970s. The observed overall decline in water levels over the monitoring period is ~5 m, which suggests that rainfall that contributes to the recharge would take much longer to reach the watertable, with the lesser volumes contributing to the recharge.

It is likely that accumulated effects of reduced recharge over a long period of time and higher extraction volumes led to groundwater over-exploitation exceeding sustainable levels.

The iteration residual error between modelled and observed potentiometric heads of the QL and TS aquifers was calculated using data from 2002. The normalised RMS values for the QL aquifer in Uley South, Uley East and Uley Wanilla are 7.7, 3.04 and 6.1%, respectively. These are less than or close to the 5% recommended by Middlemis (2000). The normalised RMSE for the TS aquifer is 6%.

5.4 SENSITIVITY ANALYSIS

To be able to assess uncertainties associated with the model parameters used in the model, a sensitivity analysis was conducted on a range of parameters. When conducting a sensitivity analysis, the impact of incremental variations of hydraulic parameters is quantified, which in turn enables identification of the drivers of the system.

Recharge, horizontal and vertical hydraulic conductivity of the QL and TS aquifers and vertical hydraulic conductivity of the TC aquitard data sets used in the calibrated steady state model were tested. The model parameters were incrementally varied to test for sensitivity. The parameter being tested was adjusted while the remaining model parameters were held constant at the calibrated values. The observed changes in statistical error for the steady state are presented in Table 12. The model sensitivity expressed in terms of RMSE is presented in Figure 22. The RMSE is plotted against the multiplication factor used to vary the parameter. The multiplication factor was applied uniformly to the entire model for the indicated parameter and ranged from 0.1 to 10.

Table 12. Steady state sensitivity analysis with respect to recharge, and horizontal and vertical conductivity, Uley Basin

Error (m)	Multiples of recharge, Uley South					
	0.4	**0.5**	**1**	**1.25**	**1.5**	**1.75**
Mean	-1.41	-1.12	**0.1**	0.64	1.16	1.65
Absolute mean	1.41	1.12	**0.29**	0.68	1.17	1.5
Root mean squared	1.65	1.34	**0.39**	0.77	1.29	1.81
	Multiples of recharge, Uley Wanilla					
Mean	-3.6	-3.02	**0.6**	2.48	4.34	6.25
Absolute mean	4.3	3.73	**0.88**	2.48	4.34	6.25
Root mean squared	4.42	3.93	**2.94**	3.94	5.24	7.13
	Multiples of recharge, Uley East					
Mean	-1.79	-2.54	**0.23**	2.69	5.22	7.79
Absolute mean	4.4	2.63	**0.34**	2.69	5.22	7.79
Root mean squared	6.09	3.28	**0.49**	2.76	5.29	7.88
	Multiples of recharge, TS aquifer					
Mean	-3.37	-2.64	**-0.37**	0.79	1.94	3.04
Absolute mean	3.37	2.64	**0.83**	1.33	2.16	3.12
Root mean squared	3.88	3.04	**1.25**	1.55	2.57	3.72

Error (m)	Multiples of K_h for QL aquifer, Uley South					
	0.1	**0.5**	**1**	**1.5**	**2**	**3**
Mean	8.28	1.78	**0.1**	-0.65	-1.11	-1.61
Absolute mean	8.28	1.78	**0.29**	0.66	1.11	1.69
Root mean squared	8.99	1.97	**0.39**	0.88	1.37	2
	Multiples of K_h for QL aquifer, Uley Wanilla					
Mean	15.68	4.69	**0.6**	-1.33	-2.38	-3.02
Absolute mean	15.68	4.69	**0.88**	2.72	3.83	4.75
Root mean squared	15.79	5.16	**2.94**	3.67	4.57	5.55

Error (m)	Multiples of K_h for QL aquifer, Uley East					
	0.1	**0.5**	**1**	**1.5**	**2**	**3**
Mean	16.21	5.66	**0.23**	-2.69	-2.42	14.82
Absolute mean	16.21	5.73	**0.34**	2.83	2.66	14.82
Root mean squared	16.73	5.87	**0.49**	2.95	3.43	15.26
	Multiples of K_h for QL aquifer, TS aquifer					
Mean	7.83	1.41	**-0.37**	-1.04	-1.28	-1.39
Absolute mean	7.83	1.66	**0.83**	1.29	1.69	2.31
Root mean squared	8.8	1.94	**1.25**	1.81	2	2.69

Error (m)	Multiples of K_v for QL aquifer, Uley South				
	0.1	**0.5**	**1**	**5**	**10**
Mean	0.1	0.05	**0.1**	0.1	0.1
Absolute mean	0.29	0.28	**0.29**	0.29	0.29
Root mean squared	0.39	0.39	**0.39**	0.39	0.39
	Multiples of K_v, for QL aquifer, Uley Wanilla				
Mean	0.65	0.81	**0.6**	0.62	0.62
Absolute mean	0.88	0.91	**0.88**	0.88	0.88
Root mean squared	2.96	3.04	**2.94**	2.93	2.93
	Multiples of K_v for QL aquifer, Uley East				
Mean	0.24	2.04	**0.23**	0.22	0.22
Absolute mean	0.35	2.21	**0.34**	0.34	0.34
Root mean squared	0.51	2.49	**0.49**	0.49	0.49
	Multiples of K_v for QL aquifer, TS aquifer				
Mean	-0.37	0.05	**-0.37**	-0.37	-0.37
Absolute mean	0.82	0.82	**0.83**	0.83	0.83
Root mean squared	1.24	1.33	**1.25**	1.25	1.25

Error (m)	Multiples of K_v for TC aquitard, Uley South				
	0.1	**0.5**	**1**	**5**	**10**
Mean	0.13	1.11	**0.1**	0.07	0.04
Absolute mean	0.28	0.29	**0.29**	0.28	0.27
Root mean squared	0.35	0.38	**0.39**	0.4	0.4
	Multiples of K_v for TC aquitard, Uley Wanilla				
Mean	-0.33	0.33	**0.6**	1.02	1.07
Absolute mean	1.49	1.01	**0.88**	1.15	1.26
Root mean squared	2.75	2.82	**2.94**	3.29	3.43
	Multiples of K_v for TC aquitard, Uley East				
Mean	1.41	0.59	**0.23**	-0.39	-0.53
Absolute mean	1.41	0.62	**0.34**	0.82	1.14
Root mean squared	1.54	0.75	**0.49**	0.97	1.28
	Multiples of K_v for TC aquitard, TS aquifer				
Mean	-0.21	-0.33	**-0.37**	-0.41	-0.39
Absolute mean	0.87	0.82	**0.83**	0.93	0.99
Root mean squared	1.29	1.24	**1.25**	1.37	1.41

Error (m)	**Multiples of K_h for TS aquifer, TS aquifer**					
	0.1	**0.5**	**1**	**1.5**	**5**	**10**
Mean	8.21	1.38	**0.1**	-0.98	-2.589	-3.239
Absolute mean	8.36	2.29	**0.29**	1.28	3.247	4.23
Root mean squared	13.09	3.3	**0.39**	1.69	4.691	6.026
	Multiples of K_h for TS aquifer, Uley South					
Mean	-0.04	0.06	**0.6**	0.11	0.122	0.01
Absolute mean	0.29	0.29	**0.88**	0.29	0.324	0.327
Root mean squared	0.43	0.41	**2.94**	0.39	0.441	0.49
	Multiples of K_h for TS aquifer, Uley Wanilla					
Mean	6.31	1.62	**0.23**	0.46	0.511	0.056
Absolute mean	6.31	1.63	**0.34**	0.83	0.79	1.088
Root mean squared	8.49	4.08	**0.49**	2.59	2.426	2.452
	Multiples of K_h for TS aquifer, Uley East					
Mean	6.87	0.96	**-0.37**	0.31	0.241	2.775
Absolute mean	6.87	0.96	**0.83**	0.46	0.744	3.429
Root mean squared	8.98	1.57	**1.25**	0.78	1.254	4.12

Error (m)	**Multiples of K_v for TS aquifer, TS aquifer**				
	0.1	**0.5**	**1**	**5**	**10**
Mean	-0.36	-0.37	**0.1**	-0.37	-.037
Absolute mean	0.82	0.83	**0.29**	0.83	0.83
Root mean squared	1.24	1.25	**0.39**	1.25	1.25
	Multiples of K_v for TS aquifer, Uley South				
Mean	0.103	0.101	**0.6**	0.1	0.101
Absolute mean	0.292	0.292	**0.88**	0.29	0.292
Root mean squared	0.394	0.394	**2.94**	0.39	0.394
	Multiples of K_v for TS aquifer, Uley Wanilla				
Mean	0.65	0.63	**0.23**	0.62	0.618
Absolute mean	0.875	0.88	**0.34**	0.88	0.879
Root mean squared	2.96	2.94	**0.49**	2.93	2.93
	Multiples of K_v for TS aquifer, Uley East				
Mean	2.24	0.23	**-0.37**	0.22	0.22
Absolute mean	0.35	0.34	**0.83**	0.34	0.34
Root mean squared	0.51	0.5	**1.25**	0.49	0.49

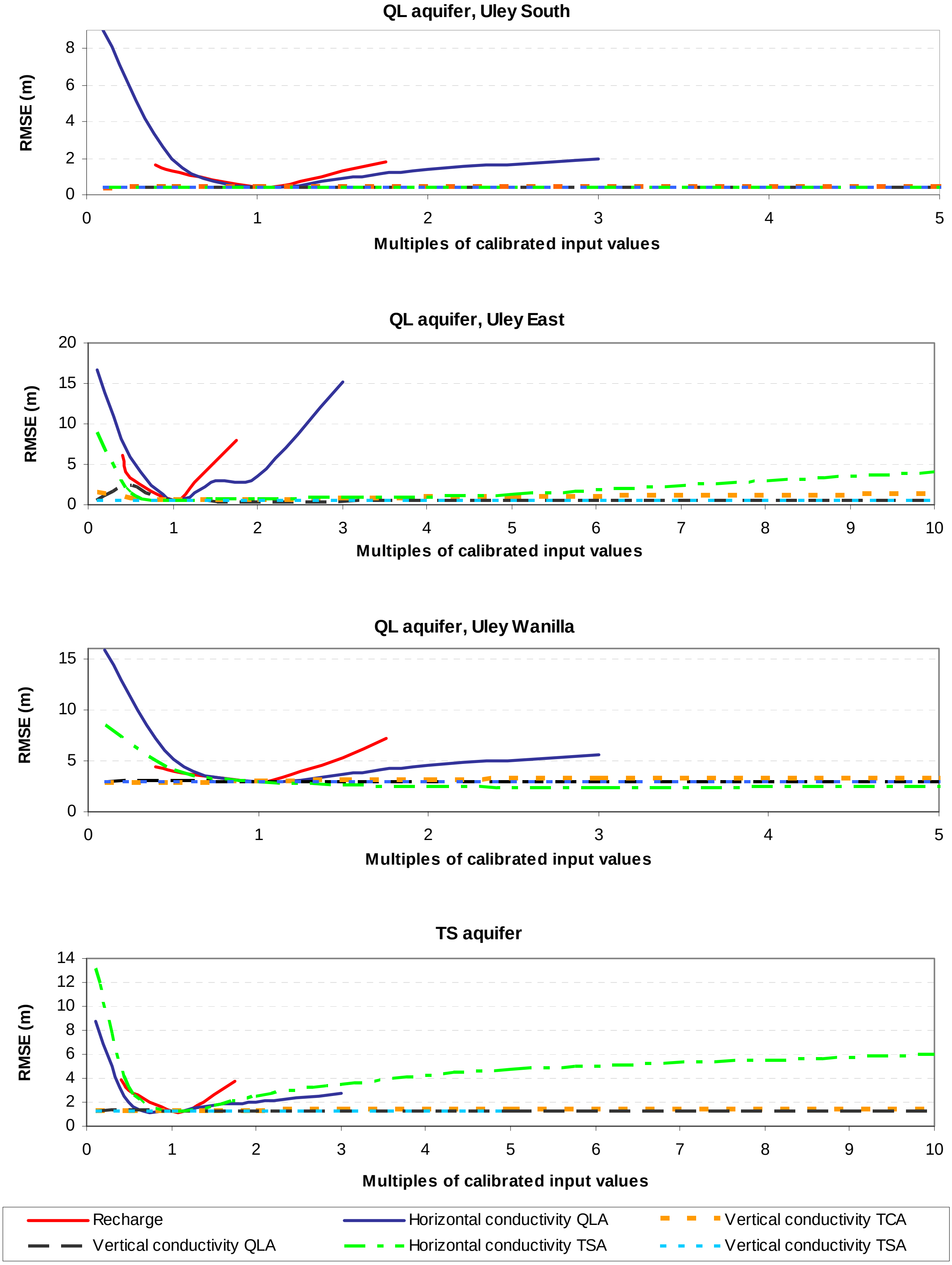


Figure 22. Steady state sensitivity analysis of Uley Basin model

In the Uley South and Uley Wanilla region, the pre-development steady state model is most sensitive to decrease in K_h of the QL aquifer. The Uley South lens is insensitive to the K_h and K_v of the TS aquifer and the K_v of the confining TC. The Uley East lens is most sensitive to recharge and the K_h of the QL aquifer. That is, there is substantial change in the model RMSE in the Uley East lens when the K_h of the QL aquifer or recharge is increased or decreased.

While the Uley South lens is insensitive to the K_h of the TS aquifer, the Uley East and Uley Wanilla lenses are sensitive to decrease in the K_h of the TS aquifer. The TS aquifer is sensitive to changes in recharge, K_h of both QL aquifers and the TS aquifer itself, but insensitive to the K_v of TS aquifer, QL aquifers and confining TC.

It can be concluded that:

- Increases or decreases in recharge values have similar effects across the study area.
- The steady state model is very sensitive to recharge due to its unconfined nature.
- The steady state model is least sensitive to changes in K_v of all three layers, with Uley Wanilla and Uley East being more sensitive than Uley South.
- The magnitude of changes in general is lower in Uley South due to the greater storage capacity of the aquifer.
- The steady state model failed to converge when the recharge was reduced by more than 60%.

Seven data sets, including recharge, specific yield, K_h and K_v of the QL aquifer, K_h and K_v of the TS aquifer, and K_v of the confining layer were tested in the transient model. The results, which are very similar to those of the steady state model, are presented in Table 13 and Figure 23.

The transient model failed to converge when the calibrated K_h values for the QL aquifer was increased by more than 100%, K_v values for the TS aquifer was decreased by more than 50%, specific yield for the QL aquifer was reduced to 50%, and specific yield for the TS aquifer was increased by 60%.

Table 13. Transient state sensitivity analysis with respect to recharge, K_h and K_v, Uley Basin

Error (m)	**Multiples of K_h for QL aquifer, Uley South**		**1**	**Multiples of K_v for QL aquifer, Uley South**		**Multiples of K_v for TC aquitard, Uley South**		**1**	**Multiples of recharge, Uley South**	
	0.1	**2**		**0.1**	**10**	**0.1**	**10**		**0.5**	**1.5**
Mean	4.981	-1.353	**-0.461**	-0.461	-0.461	-0.469	-0.508	**-0.461**	-1.495	0.468
Absolute mean	5.029	1.663	**0.807**	0.808	0.807	0.804	0.847	**0.807**	1.555	0.797
Root mean squared	5.601	2.057	**1.081**	1.083	1.08	1.069	1.134	**1.081**	1.817	1.445
	Multiples of K_h for QL aquifer, Uley Wanilla			**Multiples of K_v for QL aquifer, Uley Wanilla**		**Multiples of K_v for TC aquitard, Uley Wanilla**			**Multiples of recharge, Uley Wanilla**	
Mean	7.265	-1.616	**0.356**	0.366	0.355	-0.777	1.09	**0.356**	-1.829	2.784
Absolute mean	7.402	3.332	**1.749**	1.752	1.749	2.2	2.096	**1.749**	2.809	2.92
Root mean squared	8.527	4.286	**2.864**	2.874	2.863	2.964	3.416	**2.864**	3.446	4.198
	Multiples of K_h for QL aquifer, Uley East			**Multiples of K_v for QL aquifer, Uley East**		**Multiples of K_v for TC aquitard, Uley East**			**Multiples of recharge, Uley East**	
Mean	9.298	-3.996	**0.065**	0.068	0.065	0.852	-1.108	**0.065**	-3.120	3.332
Absolute mean	9.402	4.804	**1.444**	1.444	1.444	1.412	2.521	**1.444**	3.488	3.396
Root mean squared	10.555	5.197	**2.035**	2.035	2.035	1.992	3.05	**2.035**	3.860	4.136
	Multiples of K_h for QL aquifer, TS aquifer			**Multiples of K_v for QL aquifer, TS aquifer**		**Multiples of K_v for TC aquitard, TS aquifer**			**Multiples of recharge, TS aquifer**	
Mean	3.436	-1.452	**-0.835**	-0.835	-0.835	-0.801	-0.862	**-0.835**	-2.365	0.62
Absolute mean	3.916	2.141	**1.332**	1.33	1.332	1.497	1.483	**1.332**	2.457	1.717
Root mean squared	4.715	2.872	**1.898**	1.894	1.898	1.987	2.02	**1.898**	3.03	2.087

Error (m)	Multiples of K_h for TS aquifer, Uley South			1	Multiples of K_v for TS aquifer, Uley South			Multiples of S_y for QL aquifer, Uley South		Multiples of S_y for TS aquifer, Uley South
	0.1	**5**	**10**		**0.5**	**5**	**10**	**1.6**	**1**	**0.5**
Mean	1.648	-0.229	-0.181	**-0.461**	-0.461	-0.461	-0.461	-0.408	**-0.461**	-0.462
Absolute mean	2.991	0.714	0.758	**0.807**	0.807	0.807	0.807	0.751	**0.807**	0.807
Root mean squared	5.787	1.038	1.243	**1.081**	1.081	1.08	1.08	1.035	**1.081**	1.081
	Multiples of K_h for TS aquifer, Uley Wanilla				**Multiples of K_v for TS aquifer, Uley Wanilla**			**Multiples of S_y for QL aquifer, Uley Wanilla**		**Multiples of S_y for TS aquifer, Uley Wanilla**
Mean	0.566	1.34	1.296	**0.356**	0.358	0.354	0.353	0.771	**0.356**	-0.353
Absolute mean	1.432	2	2.191	**1.749**	1.75	1.749	1.749	1.721	**1.749**	1.075
Root mean squared	3.108	3.098	3.357	**2.864**	2.866	2.863	2.863	2.968	**2.864**	2.864
	Multiples of K_h for TS aquifer, Uley East				**Multiples of K_v for TS aquifer, Uley East**			**Multiples of S_y for QL aquifer, Uley East**		**Multiples of S_y for TS aquifer, Uley East**
Mean	2.181	0.158	0.088	**0.065**	0.066	0.064	0.064	0.178	**0.065**	0.062
Absolute mean	2.579	1.889	2.447	**1.444**	1.444	1.444	1.444	1.392	**1.444**	1.444
Root mean squared	5.132	2.645	3.265	**2.035**	2.035	2.035	2.035	2.02	**2.035**	2.035
	Multiples of K_h for TS aquifer, TS aquifer				**Multiples of K_v for TS aquifer, TS aquifer**			**Multiples of S_y for QL aquifer, Uley East**		**Multiples of S_y for TS aquifer, Uley East**
Mean	4.322	-2.611	-3.133	**-0.835**	-0.835	0.835	-0.835	-0.699	**-0.835**	-0.837
Absolute mean	5.665	3.034	3.95	**1.332**	1.331	1.333	1.333	1.336	**1.332**	1.333
Root mean squared	9.051	4.256	5.398	**1.898**	1.897	1.898	1.899	1.872	**1.898**	1.899

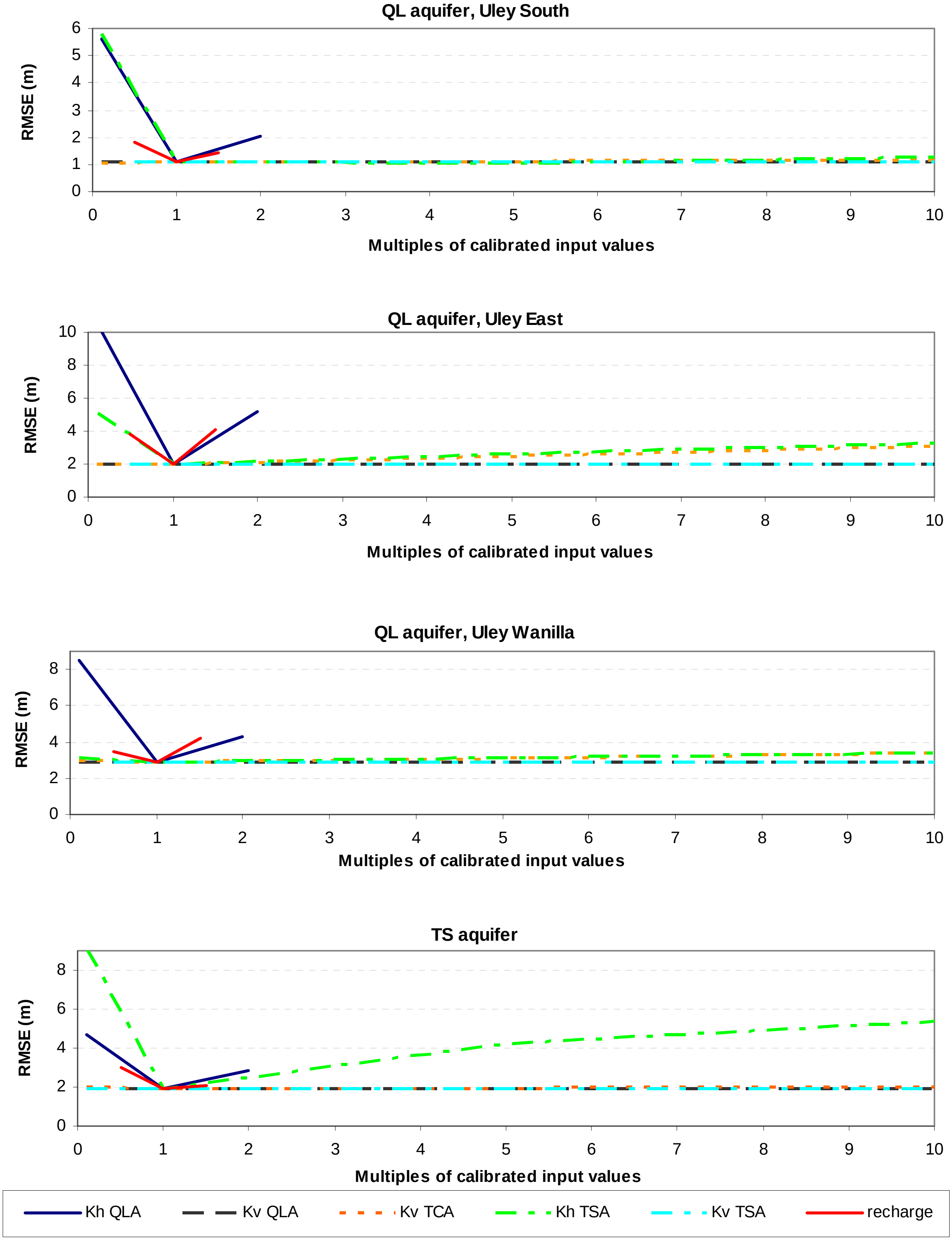


Figure 23. Transient state sensitivity analysis, Uley Basin model

6. PREDICTIVE MODELLING

6.1 SCENARIOS

The calibrated groundwater flow transient model developed in this study can be used to evaluate the response of the groundwater flow system to changes in water management policies and hydrologic conditions in the Uley Basin. The effects of groundwater management practices on the aquifer system are of great concern during periods of inadequate rainfall in winter because the main source of water is recharge by rainfall.

The transient model provides a useful tool to predict the response of the aquifer to different groundwater use scenarios and determine the long-term impact of climatic variability and over-extraction on the aquifer system in the Uley Basin. Groundwater withdrawal at current rates, increased groundwater withdrawal and altered hydrologic conditions were examples of conditions that were simulated.

Three groundwater extraction scenarios were tested. In all scenarios, groundwater extraction from the Uley Wanilla was kept constant at the current level of 300 ML/y, while extraction from Uley South was varied.

Scenario 1 Constant extraction at the current level of 7500 ML/y.

Scenario 2 An increase of 1000 ML/y to a total of 8500 ML/y until 2020.

Scenario 3 Extreme dry conditions and high water demand — a periodical increase of 2500 ML every fifth year to a total of 10 000 ML/y. Annual extractions for years between those extremes are kept at the current level of 7500 ML.

For each scenario the following recharge conditions were applied.

A. Calibrated recharge rate for the past 15 years (1990–2005) were used to predict the behaviour of the aquifer system for the next 15 years (2005–20).

B. The long-term average rainfall rates with constant values for each stress period.

C. Calibrated recharge rate for the last 15 years was reduced by 50%.

All other boundary conditions were kept constant. Recharge from Big Swamp to the QL aquifer was assumed to occur every two years. The simulation started in winter 2006 and the starting heads used for scenario modelling were model-simulated water levels for summer 2005–06. The results of the scenarios were evaluated with respect to changes in model-calculated groundwater levels (drawdown) relative to current (2005) conditions.

6.1.1 SCENARIO 1: CONSTANT EXTRACTION AT CURRENT LEVEL OF 7500 ML/Y

In Scenario 1, groundwater withdrawal from Uley South and Uley Wanilla were set at the current rate of 7500 and 300 ML/y respectively until 2020. Scenario 1 was subjected to the following climatic conditions: A) repetition of the last 15 years recharge rates, B) constant recharge at the long-term average rate, and C) 50% reduction of the last 15 years recharge rates.

A. With the current extraction rate, a maximum summer drawdown of 0.6 m would develop around the original wellfield in Uley South by summer 2007. Similar large drawdowns would be experienced in 2014 and 2015 (Fig. 24a), but the groundwater level would fully recover during winter in the following year. With the recharge similar to that of 2005, there would be a very small drawdown of 0.2 m in Uley South in summer 2020 (Fig. 24b). In summer 2020, a maximum drawdown of 0.8 m would develop in Uley Wanilla, while drawdowns between 0.2 m (central part) and 1.4 m (southern part) would be experienced in Uley East. This scenario shows that there would be no detrimental impacts in Uley South, but water levels would not recover in Uley Wanilla even though extraction rates were kept at a minimal level.

B. Constant long-term average recharge would cause greater summer drawdowns in all areas. By 2020, a maximum drawdown of 0.8 m is expected in Uley South, 1–2.6 m in Uley East, and over 1 m in Uley Wanilla at its southern end (Fig. 25a). The drawdown around the bore field in Uley Wanilla would be between 0.2 and 0.4 m. The predicted drawdowns in summer 2020 are presented in Figure 25b. The water level will not fully recover in winter and a residual drawdown of ~0.4 m would develop. Winter drawdowns or recovery in 2020 for Scenarios 1A and 1B are shown in Figures 26a and 26b.

C. If in the next 15 years recharge happens to be only 50% of the last 15 years, at the end of the year 2020 drawdowns would be between 0 and 0.2 m along the coast, and 1.2 m in the central part of Uley South (Fig. 27a). A small area on the eastern boundary of Uley South, in the vicinity of observation well ULE 143 (Fig. 16), would run dry. In Uley Wanilla, drawdowns around the well field would be 0.6–1.4 m and in Uley East the maximum drawdown would be 2.8 m. Winter 2020 recovery is shown in Figure 27b.

If the estimated distribution of groundwater extraction per well is correct, the drawdown cones (cones of depression) in each scenario would start developing around production wells USPB 3 (6028-701) and USPB 5 (6028-698) located in Uley South and would spread in a north to southeasterly direction around the original bore field. The dry cells would start appearing near the central-eastern boundary of Uley South due to high basement and consequently thinner saturated limestone. Similarly, drawdown cones in Uley Wanilla would start developing around production wells UWPB 9 (6028-1655) and UWPB 8 (6028-1656), and they would increase to almost the whole northern part of the lens under extremely low recharge conditions.

