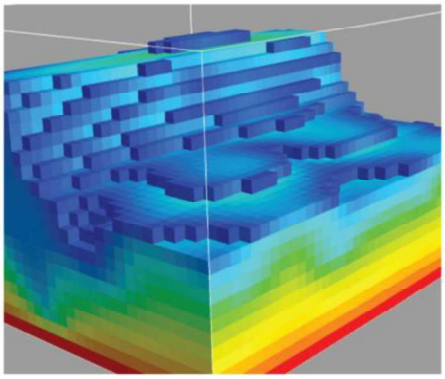
Western Australian
Geothermal
CENTRE OF EXCELLENCE

Temperature Regime in the Perth Metropolitan Area

Results of temperature and gamma logging and analysis, June/July 2010



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REPORT No: EP111422

DATE: 06 June 2011

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EXECUTIVE SUMMARY

Exploration of Perth's geothermal potential has been performed by the Western Australian Geothermal Centre of Excellence (WAGCOE) and two honours students from the University of Western Australia and Curtin University. Detailed vertical temperature and gamma ray logging of seventeen WA Department of Water's (DoW) Artesian Monitoring (AM) wells was performed throughout the Perth Metropolitan Area (PMA). In addition, temperature logs from fifty-three DoW AM wells measured in the 1980s were digitised into LAS format. The logged data are available in the WAGCOE Data Catalogue.

The temperature logs provide a picture of true formation temperatures within shallow sediments in the Perth Basin. A three-dimensional model of the temperature distribution was used to produce maps of temperature at depth, and on the top of the Yarragadee Aquifer.

The temperature data were interpreted with a one-dimensional conductive heat model. Significant difference between the model and the observations was indicative of heat moving via non-conductive mechanisms, such as advection or convection. Evidence of non-conductive or advective heat flow is demonstrated in most formations in the PMA, with significant effects in the aquifers.

The temperature data were analysed to produce average geothermal gradients for each formation, which range from a low of 13 °C km^{-1} in the Superficial formation to 39 °C km^{-1} in the South Perth Shale. In general, the gradients vary with lithology, with sandstone formations exhibiting average gradients of approximately 25 °C km^{-1}, while insulating silt/shale formations show higher average gradients of over 30 °C km^{-1}.

To produce preliminary heat flow estimates, temperature gradients were combined with thermal conductivities estimated by HDRPL [2008] for formations considered applicable to the PMA. The geometric mean heat flow estimates range between 64 mW m^{-2} to 91 mW m^{-2}, with the standard deviation of the arithmetic mean heat flow ranging between 15 and 23 mW m^{-2}.

Analysis of the gamma ray logs yielded the first estimates of radiogenic heat production in Perth Basin formations. Values by formation ranged between 0.19 and 0.85 μW m^{-3}. The gamma ray logs also helped produce a consistent set of stratigraphic formation elevations in the PMA.

This study points to several areas where future investigations will provide a more comprehensive overview of the thermal regime in the Perth area. In particular, additional temperature and calibrated three-component gamma ray logging will enhance the modern dataset. Older datasets should be digitised to provide inexpensive, albeit less accurate, spatial coverage. Quantification of the movement of heat by advective groundwater flow would indicate the significance of this mode of heat transport. Thermal properties such as thermal conductivity, specific heat, and thermal expansion should be measured in the PMA. In particular, thermal conductivity measurements are required to produce more accurate estimates of heat flow, although coupled inversion techniques may provide site-specific, initial spatial estimates of heat flow and thermal conductivity in shallow formations. Prediction of temperature at depth should include uncertainty estimates.

1. RATIONALE AND OBJECTIVES OF STUDY

The principle aim of geothermal exploration is to discover high subsurface temperatures in a location both economically and technically viable for drilling and usage. In the Perth Metropolitan Area (PMA), temperatures suitable for low-grade direct-heat use operations are provided by hot groundwater in sedimentary aquifers.

Exploration of Perth's geothermal potential has been performed through the temperature and gamma ray logging of 17 Artesian Monitoring (AM) wells. These wells are managed by the WA Department of Water's (DoW) and are distributed throughout the PMA. The purpose behind the logging component of this project was to gain true formation temperatures from shallow sediments. In addition, temperature logs from 53 DoW AM wells measured in the 1980s were digitised into LAS format. All of the wells were installed at least two years before logging; many wells were installed in the late 1970s and in some cases the wells date back to the early decades of the 20th century. Hence, groundwater temperatures will be in equilibrium with the surrounding rock, and logged temperatures will reflect true formation temperatures.

The project was part of a broader initiative within the Western Australia Geothermal Centre of Excellence (WAGCOE) to characterise the geothermal resource in the Perth Basin. As part of that work, WAGCOE is creating a geothermal data catalogue to collate geothermal information [Corbel and Poulet, 2010]. The temperature and gamma ray data, among other measurements collected in this investigation, will be added to the data catalogue. Pending approval from the DoW, the digital temperature logs generated from the older paper records will also be added to the data catalogue.

This report is organized as follows. Section 2 provides background information on the geologic and hydrogeologic framework of the PMA and summarises previous data and research on thermal properties in the region. Section 3 details the data collection, both the field logging procedure and the desktop digitization. Section 4 lays out the analysis procedure followed, and contains the main results of this report. Sections 4.1 and 4.2 describe quality control measures to ensure the validity of the data. Section 4.3 tabulates formation top depths determined from the gamma ray logs at the sixteen wells. Section 4.4 provides the first estimates of radiogenic heat production rates from PMA sediments. Section 4.5 investigates the effects of advective heat transport in the shallow formations, and indicates where non-conductive heat flow must be considered. Section 4.6 maps temperatures at depth across the PMA. Section 4.7 calculates geothermal gradients in the major formations. Section 4.8 discusses the data requirements for a preliminary heat flow analysis. Finally, section 5 discusses the limitations to the analysis and recommends future work for additional characterization of the Perth Metropolitan Area geothermal regime.

2. BACKGROUND RESEARCH IN THE PERTH METROPOLITAN AREA

This section of the report details relevant geothermal information previously known about the Perth Metropolitan Area. The large scale geology is described in section 2.1. Local geologic and hydrogeologic formations are detailed in section 2.2, from the Cattamarra Coal Measures at the base upwards to the surficial sediments. Section 2.3 provides an introduction to the physics of thermal transport, while section 2.4 describes data already known about the local geothermal regime. Geothermal gradients from four deep petroleum wells are provided in section 2.4.1. Previous measurements of thermal conductivity and radiogenic heat production, and subsequent heat flow estimates are laid out in sections 2.4.2 and 2.4.3.

2.1 Geologic Framework, Perth Basin

The Perth Basin is a sedimentary rift basin approximately 1000 km long occupying the southwest of Western Australia, extending in a north-northwesterly orientation between latitudes 27°00'S and 34°00'S. It is bounded by the Darling Fault to the east and the continental slope to the west. To the north the basin grades into the Southern Carnarvon Basin. Basement lithology consists of Precambrian rocks of the Pinjarra Orogen [Mory et al., 2005]. A map of the basin is provided in Figure 1.

Early Permian to Late Cretaceous sedimentary sequences up to 15 km thick occupy the series of sub-basins, troughs, shelves and ridges comprising the basin [Freeman & Donaldson, 2006]. Native permeabilities of the aquifer sediments throughout the Perth Basin are high [Davidson & Yu, 2006], thus facilitating groundwater circulation through these aquifers at relatively shallow depths. The attainable pumped flow rate of the Perth Basin's heated water resources may therefore be practical for hot sedimentary aquifer (HSA) geothermal use.

2.2 Local Geologic Formations and Hydrogeologic Aquifers

Descriptions of the Perth Region's stratigraphic units are found in Davidson [1995], and a generalized stratigraphic column is shown in Figure 2. The shallow portion of the Perth Basin comprises three major aquifers: the Superficial, Leederville and Yarragadee aquifers; as well as several minor aquifers: the Rockingham, Kings Park, and Mirrabooka aquifers. General characteristics for the units encountered during the logging fieldwork are noted in this section. The stratigraphy of each AM well is listed in Appendix A.

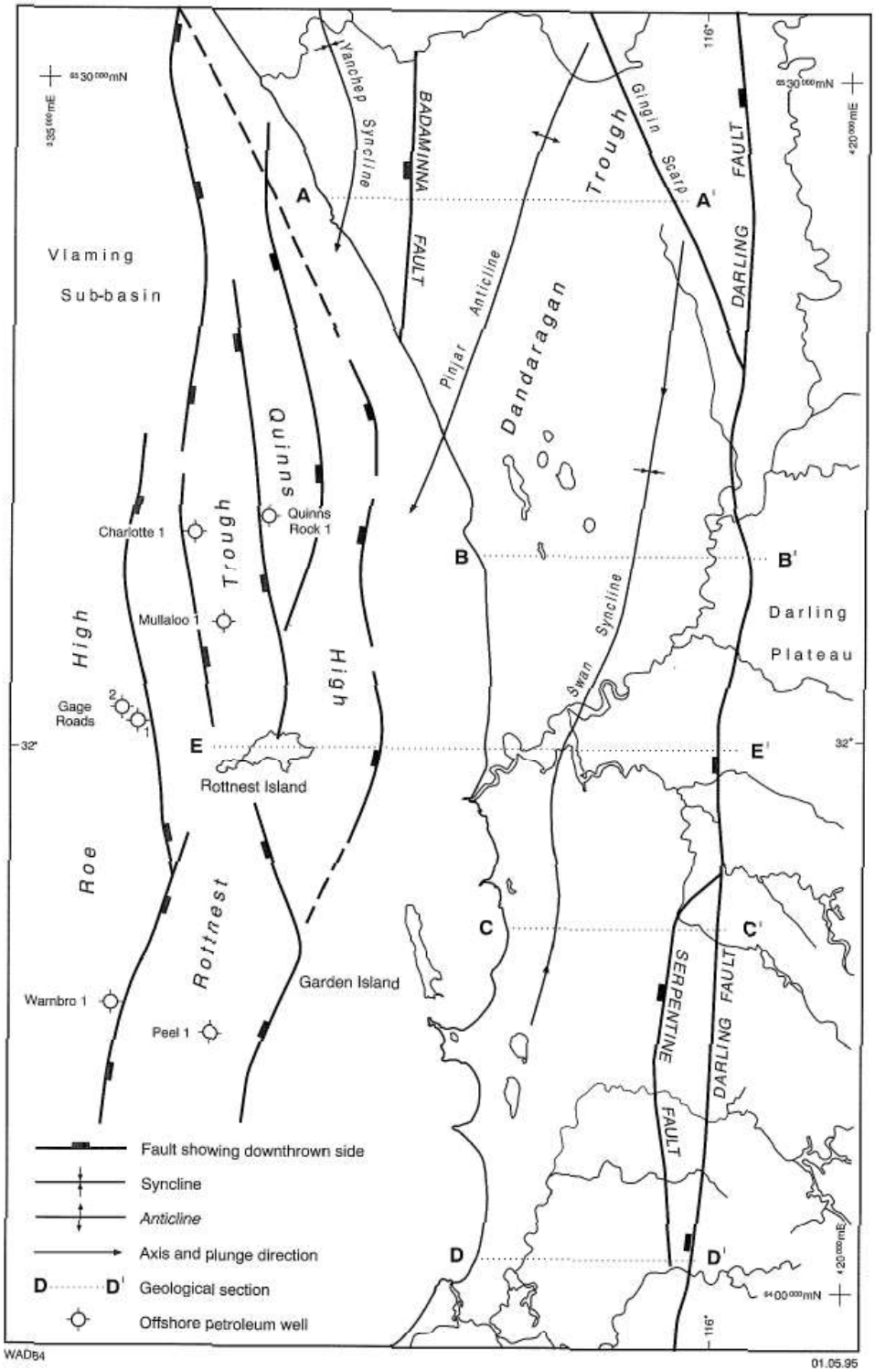


Figure 1: Perth Metropolitan area regional geology [Davidson 1995].

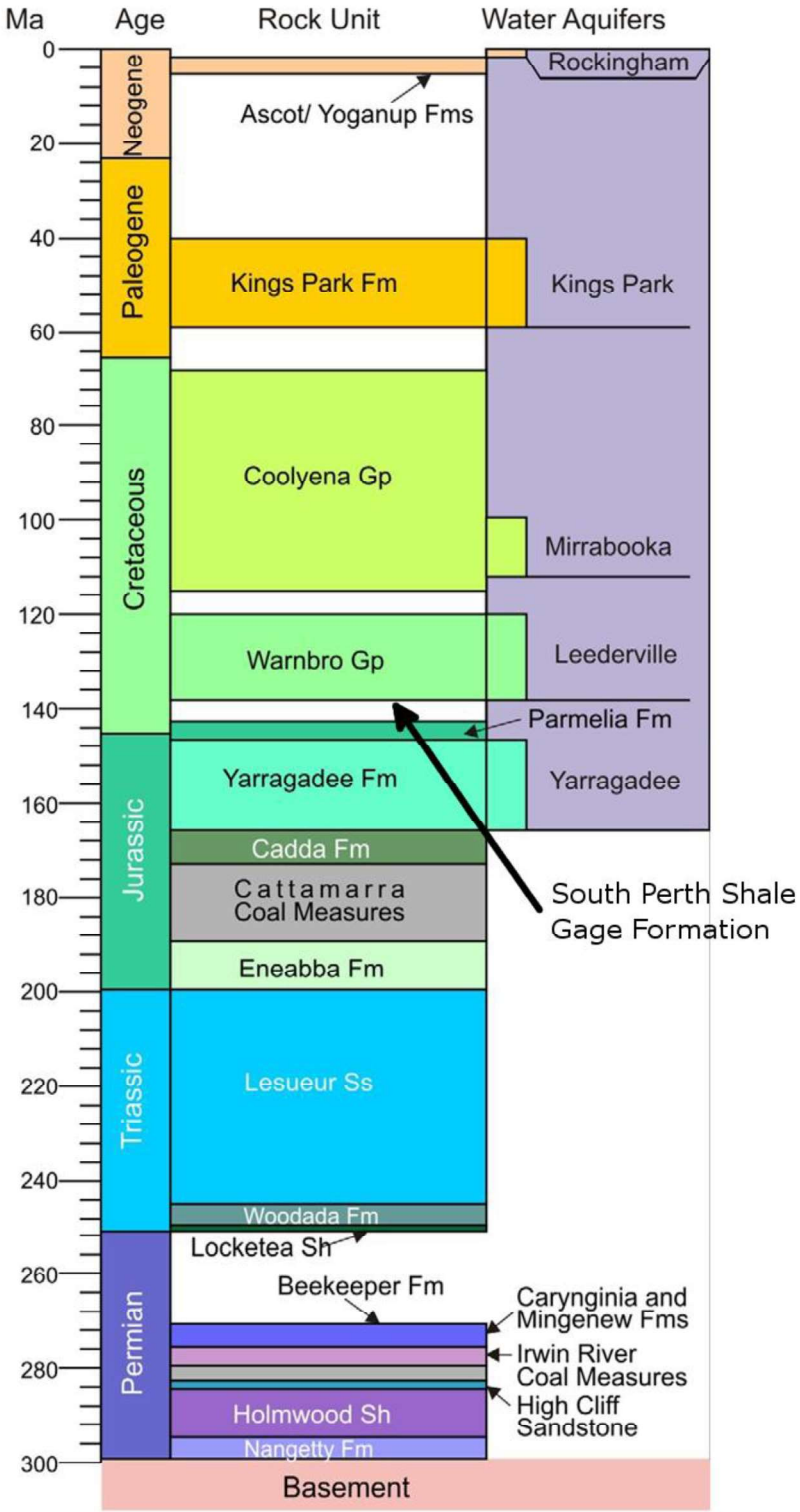


Figure 2: A generalised stratigraphic column for the Perth Basin, showing the distribution of aquifers [after Ghori, 2008]. The South Perth Shale lies below the Leederville Aquifer and above the Gage Formation. The Gage Formation lies above the Parmelia Formation.

2.2.1 Cattamarra Coal Measures

The Jurassic Cattamarra Coal Measures consist of interbedded non-marine sandstones, siltstones, and shales with minor coal seams. The sandstone beds have relatively high clay content and are thicker than the siltstone and shale sequences. The Cadda Formation and then the Yarragadee Formation conformably overlie the Cattamarra Coal Measures, except in the southeast of the PMA where members of the Leederville Formation, South Perth Shale, Gage Formation, and Superficial formations unconformably overlie it. The Cadda Formation is not described in this report because it is not observed in the studied wells.

The upper portions of the Cattamarra Coal Measures are considered to be part of the Yarragadee Aquifer [Davidson, 1995]. This classification is based on the similarity of the upper section to the overlying Yarragadee Formation.

2.2.2 Yarragadee Formation and Aquifer

The Yarragadee Formation is a laterally discontinuous mix of Jurassic aged interbedded sandstone, shale, and siltstone. The formation extends beneath the coastal plain and is generally conformably overlain by the Leederville Formation. However, in the south of the Perth Region the Yarragadee top has been eroded, and it is here unconformably overlain by the Leederville Formation, South Perth Shale, and Gage Formation. This unconformity is labelled the Neocomian Unconformity and provides a distinctive erosion marker in the Perth Basin sediment pile [Crostella and Backhouse, 2000].

The Yarragadee aquifer is a major confined aquifer consisting of the geologic Jurassic Yarragadee Formation and the Cretaceous Gage Formation for the majority of the Perth Basin, however in the south-east the aquifer is predominantly the geologic Jurassic Cattamarra Coal Measures. The Yarragadee Aquifer also includes the Parmelia Formation, where this unit is present (see section 2.3.3). It is a multilayered aquifer more than 2000 m thick consisting of discontinuous interbedded sandstones, siltstones, and shales [Davidson, 1995]. In some areas it is confined by the South Perth Shale, though in the central part of the coastal plain is it in direct hydraulic contact with the Leederville aquifer [Davidson and Yu, 2006].

2.2.3 Parmelia Formation

The Parmelia Formation consists of interbedded sandstones, siltstones, and shales of Jurassic-Cretaceous age. The sandstone beds are generally less than 5 m thick [Davidson, 1995]; the siltstones and shales form interbeds of thickness equal to the sandstones. The sandstones are lithologically similar to the upper section of the Yarragadee Formation, which the Parmelia conformably overlies. The Parmelia is unconformably overlain by the Gage Formation, South Perth Shale, or the Leederville Formation. Within the PMA, the Parmelia only occurs in the northeast section, above the Gingin Scarp (see Figure 1), although Davidson [1995] suggests it may be more widespread but simply difficult to distinguish from the Yarragadee. Hence where the Parmelia exists, the Neocomian Unconformity forms its upper surface.

The Parmelia is considered to form part of the Yarragadee Aquifer.

2.2.4 Gage Formation

The Gage Formation consists of Early Cretaceous interbedded sandstone, siltstone, and shale units. The sandstone beds vary in thickness and are similar to those in the Yarragadee Formation; hence the sandstones are thought to have originated due to erosion of the Yarragadee Formation. Generally the Gage Formation unconformably overlies the Yarragadee Formation except in the southwest where it unconformably overlies the Cattamarra Coal

Measures. In turn the South Perth Shale or Leederville Formation conformably overlies the Gage Formation until close to the Perth Central Business District (CBD) where the Kings Park Formation unconformity exists.

The Gage Formation is considered to be part of the Yarragadee Aquifer.

2.2.5 South Perth Shale Formation

The South Perth Shale is predominantly shallow-marine in origin, consisting mainly of thin siltstone and shale interbeds with minor sandy and calcareous beds. Generally in the south of the PMA the South Perth Shale is cemented and glauconitic. The South Perth Shale unconformably overlies the Cattamarra Coal Measures or Yarragadee Formation, while in other places conformably overlies the Gage Formation. Above the South Perth Shale a conformable contact with the Leederville Formation exists, except close to the CBD where the Kings Park Formation unconformity intrudes. It has a thickness of up to 300 metres [Davidson, 1995]

The South Perth Shale is a confining aquitard with low permeability.

2.2.6 Leederville Formation

The Leederville Formation consists of discontinuous interbedded sandstones, siltstones, and shales with some conglomerate found in deposits close to the Darling Scarp. The Leederville Formation unconformably overlies the Cattamarra Coal Measures and Yarragadee Formation while conformably overlying the Gage Formation or South Perth Shale. The Osborne Formation or Superficial formations unconformably overlay the Leederville Formation. Close to Perth's CBD the Leederville Formation has been eroded out and replaced by the Kings Park Formation. This Cretaceous aged formation hosts, in order of deposition, the Mariginiup, Wanneroo and Pinjar Members.

The Leederville aquifer is a major confined aquifer consisting of the Leederville Formation and Henley Sandstone Member of the Osborne Formation [Davidson, 1995]. It overlaps the Darling Fault south of the Dandaragan Plateau and extends beneath the entire coastal plain, except near the Swan Estuary where the Leederville Formation was eroded before the deposition of the Kings Park Formation [Davidson & Yu, 2006]. It is a multilayered aquifer comprising discontinuous interbedded sandstones, siltstones, and shales up to 600 m thick.

Mariginiup Member

Thinly interbedded and discontinuous siltstones and shales with thin, fine-grained sandstone beds typify the Mariginiup Member. This basal member of the Leederville Formation has a marine origin and relatively high clay content. The Mariginiup Member has a slightly greater sand content and coarser grain size to the south of the PMA. The Mariginiup Member represents the conformable boundary between the South Perth Shale below and the Wanneroo Member above.

Wanneroo Member

The Wanneroo Member consists of discontinuous interbedded sandstone, siltstone, and shale deposits of marine and non-marine origin. Granitic scree boulders occur within the Wanneroo Member close to the Darling Scarp. The Wanneroo Member conformably overlies the South Perth Shale or Mariginiup Member and in some places may unconformably overlay the Yarragadee Formation.

Pinjar Member

The Pinjar Member consists of discontinuous interbedded sandstone, siltstone, and shale deposits of marine and non-marine origin and represents the top of the Leederville Formation. It conformably overlies the Wanneroo Member but is unconformably overlain by the Osborne Formation or Superficial formations.

2.2.7 Osborne Formation

The Osborne Formation is Cretaceous in age and shallow-marine in origin, containing interbedded sandstone and shale sequences at shallower depths, a middle shale unit, and a basal sandstone sequence. In some parts of the northern Perth Region, the Osborne Formation has been eroded away prior to the deposition of the superficial sediments, while elsewhere the formation unconformably overlies members of the Leederville Formation. The Osborne Formation hosts the Henley Sandstone, Kardinya Shale, and Mirrabooka Members.

The lowest Henley Sandstone Member of the Osborne Formation is considered part of the Leederville Aquifer. The Kardinya Shale is a confining bed, while the uppermost Mirrabooka Member is considered a minor aquifer.

Henley Sandstone Member

The Henley Sandstone Member contains sandstone with minor siltstone amounts at the base of the Osborne Formation. The Henley Sandstone Member unconformably overlies members of the Leederville Formation while its upper contact with the Kardinya Shale Member is generally abrupt. In parts of the south PMA the Henley Sandstone Member is absent from the stratigraphic column.

Kardinya Shale Member

The Kardinya Shale Member has well consolidated interbedded siltstone and shale layers amongst thin fine-grained sandstone. Within the Osborne Formation, the Kardinya Shale Member conformably overlies the Henley Sandstone Member but in the south where the Henley Sandstone Member is absent, the Kardinya Shale Member overlies members of the Leederville Formation. In the northern PMA the Kardinya Shale Member is positioned conformably below the Mirrabooka Member or unconformably below Tertiary aged formations.

Mirrabooka Member

The Mirrabooka Member contains relatively coarse-grained sandstone with thin siltstone and shale interbeds. This member defines the uppermost extent of the Osborne Formation in the northern PMA, conformably overlying the Kardinya Shale Member. Overlying the Mirrabooka Member are conformable Tertiary age sediments and unconformable Superficial Formation deposits.

The Mirrabooka aquifer occurs along the eastern margin of the coastal plain in the Swan Syncline, and across the PMA [Davidson, 1995]. The Swan Syncline is a northeast-southwest trending folded structure whose axis crosses the Swan River east of the CBD. The Mirrabooka aquifer is predominantly sandy and consists of the Poison Hill Greensand, Gingin Chalk, Molecap Greensand, and the Mirrabooka Member [Davidson & Yu, 2006]. The Mirrabooka Member comprises fine to very coarse sandstone with thinly interbedded siltstone and shale. Directly underlying the aquifer is the Kardinya Shale, a confining bed which separates it from the Leederville aquifer.

The Mirrabooka aquifer is a semi-confined to confined aquifer that also extends into the overlaying Tertiary aged sediments.

2.2.8 Molecap Greensand

The Molecap Greensand is of Turonian to Santonian age and consists of fine- to medium-grained, yellowish-brown to greenish-grey, glauconitic, silty, and locally clayey sandstone occurring in the Swan Syncline and Wanneroo area. It is of shallow-marine origin and has a maximum thickness of 80 m. Conformably overlying the Molecap Greensand is the Gingin Chalk, or where this is absent, the Poison Hill Greensand or Superficial Formations unconformably overlay it. The Molecap Greensand overlies the Osborne Formation (Mirrabooka Member), mostly with transitional and conformable contacts [Davidson, 1995].

2.2.9 Gingin Chalk

The Gingin Chalk is of shallow-marine origin and Santonian to Campanian age. It has only been identified in the northern Perth area where it has a maximum onshore thickness of about 40 m and consists of pale-grey to whitish-green, slightly glauconitic chalk containing very thin beds of green sand. The Gingin Chalk unconformably overlies the Leederville Formation (Pinjar Member) and the Osborne Formation (Kardinya Shale Member), conformably overlies the Molecap Greensand, and is conformably overlain by the Poison Hill Greensand [Davidson, 1995].

2.2.10 Poison Hill Greensand

The Poison Hill Greensand has been identified in the Swan Syncline and Wanneroo area and has a maximum onshore thickness of about 90 m. Initially thought to be deposited in the Quaternary, sampling of the sediments has failed to determine the age. The sand is similar in lithology and characteristics to the Henley Sandstone Member of the Osborne Formation, though it is typically less silty and less clayey. Conformably underlying the Poison Hill Greensand is the Molecap Greensand or the Gingin Chalk, and unconformably overlying it are the Superficial Formations [Davidson, 1995].

2.2.11 Lancelin Formation

The Lancelin Formation is of marine origin and has a maximum onshore thickness of about 120 m. It is only identified in the Guilderton area where it is comprised of white to greenish-brown, glauconitic marl. The top of the Lancelin Formation is an erosional surface that is unconformably overlain by the Kings Park Formation or Superficial Formations. The Lancelin Formation typically overlies the Gingin Chalk and is of Coniacian to Maastrichtian age [Davidson, 1995].

2.2.12 Kings Park Formation

The Tertiary aged sediments of the Kings Park Formation comprise grey calcareous, glauconitic siltstone and shale, along with sandstones of the Como and Mullaloo Sandstone Members. These sandstones are minor aquifers, but their extents are unknown [Davidson & Yu, 2006]. The Kings Park Formation overlies a number of aforementioned Jurassic and Cretaceous aged sediments and is itself overlain by the Superficial Formations.

Como Sandstone Member

The Como Sandstone Member consists of moderately sorted clayey sands representing the basal member of the Kings Park Formation.

Mullaloo Sandstone Member

The Mullaloo Sandstone Member at the top of the Kings Park Formation contains poorly sorted glauconitic and clayey sand. The member fills marine sourced channels incised into the siltstones and shales of the Kings Park Formation.

2.2.13 Superficial Formation

The Superficial Formation is the collective name for the Quaternary and Tertiary aged shallow sediments on the Swan Coastal Plain with a thickness of less than 90 m and comprising variable amounts of sand, limestone, silt and clay. Coastal deposits have greater amounts of calcareous marine, eolinates and limestone, while inland deposits contain more fine to medium sized sands with minor silt, limestone and clay. The Superficial Formation has little bearing on the potential of the Perth Basin's HSA geothermal resource, but are extensively used for local reticulation.

The upper surface of the unconfined Superficial aquifer is the water table. The aquifer has a maximum saturated thickness of up to 70 m, and is highly dependent on topography. The water table intersects the surface at several locations as evidenced by the many lakes and swamps present in the Perth Basin [Davidson & Yu, 2006]. Water table fluctuations of approximately 3 m are evident in clays along the Darling Fault and Gingin Scarp, 1.5 m in the central sands and less than 0.5 m in the coastal limestone. This phenomenon is a direct result of the varying hydraulic conductivities in the different lithologies.

Rockingham Aquifer

Also included in the Superficial Formation is the Rockingham Aquifer. It is only present in the southern Perth Basin and whilst a minor aquifer, it is locally very important [Davidson & Yu, 2006]. Onshore is has a thickness of up to 80 m and is comprised of slightly silty and feldspathic, medium to coarse sand [Davidson, 1995]. The lower 70 m of the aquifer contains saline water whilst the upper 40 m contains freshwater. Regionally it is hydraulically connected to the Superficial aquifer, though lenses of clay locally confine it [Davidson & Yu, 2006].

2.3 Physics of Thermal Transport

Geothermal exploration attempts to locate subsurface areas where temperatures are high enough for economic usage. The primary sources of geothermal heat are the decay of radionuclides and the heat released by crystallisation of the molten outer core of the Earth [Beardsmore & Cull, 2001]. This heat can be transported by conduction between adjacent rock grains and pore fluids, or by water moving within the pore spaces of the rocks by advection or convection [Haenel et al., 1988].

Conduction is described by Fourier's Law, where heat flows from the greater temperatures at depth to the lower temperatures. In a one-dimensional, vertical case the steady-state conductive heat transfer is determined using the following equation:

$$Q_z = -\lambda \cdot \frac{\partial T}{\partial z} \tag{1}$$

where λ is the thermal conductivity of the rock and $\partial T/\partial z$ is the thermal gradient. If thermal conductivity is constant within each formation, then a temperature profile representing conductive heat flow will have straight-line segments within each formation. Variable thermal conductivities may generate non-linear temperature profiles.

When heat movement by water (i.e. advection or convection) is significant, the heat transfer equation involves the water flow rate w (m s^{-1}):

$$(\rho C)_m \frac{\partial T}{\partial t} = \lambda_m \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) - (\rho C)_\mathrm{f} \left(w_x \frac{\partial T}{\partial x} + w_y \frac{\partial T}{\partial y} + w_z \frac{\partial T}{\partial z} \right) + A \qquad (2)$$

where ρ is density (kg m^{-3}), C is specific heat (J kg^{-1} K^{-1}), subscript m refers to the combined (bulk) rock and fluid medium, subscript f the fluid only, and the dimensional subscripts define the direction of flow [Jessop & Majorowicz, 1994]. Here, the thermal conductivity λ (W m^{-1} K^{-1}) is assumed constant, and A is the rate of heat generation, which is further discussed in section 4.4. In general, the water flow w may be imposed by external conditions (e.g. meteoric recharge) or may be caused by buoyancy effects caused by gradients in groundwater density [Clauser, 2009]. The first type of movement is termed advection, while the second is termed convection. In formations where water flow is a significant source of heat movement, the vertical thermal profiles deviate from straight-line segments and assume a non-linear shape within these units.

To describe the temperature at depth, solving either equation (1) or (2) requires knowledge of subsurface thermal properties.

2.4 Thermal Properties

Comprehensive geothermal investigations in the PMA are relatively recent. Three studies have investigated thermal properties in the larger Perth Basin. Bestow [1982] summarised geothermal knowledge in all of Western Australia. In the Perth Basin, he describes regions of high heat flow and geothermal gradients and provides estimates of depths to the 100 °C isotherm. In the PMA Bestow states that gradients are less than 25 °C km^{-1}. Chopra and Holgate [2007] analysed subsurface temperature measurements from deep geothermal wells, calculated true formation temperatures, and estimated the depth of the 200 °C isotherm. Hot Dry Rocks Pty Ltd [HDRPL, 2008] measured thermal conductivity from core samples from formations within the Perth Basin. These measurements were combined with bottom hole temperatures (BHT) to estimate heat flow and isotherm depths.

2.4.1 Geothermal Gradient

The vertical geothermal gradient is defined as the change in temperature with respect to depth $\partial T/\partial z$. According to Tester et al. [2006], "within an individual well, the geothermal gradient can vary by up to a factor of five or more, depending on the lithology in a particular depth interval." This variation in geothermal gradient arises from variations in thermal conductivity between lithologies, and from the effects of advection and convection (see Section 2.3). Table 1 lists the geothermal gradient calculated from BHT measurements in deep petroleum wells surrounding the PMA as shown in HDRPL [2008]. However, these calculations assume a constant geothermal gradient through the depth of each hole, and thus are only a rough approximation of the actual thermal gradient in any given formation. In the present study geothermal gradients are calculated separately for each stratigraphic unit in each well. The results are presented and discussed in Section 4.7.

Table 1: Average geothermal gradients from maximum temperatures recorded in petroleum wells near the Perth Metropolitan Area. Assumed mean annual surface temperature (MAST) is 20 °C [Horowitz and Regenauer-Lieb, 2009].

Well Name	Approximate distance from Perth	Depth of Measurement (m)	Temperature (°C)	Reliability of temperature	Geothermal Gradient (°C km^{-1})
Cockburn 1	23 km SW	3048	81.1	low	20.0
Bullsbrook 1	53 km N	4257	100	low	18.8
Gingin 3	88 km N	3294	103.8	high	25.4
Pinjarra 1	80 km S	4569	115	medium	20.8

2.4.2 Thermal Conductivity and Heat Flow

Thermal conductivity is the physical property that controls the rate at which heat flows through a material by conduction for a given geothermal gradient. Thermal conductivity is dependent on lithology. In S.I. units, thermal conductivity is measured in Watts per metre-Kelvin (W m^{-1} K^{-1}). Thermal conductivity is a characteristic of each rock unit and the effects of factors such as temperature, rock saturation and porosity have been discussed in works by authors such as Vosteen and Schellschmidt [2003].

Steady-state thermal conductivity measurements were collected by HDRPL [2008] for various representative samples of the Perth Basin, using HDRPL's portable divided bar thermal conductivity apparatus. Using 36 representative core samples, thermal conductivities were measured ranging from 1.31 to 7.01 W $m^{-1}K^{-1}$. The thermal conductivity values from the HDRPL report for a number of geological units encountered in the June and July 2010 thermal logging fieldwork of this study are shown in Table 2. Note that HDRPL reported values in the shallow surficial sediments and Osborne Formation were derived from analogous sediments in the Carnarvon Basin of Western Australia. The Gage Formation samples were taken in shaly beds and may not accurately reflect the sandstone portions of this heterogeneous formation. Hence the reported values of these three formations may not be applicable to PMA sediments.

Table 2: Summary of the measured thermal conductivity value, from Hot Dry Rocks Pty Ltd. [2008]. The Harmonic Mean values represent the best estimate over the formation, with the error calculated from variation amongst measurements. The Minimum and Maximum measured values have error values based on the equipment sensitivity. Where measurements are marked N/A, estimates are taken from Carnarvon Basin analogies [Beardsmore, 2005]. Samples in the Gage marked with * were taken from shale beds.

Stratigraphic unit	Thermal conductivity (W m^{-1} K^{-1})		
	Harmonic mean	Minimum measured	Maximum measured
Surficial sediments	1.42 ± 0.14	N/A	N/A
Osborne Formation [Coolyena Group]	1.13 ± 0.08	N/A	N/A
Leederville Formation [Warnbro Group]	2.56 ± 0.18	2.43 ± 10%	2.77 ± 10%
South Perth Shale	1.71 ± 0.14	1.50 ± 10%	1.90 ± 4%
Yarragadee	3.54 ± 0.30	2.07 ± 4%	4.61 ± 10%
Gage	1.93 ± 0.04*	1.68 ± 4%*	2.24 ± 4%*
Cattamarra Coal Measures	3.73 ± 0.20	3.03 ± 4%	4.68 ± 4%

Conductive heat flow can be described most simply as the product of the temperature gradient and rock thermal conductivity. Heat flow in the Earth has horizontal as well as vertical components, but reported values are usually calculated on the assumption that all heat flow is vertical (i.e. ignoring any horizontal temperature variations). Hereafter, we use the term "conductive heat flow" to refer to vertical heat flow calculated from the geothermal gradient and thermal conductivity. Conductive heat flow was estimated in 170 wells using the thermal conductivities measured by HDRPL [2008]. They used a one-dimensional conductive heat flow modelling program in their study. Table 3 lists some results of their modelling relevant to the PMA study. In Table 3, uncertainty refers to one standard deviation of error, based on variability of thermal conductivity measurements. HDRPL found that heat flow in the Perth Basin ranges from 30 to 140 mW m^{-2}, with a median of 90 mW m^{-2} for all wells and 76.5 mW m^{-2} for single wells. The Australia median value for surface heat flow is 64.5 mW m^{-2}, obtained from the global heat flow database [HDRPL, 2008]. Heat flow calculations for data from this study are discussed in section 4.8.

Table 3: Modelled heat flow for four wells in the Perth Basin [HDRPL, 2008].

Well name	Heat flow (mW m^{-2})	Uncertainty (mW m^{-2})
Bullsbrook-1	68	2.8
Cockburn-1	76	3.1
Gingin-1	88	3.6
Pinjarra-1	78	2.4

2.4.3 Radiogenic Heat Production

Radioactive decay in sediments is a source of heat generation in sedimentary basins. Previous work by Tester et al. [2006] has shown that radioactivity can have a significant impact on heat flow at temperatures greater than 300 °C, and varies from zero to greater than 100 mW m^{-2}. A typical radioactive heat flow value is about 25 mW m^{-2}. Hot Dry Rocks Pty Ltd. [2008] estimated heat generation rates of basement rocks in the Perth Basin using data from Geoscience Australia's geochemical data base Ozchem [Geoscience Australia, 2011]. Only four samples were available within the Perth Basin, so additional samples were obtained from surrounding craton rocks. Table 4 lists the estimated heat generation values for rocks typical of the Perth Basin. Section 4.4 below details radiogenic heat production values estimated from the logging performed in this study.

Table 4: A summary of heat generation values for rock samples from and adjacent to the Perth Basin. [HDRPL, 2008].

Lithology	Number of samples	Assumed density (g cm^{-3})	Heat Generation (μW m^{-3})	
			Range	Median
Granite	35	2.68	0.54 - 20.50	4.08
Gneiss	21	2.65	0.31 - 10.30	1.97
Sedimentary	8	2.50	0.68 - 3.30	1.38

3. DATA COLLECTION

With the aim of increasing geothermal knowledge in the PMA, the Western Australian Geothermal Centre of Excellence (WAGCOE) began a logging program with the assistance of Geoscience Australia (GA). Logged data provides superior spatial coverage and depth resolution than core analysis for the purpose of investigating thermal properties of the wellhole formations [Hartmann et al., 2005]. Equipment was made available for a short time by GA; WAGCOE logged as many wells as possible around the PMA within the loan time of GA's equipment.

Temperature and gamma ray data acquisition was conducted from June 8th to July 12th 2010 in the PMA. The study area included wells as far as 40 km north, 46 km south, 14 km west, and 17 km east of the Perth CBD (Figure 3). The procedure involved in successfully collecting the field data by the logging operations is described in the following sections.

3.1 Site Selection

Scouting was conducted to ascertain which DoW AM wells were able to be logged. Figure 3 shows the locations of all the wells in the Perth Basin [Davidson, 1995] and defines the area covered by this study. Permission to log wells with continuous monitoring equipment currently installed had to be granted by the DoW. The location of a number of wells in difficult terrain and national parks rendered them inaccessible to the logging vehicle, whilst several wells could not be located at their published GPS locations. AM37A was too damaged to be logged. All wells required keys from the DoW to unlock the padlocks. Table 5 details the conditions of the scouted wells, including accessibility, damage, and presence of installed monitoring equipment.

3.2 Logging

The acquisition of temperature and gamma ray data along with other measurements, including wireline tension due to the weight of the probe and the drawn voltage by the logging equipment, was performed by fieldwork with GA's equipment.

3.2.1 Equipment

Equipment was provided by GA and operated by WAGCoE members. The probe used was an A626-4 Conductor Gamma/Temperature Sonde. Both the temperature and gamma ray sensors are capable of operating within a temperature range of 0-70 °C and at a maximum pressure of 21000 kPa. The tool used a three second time constant to filter the thermal and gamma ray data. The digital logging system is a DLS 5 and the computer software WellVISION, all from Auslog Pty Ltd. The winch was a W2000 with about 1800 m of 4 conductor wireline and powered by a Honda EU30i portable generator. The DLS 5 digital logging system contains dual processors with bi-directional communication capabilities. The WellVISION software comes standard with the system as well as an IBM TM compatible PC for live recording and displaying of the logged data. Figure 4 shows the winch and digital logging system located in a towable trailer.

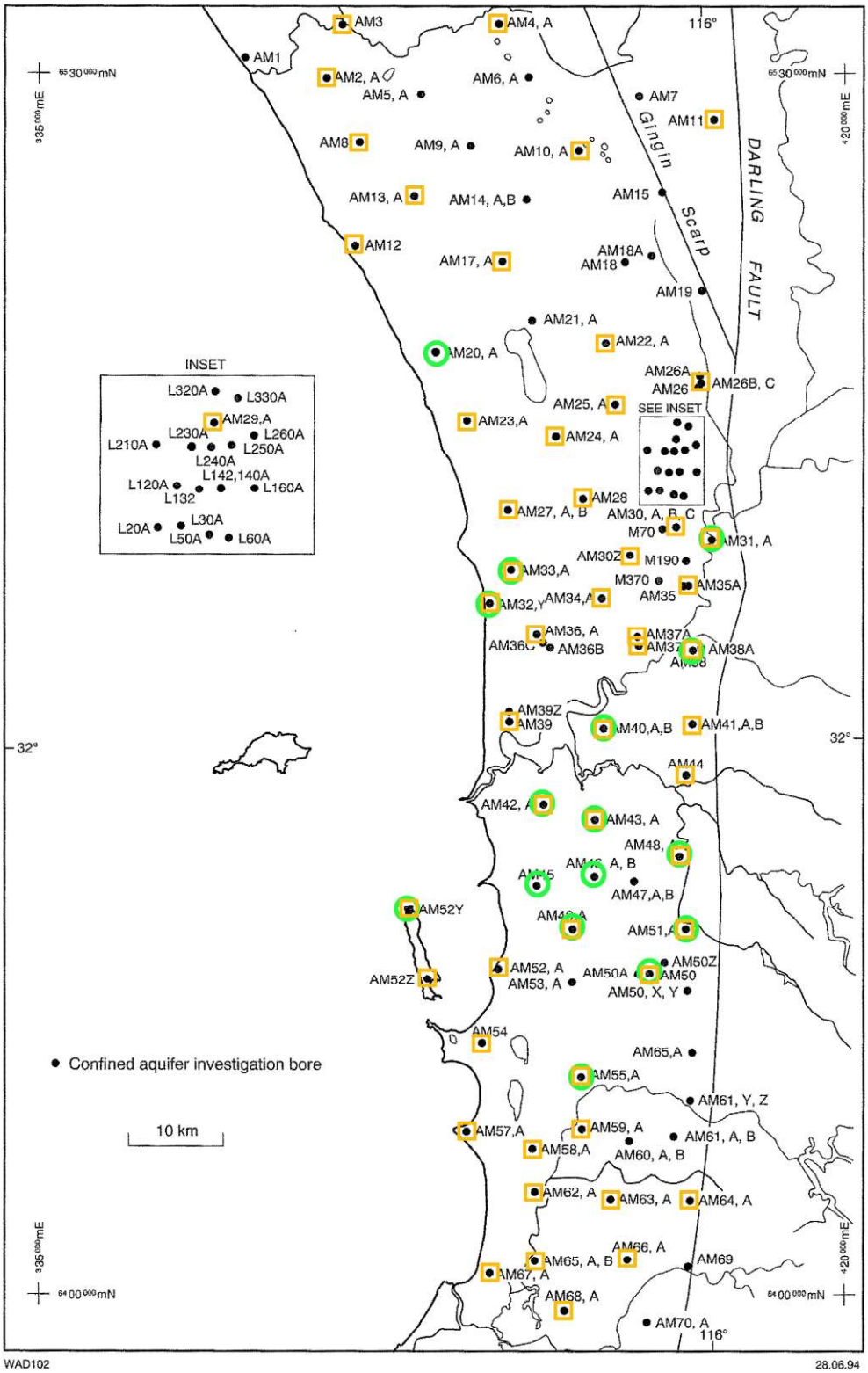


Figure 3: Locations of logged (green circles) and digitised (yellow squares) WA DoW AM wells [after Davidson, 1995]

Table 5: List of scouted wells detailing their accessibility to the vehicle fitted with the logging equipment, obvious damage and whether any third-party monitoring equipment was installed in the wellhole. *Italicised* names indicate wells that were successfully logged.

Well	Accessibility	Damage	Monitoring equipment
AM20	Easy	None	Yes
AM27	Difficult. Trees close together	None	Yes
AM31	Easy	None	No
AM30	In the middle of a median strip	None	Yes
AM30Z	Very difficult. In a nature reserve, very soft sand	None	No
AM32	Unable to be located	Unknown	Unknown
AM32Y	Reasonable. Gate key required	None	Yes
AM33	Reasonable. Gate key required	None	Yes
AM33A	Reasonable. Gate key required	None	Yes
AM34, A	Very difficult. Trees close together, very soft sand	None	Yes
AM37	Unable to be located	Unknown	Unknown
AM37A	Difficult. On HWE Maintenance Services property	Severe damage to casing, inaccessible	No
AM38	Easy	Unable to be opened	Unknown
AM38A	Easy	None	Yes
AM40, A	Easy	None	No
AM42	Easy	None	No
AM43A	Easy	None	No
AM45A	Easy	None	No
AM46, A, B	Easy. Approach from the east	None	No
AM47	Unable to be located	Unknown	Unknown
AM47C, D	Reasonable. Gate key required, in a nature reserve	None	No
AM47E	Reasonable. Gate key required, in a nature reserve	Too narrow for probe	No
AM48	Easy	None	No
AM49, A	Easy	None	No
AM50, A	Easy	None	No
AM51	Easy	None	No
AM52	Inaccessible	Being decommissioned	No
AM52Y	Reasonable. Careful manoeuvring required.	No	No
AM52Z	Very difficult. Rugged terrain, very soft sand	None	No
AM53, A	Very difficult. In the sidewalk, cover requires special lifting tools	Unknown	Unknown
AM54	Very difficult. In the sidewalk, cover requires special lifting tools	Unknown	Unknown
AM55	Reasonable. Careful manoeuvring required	No	No
UWA TP01	Buried under grass	None	No

Auslog's A626-4 Conductor Gamma/Temperature Sonde senses temperature with a fully encapsulated AD590 solid state temperature sensor and an electrode positioned at the bottom of the probe. Temperature is measured via an integrated circuit temperature sensor that produces a voltage proportional to the wellhole fluid temperature, which is fed up the four-conductor cable to the data acquisition system. The data are plotted as temperature values in the WellVISION software. The precision of the temperature tool is approximately 0.007 °C and is rated to 60 ^{0}C.

The A075 gamma ray tool is located 26 cm above the temperature sensor, with the offset between the two sensors accounted for by the WellVISION software. The tool detects the total count of natural, very high frequency gamma ray emissions from the subsurface lithology through a sodium iodide crystal sensor and excels at defining the boundaries between sedimentary beds. A shaley layer with its relatively high clay content will produce a high gamma raycount as opposed to a sandstone formation. Bursts of light generated by the passing of gamma rays through the sodium iodide crystal are converted into electrical pulses, amplified, shaped and then transmitted up the cable to the data acquisition system [ALPL 2008].

Figure 4: Geoscience Australia's mobile logging platform. The trailer housing the A626 temperature probe, Auslog winch and cable drum, DLS 5 digital logging system, computer, and petrol generator.

3.2.2 Field Procedure

Temperature logging was recorded on the downward run of the wellhole to minimize the disturbance of temperature equilibrium between the wellhole fluids and the formations. Ideally the best thermal measurements will be recorded when the displacement of the water in the wellhole associated with the logging is minimised hence representing the thermal equilibrium state of the water in the aquifer. Disturbances of the near surface water table were unavoidable where groundwater monitoring loggers that were installed inside the wells were removed shortly before the commencement of logging.

The probe's connection points were water proofed to protect from any damage during the logging runs. The probe was positioned vertically above the hole in order to minimize the horizontal offset on the cable thus placing less strain on the cable as it unwound off the drum. This centering generated a more constant logging speed, allowing for a relatively consistent 5 m min^{-1} logging rate to be established as the norm for all logging. For the purpose of eliminating

surface effects, the air temperature and water table depth were recorded. Since the logging was performed during winter, a rapid increase in the wellhole's thermal profile at a depth of less than 40 m generally signified the watertable depth. The height of the casing above the ground level was measured for Australian Height Datum (AHD) correction later.

Reaching the bottom of the wellhole was determined through a combination of monitoring the live gamma raycount to gauge where the count became relatively constant, referring to the casing depths noted in Davidson [1995] and monitoring the increase in the slack on the unwinding cable coinciding with the probe being "hung-up" at the bottom of the well.

WAGCoE sampling was conducted at 5 cm intervals with a 5 m min^{-1} descent. Table 6 details the location and date of each sample, as well as the total depth of the well, the depth of the profile, and the depth at which the water table was intersected. The data were recorded as digital LAS files and are stored in the WAGCOE Data Catalogue [Corbel & Poulet, 2010].

Table 6: Locations of wells logged, including the date logging took place, the depth of the well, the depth reached by the probe, and the depth at which the water table was intersected (metres from ground level).

Well name	Date logged	Location	Well depth (m from GL)	Profile depth (m from GL)	Water level (m from GL)
AM20	06/07/10	Alkimos	467	371.89	8.3
AM31	23/06/10	Henley Brook	800	726.00	7.0
AM32Y	09/07/10	North Beach	404	375.11	43.4
AM33A	08/07/10	Duncraig	533	535.82	29.3
AM38A	05/07/10	South Guildford	550	541.60	19.1
AM40	08/06/10	Kensington	741	689.00	34.2
AM40A	22/06/10	Kensington	459	276.56	25.4
AM42	09/06/10	Kardinya	600	570.14	19.9
AM43A	10/06/10	Leeming	794	758.24	38.8
AM45A	09/06/10	Munster	409	239.40	13.0
AM46	30/06/10	Banjup	801	616.17	37.8
AM48	08/06/10	Southern River	618	429.70	12.7
AM49	25/06/10	Mandogalup	554	535.72	45.8
AM50	29/06/10	Oakford	354	343.15	23.3
AM51	28/06/10	Darling Downs	421	393.77	10.0
AM52Y	07/07/10	Garden Island	435	390.91	4.0
AM55	01/07/10	Baldivis	401	371.85	9.8

3.2.3 Data Validity

Wells AM40 and AM40A were sampled multiple times at different sample intervals and speeds to assess the quality of the collected data. For well AM40, the temperatures gathered at 5 cm intervals at a speed of 10 m min^{-1} were consistently lower by approximately 0.04°C at the same depth as the profile compiled from data collected at a sample interval of 20 cm and speed of 5 m min^{-1} (Figure 5), potentially due to the probe having less time to equilibrate to the water temperature at the faster speed. The larger interval of 20 cm resulted in less noise in the data than sampling at 5 cm intervals.

Well AM40A was sampled 3 times on the same day, one profile immediately after the other, at interval 1 cm and speed 5 m min^{-1}, 5 cm at 3 m min^{-1} and 5 cm at 5 m min^{-1}. As with well AM40, the larger sample interval of 5 cm produced smoother plots. However, the profile plotted from data at an interval of 5 cm and speed 5 m min^{-1} produced temperatures consistently lower by approximately 0.03°C at the same depths as the profiles with sampling 5 cm at 3 m min^{-1} and 1 cm at 5 m min^{-1}. This decrease is possibly due to the probe taking an average over the sample interval as opposed to instantaneous measurements.

It can be concluded that the data collected at different speeds and sampling intervals is accurate to within 0.05 °C. However, for consistency, subsequent profiles were taken at 5 cm intervals at a speed of 5 m min^{-1}.

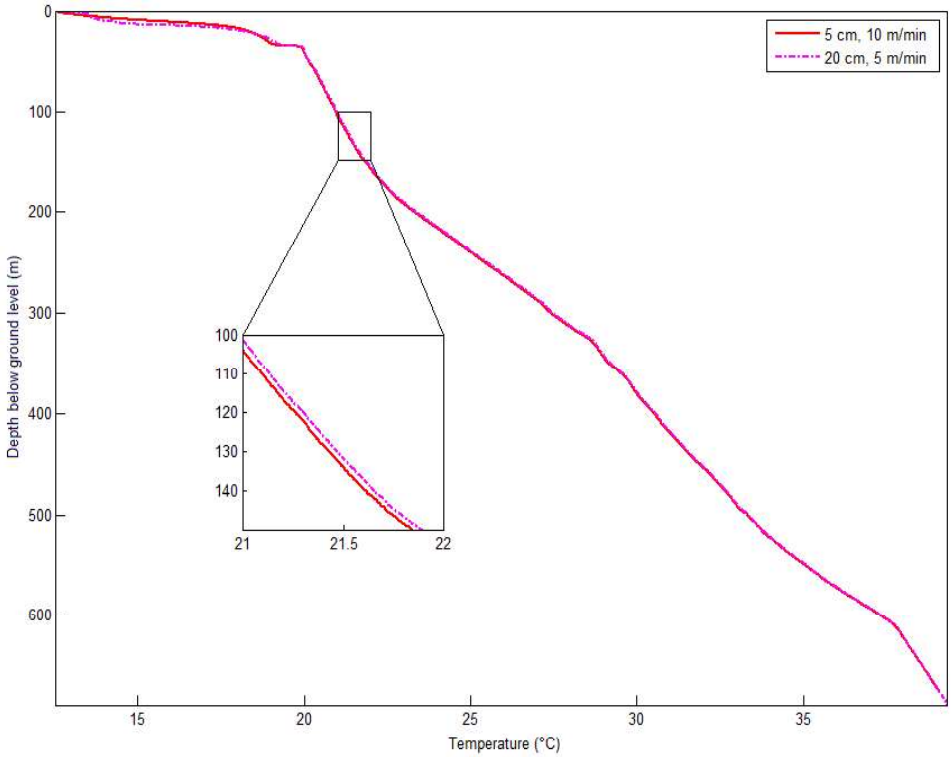


Figure 5: Temperature profile difference between a sample interval of 5 cm at 10 m min^{-1} (solid red) and a sample interval of 20 cm at 5 m min^{-1} in AM40 (dashed pink). The sampling of 5 cm at 10 m min^{-1} consistently plots at a lower temperature to 20 cm at 5 m min^{-1}

Well AM45 was sampled both as the probe was lowered down the well and as it was raised back to the surface, to observe the effect that disturbing the water column has on the temperature profile (Figure 6). This was of particular interest for well AM40A as it was sampled 3 times consecutively, potentially producing a measureable disturbance. With a sample interval of 20 cm at 5 m min^{-1}, the profiles showed significant differences in temperature readings as the probe descended and subsequently ascended. Before logging began, it was proposed that sampling downhole would produce a more accurate log, as disturbance in the water column would be reduced. As hypothesised, the ascending profile shows evidence of non-conductive heat transfer, induced by the movement of the probe both down and up the well, plotted as alternating convex- and concave-up curves of an otherwise linear plot. Also to be noted is the near-vertical gradient in the last 50 m of the ascending plot, highlighting the influence of mixing. Overall, the ascending profile showed temperatures were at least 0.1 °C higher, than at the corresponding depths on the descending profile, with the majority greater than 0.5 °C higher. This is attributed to heat redistribution due to the disturbance, coupled with small quantities of heat generated by friction and the probe itself.

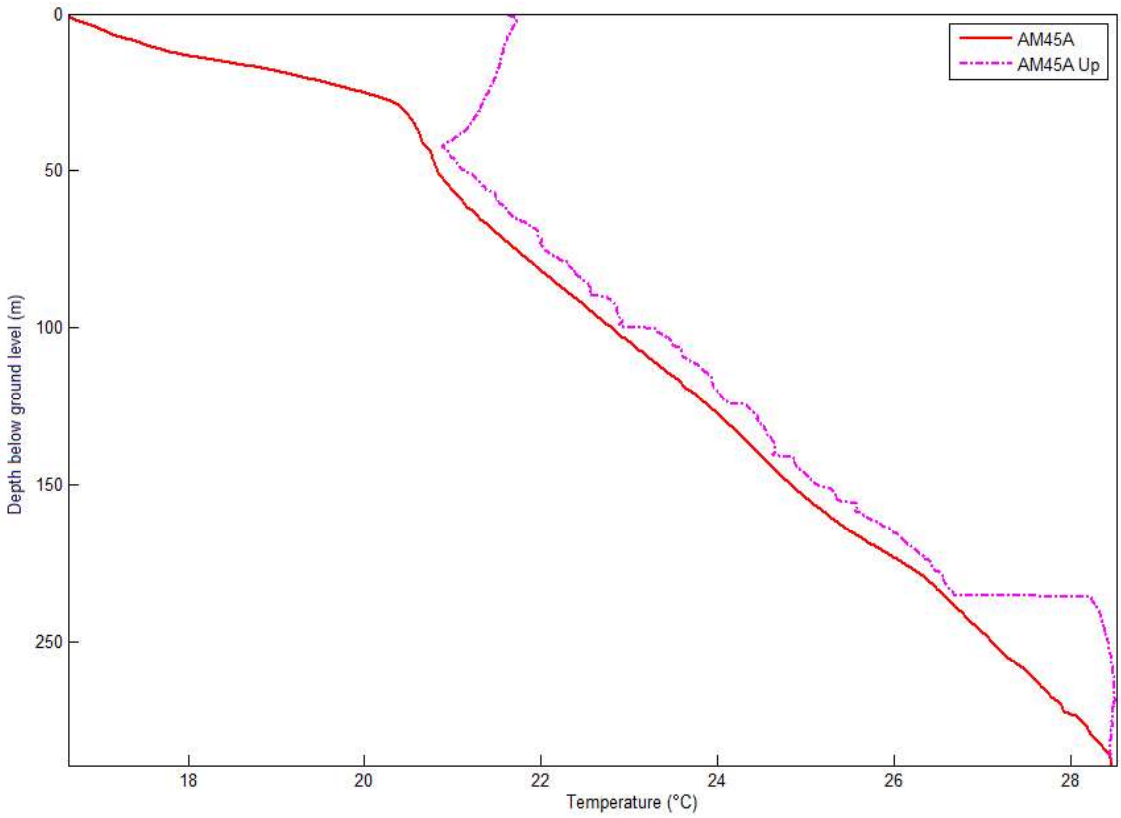


Figure 6: Temperature profile difference between logging while the probe is descending (AM45A) and logging while the probe is ascending (AM45A Up). AM45A Up shows ample evidence of non-conductive heat flow.

3.2.4 Calibrating the Probe

With every logging run of the thermal probe, a slight drift in the temperature recordings is encountered which generates a source of measurement error. The temperature sensor's drift was compensated through calibration of the probe both before (June 21) and after logging (July 9).

The probe was positioned in a bucket of heated water (>50°C initial temperature), at a temperature less than the sensor's maximum operating temperature, alongside an accurate mercury thermometer which had been calibrated in boiling and freezing water. The thermometer became the measuring standard as the temperature of the probe in counts per second (CPS) was recorded at set intervals of 0.5°C on the thermometer. These data were plotted against each other (Figure 7) and the difference between the probe and the thermometer determined (Figure 8). From these deviations, an equation relating the temperature taken by the probe and the temperature taken by the thermometer was determined for each date. The final calibrations are shown in Table 7. Within the LAS files, the linear fit calibration equation from each date was applied to generate two columns of data. A final data column was generated which interpolated between the two calibration equations, based on the date the log was actually performed.

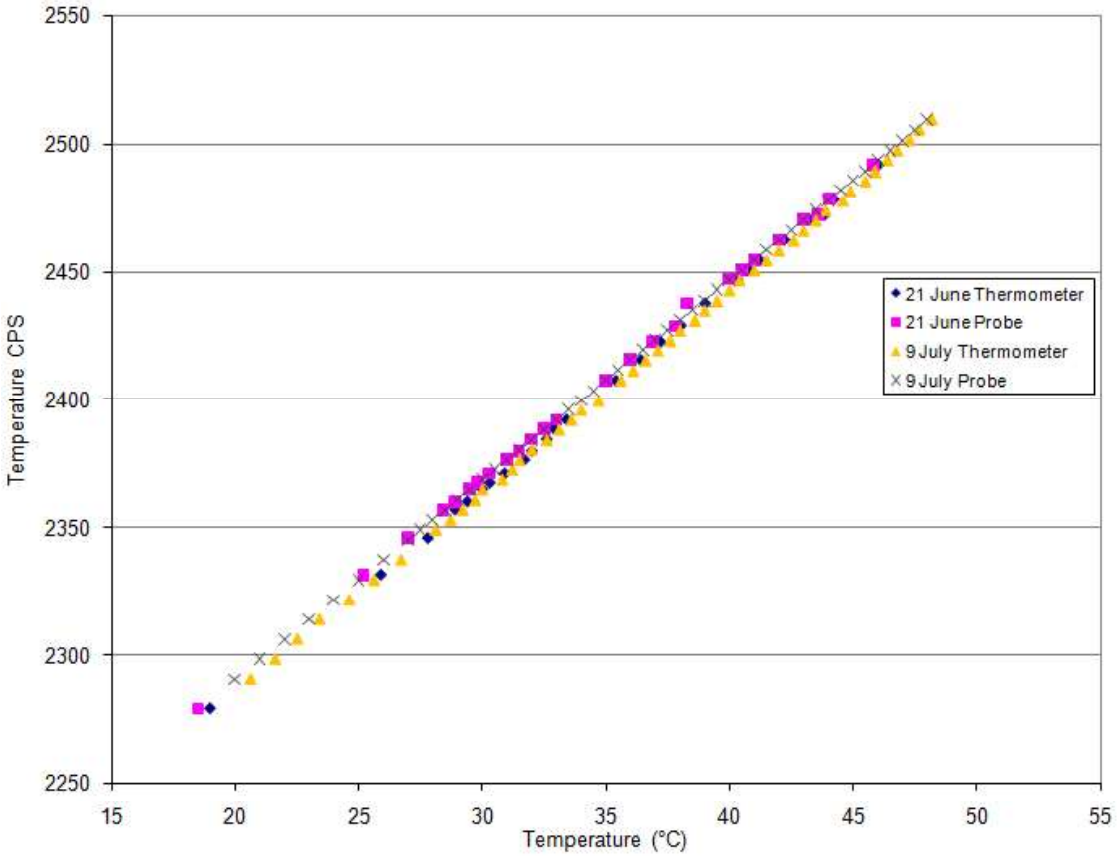


Figure 7: Comparison of thermometer and probe readings for 21st June and 9th July 2011 calibration experiments.

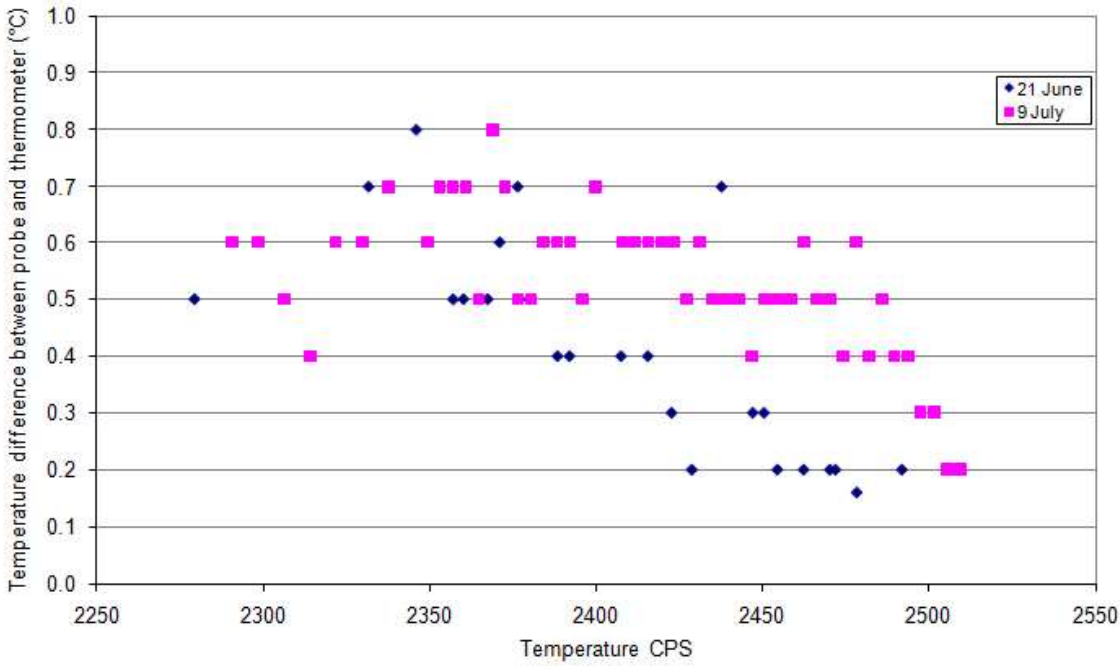


Figure 8: Temperature difference between the probe and the thermometer for the 21st June and 9th July 2011 calibration experiments. Both experiments show a decreasing temperature difference with increasing counts per second.

Table 7: Equations to convert probe counts per second (CPS) to temperature in °C from the calibration experiments.

Date	Calibration equation	R^2
21st June 2010	T (°C) = 0.1257 × CPS – 267.4	0.9996
9th July 2010	T (°C) = 0.1276 × CPS – 271.77	0.9998

3.2.5 Sources of Error

The logging procedure evolved as personnel became more experienced with the equipment. As different personnel were present at each well, top of casing measurements have an associated error that cannot easily be quantified. The same issue applies for the method used to align the collar of the probe to the top of the casing before logging began. Setting up the equipment in the incorrect order (for example, running the computer program before the logging equipment was connected to the laptop) resulted in having to reset the probe and start the log from the top of the well a second time. Another source of error includes stretching of the cable due to increased suspended weight, potentially resulting in inaccuracies in the depth measurements which are difficult to quantify. These fieldwork difficulties have been addressed by the publication of a fieldwork protocol for future work [Bloomfield, 2011].

Calibrating the temperature probe introduces an element of uncertainty of about 0.2 °C into the dataset as this is the smallest interval a human eye can accurately read on a thermometer. Time restrictions meant that on both occasions the calibration methodology was accelerated. This was achieved by stirring ice cubes into the water, potentially introducing errors.

3.3 Digitisation

A large number of AM wells were explored by the WA DoW during the early 1980's by logging temperature, sonic, flowmeter, resistance, gamma ray, induction, collar casing locator, and caliper logs. Digitising the thermal logs was undertaken in the hope of performing comparative analysis of the thermal profiles between the wells logged in the early 1980's and those logged in 2010. If these digitised wells are of sufficient quality, they will considerably extend the spatial scope of quality temperature data recorded in the PMA.

Scanned copies of 57 old thermal log records were imported into the Engauge™ software package. First, three known reference points on the depth versus temperature scale were identified on each log to act as references. Then temperature and depth values of points along the wells' thermal profiles were picked with the mouse and the software assigned values. The depth and temperature values for these points were exported into comma separated format for use in a spreadsheet program.

Quality control on the digitised logs indicated that the scanned logs were slightly distorted within the digital image and therefore additional calibration of the digitised lines was needed. The original logs contain hand-written temperature values at various depths along the recorded log. Usually, the values were precise to one tenth of a degree in Celsius and were recorded every 25 or 30 metre intervals in depth. These hand-written values were assumed accurate and were additionally added to the spreadsheet for each well. The digitised track was adjusted until it correlated with the hand-recorded values at the given depths. In between the adjustments, the temperature values at intermediate depths vary as indicated by the recorded data line.

The digitised data is unevenly spaced in depth, as the operator picked where the temperature profile changed. This uneven temperature and depth data were interpolated onto a regular grid

in depth at 0.5 m intervals. Further quality control found four wells (AM20, AM20A, AM39Z and AM45A) which were considered unreliable, due to unclear geolocation information, inadequate hand-written values, or recorded flaws in the well casing. The remaining 53 wells were formatted as a LAS file, with georeferencing included in the header. Given sufficient permissions from the DoW, these LAS files will be included in the WAGCoE data catalogue (http://www.geothermal.org.au/data) and are further used for analysis in sections 4.6 through 4.8.

The location of the wells where quality thermal data were digitised is shown as yellow squares in Figure 3. The digitization process is shown in Figure 9 where a portion of the raw data file is shown next to the original digitised log, the calibrated digitised log, and the final interpolated log.

