Government of **Western Australia**
Department of **Water**

Looking after all our water needs

Groundwater-surface water interaction along Gingin Brook Western Australia

Hydrogeological record series

Report no. HG54
January 2011

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Summary

Gingin Brook is a historically, culturally and hydraulically unique freshwater perennial brook in Western Australia. Abstraction, channel modification and a drying climate have significantly modified the hydrology of the brook resulting in no summer flow in some sections. To improve the understanding of groundwater connectivity and discharge to the brook, the Department of Water undertook a groundwater investigation in 2008, installing shallow monitoring bores at strategic locations along the brook and its tributaries.

Results of the investigation show that groundwater discharge provides baseflow to the brook from unconfined aquifers in two main areas. In the middle to lower sections of the brook downstream of the confluence with Wallering Brook groundwater discharge occurs from the superficial aquifer, and in the upper catchment to the north and east of Gingin townsite groundwater discharge occurs from the Mirrabooka aquifer.

Additional groundwater discharge to the brook from the deeper confined Leederville aquifer is also evident. This occurs to the east of Gingin townsite and downstream of the confluence with Wallering Brook, where the confining Kardinya Shale Member of the Osborne Formation has been eroded and potentiometric heads in the Leederville aquifer are above the base of the brook.

Immediately west of the Gingin Scarp along the Pinjarra Plain, the Guildford Clay is the sole constituent of the superficial aquifer. Where the Guildford Clay has a silty or fine sand facies the brook may lose water through leakage to underlying aquifers. Conversely, localised perching of the brook is evident where the Guildford Clay facies is clay rich. The superficial and Leederville aquifers underlying the Pinjarra Plain are ‘disconnected’ from the brook, having groundwater levels that are below the base of the brook. With no groundwater discharge occurring along the Pinjarra Plain to support flows in the brook, summer baseflow is diminished through evaporation, diversion and riparian use.

Innovative use of data loggers to record continuous real-time groundwater levels along the brook has demonstrated that rapid changes in groundwater level and storage occur in response to rainfall. This is evident in the superficial aquifer downstream of the confluence with Mungala Brook and in the Mirrabooka aquifer in the upper catchment of Gingin Brook. Semi-confined conditions are common in deeper sections of the superficial aquifer particularly along the Pinjarra Plain with little response to rainfall in the monitoring bore hydrographs.

A summary of recommendations and suggestions for future management is given in Section 7.8. These have been based on the following general principles:

- a move away from summer surface water abstraction in favour of winter abstraction and off-stream storage
- creating a buffer zone around the brook to prevent groundwater abstraction depleting the baseflow
- continued collection and review of monitored data
- adaptive management based on the ongoing review of data, rather than rigid rules, being used to maximise the available resources.

1 Introduction

Gingin Brook (to be referred to as ‘the brook’) is a historically, culturally and hydraulically unique freshwater brook in Western Australia, located 70 km north of Perth. In the past, summer baseflow occurred along the brook’s entire length, maintained by groundwater discharge.

Channel modification, increased abstraction and a drying climate has reduced groundwater discharge to the brook. Summer baseflow now only occurs in some sections.

In order to better understand groundwater connectivity and discharge to the brook, the Department of Water undertook a groundwater investigation with the installation of shallow monitoring bores along the brook and its tributaries. The new bores have been monitored for one year to determine water level trends and how these relate to baseflow in the brook throughout the year.

This report uses theses observations to draw up a conceptual diagram of how the brook functions. It also makes recommendations and suggestions for future management of the brook.

1.1 Background

Gingin Brook has numerous Indigenous sites of significance, particularly related to the Gingin Brook Waugal, which covers most of the brook and its tributaries. There are many recreational sites along the brook including the Gingin town weir, pool and water wheel. The social values of these recreational sites depend on a constant flow within the brook. Many significant wetland features, such as Beermullah Lake and Lake Yeal, receive flow from the brook and its tributaries (Figure 1).

Visual observation of the brook headwaters confirm that it is primarily fed by springs and seeps along the banks. In the lower reaches, where the brook meanders across the Swan Coastal Plain, the relationship between baseflow, groundwater discharge and the groundwater–surface water connection is unclear. An understanding of the hydrogeological connection of the brook along its entire length is critical for effective management.

A drying climate and horticultural expansion over the last decade has increased pressure on groundwater and surface water resources. Groundwater demand has increased with all but one superficial aquifer groundwater subarea being at or close to full allocation. Direct abstraction of surface water in perennial sections of the brook provides an important local source of water for the horticultural industry during the dry summer months. This further diminishes the already low summer baseflow within the brook.

1.2 Location

The investigation area is easily accessible from Perth by either Wanneroo Road or the Brand Highway. The brook headwaters start on the Dandaragan Plateau, 10 km east of Gingin townsite. The brook flows for 40 km to the west before its confluence with the Moore River (Figure 1). The brook also includes Quin and Mungala brooks and their respective catchments.

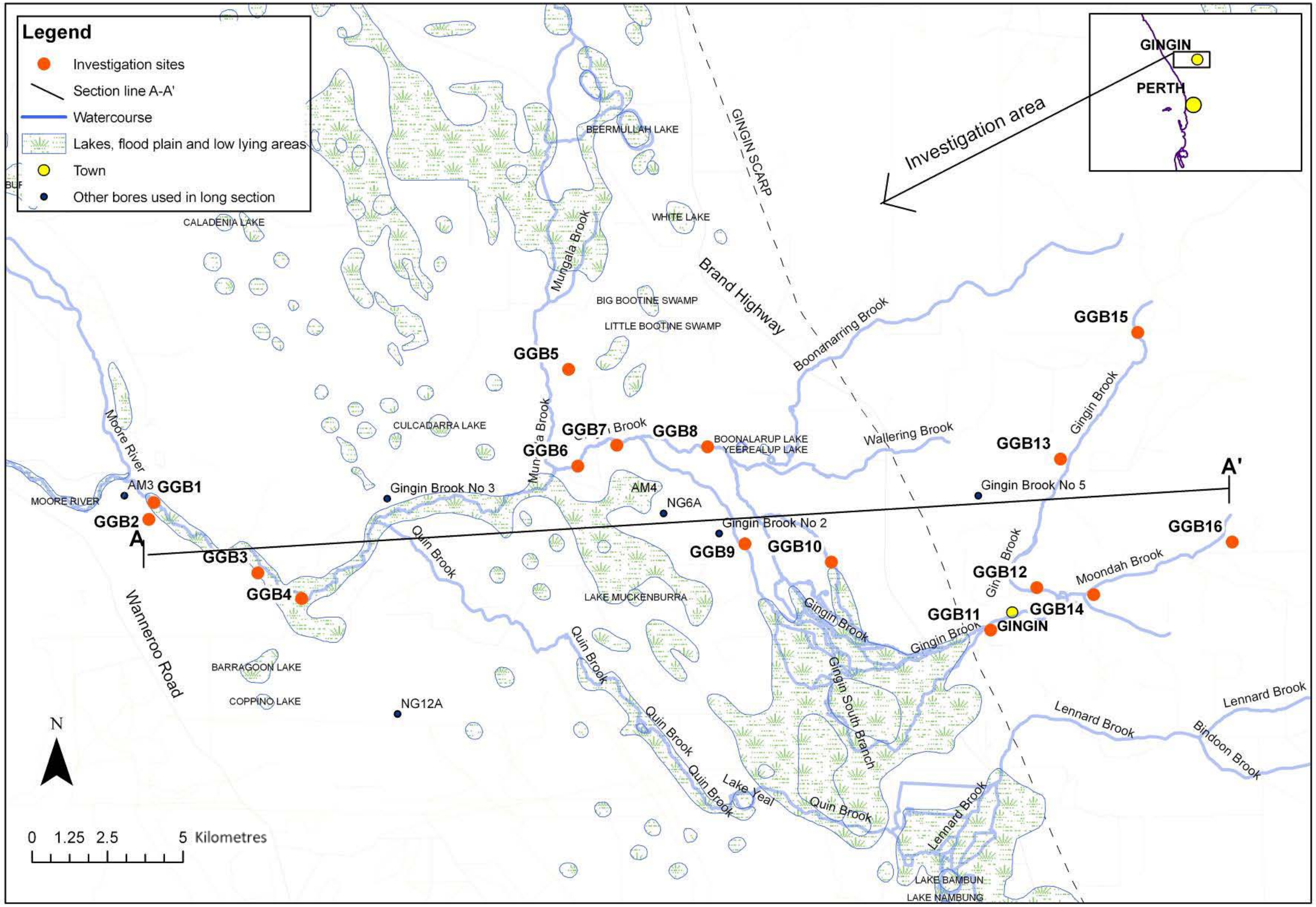


Figure 1 Location of Gingin Brook and investigation sites

1.3 Climate

The investigation area has a Mediterranean climate with mild, wet winters and hot dry summers. Long-term average rainfall at Gingin is about 740 mm/year. The majority of the rainfall occurs in the winter from May to August. Evaporation exceeds rainfall except during the winter months of May to August, while the pan evaporation is 2200 mm/year.

Figure 2 shows that rainfall has been declining since 1934 with a significant step change occurring in 1969, indicated by the two horizontal lines. Since 1969, the mean annual rainfall has been about 650 mm, a 12% reduction in rainfall over the last 40 years.

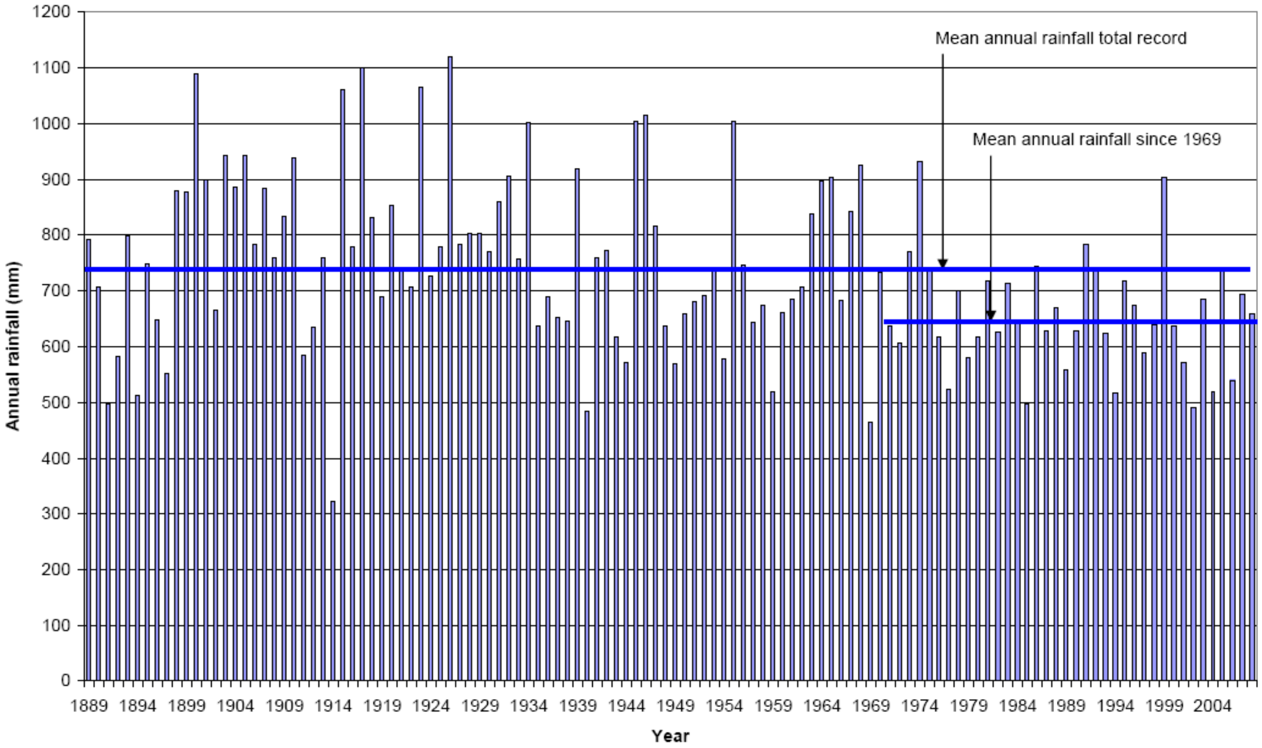


Figure 2 Long-term annual rainfall at Gingin (BoM station 009018) showing step change to a drier climate

1.4 Physiography

The headwaters of Gingin Brook originate on the Dandaragan Plateau. The brook flows south-west from a steep sided, densely vegetated valley near the headwaters, to a broad, open valley about 5 km downstream from its source. There is a distinct oxbow feature near the town of Gingin, resulting in a change in flow direction to the north-west.

The brook valley tightens through the Gingin Scarp which is an erosional feature standing at over 100 m AHD. The topography decreases away from the scarp, where the brook bifurcates as a network of streams and channels on the flat Swan Coastal

Plain, which is a piedmont and valley-flat alluvial plain (Davidson 1995). There has been significant modification to the brook along the Pinjarra Plain (Playford et al. 1976) with extensive anthropogenic drainage and diversion channels.

Gingin Brook continues as one main channel after the confluence with Mungala Brook, flowing over the gently undulating aeolian Bassendean Dune system and then the Spearwood Dune system of Tamala Limestone nearer the coast. Gingin Brook terminates at the confluence with the Moore River near the intersection of Chitna and Gingin Brook roads (Figure 3).

Quin and Lennard Brooks have not been considered in this investigation. Quin Brook downstream of Lake Yeal does not appear to have any flow derived from groundwater discharge, being dry most of the year. It may have historically been supported by groundwater discharge (Johnson 2000). Lennard Brook has permanent flows and is likely to have a large consistent baseflow from groundwater discharge. The densely vegetated headwaters of Lennard Brook make further investigations difficult.

1.5 Land use

There has been widespread development along the brook for horticulture, turf, market gardens, large commercial orchards, irrigated pasture for grazing and semi-rural residential development. The extent of development is largely restricted to within 2 km either side of the brook.

Water demand by riparian landholders is greater during the summer months when rainfall is extremely low and infrequent, which also coincides with low flow periods and drying of some sections of the brook. Water is directly pumped from the brook, or indirectly abstracted via bores within the superficial, Mirrabooka and Leederville aquifers.

1.6 Previous work

There have been numerous studies on the geology and hydrogeology of the Gingin area at a regional scale. However, there are few studies that have focused solely on the brook, highlighting the need for this investigation. In 1967, the Gingin Brook borehole line was established, consisting of five deep bores (Gingin Brook No. 1 to Gingin Brook No. 5) into the Leederville and Yarragadee Formation (Sanders 1967). These bores are no longer monitored and are screened too deep to be of significance for this investigation.

Moncrieff and Tuckson (1989) reported on the geology and hydrogeology of the superficial formations between Lancelin and Guilderton. They provided a detailed description of the superficial formations including isopach maps for most geological units, in particular the Ascot Formation.

Johnson (2000) assessed the hydrogeology of the perennial brooks east of the Brand Highway, including Gingin and Lennard brooks. The desk top study focused on the upper reaches of the brook to understand the groundwater contribution from the Mirrabooka and Leederville aquifers, interconnection between surface and groundwater, and an assessment of the impacts from direct and indirect abstraction. The study recommended additional monitoring bores and gauging stations to quantify groundwater contribution to the brook. However, neither recommendation was implemented prior to this investigation.

Kay and Diamond (2001) provided a regional hydrogeological assessment of the Gingin groundwater area. This study collected new data on groundwater exploration and production bores, which was compiled into regional scale geological sections and isopotential maps that were integrated into the work by Davidson and Yu (2006).

Storey and Davies (2002) determined preliminary ecological water requirements for Gingin and Lennard Brooks. The determination on groundwater dependency was based largely on Johnson (2000) and integrating surface water data on streamflow along the entire brook.

Rockwater (2005) assessed the potential for groundwater abstraction from the Yarragadee aquifer to affect wetlands. This assessment also briefly discussed the potential for recharge or leakage from Gingin Brook into the groundwater system.

Davidson and Yu (2006) updated the regional description of the hydrogeology of the Perth Region northward to include the Gingin groundwater area. This comprehensive review of all the published geological and hydrogeological data was incorporated into the numerical groundwater model referred to as the Perth region aquifer modelling system (PRAMS).

Lindsay et al. (2007) assessed groundwater resources and groundwater–surface water interaction in the vicinity of Gingin Brook, highlighting the fact that water levels in the underlying aquifers were declining. The review collated existing information and supported development of the proposal for the Gingin Brook investigation by Pigois (2008).

Finally, AECOM (2010) produced a report investigating the interactions between surface water and groundwater in the Gingin Brook catchment for the department’s Surface Water Assessment Section. The report details the development of a simple numerical model of the brook catchment.

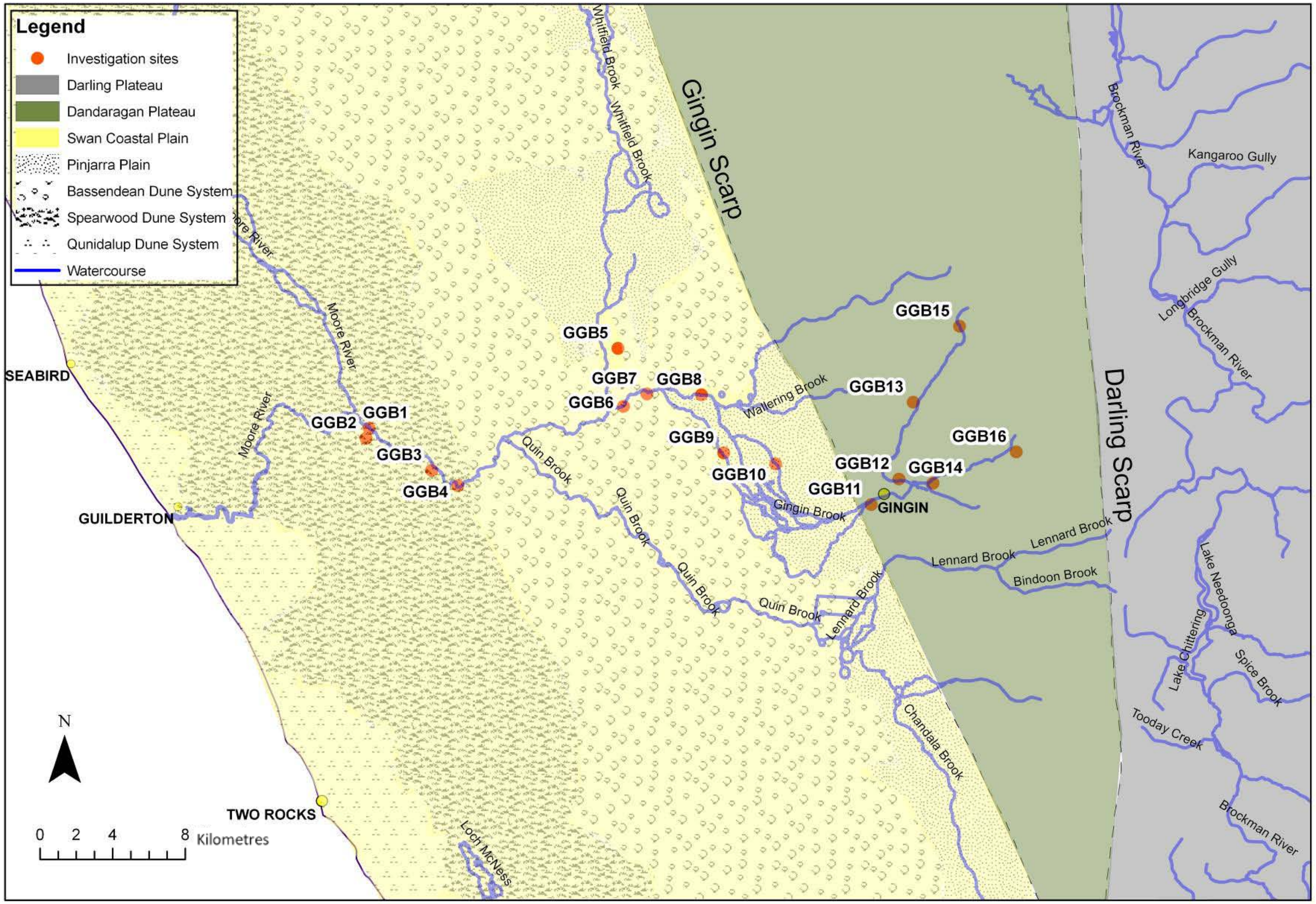


Figure 3 *Physiography of the investigation area*

2 Investigation program

2.1 Scope and purpose

The Gingin Brook groundwater investigation has established a more comprehensive groundwater monitoring network to improve understanding of groundwater–surface water interactions, and hydrogeological conditions along the brook. All flow in the brook during the summer months is sustained by groundwater discharge. It was therefore necessary to identify the extent of the gaining and losing reaches.

The investigation is an important part of the continuing assessment of groundwater discharge, trends in water levels, and possible effects of abstracting surface water and groundwater on the brook. Recommendations and suggestions from this investigation have been used in the surface water allocation plan for the brook. Findings from this report have also been used in the North Gingin groundwater allocation plan as the brook lies within several of the groundwater subareas covered by the plan. Both allocation plans are currently being updated by the Department of Water’s Water Allocation Planning Branch.

The investigation aligns with the department’s strategic plan under the Water Availability Program (Outcome 2.1 – Good knowledge to make informed management decisions), the State Water Plan under Item 3 – Invest in science, innovation and education (resource investigation and assessment) and the State Groundwater Investigation Program.

2.2 Methodology

The investigation involved the collection of lithological and groundwater data along the brook by installing monitoring bores. The data was assessed once the bores had been monitored for one year.

2.3 Drilling and bore construction

The drilling investigation involved the installation of 32 monitoring bores at 16 sites along Gingin Brook and its tributaries, Moondah and Mungala brooks (Figure 1). Monitoring bores in the superficial aquifer were drilled in pairs, with one bore to monitor the near surface watertable and another bore to the base of the superficial aquifer.

If the superficial formations were absent, were unsaturated or had only a thin saturated layer, the deep, and in some instances the shallow bores, were installed into a suitable permeable horizon in the underlying Cretaceous formations. All monitoring bores penetrated to at least 3 m below the watertable to allow for possible future groundwater level decline.

Monitoring bores were installed by Great Southern Drilling between June and October 2008 using an air core drill rig. Sixteen sites (GGB1 to GGB16) were investigated, with two bores at each site comprising a deep and a shallow bore. Deep bores were denoted with an A suffix and shallow bores with a B suffix (e.g. GGB1A, GGB1B). The deep bores are up to 75 m deep and generally screened at the base of the superficial formations.

Bores less than 50 m deep were constructed with Class 12, 50 mm PVC casing, while bores greater than 50 m were constructed using Class 18, 50 mm PVC casing. Screened sections consist of a 3 m length of slotted 50 mm PVC. All bores have a 2 m or 3 m, 50 mm PVC sump below the screened section. If the drill hole was deeper than required to install the screen and sump assembly, a cement plug was installed.

The deep bores were gravel packed to 3 m above the screen interval with the remaining annulus tremmie-grouted to surface with cement to provide an effective seal between aquifers. The shallow bores were gravel packed to within 2 m of the surface and then backfilled with standpipes cemented in place. A summary of bore construction is presented in Table 1. Tuffs (2009) provides details of bore location, construction, logging and sampling for each bore.

2.4 Sampling, logging and testing

Lithological samples were collected and logged at 1 m intervals and placed into chip trays. Selected samples were taken for palynological analysis to confirm stratigraphy and age. Bulk samples were often collected throughout the drilling program. All samples are stored at the Department of Water’s groundwater investigation depot.

Upon completion, bores were airlifted until the water was free of fines and salinity had stabilised. The airlifted groundwater was tested for pH, temperature (ºC), total dissolved solids (TDS, mg/L) and electrical conductivity (EC, µS/cm) with handheld water quality meters.

A pumped, air-free sample was also collected for laboratory analysis of major ions and nutrients. While the bores were being purged, field measurements were undertaken using a handheld water quality meter and a flow cell for pH, temperature, EC, TDS, dissolved oxygen (DO, mg/L) and oxidation reduction potential (ORP, mV).

Water level monitoring was carried out using data loggers. Chemical analysis was undertaken following bore completion and will be undertaken every year thereafter for a period of two years, for a total of three sampling events.

2.5 Levelling

Bores

All monitoring bores were surveyed by Trade Ranger between November and December 2008 providing levels referred to the Australian Height Datum (m AHD). Relative accuracy is +/- 5 mm with the top of each bore headworks (cap removed), ground surface and cement block noted. Ramset nails were also placed near each bore to provide a known datum for any future survey work. The surveying of the monitoring bores permits conversion of surface, geological and groundwater level data to mAHD.

Benchmarks installed along Gingin Brook Road in the 1960s were found to have horizontal accuracies of up to 18 mm less than when they were originally installed. This may be due to subsidence along Gingin Brook Road or errors occurring when the benchmarks were installed. The benchmarks were still used, as a possible error of 18 mm was not considered significant for converting groundwater levels to m AHD. No further work was undertaken to determine actual absolute bench marks along Gingin Brook Road.

Brook profiles

Trade Ranger also surveyed the section of brook adjacent to each investigation site. The sections consist of the ground surface (m AHD) from the bore to the opposite bank of the brook, including the lowest point of the brook bed and water level at the time of the survey. This has allowed groundwater levels in the bores to be compared directly to water levels in the brook. All brook survey data is presented in Tuffs (2009).

2.6 Monitoring

Groundwater

The bores were originally equipped with non-vented In-Situ Level Troll 100 data loggers to record pressure (water level) every six hours. One In-Situ Barotroll 100 was also installed at each site to record barometric pressure, and assist with calibration of water level measurements.

The data loggers were installed in phases between September and November 2008. Bore GGB5A has permanent artesian flow and could not be equipped with a data logger. Reliability of the loggers was initially poor with a failure rate of around 30%. Replacement In-Situ Level Troll 500 data loggers were installed in June 2010. Any gaps in bore hydrographs are likely to be a result of data logger failure. Manual dips were also taken prior to installing the loggers, to set up the loggers, and each time data from the loggers were downloaded.

Surface water

The brook forms a single channel east of the Gingin Scarp, but west of the scarp it predominantly consists of a number of poorly defined channels and agricultural drains making an estimation of flow difficult (Figure 1). The Bookine Bookine gauging station (617003) on Gingin Brook has been operating since 1957. It is located in the lower reaches of Gingin Brook, approximately 3 km upstream of the confluence with the Moore River. In May 1973, another gauging station (617058) was installed at Gingin townsite. The location of the gauging stations is presented in Figure 4.

The gauging stations confirm that the brook maintains flow all year round in the lower reaches at Bookine Bookine and near the headwaters at Gingin townsite. It has been observed that sections of the brook between the two gauging stations become ponded (no flow) or dry up completely during the summer and in some instances throughout the winter as evident along Quin Brook (tributary of Gingin Brook).

In order to record flows that occur between the two gauging stations and determine ephemeral sections of the brook, the Department of Water's Surface Water Assessment Section undertook spot gauging of streamflow between February 2007 and September 2009.

Spot flow measurements were collected from over 80 locations along Gingin, Mungala, Quin, Moondah and Lennard brooks (Figure 4). Spot flow gauging sites are denoted with the prefix G. The headwaters of Lennard Brook had a spot gauging site planned as well as three sites on Boonannaring Brook. However, access was not possible due to steep topography and dense vegetation. The spot gauging sites have up to 25 measurements each recorded between 2007 and 2009, with both winter and summer flows being noted.

Table 1 Bore construction summary

	AMG zone 50		Construction dates		Drilled depth mbgl	Elevation		Casing		Geological formation screened	Potentiometric groundwater level October 2008 m AHD	Salinity mg/L TDS	Airlift yield m^3/d
Bore	Easting	Northing	Started	Completed		Natural surface m AHD	TOC m AHD	Installed depth mbgl	Screen interval mbgl				
GGB1A	368143	6535292	19/06/2008	25/06/2008	27	13.94	14.69	26.47	21.67–24.67	Ascot Formation	12.20	430	80
GGB1B	368140	6535294	25/06/2008	25/06/2008	9	13.93	14.69	8.73	3.73–6.73	Bassendean Sand	11.80	530	4
GGB2A	367979	6534734	16/06/2008	19/06/2008	39	25.04	25.79	37.38	32.38–32.38	Ascot Formation	9.90	452	58
GGB2B	367975	6534735	26/06/2008	26/06/2008	21	24.99	25.77	20.94	15.94–18.94	Tamala Limestone	9.90	390	9
GGB3A	371581	6532971	27/06/2008	1/07/2008	30	21.8	22.58	29.93	22.93–25.93	Ascot Formation	20.25	340	104
GGB3B	371577	6532972	1/07/2008	2/07/2008	9	21.78	22.56	8.93	3.93–6.93	Bassendean Sand	21.25	417	43
GGB4A	373029	6532122	2/07/2008	8/07/2008	30	23.18	23.93	23.48	18.48–21.48	Ascot Formation	23.60	355	86
GGB4B	373027	6532123	9/07/2008	9/07/2008	15	23.15	23.92	12.71	7.71–10.71	Alluvium/Bassendean Sand	23.60	400	86
GGB5A	381859	6539699	29/07/2008	31/07/2008	42	42.39	43.16	35.00	30.00–33.00	Bassendean Sand	44.73	737	41
GGB5B	381860	6539695	31/07/2008	31/07/2008	9	42.35	43.15	9.00	4.00–7.00	Muchea Limestone	40.90	1082	19
GGB6A	382166	6536496	16/07/2008	18/07/2008	33	40.03	40.81	31.51	26.51–29.51	Ascot Formation	42.25	1109	86
GGB6B	382163	6536494	18/07/2008	21/07/2008	12	40.02	40.79	11.70	6.70–9.70	Muchea Limestone/ Bassendean Sand	38.60	1387	35
GGB7A	383455	6537188	1/08/2008	5/08/2008	42	43.89	44.65	33.95	28.95–31.95	Ascot Formation	44.10	1013	91
GGB7B	383450	6537188	6/08/2008	6/08/2008	9	43.80	44.60	8.95	3.95–6.95	Bassendean/Guildford	41.85	1583	4
GGB8A	386458	6537137	6/08/2008	12/08/2008	45	48.04	48.84	38.29	33.29–36.29	Ascot Formation	46.30	395	95
GGB8B	386454	6537139	12/08/2008	12/08/2008	9	48.07	48.86	8.94	3.94–6.94	Guildford Clay	46.80	606	6
GGB9A	387686	6533930	13/08/2008	14/08/2008	45	55.19	55.96	44.61	38.61–41.61	Ascot Formation	46.20	1396	106
GGB9B	387683	6533932	14/08/2008	15/08/2008	15	55.18	55.97	14.67	9.67–12.67	Guildford Clay/ Ascot	46.20	991	2
GB10A	390550	6533328	18/08/2008	22/08/2008	40	60.59	61.38	26.66	21.66–24.66	Guildford Clay	53.70	1550	34
GGB10B	390550	6533331	20/08/2008	22/08/2008	9	60.60	61.38	9.00	4.00–7.00	Guildford Clay	57.35	1290	na
GGB11A	395812	6531079	22/08/2008	27/08/2008	24	94.78	94.80	23.8	19.80–22.80	Leederville Formation	82.46	700	13
GGB11B	395809	6531077	26/08/2008	27/08/2008	50	94.87	94.89	48.87	43.87–46.87	Guildford Clay	81.22	991	9
GGB12A	397339	6532482	17/09/2008	19/09/2008	57	96.80	97.55	54.00	48.00–51.00	Leederville Formation	84.43	777	95
GGB12B	397339	6532488	5/09/2008	8/09/2008	16	97.13	97.89	15.12	10.12–13.12	Molecap Greensand/ Leederville Formation	97.38	1828	65

	AMG zone 50		Construction dates		Drilled depth mbgl	Elevation		Casing		Geological formation screened	Potentiometric groundwater level October 2008 m AHD	Salinity mg/L TDS	Airlift yield m^3/d
Bore	**Easting**	**Northing**	**Started**	**Completed**		**Natural surface m AHD**	**TOC m AHD**	**Installed depth mbgl**	**Screen interval mbgl**				
GGB13A	398125	6536733	3/10/2008	7/10/2008	48	122.04	122.84	38.23	32.23–35.23	Molecap Greensand	114.83	278	39
GGB13B	398129	6536732	7/10/2008	8/10/2008	21	121.89	122.69	20.42	15.42–18.42	Poison Hill Greensand	115.00	630	17
GGB14A	399222	6532253	9/10/2008	13/10/2008	57	102.55	103.31	56.73	51.73–54.73	Leederville Formation	97.08	473	4
GGB14B	399219	6532256	14/10/2008	14/10/2008	18	102.37	103.17	16.67	11.67–14.67	Molecap Greensand	99.00	2390	<1
GGB15A	400681	6540916	15/09/2008	17/09/2008	75	138.67	139.45	71.42	65.42–68.42	Molecap Greensand	126.66	171	52
GGB15B	400677	6540916	16/09/2008	17/09/2008	21	138.69	139.49	19.61	14.61–17.61	Poison Hill Greensand	127.34	121	17
GGB16A	403803	6533989	15/10/2008	16/10/2008	45	137.07	137.84	42.10	36.10–39.10	Poison Hill Greensand	124.70	350	104
GGB16B	403802	6533993	17/10/2008	17/10/2008	28	136.70	137.45	27.19	22.19–25.19	Poison Hill Greensand	122.07	171	30

mbgl	*depth in metres below ground level*	*m AHD*	*elevation in metres above Australian Height Datum*
mg/L TDS	*mg/L total dissolved solids*	*TOC*	*top of casing*
na	*not available*		

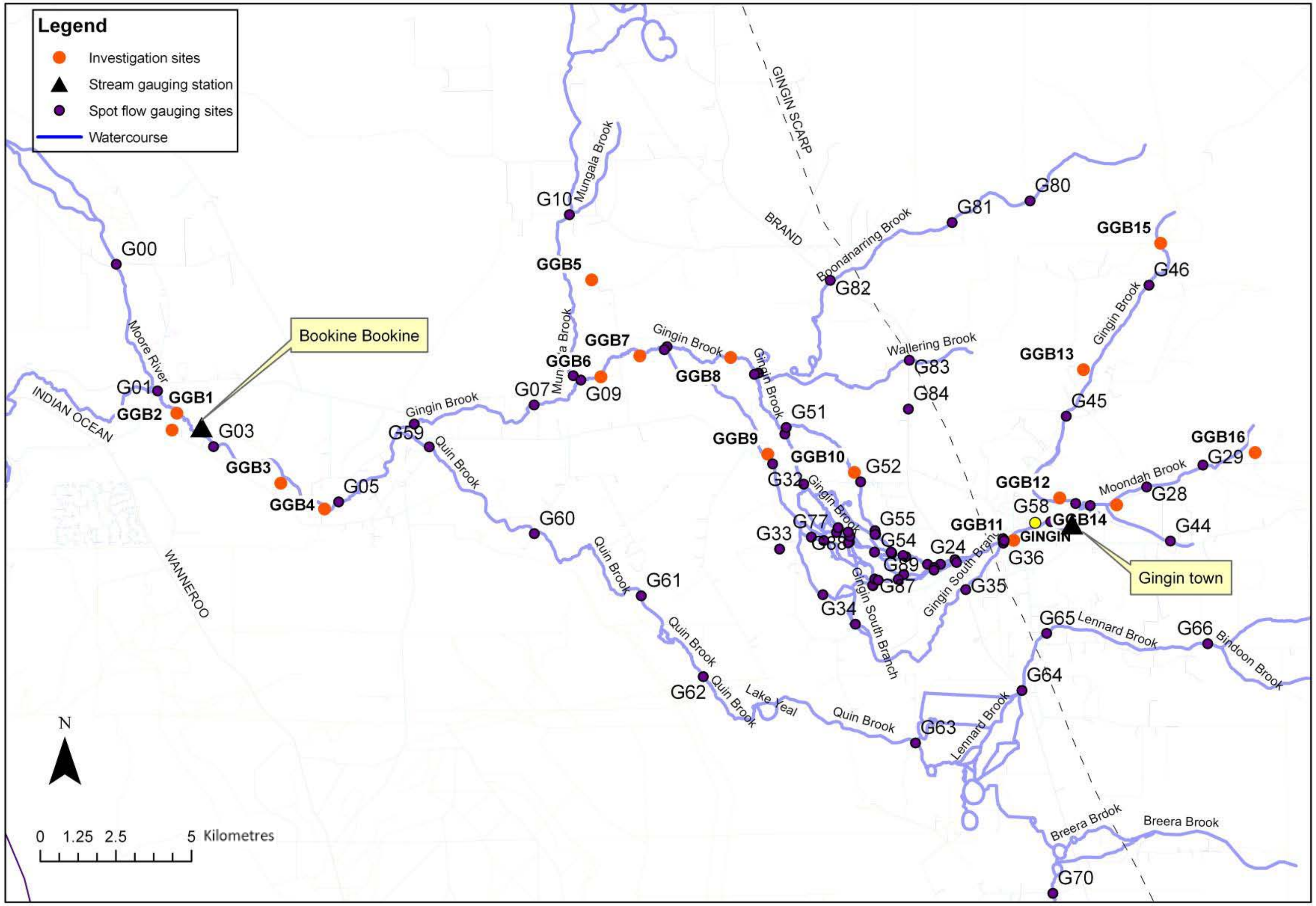


Figure 4 Location of brook gauging stations and spot flow measurement sites

3 Geology

The regional geology has been described in detail by Playford et al. (1976), Moncrieff and Tuckson (1989), Davidson (1995), Kay and Diamond (2001) and more recently Davidson and Yu (2006). This report only discusses the geology associated with Gingin Brook.