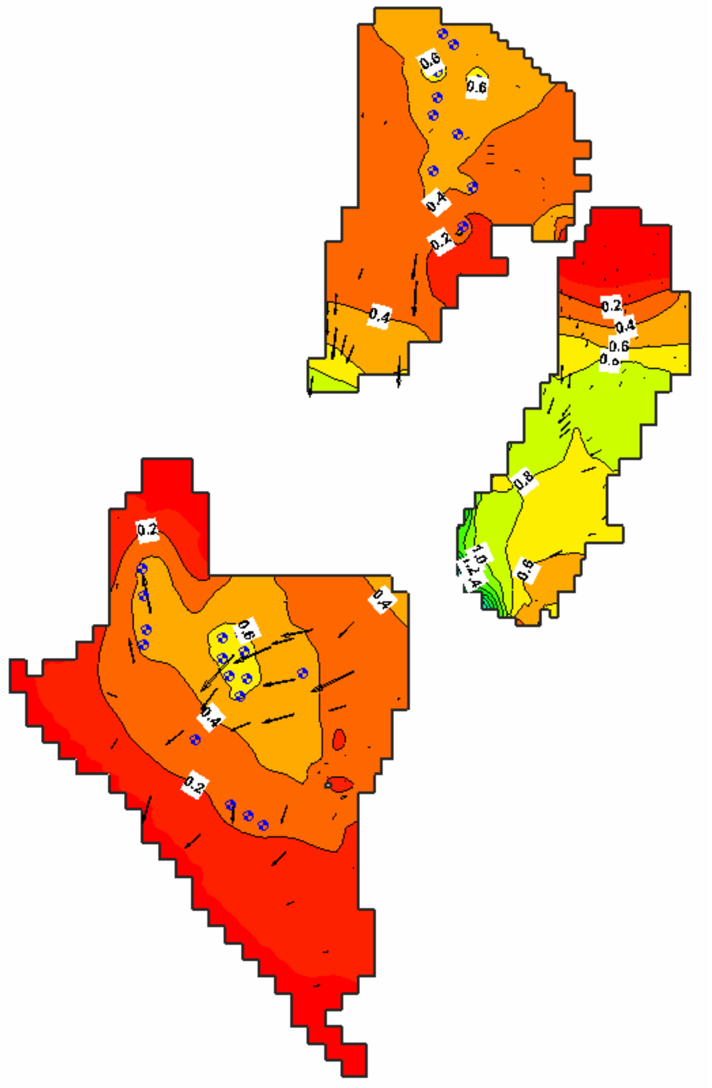


Figure 24a. Scenario 1A — predicted drawdowns (m), summer 2015

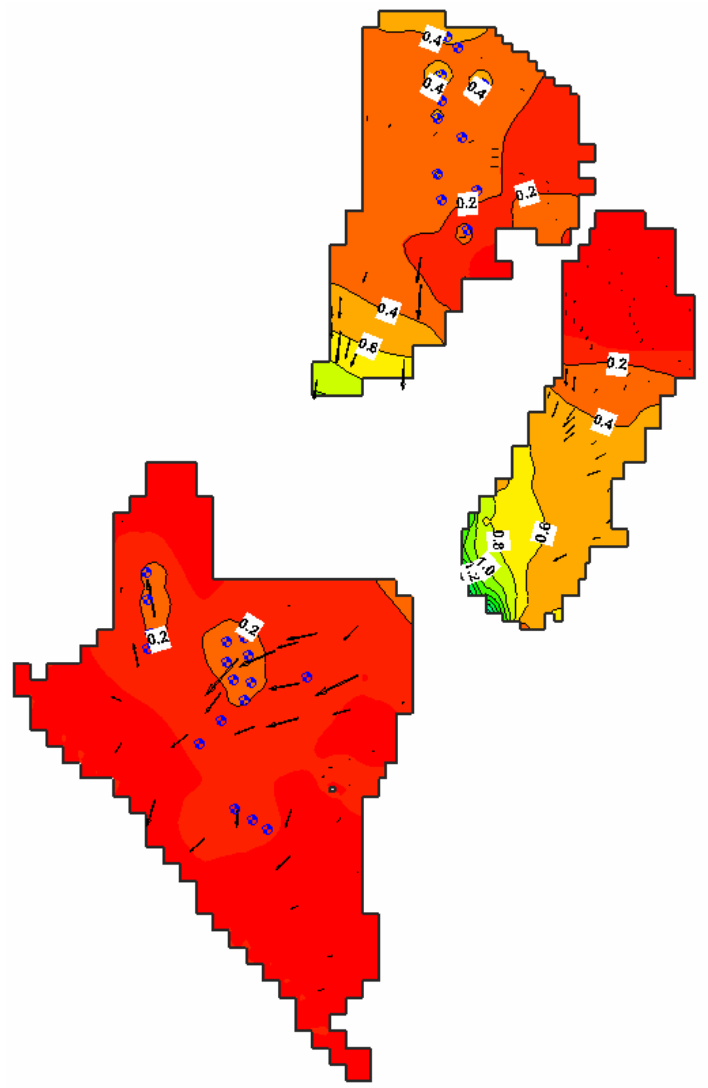


Figure 24b. Scenario 1A — predicted drawdowns (m), summer 2020

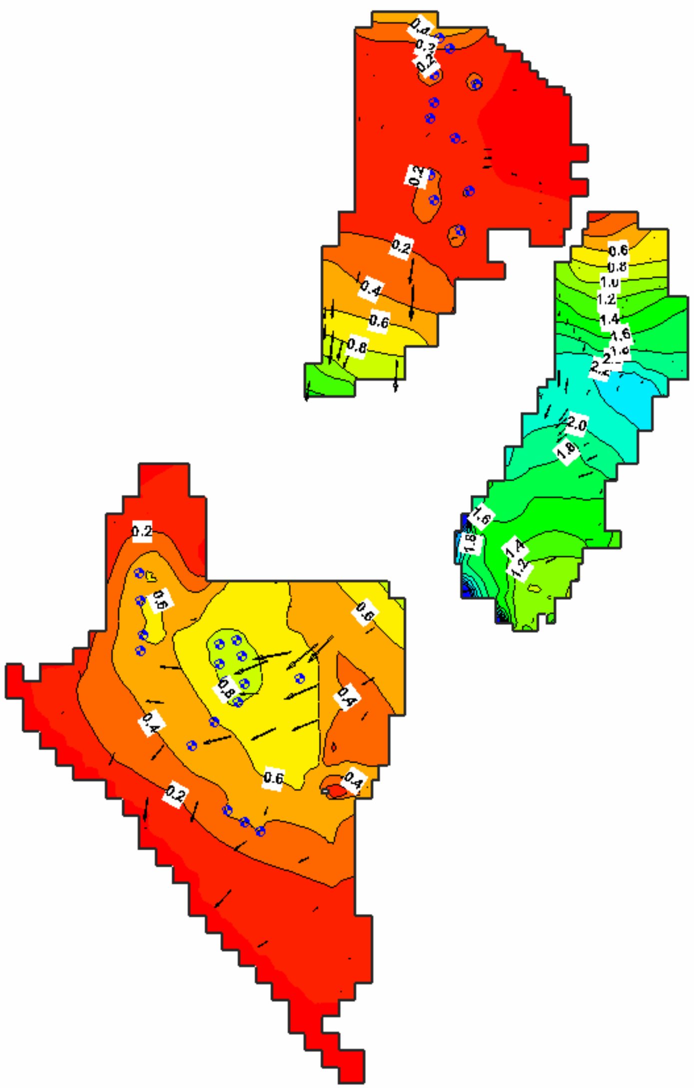


Figure 25a. Scenario 1B — predicted drawdowns (m), summer 2015

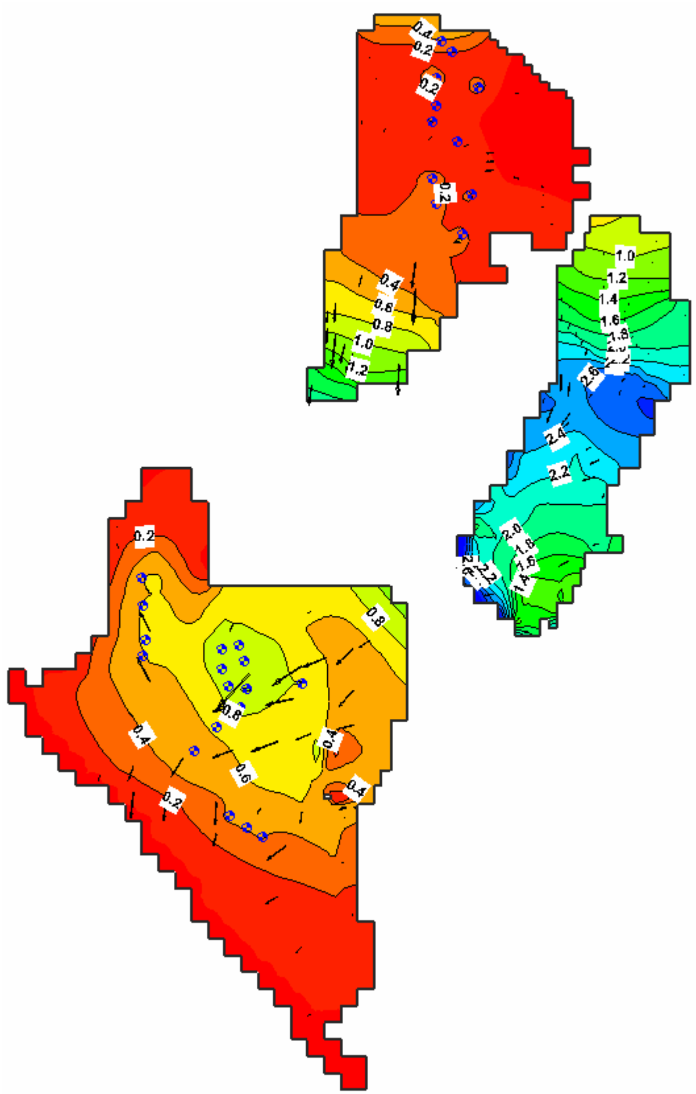


Figure 25b. Scenario 1B — predicted drawdowns (m), summer 2020

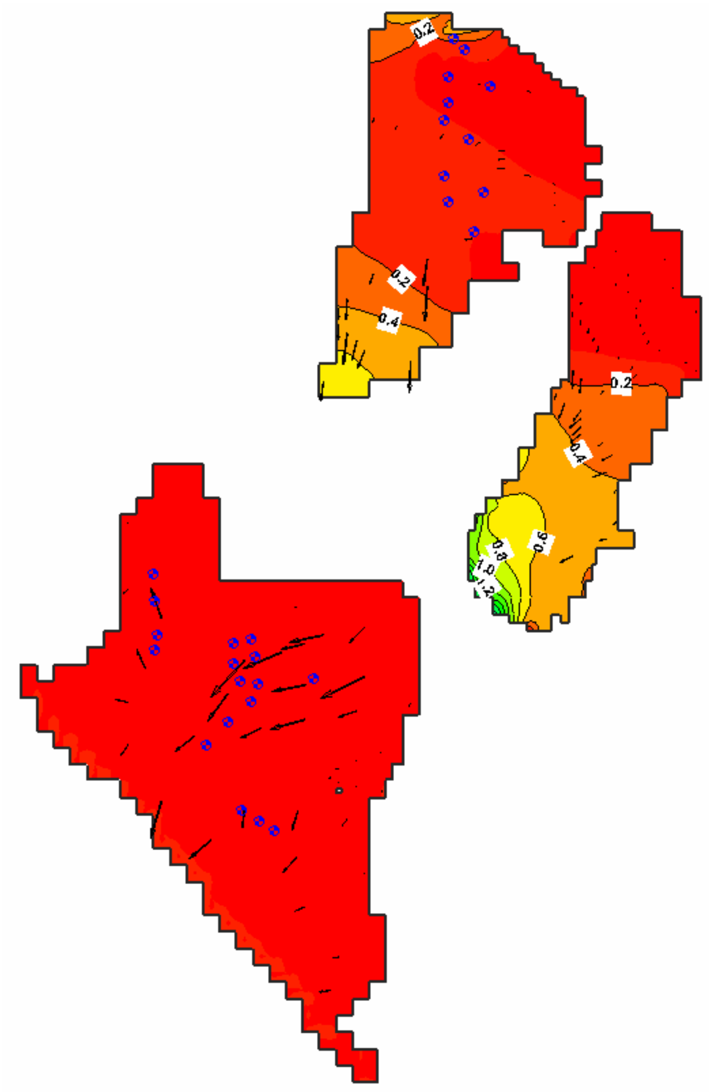


Figure 26a. Scenario 1A — predicted recovery (m), winter 2020

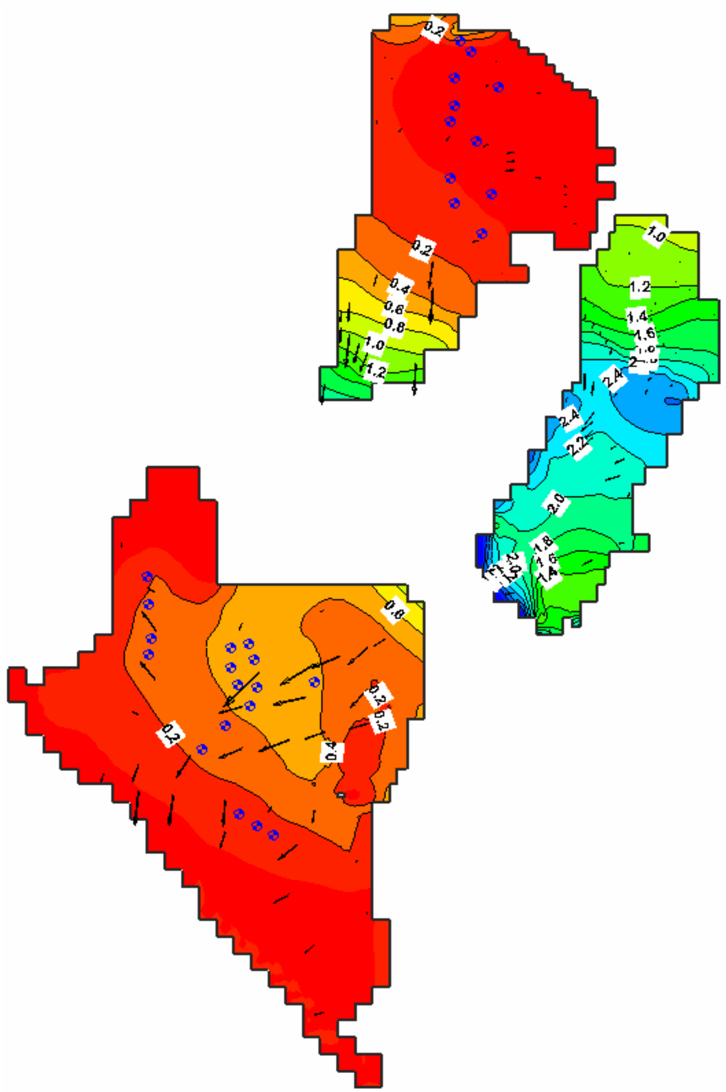


Figure 26b. Scenario 1B — predicted recovery (m), winter 2020

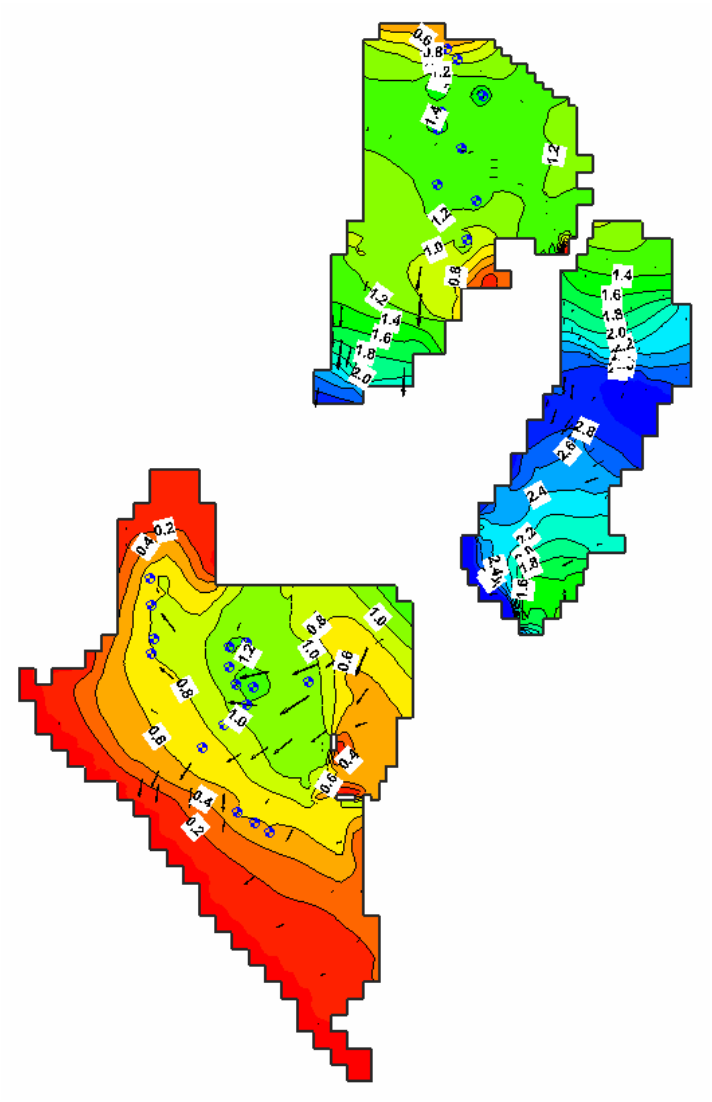


Figure 27a. Scenario 1C — predicted drawdowns (m), summer 2020

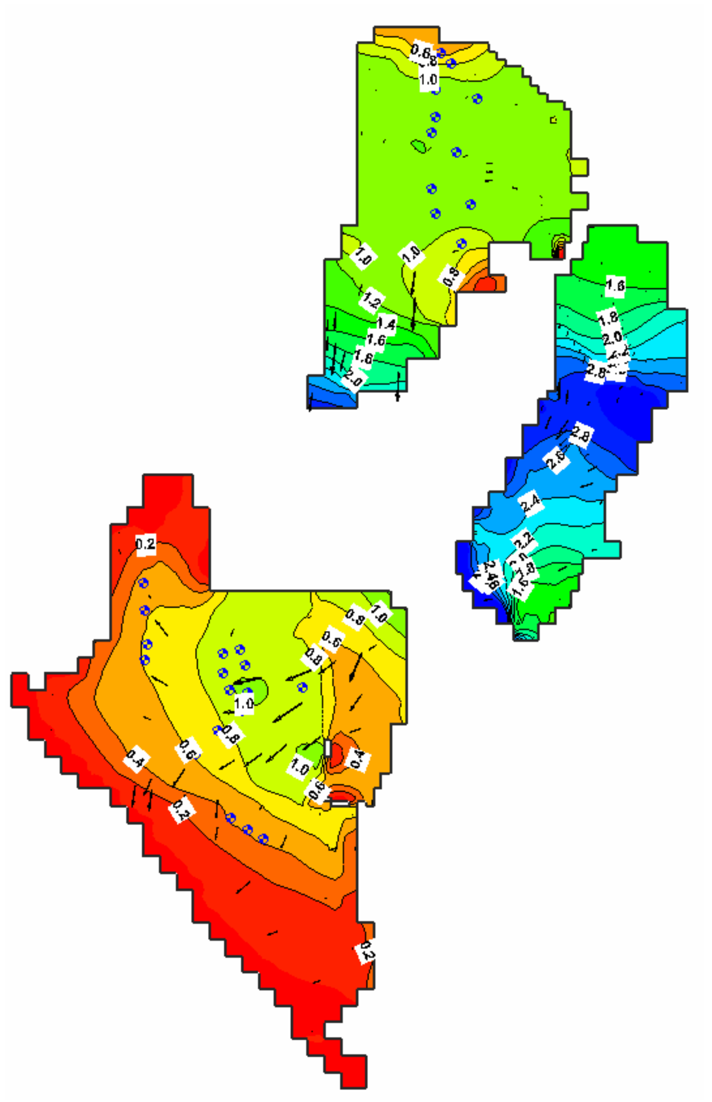


Figure 27b. Scenario 1C — predicted recovery (m), winter 2020

6.1.2 SCENARIO 2: INCREASE IN EXTRACTION IN ULEY SOUTH TO 8500 ML/Y

Scenario 2 assumes an increase in groundwater extraction to a total of 8500 ML/y until 2020 and with the same recharge applications as in Scenario 1.

A. Similarly to Scenario 1, assuming the last 15 years recharge rates are repeated as a cycle, the greatest drawdowns will be experienced in 2007. In Uley South, the model predicted drawdown in 2007 would be ~0.8 m in a small area in the centre of the lens and surrounding the original wellfield. Larger summer drawdowns to a maximum of 0.6 m would also develop in 2010, 2014 and 2015 (Fig. 28a). At the end of summer in 2020, the drawdown would be 0.4 m (Fig. 28b). In most years, full recovery is expected to occur during winter. The summer drawdowns would vary between 0.2–0.6 m in Uley Wanilla and 0.2–1.2 m in Uley East.

B. When long-term average recharge is combined with the extraction rate of 8500 ML/y, the larger drawdowns would be experienced across the whole modelled area. Summer drawdowns in Uley South would generally be 0.2 to 1 m (Fig. 29a), and by 2020 a cone of depression with 1.2 m drawdown in the centre would develop around production wells USPB 3 and USPB 5 (Fig. 29b). Winter water levels would not fully recover and by 2020 a permanent drawdown cone of 0.6 m would develop around the same wells. In Uley East, water levels would decline 1–2.8 m during summer and 0.2–1.8 m during winter. In Uley Wanilla, the drawdowns would vary from 0.2–1.2 m and would be in the order of 0.2–0.6 m in the northern extent of the lens. The winter recovery for Scenarios 2A and 2B are shown in Figures 30a and 30b.

C. With recharge at 50% of the past 15 years and extractions increased by 1000 ML/y, a drawdown pattern similar to Scenario 1C would develop. As expected, the drawdowns will be of a greater magnitude and in Uley South would be as large as 1.4 m, while the dry zone south of well ULE143 would increase (Fig. 31a). The 2020 recovery is shown in Figure 31b. There would not be much difference in Uley East and Uley Wanilla compared to Scenario 1C.

Very similar statements about development and distribution of the drawdown cones to Scenario 1 can be drawn from results of the Scenario 2 prediction runs. However, since the long-term average recharge proved to be underestimated, supported by a good match achieved during calibration using the limiting winter rainfall option, it is more likely that in both scenarios option A is more realistic. The increased extraction of over 10% or 1000 ML/y does not seem of a great concern and it should not have detrimental impact on the groundwater resource in Uley South. It is not known how a 2–3 m drawdown would impact on users in Uley East.