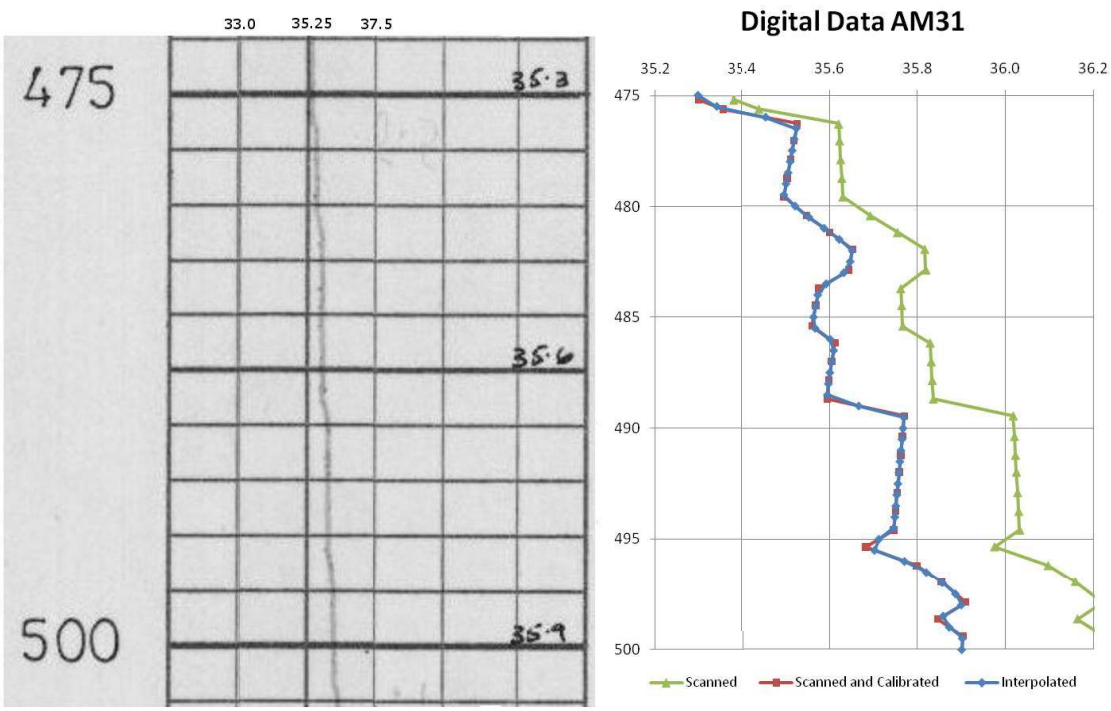


Figure 9: Comparison of historic scanned log with digitised data for Artesian Monitoring Well AM31. Depth in meters is the ordinate; temperature in degrees Celsius is the abscissa. On the right, the green line shows the original digitisation; the red line shows recalibration to handwritten temperature values; the blue line shows the final regularly spaced data which generates the LAS file.

4. DATA ANALYSIS

Raw data from the logging fieldwork required quality control before further analysis could be performed.

4.1 Quality Control of Temperature Data

A quality control analysis of the calibrated temperature data was performed in order to identify the values appropriate for inclusion in the data analysis. Both basal and surficial processes which might have affected data quality were investigated.

4.1.1 Basal Errors

The base of the temperature and gamma ray profiles was examined to determine at what depth the measurements became unreliable, assumed to be as a result of silting at the base of the well. The weight bearing load of the probe on the cable was investigated wherever recorded in the LAS files. Zones showing a change in the loading on the cable indicate the probe's progression through the wellhole has been perturbed, affecting the sampling rate of the probe. In order to maintain a consistent sampling rate throughout each well, data from the zones showing a significant change in cable loading were excluded.

In addition to the cable loading data, near-vertical gradients at the base of the temperature profiles were interpreted to be a result of silt hindering the probe's descent, thus suspending the probe at the same depth while the winch continued to unspool. The depth at which the profile becomes near-vertical is taken as the last reliable measurement and everything after this depth is discarded. Figure 11 illustrates a profile with the unreliable data disregarded.

For the digitised data, the data quality was generally not sufficient to distinguish between a change in gradient at the base of the log and simply the effect of digitising and re-stretching. As such, the bottom limit is taken as the depth of the log, except in a few cases with obvious bottom-hole errors. Table 8 indicates the depth to the deepest reliable reading for the logged wells.

Table 8: Depth to deepest reliable reading, compared to the well depth and the profile depth (m from ground level).

Well name	Well depth (m from GL)	Profile depth (m from GL)	Depth to deepest reliable value (m from GL)
AM20	467	371.89	368
AM31	800	726.00	720
AM32Y	404	375.11	364
AM33A	533	535.82	520
AM38A	550	541.60	523
AM40	741	689.00	675
AM40A	459	276.56	270
AM42	600	570.14	558
AM43A	794	758.24	751
AM45	409	239.40	219
AM46	801	616.17	607
AM48	618	429.70	422
AM49	554	535.72	532
AM50	354	343.15	340
AM51	421	393.77	389
AM52Y	435	390.91	382
AM55	401	371.85	361
UWA TP01	208	189.80	187

4.1.2 Influence of Water Table and Seasonal Variability

The initial top measurements were also investigated for reliability. Water table data were obtained from the Water Resources Information Catalogue (WRIC) [DoW, 2010] and the maximum depth to the water table estimated. This data spanned a period of at least 11 years for each location, with the most recent information collected during the same period as the thermal logging. All wells showed an increase in the depth to the water table over the period of data collection. Figure 10 illustrates this trend in AM42. The majority of wells exhibited a decrease

in the rate at which the water table is falling to a near constant level over the last 2 to 3 years. As such, the maximum depth to the water table was taken as the maximum depth recorded during the time span of data collection. This value was then increased by 5 m to eliminate the influence of the surface water which is in disequilibrium with the surrounding rocks. Data above this level was ignored in subsequent analyses.

Ground surface temperature fluctuations also have the capacity to affect the reliability of measurements at the top of the wellhole. The seasonal influence from the ground surface was calculated using the formula [Beardsmore & Cull, 2001]:

$$z = \sqrt{4\pi P\kappa} \tag{3}$$

where z is the depth to the seasonal influence (m), P is the period (s), and κ is the thermal diffusivity ($m^2\ s^{-1}$). For the annual seasonal cycle, P is 3.1557×10^7 seconds. κ was determined using the formula:

$$\kappa = \frac{k}{\rho\, c_p} \tag{4}$$

where k is the thermal conductivity ($W\ m^{-1}\ K^{-1}$), ρ is density ($kg\ m^{-3}$), and c_p is specific heat capacity ($J\ kg^{-1}\ K^{-1}$). k was assumed to be a constant of 1.42 $W\ m^{-1}\ K^{-1}$ [HDRPL, 2008] for the Superficial formation sediments. Thermal capacity (ρc_p) had to be calculated for each well as the proportion of saturated to non-saturated aquifer changes depending on location. This weighting was done using the formula:

$$(\rho c_p)_{aquifer} = (1-\phi)\cdot \rho_{solid}\cdot c_{p\ solid} + \left(\frac{z_{water}}{z_{base}}\right)\cdot\left(\phi\cdot\rho_{air}c_{p\,air}\right) + \left(1-\frac{z_{water}}{z_{base}}\right)\cdot\left(\phi\cdot\rho_{water}c_{p\,water}\right) \tag{5}$$

where z_{water} and z_{base} are the depths of the water table and the base of the superficial aquifer respectively (m from ground level), ϕ is the porosity of the superficial aquifer, ρ_{solid}, ρ_{air} and ρ_{water} are the densities of the superficial aquifer, air and water respectively ($kg\ m^{-3}$), and c_{solid}, c_{air} and c_{water} are the specific heat capacities of the superficial aquifer, air and water respectively ($J\ kg^{-1}\ K^{-1}$). The assumed constants are; $\phi = 0.2$ [Davidson, 1995]; $\rho_{solid} = 2650\ kg\ m^{-3}$; $\rho_{air} = 1.204\ kg\ m^{-3}$ [Waples & Waples, 2004]; $\rho_{water} = 1000\ kg\ m^{-3}$; $c_{P\,solid} = 1381\ J\ kg^{-1}\ K^{-1}$; $c_{P\,air} = 1005\ J\ kg^{-1}\ K^{-1}$; and $c_{P\,water} = 4208.18\ J\ kg^{-1}\ K^{-1}$ [Waples & Waples, 2004]. The calculated depths of seasonal influence calculated from equation 3 ranged between 12 m and 14 m for the logged wells. Because multiple simplifying assumptions were made in this analysis, the depth from surface to seasonal influence was slightly increased and taken as 15 meters. Table 9 summarises the final depth to reliable temperatures for each logged well.

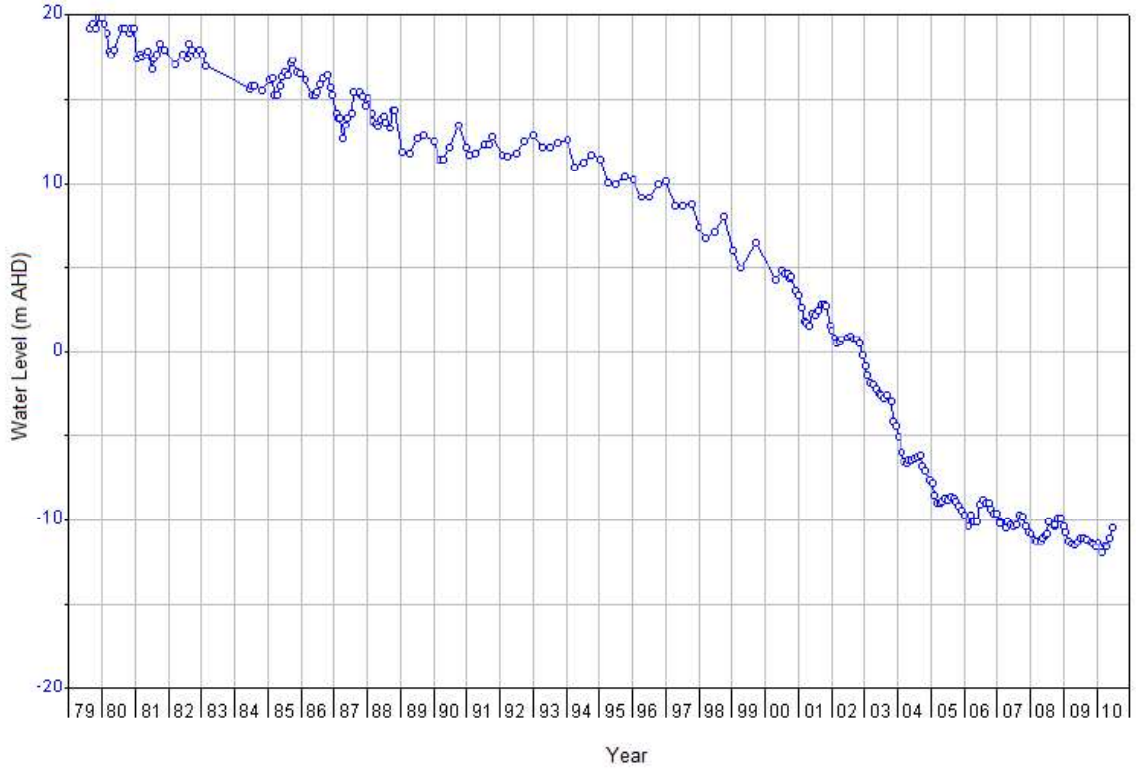


Figure 10: Seasonal water table variations in AM42 [DoW, 2010].

For the digitised wells, the depth of seasonal influence was also assumed to be 15 m. As with the wells logged by WAGCoE, water table data were collected from the DoW website and the depth of the water table influence at the time of logging was determined. As the digitised data required considerably more processing (see section 3.3), data were considered unreliable above the second hand-written control point (the values measured and recorded on the paper logs). In the event that the second control point was 15 m or less, the third control point was taken as 'reliable'. Consequently, the shallowest digitised value considered 'reliable' was 25 m, even if the depth to water table influence was shallower than that. For wells that were artesian at the time of logging, the water table analysis was disregarded and 'reliable' values taken from the second control point. Table 10 details the depths to reliable measurements for the digitised logs.

Table 9: Depths to seasonal and water table influences affecting data reliability (metres from ground level) for WAGCOE logged wells. The deepest value is taken as the depth to shallowest reliable data.

Well	Depth of water table influence at logging (m from GL)	Depth of water table influence from DoW (m from GL)	Depth of seasonal influence (m from GL)	Depth to reliable measurements (m from GL)
AM20	13.3	No data	15.0	15.0
AM31	12.0	10.6	15.0	15.0
AM32Y	48.4	61.0	15.0	61.0
AM33A	34.3	38.2	15.0	38.2
AM38A	24.1	25.2	15.0	25.2
AM40	39.2	40.7	15.0	40.7
AM40A	30.4	36.6	15.0	36.6
AM42	24.9	27.0	15.0	27.0
AM43A	43.8	44.8	15.0	44.8
AM45	18.0	48.2	15.0	48.2
AM46	42.8	43.3	15.0	43.3
AM48	17.7	19.0	15.0	19.0
AM49	50.8	51.5	15.0	51.5
AM50	28.3	28.6	15.0	28.6
AM51	15.0	16.2	15.0	16.2
AM52Y	9.0	9.0	15.0	15.0
AM55	14.8	15.4	15.0	15.4
UWA TP01	9.4	No data	15.0	15.0

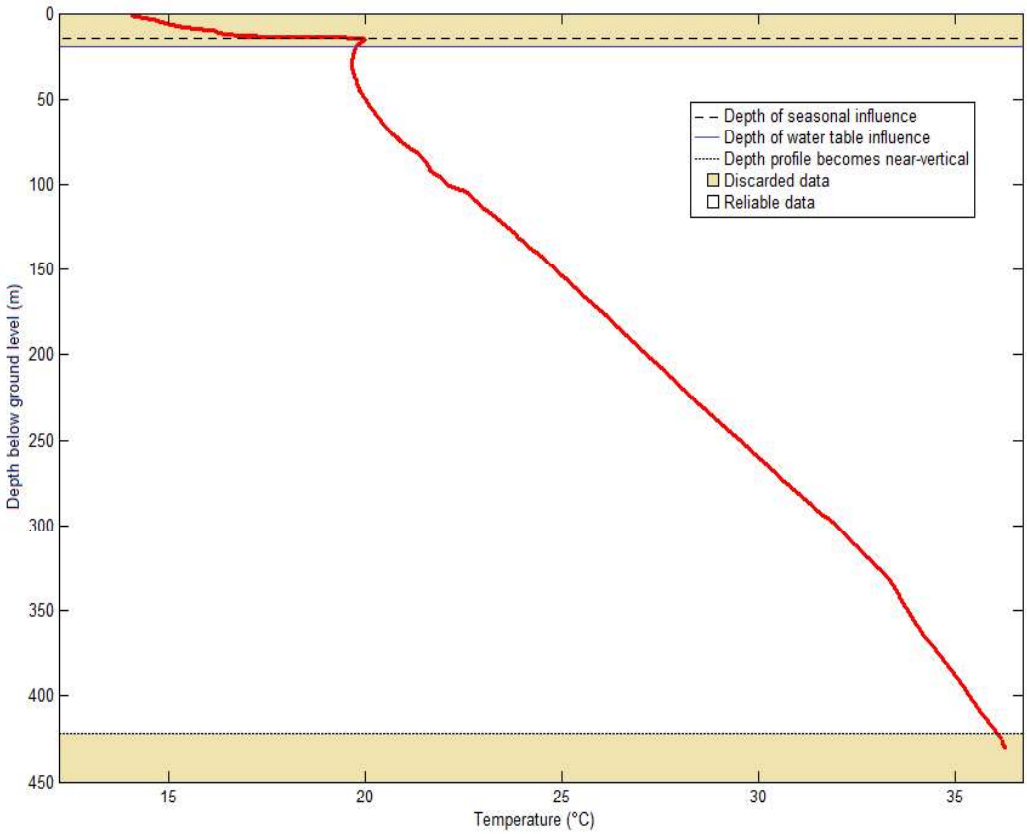


Figure 11: Temperature profile indicating the range of reliable values in the white non-shaded zone. Data between the depth of water table influence (blue line) and the depth at which the profile becomes near-vertical (lower dotted line) is considered reliable.

4.1.3 Distance to Saltwater Interface

Wells near the coast (AM20, AM32Y, AM33A, and AM52Y) and near the Swan River potentially contain sea water as well as groundwater, which may influence the temperature profile due to density differences. Davidson [1995] noted that the maximum inland extent of the saltwater-freshwater interface is about 1000 m from the coast and 500 m along the Swan Estuary. The most definitive way to determine the presence of saline water in a well is to acquire water chemistry data such as information on dissolved solid concentrations. This information was not available during this study, and all wells were assumed to contain only fresh water.

Table 10: Depths to reliable measurements for the digitised wells.

Well name	Depth of water table influence at logging (m from GL)	Depth of second control point on JPEG (m from GL)	Depth taken as reliable (m from GL)
AM2	16.65	15	30
AM3	10.66	30	30
AM4A	10.20	30	30
AM8	37.82	30	38
AM10	33.25	15	34
AM11	130.52	60	131
AM12	Artesian	25	25
AM13	No data	30	30
AM17	No data	21	36
AM22	51.98	15	52
AM23	No data	25	25
AM24	24.58	30	30
AM25	53.59	30	54
AM26B	12.40	30	30
AM27	19.06	16.5	32
AM28	48.13	30	48
AM29	31.44	30	32
AM30	31.68	15	32
AM30Z	34.37	15	35
AM31	Artesian	12.5	25
AM32	Artesian	12.5	25
AM33A	Artesian	25	25
AM34	38.03	15	38
AM35A	Artesian	25	25
AM36	Artesian	25	25
AM37	26.58	30	30
AM37A	No data	30	30
AM38A	No data	25	25
AM39	Artesian	50	50
AM40	12.68	68	68
AM41	13.81	25	25
AM42	Artesian	25	25
AM43	36.27	30	37
AM44	Artesian	25	25
AM48	No data	25	25

Well name	Depth of water table influence at logging (m from GL)	Depth of second control point on JPEG (m from GL)	Depth taken as reliable (m from GL)
AM49	29.49	25	30
AM50	10.07	25	25
AM51	10.19	58	58
AM52	Artesian	25	25
AM52Y	Artesian	25	25
AM52Z	Artesian	25	25
AM54	Artesian	12.5	25
AM55	Artesian	25	25
AM57	Artesian	25	25
AM58	Artesian	12.5	25
AM59	8.08	12.5	25
AM62	7.66	12.5	25
AM63	18.82	15	30
AM64	31.22	15	32
AM65	3.07	25	25
AM66	19.37	25	25
AM67	12.19	15	30
AM68	9.88	25	25

4.1.4 Comparison of Logged and Digitised Data

For eleven wells (AM20, AM31, AM33A, AM38A, AM40, AM42, AM48, AM50, AM51, AM52Y, AM55), data exist both from the modern temperature logging and the digitization of historical logs. The temperature profiles can be compared to see if there is a systematic difference between the two datasets. In general the data are quite similar over depth, although profiles near the top of the well are usually dissimilar due to water table and seasonal

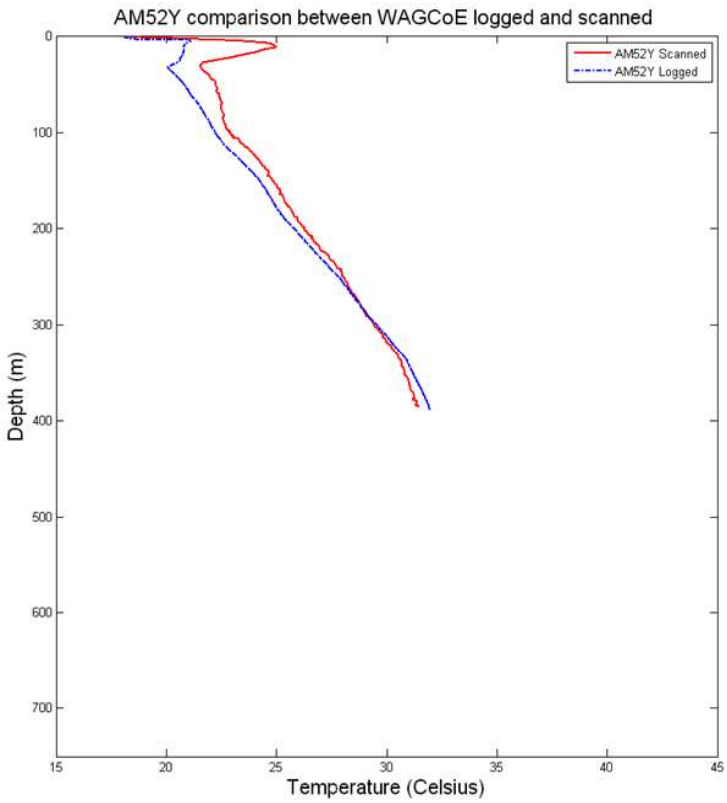


Figure 12: Comparison of logged and digitised data; AM52Y

variability. Figure 12 demonstrates a typical example showing the scanned (red line) and logged (blue line) temperature profiles. The scanned data are much rougher, due to the inaccuracy of tracing the old data recorded on film. Near the surface, the water table and shallow temperature profiles vary quite a bit. Further down the profiles are similar. Despite the considerable visual difference, this example yields temperature gradients which differ by 15 percent on average between the historical and modern data. In general, the historical data can be considered equivalent in general shape and extent to the modern logged data. For each well where both datasets exist, a comparison plot is shown in Appendix C.

4.2 Quality Control of Gamma Ray Data

The gamma ray readings of counts per second were converted to API units by the calibration contained in the probe. Due to the difficulty of obtaining radioactive calibration samples, Geoscience Australia [Gerner, 2011] indicated that they had not recalibrated the probe manually, and used the manufacturer's recommended transformation. Hence there is some uncertainty in the absolute magnitudes of the Gamma Ray log readings in API units.

In order to further confirm the values, the logs measured by WAGCOE were compared to two independent gamma ray datasets in local wells. One comparative dataset was provided by measurement using equipment provided by Curtin University, while the other was provided by Rockwater Pty Ltd. In both cases, the WAGCOE-derived data were cross-plotted against the reference dataset, and a scaling factor derived which would cause the smoothed average values of the logs to correspond. The results of this analysis were somewhat inconclusive, as the WAGCOE log compared to the independent logs was 20% smaller in one case, and 10% larger in the other. Hence, the WAGCOE values for gamma ray units were considered to be the best available, and are used in radiogenic heat production calculations in section 4.4.

Note that the absolute values of the gamma ray log are not necessary for the analysis in the following section, as the formation divisions rely on relative changes in the log shape.

4.3 Formation Divisions

The analysis in this report computes an average thermal gradient by formation. The temperature at the bottom of the formation is subtracted from that at the top of the formation; hence the vertical locations of these formation boundaries are an important factor in the overall results.

Davidson and Yu [1995] published formation boundaries for the AM wells in the PMA. Their picks were based on palynology, geophysical wireline logs, and lithology observed during drilling. Their formation boundaries were re-evaluated in this study based on the gamma ray logs. Gamma ray data are commonly used to differentiate between different lithologies. Gamma rays are produced when radioactive elements undergo radioactive decay. The most common source of radioactive decay in the crust is the decay of K, U and Th isotopes. Consequently, lithologies containing high proportions of one or more of these isotopes will produce larger amounts of gamma rays compared to the surrounding lithologies and will therefore appear as peaks on a gamma ray log. Shales commonly exhibit high radioactivity due to their higher densities and proportions of radioactive feldspars compared to sandstones with large proportions of quartz [Thomas, 2000]. Heterogeneous formations will often produce highly variable gamma ray logs due to the interbedded nature of the different lithologies. Dramatic changes in the gamma ray count are often associated with a corresponding change in lithology which is used to infer the location of formation boundaries.

Published data from Davidson [1995] was applied to each of the thermal and gamma ray profiles as an initial estimate of the location of the formation boundaries. However, in Davidson

there is no indication of where the reference ground level was measured from. This vagueness is problematic as several wells had large-diameter protective cases around them with an internal ground level different to that outside the casing, potentially resulting in errors of tens of centimetres. No geological information was available for wells AM26B, AM32Y, AM34, AM37, AM39, AM40A, AM43, and AM45A, and as such formation boundaries were inferred from AM26, AM32, AM34A, AM37A, AM39Z, AM40, AM43A, and AM45 respectively.

Once the formation boundary data from Davidson [1995] had been added to the temperature and gamma ray plots, the logged gamma ray was closely inspected to ascertain the validity of the boundary picks. The logs were filtered in order to reduce high-frequency noise and make low-frequency trends more obvious. The gamma ray plots were used to determine at what depth the changes in lithology, and thus formation (Figure 13), occurred in the temperature profile. Where there was a distinct change in lithology, a corresponding change in gradient was searched for. If there was no change in geothermal gradient, the formation boundary from Davidson [1995] was kept. Table 11 shows the corrected formation base depths, which represents a consistent set of formation boundaries across the WAGCOE logged AM wells.

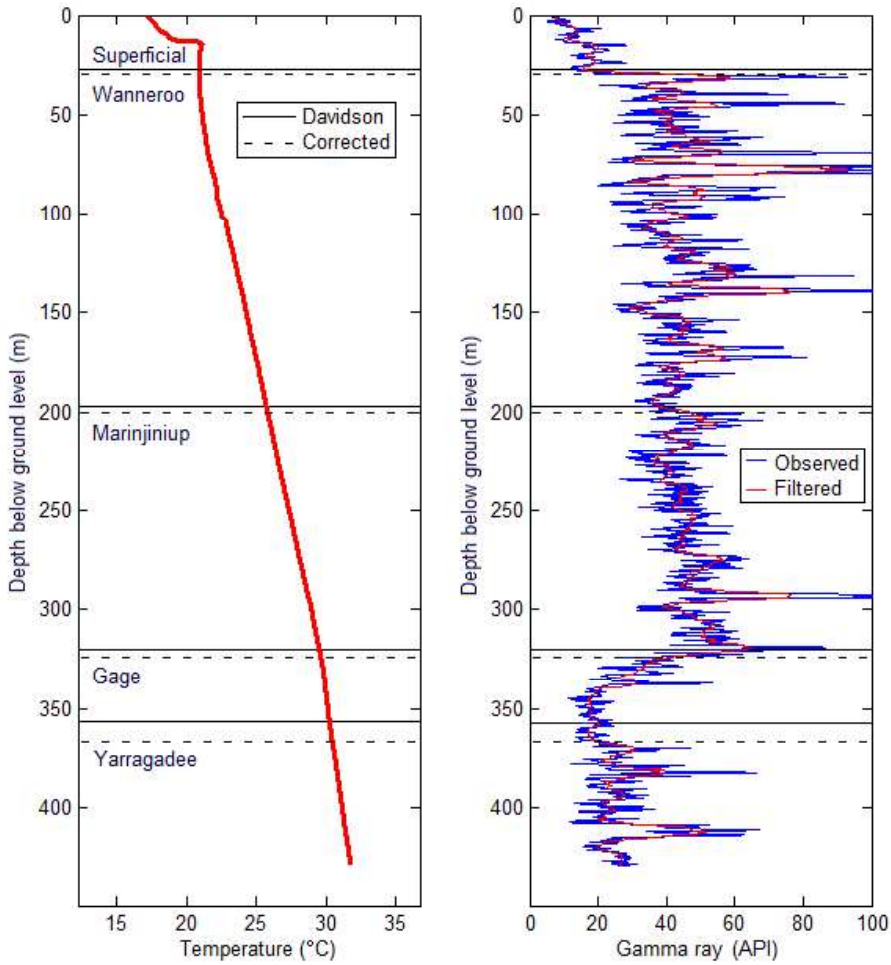


Figure 13: Temperature and gamma ray logs for AM48 showing the initial (solid line) and corrected (dashed line) formation boundaries. The filtering used for the gamma ray plot was a 20 point moving average. This log had a sample interval of 20 cm, resulting in gamma ray counts averaged over 4 m intervals.

Table 11: Corrected depths to the base of the formations for the WAGCOE-logged wells; based on the gamma ray logs

Well	Ground level (m AHD)	Base of formation below ground level (m)													
			Tk			Kco			Kwl						
		TQ	Tkm		Tkc	Kcom	Kcok	Kcoh	Kwlp	Kwlw	Kwlm	Kws	Kwg	Jy	Jc
AM20	29.32	53	-	-	-	-	-	-	70	194	269	313	-	-	-
AM31	5.59	15	-	-	-	-	91	97	102	331	408	443	-	-	-
AM32Y	13.00	57	-	176	228	-	-	-	-	-	-	294	363	-	-
AM33A	7.19	34	52	-	-	104	110	116	126	265	307	379	439	-	-
AM38A	11.22	18	-	-	-	-	31	65	137	336	381	421	541	-	-
AM40	22.68	33	183	326	383	-	-	-	-	493	515	614	689	-	-
AM40A	21.61	33	188	276	-	-	-	-	-	-	-	-	-	-	-
AM42	28.99	28	-	-	-	-	171	181	191	336	402	502	570	-	-
AM43A	28.76	48	-	-	-	-	183	-	275	369	506	558	647	-	-
AM45A	38.71	60	-	-	-	-	182	-	222	239	-	-	-	-	-
AM46	28.30	53	-	-	-	-	90	116	223	362	422	477	583	-	-
AM48	23.95	30	-	-	-	-	-	-	-	200	323	-	369	-	-
AM49	36.49	53	-	-	-	-	105	118	195	301	375	433	452	-	-
AM50	15.57	28	-	-	-	-	-	-	38	123	209	245	-	-	-
AM51	27.19	15	-	-	-	-	-	-	44	59	125	-	-	-	-
AM52Y	6.02	34	-	-	-	-	164	174	238	252	292	332	390	-	-
AM55	7.44	17	-	-	-	-	-	-	75	120	242	305	339	371	-

Notes:

TQ	Superficial formations	Tk	Kings Park Formation	Kco	Osborne Formation	Kwl	Leederville Formation
		Tkm	Mullaloo Sandstone Member	Kcom	Mirrabooka Member	Kwlp	Pinjar Member
		Tkc	Como Sandstone Member	Kcok	Kardinya Shale Member	Kwlw	Wanneroo Member
				Kcoh	Henley Sandstone Member	Kwlm	Mariginiup Member

Kws	South Perth Shale
Kwg	Gage Formation
Jy	Yarragadee Formation
Jc	Cattamarra Coal Measures

4.4 Radiogenic Heat Production

Approximately 98% of radiogenic heat in sediments is produced from the decay of K, U, and Th isotopes. The Gamma Ray logs provide an analogue for quantifying the value of this isotopic decay. Bücker and Rybach [1996] provide an equation to estimate the radiogenic heat production (RHP) from gamma ray values:

$$A = 0.0158\ (GR - 0.8) \tag{6}$$

where *A* is heat generation (μW m^{-3}) and *GR* is the broad spectrum gamma ray (API units). Using this equation, radiogenic heat generation for the bulk porous rocks was calculated for each well. For each well, formation boundaries as determined in Section 4.1.4 above, were assigned to the gamma ray logs. Within each formation, equation 6 was applied to estimate a point-wise value of heat generation. Over the formation depth, a geometric average was calculated at each well.

To obtain a formation/member-wide mean, the well results were weighted by formation interval to produce Table 12. Also shown are the standard deviation of radiogenic heat production values in each sampled formation, and the number of wells contributing to the calculated values. The mean values range from 0.19 to 0.85 μW m^{-3}, with the highest values occurring in shaly units such as the Pinjar and Mariginiup members of the Leederville Formation and the South Perth Shale Formation. Indeed, Davidson [1995] suggests that these Leederville members can be identified by their characteristically high gamma ray logs caused by micaceous and glauconitic marine siltstones and shales. The lowest mean values occur in the clean sandstones of the Superficial Formations, Como Sandstone, and Mirrabooka Members. The highest variability of radiogenic heat production occurs in the Gage Formation, where sandstones and siltstones may internally form thick beds [Davidson, 1995]. Although the sample size of 11 contributing wells in the Gage Formation is reasonable, the wells do not cover the entire formation depth and individual wells may only sample small subsets of the formation thickness.

Table 12: Radiogenic heat production by formation and member. Calculated from gamma ray logs observed in 17 AM wells in the PMA.

Formation [Member]	**Bulk Radiogenic Heat Production (μW m^{-3})**		**Number of wells in analysis**
	Mean	**Standard Deviation**	
Superficial	0.19	0.07	9
Kings Park [Mullaloo Sandstone]	0.19	0.05	3
Kings Park	0.32	0.02	2
Kings Park [Como Sandstone]	0.19	0.02	2
Osborne [Mirrabooka]	0.19	N/A	1
Osborne [Kardinya Shale]	0.57	0.14	9
Osborne [Henley Sandstone]	0.35	0.07	7
Leederville [Pinjar]	0.85	0.15	13
Leederville [Wanneroo]	0.58	0.09	14
Leederville [Mariginiup]	0.78	0.11	14
South Perth Shale	0.82	0.08	13
Gage	0.54	0.17	11
Yarragadee	0.45	0.08	10
Cattamarra Coal Measures	0.45	N/A	1

The results shown in Table 12 are values representing the bulk rock, including pore fluid (i.e. water or air). To estimate the RHP from the solid matrix alone, the values above should be divided by (1-φ), the fractional proportion of minerals. Because estimates of porosity φ are not

available at the wells, the bulk rates are presented here. As an example of the expected increase in matrix RHP values, assuming φ=0.2 in the Yarragadee Formation produces a mean radiogenic heat production rate of 0.56 μW m^{-3}.

The bulk values indicate radiogenic heat production rates in the Perth Basin sediments within the range of, but generally lower than other measured or estimated sedimentary mean values from deeper petroleum wells [Waples, 2002; Vilà, 2010].

Reasons for the low values of RHP in the shallow sediments may be due to relatively low concentrations of K, U, and Th, to lower compaction of the relatively shallow sediments in the AM wells, or to poor calibration of the gamma ray probe as discussed in section 4.1.4. Individual results for each well are shown in Appendix A.

The contribution of radiogenic heat production in the sediments to the total heat budget [Norden & Förster, 2006] can be calculated by summing the production rates per unit length times the depth interval of the formation. This analysis indicates that radiogenic heat production in the shallow sediments of the Perth Basin is an insignificant contributor to the total heat flow. For example, this summation in AM43A (total depth 794 m) yields a heat flow generated by shallow radiogenic heat generation of 0.46 mW m^{-2}, whereas the worldwide average of continental heat flow of 59 mW m^{-2} [Tester, 2006]. Hence the contribution of the shallow sediments to heat flow in the PMA is on the order of one percent.

4.5 Non-Conductive Thermal Profiles

As described in section 2.4, heat may move in the subsurface through conductive, advective, or convective mechanisms. It is often difficult to determine the heat flow regime purely by inspecting thermal profiles in depth. Groundwater confined in aquifers may have very slow horizontal water movement, resulting in a temperature field dominated by vertical conductive heat transfer thus creating an overall linear profile for the thermal gradient. Heat flow variations due to more significant groundwater flow are described in articles such as Ge [1998] and Anderson [2005]. Water flow perturbs the straight-line conductive thermal profile through infiltration of cooler water in groundwater recharge zones and upward flow of warmer water in discharge zones. Fluid convection and basement topography effects, as well as surface temperature anomalies, are other sources of heat flow variability affecting underground steady-state temperatures. It is important to determine if the thermal profiles logged as part of this study were affected by non-conductive processes.

The first step in the thermal profile analysis was to assume that vertical conduction as defined in Equation (1) is the only form of heat transport in the well [Pons, 2010]. A linear thermal gradient $\partial T/\partial z$ was calculated for each formation in each well by subtracting the temperature at the top and bottom of each formation interval and dividing by interval thickness. A one-dimensional model of the temperature profile was generated along the depth of the well. The modelling process is shown in Figure 14, where the blue line indicates the straight-line segments generated by the one-dimensional model.

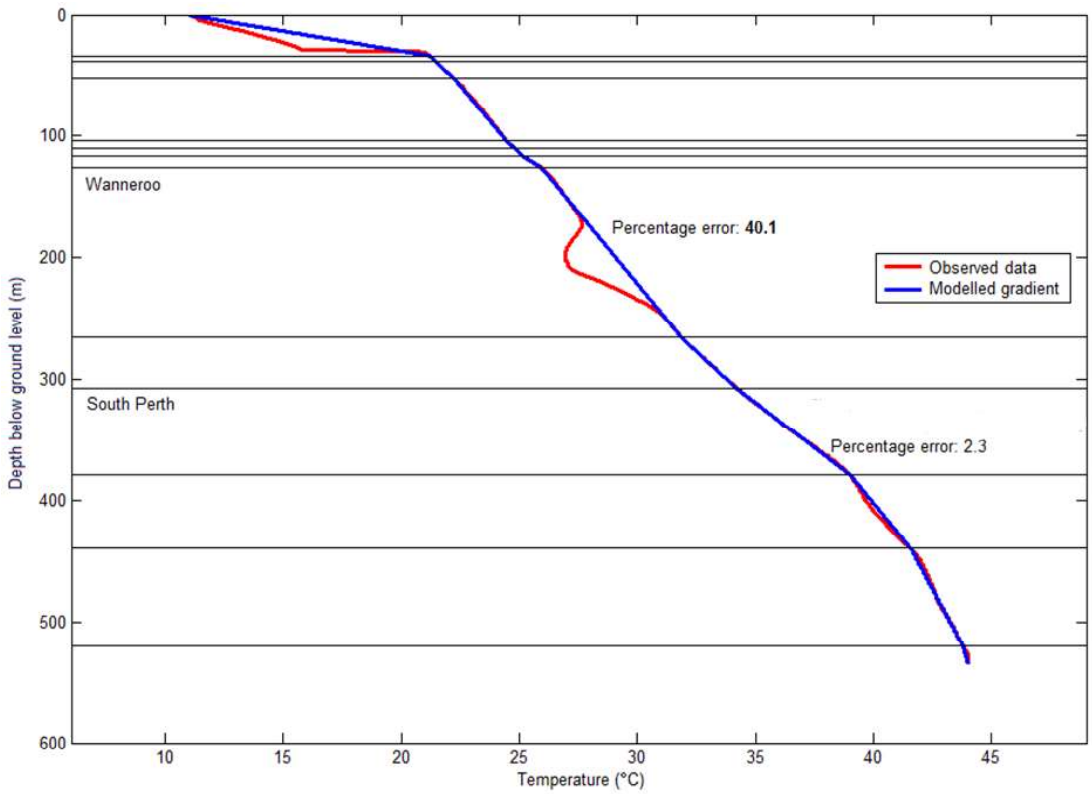


Figure 14: Temperature profile in AM33A showing non-conductive behaviour in the Wanneroo Formation

The relative error between this modelled temperature and the observed was calculated using the equation for quadratic error:

$$e = \frac{\sqrt{\Sigma_i \left(\left| T_{O(i)} - T_{M(i)} \right|^2 \right)}}{\Delta z} \tag{10}$$

where e is error per unit depth (°C m^{-1}), T_O is the observed temperature (°C), T_M is the modelled temperature (°C), and Δz is formation thickness (m). Errors between the modelled and observed gradients may be caused by many factors including seasonal fluctuations in the water table, changes in thermal conductivity within a formation, or advective or convective heat transport. Errors greater than 5% were deemed indicative of non-conductive heat flow areas. Figure 14 shows an example of misfit between the modelled (vertically conductive) and observed temperature profiles. In this example, the temperature in the Wanneroo Formation shows non-conductive behaviour with a relative error of 40%, while the relative error of 2.3% in the South Perth Shale is assumed to arise from minor thermal conductivity variation.

Consolidating the data from the conduction analysis into Table 13, each formation has either been deemed as exhibiting advection/convection or not, according to the presence of relative error values greater than 5%. This table indicates the extent of non-conductive thermal behaviour in the PMA. Hereafter we refer to any non-conductive heat flow as advection, acknowledging that convection (i.e. flow driven by buoyancy) could also play a role.

Evidence of advection was most commonly found in the major aquifers, although it was also associated with fluctuating water tables in the shallowest confining beds. Advection may be caused by regional groundwater flow or by local influences such as neighbouring pumping wells.

Locations where heat flow is non-conductive have been noted in the study area by hydrogeologic aquifer. Appendix F provides individual maps for the Yarragadee, Leederville, Mirrabooka, and Superficial aquifers, as well as the South Perth and Kardinya Shale aquitards. Figure 15 shows a typical map for the Yarragadee aquifer. Here, non-conductive heat flow is likely caused by proximity to major pumping influences such as the Water Corporations' water supply wells for Perth. The extent of the non-conductive flow shows that advection can be a significant source of subsurface heat movement and should be considered in any geothermal study in permeable formations.

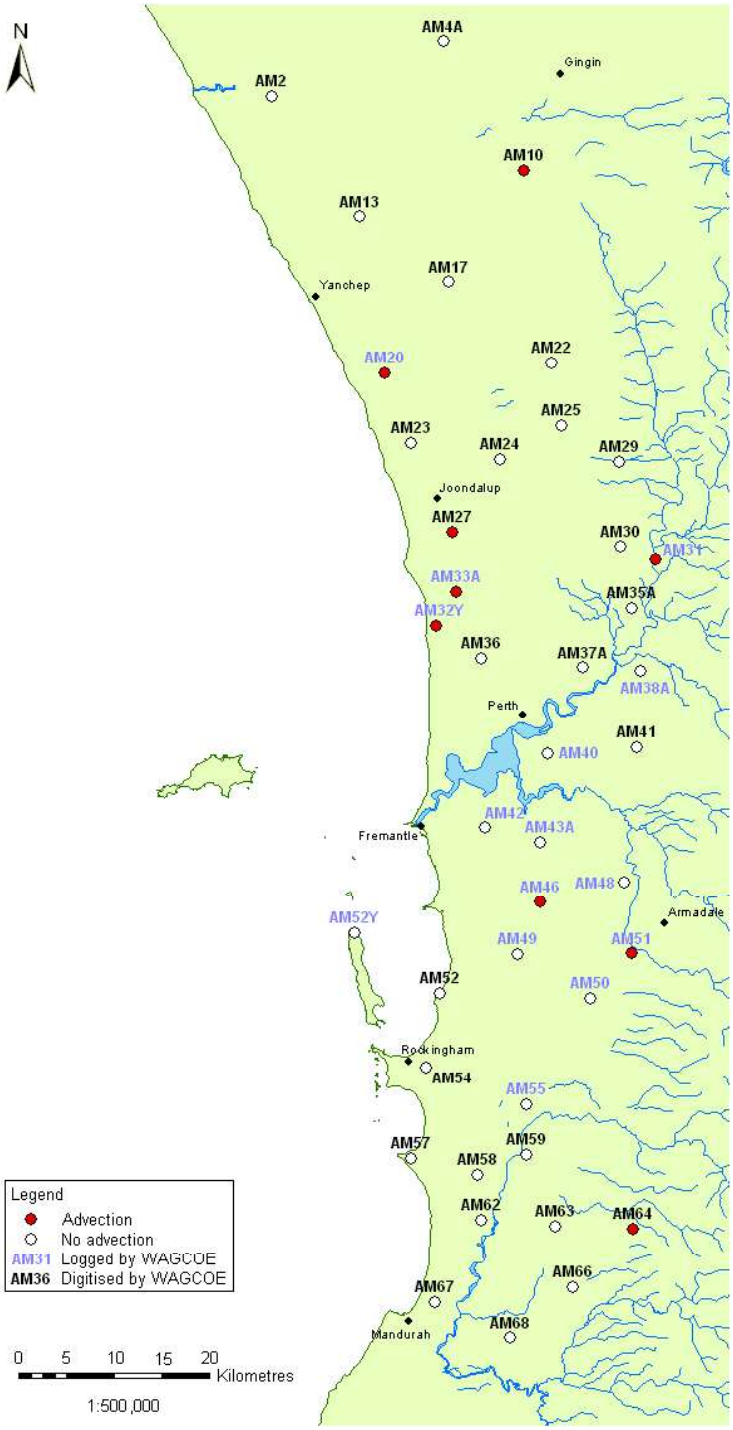


Figure 15: Locations where non-conductive heat flow was observed in the Yarragadee aquifer. See Appendix F for more details.

Table 13: Occurrence of non-conductive heat flow (advection) by formation in each well.

Well	Advection (yes) or conduction (no) by well and formation																			
			Tk							Kco			Kwl							
	TQ	Tr	Tkm		Tkc	Kcl	Kcp	Kcg	Kcm	Kcom	Kcok	Kcoh	Kwlp	Kwlw	Kwlm	Kws	Kwg	Kp	Jy	Jc
Digitised by WAGCoE																				
AM2	yes	-	-	-	-	no	-	no	no	-	no	-	no	**yes**	no	no	no	-	-	-
AM3	no	-	-	-	-	no	-	no	no	-	no	-	no	no	-	-	-	-	-	-
AM4A	no	-	-	-	-	-	-	-	-	-	-	-	no	**yes**	no	no	no	-	no	-
AM8	no	-	-	no	-	no	-	no	-	-	no	-	no	no	-	-	-	-	-	-
AM10	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	-	-	**yes**	-	-
AM11	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	-	-	-	-
AM12	no	-	-	no	-	no	-	no	no	-	no	-	no	no	-	-	-	-	-	-
AM13	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	-	-	-	no	-
AM17	no	-	-	-	-	-	-	-	-	-	-	-	-	no	no	-	-	-	no	-
AM22	no	-	-	-	-	-	-	-	-	-	-	-	no	**yes**	-	-	-	no	-	-
AM23	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	no	-	no	-
AM24	no	-	-	-	-	-	no	no	no	-	no	no	no	no	no	no	no	-	-	-
AM25	no	-	-	-	-	-	no	no	no	-	no	-	no	no	no	no	no	no	-	-
AM26B	-	-	-	-	-	-	no	no	no	-	no	no	-	no	-	-	-	-	-	-
AM27	no	-	-	-	-	-	-	-	no	-	-	no	no	no	no	no	no	-	**yes**	-
AM28	no	-	-	-	-	-	no	no	no	-	no	no	no	no	-	-	-	-	-	-
AM29	no	-	-	-	-	-	no	no	no	-	no	no	no	no	no	no	-	-	no	-
AM30	no	-	-	-	-	-	no	no	no	-	no	no	no	no	no	no	-	-	no	-
AM30Z	-	-	-	-	-	-	-	-	-	yes	no	no	no	no	-	-	-	-	-	-
AM31	-	-	-	-	-	-	-	-	-	-	no	no	no	no	no	no	-	-	no	-
AM32	no	-	-	no	**yes**	-	-	-	-	-	-	-	-	-	-	no	no	-	no	-
AM33A	**yes**	-	**yes**	-	-	-	-	-	-	no	no	no	no	no	no	no	no	-	no	-
AM34	no	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	-	-	-	-
AM35A	-	-	-	-	-	-	-	-	-	no	no	yes	no	no	no	no	-	-	no	-
AM36	no	-	-	-	-	-	-	-	no	-	no	no	no	no	no	no	no	-	no	-
AM37	-	-	-	-	-	-	-	-	-	no	**yes**	no	no	no	-	-	-	-	-	-
AM37A	-	-	-	-	-	-	-	-	-	no	**yes**	no	no	no	**yes**	no	no	-	no	-

Table 13, continued

Well	Advection (yes) or conduction (no) by well and formation																			
			Tk							Kco			Kwl							
	TQ	Tr	Tkm		Tkc	Kcl	Kcp	Kcg	Kcm	Kcom	Kcok	Kcoh	Kwlp	Kwlw	Kwlm	Kws	Kwg	Kp	Jy	Jc
AM38A	-	-	-	-	-	-	-	-	-	-	no	no	**yes**	**yes**	no	no	no	-	-	-
AM39	-	-	no	no	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AM40	-	-	no	no	no	-	-	-	-	-	-	-	-	no	no	no	no	-	-	-
AM41	-	-	-	no	-	-	-	-	-	-	no	**yes**	-	no	no	no	no	-	no	-
AM42	no	-	-	-	-	-	-	-	-	-	**yes**	no	no	no	no	no	no	-	-	-
AM43	no	-	-	-	-	-	-	-	-	-	no	-	no	no	-	-	-	-	-	-
AM44	-	-	-	-	-	-	-	-	-	-	no	no	no	no	no	-	-	-	-	-
AM48	no	-	-	-	-	-	-	-	-	-	-	-	-	no	no	-	no	-	no	-
AM49	no	-	-	-	-	-	-	-	-	-	yes	no	no	no	no	no	**yes**	-	no	-
AM50	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	no	-
AM51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	no	-	-	-	-	no
AM52	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	no	-	-	-
AM52Y	yes	-	-	-	-	-	-	-	-	-	no	no	no	no	no	no	no	-	-	-
AM52Z	**yes**	no	-	no	-	-	-	-	-	-	no	no	-	-	no	no	-	-	-	no
AM54	no	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	no
AM55	-	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	no	-	no	-
AM57	no	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	no
AM58	-	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	no
AM59	-	-	-	-	-	-	-	-	-	-	-	-	**yes**	no	no	no	no	-	no	-
AM62	-	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	no
AM63	-	-	-	-	-	-	-	-	-	-	-	-	-	no	no	no	-	-	no	-
AM64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**yes**
AM65	-	no	-	-	-	-	-	-	-	-	-	-	-	no	no	-	-	-	-	-
AM66	-	-	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	no	-
AM67	-	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	-	-	-	no
AM68	-	no	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	-

Table 13, continued.

Well	Advection (yes) or conduction (no) by well and formation																			
			Tk							Kco			Kwl							
	TQ	Tr	Tkm		Tkc	Kcl	Kcp	Kcg	Kcm	Kcom	Kcok	Kcoh	Kwlp	Kwlw	Kwlm	Kws	Kwg	Kp	Jy	Jc
Logged by WAGCoE																				
AM20	**yes**	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	**yes**	-
AM31	-	-	-	-	-	-	-	-	-	-	yes	no	no	no	no	no	-	-	**yes**	-
AM32Y	-	-	-	no	no	-	-	-	-	-	-	-	-	-	-	no	no	-	-	-
AM33A	-	-	no	-	-	-	-	-	-	no	no	no	no	yes	no	no	**yes**	-	no	-
AM38A	-	-	-	-	-	-	-	-	-	-	no	**yes**	**yes**	**yes**	no	no	no	-	-	-
AM40	-	-	no	no	no	-	-	-	-	-	-	-	-	no	no	no	no	-	-	-
AM40A	-	-	**yes**	no	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AM42	no	-	-	-	-	-	-	-	-	-	yes	no	no	no	no	no	no	-	-	-
AM43A	no	-	-	-	-	-	-	-	-	-	yes	-	no	no	no	no	no	-	no	-
AM45	no	-	-	-	-	-	-	-	-	-	no	-	no	-	-	-		-	-	-
AM46	no	-	-	-	-	-	-	-	-	-	no	no	no	no	no	**yes**	**yes**	-	no	-
AM48	no	-	-	-	-	-	-	-	-	-	-	-	-	no	no	-	no	-	no	-
AM49	**yes**	-	-	-	-	-	-	-	-	-	**yes**	no	**yes**	**yes**	no	**yes**	no	-	no	-
AM50	-	-	-	-	-	-	-	-	-	-	-	-	no	no	no	no	-	-	no	-
AM51	-	-	-	-	-	-	-	-	-	-	-	-	no	no	no	-	-	-	-	**yes**
AM52Y	**yes**	-	-	-	-	-	-	-	-	-	no	no	no	no	no	no	no	-	-	-
AM55	no	-	-	-	-	-	-	-	-	-	-	-	**yes**	no	yes	no	no	-	no	-

Notes: TQ Superficial Formations

Tk	Kings Park Formation	Kco	Osborne Formation	Kwl	Leederville Formation	Kws	South Perth Shale
Tkm	Mullaloo Sandstone Member	Kcom	Mirrabooka Member	Kwlp	Pinjar Member	Kwg	Gage Formation
Tkc	Como Sandstone Member	Kcok	Kardinya Shale Member	Kwlw	Wanneroo Member	Jy	Yarragadee Formation
		Kcoh	Henley Sandstone Member	Kwlm	Mariginiup Member	Jc	Cattamarra Coal Measures

4.6 Temperatures at Depth

The primary purpose of geothermal exploration is to predict temperatures at depth. With that aim, the quality-controlled temperature logs at 54 wells were loaded into a three-dimensional geologic data analysis and modelling package. The temperature data were upscaled to 10 metre resolution in depth and interpolated using a 15 km horizontal radius of influence. Results are shown in Figure 16, 17, and 18 below. The first two depict temperature estimates at a horizontal slice 250 and 500 meters below AHD. Figure 18 projects the temperature data onto the top of the Neocomian Unconformity. This erosional surface represents the top of the Jurassic Yarragadee formation in the central PMA, the top of the Cretaceous/Jurassic Parmelia in the north, and the top of the Cattamarra Coal Measures in the southern PMA, where the Yarragadee has been eroded. Because the Yarragadee and Parmelia Formations are part of the Yarragadee Aquifer, Figure 18 indicates temperatures at the top of a major water-bearing permeable aquifer.

For all figures 16 to 18, areas in white indicate where there is inadequate data (either in depth or horizontally) to generate an interpolated estimate. Interpolations used an inverse distance algorithm with a horizontal search radius of 15 km and 10m vertically. The coastline is shown in burgundy. Wells which utilized temperature data logged by WAGCOE in 2010 are shown in red; wells with scanned and digitised data are shown in black.

4.7 Geothermal Gradient

The average geothermal gradient was estimated by formation in each well. The gradient calculation was performed using the GeoTemp package [Ricard et al., 2011]. As discussed in section 4.5, heat flow that is controlled only by conduction will have good agreement between the straight-line gradient and the detailed temperature log. Locations that were identified in Table 13 as being affected by advection have been omitted from this analysis.

Table 14 lists average gradients by formation, the standard deviation of measurements, and the number of wells included in each formation. The fraction of wells used is listed as an indication of data reliability; some data were excluded as non-conductive while others were omitted due to quality control issues.

A full dataset is shown in Table 15, where the geothermal gradient in each well and each formation is tabulated. Individual results are listed by well in Appendix A. The analysis by formation is shown in Appendix B, including a histogram of gradients for each formation.

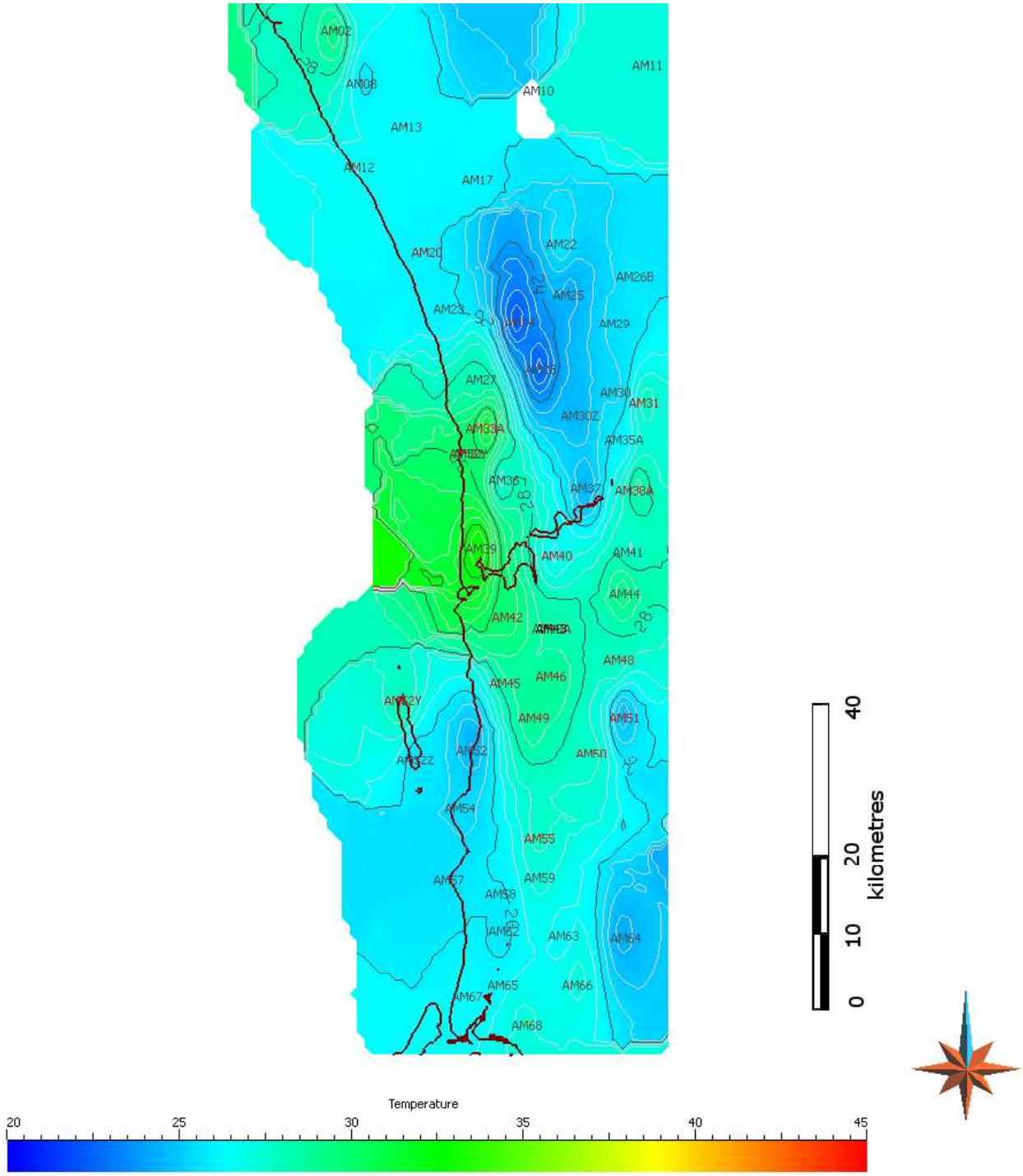


Figure 16:Temperatures (°C) at 250 m below AHD shown with colour bar and contours. Wells used in the analysis are indicated with their names: red are WAGCOE logged wells, black are digitised.

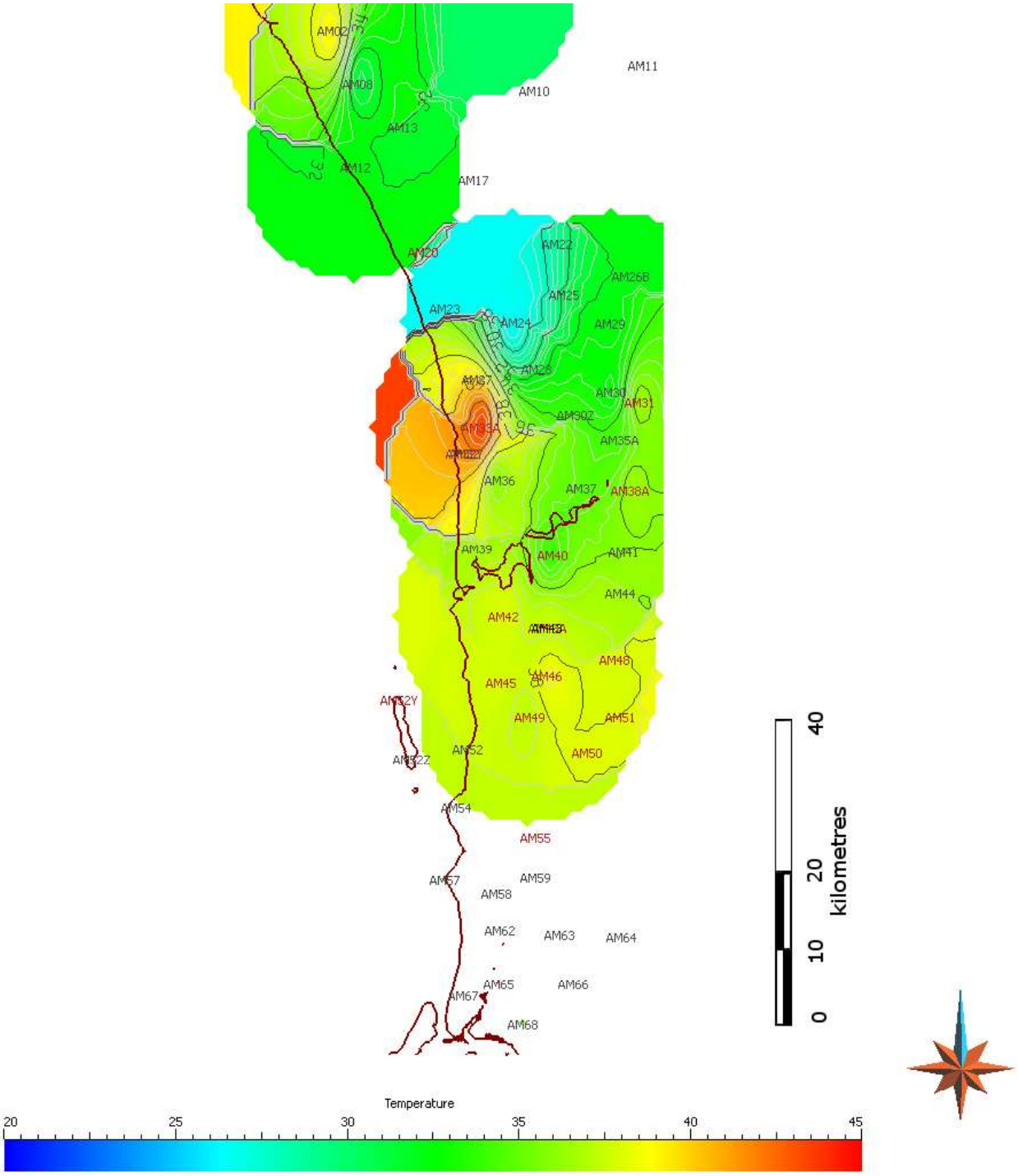


Figure 17 Temperatures (°C) at 500 m below AHD shown with colour bar and contours. Wells used in the analysis are indicated: red are WAGCOE logged wells, black are digitised.

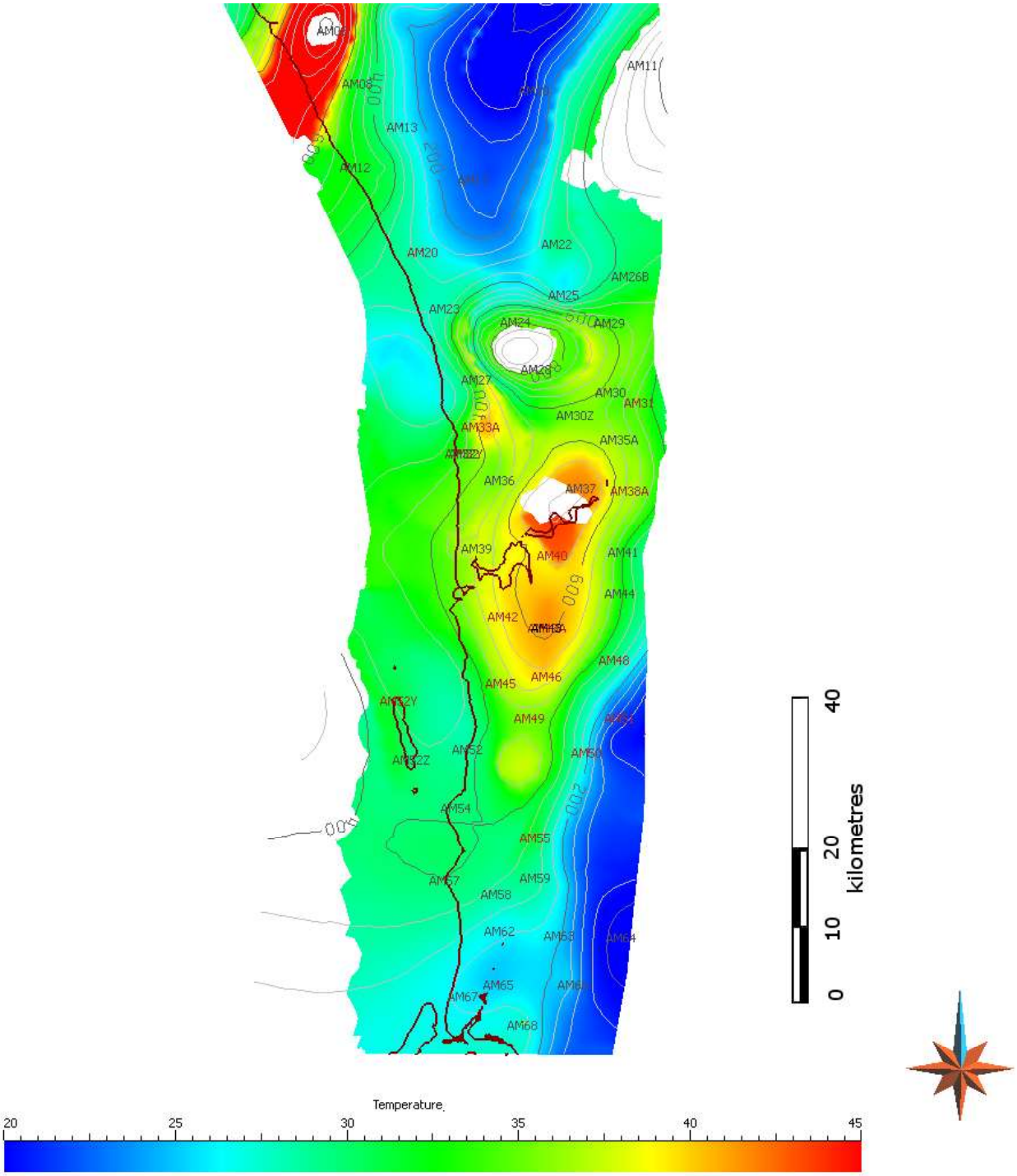


Figure 18: Temperatures (°C) at the top of the Neocomian Unconformity. Contours indicate depths (m) of unconformity below AHD.

Table 14: Average geothermal gradient for each formation.

Formation	Arithmetic mean (°C km^{-1})	Geometric mean (°C km^{-1})	Median (°C km^{-1})	Standard deviation (°C km^{-1})	Fraction of wells used
Superficial	13.5	11.4	12.3	6.9	19/40
Rockingham	16.6	15.5	15.9	5.6	7/8
Kings Park	30.7	27.4	31.5	13.2	10/10
Mullaloo	27.1	23.3	18.9	16.8	4/6
Como	28.7	28.4	28.2	3.7	3/4
Lancelin	25.5	24.7	28.7	6.0	3/4
Poison Hill	16.3	16.0	16.6	2.6	6/6
Gingin	21.0	16.8	20.2	12.1	7/10
Molecap	21.7	20.8	21.1	7.0	8/11
Mirrabooka	27.5	24.5	20.1	13.1	5/6
Kardinya	31.4	29.8	30.5	9.7	22/36
Henley	23.9	22.7	21.9	7.7	18/29
Pinjar	27.3	25.2	28.1	8.9	32/47
Wanneroo	26.2	25.1	27.0	6.9	55/62
Mariginiup	31.8	30.8	31.5	7.9	51/53
South Perth	39.1	38.3	37.7	8.4	42/46
Gage	25.6	25.0	25.8	5.7	34/37
Parmelia	38.6	36.1	38.6	13.6	2/3
Yarragadee	25.5	25.1	24.7	4.7	26/31
Cattamarra	24.0	23.8	22.8	3.2	6/9

The average gradients range from a low of 13 °C km^{-1} in the Superficial formations to 39 °C km^{-1} in the South Perth Shale. In general, the gradients follow lithological characterisation, with sandstone formations like the Wanneroo and Yarragadee Formations exhibiting gradients of approximately 25 °C km^{-1}, while silt/shale formations like the Mariginiup and Kardinya shale show higher gradients of over 30 °C km^{-1}. These gradients are inversely correlated with the expected thermal conductivities of the rock types; the silts/shales provide good thermal insulation.

The wide spread in the calculated average geothermal gradients implies that the inherent assumptions of Equation (1) and the constant heat flow are violated. One obvious violation could be caused by thermal conductivity that is not spatially homogenous. Alternatively, the temperature profiles do not follow straight-line segments by formation and instead are affected by advection or convection.

4.8 Preliminary Heat Flow

As discussed in section 5.4, the vertical heat flow is a product of the geothermal gradient and the thermal conductivity. Although this study has extensively determined the conductive geothermal gradient in the PMA, thermal conductivity estimates from HDRPL [2008] are less certain in this area. Heat flow values presented here must therefore be considered as preliminary estimates.

Table 15: Geothermal gradients in °C km^{-1} for each well and formation.

Well	Thermal gradients by well and formation (°C km^{-1})																			
			Tk							Kco			Kwl							
	TQ	Tr	Tkm		Tkc	Kcl	Kcp	Kcg	Kcm	Kcom	Kcok	Kcoh	Kwlp	Kwlw	Kwlm	Kws	Kwg	Kp	Jy	Jc
Digitised by WAGCoE																				
AM2	-19.7	-	-	-	-	30.7	-	43.0	84.3	-	43.8	-	40.4	37.7	44.1	51.3	25.2	-	-	-
AM3	20.7	-	-	-	-	4.5	-	17.1	21.3	-	32.3	-	93.0	21.8	-	-	-	-	-	-
AM4A	24.3	-	-	-	-	-	-	-	-	-	-	-	20.0	24.6	23.1	1.6	22.6	-	19.9	-
AM8	4.8	-	-	24.6	-	17.1	-	26.6	-	-	31.3	-	29.9	16.8	-	-	-	-	-	-
AM10	13.0	-	-	-	-	-	-	-	-	-	-	-	19.2	13.9	19.1	-	-	21.1	-	-
AM11	-	-	-	-	-	-	-	-	-	-	20.1	14.9	27.2	24.5	-	-	-	-	-	-
AM12	16.8	-	-	26.3	-	28.7	-	27.7	44.9	-	29.2	-	19.2	20.5	-	-	-	-	-	-
AM13	12.3	-	-	-	-	-	-	-	-	-	-	-	20.5	28.2	27.7	-	-	-	24.1	-
AM17	10.4	-	-	-	-	-	-	-	-	-	-	-	-	17.5	29.2	-	-	-	19.4	-
AM22	11.2	-	-	-	-	-	-	-	-	-	-	-	20.3	34.8	-	-	-	52.2	-	-
AM23	-4.4	-	-	-	-	-	-	-	-	-	-	-	23.6	25.6	25.7	34.0	29.6	-	20.3	-
AM24	16.6	-	-	-	-	-	18.8	8.4	14.9	-	13.1	15.2	14.4	14.0	17.5	29.5	12.8	-	-	-
AM25	11.8	-	-	-	-	-	18.5	24.0	21.8	-	26.2	-	18.4	24.6	26.7	30.0	26.7	24.9	-	-
AM26B	-	-	-	-	-	-	16.1	22.0	21.0	-	24.1	26.4	-	29.3	-	-	-	-	-	-
AM27	18.5	-	-	-	-	-	-	-	38.0	-	-	29.6	34.0	29.0	36.2	39.3	20.9	-	31.4	-
AM28	3.9	-	-	-	-	-	11.0	4.1	19.3	-	14.8	5.2	22.9	15.9	-	-	-	-	-	-
AM29	8.4	-	-	-	-	-	16.1	20.2	13.5	-	31.1	20.9	29.7	26.7	23.4	21.8	-	-	28.3	-
AM30	11.4	-	-	-	-	-	17.2	28.4	23.9	-	37.6	21.2	30.6	27.7	28.8	35.1	-	-	28.1	-
AM30Z	-	-	-	-	-	-	-	-	-	12.4	31.4	-1.8	29.8	24.0	-	-	-	-	-	-
AM31	-	-	-	-	-	-	-	-	-	-	28.0	48.3	37.8	30.6	37.6	36.8	-	-	27.0	-
AM32	20.5	-	-	46.0	24.0	-	-	-	-	-	-	-	-	-	-	47.5	25.3	-	37.7	-
AM33A	289.7	-	135.3	-	-	-	-	-	-	43.9	42.7	59.5	136.4	35.0	55.4	61.2	34.9	-	33.0	-
AM34	7.6	-	-	-	-	-	-	-	-	-	23.9	19.7	27.1	24.5	-	-	-	-	-	-
AM35A	-	-	-	-	-	-	-	-	-	20.1	29.8	32.3	30.9	30.8	35.9	43.9	-	-	22.5	-
AM36	7.2	-	-	-	-	-	-	-	-2.3	-	55.1	18.7	9.1	27.6	39.0	45.3	28.9	-	22.0	-
AM37	-	-	-	-	-	-	-	-	-	16.4	35.1	17.8	26.3	30.2	-	-	-	-	-	-
AM37A	-	-	-	-	-	-	-	-	-	14.4	30.0	12.2	28.5	24.7	29.7	38.0	33.2	-	29.8	-

Table 15, continued.

