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Hydrogeology of the Gillingarra Palaeochannel

Russell Speed

Adele Killen

Department of Primary Industries and Regional Development

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Cover: Groundwater monitoring site in the Gillingarra Palaeochannel (photo: A Killen)

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Department of Primary Industries and Regional Development
3 Baron-Hay Court, South Perth WA 6151
Telephone: +61 (0)8 9368 3333
Email: enquiries@dpird.wa.gov.au
Website: dpird.wa.gov.au

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Acknowledgements

This project was funded by Royalties for Regions (through the former Department of Regional Development and Lands, via the former Department of Water) and the former Department of Agriculture and Food, Western Australia (DAFWA). Since the project began, machinery of government changes mean that this project is now the responsibility of the Department of Primary Industries and Regional Development (DPIRD).

The project's main objective is to support priority regional development in the West Midlands region by locating, determining and quantifying new potable or 'fit-for-purpose' groundwater resources for agriculture and other industries that depend on water.

This project was undertaken in partnership with CSIRO Minerals Resources, in particular, Tim Munday and Aaron Davies. CSIRO's contribution to the project included:

- determining the optimum acquisition system parameters to achieve the aims of the project
- selecting and appointing a geophysical contractor
- supervising the airborne geophysical data acquisition and maintaining data quality control
- processing the geophysical data
- providing interpretation and analysis products
- producing a final report.

We wish to acknowledge the cooperation of the landholders in the survey area, in particular the owners of the land where we drilled: Shane and Emma Kelly, Brian Kelly, the Lidgett, Sinclair and Brown families, and the Benedictine community.

We would like to thank Grantley Stainer for helping to supervise the drilling and keeping meticulous field drill logs, and John Simons for providing the Aqtesolv analysis of the test pumping. We thank John Bruce for GIS support and contribution to many of the figures and maps presented in the report.

The Department of Water and Environmental Regulation provided technical guidance and we acknowledge the efforts of Alex Kern, Lazarus Leonhard and Chris O'Boy.

Don Bennett and John Simons provided technical review of the report, and Kathryn Buehrig (KB Editing) and Angela Rogerson edited the report.

Summary

Previous groundwater investigations had identified the presence of palaeochannel sediments under the Capitela Valley in the Perth Basin, about 25 kilometres (km) south-west of Moora. The sediments of this Capitela Palaeochannel were thought to form a discrete aquifer of good quality groundwater suitable for agriculture.

To improve our understanding of the Capitela Palaeochannel, its distribution, water quality and potential as a groundwater resource, we undertook an airborne electromagnetic (AEM) geophysical survey of the area in December 2012. This led to the discovery of a palaeochannel located in the Darling Range between Gillingarra and New Norcia, and we named this the Gillingarra Palaeochannel.

The Gillingarra Palaeochannel warranted further investigation so we undertook a drilling program to validate the geophysical interpretation and to obtain information about the aquifer's hydraulic and geochemical properties. As part of the program, we installed 16 monitoring bores and a production bore at nine sites, during October 2013 to February 2014.

Drilling results show that the Gillingarra Palaeochannel is up to 197 metres (m) deep, up to 1.18km wide and at least 18km long, and is mostly composed of coarse sand.

We conducted test pumping of the production bore to estimate the Gillingarra Palaeochannel's parameters and potential bore yields. The bore produced about 700 kilolitres (kL) per day of brackish quality water — 307 millisiemens per metre (mS/m) electrical conductivity (EC), or 1700 milligrams per litre (mg/L) total dissolved solids (TDS) — suitable for livestock watering. We estimate the annual recharge to the aquifer to be about 0.85 gigalitres per year (GL/y) and the brackish groundwater in storage to be 4.6GL.

We discovered that, although they seem to be aligned, the Gillingarra Palaeochannel is not connected to the shallower Capitela Palaeochannel.

The rising groundwater levels and salinity developing along the Bindoon–Moora Road and Midlands rail line is due to discharge from the Gillingarra Palaeochannel.

Despite not being an extensive groundwater resource, this aquifer will be able to provide a valuable local source for livestock watering and some agriculture for the Gillingarra – New Norcia area.

1 Introduction

In 2008, DAFWA undertook a drilling program to install three groundwater monitoring sites to assess salinity risk along the Capitela Valley, on behalf of the Moore Catchment Council. The drilling program discovered what was thought to be a palaeochannel aquifer at least 10km long and possibly 1km wide near the surface, and at least 60m deep aligned with the Capitela Valley. DAFWA estimated that the unconfined palaeochannel aquifer contained up to 100GL of low salinity groundwater (Speed et al. 2008).

The Capitela Valley lies about 20km south-east of Dandaragan in the Koojan – West Gillingarra area of the West Midlands (Figure 1.1). The land use here is mostly broadscale farming with a mixture of livestock and cropping activities, with some small-scale irrigated agriculture. The Capitela Valley is a series of relict playa lakes separated by low, sandy ridges, with no active or defined surface drainage.

Groundwater levels in the Koojan – West Gillingarra area have been rising at up to 0.3 metres per year (m/y) since the late 1980s (Raper et al. 2014) due to higher groundwater recharge rates following vegetation clearing in the 1950s and 1960s (Kay & Diamond 2001). This rise has resulted in extensive spreading of dryland salinity, particularly on flats associated with the Moore River.

After the above-average unseasonal rainfall that occurred in 1999, dryland salinity began to emerge and spread on flats at Gillingarra on the Bindoon–Moora Road and at Jewel Park on the Gillingarra–Glentromie Road (Figure 1.2). Dryland salinity spread rapidly, threatening farm infrastructure and transport infrastructure, such as the Bindoon–Moora Road and the Midlands rail line.

Subtle landscape features, including a relict lake feature higher in the catchment towards New Norcia, indicated that the spreading dryland salinity was being driven by discharge from a palaeochannel to the east, emanating from the Darling Range and lying between New Norcia and Gillingarra. The orientation of the hypothesised palaeochannel aligned with the Capitela Palaeochannel to the west (Hydroconcept 2012).

In 2012, DAFWA undertook an AEM survey to confirm if a palaeochannel existed on the Darling Range and to explore any hydraulic connection with the Capitela Palaeochannel. We followed this with a drilling program to validate the AEM data, by installing groundwater monitoring sites and a production bore. We carried out test pumping to estimate aquifer parameters and to assess the aquifer's potential as a groundwater resource.

This report presents the results of the AEM survey and the subsequent drilling and test-pumping program.

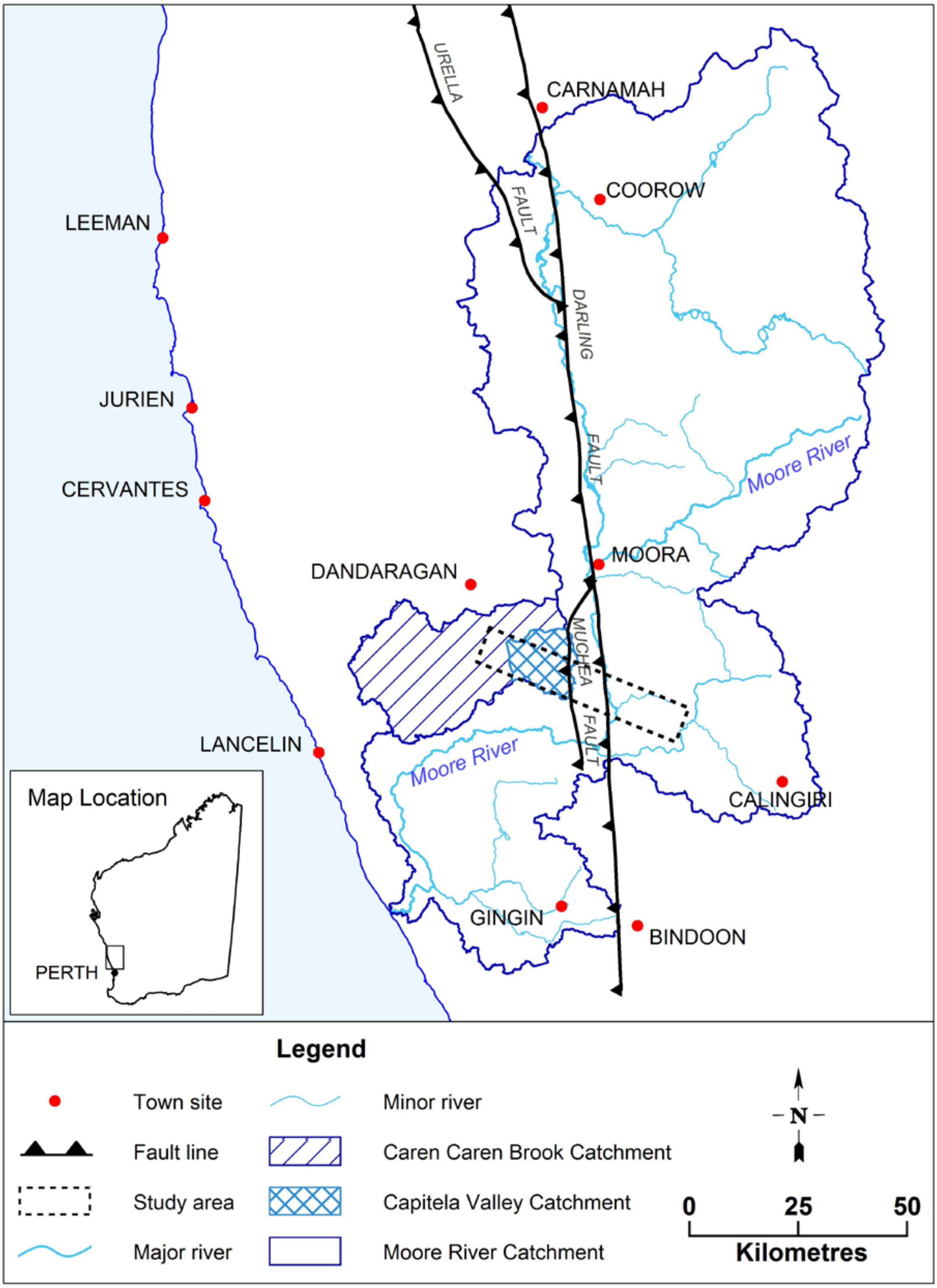


Figure 1.1 Location of the study area in relation to surface water catchments and nearby towns

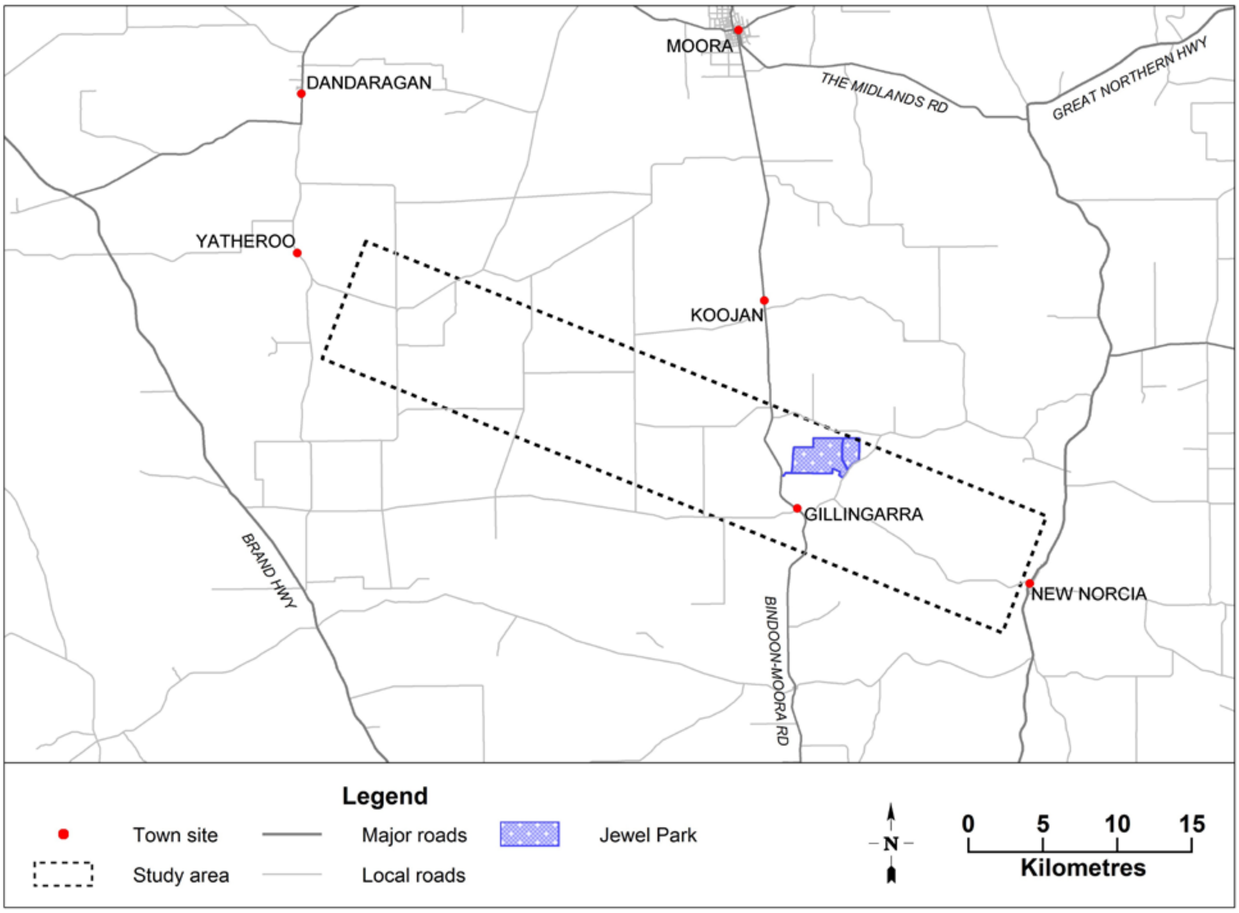


Figure 1.2 Location of the study area

2 Background

2.1 Location

The study area covers a rectangular area 50km long by 7km wide, extending from Yatheroo in the west to New Norcia in the east. Gillingarra is in the centre of the study area, about 120km north of Perth on the Bindoon–Moora Road (Figure 1.2).

2.2 Physiography

The eastern part of the study area lies within the Moore River catchment (Figure 1.1) in the zone of rejuvenated drainage where drainage is generally well defined. The eastern extremity of the study area is in the eastern branch of the Moore River catchment. The northern branch of the Moore River crosses the study area at Gillingarra.

The central western part of the study area straddles the internally drained Capitela Valley, which is characterised by a series of palaeolakes separated by low, sandy rises (Figure 2.1).

The western edge of the study area extends into the Caren Caren Brook catchment. Here, drainage is poorly defined and passes through a series of small lakes in a sandy, broad, valley floor.

Topographic relief ranges from 272m Australian Height Datum (AHD) to less than 146mAHD at Yangy Lake, located in the Caren Caren Brook catchment.

2.3 Geology

The eastern half of the study area is underlain by the Precambrian Yilgarn Craton. The western half is underlain by the Phanerozoic Perth Basin (Carter & Lipple 1982), with the Darling Fault delineating the boundary between the two major geologies (Figure 1.1).

Within the study area, the Yilgarn Craton consists of Archean granites, gneisses and schists that are intruded by mafic dykes (Carter & Lipple 1982).

The Perth Basin is a deep trough of sedimentary rocks, described as being an ‘intensely faulted half graben’ (Playford et al. 1976). The upper stratigraphic units in the Perth Basin consist of Jurassic Yarragadee Formation, overlain by the Cretaceous Parmelia Group (Otorowiri Siltstone and Parmelia Formation), Warnbro Group (Leederville Formation), Coolyena Group and Quaternary sediments (Kay & Diamond 2001).

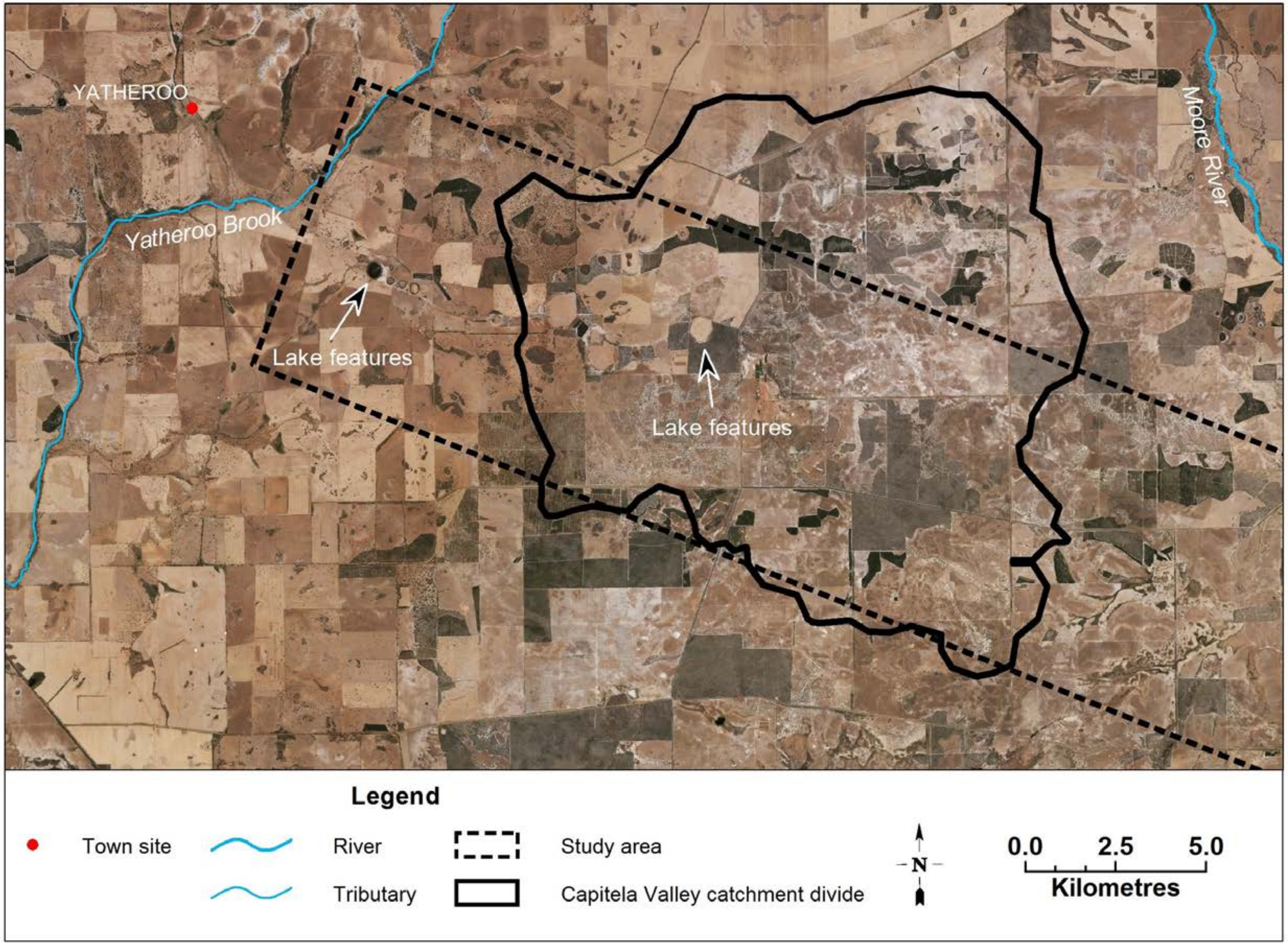


Figure 2.1 Aerial photo showing lake features within the Capitela Valley catchment

2.4 Hydrogeology

On the Yilgarn Craton, groundwater is primarily found in fractured and weathered (gritty clay saprolite) bedrock. Groundwater salinity varies from fresh in elevated areas to saline in valley floors, where it is generally too saline for livestock or domestic use. Bore yields are generally low. Groundwater resources within the Yilgarn Craton are unreliable, with water required for agricultural purposes usually being sourced from captured run-off. The area east of the Bindoon–Moora Road (Figure 2.1) is not proclaimed under the *Rights in Water and Irrigation Act 1914,* meaning that groundwater abstraction is not required to be licensed, unless the resource is artesian.

In contrast, there are significant regional aquifers in the Perth Basin that yield large, fresh groundwater resources. The entire Perth Basin is a proclaimed groundwater area and subject to groundwater licensing by the Department of Water and Environmental Regulation (DWER). The western part of the study area is within the Gingin groundwater area, where DWER allocates groundwater from the Surficial, Mirrabooka, Leederville–Parmelia and Yarragadee Perth Basin aquifers (Department of Water 2013).

2.5 Soil-landscapes

Three soil-landscape zones occur in the study area. The Eastern Darling Range Zone (253) and the Northern Zone of Rejuvenated Drainage (256) occur in the east, and the Dandaragan Plateau Zone (222) occurs in the west (Figure 2.2; Schoknecht et al. 2004).

The Eastern Darling Range Zone is a moderately to strongly dissected lateritic plateau on weathered granite, with eastward flowing streams in broad, shallow valleys that contain some surficial Eocene sediments. Soils are formed in lateritic colluvium or from in situ weathered granite (Schoknecht et al. 2004).

The Northern Zone of Rejuvenated Drainage is an erosional surface of gently undulating rises to low hills, characterised by continuous stream channels that flow in most years. Colluvial processes are active. Soils are formed in colluvium or in situ basement that is predominantly comprised of Jimperding Metamorphic Rocks (Schoknecht et al. 2004).

The Dandaragan Plateau Zone is characterised by gently undulating plateau with areas of sandplain and some laterite on Cretaceous sediments. Soils are formed in colluvium and weathered rock and are mainly deep sands with ironstone gravely soils and loamy earths (Stuart-Street & Clarke 2005).

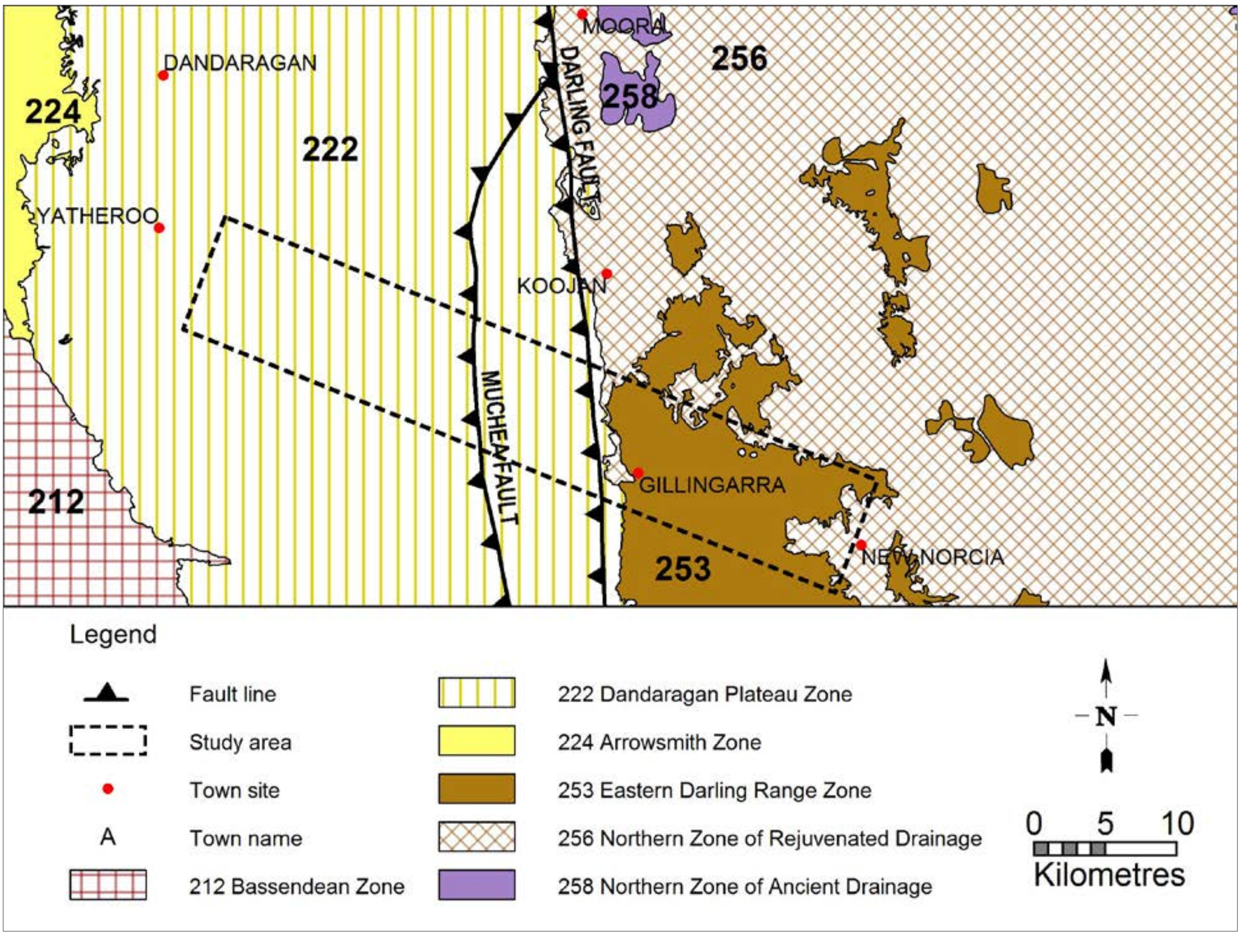


Figure 2.2 Soil-landscape zones in the project area

2.6 Climate

The climate is typical of a warm temperate to semi-arid region with predominantly winter rainfall and hot, dry summers.