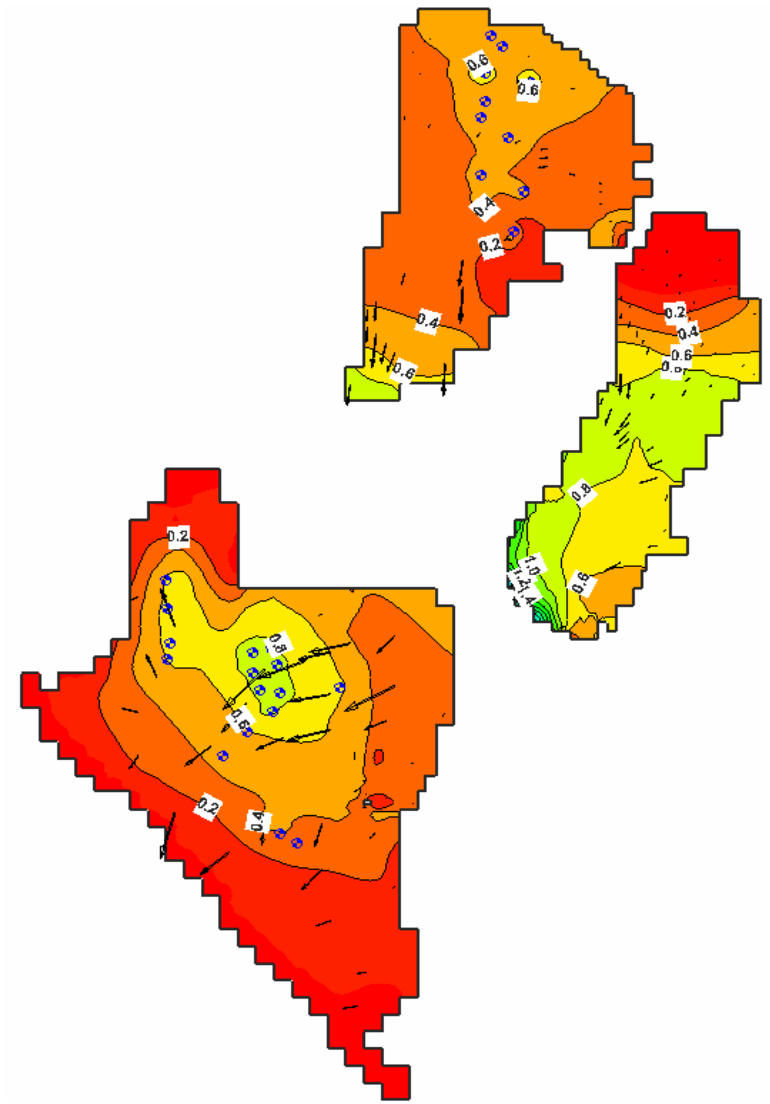


Figure 28a. Scenario 2A — predicted drawdowns (m), summer 2015

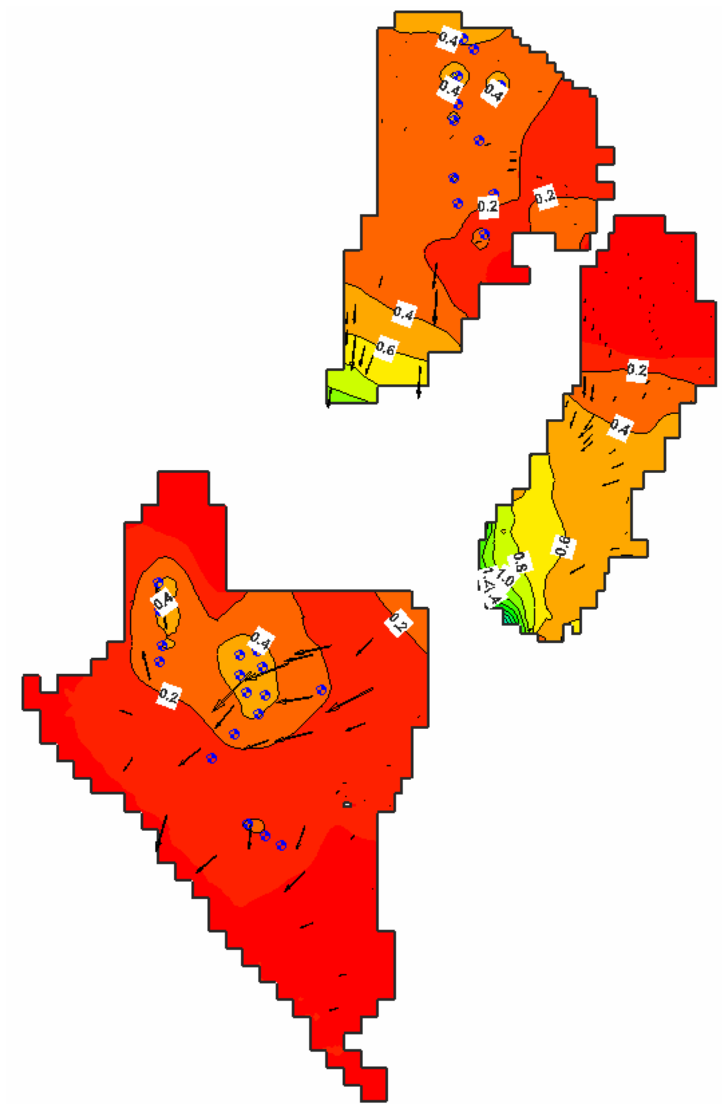


Figure 28b. Scenario 2A — predicted drawdowns (m), summer 2020

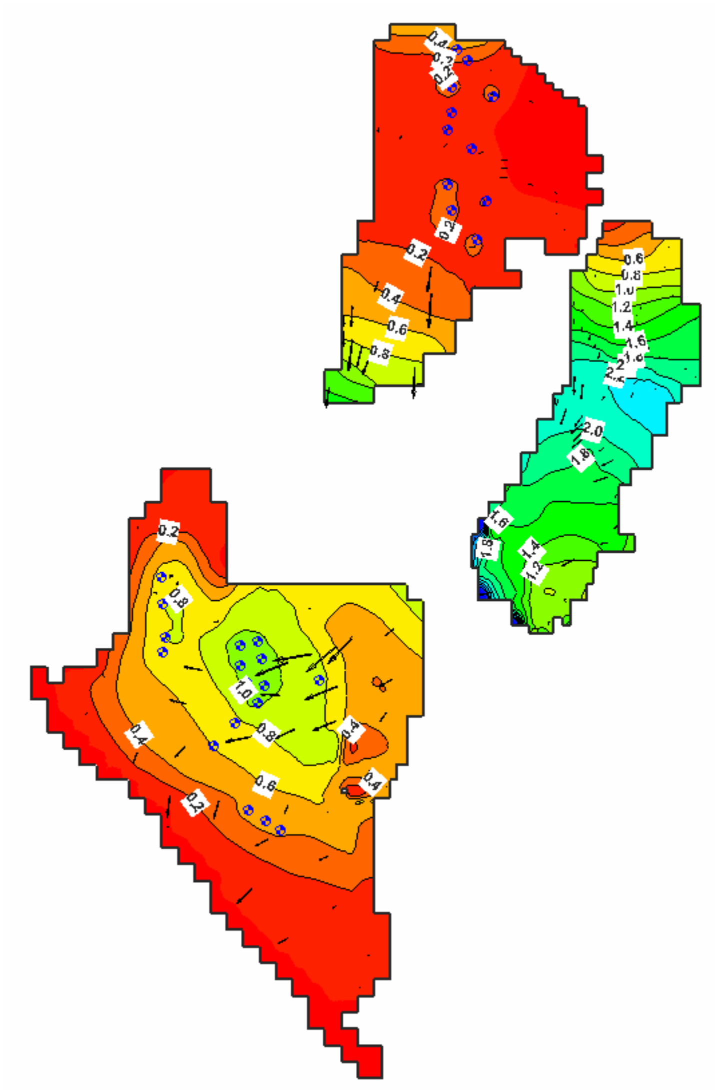


Figure 29a. Scenario 2B — predicted drawdowns (m), summer 2015

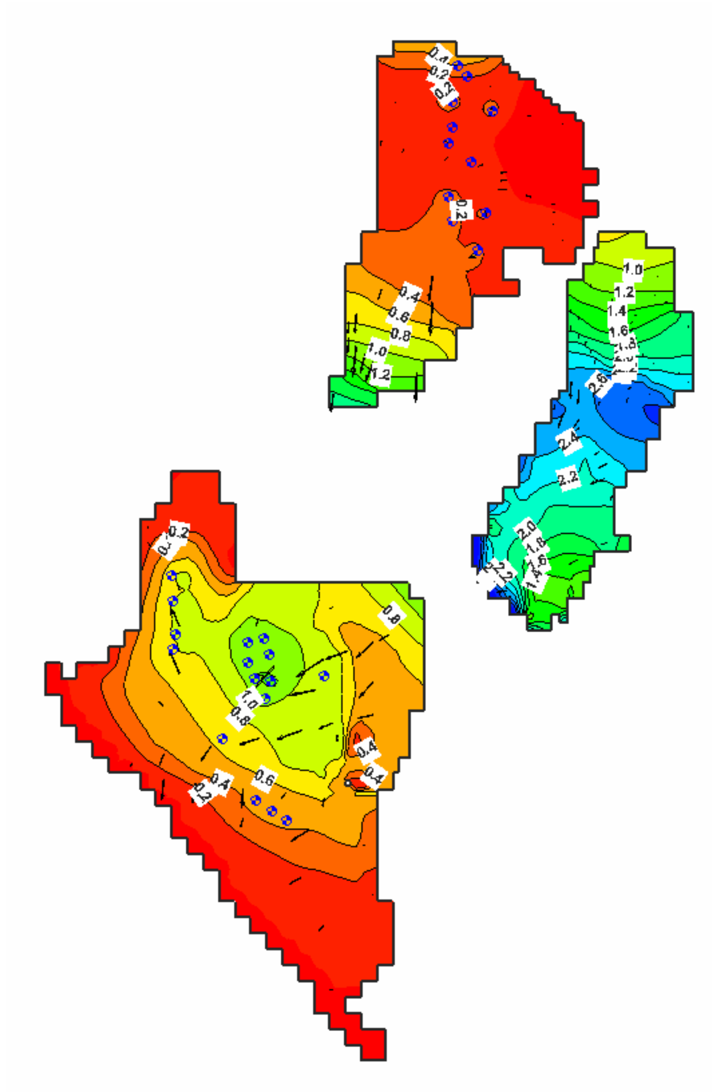


Figure 29b. Scenario 2B — predicted drawdowns (m), summer 2020

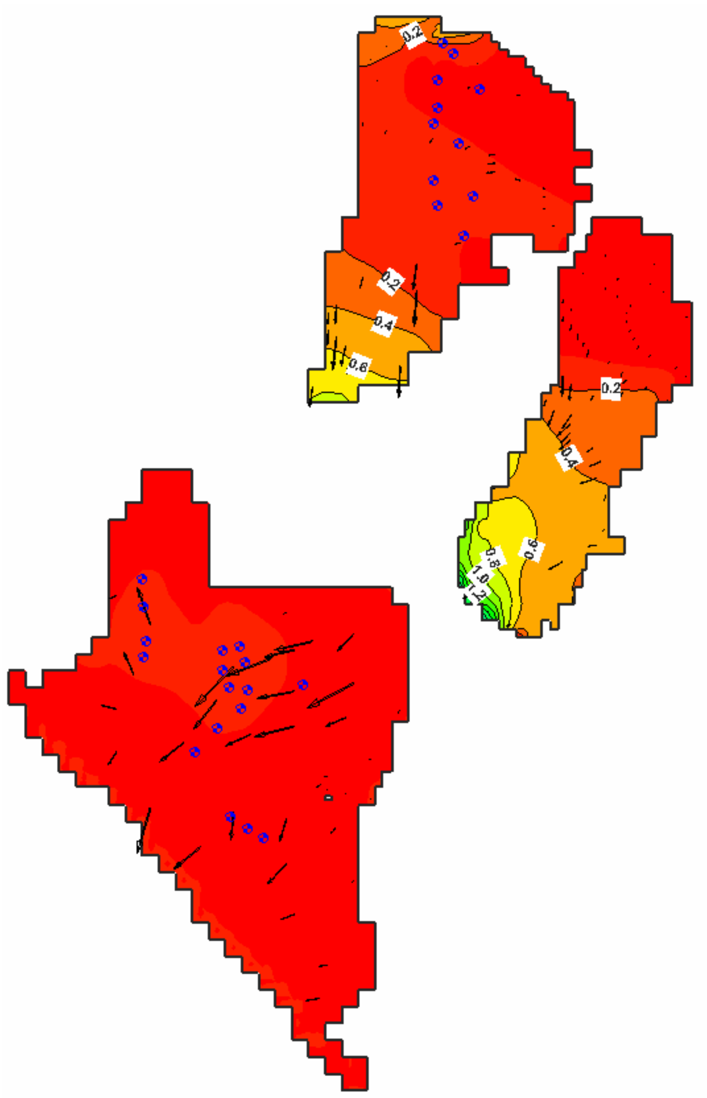


Figure 30a. Scenario 2A — predicted recovery (m), winter 2020

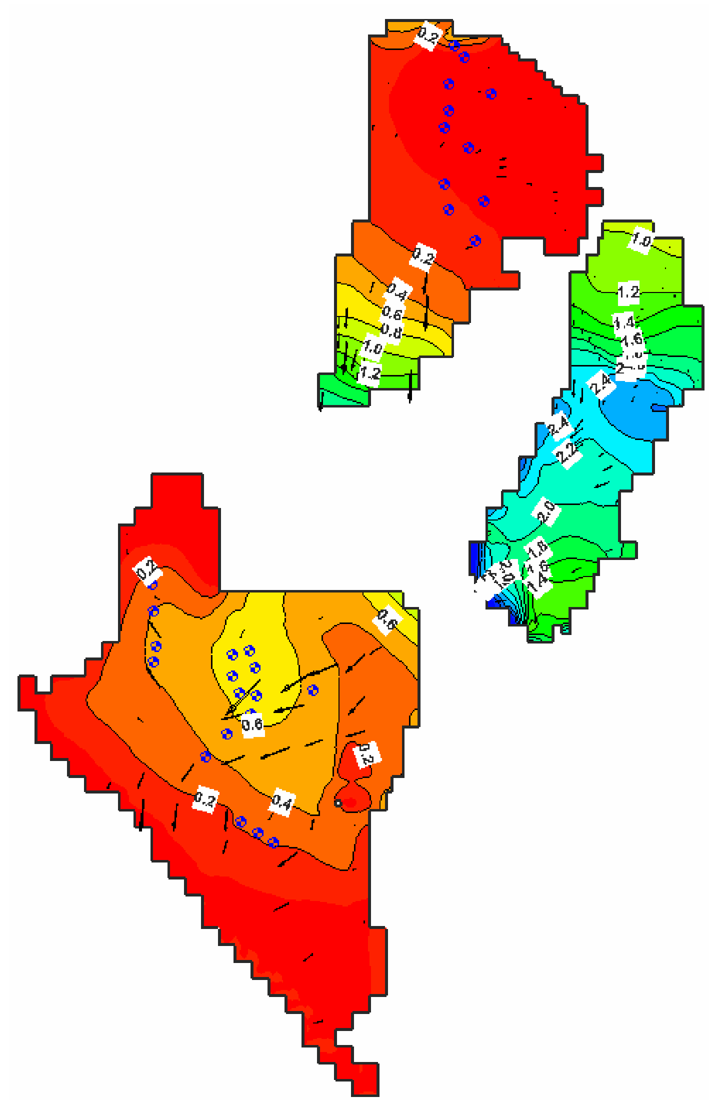


Figure 30b. Scenario 2B — predicted recovery (m), winter 2020

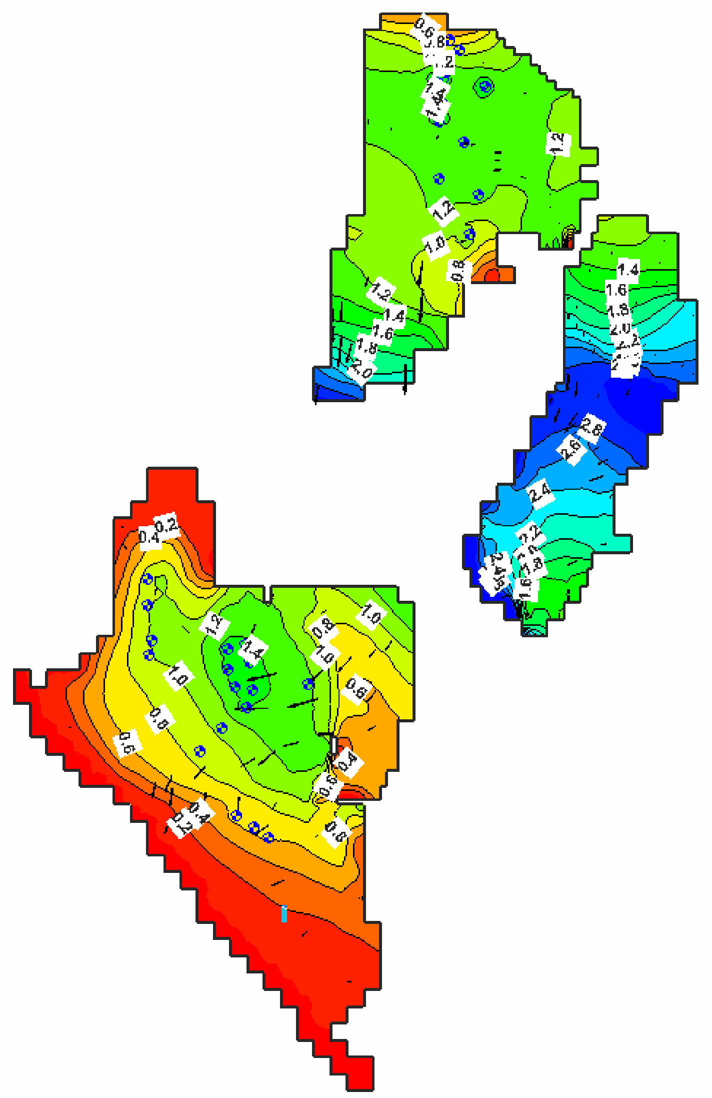


Figure 31a. Scenario 2C — predicted drawdowns (m), summer 2020

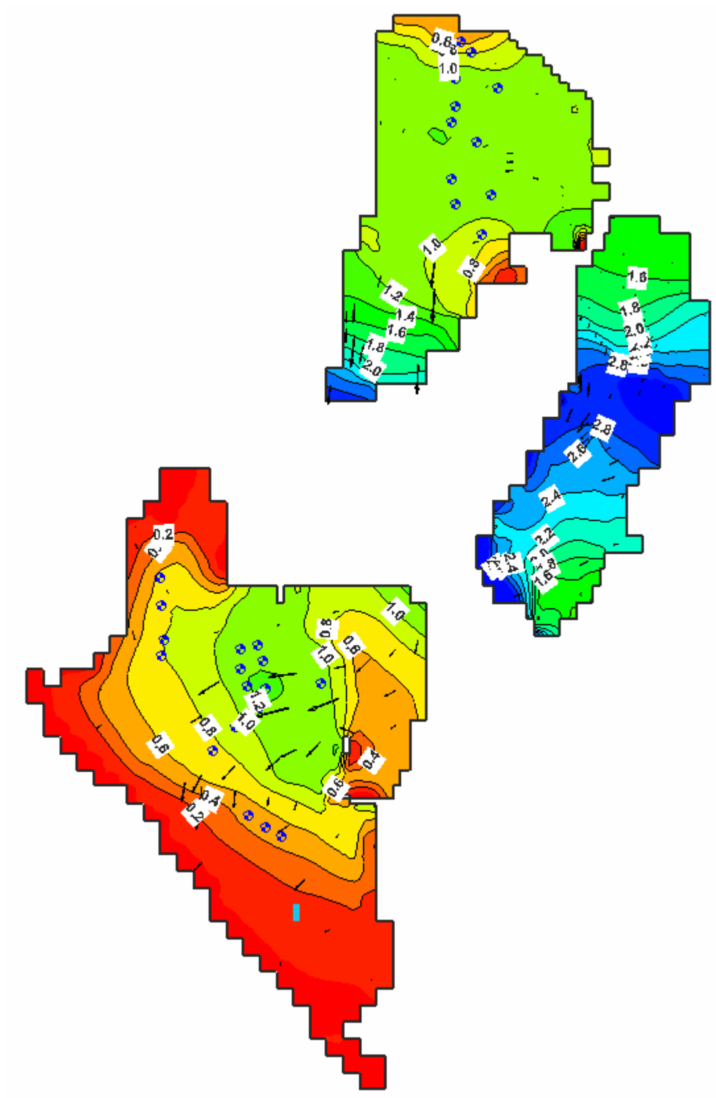


Figure 31b. Scenario 2C — predicted recovery (m), winter 2020

6.1.3 SCENARIO 3: EXTREME DRY CONDITIONS AND HIGH WATER DEMAND

Scenario 3 was set up to simulate occasional years of extremely dry conditions and high water requirements. In this scenario, two recharge regimes were tested — application of calibrated recharge rate for the past 15 years and application of 50% of calibrated recharge rate for the past 15 years. The annual extraction rate is increased from the current rates by 2500 ML every fifth year, to a total of 10 000 ML for years 2010, 2015 and 2020. The results of each run are presented below.

A. Similar to previous scenarios, without any additional extractions, a drawdown of 0.6 m would develop in the centre and along the western boundary (production wells USPB 9–12) of the Uley South lens in summer 2007 due to very low recharge in 2006. When an additional pumping of 2500 ML/y was distributed equally among all production wells, the same maximum drawdown of 0.6 m developed in the same location by 2010. A maximum drawdown of 0.8 m would be experienced in 2015 under this same set of conditions (additional pumping stress of 2500 ML/y) due to low recharge during 2014–15 (Fig. 32a). With one year of above average recharge, the water levels would completely recover during the following winter period. In 2020, a maximum drawdown of 0.4 m would be recorded (Fig. 32b). In 2015, Uley Wanilla would experience a maximum drawdown of ~0.8 m around production well UWPB 8. In Uley East, the maximum drawdown would be in the order of 0.8–1 m in the central part of the lens.

B. The long-term average recharge option was not run due to similarities to option C.

C. In this option, the groundwater extraction rates were increased by 2500 ML every fifth year while at the same period the annual 15 year cycle recharge rates were reduced by 50%. Under these stress conditions a predicted drawdown of 1.2 m would develop in the Uley South original well field by summer 2007. This would increase to 1.6 m in summer 2015 (Fig. 33a) and would not recover during winter periods. In summer 2020, the drawdown cone would be 1.4 m around production wells USPB 3 and USPB 5 (Fig. 33b) and would only recover slightly during the following winter to 1.2 m. In Uley Wanilla, the model-predicted drawdown cone would increase from 0.8 m in 2010 to 1.4 m in 2020 and would be greatest around wells UWPB 8 and UWPB 9. In Uley East, model-predicted maximum drawdown ranging between 1.4–2.8 m would develop at the end of the simulation period.

The 2020 recovery for both scenarios is shown in Figures 34a and 34b. Even though it is tempting to draw conclusion in favour of potential extraction increases, the results should be taken with caution. Firstly, it is impossible to predict the future rainfall and therefore accurately estimate potential recharge. Secondly, the model is not able to predict impacts of increased extraction on the movement of the seawater–groundwater interface for the modelled scenarios.

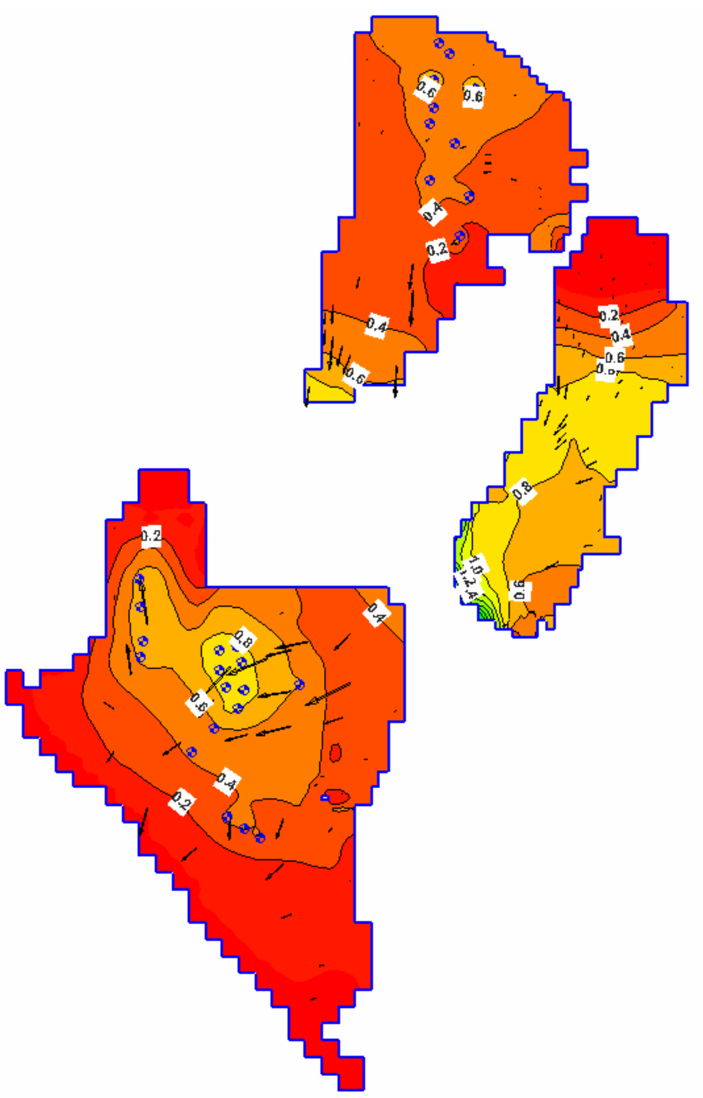


Figure 32a. Scenario 3A — predicted drawdowns (m), summer 2015

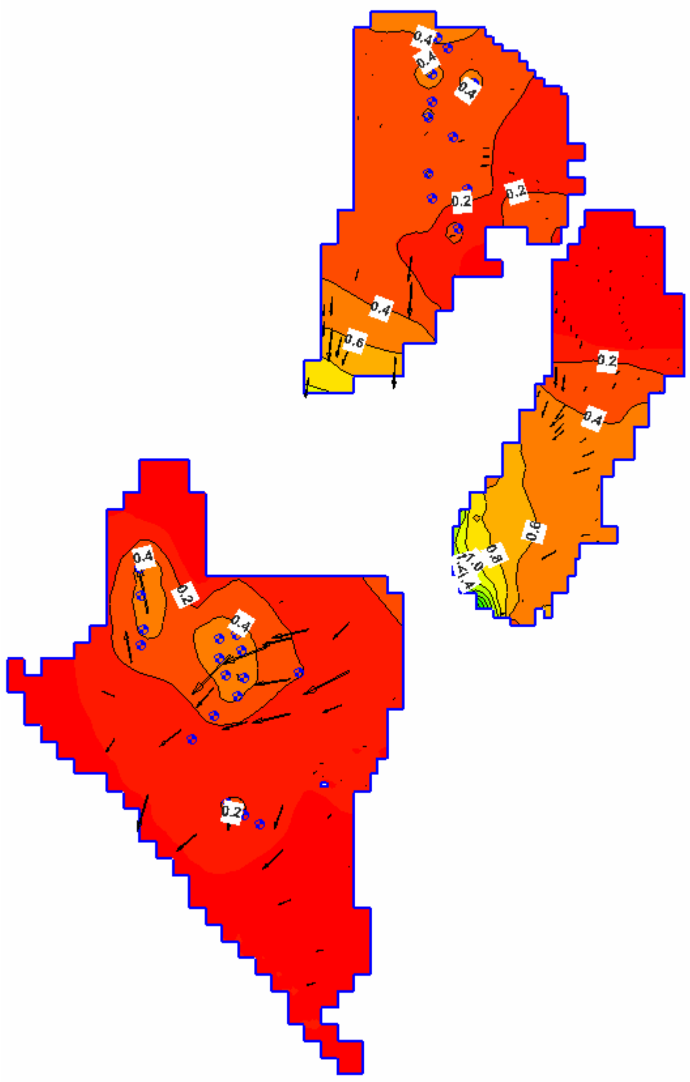


Figure 32b. Scenario 3A — predicted drawdowns (m), summer 2020

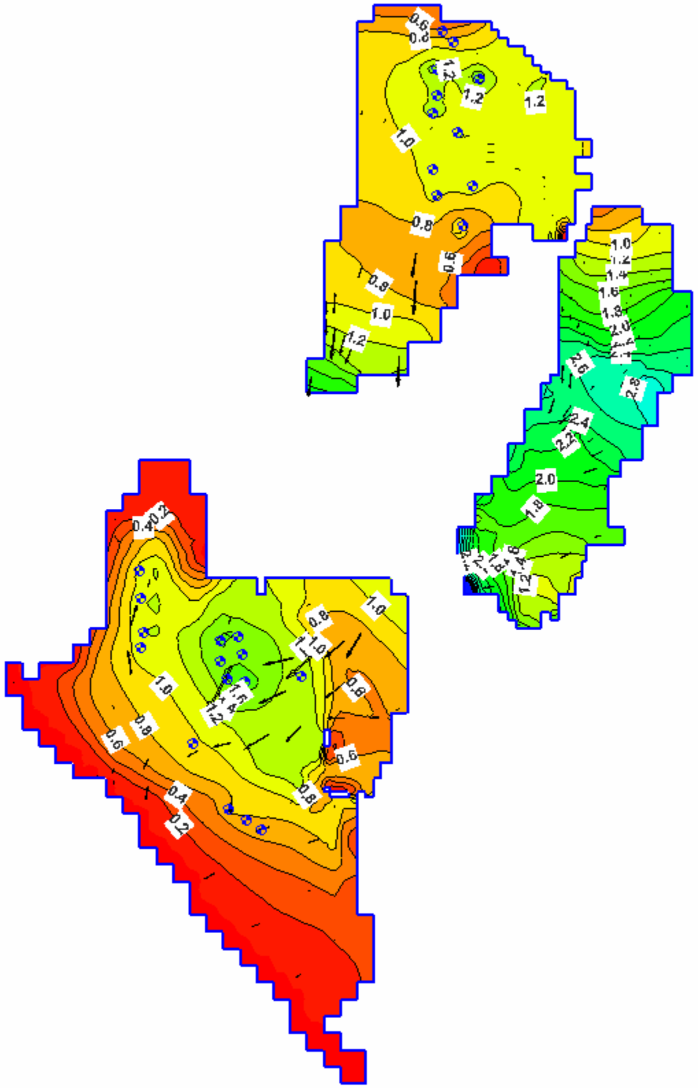


Figure 33a. Scenario 3C — predicted drawdowns (m), summer 2015

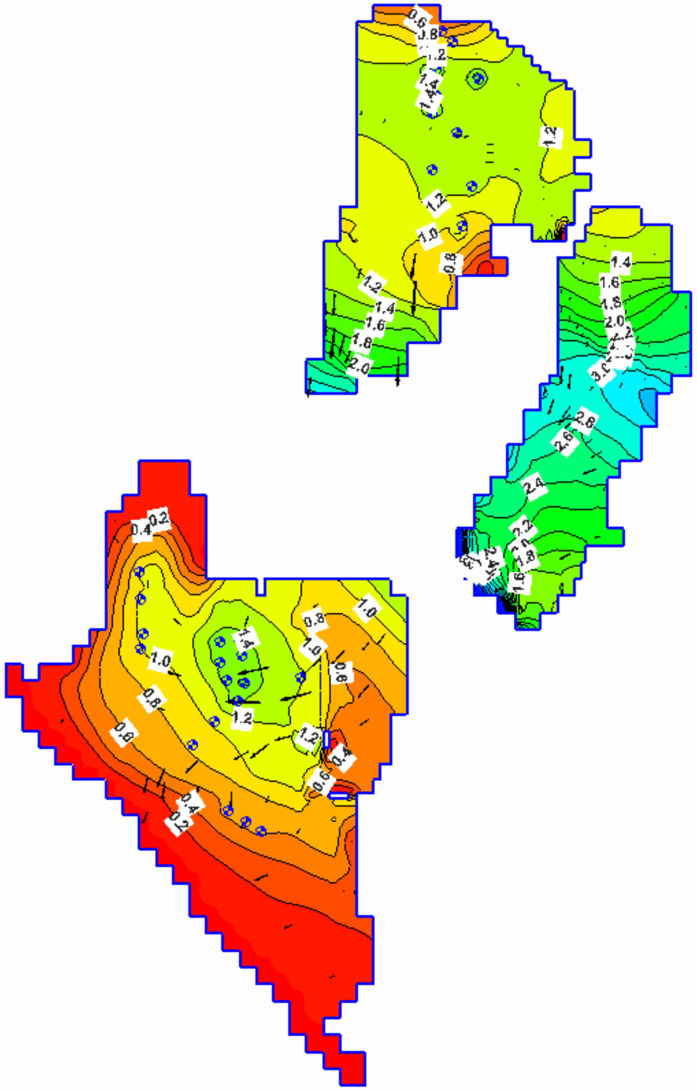


Figure 33b. Scenario 3C — predicted drawdowns (m), summer 2020

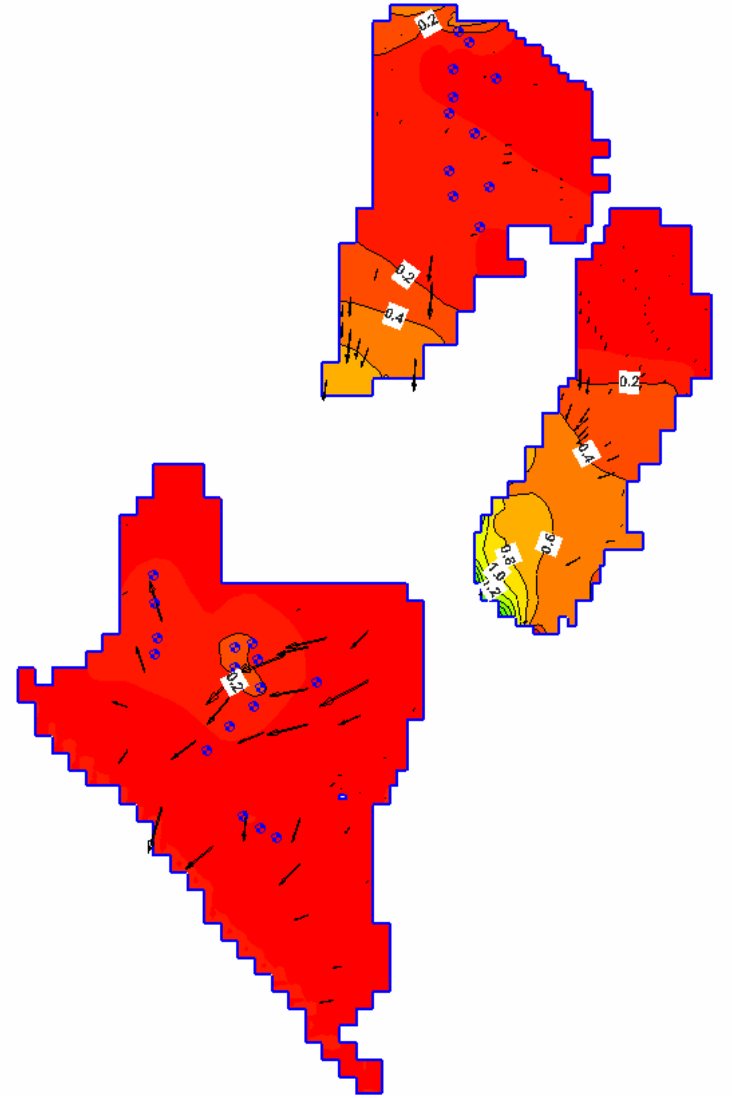


Figure 34a. Scenario 3A — predicted recovery (m), winter 2020

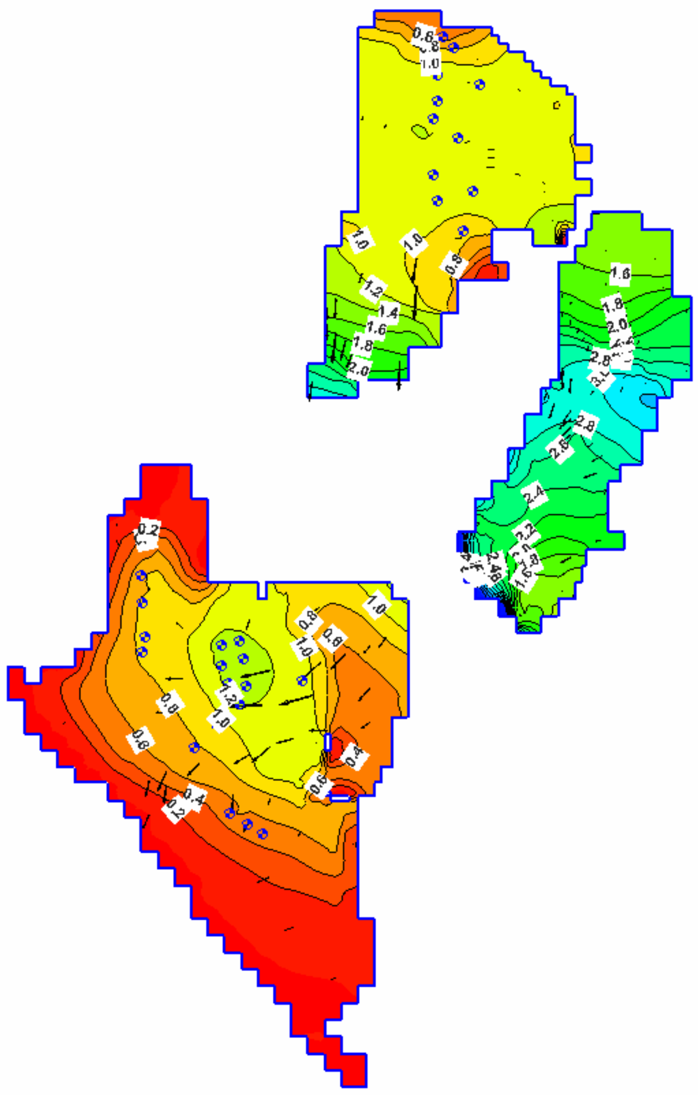


Figure 34b. Scenario 3C — predicted recovery (m), winter 2020

7. MODEL LIMITATIONS AND UNCERTAINTIES

The steady state and transient flow models presented in this report cover simulation of groundwater flow in Quaternary and Tertiary sediments in the Uley Basin. As with all computer simulated groundwater flow models of natural systems, the simplifications, assumptions and degree of accuracy incorporated into both the conceptual and numerical models cause limitations in their appropriate use and to the interpretations of simulation results. This model is limited by simplification of surface water and groundwater systems into the conceptual model, vertical discretization of the model into three layers, and lack of sufficient data to account for all the spatial variation of recharge and hydraulic properties throughout the model area.

In general, the model layers are a simplified representation of the natural thickness of the hydrostratigraphic layers (aquifers and aquitard) in the study area and may not adequately reflect the natural conditions. The use of the model as a predictive tool with which to estimate the effect of recharge and pumping and realistically manage the groundwater resources in the Uley basin is restricted by the following specific limitations in our current understanding of the conceptual model:

- Little information on the spatial distribution of hydraulic properties of the QL aquifer, particularly in the northern lenses.
- Poor knowledge of the thickness, lateral extent and hydraulic properties of the TS aquifer north of Uley South. A constant thickness was assumed for TS in this zone. The lack of sufficient elevation data necessitated this simplification.
- Lack of information on the inflows to the TS aquifer in the north of the Uley Basin.
- Limited knowledge of hydraulic parameters of the TS aquifer across the study area.
- Lack of information on the spatial distribution of hydraulic properties of the TC aquitard across the region. There is no information on horizontal conductivity of TC.
- Limited data on inter-aquifer leakage.
- Evapotranspiration was not modelled, even though it can represent a large portion of the basin water budget because of dense vegetation cover.
- The analysis of alternative models shows that the calibrated models are not necessarily unique, i.e. there is more than one parameter that affects calibration results.
- The temporal and spatial scales of the model are limits to the model use and accuracy. Hydrologic processes and hydraulic stresses in the transient model were represented as seasonal averages. The model is not intended to be used to simulate changes at time scales such as daily or monthly values. The spatial resolution of the simulation results is limited by the size of the grid cells. Water withdrawal, recharge and water-level observations were averaged within grid cells. Pumping and recharge rates were kept constant in each stress period. Rates may be variable in each stress period. The lack of or limited spatial data that are available also limit the model accuracy.

- The response of the hydrologic system to rainfall events is not very well understood. For example, unsaturated-zone processes are not simulated in the groundwater flow model. Storage and flow in the unsaturated zone affect the timing of the groundwater recharge and affect groundwater level fluctuations. Lack of detailed knowledge about the unsaturated-zone processes and the inability to account for them in the model affects the calibration results. These effects are significant for the transient results because unsaturated-zone processes would be expected to influence the timing of recharge.
- The model is not capable of simulating variable density flow, which would have enabled simulation and assessment of movement of the seawater–groundwater interface under different stress conditions.

8. CONCLUSIONS AND RECOMMENDATIONS

A numerical groundwater flow model has been developed by DWLBC (in conjunction with SA Water and the EPNRMB) to increase understanding of the groundwater system and assist in the long-term management of the Uley Basin. This model incorporates our current understanding of the groundwater flow system. One important result from this study is identification of critical knowledge gaps and the further work required to ensure that model predictions of aquifer response to management scenarios are as accurate as possible.

This model is generally capable of simulating the groundwater flow of the regional aquifer system in the Uley Basin. It accounts for the hydraulic interaction between the Quaternary Bridgewater Formation limestone (QL), Tertiary Uley Formation clay (TC) and Wanilla Formation sand (TS).

8.1 GENERAL MODELLING RESULTS

In general, the groundwater flow model indicates that:

- The QL aquifer responds rapidly to changes in rainfall.
- The average annual rainfall recharge rates estimated by Evans (1997) provided good spatial distribution estimates, while Barnett (1978) estimated temporal distribution of rainfall recharge using limiting winter rainfall. These two methods are supported by the modelling results and proved to be most useful in this type of environment.
- The QL and TS aquifers are hydraulically connected due to the leaky nature of the TC aquitard or its absence in parts of the study area. Connection between aquifers occurs through inter-aquifer leakage. The QL aquifers are sensitive to the magnitude of this interaction.
- The model is very sensitive to spatial distribution and values of hydraulic properties used for the TC aquitard.
- All three lenses (Uley South, Uley Wanilla and Uley East) are connected through the TS aquifer. In the northern parts of Uley East and Uley Wanilla, the QL aquifer will gain from upward leakage from the TS aquifer although it is not a significant part of its water budget. In the southern extents of those lenses, significant discharge from the QL aquifer occurs, contributing major inflow to the TS aquifer. Beneath Uley South, a large portion of the received groundwater inflow will be returned to the QL aquifer through upward leakage. This is supported by hydrochemical studies that found magnesium (Mg) type groundwater in the QL aquifer of Uley Wanilla (south part), the TS aquifer in the central zone and the QL aquifer in Uley South (Harrington et al. 2006).
- Recharge to the TS aquifer occurs through leakage from the QL aquifer beneath the southern parts of Uley East and Uley Wanilla, as well as through TC in the central zone of the study area. It is also very likely that some lateral recharge occurs north of Uley East, where the Tertiary sediments crop out. The model is very sensitive to the magnitude of this lateral recharge in the north.
- The flow in the TS aquifer is generally towards the south, but it is possible that it is not well represented and understood due to its discontinuous nature.
- Recharge contribution from Big Swamp to the QL aquifer is relatively insignificant on the regional scale.

Specific model findings are summarised below:

- An approach used to simulate temporal variation in recharge from rainfall (difference between effective (winter) rainfall and specified base winter rainfall of 250 mm) produced very good results and generally followed hydrograph trends very well.
- The model could not adequately simulate flood events and proved to be sensitive to the frequency and magnitude of heavy rainfall events and therefore high recharge.
- The model is very sensitive to recharge due to the unconfined nature of the QL aquifer. Increases or decreases in recharge values have similar effects across the study area.
- The largest sources of water are recharge from rainfall. Simulated recharge from rainfall within the lenses ranges from 10–100 mm/y, which fall within the ranges estimated by Evans (1997), Barnett (1978) and Harrington et al. (2006).
- The results from the transient model has revealed the degree of accuracy and reliability of the methods used in determining recharge from rainfall The transient model highlights a change in the recharge pattern since the early 1990s. It seems that in the last 15 years rainfall contributed less to recharge — ~10% less in Uley South and Uley East, and as much as 50% in Uley Wanilla.
- The transient calibration results indicate that the timing of recharge to the watertable from rainfall is not well understood.
- The Uley South and Uley Wanilla lenses are less sensitive to increases in horizontal conductivity values.
- Substantial changes occur in model errors in the Uley East lens when the horizontal hydraulic conductivity or recharge is increased or decreased.
- Discharge from the QL aquifer to the TS aquifer in the southern extent of Uley East is much greater than in Uley Wanilla.
- The Uley East and Uley Wanilla lenses are more sensitive to reduction in the horizontal hydraulic conductivity of the TS aquifer.
- The Uley South lens is insensitive to changes in the horizontal hydraulic conductivity of TS aquifer.
- The model is least sensitive to changes in vertical hydraulic conductivities of all three layers, with Uley Wanilla and Uley East being more sensitive than Uley South.
- The monthly extraction volumes for each production well since 1949 (Uley Wanilla) and 1976 (Uley South) were estimated based on sporadic monthly extraction data records for each well in 1998, 1999 and 2001. It is possible that this method is inaccurate and estimated volumes may differ significantly from the real extractions from each well. This may explain the inability of the transient model to achieve good match between observed and simulated heads in some areas.
- After steady state calibration, the simulated heads in Uley South were within 0.02–0.68 m of the observed (measured) water level, with RMSE of 0.39 and ME 0.1.
- A normalised RMS value for the QL aquifer in Uley South is 3.5%, 0.75% in Uley East and 6.4% in Uley Wanilla. These values are less than or close to the 5% recommended by Middlemis (2000). A normalised RMSE for the TS aquifer is 1.25%.