Well	Thermal gradients by formation and well (°C km^{-1})																			
			Tk							Kco			Kwl							
	TQ	Tr	Tkm		Tkc	Kcl	Kcp	Kcg	Kcm	Kcom	Kcok	Kcoh	Kwlp	Kwlw	Kwlm	Kws	Kwg	Kp	Jy	Jc
AM38A	-	-	-	-	-	-	-	-	-	-	-8.2	43.2	48.0	21.7	30.7	35.0	26.2	-	-	-
AM39	-	-	14.6	11.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
AM40	-	-	19.2	36.7	33.4	-	-	-	-	-	-	-	-	26.8	32.1	41.8	18.3	-	-	-
AM41	-	-	-	16.1	-	-	-	-	-	-	-3.5	27.4	-	37.9	35.4	35.3	33.5	-	25.8	-
AM42	-2.2	-	-	-	-	-	-	-	-	-	40.0	22.5	37.7	29.7	32.5	37.7	27.4	-	-	-
AM43	0.0	-	-	-	-	-	-	-	-	-	43.4	-	36.0	26.6	-	-	-	-	-	-
AM44	-	-	-	-	-	-	-	-	-	-	28.8	20.6	40.5	26.2	35.8	-	-	-	-	-
AM48	14.5	-	-	-	-	-	-	-	-	-	-	-	-	31.9	28.6	-	20.5	-	20.9	-
AM49	7.1	-	-	-	-	-	-	-	-	-	48.2	31.4	37.9	30.7	35.8	42.1	30.0	-	24.9	-
AM50	3.4	-	-	-	-	-	-	-	-	-	-	-	17.4	24.1	24.9	34.0	-	-	24.3	-
AM51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.0	-	-	-	-	21.6
AM52	4.8	-	-	-	-	-	-	-	-	-	-	-	19.0	24.7	39.6	29.4	20.3	-	-	-
AM52Y	-88.0	-	-	-	-	-	-	-	-	-	27.5	29.1	34.9	29.1	26.0	33.6	17.0	-	-	-
AM52Z	-88.7	21.0	-	14.2	-	-	-	-	-	-	28.7	16.9	-	-	31.6	35.4	-	-	-	114.3
AM54	5.2	19.1	-	-	-	-	-	-	-	-	-	-	-	21.1	31.5	38.3	20.6	-	-	21.7
AM55	-	-	-	-	-	-	-	-	-	-	-	-	21.2	27.7	38.4	46.8	28.6	-	22.8	-
AM57	2.2	25.6	-	-	-	-	-	-	-	-	-	-	-	35.2	29.3	37.7	24.3	-	-	21.1
AM58	-	7.6	-	-	-	-	-	-	-	-	-	-	-	36.6	32.3	38.8	22.9	-	-	22.8
AM59	-	-	-	-	-	-	-	-	-	-	-	-	-41.6	23.2	38.1	37.1	20.3	-	24.8	-
AM62	-	-11.7	-	-	-	-	-	-	-	-	-	-	-	10.3	30.3	34.8	22.7	-	-	29.0
AM63	-	-	-	-	-	-	-	-	-	-	-	-	-	16.7	29.1	31.3	-	-	23.9	-
AM64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.7
AM65	-	11.1	-	-	-	-	-	-	-	-	-	-	-	27.0	26.2	-	-	-	-	-
AM66	-	-	-	-	-	-	-	-	-	-	-	-	-	8.3	23.3	49.3	29.3	-	24.2	-
AM67	-	15.8	-	-	-	-	-	-	-	-	-	-	-	31.4	24.7	29.7	-	-	-	28.0
AM68	-	15.9	-	-	-	-	-	-	-	-	-	-	-	37.1	34.0	26.1	35.0	-	-	-

Table 15, continued.

Well	Thermal gradients by formation and well (°C km^{-1})																			
			Tk							Kco			Kwl							
	TQ	Tr	Tkm		Tkc	Kcl	Kcp	Kcg	Kcm	Kcom	Kcok	Kcoh	Kwlp	Kwlw	Kwlm	Kws	Kwg	Kp	Jy	Jc
Logged by WAGCoE																				
AM20	1.8	-	-	-	-	-	-	-	-	-	-	-	27.7	27.5	33.3	43.2	-	-	27.8	-
AM31	-	-	-	-	-	-	-	-	-	-	32.5	29.6	30.1	32.5	36.4	42.4	-	-	27.7	-
AM32Y	-	-	-	50.1	28.2	-	-	-	-	-	-	-	-	-	-	49.0	27.6	-	31.2	-
AM33A	-	-	56.0	-	-	-	-	-	-	43.0	60.7	50.4	82.2	42.5	55.9	66.9	42.4	-	27.3	-
AM38A	-	-	-	-	-	-	-	-	-	-	34.3	46.7	57.7	18.4	31.1	36.4	27.9	-	-	-
AM40	-	-	18.7	40.2	24.4	-	-	-	-	-	-	-	-	26.6	30.7	40.1	18.4	-	-	-
AM40A	-	-	17.4	41.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AM42	16.5	-	-	-	-	-	-	-	-	-	39.2	28.7	35.8	30.0	32.2	40.1	29.4	-	-	-
AM43A	-39.9	-	-	-	-	-	-	-	-	-	27.5	-	36.9	29.1	36.0	46.1	32.4	-	24.6	-
AM45A	26.2	-	-	-	-	-	-	-	-	-	42.6	-	36.7	-	-	-		-	-	-
AM46	28.4	-	-	-	-	-	-	-	-	-	43.0	29.0	42.2	34.1	43.7	48.0	34.9	-	27.9	-
AM48	-5.5	-	-	-	-	-	-	-	-	-	-	-	-	28.2	29.9	-	18.9	-	20.5	-
AM49	36.8	-	-	-	-	-	-	-	-	-	42.0	31.9	41.4	32.6	37.8	42.9	33.8	-	25.1	-
AM50	-	-	-	-	-	-	-	-	-	-	-	-	13.7	25.6	28.1	34.6	-	-	25.3	-
AM51	-	-	-	-	-	-	-	-	-	-	-	-	4.1	12.1	17.3	-	-	-	-	21.7
AM52Y	-36.7	-	-	-	-	-	-	-	-	-	34.8	26.5	37.9	40.6	33.0	37.6	22.5	-	-	-
AM55	-17.3	-	-	-	-	-	-	-	-	-	-	-	15.6	29.3	39.7	47.5	33.6	-	38.7	-

Notes: TQ Superficial Formations

Tk Kings Park Formation
Tkm Mullaloo Sandstone Member
Tkc Como Sandstone Member

Kco Osborne Formation
Kcom Mirrabooka Member
Kcok Kardinya Shale Member
Kcoh Henley Sandstone Member

Kwl Leederville Formation
Kwlp Pinjar Member
Kwlw Wanneroo Member
Kwlm Mariginiup Member

Kws South Perth Shale
Kwg Gage Formation
Jy Yarragadee Formation
Jc Cattamarra Coal Measures

The mean thermal conductivity λ for the Leederville Formation, South Perth Shale, Yarragadee Formation, and Cattamarra Coal Measures was taken from Table 2 [HDRPL, 2008]. These values are considered possibly representative of PMA sediments, and are the only available measurements. For the assumed constant λ for each formation, the heat flow was calculated across wells sampling these formations. Histograms of the heat flow are provided in Appendix B. Table 16 provides a summary of the results; the proportion of wells exhibiting conductive profiles which were used in the analysis are shown in the last column.

Table 16: Average estimated heat flow by formation

Formation	Geometric mean (mW m^{-2})	Arithmetic mean (mW m^{-2})	Median (mW m^{-2})	Standard deviation (mW m^{-2})	Fraction of wells used
Pinjar	64.5	69.9	72.0	22.9	32/47
Wanneroo	64.2	67.1	69.1	17.6	55/62
Mariginiup	78.9	81.4	80.7	20.2	51/53
South Perth	66.9	65.4	64.4	14.4	42/46
Yarragadee	88.9	90.3	87.4	16.8	26/31
Cattamarra	89.6	88.8	82.9	12.0	6/9

In general, the geometric mean heat flow estimates range from 64 mW m^{-2} to 91 mW m^{-2}, slightly higher than the median continental value of 64.5 mW m^{-2} and within the range of values estimated by HDRPL [2008] in the Perth Basin. However, these estimates cannot be considered independent of the HDRPL values, as the thermal conductivity values used were obtained from that report.

Also informative is the standard deviation of the arithmetic mean heat flow, which ranges between 15 and 23 mW m^{-2}. These relatively high values, and the histogram spreads shown in Appendix E, indicate that either the assumption of spatially constant heat flow or constant thermal conductivity or conductive heat flow, or some combination of assumptions, are violated. Powell et al. [1988] give an extensive discussion of determining the reliability of heat flow estimates. They point out that the certainty of the heat flow estimate is usually determined by the reliability of the thermal conductivity measurements, and suggest that to obtain a coefficient of variation less than 5% of the mean, at least 16 samples of thermal conductivities should be measured in each formation. The available thermal conductivity measurements shown in table 2, section 2.4.2 are composed of considerably less measurements. Hence the reliability of these heat flow estimates is low.

Future work should focus on quantifying the variability of thermal conductivity in the PMA sediments, in order to better estimate the heat flow.

5. DISCUSSION AND CONCLUSIONS

This report contains several important research contributions on the sub-surface temperature regime in the PMA. For the first time, it presents an extensive database of temperature measurements and maps the temperature distribution in three dimensions. Other contributions include:

- A consistent set of formation tops for 18 Artesian Monitoring Wells; see Table 11.
- Radiogenic heat production rates for Perth Basin sediments; see Table 12.
- Locations affected by non-conductive heat flow; see Table 13.
- Temperature values at the top of the Yarragadee Aquifer; see Figure 18.
- Geothermal gradients in conductive heat-flow wells and formations; see Table 14 and Table 15.

In addition, the preliminary heat flow investigation of section 4.8 points to important areas of future research. The Appendices provide comprehensive analysis by each individual AM well and by formation, comparison of logged and digitised wells, calculated geothermal gradients and heat flow by formation, and aquifers and aquitards exhibiting non-conductive heat flow.

5.1 Limitations to analysis

Despite the comprehensive nature of this study, there are still several limitations to the analysis which affect the validity of the results.

First, a small error may be caused by incomplete or contradictory top of casing (TOC) elevations, affecting the calculation of the geothermal gradient by formation. These formation boundaries were addressed for the logged WAGCOE wells, but the scanned/digitised logs rely upon Davidson [1995]. These inaccuracies, and the quality of the digitised logs limit the accuracy of the geothermal gradient (and hence heat flow) estimates. Temperature estimates at depth are also affected by any possible discrepancies.

The geothermal gradient calculation was performed by straight-line interpolation between tops and bottoms of formations. This straightforward method has the advantage of producing simple continuous temperature models. One alternate method would be to fit a geothermal gradient by least-square fits within each formation, which has less reliance on the top and bottom temperature measurements [Powell, 1988], or by a statistical technique. However, because this study analyses non-conductive profiles within formations, and omits this data from future analysis, the geothermal gradients produced by the alternate techniques could not vary by more than 5%.

Temperature maps are affected by spatial data coverage and the interpolation algorithm. The white areas in Figures 15 to 17 highlight where data are unavailable. Moreover, the assumed correlation of 15 km horizontally has not been rigorously tested and affects the spatial data mapping.

The non-conductive regime analysis depends upon one-dimensional vertical temperature profiles. It is not possible to quantify horizontal advective flux from this data without additional assumptions or analysis [e.g. Lu & Ge, 1996].

The radiogenic heat production analysis is not calibrated against independent measurements. The relative variability of the results is valid, but the absolute magnitude of values may be in doubt. These bulk values do not reflect porosity corrections to obtain matrix heat production rates.

Finally, thermal conductivity of each stratigraphic unit is not well known in the PMA. Thermal conductivity varies significantly within each formation due to the presence of varied lithologies. Appropriately up-scaled thermal conductivity estimates for the major Perth formations are lacking. Hence heat flow estimates for the PMA carry significant uncertainty.

5.2 Recommendations for future work

Based on the results of this study and the limitations described above, several recommendations can be made to increase the knowledge of the thermal regime in the PMA.

First, additional logging of detailed temperature and gamma ray profiles should be implemented in the PMA. Priority should be given to increasing data coverage spatially and selecting the deepest accessible wells for logging; Table 5 can assist with scouting accessible wells. This research plan is contingent upon available logging equipment and personnel.

Another source of temperature data are historical records, either complete logs or point measurements. These measurements are particularly valuable in wells which are no longer accessible. Priority should again be given to wells which increase the spatial coverage. In particular, data from the DoW transect series [e.g. Deeney. 1989a, 1989b] could provide valuable Perth Basin coverage outside of the range of the AM wells. These older logs should be digitised with mapping methods which automatically correct for distortion, which would reduce the amount of manual post-processing.

Temperature logs can provide quantitative information on the heat transported by advective groundwater flow. Several authors [Reiter, 2001; She & Gu, 1996; Pons, 2010] provide methods to fit the curvature of the temperature log by assuming horizontal or vertical groundwater flow. In addition, paleoclimate changes may affect curvature of precision logs [Reiter, 2005] and the possible influence of historical climate change should be investigated. These methods should be combined with groundwater piezometric head data to help determine water and heat flow directions and constrain the estimates of groundwater-mediated heat flow.

Thermal parameters should also be further investigated. Neither specific heat nor thermal expansion parameters have been considered in this report, which affect time-varying behaviour of heat flow. The most important parameter for prediction of heat flow is thermal conductivity. Thermal conductivity measurements from core samples and wireline analysis should be analysed to determine average values for PMA formations, and to determine spatial variability. A prudent course of action would be to request coring from AM wells which will be drilled in the near future.

Radiogenic heat production estimates would be greatly improved by performing wireline logging with a calibrated probe. If possible, a spectral three-component (U, K, Th) probe would provide better indication of possible reasons for the low heat production rates estimated in this study.

With the results of the thermal parameter measurements, heat flow estimates across the PMA could be obtained. As a first step, a joint inversion should be performed which utilises all the conductive temperature data to estimate heat flow by well and thermal conductivity by formation, similar to that performed by Botman and Horowitz [Botman, 2010; Botman et al., 2011].

Knowledge of the reservoir temperature at locations deeper than those measured in this study is essential for medium- to large-scale geothermal developments. The simplest method for predicting temperatures at depth assumes a conductive regime, with vertical, one-dimensional heat flow. Extrapolating the existing temperature profiles to greater depths requires parameters such as formation thicknesses, thermal conductivities, and estimates of local vertical heat flow [Beardsmore & Cull, 2001]. By considering the uncertainty of these parameters, the resulting uncertainty on the temperature at depth can be determined. A second level of prediction should be a regional conductive-regime model which considers lateral geologic variability. A three-dimensional geologic structural model should be populated with porosity, heat capacity, and thermal conductivity to predict temperatures at depth. The model can be calibrated with temperature data as provided in this report. Finally, a third level of prediction would incorporate hydrogeologic knowledge to perform a three-dimensional hydrothermal modelling study, which considers the effects of conduction and heat transport by moving water [Mottaghy et al., 2010]. Such a model could be used to explore for, and eventually manage, hot sedimentary aquifer prospects.

6. ACKNOWLEDGEMENTS

The Western Australian Geothermal Centre of Excellence is funded by the Western Australian government. We also receive financial support from our industry partners, Green Rock Energy and GT Power.

We are extremely grateful to Geoscience Australia for the loan of the logging equipment used in this study. In particular we acknowledge the expert training and advice provided by John Spring and Rikki Weber.

The logging was primarily performed by two Honours students: Gemma Bloomfield, from the University of Western Australia (UWA) in the School of Earth Sciences, and Chris Botman, from Curtin University of Technology (CUT) in the Department of Exploration Geophysics, together with WAGCOE researchers. We are grateful to their supervisors not listed on this report: Professor Christoph Hinz of UWA, Professor Frank Horowitz of UWA, and Dr. Christian Dupuis from CUT.

This report was greatly improved by detailed feedback from Heather Sheldon and Allison Hortle.

7. REFERENCES

ALPL, 2008. A626 Gamma/temperature sonde, serial number T210 - instruction manual. AusLog Pty Ltd, Sumner Park.

Anderson, M.P., 2005. Heat as a groundwater tracer, *Ground Water*, 43(6), 951-968.

Beardsmore G. R. & Cull J. P., 2001. *Crustal heat flow: A guide to measurement and modelling*. Cambridge University Press.

Beardsmore G. R., 2005. High-resolution heat-flow measurements in the Southern Carnarvon Basin, Western Australia, *Exploration Geophysics*, 36(2), 206-215.

Bestow, T.T., 1982. The potential for geothermal energy development in Western Australia. Geological Survey of Western Australia Record 1982/6. Perth.

Bloomfield, G., Ricard, L.P., Reid, L.B., Wilkes, P. , 2011. Temperature Logging and Analysis Protocol, CSIRO / WAGCOE internal report EP112037, 38 pages.

Botman C., 2010. Determining the geothermal properties of the Perth Basin lithology to aid geothermal energy projects. Honours thesis, Curtin University of Technology, Perth (unpubl.).

Botman, C., Horowitz, HG, Wilkes, P., 2011. Detailed thermal profiling and inversion for thermal conductivities and heat fluxes in the Perth Metropolitan hot sedimentary aquifer play of Western Australia. 2011 Stanford Geothermal Workshop, ed. R. Horne.

Bücker C. and Rybach, L., 1996. A simple method to determine heat production from gamma ray logs, *Marine and Petroleum Geology*, 13(4) 373-375.

Chopra, P.N. and Holgate, F., 2007. Geothermal energy potential in selected areas of Western Australia; a consultancy report by earthinsite.com Pty Ltd for Geological Survey of Western Australia: Geological Survey of Western Australia, Statutory petroleum exploration report, G31888 A1 (unpublished).

Clauser C., 2009. Heat transport processes in the Earth's crust. Surveys in Geophysics 30, 163-191.

Corbel, S. and Poulet, T., 2010 WAGCoE data catalogue for geothermal exploration, eScience 2010, *The Sixth IEEE International Conference on eScience*, Brisbane, December 7-10.

Crostella A. and Backhouse, J., 2000. Geology and petroleum exploration of the Central and Southern Perth Basin, Western Australia. Geological Survey of Western Australia Report 57, Perth.

Davidson W. A., 1995. Hydrogeology and groundwater resources of the Perth Region, Western Australia: Western Australia. Western Australia Geological Survey Bulletin 142.

Davidson W. A. & Yu X., 2006. Perth regional aquifer modelling system (PRAMS) model development: Hydrogeology and groundwater modelling. Western Australia Department of Water Hydrogeological record series HG 20.

Deeney, A.C., 1989a. Hydrogeology of the Binningup Borehole Line, Perth Basin. Geological Survey of Western Australia, Report 25, p.7-16.

Deeney, A.C., 1989b. Hydrogeology of the Harvey Borehole Line, Perth Basin. Geological Survey of Western Australia, Report 26, pp. 58-68.

DoW [Western Australia Department of Water], 2010. Water Resources Information Catalogue Accessed 7 June 2010. http://kumina.water.wa.gov.au/waterinformation/wric/wric.asp.

Freeman M. J. & Donaldson M. J., 2006. Geology of the southern Perth Basin and Margaret River wine district, southwestern Western Australia – a field guide. Western Australia Geological Survey 2006/20.

Ge, S., 1998, Estimation of groundwater velocity in localized fracture zones from well temperature profiles. *Journal of Volcanology and Geothermal Research*, **84**, 93-101.

Geoscience Australia, 2008. Perth Basin, Viewed 10 February 2011. http://www.ga.gov.au/oceans/sa_perth.jsp

Geoscience Australia, 2011. OZCHEM National Whole Rock Geochemistry Database. Accessed 17 January 2011. http://www.ga.gov.au/meta/ANZCW0703011055.html.

Gerner, E., 2011. Personal communication to Paul Wilkes, WAGCOE.

Ghori, K., 2008, Western Australia's Geothermal Resources: Presented at the *AAPG Annual Convention & Exhibition*, San Antonio, TX, USA

HDRPL [Hot Dry Rocks Pty. Ltd.], 2008. Geothermal energy potential in selected areas of Western Australia (Perth Basin): A report prepared for the Department of Industry and Resources, Western Australia. Hot Dry Rocks Pty Ltd.

Haenel, R., Rybach, L., & Stegena, L., 1988. Fundamentals of geothermics in *Handbook of Terrestrial Heat-Flow Density Determination*, R. Haenel, L. Rybach, and L. Stegena, eds. Kluwer Academic Publishers, London.

Hartmann, A., V. Rath, and Clauser, C., 2005, Thermal conductivity from core and well log data. *International Journal of Rock Mechanics and Mining Sciences*, **42**, 1042-1055.

Horowitz, F.G. and Regenauer-Lieb, K., 2009. Mean Annual Surface Temperatures (MAST) and other thermal estimates for Australia and New Zealand from 6 years of remote sensing observations. Proceedings, 2009 NZ Geothermal Workshop, 65—68.

Jessop A. M. & Majorowicz J. A., 1994. Fluid flow and heat transfer in sedimentary basins. Geological Society, London, Special Publications 78, 43-54.

Lu, N. & Ge, S., 1996. Effect of horizontal heat and fluid flow on the vertical temperature distribution in a semiconfining layer. *Water Resources Research*, 32(5), 149-1453.

Mory A. J., Haig D. W., Mcloughlin S. & Hocking R. M., 2005. Geology of the northern Perth Basin, Western Australia – a field guide. Western Australia Geological Survey 2005/9.

Moattagy, D., Pechnig, R., Buik, N., and Simmelink, E., 2010. 3-D numerical models for temperature prediction and reservoir simulation, Proceedings World Geothermal Congress 2010, Bali Indonesia, 8 pages.

Norden, B., & Förster, A., 2006. Thermal conductivity and radiogenic heat production of sedimentary and magmatic rocks in the Northeast German Basin, AAPG Bulletin 90(6), 939-962.

Pons G., 2010. Study of temperature in geothermal and petroleum wells. CSIRO (unpubl.).

Powell, W.G., Chapman, D.S., Balling, N., and Beck, A.E., 1988. Continental heat-flow density in *Handbook of Terrestrial Heat-Flow Density Determination*, R. Haenel, L. Rybach, and L. Stegena, eds. Kluwer Academic Publishers, London.

Reiter, M., 2001. Using precision temperature logs to estimate horizontal and vertical groundwater flow components, Water Resources Research 37(3), 663-674.

Reiter, M., 2005. Possible ambiguities in subsurface temperature logs: Consideration of groundwater flow and ground surface temperature change, Pure & Applied Geophysics 162, 343-355.

Ricard L.P., Pons, G., and Chanu, J-B., 2011. Temperature interpretation and modeling for geothermal applications: GeoTemp. *Western Australian Geothermal Energy Symposium*, March 2011.

Tester J. W., Anderson B. J., Batchelor A. S., Blackwell D. D., DiPippo R., Drake E. M., Garnish J., Livesay B., Moore M. C., Nichols K., Petty S., Principal B., Toksöz M. N., Ralph W. Veatch J., Baria R., Augustine C., Murphy E., Negraru P. & Richards M., 2006. The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st Century. Massachusetts Institute of Technology.

Thomas J. B., 2000. Lithology-driven rock calibration: "Laboratory" modeling. In: Bouma A. H. & Stone C. G. eds., *Fine-grained turbidite systems* (AAPG Memoir 72/SEPM Special Publication 68), pp 307-316.

Thorpe P. M. & Davidson W. A., 1990. Groundwater age and hydrodynamics of the confined aquifers, Perth, Western Australia. *International Conference on Groundwater in Large Sedimentary Basins*, Perth, Western Australia, pp. 420–436. Australian Water Resources Council.

Vilà, M.F., Fernández, M., and Jiménez-Munt, I., 2010. Radiogenic heat production variability of some common lithological groups and its significance to lithospheric thermal modeling, *Tectonophysics*, 490, 152-164.

Vosteen, H.-D., and Schellschmidt, R., 2003, Influence of temperature on thermal conductivity, thermal capacity and thermal diffusivity for different types of rock. *Physics and Chemistry of the Earth*, **28**, 499-509.

Waples, D.W., 2002, A new model for heat flow in extensional basins: Estimating radiogenic heat production. *Natural Resources Research*, **11(2)**, 125-133.

Waples D. & Waples J., 2004. A review and evaluation of specific heat capacities of rocks, minerals, and subsurface fluids. Part 2: Fluids and porous rocks. *Natural Resources Research* 13, 123-130.

APPENDIX A – SUMMARY SHEETS OF DATA BY WELL LOGGED BY WAGCOE

This appendix contains summary sheets of the data available for each well logged by WAGCOE; these temperature data can be considered of high reliability. Each page compiles the available information about the well:

- A *chart* of the temperature log in red, and the conductive model overlain in blue. The logging speed and interval are also represented below the chart.
- The *well specifics* table describes the construction and logging date , georeferencing data, elevations of ground, top of casing, and total depth, the perforated interval and formation, the current status, and the depth to reliable measurements as determined in section 4.1.
- The *logging results* table describes the formation divisions, and within each formation data includes
    - Temperature,
    - Thermal gradient,
    - Error between model and observed data,
    - Average heat production,
    - Whether advection is observed,

Appendix A: Source of data & explanation of terms

Much of the geoereferencing data was obtained from the Western Australian Department of Water. The DoW produces an "All Site Details Report" for each well in their monitoring network.

Date construction completed: 'To Date' under 'Construction Events' in All Site Details Report. A designation of N/A means the information is neither in the All Site Details Report or Davidson [1995].

Date logged: 'Date' in header of original JPEG.

Geodetic datum: 'GDAT' in LAS file.

Horizontal coordinate system: 'HZCS' in LAS file.

Easting (X): 'Easting' in All Site Details report.

Northing (Y): 'Northing' in All Site Details Report.

Ground level (m AHD): 'GL' under 'Datum Planes' in All Site Details Report. If it was not in the All Site Details Report, it was taken from 'Ground level' in Table 4 of Davidson [1995].

Top of casing (m AHD): 'TOC' under 'Datum Planes' in All Site Details Report. If it was not included in the All Site Details Report, it was taken from 'Top casing' in Table 4 of Davidson [1995].

Total well depth below GL (m): There was often conflicting values for the total well depth below ground level. In the cases where the value from 'Construction Events' in the All Site Details Reports was different to the value from 'Depth below GL' in Table 4 of Davidson [1995], the depth in the All Site Details Report was taken to be correct. A designation of N/A means the information is neither in the All Site Details Report or Davidson [1995].

Perforated interval (m) (formation): 'Perforations below GL' and 'Aquifer' in Table 4 of Davidson [1995]. A designation of N/A means the information is neither in the All Site Details Report or Davidson [1995].

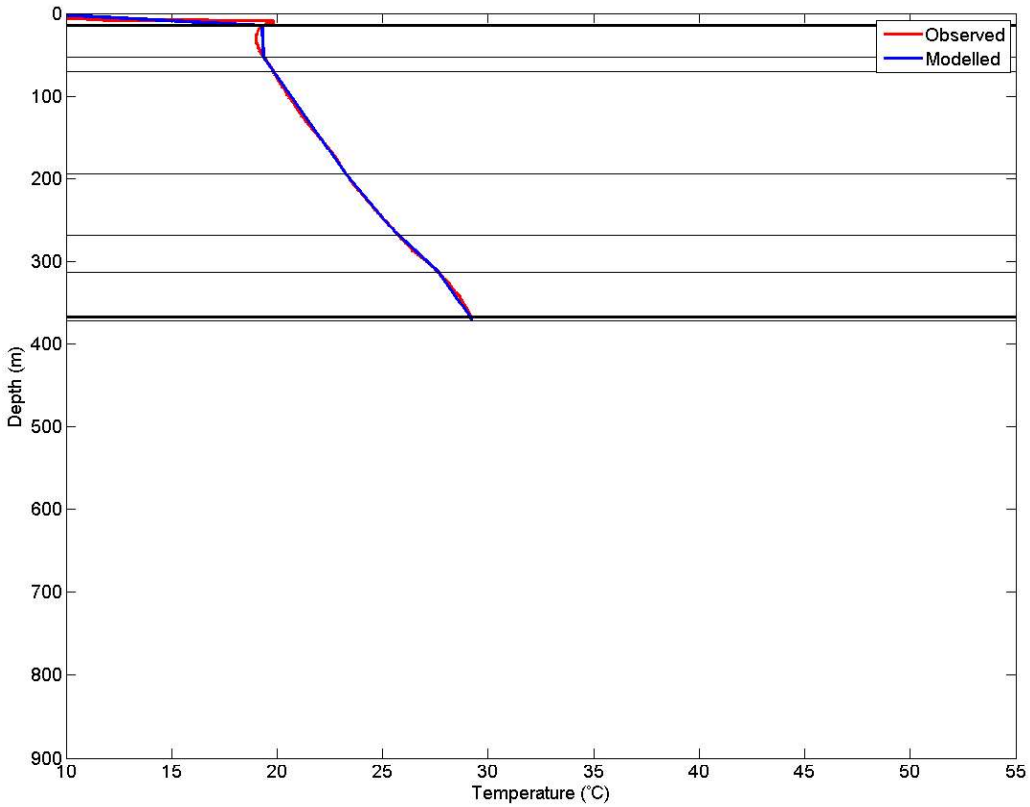
Status: 'Status' in All Site Details Report. E.g. Operating, abandoned, replaced by, decommissioned.

Depth to reliable measurements: The depth at which the analysis commenced. Thermal gradients and errors for the top formations were measured from this depth, not the top of the formation. Eg. AM20: the top of the superficial is 0 m, the top of the Pinjar is 53 m and the depth to reliable measurements is 15 m. Therefore, the analysis for the superficial was conducted over the interval 15 – 53 m, not 0 – 53 m. Depths to reliable measurements were determined by which was the deepest out of seasonal influence (estimated at 15 m) or the depth to the base of the water table influence (estimated from water table data retrieved from the WA DoW Water Resources Information Catalogue).

Bottom limit: The depth of the last reading deemed reliable. E.g. AM20: the top of the Yarragadee is 313 m, the bottom limit is 368 m and the depth of the log is 371.790 m. Therefore, the analysis for the Yarragadee was conducted over the interval 313 – 368 m, not 313 – 371.790 m.

AM20

Logged by WAGCOE, July 2010



Temperature vs depth for AM20 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

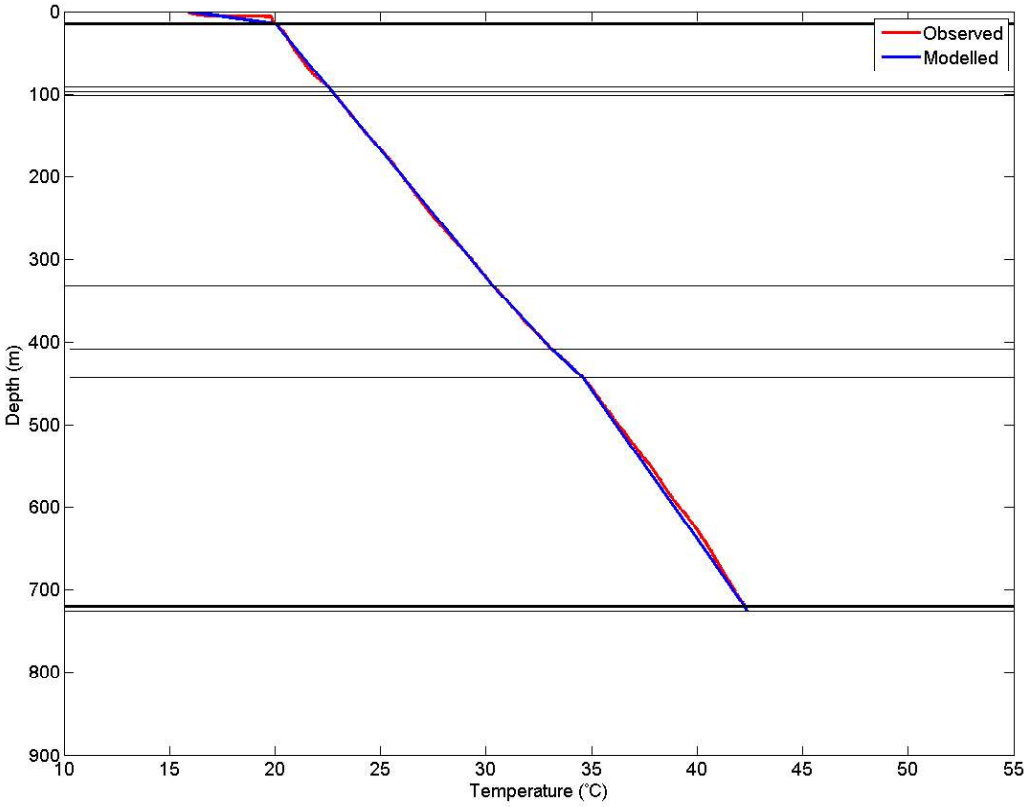
Date construction completed:	15/01/1978	**Ground level (m AHD):**	29.320
Date logged:	06/07/2010	**Top of casing (m AHD):**	29.830
Geodetic datum:	GDA94	**Total well depth below GL (m):**	467
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	375 - 380 (Yarragadee)
Easting (X):	377578	**Status:**	Operating
Northing (Y):	6500454	**Depth to reliable measurements (m):**	15.0

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	1.8	16.6	0.13	yes
Pinjar	53	19.4	27.7	1.2	0.63	no
Wanneroo	70	19.8	27.5	3.2	0.46	no
Mariginiup	194	23.2	33.3	1.6	0.80	no
South Perth	269	25.7	43.2	3.2	0.84	no
Yarragadee	313	27.6	27.8	6.9	0.38	yes
Bottom limit	368	29.2	N/A	N/A	N/A	N/A
Depth of log	371.790	29.2	N/A	N/A	N/A	N/A

AM31 (Whitfords No 5)

Logged by WAGCOE, June 2010



Temperature vs depth for AM31 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

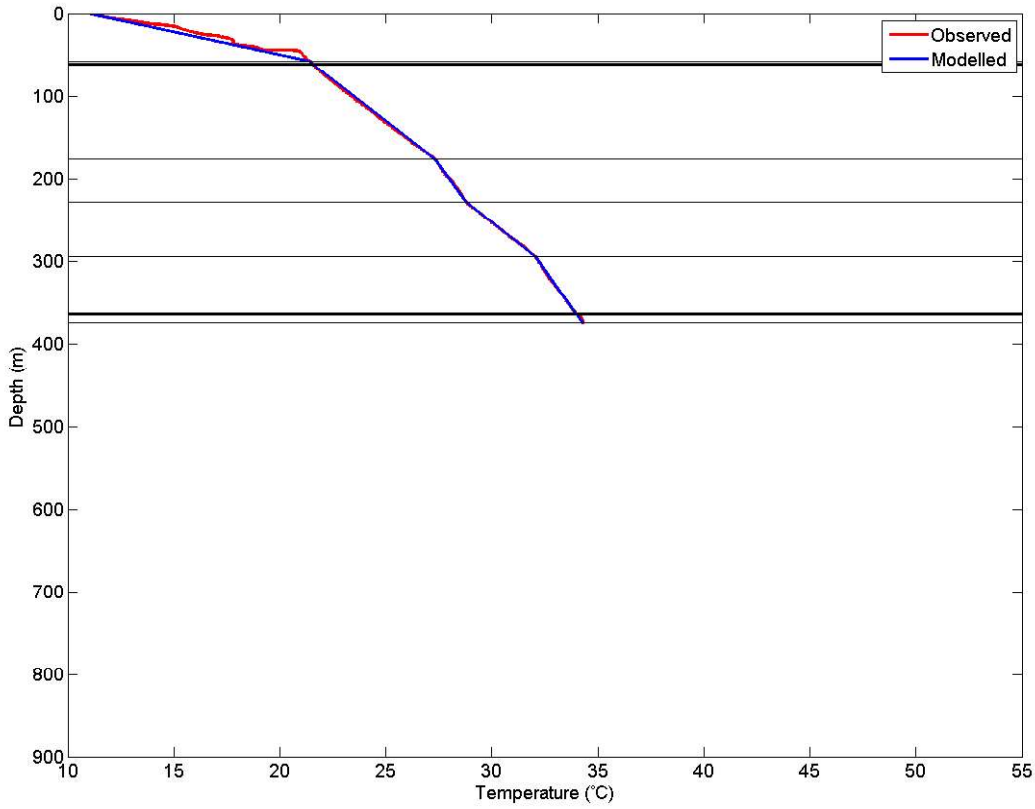
Date construction completed:	N/A	**Ground level (m AHD):**	5.587
Date logged:	23/06/2010	**Top of casing (m AHD):**	6.240
Geodetic datum:	GDA94	**Total well depth below GL (m):**	800
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	722 - 725 (Yarragadee)
Easting (X):	406171	**Status:**	Operating
Northing (Y):	6480712	**Depth to reliable measurements (m):**	15.0

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A	N/A
Kardinya	15	20.0	32.5	6.4	0.30	yes
Henley	91	22.5	29.6	1.0	0.54	no
Pinjar	97	22.7	30.1	1.2	0.83	no
Wanneroo	102	22.9	32.5	1.6	0.61	no
Mariginiup	331	30.3	36.4	1.4	0.71	no
South Perth	408	33.1	42.4	3.9	0.69	no
Yarragadee	443	34.6	27.7	5.0	0.46	yes
Bottom limit	720	42.2	N/A	N/A	N/A	N/A
Depth of log	725.950	42.3	N/A	N/A	N/A	N/A

AM32Y

Logged by WAGCOE, July 2010



Temperature vs depth for AM32Y (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

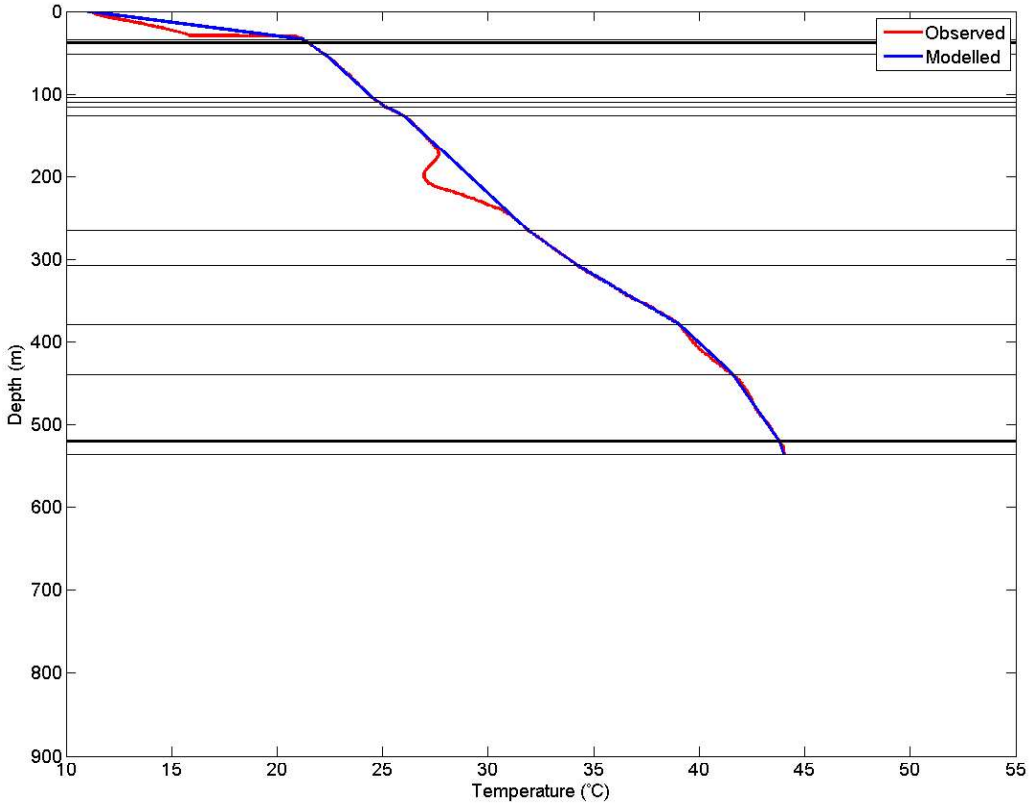
Date construction completed:	11/02/1998	**Ground level (m AHD):**	11.400
Date logged:	09/07/2010	**Top of casing (m AHD):**	11.823
Geodetic datum:	GDA94	**Total well depth below GL (m):**	389
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	369 - 375 (Yarragadee)
Easting (X):	383037	**Status:**	Operating
Northing (Y):	6473764	**Depth to reliable measurements (m):**	61.0

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A	N/A
Kings Park	57	N/A	50.1	4.8	0.34	no
Como	176	27.3	28.2	2.0	0.17	no
South Perth	228	28.8	49.0	1.8	0.71	no
Gage	294	32.0	27.6	1.8	0.30	no
Yarragadee	363	33.9	31.2	3.9	0.27	no
Bottom limit	364	34.0	N/A	N/A	N/A	N/A
Depth of log	374.960	34.3	N/A	N/A	N/A	N/A

AM33A

Logged by WAGCOE, July 2010



Temperature vs depth for AM33A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

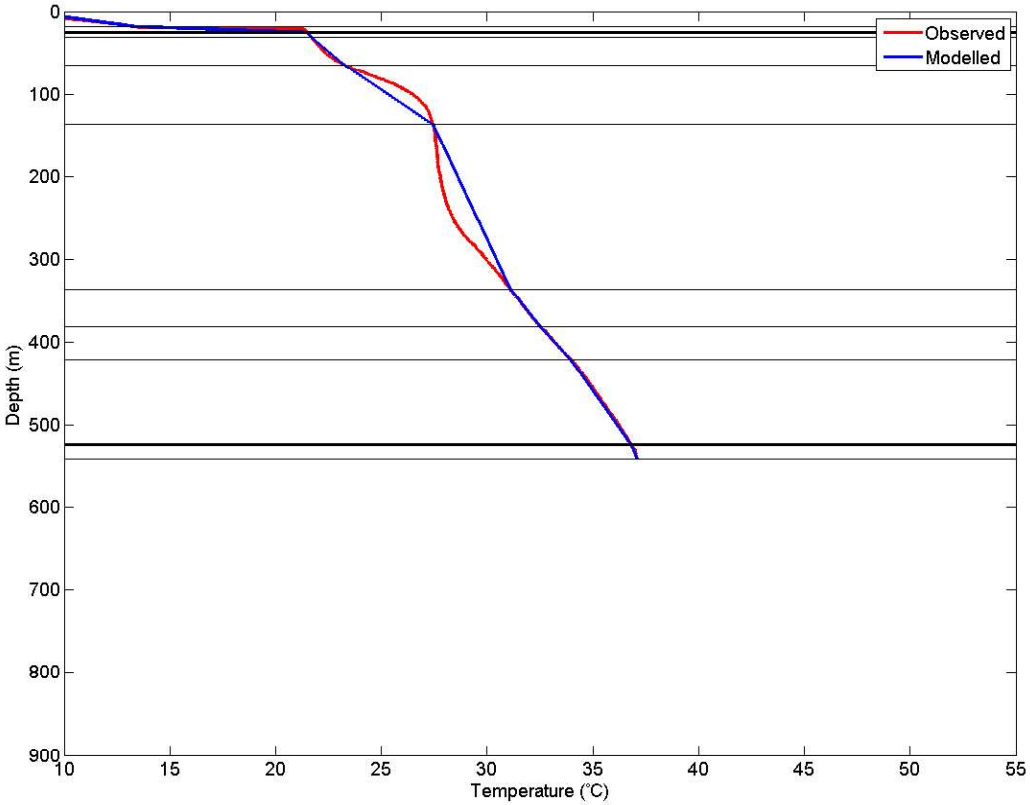
Date construction completed:	15/08/1983	**Ground level (m AHD):**	7.182
Date logged:	08/07/2010	**Top of casing (m AHD):**	7.662
Geodetic datum:	GDA94	**Total well depth below GL (m):**	535
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	495 - 505 (Yarragadee)
Easting (X):	385150	**Status:**	Operating
Northing (Y):	6477342	**Depth to reliable measurements (m):**	38.2

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A	N/A
Mullaloo	34	N/A	56.0	1.6	0.16	no
Mirrabooka	52	22.3	43.0	3.3	0.19	no
Kardinya	104	24.5	60.7	1.1	0.38	no
Henley	110	24.9	50.4	1.4	0.26	no
Pinjar	116	25.2	82.2	1.7	1.17	no
Wanneroo	126	26.0	42.5	40.1	0.56	yes
Mariginiup	265	31.9	55.9	1.2	0.94	no
South Perth	307	34.2	66.9	2.2	0.88	no
Gage	379	39.0	42.4	10.5	0.44	yes
Yarragadee	439	41.6	27.3	3.3	0.39	no
Bottom limit	520	43.8	N/A	N/A	N/A	N/A
Depth of log	535.715	44.0	N/A	N/A	N/A	N/A

AM38A

Logged by WAGCOE, July 2010



Temperature vs depth for AM38A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

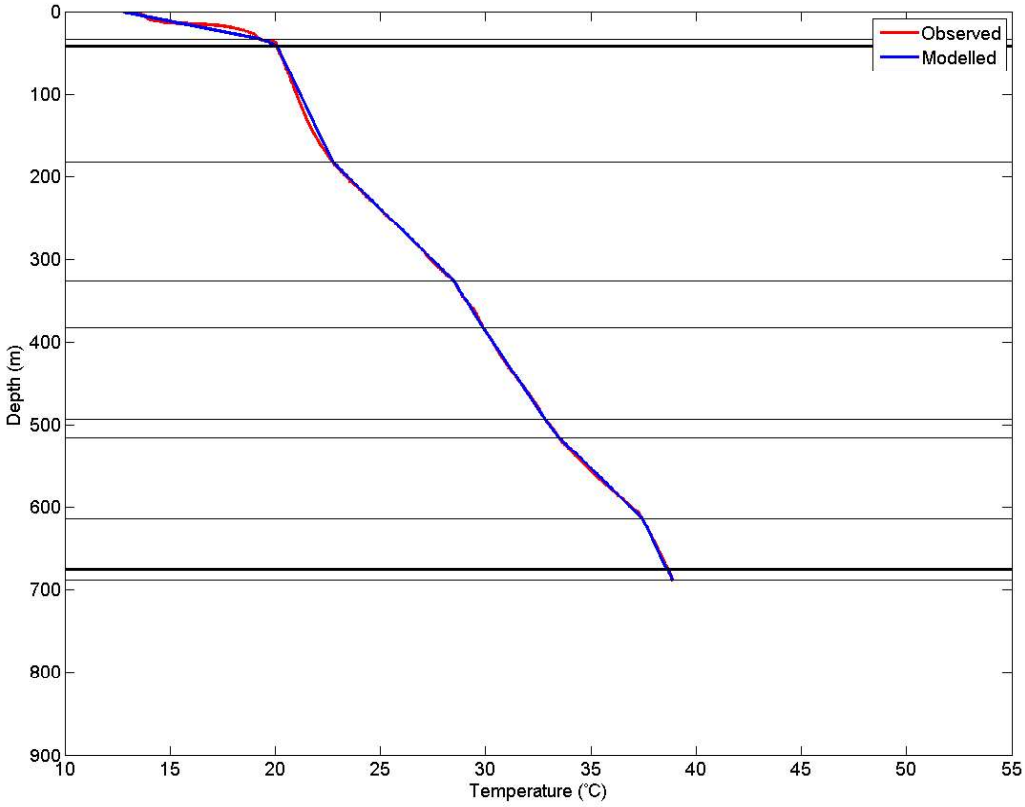
Date construction completed:	15/04/1982	**Ground level (m AHD):**	11.220
Date logged:	05/07/2010	**Top of casing (m AHD):**	11.880
Geodetic datum:	GDA94	**Total well depth below GL (m):**	550
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	500 - 507 (Yarragadee)
Easting (X):	404507	**Status:**	Operating
Northing (Y):	6468894	**Depth to reliable measurements (m):**	25.2

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A	N/A
Kardinya	18	N/A	34.3	0.7	0.60	no
Henley	31	21.7	46.7	11.0	0.36	yes
Pinjar	65	23.3	57.7	41.2	0.85	yes
Wanneroo	137	27.4	18.4	23.7	0.73	yes
Mariginiup	336	31.1	31.1	1.8	0.79	no
South Perth	381	32.5	36.4	1.3	0.79	no
Gage	421	33.9	27.9	3.4	0.74	no
Bottom limit	523	36.8	N/A	N/A	N/A	N/A
Depth of log	541.500	37.1	N/A	N/A	N/A	N/A

AM40

Logged by WAGCOE, June 2010



Temperature vs depth for AM40 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 20 cm

Well specifics

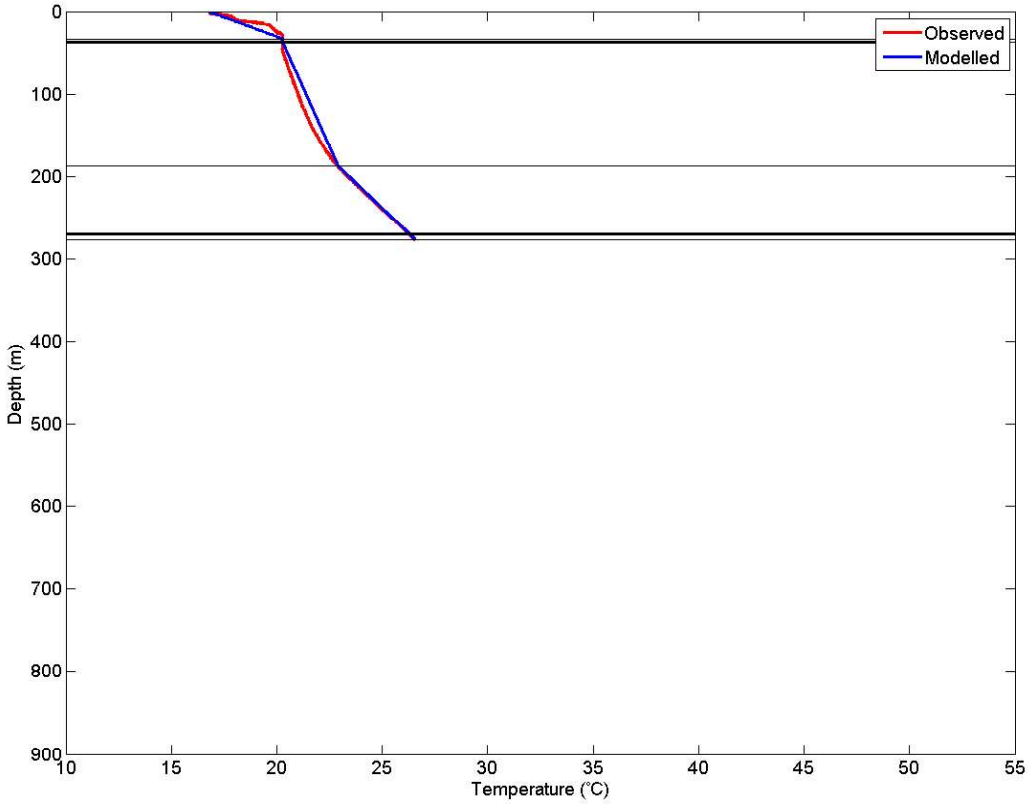
Date construction completed:	15/04/1979	**Ground level (m AHD):**	22.680
Date logged:	08/06/2010	**Top of casing (m AHD):**	22.965
Geodetic datum:	GDA94	**Total well depth below GL (m):**	730
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	687 - 696 (Yarragadee)
Easting (X):	394744	**Status:**	Operating
Northing (Y):	6460282	**Depth to reliable measurements (m):**	40.7

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A	N/A
Mullaloo	33	N/A	18.7	3.1	0.21	no
Kings Park	183	22.7	40.2	0.9	0.31	no
Como	326	28.5	24.4	1.3	0.20	no
Wanneroo	383	29.9	26.6	0.8	0.60	no
Mariginiup	493	32.8	30.7	1.3	0.85	no
South Perth	515	33.5	40.1	1.9	0.88	no
Gage	614	37.4	18.4	1.3	0.31	no
Bottom limit	675	38.7	N/A	N/A	N/A	N/A
Depth of log	688.600	38.9	N/A	N/A	N/A	N/A

AM40A

Logged by WAGCOE, June 2010



Temperature vs depth for AM40A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 1 cm

Well specifics

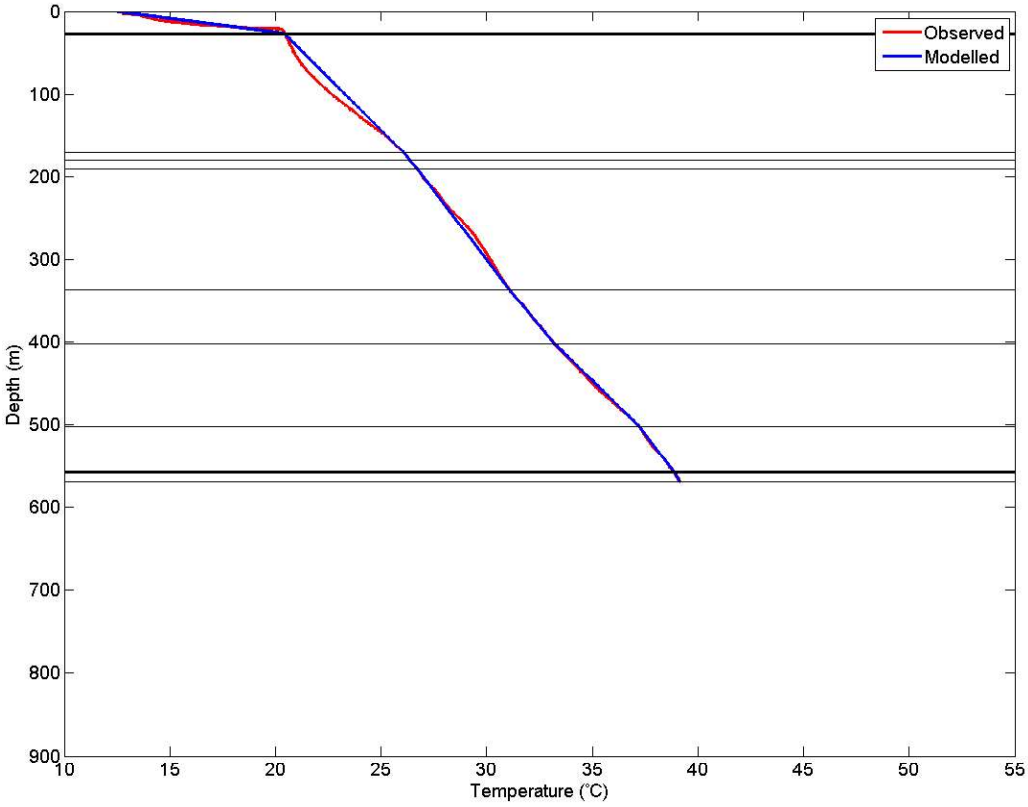
Date construction completed:	15/04/1981	**Ground level (m AHD):**	21.610
Date logged:	22/06/2010	**Top of casing (m AHD):**	21.940
Geodetic datum:	GDA94	**Total well depth below GL (m):**	459
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	442 - 447 (Leederville)
Easting (X):	394768	**Status:**	Operating
Northing (Y):	6460258	**Depth to reliable measurements (m):**	36.6

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A	N/A
Mullaloo	33	N/A	17.4	25.5	0.13	yes
Kings Park	188	22.9	41.2	2.9	N/A	no
Bottom limit	270	26.3	N/A	N/A	N/A	N/A
Depth of log	276.550	26.5	N/A	N/A	N/A	N/A

AM42

Logged by WAGCOE, June 2010



Temperature vs depth for AM42 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 20 cm

Well specifics

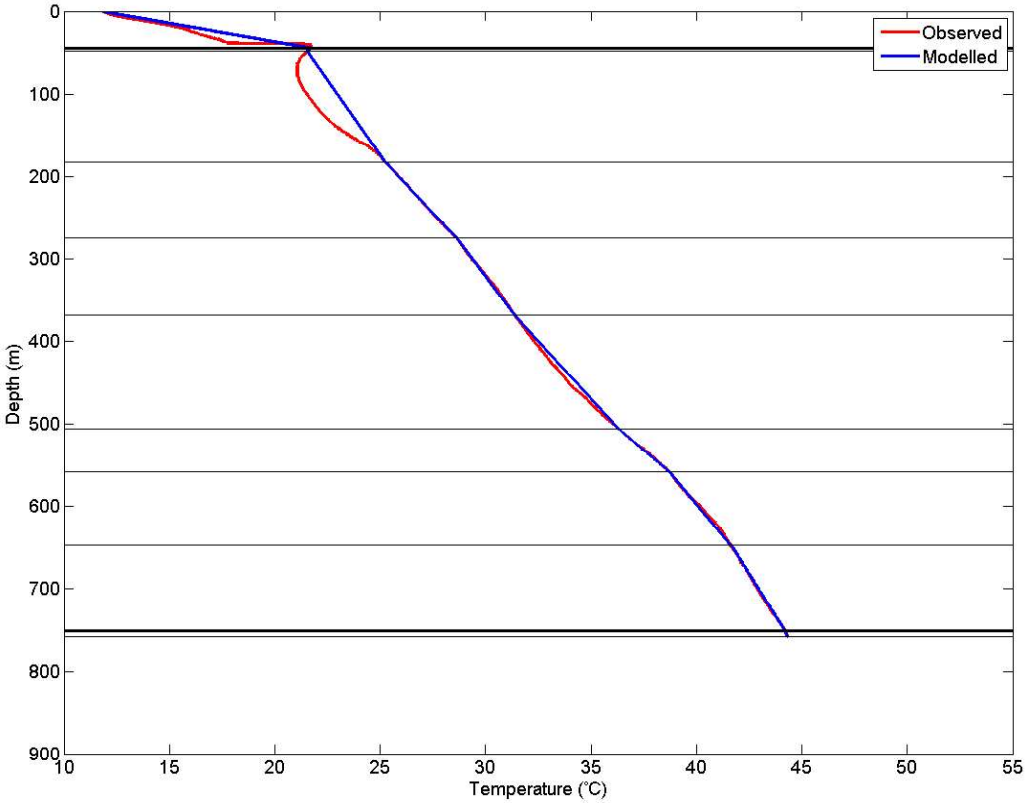
Date construction completed:	15/06/1979	**Ground level (m AHD):**	8.988
Date logged:	09/06/2010	**Top of casing (m AHD):**	9.648
Geodetic datum:	GDA94	**Total well depth below GL (m):**	600
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	569.5 - 576 (Yarragadee)
Easting (X):	388123	**Status:**	Operating
Northing (Y):	6452372	**Depth to reliable measurements (m):**	27.0

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	16.5	1.3	0.37	no
Kardinya	28	20.5	39.2	8.4	0.60	yes
Henley	171	26.1	28.7	0.6	0.41	no
Pinjar	181	26.4	35.8	0.4	0.80	no
Wanneroo	191	26.7	30.0	3.1	0.58	no
Mariginiup	336	31.1	32.2	0.5	0.91	no
South Perth	402	33.2	40.1	1.9	0.95	no
Gage	502	37.2	29.4	1.3	0.61	no
Bottom limit	558	38.9	N/A	N/A	N/A	N/A
Depth of log	569.940	39.1	N/A	N/A	N/A	N/A

AM43A

Logged by WAGCOE, June 2010



Temperature vs depth for AM43A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 20 cm

Well specifics

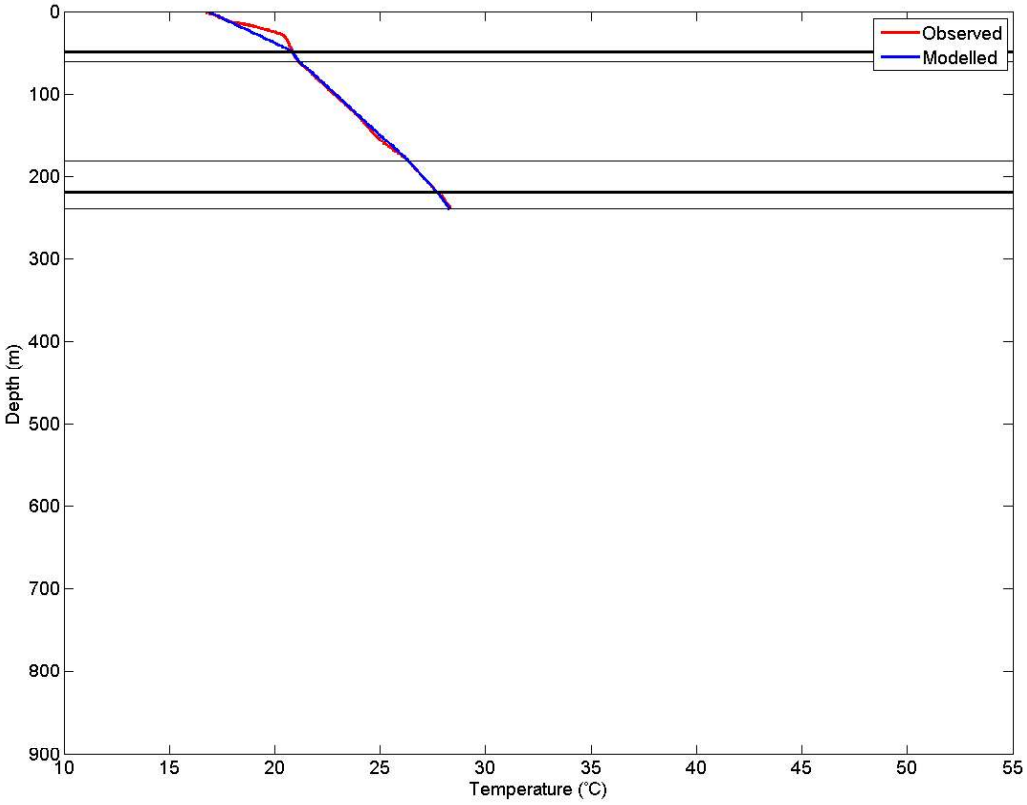
Date construction completed:	05/06/1999	**Ground level (m AHD):**	28.755
Date logged:	10/06/2010	**Top of casing (m AHD):**	29.218
Geodetic datum:	GDA94	**Total well depth below GL (m):**	794
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	753 - 760 (Yarragadee)
Easting (X):	393965	**Status:**	Operating
Northing (Y):	6450856	**Depth to reliable measurements (m):**	44.8

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	-39.9	0.7	0.34	no
Kardinya	48	21.5	27.5	20.5	0.53	yes
Pinjar	183	25.2	36.9	0.7	0.81	no
Wanneroo	275	28.6	29.1	1.3	0.47	no
Mariginiup	369	31.4	36.0	4.5	0.72	no
South Perth	506	36.3	46.1	1.3	0.74	no
Gage	558	38.7	32.4	2.5	0.70	no
Yarragadee	647	41.6	24.6	0.9	0.47	no
Bottom limit	751	44.2	N/A	N/A	N/A	N/A
Depth of log	757.840	44.3	N/A	N/A	N/A	N/A

AM45A

Logged by WAGCOE, June 2010



Temperature vs depth for AM45A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 20 cm

Well specifics

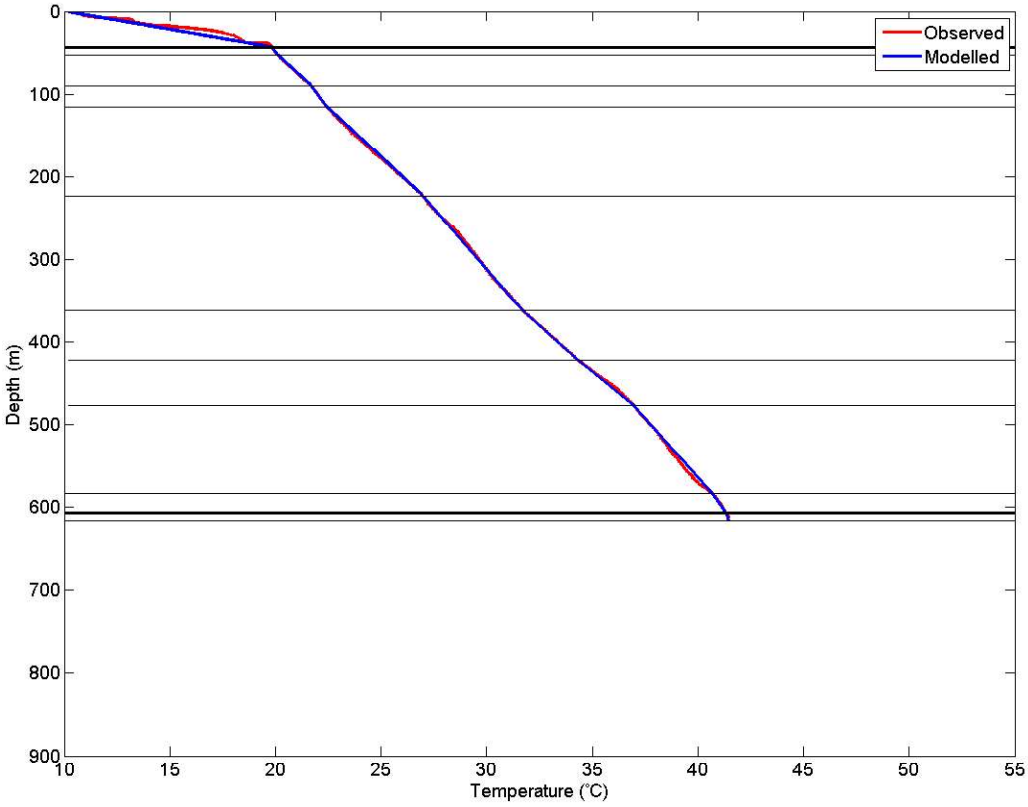
Date construction completed:	N/A	**Ground level (m AHD):**	38.824
Date logged:	09/06/2010	**Top of casing (m AHD):**	39.608
Geodetic datum:	GDA94	**Total well depth below GL (m):**	N/A
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	N/A
Easting (X):	387835	**Status:**	Operating
Northing (Y):	6443550	**Depth to reliable measurements (m):**	48.2

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	26.2	1.3	0.20	no
Kardinya	60	21.1	42.6	2.3	0.77	no
Pinjar	182	26.3	36.7	0.5	1.16	no
Bottom limit	219	27.7	N/A	N/A	N/A	N/A
Depth of log	239.200	28.3	N/A	N/A	N/A	N/A

AM46 (Woodman Pt No 1)

Logged by WAGCOE, June 2010



Temperature vs depth for AM46 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

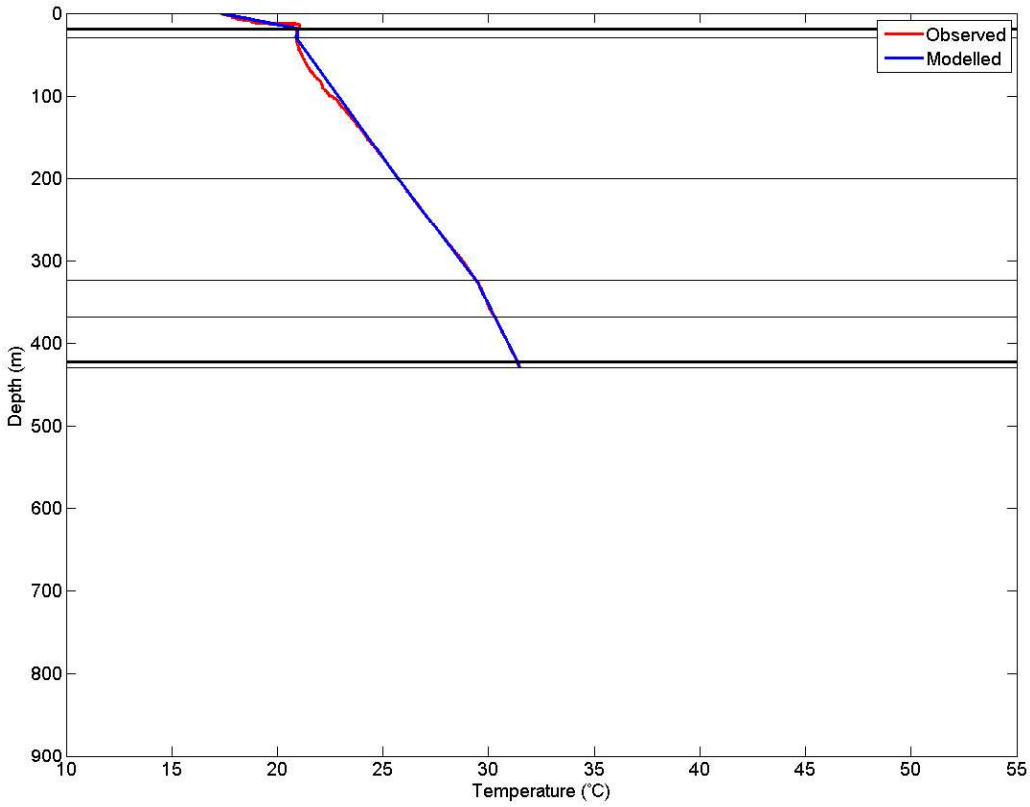
Date construction completed:	07/04/1975	**Ground level (m AHD):**	28.300
Date logged:	30/06/2010	**Top of casing (m AHD):**	28.640
Geodetic datum:	GDA94	**Total well depth below GL (m):**	801
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	597 - 602 (Yarragadee)
Easting (X):	393953	**Status:**	Operating
Northing (Y):	6444474	**Depth to reliable measurements (m):**	43.3