The average annual rainfall (1975–2013) decreases to the east, ranging from 581 millimetres (mm) at Yathroo in the west to 452mm at New Norcia in the east (Bureau of Meteorology 2014). At Mogumber, 14km south of Gillingarra, the average annual rainfall (1975–2013) is 476mm (Figure 2.3).

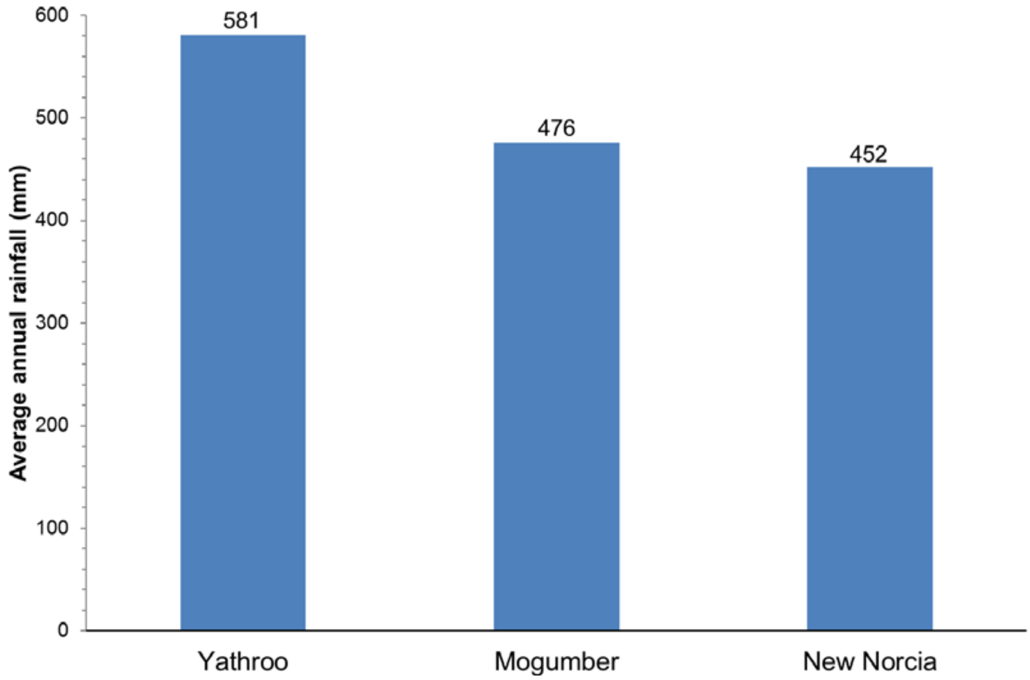


Figure 2.3 Average annual rainfall at Yathroo, Mogumber and New Norcia, 1975–2013

Summer rainfall events can be significant in the Wheatbelt region of Western Australia. Often, the highest daily rainfall totals of the year are recorded in summer or early autumn. For example, the highest daily rainfall observed at New Norcia was 121mm and at Mogumber was 175mm, both recorded on 16 February 1955 (Bureau of Meteorology 2014).

The average annual evaporation (1975–2013) is 2123mm at New Norcia, 2094mm at Mogumber and 2084mm at Yathroo. Average monthly rainfall exceeds average monthly evaporation during June and July at New Norcia and Mogumber, and during June, July and August at Yathroo (Bureau of Meteorology 2014).

3 Previous investigations

3.1 West Gillingarra

In 1988, DAFWA installed shallow (<5m deep) monitoring bores on the flats of a property about 3km west of Gillingarra (Figure 3.1, site 88WG6). The bores were regularly monitored from 1988 until 1999 to investigate the groundwater resource.

Figure 3.2 shows the hydrographs for the shallow and deep bores at this site. The hydrograph for the very shallow (1.1m deep) bore, 88WG6A, shows the effect of temporary waterlogging in the deep duplex soil during winter. The hydrograph for the deeper (5m deep) bore, 88WG6B, shows that the shallow watertable has a rising trend of about 0.2m/y that also overprints the seasonal cycle.

3.2 Forest Products Commission

In 2008, DAFWA installed two groundwater monitoring bores with the Forest Products Commission (Figure 3.1). One site was within a *Pinus pinaster* plantation located in an upper hillslope position, and the other was outside of the plantation. Both sites show a rising groundwater trend of 0.23m/y (Figure 3.3).

3.3 Moore Catchment Council

In 2008, DAFWA undertook a small drilling program along the Capitela Valley on behalf of the Moore Catchment Council to assess salinity risk. Three groundwater monitoring sites were installed along a transect in the Capitela Valley (Figure 3.1). Drilling results indicated the presence of an approximately 10km length of palaeochannel sediments which were at least 61m thick — the maximum depth of drilling (Speed et al. 2008).

The hydrographs for these monitoring sites are shown in Figure 3.4. All three sites show a rising groundwater trend of about 0.2m/y.

3.4 Bulla Bulla

In 2012, Hydroconcept Pty Ltd undertook a groundwater resources assessment on Bulla Bulla, a property within the Capitela Valley (Figure 3.1). Hydroconcept (2012) recognised and named the Capitela Palaeochannel aquifer and carried out test pumping on two bores screened entirely within the palaeochannel. Both bores were 200mm in diameter, screened from 16 to 40m below ground level and were tested at pumping rates in excess of 30 litres per second (L/s).

Hydroconcept (2012) noted that the maximum thickness of the Capitela Palaeochannel aquifer was unknown.

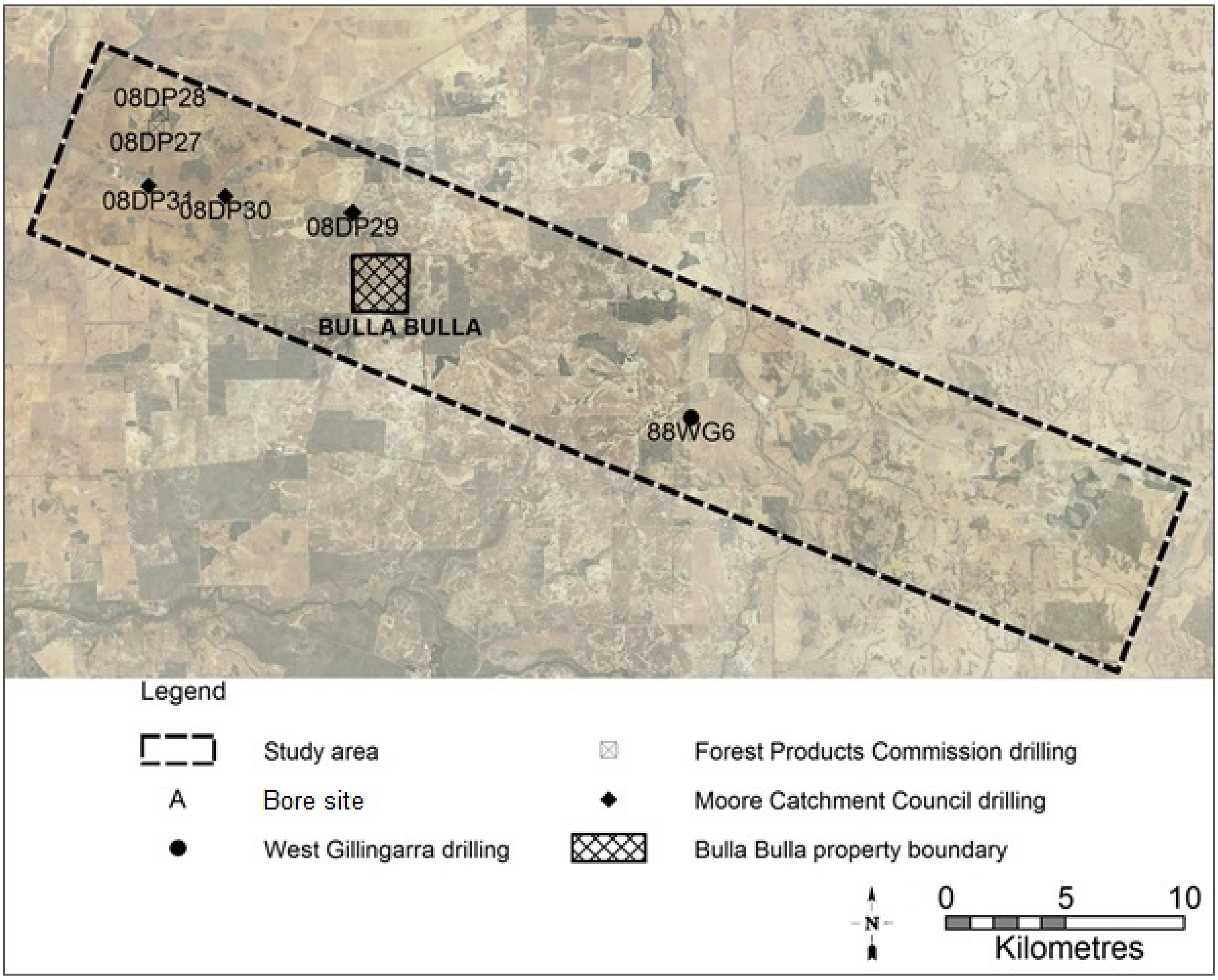


Figure 3.1 Location of existing bores and the Bulla Bulla groundwater investigation area

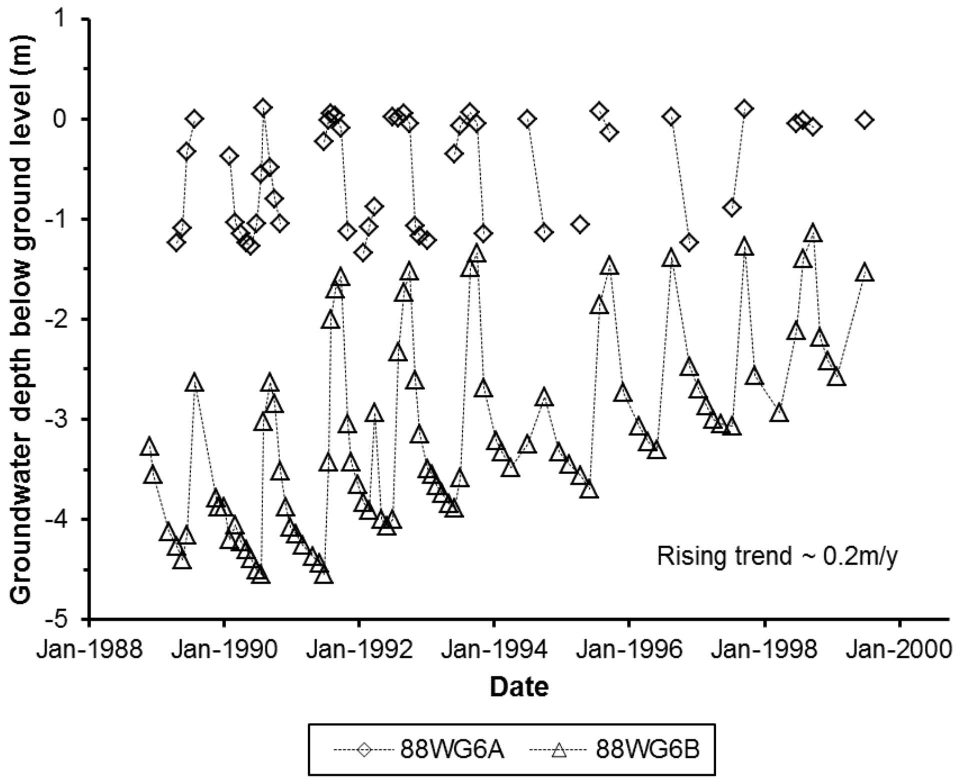


Figure 3.2 Hydrographs for groundwater monitoring at site 88WG6

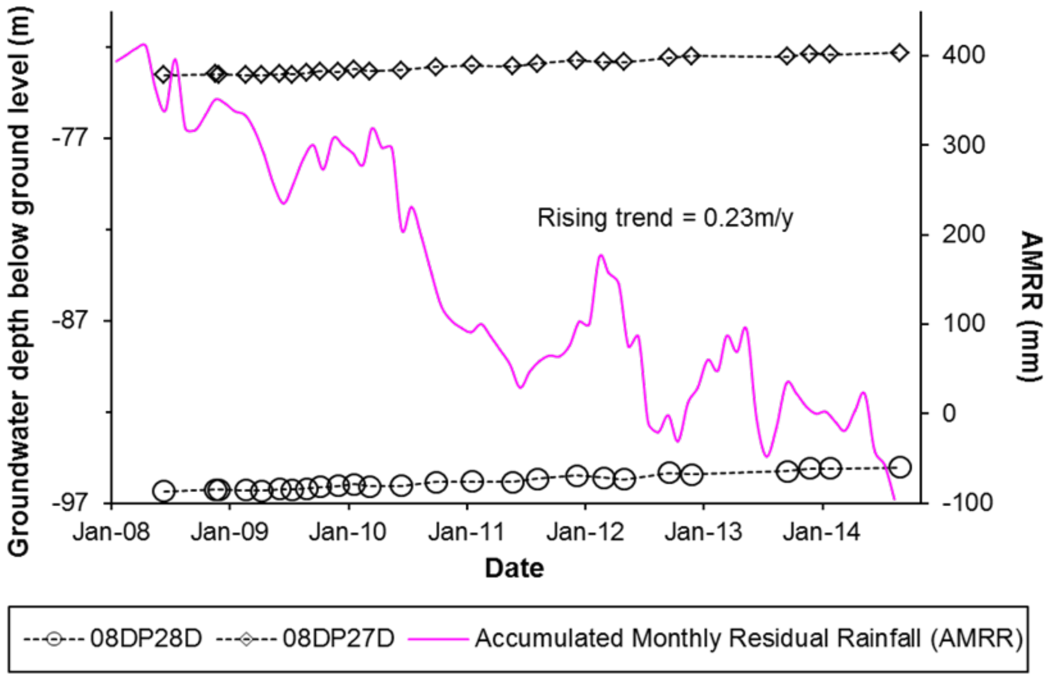


Figure 3.3 Hydrographs for Forest Products Commission's groundwater monitoring sites 08DP27D and 08DP28D

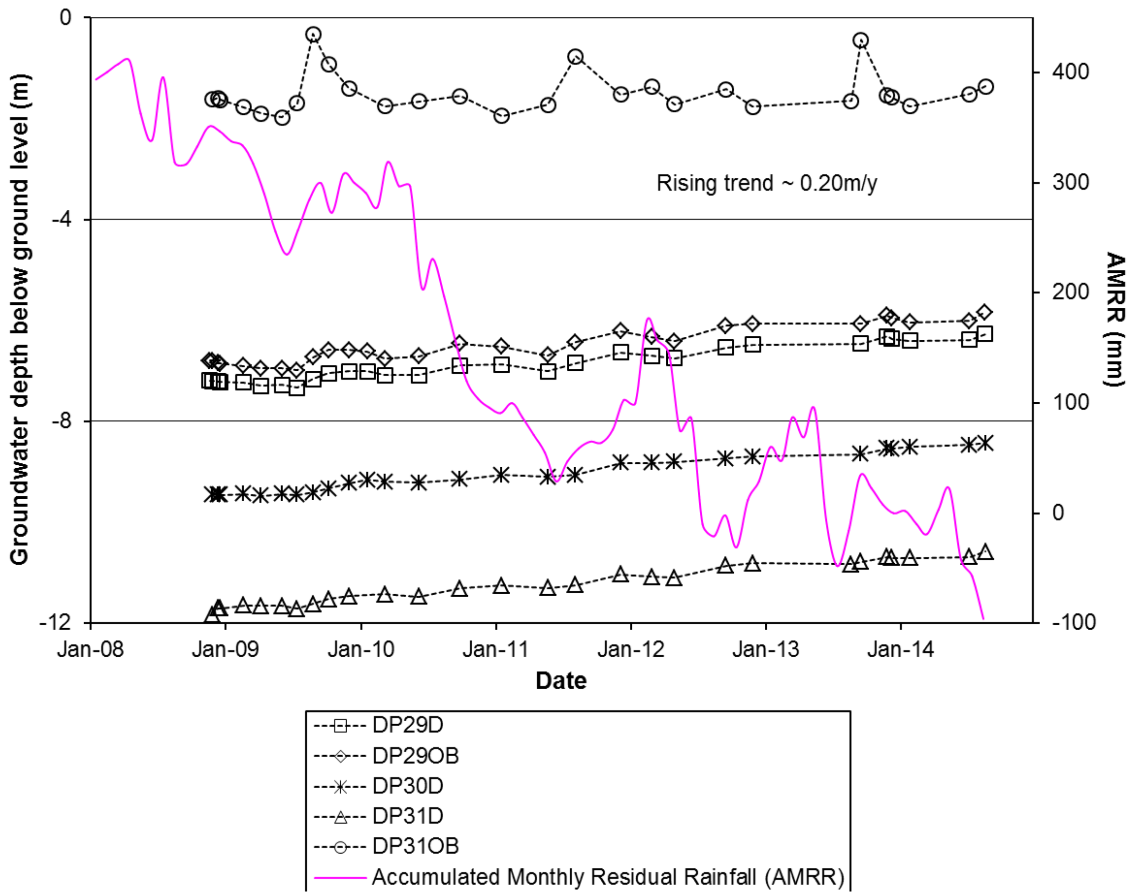


Figure 3.4 Hydrographs for groundwater monitoring sites along the Capitela Valley, drilled for the Moore Catchment Council

4 Methods

4.1 Airborne geophysics

DAFWA and CSIRO developed a collaborative research agreement to facilitate the planning, acquisition and processing of AEM data.

We considered several different time-domain AEM systems for the survey, including helicopter and fixed-wing systems. We selected CGG's TEMPEST fixed-wing time-domain AEM system because:

- we needed information about groundwater salinity
- we needed to define geological features that might influence groundwater and salinity variability at the regional scale
- the TEMPEST system provided the appropriate capability within the project's budget.

4.1.1 Collecting the AEM data

We collected AEM data between 23 September and 2 October 2012 from a rectangular survey area 7km wide by 50km long (Figure 1.1). The flight lines were orientated at right angles to the long edge of the rectangle, along a bearing of 20–200 degrees true because we anticipated the target geological features to be parallel with the long side of the rectangle. Line spacing was 250m with a sampling interval of about 15m along each line. A total of 1497 line-kilometres of data was collected.

4.1.2 Processing the AEM data

CSIRO processed the AEM data to remove baseline and anthropogenic noise and to correct for altitude.

The data was inverted using the 'layered-earth inversion for conductivity-depth' method developed by Geoscience Australia. This is a smooth-layer inversion where the thickness of each layer is constrained and the conductivity is allowed to vary.

4.1.3 Analysing the AEM data

The primary AEM-processed product was a series of conductivity-depth slices, also called interval conductivities. An example is shown in Figure 4.1. Conductivity-depth slices were provided for depths of:

- 10–15m
- 20–25m
- 50–55m
- 70–75m
- 97–107m
- 125–130m
- 150–155m.

The conductivity-depth slice that provided the most contrast in deep hydrogeological information was the 125–130m slice. An image of the 125–130m conductivity-depth slice data is shown in Figure 4.2, as an overlay on aerial photography.

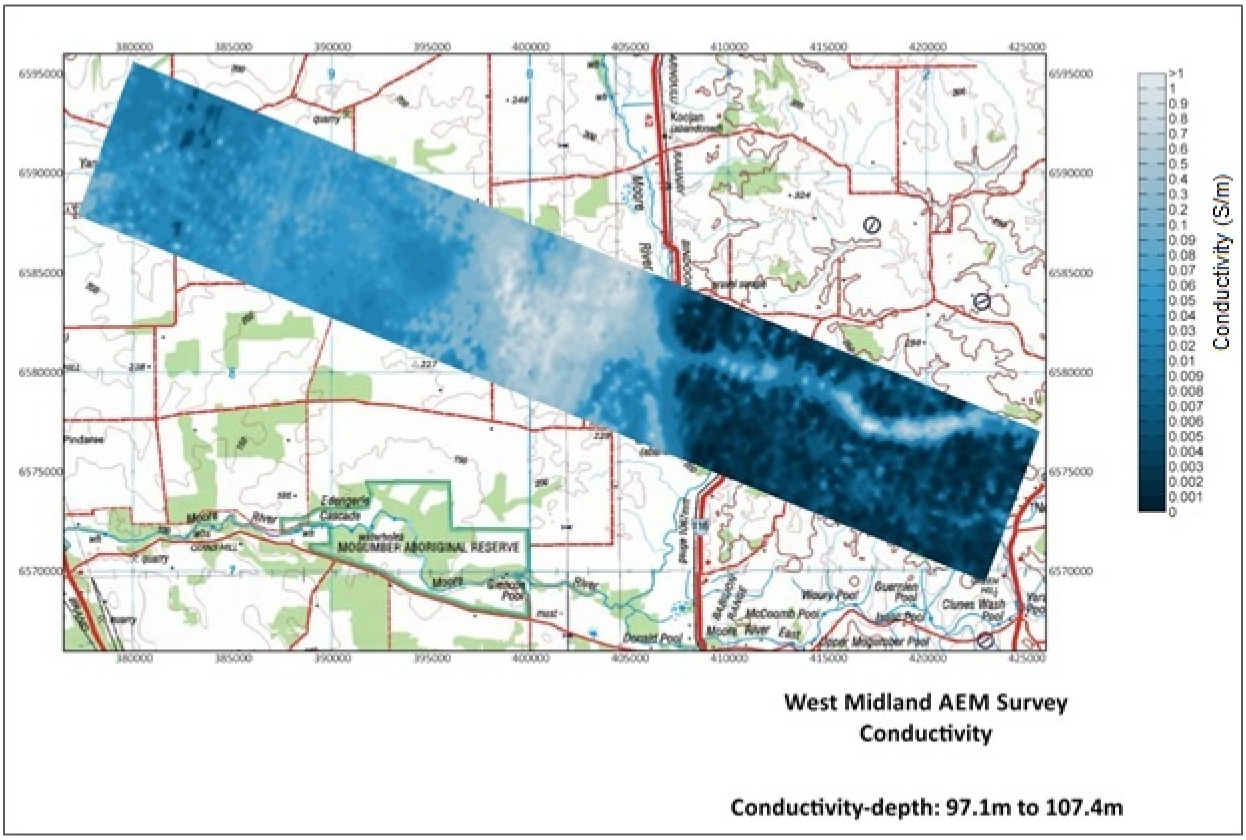


Figure 4.1 Example of conductivity-depth slice processed by CSIRO for 97–107m below ground level

In Figure 4.1, three main hydrogeological features are apparent:

- There is a thin zone of higher conductivity within the strongly resistive rocks of the Yilgarn Craton, meandering through the eastern part of the image. This provides a strong indication that there is a palaeochannel in this area.
- The north–south trending Darling Fault, located just west of the Bindoon–Moora Road, marks the western edge of the Yilgarn Craton.
- There is a zone of higher conductivity west of the Darling Fault, bordered to the west by the Muchea Fault.