3.1 Regional setting

The investigation area is located in the central part of the Perth Basin. There are three distinct, geological units of the superficial formations on the coastal plain; the Quaternary Guildford Clay in the east, Bassendean Sand in the central portion and Tamala Limestone in the west. The superficial formations also include the Tertiary Ascot and Yoganup formations at the base.

The lithological contact between units is often not obvious due to their interfingering nature. The superficial formations can be up to 50 m thick. The superficial formations were deposited onto the Cretaceous Coolyena Group, Warnbro Group (e.g. Leederville Formation) or Jurassic Parmelia Group. On the Dandaragan Plateau, east of the Gingin Scarp, there are extensive outcrops of the Cretaceous sequence comprising; the Coolyena (including the Osborne Formation) and Warnbro groups (e.g. Leederville Formation).

The structure of the Perth Basin is dominated by north to north-west trending faults, probably caused by movement along growth faults. The movement along growth faults is associated with differential compaction and subsidence within deeper basement fault blocks (Cope 1972).

The Carnac Formation of the Parmelia Group was intercepted but not fully penetrated at site GGB10. This has improved our understanding of the distribution of the Parmelia Group subcrop. Previous understanding was that the Parmelia Group only occurred further to the north of the investigation area (Davidson and Yu 2006).

The Parmelia Group subcrop area is likely to be 3 km to 4 km wider than previously identified and extend further to the south. The State Groundwater Investigation Program undertook a drilling program in August 2009 as an extension to the North Gnangara investigation (Pigois 2009) to better define the southern Parmelia Group subcrop area.

The stratigraphy of the investigation area is summarised in Table 2. Figure 5 presents a schematic geological long-section beneath the brook showing stratigraphic relationships. The geological section is based on the investigation bores and deeper bores from previous investigations which are close to the brook, in conjunction with the surface geology map sheet for Gingin (Wild and Lowe 1978).