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	28.4	1.6	0.27	no
Kardinya	53	20.1	43.0	2.2	0.55	no
Henley	90	21.7	29.0	0.9	0.28	no
Pinjar	116	22.4	42.2	3.4	0.84	no
Wanneroo	223	27.0	34.1	2.6	0.53	no
Mariginiup	362	31.7	43.7	1.0	0.86	no
South Perth	422	34.3	48.0	6.0	0.79	yes
Gage	477	37.0	34.9	7.0	0.63	yes
Yarragadee	583	40.7	27.9	2.7	0.41	no
Bottom limit	607	41.3	N/A	N/A	N/A	N/A
Depth of log	616.115	41.5	N/A	N/A	N/A	N/A

AM48 (Woodman Pt No 3)

Logged by WAGCOE, June 2010



Temperature vs depth for AM48 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; time constant: 20 cm

Well specifics

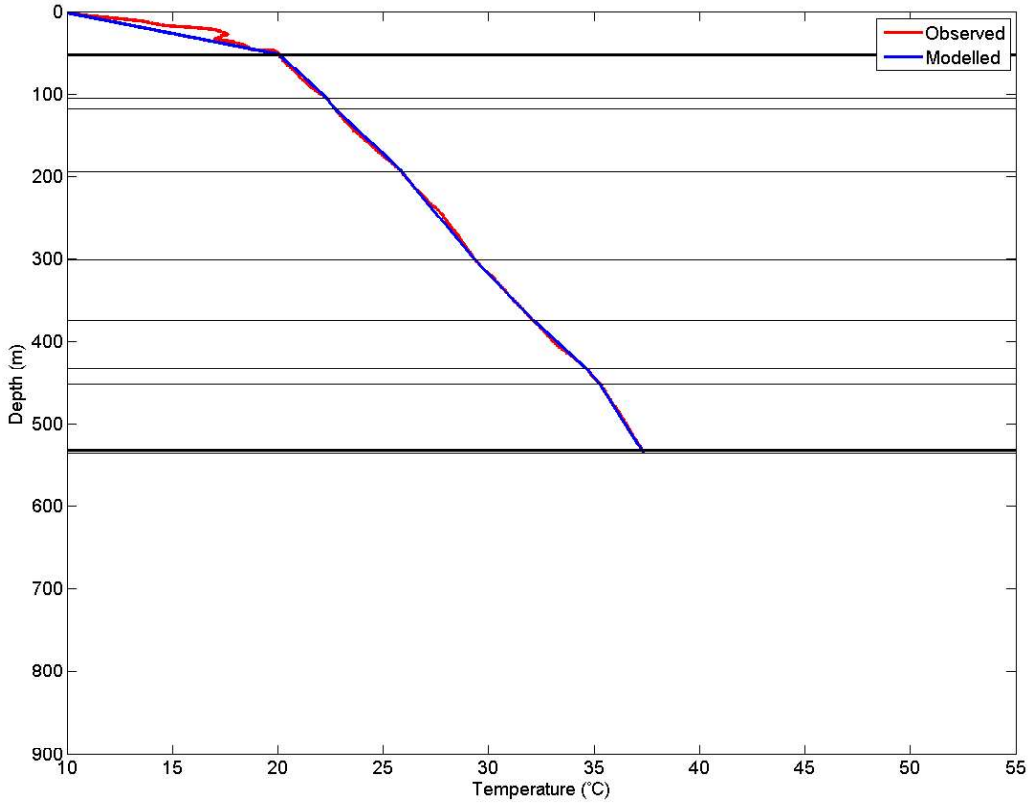
Date construction completed:	13/07/1978	**Ground level (m AHD):**	23.952
Date logged:	08/06/2010	**Top of casing (m AHD):**	24.342
Geodetic datum:	GDA94	**Total well depth below GL (m):**	444
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	421 - 426 (Yarragadee)
Easting (X):	402841	**Status:**	Operating
Northing (Y):	6446614	**Depth to reliable measurements (m):**	19

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	-5.5	1.3	0.27	no
Wanneroo	30	20.9	28.2	4.3	0.67	no
Mariginiup	200	25.7	29.9	0.6	0.72	no
Gage	323	29.4	18.9	0.6	0.34	no
Yarragadee	369	30.3	20.5	0.3	0.40	no
Bottom limit	422	31.4	N/A	N/A	N/A	N/A
Depth of log	429.500	31.5	N/A	N/A	N/A	N/A

AM49

Logged by WAGCOE, June 2010



Temperature vs depth for AM49 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

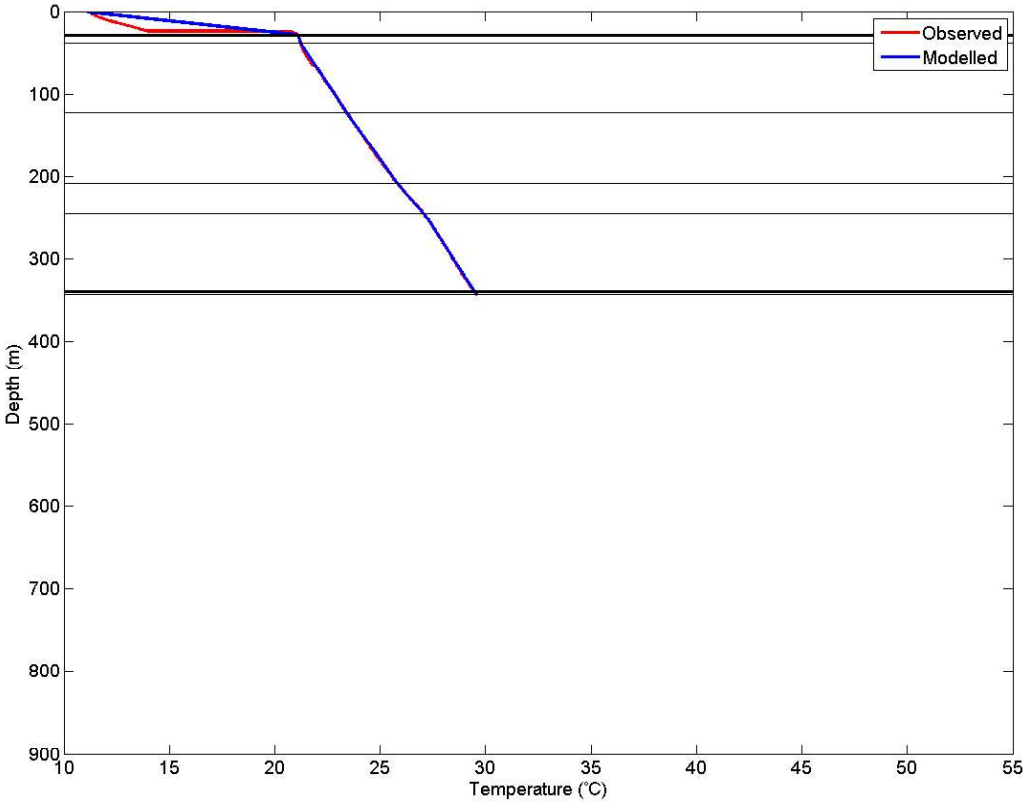
Date construction completed:	N/A	**Ground level (m AHD):**	36.490
Date logged:	25/06/2010	**Top of casing (m AHD):**	36.830
Geodetic datum:	GDA94	**Total well depth below GL (m):**	554
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	526 - 533 (Yarragadee)
Easting (X):	391636	**Status:**	Operating
Northing (Y):	6438965	**Depth to reliable measurements (m):**	51.5

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	36.8	5.5	0.27	yes
Kardinya	53	20.1	42.0	8.4	0.62	yes
Henley	105	22.3	31.9	0.9	0.34	no
Pinjar	118	22.7	41.4	5.8	0.83	yes
Wanneroo	195	25.9	32.6	5.6	0.55	yes
Mariginiup	301	29.3	37.8	0.9	0.92	no
South Perth	375	32.1	42.9	5.1	0.84	yes
Gage	433	34.6	33.8	3.1	0.55	no
Yarragadee	452	35.3	25.1	1.9	0.37	no
Bottom limit	532	37.3	N/A	N/A	N/A	N/A
Depth of log	535.620	37.4	N/A	N/A	N/A	N/A

AM50

Logged by WAGCOE, June 2010



Temperature vs depth for AM50 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

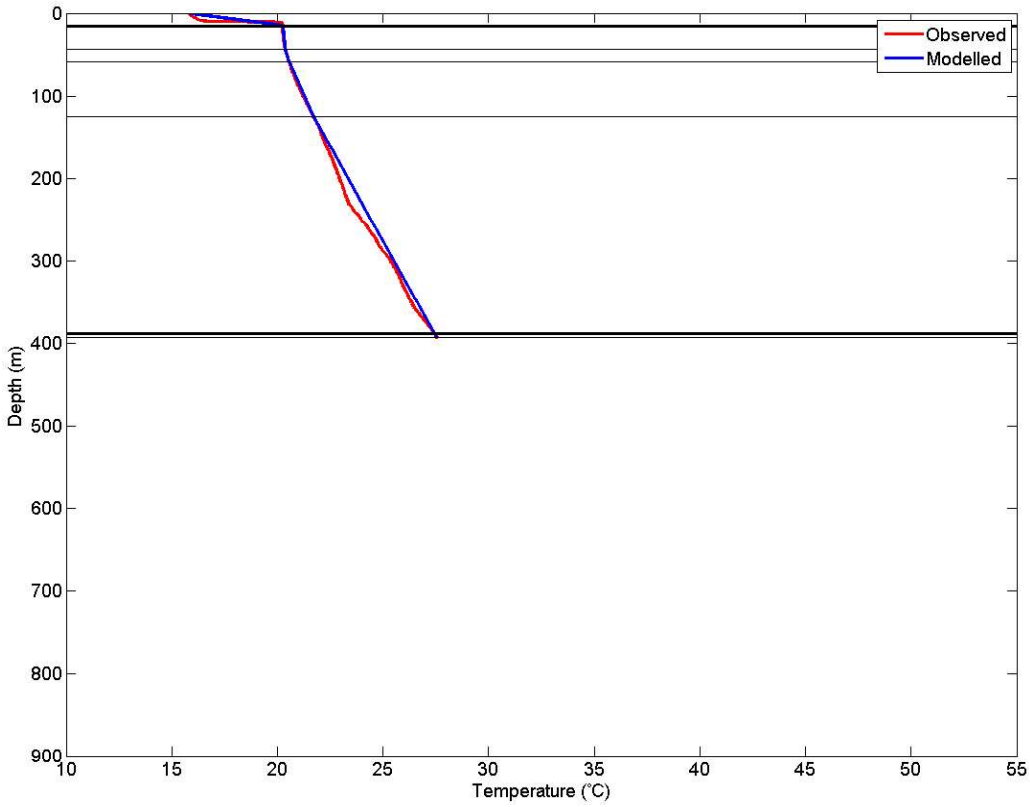
Date construction completed:	21/04/1978	**Ground level (m AHD):**	15.569
Date logged:	29/06/2010	**Top of casing (m AHD):**	15.517
Geodetic datum:	GDA94	**Total well depth below GL (m):**	354
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	314 - 319 (Yarragadee)
Easting (X):	399219	**Status:**	Operating
Northing (Y):	6434287	**Depth to reliable measurements (m):**	28.6

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A	N/A
Pinjar	28	N/A	13.7	0.7	0.89	no
Wanneroo	38	21.2	25.6	2.8	0.47	no
Mariginiup	123	23.4	28.1	1.5	0.72	no
South Perth	209	25.8	34.6	1.4	0.76	no
Yarragadee	245	27.1	25.3	0.9	0.57	no
Bottom limit	340	29.5	N/A	N/A	N/A	N/A
Depth of log	343.050	29.6	N/A	N/A	N/A	N/A

AM51

Logged by WAGCOE, June 2010



Temperature vs depth for AM51 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

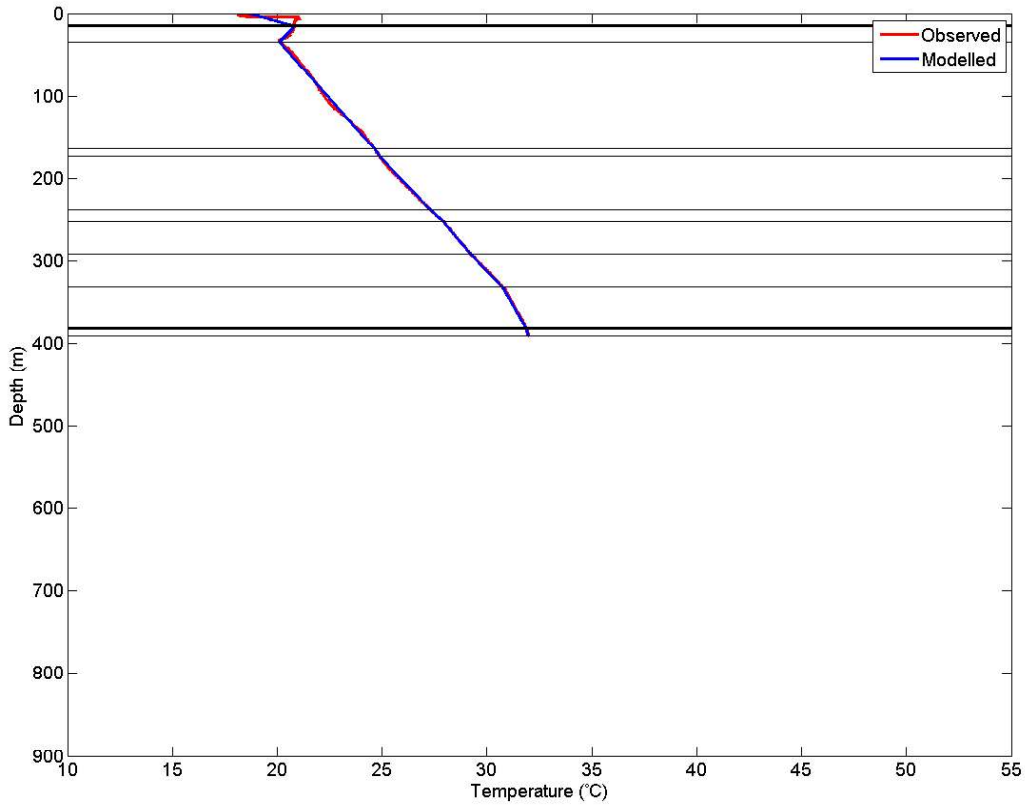
Date construction completed:	15/05/1979	**Ground level (m AHD):**	27.180
Date logged:	28/06/2010	**Top of casing (m AHD):**	27.710
Geodetic datum:	GDA94	**Total well depth below GL (m):**	421
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	335 - 345 (Yarragadee)
Easting (X):	403687	**Status:**	Operating
Northing (Y):	6439011	**Depth to reliable measurements (m):**	16.2

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A	N/A
Pinjar	15	N/A	4.1	3.1	0.48	no
Wanneroo	44	20.4	12.1	0.5	0.57	no
Mariginiup	59	20.6	17.3	3.1	0.61	no
Cattamarra	125	21.7	21.7	8.4	0.45	yes
Bottom limit	389	27.4	N/A	N/A	N/A	N/A
Depth of log	393.670	27.6	N/A	N/A	N/A	N/A

AM52Y (Garden Island North)

Logged by WAGCOE, July 2010



Temperature vs depth for AM52Y (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

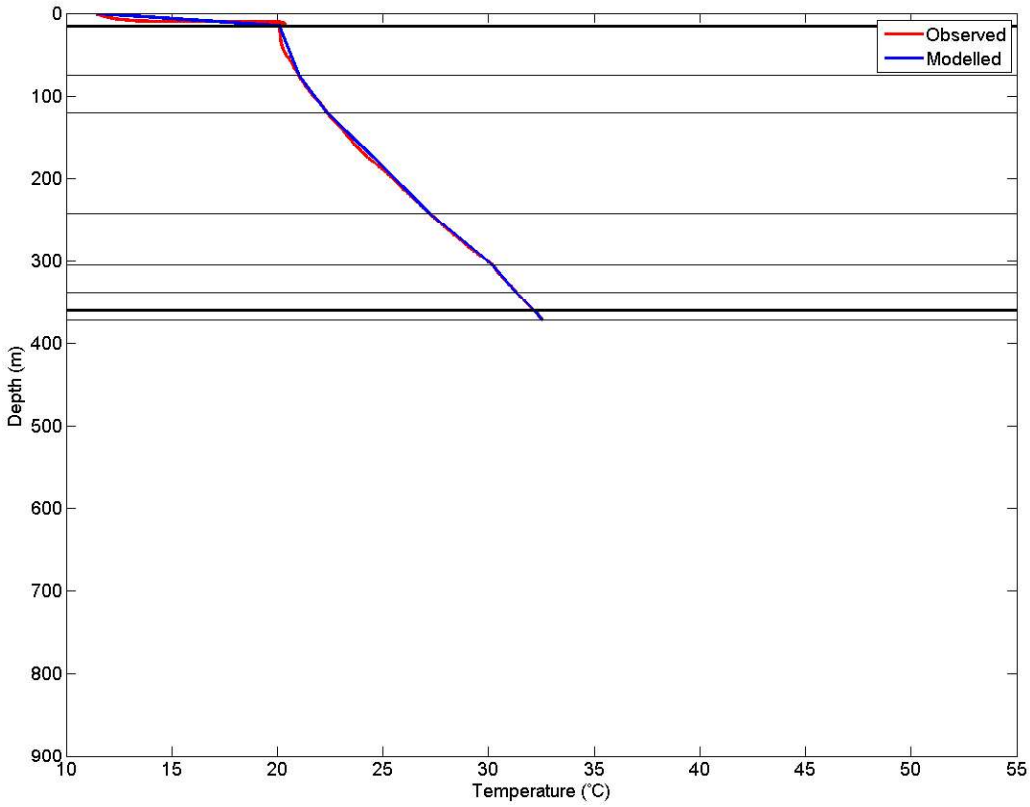
Date construction completed:	30/06/1943	**Ground level (m AHD):**	6.020
Date logged:	07/07/2010	**Top of casing (m AHD):**	6.800
Geodetic datum:	GDA94	**Total well depth below GL (m):**	436
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	381 - 396 (Yarragadee)
Easting (X):	374326	**Status:**	Operating
Northing (Y):	6441206	**Depth to reliable measurements (m):**	15.0

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	-36.7	11.7	0.18	yes
Kardinya	34	20.1	34.8	4.2	0.56	no
Henley	164	24.6	26.5	1.2	0.38	no
Pinjar	174	24.9	37.9	3.7	1.00	no
Wanneroo	238	27.3	40.6	0.7	0.93	no
Mariginiup	252	27.9	33.0	0.5	1.10	no
South Perth	292	29.2	37.6	2.3	0.86	no
Gage	332	30.7	22.5	2.4	0.54	no
Bottom limit	382	31.9	N/A	N/A	N/A	N/A
Depth of log	390.810	32.0	N/A	N/A	N/A	N/A

AM55

Logged by WAGCOE, July 2010



Temperature vs depth for AM55 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 5 m min^{-1}; logging interval: 5 cm

Well specifics

Date construction completed:	N/A	**Ground level (m AHD):**	7.440
Date logged:	01/07/2010	**Top of casing (m AHD):**	7.930
Geodetic datum:	GDA94	**Total well depth below GL (m):**	405
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	360 - 366 (Yarragadee)
Easting (X):	392475	**Status:**	Operating
Northing (Y):	6423101	**Depth to reliable measurements (m):**	15.4

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Average heat production (µW m^{-3})	Advection (yes/no)
Superficial	0	N/A	-17.3	1.3	0.23	no
Pinjar	17	20.1	15.6	9.7	0.77	yes
Wanneroo	75	21.0	29.3	3.2	0.48	no
Mariginiup	120	22.3	39.7	5.8	0.74	yes
South Perth	242	27.2	47.5	3.8	0.77	no
Gage	305	30.2	33.6	2.0	0.51	no
Yarragadee	339	31.3	38.7	1.3	0.68	no
Bottom limit	361	32.2	N/A	N/A	N/A	N/A
Depth of log	371.748	32.5	N/A	N/A	N/A	N/A

APPENDIX B – SUMMARY SHEETS OF DATA BY WELL DIGITISED BY WAGCOE

This appendix contains summary sheets of the data available for each well digitised by WAGCOE; the results are less reliable than the high precision measurements of Appendix A. Each page compiles the available information about the well:

- A *chart* of the temperature log in red, and the conductive model overlain in blue. The logging speed and interval are also represented below the chart.
- The *well specifics* table describes the construction and logging date, georeferencing data, elevations of ground, top of casing, and total depth, the perforated interval and formation, the current status, and the depth to reliable measurements as determined in section 4.1.
- The *logging results* table describes the formation divisions, and within each formation data includes
    - Temperature,
    - Thermal gradient,
    - Error between model and observed data,
    - Average heat production,
    - Whether advection is observed.

Appendix B: Source of data & explanation of terms

Much of the geoereferencing data was obtained from the Western Australian Department of Water. The DoW produces an "All Site Details Report" for each well in their monitoring network.

Date construction completed: 'To Date' under 'Construction Events' in All Site Details Report. A designation of N/A means the information is neither in the All Site Details Report or Davidson [1995].

Date logged: 'Date' in header of original JPEG.

Geodetic datum: 'GDAT' in LAS file.

Horizontal coordinate system: 'HZCS' in LAS file.

Easting (X): 'Easting' in All Site Details report.

Northing (Y): 'Northing' in All Site Details Report.

Ground level (m AHD): 'GL' under 'Datum Planes' in All Site Details Report. If it was not in the All Site Details Report, it was taken from 'Ground level' in Table 4 of Davidson [1995].

Top of casing (m AHD): 'TOC' under 'Datum Planes' in All Site Details Report. If it was not included in the All Site Details Report, it was taken from 'Top casing' in Table 4 of Davidson [1995].

Total well depth below GL (m): There was often conflicting values for the total well depth below ground level. In the cases where the value from 'Construction Events' in the All Site Details Reports was different to the value from 'Depth below GL' in Table 4 of Davidson [1995], the depth in the All Site Details Report was taken to be correct. A designation of N/A means the information is neither in the All Site Details Report or Davidson [1995].

Perforated interval (m) (formation): 'Perforations below GL' and 'Aquifer' in Table 4 of Davidson [1995]. A designation of N/A means the information is neither in the All Site Details Report or Davidson [1995].

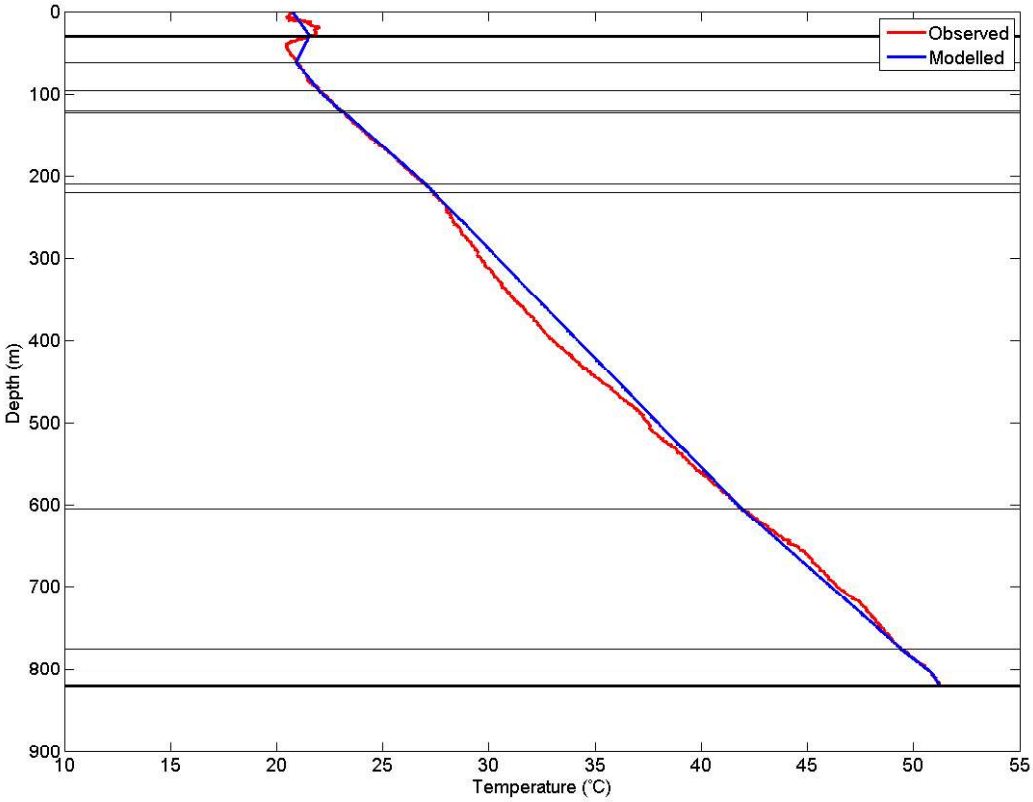
Status: 'Status' in All Site Details Report. E.g. Operating, abandoned, replaced by, decommissioned.

Depth to reliable measurements: The depth at which the analysis commenced. Thermal gradients and errors for the top formations were measured from this depth, not the top of the formation. Eg. AM20: the top of the superficial is 0 m, the top of the Pinjar is 53 m and the depth to reliable measurements is 15 m. Therefore, the analysis for the superficial was conducted over the interval 15 – 53 m, not 0 – 53 m. Depths to reliable measurements were determined by which was the deepest out of seasonal influence (estimated at 15 m) or the depth to the base of the water table influence (estimated from water table data retrieved from the WA DoW Water Resources Information Catalogue).

Bottom limit: The depth of the last reading deemed reliable. E.g. AM20: the top of the Yarragadee is 313 m, the bottom limit is 368 m and the depth of the log is 371.790 m. Therefore, the analysis for the Yarragadee was conducted over the interval 313 – 368 m, not 313 – 371.790 m.

AM2 (Barragoon No 1)

Digitised by WAGCOE, April 2010



Temperature vs depth for AM2 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 3 sec

Well specifics

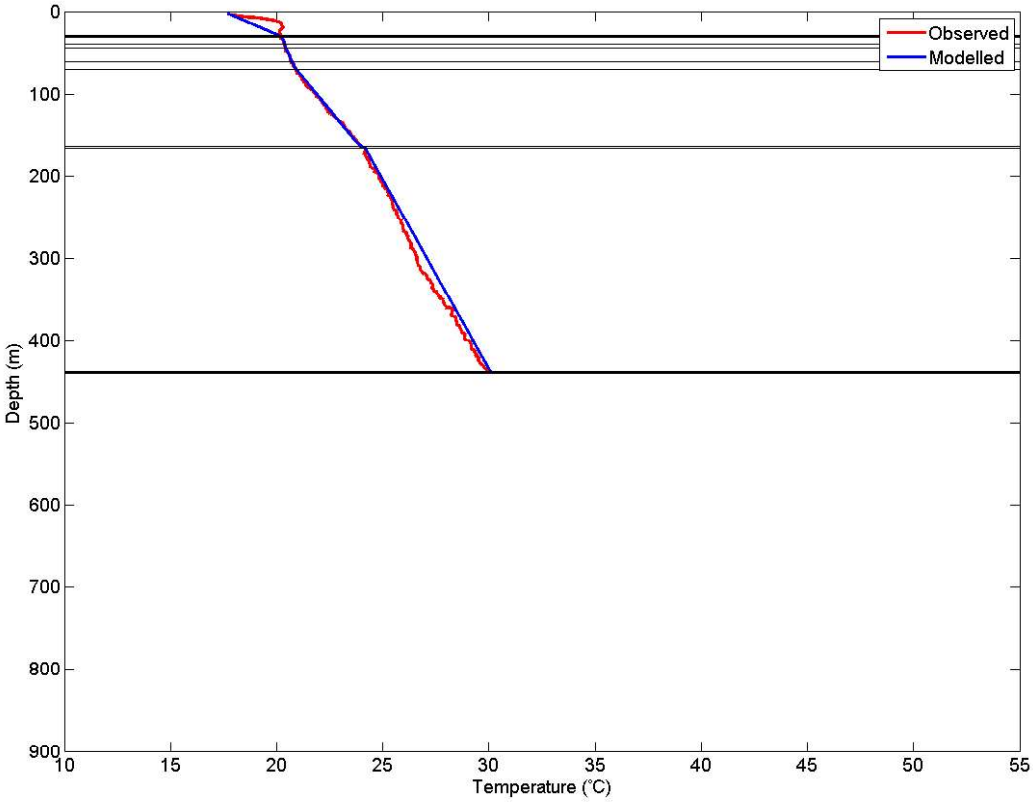
Date construction completed:	30/06/1976	**Ground level (m AHD):**	35.650
Date logged:	01/10/1980	**Top of casing (m AHD):**	36.176
Geodetic datum:	GDA94	**Total well depth below GL (m):**	836
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	819 - 825 (Yarragadee)
Easting (X):	365659	**Status:**	Operating
Northing (Y):	6529664	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	-19.7	14.1	yes
Lancelin	61	20.9	30.7	1.7	no
Gingin	96	22.0	43.0	1.5	no
Molecap	120	23.0	84.3	1.2	no
Kardinya	123	23.2	43.8	1.3	no
Pinjar	210	27.0	40.4	1.2	no
Wanneroo	220	27.4	37.7	5.3	yes
Mariginiup	605	41.9	44.1	3.8	no
South Perth	775	49.4	51.3	1.0	no
Gage	803	50.8	25.2	1.0	no
Depth of log	821.0	51.2	N/A	N/A	N/A

AM3

Digitised by WAGCOE, April 2010



Temperature vs depth for AM3 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

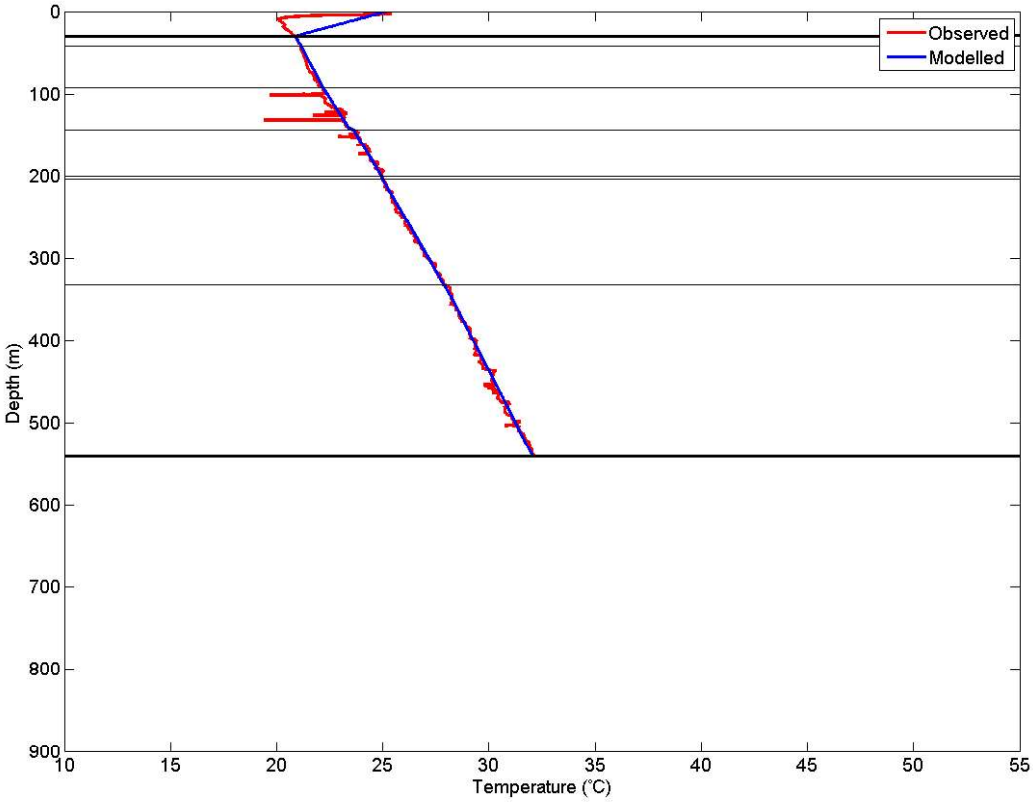
Date construction completed:	30/06/1981	**Ground level (m AHD):**	26.660
Date logged:	09/09/1982	**Top of casing (m AHD):**	27.600
Geodetic datum:	GDA94	**Total well depth below GL (m):**	729
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	400 - 408 (Leederville)
Easting (X):	367230	**Status:**	Operating
Northing (Y):	6535516	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	20.7	2.2	no
Lancelin	39	20.4	4.5	0.1	no
Gingin	44	20.4	17.1	1.4	no
Molecap	60	20.7	21.3	1.4	no
Kardinya	70	20.9	32.3	1.2	no
Pinjar	164	23.9	93.0	3.3	no
Wanneroo	167	24.2	21.8	2.6	no
Depth of log	440.0	30.1	N/A	N/A	N/A

AM4A

Digitised by WAGCOE, April 2010



Temperature vs depth for AM4A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

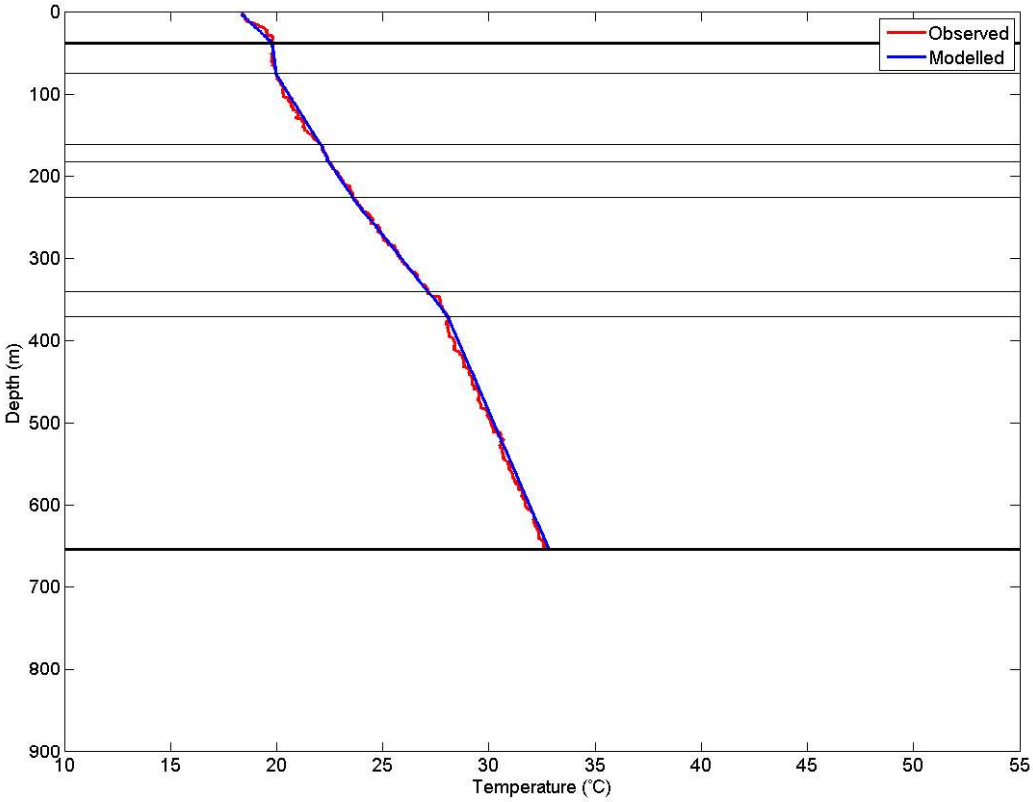
Date construction completed:	N/A	**Ground level (m AHD):**	50.200
Date logged:	01/03/1983	**Top of casing (m AHD):**	50.400
Geodetic datum:	GDA94	**Total well depth below GL (m):**	550
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	434 - 440 (Yarragadee)
Easting (X):	383765	**Status:**	Being decommissioned
Northing (Y):	6535457	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	24.3	1.4	no
Pinjar	41	21.1	20.0	2.9	no
Wanneroo	92	22.2	24.6	10.9	yes
Mariginiup	143	23.6	23.1	3.0	no
South Perth	200	24.9	1.6	3.2	no
Gage	204	25.0	22.6	1.3	no
Yarragadee	332	27.9	19.9	1.3	no
Depth of log	541.0	32.1	N/A	N/A	N/A

AM8

Digitised by WAGCOE, April 2010



Temperature vs depth for AM8 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

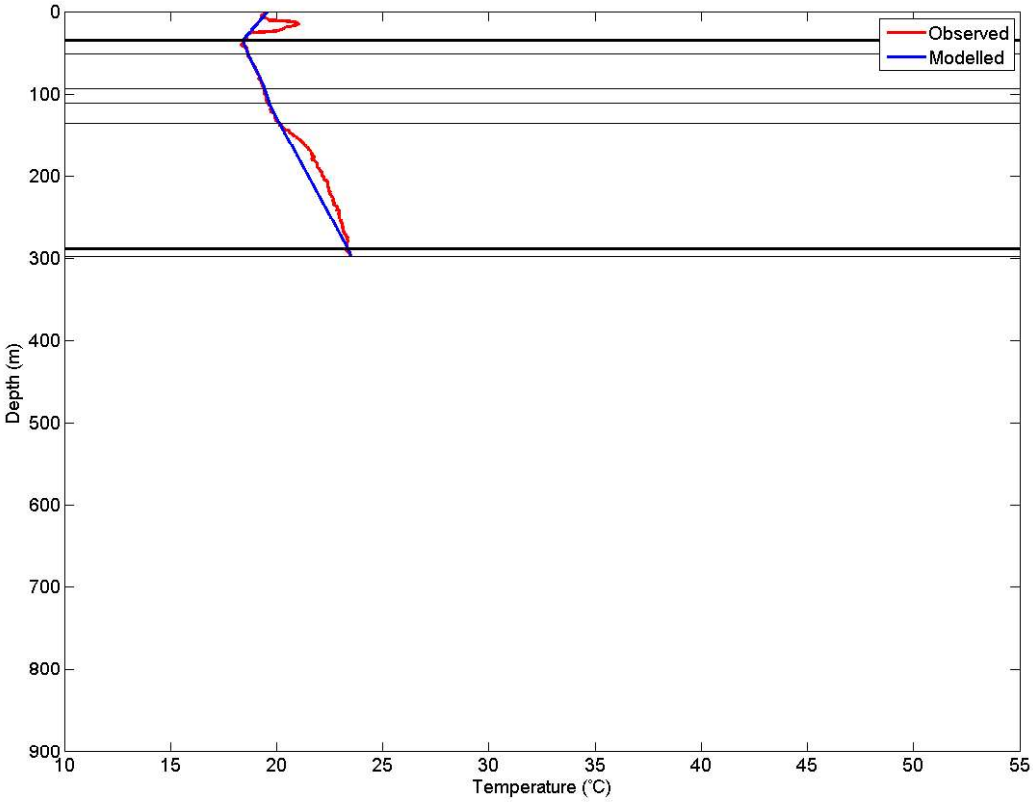
Date construction completed:	30/06/1981	**Ground level (m AHD):**	52.320
Date logged:	18/08/1982	**Top of casing (m AHD):**	52.752
Geodetic datum:	GDA94	**Total well depth below GL (m):**	810
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	636 - 642 (Leederville)
Easting (X):	369021	**Status:**	Operating
Northing (Y):	6522809	**Depth to reliable measurements (m):**	38

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	4.8	1.4	no
Kings Park	75	19.9	24.6	2.7	no
Lancelin	162	22.1	17.1	1.3	no
Gingin	183	22.4	26.6	1.8	no
Kardinya	226	23.5	31.3	1.1	no
Pinjar	340	27.1	29.9	3.7	no
Wanneroo	371	28.0	16.8	1.4	no
Depth of log	654.5	32.8	N/A	N/A	N/A

AM10

Digitised by WAGCOE, April 2010



Temperature vs depth for AM10 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

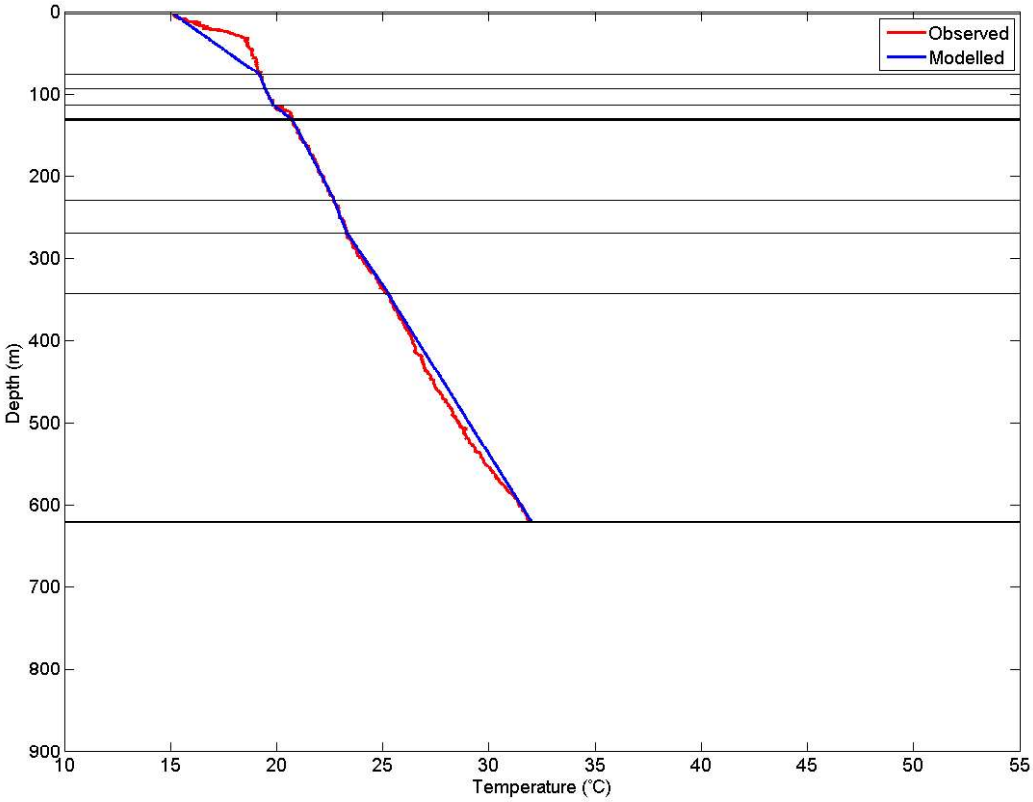
Date construction completed:	15/05/1977	**Ground level (m AHD):**	69.250
Date logged:	03/10/1980	**Top of casing (m AHD):**	69.860
Geodetic Datum:	GDA94	**Total well depth below GL (m):**	298
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	286 - 291 (Yarragadee)
Easting (X):	392252	**Status:**	Operating
Northing (Y):	6521849	**Depth to reliable measurements (m):**	34

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	13.0	2.8	no
Pinjar	51	18.6	19.2	0.7	no
Wanneroo	93	19.4	13.9	1.8	no
Mariginiup	111	19.6	19.1	1.3	no
Parmelia	135	20.1	21.1	6.2	yes
Bottom limit	288	23.3	N/A	N/A	N/A
Depth of log	297.5	23.5	N/A	N/A	N/A

AM11

Digitised by WAGCOE, April 2010



Temperature vs depth for AM11 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

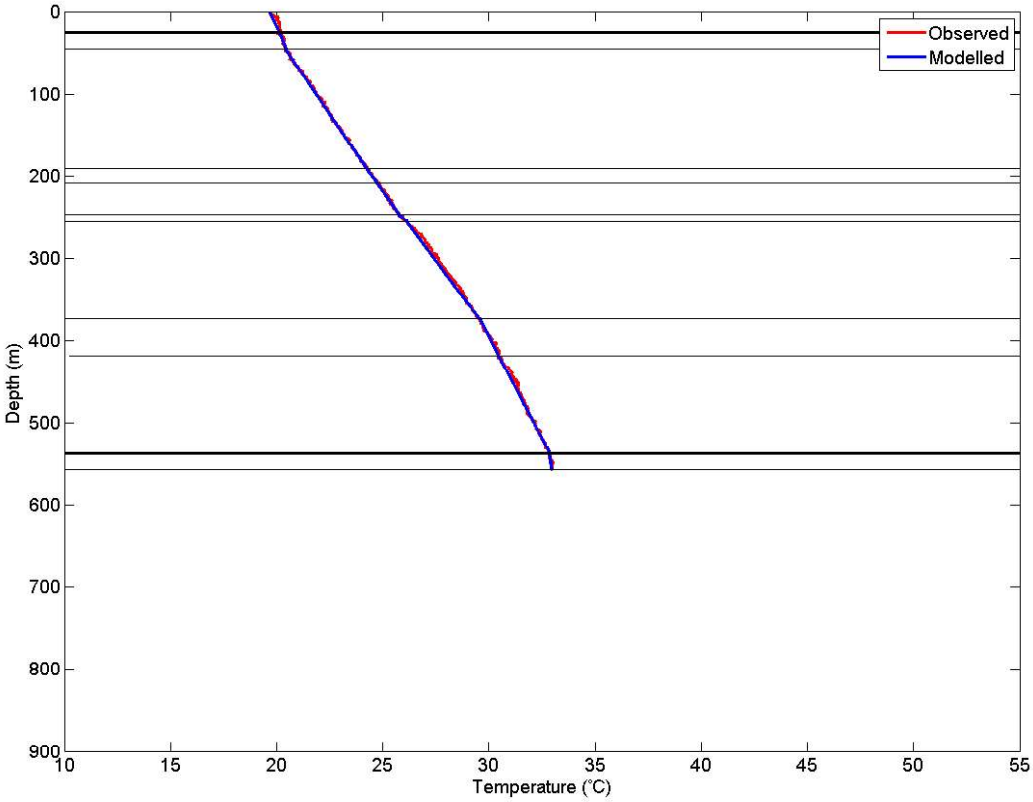
Date construction completed:	30/06/1981	**Ground level (m AHD):**	190.300
Date logged:	14/09/1982	**Top of casing (m AHD):**	191.020
Geodetic datum:	GDA94	**Total well depth below GL (m):**	810
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	603 - 609 (Leederville)
Easting (X):	406614	**Status:**	Operating
Northing (Y):	6525106	**Depth to reliable measurements (m):**	131

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Poison Hill	3	N/A	N/A	N/A	N/A
Gingin	76	N/A	N/A	N/A	N/A
Molecap	93	N/A	N/A	N/A	N/A
Kardinya	113	N/A	20.1	0.7	no
Henley	229	22.7	14.9	1.2	no
Pinjar	270	23.3	27.2	2.1	no
Wanneroo	342	25.2	24.5	3.1	no
Depth of log	620.5	32.0	N/A	N/A	N/A

AM12

Digitised by WAGCOE, April 2010



Temperature vs depth for AM12 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

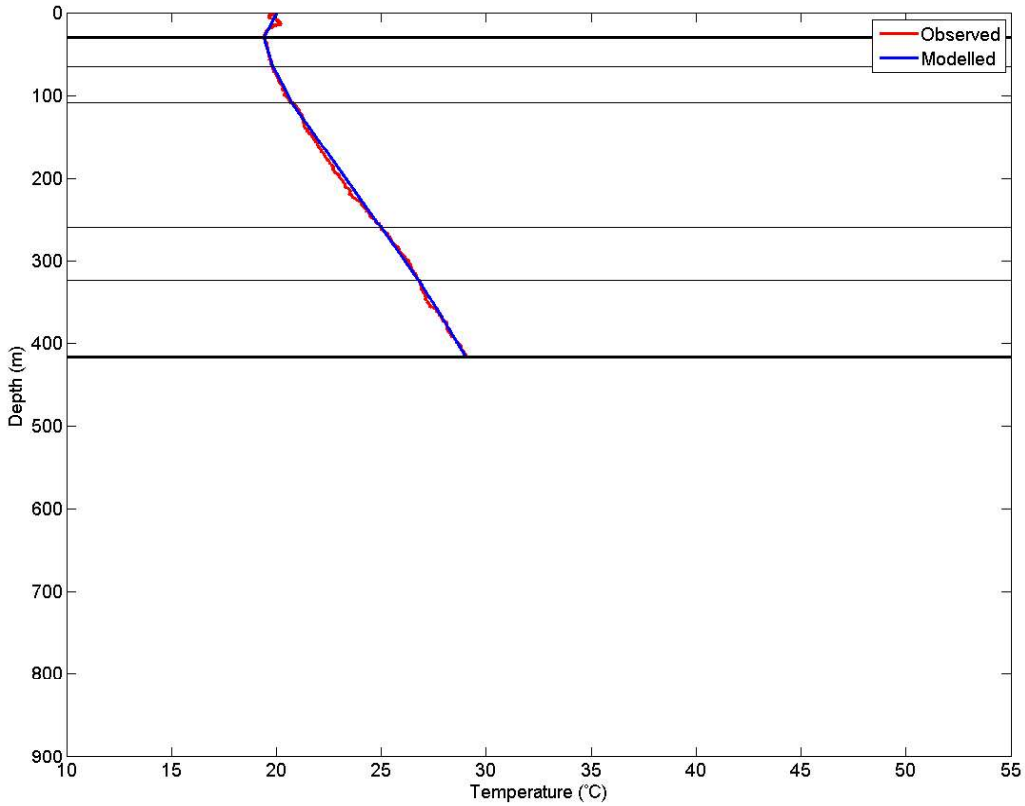
Date construction completed:	15/05/1977	**Ground level (m AHD):**	16.050
Date logged:	13/07/1982	**Top of casing (m AHD):**	16.742
Geodetic datum:	GDA94	**Total well depth below GL (m):**	572
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	548 - 553 (Leederville)
Easting (X):	368586	**Status:**	Operating
Northing (Y):	6511729	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	16.8	1.9	no
Kings Park	45	20.4	26.3	0.6	no
Lancelin	191	24.2	28.7	1.9	no
Gingin	208	24.7	27.7	1.5	no
Molecap	247	25.8	44.9	2.7	no
Kardinya	256	26.1	29.2	1.9	no
Pinjar	373	29.6	19.2	1.8	no
Wanneroo	419	30.4	20.5	1.2	no
Bottom limit	537	32.9	N/A	N/A	N/A
Depth of log	557.0	33.0	N/A	N/A	N/A

AM13 (Wreck Pt No 2)

Digitised by WAGCOE, April 2010



Temperature vs depth for AM13 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

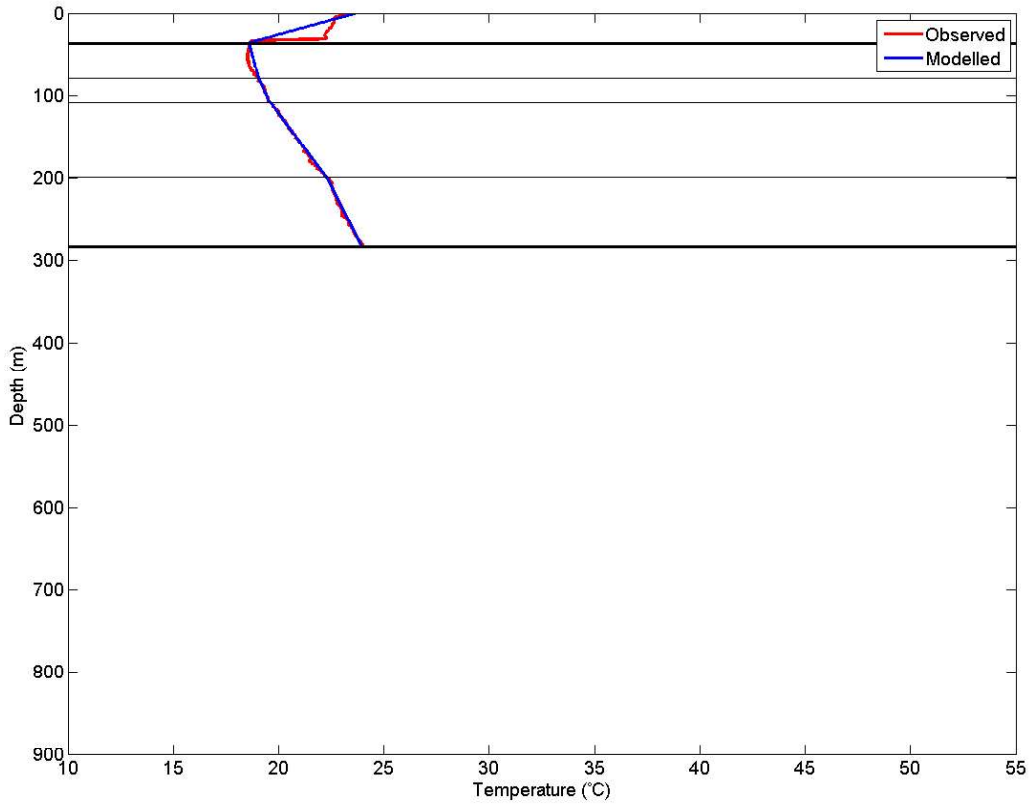
Date construction completed:	30/06/1977	**Ground level (m AHD):**	53.580
Date logged:	26/09/1980	**Top of casing (m AHD):**	54.620
Geodetic datum:	GDA94	**Total well depth below GL (m):**	798
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	392 - 397 (Yarragadee)
Easting (X):	374938	**Status:**	Operating
Northing (Y):	6516946	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	12.3	0.8	no
Pinjar	65	19.8	20.5	1.5	no
Wanneroo	108	20.7	28.2	2.2	no
Mariginiup	259	25.0	27.7	1.5	no
Yarragadee	323	26.8	24.1	1.7	no
Depth of log	416.5	29.0	N/A	N/A	N/A

AM17

Digitised by WAGCOE, April 2010



Temperature vs depth for AM17 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 5sec

Well specifics

Date construction completed:	15/04/1977	**Ground level (m AHD):**	72.260
Date logged:	25/09/1980	**Top of casing (m AHD):**	73.030
Geodetic datum:	GDA94	**Total well depth below GL (m):**	303
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	259 - 264 (Yarragadee)
Easting (X):	384310	**Status:**	Operating
Northing (Y):	6510058	**Depth to reliable measurements (m):**	36

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	10.4	4.4	no
Wanneroo	80	19.1	17.5	1.3	no
Mariginiup	108	19.6	29.2	1.1	no
Yarragadee	199	22.3	19.4	1.0	no
Depth of log	283.5	24.0	N/A	N/A	N/A

AM22

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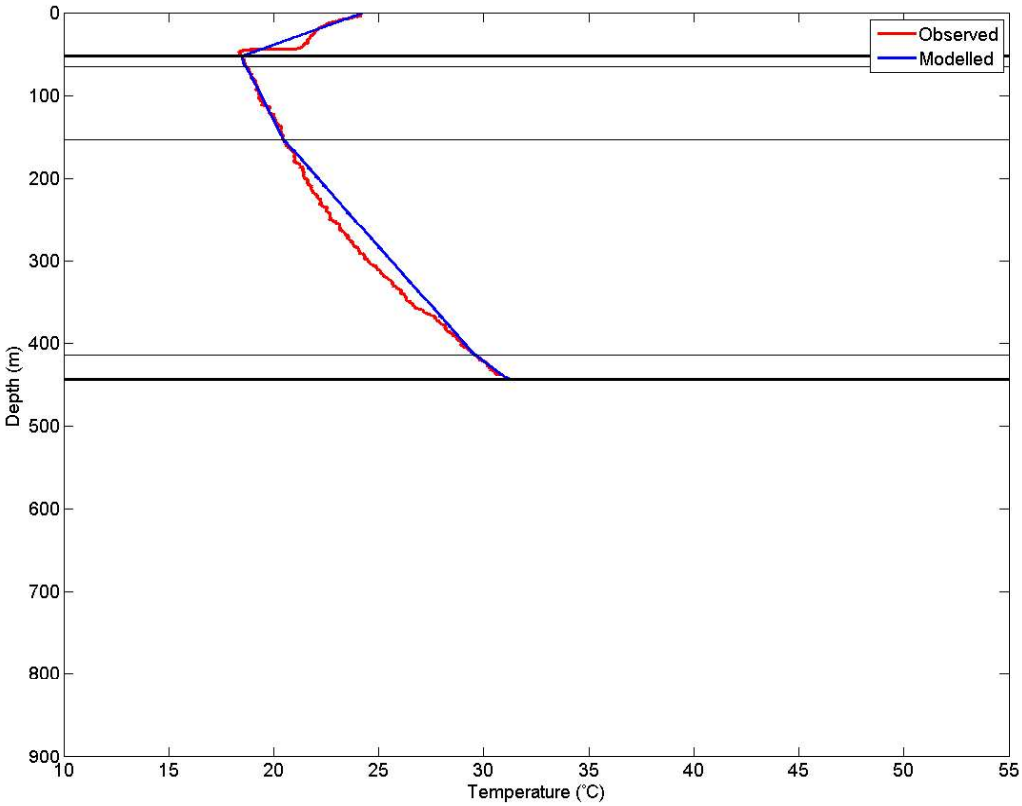


Temperature vs depth for AM22 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

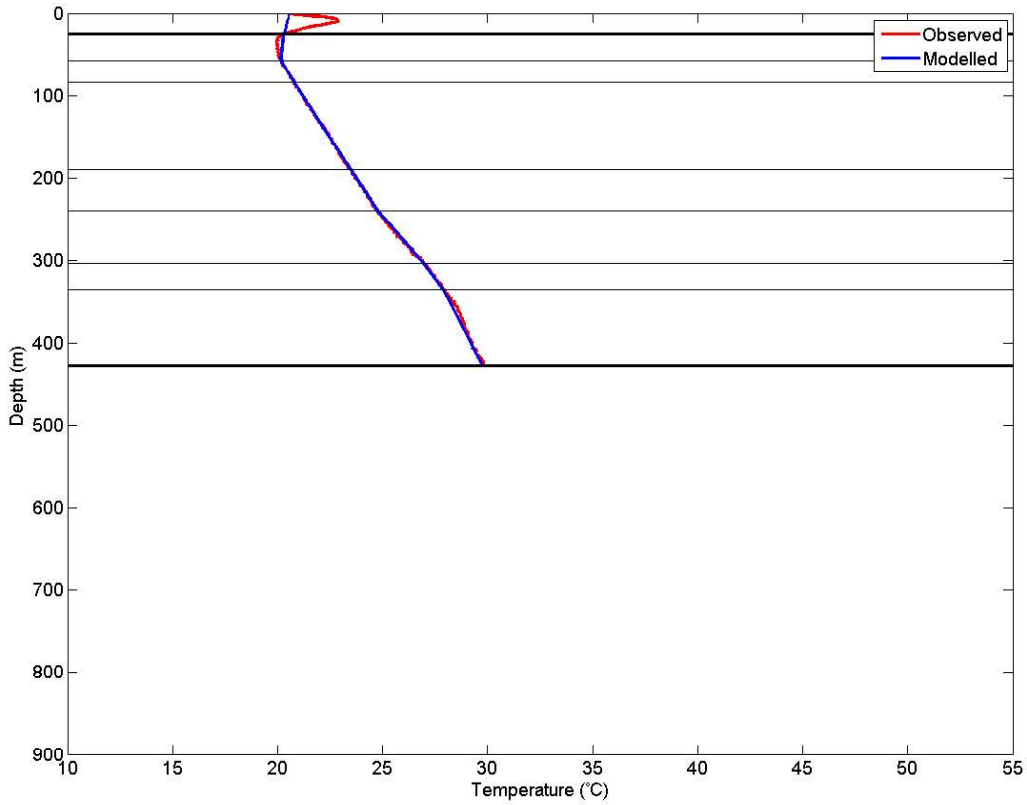
Date construction completed:	15/03/1978	**Ground level (m AHD):**	80.980
Date logged:	03/02/1981	**Top of casing (m AHD):**	81.447
Geodetic datum:	GDA94	**Total well depth below GL (m):**	610
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	540 - 549 (Yarragadee)
Easting (X):	395225	**Status:**	Operating
Northing (Y):	6501475	**Depth to reliable measurements (m):**	52

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	11.2	1.2	no
Pinjar	64	18.7	20.3	1.4	no
Wanneroo	153	20.5	34.8	6.7	yes
Parmelia	414	29.6	52.2	3.3	no
Depth of log	444.0	31.2	N/A	N/A	N/A

AM23

Digitised by WAGCOE, April 2010



Temperature vs depth for AM23 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

Date construction completed:	15/04/1979	**Ground level (m AHD):**	29.281
Date logged:	13/07/1982	**Top of casing (m AHD):**	29.981
Geodetic datum:	GDA94	**Total well depth below GL (m):**	470
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	403 - 412 (Yarragadee)
Easting (X):	380401	**Status:**	Operating
Northing (Y):	6493081	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	-4.4	4.9	no
Pinjar	57	20.1	23.6	0.8	no
Wanneroo	84	20.8	25.6	0.6	no
Mariginiup	190	23.5	25.7	0.8	no
South Perth	240	24.8	34.0	1.5	no
Gage	304	27.0	29.6	1.5	no
Yarragadee	335	27.9	20.3	2.0	no
Depth of log	426.5	30.0	N/A	N/A	N/A

AM24

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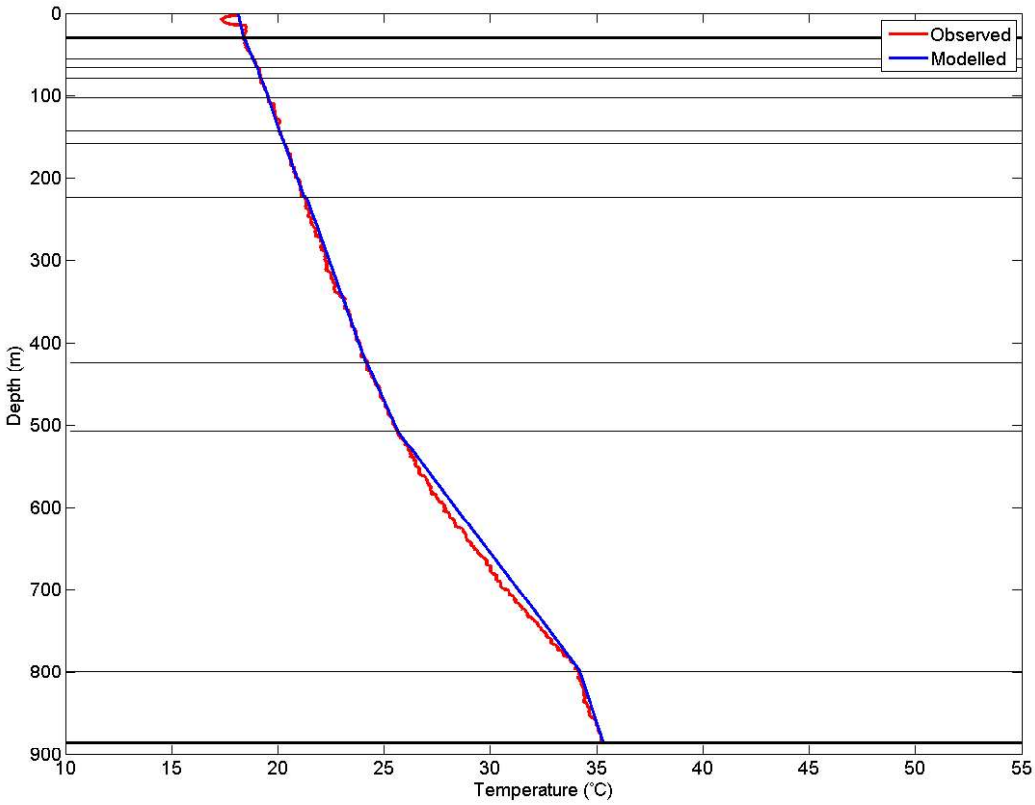


Temperature vs depth for AM24 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

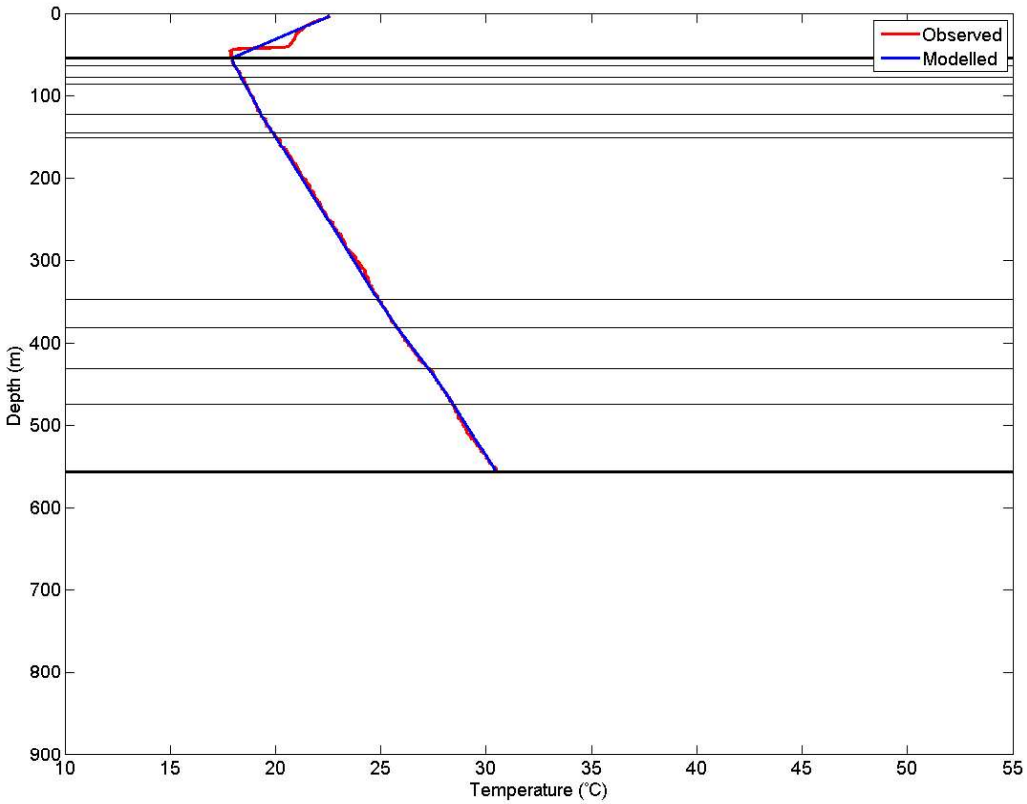
Date construction completed:	15/03/1979	**Ground level (m AHD):**	49.580
Date logged:	23/10/1980	**Top of casing (m AHD):**	49.982
Geodetic datum:	GDA94	**Total well depth below GL (m):**	908
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	882 - 890 (Yarragadee)
Easting (X):	389756	**Status:**	Operating
Northing (Y):	6491298	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	16.6	1.5	no
Poison Hill	55	18.8	18.8	1.5	no
Gingin	66	19.0	8.4	1.4	no
Molecap	80	19.2	14.9	1.2	no
Kardinya	103	19.5	13.1	2.0	no
Henley	142	20.1	15.2	0.8	no
Pinjar	157	20.3	14.4	0.8	no
Wanneroo	223	21.3	14.0	1.3	no
Mariginiup	423	24.2	17.5	0.8	no
South Perth	507	25.6	29.5	3.7	no
Gage	798	34.2	12.8	2.0	no
Depth of log	885.5	35.3	N/A	N/A	N/A

AM25

Digitised by WAGCOE, April 2010



Temperature vs depth for AM25 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

Date construction completed:	15/02/1978	**Ground level (m AHD):**	72.590
Date logged:	14/01/1983	**Top of casing (m AHD):**	72.901
Geodetic datum:	GDA94	**Total well depth below GL (m):**	619
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	316 - 322 (Leederville)
Easting (X):	396235	**Status:**	Operating
Northing (Y):	6494929	**Depth to reliable measurements (m):**	54

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	11.8	1.1	no
Poison Hill	63	18.1	18.5	1.3	no
Gingin	78	18.3	24.0	3.4	no
Molecap	87	18.5	21.8	1.0	no
Kardinya	122	19.3	26.2	1.3	no
Pinjar	144	19.9	18.4	2.3	no
Wanneroo	150	20.0	24.6	1.1	no
Mariginiup	348	24.9	26.7	0.7	no
South Perth	382	25.8	30.0	1.2	no
Gage	430	27.2	26.7	0.9	no
Parmelia	474	28.4	24.9	1.6	no
Depth of log	557.0	30.5	N/A	N/A	N/A

AM26B (RAAF No 4)