8.1.1 Prediction results and recommendations

8.1.1.1 Prediction results

During the calibration process, a particularly good match was achieved for the last 10 years, which gives a reasonable level of confidence in the outcomes of the model. Predictive modelling results are summarised bellow:

- Assuming that the estimated distribution of groundwater extraction volumes per well is correct, the drawdown cones in each scenario would start developing around production wells USPB 3 (6028-701) and USPB 5 (6028-698), and would spread in a north to southeasterly direction around the original wellfield. Dry cells would start appearing near the central-eastern boundary of Uley South due to high basement and consequently thinner saturated limestone. The drawdowns would be least prominent along the coastal boundary of the model. The maximum summer drawdowns in this lens would be between 0.6 and 1.6 m.
- Similarly, drawdowns in Uley Wanilla would start developing around production wells UWPB 9 (6028-1655) and UWPB 8 (6028-1656), and would increase to almost the whole of northern part of the lens under extremely low recharge conditions. The maximum summer drawdowns would be in the order of 0.8–1.4 m, depending on the scenario.
- In Uley East, summer drawdowns would be greatest in the central and southern part of the lens and would vary between 0.2 and 3 m, depending on the scenario. The northern extent of the lens would be least affected by extreme conditions.
- Water levels would fully recover in winter under most favourable recharge conditions used in predictive modelling. However, in the worst-case scenario with 50% of the last 15-years rainfall repeated, the permanent drawdown for 2020 will be 1.2–1.4 m, which may be unsustainable.
- Very similar development and distribution of the drawdown cones would occur under assumed conditions of each scenario in each lens; however, under long-term average recharge, all drawdowns would be significantly greater.
- The calibration results proved that the long-term average recharge is underestimated, and therefore it is more likely that use of the 15-year repeat recharge would have given more realistic results.
- The previous conclusion supports the assumption that an increase in extraction of ~10% or 1000 ML/y should not be of great concern and it should not have a detrimental impact on the groundwater resource in Uley South. However, it would cause a 2–3 m drawdown in Uley East, which in turn might affect current users and limit future development in this lens.

8.1.1.2 Recommendations

To address some of the model limitations, the following work is recommended:

- More investigations and sampling is required to define both the magnitude of inter-aquifer leakage and zones where this leakage is predicted to occur.
- Additional piezometer nests would be required to further map the occurrence of upward hydraulic potentials between Tertiary and Quaternary aquifers.
- Further modelling will be required to determine the impact of reduced frequency and timing of high intensity rainfall and recharge events.

- Alternative methods of modelling will be required to predict possible seawater intrusion in the QL aquifer in Uley South and the potential to impact on current production wellfields.
- Potential movement of the seawater–groundwater interface could be better defined with conventional methods, such is monitoring. Since the movement of the interface is a function not only of groundwater levels and extraction, but also tidal fluctuations, monitoring seems to be a more relevant and reliable method.
- Given the dense vegetative cover across most of the Uley Basin, evapotranspiration is likely to be the major driver of groundwater salinity. Despite this, there have been no studies of evapotranspiration in the basin.

APPENDICES

A. TEMPORAL RAINFALL DISTRIBUTION

Stress period	Recharge (mm)								
	100	**60**	**50**	**40**	**30**	**25**	**20**	**10**	**0.15**
01/10/1949	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
29/04/1950	0.00092839	0.00055703	0.00046419	0.00037135	0.00027852	0.00023210	0.00018568	0.00009284	0.00007427
01/10/1950	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
29/04/1951	0.00157032	0.00094219	0.00078516	0.00062813	0.00047110	0.00039258	0.00031406	0.00015703	0.00012563
28/04/1952	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
28/04/1952	0.00099806	0.00059884	0.00049903	0.00039923	0.00029942	0.00024952	0.00019961	0.00009981	0.00007985
28/04/1953	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
28/04/1953	0.00068839	0.00041303	0.00034419	0.00027535	0.00020652	0.00017210	0.00013768	0.00006884	0.00005507
28/04/1954	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
28/04/1954	0.00042516	0.00025510	0.00021258	0.00017006	0.00012755	0.00010629	0.00008503	0.00004252	0.00003401
28/04/1955	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
28/04/1955	0.00111355	0.00066813	0.00055677	0.00044542	0.00033406	0.00027839	0.00022271	0.00011135	0.00008908
27/04/1956	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
27/04/1956	0.00175419	0.00105252	0.00087710	0.00070168	0.00052626	0.00043855	0.00035084	0.00017542	0.00014034
27/04/1957	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
27/04/1957	0.00023097	0.00013858	0.00011548	0.00009239	0.00006929	0.00005774	0.00004619	0.00002310	0.00001848
27/04/1958	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
27/04/1958	0.00102774	0.00061665	0.00051387	0.00041110	0.00030832	0.00025694	0.00020555	0.00010277	0.00008222
27/04/1959	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
27/04/1959	0.00002903	0.00001742	0.00001452	0.00001161	0.00000871	0.00000726	0.00000581	0.00000290	0.00000232
26/04/1960	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
26/04/1960	0.00104194	0.00062516	0.00052097	0.00041677	0.00031258	0.00026048	0.00020839	0.00010419	0.00008335
26/04/1961	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
26/04/1961	0.00053935	0.00032361	0.00026968	0.00021574	0.00016181	0.00013484	0.00010787	0.00005394	0.00004315
26/04/1962	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
26/04/1962	0.00064129	0.00038477	0.00032065	0.00025652	0.00019239	0.00016032	0.00012826	0.00006413	0.00005130
26/04/1963	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
26/04/1963	0.00137871	0.00082723	0.00068935	0.00055148	0.00041361	0.00034468	0.00027574	0.00013787	0.00011030
25/04/1964	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
25/04/1964	0.00161419	0.00096852	0.00080710	0.00064568	0.00048426	0.00040355	0.00032284	0.00016142	0.00012914
25/04/1965	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
25/04/1965	0.00075935	0.00045561	0.00037968	0.00030374	0.00022781	0.00018984	0.00015187	0.00007594	0.00006075
25/04/1966	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
25/04/1966	0.00164710	0.00098826	0.00082355	0.00065884	0.00049413	0.00041177	0.00032942	0.00016471	0.00013177
25/04/1967	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
25/04/1967	0.00059355	0.00035613	0.00029677	0.00023742	0.00017806	0.00014839	0.00011871	0.00005935	0.00004748

Stress period	Recharge (mm)								
	100	60	50	40	30	25	20	10	0.15
24/04/1968	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
24/04/1968	0.00177032	0.00106219	0.00088516	0.00070813	0.00053110	0.00044258	0.00035406	0.00017703	0.00014163
24/04/1969	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
24/04/1969	0.00043742	0.00026245	0.00021871	0.00017497	0.00013123	0.00010935	0.00008748	0.00004374	0.00003499
24/04/1970	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
24/04/1970	0.00071484	0.00042890	0.00035742	0.00028594	0.00021445	0.00017871	0.00014297	0.00007148	0.00005719
24/04/1971	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
24/04/1971	0.00184452	0.00110671	0.00092226	0.00073781	0.00055335	0.00046113	0.00036890	0.00018445	0.00014756
23/04/1972	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
23/04/1972	0.00057097	0.00034258	0.00028548	0.00022839	0.00017129	0.00014274	0.00011419	0.00005710	0.00004568
23/04/1973	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
23/04/1973	0.00108645	0.00065187	0.00054323	0.00043458	0.00032594	0.00027161	0.00021729	0.00010865	0.00008692
23/04/1974	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
23/04/1974	0.00125419	0.00075252	0.00062710	0.00050168	0.00037626	0.00031355	0.00025084	0.00012542	0.00010034
23/04/1975	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
23/04/1975	0.00177226	0.00106335	0.00088613	0.00070890	0.00053168	0.00044306	0.00035445	0.00017723	0.00014178
22/04/1976	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
22/04/1976	0.00083871	0.00050323	0.00041935	0.00033548	0.00025161	0.00020968	0.00016774	0.00008387	0.00006710
22/04/1977	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
22/04/1977	0.00039419	0.00023652	0.00019710	0.00015768	0.00011826	0.00009855	0.00007884	0.00003942	0.00003154
22/04/1978	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
22/04/1978	0.00218258	0.00130955	0.00109129	0.00087303	0.00065477	0.00054565	0.00043652	0.00021826	0.00017461
22/04/1979	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
22/04/1979	0.00144516	0.00086710	0.00072258	0.00057806	0.00043355	0.00036129	0.00028903	0.00014452	0.00011561
21/04/1980	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
21/04/1980	0.00101161	0.00060697	0.00050581	0.00040465	0.00030348	0.00025290	0.00020232	0.00010116	0.00008093
21/04/1981	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
21/04/1981	0.00200258	0.00120155	0.00100129	0.00080103	0.00060077	0.00050065	0.00040052	0.00020026	0.00016021
21/04/1982	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
21/04/1982	0.00037290	0.00022374	0.00018645	0.00014916	0.00011187	0.00009323	0.00007458	0.00003729	0.00002983
21/04/1983	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
21/04/1983	0.00112258	0.00067355	0.00056129	0.00044903	0.00033677	0.00028065	0.00022452	0.00011226	0.00008981
20/04/1984	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
20/04/1984	0.00181161	0.00108697	0.00090581	0.00072465	0.00054348	0.00045290	0.00036232	0.00018116	0.00014493
20/04/1985	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
20/04/1985	0.00108129	0.00064877	0.00054065	0.00043252	0.00032439	0.00027032	0.00021626	0.00010813	0.00008650
20/04/1986	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
20/04/1986	0.00144000	0.00086400	0.00072000	0.00057600	0.00043200	0.00036000	0.00028800	0.00014400	0.00011520
22/09/1986	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
20/04/1987	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
20/04/1987	0.00069677	0.00041806	0.00034839	0.00027871	0.00020903	0.00017419	0.00013935	0.00006968	0.00005574
19/04/1988	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
19/04/1988	0.00077935	0.00046761	0.00038968	0.00031174	0.00023381	0.00019484	0.00015587	0.00007794	0.00006235

Stress period	**Recharge** (mm)								
	100	**60**	**50**	**40**	**30**	**25**	**20**	**10**	**0.15**
19/04/1989	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
19/04/1989	0.00204000	0.00122400	0.00102000	0.00081600	0.00061200	0.00051000	0.00040800	0.00020400	0.00016320
19/04/1990	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
19/04/1990	0.00173484	0.00104090	0.00086742	0.00062454	0.00052045	0.00043371	0.00034697	0.00017348	0.00013879
19/04/1991	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
19/04/1991	0.00062581	0.00037548	0.00031290	0.00022529	0.00018774	0.00015645	0.00012516	0.00006258	0.00005006
18/04/1992	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
18/04/1992	0.00231355	0.00138813	0.00115677	0.00083288	0.00069406	0.00057839	0.00046271	0.00023135	0.00018508
18/04/1993	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
18/04/1993	0.00080903	0.00048542	0.00040452	0.00029125	0.00024271	0.00020226	0.00016181	0.00008090	0.00006472
18/04/1994	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
18/04/1994	0.00055871	0.00033523	0.00027935	0.00020114	0.00016761	0.00013968	0.00011174	0.00005587	0.00004470
18/04/1995	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
18/04/1995	0.00103226	0.00061935	0.00051613	0.00037161	0.00030968	0.00025806	0.00020645	0.00010323	0.00008258
17/04/1996	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
17/04/1996	0.00142710	0.00085626	0.00071355	0.00051375	0.00042813	0.00035677	0.00028542	0.00014271	0.00011417
17/04/1997	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
17/04/1997	0.00098129	0.00058877	0.00049065	0.00035326	0.00029439	0.00024532	0.00019626	0.00009813	0.00007850
17/04/1998	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
17/04/1998	0.00037355	0.00022413	0.00018677	0.00013448	0.00011206	0.00009339	0.00007471	0.00003735	0.00002988
17/04/1999	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
17/04/1999	0.00082516	0.00049510	0.00041258	0.00029706	0.00024755	0.00020629	0.00016503	0.00008252	0.00006601
16/04/2000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
16/04/2000	0.00185548	0.00111329	0.00092774	0.00066797	0.00055665	0.00046387	0.00037110	0.00018555	0.00014844
16/04/2001	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
16/04/2001	0.00108774	0.00065265	0.00054387	0.00039159	0.00032632	0.00027194	0.00021755	0.00010877	0.00008702
16/04/2002	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
16/04/2002	0.00083677	0.00050206	0.00041839	0.00030124	0.00025103	0.00020919	0.00016735	0.00008368	0.00006694
16/04/2003	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
16/04/2003	0.00135032	0.00081019	0.00067516	0.00048612	0.00040510	0.00033758	0.00027006	0.00013503	0.00010803
15/04/2004	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
15/04/2004	0.00099742	0.00059845	0.00049871	0.00035907	0.00029923	0.00024935	0.00019948	0.00009974	0.00007979
15/04/2005	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000

B. GROUNDWATER USE

Uley Wanilla

	Extraction rate (m^3/d)										
Well No.	**1528**	**1514**	**915**	**924**	**938**	**947**	**1694**	**1656**	**1655**	**2287**	**2288**
30/04/1950	180.1	900.4	540.2	1260.5	810.3	1170.5	1080.4	1620.7	1350.6	45.0	45.0
30/09/1950	20.6	103.0	61.8	144.2	92.7	133.9	123.6	185.4	154.5	5.1	5.1
30/04/1951	50.3	251.4	150.8	352.0	226.3	326.8	301.7	452.5	377.1	12.6	12.6
30/09/1951	25.0	124.9	74.9	174.8	112.4	162.3	149.9	224.8	187.3	6.2	6.2
30/04/1952	74.8	374.0	224.4	523.5	336.6	486.1	448.7	673.1	560.9	18.7	18.7
30/09/1952	29.4	146.8	88.1	205.5	132.1	190.8	176.1	264.2	220.1	7.3	7.3
30/04/1953	81.6	408.0	244.8	571.2	367.2	530.4	489.6	734.4	612.0	20.4	20.4
30/09/1953	40.8	203.9	122.3	285.5	183.5	265.1	244.7	367.0	305.8	10.2	10.2
30/04/1954	108.4	542.1	325.3	759.0	487.9	704.8	650.6	975.9	813.2	27.1	27.1
30/09/1954	58.9	294.6	176.8	412.4	265.1	383.0	353.5	530.3	441.9	14.7	14.7
30/04/1955	119.9	599.5	359.7	839.3	539.6	779.4	719.4	1079.1	899.3	30.0	30.0
30/09/1955	53.4	267.2	160.3	374.0	240.5	347.3	320.6	480.9	400.8	13.4	13.4
30/04/1956	129.0	645.2	387.1	903.3	580.7	838.8	774.3	1161.4	967.9	32.3	32.3
30/09/1956	53.0	265.1	159.1	371.1	238.6	344.6	318.1	477.2	397.6	13.3	13.3
30/04/1957	128.6	643.0	385.8	900.2	578.7	835.9	771.6	1157.3	964.5	32.1	32.1
30/09/1957	71.3	356.4	213.8	498.9	320.7	463.3	427.6	641.4	534.5	17.8	17.8
30/04/1958	167.9	839.7	503.8	1175.6	755.7	1091.6	1007.7	1511.5	1259.6	42.0	42.0
30/09/1958	122.8	614.1	368.5	859.7	552.7	798.3	736.9	1105.4	921.1	30.7	30.7
30/04/1959	140.9	704.3	422.6	986.0	633.8	915.5	845.1	1267.7	1056.4	35.2	35.2
30/09/1959	88.6	442.9	265.7	620.1	398.6	575.8	531.5	797.2	664.4	22.1	22.1
30/04/1960	176.1	880.5	528.3	1232.7	792.5	1144.7	1056.6	1585.0	1320.8	44.0	44.0
30/09/1960	130.2	650.8	390.5	911.1	585.7	846.0	780.9	1171.4	976.2	32.5	32.5
30/04/1961	169.7	848.3	509.0	1187.7	763.5	1102.8	1018.0	1527.0	1272.5	42.4	42.4
30/09/1961	131.0	655.0	393.0	917.0	589.5	851.5	786.0	1179.0	982.5	32.7	32.7
30/04/1962	155.7	778.6	467.2	1090.1	700.8	1012.2	934.4	1401.5	1167.9	38.9	38.9
30/09/1962	146.4	732.0	439.2	1024.8	658.8	951.6	878.4	1317.6	1098.0	36.6	36.6
30/04/1963	117.6	587.8	352.7	823.0	529.1	764.2	705.4	1058.1	881.8	29.4	29.4
30/09/1963	20.2	101.0	60.6	141.4	90.9	131.3	121.2	181.8	151.5	5.1	5.1
30/04/1964	28.7	143.5	86.1	201.0	129.2	186.6	172.3	258.4	215.3	7.2	7.2
30/09/1964	14.9	74.7	44.8	104.6	67.2	97.1	89.6	134.5	112.1	3.7	3.7
30/04/1965	11.5	57.6	34.6	80.6	51.8	74.9	69.1	103.7	86.4	2.9	2.9
30/09/1965	21.2	106.0	63.6	148.4	95.4	137.8	127.2	190.8	159.0	5.3	5.3
30/04/1966	38.4	191.8	115.1	268.6	172.7	249.4	230.2	345.3	287.8	9.6	9.6
30/09/1966	33.1	165.5	99.3	231.7	148.9	215.1	198.6	297.9	248.2	8.3	8.3
30/04/1967	70.4	351.8	211.1	492.5	316.6	457.3	422.1	633.2	527.6	17.6	17.6
30/09/1967	47.8	239.1	143.5	334.8	215.2	310.9	287.0	430.4	358.7	12.0	12.0

	Extraction rate (m³/d)										
Well No.	**1528**	**1514**	**915**	**924**	**938**	**947**	**1694**	**1656**	**1655**	**2287**	**2288**
30/04/1968	92.8	464.1	278.5	649.8	417.7	603.4	557.0	835.4	696.2	23.2	23.2
30/09/1968	24.5	122.5	73.5	171.4	110.2	159.2	146.9	220.4	183.7	6.1	6.1
30/04/1969	34.7	173.7	104.2	243.2	156.3	225.8	208.4	312.6	260.5	8.7	8.7
30/09/1969	14.9	74.7	44.8	104.6	67.2	97.1	89.6	134.5	112.1	3.7	3.7
30/04/1970	76.9	384.5	230.7	538.3	346.1	499.9	461.4	692.1	576.8	19.2	19.2
30/09/1970	45.3	226.3	135.8	316.8	203.7	294.2	271.5	407.3	339.4	11.3	11.3
30/04/1971	115.2	575.8	345.5	806.2	518.3	748.6	691.0	1036.5	863.8	28.8	28.8
30/09/1971	39.5	197.3	118.4	276.2	177.5	256.4	236.7	355.1	295.9	9.9	9.9
30/04/1972	64.5	322.3	193.4	451.2	290.1	419.0	386.8	580.2	483.5	16.1	16.1
30/09/1972	56.4	282.1	169.2	394.9	253.9	366.7	338.5	507.7	423.1	14.1	14.1
30/04/1973	83.2	415.8	249.5	582.1	374.2	540.5	498.9	748.4	623.6	20.8	20.8
30/09/1973	59.9	299.3	179.6	419.0	269.3	389.0	359.1	538.7	448.9	15.0	15.0
30/04/1974	108.7	543.6	326.2	761.1	489.3	706.7	652.4	978.6	815.5	27.2	27.2
30/09/1974	60.2	300.8	180.5	421.1	270.7	391.0	360.9	541.4	451.2	15.0	15.0
30/04/1975	125.7	628.5	377.1	879.9	565.7	817.1	754.2	1131.4	942.8	31.4	31.4
30/09/1975	95.7	478.6	287.2	670.1	430.8	622.2	574.4	861.6	718.0	23.9	23.9
30/04/1976	141.6	707.9	424.8	991.1	637.1	920.3	849.5	1274.3	1061.9	35.4	35.4
30/09/1976	141.4	707.0	424.2	989.8	636.3	919.1	848.4	1272.6	1060.5	35.3	35.3
30/04/1977	153.8	769.2	461.5	1076.9	692.3	1000.0	923.1	1384.6	1153.9	38.5	38.5
30/09/1977	131.4	656.9	394.1	919.7	591.2	854.0	788.3	1182.4	985.4	32.8	32.8
30/04/1978	86.9	434.3	260.6	608.0	390.9	564.6	521.1	781.7	651.4	21.7	21.7
30/09/1978	4.3	21.3	12.8	29.8	19.2	27.7	25.5	38.3	31.9	1.1	1.1
30/04/1979	28.7	143.3	86.0	200.7	129.0	186.3	172.0	258.0	215.0	7.2	7.2
30/09/1979	11.5	57.4	34.5	80.4	51.7	74.6	68.9	103.4	86.1	2.9	2.9
30/04/1980	13.6	68.1	40.9	95.3	61.3	88.5	81.7	122.6	102.1	3.4	3.4
30/09/1980	9.4	47.1	28.3	65.9	42.4	61.2	56.5	84.8	70.6	2.4	2.4
30/04/1981	68.1	340.5	204.3	476.7	306.4	442.6	408.6	612.9	510.7	17.0	17.0
30/09/1981	47.5	237.4	142.5	332.4	213.7	308.6	284.9	427.4	356.1	11.9	11.9
30/04/1982	46.0	230.0	138.0	322.0	207.0	299.0	276.0	414.0	345.0	11.5	11.5
30/09/1982	14.6	72.9	43.7	102.1	65.6	94.8	87.5	131.2	109.4	3.6	3.6
30/04/1983	52.2	261.0	156.6	365.3	234.9	339.2	313.1	469.7	391.4	13.0	13.0
30/09/1983	11.7	58.7	35.2	82.2	52.8	76.3	70.5	105.7	88.1	2.9	2.9
30/04/1984	39.9	199.5	119.7	279.3	179.6	259.4	239.4	359.1	299.3	10.0	10.0
30/09/1984	18.5	92.3	55.4	129.2	83.0	119.9	110.7	166.1	138.4	4.6	4.6
30/04/1985	53.2	266.2	159.7	372.7	239.6	346.0	319.4	479.1	399.3	13.3	13.3
30/09/1985	17.9	89.7	53.8	125.5	80.7	116.6	107.6	161.4	134.5	4.5	4.5
30/04/1986	47.0	234.8	140.9	328.7	211.3	305.2	281.7	422.6	352.1	11.7	11.7
30/09/1986	19.6	98.1	58.8	137.3	88.3	127.5	117.7	176.5	147.1	4.9	4.9
30/04/1987	79.4	397.1	238.3	556.0	357.4	516.3	476.6	714.9	595.7	19.9	19.9
30/09/1987	44.8	223.9	134.3	313.4	201.5	291.0	268.6	403.0	335.8	11.2	11.2

	Extraction rate (m^3/d)										
Well No.	**1528**	**1514**	**915**	**924**	**938**	**947**	**1694**	**1656**	**1655**	**2287**	**2288**
30/04/1988	102.8	513.8	308.3	719.3	462.4	667.9	616.5	924.8	770.7	25.7	25.7
30/09/1988	48.6	242.9	145.7	340.0	218.6	315.7	291.5	437.2	364.3	12.1	12.1
30/04/1989	93.3	466.4	279.8	652.9	419.7	606.3	559.6	839.5	699.6	23.3	23.3
30/09/1989	48.2	241.0	144.6	337.4	216.9	313.3	289.2	433.9	361.6	12.1	12.1
30/04/1990	69.6	347.8	208.7	487.0	313.0	452.2	417.4	626.1	521.7	17.4	17.4
30/09/1990	59.1	295.6	177.4	413.8	266.0	384.3	354.7	532.1	443.4	14.8	14.8
30/04/1991	120.8	604.0	362.4	845.6	543.6	785.2	724.8	1087.2	906.0	30.2	30.2
30/09/1991	42.9	214.4	128.6	300.1	193.0	278.7	257.3	385.9	321.6	10.7	10.7
30/04/1992	119.2	595.9	357.6	834.3	536.3	774.7	715.1	1072.7	893.9	29.8	29.8
30/09/1992	95.1	475.7	285.4	666.0	428.2	618.4	570.9	856.3	713.6	23.8	23.8
30/04/1993	95.7	478.5	287.1	669.9	430.6	622.0	574.2	861.3	717.7	23.9	23.9
30/09/1993	54.9	274.6	164.7	384.4	247.1	357.0	329.5	494.2	411.9	13.7	13.7
30/04/1994	65.4	327.1	196.3	458.0	294.4	425.3	392.6	588.9	490.7	16.4	16.4
30/09/1994	1.9	9.7	5.8	13.5	8.7	12.6	11.6	17.4	14.5	0.5	0.5
30/04/1995	58.7	293.6	176.1	411.0	264.2	381.6	352.3	528.4	440.4	14.7	14.7
30/09/1995	67.0	334.8	200.9	468.8	301.4	435.3	401.8	602.7	502.3	16.7	16.7
30/04/1996	23.4	117.1	70.3	164.0	105.4	152.3	140.6	210.9	175.7	5.9	5.9
30/09/1996	54.8	274.2	164.5	383.9	246.8	356.5	329.0	493.5	411.3	13.7	13.7
30/04/1997	43.7	218.6	131.1	306.0	196.7	284.1	262.3	393.4	327.9	10.9	10.9
30/09/1997	38.6	192.9	115.7	270.1	173.6	250.8	231.5	347.2	289.4	9.6	9.6
30/04/1998	47.8	239.0	143.4	334.7	215.1	310.8	286.9	430.3	358.6	12.0	12.0
30/09/1998	14.6	72.9	43.7	102.1	65.6	94.8	87.5	131.2	109.4	3.6	3.6
30/04/1999	49.7	248.6	149.1	348.0	223.7	323.1	298.3	447.4	372.9	12.4	12.4
30/09/1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/2000	25.4	127.1	76.3	178.0	114.4	165.3	152.6	228.9	190.7	6.4	6.4
30/09/2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/2001	27.1	135.7	81.4	190.0	122.1	176.4	162.9	244.3	203.6	6.8	6.8
30/09/2001	0.5	2.6	1.5	3.6	2.3	3.4	3.1	4.6	3.9	0.1	0.1
30/04/2002	23.5	117.6	70.6	164.7	105.9	152.9	141.1	211.7	176.4	5.9	5.9
30/09/2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/2003	25.3	126.7	76.0	177.3	114.0	164.7	152.0	228.0	190.0	6.3	6.3
30/09/2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/2004	19.8	99.0	59.4	138.6	89.1	128.7	118.8	178.2	148.5	5.0	5.0
30/09/2004	3.0	14.8	8.9	20.7	13.3	19.2	17.7	26.6	22.2	0.7	0.7
30/04/2005	25.0	124.9	74.9	174.9	112.4	162.4	149.9	224.8	187.4	6.2	6.2

Uley South

	Extraction rate (m³/d)																
Well No.	**703**	**702**	**701**	**700**	**698**	**697**	**696**	**699**	**2156**	**2158**	**2159**	**2169**	**2168**	**2160**	**2163**	**2164**	**2166**
30/09/1976	1173.8	1017.3	1330.3	704.3	1565.0	469.5	1017.3	547.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1977	1450.5	1257.1	1643.8	870.3	1933.9	580.2	1257.1	676.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1977	2850.7	2470.6	3230.8	1710.4	3801.0	1140.3	2470.6	1330.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1978	1987.7	1722.7	2252.8	1192.6	2650.3	795.1	1722.7	927.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1978	2580.0	2236.0	2924.0	1548.0	3440.0	1032.0	2236.0	1204.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1979	2207.4	1913.1	2501.7	1324.5	2943.2	883.0	1913.1	1030.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1979	2367.1	2051.5	2682.8	1420.3	3156.2	946.9	2051.5	1104.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1980	1253.2	1086.1	1420.3	751.9	1671.0	501.3	1086.1	584.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1980	2739.3	2374.0	3104.5	1643.6	3652.4	1095.7	2374.0	1278.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1981	1555.2	1347.8	1762.5	933.1	2073.5	622.1	1347.8	725.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1981	3045.7	2639.6	3451.8	1827.4	4061.0	1218.3	2639.6	1421.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1982	2077.7	1800.7	2354.8	1246.6	2770.3	831.1	1800.7	969.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1982	2939.3	2547.4	3331.2	1763.6	3919.0	1175.7	2547.4	1371.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1983	1710.0	1482.0	1938.0	1026.0	2280.0	684.0	1482.0	798.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1983	2830.7	2453.3	3208.1	1698.4	3774.3	1132.3	2453.3	1321.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1984	1386.8	1201.9	1571.7	832.1	1849.0	554.7	1201.9	647.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1984	2904.3	2517.0	3291.5	1742.6	3872.4	1161.7	2517.0	1355.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1985	1301.6	1128.1	1475.2	781.0	1735.5	520.6	1128.1	607.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1985	2711.4	2349.9	3073.0	1626.9	3615.2	1084.6	2349.9	1265.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1986	1967.4	1705.1	2229.7	1180.5	2623.2	787.0	1705.1	918.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1986	2325.0	2015.0	2635.0	1395.0	3100.0	930.0	2015.0	1085.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1987	1956.8	1695.9	2217.7	1174.1	2609.0	782.7	1695.9	913.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1987	2661.5	2306.6	3016.3	1596.9	3548.6	1064.6	2306.6	1242.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Extraction rate (m³/d)																
Well No.	**703**	**702**	**701**	**700**	**698**	**697**	**696**	**699**	**2156**	**2158**	**2159**	**2169**	**2168**	**2160**	**2163**	**2164**	**2166**
30/04/1988	2439.1	2113.9	2764.3	1463.4	3252.1	975.6	2113.9	1138.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1988	2566.3	2224.1	2908.5	1539.8	3421.7	1026.5	2224.1	1197.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1989	1243.1	1077.4	1408.8	745.9	1657.5	497.2	1077.4	580.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1989	1797.2	1557.6	2036.9	1078.3	2396.3	718.9	1557.6	838.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1990	1412.0	1223.8	1600.3	847.2	1882.7	564.8	1223.8	659.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1990	1703.1	1476.0	1930.2	1021.9	2270.8	681.2	1476.0	794.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1991	1096.1	949.9	1242.2	657.6	1461.4	438.4	949.9	511.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1991	1976.8	1713.3	2240.4	1186.1	2635.8	790.7	1713.3	922.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1992	889.7	771.1	1008.4	533.8	1186.3	355.9	771.1	415.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1992	1169.3	1013.4	1325.2	701.6	1559.0	467.7	1013.4	545.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1993	649.4	562.8	735.9	389.6	865.8	259.7	562.8	303.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1993	2159.3	1871.4	2447.2	1295.6	2879.0	863.7	1871.4	1007.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1994	1495.2	1295.8	1694.5	897.1	1993.5	598.1	1295.8	697.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1994	2317.1	2008.2	2626.1	1390.3	3089.5	926.9	2008.2	1081.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1995	1425.5	1235.4	1615.5	855.3	1900.6	570.2	1235.4	665.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1995	2092.9	1813.8	2371.9	1255.7	2790.5	837.1	1813.8	976.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1996	1631.6	1414.1	1849.2	979.0	2175.5	652.6	1414.1	761.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1996	2469.3	2140.0	2798.5	1481.6	3292.4	987.7	2140.0	1152.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1997	2006.1	1738.6	2273.6	1203.7	2674.8	802.5	1738.6	936.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1997	2285.0	1980.3	2589.7	1371.0	3046.7	914.0	1980.3	1066.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1998	1791.3	1552.5	2030.1	1074.8	2388.4	716.5	1552.5	835.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1998	2657.1	2302.9	3011.4	1594.3	3542.9	1062.9	2302.9	1240.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/04/1999	2228.7	1931.5	2525.9	1337.2	2971.6	891.5	1931.5	1040.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30/09/1999	3092.4	2682.4	3467.6	1897.1	3995.7	1230.0	2647.6	1417.6	347.6	382.4	278.1	243.3	104.3	69.5	173.8	104.3	104.3
30/04/2000	1378.1	1205.8	1378.1	1033.5	1205.8	516.8	1033.5	516.8	1722.6	1894.8	1378.1	1205.8	516.8	344.5	861.3	516.8	516.8