Table 2 Stratigraphic sequence

Age	Depth mbgl[1]	Formation	Lithology	System type
Quaternary		**Superficial formations**		
	0–10	Alluvium/Colluvium	Clay, silt and sand	Aquiclude
	0–25	Tamala Limestone	Sand and limestone	Unconfined aquifer
	0–14	Muchea Limestone	Sand and limestone	Unconfined aquifer
	0–34	Bassendean Sand	Sand	Unconfined aquifer
	0–31	Guildford Clay	Clay and sand	Aquitard
Tertiary	12–42	Ascot Formation	Limestone, sand and shell grit	Semi-confined aquifer
~~~~~~~~~~ Unconformity ~~~~~~~~~~				
Cretaceous		**Coolyena Group**		
	25–> 39	Lancelin Formation	Silty, clayey marl	Aquitard
	0–> 45	Poison Hill Greensand	Glauconitic sand/silt	unconfined aquifer
	3–6	Gingin Chalk	Chalk and calcrete	Aquiclude
	6–69	Molecap Greensand	Glauconitic sand	Semi-confined/ unconfined aquifer
Osborne Formation:				
	na	Mirrabooka Member	Sand, silt and shale	Aquitard/aquifer
	69–> 75	Kardinya Shale	Shale and siltstone	Aquitard
	na	Henley Sandstone	Sandstone and sand	Confined aquifer
~~~~~~~~~~ Unconformity ~~~~~~~~~~				
Cretaceous		**Warnbro Group**		
Leederville Formation:				
	12–> 54	Wanneroo Member	Sandstone, Semi-confined	silt and shale confined aquifer
~~~~~~~~~~ Unconformity ~~~~~~~~~~				
Jurassic-Cretaceous		**Parmelia Group**		
	29–> 40	Carnac Formation	Shale and siltstone	Aquitard

[1] Note: Depth is minimum and maximum depth each formation was logged, '>' denotes formation was not fully penetrated during investigation. mbgl – depth in metres below ground level.

na – not applicable (not encountered during the investigation)

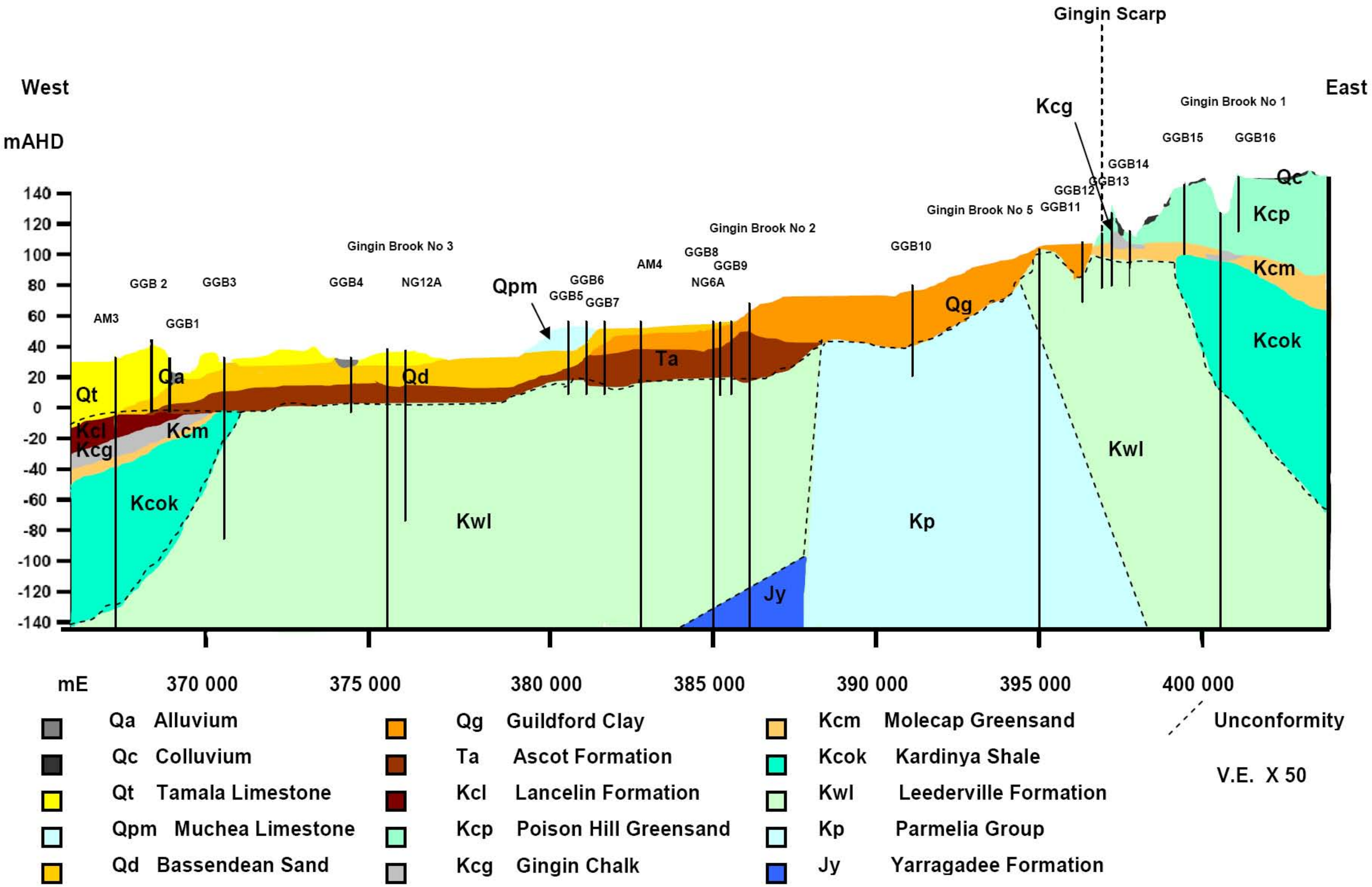


Figure 5 Interpreted Gingin Brook geological long-section

3.2 Parmelia Group

The Parmelia Group consists of interbedded sandstones, siltstones and shales. The Carnac Formation of the Parmelia Group was intersected in GGB10A at 29 mbgl but not fully penetrated. The Carnac Formation at GGB10A was clay and pyritic cemented sandstone. Its presence was confirmed by palynological samples from GGB10A with *B. eneabbaensis* spore-pollen zone assemblage, of Berriasian age (Backhouse Biostrat Pty Ltd 2009a).

3.3 Leederville Formation

The Leederville Formation consists of an interbedded sequence of sandstone, shale, siltstone and claystone. The Leederville Formation encountered during the investigation is thought to be the Wanneroo Member, with sandy facies being grey, fine to medium grained, well sorted, subangular to subrounded quartz with white to grey feldspar, minor pyrite cemented sand and fossilised wood. The clay facies were dark brown to black, stiff and sticky. The sand and clay horizons were typically only 2 to 3 m thick.

Distinction between the different Leederville Formation members is only possible through downhole geophysical logging which was not conducted during the investigation. The Leederville Formation is disconformably overlain by the Osborne Formation (Henley Sandstone Member and Kardinya Shale Member), Molecap Greensand, Gingin Chalk and/or the superficial formations on the Swan Coastal Plain.

The Leederville Formation outcrops along and to the east of Gingin Scarp, in vicinity of Gingin townsite and GGB11. The Leederville Formation was intersected at 11 locations (GGB4 to GGB14) but not fully penetrated during the investigation.

Palynology samples were used to confirm the presence of the Leederville Formation. The Leederville Formation is characterised by the *Balmeiopsis limbata* spore pollen zone, placing the Leederville Formation age at Late Valanginian to Aptian (Lower Cretaceous). The Leederville Formation was identified as a fluviatile environment in all viable palynology samples during the investigation apart from a sample at GGB13, which indicated a shallow, possibly restricted, marine environment (Backhouse Biostrat Pty Ltd 2009b).

The geological boundary between the Leederville Formation and superficial formations near the base of Gingin Scarp appears to have a relatively unconformable contact. Figure 5 indicates that the Leederville Formation has been completely eroded towards the eastern end of the Swan Coastal Plain with the Parmelia Group subcropping the superficial formations.

Near Gingin townsite the Leederville Formation is overlain by the Molecap Greensand at GGB12, GGB13 and GGB14. Further to the east at GGB15, the

Kardinya Shale overlies the Leederville Formation separating it from the Molecap Greensand.

3.4 Coolyena Group

The Coolyena Group, as defined by Playford et al. (1976), comprises the Osborne Formation, Molecap Greensand, Gingin Chalk and Poison Hill Greensand. The Coolyena Group has been extended to include the contiguous Lancelin Formation. The Coolyena Group unconformably overlies the Leederville Formation and was deposited under shallow marine conditions during a period of tectonic stability (Davidson and Yu 2006).

The Molecap Greensand, Gingin Chalk and Poison Hill Greensand outcrop to the east of Gingin Scarp. They are extensive in the upper headwaters of Gingin Brook and Moondah Brook. It can be difficult to distinguish between the Poison Hill Greensand and Molecap Greensand based on lithology. It is often necessary to compare palynology samples, in conjunction with drill cuttings, to accurately determine the formation.

Osborne Formation

The Osborne Formation consists of three members – Mirrabooka, Kardinya Shale and Henley Sandstone. The Kardinya Shale Member was the only part of the Osborne Formation encountered during the investigation.

The Kardinya Shale Member comprises dark grey to black shale and clays with a greasy, oily appearance. The member is commonly glauconitic, with minor thin beds of mostly fine grained sand. The Kardinya Shale Member was not fully penetrated during the investigation, but was identified at two locations, GGB3A and GGB15A. It consisted of dense, black, shale underlying the Ascot Formation (GGB3A) or Molecap Greensand (GGB15A).

Palynology samples indicate the presence of *Endoceratium turneri* and the absence of common *E. ludbrookiae* and *Diconodinium spp*., suggesting these assemblages are older than the *E. ludbrookiae* dinocyst zone. The absence of *Muderongia tetracantha* and *Diconodinium davidii* indicates a biostratigraphic pick above the *M. tetracantha* dinocyst zone indicating the spore pollen zone is Early Albian in age (Lower Cretaceous), but not lowest Albian. The depositional environment was probably a shelfal marine environment (Backhouse Biostrat Pty Ltd, 2008a and 2009c).

Johnson (2000) mapped the beginning of the Kardinya Shale Member at about 4 km north-east of Gingin. The investigation broadly concurs with this assessment as the Kardinya Shale Member is absent from GGB12 and GGB14 at 5 km and 7 km north of Gingin.

Molecap Greensand

The Molecap Greensand is a poorly consolidated fine to coarse grained, grey to dark green, sometimes silty, glauconitic sand and sandstone. When weathered, the colours are typically yellow and brown from the breakdown of glauconite into pellets of iron oxides (Baxter 1977). The unit was present to the north-east of Gingin and fully penetrated in GGB12 to GGB15.

The base of the Molecap Greensand slopes slightly to the north (Appendix A, Figure A1). A maximum thickness of 30 m was recorded in GGB15 with the unit increasing in thickness to the north of Gingin (Appendix A, Figure A2). The unit outcrops along the Gingin Scarp, commonly being about 20 m thick.

The Molecap Greensand appears to pinch out towards the east of Gingin with only 10 m thickness at GGB14 next to Moondah Brook. The Molecap Greensand is overlain conformably by the Gingin Chalk to the east and Poison Hill Greensand to the north of Gingin.

The Molecap Greensand conformably overlies the Osborne Formation at distances of about 10 km to the east and north of Gingin or the Leederville Formation closer to the townsite (GGB12, GGB13 and GGB14). Palynology samples were not taken from the Molecap Greensand as the lithology was not suitable for analysis.

Gingin Chalk

The Gingin Chalk consists of weakly consolidated white to grey, friable, richly fossiliferous, slightly glauconitic chalk, occasionally containing thin beds of greensand (Davidson 1995). The Gingin Chalk lies conformably between the Poison Hill Greensand and the Molecap Greensand. The unit was only intercepted at GGB14, with a thin 3 m thick horizon consisting of very dense grey to white calcrete with a minor chalky residue.

Poison Hill Greensand

The Poison Hill Greensand lies conformably over the Gingin Chalk (GGB14) or Molecap Greensand (GGB12, GGB13, and GGB15). To the north of Gingin (GGB12 to GGB15) it consists of dark-brown, orange (oxidised) to green, glauconitic, well sorted medium to coarse grained quartz. While east of Gingin at GGB16, the Poison Hill Greensand also contained bands of ferruginous sandstone and sandy kaolinitic clay.

The Poison Hill Greensand was identified at outcrop and fully penetrated in GGB12 to GGB15. Maximum thickness of 45 m was recorded in GGB16 which did not fully penetrate the unit.

The base and thickness of the Poison Hill Greensand is depicted in Appendix A, figures A3 and A4. The base is relatively uniform at about 90 m AHD to 100 m AHD. However the thickness of the unit appears to increase markedly to the north and east of Gingin.

Palynology samples taken at GGB16 suggest that the Poison Hill Greensand may be reworked from the Mirrabooka Member of the Osborne Formation. The palynology samples had spore pollen assemblages somewhere in the Isabelidinium superzone of Helby et al. (1987). With reference to the unpublished thesis of Marshall (1984), the likely age of the Poison Hill Greensand is Campanian (Upper Cretaceous). The palynology suggests the samples were from the Lancelin Formation which is the lateral equivalent of the Poison Hill Greensand (Backhouse Biostrat Pty Ltd, 2009d).

Lancelin Formation

The Lancelin Formation consists of a white to greenish-brown, glauconitic marl (Davidson 1995). The unit was intercepted at two sites (GGB1 and GGB2) in the lower brook towards the western end of Chitna Road. Only the top 2 m of the formation was penetrated, which was micaceous clay. This clayey top section of the formation representing the light-brown weathered zone identified by Moncrieff and Tuckson (1989).

The Lancelin Formation is unconformably overlain by the Ascot Formation. Palynology samples confirmed spore pollen zone *I. pellucida to C. bretonica* with the age of the Lancelin Formation as Maastrichtian to Late Campanian/Late Cretaceous (Backhouse Biostrat Pty Ltd 2008b, 2008c.) The Lancelin Formation was deposited in transgressive and regressive marine (probably offshore) conditions.

3.5 Superficial formations

The superficial formations occur within the Swan Coastal Plain, west of the Gingin Scarp, comprising (from west to east) the Safety Bay Sand, Tamala Limestone, Bassendean Sand, Muchea Limestone and Guildford Clay. They also include the basal Ascot and Yoganup Formations. The superficial formations have been described in detail by Playford et al. (1976), Moncrieff and Tuckson (1989), Kern (1993) and Davidson (1995).

The extent of the superficial formations along the brook have been mapped using bore logs from this and previous investigations (Appendix A, figures A5 and A6). The base of the superficial formations (top of the Cretaceous deposits) slopes gradually to the west, across the Swan Coastal Plain between GGB8 (10 m AHD) and GGB1 (–10 m AHD). The base of the superficial formations then rapidly rises to the east from 10 m AHD to 100 m AHD between GGB8 and Gingin Brook No 5 part of the Gingin Brook Line (Sanders 1967).

The superficial formations greatest thickness (35 m to 50 m) occurs between GGB5 to GGB8 in the centre of the brook. The overall thickness of the superficial formations then decrease to the west and more significantly to the east along the brook. The superficial formations predominately terminate at Gingin Scarp, although Guildford Clay is present along the low lying brook channel as far east as Gingin townsite.

Ascot Formation

The Ascot Formation (also known as the Ascot Beds) is present beneath much of the superficial formations. It unconformably overlies the Lancelin Formation, Osborne Formation or Leederville Formation. The Ascot Formation was intercepted and fully penetrated from GGB1 to GGB9 with thickness increasing to the west and more significantly to the east of GGB5. A maximum thickness of 30 m was recorded in GGB9.

The Ascot Formation appears to have three distinct facies: the upper unit consisting of grey to light-brown marly limestone that is silicified with fine to very coarse, frosted, subangular to rounded quartz grains: the middle unit consisting of light brown, fine to medium grained, subangular, partially sorted sand with abundant shell and grit fragments: the basal unit consisting of black, fine grained, subangular partially to well sorted sand and silt.

The three facies represent different Pliocene shoreline environments. The upper limestone facies was deposited in a coral reef environment, with the middle shells and grit and lower silty sand facies accumulating under different energy shorelines facilitating the sorting which is evident in the deposits. Palynological interpretation was not possible as suitable samples were not encountered.

The Yoganup Formation, comprising a thin, discontinuous layer of fine to coarse grained sand, overlying the Ascot Formation with heavy minerals constituting up to 2% of some samples (Baxter 1977), was not identified during the investigation. However, it was intercepted in the Salvado bores to the north of Gingin Brook. Its occurrence seems to be more widespread and continuous to the north (Moncrieff and Tuckson 1989).

Guildford Clay

The Guildford Clay is generally restricted to the eastern portion of the Swan Coastal Plain with the formation becoming more sandy and silty towards the base of the Gingin Scarp. Guildford Clay is present at GGB1, GGB3, GGB5 and GGB7 to GGB11. The Guildford Clay is near the surface between GGB8 to GGB11.

The Guildford Clay appears to be the only unit of the superficial formations present east of Gingin Scarp. East of the Gingin Scarp the deposit is restricted to the low lying brook channel as indicated by the 1:250,000 Gingin geology map sheet (Wild and Lowe 1978).

The Guildford Clay is composed predominantly of light-grey, brown or grey-green clay with sandy lenses of moderately to well sorted quartz grains. Ferruginous sandstone or ‘coffee rock’ is developed near, and in some areas below the watertable. Minor cobble size angular black chert clasts were observed in GGB7 within a mottled brown to orange and black clay.

The Guildford Clay is of Pleistocene age, and unconformably overlies the Ascot Formation, Leederville Formation or Parmelia Group. It is often unconformably overlain and inter-fingered by the Bassendean Sand.