The zone of higher conductivity between the Darling Fault and the Muchea Fault is most likely to be a feature of the higher salinity groundwater and higher clay content that is known to occur within the Kardinya Shales of the Osborne Formation. The Osborne Formation forms part of the Coolyena Group, which overlies the Leederville Formation (Department of Water 2017).

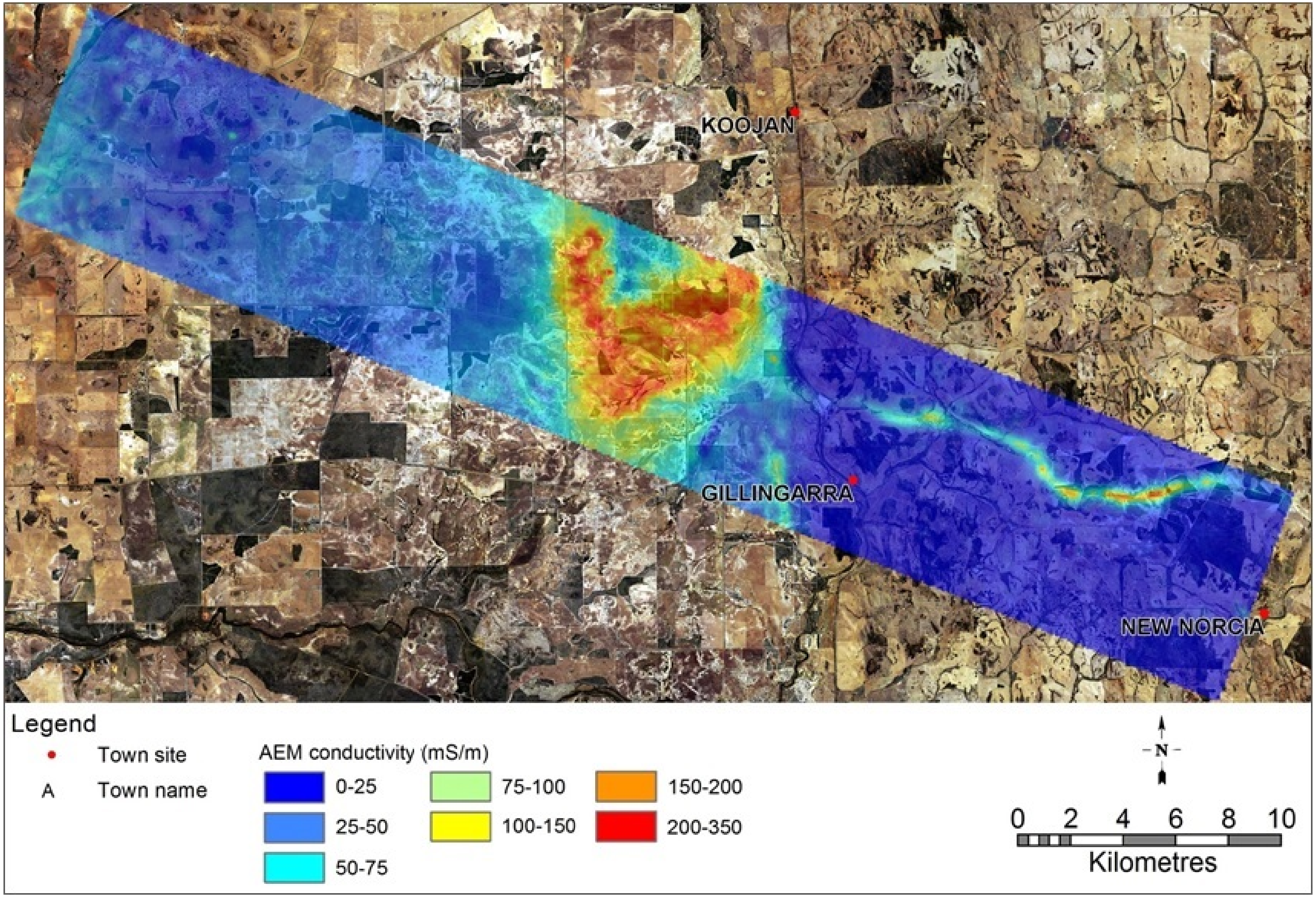


Figure 4.2 Conductivity-depth slice data for 125–130m below ground, displayed over aerial photography

4.1.4 Selecting the drill sites

In September 2013, DAFWA and CSIRO used the AEM data to refine drill targets for the drilling program. Conductivity-depth section images for each flight line were generated and presented alongside the relevant aerial photo, as per the example shown in Figure 4.3. We chose drilling targets using a combination of these images and we prioritised sites to maximise the acquisition of hydrogeological information on:

- groundwater resource potential in the upper landscape
- aquifer properties from test pumping a production bore
- continuity of the Gillingarra Palaeochannel into the Perth Basin and connectivity with the Capitela Palaeochannel.

4.2 Drilling

Smithdrill undertook drilling using the mud-rotary technique in two phases:

- 14 October – 7 November 2013
- 18–21 February 2014.

Drilling was completed at eight groundwater monitoring sites and one production bore site (Figure 4.4).

At each monitoring site, two 165mm diameter holes were drilled to install a deep monitoring bore (piezometer) and an adjacent shallow watertable observation bore. The deep bores are denoted with the suffix ‘D’ in their name and the observation bores are denoted with the suffix ‘OB’. On the Yilgarn Craton, deep holes were drilled to the basement. On the Perth Basin, drilling continued until it was clear that identifiable sedimentary units of the Perth Basin were reached — past the maximum depth of palaeochannel sediments.

The production bore, 13CPPB, was drilled to 60m using a 340mm diameter drill bit. Monitoring bores at sites 13CP2 and 13CP3 were drilled 110m away from the production bore in line with the palaeochannel, and 103m from the production bore at right angles to the palaeochannel.

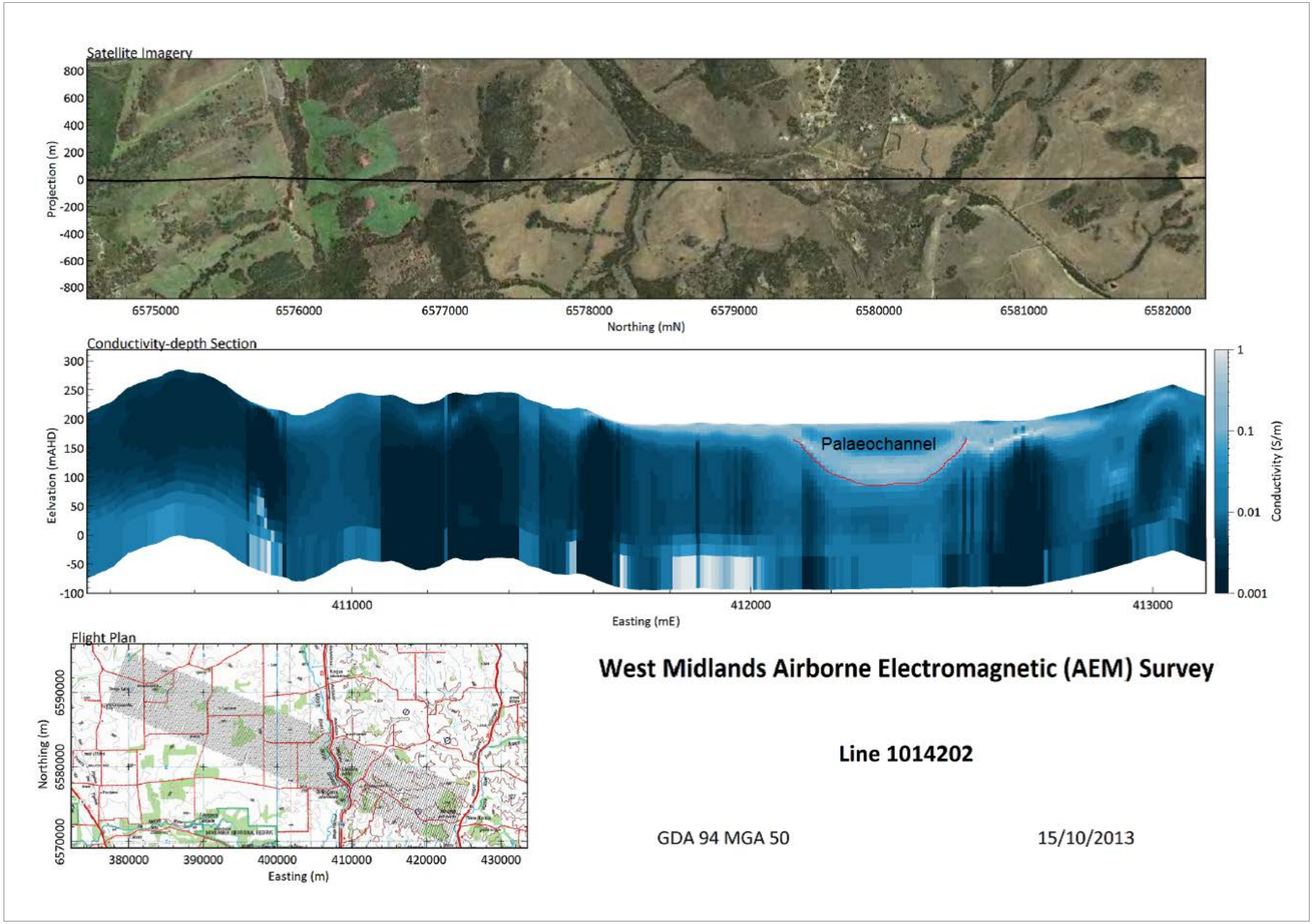


Figure 4.3 Conductivity-depth section provided by CSIRO for line 1014202

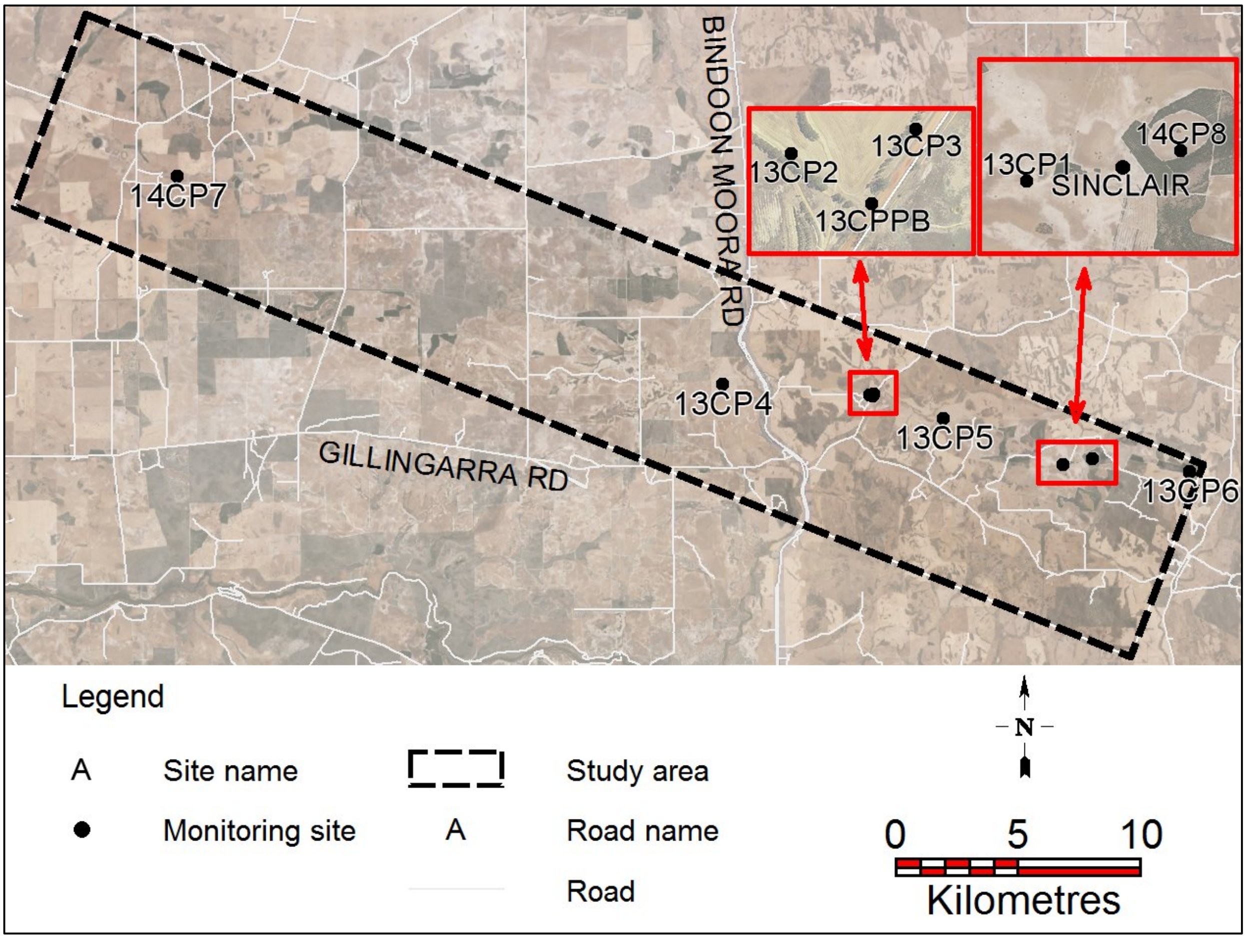


Figure 4.4 Drill locations in the study area

4.2.1 Bore construction

Monitoring bores were constructed with PN18 50mm uPVC casing with PN18 uPVC end caps. The casing intake sections were machine slotted at 0.5mm aperture. All monitoring bores were constructed with 6m slotted intake sections. The bottom of the slotted intake sections of all but one of the deep piezometers were set at the base of the palaeochannel sediments as interpreted from the drill cuttings. For the deep piezometer installed adjacent to the production bore, we placed the slotted intake at the midpoint of the slotted intake section of the production bore.

Most deep piezometers had unslotted casing sumps installed below the slotted sections, corresponding to the interval drilled that was below the base of the palaeochannel aquifer to ensure the water sampled is coming from the palaeochannel aquifer and not underlying saprolite.

The shallow observation bores were constructed with 6m slotted intake sections on the lowest part of the casing.

The production bore was constructed with PN12 200mm uPVC blank casing above 18m of commercial stainless steel wire-wound screen. Apertures were 0.5mm over the upper 6m screen length and 0.6mm over the lower 12m. The production bore was screened from 40.6–58.6m below ground level.

The annulus around the slotted intake section of all bores was packed with 1.6–3.2mm diameter graded gravel. Bentonite pellets were used to seal the annulus above the slotted intake section in the piezometers and the production bore. The annuli of all bores were back-filled to the ground surface with gravel or drill cuttings.

Bore tube tops were cut off at about 0.7m above the ground surface. A 125mm diameter, 1m long, lockable steel collar was placed over the monitoring bores and a 250mm diameter steel collar was placed over the production bore. The steel collars were pushed into the ground to provide protective headworks and set in concrete.

All monitoring bores were cleaned and developed by airlift, immediately after construction. The production bore was developed for three days by airlift through the drill stem. Following this, the production bore was still producing some fine sand.

Bore construction details are provided in Appendix A.

4.2.2 Bore sampling and logging

We collected drill samples at 1m intervals during drilling at all sites. Samples were oven-dried at 60°C and chip trays were prepared and stored at DPIRD's Geraldton office. Duplicate chip trays were forwarded to the landholders of properties where drilling occurred.

Bores were geophysically logged from 9–11 December 2013 with the Auslog® system recording natural gamma and EC. The profiles of the two sites drilled in February 2014 were logged on 22 October 2014 with a Geonics EM39® system comprising natural gamma and conductivity probes.

We compiled composite drill logs from field notes, review of chip trays, geophysical logs, groundwater sampling and survey data (Appendix A).

Groundwater sampling was carried out from 18 to 21 August 2014 using a Grundfos MP1 submersible pump. Some shallow observation bores had insufficient yield to enable pumping and were first purged and then sampled using a stainless steel bailer. Prior to sampling, bores were purged to evacuate all water from the casing and draw in a fresh sample of groundwater from the aquifer. In bores that had sufficient yield, purging was undertaken by pumping until dissolved oxygen, EC and pH levels stabilised. A YSI Professional plus® meter was placed in the outlet stream to continuously monitor the aforementioned parameters.

Groundwater samples were prepared according to South Australian Environment Protection Authority guidelines (Johnston 2007). Samples were refrigerated and delivered to ChemCentre on 22 August 2014.

All bore water samples were analysed for general chemistry and nutrients.

Bores 13CP1D, 13CP1OB, 13CPPB and Sinclair's bore (a private bore subsequently drilled into the palaeochannel) were also sampled for atrazine and minerals. Samples taken for minerals were filtered through a 45 micrometre (µm) cellulose acetate syringe filter, acidified to pH 2 and refrigerated. Samples collected for atrazine were placed in an acid-washed, brown glass bottle and refrigerated. Care was taken to ensure atrazine samples did not contact the air during the sampling and storage process.

4.3 Surveying

Locations of the groundwater monitoring sites and the production bore were identified using a real-time kinematic GPS surveying system and subsequently corrected using the AUSPOS GPS data processing service provided by Geoscience Australia.

4.4 Test pumping

Airwell Group Pty Ltd conducted test pumping on production bore 13CPPB from 17 to 20 March 2014 using a Grundfos SP45-12 electric submersible pump with a 15kW motor. Water produced was discharged 80m south-west of the production bore, 190m south-west of one of the monitoring sites and 130m south-east of the other monitoring site via lay flat hosing into a culvert. The culvert discharged into a drain flowing south-east away from the test-pumping site.

Initially, a step test was performed to determine a pumping rate for a 48-hour constant rate test (CRT). The pumping discharge rate was held constant at each step until the drawdown in the production bore stabilised. The discharge rate was then incrementally increased. In total, there were eight steps until the bore forked, triggering a sensor which switched off the pump. The production bore was then allowed to fully recover before beginning the CRT.

Using the results of the step test, a discharge rate of 8L/s was chosen for the CRT. We conducted the CRT for 48 hours (2879.5 minutes). Bore recovery was monitored for a further 14 hours (840.5 minutes).

Water levels in the production bore 13CPPB and piezometers 13CP2D and 13CP3D were recorded every 30 seconds. The discharge rate, EC and temperature of the production bore water were also recorded at 30-second intervals.

We used additional Schlumberger CTD Diver® dataloggers to record watertable fluctuations in observation bores 13CP2OB and 13CP3OB at 1-minute intervals during the test pumping.

A Vaisala pressure transducer and Campbell Scientific CR200® datalogger were used to record changes in barometric pressure at 30-minute intervals throughout the test pumping.

The data from the test pumping was analysed using Aquifer Test Pro® published by Schlumberger Water Services and Aqtesolv® published by Hydrosolve.

5 Results

5.1 Drilling and profile

Site13CP1 is in the Darling Range on the Yilgarn Craton (Figure 4.4). Its lithology confirmed the AEM survey indications that there are deep palaeochannel sediments in this area. The profile is 197m of palaeochannel sediments, overlying a thin 1.5m zone of gritty clay saprolite, above granitic basement material that was too hard to drill into with the mud-rotary method (Appendix A).

Similar lithology was encountered at site 13CP2 (Figure 4.4), also located in the Darling Range, about 14.5km west-north-west of New Norcia. Here, 192m of palaeochannel sediments also overlie granitic basement material that was too hard to drill into. The lithologies at sites 13CP1, 13CP2, 13CP5, 13CP6 and 14CP8 (Table 5.1 and Appendix A) all confirm the existence of a palaeochannel cutting through the Darling Range in this area, aligned to the thin zone of higher conductivity that snakes through the eastern part of the AEM survey (Figure 4.1)

Based on chip trays and geophysical logs, the profile at 13CP4, west of the Darling Fault, appears very similar to site 13CP2 (Figure 4.4). However, subsequent palynological analysis (Appendix B) revealed that the dark-grey clay layer from site 13CP4 at 92–94m deep is of the Leederville Formation.

The profile to 82m deep at site 14CP7, also west of the Darling Fault, has similar lithology to the other sites, but contains less clay and more gravel. Below 82m, the profile changes to dark grey and then becomes silty at 90m. Palynological analysis of a sample retrieved from 98–99m deep also assigned this material to the Leederville Formation (Appendix B).

Table 5.1 Summary of bore location, construction, strata and groundwater data

Bore	Easting[a] (m)	Northing[a] (m)	Elevation (mAHD)	Tube top (m)	Total depth (mBGL)	Screen interval (mBGL)	Depth of palaeochannel sediments (m)	SWL August 2014 (mBGL)	EC August 2014 (mS/m)	TDS August 2014 (mg/L)
13CP1D	420030	6577235	241.65	0.80	196.62	188.63–194.63	197	26.05	2 090	12 000
13CP1OB	420030	6577234	241.65	0.80	18.30	12.30–18.30	n/a	5.01	24	130
13CP2D	412143	6580086	191.43	0.70	190.74	46.50–52.50	192	+0.40	1 420	8400
13CP2OB	412142	6580087	191.43	0.77	7.12	1.12–7.12	n/a	+0.01	3 050	18 000
13CPPB	412237	6580028	191.95	0.65	58.64	40.64–58.64	n/a	+0.17	339	1 800
13CP3D	412289	6580117	192.49	0.65	54.40	48.40–54.40	n/a	0.26	333	1 700
13CP3OB	412290	6580117	192.49	0.65	7.04	1.04–7.04	n/a	0.59	1 990	12 000
13CP4D	406087	6580538	179.50	0.65	152.86	110.80–116.80	<92	1.16	282	1 500
13CP4OB	406087	6580540	179.50	0.62	7.11	1.11–7.11	n/a	1.70	4 040	26 000
13CP5D	415163	6579134	202.87	0.70	194.65	158.60–164.60	176	3.04	1 500	9 100
13CP5OB	415165	6579134	202.87	0.72	6.93	0.93–6.93	n/a	1.60	80	400
13CP6D	425232	6576960	217.10	0.60	134.30	128.30–134.30	136	4.81	1 970	12 000
13CP6OB	425233	6576961	217.09	0.61	12.93	6.93–12.93	n/a	4.02	136	760
14CP7D	383790	6589045	152.21	0.85	106.70	82.67–88.67	<90	9.10	108	560
14CP7OB	383790	6589043	152.12	0.88	11.06	5.06–11.06	n/a	2.56	27	160
14CP8D	421258	6577479	246.13	0.76	191.17	183.17–189.17	190	29.48	2 140	13 000
14CP8OB	421259	6577477	246.11	0.84	17.39	11.39–17.39	n/a	15.07	189	1000

SWL = standing water level; EC = electrical conductivity; TDS = total dissolved solids; n/a = not assessed

a Eastings and northings are in GDA94, Zone 50.