	Extraction rate (m³/d)																
Well No.	**703**	**702**	**701**	**700**	**698**	**697**	**696**	**699**	**2156**	**2158**	**2159**	**2169**	**2168**	**2160**	**2163**	**2164**	**2166**
30/09/2000	1889.9	1653.7	1889.9	1417.4	1653.7	708.7	1417.4	708.7	2362.4	2598.6	1889.9	1653.7	708.7	472.5	1181.2	708.7	708.7
30/04/2001	1367.2	1196.3	1367.2	1025.4	1196.3	512.7	1025.4	512.7	1709.0	1879.9	1367.2	1196.3	512.7	341.8	854.5	512.7	512.7
30/09/2001	1763.0	1542.7	1763.0	1322.3	1542.7	661.1	1322.3	661.1	2203.8	2424.2	1763.0	1542.7	661.1	440.8	1101.9	661.1	661.1
30/04/2002	1520.0	1330.0	1520.0	1140.0	1330.0	570.0	1140.0	570.0	1900.0	2090.0	1520.0	1330.0	570.0	380.0	950.0	570.0	570.0
30/09/2002	1842.7	1612.3	1842.7	1382.0	1612.3	691.0	1382.0	691.0	2303.3	2533.7	1842.7	1612.3	691.0	460.7	1151.7	691.0	691.0
30/04/2003	1288.8	1127.7	1288.8	966.6	1127.7	483.3	966.6	483.3	1611.0	1772.1	1288.8	1127.7	483.3	322.2	805.5	483.3	483.3
30/09/2003	1981.3	1733.7	1981.3	1486.0	1733.7	743.0	1486.0	743.0	2476.7	2724.3	1981.3	1733.7	743.0	495.3	1238.3	743.0	743.0
30/04/2004	1197.4	1047.7	1197.4	898.1	1047.7	449.0	898.1	449.0	1496.8	1646.5	1197.4	1047.7	449.0	299.4	748.4	449.0	449.0
30/09/2004	1918.9	1679.0	1918.9	1439.1	1679.0	719.6	1439.1	719.6	2398.6	2638.4	1918.9	1679.0	719.6	479.7	1199.3	719.6	719.6
30/04/2005	594.1	519.8	594.1	445.5	519.8	222.8	445.5	222.8	742.6	816.8	594.1	519.8	222.8	148.5	371.3	222.8	222.8

C. COMPARISON OF MEASURED AND CALCULATED HEADS — STEADY STATE

Observation well	**Lens**	**Aquifer monitored**	**Pre-development head** (m AHD)		
			Observed	*Calculated*	*Residual*
ULE91	US	QLA	2.42	2.76	0.34
ULE92	US	QLA	2.70	3.22	0.52
ULE93	US	QLA	2.36	2.46	0.10
ULE94	US	QLA	2.38	2.53	0.15
ULE95	US	QLA	2.43	2.71	0.28
ULE42	UE	QLA	102.10	102.02	-0.08
ULE43	UE	QLA	100.10	100.94	0.84
ULE50	UE	QLA	79.63	79.76	0.13
WNL4	UW	QLA	89.20	89.02	-0.18
WNL6	UW	QLA	89.60	89.69	0.09
WNL7	UW	QLA	89.70	89.27	-0.43
WNL9	UW	QLA	88.46	88.52	0.06
WNL22	UW	QLA	91.25	91.38	0.13
WNL24	UW	QLA	92.23	91.88	-0.35
ULE2	UW	QLA	90.55	90.44	-0.11
ULE14	UW	QLA	83.50	83.37	-0.13
ULE15	UW	QLA	84.50	84.40	-0.10
ULE16	UW	QLA	86.05	86.04	-0.01
ULE17	UW	QLA	87.29	87.01	-0.28
ULE19	UW	QLA	92.09	92.08	-0.01
ULE21	UW	QLA	93.77	93.85	0.08
ULE22	UW	QLA	95.50	94.93	-0.57
ULE27	UW	QLA	96.50	96.46	-0.04
ULE35	UW	QLA	86.09	85.93	-0.16
ULE38	UW	QLA	88.35	88.12	-0.23
ULE39	UW	QLA	89.10	89.03	-0.07
ULE45	UE	QLA	96.05	96.43	0.38
ULE46	UE	QLA	91.99	92.00	0.01
ULE47	UE	QLA	90.46	90.49	0.03
ULE48	UE	QLA	89.90	89.50	-0.40
ULE49	UE	QLA	85.08	85.19	0.11
ULE52	UE	QLA	97.01	97.59	0.58
ULE53	UE	QLA	96.60	96.84	0.24
ULE55	UE	QLA	94.35	94.32	-0.03

Observation well	Lens	Aquifer monitored	Pre-development head (m AHD)		
			Observed	*Calculated*	*Residual*
ULE56	UE	QLA	97.80	97.67	-0.13
ULE57	UE	QLA	98.77	98.63	-0.14
ULE58	UE	QLA	98.50	98.81	0.31
ULE59	UE	QLA	101.00	100.70	-0.30
ULE63	UE	QLA	99.90	100.14	0.24
WNL3	UW	QLA	90.20	90.12	-0.08
ULE39	UW	QLA	88.51	88.18	-0.33
ULE40	UW	QLA	87.80	87.91	0.11
ULE166	UE	QLA	38.80	39.40	0.60
ULE86	UE	QLA	60.45	62.03	1.58
ULE60	UE	QLA	100.50	100.82	0.32
ULE7	UW	QLA	74.00	77.34	3.34
ULE171	UW	QLA	55.50	69.45	13.95
ULE32	UW	QLA	85.50	85.74	0.24
SLE6	US	QLA	1.34	1.36	0.02
SLE5	US	QLA	0.93	0.75	-0.18
SLE4	US	QLA	1.02	1.13	0.11
SLE18	US	QLA	1.82	2.31	0.49
SLE7	US	QLA	2.03	1.82	-0.21
SLE8	US	QLA	1.40	1.52	0.12
SLE11	US	QLA	0.63	0.75	0.12
SLE9	US	QLA	1.09	1.07	-0.02
SLE10	US	QLA	0.17	0.28	0.11
ULE96	US	QLA	2.38	2.85	0.47
ULE125	US	QLA	10.66	10.83	0.17
ULE118	US	QLA	6.50	6.26	-0.24
ULE124	US	QLA	13.43	13.74	0.31
ULE121	US	QLA	9.43	9.20	-0.23
ULE119	US	QLA	7.50	7.31	-0.19
ULE139	US	QLA	6.54	6.69	0.15
ULE120	US	QLA	7.67	8.35	0.68
ULE140	US	QLA	7.38	7.78	0.40
ULE142	US	QLA	9.05	7.45	-1.60
ULE143	US	QLA	5.58	6.05	0.47
ULE103	US	QLA	3.45	3.93	0.48
ULE102	US	QLA	3.00	3.24	0.24
ULE134	US	QLA	2.71	2.42	-0.29
ULE145	US	QLA	5.62	5.27	-0.35

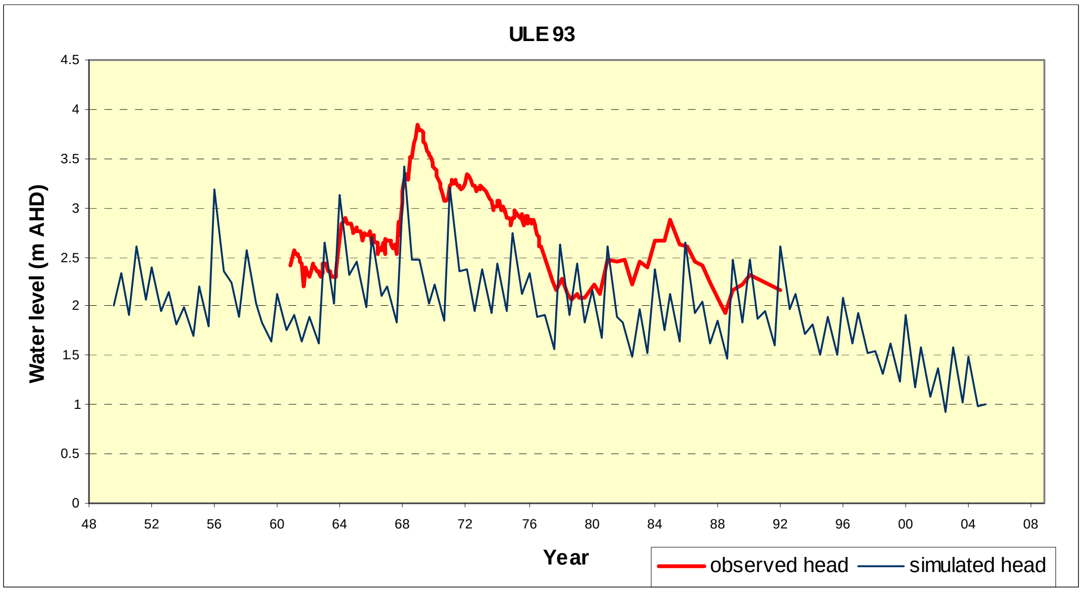
Observation well	Lens	Aquifer monitored	Pre-development head (m AHD)		
			Observed	*Calculated*	*Residual*
ULE144	US	QLA	5.58	5.41	-0.17
ULE138	US	QLA	5.42	5.53	0.11
ULE116	US	QLA	5.32	5.38	0.06
ULE104	US	QLA	4.24	4.18	-0.06
ULE105	US	QLA	3.51	3.66	0.15
ULE99	US	QLA	3.06	3.47	0.41
ULE100	US	QLA	3.00	2.94	-0.06
ULE98	US	QLA	2.55	2.72	0.17
ULE106	US	QLA	3.15	3.79	0.64
ULE133	US	QLA	0.90	1.03	0.13
ULE147	US	QLA	1.95	2.23	0.28
ULE146	US	QLA	2.99	3.75	0.76
ULE148	US	QLA	2.85	3.23	0.38
ULE126	US	QLA	11.35	10.84	-0.51
LKW34	US	TSA	2.33	2.41	0.08
SLE013	US	TSA	4.57	5.34	0.77
ULE65		TSA	95.95	94.98	-0.97
ULE84	UE	TSA	63.28	60.34	-2.94
ULE89		TSA	18.20	18.82	0.62
ULE109	US	TSA	6.16	6.41	0.25
ULE127	US	TSA	7.51	8.27	0.76
ULE133	US	TSA	1.70	1.04	-0.66
ULE135	US	TSA	2.74	2.63	-0.11
ULE163		TSA	28.10	27.80	-0.30
ULE164		TSA	25.60	25.68	0.08
ULE169		TSA	24.30	24.39	0.09
ULE175		TSA	32.50	33.17	0.67
ULE185	US	TSA	5.09	5.42	0.33
ULE195	UE	TSA	102.50	99.21	-3.29
ULE141	US	TSA	11.00	9.65	-1.35

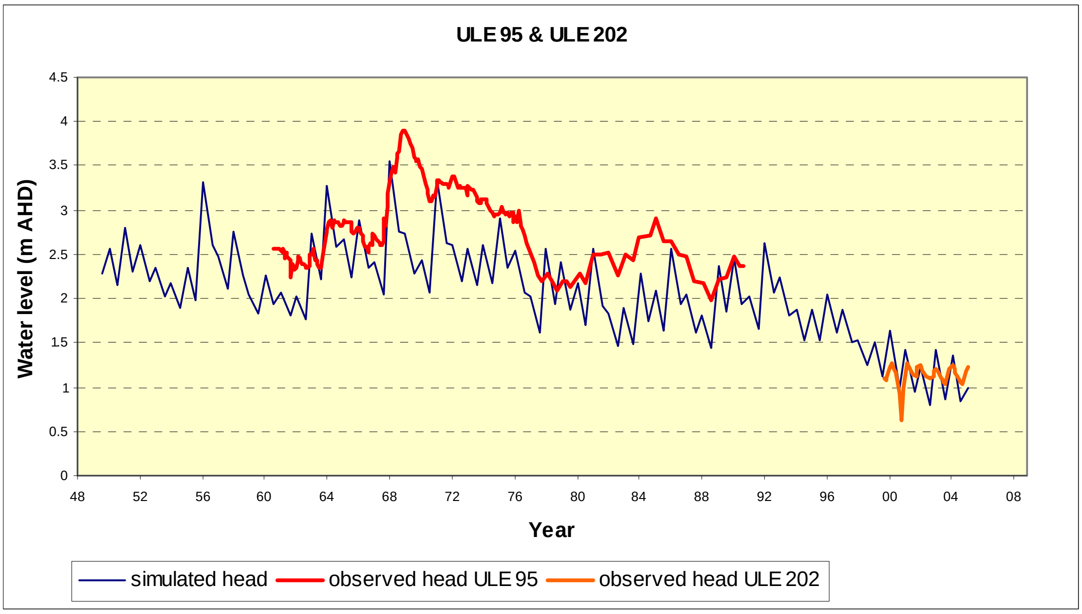
US Uley South
UW Uley Wanilla
UE Uley East

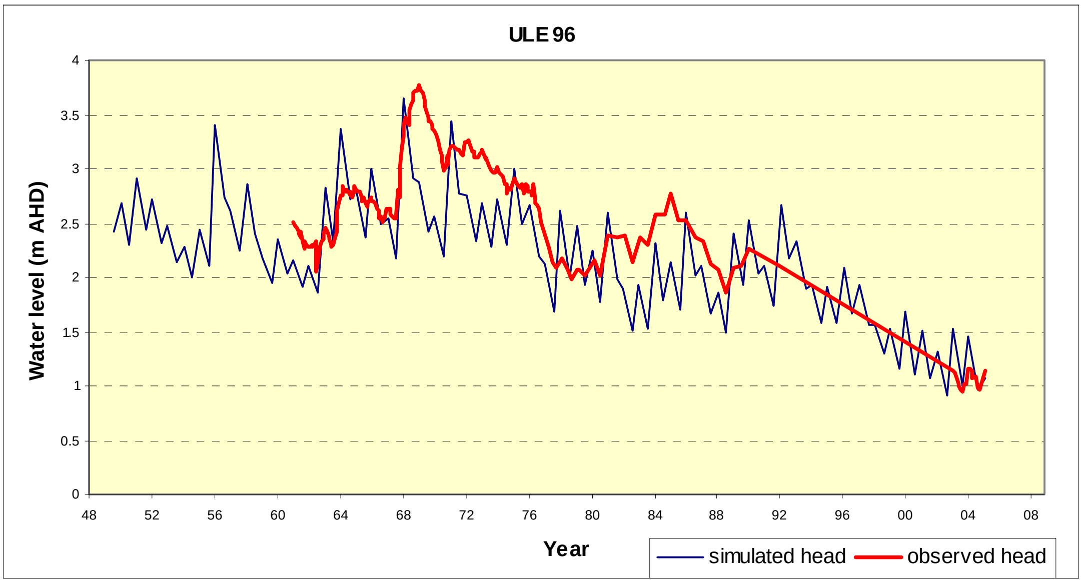
QLA Quaternary limestone aquifer
TSA Tertiary sand aquifer

D. MODELLED AND OBSERVED HEADS — TRANSIENT STATE

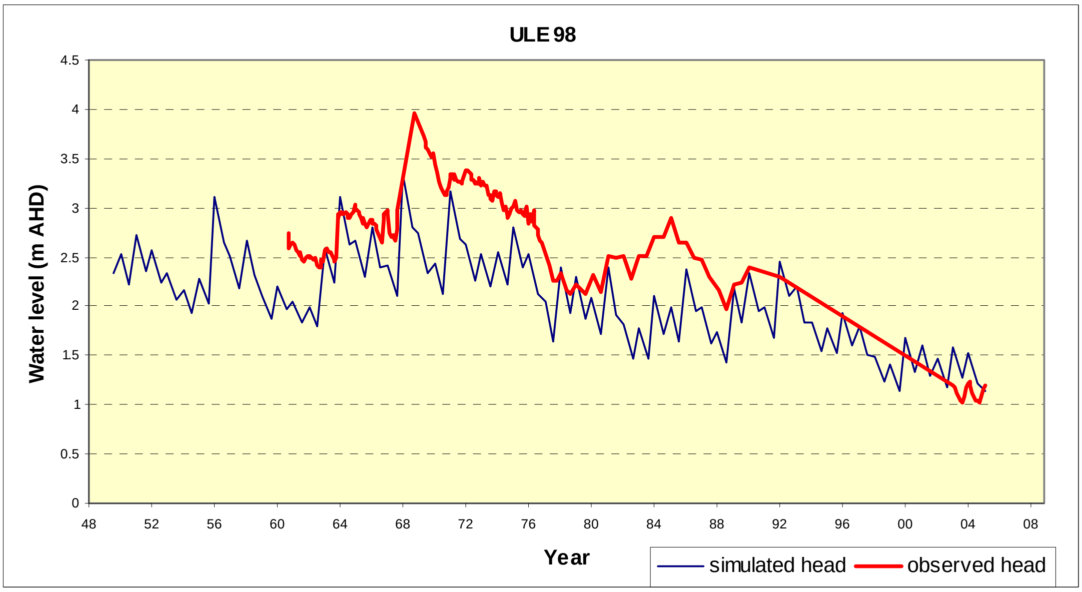
Uley South



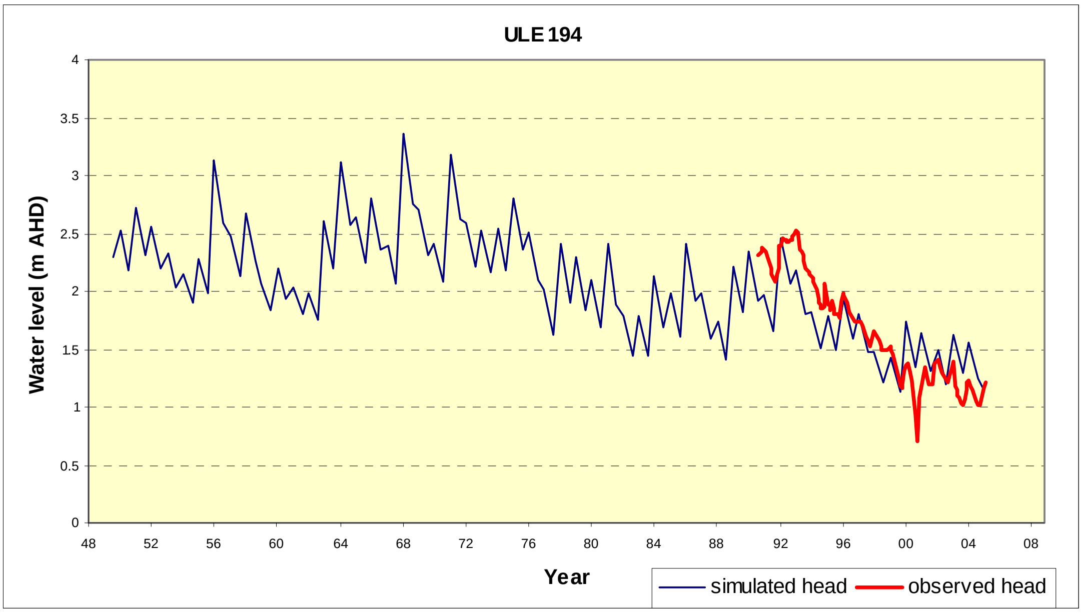




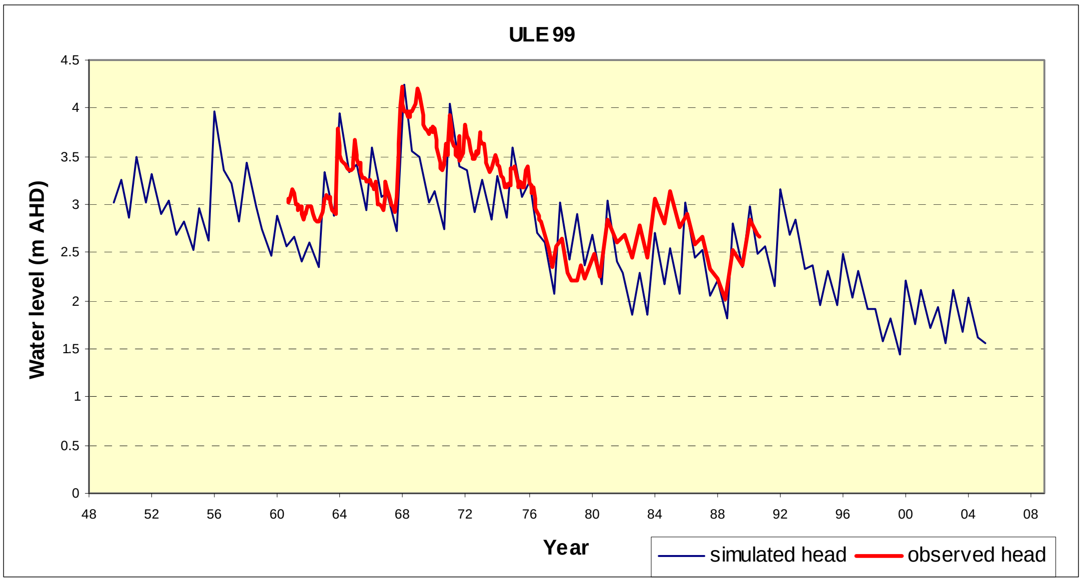
ULE 96
Water level (m AHD)
4
3.5
3
2.5
2
1.5
1
0.5
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

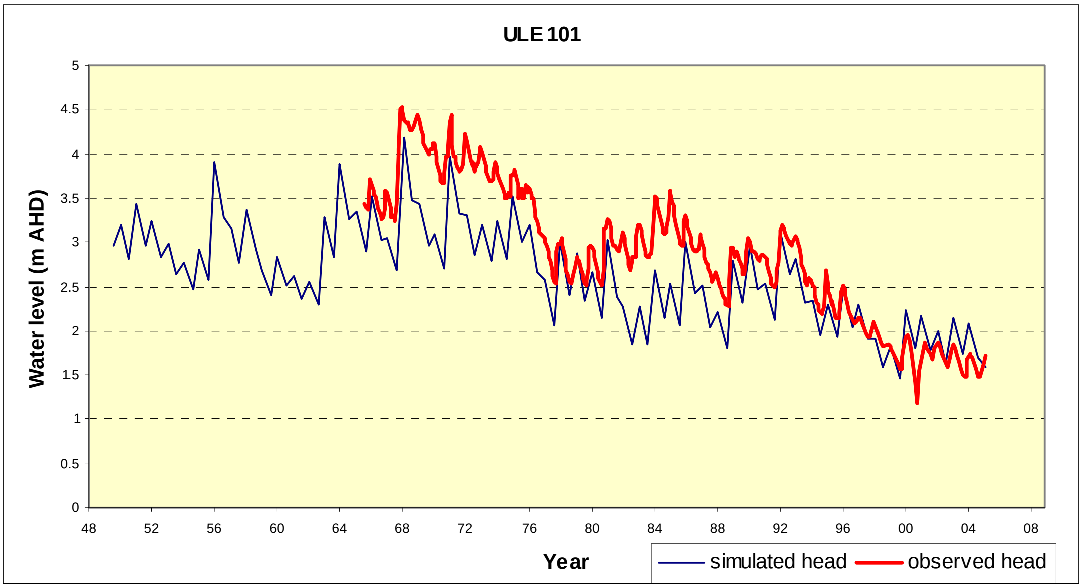


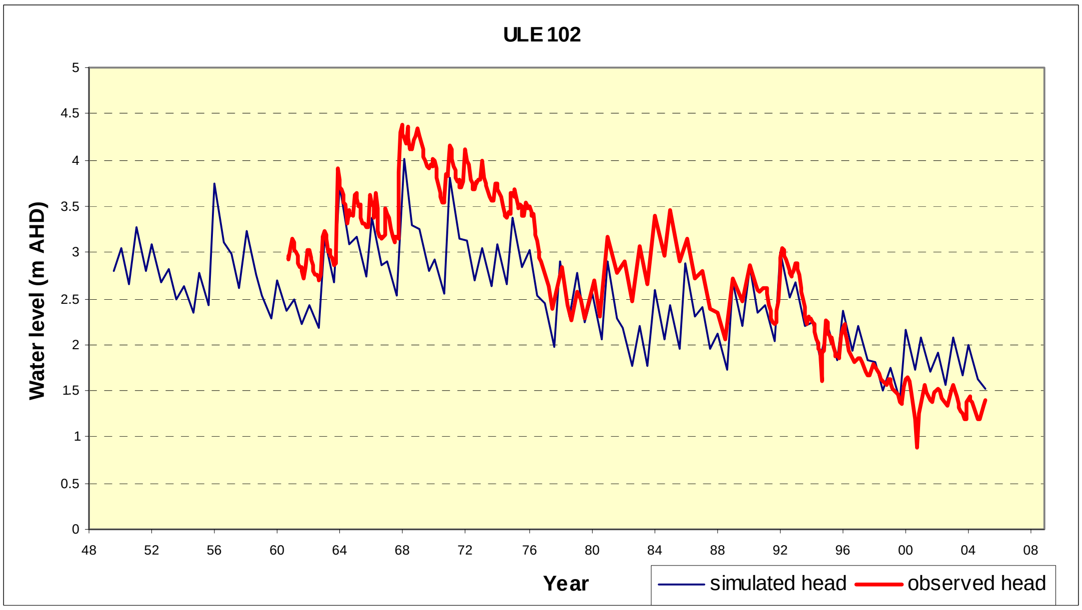
ULE 98
Water level (m AHD)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

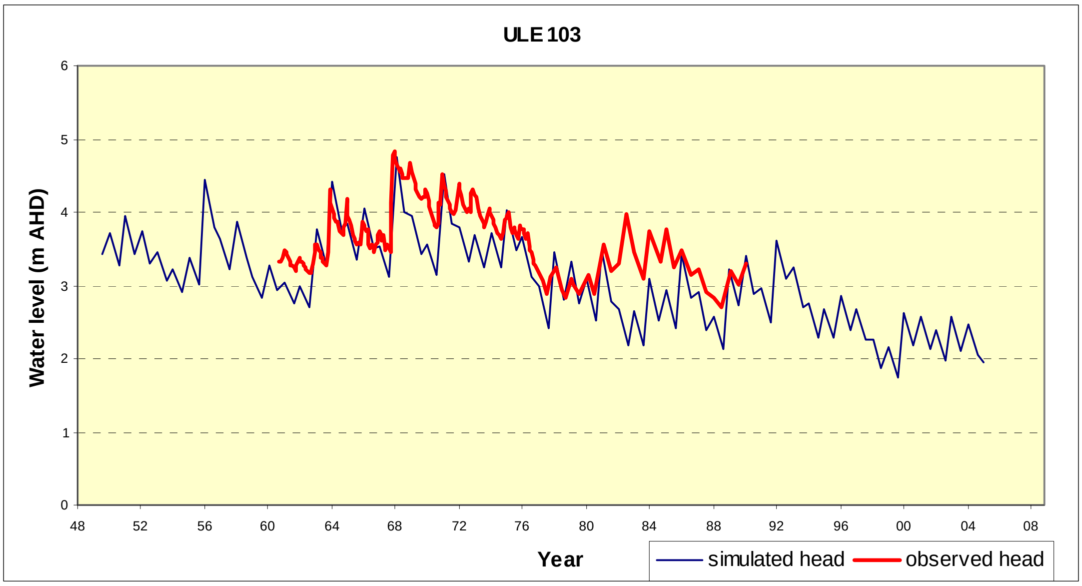


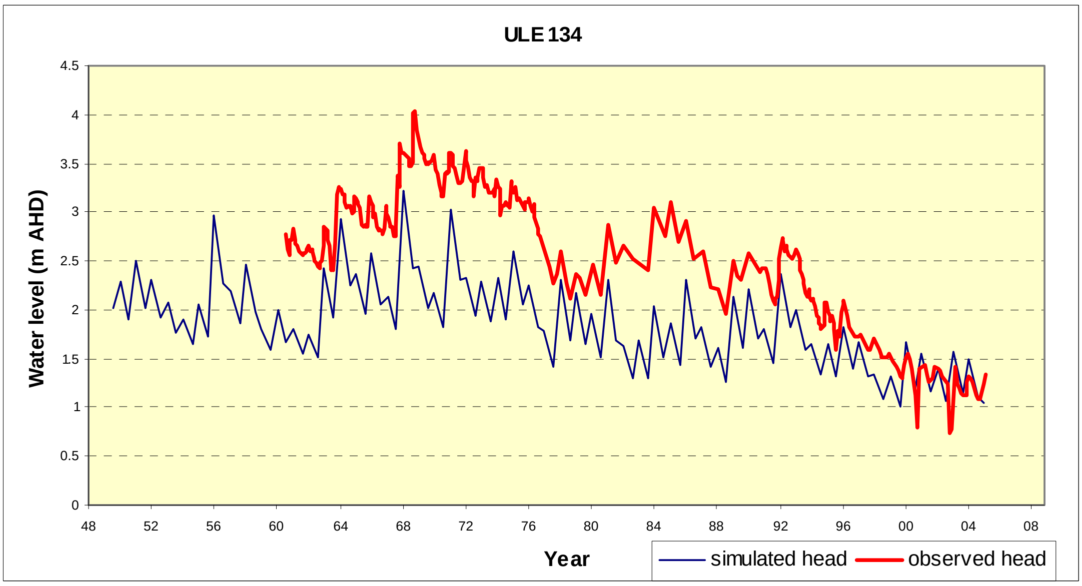
ULE 194
Water level (m AHD)
4
3.5
3
2.5
2
1.5
1
0.5
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