Palynology samples from GGB5A contain a range of modern angiosperm pollen and one spore type known to occur in fairly recent deposits. The pollen present include; *Acacia sp*., *Casuarina sp*.,*Chenopodaceae*, *Haloragacidites sp*. and *Poaceae* (grass pollen). The samples also contained some small translucent dinocysts which are suspected to be recent freshwater dinocysts. Such dinocysts are recorded from several freshwater localities in south western Australia. The age of the samples is between Pliocene and Holocene with the depositional environment probably freshwater swamp or lagoon (Backhouse Biostrat Pty Ltd 2009e).

Muchea Limestone

The Muchea Limestone consists of a soft to hard, cream to yellowish brown, sandy and marly limestone. It is often present along the western edge of the Pinjarra Plain forming a narrow discontinuous belt which has historically been subject to small scale quarrying. Muchea Limestone was identified in GGB5 and GGB6 from the surface to a maximum depth of 14 m. The limestone was probably deposited during the late Pleistocene, mainly in a lacustrine environment associated with springs (Moncrieff and Tuckson 1989).

Bassendean Sand

The Bassendean Sand is up to 16 m thick (GGB6A), and was fully penetrated from GGB1A to GGB7A. The deposit is generally thicker towards the west gradually thinning and pinching out to the east. The Bassendean Sand overlies the Ascot Formation and interfingers with the Guildford Clay, and is also overlain by Tamala Limestone towards the west.

The Bassendean Sand comprises light-grey, fine to medium grained, subangular to subrounded and moderately sorted quartz sand with traces of heavy minerals. The sands represent shoreline and dune deposits of Pleistocene age (Davidson 1995). Thin clay beds can occur as well as weakly cemented ferruginous sandstone – ‘coffee rock’ which is common near the watertable. Palynological interpretation was not possible.

Fine to very coarse grained, very poorly sorted, subrounded to rounded quartz sand with abundant feldspar was intercepted in GGB1A and GGB4A. This was initially described as Gnangara Sand. However, it is now amalgamated into the Bassendean Sand because it is not a mappable unit.

Tamala Limestone

The Tamala Limestone is commonly a coarse to medium grained calcarenite with skeletal fragments of foraminifera and molluscs. It can be cream to light-grey to yellow-brown with ferruginised zones. When oxidised the Tamala Limestone is light - grey to green-grey, compact and hard. Calcified root structures are common. These dissolve into tubular hollow structures (Davidson 1995). The Tamala Limestone is underlain by the Ascot Formation to the west and Bassendean Sand to the east.

The Tamala Limestone forms a coastal belt, up to 20 km inland extending eastward to GGB4. It forms large dune ridges of calcarenite at the coast that grade into calcareous sand further inland.

3.6 Surficial deposits

Alluvium

Alluvium occurs along the lower banks of Gingin Brook. It was encountered at GGB1 and GGB4 near the ground surface within the first few metres of drilling. The alluvium consists of a richly organic, black to brown sandy clay or clay up to 10 m thick (GGB4). It is likely that much of the lower floodplain has alluvium present at the near surface. Alluvium was not encountered to the east of GGB4, suggesting that deposition is restricted to the wider lower energy flood plain present in the lower reaches of the brook.

Colluvium

Colluvium covers wide areas of the Dandaragan Plateau, consisting of poorly sorted gravel, sand, silt or clay transported down slope by gravity. It is derived from the laterite profile and underlying Mesozoic rocks (Playford et al. 1976). Colluvium was not encountered during the investigation.

4 Hydrogeology

4.1 Groundwater occurrence

The regional hydrogeology has previously been described by Sanders (1967), Moncrieff and Tuckson (1989), Davidson (1995), Kay and Diamond (2001) and Davidson and Yu (2006). For a simplified description of the hydrogeology, geological formations have been combined into distinct aquifer systems. The superficial aquifer includes all superficial formations. The Mirrabooka aquifer comprises the Poison Hill Greensand, Gingin Chalk, Molecap Greensand and the Mirrabooka Member of the Osborne Formation.

4.2 Superficial aquifer

The superficial aquifer forms a major, unconfined to semi-confined aquifer, present beneath the coastal plain. The superficial aquifer matrix ranges from predominantly clayey sand and silt (Guildford Clay) at the base of the Gingin Scarp, a sandy succession (Bassendean Sand) in the central coastal plain, to sand and limestone (Tamala Limestone) in coastal areas.

The Ascot Formation forms the basal unit of the superficial aquifer over much of the coastal plain with a marly limestone and shell grit/sand lithology. Over much of the area the aquifer directly overlies sediments of Cretaceous age.

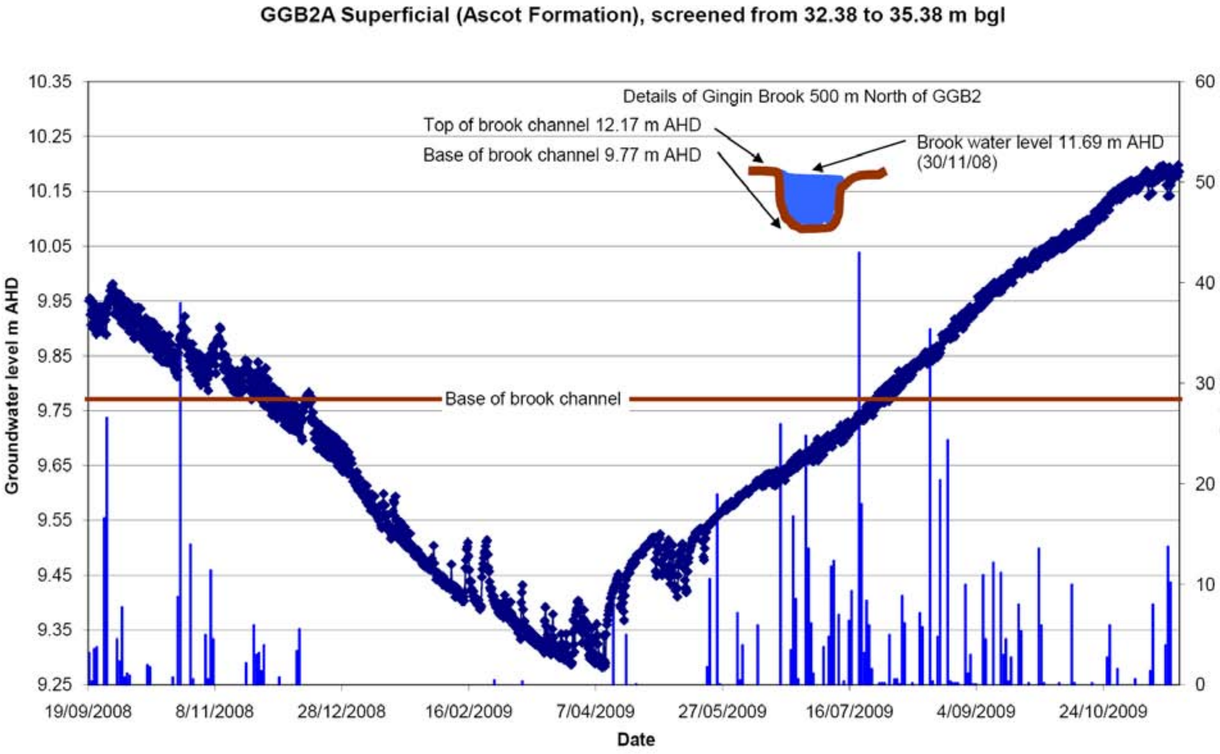
Appendix A, Figure A7 presents an isopach map of the superficial aquifer indicating a saturated thickness of 35 m to 40 m in the central area of the brook near GGB5 to GGB8, decreasing to the west and south. Hydrographs from the new monitoring bores along the brook are presented in Appendix B, figures B1 to B16. The watertable is highest during September to October and lowest during April to May.

The hydrographs show a rapid response to rainfall in superficial aquifer bores screened within deposits of sand or limestone. For example, rainfall of 8.8 mm on 14 April 2009 lead to an increase of 0.15 m in groundwater level within the space of two days in GGB2B.

A similar hydrograph trend is noted in the deep bore GGB2A at the same site which is screened at the base of the superficial aquifer into the Ascot Formation. These two hydrographs indicate a good response to recharge and excellent hydraulic connection between the shallow and deep sections of the superficial aquifer (Figure 6).

The Tamala Limestone and Bassendean Sand constitute much of the superficial aquifer in the lower reaches of the brook. Hydrographs indicate that good hydraulic connection exists at different depths with the superficial aquifer in this area.

The Bassendean Sand, Tamala Limestone and underlying Ascot Formation can also have good hydraulic connection in the central area of the brook where the Guildford Clay is absent, sand rich or sporadic.



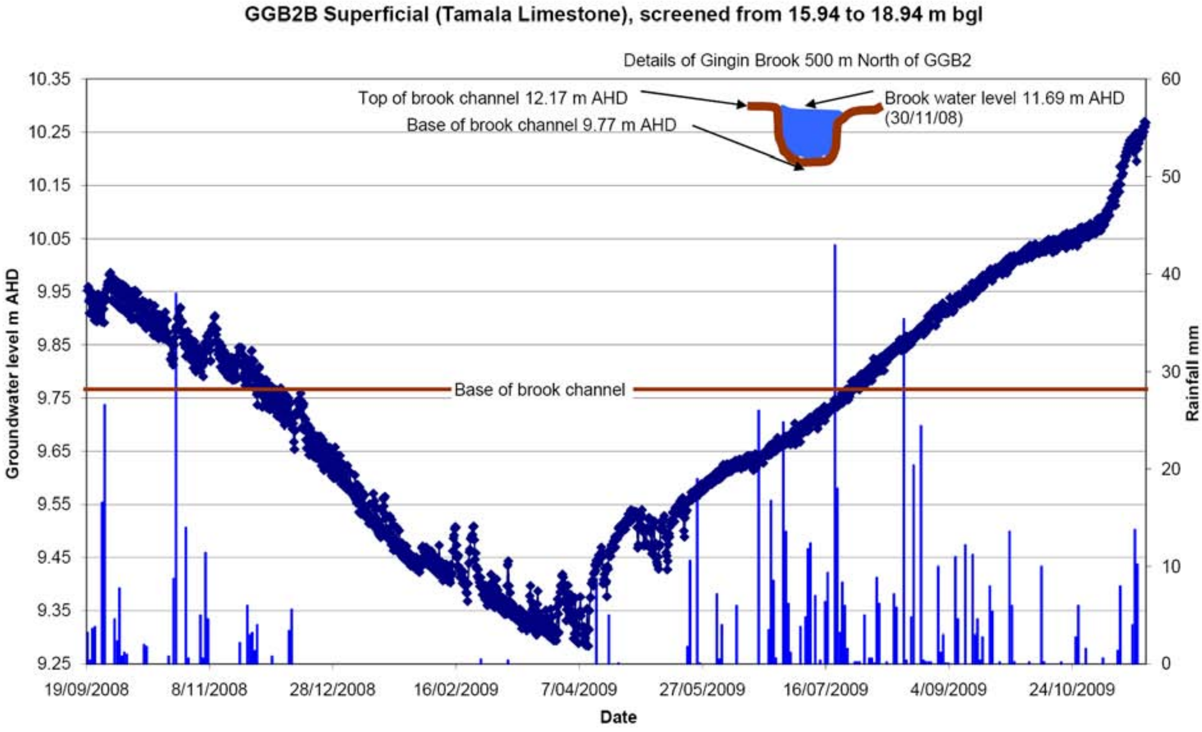


Figure 6 GGB2A/B hydrographs showing good aquifer connectivity

However, where significant Guildford Clay is present the base of the superficial aquifer is semi-confined. Semi-confined conditions are demonstrated by the hydrographs for monitoring bores screened in clayey superficial deposits such as GGB10A/B (Appendix B, Figure B10). The hydrographs show a muted response to rainfall, with little correlation between shallow and deep sections of the Superficial aquifer.

Perching of groundwater is evident along the Pinjarra Plain. Here it is likely that only a small percentage of rainfall results in recharge to the superficial aquifer. Water that does infiltrate into the ground is slow moving through the clayey soils of the Guildford Clay which act as an aquitard. The slow moving water is subject to loss through evapotranspiration before eventually reaching the deeper regional superficial aquifer.

The Guildford Clay on the Pinjarra Plain is characterised by surface water inundation and water logging in winter months, wetland features and an extensive anthropogenic drainage network. The thickness of the Guildford Clay is typically between 2 and 3 m in the west but may be as much as 20 m in the east towards Gingin Scarp.

Guildford Clay facies become more of a fine grained sand or silt near the Gingin Scarp. This transition in facies and its effect on the superficial aquifer is evident in hydrograph GGB9B (Appendix B, Figure B9) with the bore screened in clayey deposits. The watertable here is ‘perched’ with a tight range varying less than 0.1 m, showing no response to rainfall. Compared to GGB10B (Appendix B, Figure B10) which is closer to Gingin Scarp, and screened in a silty fine sand. The watertable here has a larger range of 0.3 m, showing some response to rainfall.

At GGB5A (Appendix B, Figure B5) the Bassendean Sand is in hydraulic connection with the underlying Ascot Formation. The Bassendean Sand and Ascot Formation are locally confined by the presence of 6 m of Guildford Clay, resulting in artesian groundwater conditions of around 1.7 m above ground level in bore GGB5A. This shows that in localised areas the Guildford Clay is an affective aquitard, confining sections of the deeper superficial aquifer. The shallow bore GGB5B (Appendix B, Figure B5) next to GGB5A is subartesian as it is screened above the Guildford Clay confining layer.

The Ascot Formation forms a semi-confined aquifer at the base of the overlying superficial formations. It is an important source of groundwater with reports from landowners and local drillers indicating that the Ascot Formation may yield up to 500 kL/day of potable to marginal quality water from suitably constructed production bores.

The hydrograph from GGB3A (Appendix B, Figure B3) screened in the Ascot Formation shows pumping effects of about 1.1 m from three production bores at a turf farm, located 300 m from GGB3A. The shallow bore GGB3B (Appendix B, Figure B3) screened in the Bassendean Sand above the Ascot Formation records only a muted pumping effect from the production bores. This demonstrates that pumping impacts are not readily transmitted from deep to shallow sections of the superficial aquifer where the Guildford Clay is present with a clay rich facies.

4.3 Mirrabooka aquifer

The Mirrabooka aquifer is an unconfined aquifer comprising three formations – the Poison Hill Greensand, Gingin Chalk and Molecap Greensand (Mirrabooka Member of the Osborne Formation, not encountered during the investigation). The Mirrabooka aquifer is predominantly recharged by rainfall and is the primary source of groundwater discharge in the headwaters of Gingin Brook.

The depth to watertable is greatest beneath catchment divides and shallower near the brook. Saturated thickness within the Mirrabooka aquifer is a subtle reflection of the topography (Appendix A, Plate 8) suggesting that recharge occurs along the topographic highs with discharge towards low lying features like the brook.

The Kardinya Shale Member of the Osborne Formation is a confining layer (aquiclude) between the Mirrabooka and Leederville aquifers east of GGB15. It comprises dense, dark green siltstone and shale. Discharge from the Leederville aquifer into the Mirrabooka aquifer occurs where the Kardinya Shale Member is absent.

The hydraulic properties of the Mirrabooka aquifer vary along the brook. At site GGB14, 3 km to the east of Gingin next to Moondah Brook (tributary of Gingin Brook), the Mirrabooka aquifer consists of silty sand in the Poison Hill and Molecap Greensands with a dense calcrete layer in the Gingin Chalk, acting as an aquitard. This results in a poor aquifer providing only limited discharge to Moondah Brook. Aquifer connectivity between the Mirrabooka (GGB14B) and the underlying Leederville aquifer (GGB14A) is also poor with hydrographs showing completely different seasonal variation in the two aquifers (Figure 7).

The Mirrabooka aquifer 12 km east of Gingin (GGB16) comprises thicker Poison Hill Greensand (> 45 m) with a coarse grained sand and sandstone facies, resulting in a better aquifer, providing significant discharge to Moondah Brook.

4.4 Leederville aquifer

The Leederville aquifer is a major aquifer underlying the investigation area. It is semi-confined where it directly underlies the superficial aquifer, but over short distances and with increased depth it becomes confined by discontinuous interbeds of siltstone and shale. The Kardinya Shale Member has been eroded across the majority of the brook area (GGB4 to GGB14) leaving the Leederville aquifer in direct hydraulic connection with the overlying aquifer(s).

At the base of the Gingin Scarp the Leederville aquifer occurs at shallow depth and in some areas has been eroded completely. Johnson (2000) concluded that in the town of Gingin the aquifer had a direct connection with the brook. However, groundwater levels in bore GGB11A screened in the Leederville aquifer and GGB11B (Appendix B, Figure B11) screened into the Guildford Clay are below the base of the brook.

The direction of groundwater flow in the Mirrabooka aquifer was poorly understood prior to the investigation. Groundwater flow appears to be south-east (Figure 9) with much of the local throughflow in the Mirrabooka aquifer eventually discharging to the brook or superficial aquifer.

In low lying areas near the brook high groundwater levels occur. Bores screened in the Mirrabooka aquifer may discharge minor artesian flow, as is the case with production bores near GGB13 along Cheriton Road north-east of Gingin.

The Mirrabooka and Leederville aquifers to the east of Gingin are likely to provide most of the baseflow associated with the brook as it meanders through the town of Gingin. Further to the north and east of the town the Kardinya Shale Member of the Osborne Formation is likely to prevent hydraulic connection between the Leederville and Mirrabooka aquifers.

The Leederville aquifer potentiometric surface has been determined from deeper bores near the brook (Figure 10). The potentiometric surface indicates that there are two main groundwater flow directions present in the aquifer. One flow direction is to the south (on the eastern side of Gingin Scarp) and another to the west (to the west of Gingin Scarp) denoted by the two arrows in Figure 10.

The different flow directions are a result of the low hydraulic conductivity Parmelia Group which subcrops the superficial formations in the area near the Brand Highway, effectively separating the Leederville aquifer locally into two separate flow systems.

Historically, groundwater levels in the Leederville aquifer at Gingin townsite may have been above the base of the brook. However, abstraction from the town water supply borefield and a drying climate may have contributed to water levels declining below the base of the brook. A daily pumping effect of about 0.6 m from the operation of the Gingin borefield is evident in the hydrograph of bore GGB11A.

There are anecdotal reports by local drillers that artesian groundwater levels in the Leederville aquifer are still present in some northern parts of the Pinjarra Plain, near Beermullah Lake. Salvado Project bore 15A historically recorded artesian groundwater levels of up to 1 m above ground level (1996). However it has been subartesian since 2006.