5.2 Groundwater chemistry

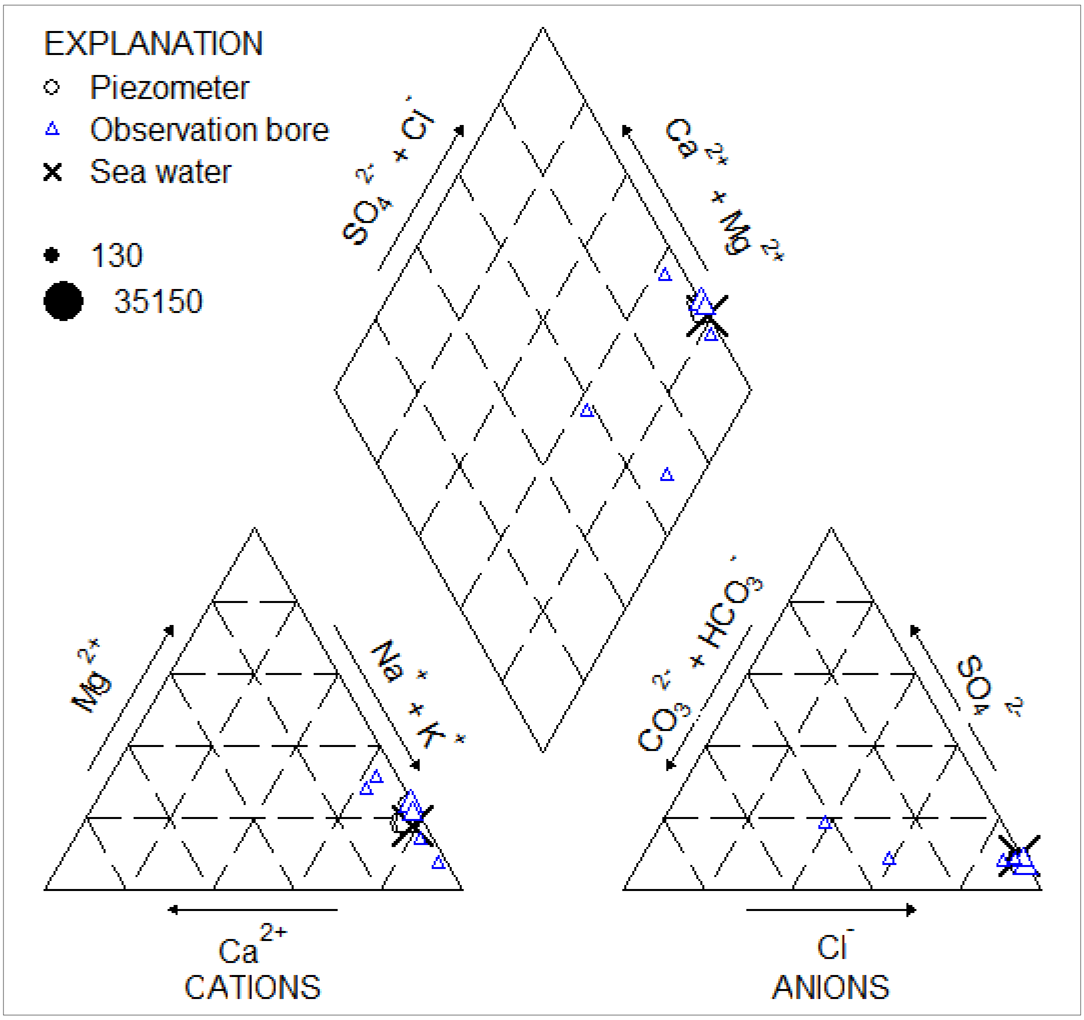
The EC of groundwater sampled from all bores is shown in Table 5.1. On the Darling Range, the basal groundwater in the palaeochannel was saline, having an EC ranging from 1500 to 2140mS/m. However, at the watertable it was much lower, ranging from 24 to 189mS/m. The higher ECs at sites 13CP2 and 13CP3 (3050mS/m and 1990mS/m respectively), correspond to an area of active groundwater discharge, where moderate to severe dryland salinity has developed because of the evaporative concentration of salts in the soil profile.

At site 13CP4, in Perth Basin just west of the Darling Fault, the EC of groundwater at the watertable was 4040mS/m (observation bore 13PC4OB). However, the EC of the deep groundwater at this site, measured from piezometer 13CP4D, is much lower at 282mS/m. This piezometer’s screened interval is 110.8–116.8m below ground, just above the horizon of black clay at 118m. During drilling, we thought the black clay marked the top of the Leederville Formation and our intention was to place the bore screen above this horizon. However, subsequent palynological analysis (Appendix B) determined that the screen was placed at least 18m into the Leederville Formation.

The groundwater at site 14CP7 — also in the Perth Basin — is fresh, with an EC at the watertable of 27mS/m and an EC of 108mS/m at 85m deep. The low groundwater ECs also correspond with the generally low ECs of the regolith recorded by the EM39 (Appendix A)

The Piper diagram classifies the groundwater in terms of major ion proportions for the deep piezometers and shallow observation bores within the Gillingarra Palaeochannel (Figure 5.1). The relative proportions of the major ion groups are displayed. The absolute values are provided in Appendix C. For comparison, Figure 5.1 also shows the ionic proportions of seawater (data from Appendix C).

Figure 5.1 shows that most of the bores have an evaporation signature dominated by sodium chloride ions similar to that of sea water (Gibbs 1970). Two of the shallow observation bores have lower TDS levels. While originally having a chemical signature similar to rainfall, they are now dominated by bicarbonate, likely to be the result of geological weathering (Gibbs 1970).



Note: The larger the symbol, the higher the level of TDS.

Figure 5.1 Piper diagram of major ions of groundwater from the Gillingarra Palaeochannel

5.3 Hydrogeological cross-sections

There are two cross-sections through the study area and the route of the cross-sections is shown in Figure 5.2.

Figure 5.3 shows a cross-section through the entire study area. It shows the base of the palaeochannel at site 13CP2 and is at 0mAHD. The base of the palaeochannel at site 13CP2 is 86m lower than a drill sample that was assigned to the Leederville Formation at site 13CP4.

Figure 5.4 is a cross-section along a portion of the inferred palaeochannel located on the Darling Range. It shows a groundwater divide, corresponding to the major topographic divide, occurring in the vicinity of sites 13CP1 and 14CP8.

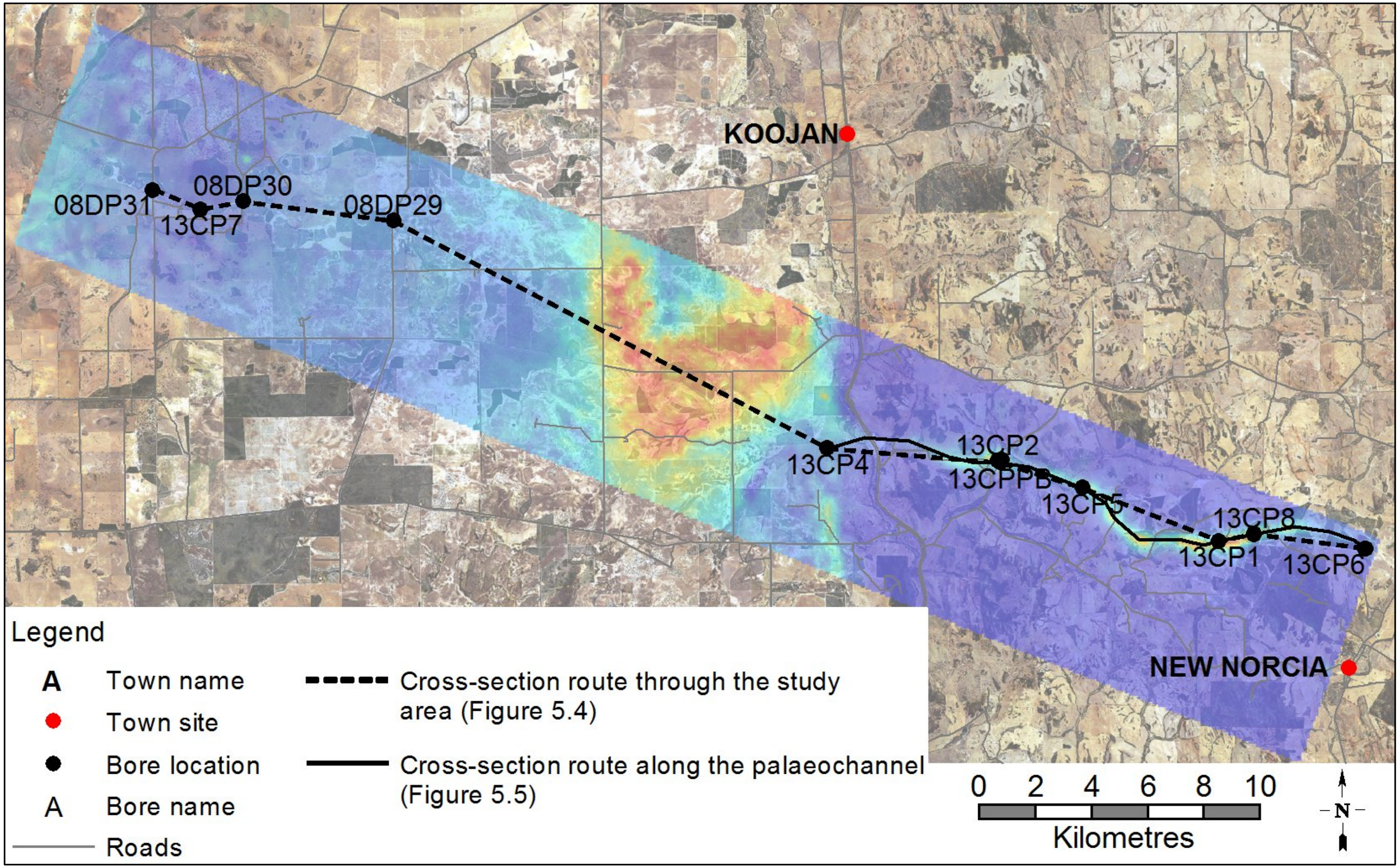


Figure 5.2 Route of cross-sections shown in Figure 5.3 and Figure 5.4

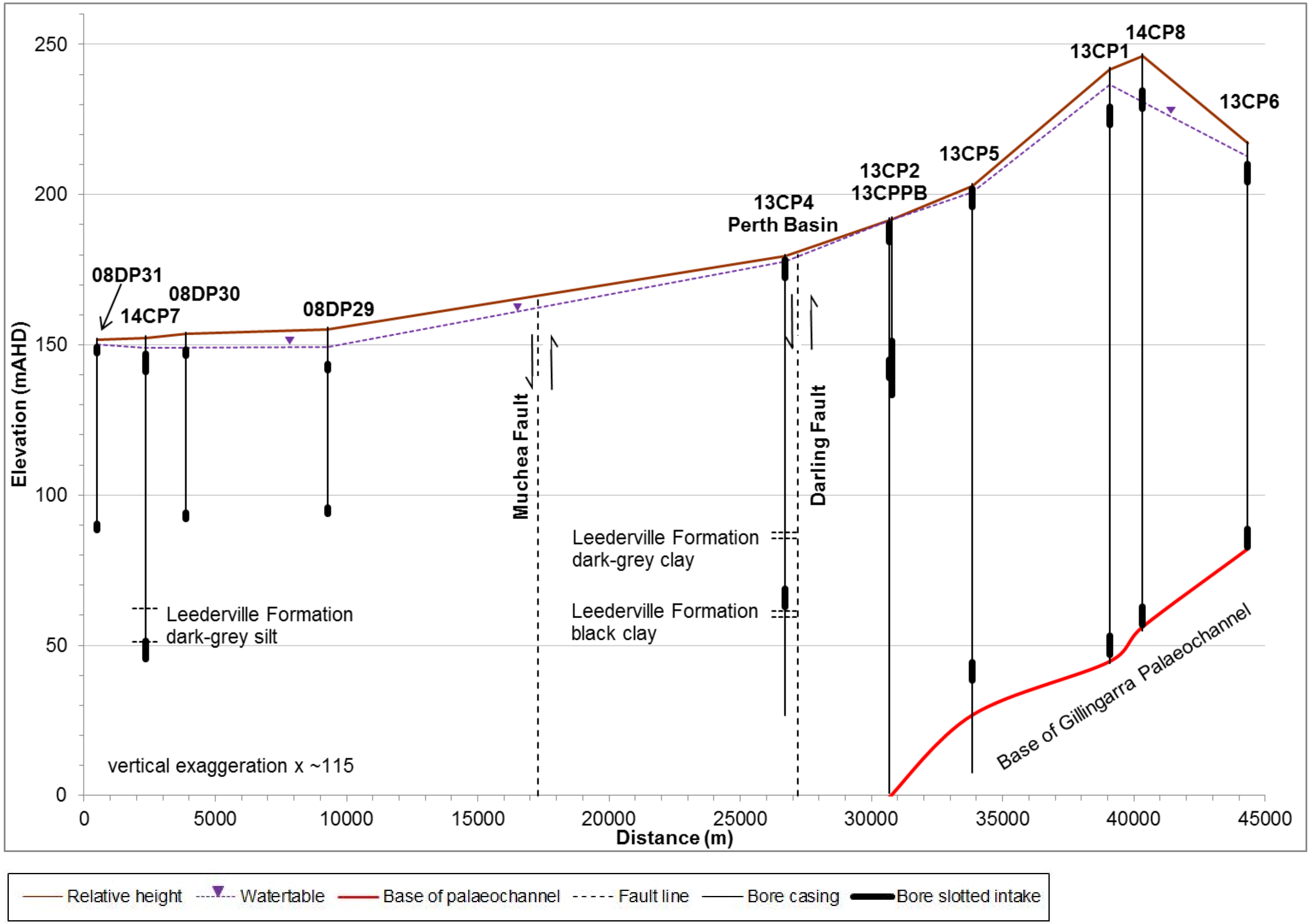


Figure 5.3 Cross-section through the study area showing the relative heights of all drill sites, the base of the Gillingarra Palaeochannel on the Darling Range, and the depths where the results of palynological analysis (Appendix B) confirmed the Leederville Formation

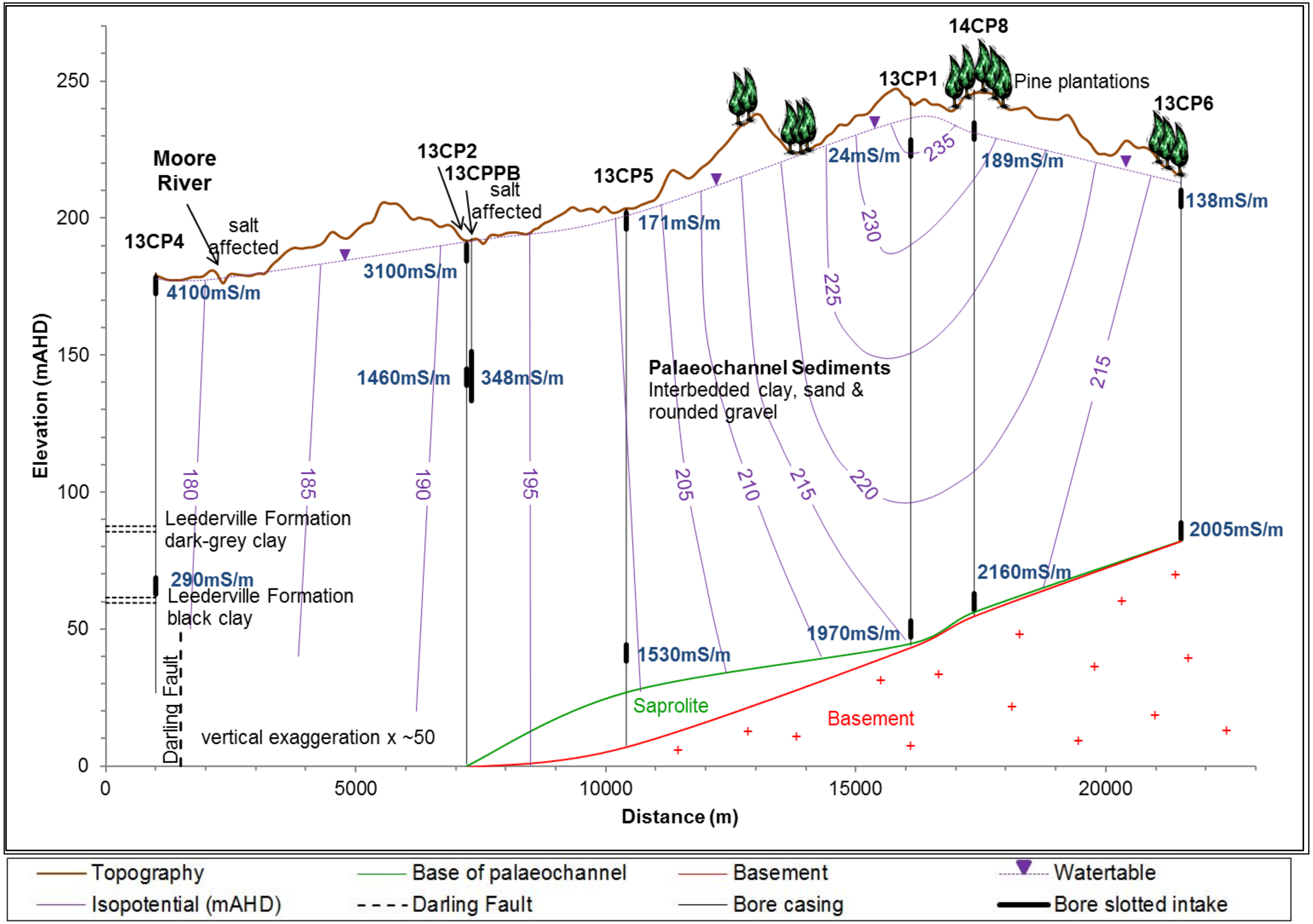


Figure 5.4 Cross-section along the Gillingarra Palaeochannel on the Darling Range

5.4 Test pumping

During the step test, the maximum drawdowns in the monitoring bores were:

- –0.11m in piezometer 13CP2D, which is 110m away from the production bore 13CPPB
- 0.15m in piezometer 13CP3D, which is 103m away from the production bore 13CPPB.

This drawdown in the monitoring bores is negligible compared to the 38.87m drawdown observed in production bore 13CPPB (Figure 5.5).

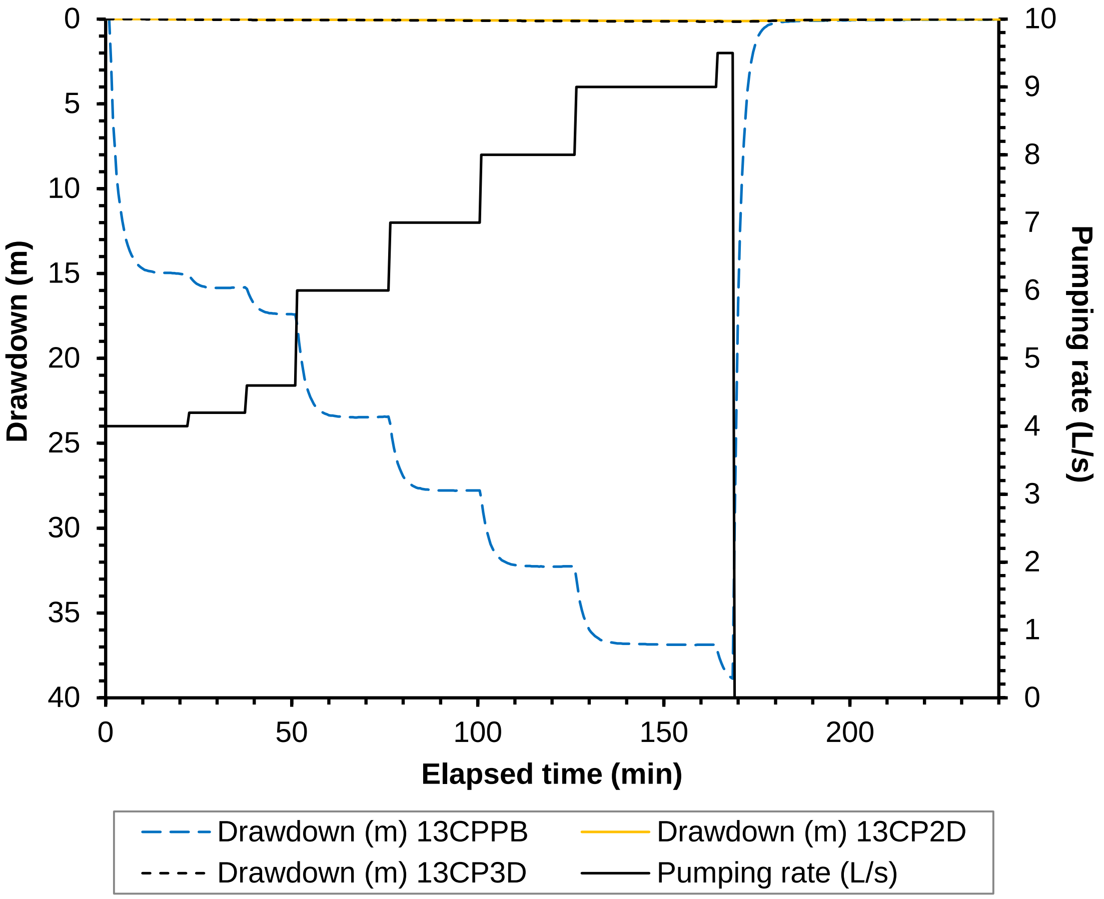


Figure 5.5 Drawdowns recorded during the step test

Towards the end of the CRT, the maximum drawdown observed in the piezometers was 0.24m (13CP2D) and 0.27m (13CP3D), and in the production bore was 32.38m (Figure 5.6).

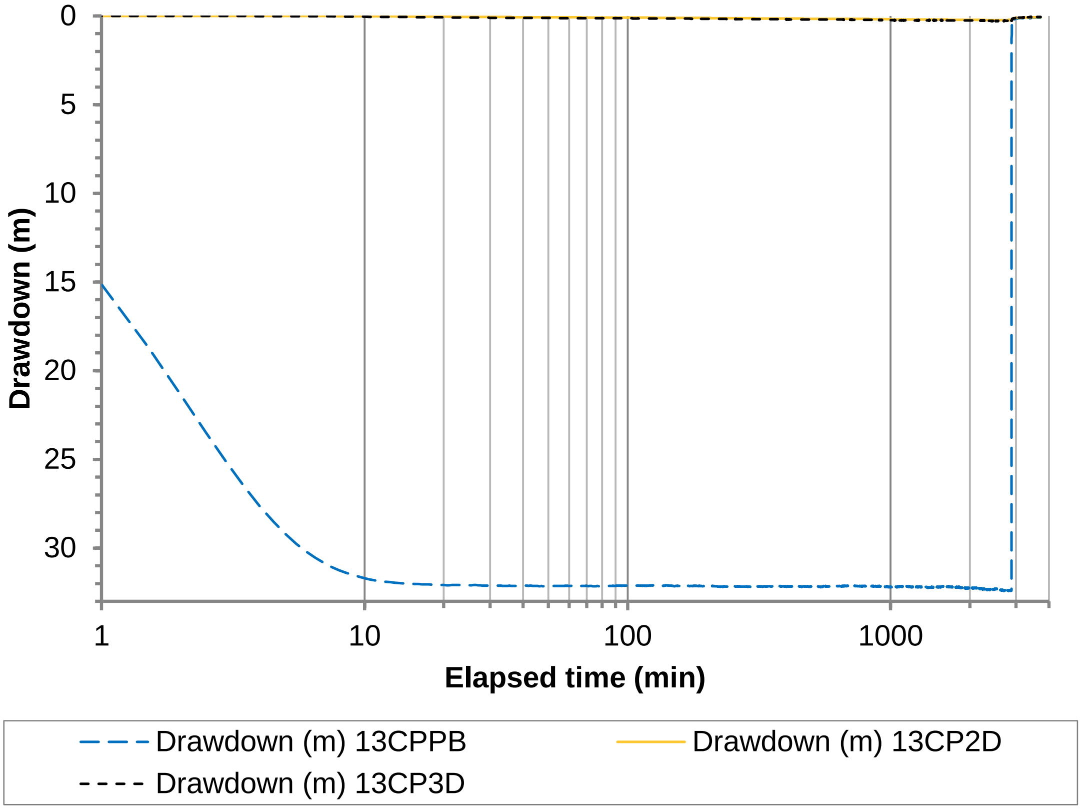


Figure 5.6 Drawdowns recorded during the constant rate test

The step test events, duration, discharge rate and drawdown are presented in Table 5.2 along with the CRT and final recovery phase.

Table 5.2 Test-pumping events and discharge rate

Event	Start time (min)	End time (min)	Duration (min)	Dis-charge rate (L/s)	Drawdown 13CPPB (m)	Drawdown 13CP2D (m)	Drawdown 13CP3D (m)
Step 1	0	22	22	4	15.05	0.02	0.03
Step 2	22.5	37.5	15	4.2	15.82	0.03	0.05
Step 3	38	51	13	4.6	17.40	0.04	0.07
Step 4	51.5	76	24.5	6	23.43	0.06	0.07
Step 5	76.5	100.5	24	7	27.78	0.07	0.10
Step 6	101	126	25	8	32.25	0.09	0.12
Step 7	126.5	164	37.5	9	36.88	0.11	0.15
Step 8	164.5	168.5	4	9.5	38.87	0.11	0.15
Recovery	169	241	72	0	0.02	0.02	0.01
CRT	241.5	3121	2879.5	8	32.38	0.24	0.27
Recovery	3121.5	3962	840.5	0	0.08	0.08	0.06

Water levels in the palaeochannel aquifer were influenced by changes in barometric pressure during the test pumping. Figure 5.7 plots the water levels in the piezometers with barometric pressure for the duration of the test pumping.