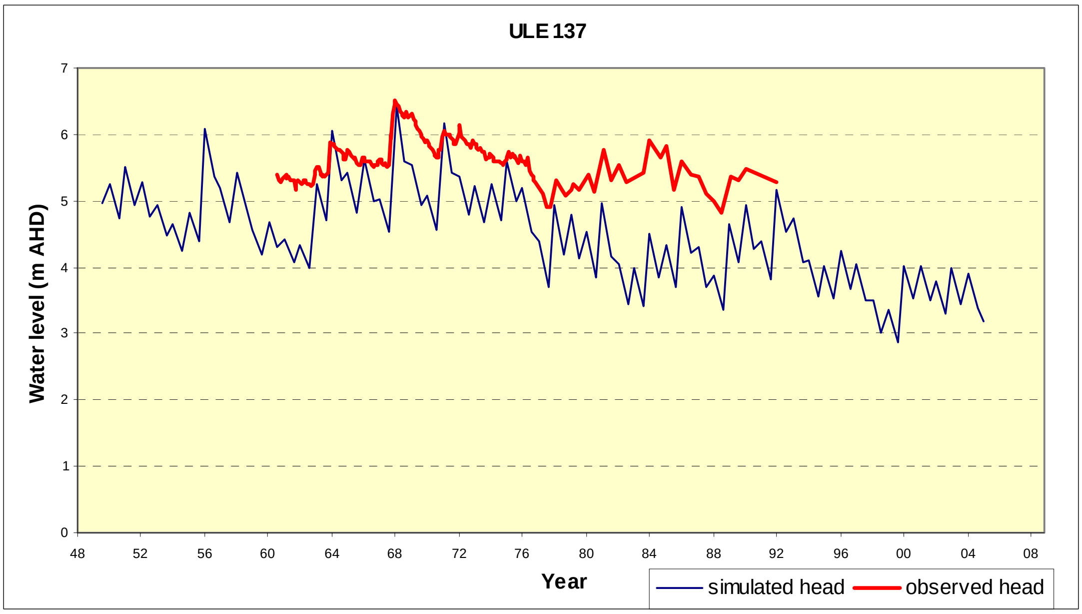

ULE 99
Water level (m AHD)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

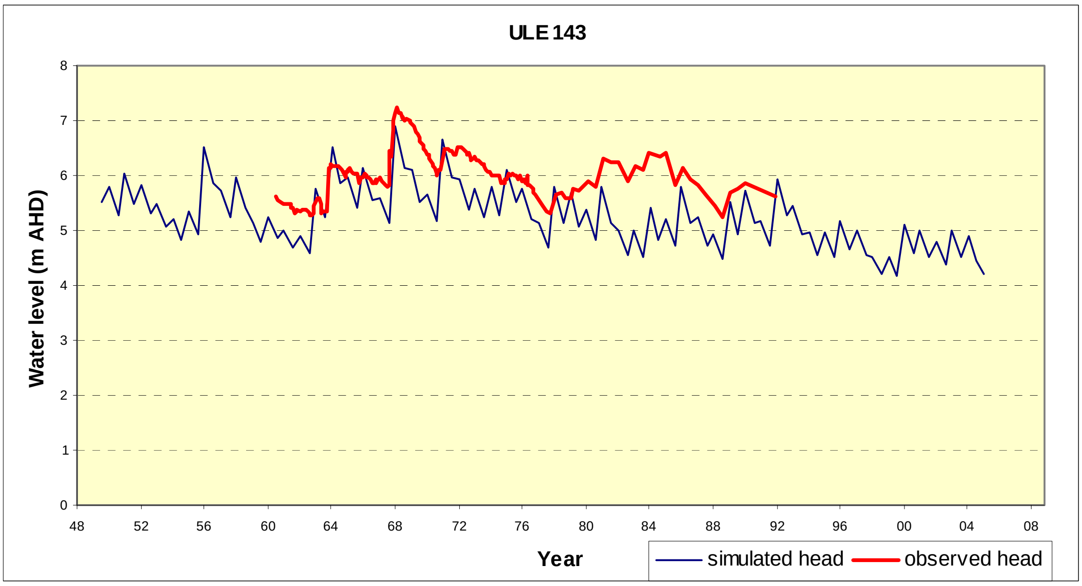

ULE 101
Water level (m AHD)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


ULE 102
Water level (m AHD)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

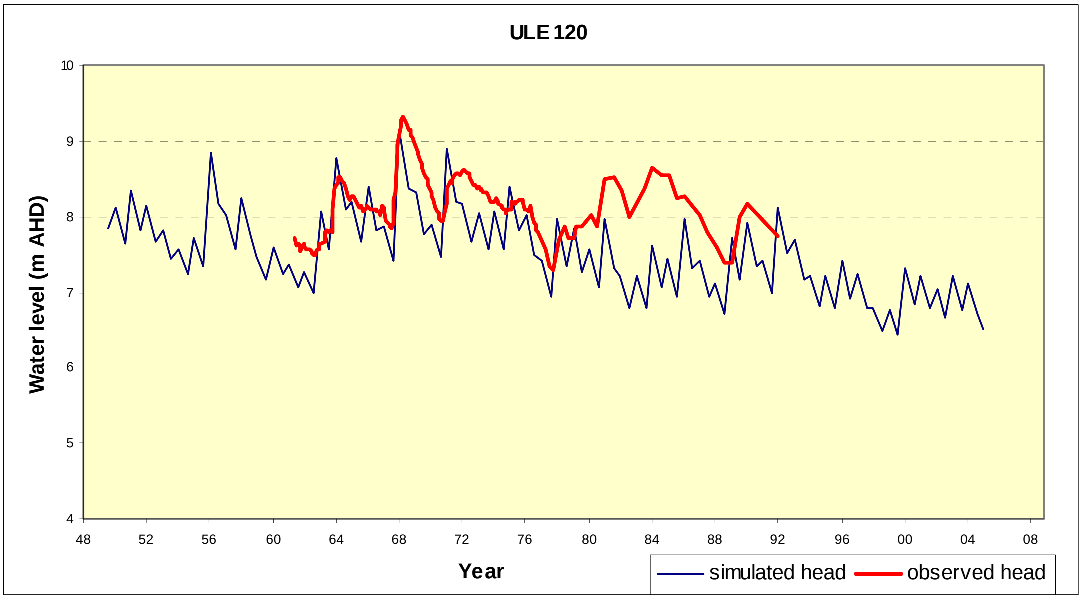

ULE 103
Water level (m AHD)
Year
simulated head
observed head


ULE 134
Water level (m AHD)
Year
simulated head
observed head

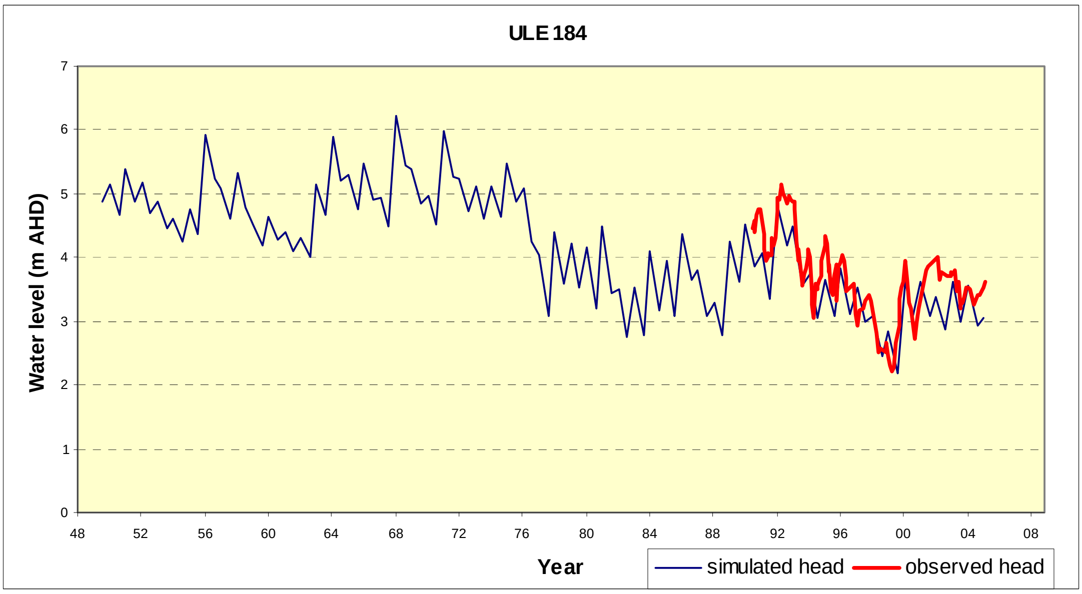

ULE 137
Water level (m AHD)
Year
simulated head
observed head



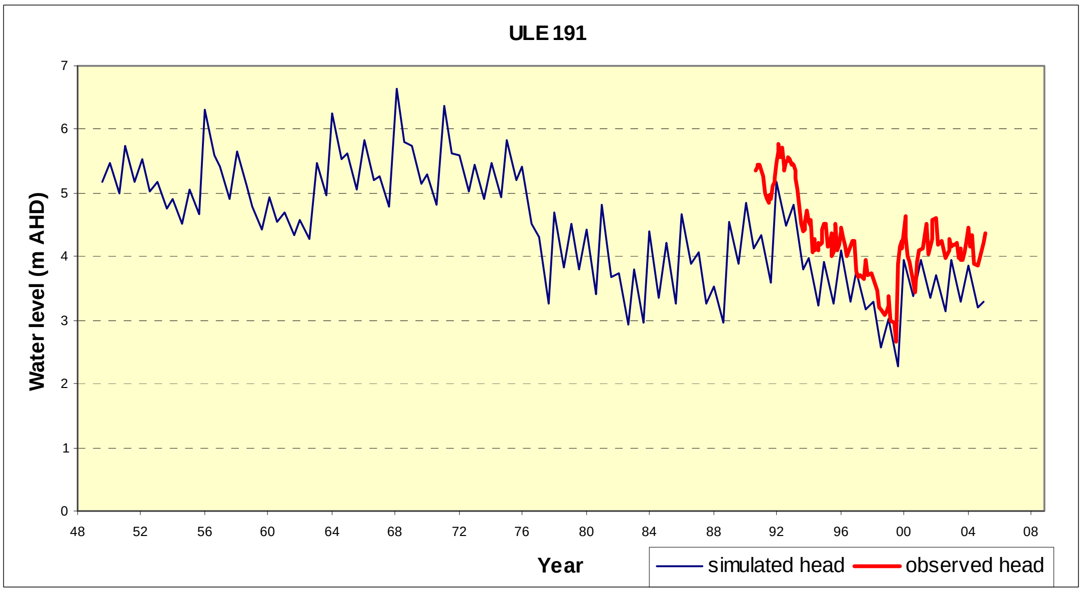
ULE 143
Water level (m AHD)
0
1
2
3
4
5
6
7
8
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head



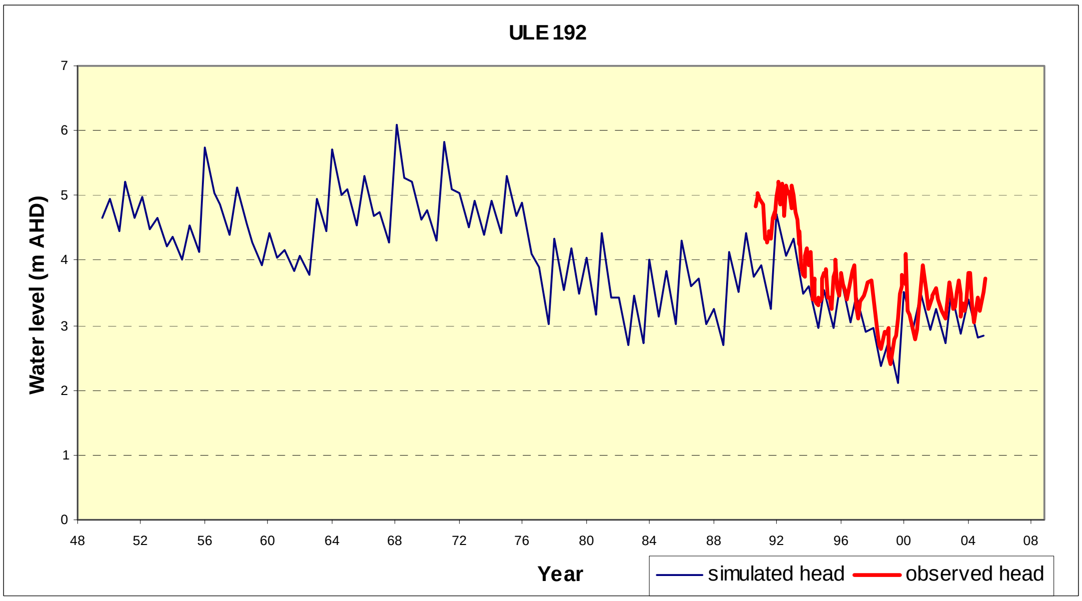
ULE 120
Water level (m AHD)
4
5
6
7
8
9
10
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head



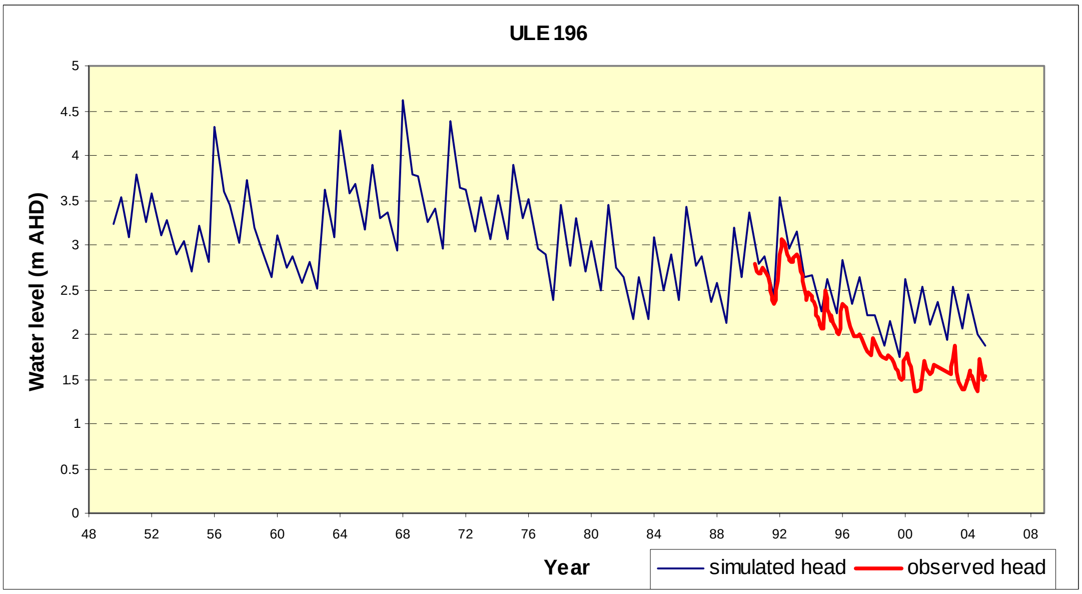
ULE 184
Water level (m AHD)
0
1
2
3
4
5
6
7
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head



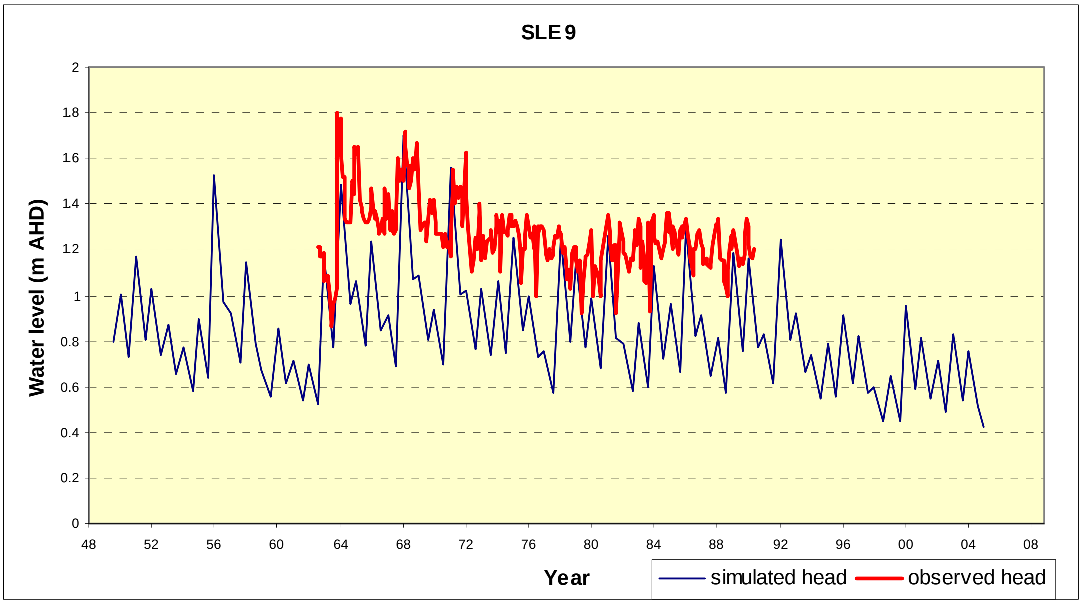
ULE 191
Water level (m AHD)
7
6
5
4
3
2
1
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

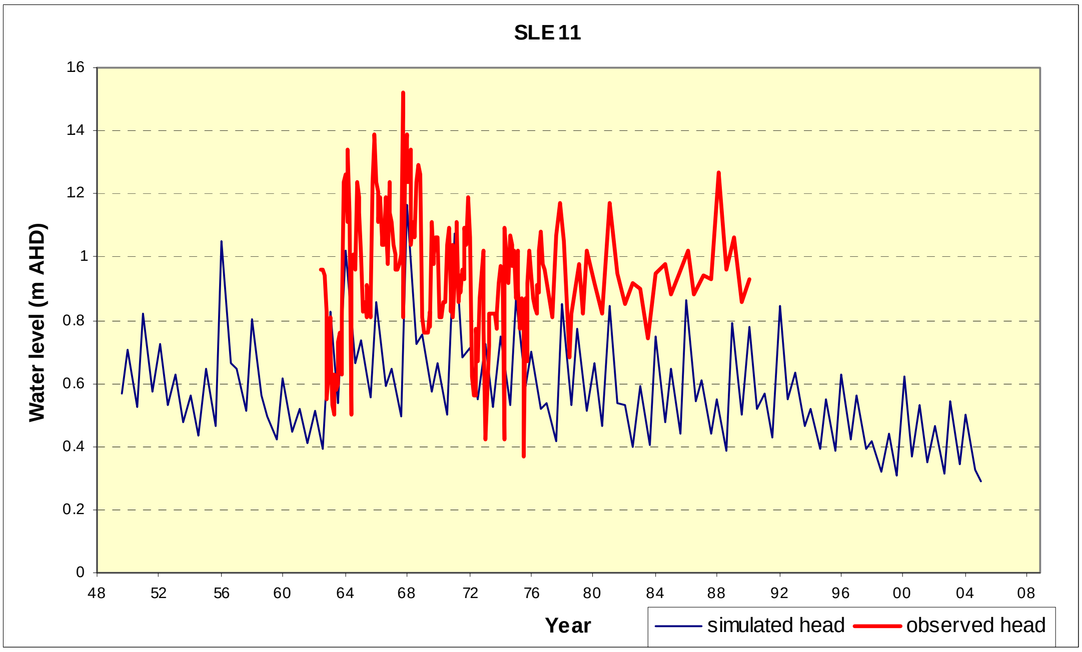


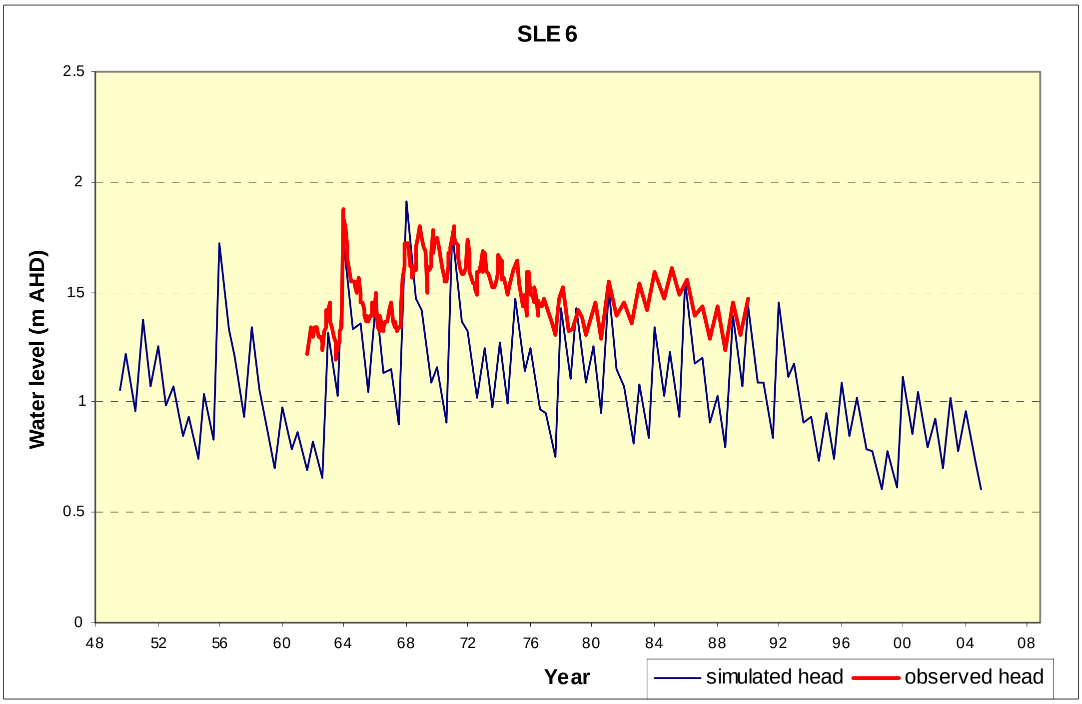
ULE 192
Water level (m AHD)
7
6
5
4
3
2
1
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head



ULE 196
Water level (m AHD)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

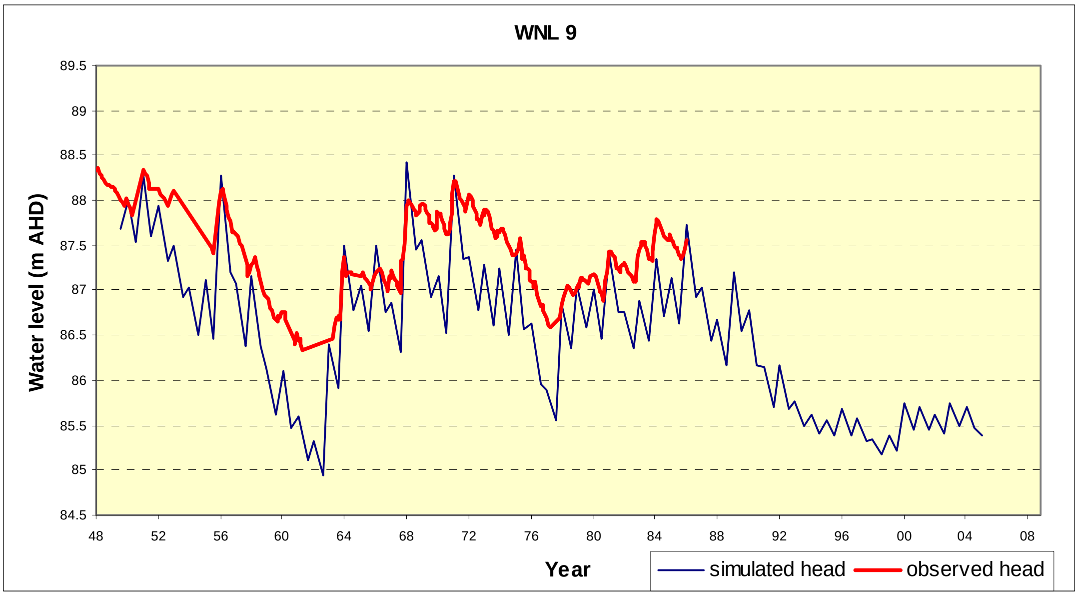

SLE 9
Water level (m AHD)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

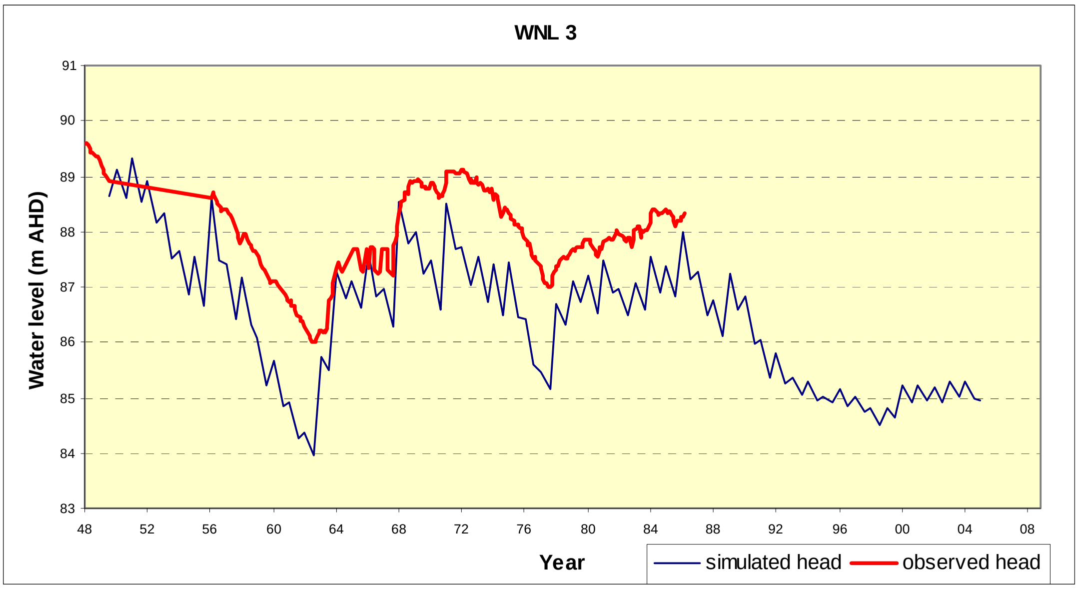

SLE 11
Water level (m AHD)
16
14
12
1
0.8
0.6
0.4
0.2
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

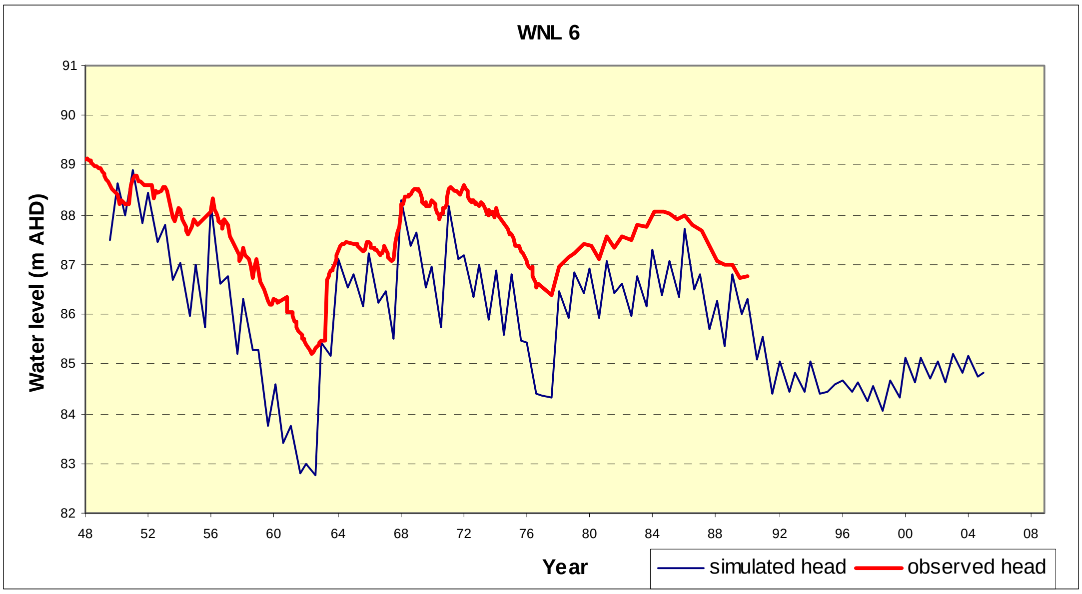


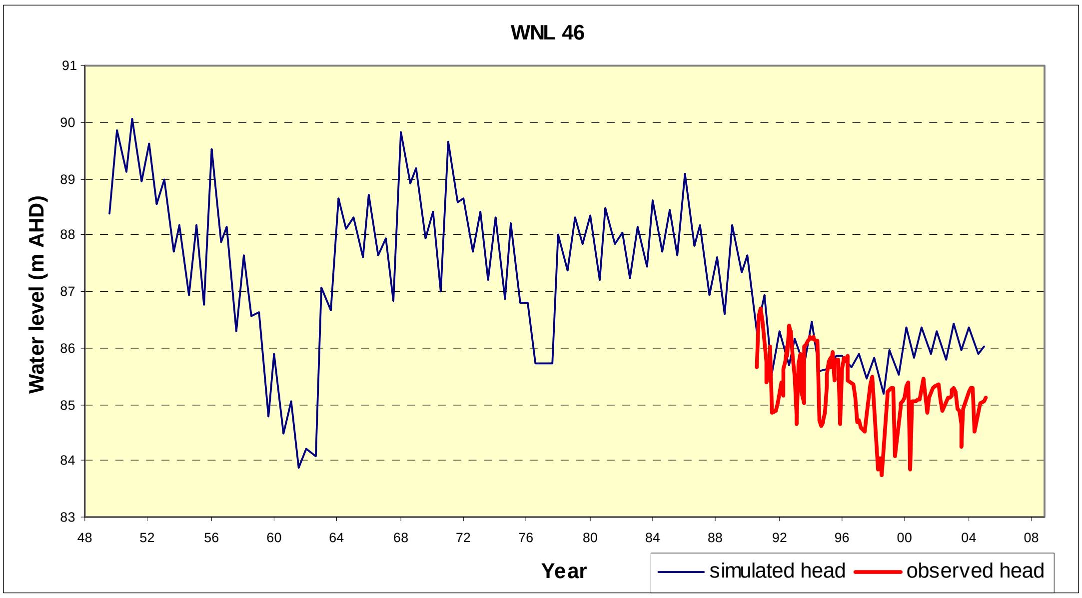
SLE 6
2.5
2
15
1
0.5
0
Water level (m AHD)
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

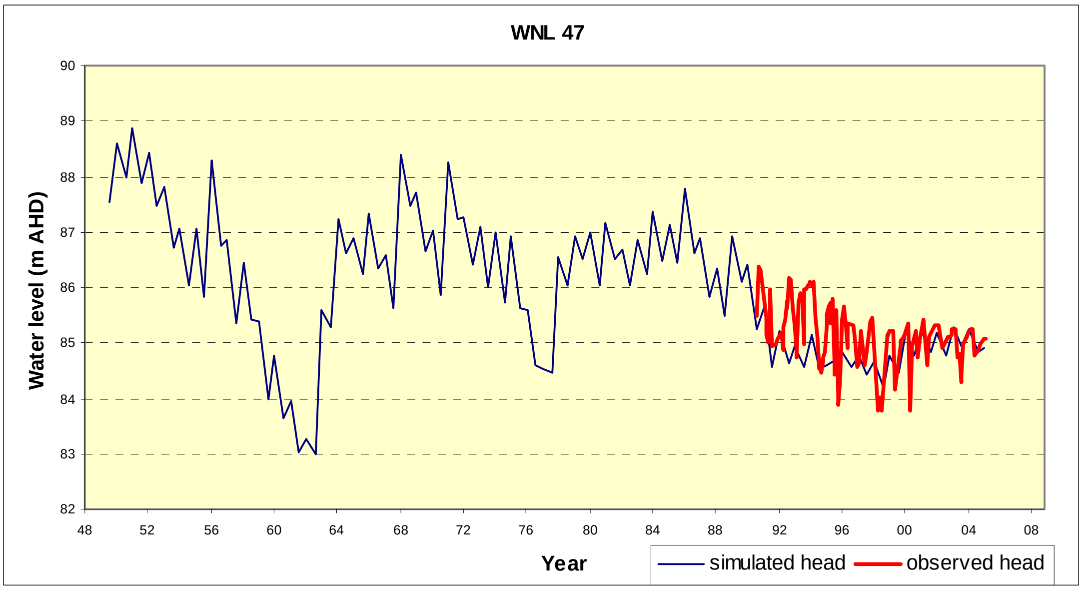
Uley Wanilla

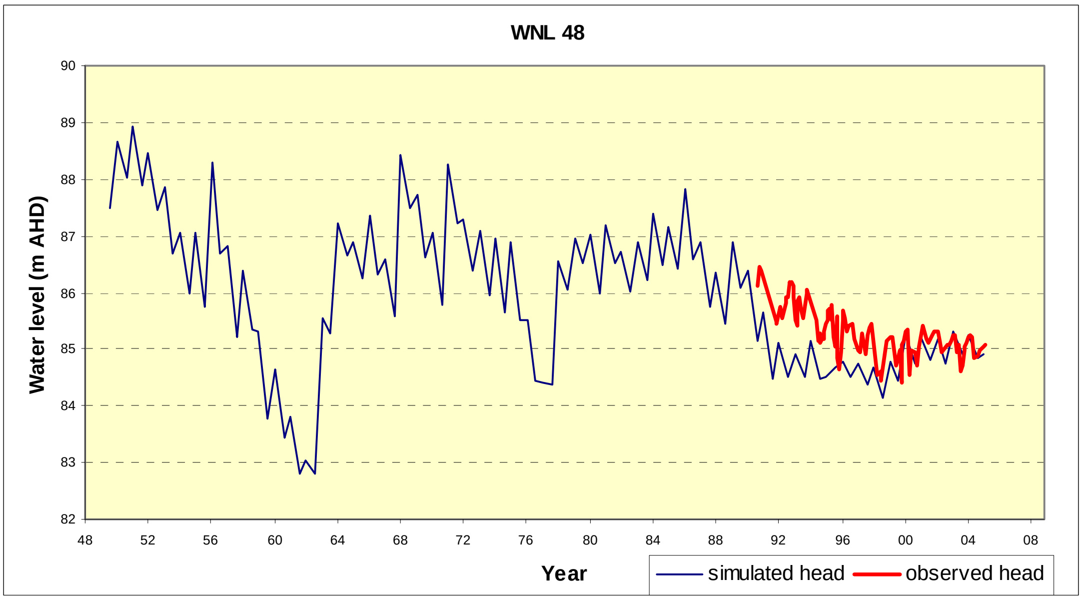




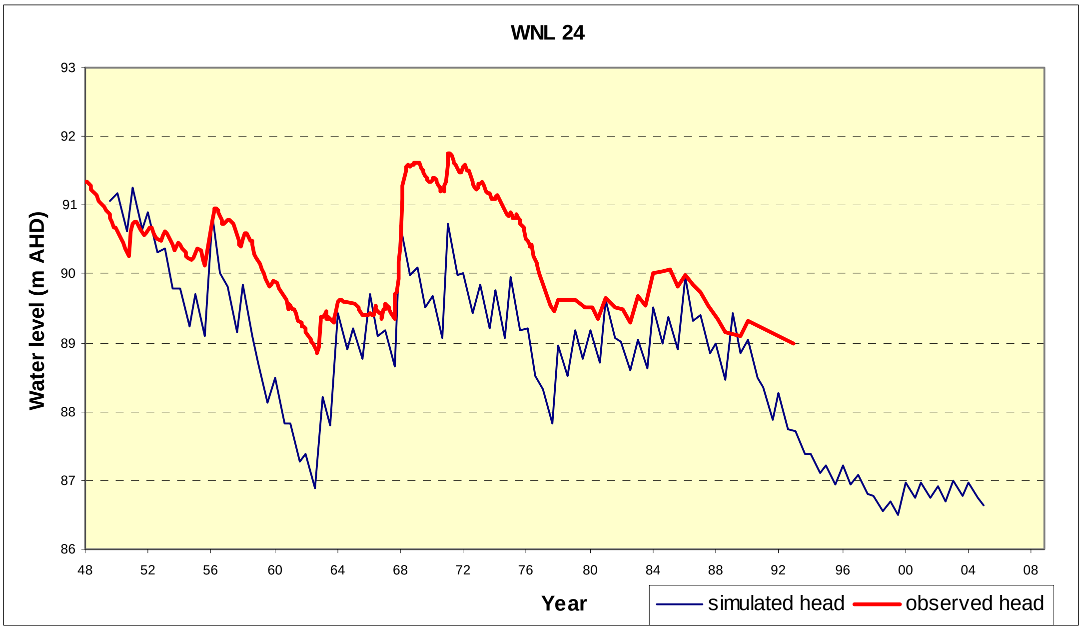

WNL 6
Water level (m AHD)
91
90
89
88
87
86
85
84
83
82
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