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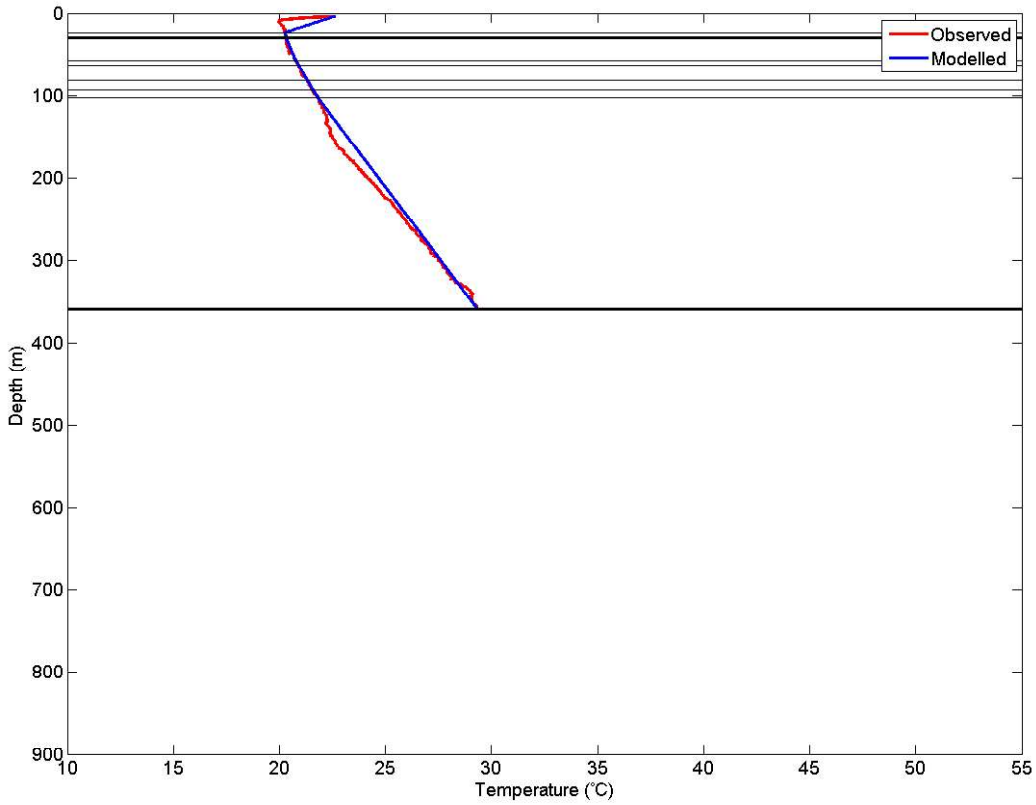

Temperature vs depth for AM26B (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

Date construction completed:	30/06/1966	**Ground level (m AHD):**	37.400
Date logged:	18/01/1983	**Top of casing (m AHD):**	38.287
Geodetic datum:	GDA94	**Total well depth below GL (m):**	375
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	N/A (Leederville)
Easting (X):	404935	**Status:**	Operating
Northing (Y):	6497315	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Poison Hill	24	N/A	16.1	1.9	no
Gingin	57	20.8	22.0	0.7	no
Molecap	63	20.9	21.0	1.6	no
Kardinya	82	21.3	24.1	1.3	no
Henley	94	21.6	26.4	1.8	no
Wanneroo	103	21.8	29.3	3.5	no
Depth of log	359.0	29.3	N/A	N/A	N/A

AM27 (Whitfords No 1)

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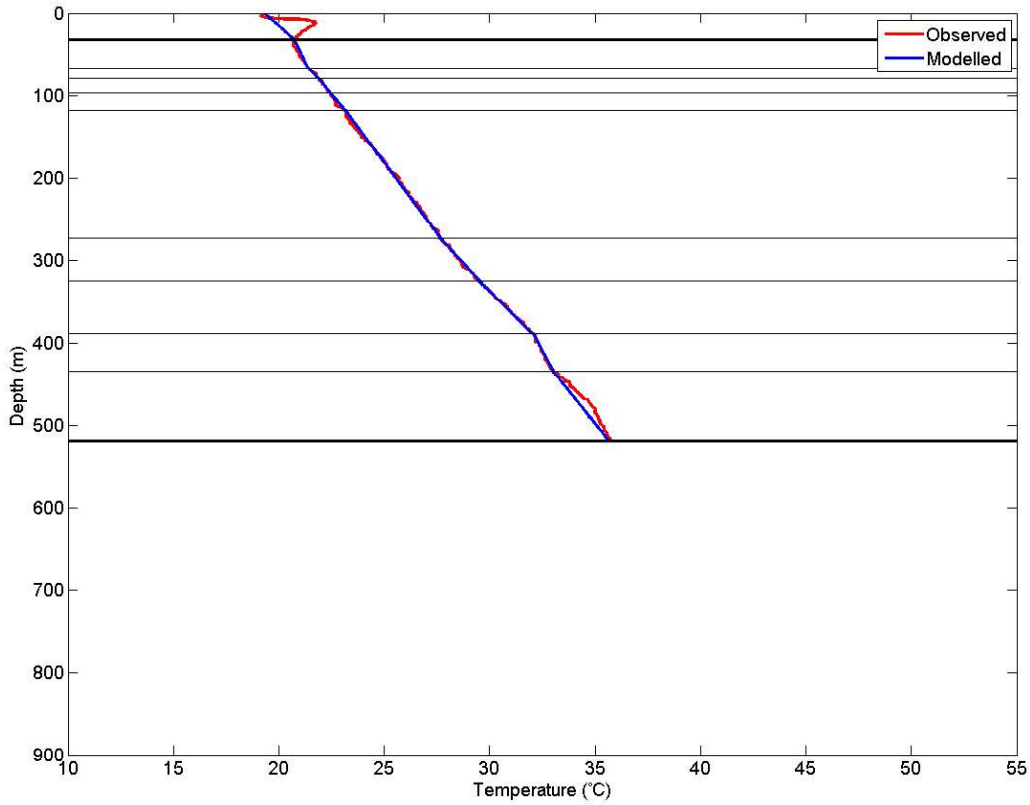


Temperature vs depth for AM27 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

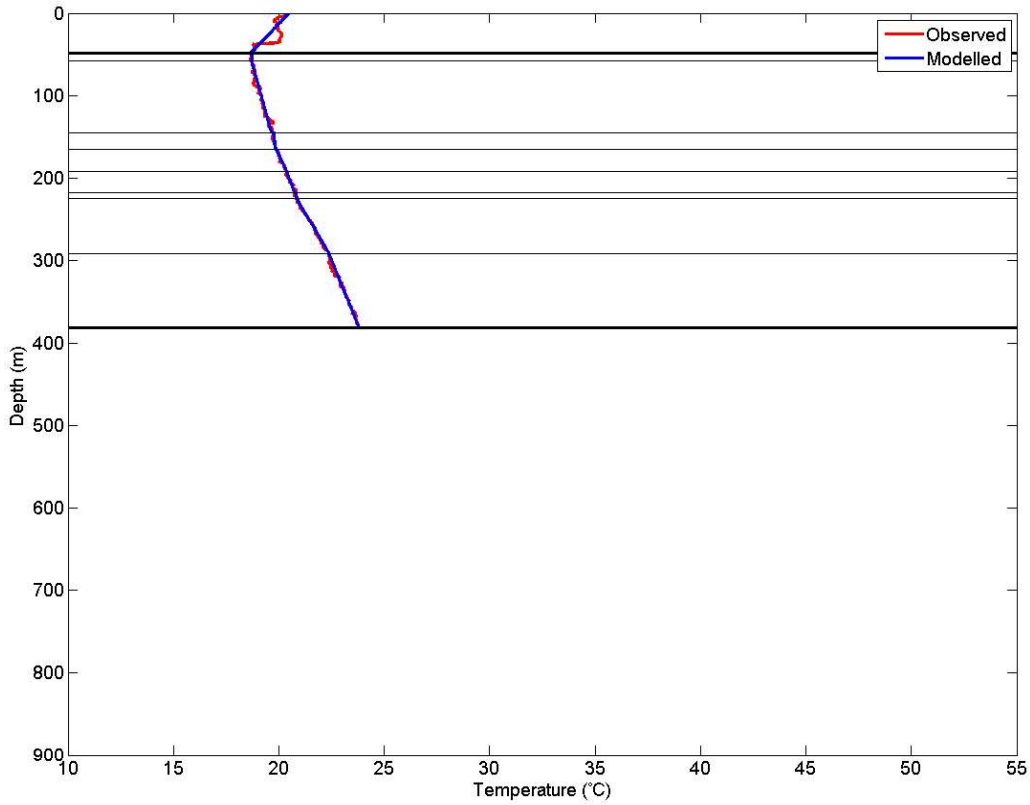
Date construction completed:	20/02/1973	**Ground level (m AHD):**	34.059
Date logged:	23/09/1980	**Top of casing (m AHD):**	34.337
Geodetic datum:	GDA94	**Total well depth below GL (m):**	763
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	522 - 528 (Yarragadee)
Easting (X):	384682	**Status:**	Operating
Northing (Y):	6483683	**Depth to reliable measurements (m):**	32

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	18.5	2.2	no
Molecap	67	21.4	38.0	1.5	no
Henley	80	21.9	29.6	1.0	no
Pinjar	97	22.4	34.0	3.8	no
Wanneroo	118	23.2	29.0	1.1	no
Mariginiup	273	27.6	36.2	1.5	no
South Perth	325	29.5	39.3	0.7	no
Gage	389	32.1	20.9	0.9	no
Yarragadee	434	33.0	31.4	5.3	yes
Depth of log	518.0	35.7	N/A	N/A	N/A

AM28

Digitised by WAGCOE, April 2010



Temperature vs depth for AM28 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

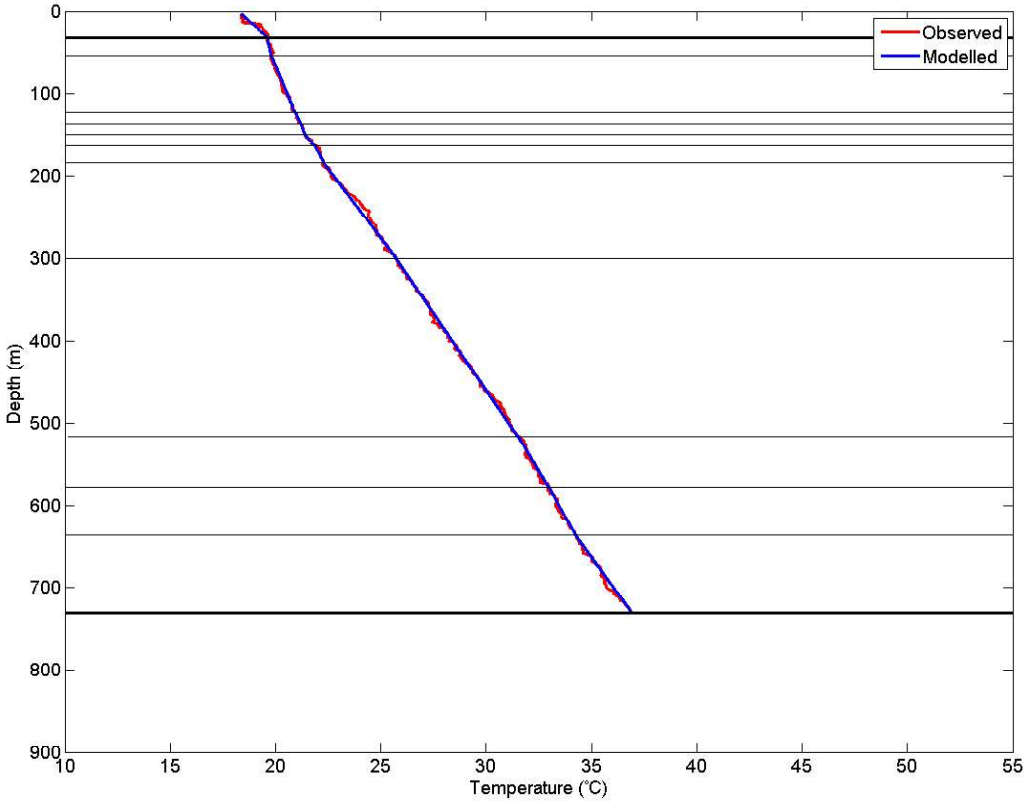
Date construction completed:	30/06/1978	**Ground level (m AHD):**	52.633
Date logged:	12/11/1980	**Top of casing (m AHD):**	53.360
Geodetic datum:	GDA94	**Total well depth below GL (m):**	625
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	381 - 390 (Leederville)
Easting (X):	392626	**Status:**	Replaced by AM28A
Northing (Y):	6485036	**Depth to reliable measurements (m):**	48

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	3.9	1.9	no
Poison Hill	58	18.7	11.0	1.4	no
Gingin	144	19.7	4.1	1.6	no
Molecap	165	19.8	19.3	1.2	no
Kardinya	192	20.3	14.8	1.6	no
Henley	218	20.8	5.2	3.2	no
Pinjar	225	20.8	22.9	0.9	no
Wanneroo	292	22.4	15.9	1.2	no
Depth of log	381.5	23.8	N/A	N/A	N/A

AM29

Digitised by WAGCOE, April 2010



Temperature vs depth for AM29 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

Date construction completed:	21/08/1980	**Ground level (m AHD):**	48.440
Date logged:	28/08/1982	**Top of casing (m AHD):**	48.962
Geodetic datum:	GDA94	**Total well depth below GL (m):**	755
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	729 - 735 (Yarragadee)
Easting (X):	402299	**Status:**	Operating
Northing (Y):	6491054	**Depth to reliable measurements (m):**	32

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	8.4	2.1	no
Poison Hill	54	19.8	16.1	1.3	no
Gingin	122	20.9	20.2	1.3	no
Molecap	137	21.2	13.5	0.8	no
Kardinya	149	21.4	31.1	1.8	no
Henley	163	21.8	20.9	2.4	no
Pinjar	184	22.3	29.7	2.2	no
Wanneroo	300	25.7	26.7	1.0	no
Mariginiup	516	31.5	23.4	2.1	no
South Perth	578	33.0	21.8	1.7	no
Yarragadee	636	34.2	28.3	2.0	no
Depth of log	731.0	37.0	N/A	N/A	N/A

AM30 (Whitfords No 4)

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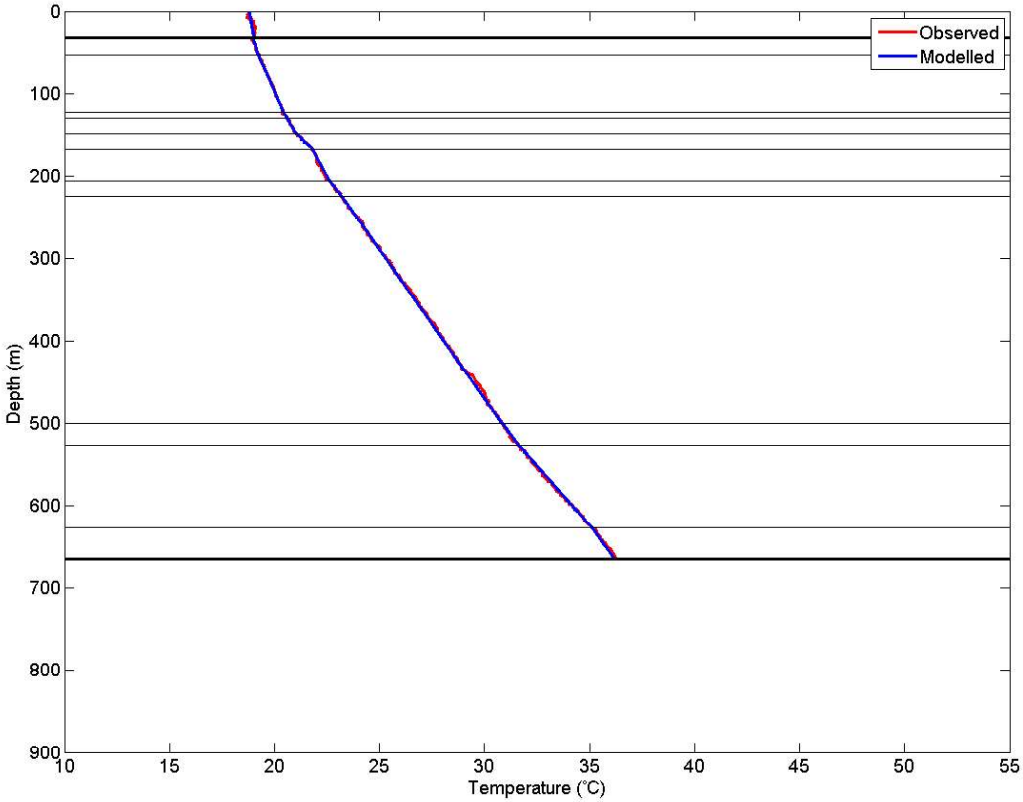

Temperature vs depth for AM30 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

Date construction completed:	15/04/1973	**Ground level (m AHD):**	48.676
Date logged:	27/10/1980	**Top of casing (m AHD):**	48.676
Geodetic datum:	GDA94	**Total well depth below GL (m):**	753
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	665 - 668 (Yarragadee)
Easting (X):	402434	**Status:**	Operating
Northing (Y):	6482068	**Depth to reliable measurements (m):**	32

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	11.4	1.4	no
Poison Hill	53	19.2	17.2	0.6	no
Gingin	122	20.4	28.4	2.6	no
Molecap	129	20.6	23.9	1.0	no
Kardinya	148	21.1	37.6	1.2	no
Henley	168	21.8	21.2	1.6	no
Pinjar	206	22.6	30.6	1.2	no
Wanneroo	225	23.2	27.7	0.7	no
Mariginiup	500	30.9	28.8	2.1	no
South Perth	527	31.6	35.1	1.0	no
Yarragadee	626	35.1	28.1	2.2	no
Depth of log	665.0	36.2	N/A	N/A	N/A

AM30Z

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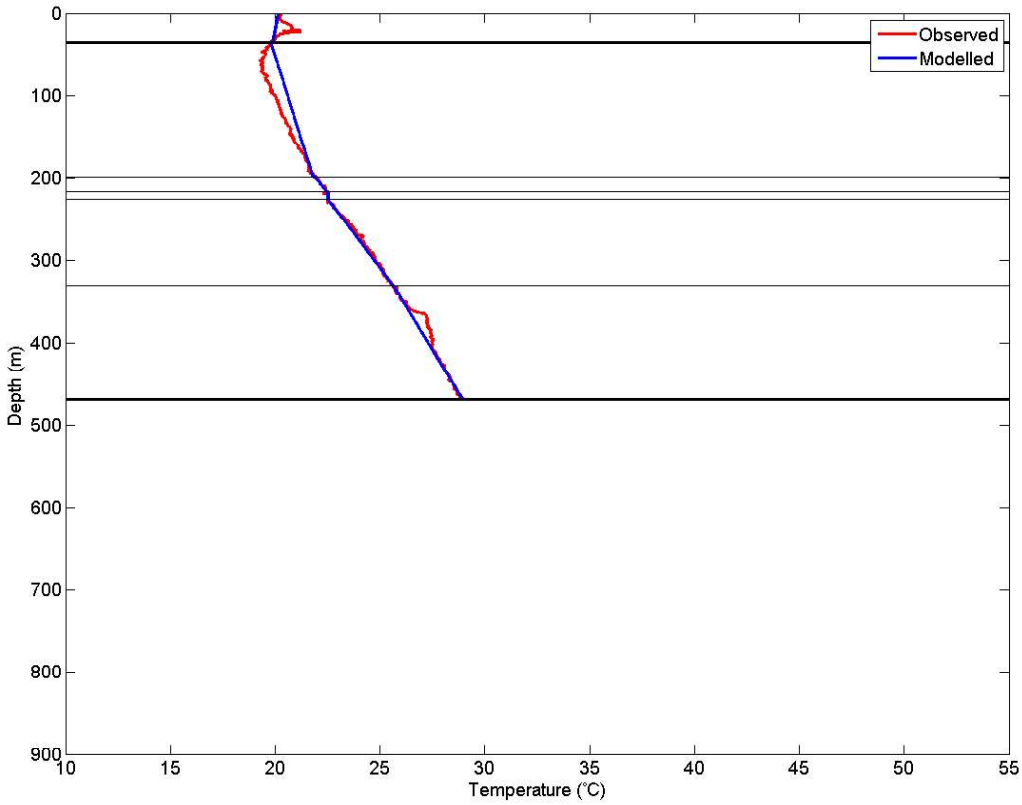


Temperature vs depth for AM30Z (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

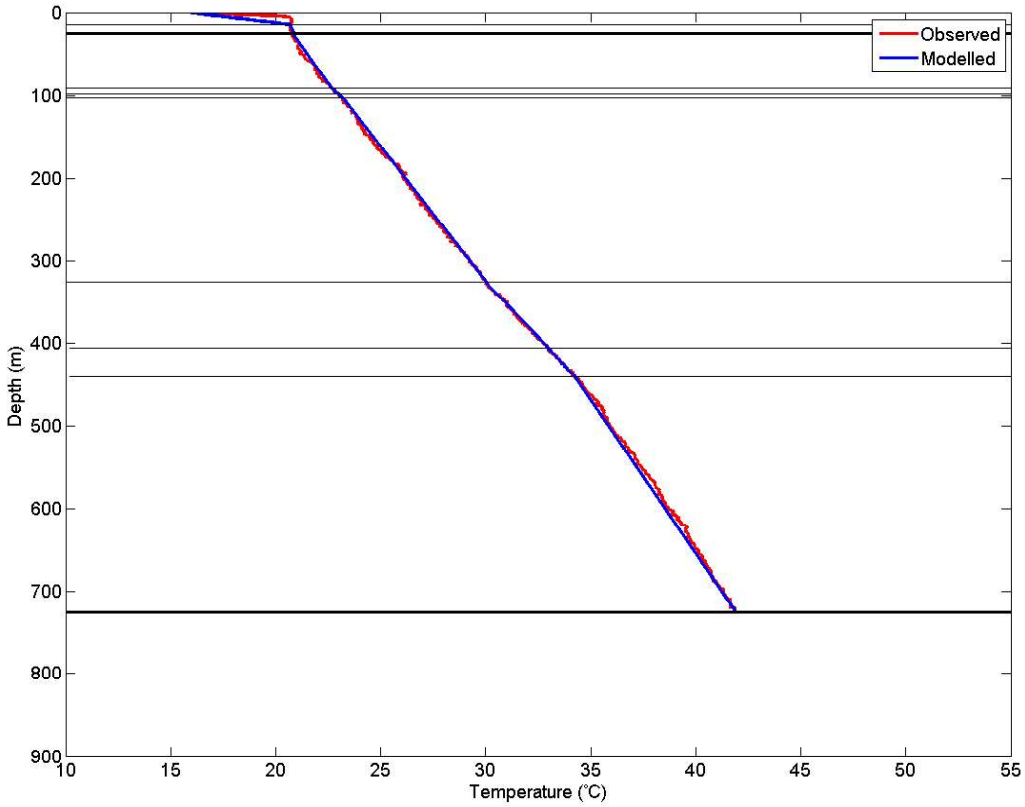
Date construction completed:	15/05/1980	**Ground level (m AHD):**	39.370
Date logged:	17/11/1980	**Top of casing (m AHD):**	39.476
Geodetic datum:	GDA94	**Total well depth below GL (m):**	567
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	333 - 410 (Leederville)
Easting (X):	397699	**Status:**	Operating
Northing (Y):	6478981	**Depth to reliable measurements (m):**	35

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Mirrabooka	34	N/A	12.4	5.7	yes
Kardinya	199	21.9	31.4	1.9	no
Henley	217	22.5	-1.8	4.5	no
Pinjar	226	22.5	29.8	1.7	no
Wanneroo	330	25.6	24.0	3.2	no
Depth of log	468.0	29.0	N/A	N/A	N/A

AM31 (Whitfords No 5)

Digitised by WAGCOE, April 2010



Temperature vs depth for AM31 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

Date construction completed:	N/A	**Ground level (m AHD):**	5.587
Date logged:	09/07/1982	**Top of casing (m AHD):**	6.240
Geodetic datum:	GDA94	**Total well depth below GL (m):**	800
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	722 - 725 (Yarragadee)
Easting (X):	406171	**Status:**	Operating
Northing (Y):	6480712	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Kardinya	15	N/A	28.0	2.7	no
Henley	91	22.6	48.3	3.8	no
Pinjar	98	23.0	37.8	2.9	no
Wanneroo	103	23.2	30.6	1.2	no
Mariginiup	326	30.0	37.6	1.2	no
South Perth	406	33.0	36.8	1.3	no
Yarragadee	441	34.2	27.0	1.6	no
Depth of log	725.0	41.9	N/A	N/A	N/A

AM32 (Triggs No 1)

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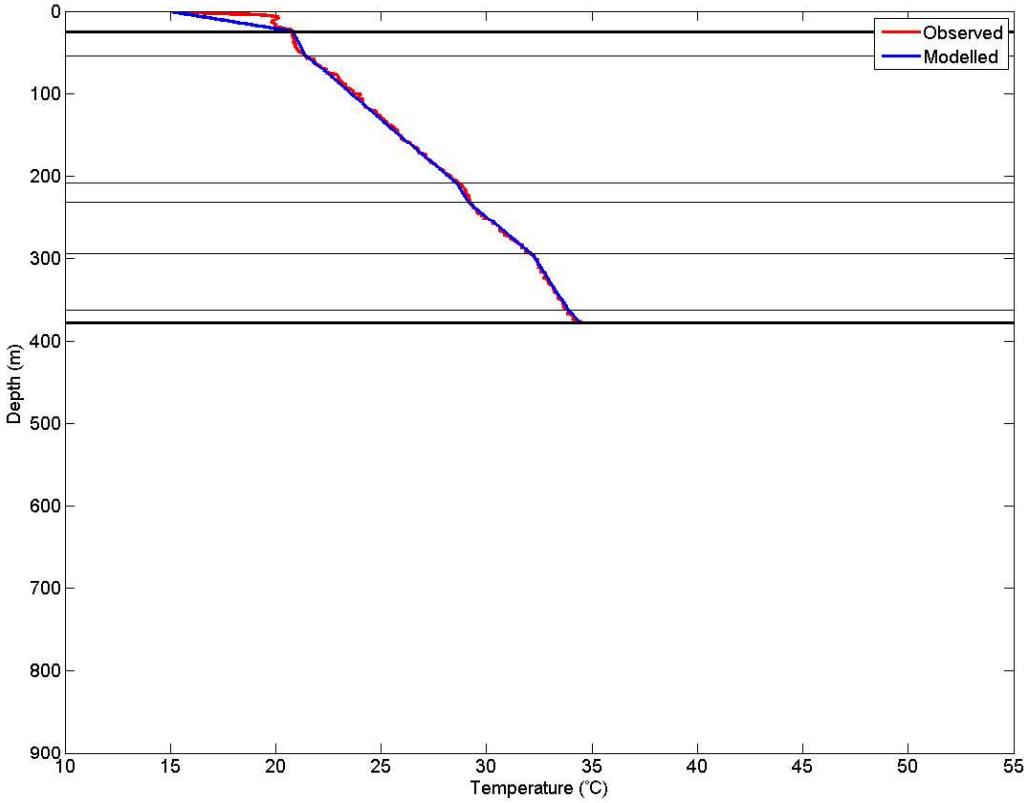


Temperature vs depth for AM32 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

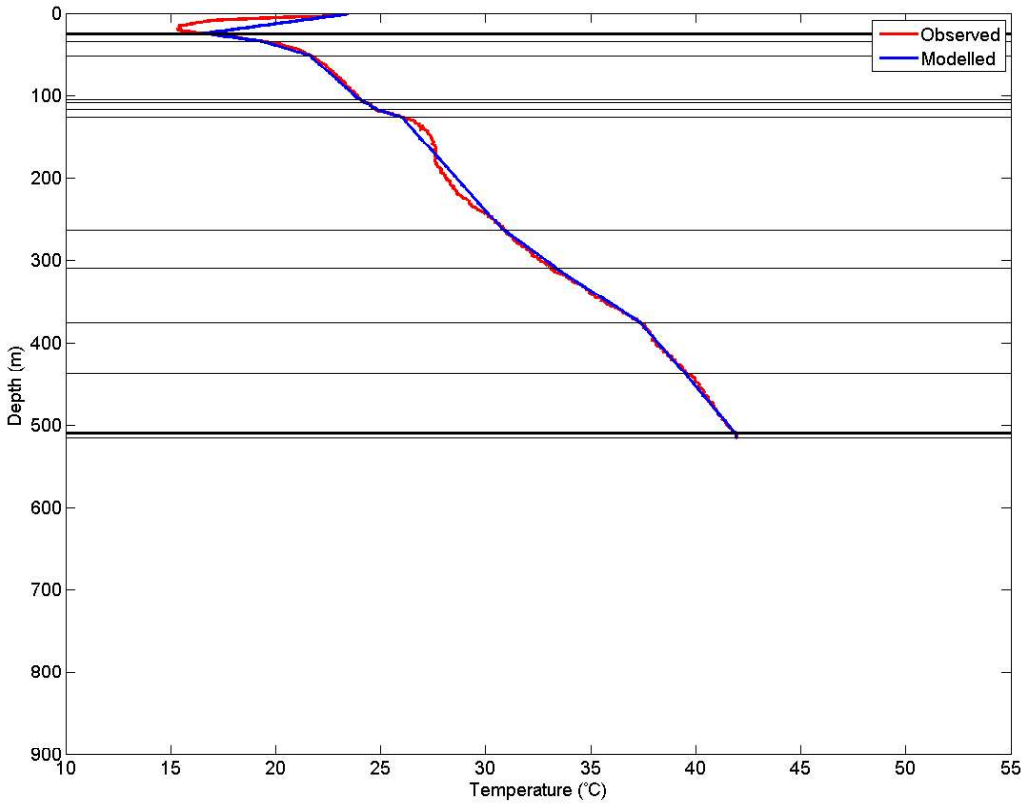
Date construction completed:	15/04/1976	**Ground level (m AHD):**	12.980
Date logged:	02/07/1982	**Top of casing (m AHD):**	13.550
Geodetic datum:	GDA94	**Total well depth below GL (m):**	404
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	374 - 379 (Yarragadee)
Easting (X):	382877	**Status:**	Abandoned
Northing (Y):	6473751	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	20.5	4.4	no
Kings Park	54	21.5	46.0	1.5	no
Como	209	28.6	24.0	5.0	yes
South Perth	232	29.1	47.5	1.8	no
Gage	294	32.1	25.3	1.4	no
Yarragadee	363	33.9	37.7	4.5	no
Depth of log	378.5	34.5	N/A	N/A	N/A

AM33A

Digitised by WAGCOE, April 2010



Temperature vs depth for AM33A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

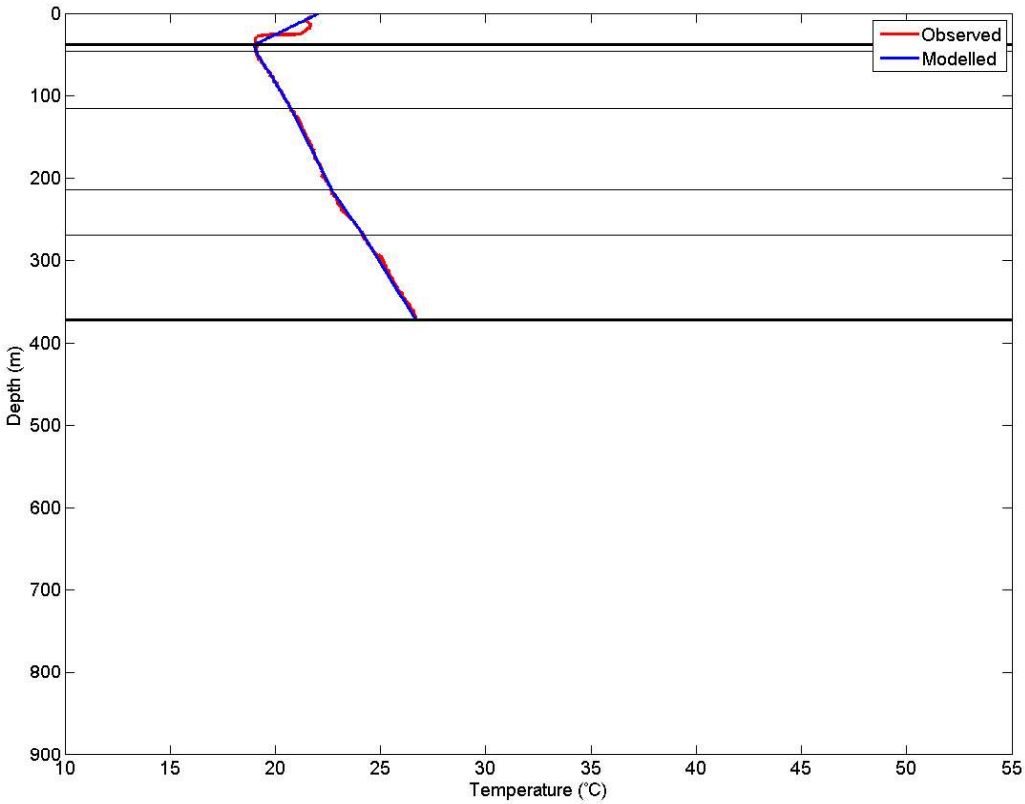
Date construction completed:	N/A	**Ground level (m AHD):**	7.182
Date logged:	02/02/1983	**Top of casing (m AHD):**	7.662
Geodetic datum:	GDA94	**Total well depth below GL (m):**	535
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	495 - 505 (Yarragadee)
Easting (X):	385150	**Status:**	Operating
Northing (Y):	6477342	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	289.7	5.4	yes
Mullaloo	34	19.3	135.3	11.1	yes
Mirrabooka	52	21.6	43.9	3.3	no
Kardinya	105	24.1	42.7	4.2	no
Henley	109	24.3	59.5	3.9	no
Pinjar	117	24.8	136.4	4.0	no
Wanneroo	126	26.0	35.0	4.8	no
Mariginiup	264	30.9	55.4	4.1	no
South Perth	309	33.3	61.2	2.7	no
Gage	376	37.4	34.9	1.5	no
Yarragadee	437	39.5	33.0	2.1	no
Bottom limit	509	41.9	N/A	N/A	N/A
Depth of log	515.0	41.9	N/A	N/A	N/A

AM34

Digitised by WAGCOE, April 2010



Temperature vs depth for AM34 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

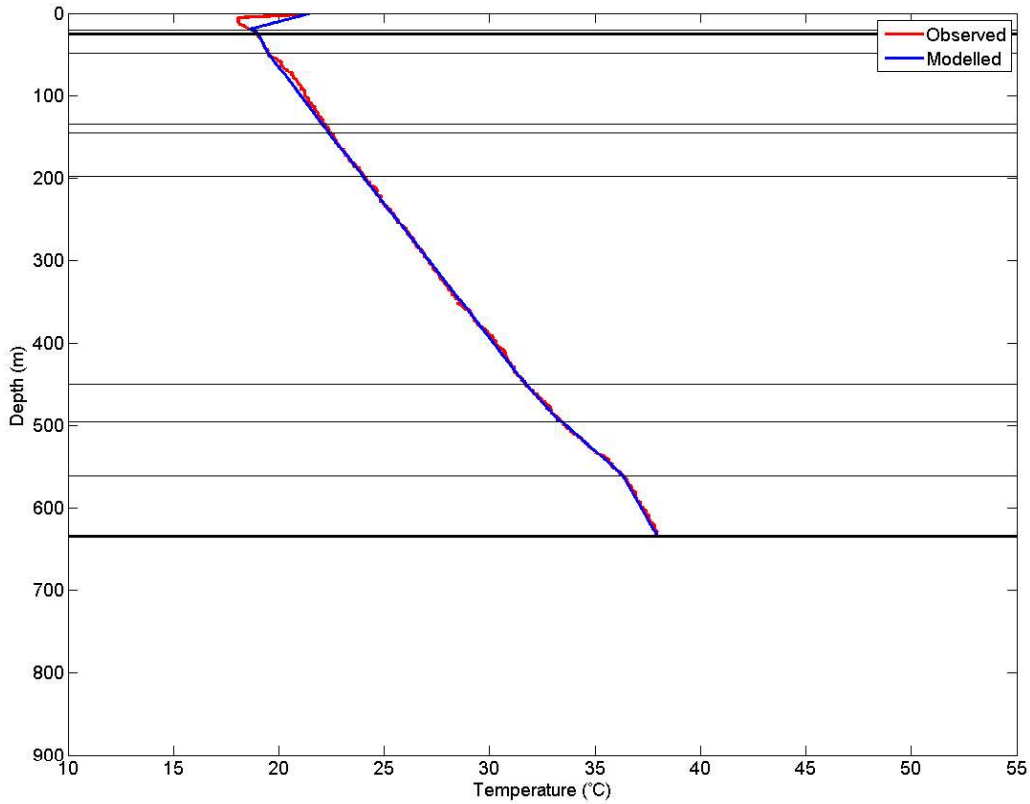
Date construction completed:	30/06/1978	**Ground level (m AHD):**	40.030
Date logged:	12/11/1980	**Top of casing (m AHD):**	41.128
Geodetic datum:	GDA94	**Total well depth below GL (m):**	521
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	380 - 388 (Leederville)
Easting (X):	394660	**Status:**	Operating
Northing (Y):	6474353	**Depth to reliable measurements (m):**	38

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	7.6	1.9	no
Kardinya	46	19.1	23.9	0.7	no
Henley	116	20.7	19.7	1.1	no
Pinjar	214	22.7	27.1	1.6	no
Wanneroo	270	24.2	24.5	1.5	no
Depth of log	372.5	26.7	N/A	N/A	N/A

AM35A

Digitised by WAGCOE, April 2010



Temperature vs depth for AM35 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

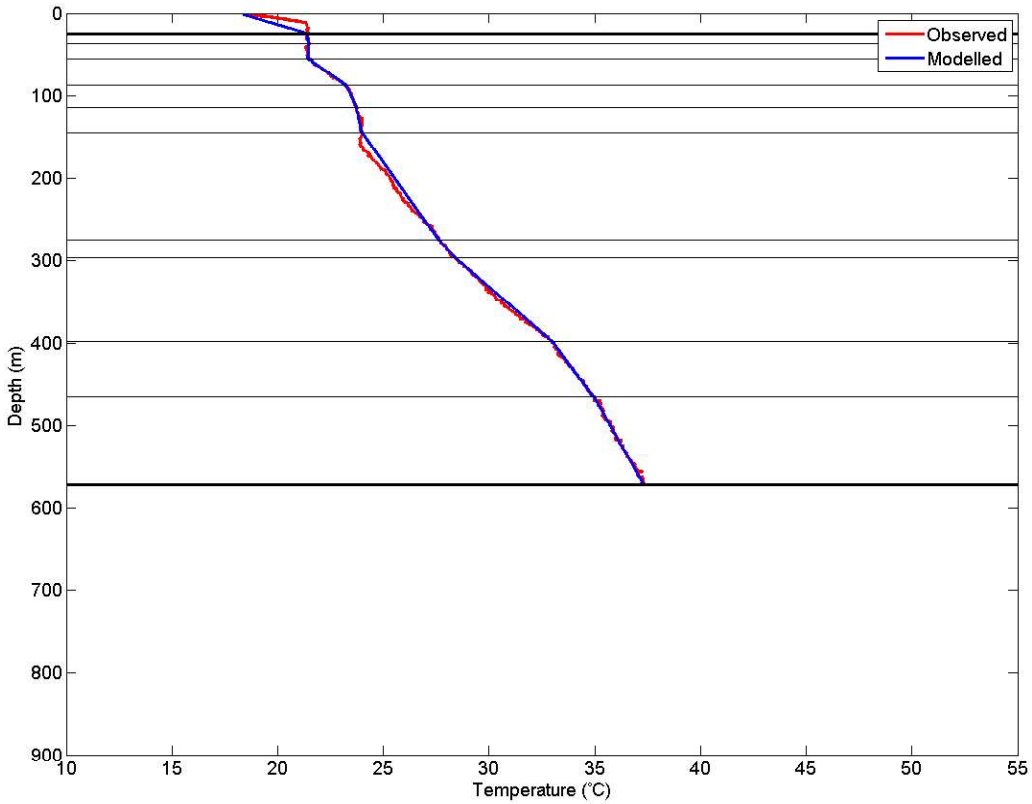
Date construction completed:	15/03/1982	**Ground level (m AHD):**	16.860
Date logged:	01/02/1983	**Top of casing (m AHD):**	17.530
Geodetic datum:	GDA94	**Total well depth below GL (m):**	650
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	619 - 630 (Yarragadee)
Easting (X):	403601	**Status:**	Operating
Northing (Y):	6475592	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Mirrabooka	20	N/A	20.1	1.0	no
Kardinya	48	19.5	29.8	3.8	no
Henley	134	22.0	32.3	5.0	yes
Pinjar	144	22.3	30.9	1.3	no
Wanneroo	198	24.0	30.8	0.8	no
Mariginiup	450	31.7	35.9	1.9	no
South Perth	495	33.4	43.9	1.1	no
Yarragadee	561	36.3	22.5	1.5	no
Depth of log	635.0	38.0	N/A	N/A	N/A

AM36

Digitised by WAGCOE, April 2010



Temperature vs depth for AM36 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

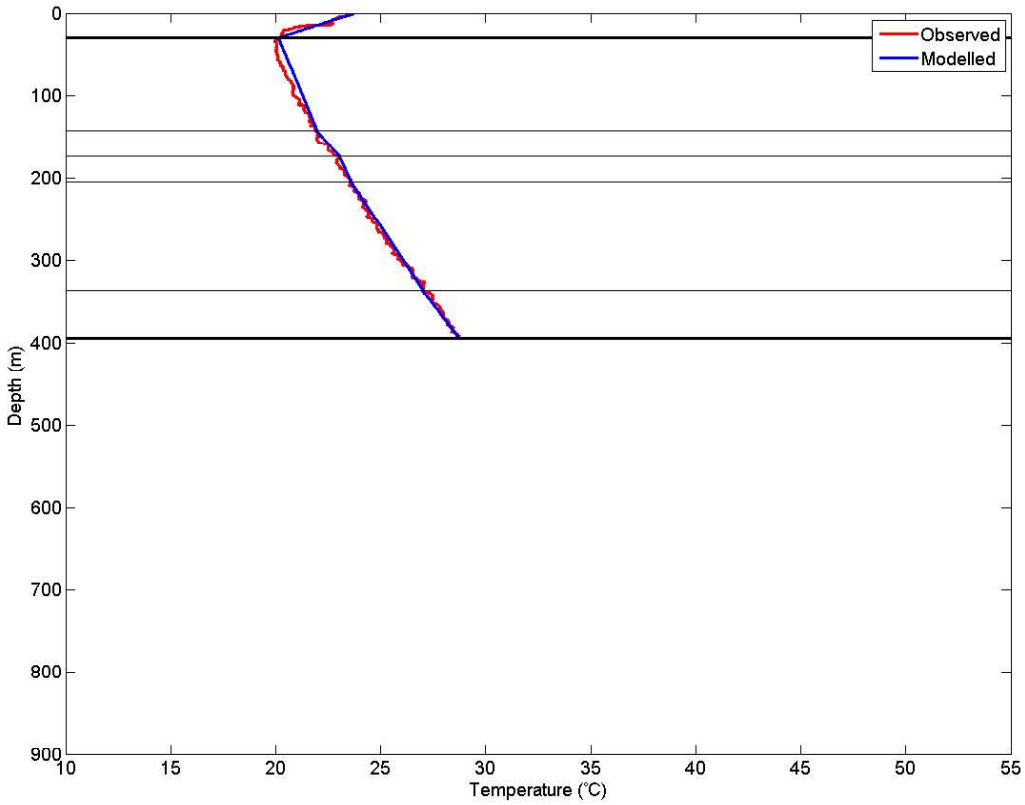
Date construction completed:	15/04/1982	**Ground level (m AHD):**	15.941
Date logged:	16/07/1982	**Top of casing (m AHD):**	15.957
Geodetic datum:	GDA94	**Total well depth below GL (m):**	616
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	526 - 532 (Yarragadee)
Easting (X):	387766	**Status:**	Operating
Northing (Y):	6470299	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	7.2	2.1	no
Molecap	36	21.5	-2.3	2.3	no
Kardinya	55	21.4	55.1	1.6	no
Henley	88	23.2	18.7	1.3	no
Pinjar	114	23.7	9.1	1.9	no
Wanneroo	144	24.0	27.6	3.5	no
Mariginiup	276	27.6	39.0	1.6	no
South Perth	297	28.4	45.3	2.4	no
Gage	398	33.0	28.9	1.1	no
Yarragadee	465	34.9	22.0	1.1	no
Depth of log	571.5	37.4	N/A	N/A	N/A

AM37

Digitised by WAGCOE, April 2010



Temperature vs depth for AM37 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 8 m min^{-1}; time constant: 0.5 sec

Well specifics

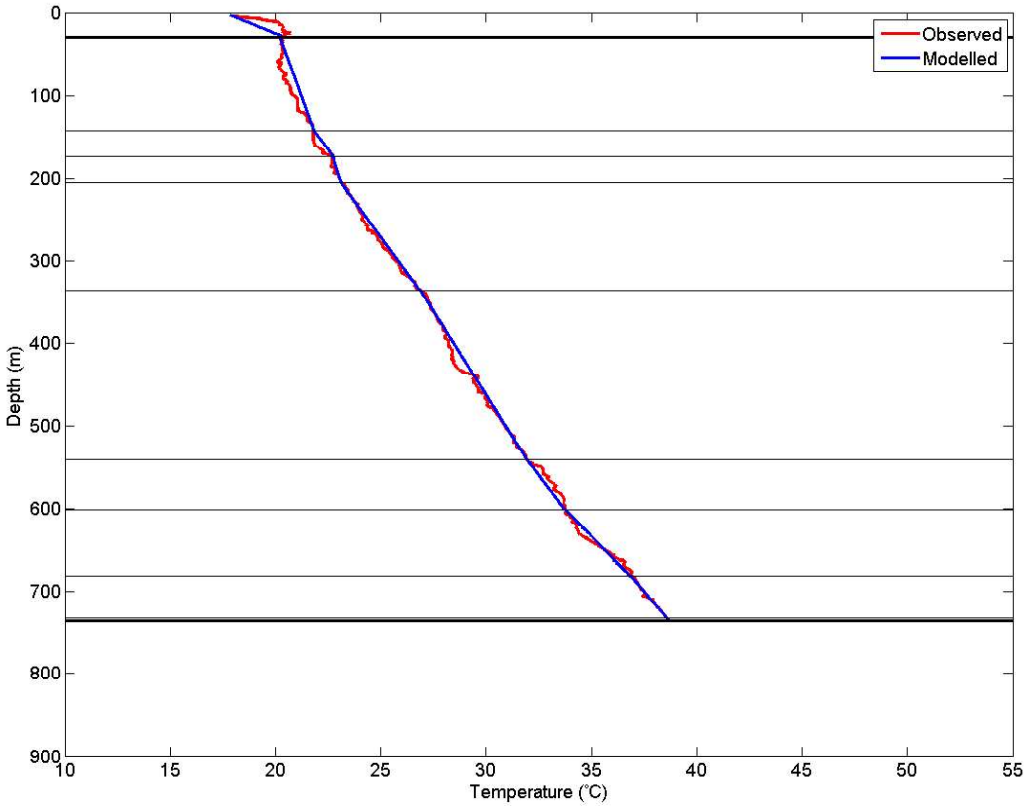
Date construction completed:	14/06/1978	**Ground level (m AHD):**	21.080
Date logged:	10/12/1980	**Top of casing (m AHD):**	22.005
Geodetic datum:	GDA94	**Total well depth below GL (m):**	501
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	359 - 369 (Leederville)
Easting (X):	398489	**Status:**	Operating
Northing (Y):	6469330	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Mirrabooka	29	N/A	16.4	4.0	no
Kardinya	142	21.9	35.1	5.4	yes
Henley	174	23.0	17.8	3.9	no
Pinjar	205	23.6	26.3	1.9	no
Wanneroo	336	27.0	30.2	2.6	no
Depth of log	394.0	28.7	N/A	N/A	N/A

AM37A

Digitised by WAGCOE, April 2010



Temperature vs depth for AM37A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

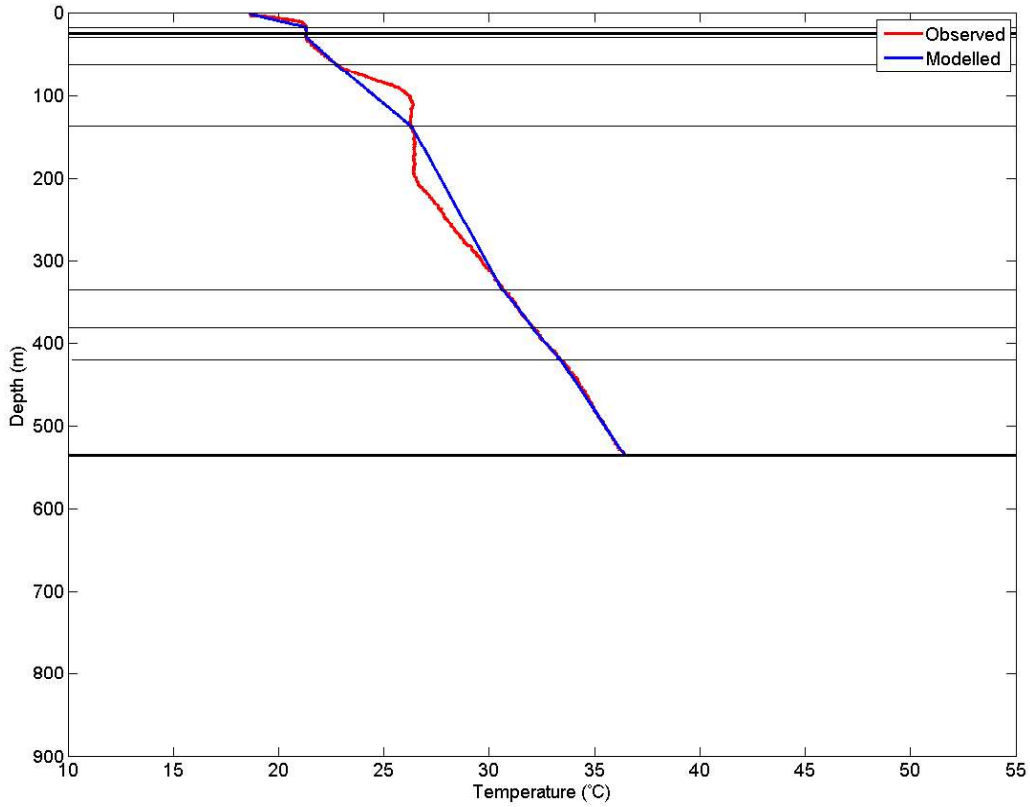
Date construction completed:	15/06/1982	**Ground level (m AHD):**	21.371
Date logged:	16/09/1982	**Top of casing (m AHD):**	22.060
Geodetic datum:	GDA94	**Total well depth below GL (m):**	803
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	765 - 775 (Yarragadee)
Easting (X):	398469	**Status:**	Operating
Northing (Y):	6469322	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Mirrabooka	29	N/A	14.4	4.4	no
Kardinya	142	21.8	30.0	7.9	yes
Henley	174	22.7	12.2	2.7	no
Pinjar	205	23.1	28.5	1.9	no
Wanneroo	336	26.9	24.7	2.2	no
Mariginiup	540	31.9	29.7	5.4	yes
South Perth	601	33.8	38.0	3.9	no
Gage	681	36.9	33.2	1.3	no
Yarragadee	732	38.6	29.8	0.0	no
Depth of log	736.0	38.7	N/A	N/A	N/A

AM38A

Digitised by WAGCOE, April 2010



Temperature vs depth for AM38A (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

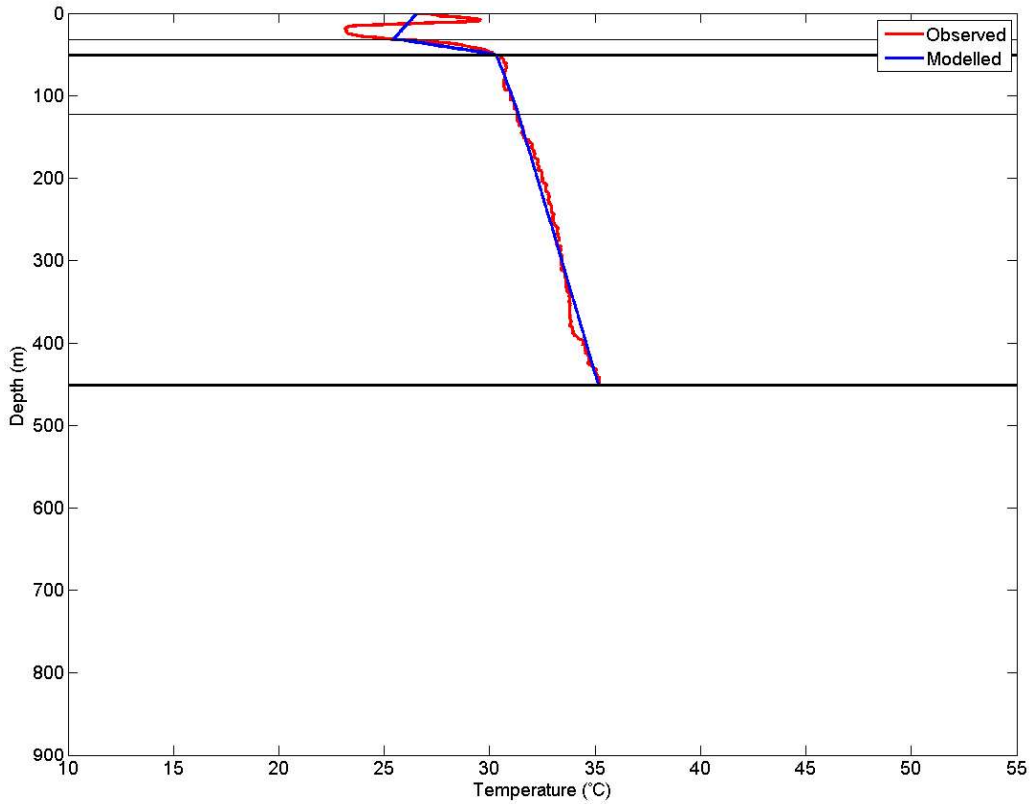
Date construction completed:	15/04/1982	**Ground level (m AHD):**	11.220
Date logged:	12/08/1982	**Top of casing (m AHD):**	11.880
Geodetic datum:	GDA94	**Total well depth below GL (m):**	550
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	500 - 507 (Yarragadee)
Easting (X):	404507	**Status:**	Operating
Northing (Y):	6468894	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Kardinya	18	N/A	-8.2	1.9	no
Henley	30	21.3	43.2	2.7	no
Pinjar	62	22.7	48.0	17.3	yes
Wanneroo	137	26.3	21.7	6.8	yes
Mariginiup	335	30.6	30.7	1.1	no
South Perth	381	32.0	35.0	1.1	no
Gage	420	33.4	26.2	1.0	no
Depth of log	536.0	36.4	N/A	N/A	N/A

AM39 (Claremont No 1)

Digitised by WAGCOE, April 2010



Temperature vs depth for AM39 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

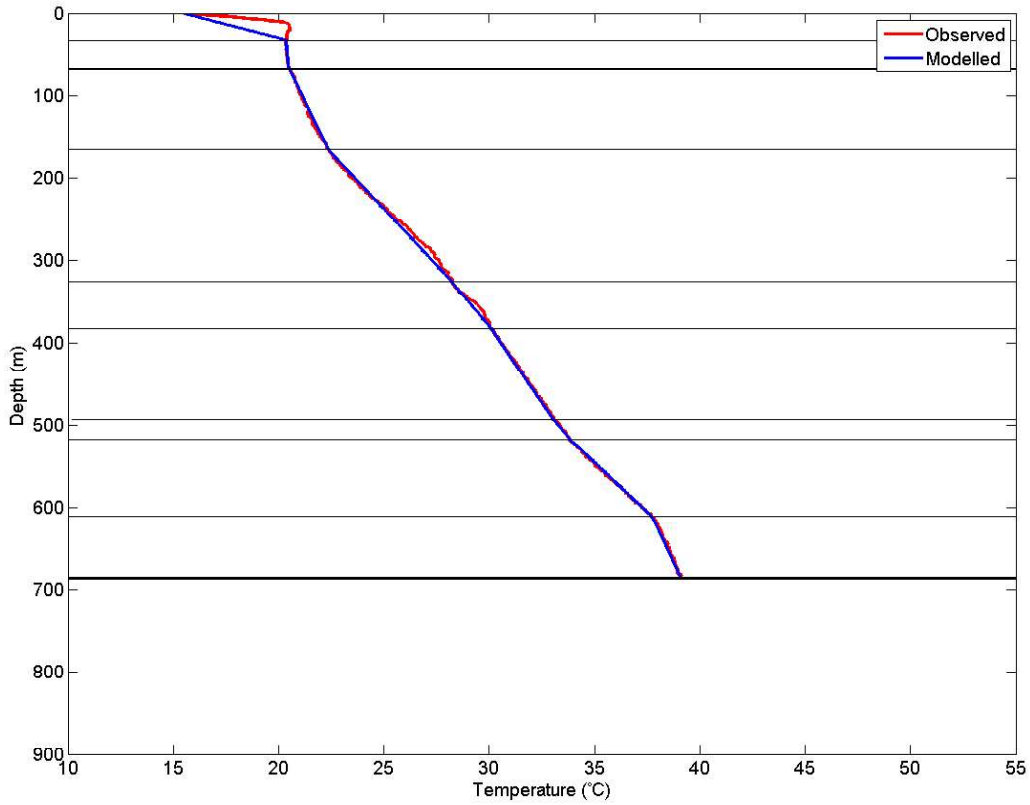
Date construction completed:	30/06/1903	**Ground level (m AHD):**	8.190
Date logged:	09/02/1983	**Top of casing (m AHD):**	8.408
Geodetic datum:	GDA94	**Total well depth below GL (m):**	459
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	N/A
Easting (X):	384742	**Status:**	Operating
Northing (Y):	6461214	**Depth to reliable measurements (m):**	50

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Mullaloo	32	N/A	14.6	2.5	no
Kings Park	122	31.4	11.6	1.7	no
Depth of log	451.5	35.2	N/A	N/A	N/A

AM40

Digitised by WAGCOE, April 2010



Temperature vs depth for AM40 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

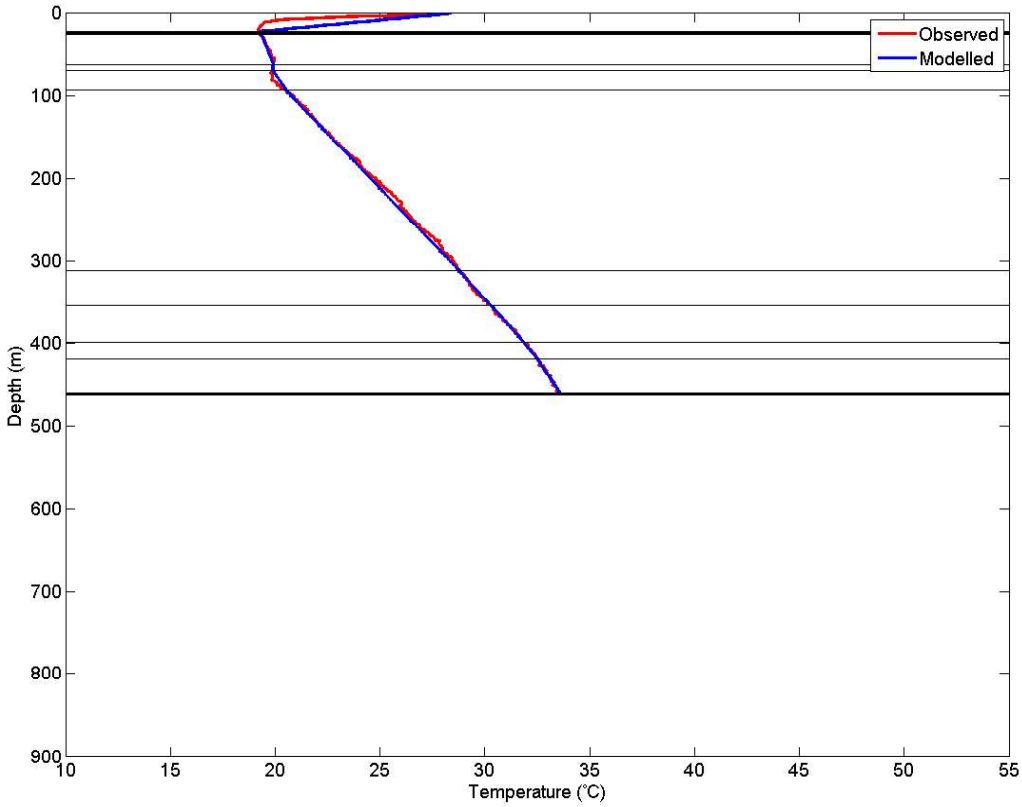
Date construction completed:	15/04/1979	**Ground level (m AHD):**	22.680
Date logged:	19/09/1980	**Top of casing (m AHD):**	22.965
Geodetic datum:	GDA94	**Total well depth below GL (m):**	730
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	687 - 696 (Yarragadee)
Easting (X):	394744	**Status:**	Operating
Northing (Y):	6460282	**Depth to reliable measurements (m):**	68

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Mullaloo	33	N/A	19.2	1.1	no
Kings Park	166	22.4	36.7	2.3	no
Como	326	28.2	33.4	3.5	no
Wanneroo	383	30.1	26.8	1.0	no
Mariginiup	493	33.1	32.1	1.8	no
South Perth	517	33.8	41.8	1.1	no
Gage	610	37.7	18.3	1.4	no
Depth of log	685.5	39.1	N/A	N/A	N/A

AM41

Digitised by WAGCOE, April 2010



Temperature vs depth for AM41 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

Date construction completed:	15/06/1979	**Ground level (m AHD):**	20.814
Date logged:	03/02/1983	**Top of casing (m AHD):**	20.814
Geodetic datum:	GDA94	**Total well depth below GL (m):**	505
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	457 - 463 (Yarragadee)
Easting (X):	404135	**Status:**	Operating
Northing (Y):	6460863	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Kings Park	23	N/A	16.1	1.8	no
Kardinya	62	19.9	-3.5	0.7	no
Henley	69	19.8	27.4	5.9	yes
Wanneroo	94	20.5	37.9	1.7	no
Mariginiup	312	28.8	35.4	1.8	no
South Perth	355	30.3	35.3	1.3	no
Gage	399	31.8	33.5	2.0	no
Yarragadee	419	32.5	25.8	1.3	no
Depth of log	461.5	33.6	N/A	N/A	N/A

AM42

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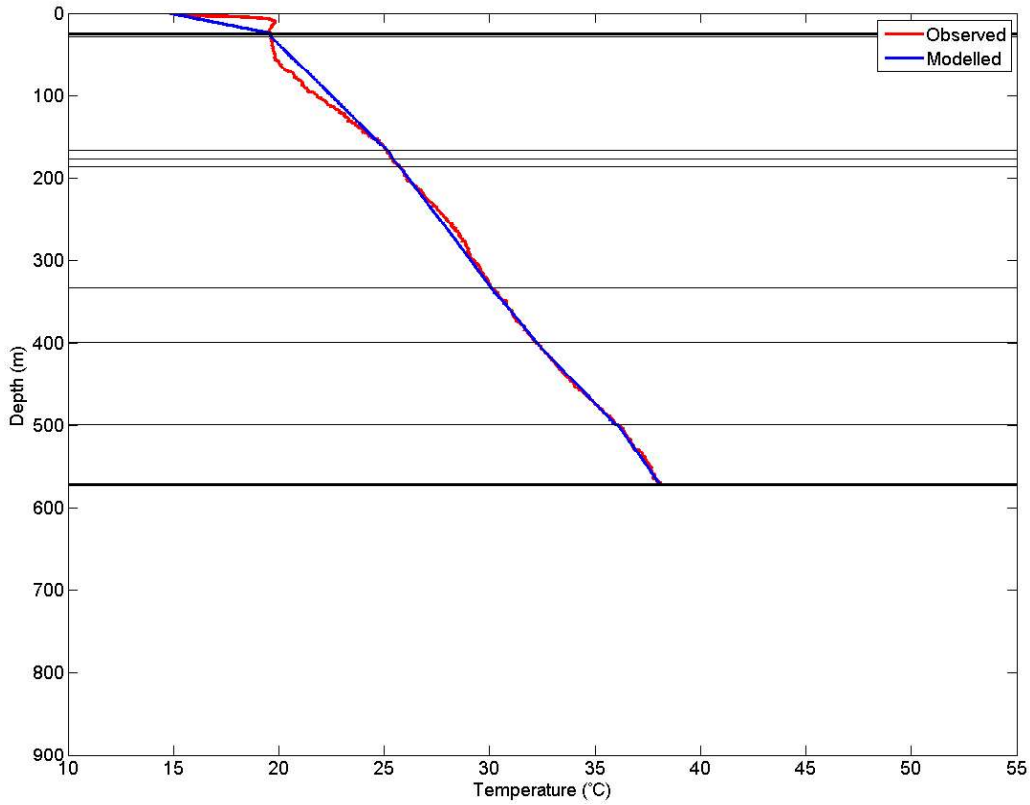


Temperature vs depth for AM42 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

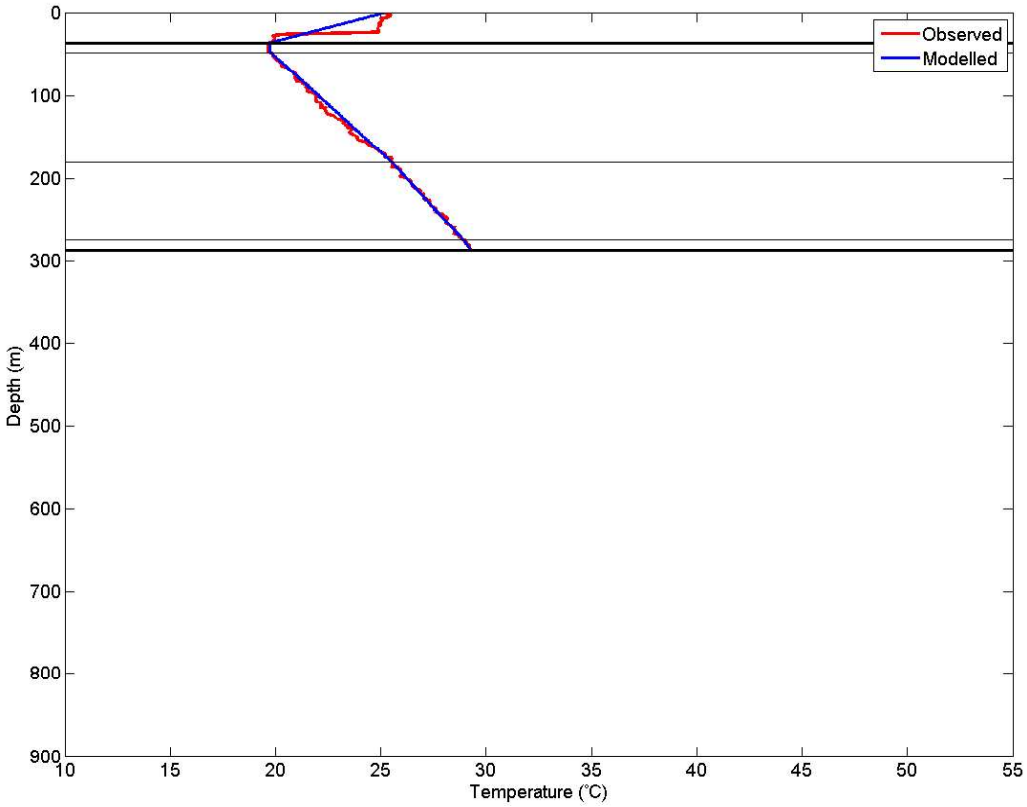
Date construction completed:	15/06/1979	**Ground level (m AHD):**	8.988
Date logged:	17/06/1982	**Top of casing (m AHD):**	9.648
Geodetic datum:	GDA94	**Total well depth below GL (m):**	600
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	569.5 - 576 (Yarragadee)
Easting (X):	388123	**Status:**	Operating
Northing (Y):	6452372	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	-2.2	1.6	no
Kardinya	28	19.6	40.0	7.0	yes
Henley	167	25.2	22.5	2.3	no
Pinjar	177	25.4	37.7	3.2	no
Wanneroo	186	25.7	29.7	2.6	no
Mariginiup	333	30.1	32.5	1.2	no
South Perth	399	32.2	37.7	1.2	no
Gage	499	36.1	27.4	1.7	no
Depth of log	571.5	38.1	N/A	N/A	N/A

AM43

Digitised by WAGCOE, April 2010



Temperature vs depth for AM43 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 8 m min^{-1}; time constant: 0.5 sec