Sanders (1967) suggested that there were artesian conditions from the underlying Leederville aquifer at Gingin Brook No. 3 from depths of 200 m to 300 m. Artesian conditions within the Leederville aquifer were also noted during this investigation at several locations along the brook. At bore GGB4A, GGB5A and GGB7A artesian flow occurred when the top of the Leederville Formation was penetrated by the drill string.

4.5 Recharge and discharge

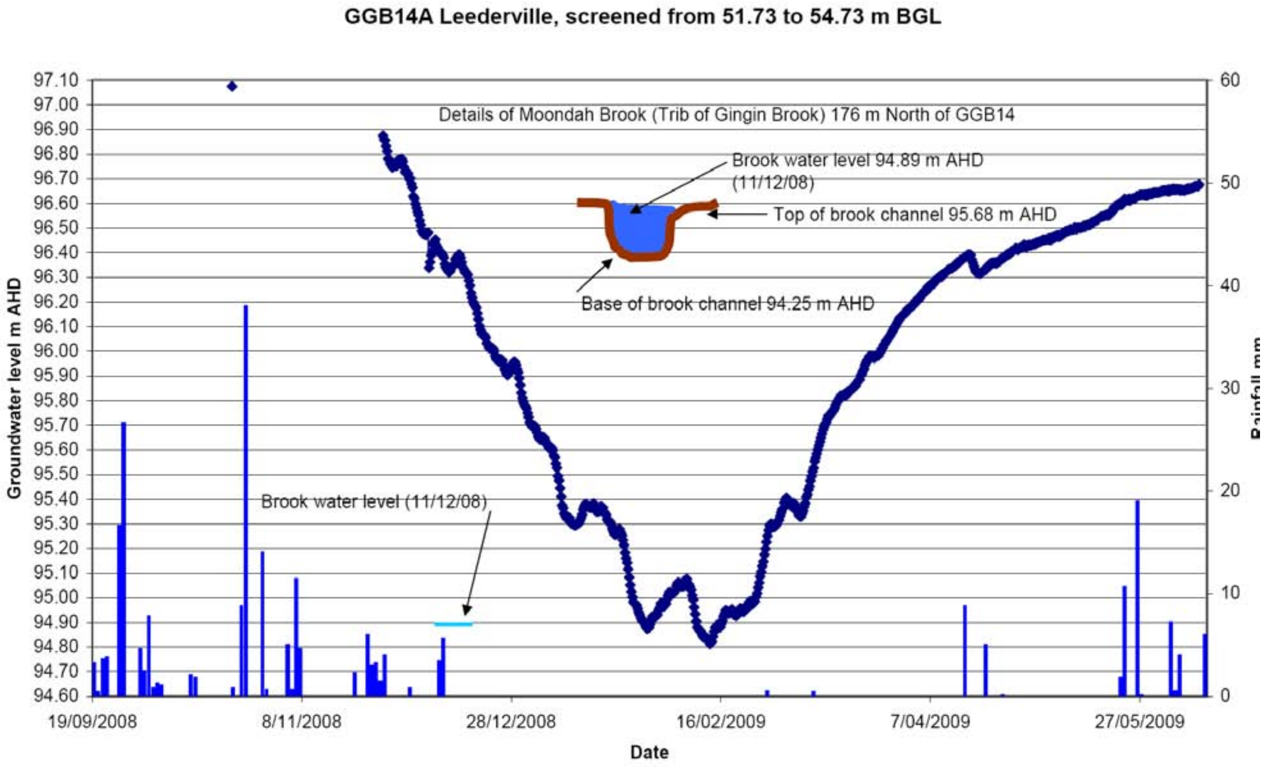
Groundwater moves very slowly through the superficial aquifer. It is eventually discharged at the hydraulic boundaries formed by the brook, some of the lakes, anthropogenic drainages into wetlands, at springs and latterly the Indian Ocean. Springs occur mainly adjacent to the brook where the watertable has intersected the banks of the brook. This can be observed as a damp area at the land surface, but at some localities springs may be visible, as is the case in the brook headwaters near GGB15.

Discharge also occurs by evaporation from wetlands, transpiration from vegetation where roots are able to reach the capillary fringe associated with the watertable, leakage into underlying aquifers where there are downward hydraulic gradients and confining beds are absent, and by abstraction of groundwater from bores.

The superficial aquifer has groundwater flow divides associated with topographic highs, with groundwater moving locally towards the low lying brook. The regional direction of groundwater flow in the superficial aquifer is westward to the coast (Figure 8).

Groundwater recharge to the superficial aquifer along the brook is highly variable. The areas where recharge occurs can be broadly split into three zones. These are Tamala Limestone of the lower brook, the Bassendean Sand of the middle brook and the clayey sand and silt of the Guildford Clay along the Pinjarra Plain and the Greensand on the foothills of the Dandaragan Plateau.

Estimation of rainfall recharge within these three zones following the methodology of Davidson (1995) is about 18% in the lower brook, 15% in the middle brook and 6.5% in the upper brook along the Pinjarra Plain and Dandaragan Plateau.



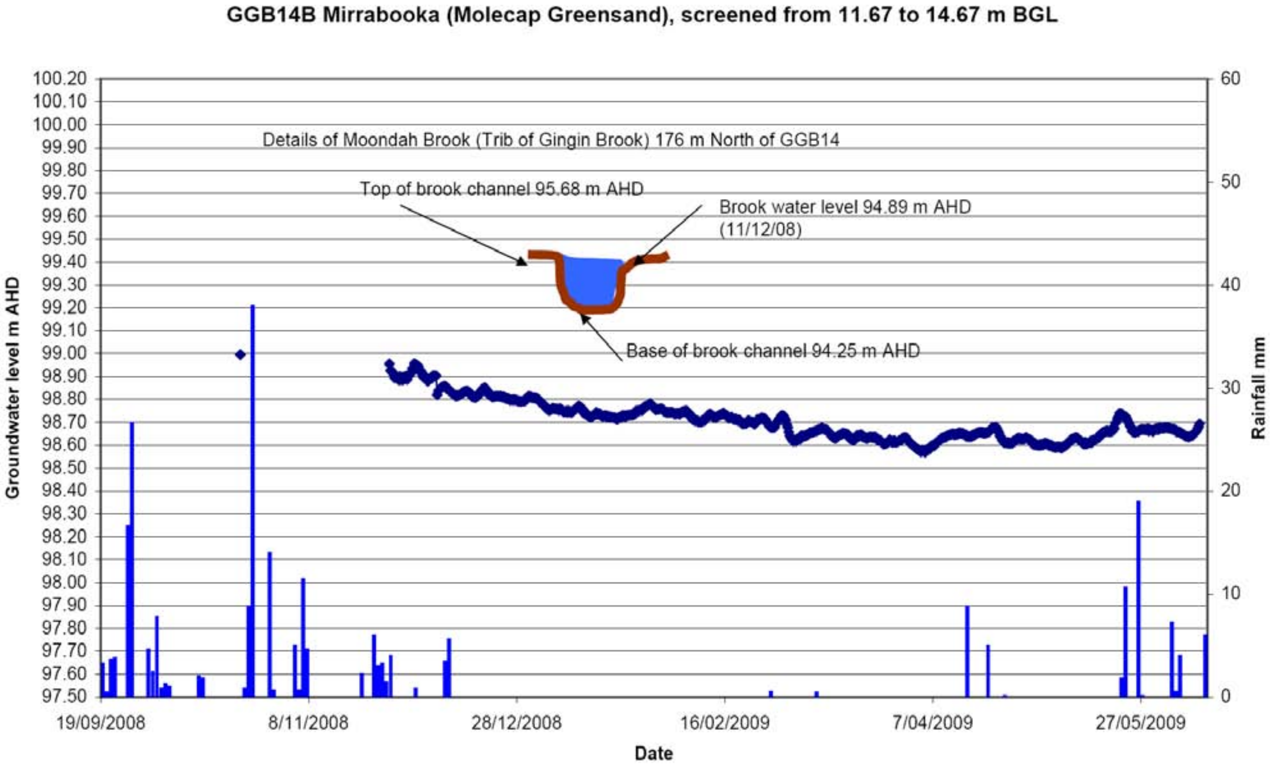


Figure 7 GGB14A/B hydrographs showing poor aquifer connectivity

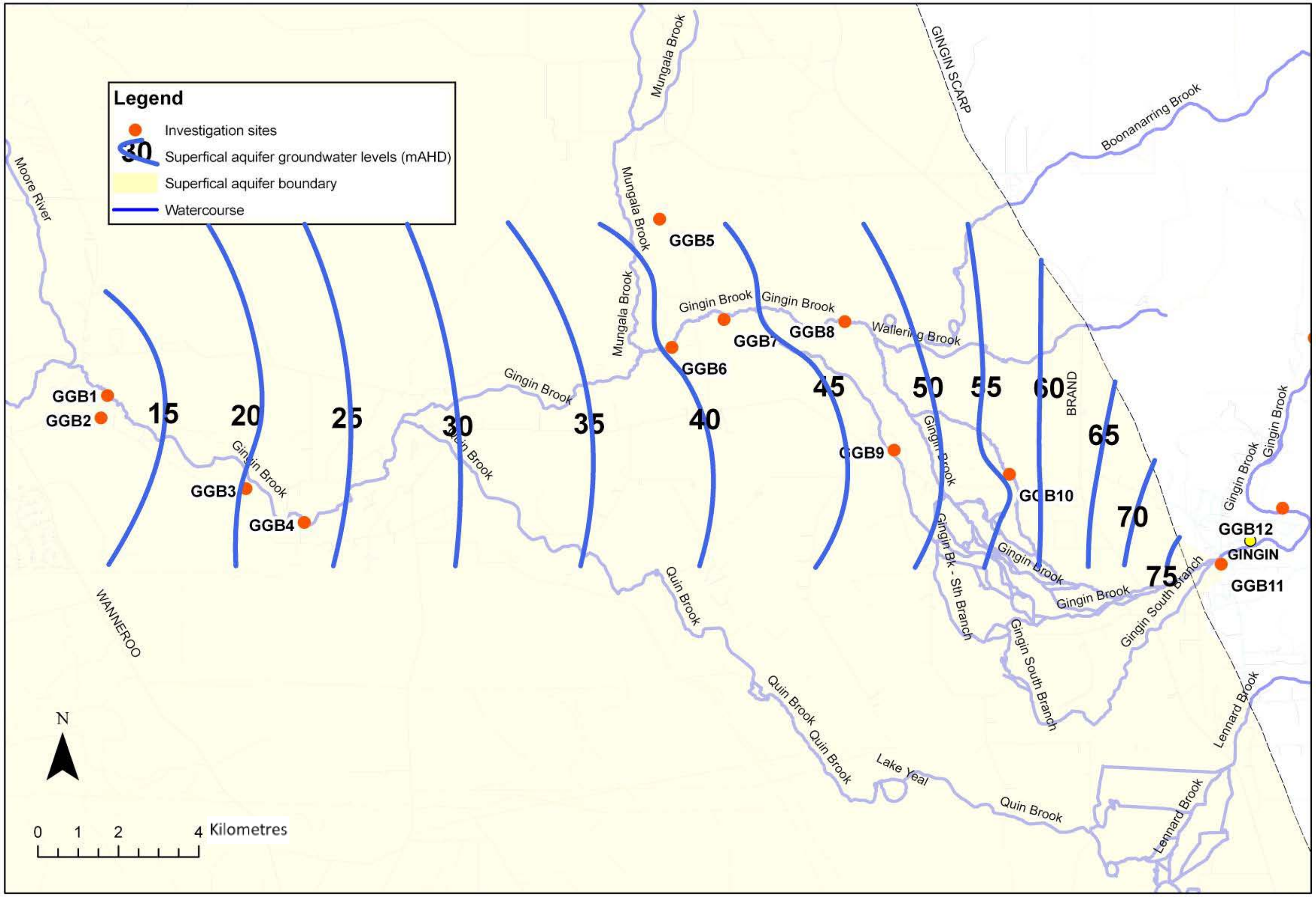


Figure 8 Superficial aquifer groundwater levels along Gingin Brook (May 2009)

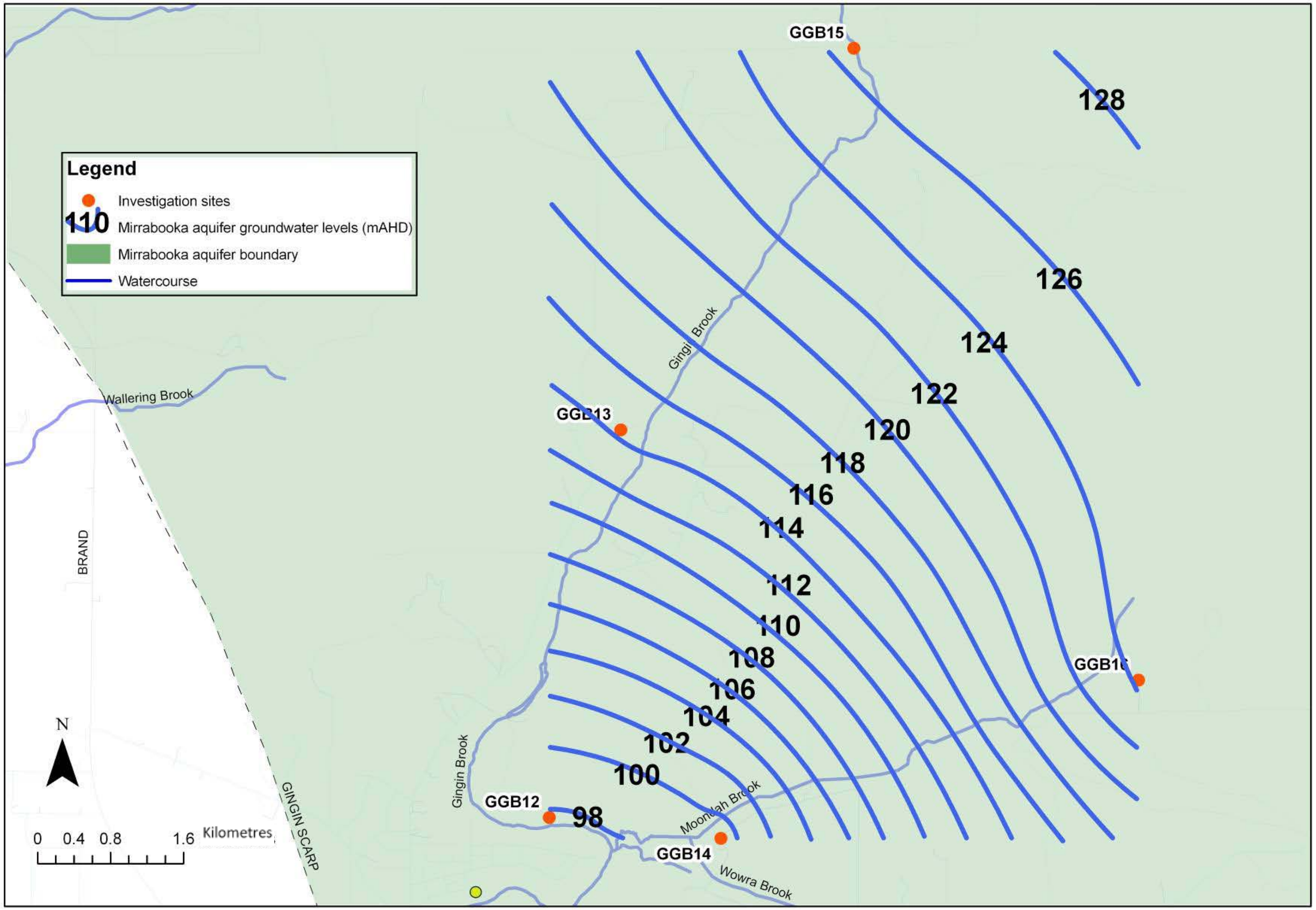


Figure 9 Mirrabooka aquifer groundwater levels along Gingin Brook (May 2009)

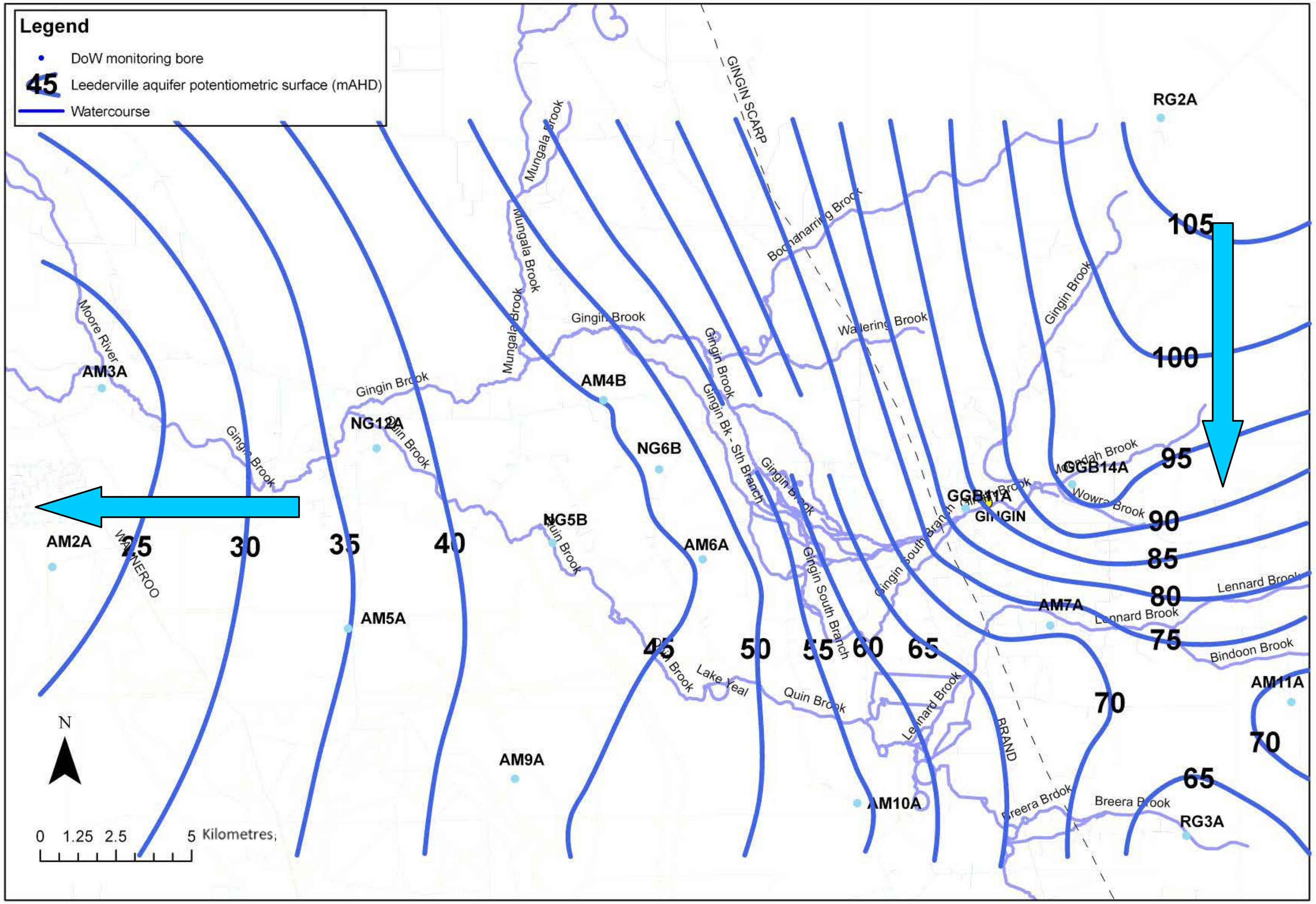


Figure 10 Leederville aquifer potentiometric surface along Gingin Brook (May 2009)

5 Hydrochemistry

Groundwater samples were taken at the completion of drilling. Results from the laboratory analysis of groundwater samples are presented in Table 3. The samples were compared to Australian Drinking Water Health, Aesthetic, Irrigation and Livestock guidelines (NHMRC & ARMCANZ 2000). Field measurements were also recorded using a flow cell and water quality meters for pH, temperature, EC, TDS, DO and ORP. The field measurements were consistent with those recorded in the laboratory analysis.

The groundwater samples from the 32 monitoring bores have been plotted in a Piper diagram (Figure 11). Symbols in the Piper diagram represent the different formation each bore was screened against. The hydrochemistry has been interpreted to understand the processes that have occurred during the movement of groundwater through the different aquifers.

5.1 Superficial aquifer

The groundwater within the superficial aquifer can be described as fresh to marginally brackish, ranging between 470 mg/L (GGB1A and GGB3A) and 1800 mg/L TDS (GGB9A and GGB10A). Groundwater salinity in the superficial aquifer is closely related to the lithology, with fresh groundwater in the Bassendean Sand and Tamala Limestone through to marginally brackish water in the Guildford Clay and basal Ascot Formation.

Marginally brackish groundwater was sampled in bores GGB9B, GGB10A and GGB10B screened in the Guildford Clay, recording salinity of between 1290 mg/L and 1800 mg/L TDS. Bores screened in the Ascot Formation (GGB6A, GGB7A and GGB9A) also recorded marginally brackish groundwater of between 1190 mg/L and 1800 mg/L TDS. The basal facies of the Ascot Formation are often silty sand, resulting in limited groundwater movement.

Aerosols containing sodium and chloride from the Indian Ocean are deposited in rainfall near the coast. In areas of slow groundwater movement through the superficial aquifer these salts build up increasing the groundwater salinity. Where groundwater is subject to long resident times in the shallow superficial aquifer it is also exposed to the process of evapotranspiration, further concentrating salts and increasing salinity.

Groundwater contained within the superficial aquifer (GGB1 to GGB10 and GGB11B) is mostly sodium and chloride type due to the proximity of the Indian Ocean. Some samples are calcium bicarbonate type, mostly from the Tamala Limestone or Ascot Formation due to the high alkalinity ($HC0_3$) of the limestone and shells within the deposits.

There is some grouping evident in the Piper diagram between the different lithologies of the superficial formations, although groundwater samples from the superficial aquifer predominantly represent a mix of waters given the heterogeneity of the lithology logged during the investigation. The pH in the superficial aquifer varies between a marginally acidic pH of 5.9 (GGB11B) to alkaline pH of 8.8 (GGB5A). The pH is generally associated with $HC0_3$ levels in the samples taken. The highest $HC0_3$ level of 320 mg/L (GGB5B) also corresponding to one of the highest pH measurements of 7.9. However, the elevated pH in GGB5A is not linked to $HC0_3$ levels as this is relatively low in the sample (25 mg/L). The elevated pH in GGB5A appears to be a result of carbonate dissolution as $CaC0_3$ (Appelo and Postma 2005).

The superficial aquifer groundwater generally exceeds aesthetic drinking water guideline values for iron, ranging from 0.02 mg/L (GGB5A) to 14 mg/L (GGB10A). The iron may result from a chemical reaction between acidic groundwater and ilmenite grains, which are contained mainly within the Bassendean Sand (Baxter 1977) or from yellow goethite coatings on sand grains (Glassford and Kelligrew 1976). Oxidised red to brown sand was often noted at the watertable cut during the investigation.

In the superficial aquifer, ORP measurements range from between -185 mV (GGB2A) and 170 mV (GGB2B). The deeper superficial aquifer is a reducing environment, while the shallow superficial aquifer near the watertable is an oxidising environment. Measurements of ORP taken from groundwater samples near recharge areas are generally more oxic than groundwater which is distal to recharge.

Nitrate values are low at less than 0.010 mg/L (GGB4A,B, GGB5A, GGB6A, GGB8A and GGB10A) to 4.5 mg/L (GGB8B). Nitrate tends to decrease with depth due to natural attenuation (dilution) and microbial activity, with samples from deep superficial bores having lower nitrate.

5.2 Mirrabooka aquifer

The groundwater in the Mirrabooka aquifer can be described as fresh to brackish, having a broad range between 150 mg/L (GGB15B) and 2620 mg/L TDS (GGB14B). The brackish samples represent groundwater that is distal to recharge, with long residence times, being subject to evapotranspiration.

Brackish groundwater was sampled in GGB14B where the Mirrabooka aquifer is confined beneath 3 m of dense calcrete (Gingin Chalk). The underlying sand at this site was silty resulting in low hydraulic conductivity and slower groundwater movement.

Samples from GGB15A and GGB15B recorded the lowest salinity, being located at the headwaters of Gingin Brook and proximal to recharge. Here the Poison Hill and Molecap Greensands forming the matrix of the Mirrabooka aquifer are coarse grained sand, resulting in higher hydraulic conductivity and quicker groundwater movement.

Groundwater contained within the Mirrabooka aquifer is dominated by rainfall derived sodium and chloride ions. Magnesium is a subdominant groundwater type in some samples. The pH is acidic to marginally acidic between 4.1 (GGB13B) and 6.9 (GGB14B), corresponding to the concentration of $HC0_3$ present in the groundwater.

The ORP measurements confirm an oxic environment ranging between 34 mV (GGB14B) and 260 mV (GGB15B), typical of groundwater that is generally proximal to recharge. Nitrates were less than 0.010 mg/L (GGB12B and GGB15A) to 10 mg/L (GGB13A), with the higher nitrate samples associated with land use and recharge rates.

5.3 Leederville aquifer

Groundwater contained within the Leederville aquifer (GGB11A, GGB12A and GGB14A) is marginally brackish having a tight range of salinity between 570 mg/L (GGB14A) and 910 mg/L TDS (GGB12A).

The Leederville aquifer has sodium chloride groundwater type. The pH is marginally acidic between 6 (GGB11A) and 6.7 (GGB14A). ORP measurements were only available from one bore GGB14A, indicating a slightly oxic environment at 30 mV. Nitrates were less than 0.010 mg/L, indicating groundwater is moderately distal to recharge.

Table 3 Groundwater chemical analysis

Monitoring bore	Date sampled	Top of screen mbgl	Bottom of screen mbgl	General characteristics							Anions					Cations								Other analytes	
				pH	TDS (evap) mg/l	EC µS/cm	Temp ºC	ORP mV	DO mg/L	DO %	Cl^- mg/L	SO_4 mg/L	F^- mg/L	HCO_3^- mg/L	$N\text{-}NO_3^-$ mg/L	Ca^{2+} mg/L	Fe^{2+} (Sol) mg/L	Fe^{2+} (total) mg/L	K $(sol)^+$ mg/L	Mg $(sol)^{2+}$ mg/L	Mn (sol mg/L	Na $(sol)^+$ mg/L	B mg/L	SiO_2 mg/ L
GGB1A	11.12.08	21.67	24.67	8.0	470	880	20.6	-145	1.00	11.0	180	7	>0.2	170	0.01	59	**0.390**	0.42	4	11	0.053	100	0.036	19
GGB1B	11.12.08	3.73	6.73	7.9	**710**	1210	20.2	-26	1.01	10.9	**280**	24	>0.2	160	0.03	83	0.049	0.68	5	18	0.250	120	0.022	13
GGB2A	2.02.09	32.38	32.38	7.7	**580**	1060	21.0	-185	6.09	69.2	230	22	>0.2	190	<0.01	57	0.024	0.13	6	14	0.003	130	0.040	20
GGB2B	2.02.09	15.94	18.94	7.7	**540**	830	21.5	170	7.36	83.3	140	92	>0.2	140	8.50	89	0.620	9.80	2	8	0.039	60	0.056	18
GGB3A	11.12.08	22.93	25.93	7.9	470	860	20.5	-115	1.01	11.1	130	0	>0.2	**220**	<0.01	62	**1.100**	1.30	5	11	0.065	100	0.025	15
GGB3B	11.12.08	3.93	6.93	6.6	**720**	1190	19.1	161	4.34	46.6	250	120	>0.2	46	1.90	61	0.084	0.11	20	10	0.012	140	0.031	5
GGB4A	11.12.08	18.48	21.48	7.6	490	830	21.2	-108	1.69	18.9	140	0	>0.2	**210**	<0.01	68	**2.700**	2.70	4	11	0.004	80	0.028	13
GGB4B	11.12.08	7.71	10.71	7.6	**520**	930	20.7	-108	2.97	35.7	190	0	>0.2	**220**	<0.01	71	**2.700**	2.70	3	11	0.029	100	0.025	16
GGB5A	10.12.08	30.00	33.00	8.8	**750**	1460	20.8	165	0.85	9.5	**400**	55	0.2	25	<0.01	10	0.020	0.52	18	8	0.014	**250**	0.062	11
GGB5B	10.12.08	4.00	7.00	7.9	**1400**	2400	20.0	151	3.30	36.1	**560**	70	0.5	**320**	2.10	110	0.021	0.03	14	48	0.031	**320**	0.093	60
GGB6A	11.12.08	26.51	29.51	7.7	**1390**	2590	22.0	-117	1.45	16.6	**680**	54	0.3	**240**	<0.01	75	**0.830**	1.00	9	33	0.016	**390**	0.120	25
GGB6B	11.12.08	6.70	9.70	7.9	**1510**	2720	21.8	-149	2.06	23.4	**720**	55	0.4	**230**	0.37	66	**0.780**	0.93	10	33	0.016	**420**	0.100	17
GGB7A	10.12.08	28.95	31.95	7.7	**1190**	2260	21.5	-118	0.96	10.9	**590**	34	0.4	**230**	0.71	69	**1.300**	1.70	10	23	0.035	**350**	0.110	30
GGB7B	10.12.08	3.95	6.95	6.5	**730**	1240	22.1	na	na	na	**330**	36	0.4	47	1.70	27	**1.200**	2.60	6	15	0.053	**190**	0.040	45
GGB8A	10.12.08	33.29	36.29	7.4	**510**	910	21.5	-146	2.46	27.9	160	19	0.2	190	<0.01	68	**2.700**	3.10	8	13	0.250	100	0.047	33
GGB8B	10.12.08	3.94	6.94	7.5	**830**	1440	21.6	149	3.81	42.9	**280**	54	0.2	**260**	4.50	69	0.031	0.29	7	22	0.065	**200**	0.058	62
GGB9A	12.12.08	38.61	41.61	7.8	**1800**	3040	21.9	-63	4.20	48.0	**820**	36	0.4	**270**	1.00	120	**0.670**	0.71	9	51	0.012	**420**	0.100	29
GGB9B	10.12.08	9.67	12.67	7.9	**1290**	2310	19.8	64	na	na	**580**	50	0.3	**250**	0.32	100	0.140	7.60	9	40	0.550	**300**	0.100	17
GGB10A	9.12.08	21.66	24.66	7.3	**1800**	3000	21.2	-130	3.11	25.0	**840**	54	0.4	**210**	<0.01	110	**14.000**	15.00	11	43	0.002	**450**	0.100	41
GGB10B	9.12.08	4.00	7.00	7.7	**1600**	2680	21.2	na	na	na	**540**	37	2.3	>1	0.04	9	**0.770**	5.70	2	43	0.068	**530**	0.065	77
GGB11A	9.12.08	19.80	22.80	6.0	**780**	1460	22.0	na	na	na	**400**	43	<0.2	43	<0.01	14	**6.100**	6.50	13	25	0.130	**230**	0.095	40
GGB11B	9.12.08	43.87	46.87	5.9	**580**	1100	22.2	na	na	na	**290**	36	0.2	25	0.57	6	0.062	1.40	6	17	0.016	**180**	0.054	36
GGB12A	9.12.08	48.00	51.00	6.4	**910**	1730	21.9	na	na	na	**460**	34	0.3	100	<0.01	38	**5.800**	6.10	10	26	<0.001	**260**	0.140	34
GGB12B	9.12.08	10.12	13.12	6.1	**2150**	3610	21.1	na	na	na	**1100**	64	0.6	45	<0.01	45	**4.400**	4.40	18	79	0.002	**570**	0.160	45
GGB13A	9.12.08	32.23	35.23	5.8	360	670	21.0	na	na	na	140	24	<0.2	8	10.00	3	0.010	0.01	3	11	0.011	100	0.088	26
GGB13B	9.12.08	15.42	18.42	4.1	**1050**	1950	20.6	na	na	na	**530**	78	0.6	>1	3.90	2	0.062	0.15	9	37	0.130	**300**	0.160	53
GGB14A	8.12.08	51.73	54.73	6.7	**570**	1050	21.9	30	0.88	9.8	250	23	0.4	91	<0.01	13	**4.000**	4.20	9	15	0.200	160	0.080	38
GGB14B	8.12.08	11.67	14.67	6.9	**2620**	4850	22.7	34	2.87	34.0	**1500**	99	0.7	120	0.01	47	**0.960**	1.10	24	76	0.130	**840**	0.270	39
GGB15A	8.12.08	65.42	68.42	5.9	210	440	20.5	80	2.73	27.1	100	12	>0.2	17	<0.01	2	**3.900**	6.80	2	6	0.490	60	0.031	15

Monitoring bore	Date sampled	Top of screen mbgl	Bottom of screen mbgl	General characteristics							Anions					Cations							Other analytes	
				pH	TDS (evap) mg/l	EC µS/cm	Temp ºC	ORP mV	DO mg/L	DO %	Cl$^-$ mg/L	SO$_4$ mg/L	F$^-$ mg/L	HCO$_3^-$ mg/L	N-NO$_3^-$ mg/L	Ca^{2+} mg/L	Fe^{2+} (Sol) mg/L	Fe^{2+} (total) mg/L	K (sol)$^+$ mg/L	Mg (sol)$^{2+}$ mg/L	Mn (sol mg/L	Na (sol)$^+$ mg/L	B mg/L	SiO$_2$ mg/L
GGB15B	8.12.08	14.61	17.61	5.4	150	280	20.5	260	9.91	11.3	70	5	>0.2	4	0.57	1	0.008	0.10	<1	4	0.043	40	0.011	9
GGB16A	8.12.08	36.10	39.10	5.8	370	690	21.1	243	5.57	63.5	180	5	>0.2	8	1.50	5	0.011	0.36	2	18	0.044	90	0.040	15
GGB16B	8.12.08	22.19	25.19	5.6	190	350	21.0	262	5.47	61.5	70	5	>0.2	5	6.50	1	<0.005	0.07	1	6	0.130	50	0.029	12
Australian Drinking Water Guidelines health guideline values												500	1.5		50									
Australian Drinking Water Guidelines aesthetic guideline values				6.5–8.5	500						250	250		200		200*	0.3					180		
Water Quality Guidelines (2000) Primary Industries: Irrigation				<5 high corrs. pot. 5–6 likely corrs. pot.		Apple 1000 Potato 1700 Lucerne 2000 Olive 4000					Grape 175 Potato 175–350 Lucerne 250-700		1 – long term 2 – short term	no trigger value, but can cause scaling	5 - long term 25-125 – short term		0.2 – long term 10 – short term					Grape 115 Potato 115-230 Lucerne 230-460		
Water Quality Guidelines (2000) Primary Industries: Livestock					Poultry 2000 Dairy 2500 Beef 4000 Sheep 5000							1000	2							>2000				

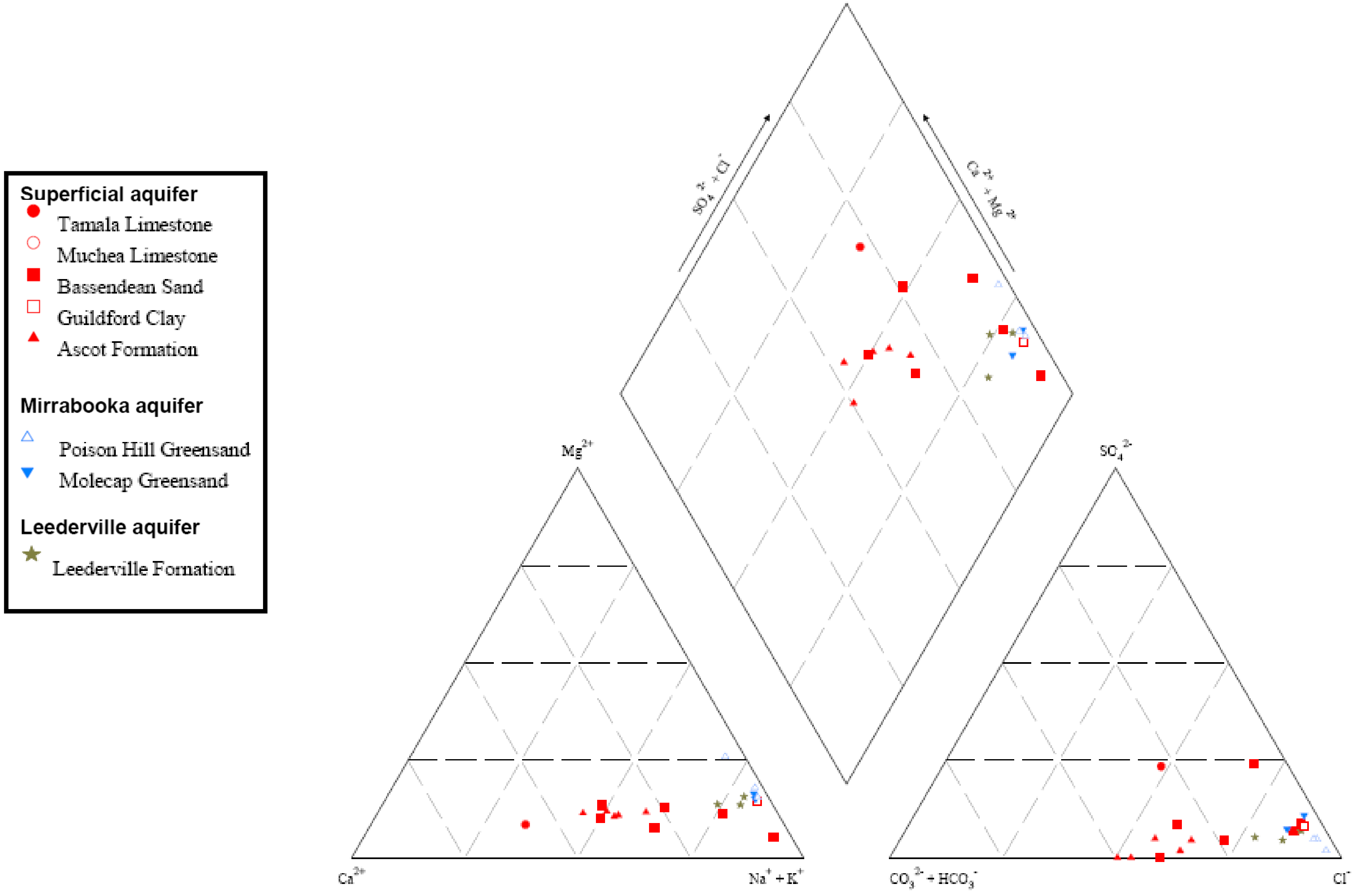


Figure 11 Piper diagram

6 Groundwater and surface water interaction

6.1 Groundwater contribution