WNL 46
Water level (m AHD)
91
90
89
88
87
86
85
84
83
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

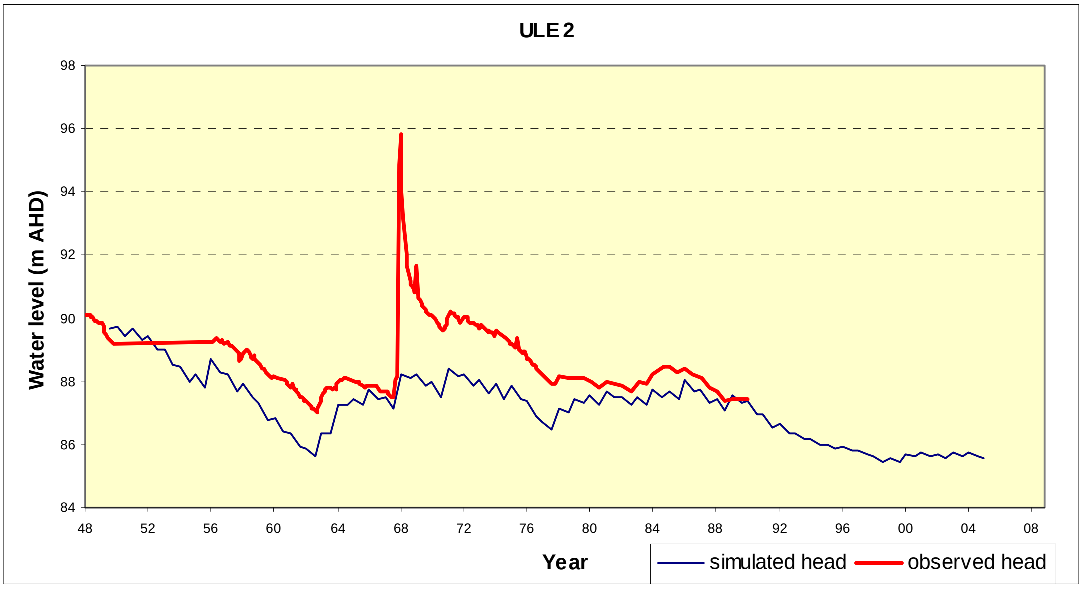

WNL 47
Water level (m AHD)
90
89
88
87
86
85
84
83
82
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head



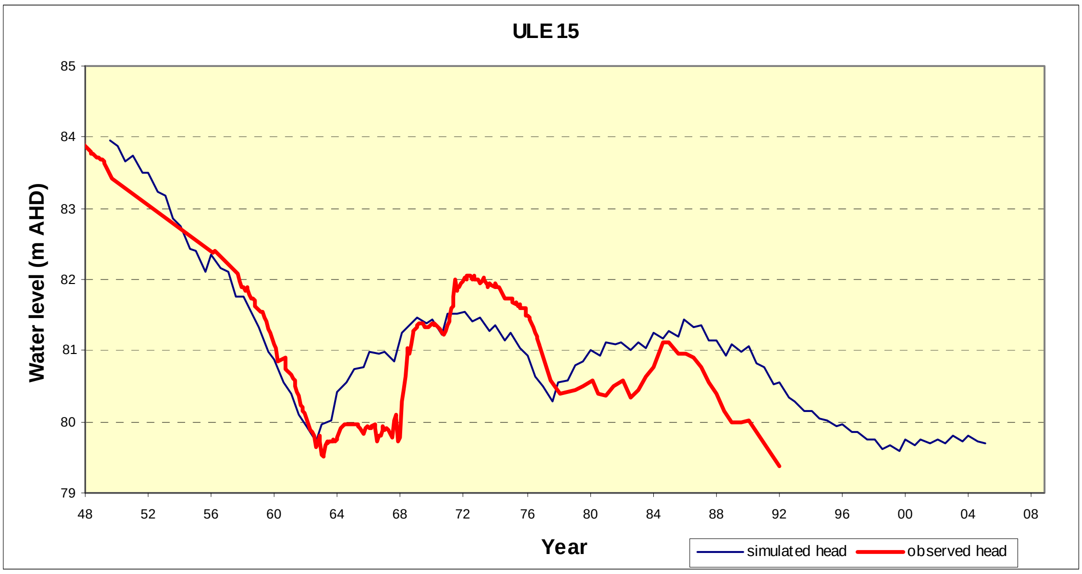
WNL 48
Water level (m AHD)
90
89
88
87
86
85
84
83
82
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

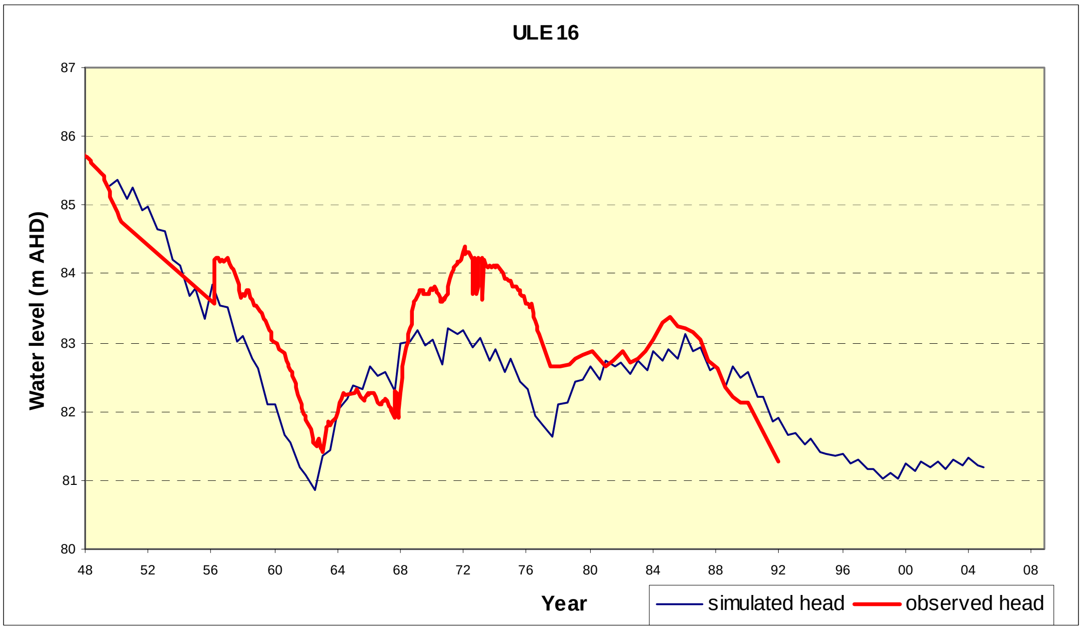


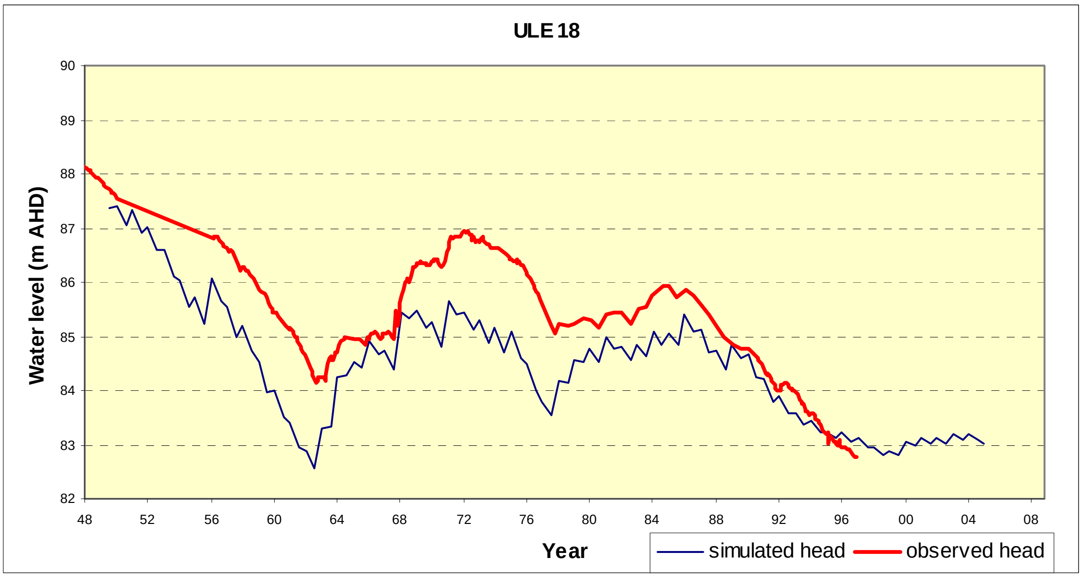
WNL 24
Water level (m AHD)
93
92
91
90
89
88
87
86
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

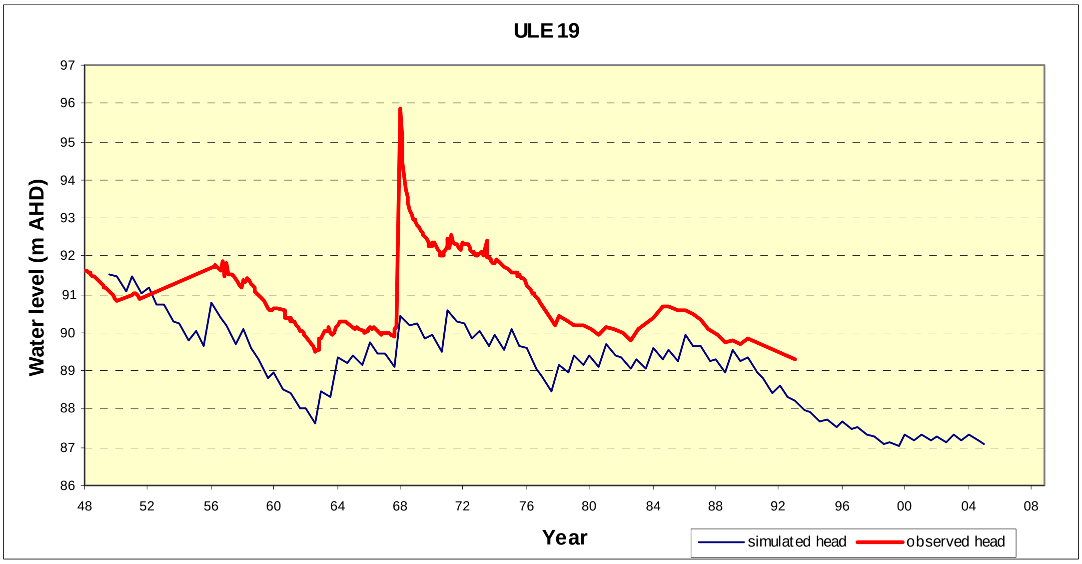


ULE 2
Water level (m AHD)
98
96
94
92
90
88
86
84
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

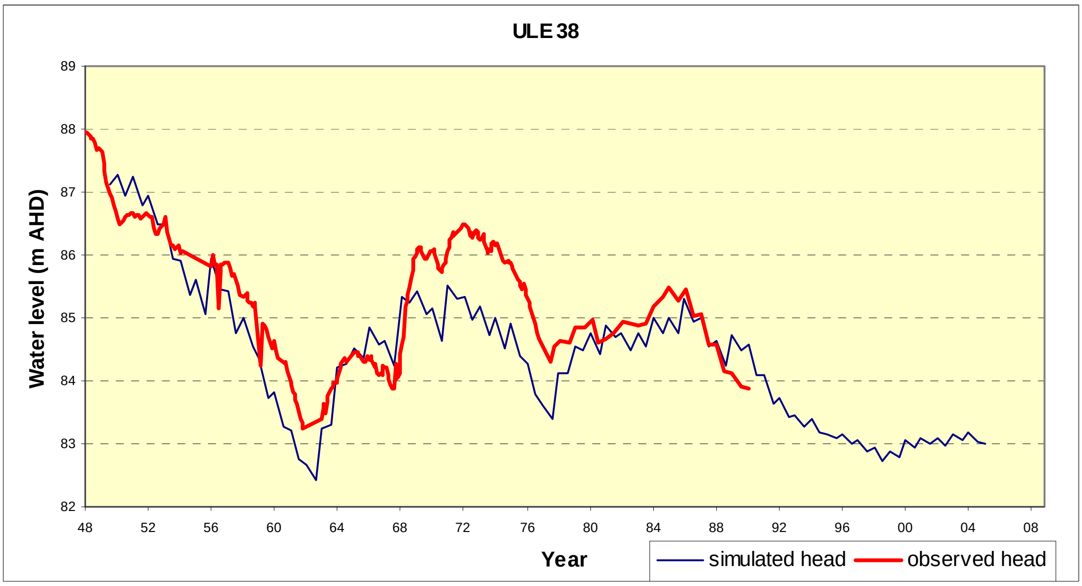

ULE 15
Water level (m AHD)
85
84
83
82
81
80
79
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

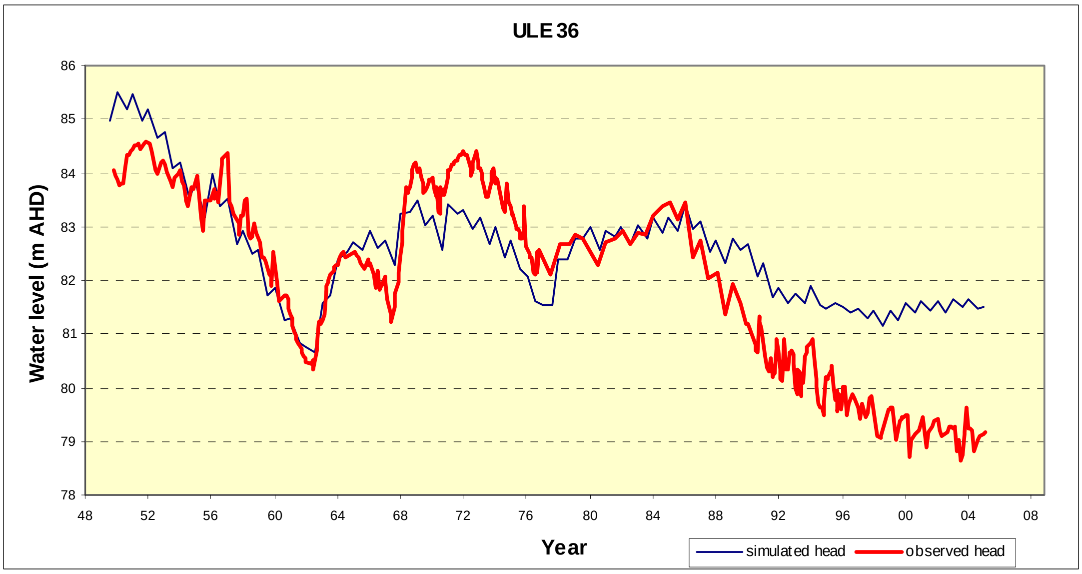

ULE 16
Water level (m AHD)
87
86
85
84
83
82
81
80
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


ULE 18
Water level (m AHD)
90
89
88
87
86
85
84
83
82
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

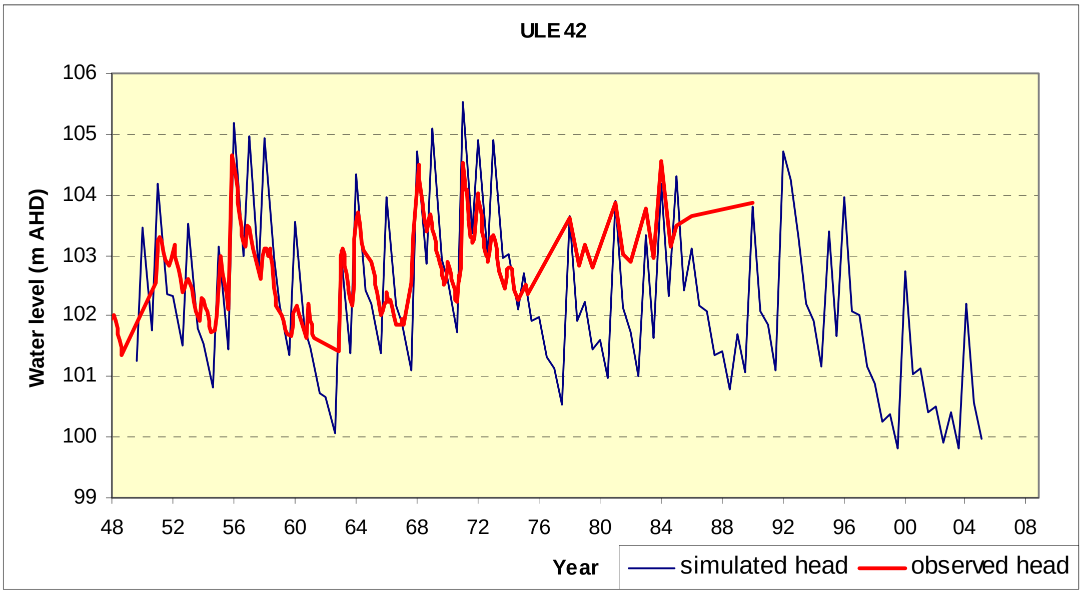

ULE 19
Water level (m AHD)
97
96
95
94
93
92
91
90
89
88
87
86
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

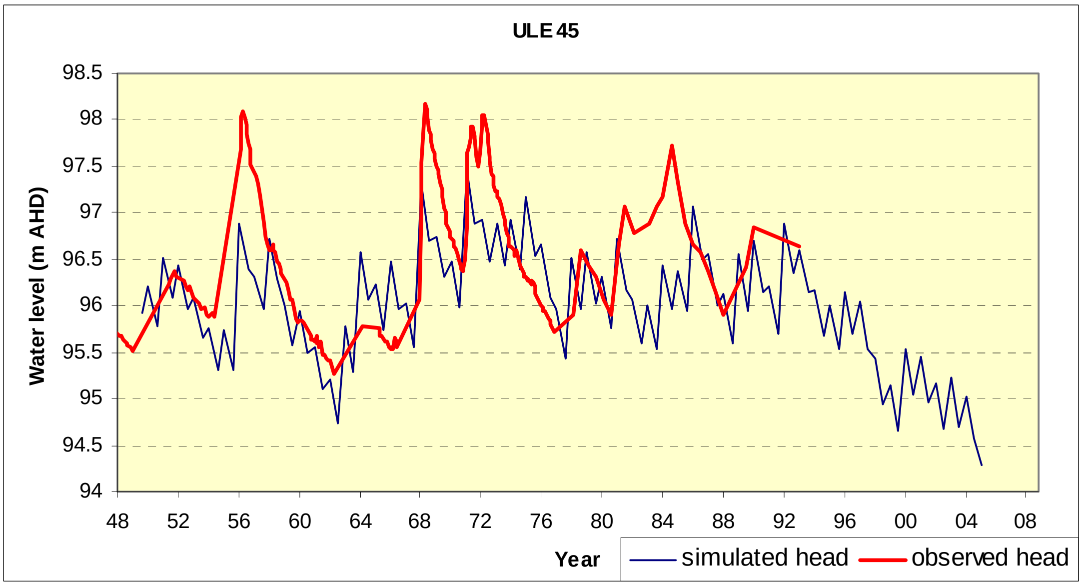

ULE 34
Water level (m AHD)
89
88
87
86
85
84
83
82
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

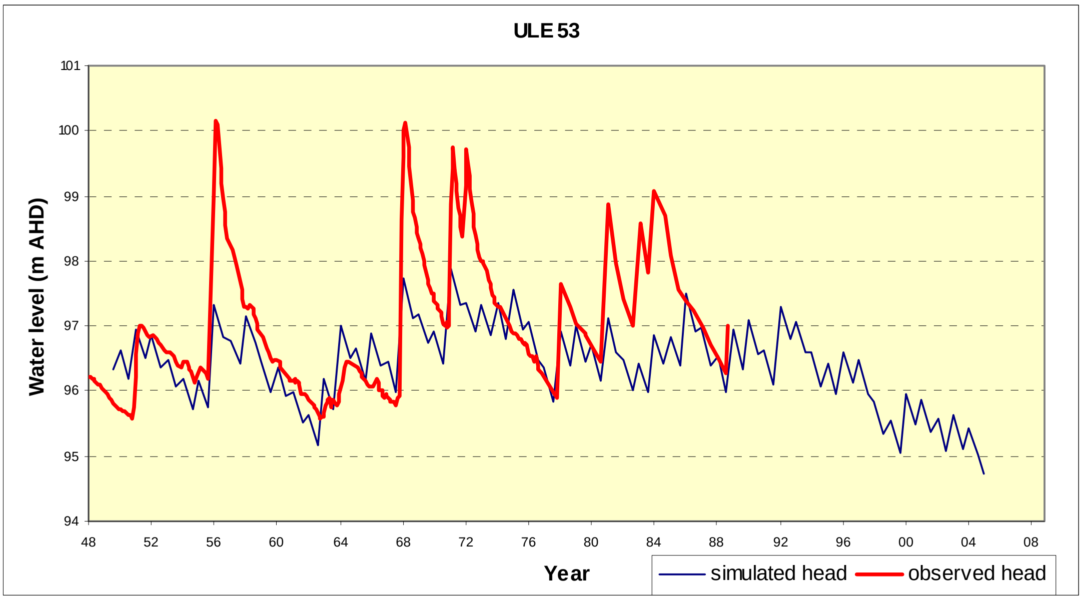

ULE 38
Water level (m AHD)
89
88
87
86
85
84
83
82
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

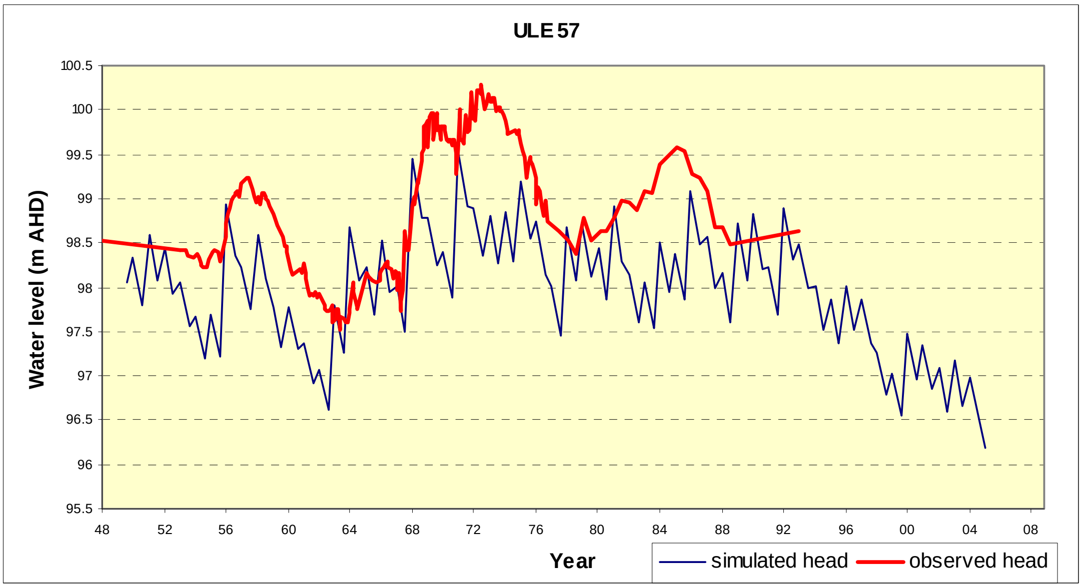

ULE 36
Water level (m AHD)
86
85
84
83
82
81
80
79
78
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

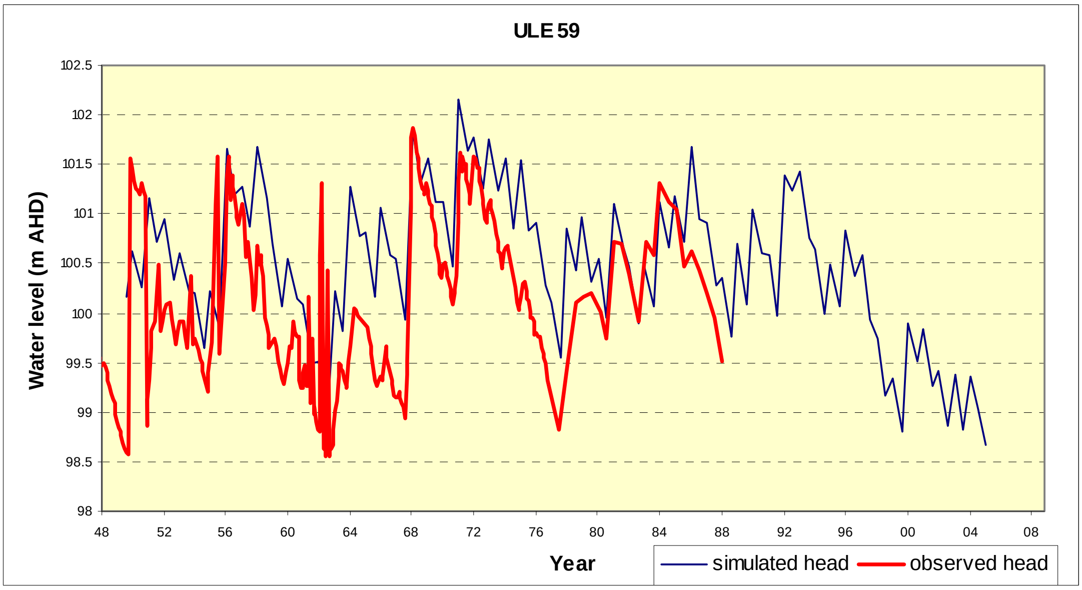
Uley East

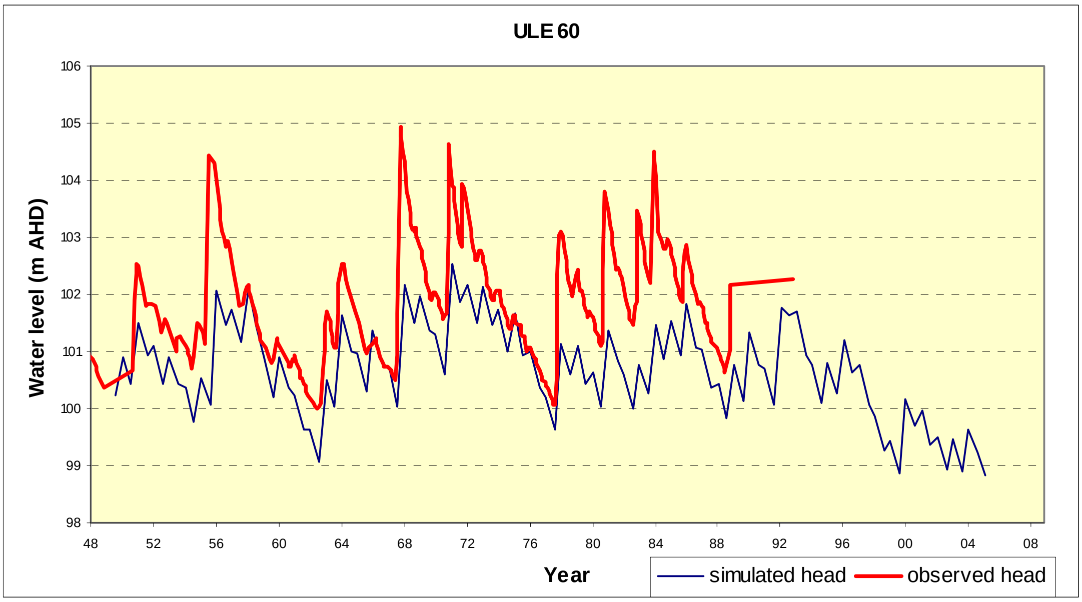

ULE 42
Water level (m AHD)
106
105
104
103
102
101
100
99
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

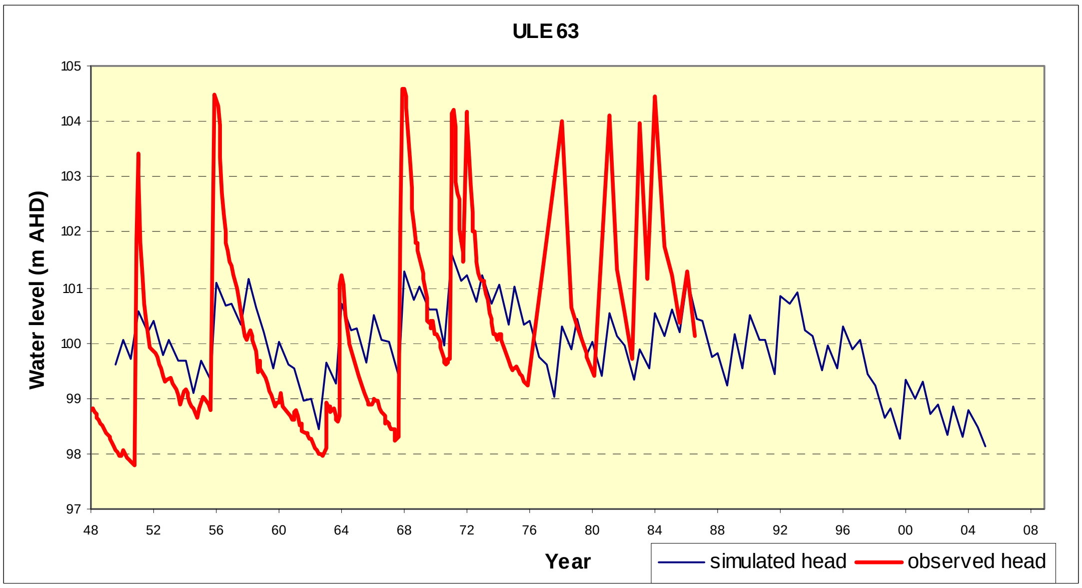

ULE 45
Water level (m AHD)
98.5
98
97.5
97
96.5
96
95.5
95
94.5
94
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

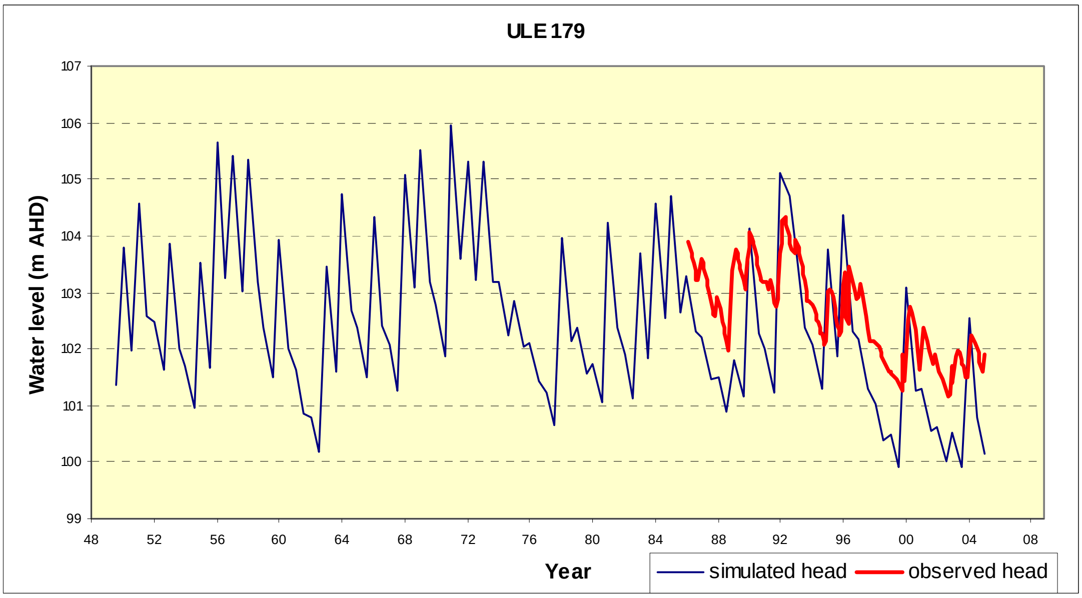

ULE 53
Water level (m AHD)
101
100
99
98
97
96
95
94
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