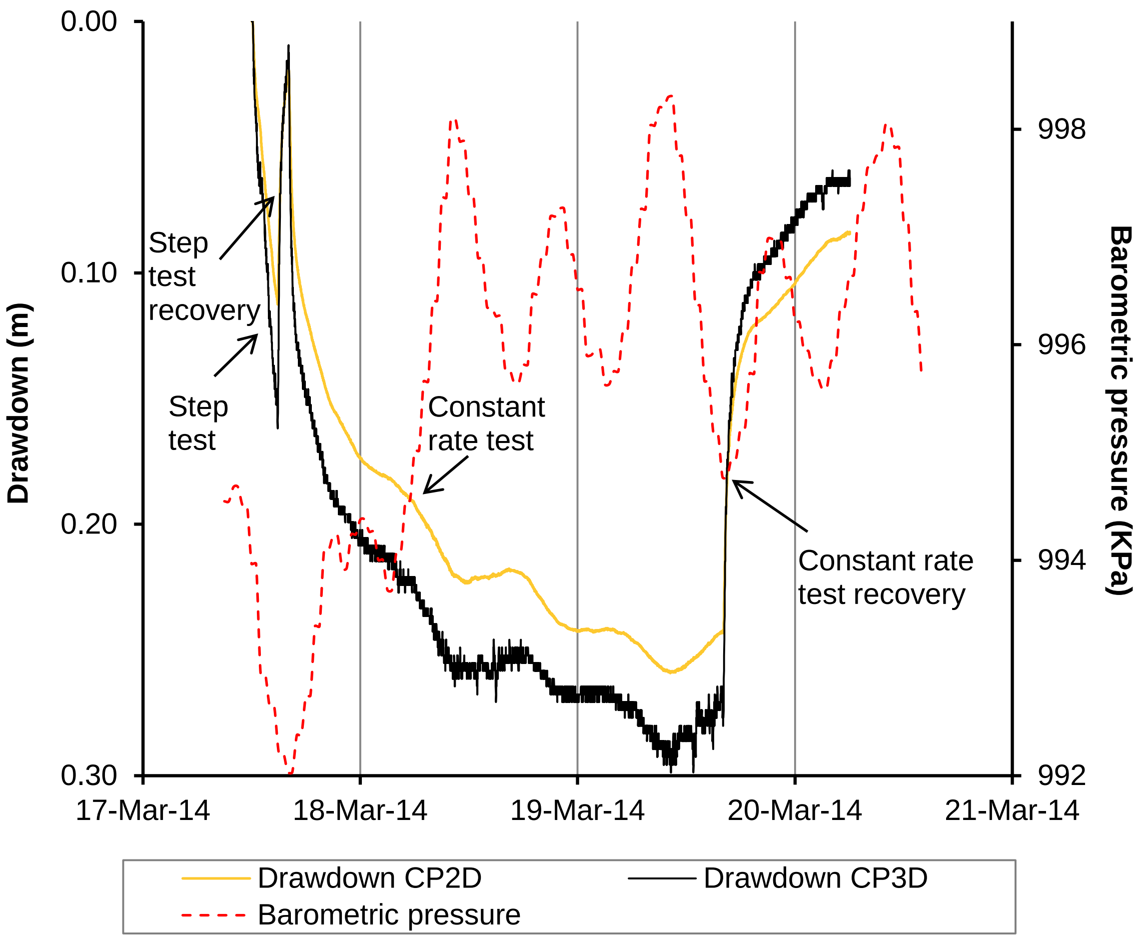


Figure 5.7 Water levels in piezometers 13CP2D and 13CP3D plotted with changes in barometric pressure for the duration of the test pumping

During the test pumping, there was a drawdown of the watertable at the two monitoring sites. At observation bore 13CP2OB, 110m away from the production bore, the watertable was drawn down by up to 0.12m. In observation bore 13CP3OB, 103m away from the production bore, the watertable was drawn down by up to 0.15m. This data is presented in Figure 5.8, without correction for barometric pressure.

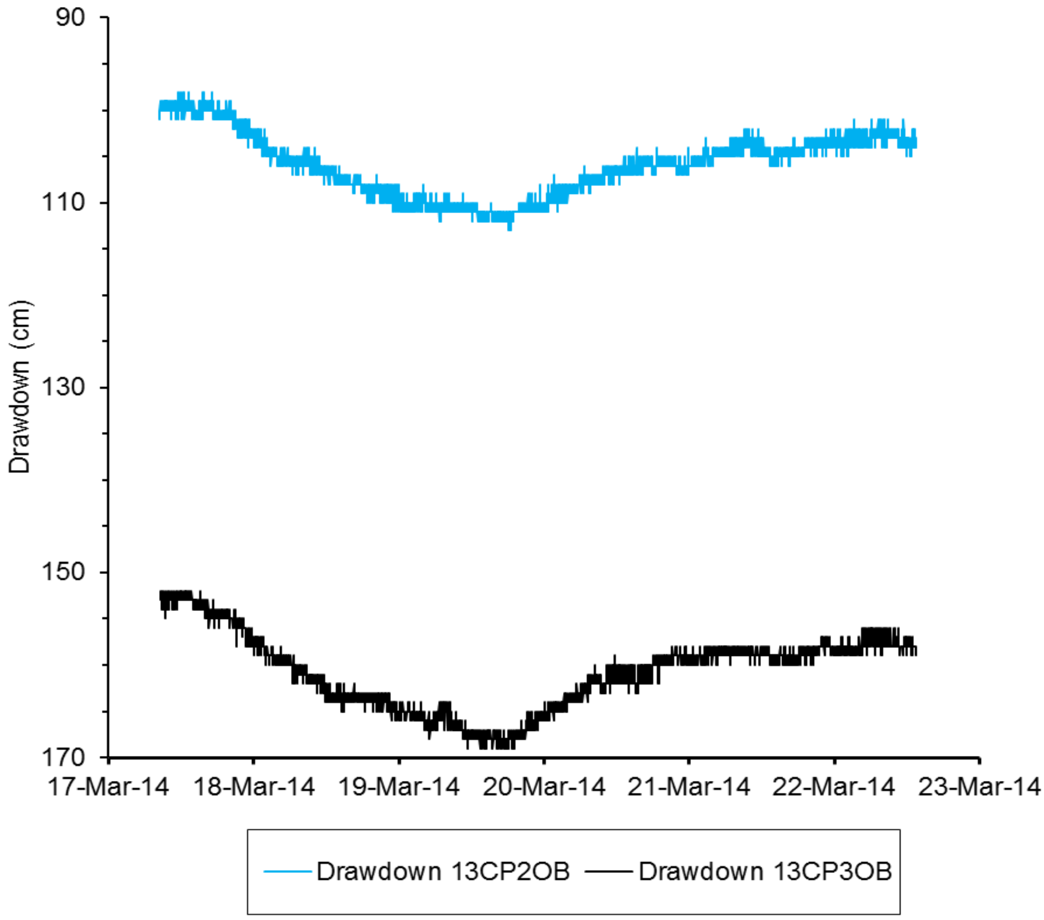


Figure 5.8 Watertable drawdown in observation bores 13CP2OB and 13CP3OB

The test-pumping data was analysed using several methods to estimate the aquifer's parameters. Graphical analyses are presented in Appendix D. The results of the graphical and software analyses are summarised in Table 5.3 and Table 5.4.

Table 5.3 Transmissivity and hydraulic conductivity results from the test-pump analyses

Method	Analysis	Transmissivity (m^2/d)	Hydraulic conductivity (m/d)
Time-drawdown in monitoring bores	Driscoll (1987)	1150	6.0
Residual drawdown plotted against ratio t/t' on semilog for the monitoring bores	Driscoll (1987)	1420	7.5
Residual drawdown plotted against ratio t/t' on semilog for the production bore	Driscoll (1987)	1150	6.0
Theis with Jacob Correction for the monitoring bore 13CP2D step test	Aquifer Test Pro®	1820	9.5
Theis with Jacob Correction for monitoring bore 13CP3D step test	Aquifer Test Pro®	1620	8.5
Theis with Jacob Correction for monitoring bore 13CP2D CRT	Aquifer Test Pro®	1200	6.3
Theis with Jacob Correction for monitoring bore 13CP3D CRT	Aquifer Test Pro	1280	6.6
AGARWAL + Boulton for production bore 13CPPB Constant Rate Recovery	Aquifer Test Pro®	1490	7.7
AGARWAL + Boulton for monitoring bore 13CP2D Constant Rate Recovery	Aquifer Test Pro®	1930	10.0
Theis Unconfined	Aqtesolv®	1386	7.3
Cooper Jacob Unconfined	Aqtesolv®	1513	8.0
Theis Confined	Aqtesolv®	1385	7.3
Average		**1445**	**7.6**

Table 5.4 Coefficient of storage results of the test-pump analyses

Method	Analysis	Storage
Theis with Jacob Correction for monitoring bore 13CP2D step test	Aquifer Test Pro®	0.0014
Theis with Jacob Correction for monitoring bore 13CP3D step test	Aquifer Test Pro®	0.0008
Theis with Jacob Correction for monitoring bore 13CP2D CRT	Aquifer Test Pro®	0.0034
Theis with Jacob Correction for monitoring bore 13CP3D CRT	Aquifer Test Pro®	0.0013
Theis Unconfined	Aqtesolv®	0.008
Cooper Jacob Unconfined	Aqtesolv®	0.0009
Theis Confined	Aqtesolv®	0.008
Average		**0.0034**

6 Discussion

6.1 Two palaeochannels

We collected AEM, stratigraphy, groundwater monitoring and palynology data during this study. The combination of this data strongly indicates that the Capitela Palaeochannel does not extend east of the Darling Fault. It also indicates that extensive palaeochannel sediments identified in this area are from a separate palaeochannel system. We named this the Gillingarra Palaeochannel. Figure 6.1 shows our interpretation of the locations and orientations of the two palaeochannels.

The base of the Gillingarra Palaeochannel appears to be much deeper than the Capitela Palaeochannel. For example, the base of the Gillingarra is 0mAHD at site 13CP2, while the base of the Capitela is above The Leederville Formation at 62mAHD at site 14CP7 (Figure 5.3).

We are unsure if the upper sediments in the area between the Muchea Fault and Darling Fault belong to the Capitela or Gillingarra palaeochannel. However, it seems unlikely that they are associated with either palaeochannel. Palynological analysis of drill cuttings at site 13CP4 indicate that the top of the Leederville Formation is at least 87mAHD (Figure 5.3). Here, if the Gillingarra Palaeochannel was present, we would expect its base to be below 0mAHD, indicating that it is older than the Leederville Formation.

The Gillingarra Palaeochannel appears to be an ancient drainage system that is preserved on the Yilgarn Craton east of the Darling Fault and deeply buried by sediments of the Perth Basin on the western down thrown side of the Darling Fault.

Conversely, the lithological and palynological evidence indicates that the Capitela Palaeochannel is younger than the Leederville Formation and has a much shallower base. For example, the Capitela Palaeochannel has a maximum depth of 90m at site 14CP7 (Figure 5.3).

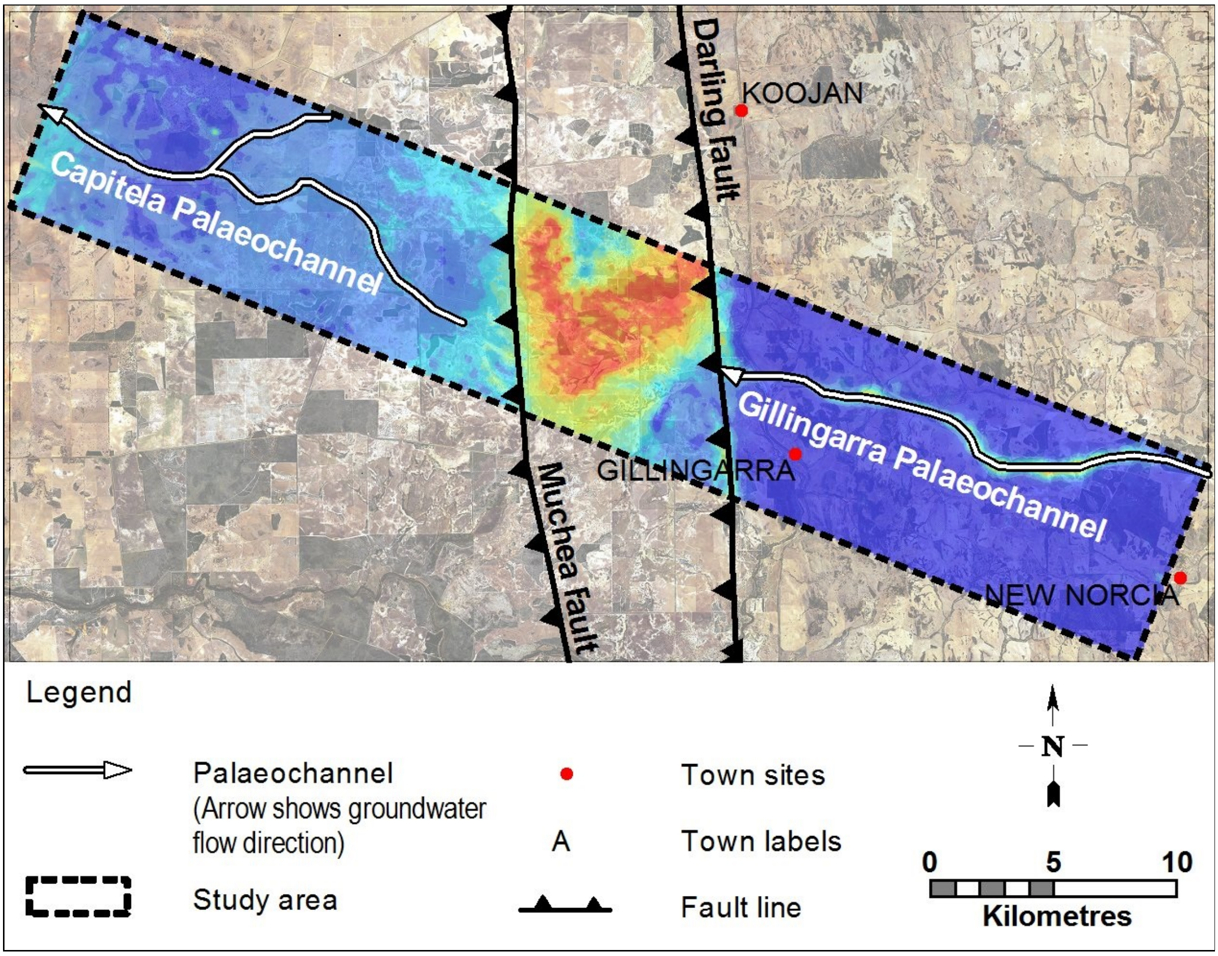


Figure 6.1 Location of the Gillingarra and Capitela palaeochannels in the study area

6.2 Test pumping

The drawdown of the watertable during test pumping indicates that the Gillingarra Palaeochannel aquifer is unconfined. However, subsequent analysis of test-pumping data derived coefficients of storage of 0.0008 to 0.008, which are more indicative of a semi-confined to confined aquifer (Table 5.4).

Changes in barometric pressure can produce fluctuations in piezometers that penetrate confined aquifers. An increase in barometric pressure creates a decline in water levels (Freeze & Cheery 1979). This was evident during our test pumping for piezometers 13CP2D and 13CP3D, which showed enhanced drawdown when barometric pressure was higher (Figure 5.7). Decreases in barometric pressure allowed a slight recovery in water levels and increases in barometric pressure appear to enhance drawdown.

The barometric response observed in the piezometers is consistent with confined aquifers. The resolution of the drawdown of the watertable (Figure 5.8) is not detailed enough to determine if changes in barometric pressure caused fluctuations of the watertable during the test pumping.

The hydraulic conductivity values from the analyses ranged from 6 to 10 metres per day (m/d), with the average being 7.6m/d. This is considered to be mid-range for an unconsolidated, fine to coarse sand aquifer (Driscoll 1987). The average transmissivity

is 1445 square metres per day (m^2/d), which is at the low end for a good aquifer (Freeze & Cherry 1979).

6.3 Groundwater resources

6.3.1 Capitela Palaeochannel

We could not accurately distinguish the dimensions of the Capitela Palaeochannel sediments in the Perth Basin using the results of the AEM survey. Field descriptions of drill cuttings and borehole geophysics methods did not assist in accurately determining the base of the Capitela Palaeochannel sediments. Therefore, it was not possible for us to estimate the magnitude of the groundwater resources in the Capitela Palaeochannel in this study.

6.3.2 Gillingarra Palaeochannel

The dimensions of the Gillingarra Palaeochannel can be more clearly defined from the AEM survey and drilling results. Figure 4.3 shows the conductivity-depth section across the Gillingarra Palaeochannel at the production bore site. It also shows our inferred cross-sectional boundary of the palaeochannel sediments. Here, the palaeochannel sediments are about 190m thick, about 1.18km wide and are fully saturated.

Within the Gillingarra Palaeochannel, the downhole EM39 logs (Appendix A) indicate increased conductivity below about 80m deep at each monitoring site. The EC of groundwater sampled from bores screened at the base of the Gillingarra Palaeochannel exceeds 1500mS/m at all sites (Figure 5.4). Below 80m, the groundwater salinity appears to be too high to be useful for agriculture.

To estimate the total volume of groundwater contained in the Gillingarra Palaeochannel, we derived a cross-sectional area of the palaeochannel, based on a width of 1180m and a depth of 190m (Figure 6.2). The cross-sectional area was calculated to be about 120 000m^2. We also calculated the cross-sectional area of the fresher, potentially useful groundwater — the upper 80m portion — to be about 75 000m^2. When multiplied by the 18km length, the Gillingarra Palaeochannel has an estimated volume of $2.16 \times 10^9 m^3$ at full depth, or $1.35 \times 10^9 m^3$ at 80m.

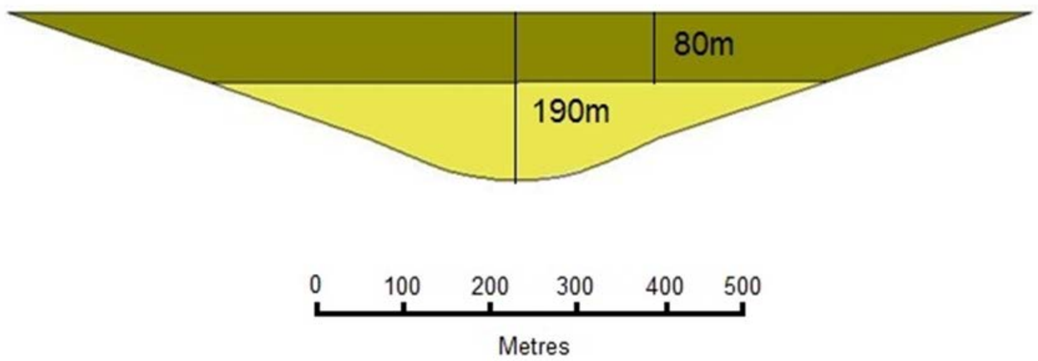


Figure 6.2 Profile shape of the Gillingarra Palaeochannel derived from AEM data

We estimated the water storage in the Gillingarra Palaeochannel by multiplying the average coefficient of storage (0.0034, from Table 5.2) by the estimated volume ($2.16x10^9 m^3$), giving a total of about 7.3GL. However, considering that only the upper 80m contains water that is suitable for agriculture, the volume of fit-for-purpose groundwater is only about 4.6GL.

We then calculated the volume of groundwater available for sustainable abstraction. We assumed that average annual recharge is 10% of the average annual rainfall (400mm). We also assumed that the recharge area corresponds to the areal dimensions of the palaeochannel. Based on these assumptions, the annual volume of average recharge is about 0.85GL/y. However, only a portion of this may be available for abstraction.

6.3.3 Water shortages in the area

In the Gillingarra – New Norcia area, farm water supplies are generally captured via surface run-off into dams. With the adoption of minimum tillage farming techniques and reduced rainfall since 2000, run-off into farm dams has become unreliable, leading to severe on-farm water deficiencies.

Since this study, two private production bores have been constructed in the Gillingarra Palaeochannel, located in unproclaimed groundwater areas. One was constructed between sites 13CP1 and 14CP8 in February 2014. Water from this bore is pumped over the hill to the north to provide for a severely water-deficient property that is remote from the palaeochannel.

The second production bore was constructed east of site 13CP5 in October 2014 by a landholder who is assessing the potential for crop irrigation.

The groundwater resource in the Gillingarra Palaeochannel can provide an important water resource for dryland farming operations in the Gillingarra – New Norcia area. Its importance as a local resource will increase if rainfall continues to decline and reduce the reliability of water resources using surface run-off.

6.4 Salinity

The test-pumping site is in an area of active groundwater discharge where there is an upward piezometric gradient. The watertable seasonally outcrops at the 13CP2 monitoring site (see front cover) and artesian conditions prevail in piezometer 13CP2D. The discharge area has become saline, likely as a result of evaporative concentration, with the EC of near-surface groundwater ranging from 1990 to 3050mS/m (Appendices A and B).

Another area of active groundwater discharge occurs further along the palaeochannel, where the topography is depressed and the watertable intersects the surface (Figure 5.4). At the western edge of this salt-affected area, discharge from the palaeochannel contributes to base flow in the Moore River.

We used Darcy's equation to estimate the volume of water discharging from the end of the Gillingarra Palaeochannel into the Perth Basin sediments:

$Q = K.i.A$

Where:

Q = outflow
K = hydraulic conductivity
i = hydraulic gradient
A = cross-sectional area

Using a hydraulic conductivity value of 7.6m/d (Table 5.3), a gradient of 0.2% (from Table 5.4) and a cross-sectional area of 120 000m^2 (Section 6.3.2), the groundwater through-flow discharging into the Perth Basin is about 0.002GL/d, or 0.7GL/y.

7 Conclusion

Following an AEM survey, an exploratory drilling program and associated groundwater and lithological analysis and interpretation, we discovered a new palaeochannel and named it the Gillingarra Palaeochannel. It is on the Darling Range between New Norcia and Gillingarra and is composed of saturated sedimentary sands which are up to 197m deep, up to 1.18km wide and at least 18km long.

We conservatively estimate that the Gillingarra Palaeochannel contains about 4.6GL of fresh to brackish water, and we estimate the annual recharge to the palaeochannel to be about 0.85GL/y.

This resource could provide a local water supply that can be used for livestock and some other agricultural ventures on the Darling Range, where groundwater resources in the underlying fractured and weathered bedrock are limited. Its importance will increase as rainfall continues to decline and reduce surface water run-off.

Groundwater discharge from the Gillingarra Palaeochannel is causing dryland salinity in the vicinity of Gillingarra–Glentromie Road and Bindoon–Moora Road, before it is likely truncated by the Darling Fault.

The Gillingarra Palaeochannel sediments are much deeper and are likely to be much older than those in the nearby Capitela Palaeochannel, located on the Dandaragan Plateau to the west.