Well specifics

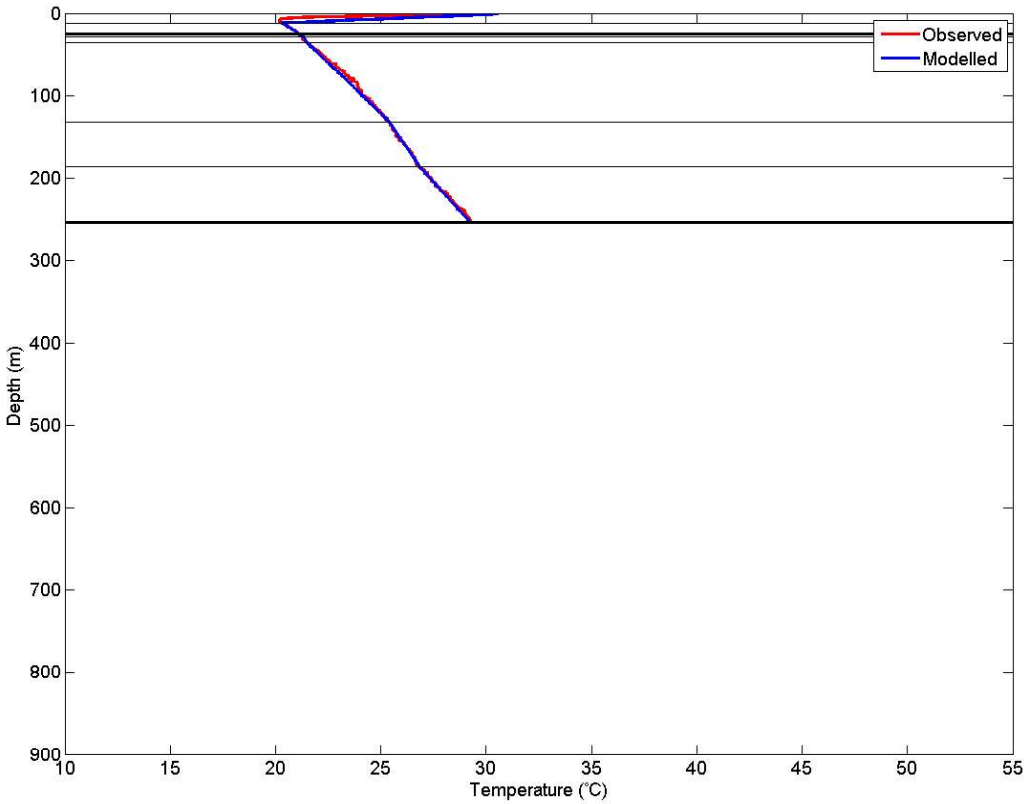
Date construction completed:	N/A	**Ground level (m AHD):**	28.768
Date logged:	08/12/1980	**Top of casing (m AHD):**	29.554
Geodetic datum:	GDA94	**Total well depth below GL (m):**	610
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	274 - 282 (Leederville)
Easting (X):	393973	**Status:**	Operating
Northing (Y):	6450862	**Depth to reliable measurements (m):**	37

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	0.0	2.5	no
Kardinya	48	19.8	43.4	3.0	no
Pinjar	180	25.5	36.0	1.4	no
Wanneroo	275	28.9	26.6	2.0	no
Depth of log	287.5	29.3	N/A	N/A	N/A

AM44

Digitised by WAGCOE, April 2010



Temperature vs depth for AM44 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

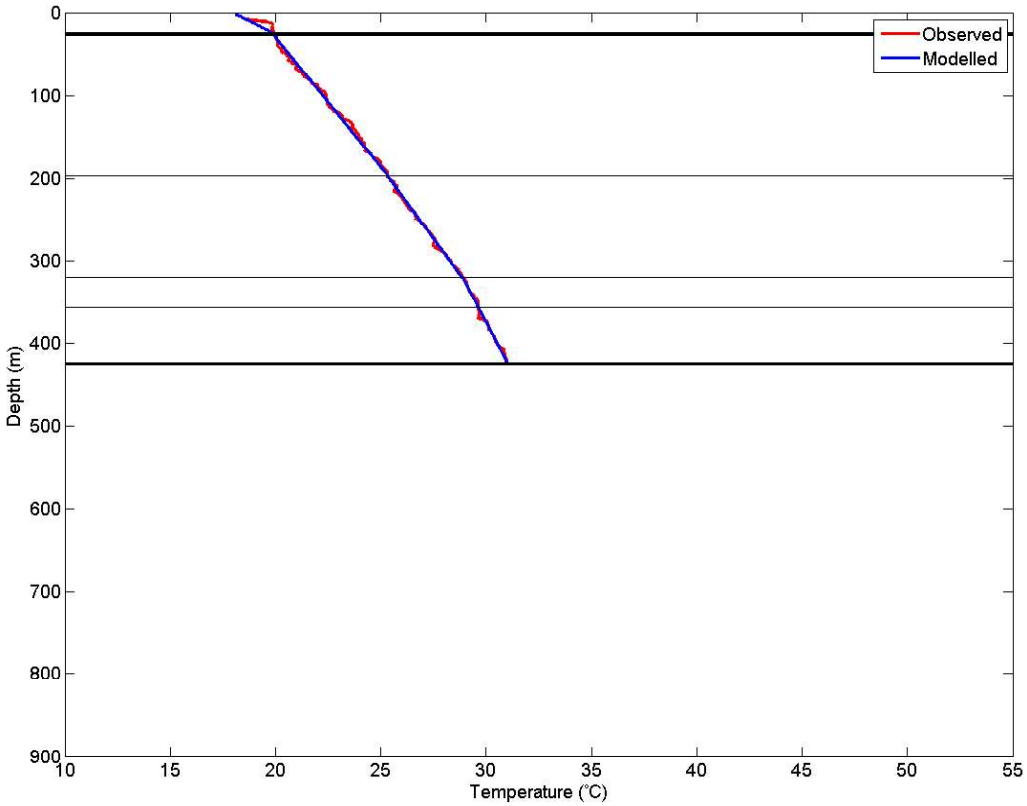
Date construction completed:	15/06/1979	**Ground level (m AHD):**	6.368
Date logged:	03/02/1983	**Top of casing (m AHD):**	6.940
Geodetic datum:	GDA94	**Total well depth below GL (m):**	336
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	135 - 145 (Leederville)
Easting (X):	403562	**Status:**	Operating
Northing (Y):	6455394	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Kardinya	12	N/A	28.8	2.9	no
Henley	28	21.3	20.6	4.3	no
Pinjar	35	21.5	40.5	2.4	no
Wanneroo	132	25.4	26.2	1.1	no
Mariginiup	186	26.8	35.8	1.8	no
Depth of log	255.0	29.2	N/A	N/A	N/A

AM48

Digitised by WAGCOE, April 2010



Temperature vs depth for AM48 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.01 sec

Well specifics

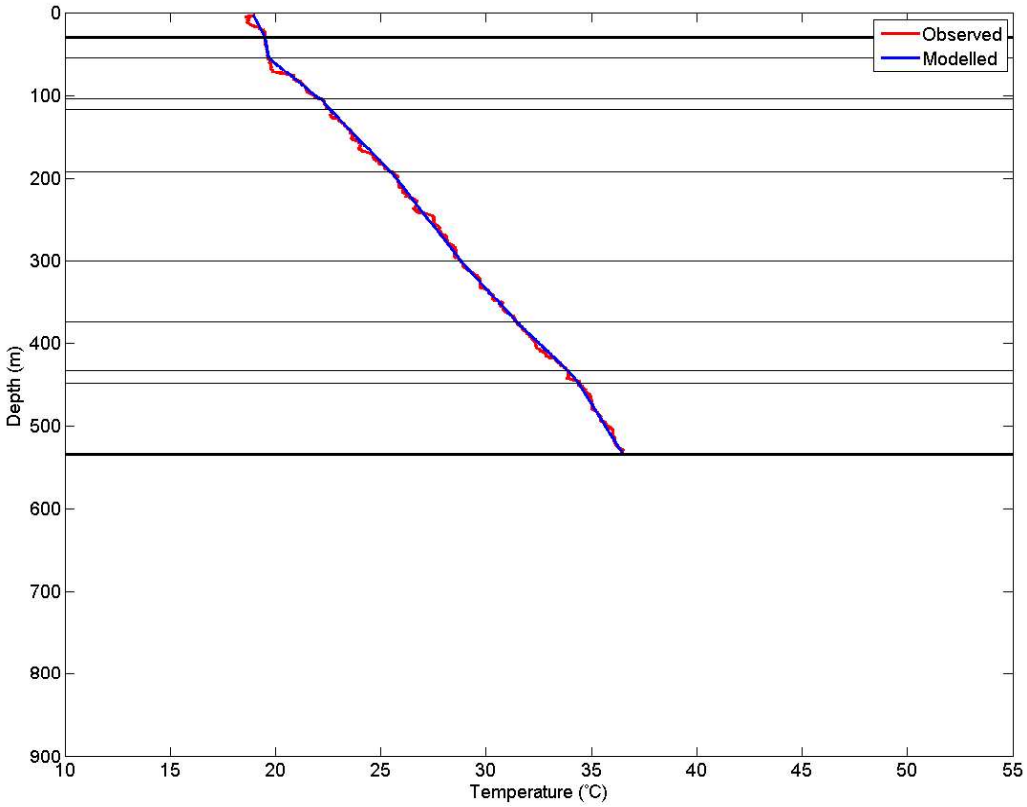
Date construction completed:	13/07/1978	**Ground level (m AHD):**	23.952
Date logged:	09/10/1982	**Top of casing (m AHD):**	24.342
Geodetic datum:	GDA94	**Total well depth below GL (m):**	444
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	421 - 426 (Yarragadee)
Easting (X):	402841	**Status:**	Operating
Northing (Y):	6446614	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	14.5	0.5	no
Wanneroo	27	19.9	31.9	1.5	no
Mariginiup	197	25.3	28.6	1.1	no
Gage	320	28.9	20.5	1.8	no
Yarragadee	357	29.6	20.9	1.5	no
Depth of log	424.0	31.0	N/A	N/A	N/A

AM49

Digitised by WAGCOE, April 2010



Temperature vs depth for AM49 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.01 sec

Well specifics

Date construction completed:	N/A	**Ground level (m AHD):**	36.490
Date logged:	07/10/1982	**Top of casing (m AHD):**	36.830
Geodetic datum:	GDA94	**Total well depth below GL (m):**	554
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	526 - 533 (Yarragadee)
Easting (X):	391636	**Status:**	Operating
Northing (Y):	6438965	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	7.1	0.7	no
Kardinya	54	19.7	48.2	5.2	yes
Henley	104	22.2	31.4	1.9	no
Pinjar	117	22.6	37.9	2.9	no
Wanneroo	192	25.5	30.7	2.1	no
Mariginiup	300	28.8	35.8	1.4	no
South Perth	375	31.4	42.1	3.1	no
Gage	432	33.9	30.0	5.8	yes
Yarragadee	449	34.4	24.9	1.6	no
Depth of log	534.5	36.5	N/A	N/A	N/A

AM50

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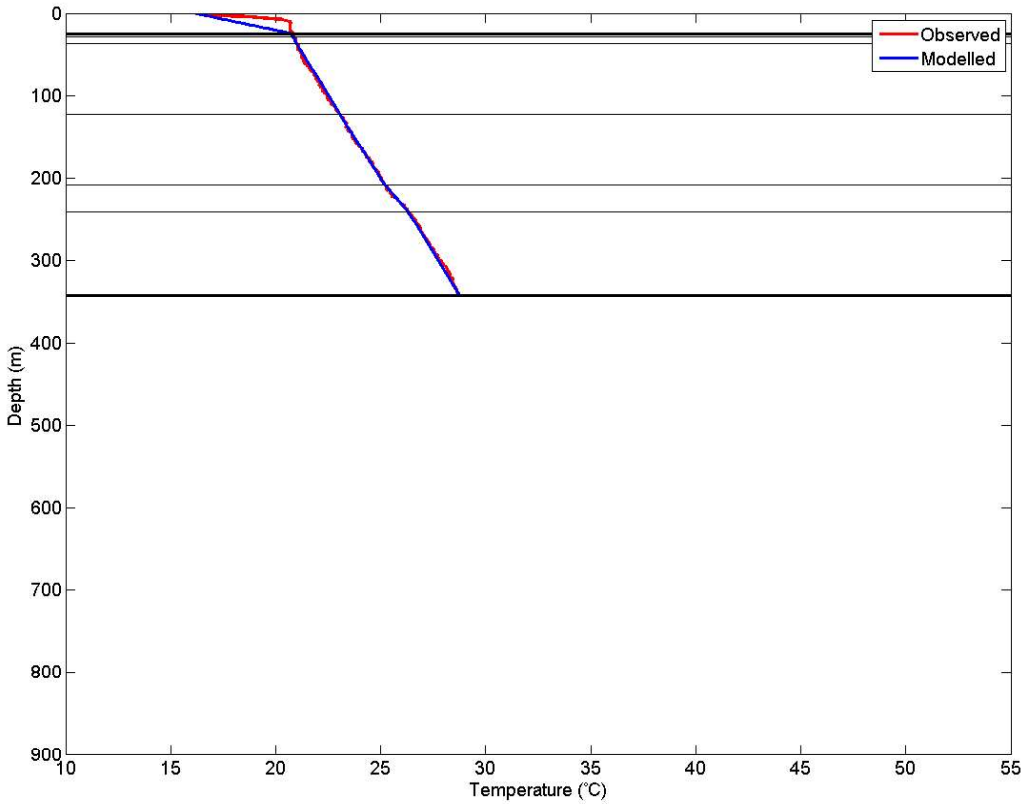


Temperature vs depth for AM50 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

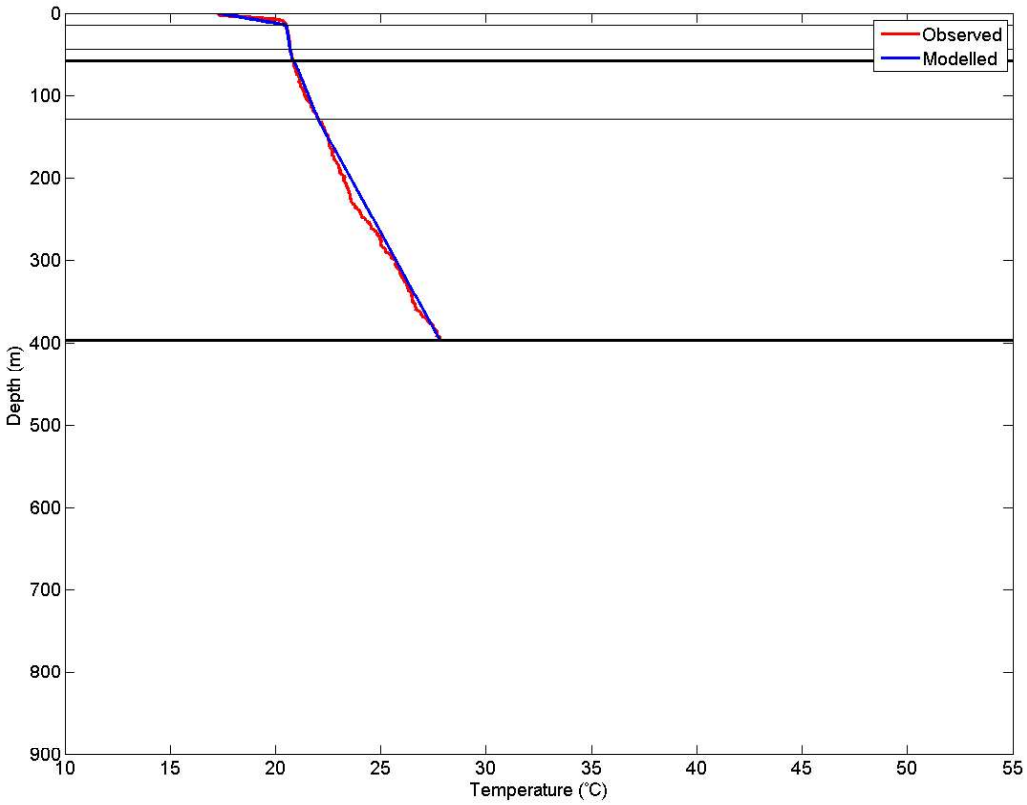
Date construction completed:	21/04/1978	**Ground level (m AHD):**	15.569
Date logged:	26/08/1982	**Top of casing (m AHD):**	15.730
Geodetic datum:	GDA94	**Total well depth below GL (m):**	343
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	314 - 319 (Yarragadee)
Easting (X):	399219	**Status:**	Operating
Northing (Y):	6434287	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	3.4	1.7	no
Pinjar	28	20.8	17.4	2.3	no
Wanneroo	37	21.0	24.1	1.5	no
Mariginiup	123	23.1	24.9	0.7	no
South Perth	209	25.2	34.0	1.5	no
Yarragadee	241	26.3	24.3	1.3	no
Depth of log	342.5	28.8	N/A	N/A	N/A

AM51

Digitised by WAGCOE, April 2010



Temperature vs depth for AM50 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

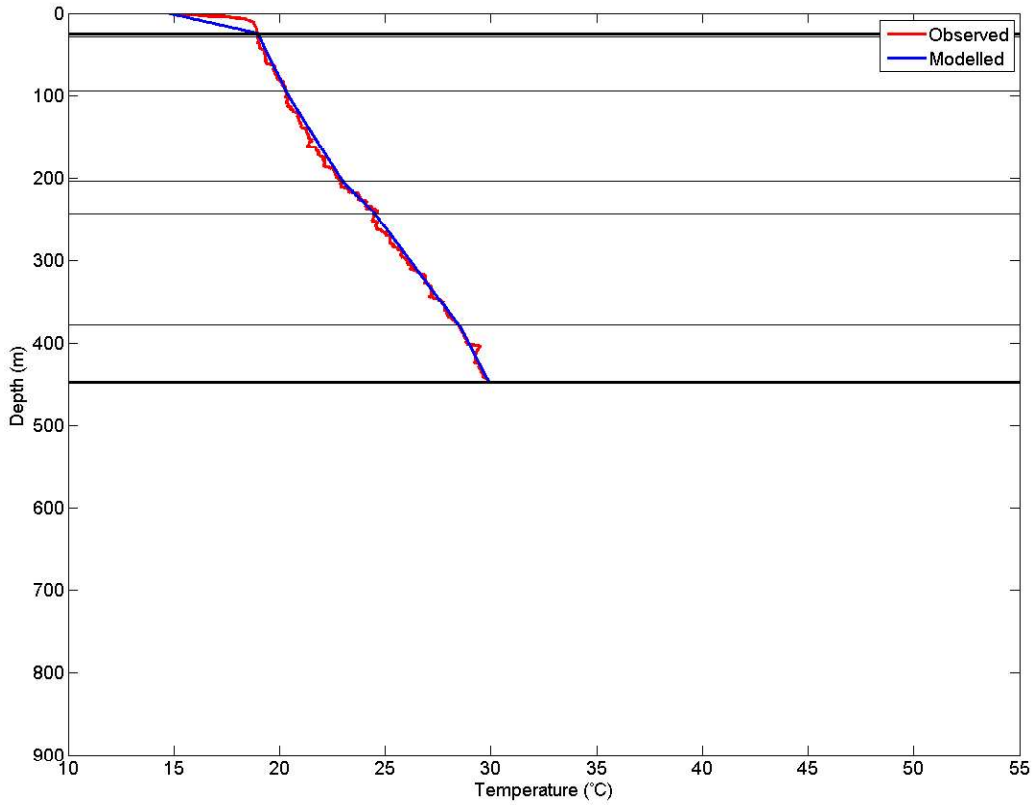
Date construction completed:	15/05/1979	**Ground level (m AHD):**	27.180
Date logged:	22/09/1980	**Top of casing (m AHD):**	27.710
Geodetic datum:	GDA94	**Total well depth below GL (m):**	421
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	335 - 345 (Yarragadee)
Easting (X):	403687	**Status:**	Operating
Northing (Y):	6439011	**Depth to reliable measurements (m):**	58

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Pinjar	15	N/A	N/A	N/A	N/A
Wanneroo	44	N/A	N/A	N/A	N/A
Mariginiup	57	N/A	16.0	1.9	no
Cattamarra	128	22.0	21.6	2.2	no
Depth of log	396.5	27.8	N/A	N/A	N/A

AM52

Digitised by WAGCOE, April 2010



Temperature vs depth for AM52 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 1 sec

Well specifics

Date construction completed:	15/04/1980	**Ground level (m AHD):**	3.990
Date logged:	23/06/1982	**Top of casing (m AHD):**	4.750
Geodetic datum:	GDA94	**Total well depth below GL (m):**	481
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	457 - 462 (Yarragadee)
Easting (X):	383439	**Status:**	Operating
Northing (Y):	6434823	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	4.8	2.7	no
Pinjar	28	19.0	19.0	2.3	no
Wanneroo	95	20.3	24.7	3.5	no
Mariginiup	204	23.0	39.6	3.5	no
South Perth	243	24.5	29.4	2.3	no
Gage	378	28.5	20.3	2.3	no
Depth of log	448.0	29.9	N/A	N/A	N/A

AM52Y (Garden Island North)

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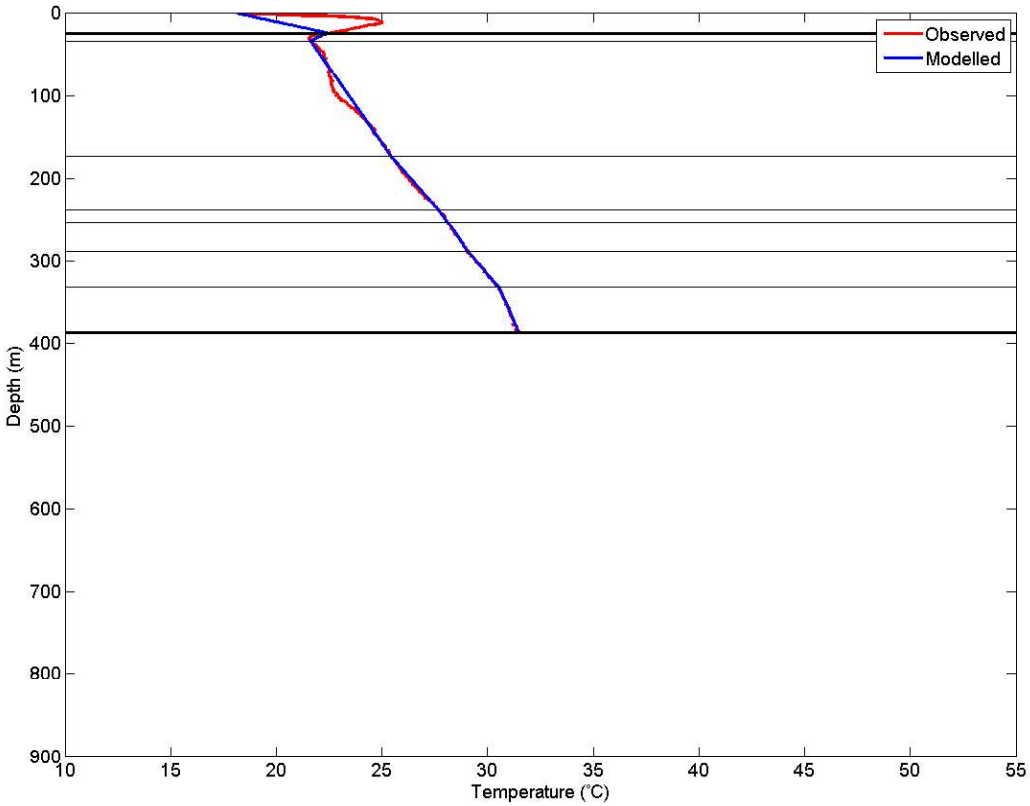

Temperature vs depth for AM52Y (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

Date construction completed:	30/06/1943	**Ground level (m AHD):**	6.020
Date logged:	26/07/1982	**Top of casing (m AHD):**	6.800
Geodetic datum:	GDA94	**Total well depth below GL (m):**	436
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	381 - 396 (Yarragadee)
Easting (X):	374326	**Status:**	Operating
Northing (Y):	6441206	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	-88.0	13.5	yes
Kardinya	34	21.6	27.5	3.3	no
Henley	164	25.1	29.1	2.5	no
Pinjar	174	25.4	34.9	1.5	no
Wanneroo	238	27.7	29.1	1.6	no
Mariginiup	252	28.1	26.0	0.8	no
South Perth	288	29.0	33.6	0.7	no
Gage	331	30.5	17.0	0.6	no
Depth of log	387.0	31.5	N/A	N/A	N/A

AM52Z (Garden Island South)

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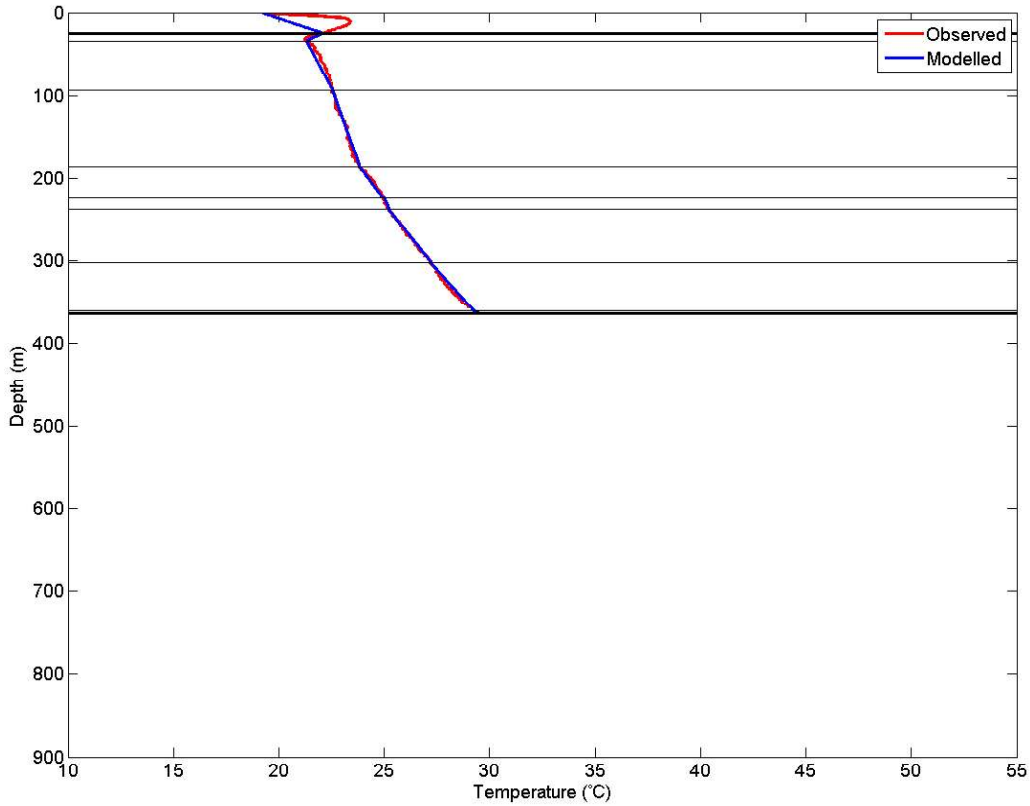

Temperature vs depth for AM52Z (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

Date construction completed:	31/07/1980	**Ground level (m AHD):**	4.090
Date logged:	26/07/1982	**Top of casing (m AHD):**	4.850
Geodetic datum:	GDA94	**Total well depth below GL (m):**	386
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	362 - 367 (Yarragadee)
Easting (X):	376115	**Status:**	Operating
Northing (Y):	6433422	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	-88.7	9.6	yes
Rockingham	34	21.3	21.0	3.6	no
Kings Park	94	22.5	14.2	1.2	no
Kardinya	186	23.8	28.7	2.4	no
Henley	223	25.0	16.9	2.2	no
Mariginiup	238	25.2	31.6	1.0	no
South Perth	302	27.2	35.4	2.8	no
Cattamarra	361	29.2	114.3	4.8	no
Depth of log	363.5	29.4	N/A	N/A	N/A

AM54

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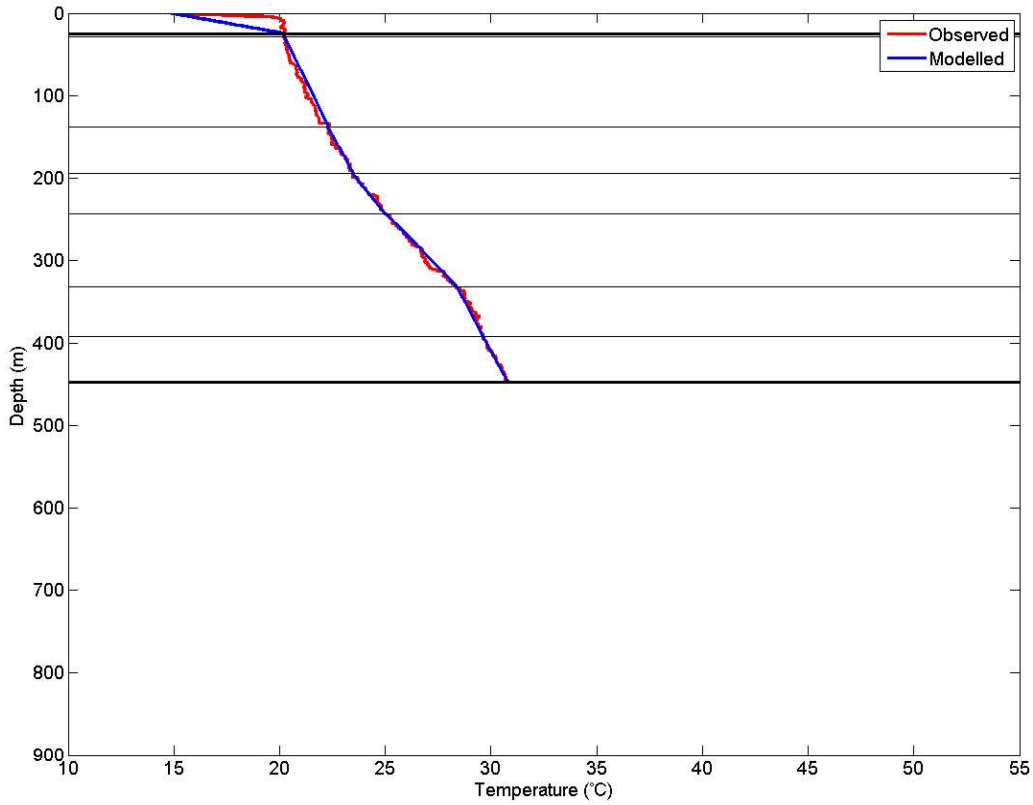

Temperature vs depth for AM54 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 3 sec

Well specifics

Date construction completed:	15/03/1980	**Ground level (m AHD):**	5.248
Date logged:	01/07/1982	**Top of casing (m AHD):**	5.076
Geodetic datum:	GDA94	**Total well depth below GL (m):**	448
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	405 - 412 (Yarragadee)
Easting (X):	381972	**Status:**	Operating
Northing (Y):	6426982	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	5.2	3.1	no
Rockingham	28	20.2	19.1	3.0	no
Wanneroo	138	22.3	21.1	1.8	no
Mariginiup	194	23.4	31.5	2.1	no
South Perth	243	25.0	38.3	2.7	no
Gage	331	28.4	20.6	2.5	no
Cattamarra	392	29.6	21.7	1.1	no
Depth of log	448.0	30.8	N/A	N/A	N/A

AM55

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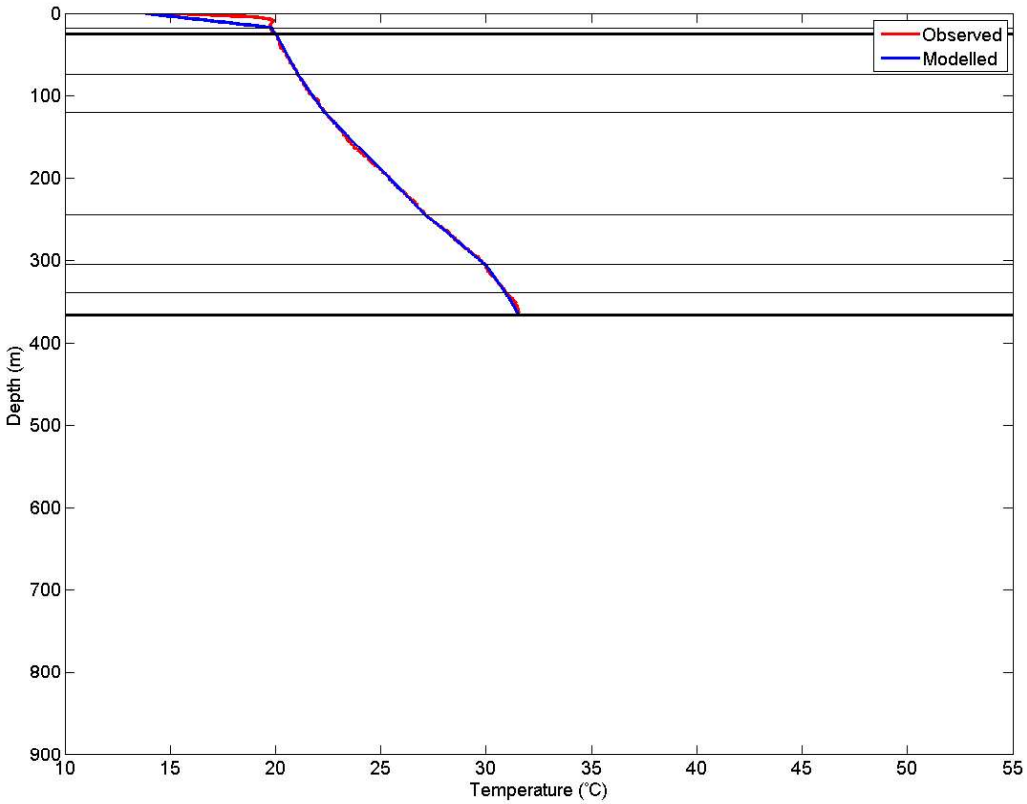

Temperature vs depth for AM55 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

Date construction completed:	N/A	**Ground level (m AHD):**	7.440
Date logged:	28/07/1982	**Top of casing (m AHD):**	7.930
Geodetic datum:	GDA94	**Total well depth below GL (m):**	405
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	360 - 366 (Yarragadee)
Easting (X):	392475	**Status:**	Operating
Northing (Y):	6423101	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Pinjar	18	N/A	21.2	0.9	no
Wanneroo	75	21.1	27.7	1.1	no
Mariginiup	120	22.3	38.4	1.2	no
South Perth	245	27.1	46.8	0.8	no
Gage	305	30.0	28.6	1.3	no
Yarragadee	339	30.9	22.8	3.4	no
Depth of log	366.5	31.6	N/A	N/A	N/A

AM57 (Becher Pt No 1)

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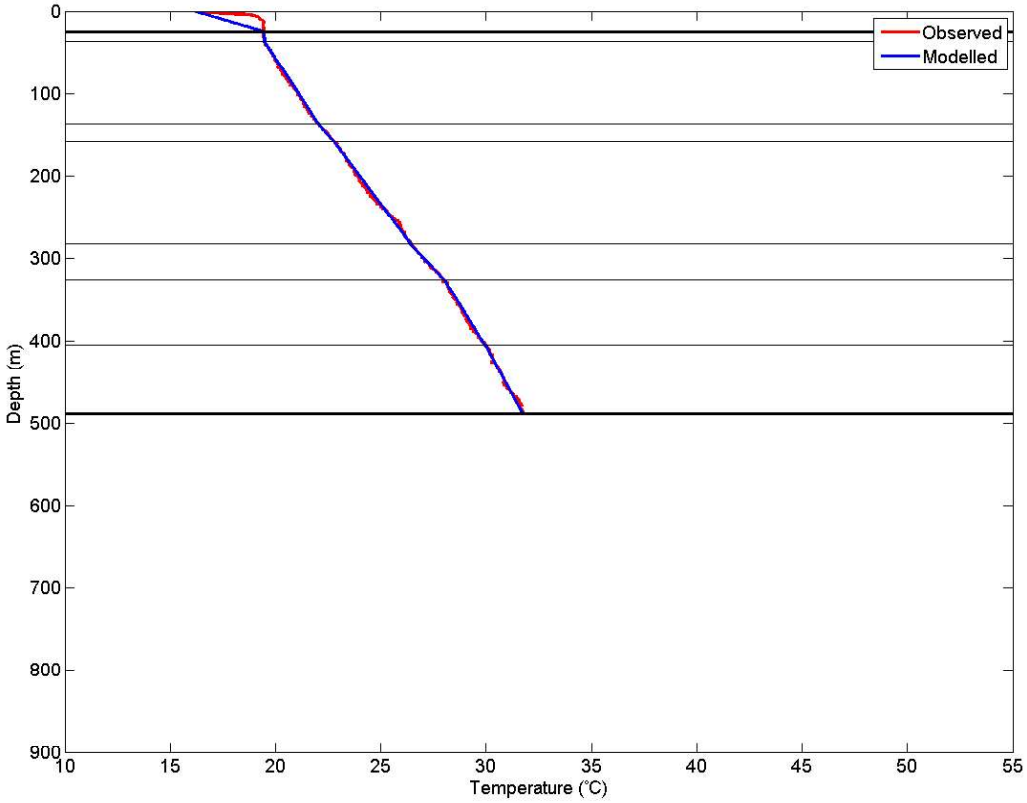


Temperature vs depth for AM57 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

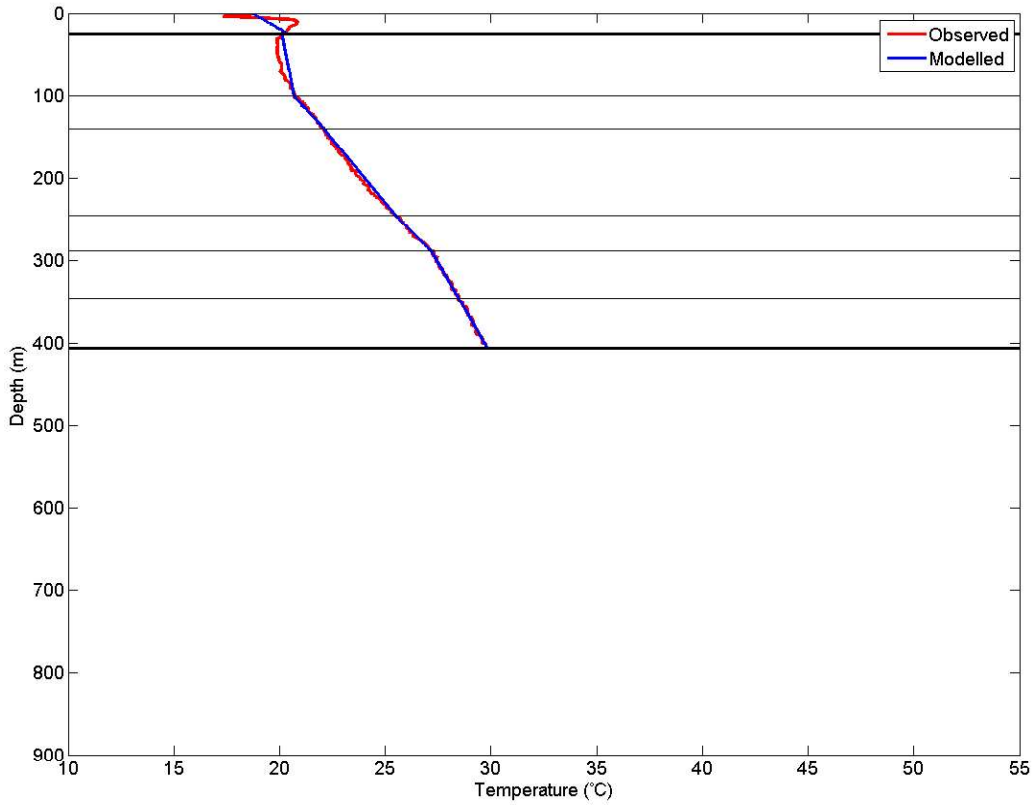
Date construction completed:	15/12/1976	**Ground level (m AHD):**	2.260
Date logged:	27/07/1982	**Top of casing (m AHD):**	2.710
Geodetic datum:	GDA94	**Total well depth below GL (m):**	806
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	483 - 488 (Yarragadee)
Easting (X):	380392	**Status:**	Operating
Northing (Y):	6417422	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	2.2	1.1	no
Rockingham	37	19.5	25.6	1.1	no
Wanneroo	136	22.0	35.2	1.1	no
Mariginiup	157	22.7	29.3	1.3	no
South Perth	283	26.4	37.7	0.9	no
Gage	326	28.0	24.3	1.5	no
Cattamarra	405	30.0	21.1	1.3	no
Depth of log	488.5	31.8	N/A	N/A	N/A

AM58 (Becher Pt No 2)

Digitised by WAGCOE, April 2010



Temperature vs depth for AM58 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

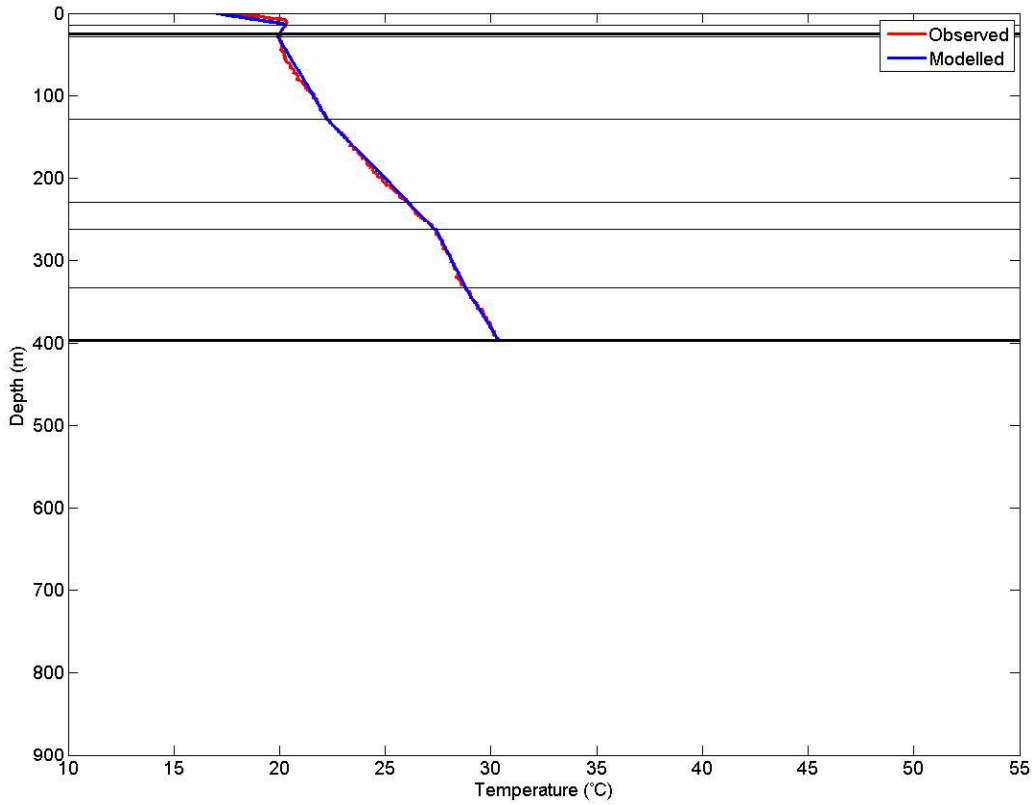
Date construction completed:	15/04/1977	**Ground level (m AHD):**	9.150
Date logged:	08/07/1982	**Top of casing (m AHD):**	10.120
Geodetic datum:	GDA94	**Total well depth below GL (m):**	742
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	379 - 384 (Yarragadee)
Easting (X):	387338	**Status:**	Operating
Northing (Y):	6415685	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Rockingham	24	N/A	7.6	4.7	no
Wanneroo	101	20.7	36.6	2.0	no
Mariginiup	140	22.1	32.3	2.5	no
South Perth	246	25.5	38.8	1.5	no
Gage	288	27.1	22.9	1.1	no
Yarragadee	345	28.4	22.8	1.2	no
Depth of log	405.5	29.8	N/A	N/A	N/A

AM59 (Becher Pt No 3)

Digitised by WAGCOE, April 2010



Temperature vs depth for AM59 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

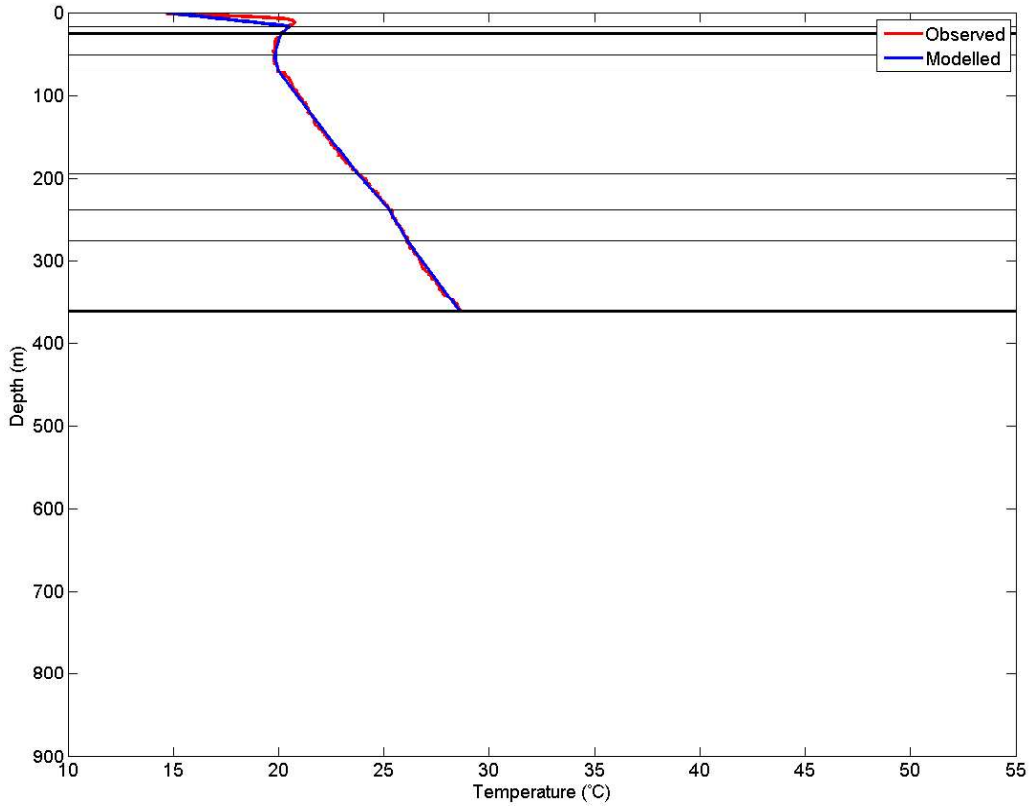
Date construction completed:	15/03/1977	**Ground level (m AHD):**	8.080
Date logged:	08/07/1982	**Top of casing (m AHD):**	8.956
Geodetic datum:	GDA94	**Total well depth below GL (m):**	796
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	375 - 380 (Yarragadee)
Easting (X):	392454	**Status:**	Operating
Northing (Y):	6417800	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Pinjar	14	N/A	-41.6	5.1	yes
Wanneroo	28	19.9	23.2	2.3	no
Mariginiup	128	22.2	38.1	2.0	no
South Perth	229	26.1	37.1	1.8	no
Gage	263	27.4	20.3	1.1	no
Yarragadee	333	28.8	24.8	1.0	no
Depth of log	396.0	30.3	N/A	N/A	N/A

AM62

Digitised by WAGCOE, April 2010



Temperature vs depth for AM62 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

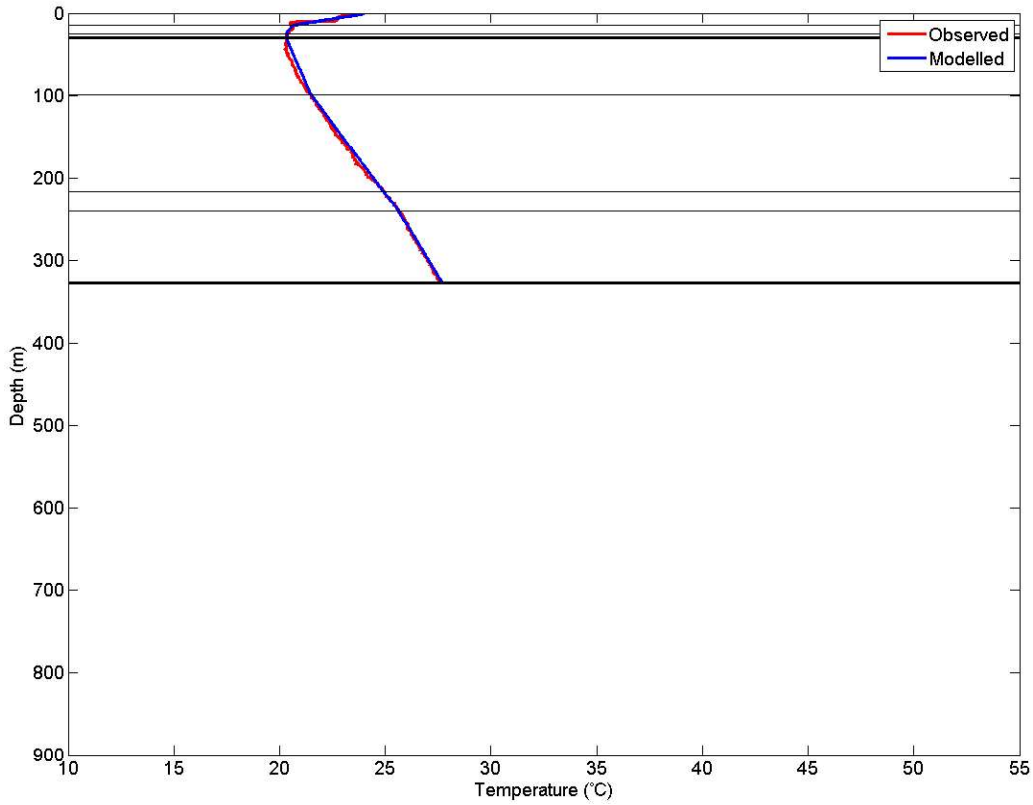
Date construction completed:	15/03/1980	**Ground level (m AHD):**	7.660
Date logged:	07/07/1982	**Top of casing (m AHD):**	8.280
Geodetic datum:	GDA94	**Total well depth below GL (m):**	386
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	333 - 339 (Yarragadee)
Easting (X):	387727	**Status:**	Operating
Northing (Y):	6410862	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Rockingham	17	N/A	-11.7	3.0	no
Wanneroo	51	19.8	10.3	1.7	no
Mariginiup	70	20.0	30.3	1.5	no
South Perth	195	23.8	34.8	1.6	no
Gage	237	25.2	22.7	1.3	no
Cattamarra	276	26.1	29.0	1.7	no
Depth of log	361.5	28.6	N/A	N/A	N/A

AM63

Digitised by WAGCOE, April 2010



Temperature vs depth for AM63 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

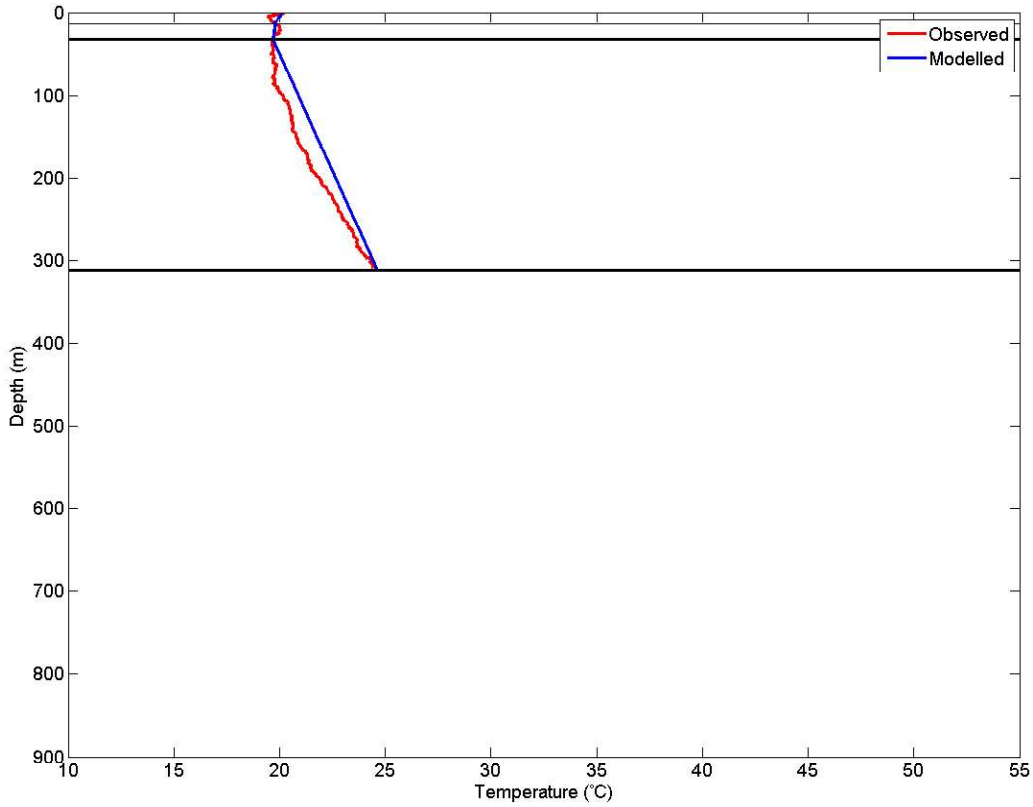
Date construction completed:	15/02/1980	**Ground level (m AHD):**	21.820
Date logged:	29/10/1980	**Top of casing (m AHD):**	22.270
Geodetic datum:	GDA94	**Total well depth below GL (m):**	350
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	312 - 320 (Yarragadee)
Easting (X):	395615	**Status:**	Operating
Northing (Y):	6410203	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Pinjar	15	N/A	N/A	N/A	N/A
Wanneroo	25	N/A	16.7	3.4	no
Mariginiup	99	21.5	29.1	2.0	no
South Perth	216	24.9	31.3	1.0	no
Yarragadee	240	25.6	23.9	1.0	no
Depth of log	327.0	27.7	N/A	N/A	N/A

AM64

Digitised by WAGCOE, April 2010



Temperature vs depth for AM64 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

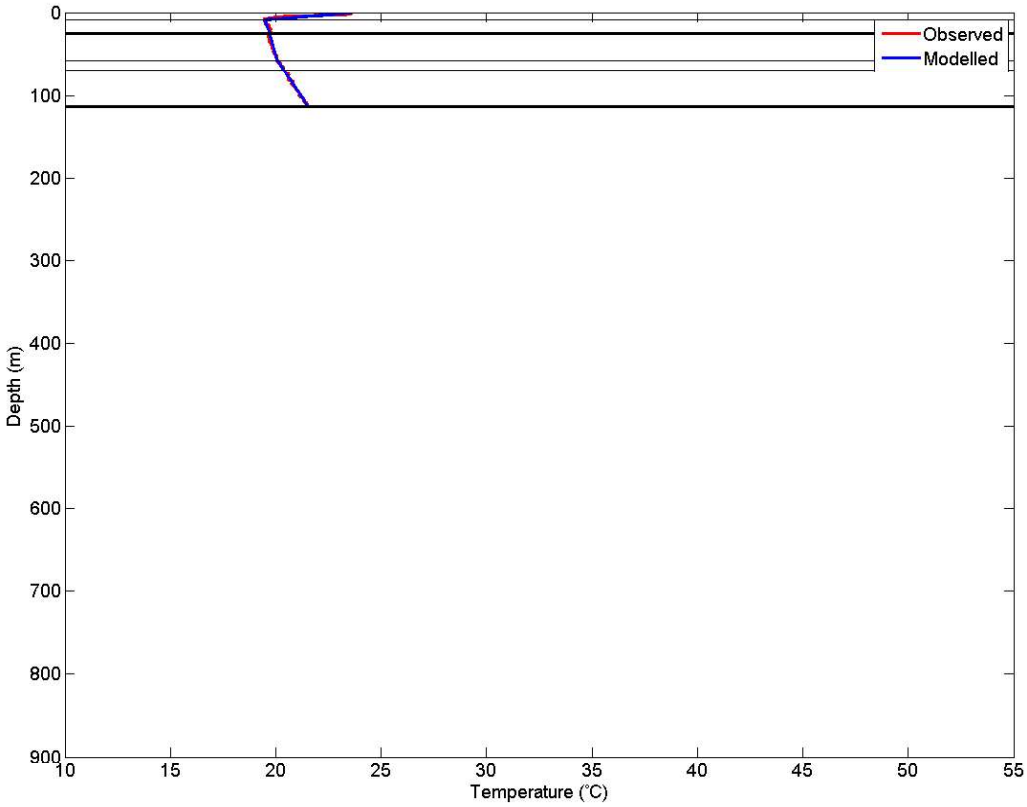
Date construction completed:	11/05/1978	**Ground level (m AHD):**	54.716
Date logged:	18/11/1980	**Top of casing (m AHD):**	55.165
Geodetic datum:	GDA94	**Total well depth below GL (m):**	358
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	307 - 318 (Yarragadee)
Easting (X):	403825	**Status:**	Operating
Northing (Y):	6410003	**Depth to reliable measurements (m):**	32

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Cattamarra	13	N/A	17.7	5.6	yes
Depth of log	311.5	24.6	N/A	N/A	N/A

AM65

Digitised by WAGCOE, April 2010



Temperature vs depth for AM65 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 10 m min^{-1}; time constant: 0.5 sec

Well specifics

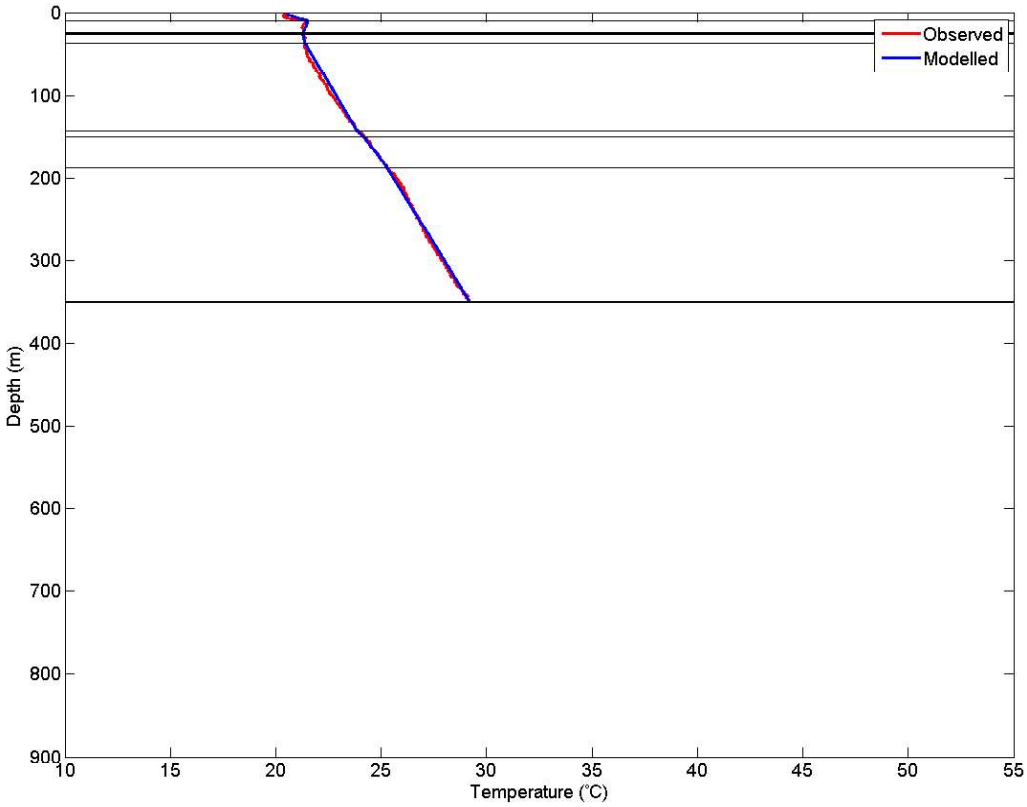
Date construction completed:	15/02/1980	**Ground level (m AHD):**	2.070
Date logged:	04/02/1983	**Top of casing (m AHD):**	2.920
Geodetic datum:	GDA94	**Total well depth below GL (m):**	363
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	114 - 123 (Leederville)
Easting (X):	387523	**Status:**	Operating
Northing (Y):	6403674	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Rockingham	9	N/A	11.1	1.7	no
Wanneroo	57	20.1	27.0	1.6	no
Mariginiup	69	20.4	26.2	1.0	no
Depth of log	113.0	21.5	N/A	N/A	N/A

AM66

Digitised by WAGCOE, April 2010



Temperature vs depth for AM66 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

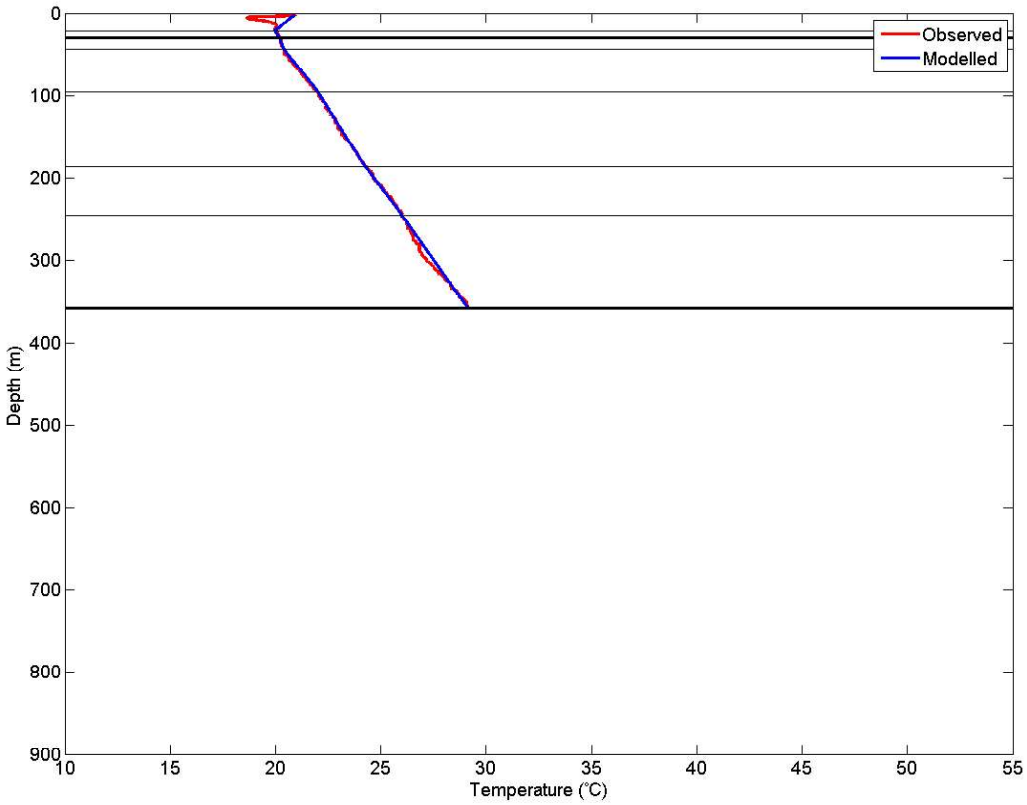
Date construction completed:	15/02/1981	**Ground level (m AHD):**	20.870
Date logged:	16/08/1982	**Top of casing (m AHD):**	21.430
Geodetic datum:	GDA94	**Total well depth below GL (m):**	384
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	341 - 347 (Yarragadee)
Easting (X):	397363	**Status:**	Operating
Northing (Y):	6403772	**Depth to reliable measurements (m):**	25

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Wanneroo	10	N/A	8.3	0.8	no
Mariginiup	36	21.4	23.3	2.4	no
South Perth	142	23.8	49.3	3.5	no
Gage	149	24.2	29.3	1.1	no
Yarragadee	188	25.3	24.2	1.1	no
Depth of log	350.0	29.2	N/A	N/A	N/A

AM67

Digitised by WAGCOE, April 2010



Temperature vs depth for AM67 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

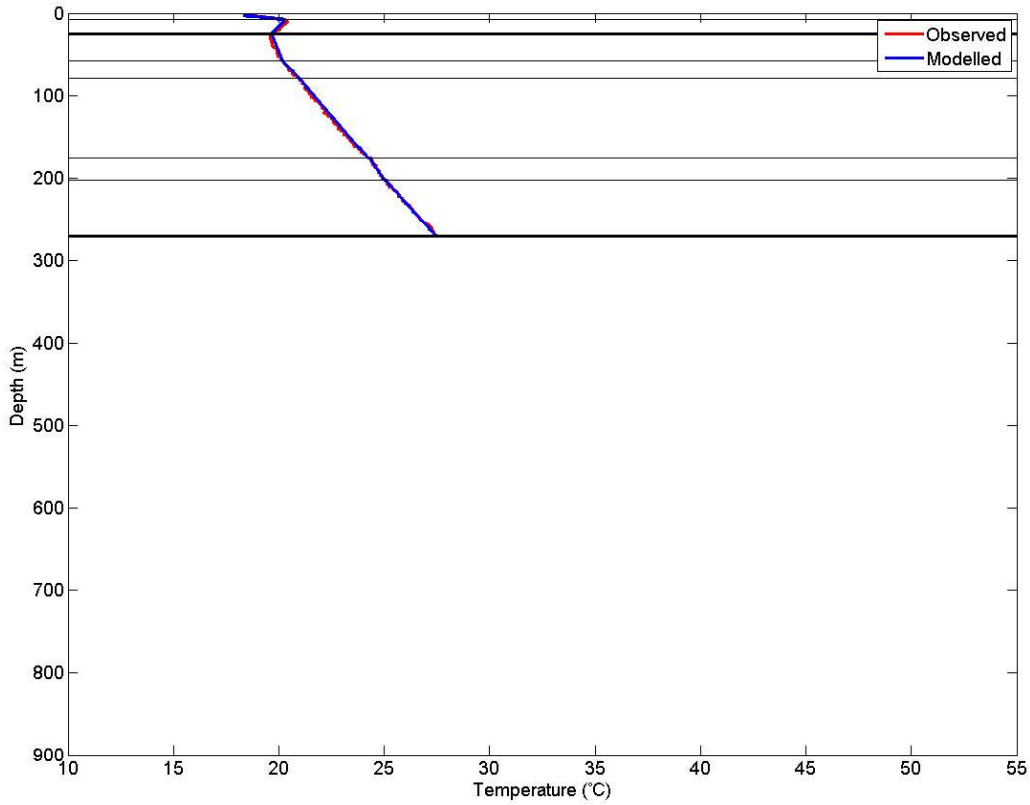
Date construction completed:	30/06/1980	**Ground level (m AHD):**	11.610
Date logged:	11/11/1980	**Top of casing (m AHD):**	12.238
Geodetic datum:	GDA94	**Total well depth below GL (m):**	375
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	342 - 347 (Yarragadee)
Easting (X):	382835	**Status:**	Operating
Northing (Y):	6402182	**Depth to reliable measurements (m):**	30

Logging results

Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Rockingham	21	N/A	15.8	1.3	no
Wanneroo	44	20.4	31.4	2.1	no
Mariginiup	96	22.0	24.7	0.9	no
South Perth	186	24.2	29.7	1.2	no
Cattamarra	246	26.0	28.0	2.6	no
Depth of log	358.5	29.1	N/A	N/A	N/A

AM68

Digitised by WAGCOE, April 2010



Temperature vs depth for AM68 (red line) and subsequent linearly modelled gradients (blue line)
Bold lines indicate interval analysis was conducted over. Logging speed: 9 m min^{-1}; time constant: 0.5 sec

Well specifics

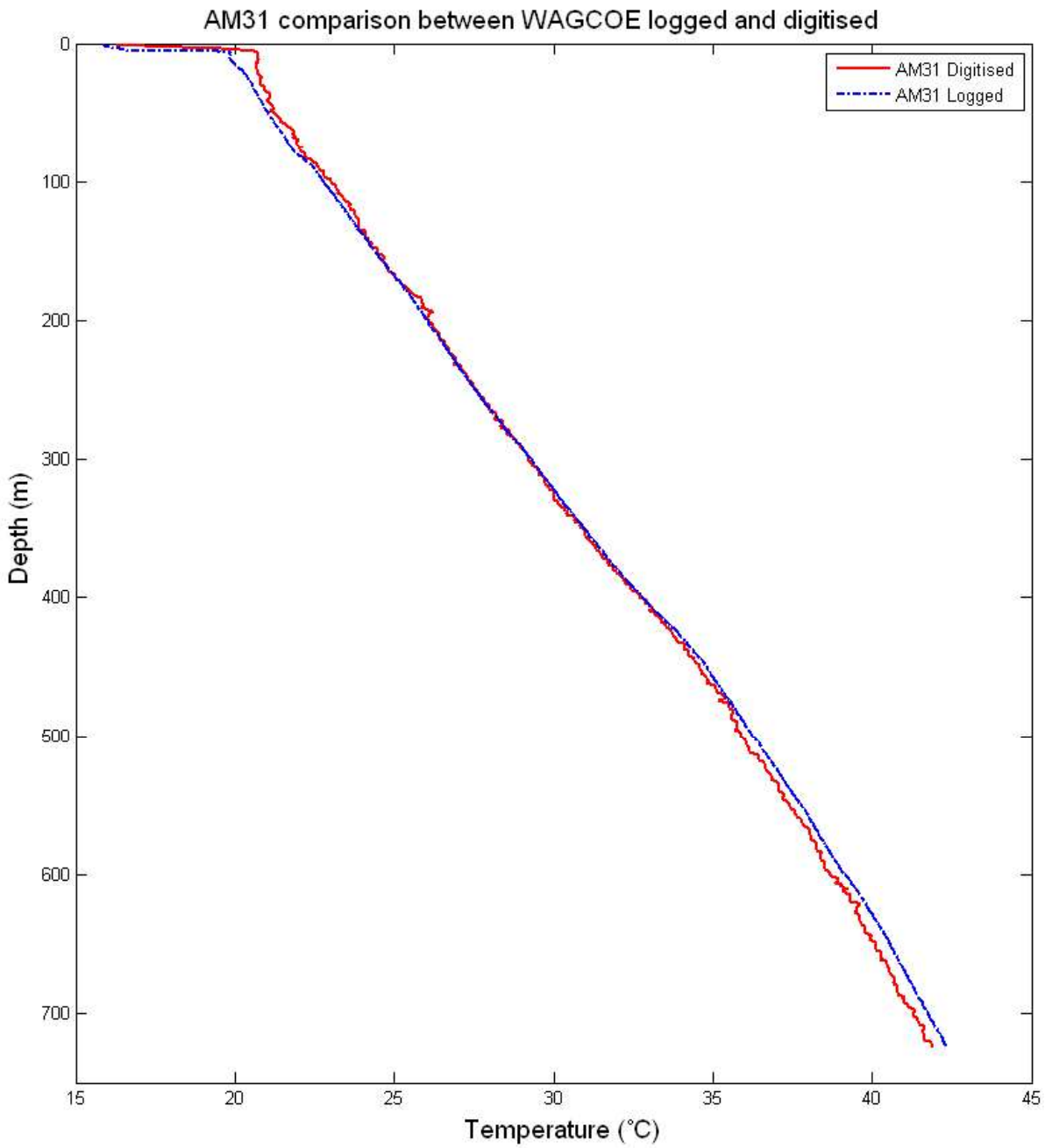
Date construction completed:	15/02/1980	**Ground level (m AHD):**	9.380
Date logged:	11/08/1982	**Top of casing (m AHD):**	9.810
Geodetic datum:	GDA94	**Total well depth below GL (m):**	327
Horizontal coordinate system:	MGA94 Zone 50	**Perforated interval (m) (formation):**	296 - 304 (Yarragadee)
Easting (X):	390782	**Status:**	Operating
Northing (Y):	6398413	**Depth to reliable measurements (m):**	25