In systems that are hydraulically connected, flow can take place between different parts of the system. In the case of a river and an aquifer, this mainly occurs where river bed and groundwater elevations are similar to each other (Brodie et al. 2007). To assess the degree of connection between the brook and the aquifers, and hence to assess the contribution from the brook to groundwater or from groundwater to the brook, the elevation of the base of the brook channel was compared to groundwater levels. The surveying of brook sections and monitoring bores to m AHD enabled this comparison to be made. Results of the comparison are presented for the superficial and Mirrabooka (Figure 12) and Leederville aquifers (Figure 13).

Superficial aquifer groundwater levels are predominantly above the base of the brook in the middle and lower reaches. Along the Pinjarra Plain groundwater levels are ‘disconnected’ below the base of the brook. The area of ‘disconnection’ and low groundwater levels starts at Gingin townsite, continuing west to the confluence with Wallering Brook and Gingin Brook. In the headwaters of the brook Mirrabooka aquifer groundwater levels are above the base of the brook in all bores, with groundwater levels increasing towards Gingin townsite.

The Leederville aquifer potentiometric surface is above the brook base along the western portion of the Swan Coastal Plain from the confluence with Wallering brook and in the area just to the north-east of Gingin townsite. Along the Pinjarra Plain and in the headwaters of Gingin and Moondah Brooks there are not many Leederville aquifer monitoring bores. The Leederville aquifer potentiometric surface here appears to be predominantly below the base of the brook with the limited monitoring available.

6.2 Gaining and losing brook sections

The connectivity mapping of the different aquifers along the brook has been compared to summer spot flow gauging measurements in Appendix C to confirm which sections of the brook are gaining or losing flow (Table 4). This information has been used to generate Figure 14, summarising the main areas of groundwater contribution to the brook, including which sections are gaining or losing flow.

In the headwaters and lower reaches of the brook the Kardinya Shale Member is at subcrop, confining the underlying Leederville aquifer. Here the brook is gaining water, solely from the Mirrabooka or superficial aquifer discharge. In the headwaters west of GGB15 and GGB16 or lower reaches east of GGB2, the brook is also ‘gaining’ from the Leederville aquifer where the potentiometric surface is above the brook base and the Kardinya Shale Member is absent.

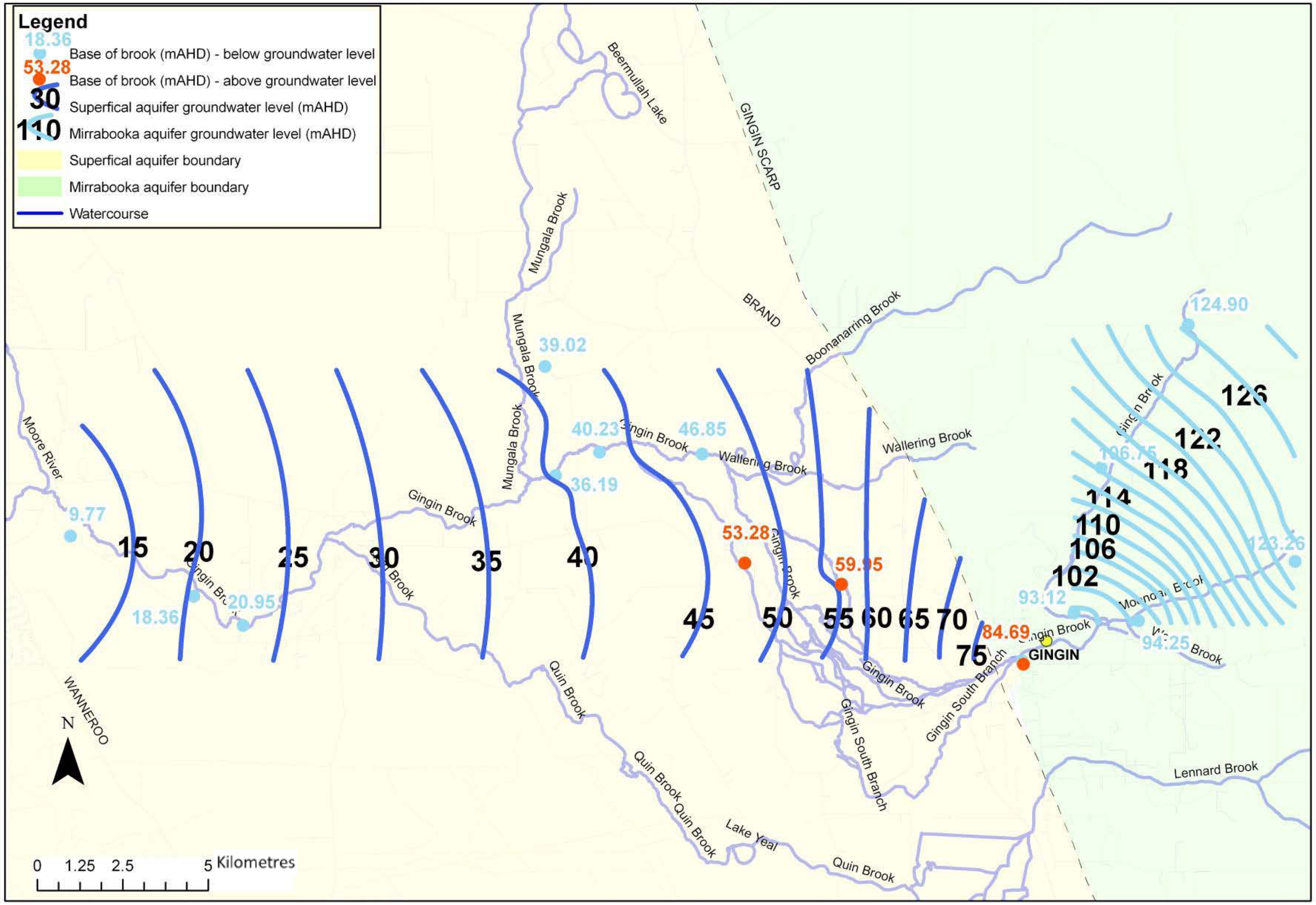


Figure 12 Superficial and Mirrabooka aquifer groundwater levels compared to Gingin Brook base (May 2009)

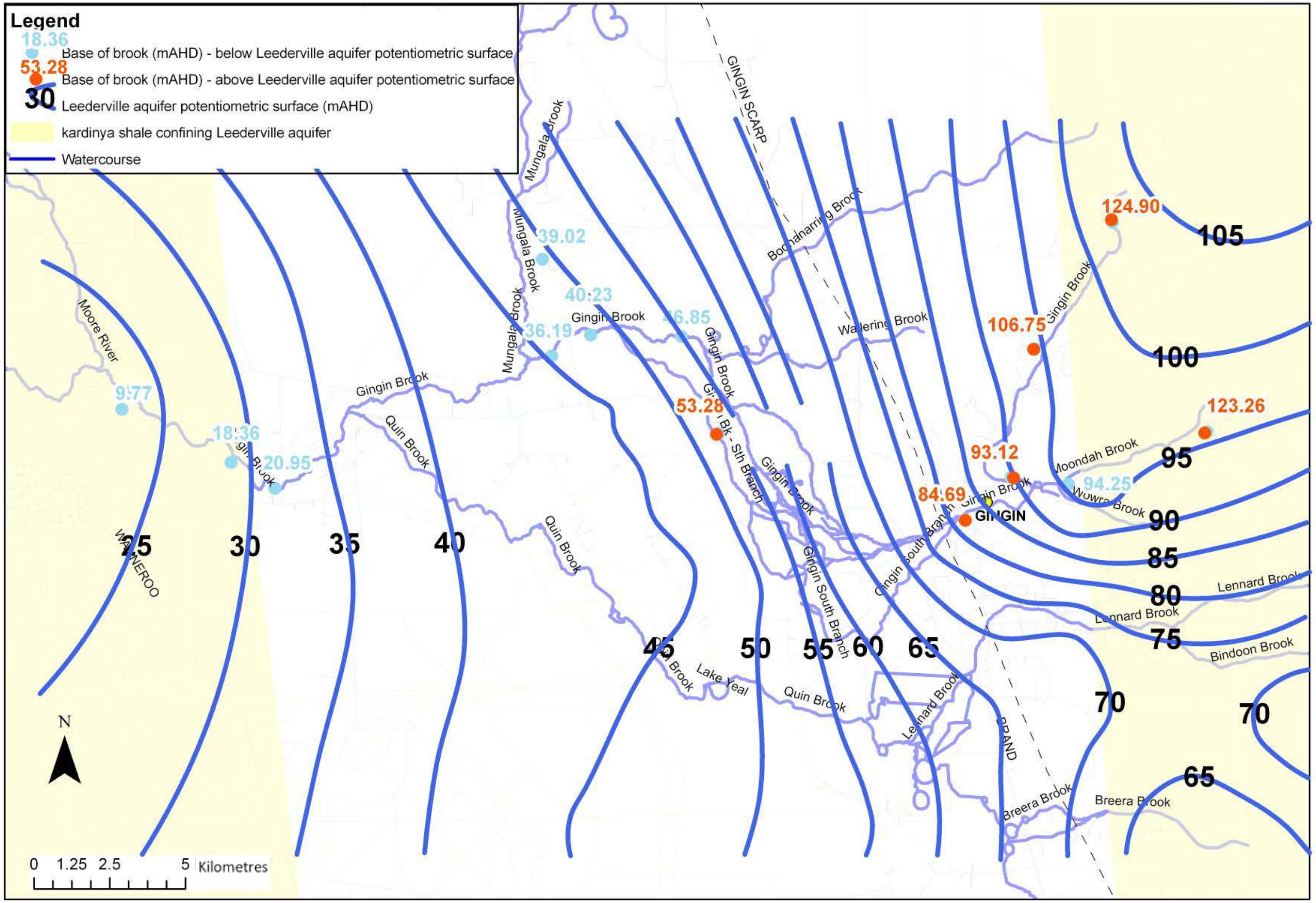


Figure 13 Leederville aquifer potentiometric surface compared to Gingin Brook base (May 2009)

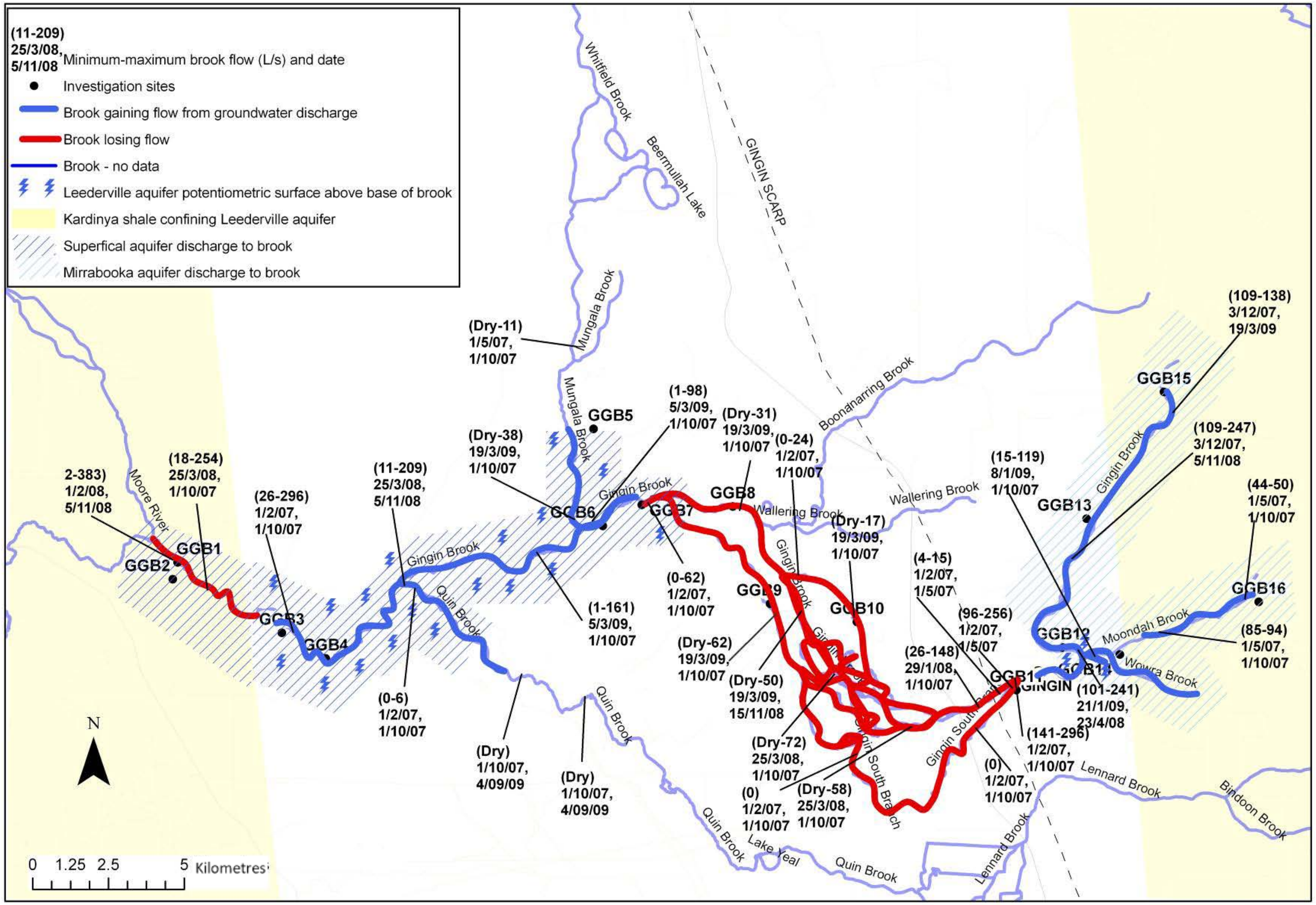


Figure 14 *Connectivity mapping and spot flow analysis of Gingin Brook*

Table 4 Groundwater levels and brook flow comparison

Bore and closest upstream and downstream gauging sites	Aquifer	Minimum groundwater level relative to base of brook m	Maximum groundwater level relative to base of brook m	Brook section in summer
GGB1A Upstream G03 Downstream G01	Superficial	2.00	2.50	Losing
GGB1B Upstream G03 Downstream G01	Superficial	1.50	2.30	
GGB2A Upstream G03 Downstream G01	Superficial	–0.40	0.20	Losing
GGB2B Upstream G03 Downstream G01	Superficial	–0.40	0.20	
GGB3A Upstream G05 Downstream G03	Superficial	0.40	2.20	Losing
GGB3B Upstream G05 Downstream G03	Superficial	2.40	2.20	
GGB4A Upstream G06 Downstream G05	Superficial	1.55	3.00	Gaining
GGB4B Upstream G06 Downstream G05	Superficial	1.55	3.00	
GGB5A Upstream G010 Downstream G08	Superficial	5.00	5.90	Gaining
GGB5B Upstream G010 Downstream G08	Superficial	0.85	2.00	
GGB6A Upstream G31 Downstream G09	Superficial	5.65	6.20	Gaining
GGB6B Upstream G31 Downstream G09	Superficial	1.90	2.50	
GGB7A Upstream G12 Downstream G31	Superficial	3.00	4.00	Losing
GGB7B Upstream G12 Downstream G31	Superficial	0.30	1.80	
GGB8A Upstream G12 Downstream G31	Superficial	–1.30	–0.50	Losing
GGB8B Upstream G12 Downstream G31	Superficial	–1.70	0.20	
GGB9A Upstream G32 Downstream G31	Superficial	–7.50	–7.00	Losing
GGB9B Upstream G32 Downstream G31	Superficial	–7.30	–7.00	
GGB10A Upstream G55 Downstream G52	Superficial	–6.60	–6.20	Losing
GGB10B Upstream G55 Downstream G52	Superficial	–3.30	–2.70	

Bore and closest upstream and downstream gauging sites	Aquifer	Minimum groundwater level relative to base of brook m	Maximum groundwater level relative to base of brook m	Brook section in summer
GGB11A Upstream G26 Downstream G58	Leederville	–3.10	–2.30	Losing
GGB11B Upstream G26 Downstream G58	Superficial	–4.25	–3.50	
GGB12A Upstream G45 Downstream G26	Leederville	–10.00	–8.70	Gaining
GGB12B Upstream G45 Downstream G26	Superficial	2.60	4.25	
GGB13A Upstream G46 Downstream G45	Mirrabooka	7.60	8.10	Gaining
GGB13B Upstream G46 Downstream G45	Mirrabooka	7.85	8.25	
GGB14A Upstream G28 Downstream G27	Leederville	0.55	2.85	Gaining
GGB14B Upstream G28 Downstream G27	Mirrabooka	4.35	4.75	
GGB15A Upstream G46 Downstream G45	Mirrabooka	1.65	1.75	Gaining
GGB15B Upstream G46 Downstream G45	Mirrabooka	2.40	2.45	
GGB16A Upstream G29 Downstream G28	Mirrabooka	1.30	1.45	Gaining
GGB16B Upstream G29 Downstream G28	Mirrabooka	–1.25	–1.10	

The connectivity mapping indicates that from GGB1 to GGB7 minimum summer groundwater levels within the superficial aquifer are predominantly above the base of the brook. In this area deeper bores indicate the potentiometric surface of the Leederville aquifer is also above the base of the brook.

Spot flow gauging and comparison of groundwater levels with the base of the brook suggests that there is no groundwater discharge from the Guildford Clay (superficial aquifer) on the Pinjarra Plain. This section of the brook loses flow and does not record any flow towards the end of the summer.

Based on brook bed elevations, the brook is between 0.5 m (GGB8A) and 7.0 m (GGB9A/B) above maximum groundwater levels in all bores between GGB8 and GGB11 along the Pinjarra Plain, apart from GGB8B, which is around 0.2 m above the base of the brook for the winter before dropping below the bed of the brook throughout the summer.

Along the Pinjarra Plain localised perching of the brook may result from the low hydraulic conductivity of the Guildford Clay. The series of wetlands (Beermullah and White Lake, Bootine Swamp) located at the base of Gingin Scarp on the Guilford

Clay support this idea. In areas where the Guildford Clay has a silty or fine sand facies the brook may lose water through leakage to underlying aquifers. However, along the Pinjarra Plain in the summer, most surface water in the brook would be lost through evaporation, diversion and riparian use.

The investigation results have been used to construct a conceptual diagram of Gingin Brook (Figure 15). The main areas of recharge to and discharge from the superficial, Mirrabooka and Leederville aquifers are noted. The importance of the Kardinya Shale Member to the west and east is also evident, with the unit confining the Leederville aquifer. There is also a disruption in the Leederville aquifer regional flow system caused by the absence of the Leederville Formation near GGB10, and the uplifted Parmelia Group block, which acts as an aquitard. This effectively separates the Leederville aquifer locally into two separate flow systems.

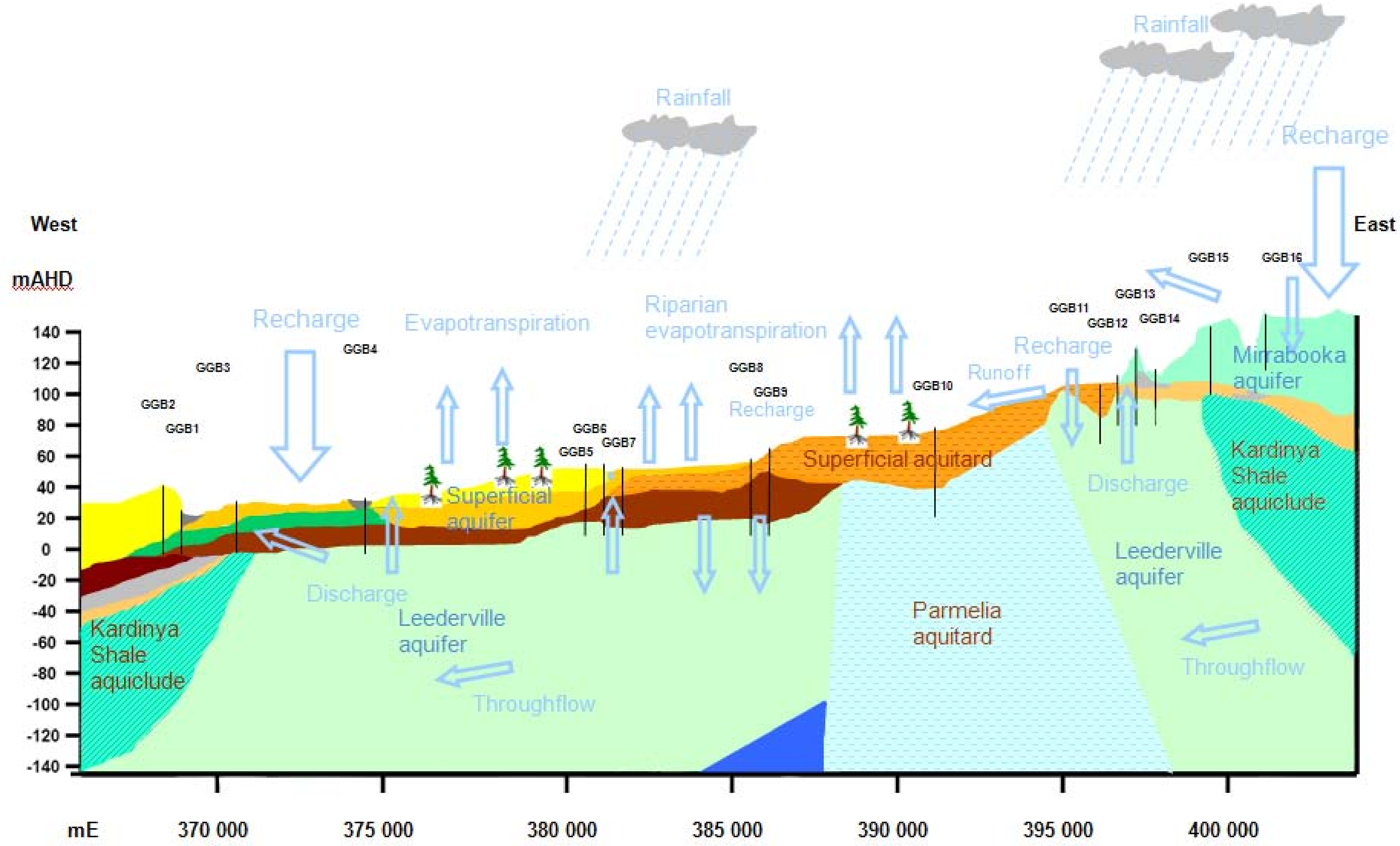


Figure 15 Conceptual diagram of Gingin Brook hydrogeology

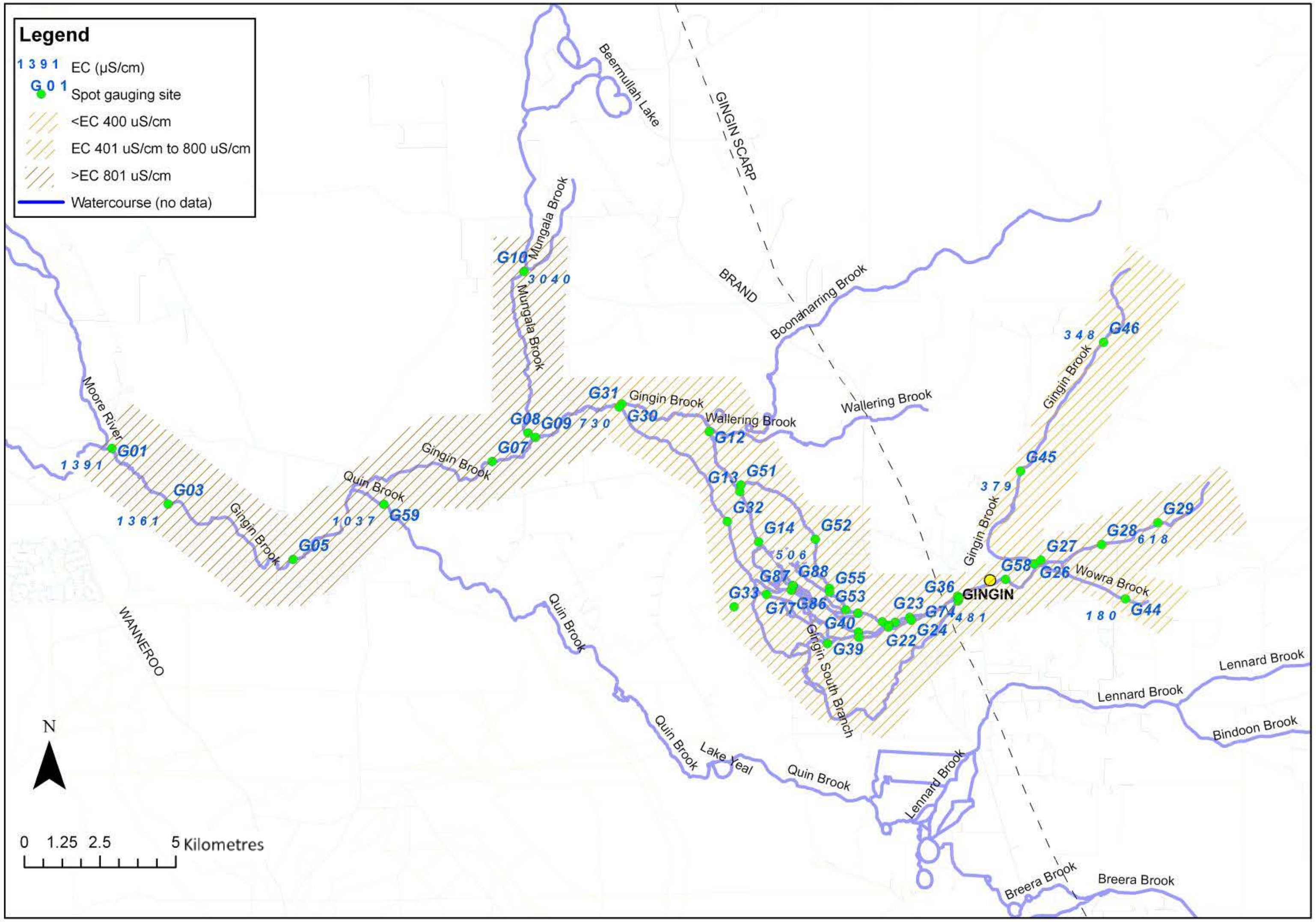


Figure 16 Summary of electrical conductivity survey of Gingin Brook

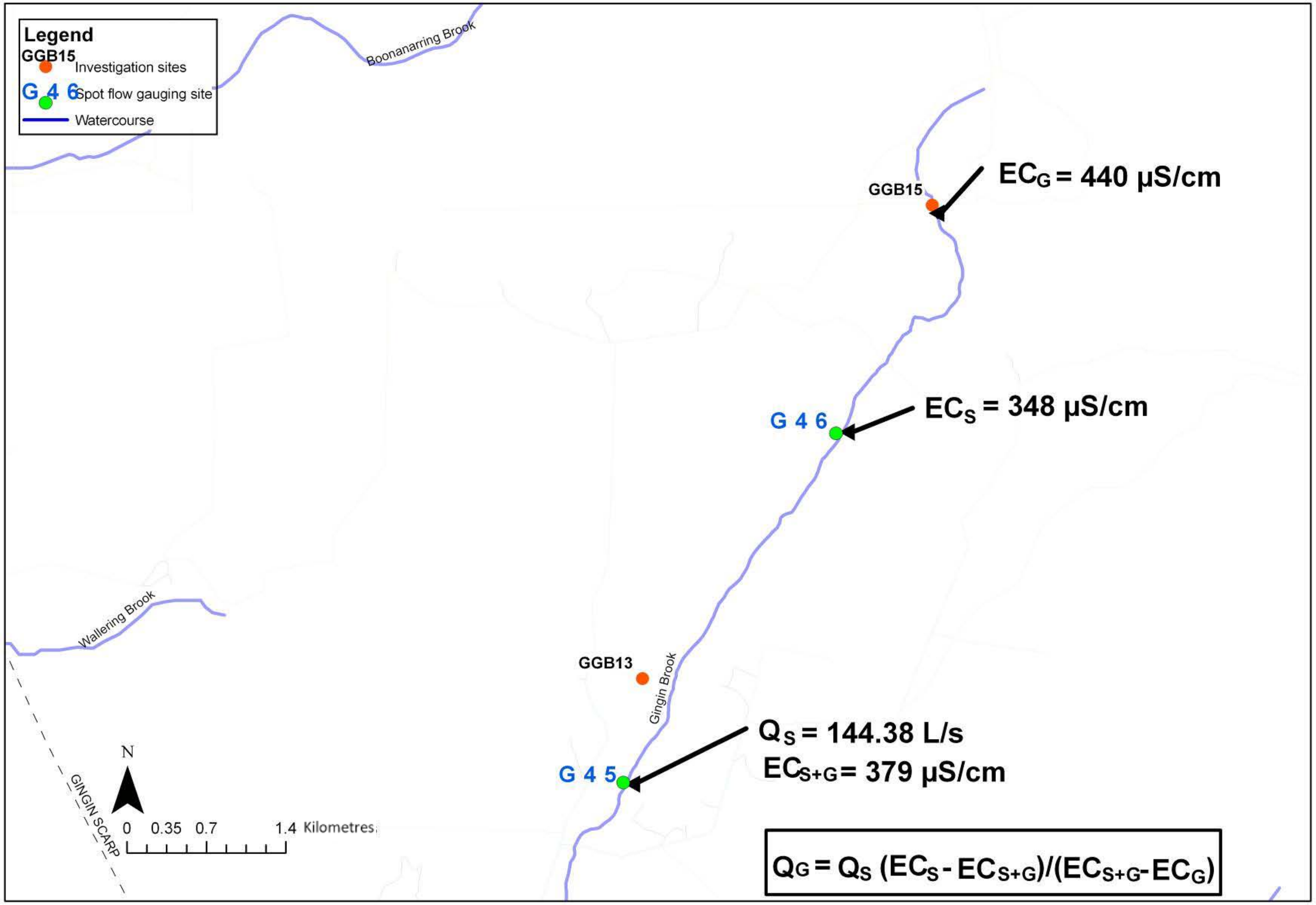


Figure 17 Depiction of mass balance electrical conductivity equation used on Gingin Brook headwaters

6.3 Summer surface water flows – groundwater discharge

The spot flow gauging in Figure 14 generally indicates that areas of the brook which are hydraulically connected to aquifers sustain a flow all year round. The section of the brook from 5 km west of Gingin to 3 km east of the confluence with Mungala Brook records no flow or is dry during the summer months.

Riparian evaporative processes dominate in this area as the brook deviates from one or two main channels to become a network of small drains, ditches and wetland sumps. This results in periods of no flow and drying of the brook in the summer.

The investigation shows that baseflow in the brook after a period of no rainfall is derived from and maintained solely by groundwater discharge. A reduction in groundwater discharge from the headwaters of the brook would result in larger downstream sections of the brook (as far west as the Gingin Brook and Mungala Brook confluence) drying out or recording no flow in the summer months.

6.4 Electrical conductivity survey of Gingin Brook

The measurement of surface water electrical conductivity at a number of locations along a river reach can determine if any noticeable pattern exists. This pattern may then be related to local groundwater EC, identifying contributions to streams from groundwater discharges (Porter 2001; Stelfox 2004).

The EC survey is specifically useful in areas where the shallow groundwater has relatively higher EC compared to the stream and is a significant contributor to the overall salt load of the stream. In this situation, groundwater inflows can be located by a corresponding peak in stream salinity.

During the spot flow gauging an EC survey was undertaken at some sites on Gingin Brook in February, May and October 2007. The results of the EC survey in February 2007 are most representative of brook baseflow and are summarised in Figure 16. These EC samples primarily represent groundwater discharge into the brook, as no rainfall had been recorded at Gingin for a period of 37 days. Full results of the EC survey are presented in Appendix D.

The EC of the brook baseflow has a broad range between 348 µS/cm (spot gauging site G46) in the headwaters of Moondah Brook and 2970 µS/cm (spot gauging site G9) at the confluence of Mungala Brook and Gingin Brook. The headwaters of Gingin Brook have the lowest EC (< 400 µS/cm) where discharge occurs solely from the Mirrabooka aquifer.

Surface water EC increases just to the north and east of Gingin townsite. Here the Kardinya Shale Member is absent resulting in Leederville aquifer discharge to the brook increasing the salt load.

An EC range of 401 µS/cm to 800 µS/cm was recorded in the brook along the Pinjarra Plain, where Guildford Clay outcrops (GGB8 to GGB11) and groundwater levels are ‘disconnected’ from the brook. Groundwater beneath the brook along the Pinjarra Plain has significantly higher EC (between 910 µS/cm in GGB8A and 3040 µS/cm in GGB9A) than water in the brook which is primarily derived from Mirrabooka and Leederville aquifer groundwater discharge further up in the headwaters.

In the lower reaches of the brook (GGB1 to GGB7) surface water is moderately brackish with EC greater than 801 µS/cm and up to 2970 µS/cm. Here the brook is again supported by groundwater discharge from the superficial and Leederville aquifers. These aquifers have a similar EC range of between 830 µS/cm (GGB2B and GGB4A) and 2720 µS/cm (GGB6B) to that of the brook surface water.

Deep aquifer contribution to brook baseflow

Differences in EC between shallow and deep aquifers can be used as a basis for calculating the respective discharge from each aquifer to baseflow in watercourse headwaters. The relative contribution from the deeper aquifer system (Q_G) can be estimated using the following mass balance equation (Oxtobee and Novakowski, 2002):

$$\mathbf{Q_G = Q_S \frac{EC_S - EC_{S+G}}{EC_{S+G} - EC_G}}$$

Where :

- Q_G is the relative contribution from the deep aquifer system
- Q_S is the ambient stream discharge
- EC_S is the measured ambient EC of the stream (top of watercourse headwater)
- EC_G is the measured EC of the deep discharging aquifer groundwater
- EC_{S+G} is the EC of the stream resulting from the mixing of the groundwater input (further down the watercourse from the headwater)

This method has been applied to Gingin Brook. Baseflow of the watercourse is measured (QS). From the available spot flow data, those for September 2007 are most indicative of baseflow. The ambient watercourse discharge EC is recorded (EC_S) at the top of the watercourse headwater. The deep aquifer EC is noted (EC_G), and finally further downstream from the headwater the watercourse EC is measured again (EC_{S+G}), which has been altered from mixing with the deep aquifer groundwater discharge.

The mass balance equation was used on the headwaters of Gingin Brook as the deep aquifer EC (GGB15A) is greater than that of the brook surface water. The mass balance equation applied to the headwaters of Gingin Brook is presented in Figure 17.

In this section of the brook, the watercourse EC increased by 31 µS/cm between measurement site G46 and G45, as a result of deeper aquifer discharge (higher EC) contributing to brook baseflow. The mass balance equation indicates that the relevant contribution from the deep aquifer system to the brook (QG) is 73.37 L/s or 50.8% of brook baseflow.

The mass balance equation could not be applied to Mungala Brook or Moondah Brook headwaters as the brook ambient EC (EC_S) is higher than that of the groundwater recorded in the shallow and deep bores at GGB5 and GGB16 (EC_G). This is significant, indicating that the majority of the baseflow in the Mungala Brook and Moondah Brook headwaters is derived from deeper aquifer systems (higher EC). In the case of Mungala Brook this deeper aquifer system would be the Leederville aquifer, while at Moondah Brook it would be a deeper section of the Mirrabooka aquifer.

At the confluence of Mungala Brook and Gingin Brook the brook flow is maintained all year round. Upstream of the confluence along the Pinjarra Plain the brook is dry or ponded in the summer. Brook surface water downstream of the confluence at spot gauging site G09 had an EC of 2970 µS/cm, significantly higher than the deep superficial aquifer at GGB7A (EC of 2260 µS/cm) and the shallow superficial aquifer at GGB7B (EC of 1240 µS/cm). This indicates that a significant amount of the baseflow in the brook downstream of the confluence with Mungala Brook is derived from higher EC groundwater than that present in the superficial aquifer.

This higher EC groundwater must be from the Leederville aquifer which underlies the superficial aquifer. The mass balance equation used in the headwaters of the brook could not be applied in the area downstream of the confluence with Mungala Brook due to lack of surface water monitoring data.