Appendixes

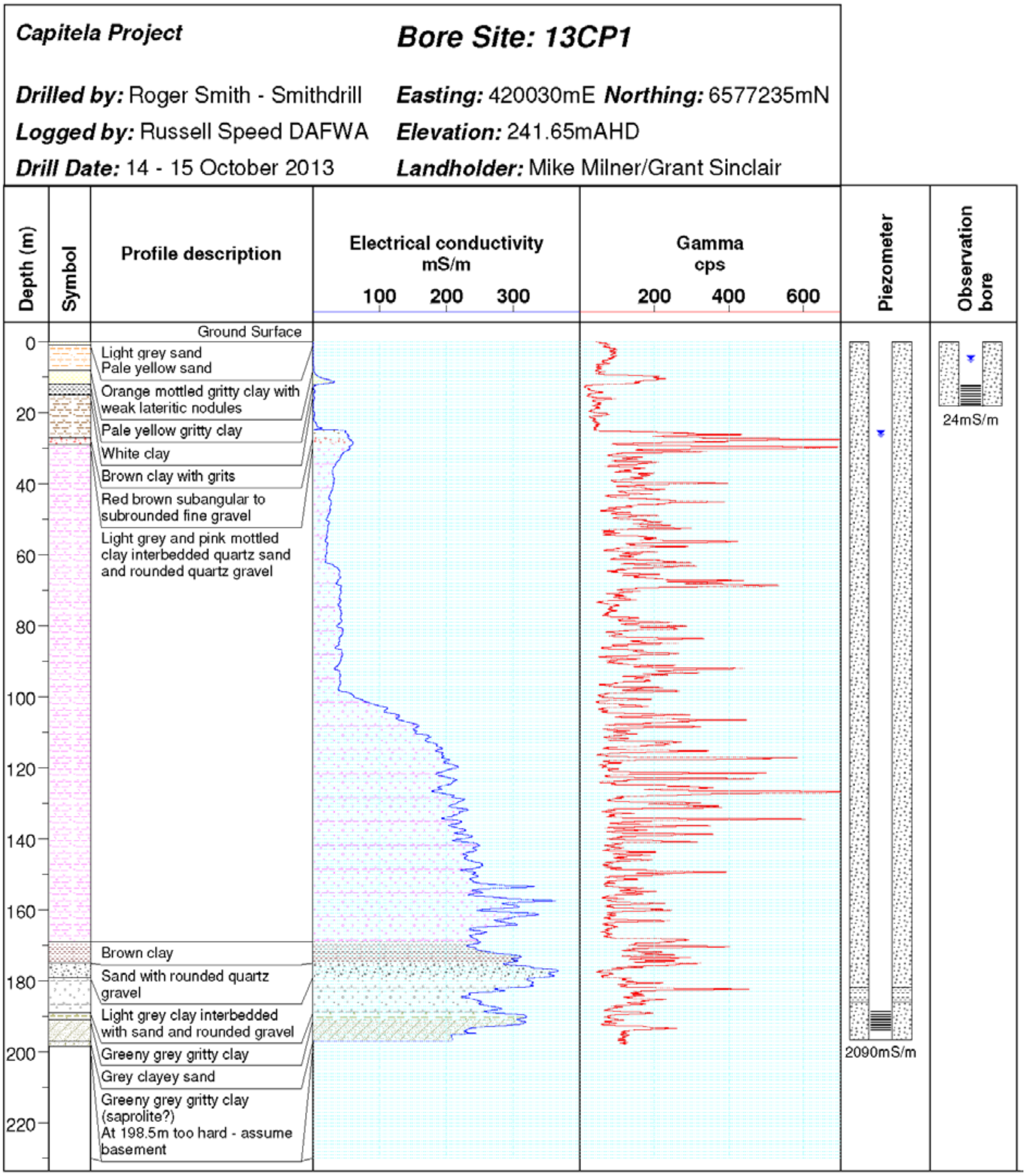
A Drill logs

B Palynology reports

C Water chemistry results

D Test-pumping analyses

Appendix A Drill logs



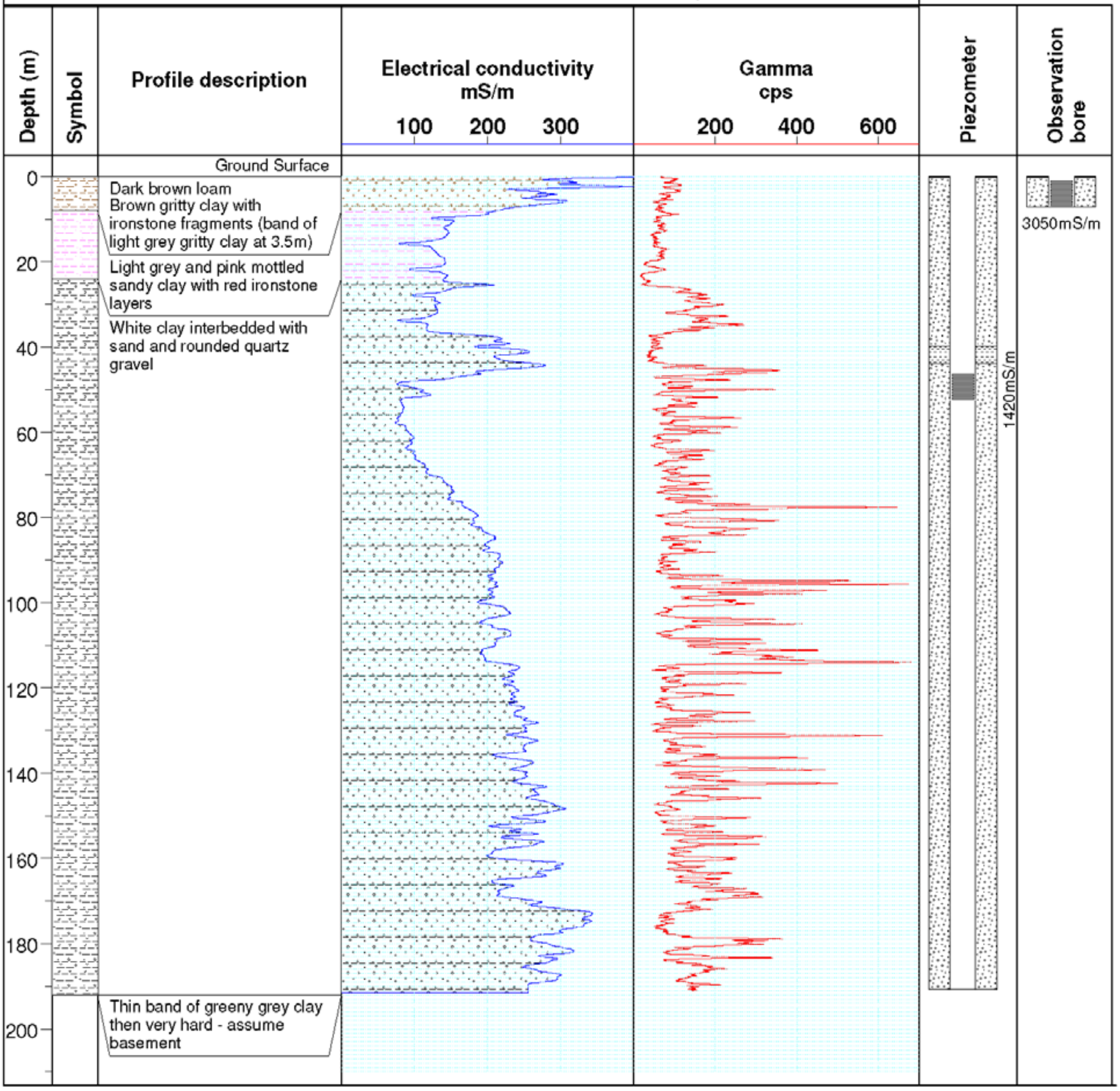
Depth drilled piezometer: 198.5m
Depth drilled observation bore: 18m
Drill method: Mud rotary
Casing type: PN18 50mm uPVC
Casing above ground piezometer: 0.80m
Casing above ground observation bore: 0.80m
Piezometer screen length: 6m
Piezometer screened interval below ground: 188.63-194.63m
Observation bore screen length: 6m

Deep piezometer total casing length: 197.43
Observation bore total casing length: 19.10m
Est. yield piezometer (cubic m/day): 170
Groundwater depth piezometer: 26.05m
Groundwater EC piezometer: 2090mS/m
Groundwater depth observation bore: 5.01m
Groundwater EC observation bore: 24mS/m
Date of groundwater observation: 18 Aug 2014
Date groundwater sampled: 18 Aug 2014

Figure A1 Drill log for bore site 13CP1

Capitela Project | **Bore Site: 13CP2**

Drilled by: Roger Smith - Smithdrill
Logged by: Russell Speed DAFWA
Drill Date: 16 - 17 October 2013
Easting: 412143mE ***Northing:*** 6580086mN
Elevation: 191.43mAHD
Landholder: Shane Kelly

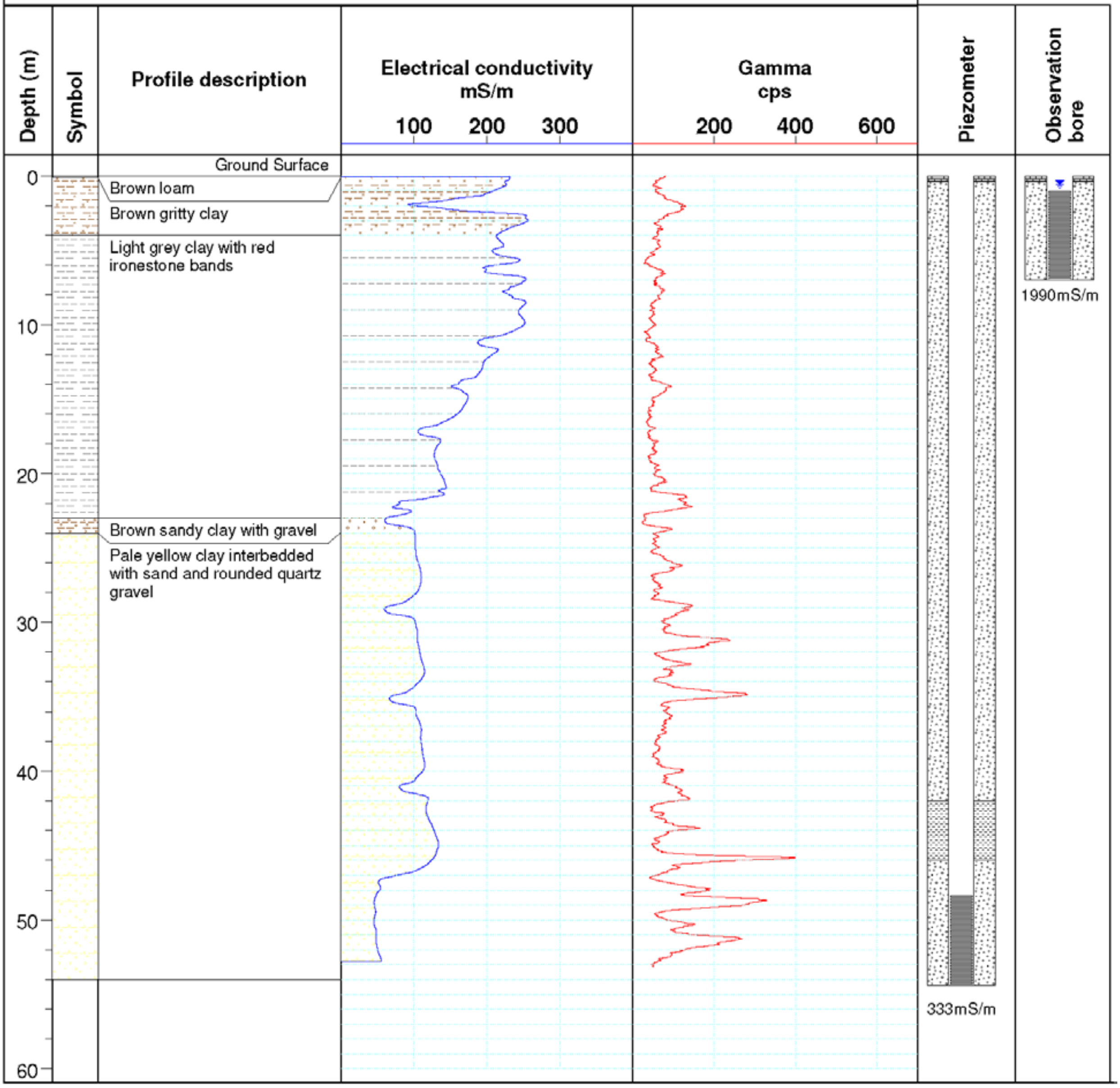


Depth drilled piezometer: 192m
Depth drilled observation bore: 7m
Drill method: Mud rotary
Casing type: PN18 50mm uPVC
Casing above ground piezometer: 0.70m
Casing above ground observation bore: 0.77m
Piezometer screen length: 6m
Piezometer screened interval below ground: 46.50 - 52.50m
Observation bore screen length: 6m
Deep piezometer total casing length: 191.44m
Observation bore total casing length: 7.89m
Est. yield piezometer (cubic m/day): 150
Groundwater depth piezometer: +0.40m
Groundwater EC piezometer: 1420mS/m
Groundwater depth observation bore: +0.01m
Groundwater EC observation bore: 3050mS/m
Date of groundwater observation: 19 Aug 2014
Date groundwater sampled: 19 Aug 2014

Figure A2 Drill log for bore site 13CP2

Capitela Project | ***Bore Site: 13CP3***

Drilled by: Roger Smith - Smithdrill | ***Easting:*** 412289mE ***Northing:*** 6580117mN
Logged by: Russell Speed DAFWA | ***Elevation:*** 192.49mAHD
Drill Date: 28 October 2013 | ***Landholder:*** Shane Kelly



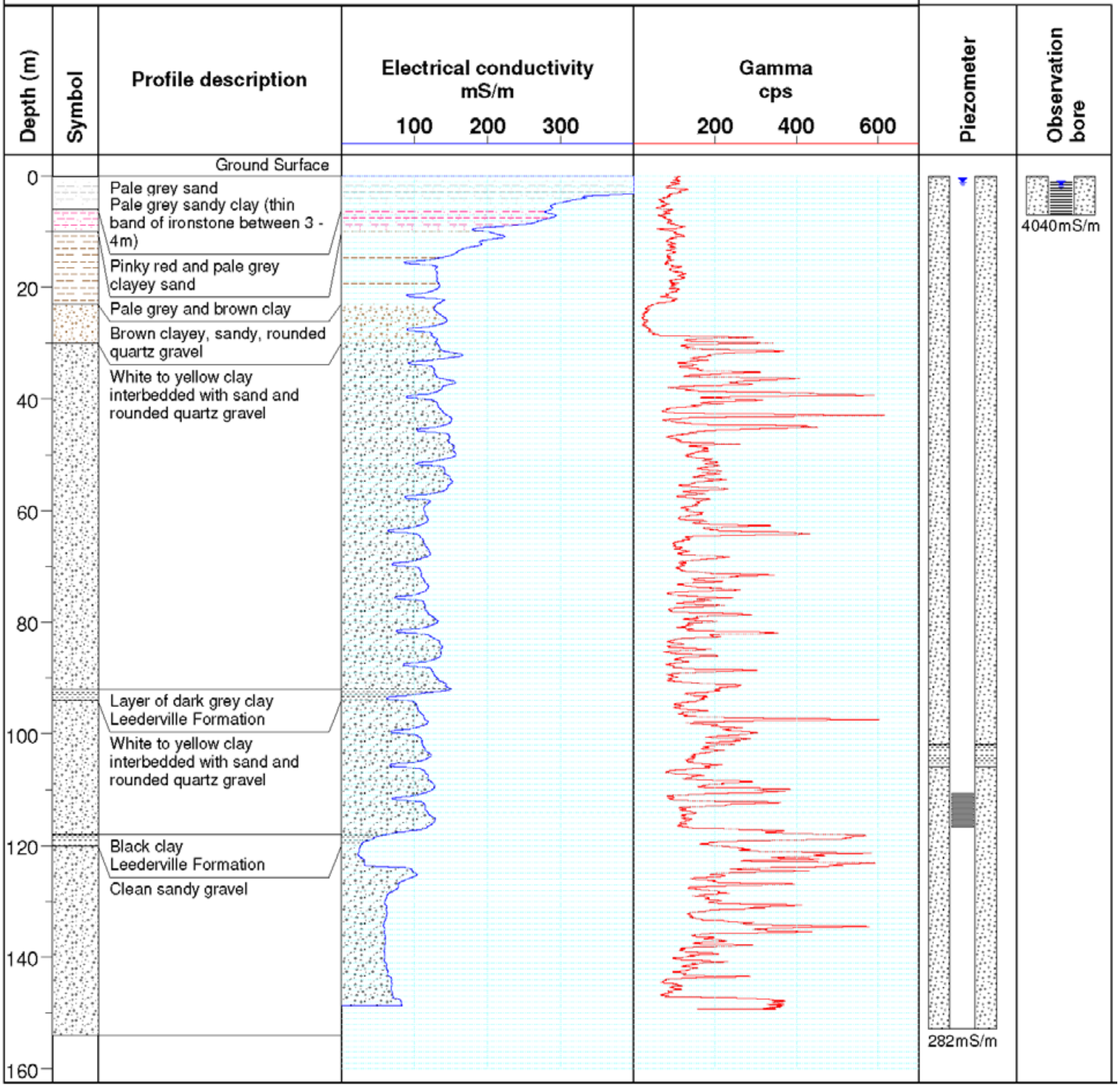
Depth drilled piezometer: 54m
Depth drilled observation bore: 7m
Drill method: Mud rotary
Casing type: PN18 50mm uPVC
Casing above ground piezometer: 0.65m
Casing above ground observation bore: 0.65m
Piezometer screen length: 6m
Piezometer screened interval below ground: 48.40 - 54.40m
Observation bore screen length: 6m

Deep piezometer total casing length: 55.05
Observation bore total casing length: 7.69
Est. yield piezometer (cubic m/day): 130
Groundwater depth piezometer: 0.26m
Groundwater EC piezometer: 333mS/m
Groundwater depth observation bore: 0.59m
Groundwater EC observation bore: 1990mS/m
Date of groundwater observation: 18 Aug 2014
Date groundwater sampled: 18 Aug 2014

Figure A3 Drill log for bore site 13CP3

Capitela Project | ***Bore Site: 13CP4***

Drilled by: Roger Smith - Smithdrill | ***Easting:*** 406087mE ***Northing:*** 6580538mN
Logged by: Russell Speed DAFWA | ***Elevation:*** 179.50mAHD
Drill Date: 28 - 29 October 2013 | ***Landholder:*** Brian Kelly



Depth drilled piezometer: 154m
Depth drilled observation bore: 7m
Drill method: Mud rotary
Casing type: PN18 50mm uPVC
Casing above ground piezometer: 0.65m
Casing above ground observation bore: 0.62m
Piezometer screen length: 6m
Piezometer screened interval below ground: 110.80 - 116.80m
Observation bore screen length: 6m

Deep piezometer total casing length: 153.51m
Observation bore total casing length: 7.73m
Est. yield piezometer (cubic m/day): 400
Groundwater depth piezometer: 1.16m
Groundwater EC piezometer: 282mS/m
Groundwater depth observation bore: 1.70m
Groundwater EC observation bore: 4040mS/m
Date of groundwater observation: 20 Aug 2014
Date groundwater sampled: 20 Aug 2014

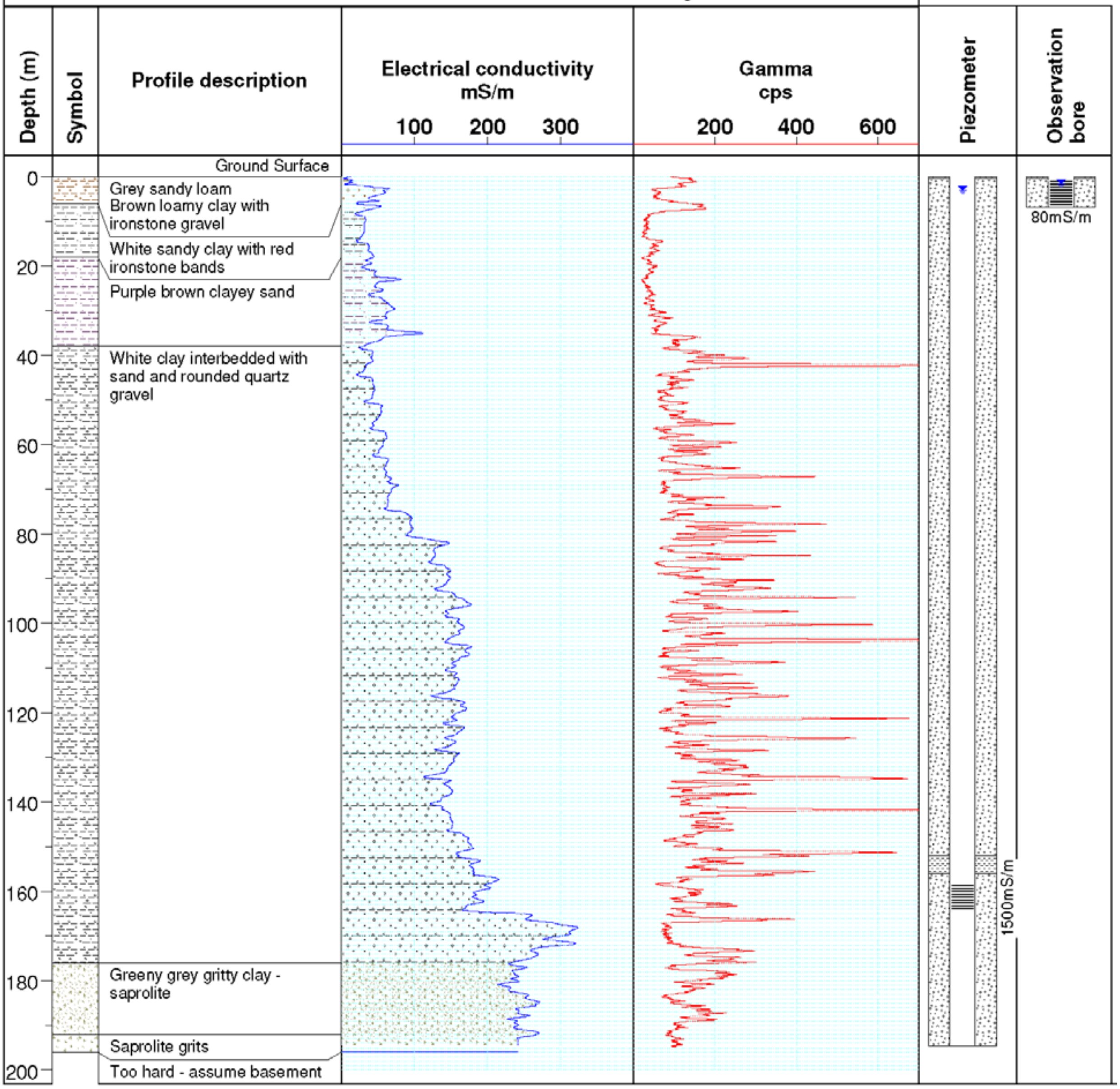
Figure A4 Drill log for bore site 13CP4

Capitela Project | ***Bore Site: 13CP5***

Drilled by: Roger Smith - Smithdrill | ***Easting:*** 415163mE ***Northing:*** 6579134mN

Logged by: Russell Speed DAFWA | ***Elevation:*** 202.87mAHD

Drill Date: 30 - 31 October 2014 | ***Landholder:*** Bruce Maguire



Depth drilled piezometer: 196m
Depth drilled observation bore: 7m
Drill method: Mud rotary
Casing type: PN18 50mm uPVC
Casing above ground piezometer: 0.70m
Casing above ground observation bore: 0.72m
Piezometer screen length: 6m
Piezometer screened interval below ground: 158.60 - 164.60m
Observation bore screen length: 6m

Deep piezometer total casing length: 195.35m
Observation bore total casing length: 7.65m
Est. yield piezometer (cubic m/day): n/a
Groundwater depth piezometer: 3.04m
Groundwater EC piezometer: 1500mS/m
Groundwater depth observation bore: 1.60m
Groundwater EC observation bore: 80mS/m
Date of groundwater observation: 19 Aug 2014
Date groundwater sampled: 19 Aug 2014