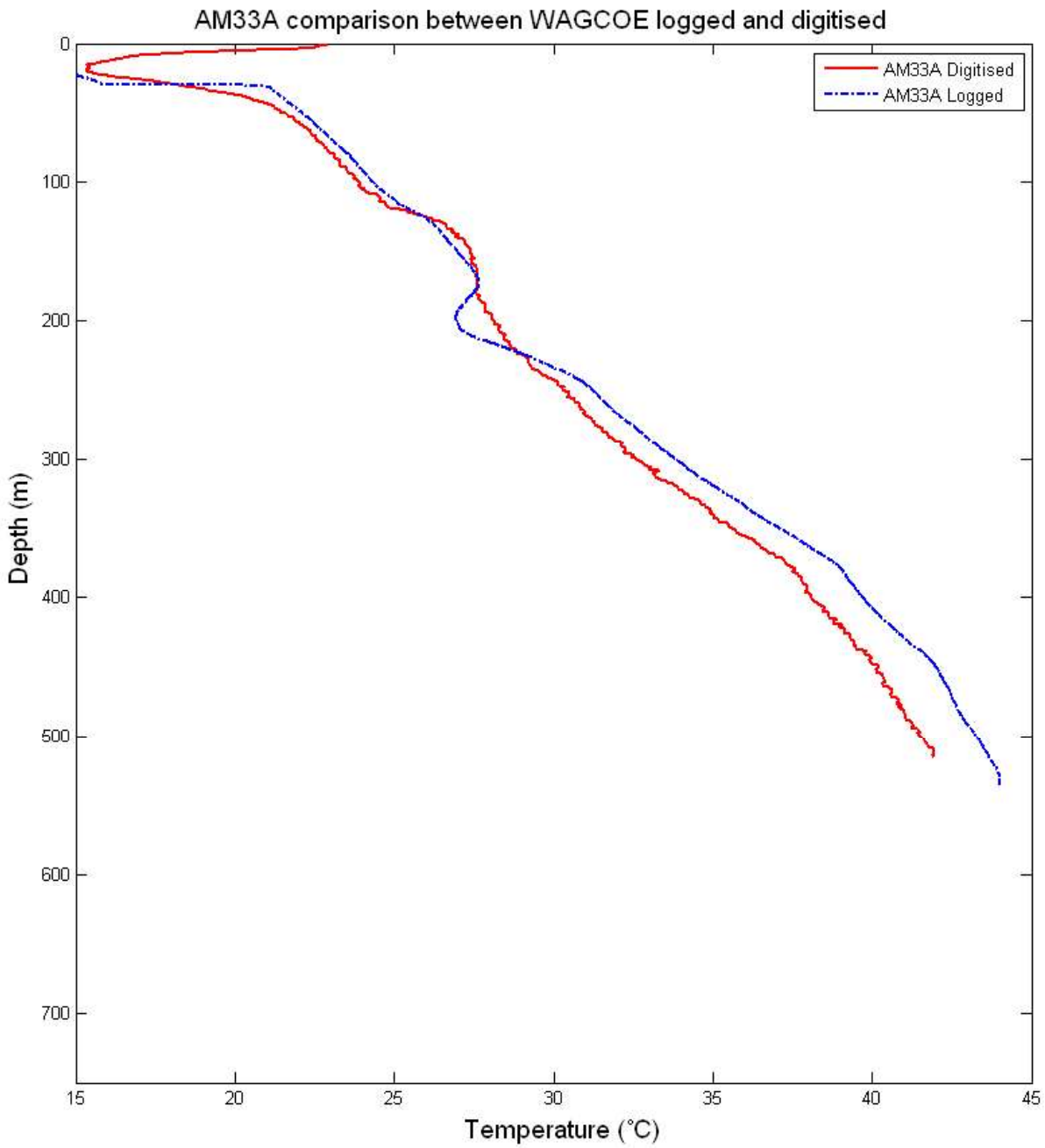
Logging results

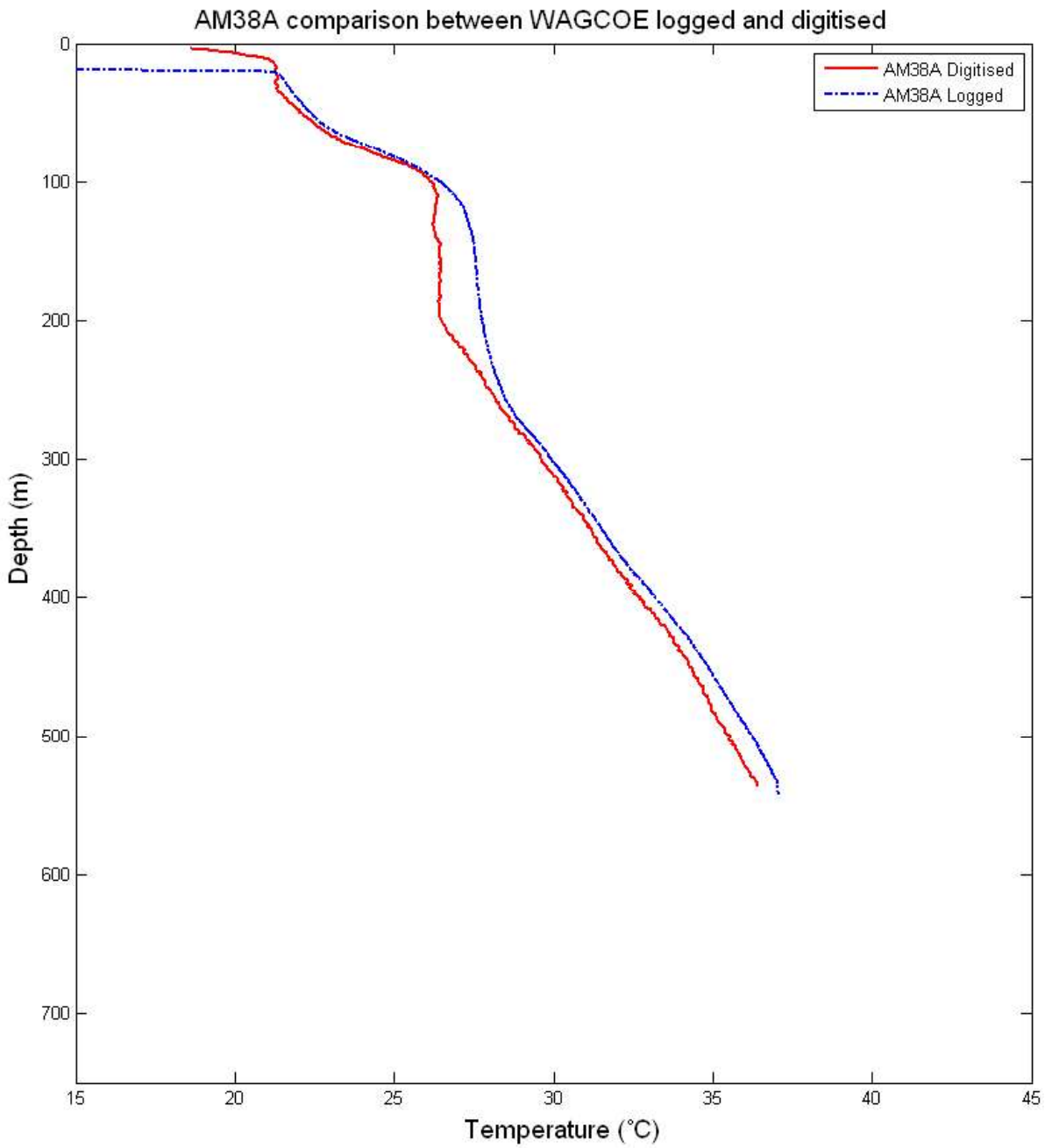
Formation	Depth of top below GL (m)	Temperature at top of formation (°C)	Thermal gradient (°C km^{-1})	Error between observed and modelled data (%)	Advection (yes/no)
Superficial	0	N/A	N/A	N/A	N/A
Rockingham	8	N/A	15.9	2.7	no
Wanneroo	58	20.2	37.1	2.5	no
Mariginiup	80	21.0	34.0	1.5	no
South Perth	176	24.3	26.1	1.1	no
Gage	203	25.1	35.0	0.9	no
Depth of log	271.0	27.5	N/A	N/A	N/A

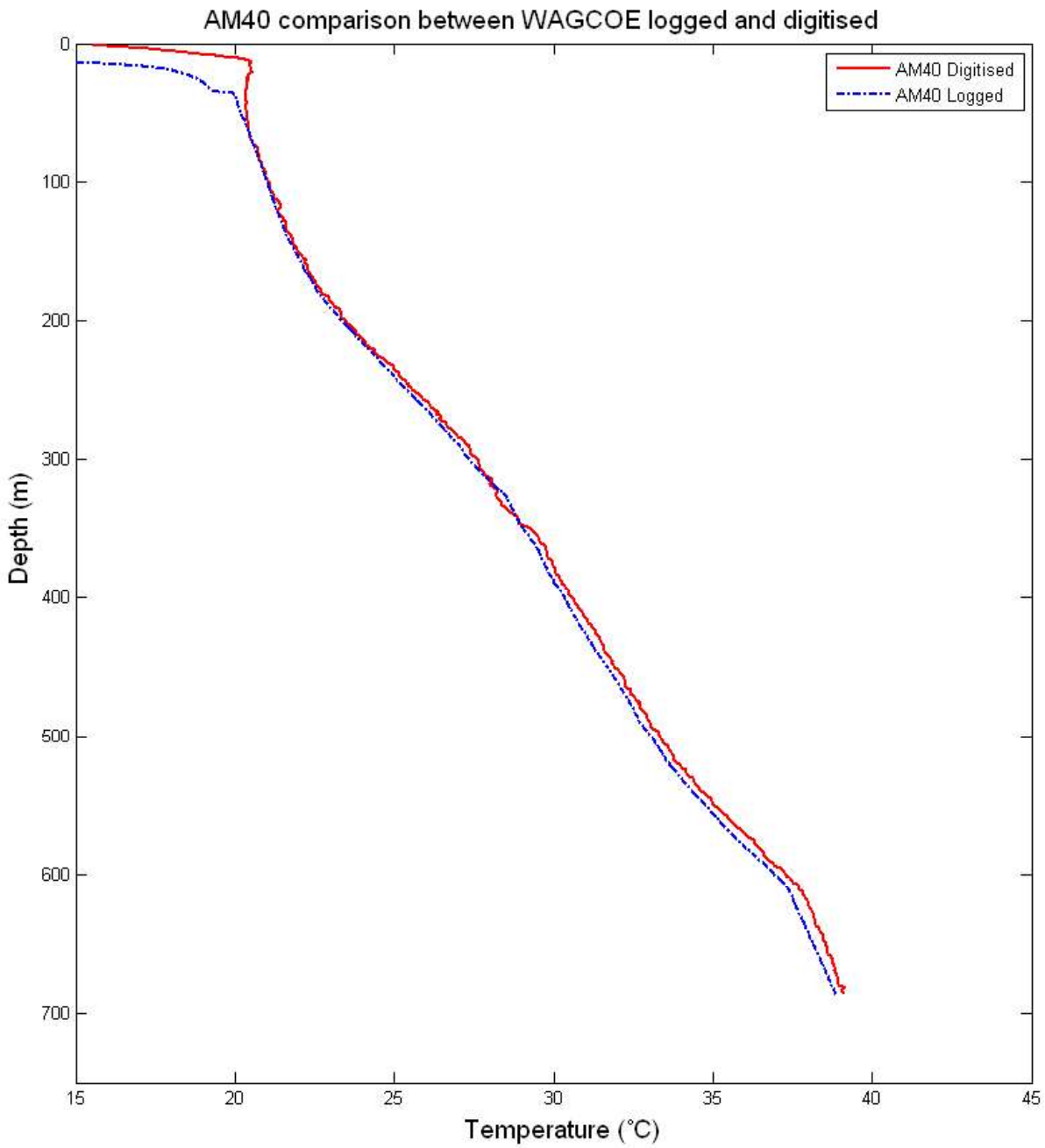
APPENDIX C – COMPARISON BETWEEN LOGGED AND DIGITISED WELLS

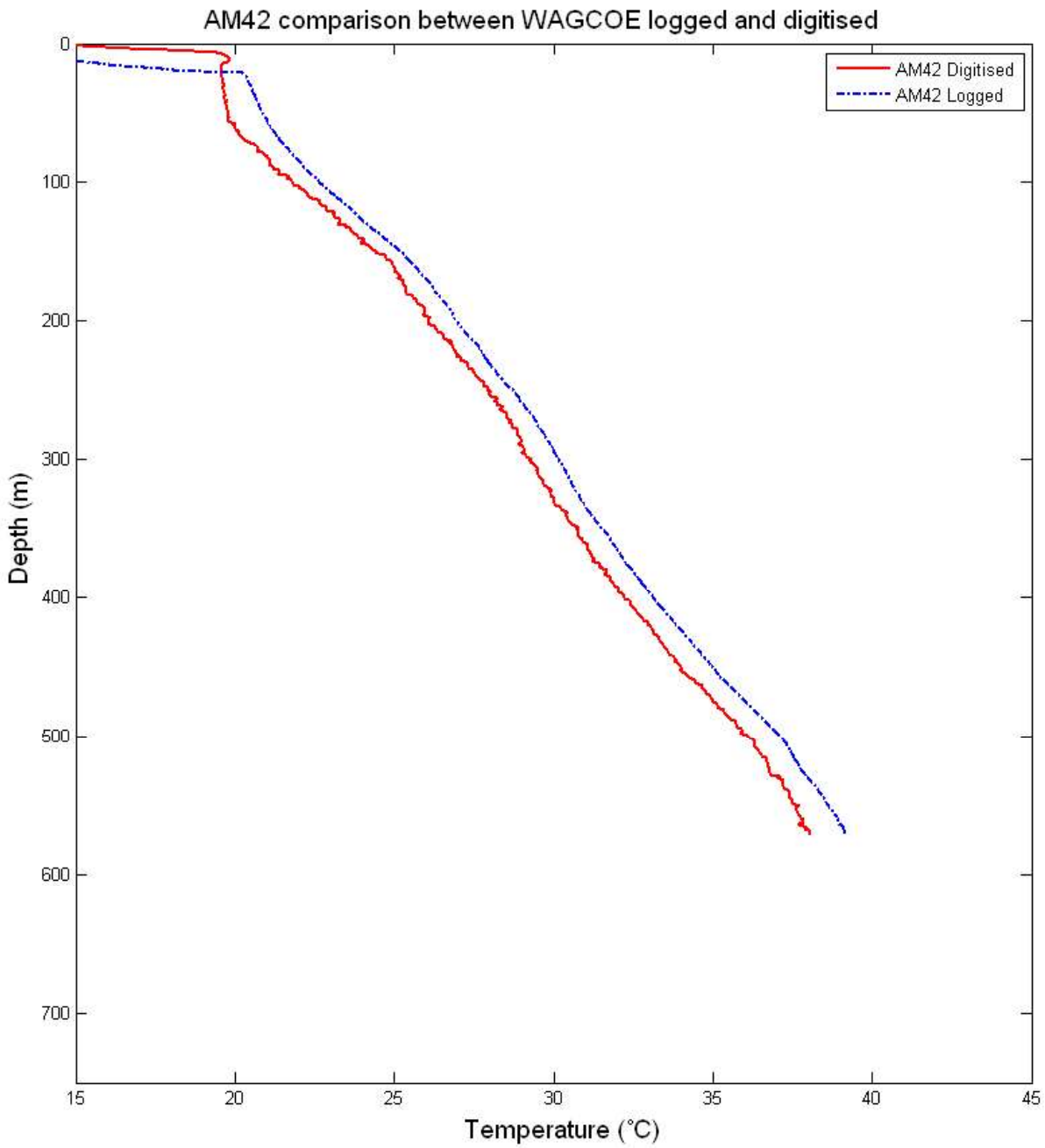
This appendix presents comparison plots between the 11 wells which were both precision logged and digitised from older paper logs. The vertical scale on each chart is the same across the wells for ease of comparison.

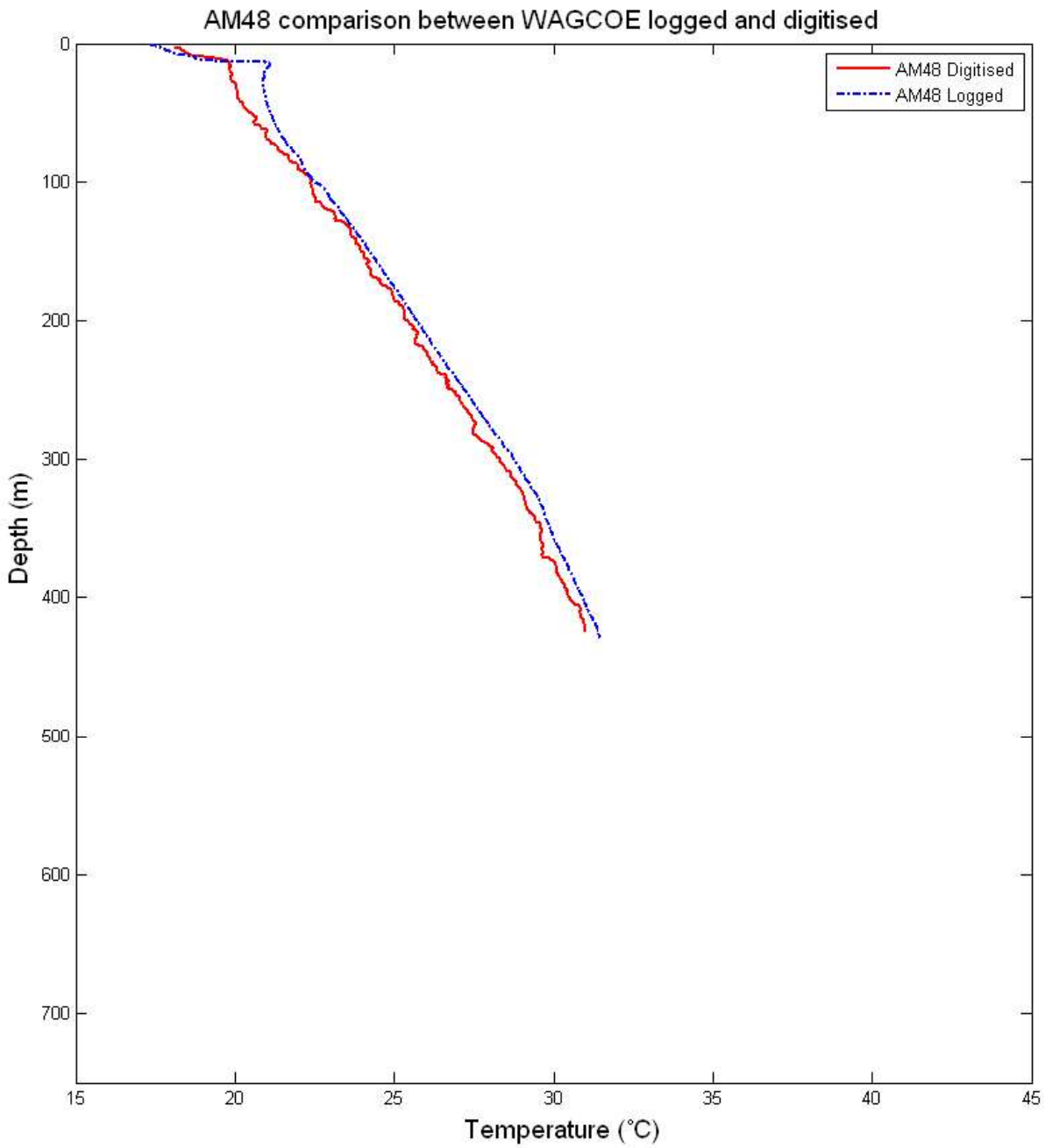

AM31 comparison between WAGCOE logged and digitised
AM31 Digitised
AM31 Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)

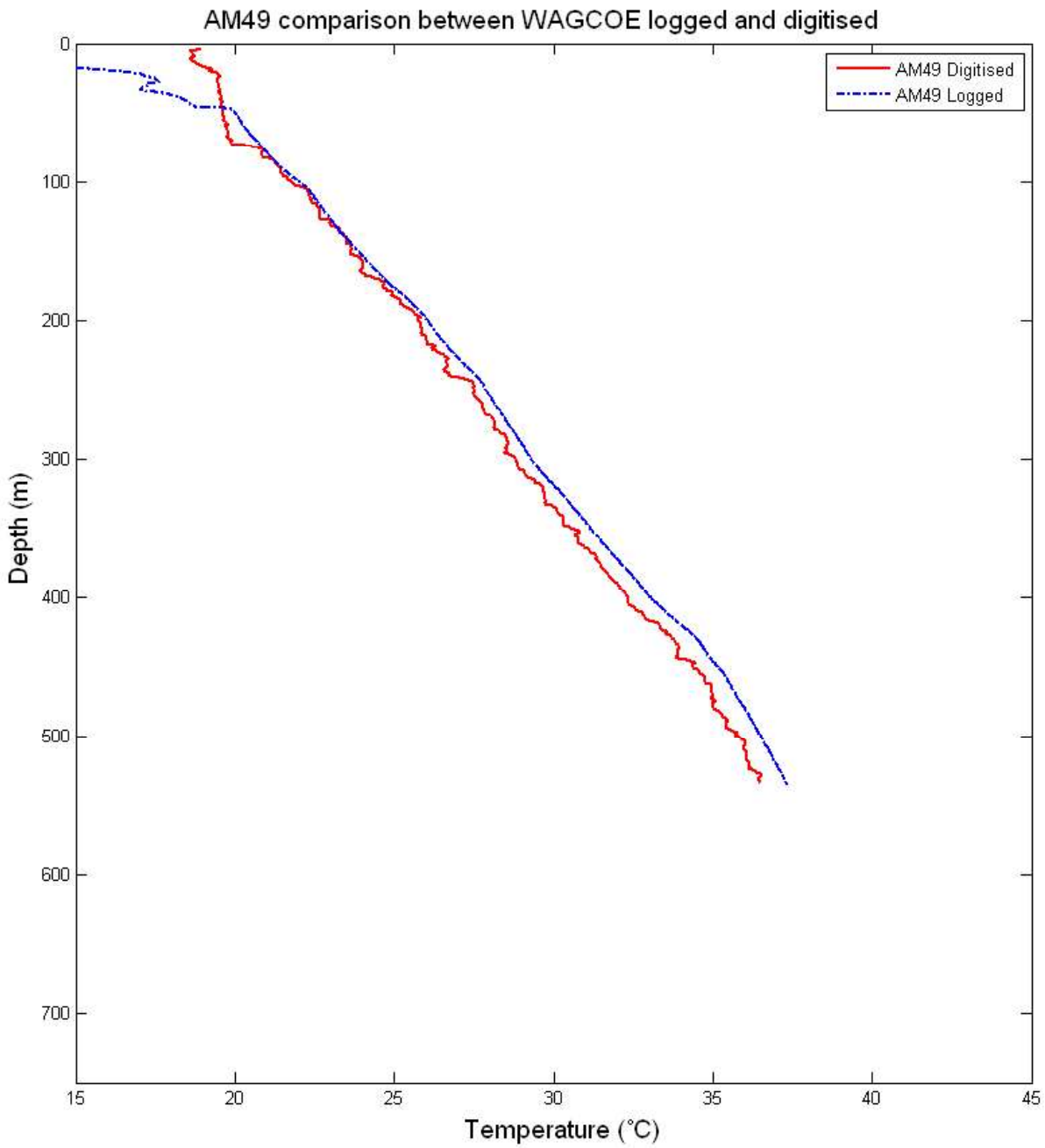

AM33A comparison between WAGCOE logged and digitised
AM33A Digitised
AM33A Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)

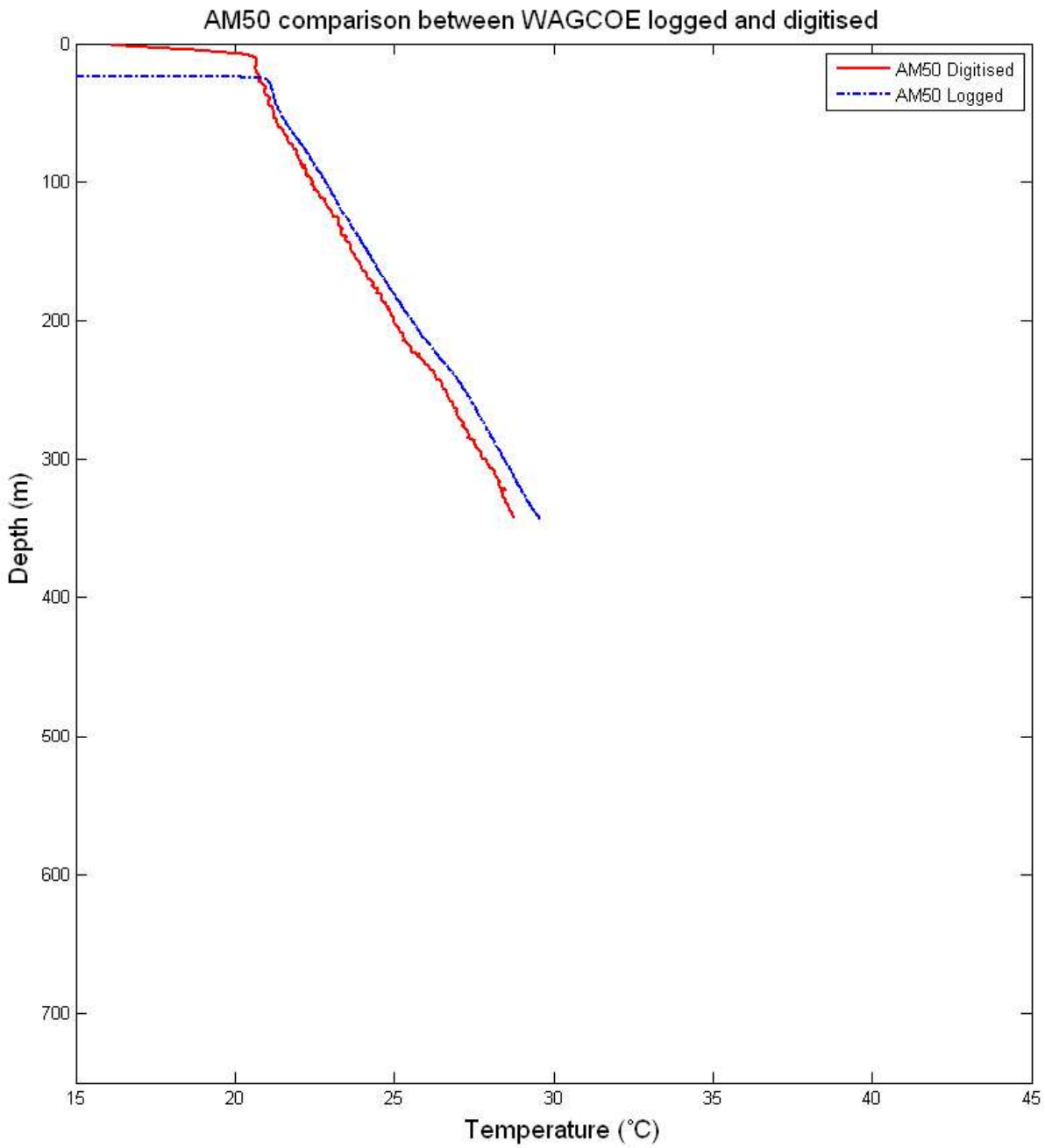

AM38A comparison between WAGCOE logged and digitised
AM38A Digitised
AM38A Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)

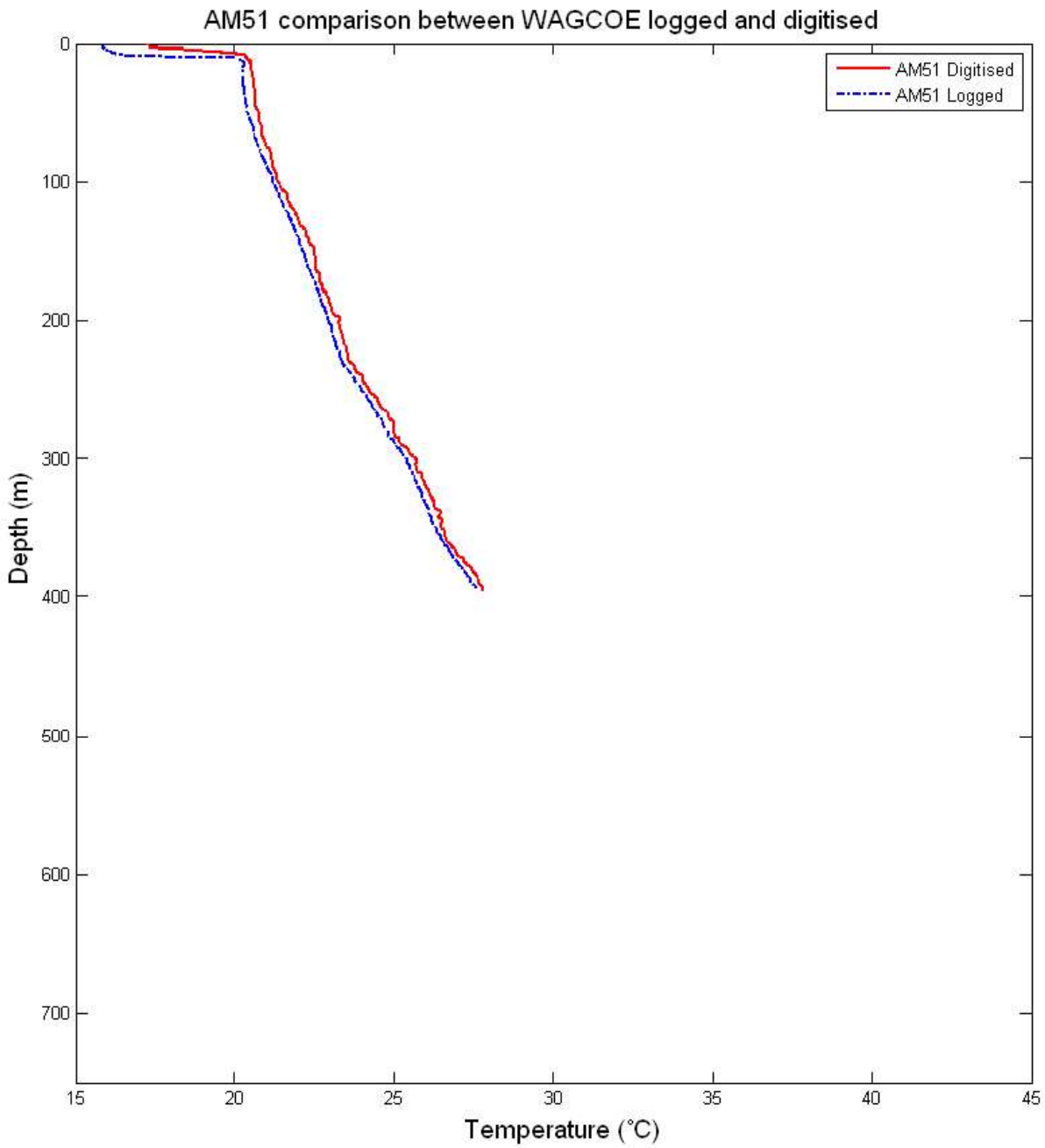

AM40 comparison between WAGCOE logged and digitised
AM40 Digitised
AM40 Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)

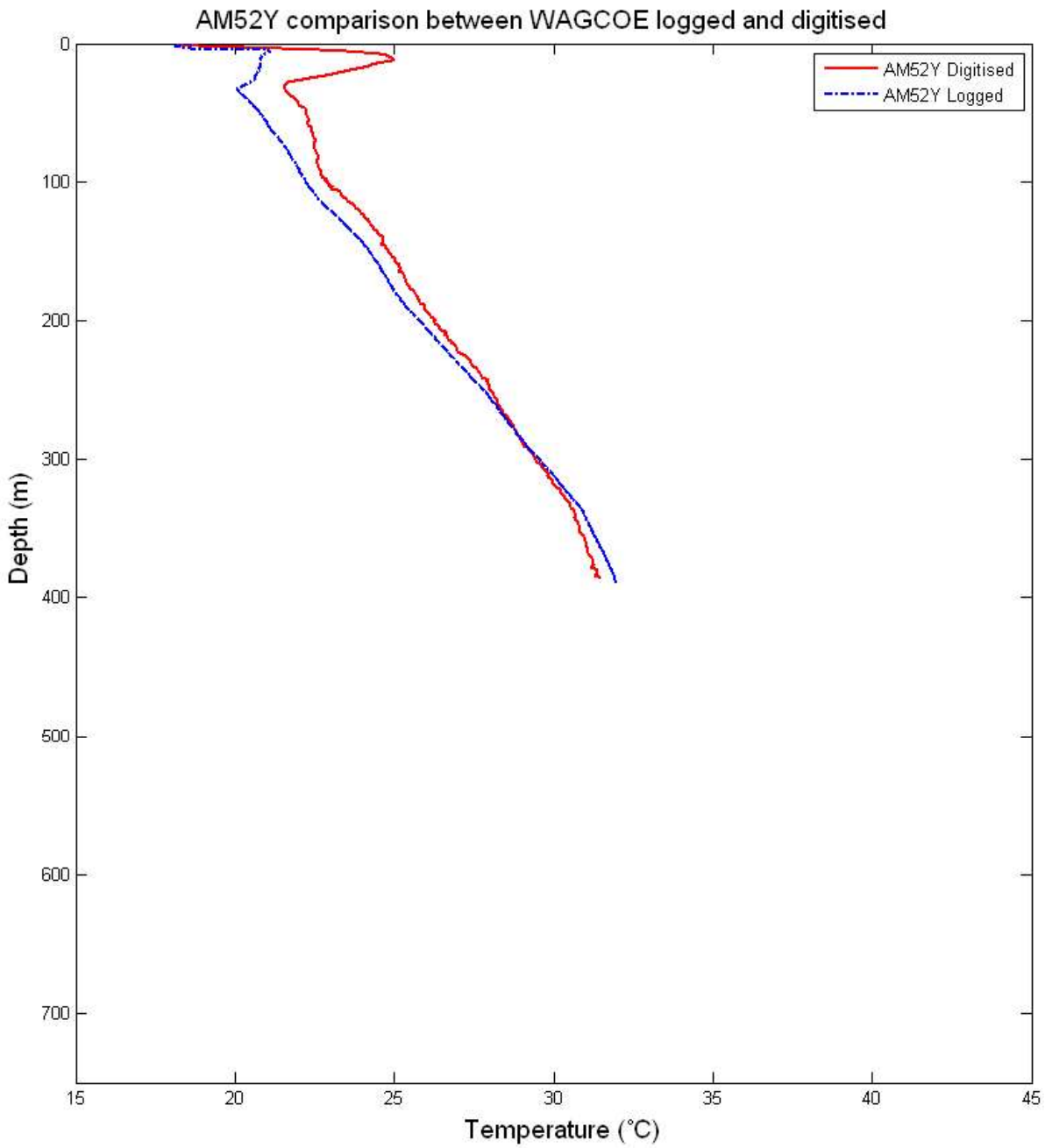

AM42 comparison between WAGCOE logged and digitised
AM42 Digitised
AM42 Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)

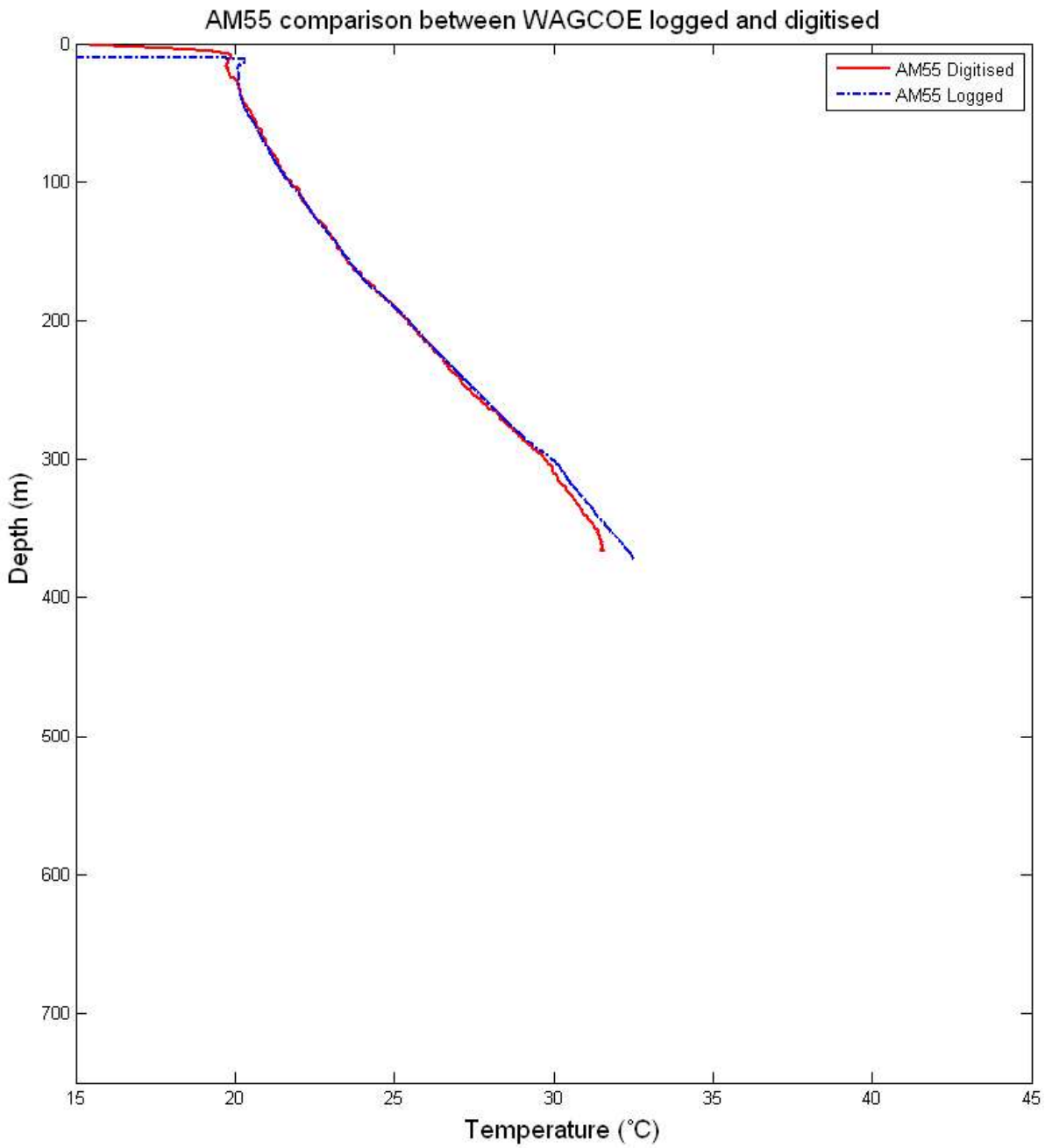

AM48 comparison between WAGCOE logged and digitised
AM48 Digitised
AM48 Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)


AM49 comparison between WAGCOE logged and digitised
AM49 Digitised
AM49 Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)


AM50 comparison between WAGCOE logged and digitised
AM50 Digitised
AM50 Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)


AM51 comparison between WAGCOE logged and digitised
AM51 Digitised
AM51 Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)


AM52Y comparison between WAGCOE logged and digitised
AM52Y Digitised
AM52Y Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)


AM55 comparison between WAGCOE logged and digitised
AM55 Digitised
AM55 Logged
Depth (m)
0
100
200
300
400
500
600
700
15
20
25
30
35
40
45
Temperature (°C)

APPENDIX D – SUMMARY SHEETS OF GEOTHERMAL GRADIENT BY FORMATION

This appendix presents an analysis of the geothermal gradient by formation, as discussed in section 4.7. The analyses are organized in the stratigraphic order described in section 2.2. For each formation, the following are shown:

- A *histogram* showing the spread of measurement and the histogram bin size.
- A table of *statistical results* with arithmetic and geometric means, median, standard deviation and variance, and the sample size.
- A table showing *which wells contain the formation* and whether those wells were considered due to advection or quality control issues.

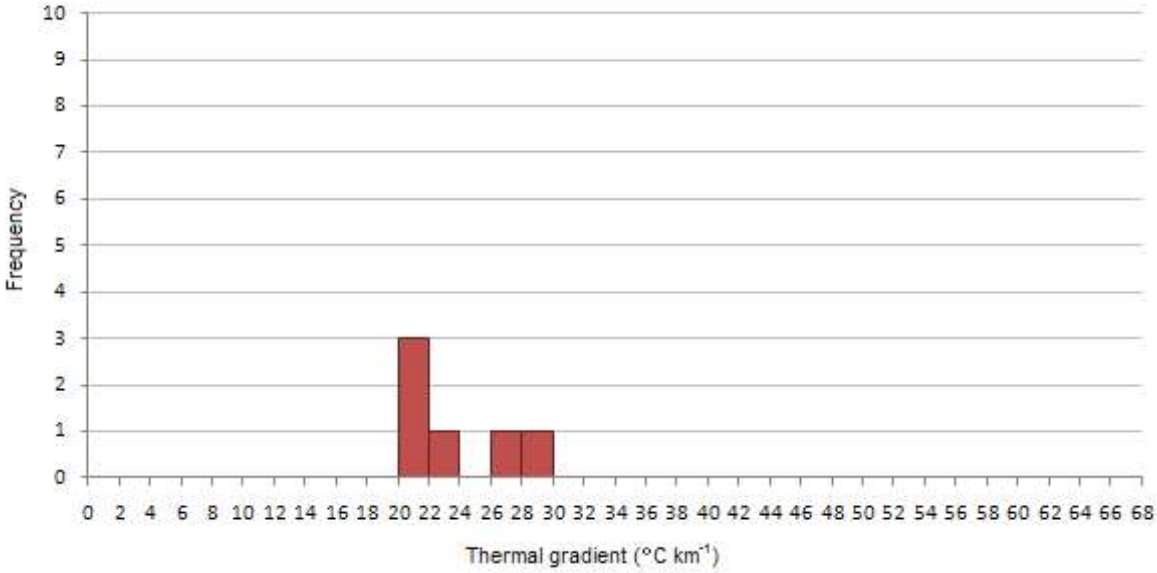
Explanation of terms

Number of thermal gradient values for well: Number of wells that the formation appeared in, and a thermal gradient was calculated for the formation. There are some instances where a formation has appeared in a well above the depth to reliable measurements, and as such no thermal gradient was calculated for it.

Number of values used in analysis: Number of wells that the gradient calculated for the formation was deemed representative of the actual thermal gradient within the formation. Data was excluded if the mismatch between the model and the observed data was greater than 5%, the gradient was unrealistic (< 0 or > 80 °C km^{-1}) or the thickness of the unit was less than 10 m.

Well names that are *italicised* indicate they were logged by WAGCOE; well names in ordinary font were digitised by WAGCOE

Cattamarra Coal Measures [Jc]



Histogram of thermal gradients in the Cattamarra Coal Measures. Bin size: 2 °C km^{-1}

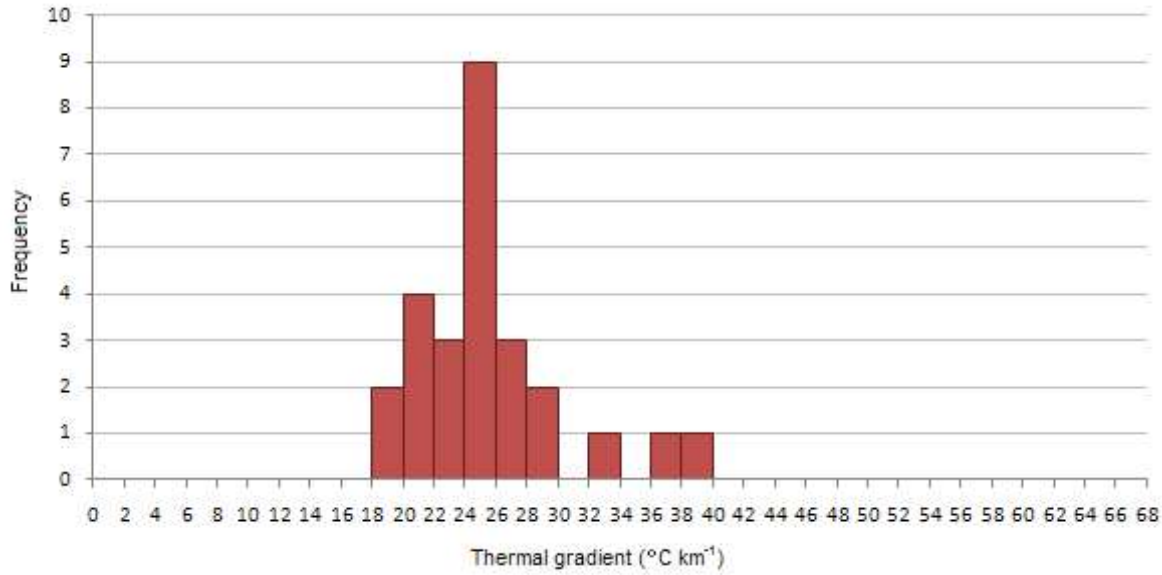
Statistical analysis results

Arithmetic mean:	24.0
Geometric mean:	23.8
Median:	22.8
Standard deviation:	3.2
Variance:	10.4
Number of thermal gradient values for well:	9
Number of values used in analysis:	6 (67% of total dataset)

Details of logged AM wells formation present in

Used:	51, 54, 57, 58, 62, 67
Disregarded due to apparent advection (> 5% mismatch):	*51*, 64
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	52Z
Disregarded due to unit thickness < 10 m:	-

Yarragadee Formation [Jy]



Histogram of thermal gradients in the Yarragadee Formation. Bin size: 2 °C km^{-1}

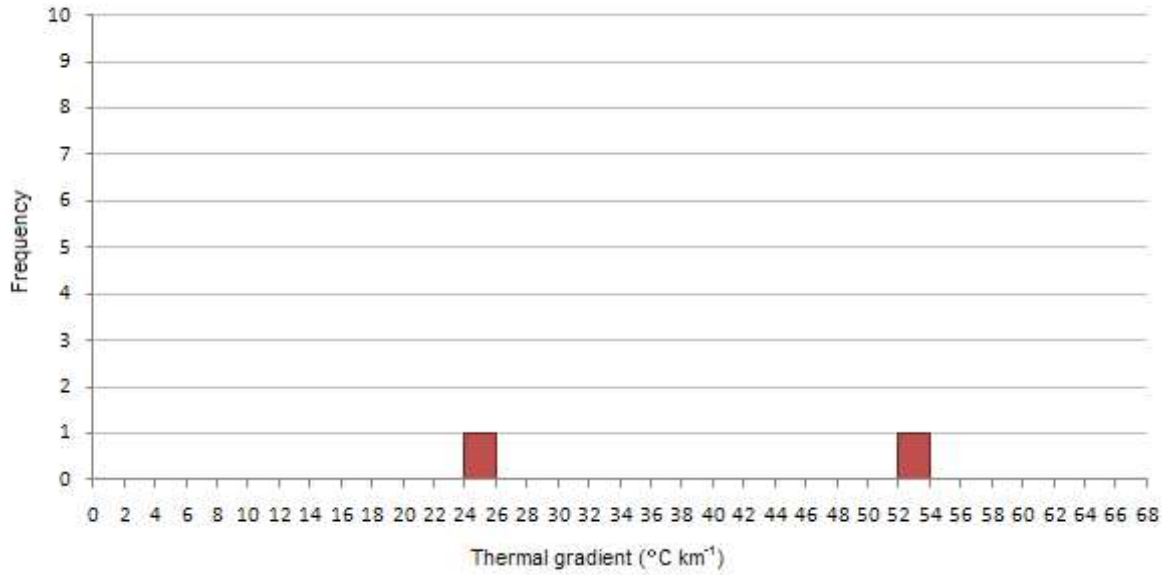
Statistical analysis results

Arithmetic mean:	25.5
Geometric mean:	25.1
Median:	24.7
Standard deviation:	4.7
Variance:	22.5
Number of thermal gradient values for well:	31
Number of values used in analysis:	26 (84% of total dataset)

Details of logged AM wells formation present in

Used:	4A, 13, 17, 23, 29, 30, 31, 32, *33A*, 33A, 35A, 36, 41, *43A*, *46*, *48*, 48, *49*, 49, *50*, 50, *55*, 55, 59, 63, 66
Disregarded due to apparent advection (> 5% mismatch):	*20*, 27, *31*, *32Y*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	37A

Parmelia Formation [Kp]



Histogram of thermal gradients in the Parmelia Formation. Bin size: 2 °C km^{-1}

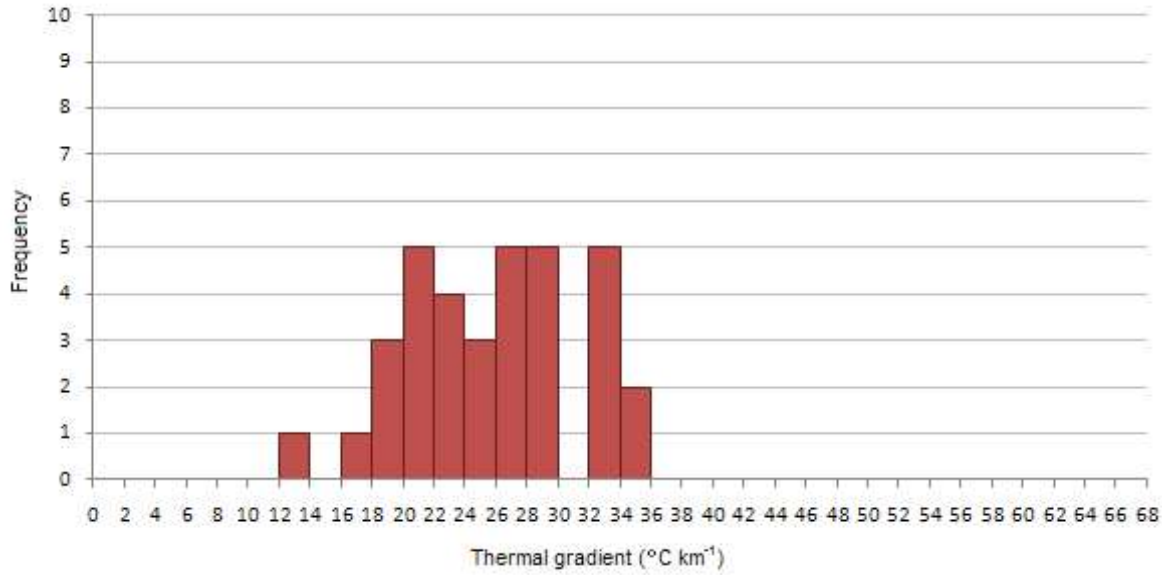
Statistical analysis results

Arithmetic mean:	38.6
Geometric mean:	36.1
Median:	38.6
Standard deviation:	13.6
Variance:	185.9
Number of thermal gradient values for well:	3
Number of values used in analysis:	2 (67% of total dataset)

Details of logged AM wells formation present in

Used:	22, 25
Disregarded due to apparent advection (> 5% mismatch):	10
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Gage Formation [Kwg]



Histogram of thermal gradients in the Gage Formation. Bin size: 2 °C km^{-1}

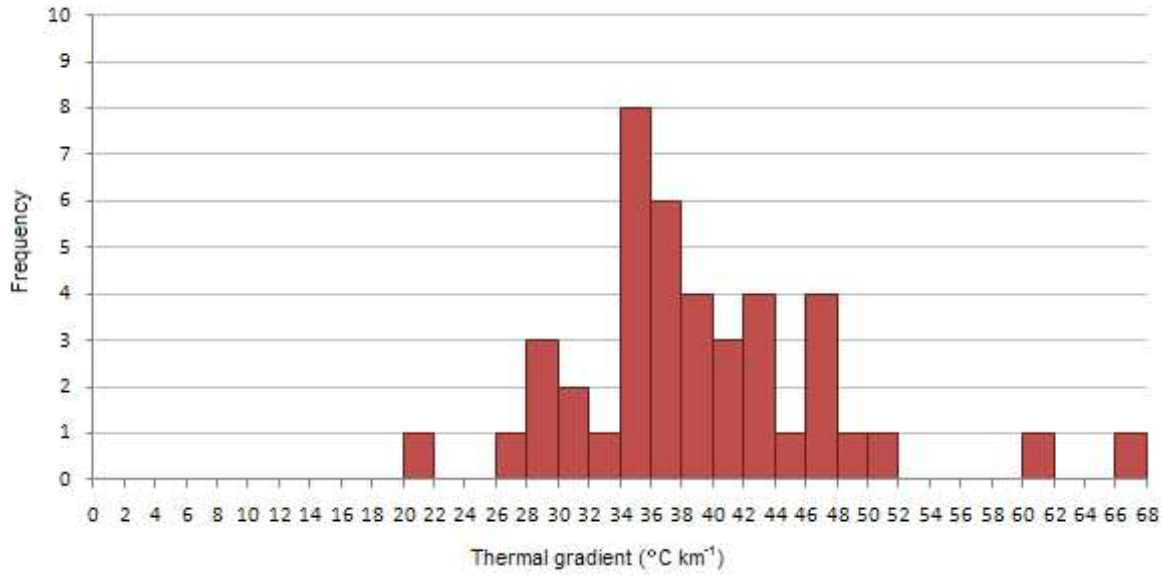
Statistical analysis results

Arithmetic mean:	25.6
Geometric mean:	25.0
Median:	25.8
Standard deviation:	5.7
Variance:	32.5
Number of thermal gradient values for well:	37
Number of values used in analysis:	34 (92% of total dataset)

Details of logged AM wells formation present in

Used:	2, 4A, 23, 24, 25, 27, 32, *32Y*, 33A, 36, 37A, *38A*, 38A, *40*, 40, 41, *42*, 42, *43A*, *48*, 48, *49*, 52, *52Y*, 52Y, 54, *55*, 55, 57, 58, 59, 62, 66, 68
Disregarded due to apparent advection (> 5% mismatch):	*33A*, *46*, 49
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

South Perth Shale [Kws]



Histogram of thermal gradients in the South Perth Shale. Bin size: 2 °C km^{-1}

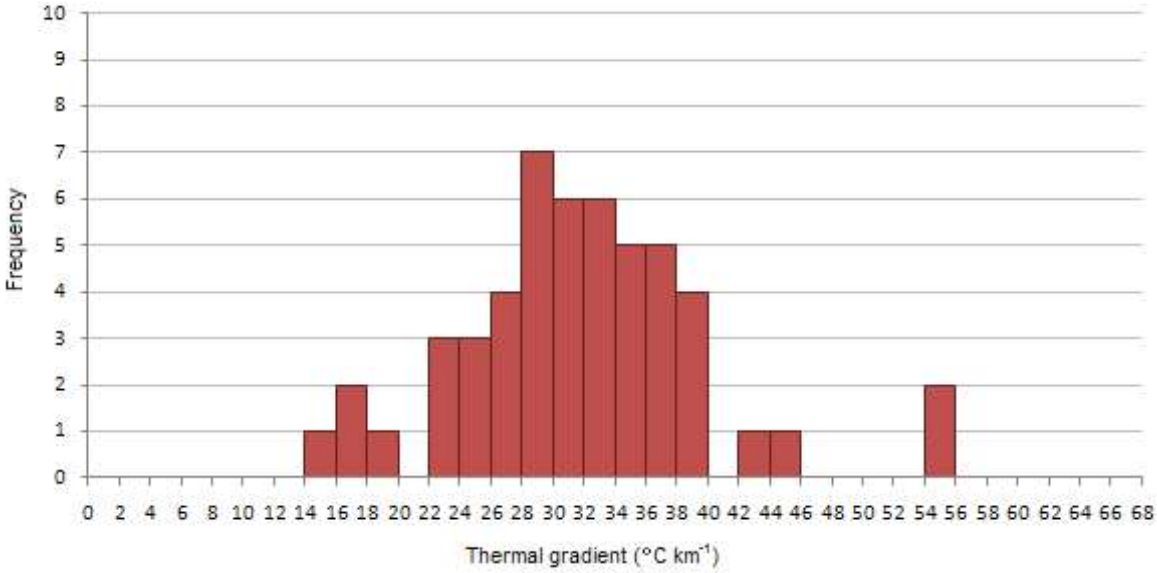
Statistical analysis results

Arithmetic mean:	39.1
Geometric mean:	38.3
Median:	37.7
Standard deviation:	8.4
Variance:	70.5
Number of thermal gradient values for well:	46
Number of values used in analysis:	42 (91% of total dataset)

Details of logged AM wells formation present in

Used:	2, *20*, 23, 24, 25, 27, 29, 30, *31*, 31, 32, *32Y*, *33A*, 33A, 35A, 36, 37A, *38A*, 38A, *40*, 40, 41, *42*, 42, *43A*, 49, *50*, 50, 52, *52Y*, 52Y, 52Z, 54, *55*, 55, 57, 58, 59, 62, 63, 67, 68
Disregarded due to apparent advection (> 5% mismatch):	*46*, *49*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	4A, 66

Mariginiup Member [Kwlm] (Leederville Formation)



Histogram of thermal gradients in the Mariginiup Member. Bin size: 2 °C km^{-1}

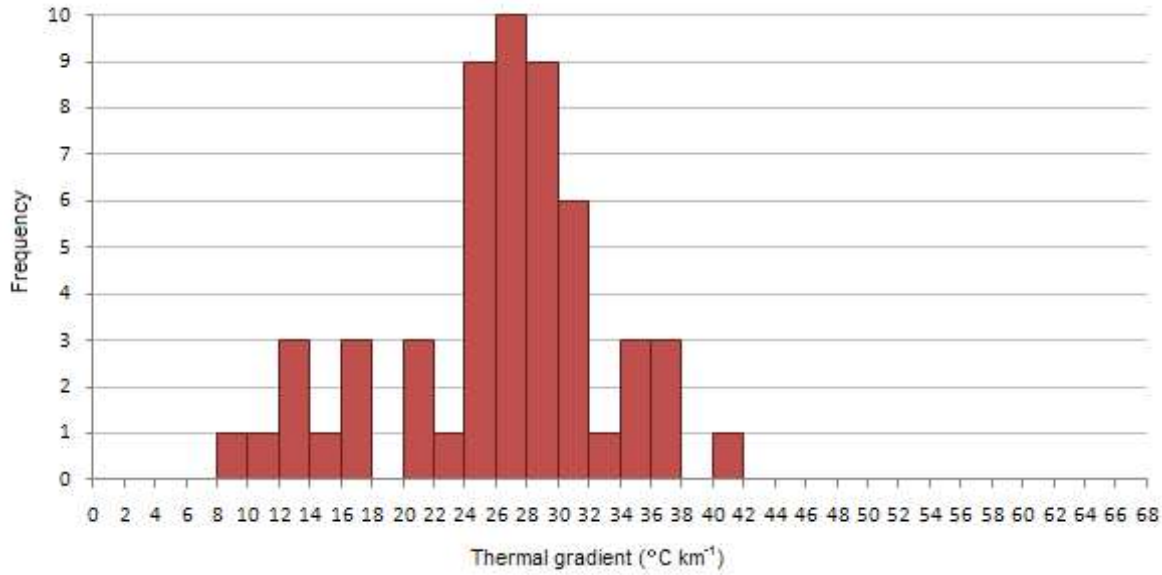
Statistical analysis results

Arithmetic mean:	31.8
Geometric mean:	30.8
Median:	31.5
Standard deviation:	7.9
Variance:	62.2
Number of thermal gradient values for well:	53
Number of values used in analysis:	51 (96% of total dataset)

Details of logged AM wells formation present in

Used:	2, 4A, 10, 13, 17, *20*, 23, 24, 25, 27, 29, 30, *31*, 31, *33A*, 33A, 35A, 36, *38A*, 38A, *40*, 40, 41, *42*, 42, *43A*, 44, *46*, *48*, 48, *49*, 49, *50*, 50, *51*, 51, 52, *52Y*, 52Y, 52Z, 54, 55, 57, 58, 59, 62, 63, 65, 66, 67, 68
Disregarded due to apparent advection (> 5% mismatch):	37A, *55*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Wanneroo Member [Kwlw] (Leederville Formation)



Histogram of thermal gradients in the Wanneroo Member. Bin size: 2 °C km^{-1}

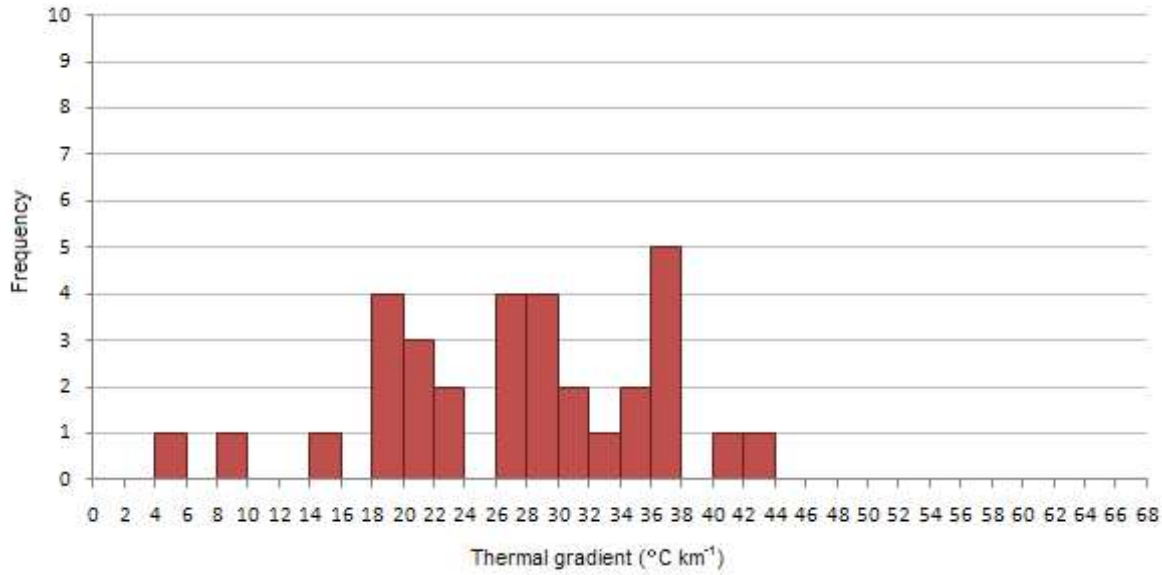
Statistical analysis results

Arithmetic mean:	26.2
Geometric mean:	25.1
Median:	27.0
Standard deviation:	6.9
Variance:	47.2
Number of thermal gradient values for well:	62
Number of values used in analysis:	55 (89% of total dataset)

Details of logged AM wells formation present in

Used:	3, 8, 10, 11, 12, 13, 17, *20*, 23, 24, 25, 26B, 27, 28, 29, 30, 30Z, *31*, 31, 33A, 34, 35A, 36, 37, 37A, *40*, 40, 41, *42*, 42, 43, *43A*, 44, *46*, *48*, 48, 49, *50*, 50, *51*, 52, *52Y*, 52Y, 54, *55*, 55, 57, 58, 59, 62, 63, 65, 66, 67, 68
Disregarded due to apparent advection (> 5% mismatch):	2, 4A, 22, *33A, 38A*, 38A, *49*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Pinjar Member [Kwlp] (Leederville Formation)



Histogram of thermal gradients in the Pinjar Member. Bin size: 2 °C km^{-1}

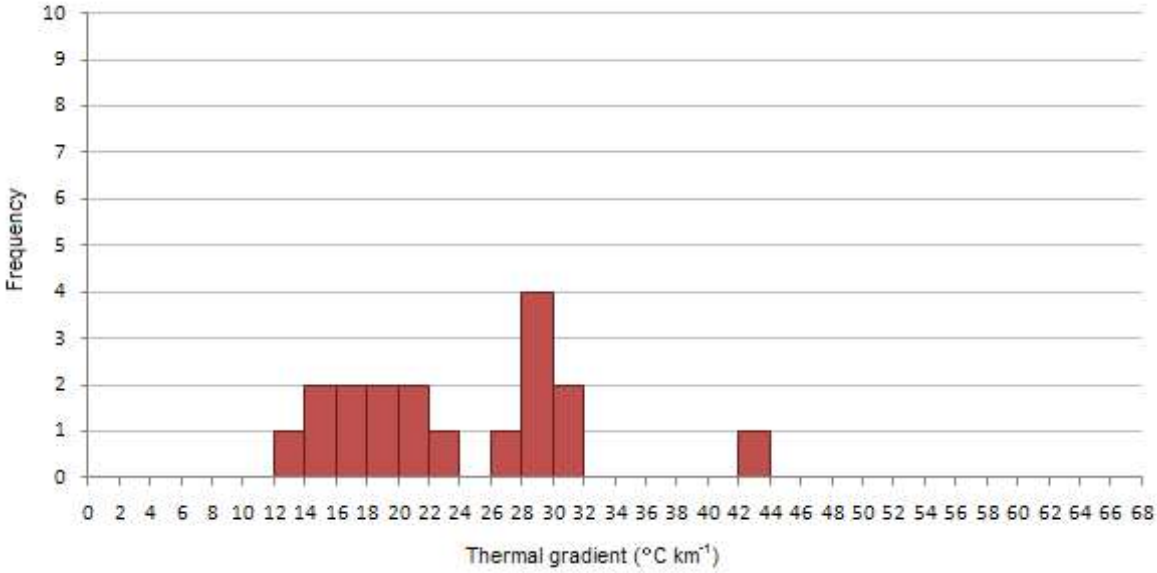
Statistical analysis results

Arithmetic mean:	27.3
Geometric mean:	25.2
Median:	28.1
Standard deviation:	8.9
Variance:	79.9
Number of thermal gradient values for well:	47
Number of values used in analysis:	32 (68% of total dataset)

Details of logged AM wells formation present in

Used:	4A, 8, 10, 11, 12, 13, *20*, 22, 23, 24, 27, 28, 29, 30, 30Z, 34, 35A, 36, 37, 37A, *42*, 43, *43A*, 44, *45A*, *46*, 49, *51*, 52, *52Y*, 52Y, 55
Disregarded due to apparent advection (> 5% mismatch):	*38A*, 38A, *49*, *55*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	3, *33A*, 33A
Disregarded due to unit thickness < 10 m:	2, 25, *31*, 31, 42, *50*, 50, 59

Henley Sandstone Member [Kcoh] (Osborne Formation)



Histogram of thermal gradients in the Henley Sandstone Member. Bin size: 2 °C km^{-1}

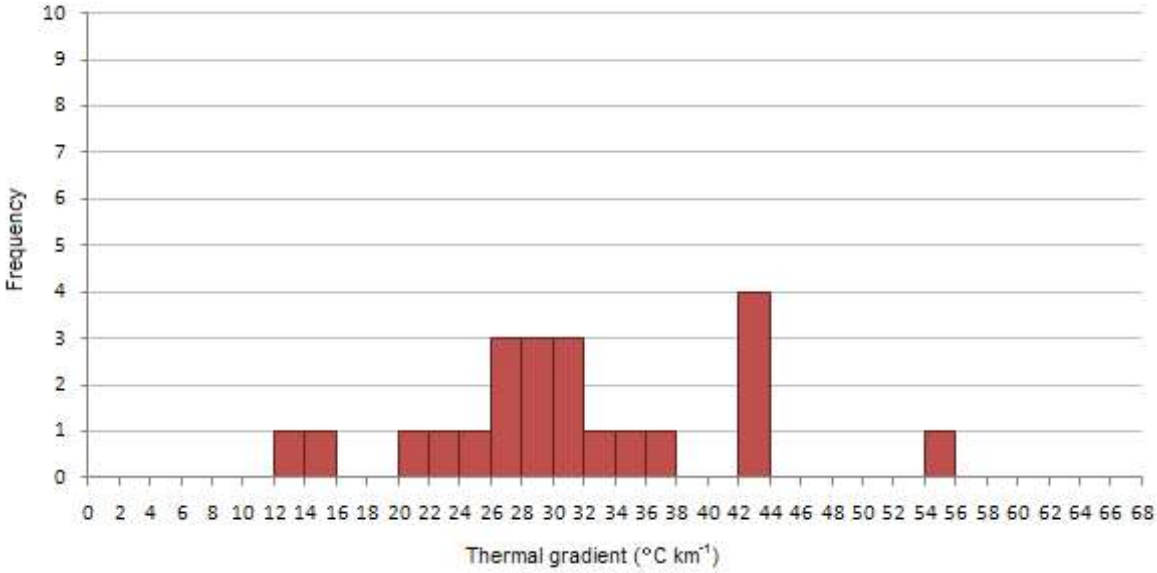
Statistical analysis results

Arithmetic mean:	23.9
Geometric mean:	22.7
Median:	21.9
Standard deviation:	7.7
Variance:	58.6
Number of thermal gradient values for well:	29
Number of values used in analysis:	18 (62% of total dataset)

Details of logged AM wells formation present in

Used:	11, 24, 27, 29, 30, 34, 36, 37, 37A, 38A, *42*, 42, *46*, *49*, 49, *52Y*, 52Y, 52Z
Disregarded due to apparent advection (> 5% mismatch):	35A, *38A*, 41
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	26B, 28, 30Z, *31*, 31, *33A*, 33A, 44