Further downstream of the Mungala Brook confluence the EC of the brook baseflow decreases from 2130 µS/cm (spot gauging site G07) to 1361 µS/cm (spot gauging site G03). This decrease in the EC of baseflow is coincident with the confining of the Leederville aquifer by Kardinya Shale Member.

Once the Leederville aquifer is confined, the EC of the brook baseflow decreases to a similar range to that of the superficial aquifer groundwater in the area surrounding the brook. The superficial groundwater EC sampled from investigation sites in the lower brook (GGB1 to GGB4) ranges between 830 µS/cm and 1210 µS/cm.

7 Management considerations

Water allocation and conservation is administrated by the Department of Water in accordance with the *Rights in Water and Irrigation Act 1914*, amended 2000. Under the Act, the right to use, flow and control groundwater and surface water is vested in the Crown. The Act requires the compulsory licensing of groundwater and surface water except where a right is conferred under section 26L of the Act.

Groundwater management in the Gingin groundwater area is implemented through an interim groundwater allocation strategy (Water and Rivers Commission 2002) which is currently being revised to full allocation plan status. This strategy describes how groundwater allocation limits were determined, and how groundwater is to be licensed in the various groundwater subareas.

Surface water in the brook is managed in accordance with the *Gingin surface water allocation plan* (Department of Water 2009a). The allocation plan details allocation limits for different catchments in the brook, management objectives and conditions for licence holders.

The groundwater and surface water management strategy objectives and conditions are reviewed below, based on the results of the Gingin Brook hydrogeological investigation. Hydrogeological advice has been provided to the Department's Water Allocation Planning Branch based on the results of the investigation and recommendations outlined below.

7.1 Groundwater abstraction

The department's approach to groundwater management is to manage groundwater resources so that they are sustainable in the long term. This means that demand and usage should not continuously exceed recharge. Management strategies attempt to also consider the current and future development in a groundwater area, as well as the potential impacts of sustained abstraction. The Gingin groundwater area is located in the Perth Basin, between 40 km and 150 km north of Perth and covers an area of 6147 km^2, split into 23 subareas.

Unconfined subareas – Superficial and Mirrabooka aquifers

Only a portion of each aquifer within the unconfined superficial and Mirrabooka subareas will provide groundwater discharge to the brook. These are primarily areas that are close to the brook, have groundwater levels above the base of the brook and have a sloping topography towards the brook channel.

The most productive groundwater resources in the area around Gingin Brook are either fully allocated or over-allocated. The only significant unallocated groundwater resource in the superficial aquifer is currently in the Deepwater Lagoon groundwater subarea.

The Deepwater Lagoon subarea is largely coincident with the Pinjarra Plain, dominated by the Guildford Clay, which is a poor aquifer for groundwater development. Groundwater is 'disconnected' below the base of the brook in this area along the Pinjarra Plain. Development of the Deepwater Lagoon groundwater resource to the allocation limit is therefore unlikely to affect baseflow in the brook.

Applications for a groundwater licence in superficial aquifer subareas should be closely scrutinised because the saturated thickness of the superficial aquifer is small. Comparison of existing production bore screen depths with lithological data collected throughout the investigation suggests that the first few metres of underlying Leederville aquifer are often screened to maintain production bore yield in a bore which is licensed against the superficial aquifer.

To prevent this, lithological and geophysical logs should be reviewed by a Department of Water hydrogeologist with experience of the local lithology. The proponent should retain the lithological samples and may also be requested to submit palynology samples for analysis to confirm lithology and ensure suitable screen intervals are set only within the superficial aquifer. Currently the only requirement is to provide lithological and geophysical logs to the department.

The Mirrabooka aquifer is a significant source of discharge into the brook in the headwaters to the north and east of Gingin. The investigation has also shown that the brook does not receive groundwater discharge to the west of Gingin townsite, until downstream of the confluence with Wallering Brook.

Maintaining groundwater discharge in the brook’s headwaters is critical to prolonging flow permanence in the brook along the Pinjarra Plain during the summer. It is therefore recommended that the Mirrabooka aquifer allocation has a significant proportion reserved for environmental requirements.

Confined subareas – Leederville and Parmelia aquifers

The confined Leederville (SA3) and Leederville–Parmelia (SA6) groundwater subareas underlie the whole of Gingin Brook and its tributaries. Groundwater subareas for the confined aquifers are over-allocated by between 10% and 20%. The effects of over-use within these subareas, propagation of drawdown from other areas in the confined aquifers and a drying climate has resulted in a significant reduction of groundwater levels within the confined aquifers under Gingin Brook.

The artesian monitoring (AM) series of bores to the south of Gingin Brook indicate a reduction in groundwater levels of 6 m since the 1980s. The investigation has shown that despite this reduction the potentiometric surface in the Leederville aquifer is still above the base of Gingin Brook to the west of the confluence with Wallering Brook and in a small area to the east of Gingin townsite (Figure 13).

In these areas, where the Kardinya Shale Member is absent, the Leederville aquifer potentiometric surface supports the watertable in the aquifers above that subsequently discharge to the brook. It is therefore critical to maintain Leederville aquifer groundwater levels under the brook. Allocation limits should be returned to sustainable levels within groundwater subareas SA3 and SA6.

7.2 Surface water abstraction of baseflow

The allocation limits in the Gingin Surface Water Allocation plan are based on the volume of water that can be sustainably abstracted from a resource (section of brook). The current plan stipulates no ‘new’ water available for allocation. Allocation limits indicating that all surface water resource units are either fully, or over-allocated.

The allocation limits mostly pertain to summer surface water (baseflow) abstraction as this is when the majority of water is used. The amount of recharge from winter flows in the brook to underlying aquifer(s) is likely to be minimal compared to the recharge received from rainfall over the groundwater catchment area supporting the brook.

Therefore further consideration should be given to licensing high winter flows. Winter flows in the brook could be licensed from May to August when the brook catchment receives 70% of its annual rainfall. The winter flows could be pumped to off-stream storage for summer use. Currently there is no demand for winter abstraction from the brook, as off-stream storage is uneconomical. These options may become more cost effective if summer flows continue to be unreliable and small.

In 2007, there was below average rainfall in the Gingin area. However, winter flows in the brook were still significant, particularly when compared with allocation limits detailed in the surface water allocation plan. If a portion of these high winter flows could be stored and used during the summer months it would significantly reduce the demand on the brook during low flow periods in the summer (Department of Water 2009a).

7.3 Adaptive management

Average annual rainfall data from 1975–2003 has been used to calculate recharge for the groundwater and surface water allocation plans. The 1975–2003 isohyets data was used as it appropriately represents the step change that has occurred in Western Australia towards a drier climate.

The Department of Water predicts a further 15% reduction in rainfall by the year 2030 (Department of Water 2009b). Independent climate predictions by CSIRO over the same period for south-western Australia estimate a mean annual rainfall reduction of between 2% and 14% (CSIRO 2009). The 1975–2003 mean annual rainfall data has therefore been reduced by 15% before being used for the recharge calculations to allow for a continued drying climate scenario over the life of the allocation plans.

A further long-term shift to a drier climate will continue to reduce rainfall which may result in lower allocation limits. This would require a reduction in water entitlements and use as, in most instances, the licensed groundwater and surface water resource is already at the allocated limit or slightly above.

In the brook catchment a drying climate has in part been mitigated by land clearing, reducing evapotranspiration and increasing recharge. However, a drying climate and abstraction of groundwater have still been the dominant factors causing reduced recharge, resulting in a decrease in groundwater levels and discharge to the brook.

This is evident in the historical baseflow in the brook which gives an indication of the groundwater resource status around the brook before groundwater monitoring networks were in place. The gauging station at Bookine Bookine indicates that that minimum baseflow (6–8 ML/day) in the brook was recorded in the 1950s and early 1960s before major land clearing took place (Figure 18). Since the major land clearing, baseflow has been reasonably stable (8–10 ML/day) probably due to continued minor land clearing and brook channel modifications, mitigating the effect of reduced rainfall and groundwater abstraction.

The gauging station at Gingin townsite indicates that baseflows were relatively stable from the 1970s to 1980s at around 5–10 ML/day (Figure 19). Major land clearing probably helped to mitigate the impact of a drying climate and groundwater abstraction. However, since the 1990s baseflow has receded at around 1–5 ML/day with major land clearing no longer taking place.

On the 30 March 2008, a record low baseflow of only 0.63 ML/day was recorded at Gingin townsite, equating to an instantaneous flow rate of just 7.3 L/s. It is clear that a drying climate and abstraction will continue to reduce baseflow in the brook, particularly in the headwaters north and east of Gingin townsite.

The dynamic management of the brook’s finite resources and a move away from rigid allocation limits would help minimise effects on the brook in times of low flows and maximise the economic use of water. This approach is particularly suitable for use in a drying climate scenario where rainfall recharge is sporadic and demand for water resources is high.

7.4 Water resource licensing rules and conditions

The current strategies for groundwater and surface water management are based on allocation limits governing water resource management areas (river sections) and groundwater subareas. Suggestions for more dynamic management of the brook resources to maximise the available water and minimise effects on the brook in times of low flow are outlined below.

Surface water

Existing licence holders should be encouraged to switch from summer surface water abstraction to winter surface water abstraction and off-stream storage. New applications for winter off-stream storage should be considered (Department of Water 2009a).

Any new winter surface water licence could include the provision of a minimum flow threshold in the brook before abstraction can occur. The flow threshold would be in place to prevent abstraction of water from the brook in a low rainfall winter. Similar restriction could also be applied to existing summer surface water licences.

Groundwater

Johnson (2000) described the use of a groundwater model to determine the optimum position for bores into the unconfined aquifers along Lennard Brook while minimising effects on brook baseflow. Although based on Lennard Brook, the results of the modelling are considered relevant to Gingin Brook.

Results of the groundwater modelling indicated that production bores should be located at least 400 m from the brook, to minimise impacts on baseflow. Proponents who apply for groundwater licences with production bores close to the brook should confirm that no significant reduction in the brook baseflow occurs from the pumping of the bores. Monitoring bores may need to be installed as part of any licence conditions to determine drawdown close to the brook.

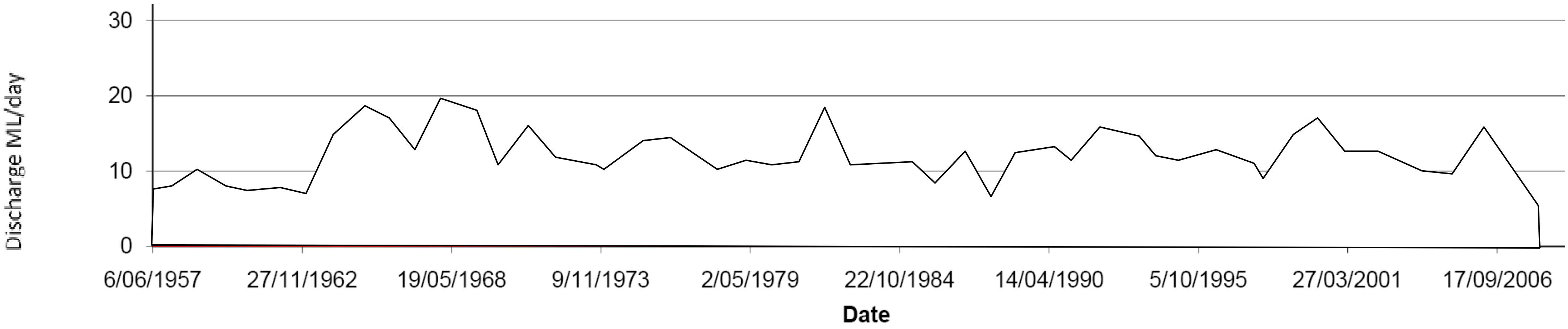


Figure 18 Minimum flows recorded at Bookine Bookine gauging station

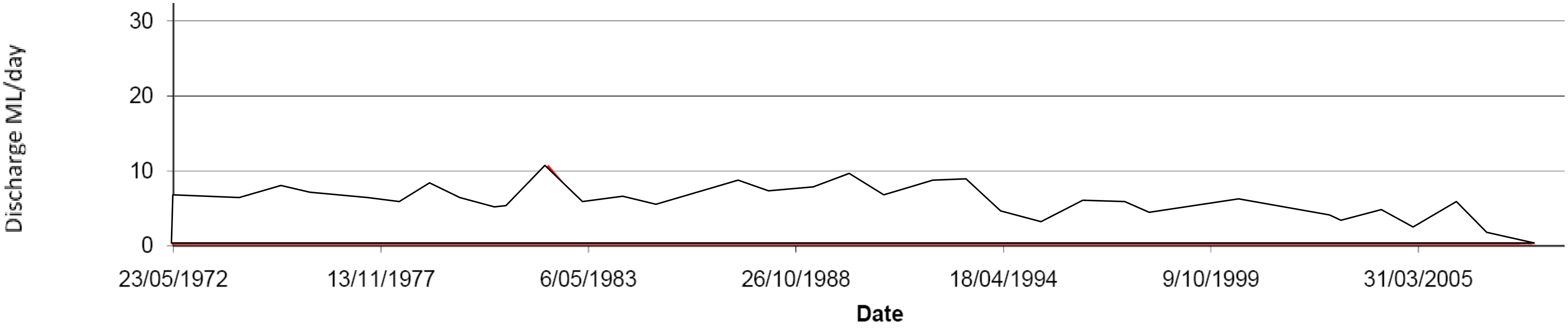


Figure 19 Minimum flows recorded at Gingin townsite gauging station

7.5 Modifications to the brook channel

The brook channel has been significantly modified, particularly over the Pinjarra Plain. The use of cut-off drains and diversions to direct surface water over properties bordering the brook, has diminished flow and reduced flow permanence in downstream sections.

The majority of the modifications were conducted historically or under the relevant licences. However, there is evidence that channel modifications are still taking place without the relevant consultation and consent.

Efforts to reduce allocated resources along the brook will be ineffective if continued channel modification is permitted. An enforcement survey should be conducted along the brook to determine which channel modifications have been given consent and where action needs to be taken to remove illegal modifications that impede flow.

7.6 Environmental water considerations

The management of groundwater and surface water allocation includes the determination of the volume of water required to sustain ecosystems dependent on this water. This requirement is formally known as the ecological water requirement.

The volume of water that will actually be provided to the environment is formally known as the environmental water provision. The level of this provision will depend on the cost benefit analysis of the social and economic impact compared with the ecosystem value.

A preliminary ecological water requirement study for Gingin and Lennard Brooks was completed by Storey and Davies (2002). The determination of groundwater dependency and water requirements was based largely on groundwater data by Johnson (2000) as well as integrating surface water data on streamflow along the entire brook. The ecological water requirement for the brook should be reviewed in view of the information provided from this investigation. This will enable environmental water provisions to be set in allocation plans that reflect the improved conceptualisation of the brook.