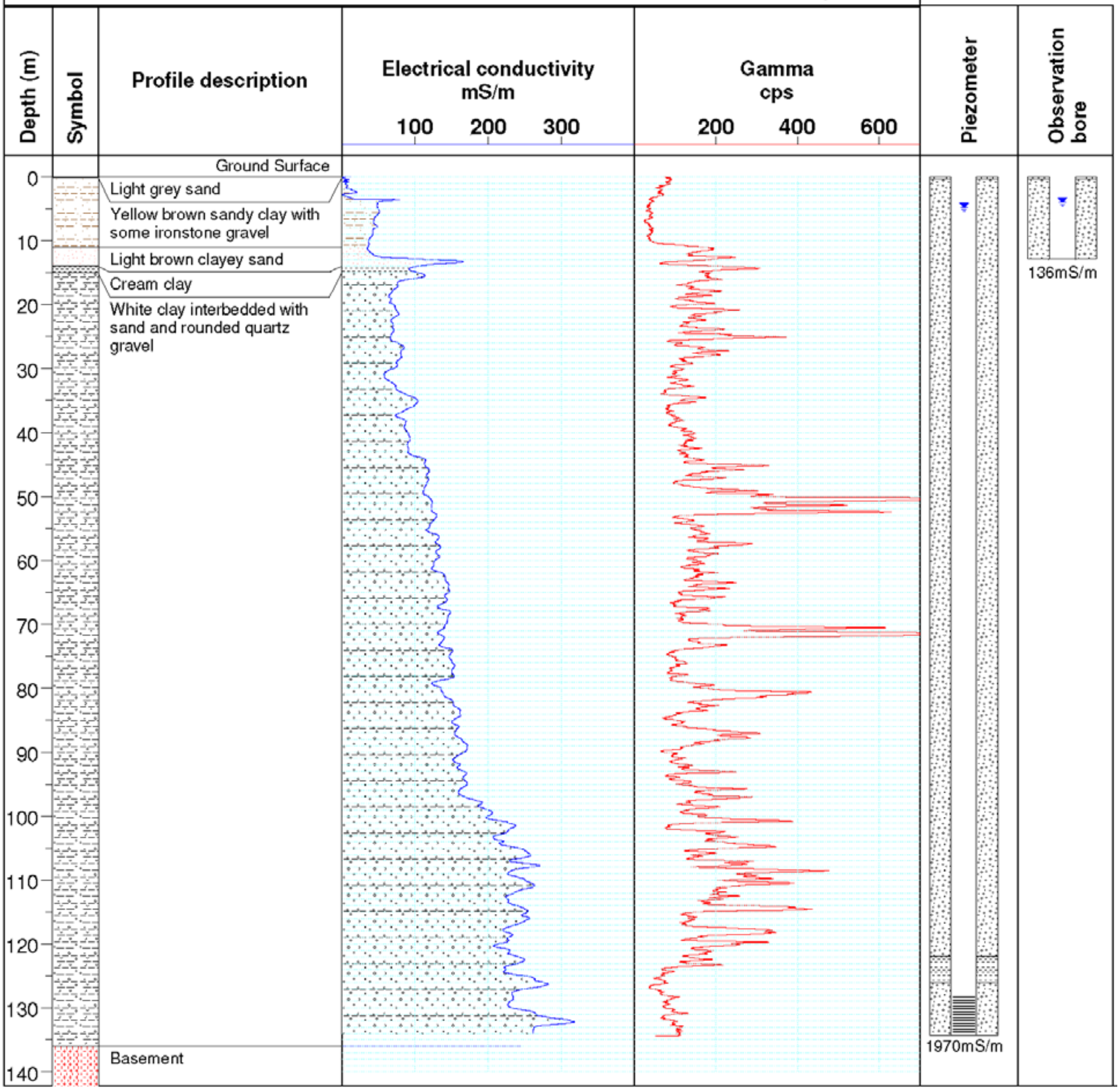
Figure A5 Drill log for bore site 13CP5

Capitela Project | ***Bore Site: 13CP6***

Drilled by: Roger Smith - Smithdrill | ***Easting:*** 425232mE ***Northing:*** 6576960mN

Logged by: Grant Stainer DAFWA | ***Elevation:*** 217.10m

Drill Date: 4 November 2013 | ***Landholder:*** Benedictine Community



Depth drilled piezometer: 135m	**Deep piezometer total casing length:** 134.90m
Depth drilled observation bore: 13m	**Observation bore total casing length:** 13.54m
Drill method: Mud rotary	**Est. yield piezometer (cubic m/day):** n/a
Casing type: PN18 50mm uPVC	**Groundwater depth piezometer:** 4.81m
Casing above ground piezometer: 0.60m	**Groundwater EC piezometer:** 1970mS/m
Casing above ground observation bore: 0.61m	**Groundwater depth observation bore:** 4.02m
Piezometer screen length: 6m	**Groundwater EC observation bore:** 136mS/m
Piezometer screened interval below ground: 128.30 - 134.30m	**Date of groundwater observation:** 19 Aug 2013
Observation bore screen length: 6m	**Date groundwater sampled:** 19 Aug 2013

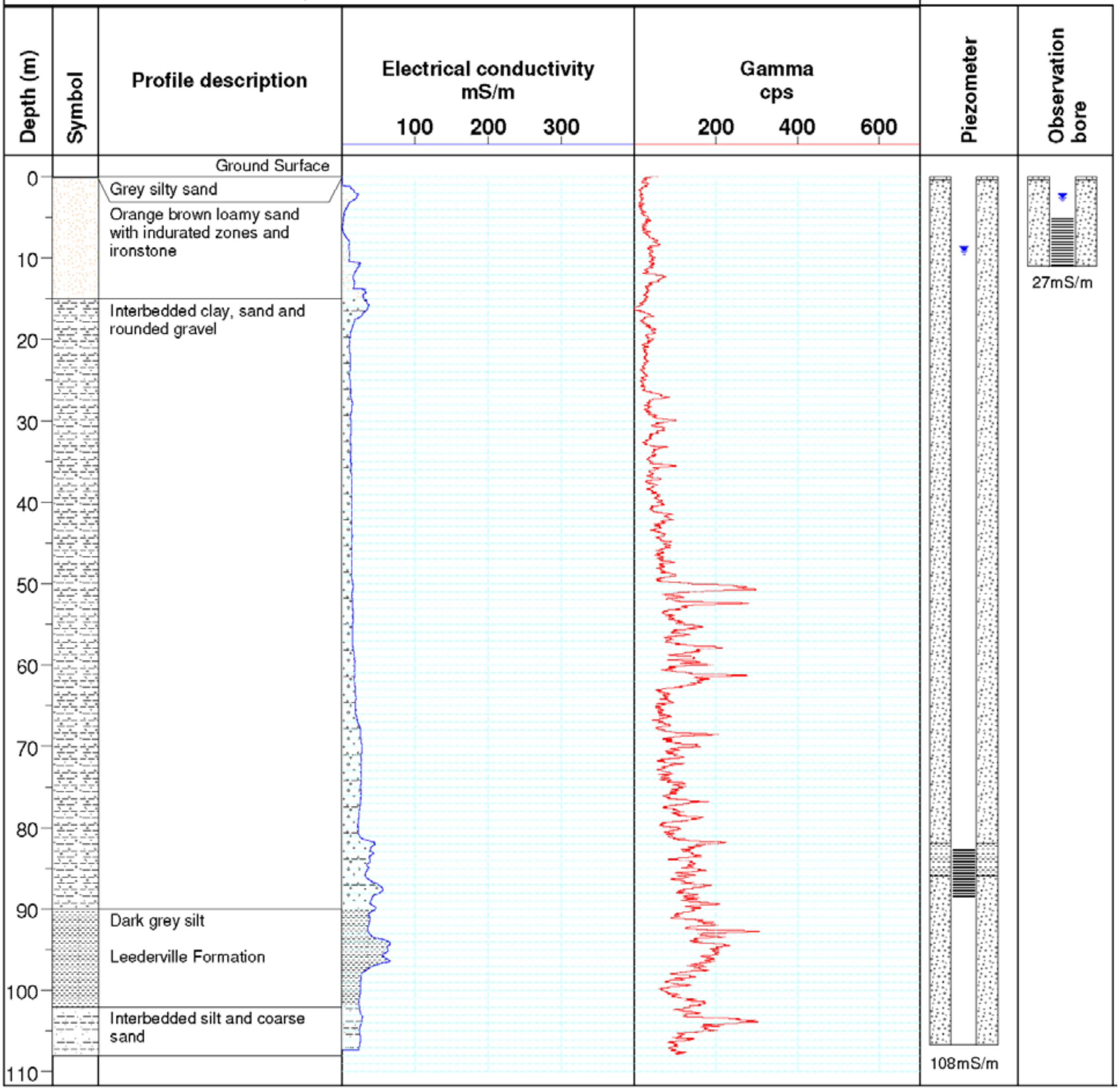
Figure A6 Drill log for bore site 13CP6

Capitela Project ***Bore Site: 14CP7***

Drilled by: Roger Smith - Smithdrill ***Easting:*** 383790mE ***Northing:*** 6589045mN

Logged by: Russell Speed DAFWA ***Elevation:*** 152.21mAHD

Drill Date: 18 - 19 February 2014 ***Landholder:*** David Brown



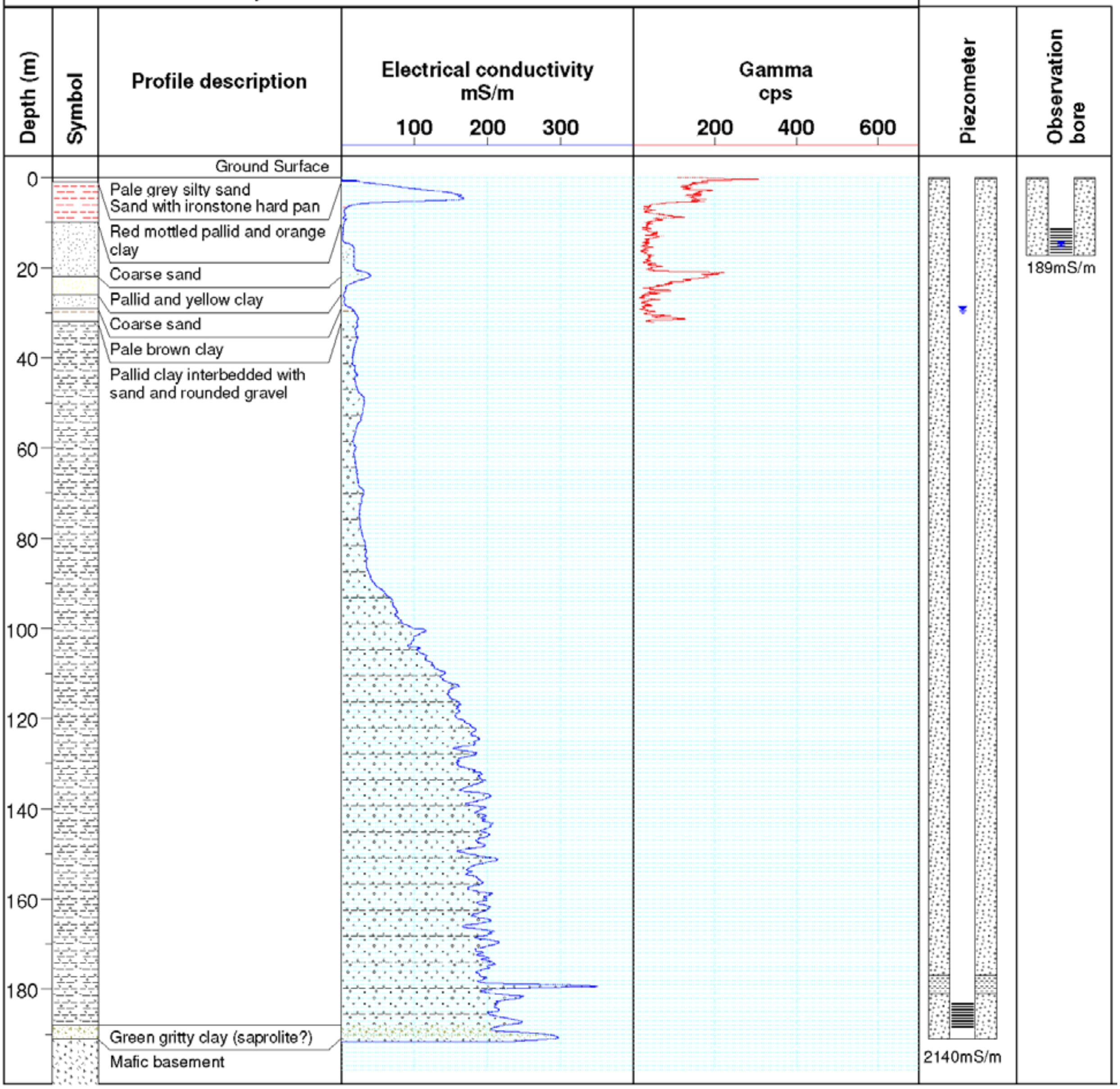
Depth drilled piezometer: 108m
Depth drilled observation bore: 12m
Drill method: Mud rotary
Casing type: PN18 50mm uPVC
Casing above ground piezometer: 0.85m
Casing above ground observation bore: 0.88m
Piezometer screen length: 6m
Piezometer screened interval below ground: 82.67 - 88.67m
Observation bore screen length: 6m

Deep piezometer total casing length: 107.55m
Observation bore total casing length: 11.94m
Est. yield piezometer (cubic m/day): 40
Groundwater depth piezometer: 9.10m
Groundwater EC piezometer: 108mS/m
Groundwater depth observation bore: 2.56m
Groundwater EC observation bore: 27mS/m
Date of groundwater observation: 20 Aug 2014
Date groundwater sampled: 20 Aug 2014

Figure A7 Drill log for bore site 14CP7

Capitela Project | ***Bore Site: 14CP8***

Drilled by: Roger Smith - Smithdrill
Logged by: Russell Speed DAFWA
Drill Date: 20 February
Easting: 421258mE ***Northing:*** 6577479mN
Elevation: 246.13mAHD
Landholder: Mike Milner/Grant Sinclair



Depth drilled piezometer: 191.5m
Depth drilled observation bore: 18m
Drill method: Mud rotary
Casing type: PN18 50mm uPVC
Casing above ground piezometer: 0.76m
Casing above ground observation bore: 0.84m
Piezometer screen length: 6m
Piezometer screened interval below ground: 183.17 - 189.17m
Observation bore screen length: 6m

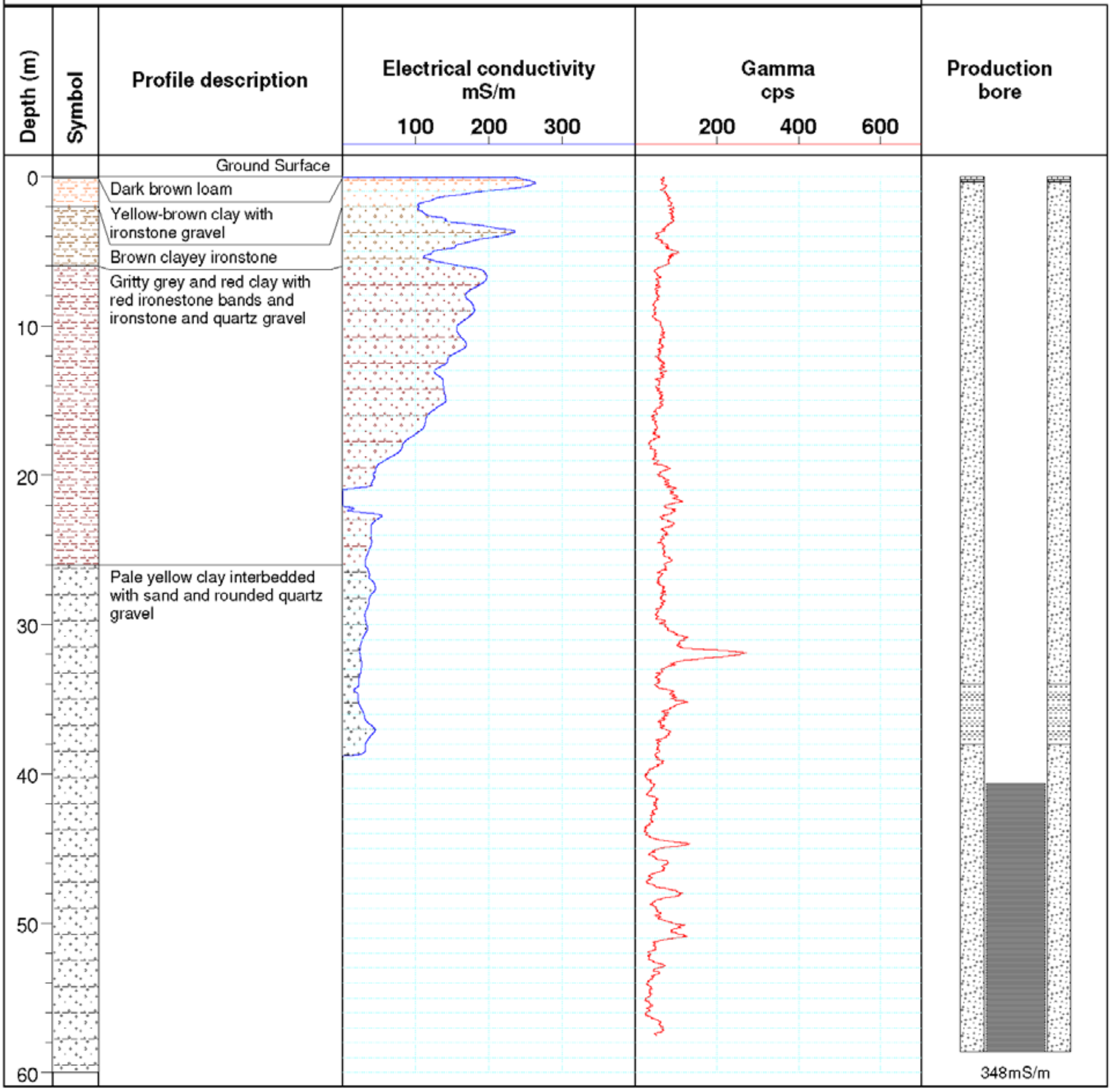
Deep piezometer total casing length: 191.93m
Observation bore total casing length: 18.23m
Est. yield piezometer (cubic m/day): n/a
Groundwater depth piezometer: 29.84m
Groundwater EC piezometer: 2140mS/m
Groundwater depth observation bore: 15.07m
Groundwater EC observation bore: 189mS/m
Date of groundwater observation: 19 Aug 2014
Date groundwater sampled: 19 Aug 2014

Figure A8 Drill log for bore site 14CP8

Capitela Project **Bore Site: 13CPPB**

Drilled by: Roger Smith - Smithdrill
Logged by: Grant Stainer DAFWA
Drill Date: 21 October 2013

Easting: 412237mE ***Northing:*** 6580028mN
Elevation: 191.95mAHD
Landholder: Shire of Victoria Plains



Depth drilled: 60m
Drill method: Mud rotary
Blank casing type: PN12 200mm uPVC
Casing above ground: 0.65m
Screen type: Stainless steel
Screen length: 18m
Screen slots upper: 0.5mm over upper 6m
Screen slots lower: 0.6mm over lower 12m
Screened interval below ground: 40.64 - 58.64m

Production bore total casing length: 59.29m
Production bore headworks: Steel set in cement
Production bore development: 3 days airlift with drill stem
Estimated yield (cubic m/day): 520
Groundwater depth: +0.17m
Groundwater conductivity: 348mS/m
Groundwater pH: 5.68
Date of groundwater observation: 19 Aug 2014
Date groundwater sampled: 19 Aug 2014

Figure A9 Drill log for bore site 13CPPB

Appendix B Palynology reports

Backhouse Biostrat Pty Ltd

Report BB460

Palynology results of 1 sample from 13CP7 borehole

by

John Backhouse

Prepared for

Department of Agriculture and Food **August 2014**

BB460: Palynology results of 1 sample from 13CP7 borehole

Summary of results

Sample no.	Borehole	Depth (m)	Palynological Zone	Age	Suggested unit
6	13CP7	98–99	Probably B. limbata*	Late Valanginian to Aptian	Probably Leederville Formation

* Spore-pollen zone

INTRODUCTION

Location Site 14CP7, Depth 98–99m, Perth Basin, Bidgerabbie. Top of Leederville 383790mE, 6589045mN, 153.06mAHD (Top of Casing) Zone 50 GDA94

Appendix Range chart as an Excel table.

PALYNOLOGY

13CP4, 2 samples

Yield: High.

Zone: As with the 13CP4 samples, there is a lack of index spore-pollen species and no dinocysts. The assemblage is quite rich with moderate diversity and is dominated by *Corollina torosa, Cyatidites* spp. and saccate pollen. The comments in report BB459 on 13CP4 apply to this sample, i.e. the diverse spore associations associated with the *B. eneabbaensis* Zone (=Parmelia Group) are not seen. The sample is assigned to the *Balmeiopsis limbata* Spore-pollen zone of Backhouse (1988), although the index species for this zone was not seen.

Stratigraphic unit: This zone is present in the Warnbro Group and may extend into the Late Aptian. Therefore, the samples are tentatively placed in the Leederville Formation.

REFERENCES

Backhouse, J 1988, ‘Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia’, Geol. Survey W. A. Bulletin 135, 233p.

Backhouse Biostrat Pty Ltd

Report BB459

Palynology results of 2 samples from 13CP4 borehole

by

John Backhouse

Prepared for

Department of Agriculture and Food **August 2014**

BB459: Palynology results of 2 samples from 13CP4 borehole

Summary of results

Sample No.	Borehole	Depth (m)	Palynological Zone	Age	Suggested unit
1	13CP4	92-94	Probably B. limbata*	Late Valanginian to Aptian	Probably Leederville Formation
2	13CP4	118-119	Probably B. limbata*	Late Valanginian to Aptian	Probably Leederville Formation

*** Spore-pollen zone**

INTRODUCTION

Location Perth Basin Gillingarra area. Samples 1 & 2: 13CP4 406087.37 mE 6580538.47 mN 180.15 m AHD (Top of casing) Zone 50 GDA94 (Casing above ground = 0.65 m)

Appendix Range chart as an Excel table.

PALYNOLOGY

13CP4, 2 samples

Yield. High. The higher sample gave a very low yield, but the yield from the lower sample was moderate.

Zone. Both samples lack index spore-pollen species and are devoid of dinocysts. The assemblages of both samples are dominated by Corollina torosa and saccate pollen. The diverse spore associations associated with the B. eneabbaensis Zone (=Parmelia Group) are not seen. The absence of dinocysts and spores associated with the Albian and younger strata are also not seen. Therefore, an assignment to the Balmeiopsis limbata Spore-pollen zone of Backhouse (1988) is favoured on largely negative evidence.

Stratigraphic unit. This zone is present in the Warnbro Group and may extend into the Late Aptian. However, it seems unlikely, based on the absence of marine indicators, that this interval is Late Aptian in age or belongs in the lower part of the Warnbro Group. Therefore, the samples are tentatively placed in the Leederville Formation.

REFERENCES

Backhouse, J., 1988, Late Jurassic and Early Cretaceous palynology of the Perth Basin, Western Australia. Geol. Survey W. A. Bulletin 135, 233p.