Kardinya Shale Member [Kcok] (Osborne Formation)



Histogram of thermal gradients in the Kardinya Shale Member. Bin size: 2 °C km^{-1}

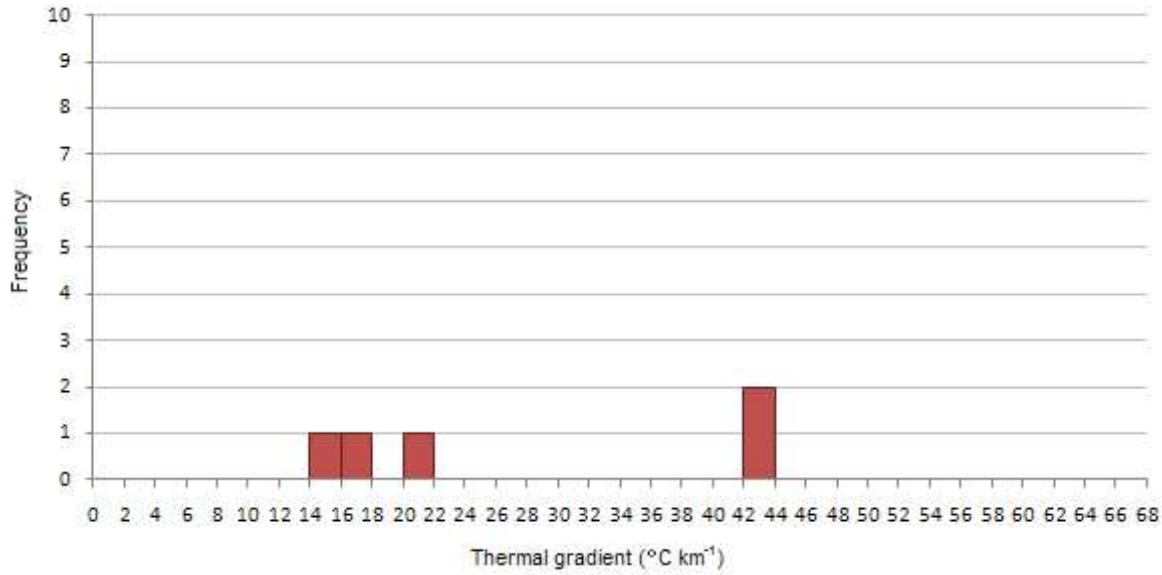
Statistical analysis results

Arithmetic mean:	31.4
Geometric mean:	29.8
Median:	30.5
Standard deviation:	9.7
Variance:	95.0
Number of thermal gradient values for well:	36
Number of values used in analysis:	22 (61% of total dataset)

Details of logged AM wells formation present in

Used:	2, 3, 8, 11, 12, 24, 25, 26B, 28, 29, 30, 30Z, 31, 34, 35A, 36, 43, *45A*, *46*, *52Y*, 52Y, 52Z
Disregarded due to apparent advection (> 5% mismatch):	*31*, 37, 37A, *42*, 42, *43A*, *49*, 49
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	*33A*, 33A, *38A*, 38A, 41, 44

Mirrabooka Member [Kcom] (Osborne Formation)



Histogram of thermal gradients in the Mirrabooka Member. Bin size: 2 °C km^{-1}

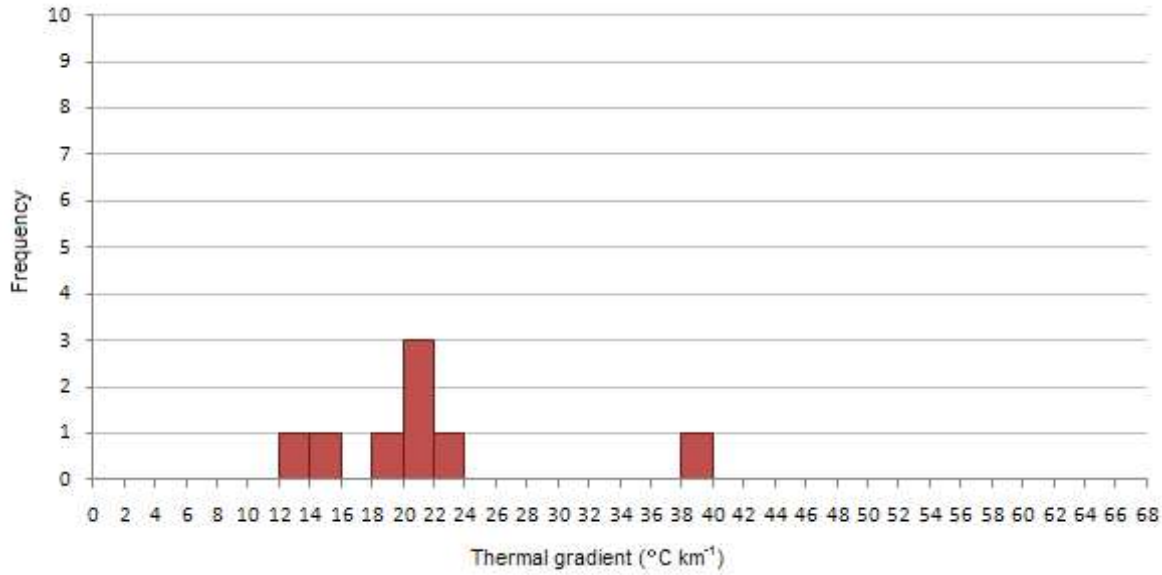
Statistical analysis results

Arithmetic mean:	27.5
Geometric mean:	24.5
Median:	20.1
Standard deviation:	13.1
Variance:	171.6
Number of thermal gradient values for well:	6
Number of values used in analysis:	5 (83% of total dataset)

Details of logged AM wells formation present in

Used:	*33A*, 33A, 35A, 37, 37A
Disregarded due to apparent advection (> 5% mismatch):	30Z
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Molecap Greensand [Kcm]



Histogram of thermal gradients in the Molecap Greensand. Bin size: 2 °C km^{-1}

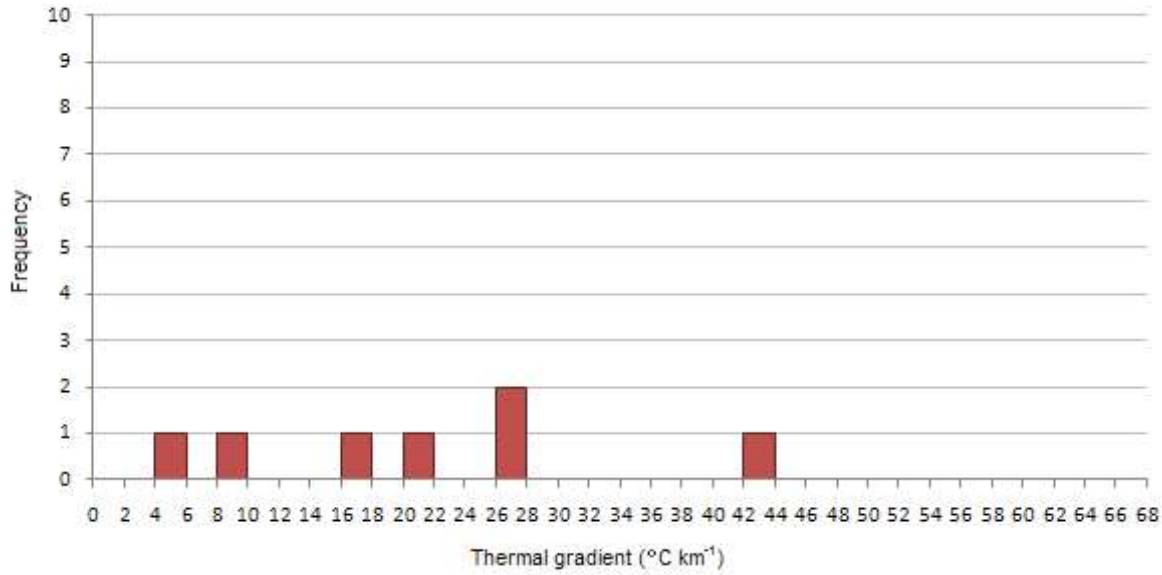
Statistical analysis results

Arithmetic mean:	21.7
Geometric mean:	20.8
Median:	21.1
Standard deviation:	7.0
Variance:	49.0
Number of thermal gradient values for well:	11
Number of values used in analysis:	8 (73% of total dataset)

Details of logged AM wells formation present in

Used:	3, 24, 25, 26B, 27, 28, 29, 30
Disregarded due to apparent advection (> 5% mismatch):	-
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	2, 36
Disregarded due to unit thickness < 10 m:	12

Gingin Chalk [Kcg]



Histogram of thermal gradients in the Gingin Chalk. Bin size: 2 °C km^{-1}

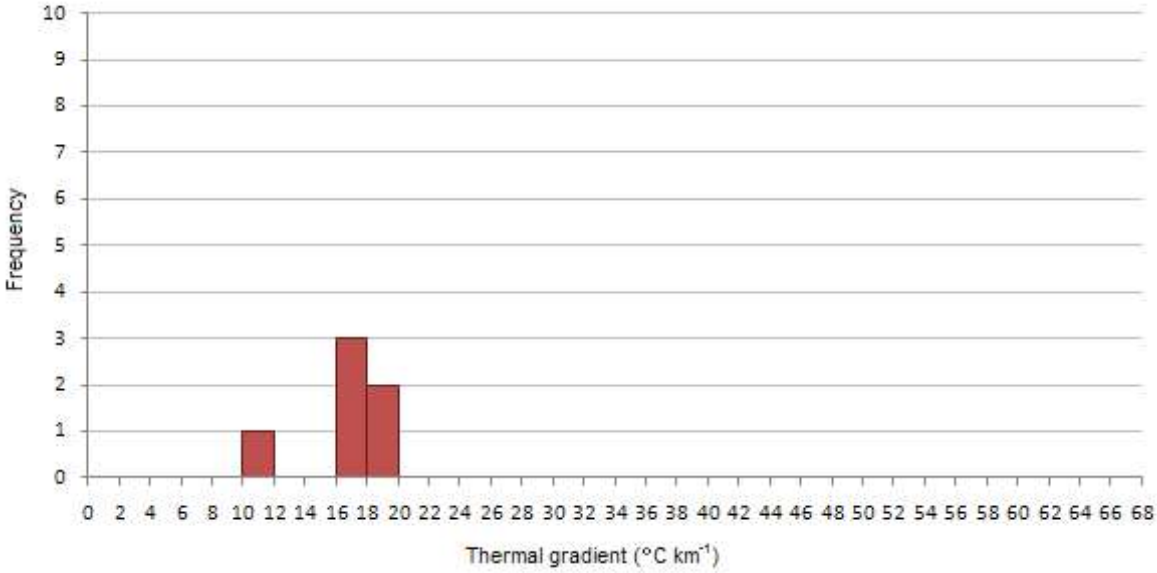
Statistical analysis results

Arithmetic mean:	21.0
Geometric mean:	16.8
Median:	20.2
Standard deviation:	12.1
Variance:	145.7
Number of thermal gradient values for well:	10
Number of values used in analysis:	7 (70% of total dataset)

Details of logged AM wells formation present in

Used:	2, 3, 8, 12, 24, 28, 29
Disregarded due to apparent advection (> 5% mismatch):	-
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	25, 26B, 30

Poison Hill Greensand [Kcp]



Histogram of thermal gradients in the Poison Hill Greensand. Bin size: 2 °C km^{-1}

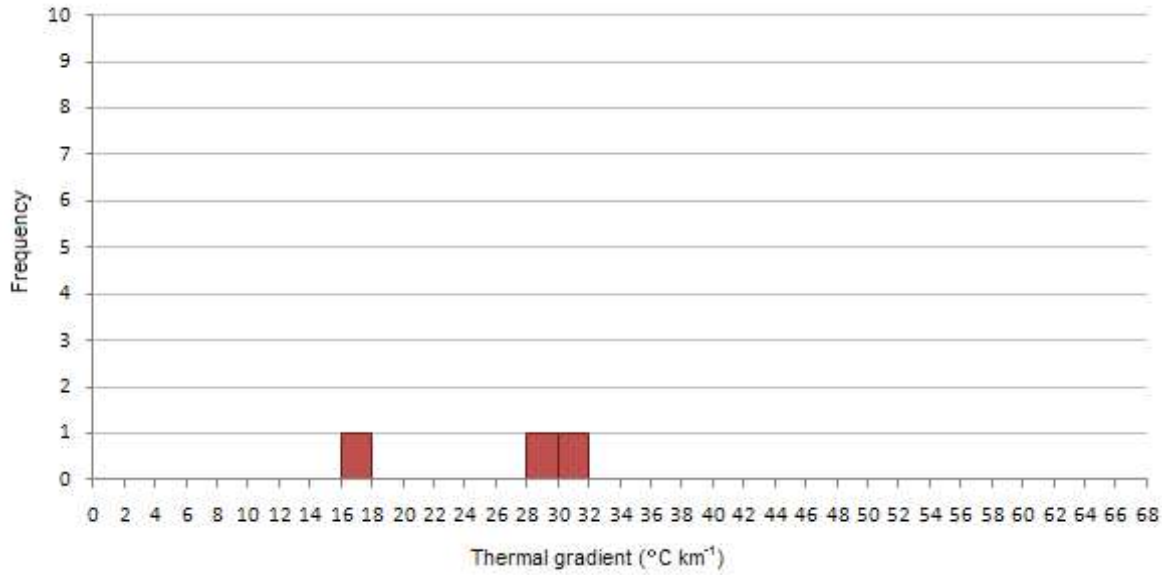
Statistical analysis results

Arithmetic mean:	16.3
Geometric mean:	16.0
Median:	16.6
Standard deviation:	2.6
Variance:	6.7
Number of thermal gradient values for well:	6
Number of values used in analysis:	6 (100% of total dataset)

Details of logged AM wells formation present in

Used:	24, 25, 26B, 28, 29, 30
Disregarded due to apparent advection (> 5% mismatch):	-
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Lancelin Formation [Kcl]



Histogram of thermal gradients in the Lancelin Formation. Bin size: 2 °C km^{-1}

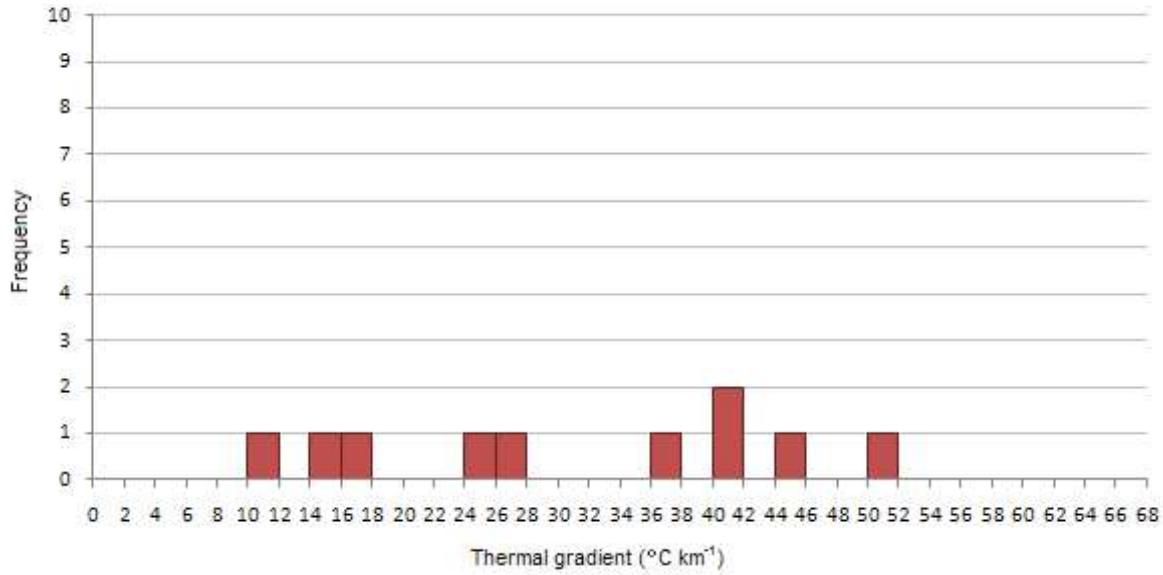
Statistical analysis results

Arithmetic mean:	25.5
Geometric mean:	24.7
Median:	28.7
Standard deviation:	6.0
Variance:	36.0
Number of thermal gradient values for well:	4
Number of values used in analysis:	3 (75% of total dataset)

Details of logged AM wells formation present in

Used:	2, 8, 12
Disregarded due to apparent advection (> 5% mismatch):	-
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	3

Kings Park Formation [Tk]



Histogram of thermal gradients in the Kings Park Formation. Bin size: 2 °C km^{-1}

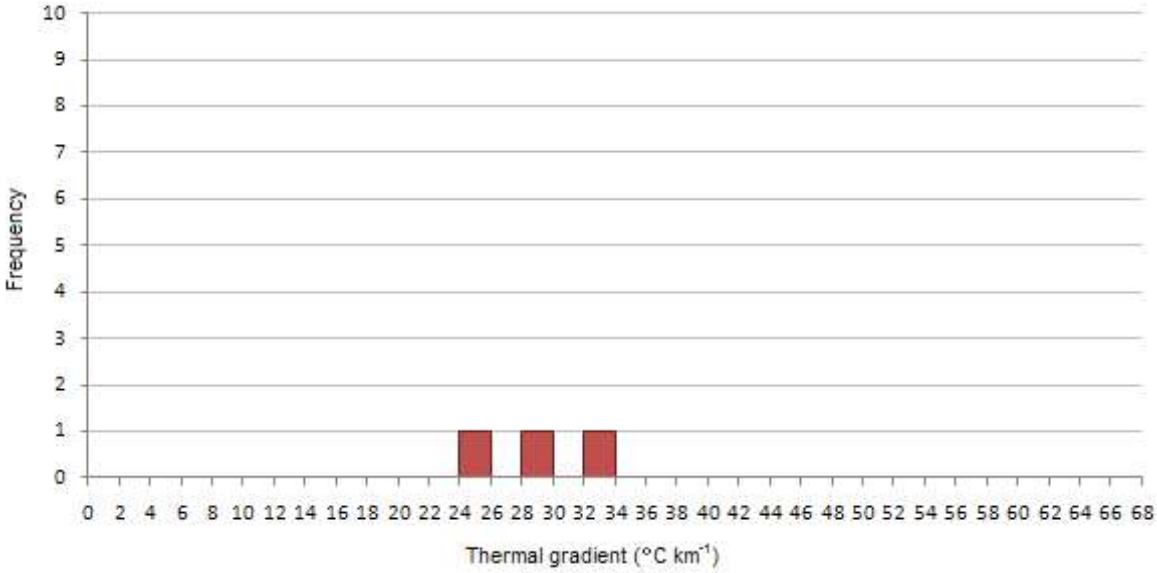
Statistical analysis results

Arithmetic mean:	30.7
Geometric mean:	27.4
Median:	31.5
Standard deviation:	13.2
Variance:	175.4
Number of thermal gradient values for well:	10
Number of values used in analysis:	10 (100% of total dataset)

Details of logged AM wells formation present in

Used:	8, 12, 32, *32Y*, 39, *40*, 40, *40A*, 41, 52Z
Disregarded due to apparent advection (> 5% mismatch):	-
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Como Sandstone Member [Tkc] (Kings Park Formation)



Histogram of thermal gradients in the Como Sandstone Member. Bin size: 2 °C km^{-1}

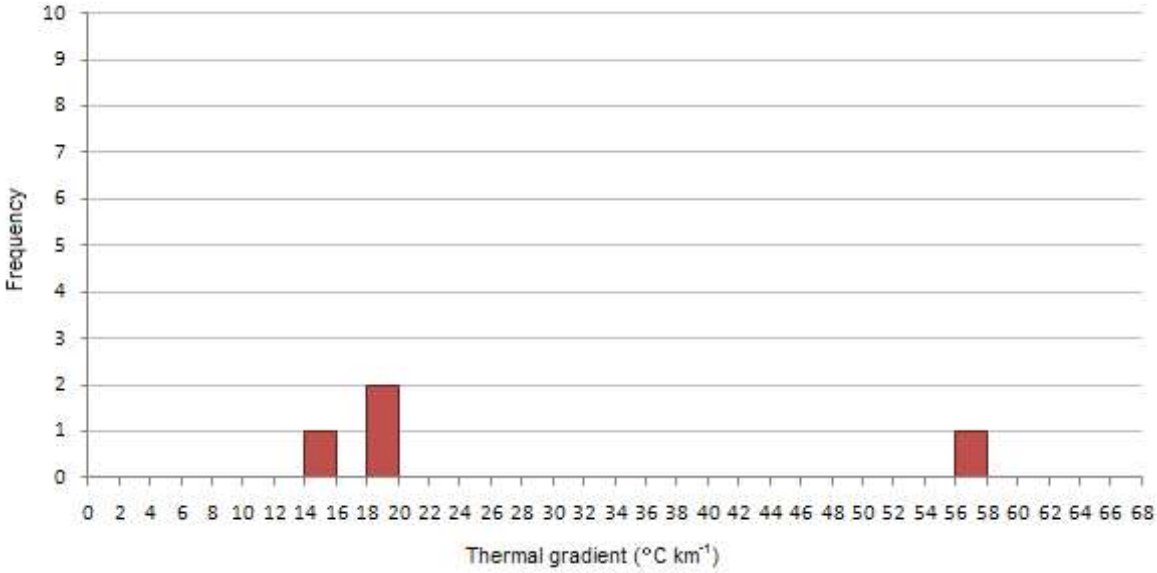
Statistical analysis results

Arithmetic mean:	28.7
Geometric mean:	28.4
Median:	28.2
Standard deviation:	3.7
Variance:	13.8
Number of thermal gradient values for well:	4
Number of values used in analysis:	3 (75% of total dataset)

Details of logged AM wells formation present in

Used:	*32Y,40*, 40
Disregarded due to apparent advection (> 5% mismatch):	32
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Mullaloo Sandstone Member [Tkm] (Kings Park Formation)



Histogram of thermal gradients in the Mullaloo Sandstone Member. Bin size: 2 °C km^{-1}

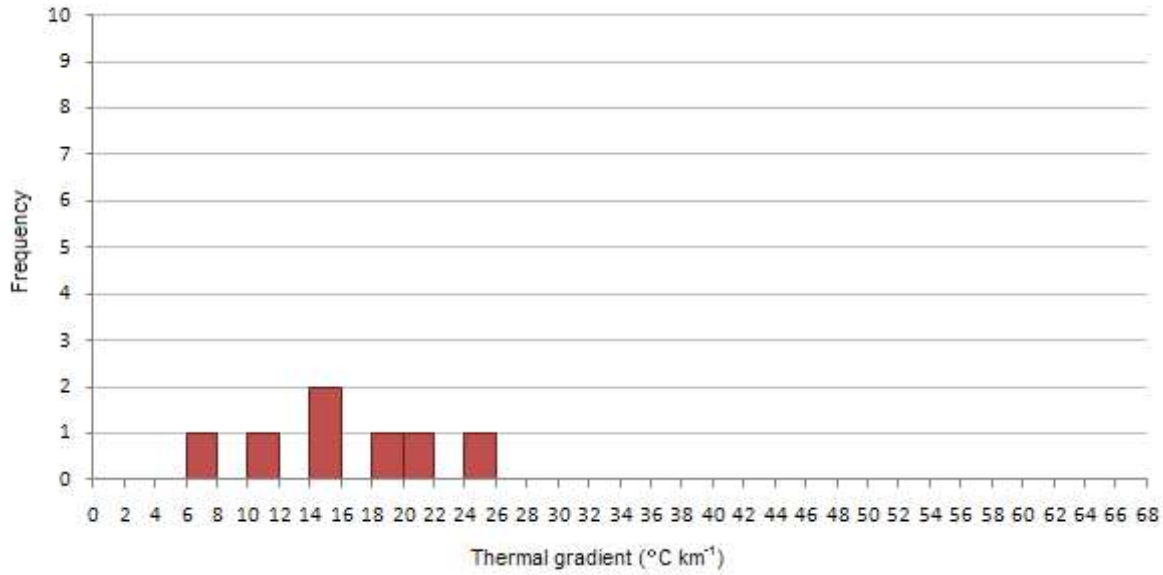
Statistical analysis results

Arithmetic mean:	27.1
Geometric mean:	23.3
Median:	18.9
Standard deviation:	16.8
Variance:	281.7
Number of thermal gradient values for well:	6
Number of values used in analysis:	4 (67% of total dataset)

Details of logged AM wells formation present in

Used:	*33A*, 39, *40*, 40
Disregarded due to apparent advection (> 5% mismatch):	33A, *40A*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Rockingham Sand [Tr]



Histogram of thermal gradients in the Rockingham Sand. Bin size: 2 °C km^{-1}

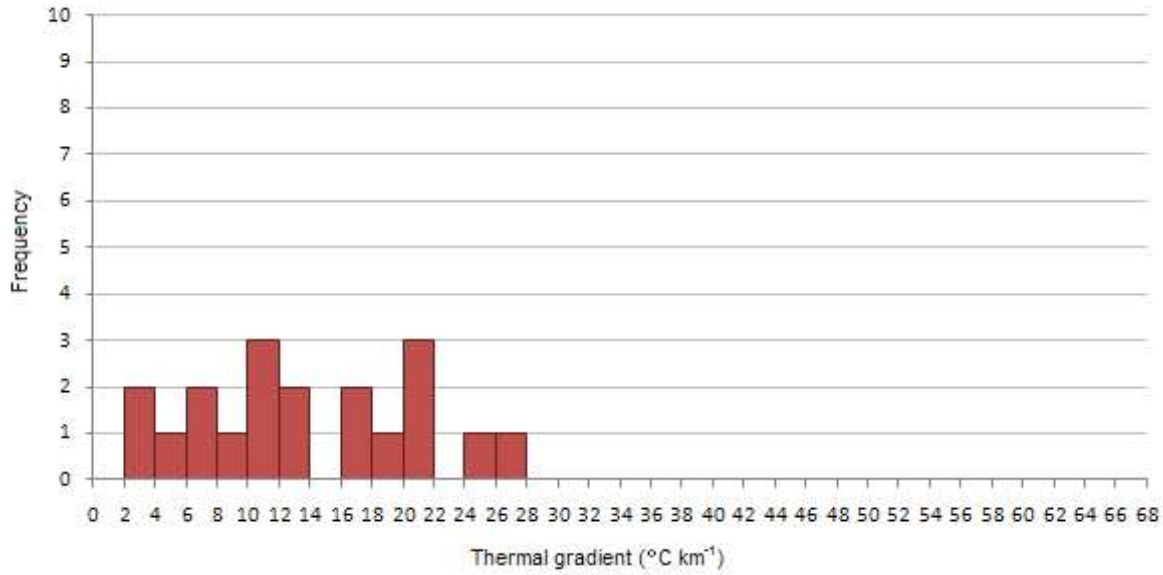
Statistical analysis results

Arithmetic mean:	16.6
Geometric mean:	15.5
Median:	15.9
Standard deviation:	5.6
Variance:	31.5
Number of thermal gradient values for well:	8
Number of values used in analysis:	7 (88% of total dataset)

Details of logged AM wells formation present in

Used:	52Z, 54, 57, 58, 65, 67, 68
Disregarded due to apparent advection (> 5% mismatch):	-
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	62
Disregarded due to unit thickness < 10 m:	-

Superficial formations [TQ]



Histogram of thermal gradients in the superficial formations. Bin size: 2 °C km^{-1}

Statistical analysis results

Arithmetic mean:	13.5
Geometric mean:	11.4
Median:	12.3
Standard deviation:	6.9
Variance:	47.5
Number of thermal gradient values for well:	40
Number of values used in analysis:	19 (48% of total dataset)

Details of logged AM wells formation present in

Used:	3, 4A, 8, 10, 12, 13, 17, 22, 24, 27, 28, 29, 30, 32, 36, *45A*, 49, 57, 67
Disregarded due to apparent advection (> 5% mismatch):	*20*, 33A, 43
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	2, 23, *48*, *52Y*
Disregarded due to unit thickness < 10 m:	25, 34, *42*, 42, *43A*, *46*, 48, *49*, 50, 52, 52Y, 52Z, 54, *55*

APPENDIX E – SUMMARY SHEETS OF HEAT FLOW BY FORMATION

This appendix presents an analysis of the heat flow by formation, as discussed in section 4.8. The analyses are organized in the stratigraphic order described in section 2.2; note that not every formation has a heat flow estimate due to lack of thermal conductivity data. For each formation, the following are shown:

- A *histogram* showing the spread of measurements and the histogram bin size.
- A table of *statistical results* with arithmetic and geometric means, median, standard deviation and variance, and the sample size.
- A table showing *which wells contain the formation* and whether those wells were considered due to advection or quality control issues.

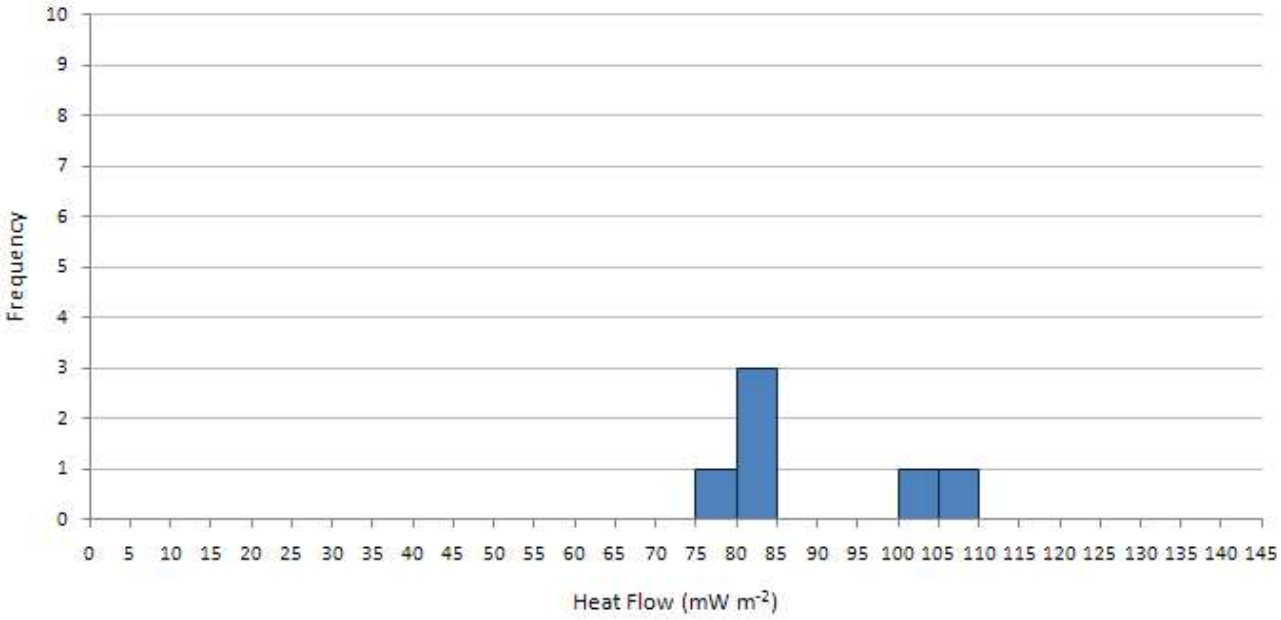
Explanation of terms

Number of thermal gradient values for well: Number of wells that the formation appeared in and a thermal gradient was calculated for the formation. There are some instances where a formation has appeared in a well above the depth to reliable measurements, and as such no thermal gradient was calculated for it.

Number of values used in analysis: Number of wells that the gradient calculated for the formation was deemed representative of the actual thermal gradient within the formation. Data was excluded if the mismatch between the model and the observed data was greater than 5%, the gradient was unrealistic (< 0 or > 80 °C km^{-1}) or the thickness of the unit was less than 10 m. These thermal gradient values were subsequently used to calculate the heat flow values used in this analysis.

Well names that are *italicised* indicate they were logged by WAGCOE; well names in ordinary font were digitised by WAGCOE

Cattamarra Coal Measures [Jc]



Histogram of heat flow in the Cattamarra Coal Measures. Bin size: 5 mW m^{-2}

Thermal conductivity: 3.73 ± 0.20 W m^{-1}K^{-1} (HDRPL)

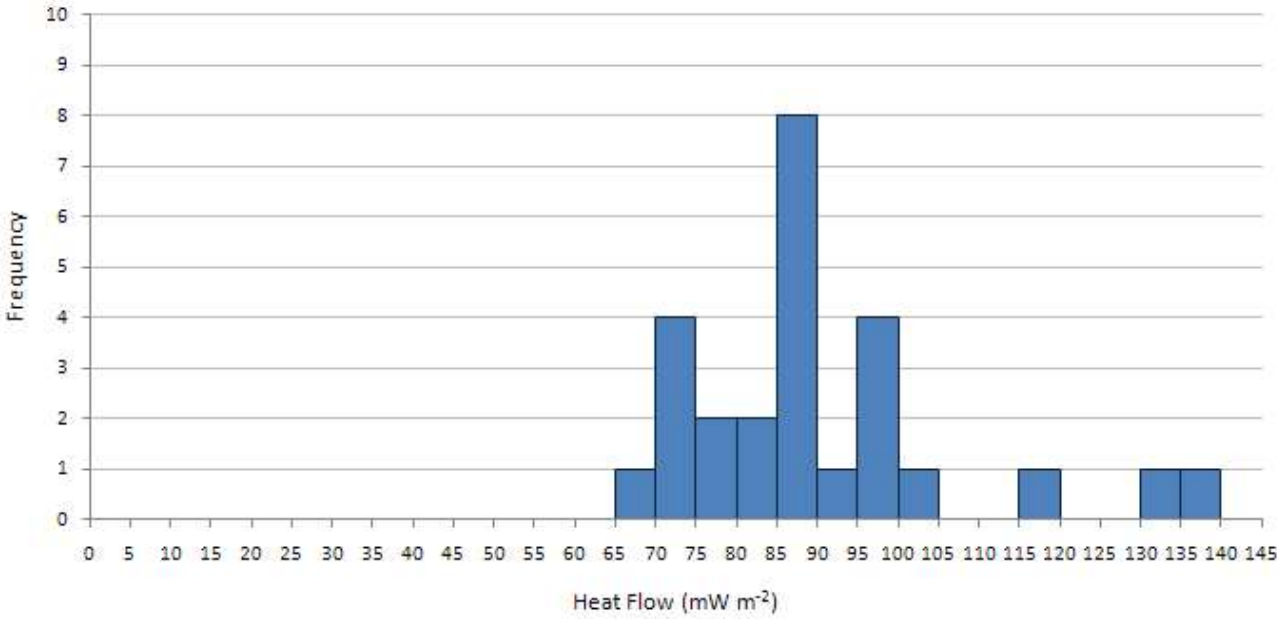
Statistical analysis results

Arithmetic mean:	89.6
Geometric mean:	88.8
Median:	82.9
Standard deviation:	12.0
Variance:	144.9
Number of thermal gradient values for well:	9
Number of values used in analysis:	6 (67% of total dataset)

Details of logged AM wells formation present in

Used:	51, 54, 57, 58, 62, 67
Disregarded due to apparent advection (> 5% mismatch):	*51*, 64
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	52Z
Disregarded due to unit thickness < 10 m:	-

Yarragadee Formation [Jy]



Histogram of heat flow in the Yarragadee Formation. Bin size: 5 mW m^{-2}

Thermal conductivity: 3.54 ± 0.30 W m^{-1}K^{-1} (HDRPL)

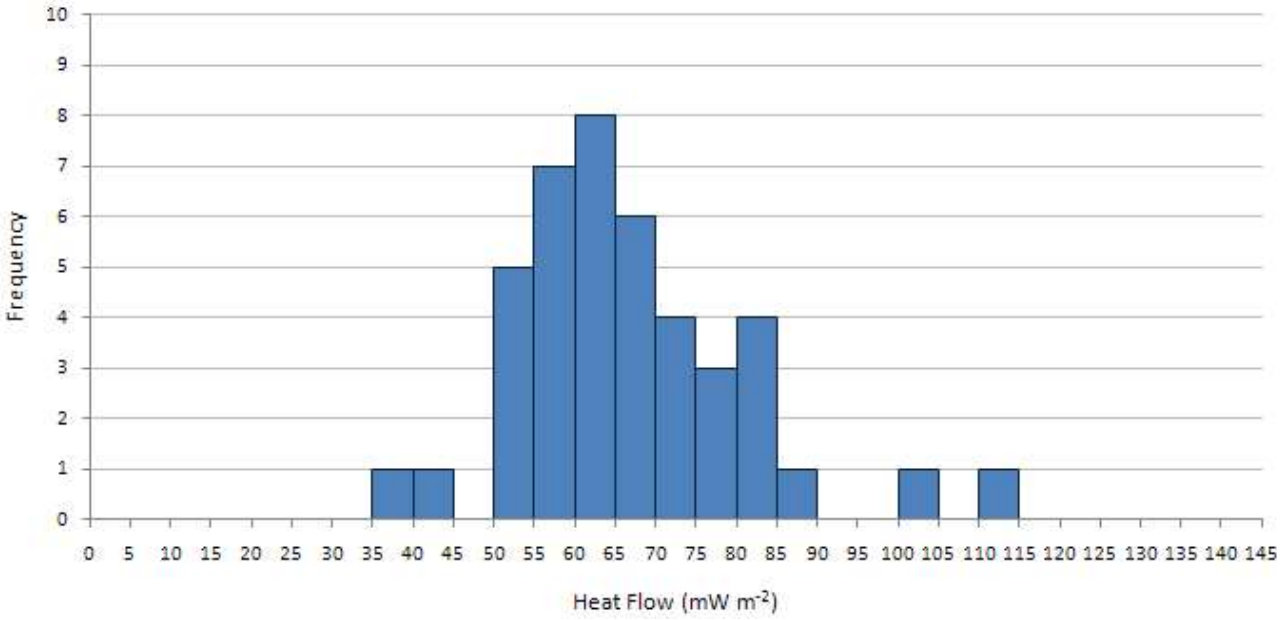
Statistical analysis results

Arithmetic mean:	90.3
Geometric mean:	88.9
Median:	87.4
Standard deviation:	16.8
Variance:	282.1
Number of thermal gradient values for well:	31
Number of values used in analysis:	26 (84% of total dataset)

Details of logged AM wells formation present in

Used:	4A, 13, 17, 23, 29, 30, 31, 32, *33A*, 33A, 35A, 36, 41, *43A*, *46*, *48*, 48, *49*, 49, *50*, 50, *55*, 55, 59, 63, 66
Disregarded due to apparent advection (> 5% mismatch):	*20*, 27, *31*, *32Y*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	37A

South Perth Shale [Kws]



Histogram of heat flow in the South Perth Shale. Bin size: 5 mW m^{-2}

Thermal conductivity: 1.71 ± 0.14 W m^{-1}K^{-1} (HDRPL)

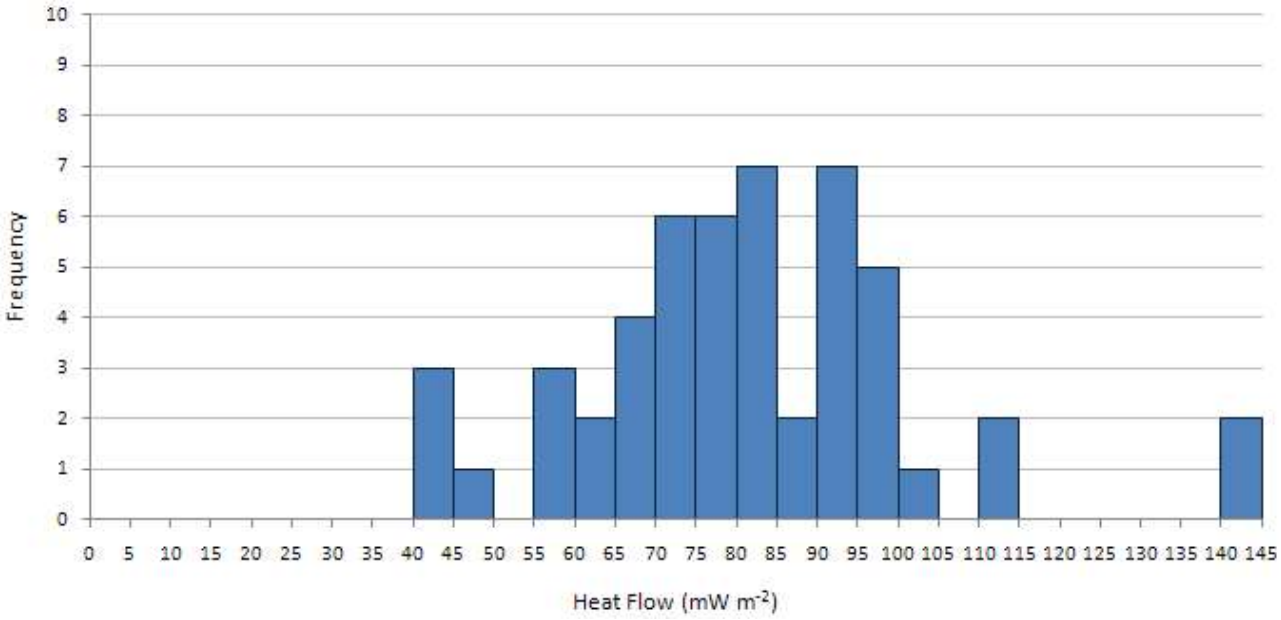
Statistical analysis results

Arithmetic mean:	66.9
Geometric mean:	65.4
Median:	64.4
Standard deviation:	14.4
Variance:	206.1
Number of thermal gradient values for well:	46
Number of values used in analysis:	42 (91% of total dataset)

Details of logged AM wells formation present in

Used:	2, *20*, 23, 24, 25, 27, 29, 30, *31*, 31, 32, *32Y*, *33A*, 33A, 35A, 36, 37A, *38A*, 38A, *40*, 40, 41, *42*, 42, *43A*, 49, *50*, 50, 52, *52Y*, 52Y, 52Z, 54, *55*, 55, 57, 58, 59, 62, 63, 67, 68
Disregarded due to apparent advection (> 5% mismatch):	*46*, *49*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	4A, 66

Mariginiup Member [Kwlm] (Leederville Formation)



Histogram of heat flow in the Mariginiup Member. Bin size: 5 mW m^{-2}

Thermal conductivity: 2.56 ± 0.18 W m^{-1}K^{-1} (HDRPL)

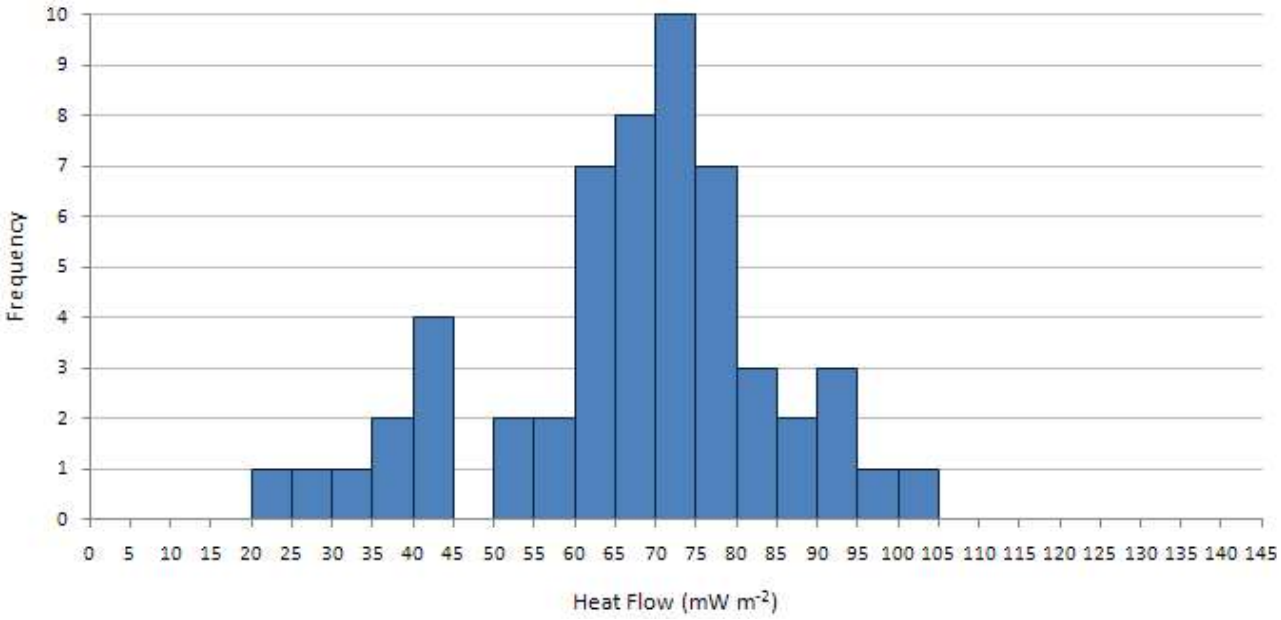
Statistical analysis results

Arithmetic mean:	81.4
Geometric mean:	78.9
Median:	80.7
Standard deviation:	20.2
Variance:	407.9
Number of thermal gradient values for well:	53
Number of values used in analysis:	51 (96% of total dataset)

Details of logged AM wells formation present in

Used:	2, 4A, 10, 13, 17, *20*, 23, 24, 25, 27, 29, 30, *31*, 31, *33A*, 33A, 35A, 36, *38A*, 38A, *40*, 40, 41, *42*, 42, *43A*, 44, *46*, *48*, 48, *49*, 49, *50*, 50, *51*, 51, 52, *52Y*, 52Y, 52Z, 54, 55, 57, 58, 59, 62, 63, 65, 66, 67, 68
Disregarded due to apparent advection (> 5% mismatch):	37A, *55*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Wanneroo Member [Kwlw] (Leederville Formation)



Histogram of heat flow in the Wanneroo Member. Bin size: 5 mW m^{-2}

Thermal conductivity: 2.56 ± 0.18 W m^{-1}K^{-1} (HDRPL)

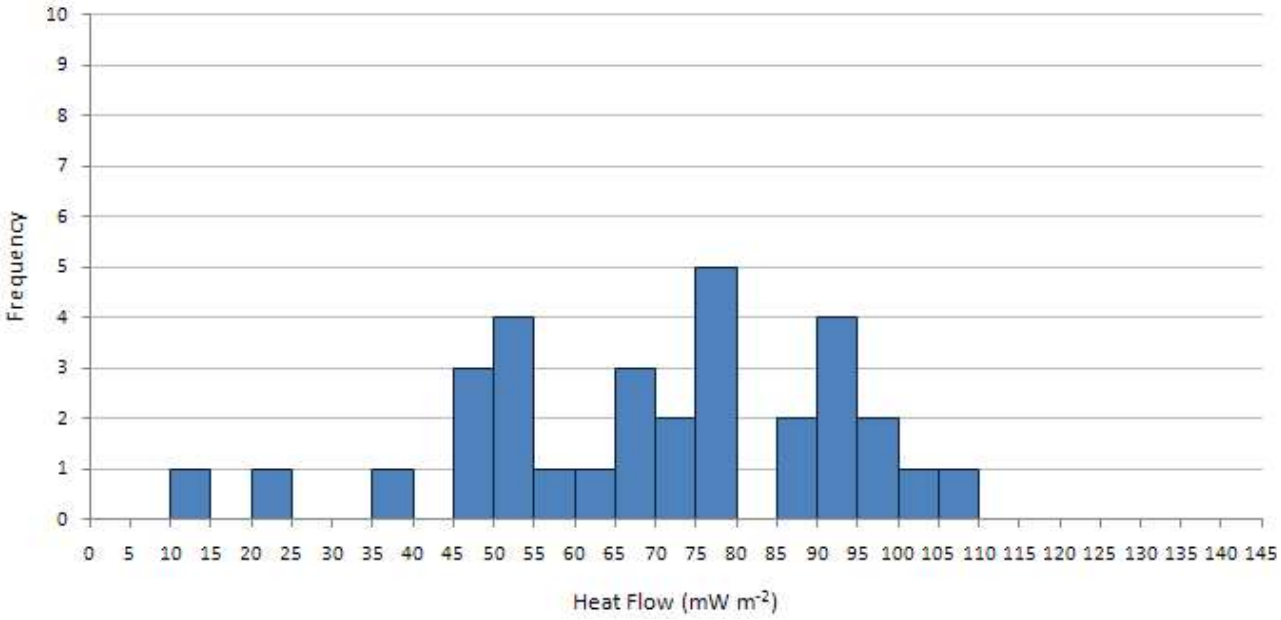
Statistical analysis results

Arithmetic mean:	67.1
Geometric mean:	64.2
Median:	69.1
Standard deviation:	17.6
Variance:	309.2
Number of thermal gradient values for well:	62
Number of values used in analysis:	55 (89% of total dataset)

Details of logged AM wells formation present in

Used:	3, 8, 10, 11, 12, 13, 17, *20*, 23, 24, 25, 26B, 27, 28, 29, 30, 30Z, *31*, 31, 33A, 34, 35A, 36, 37, 37A, *40*, 40, 41, *42*, 42, 43, *43A*, 44, *46*, *48*, 48, 49, *50*, 50, *51*, 52, *52Y*, 52Y, 54, *55*, 55, 57, 58, 59, 62, 63, 65, 66, 67, 68
Disregarded due to apparent advection (> 5% mismatch):	2, 4A, 22, *33A, 38A*, 38A, *49*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	-
Disregarded due to unit thickness < 10 m:	-

Pinjar Member [Kwlp] (Leederville Formation)



Histogram of heat flow in the Pinjar Member. Bin size: 5 mW m^{-2}

Thermal conductivity: 2.56 ± 0.18 W m^{-1}K^{-1} (HDRPL)

Statistical analysis results

Arithmetic mean:	69.9
Geometric mean:	64.5
Median:	72.0
Standard deviation:	22.9
Variance:	523.5
Number of thermal gradient values for well:	47
Number of values used in analysis:	32 (68% of total dataset)

Details of logged AM wells formation present in

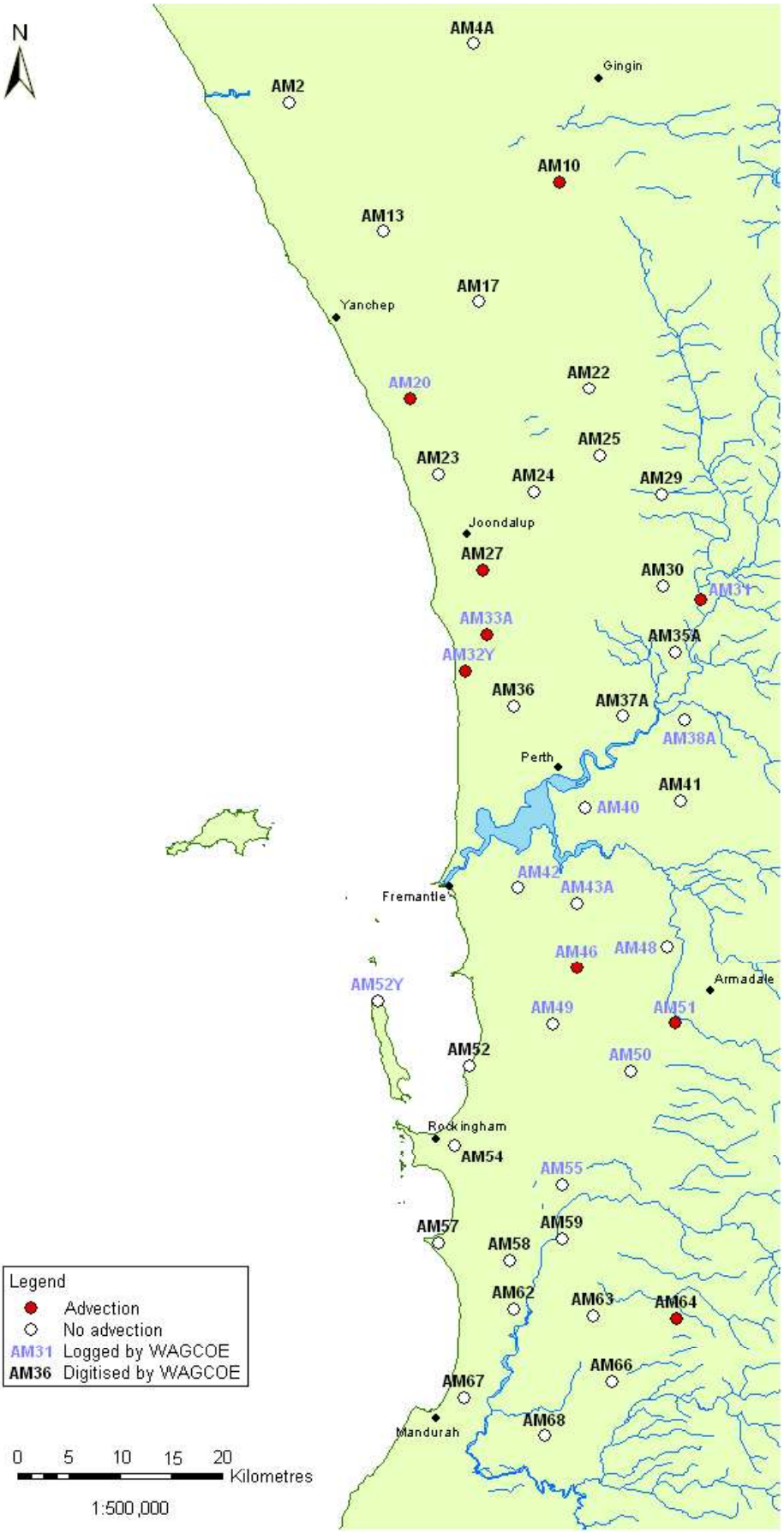
Used:	4A, 8, 10, 11, 12, 13, *20*, 22, 23, 24, 27, 28, 29, 30, 30Z, 34, 35A, 36, 37, 37A, *42*, 43, *43A*, 44, *45A*, *46*, 49, *51*, 52, *52Y*, 52Y, 55
Disregarded due to apparent advection (> 5% mismatch):	*38A*, 38A, *49*, *55*
Disregarded due to being unrealistic (< 0 or > 80 °C km^{-1}):	3, *33A*, 33A
Disregarded due to unit thickness < 10 m:	2, 25, *31*, 31, 42, *50*, 50, 59

APPENDIX F – ADVECTION MAPS BY HYDROGEOLOGIC UNIT

This appendix presents maps displaying the locations of the wells used in this study and whether they exhibit advection or not. Further discussion of the advection results is provided in section 4.5.

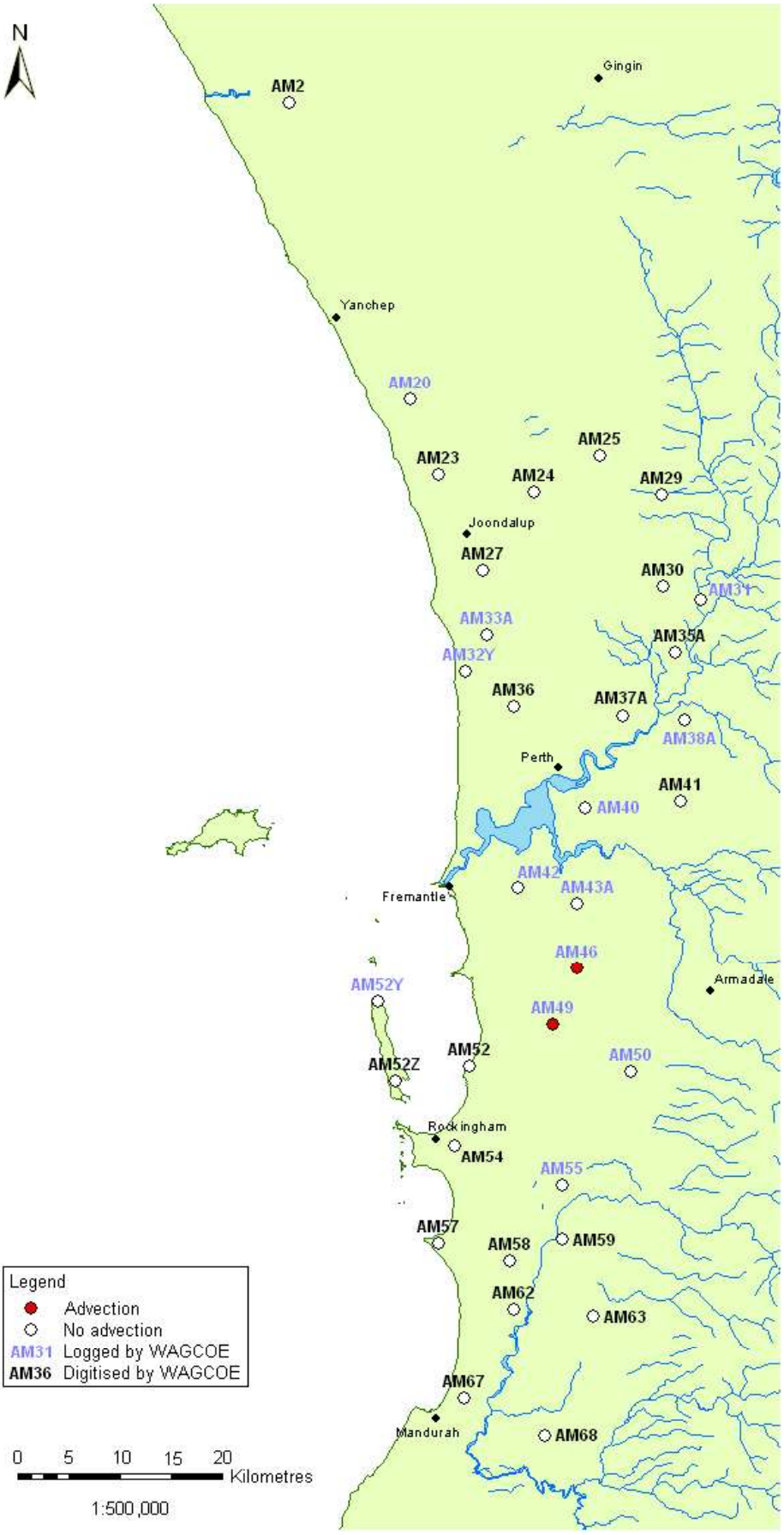
Yarragadee Aquifer

Gage Formation, Parmelia formation, Yarragadee Formation, Cattamarra Coal Measures



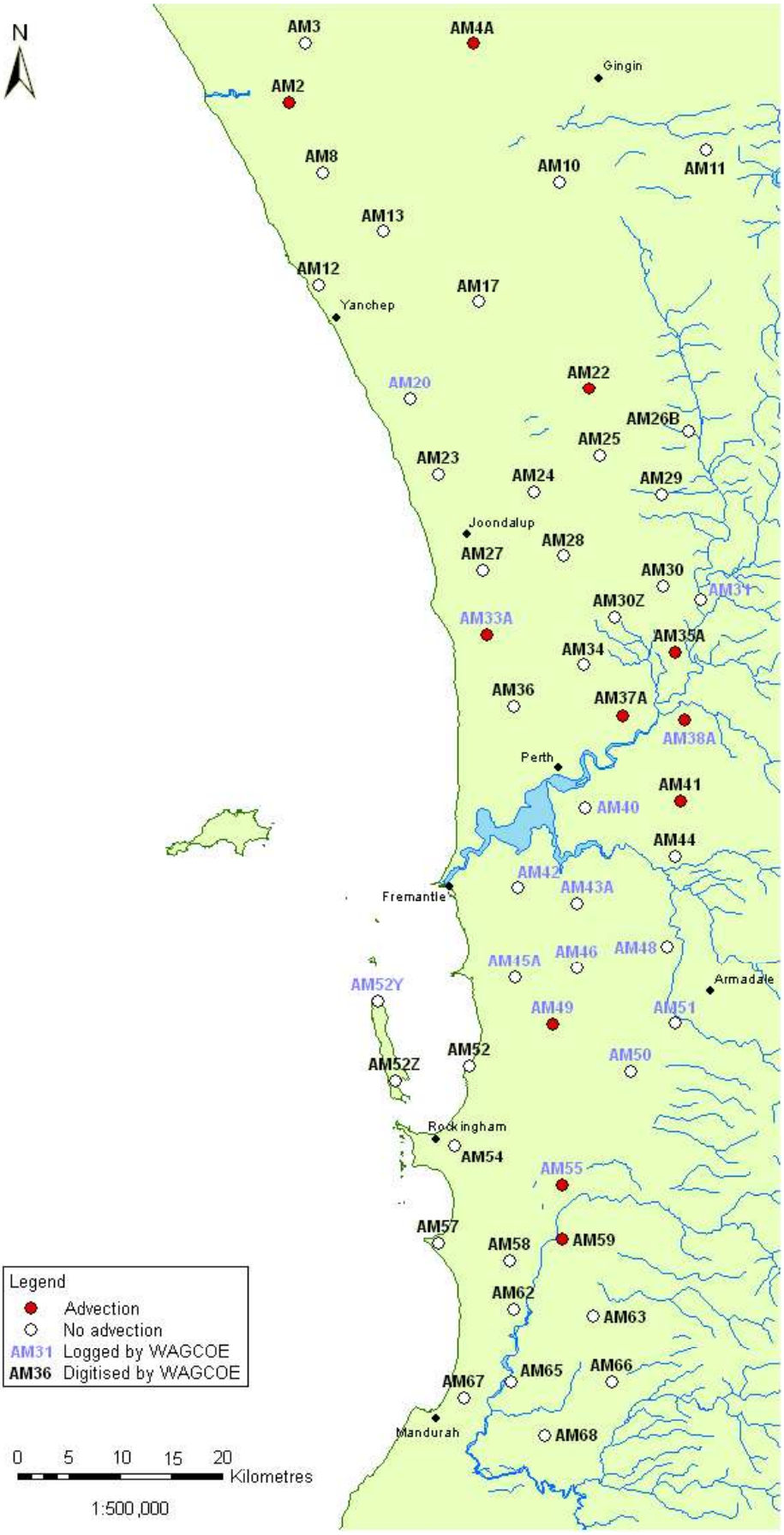
South Perth Shale

Confining bed



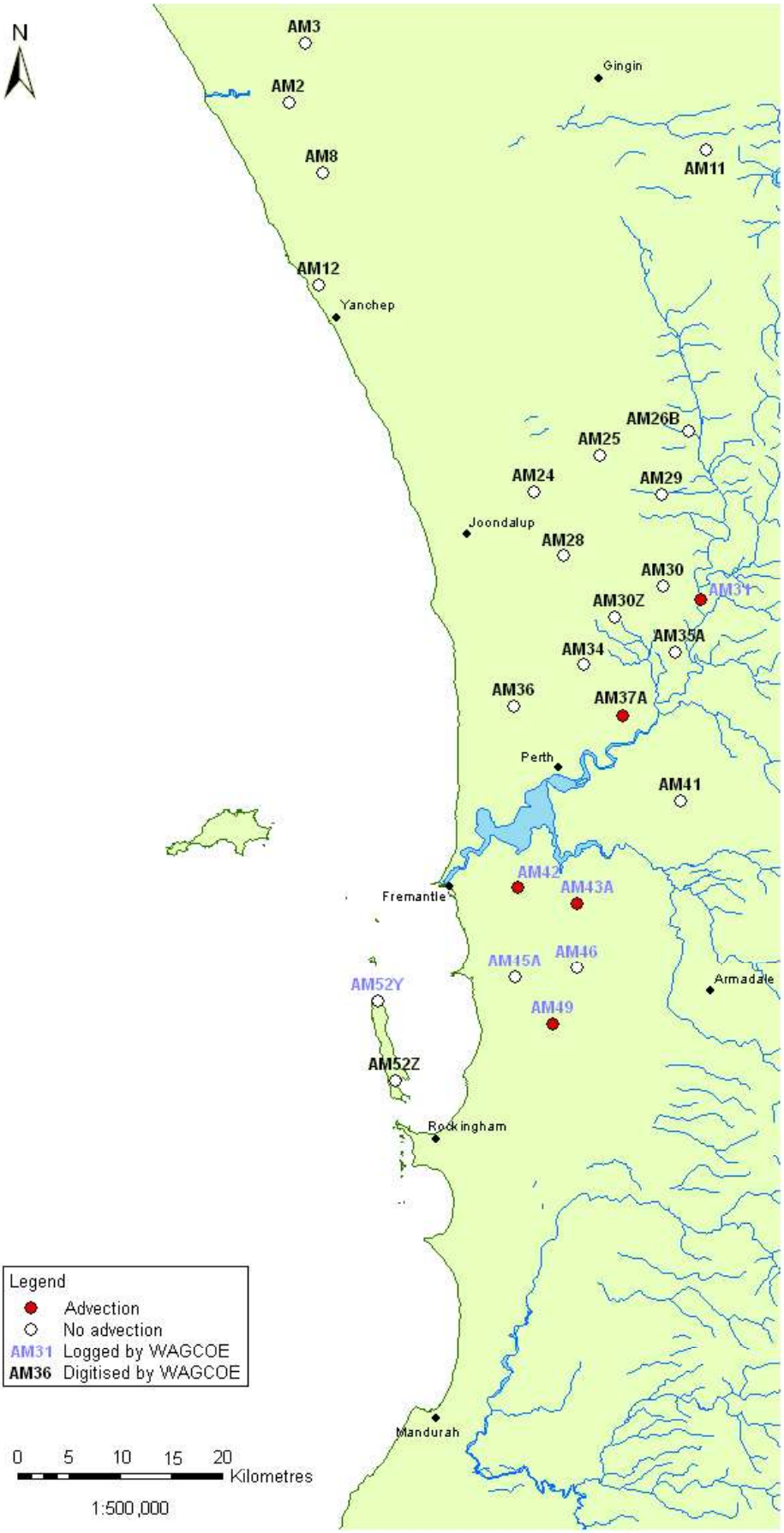
Leederville Aquifer

Henley Sandstone Member, Pinjar Member, Wanneroo Member, Mariginiup Member

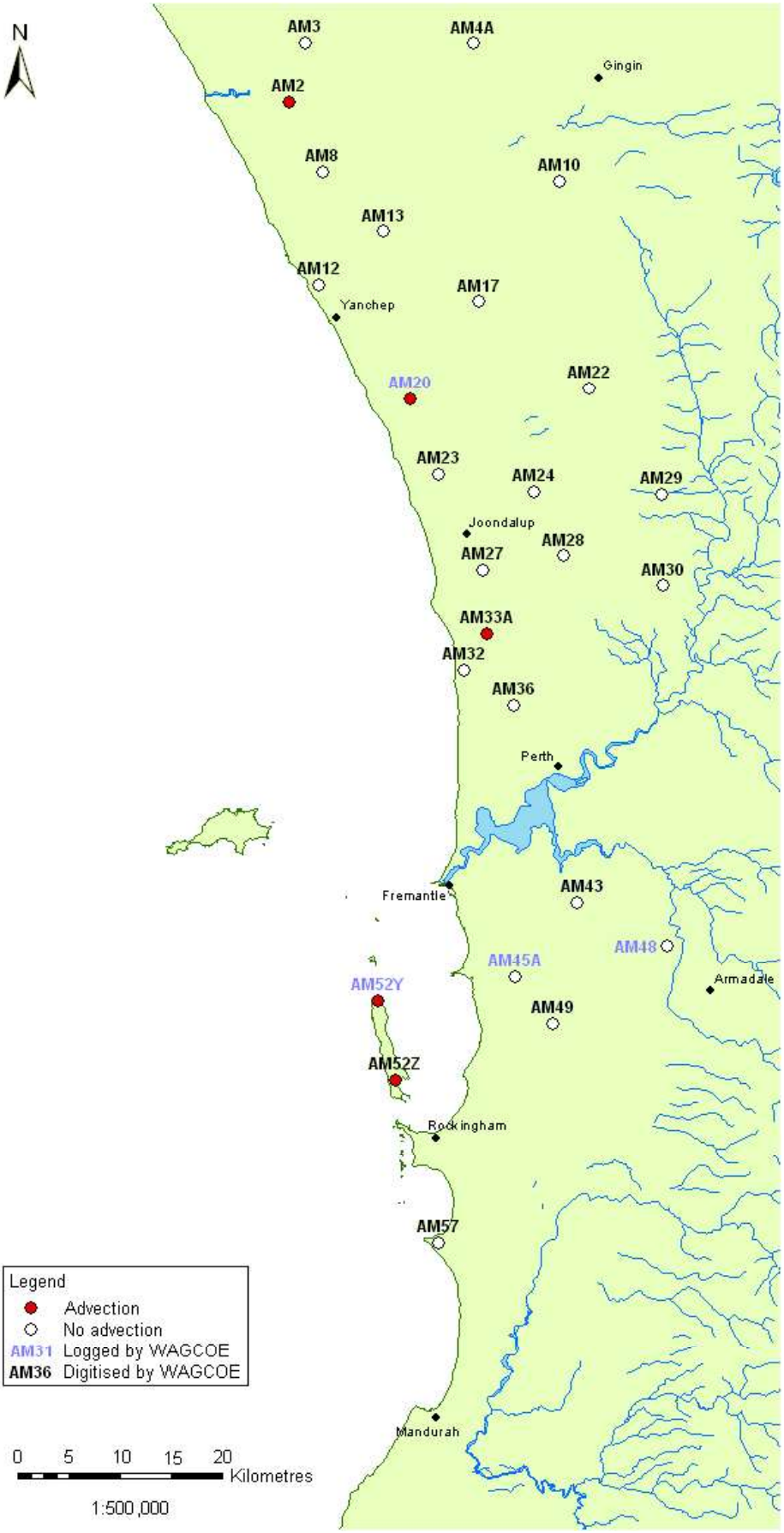


Kardinya Shale Member (Osborne Formation)

Confining bed



Mirrabooka Aquifer

Poison Hill Greensand, Molecap Greensand, Mirrabooka Member

Superficial aquifers
Superficial formations