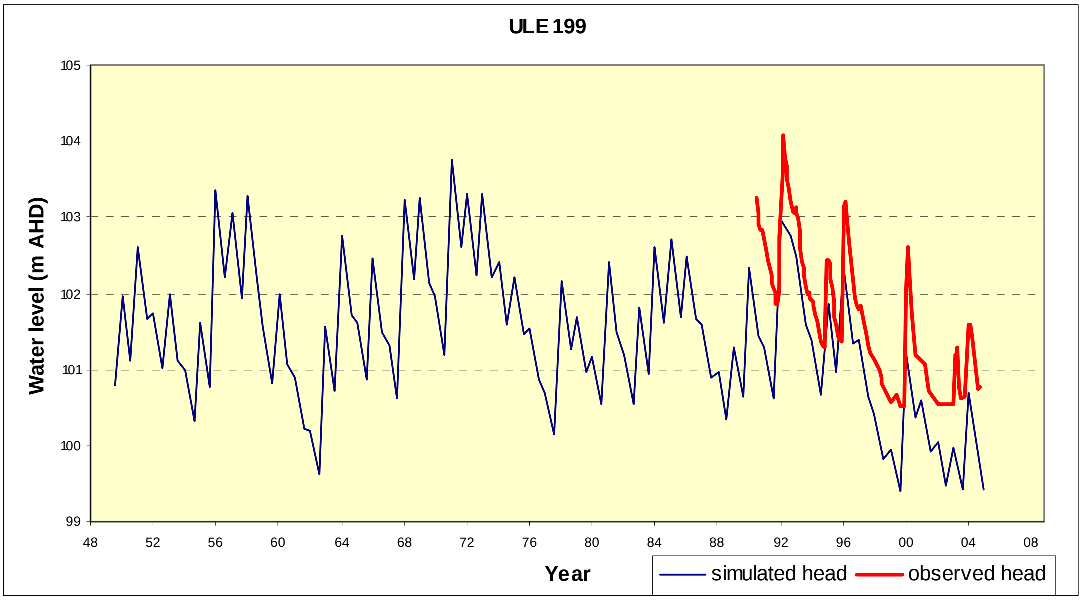

ULE 57
Water level (m AHD)
100.5
100
99.5
99
98.5
98
97.5
97
96.5
96
95.5
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


ULE 59
Water level (m AHD)
102.5
102
101.5
101
100.5
100
99.5
99
98.5
98
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

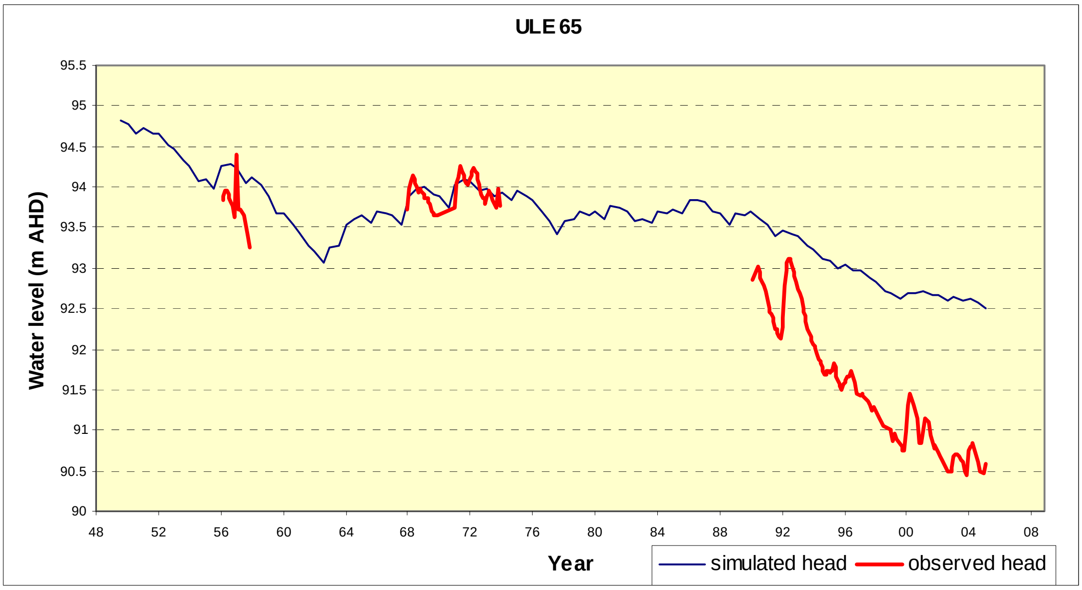

ULE 60
Water level (m AHD)
106
105
104
103
102
101
100
99
98
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

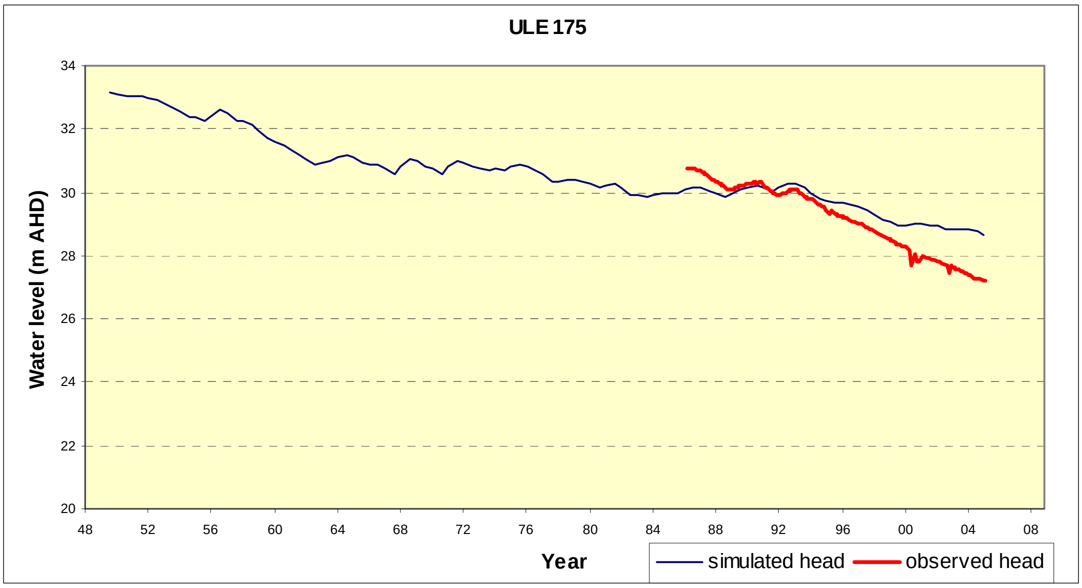

ULE 63
Water level (m AHD)
105
104
103
102
101
100
99
98
97
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

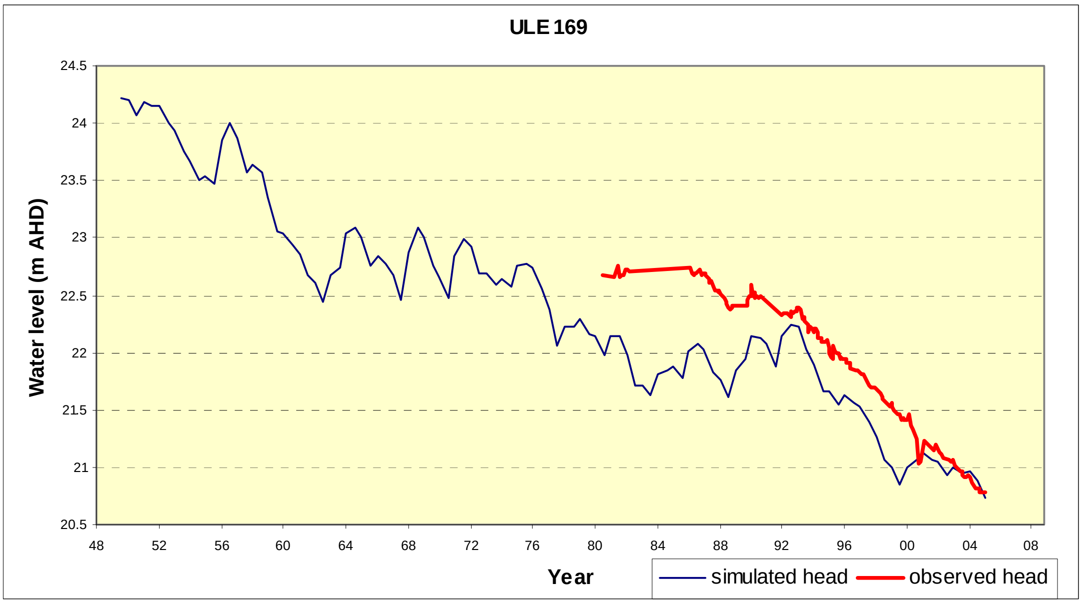

ULE 179
Water level (m AHD)
107
106
105
104
103
102
101
100
99
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

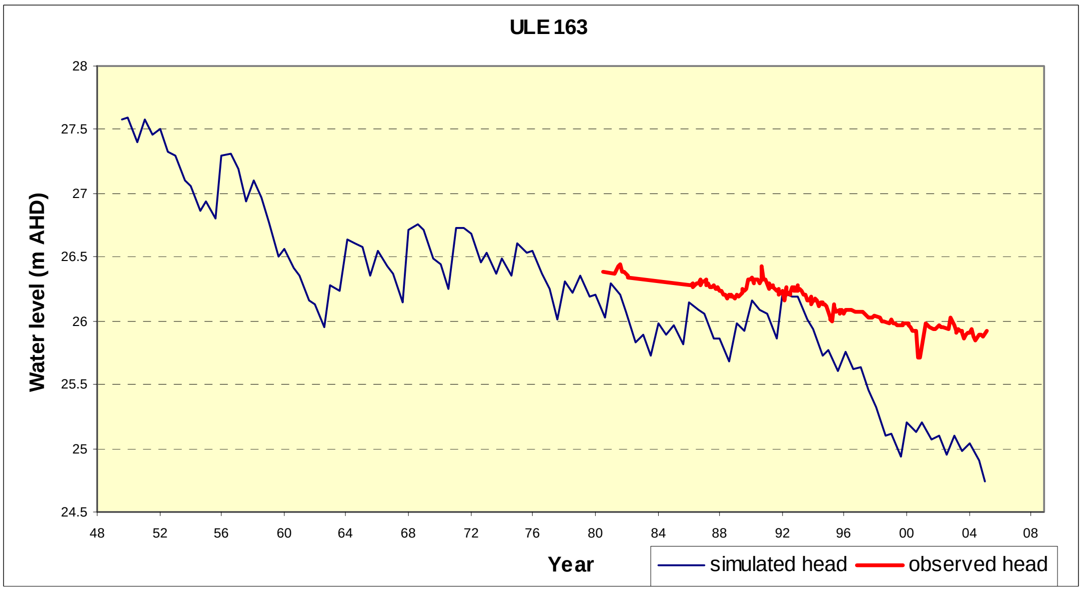

ULE 199
Water level (m AHD)
105
104
103
102
101
100
99
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

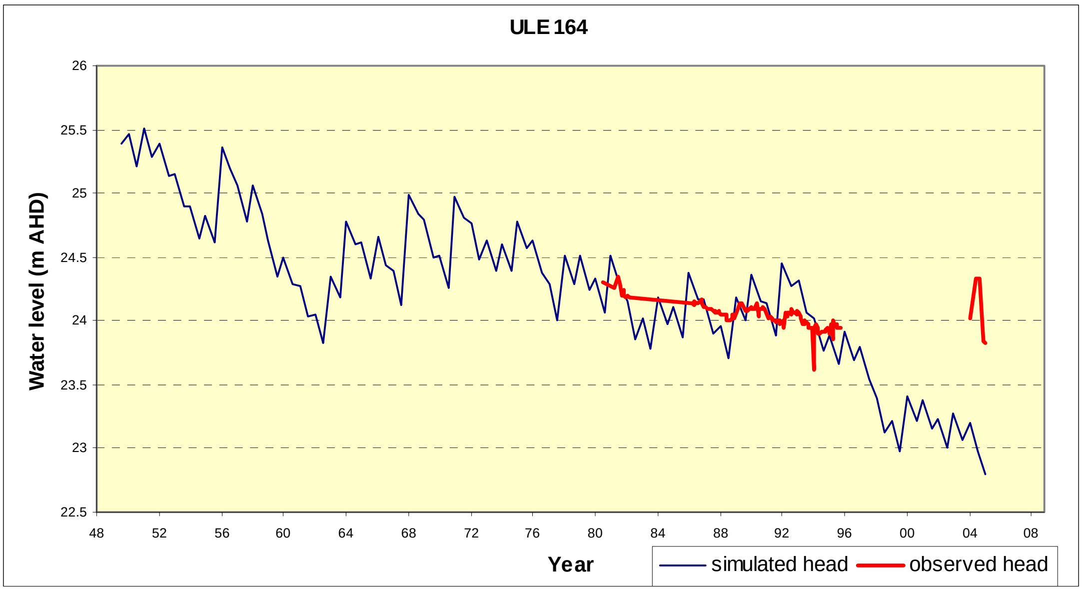
Tertiary Sand aquifer

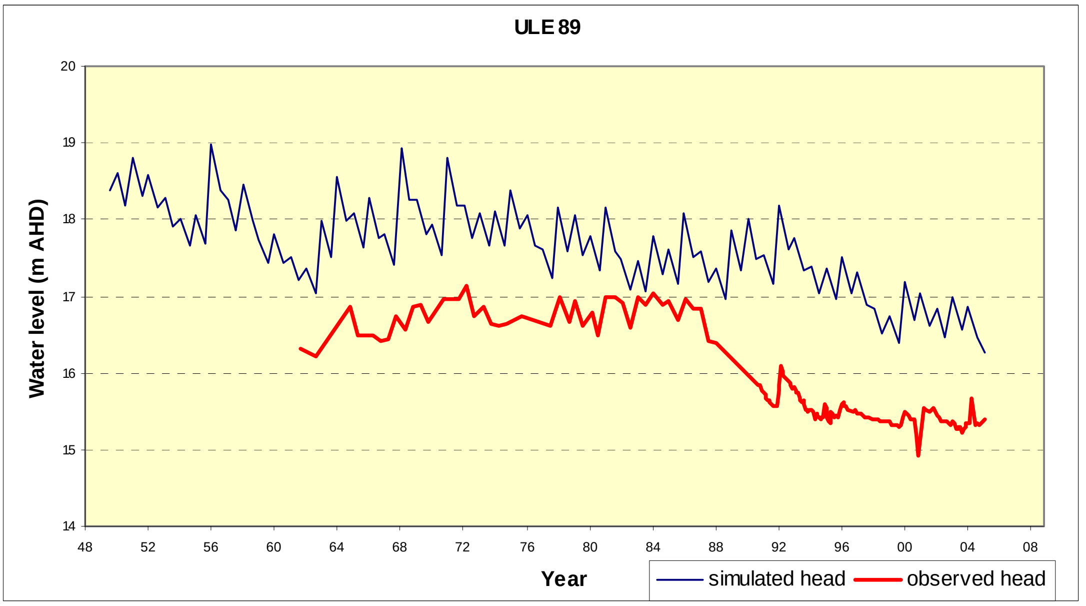


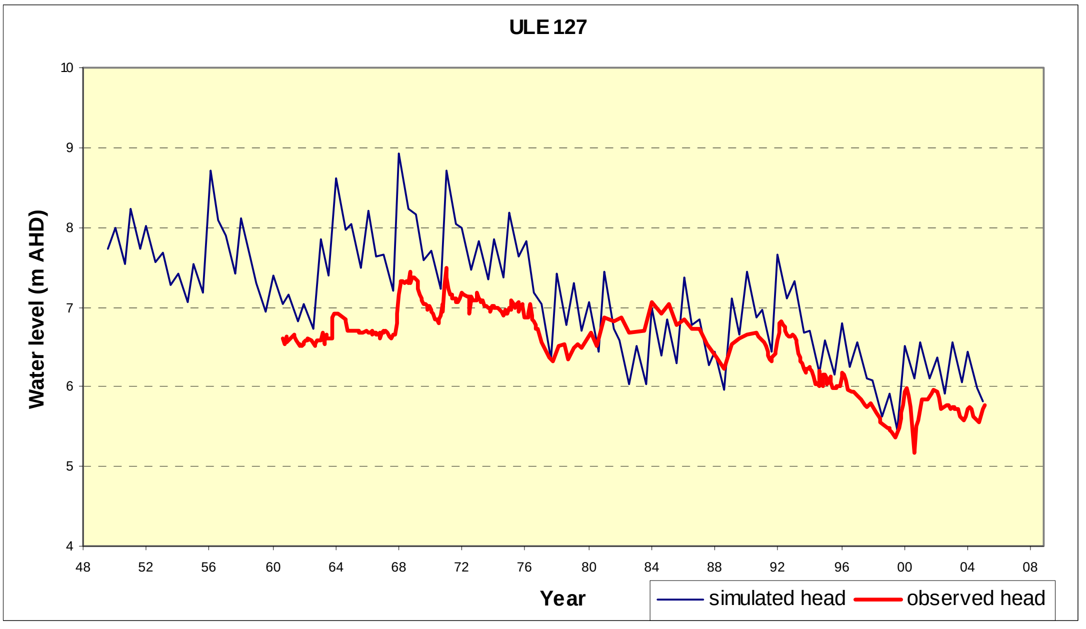


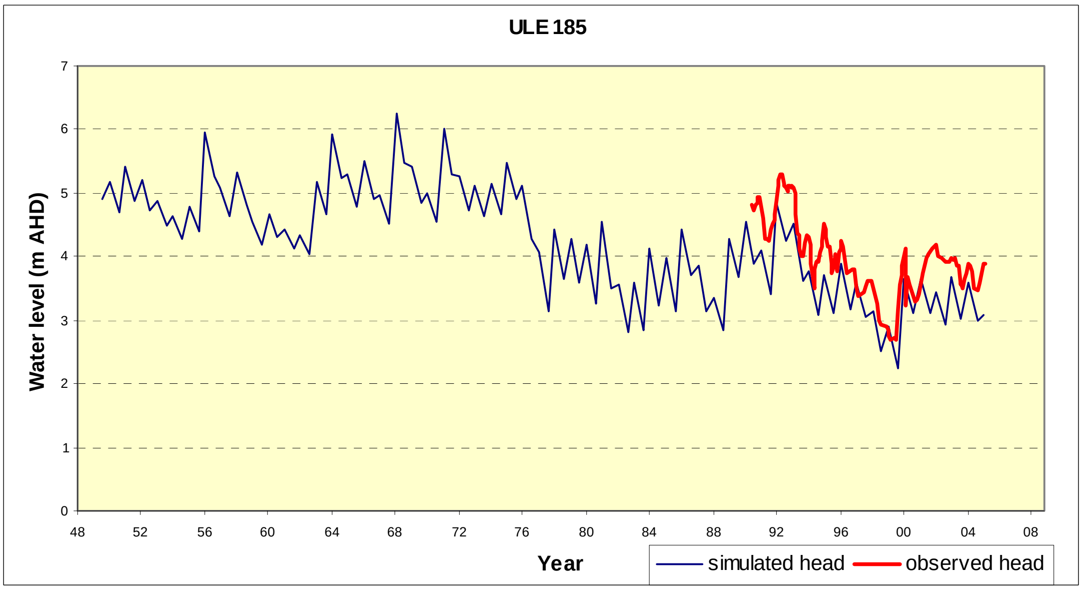

ULE 169
Water level (m AHD)
24.5
24
23.5
23
22.5
22
21.5
21
20.5
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

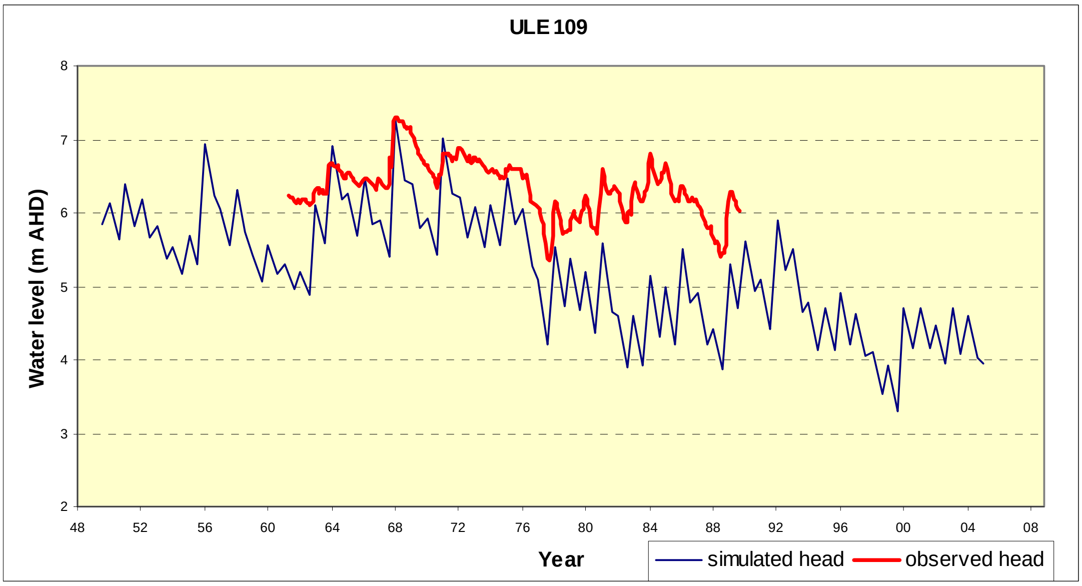

ULE 163
Water level (m AHD)
28
27.5
27
26.5
26
25.5
25
24.5
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

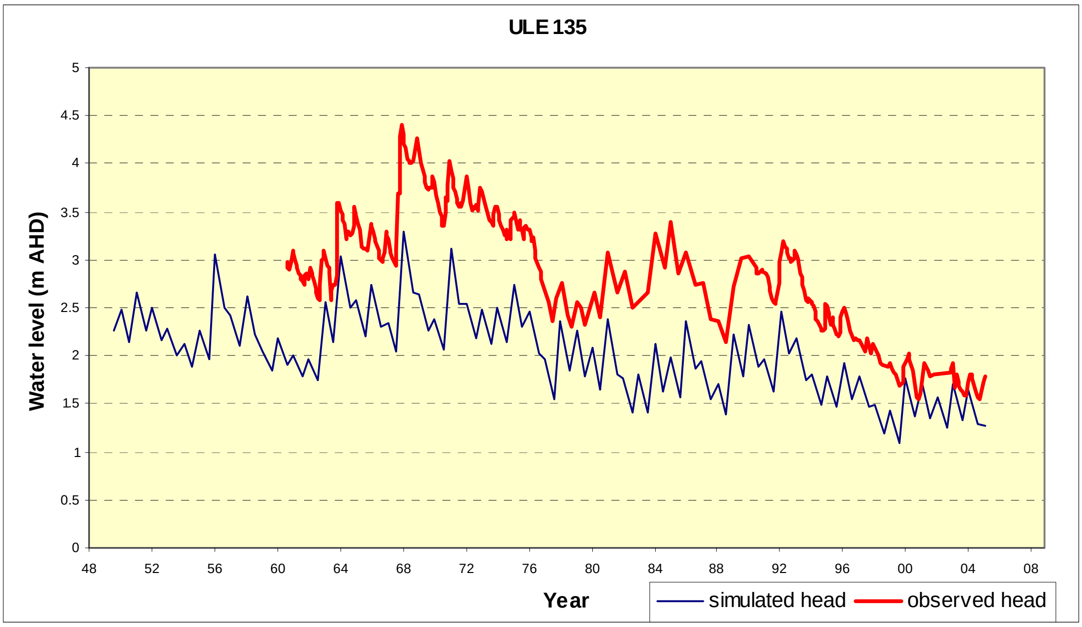

ULE 164
Water level (m AHD)
26
25.5
25
24.5
24
23.5
23
22.5
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

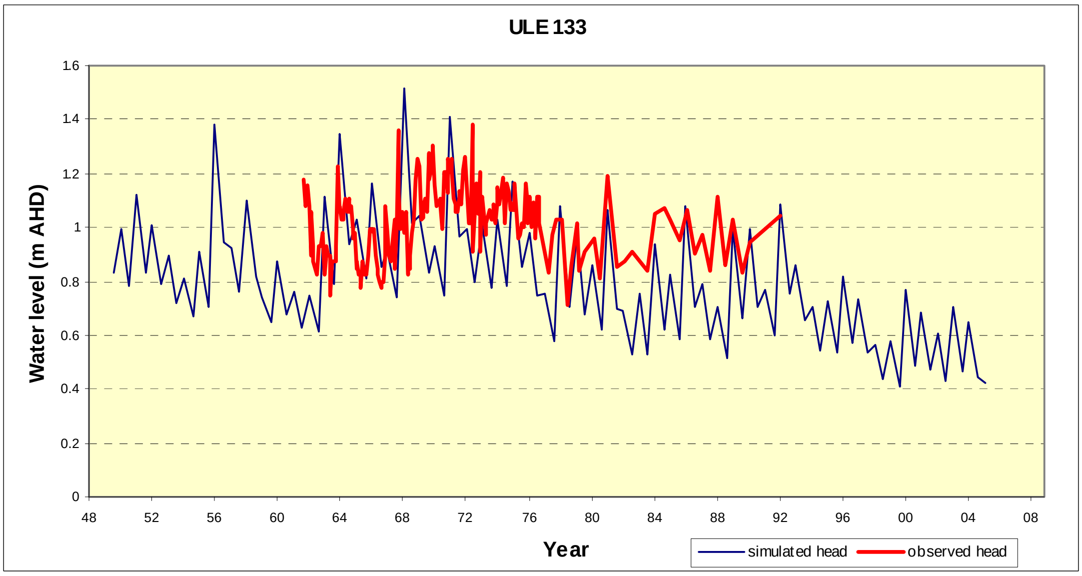

ULE 89
Water level (m AHD)
20
19
18
17
16
15
14
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

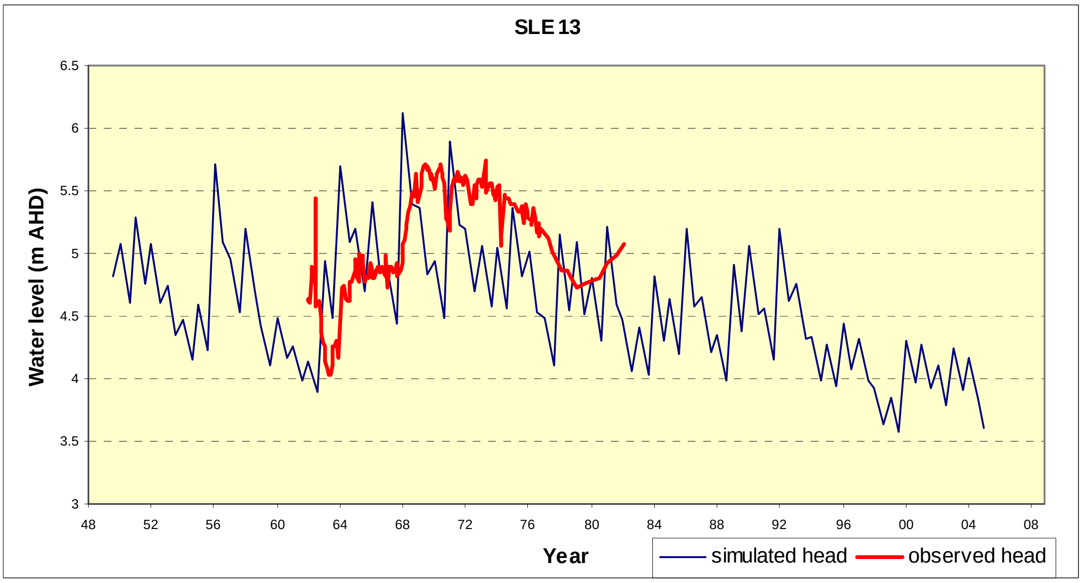

ULE 127
Water level (m AHD)
10
9
8
7
6
5
4
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


ULE 185
Water level (m AHD)
7
6
5
4
3
2
1
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


ULE 109
Water level (m AHD)
8
7
6
5
4
3
2
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


ULE 135
Water level (m AHD)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


ULE 133
Water level (m AHD)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head


SLE 13
Water level (m AHD)
6.5
6
5.5
5
4.5
4
3.5
3
48
52
56
60
64
68
72
76
80
84
88
92
96
00
04
08
Year
simulated head
observed head

UNITS OF MEASUREMENT

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

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

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

GLOSSARY

Act (the) — In this document, refers to the *Natural Resources Management Act* (South Australia) *2004*.

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

Aquifer, confined — Aquifer in which the upper surface is impervious and the water is held at greater than atmospheric pressure. Water in a penetrating well will rise above the surface of the aquifer.

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

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

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

Arid lands — In South Australia, arid lands are usually considered to be areas with an average rainfall of less than 250 mm and support pastoral activities instead of broadacre cropping.

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

Bore — *See well.*

Catchment — That area of land determined by topographic features within which rainfall will contribute to runoff at a particular point.

Catchment Water Management Board — A statutory body established under Part 6, Division 3, s. 53 of the Act whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area.

Catchment water management plan — The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the *Water Resources Act 1997*.

Codes of practice — Standards of management developed by industry and government, promoting techniques or methods of environmental management by which environmental objectives may be achieved.

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

Conjunctive use — The utilisation of more than one source of water to satisfy a single demand.

CWMB — Catchment Water Management Board.

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

EC — Abbreviation for electrical conductivity. 1 EC unit = 1 micro-Siemens per centimetre (µS/cm) measured at 25 degrees Celsius. Commonly used to indicate the salinity of water.

EP — Eyre Peninsula.

Ephemeral streams, wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Erosion — Natural breakdown and movement of soil and rock by water, wind or ice. The process may be accelerated by human activities.

ESD — Ecologically sustainable development *(see above for definition)*.

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

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

GIS (geographic information system) — Computer software allows for the linking of geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis.

GL — *See gigalitre.*

Geological features — Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

Groundwater — *See underground water.*

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

Integrated catchment management — Natural resources management that considers in an integrated manner the total long-term effect of land and water management practices on a catchment basis, from production and environmental viewpoints.

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

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

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

Licence — A licence to take water in accordance with the *Water Resources Act 1997*. *(See water licence.)*

Licensee — A person who holds a water licence.

Local water management plan — A plan prepared by a council and adopted by the Minister in accordance with Part 7, Division 4 of the Act.

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

ML — *See megalitre.*

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

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

Natural resources — Soil; water resources; geological features and landscapes; native vegetation, native animals and other native organisms; ecosystems.

Natural Resources Management (NRM) — All activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively.

Palaeochannels — Ancient buried river channels in arid areas of the state. Aquifers in palaeochannels can yield useful quantities of groundwater or be suitable for ASR.

Permeability — A measure of the ease with which water flows through an aquifer or aquitard.

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

Potable water — Water suitable for human consumption.

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer.

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the *Water Resources Act 1997*.

PWA — Prescribed Wells Area.

PWRA — Prescribed Water Resources Area.

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

Reticulated water — Water supplied through a piped distribution system.

Seasonal watercourses or wetlands — Those watercourses and wetlands that contain water on a seasonal basis, usually over the winter–spring period, although there may be some flow or standing water at other times.

Specific storage (S_s) — Specific storativity. The amount of stored water realised from a unit volume of aquifer per unit decline in head.

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

State water plan — The plan prepared by the Minister under Part 7, Division 1, s. 90 of the Act.

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act).

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

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

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

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

Water allocation — (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s. 11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water allocation plan (WAP) — A plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with Division 3 of Part 7 of the Act.

Water licence — A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area. This grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water. A water licence confers a property right on the holder of the licence and this right is separate from land title.

Water plans — The State Water Plan, catchment water management plans, water allocation plans and local water management plans prepared under Part 7 of the Act.

Waterbody — Waterbodies include watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers.

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

Water-use year — The period between 1 July in any given calendar year and 30 June the following calendar year. This is also called a licensing year.

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

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed six metres.

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