Appendix C Water chemistry results

Table C1 Details about the different parameters analysed in this study

Symbol	Parameter	Method code	Limit of reporting	Units
Acidity	acidity	iACID1WATI	2	mg/L
Ag	silver	iMET1WCMS	0.0001	mg/L
Al	aluminium	iMET1WCICP	0.005	mg/L
Alkalin	alkalinity	iALK1WATI	1	mg/L
As	arsenic	iMET1WCMS	0.001	mg/L
B	boron	iMET1WCICP	0.02	mg/L
Ba	barium	iMET1WCMS	0.0001	mg/L
Be	beryllium	iMET1WCMS	0.0001	mg/L
Bi	bismuth	iMET1WCMS	0.0001	mg/L
Br	bromide	iBRLOW1WAIC	0.02	mg/L
CO_3	carbonate	iALK1WATI	1	mg/L
Ca	calcium	iMET1WCICP	0.1	mg/L
Cd	cadmium	iMET1WCMS	0.0001	mg/L
Cl	chloride	iCO1WCDA	1	mg/L
Co	cobalt	iMET1WCMS	0.0001	mg/L
Cr	chromium	iMET1WCMS	0.0005	mg/L
Cu	copper	iMET1WCMS	0.0001	mg/L
ECond	electrical conductivity	iEC1WZSE	0.2	mS/m
F	fluoride	iF1WASE	0.05	mg/L
Fe	iron	iMET1WCICP	0.005	mg/L
Ga	gallium	iMET1WCMS	0.0001	mg/L
HCO_3	bicarbonate	iALK1WATI	1	mg/L
Hardness	hardness	iHTOT2WACA	1	mg/L
Hg	mercury	iHGL1WCVG	0.00005	mg/L
K	potassium	iMET1WCICP	0.1	mg/L
La	lanthanum	iMET1WCMS	0.0001	mg/L
Li	lithium	iMET1WCMS	0.0001	mg/L
Mg	magnesium	iMET1WCICP	0.1	mg/L
Mn	manganese	iMET1WCICP	0.001	mg/L

(continued)

Table C1 continued

Symbol	Parameter	Method code	Limit of reporting	Units
Mo	molybdenum	iMET1WCMS	0.001	mg/L
Na	sodium	iMET1WCICP	0.1	mg/L
Ni	nickel	iMET1WCMS	0.001	mg/L
N_NO_x	nitrogen as nitrate	iNTAN1WFIA	0.01	mg/L
N_total	total nitrogen	iNP1WTFIA	0.01	mg/L
OH	hydroxide	iALK1WATI	1	mg/L
Pb	lead	iMET1WCMS	0.0001	mg/L
P_total	total phosphorus	iPP1WTFIA	0.005	mg/L
SO_4_S	sulfate from sulfur	iMET1WCICP	0.1	mg/L
Sb	antimony	iMET1WCMS	0.0001	mg/L
Se	selenium	iMET1WCMS	0.001	mg/L
Si	silicon	iMET1WCICP	0.05	mg/L
Sn	tin	iMET1WCMS	0.0001	mg/L
TDSsum	total dissolved solids by summation	ixTDS_Sum	1	mg/L
Ti	titanium	iMET1WCMS	0.0005	mg/L
Tl	thallium	iMET1WCMS	0.0001	mg/L
U	uranium	iMET1WCMS	0.0001	mg/L
V	vanadium	iMET1WCMS	0.0001	mg/L
Zn	zinc	iMET1WCICP	0.005	mg/L
pH	pH	iPH1WASE	0.1	–
aION_BAL	ion balance	ixIONBAL	–50	%

Table C2 Water chemistry results for bores 13CP1D, 13CP1OB, 13CPPB1 and SincBore

Parameter	Units	13CP1D	13CP1OB	13CPPB1	SincBore
Date sampled		18/01/2014	19/01/2014	21/08/2014	19/01/2014
Acidity	mg/L	10	3	4	3
Ag	mg/L	<0.0005	<0.0001	<0.0001	<0.0001
Al	mg/L	0.014	<0.005	0.007	<0.005
Alkalin	mg/L	112	26	29	33
As	mg/L	<0.005	<0.001	<0.001	<0.001
B	mg/L	0.97	<0.02	0.03	<0.02
Ba	mg/L	0.042	0.0008	0.033	0.0022
Be	mg/L	<0.0005	<0.0001	<0.0001	<0.0001
Bi	mg/L	<0.0005	<0.0001	<0.0001	<0.0001
Br	mg/L	23	0.08	3.2	0.46
CO_3	mg/L	<1	<1	<1	<1
Ca	mg/L	176	2	10.2	7.8
Cd	mg/L	<0.0005	<0.0001	0.0004	<0.0001
Cl	mg/L	7 190	18	1 010	101
Co	mg/L	0.0052	0.0001	0.0057	0.0001
Cr	mg/L	<0.0025	<0.0005	0.081	<0.0005
Cu	mg/L	<0.0005	<0.0001	<0.0001	0.0004
ECond	mS/m	2 090	23.7	339	47.6
F	mg/L	0.23	0.05	<0.05	<0.05
Fe	mg/L	8.8	0.13	1.7	0.007
Ga	mg/L	<0.0005	<0.0001	<0.0001	<0.0001
HCO_3	mg/L	136	32	35	40
Hardness	mg/L	2 300	36	370	56
Hg	mg/L	<0.00005	<0.00005	<0.00005	<0.00005
K	mg/L	43	0.7	4.9	0.6
La	mg/L	<0.0005	0.0019	0.0058	0.0046
Li	mg/L	0.0089	0.0001	0.0006	0.0001
Mg	mg/L	458	7.6	83.6	8.9
Mn	mg/L	0.42	0.003	0.015	<0.001
Mo	mg/L	<0.005	<0.001	<0.001	<0.001

(continued)

Table C2 continued

Parameter	Units	13CP1D	13CP1OB	13CPPB1	SincBore
Na	mg/L	3 680	29.1	494	61.1
Ni	mg/L	0.009	<0.001	0.17	<0.001
N_NO_x	mg/L	<0.01	11	0.05	4
N_total	mg/L	0.08	12	0.07	4.3
OH	mg/L	<1	<1	<1	<1
Pb	mg/L	<0.0005	<0.0001	0.0001	0.0002
P_total	mg/L	0.022	0.019	<0.010	0.01
SO_4_S	mg/L	864	11.3	130	17.8
Sb	mg/L	<0.0005	<0.0001	<0.0001	<0.0001
Se	mg/L	<0.005	<0.001	0.003	<0.001
Si	mg/L	20	7.8	9	4.9
Sn	mg/L	<0.0005	<0.0001	<0.0001	<0.0001
TDSsum	mg/L	12 000	130	1 800	240
Ti	mg/L	<0.0025	<0.0005	<0.0005	<0.0005
Tl	mg/L	<0.0005	<0.0001	0.0008	<0.0001
U	mg/L	<0.0005	<0.0001	<0.0001	<0.0001
V	mg/L	<0.0005	0.0002	<0.0001	<0.0001
Zn	mg/L	0.016	0.015	0.033	0.014
pH	–	6.3	6.3	6	6.2
aION_BAL	%	–3.6	–2.4	–4.7	–5.1

Table C3 Water chemistry results for bores 13CP2D, 13CP2OB, 13CP3D, 13CP3OB, 13CP4D and 13CP4OB

Parameter	Units	13CP2D	13CP2OB	13CP3D	13CP3OB	13CP4D	13CP4OB
Date sampled		19/08/2014	19/08/2014	18/08/2014	18/08/2014	18/08/2014	18/08/2014
Acidity	mg/L	3	5	3	10	10	5
Alkalin	mg/L	70	1	27	2	41	230
Br	mg/L	14	35	3.2	22	2.7	47
CO_3	mg/L	<1	<1	<1	<1	<1	<1
Ca	mg/L	118	32.9	14.3	60.5	11.5	198
Cl	mg/L	4 900	10 600	972	6 670	798	13 400
ECond	mS/m	1 420	3 050	333	1 990	282	4 040
F	mg/L	0.15	0.17	0.07	0.15	0.12	0.11
HCO_3	mg/L	86	2	33	2	49	280
Hardness	mg/L	1 600	4 000	360	2 300	280	3 600
K	mg/L	31.2	65.5	5.3	39.2	10.2	111
Mg	mg/L	326	960	78.4	514	61.7	746
Na	mg/L	2 430	5 710	541	3 570	454	8 920
N_NO_x	mg/L	0.02	<0.01	0.1	10	<0.01	0.21
N_total	mg/L	0.1	0.27	0.1	11	1.5	2.1
OH	mg/L	<1	<1	<1	<1	<1	<1
P_total	mg/L	<0.010	<0.010	<0.010	<0.010	0.066	<0.010
SO_4_S	mg/L	536	1 060	112	827	100	2 740
TDSsum	mg/L	8 400	18 000	1 700	12 000	1 500	26 000
pH	–	6.2	4.8	5.9	4.9	6	6.4
aION_BAL	%	–4	1.3	0.8	–1.1	0.4	2.4

Table C4 Water chemistry results for bores 13CP5D, 13CP5OB, 13CP6D, 13CP6OB, 13CP7D and 13CP7OB

Parameter	Units	13CP5D	13CP5OB	13CP6D	13CP6OB	13CP7D	13CP7OB
Acidity	mg/L	3	3	5	4	5	4
Alkalin	mg/L	87	17	143	219	34	7
Br	mg/L	15	0.49	21	0.69	0.69	0.13
CO_3	mg/L	<1	<1	<1	<1	<1	<1
Ca	mg/L	104	12.5	204	5.1	11.6	3.8
Cl	mg/L	5240	221	6960	285	310	27
ECond	mS/m	1500	80	1970	136	108	26.5
F	mg/L	0.09	0.09	0.28	0.3	0.3	<0.05
HCO_3	mg/L	106	21	175	267	41	9
Hardness	mg/L	1700	130	2400	58	110	43
K	mg/L	29.7	2.1	45.1	1	11.3	3.4
Mg	mg/L	348	22.8	448	10.9	18.9	8.2
Na	mg/L	2700	97.9	3550	269	150	30.5
N_NO_x	mg/L	0.04	1.8	<0.01	0.96	<0.01	16
N_total	mg/L	0.28	3.4	0.24	7.5	0.06	17
OH	mg/L	<1	<1	<1	<1	<1	<1
P_total	mg/L	<0.010	0.034	<0.010	0.041	0.021	0.019
SO_4_S	mg/L	624	26.4	733	54.7	34.1	8.3
TDSsum	mg/L	9100	400	12000	760	560	160
pH	–	6.1	6.5	6.4	7.6	6.1	6.2
aION_BAL	%	–3.3	–3.4	–2.9	–2.9	–6.5	0.4

Table C5 Water chemistry results for bores 14CP8D and 14CP8OB

Parameter	Units	14CP8D	14CP8OB
Acidity	mg/L	5	5
Alkalin	mg/L	128	17
Br	mg/L	24	1.3
CO_3	mg/L	<1	<1
Ca	mg/L	186	10.5
Cl	mg/L	7 590	558
ECond	mS/m	2 140	189
F	mg/L	0.23	<0.05
HCO_3	mg/L	156	21
Hardness	mg/L	2 500	140
K	mg/L	49.6	2
Mg	mg/L	487	28.1
Na	mg/L	3 950	315
N_NO_x	mg/L	<0.01	2.3
N_total	mg/L	0.17	4.1
OH	mg/L	<1	<1
P_total	mg/L	<0.010	0.11
SO_4_S	mg/L	833	69.8
TDSsum	mg/L	13 000	1 000
pH	–	6.3	5.9
aION_BAL	%	–2.5	–3.5

Table C6 Water chemistry results for bores DP29D, DP29OB, DP30D, DP31D, DP31S and DP31OB

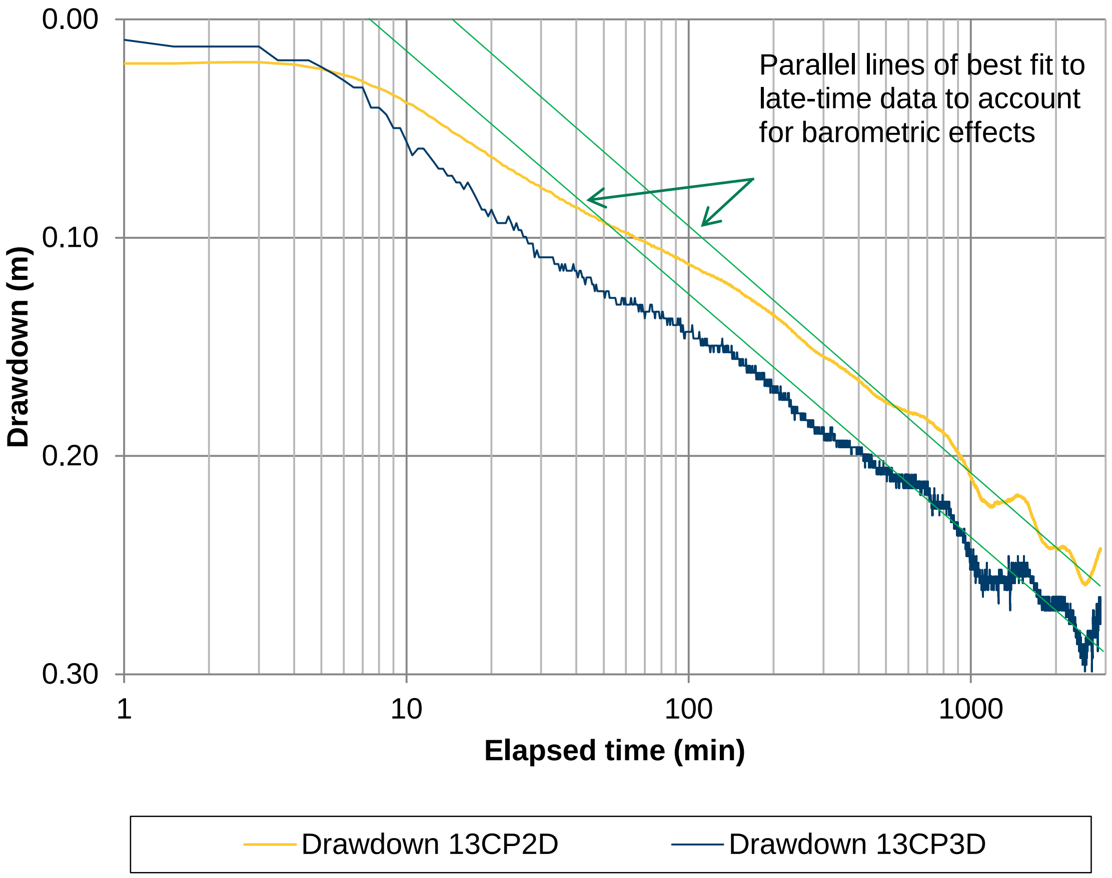
Parameter	Units	DP29D	DP29OB	DP30D	DP31D	DP31S	DP31OB
Acidity	mg/L	5	3	4	3	<2	5
Alkalin	mg/L	14	3	49	22	21	86
Br	mg/L	1.3	0.28	0.13	0.41	0.43	0.32
CO_3	mg/L	<1	<1	<1	<1	<1	<1
Ca	mg/L	10.4	1.3	1.6	4.4	4.4	3.5
Cl	mg/L	474	129	63	188	190	125
ECond	mS/m	163	47.8	32.6	72.4	72.8	73.9
F	mg/L	0.1	<0.05	0.34	0.54	0.54	0.27
HCO_3	mg/L	17	3	60	27	26	105
Hardness	mg/L	140	40	28	52	52	52
K	mg/L	12.9	0.4	4.8	4.8	4.8	3.8
Mg	mg/L	27.6	8.9	5.7	9.9	9.9	10.6
Na	mg/L	249	71.9	53.8	118	117	132
N_NO_x	mg/L	<0.01	1.7	0.03	3.5	3.6	<0.01
N_total	mg/L	<0.02	1.7	0.34	3.7	3.8	2.7
OH	mg/L	<1	<1	<1	<1	<1	<1
P_total	mg/L	0.13	0.015	0.075	1.1	1.2	0.45
SO_4_S	mg/L	46.1	3.8	5.2	22.6	22.3	72.6
TDSsum	mg/L	830	230	170	380	380	400
pH	–	5.9	5.4	6.9	6	6	6.6
aION_BAL	%	–2.4	–0.1	1.6	–1.5	–2.4	0.5

Appendix D Test-pumping analyses

Analysis of the test-pumping data was undertaken using two published software packages — Aquifer Test Pro® and Aqtesolv® — and manual graphical analysis. The manual graphical analyses are presented here.

Driscoll (1987) derives equations to analyse test-pumping data using the relationship between elapsed time plotted on a logarithmic scale and drawdown plotted on an arithmetic scale. Figure D1 shows the time-drawdown graph for the two piezometers 13CP2D and 13CP3D, plotted on a semi-logarithmic scale.

Parallel lines of best fit were applied to the late-time data taking barometric effects into consideration. The coefficient of transmissivity is calculated using the relationship presented in Driscoll (1987) from the slope of the line of best fit and pumping rate. We calculated the coefficient of transmissivity to be 1150m^2/d. The aquifer is 190m thick at the test-pumping site, so the hydraulic conductivity is calculated to be 6m/d.



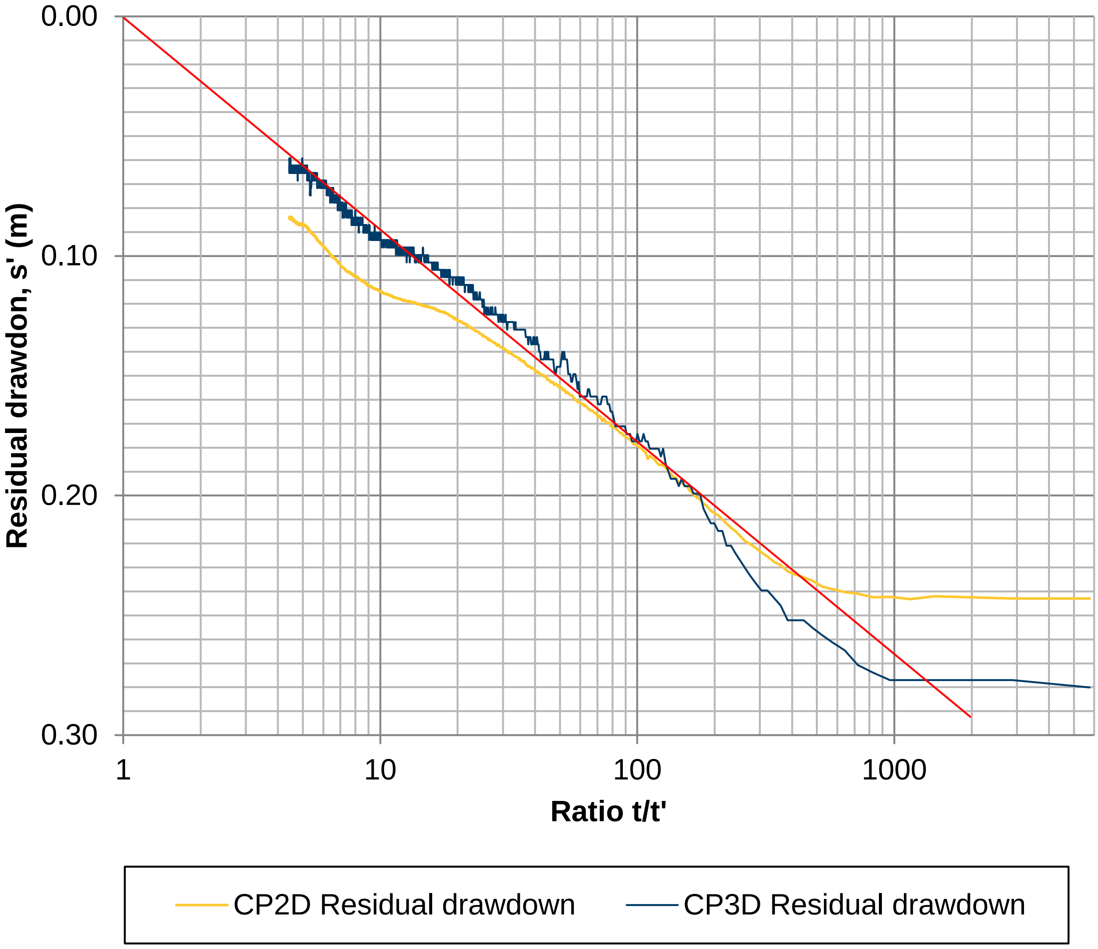
Driscoll (1987)
T = 0.183Q/ds
ds = 0.11
Aquifer thickness = 190m

Time-drawdown in monitoring bores
Q = 691.2m^3/d
T = 1150m^2/d
K = 6m/d

Figure D1 Time-drawdown graph for piezometers 13CP2D and 13CP3D

Driscoll (1987) also derives equations to analyse data from the recovery phase following a test pump using the ratio of time from the beginning of the test pumping (t) and the beginning of the recovery period (t') plotted against water level recovery (residual drawdown) on semi-logarithmic axes. This analysis can be applied to monitoring bores and the production bore.

Figure D2 shows residual drawdown (s') plotted against the ratio t/t' for the two piezometers 13CP2D and 13CP3D. Because of the way the ratio t/t' is derived, time during the recovery period increases towards the left of the plot. The line of best fit is biased towards late-time recovery in piezometer 13CP3D. Using this method, we calculated the transmissivity to be 1420m^2/d and the hydraulic conductivity to be 7.5m/d.

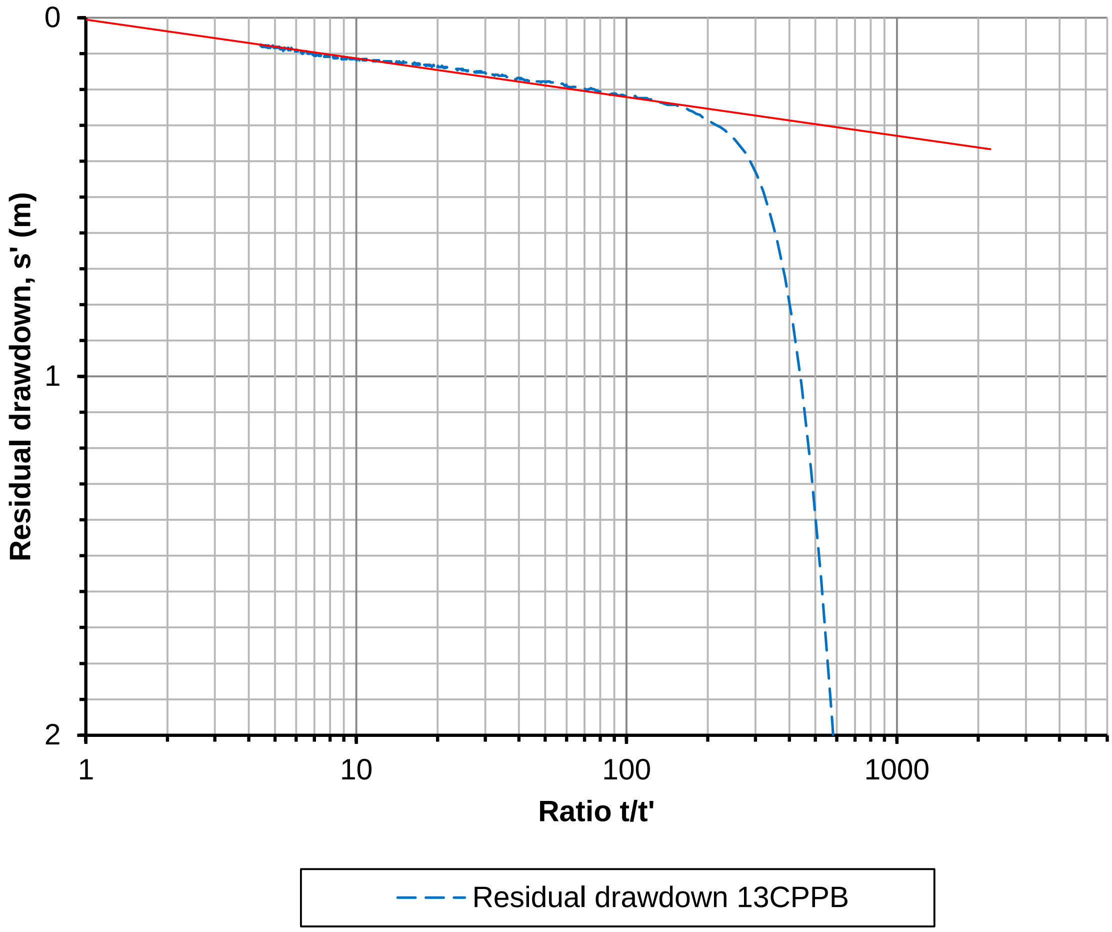


Driscoll (1987)
ds' = 0.089
T = 0.183Q/ds
K = 7.5m/d

Residual drawdown s' vs ratio t/t'
Q = 691.2m^3/d
T = 1420m^2/d

Figure D2 Residual drawdown plotted against the ratio t/t' for monitoring bores 13CP2D and 13CP3D

Figure D3 shows residual drawdown plotted against the ratio t/t' for the production bore 13CPPB. A line is fitted to the later time data. The derived value of transmissivity is 1150m^2/d which gives a hydraulic conductivity of 6m/d.



Driscoll (1987)
ds = 0.11
T = 0.183Q/ds
K = 6m/d

Residual drawdown vs ratio t/t'
Q = 691.2m^3/d
T = 1150m^2/d

Figure D3 Residual drawdown plotted against the ratio t/t’ for production bore 13CPPB

Shortened forms

Short form	Long form
µm	micrometre
AEM	airborne electromagnetic
AHD	Australian Height Datum
BGL	below ground level
CRT	constant rate test
CSIRO	Commonwealth Science and Industrial Research Organisation
d	day
DAFWA	Department of Agriculture and Food, Western Australia
DPIRD	Department of Primary Industries and Regional Development
DWER	Department of Water and Environmental Regulation
EC	electrical conductivity
GL	gigalitre
GPS	global positioning system
kL	kilolitre
km	kilometre
L/s	litres per second
m, m^2, m^3	metre, square metre, cubic metre
min	minute
mS/m	microsiemens per metre
mg/L	milligrams per litre
SWL	standing water level
TDS	total dissolved solids
y	year

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