7.7 Future monitoring and review

Groundwater systems are dynamic and adjust continually to changes in climate, groundwater abstraction and land use. The systematic collection of water level measurements over time provides critical data in the evaluation of changes in aquifers and groundwater resources over time.

Water level data is used to develop groundwater models; predict trends, and to monitor the effectiveness of groundwater management and protection strategies.

The following groundwater monitoring regime along Gingin Brook is therefore recommended that:

- at a minimum, groundwater level measurements be collected in May, June, July, October, November and December each year.
- automatic measurements using data loggers in bores be continued to improve monitoring frequency and avoid difficulties identifying minimum and maximum groundwater levels and observing pumping effects from nearby production bores.
- the bores be purged every five years for a field sample of pH, EC and temperature. This is next due in October 2013.
- the bores be purged every ten years to obtain a groundwater sample for laboratory analysis in conjunction with the field sampling. Groundwater samples from the bores were last tested by a laboratory in 2008, therefore sampling should occur again in 2018.

A groundwater monitoring review should be carried out in 2014. The review would assess data collected from the new Gingin Brook bores. The review will evaluate the performance and status of the monitoring bores, analyse performance of the groundwater resource surrounding the brook and provide recommendations for ongoing monitoring.

The continued use of data loggers in the monitoring bores along the brook may permit changes in groundwater levels to be compared to discharge within the brook. This relationship between aquifer storage and discharge to the brook could be modelled to predict the occurrence of low flow events in the brook and determine the long-term impacts of a drying climate and abstraction on brook baseflow.

7.8 Summary of recommendations and suggestions

Section	Recommendation or suggestion
7.1	Applications for a groundwater licence in superficial aquifer subareas should be closely scrutinised to prevent bores which are licensed against the superficial aquifer from taking water out of the top of the Leederville aquifer. The Mirrabooka aquifer allocation should have a significant proportion reserved for environmental requirements. Licence entitlements and use should be returned to sustainable levels within groundwater subareas SA3 and SA6 to maintain the critical Leederville aquifer groundwater levels under the brook.
7.2	Consideration should be given to licensing high winter flow in the brook. These could be licensed from May to August.
7.3	The brook’s resources should be managed in a dynamic way to minimise effects on the brook in times of low flows and maximise the use of water when flows are available.
7.4	Existing licence holders should be encouraged to switch from summer surface water abstraction to winter surface water abstraction and off-stream storage. Proponents who apply for groundwater licences for bores close to the brook should confirm that no significant reduction in the brook baseflow occurs from the pumping of the bores.
7.5	An enforcement survey should be conducted along the brook to identify and remove illegal channel modifications that impede flow.
7.6	The ecological water requirement for the brook should be reviewed to take into account the information provided by this investigation.
7.7	Groundwater level measurements should be collected at least in May, June, July, October, November and December each year. Automatic measurements using data loggers in bores be continued. Bores be purged every five years for a field sample of pH, EC and temperature. Bores be purged every ten years for laboratory analysis in conjunction with the field sampling. A groundwater monitoring review should be carried out in 2014. Data logging information should be used in the future to try to model the relationship between groundwater levels and flow in the brook.

8 Conclusion

The Gingin Brook groundwater investigation indicates that groundwater discharge provides baseflow to the brook from unconfined aquifers in two main areas. In the middle to lower sections of the brook downstream of the confluence with Wallering Brook groundwater discharge occurs from the superficial aquifer and in the upper catchment to the north and east of Gingin townsite groundwater discharge occurs from the Mirrabooka aquifer.

Additional groundwater discharge to the brook from the deeper confined Leederville aquifer is also evident to the east of Gingin townsite and downstream of the confluence with Wallering Brook, where the confining Kardinya Shale Member of the Osborne Formation has been eroded and potentiometric heads in the Leederville aquifer are above the base of the brook.

Immediately west of the Gingin Scarp along the Pinjarra Plain, the Guildford Clay is the sole constituent of the superficial aquifer. Where the Guildford Clay has a silty or fine sand facies the brook may lose water through leakage to underlying aquifers. Conversely, localised perching of the brook is evident where the Guildford Clay facies is clay rich.

The superficial and Leederville aquifers underlying the Pinjarra Plain are ‘disconnected’ from the brook with groundwater levels below the base of the brook. With no groundwater discharge occurring along the Pinjarra Plain to support flows in the brook, summer baseflow is diminished through evaporation, diversion and riparian use.

This investigation’s innovative use of data loggers to record continuous real-time groundwater levels in the unconfined aquifers along the brook has demonstrated that rapid changes in groundwater level occur in response to rainfall. This is evident in the superficial aquifer downstream of the confluence with Mungala Brook and in the Mirrabooka aquifer in the upper catchment of Gingin Brook. Semi-confined conditions are common in deeper sections of the superficial aquifer particularly along the Pinjarra Plain with little response to rainfall evident in the monitoring bore hydrographs.

A electrical conductivity survey along the brook has recorded fresh water in the headwaters that becomes moderately brackish in the middle reaches before it becomes fresh again. It is likely that the increased salt load in the middle of the brook is caused by higher salinity groundwater discharging from the deeper Leederville aquifer where the confining Kardinya Shale Member has been eroded.

A summary of recommendations and suggestions for future management has been given in Section 7.8 above. These have been based on the following general principles:

- a move away from summer surface water abstraction in favour of winter abstraction and off-stream storage
- creating a buffer zone around the brook to prevent groundwater abstraction depleting the baseflow

- continued collection and review of monitored data
- adaptive management based on the ongoing review of data, rather than rigid rules, being used to maximise the available resources.

Appendices

Appendix A — Aquifer characteristics

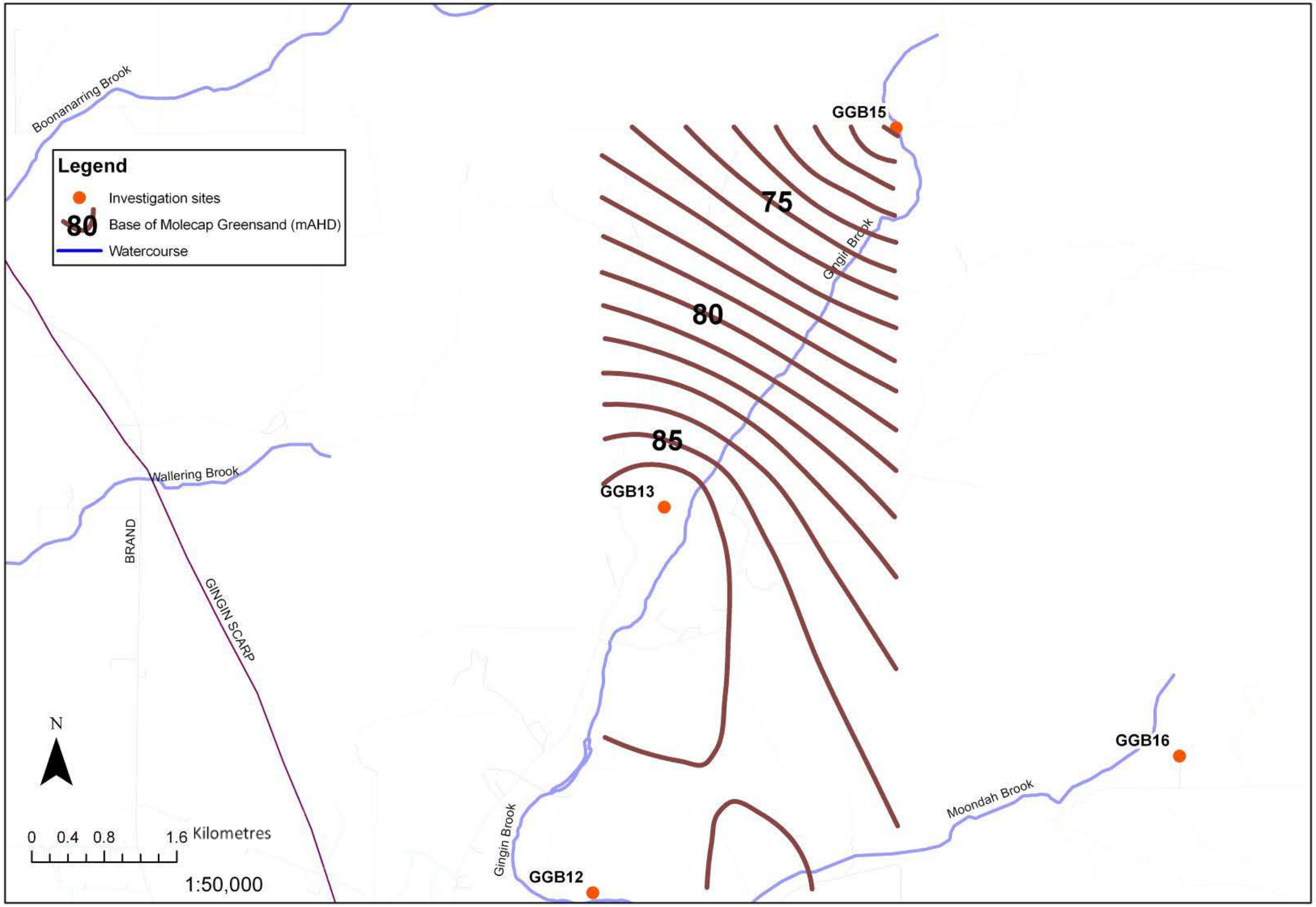


Figure A1 Molecap Greensand: contours on base of unit

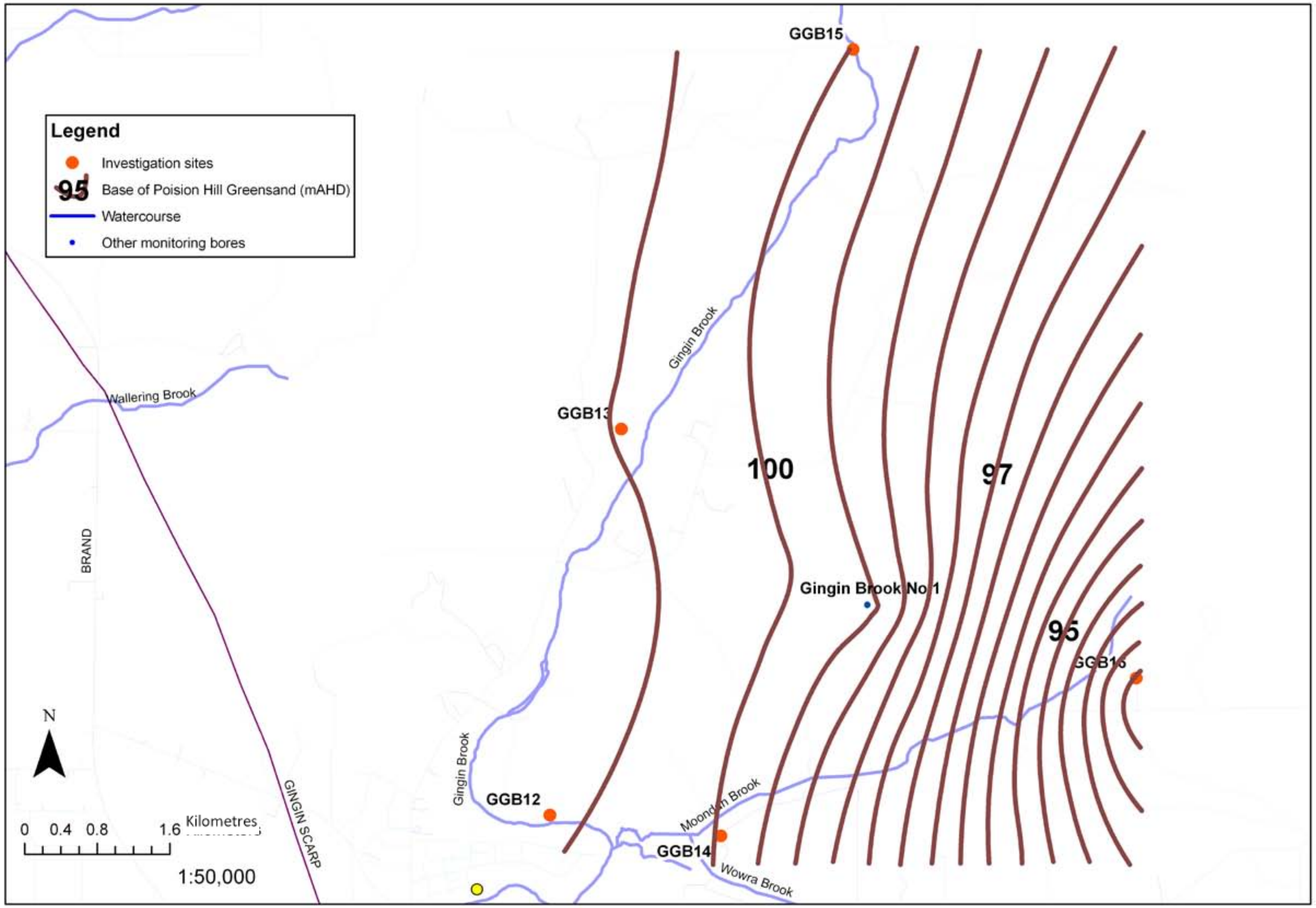


Figure A2 Molecap Greensand isopachs

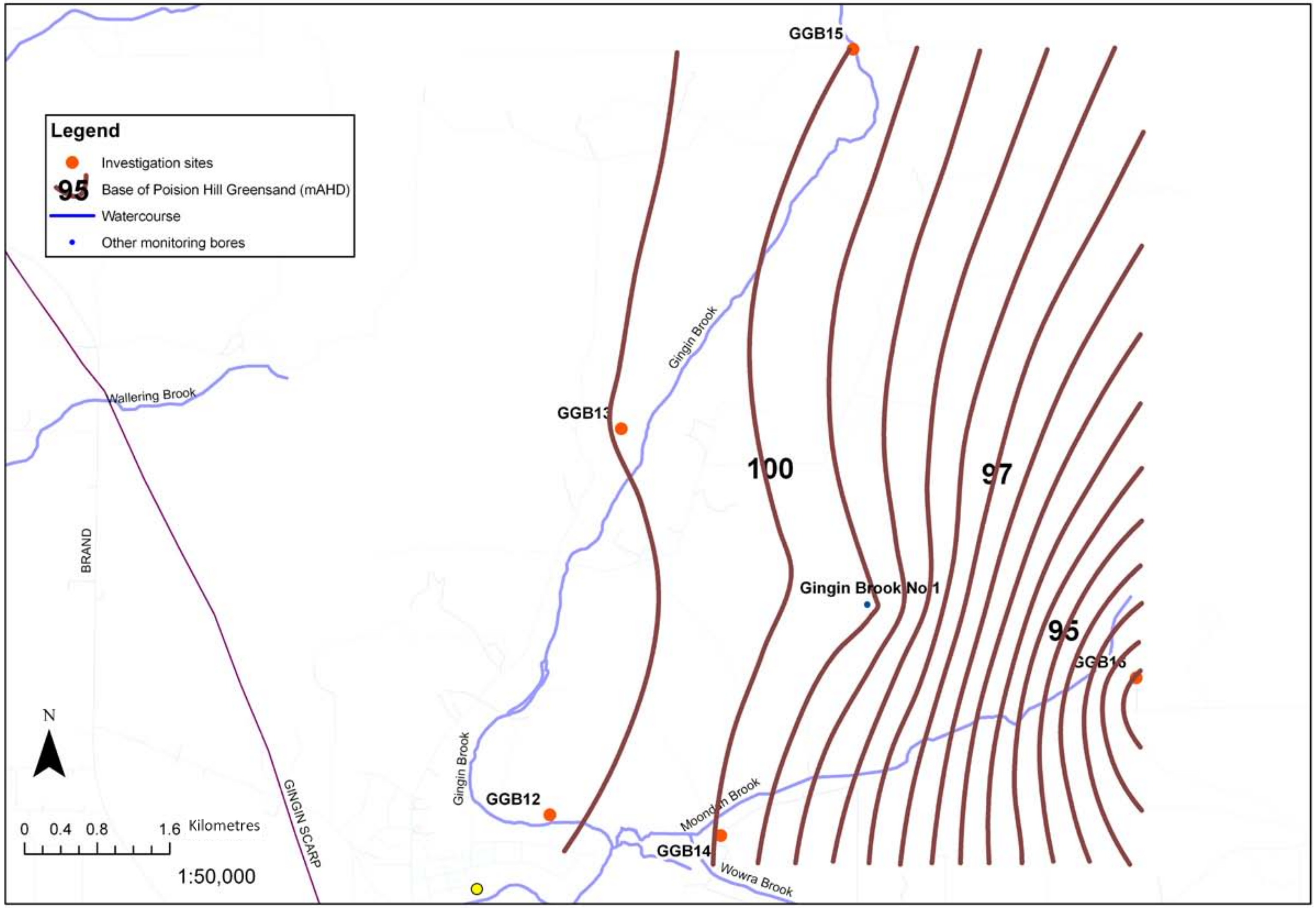


Figure A3 Poison Hill Greensand: contours on base of unit

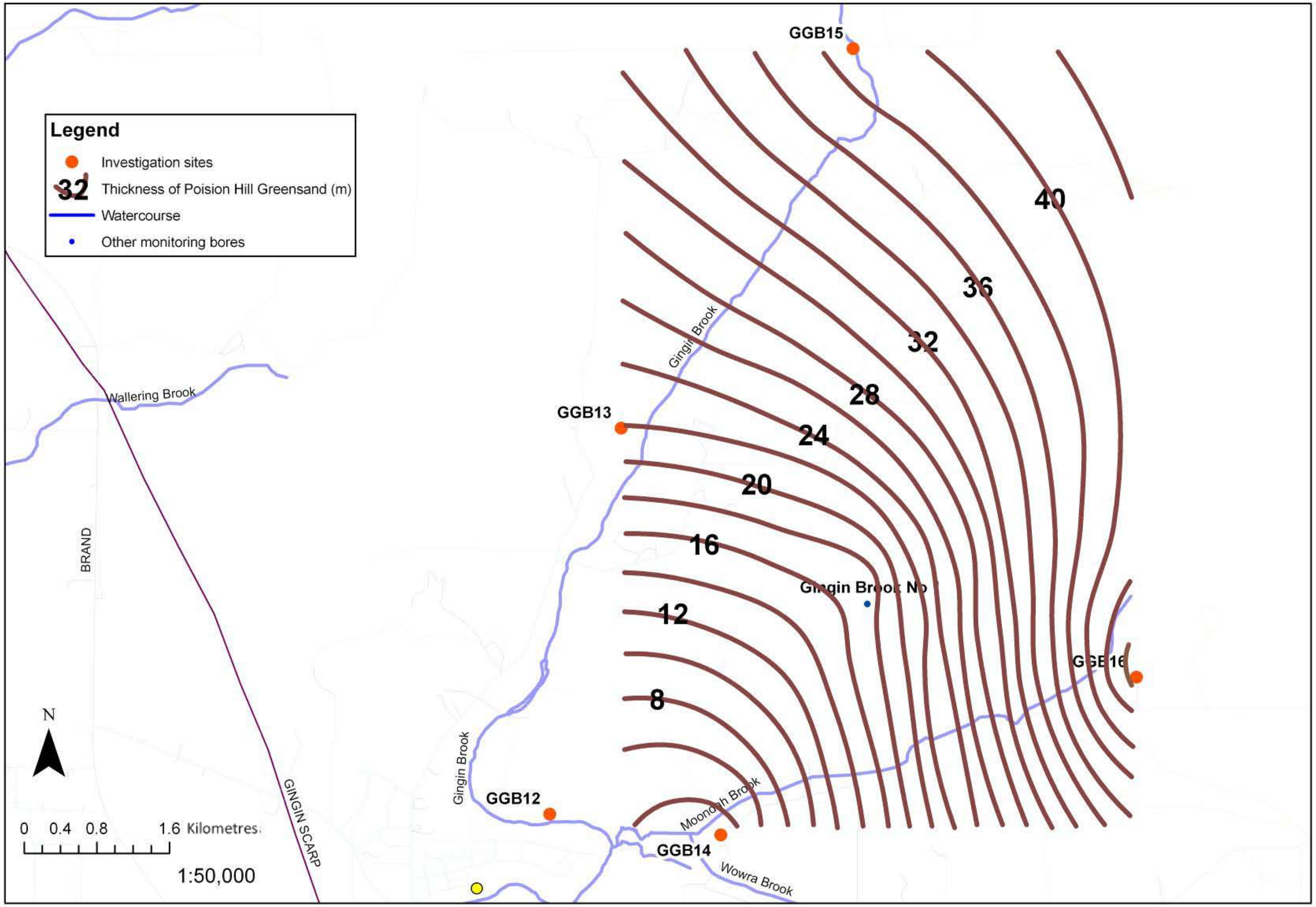


Figure A4 Poison Hill Greensand: isopachs

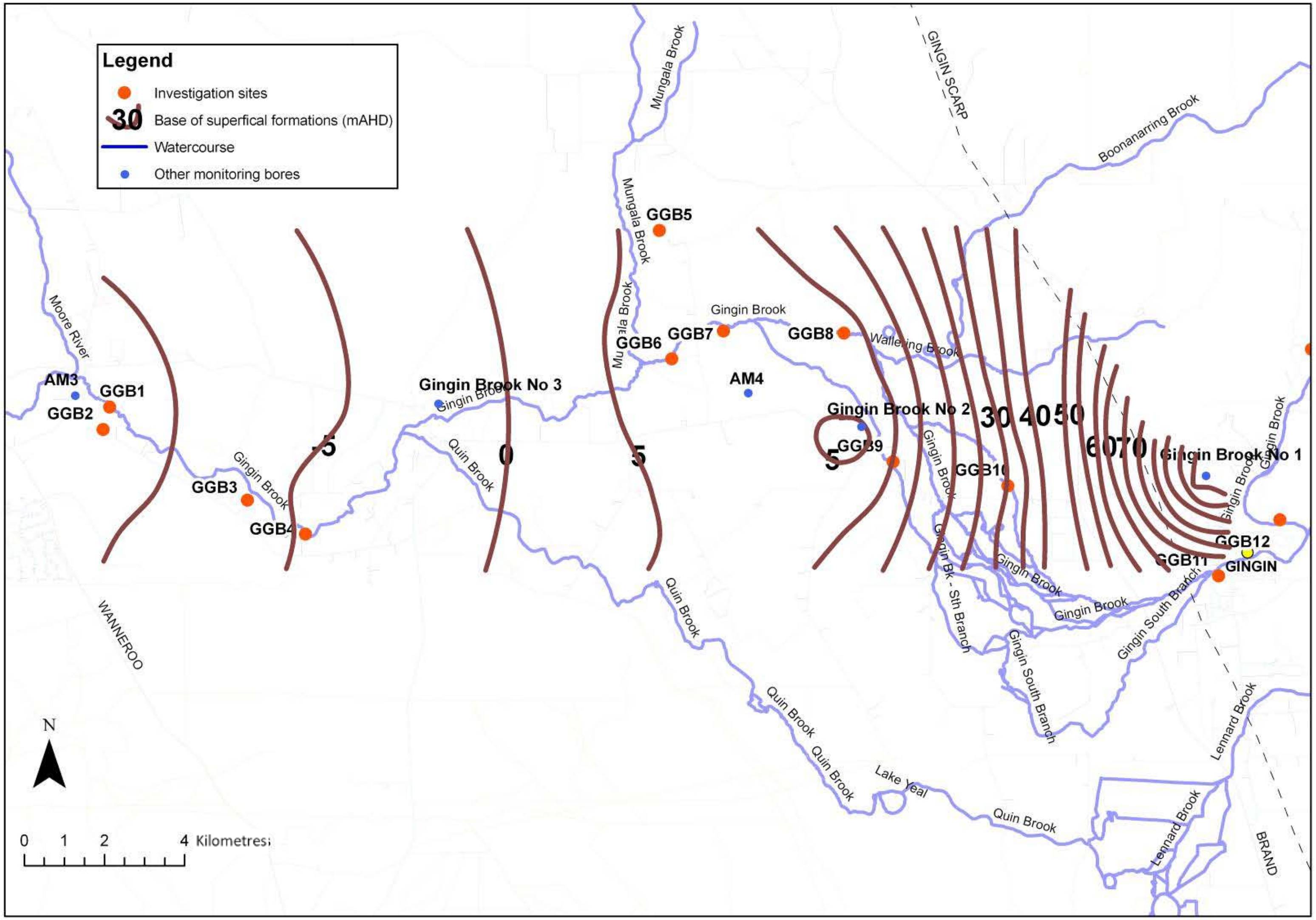


Figure A5 Superficial formations: contours on base of unit

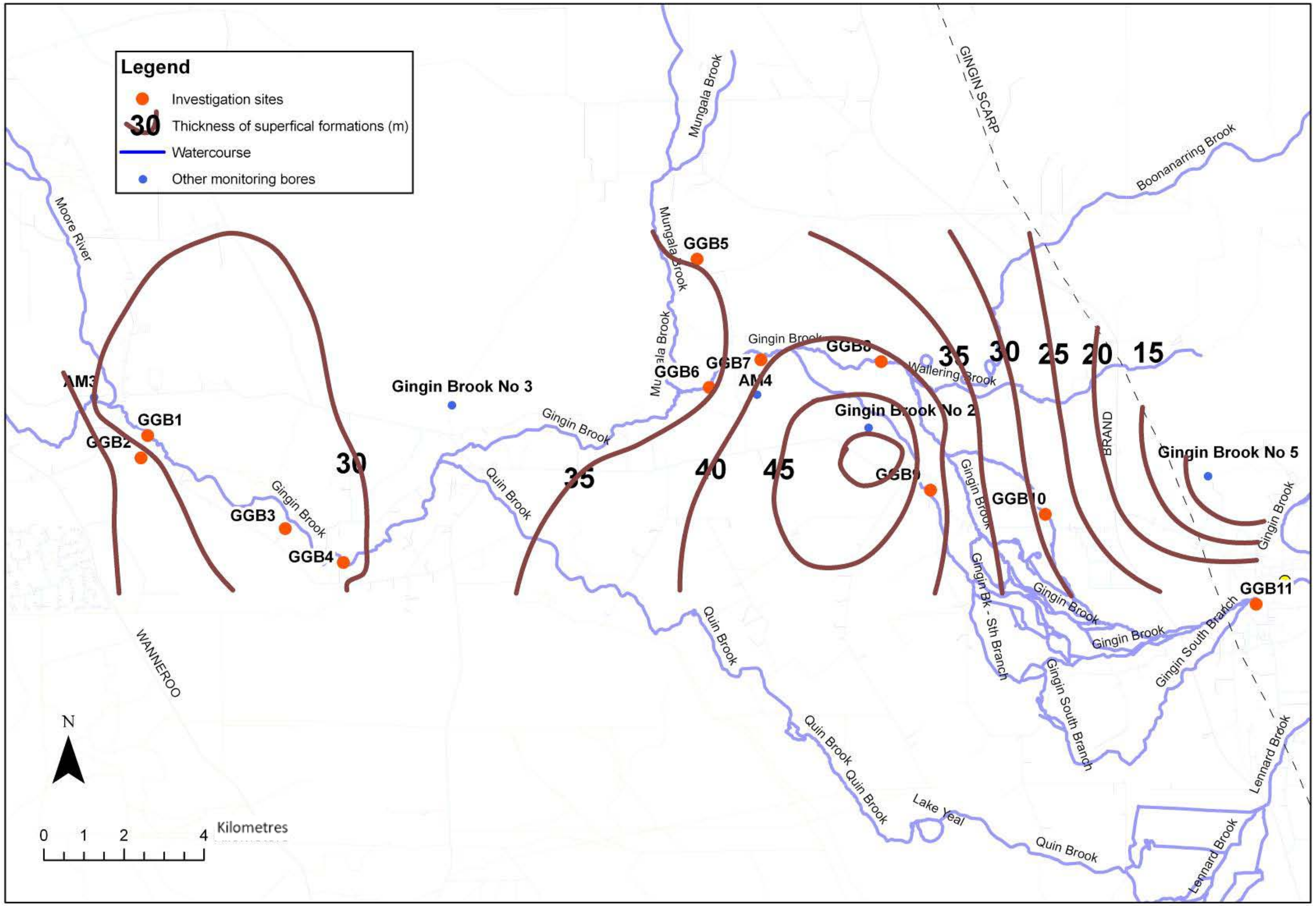


Figure A6 *Superficial formations: isopachs*

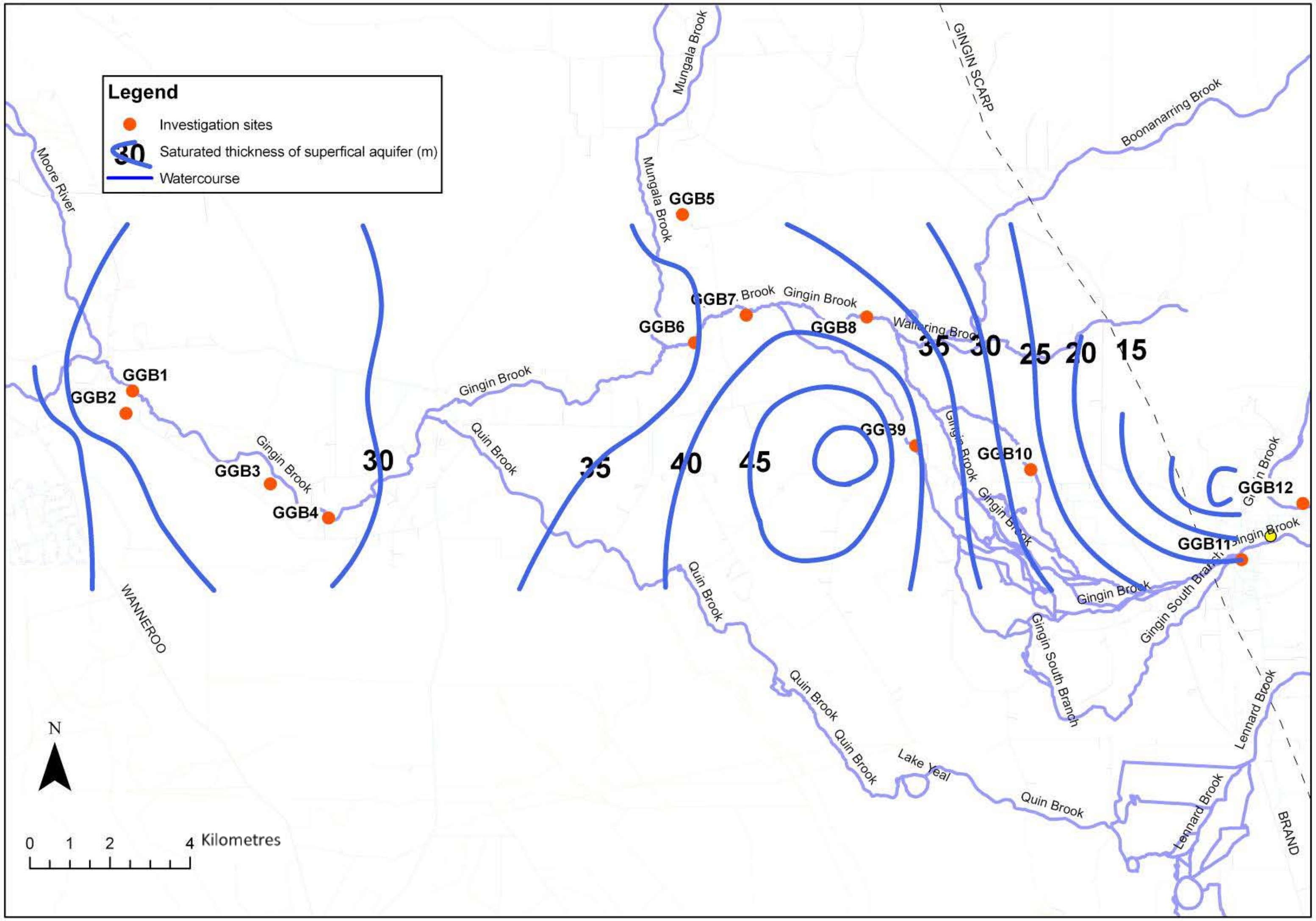


Figure A7 *Superficial aquifer saturated thickness*

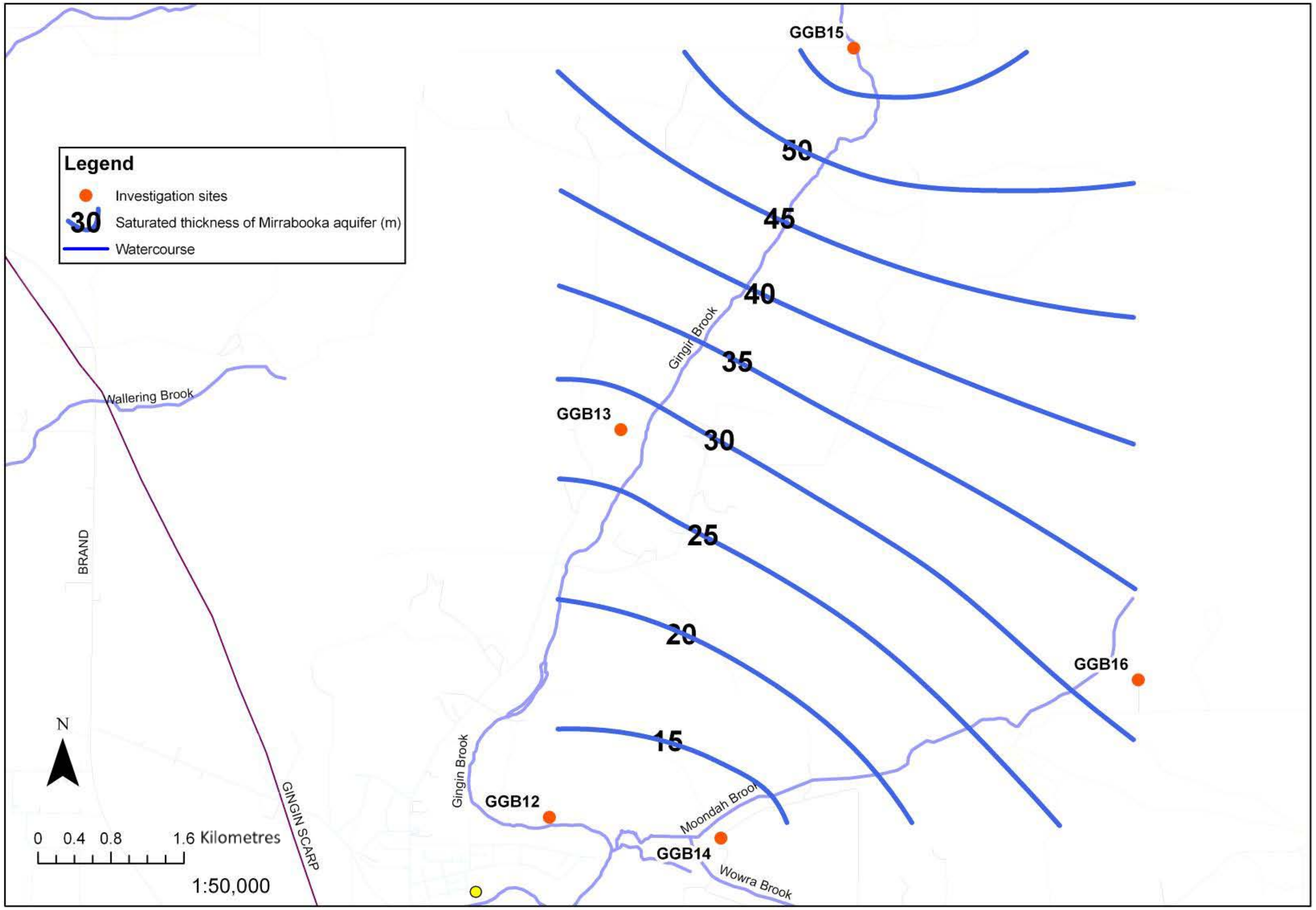


Figure A8 Mirrabooka aquifer saturated thickness

Appendix B — Hydrographs GGB1A to GGB16B

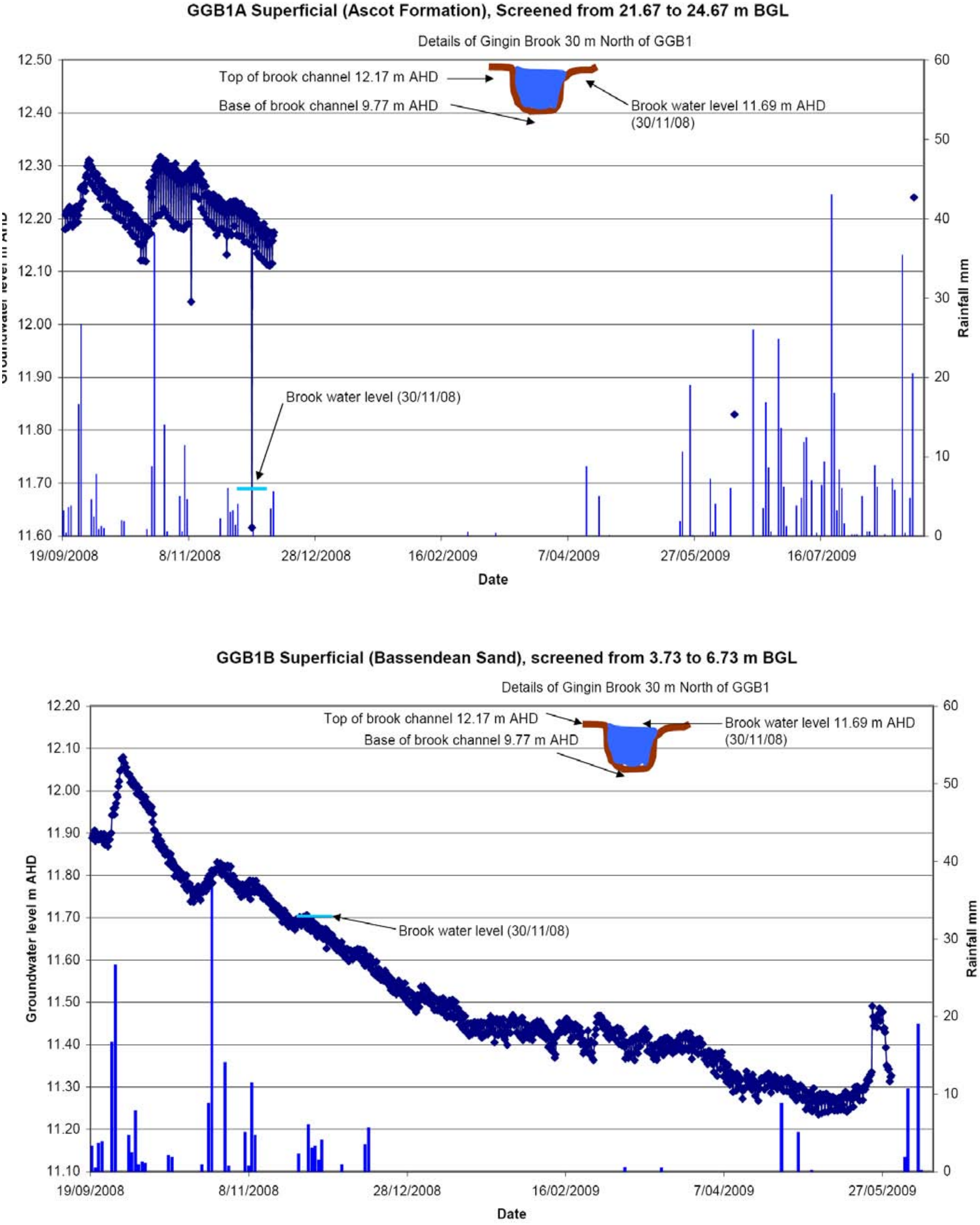
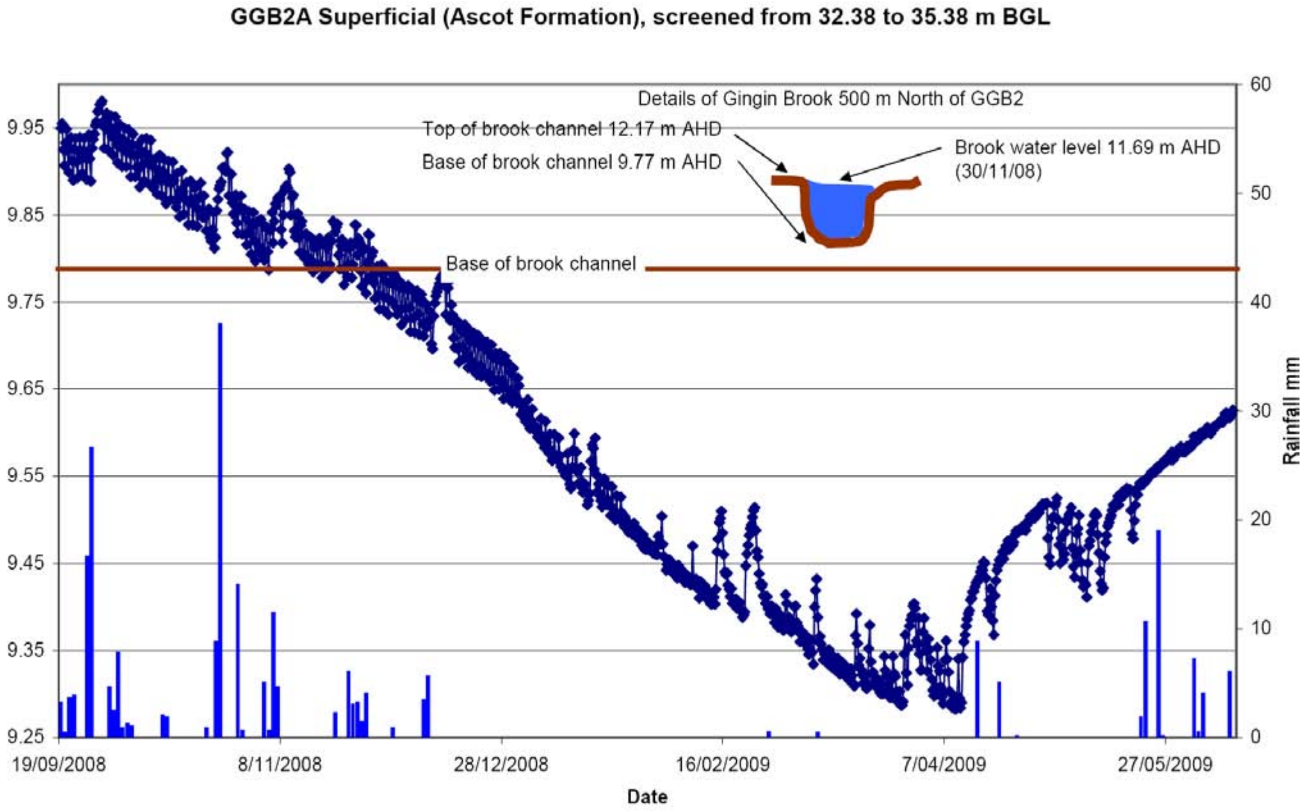


Figure B1 GGB1A/B hydrographs



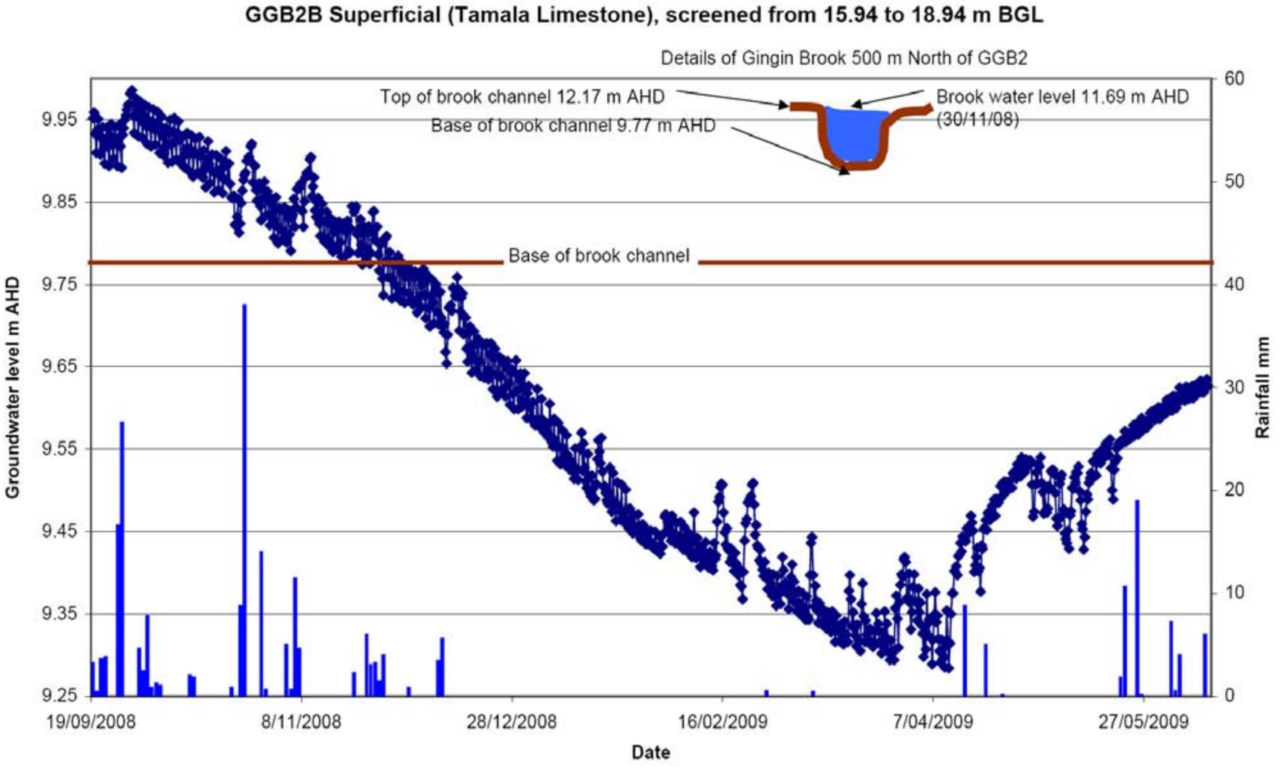
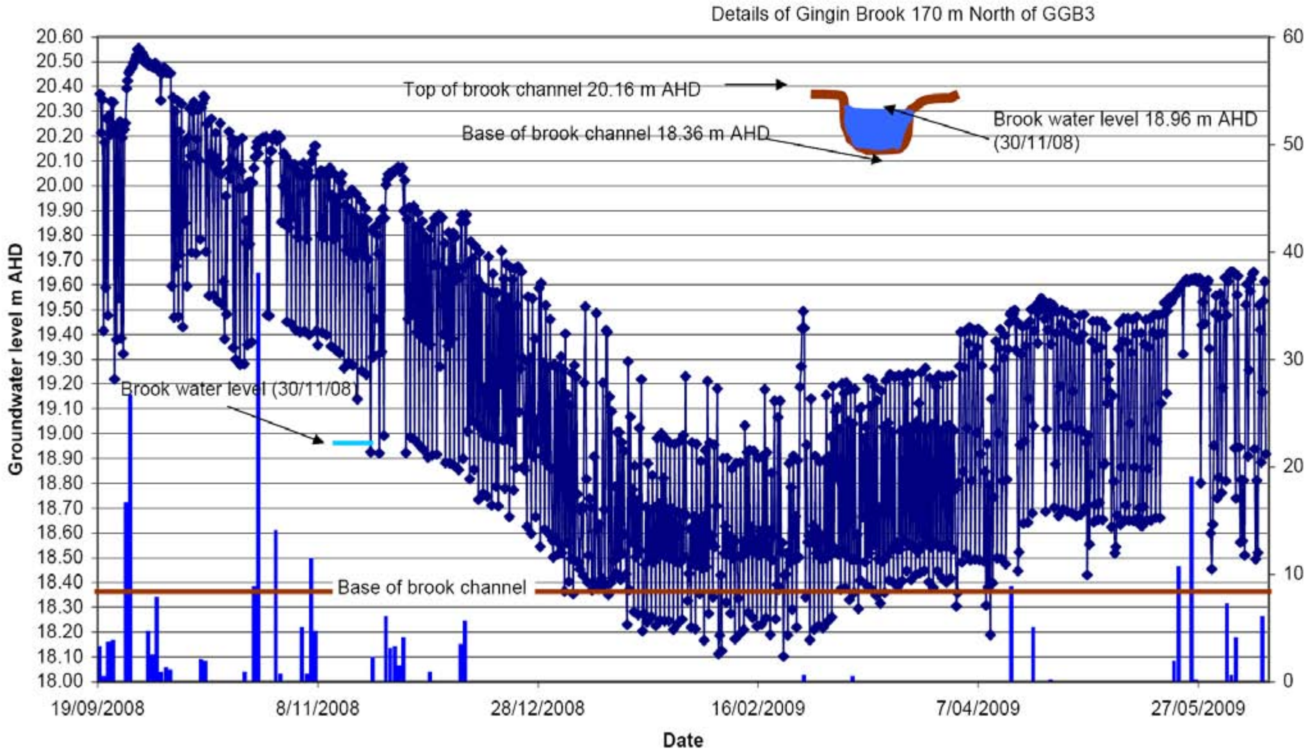


Figure B2 GGB2A/B hydrographs

GGB3A Superficial (Ascot Formation), screened from 22.93 to 25.93 m BGL



GGB3B Superficial (Bassendean Sand), screened from 3.93 to 6.93 m BGL

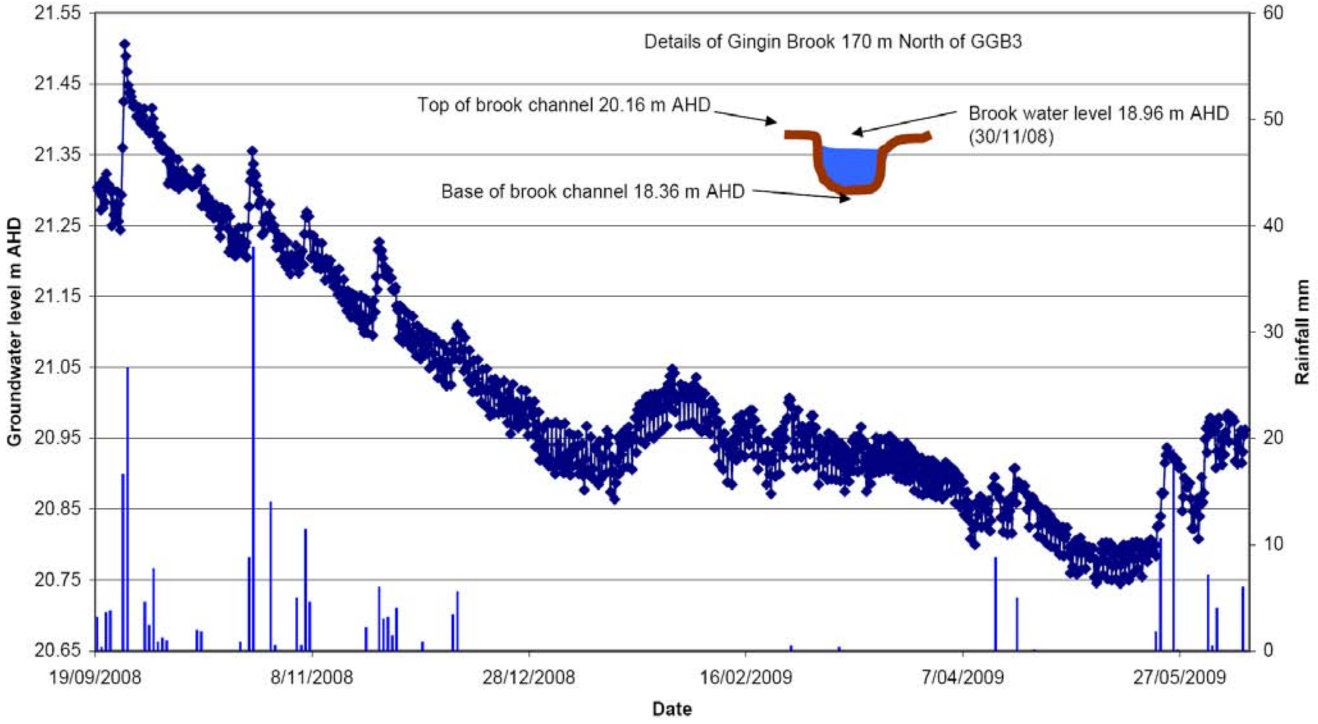
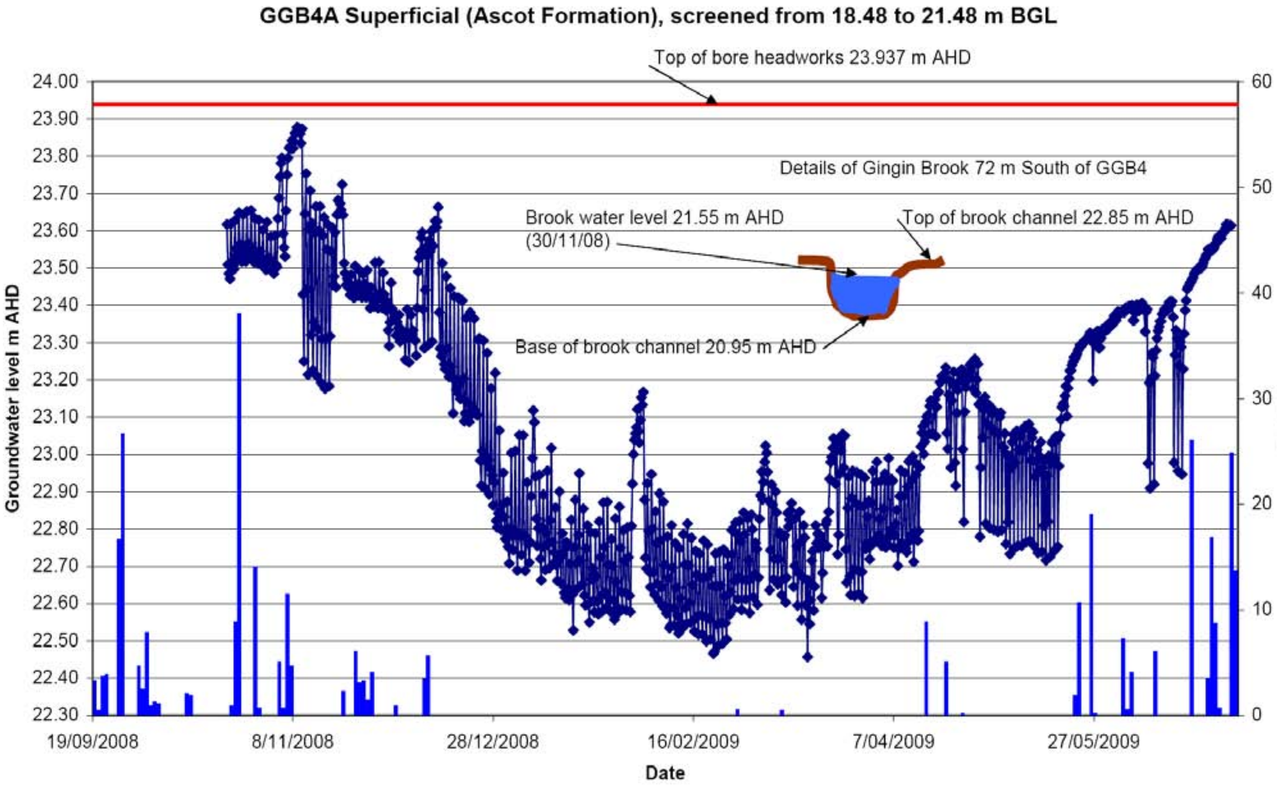


Figure B3 GGB3A/B hydrographs



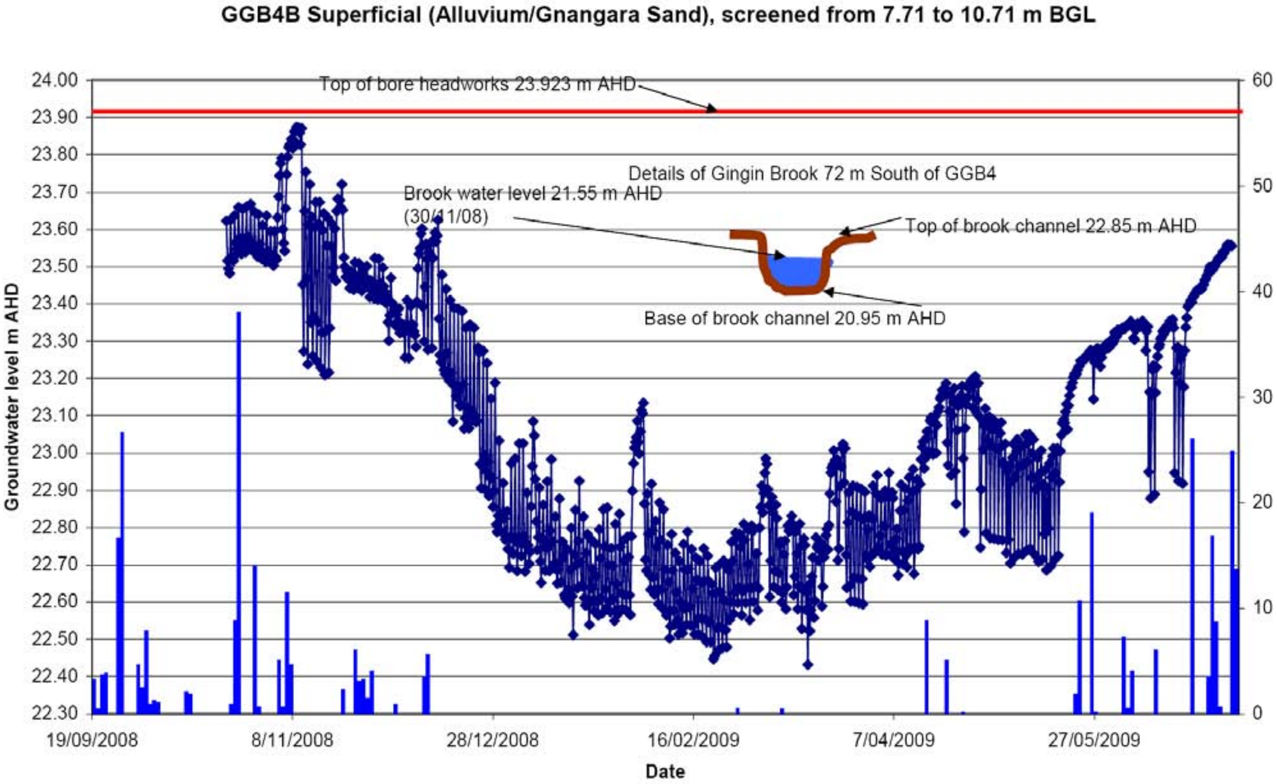
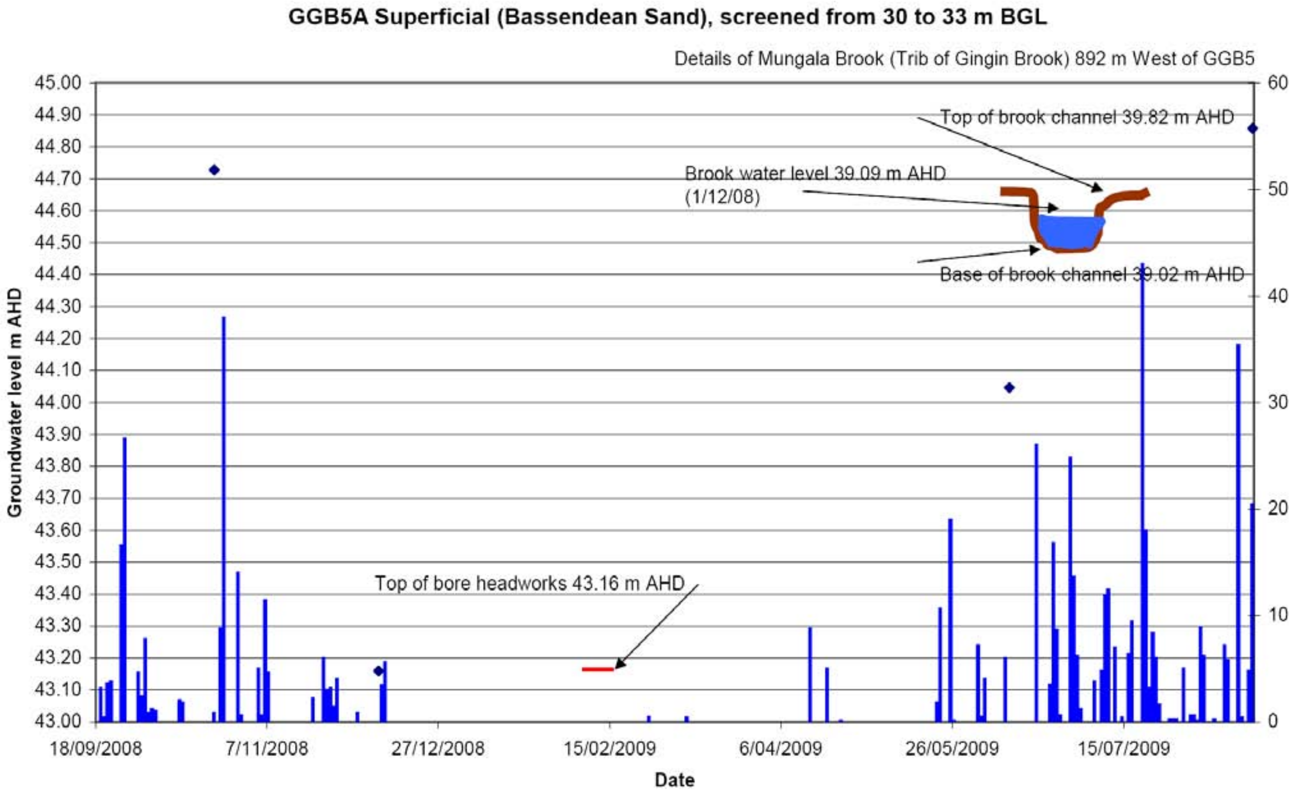


Figure B4 GGB4A/B hydrographs



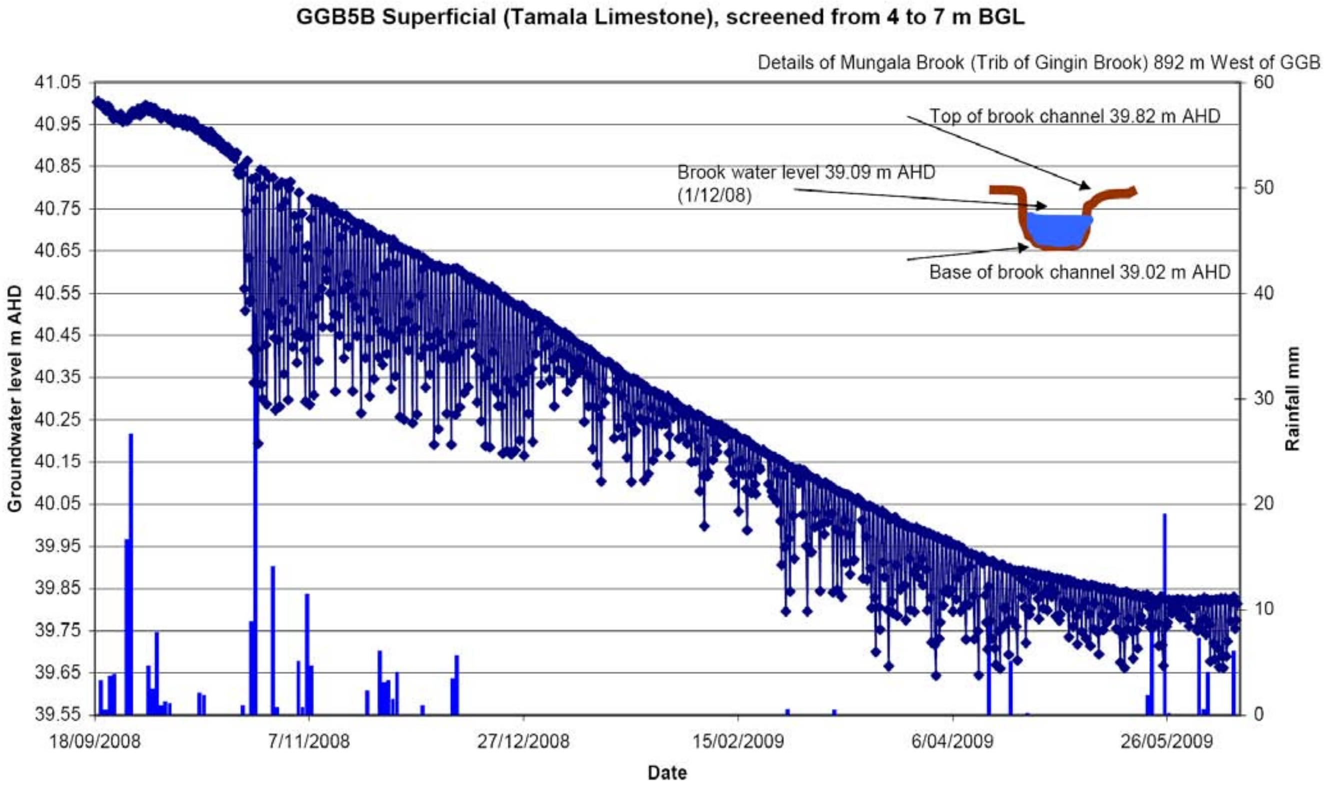
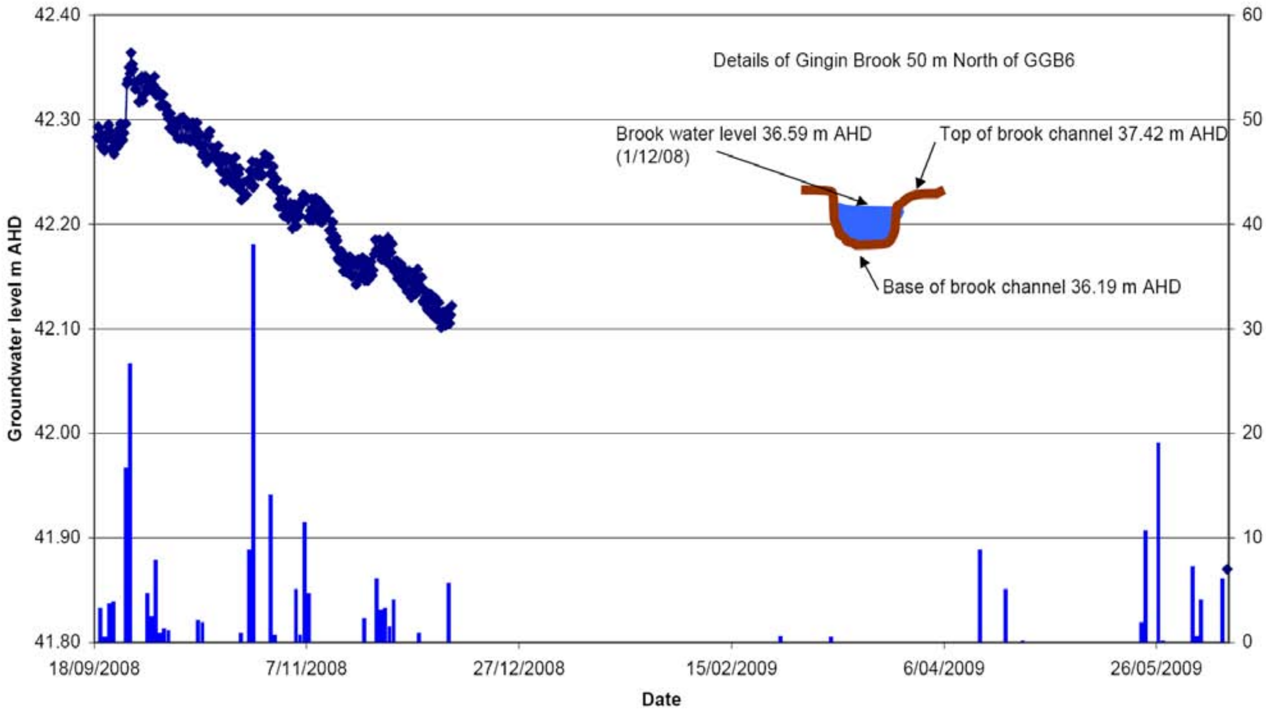


Figure B5 GGB5A/B hydrographs

GGB6A Superficial (Ascot Formation), screened from 26.51 to 29.51 m GBL



GGB6B Superficial (Tamala Limestone/Bassendean Sand), screened from 6.7 to 9.7 m BGL

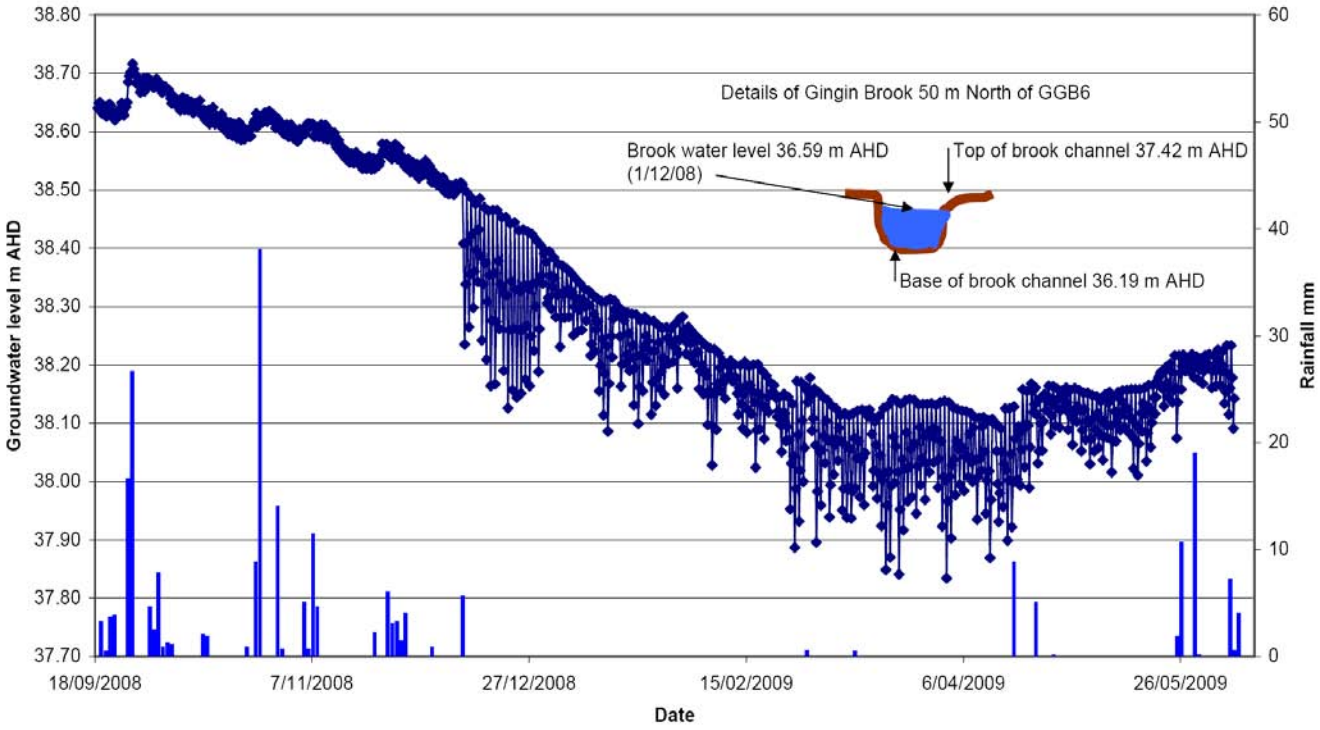
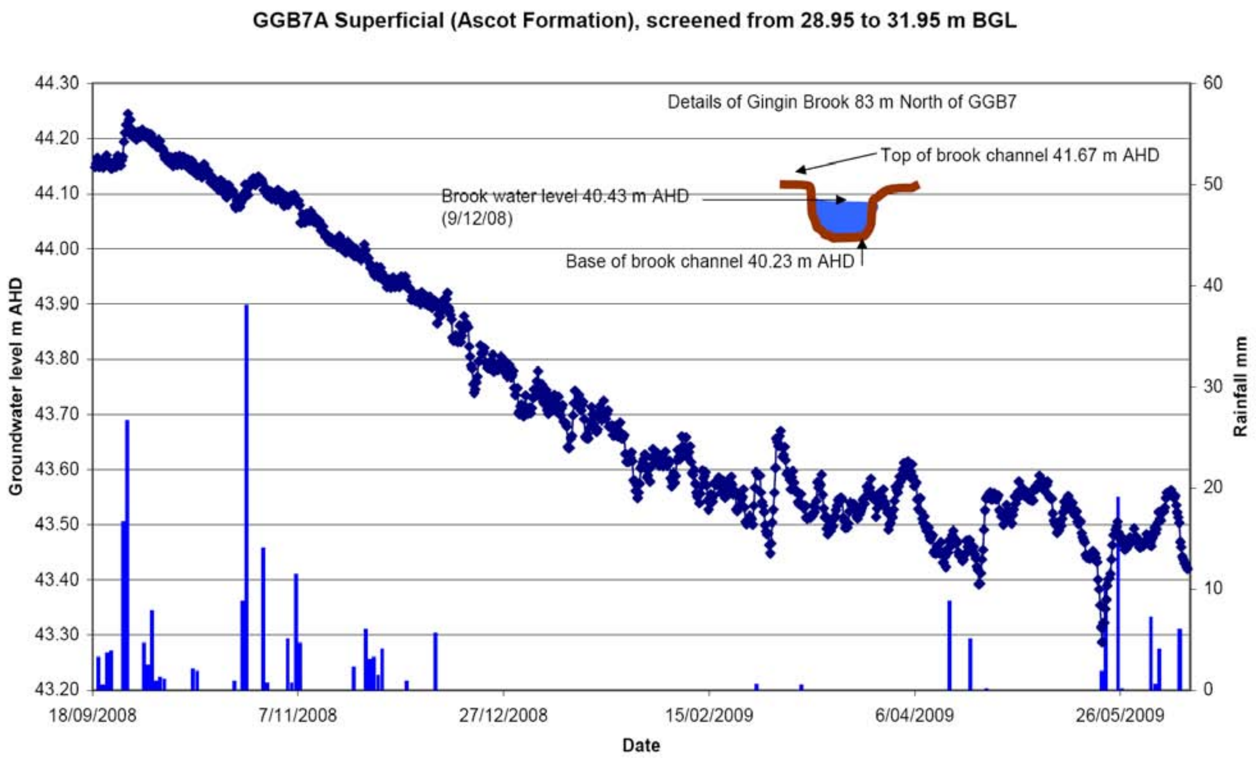


Figure B6 GGB6A/B hydrographs


GGB7A Superficial (Ascot Formation), screened from 28.95 to 31.95 m BGL

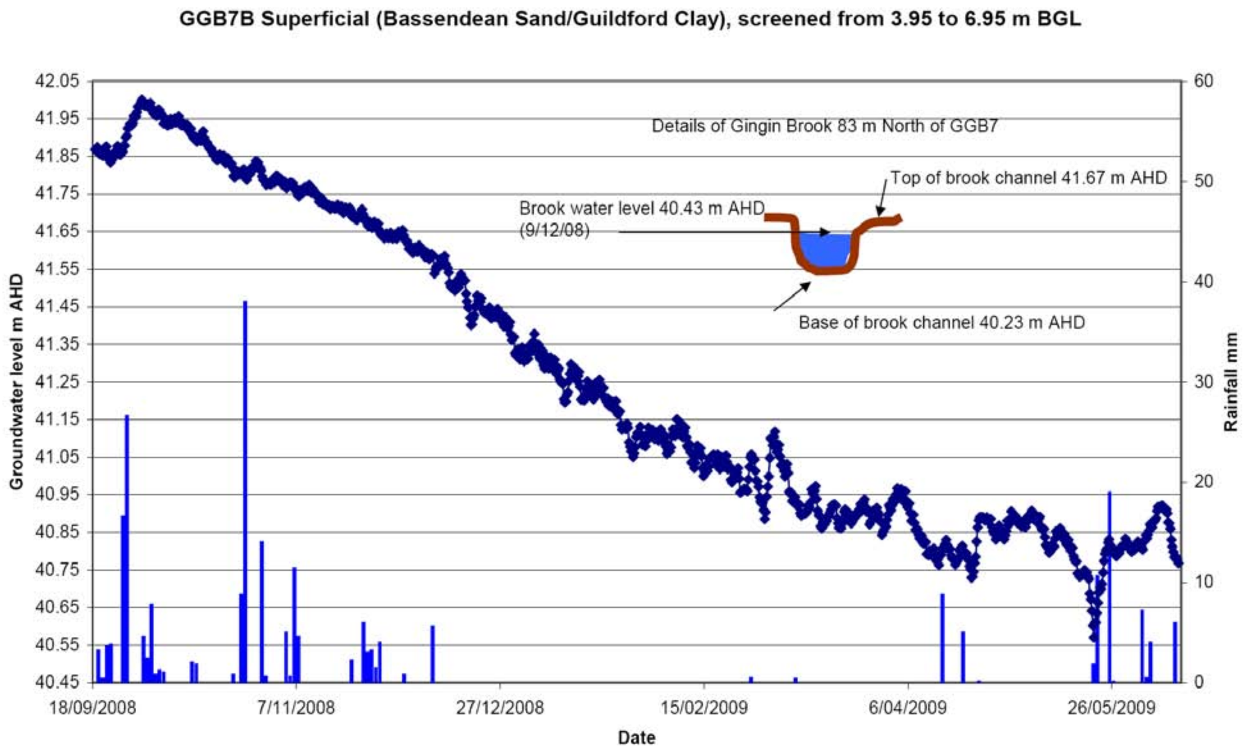
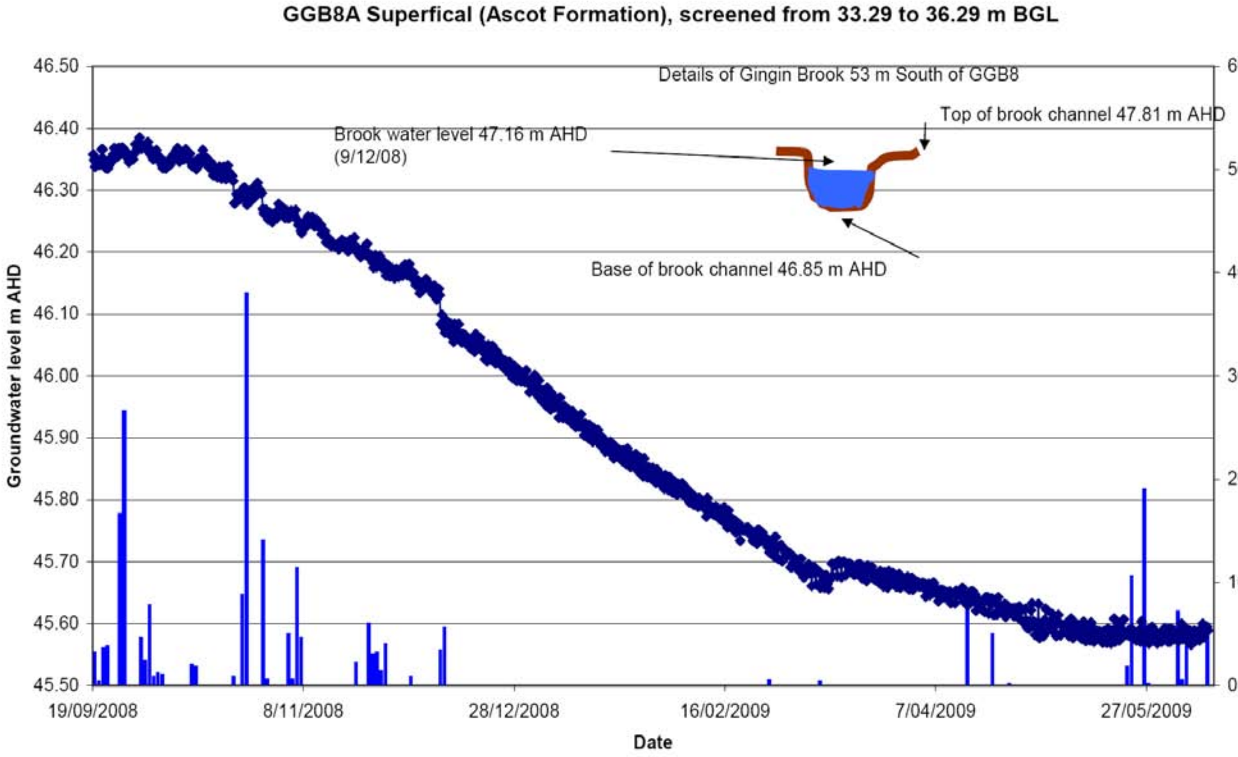

GGB7B Superficial (Bassendean Sand/Guildford Clay), screened from 3.95 to 6.95 m BGL

Figure B7 GGB7A/B hydrographs



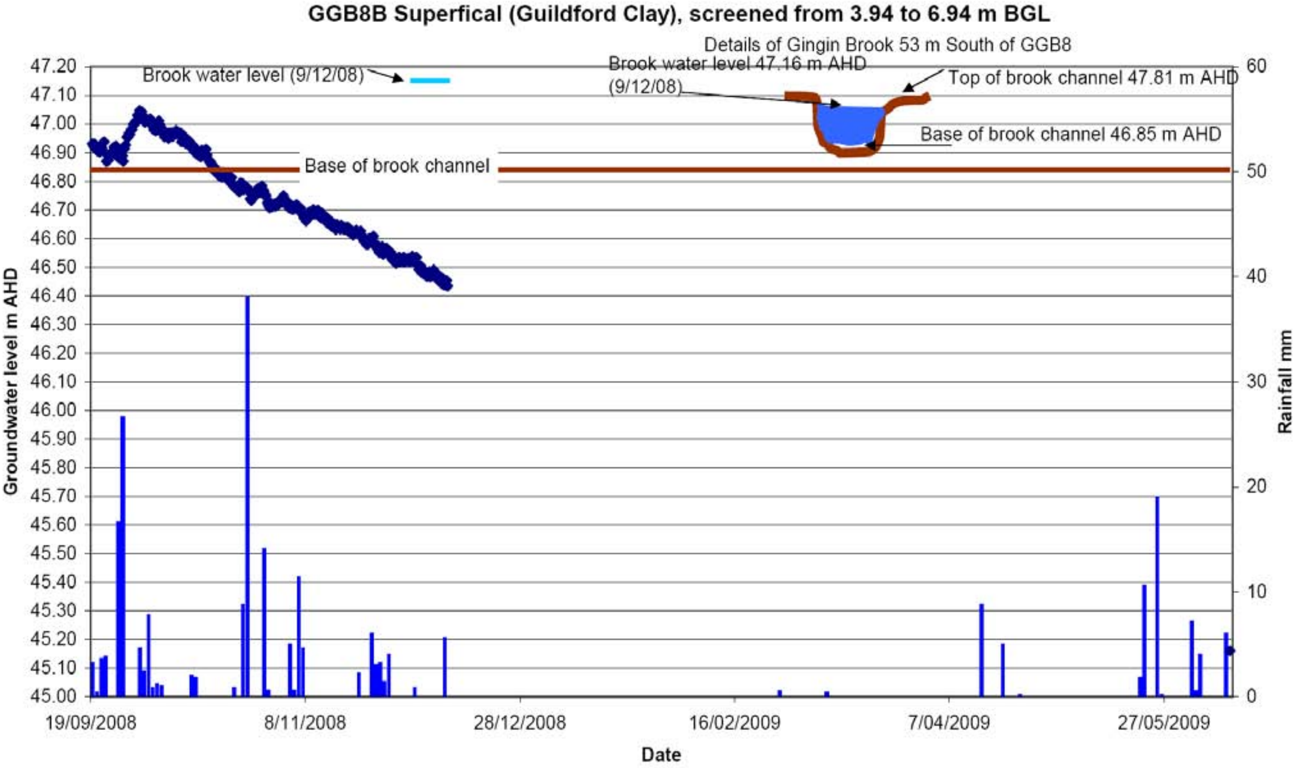
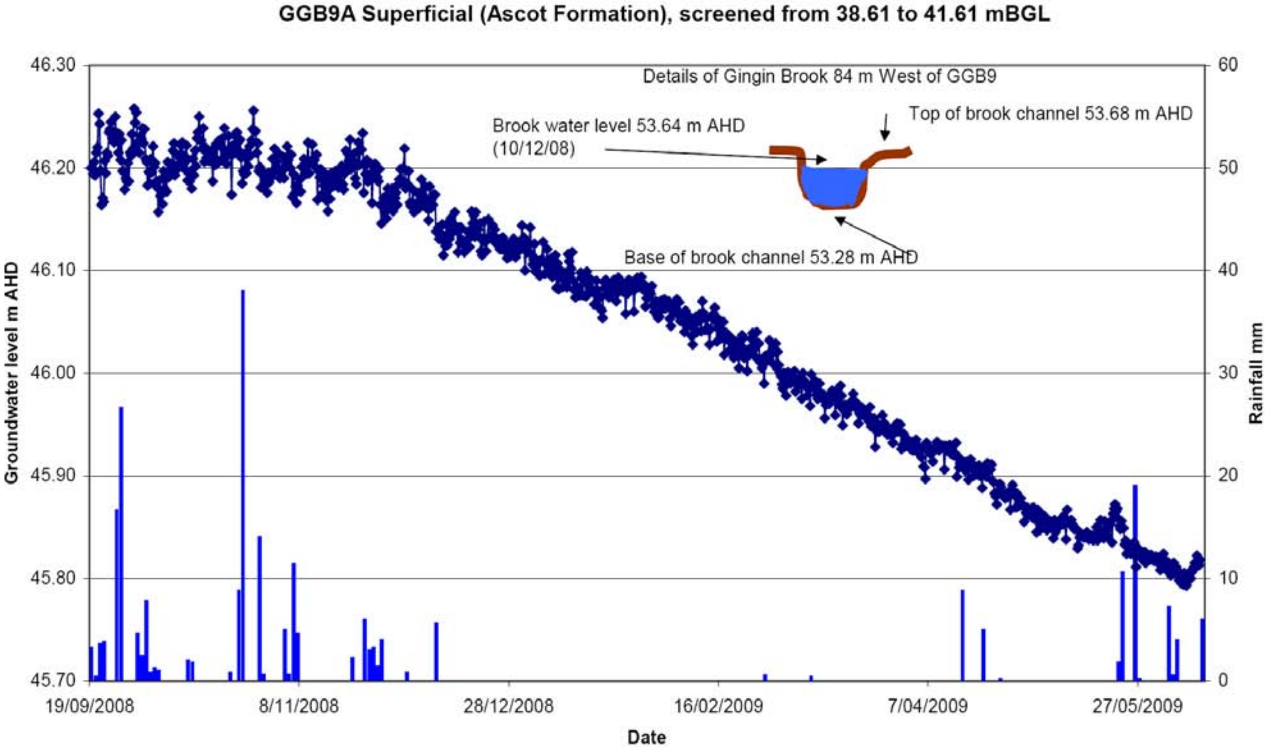


Figure B8 GGB8A/B hydrographs



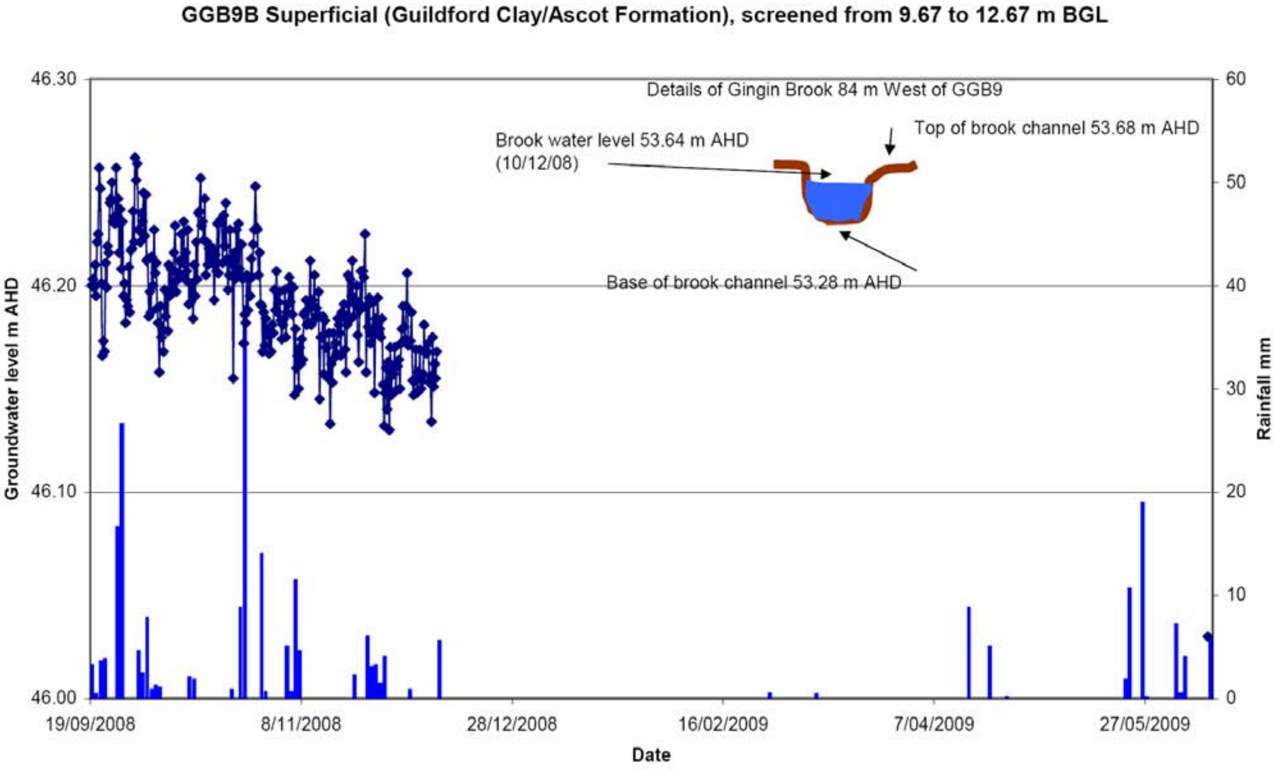
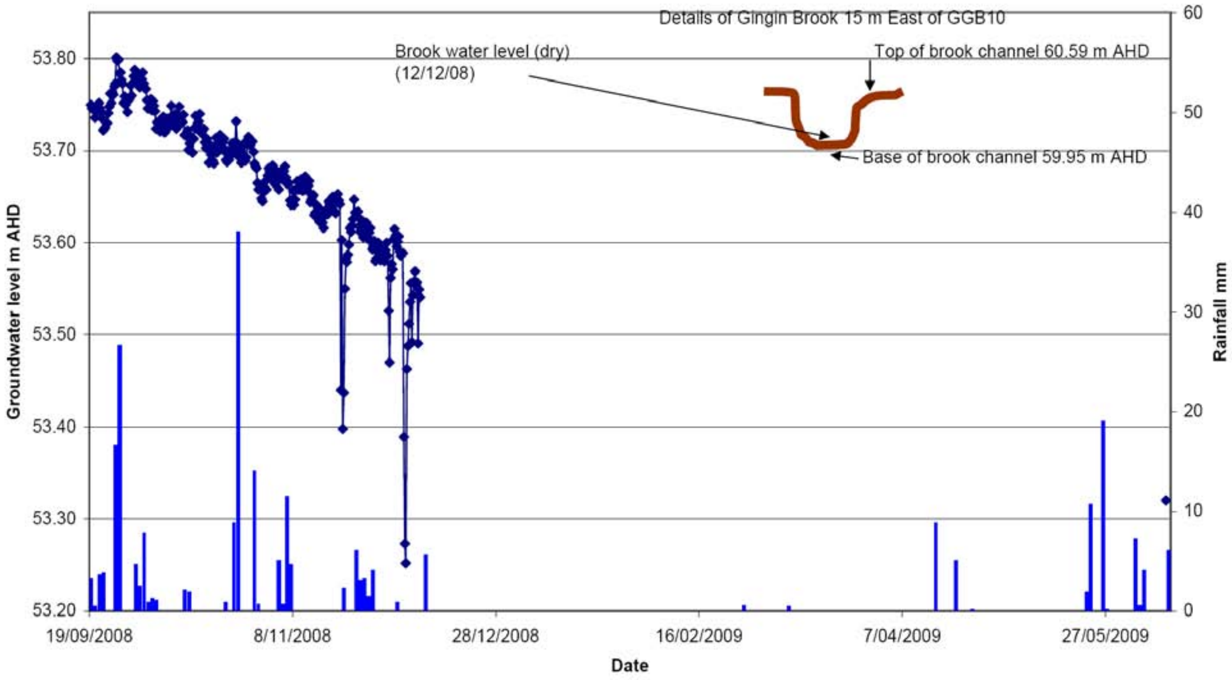
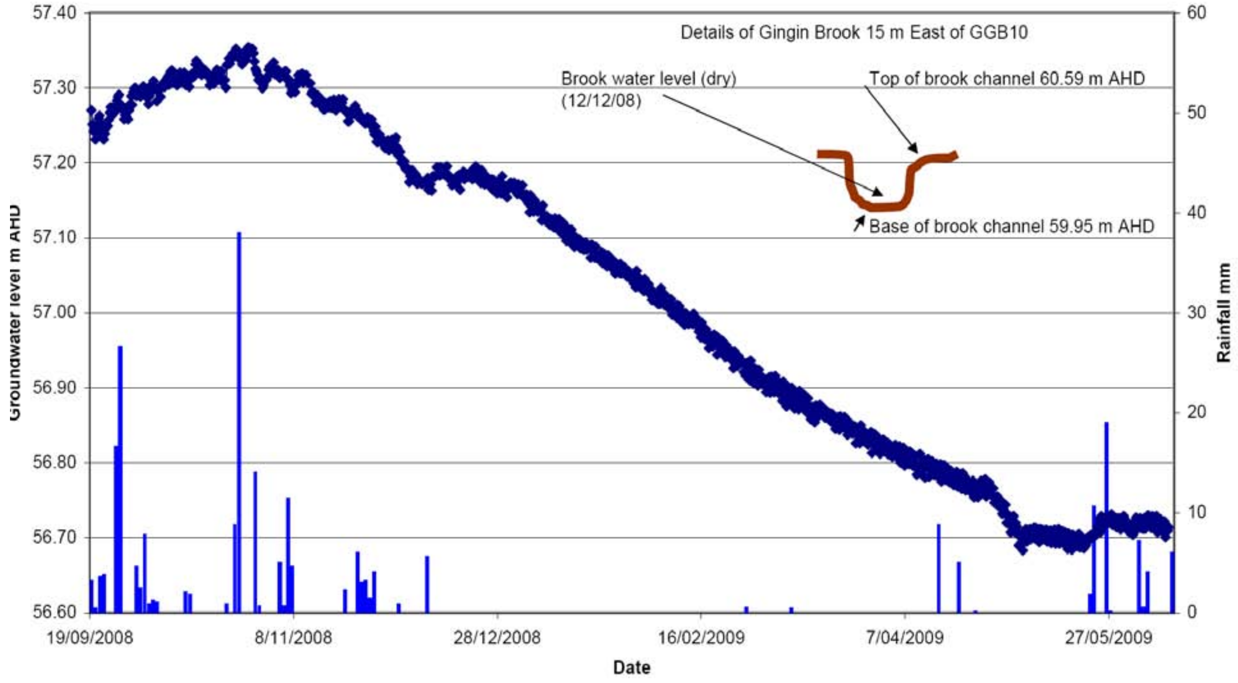


Figure B9 GGB9A/B hydrographs

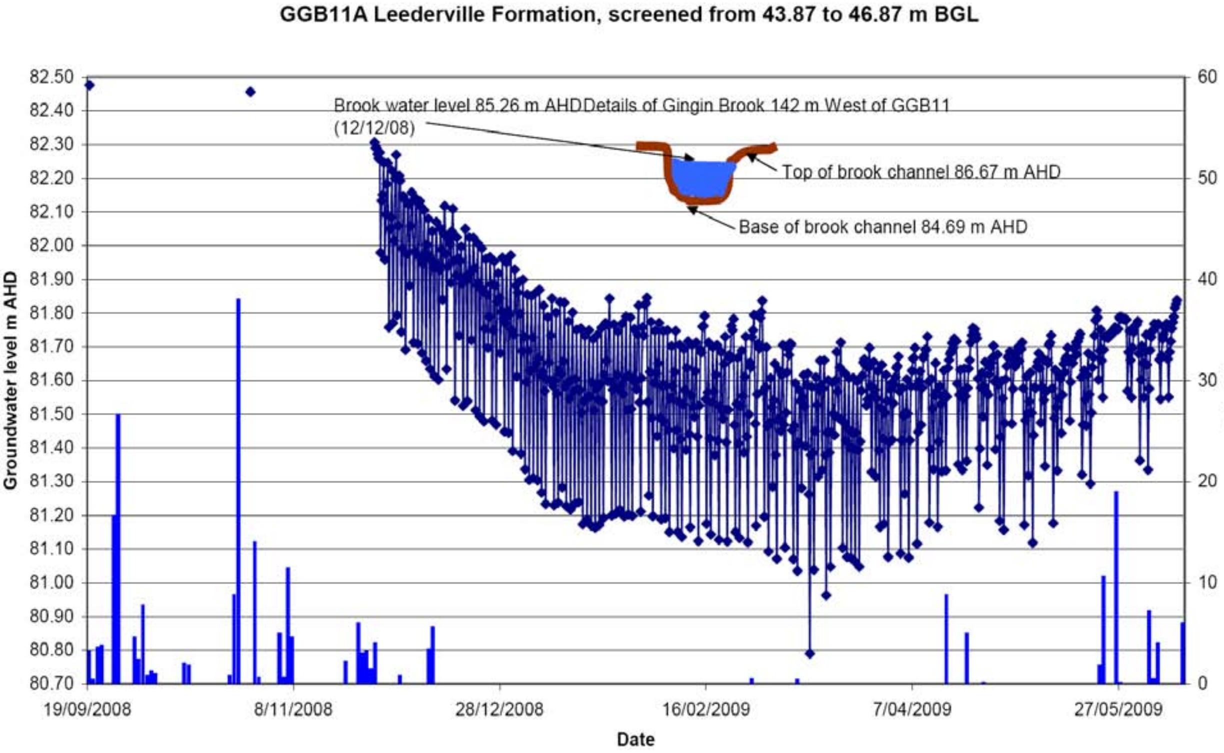


GGB10A Superficial (Guildford Clay), screened from 21.66 to 24.66 m BGL



GGB10B Superficial (Guildford Clay), screened from 4 to 7 m BGL

Figure B10 GGB10A/B hydrographs



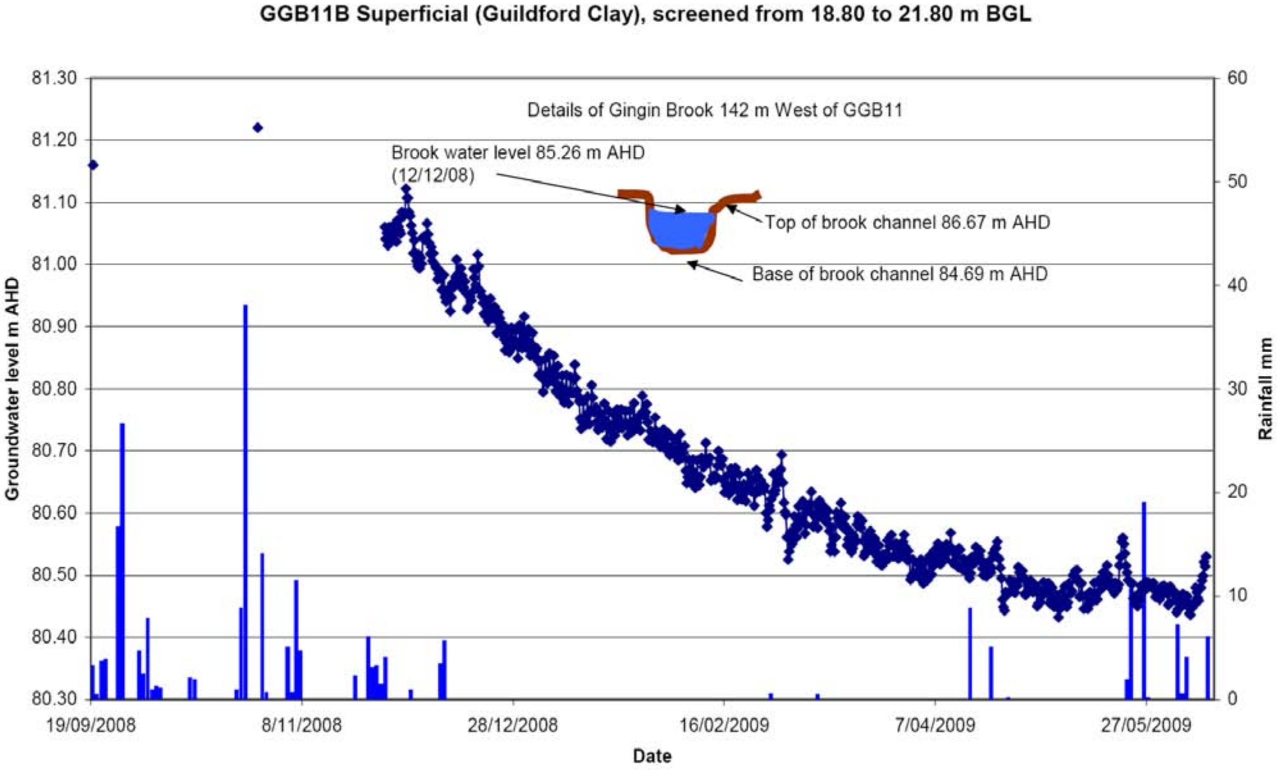
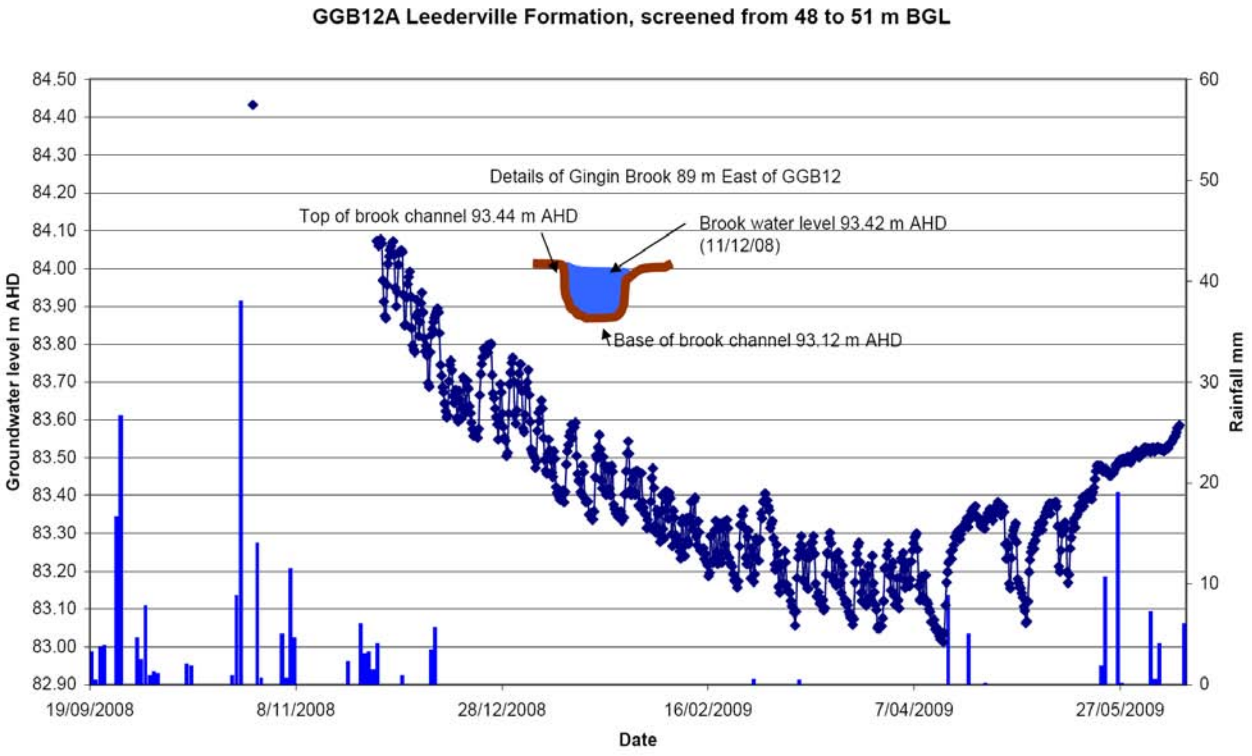


Figure B11 GGB11A/B hydrographs



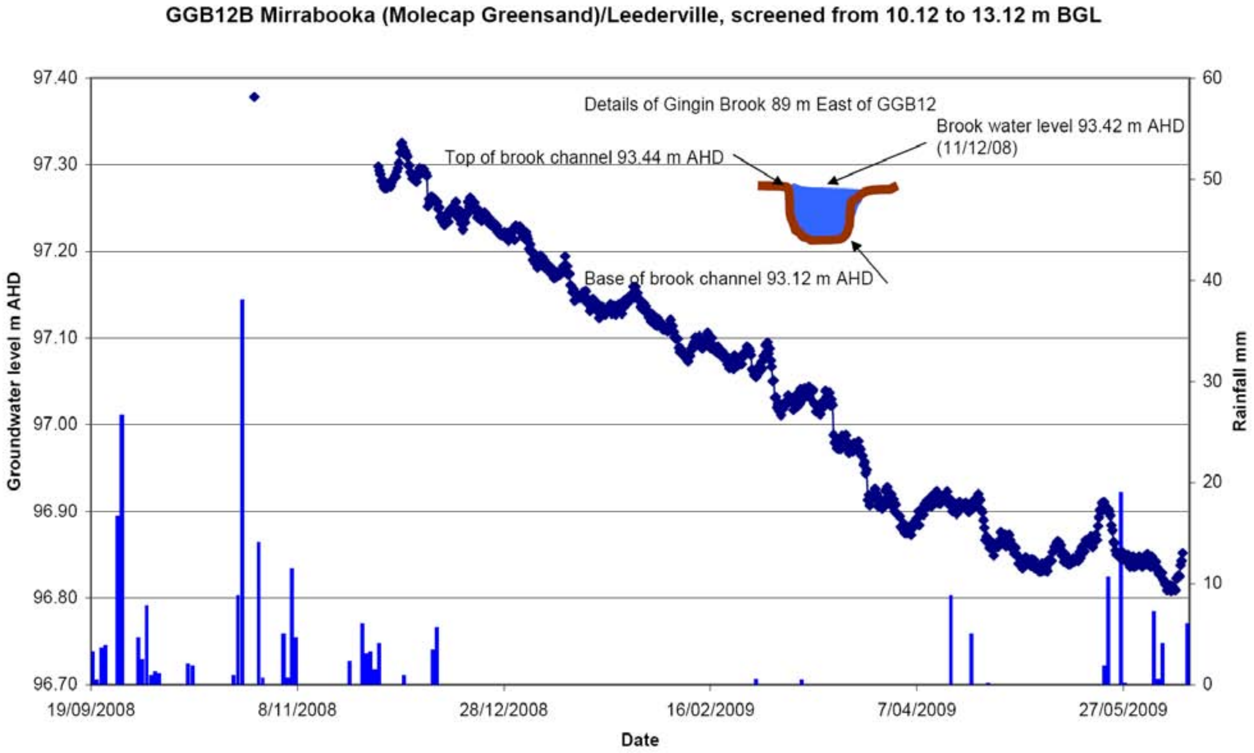
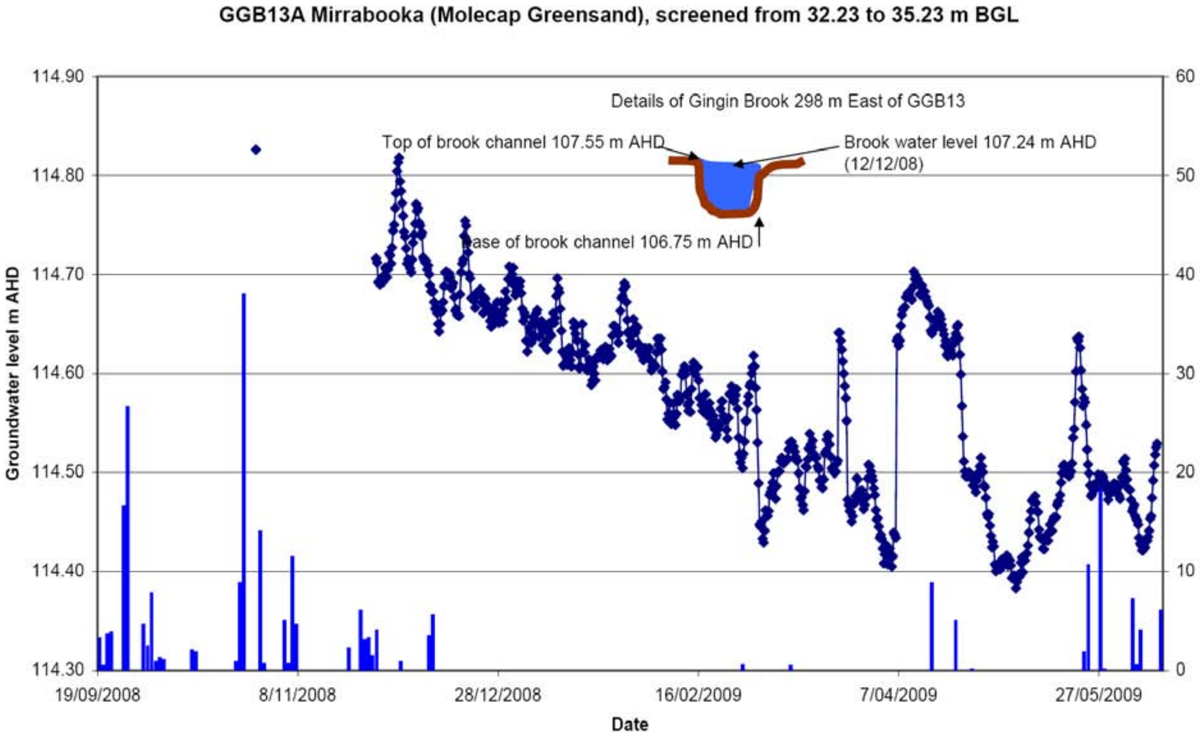


Figure B12 GGB12A/B hydrographs



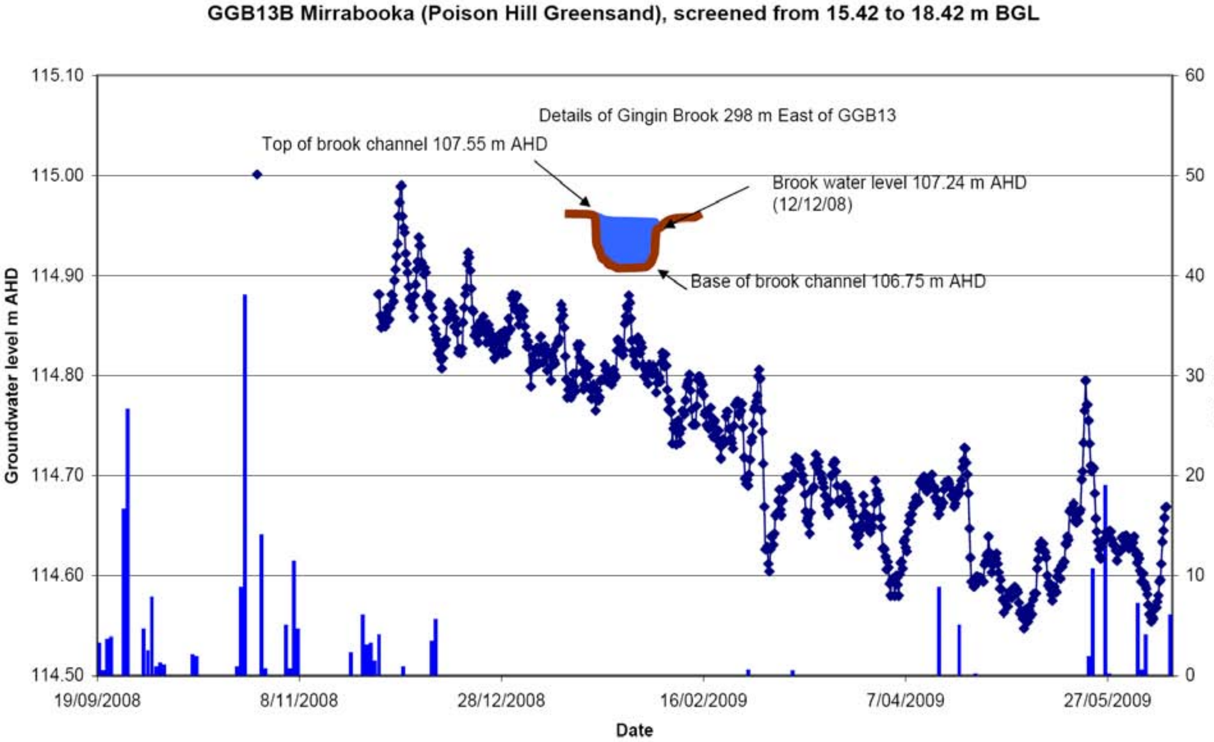
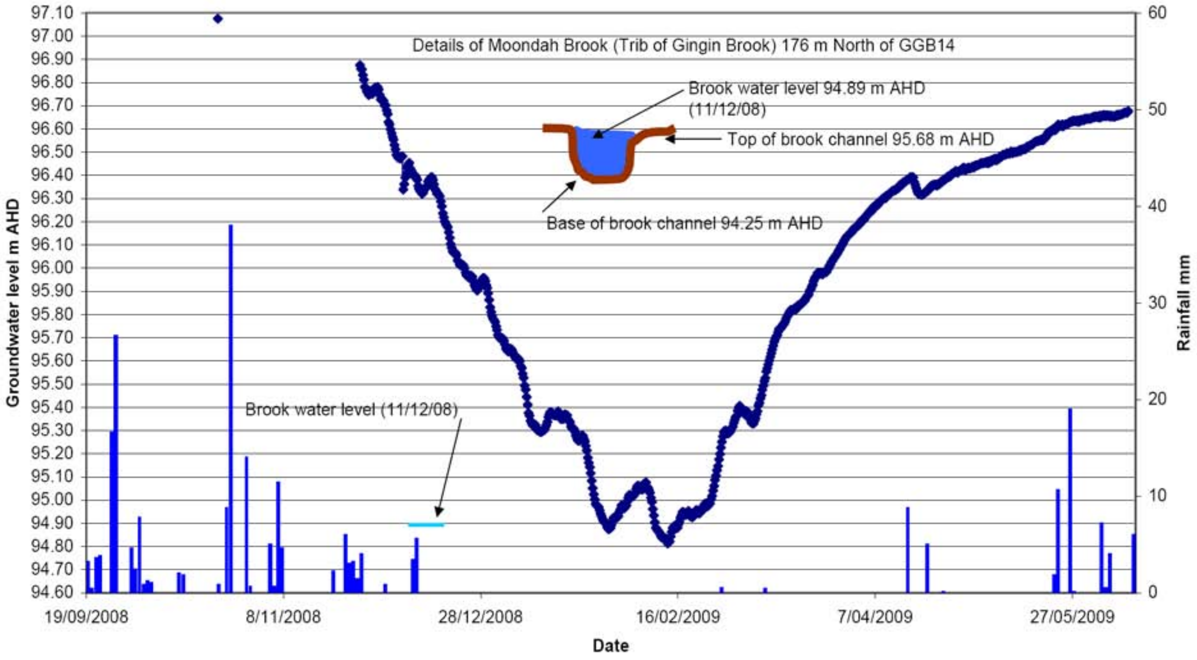


Figure B13 GGB13A/B hydrographs

GGB14A Leederville, screened from 51.73 to 54.73 m BGL



GGB14B Mirrabooka (Molecap Greensand), screened from 11.67 to 14.67 m BGL

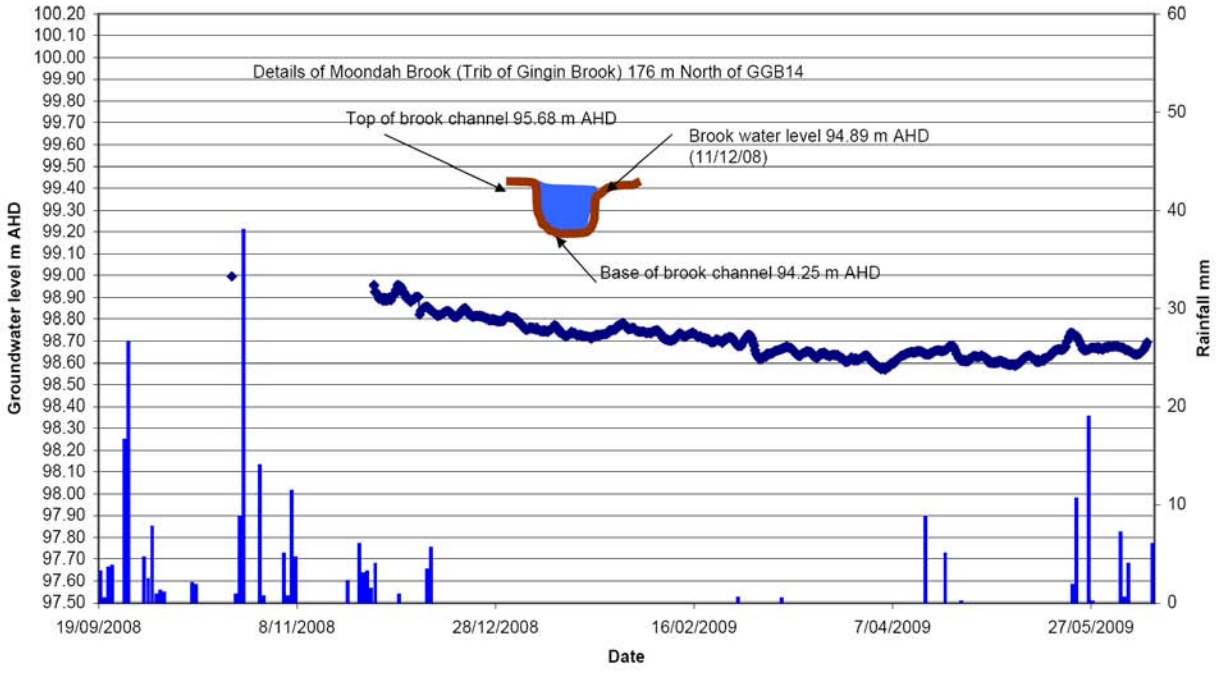
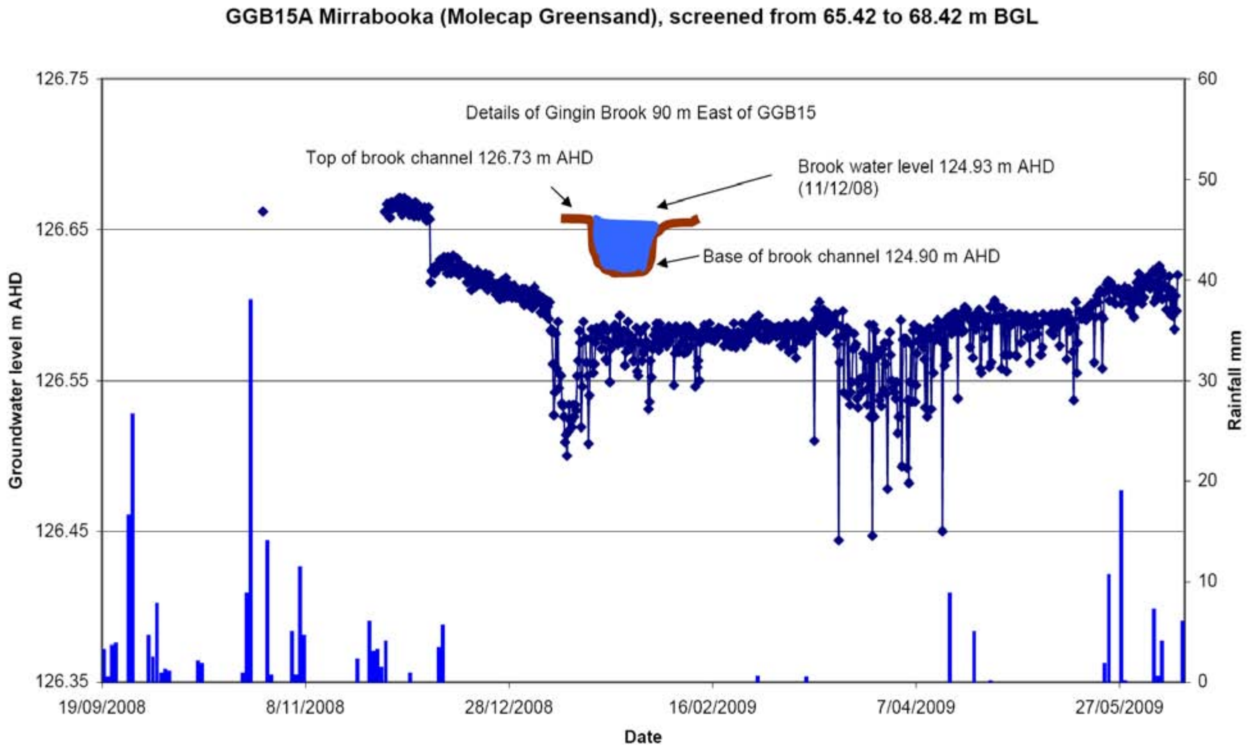


Figure B14 GGB14A/B hydrographs



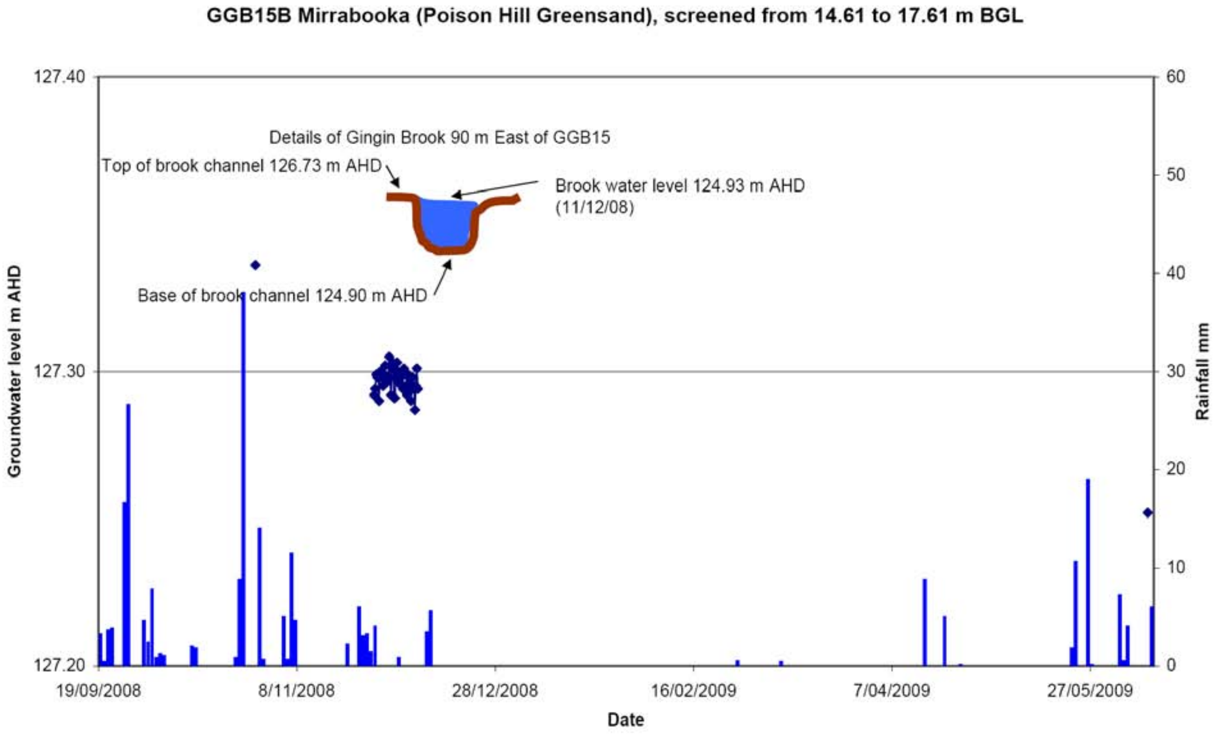
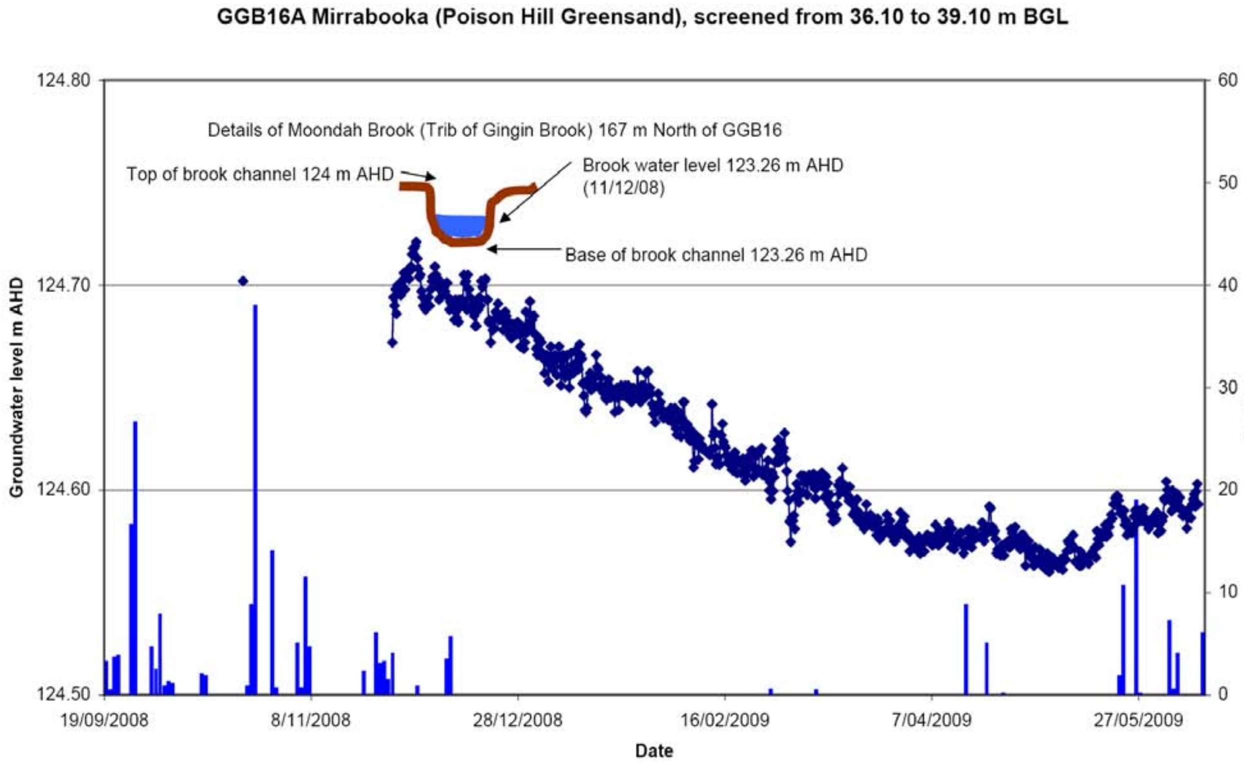


Figure B15 GGB15A/B hydrographs



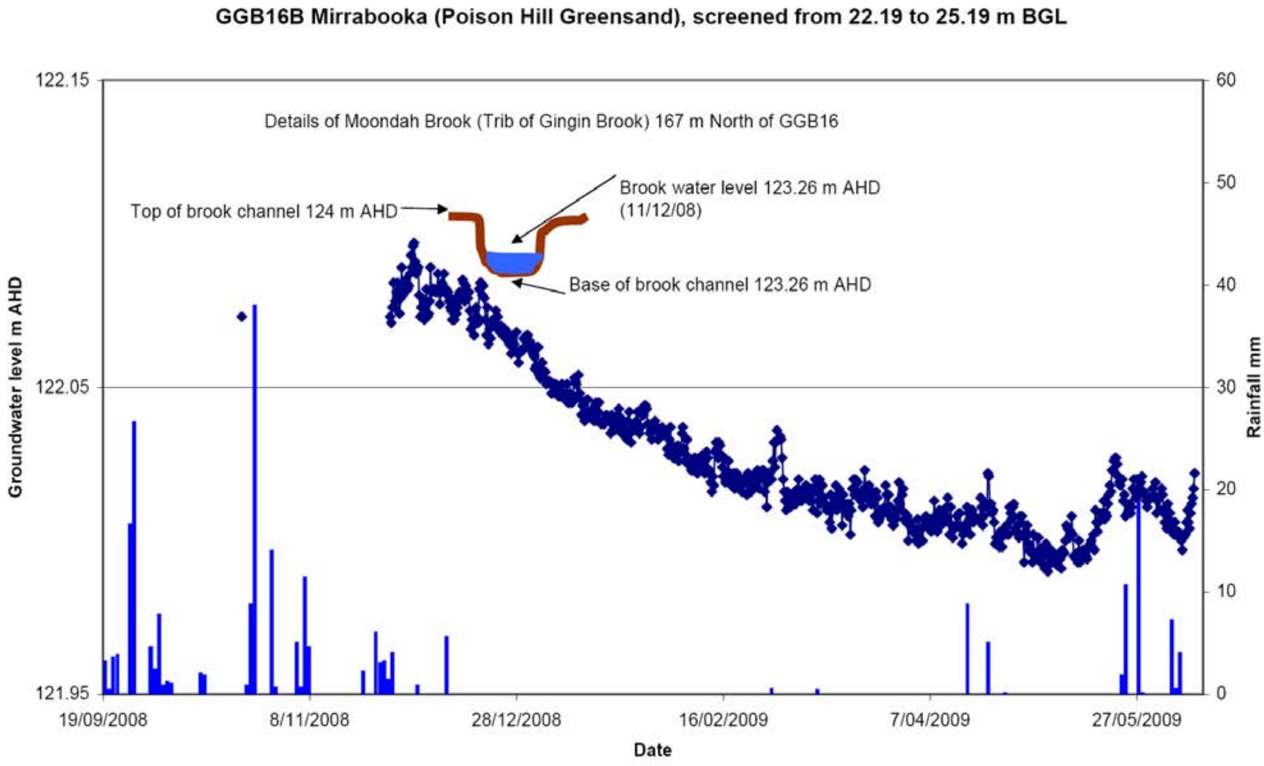


Figure B16 GGB16A/B hydrographs

Appendix C — Gingin Brook site data and spot flows

Site data					
Site no.	**AWRC**	**Stream**	**Name**	**Easting**	**Northing**
G01	6171001	Gingin Brook	Gingin Brook Road - Chitna Rd	367499	6536027
G03	617003	Gingin Brook	Chitna	369355	6534184
G05	617005	Gingin Brook	Chitna or Bookine	373490	6532357
G06	6171188	Gingin Brook	Gingin Brook Road - Spiders	375989	6534933
G07	6171227	Gingin Brook	Murray Rd	379953	6535566
G08	6171228	Mungala Brook	Track Xing - above Gingin/Mungala confluence	381250	6536530
G09	6171229	Gingin Brook	Beatie Rd - above Gingin/Mungala confluence	381501	6536384
G10	6171190	Mungala Brook	Bootine Rd	381125	6541860
G11	6171230	Wallering Brook	Wire Rd + Walking - above confluence with Gingin	387380	6536620
G12	6171231	Gingin Bk Main	Wire Rd + Walking - above confluence with Wallering	387240	6536580
G13	6171232	Gingin Bk Main	Granville Farm	388250	6534600
G14	6171233	Gingin Bk Main	Gingin Brook Road - Cent branch Mann outflow	388874	6532939
G15	6171234	Gingin Bk Main	Cockram Farm Lower - after convergence of G56 and G16	391211	6530696
G16	6171235	Gingin Bk Main	Cockram Farm Upper	392179	6529956
G19	617019	Gingin Bk North	Forking	393390	6530287
G20	617020	Gingin Bk North	GG North - section 330m (Alinta pipeline) Nth fork	392963	6530289
G21	617021	Gingin Bk Middle	GG South - section 120m (Alinta pipeline) Sth fork	393185	6530186
G22	6171236	Gingin Bk Middle	Vet property ~200m (Alinta pipeline) SS branch	393175	6530100
G23	6171033	Gingin Bk North	Brand Hwy (Nth Branch) - derived from G20+G21	393870	6530445
G24	6171034	Gingin Bk Middle	Brand Hwy (Mid Branch)	393925	6530350
G25	6171237	Gingin Bk North	Roe Street (Nth End)	395457	6531141
G26	6171238	Gingin Upper	Lefroy St (300m East)	397865	6532305
G27	6171239	Moondah Brook	Lefroy St (300m East)	398346	6532233
G28	6171258	Moondah Brook	Peterson	400211	6532854
G29	6171259	Moondah Brook	Ashworth	402071	6533573
G30	6171240	Gingin Bk Main	Muckenburra Farm - Gingin brook before confluence	384350	6537495

Site data

Site no.	AWRC	Stream	Name	Easting	Northing
G31	6171241	Gingin Bk South	Muckenburra Farm - Gingin brook before confluence	384265	6537395
G32	6171219	Gingin Bk South	Gingin Brook Road - Sth Branch Coonabidgee outflow	387844	6533610
G33	6171242	Gingin Bk South	Coonabidge Rd	388070	6530791
G34	6171243	Gingin Bk South	Coonabidge Rd	390580	6528310
G35	6171244	Gingin Bk South	Brand Hwy (Sth Branch)	394230	6529450
G36	6171032	Gingin Bk South	Roe Street (Nth End)	395474	6530990
G39	6171245	Gingin Bk Xover	Entry to Greville	391155	6529580
G39D		Drain offtake	Greville all north drains	391150	6529595
G39E		Gingin Bk Xover	Greville drain to wetland		
G40	6171246	Gingin Bk Xover	Cockram Farm Upper	391997	6529787
G44	6171260	Wowra Brook	Peterson	401000	6531057
G45	6171060	Gingin Upper	Whakee Rd	397555	6535187
G46	6171247	Gingin Upper	Cheriton RD (Overhay property)	400286	6539527
G51	6171248	Gingin Bk North	Granville Farm	388295	6534820
G52	6171030	Gingin Bk North	Gingin Brook Road - Cockram outflow	390756	6533021
G53	6171249	Gingin Bk North	Cockram Farm - 1 Nth	391225	6531400
G54	6171250	Gingin Bk North	Cockram Farm - 2 Mid natural	391250	6531280
G55	6171251	Gingin Bk North	Cockram Farm - 1 Sth	391225	6531280
G56N		Gingin Bk North	Cockram East boundary North	392245	6530545
G56S	6171268	Gingin Bk North	Cockram East boundary South	392159	6530582
G57N		Gingin Bk North	Cockram Farm - Nth branch	391780	6530665
G57C		Gingin Bk North	Cockram Farm - Mid branch	391780	6530645
G57S	6171269	Gingin Bk North	Cockram Farm - Sth branch	391760	6530697
G58	617058	Gingin Upper	Town	397040	6531700
G59	6171186	Quins Brook	Military Rd	376485	6534175
G60	6171187	Quins Brook	Quin Rd	379965	6531300
G61	6171252	Quins Brook	Sandrinham Rd	383500	6529245
G62	6171253	Quins Brook	Wapet Rd	385550	6526570

Site data

Site no.	AWRC	Stream	Name	Easting	Northing
G63	6171254	Quins Brook	Sullivan Rd	392570	6524375
G64	6171255	Lennard Brook	Brand Hwy	396086	6526117
G65	617165	Lennard Brook	Molecap Hill	396905	6528000
G66	6171262	Lennard Brook	Middle	402230	6527660
G70	6160732	Chandala Bk	Airfield Road	397110	6519400
G74	6171256	Gingin Bk Main	Roe Street (Mid)	395503	6531077
G75		Mann Drain East	Greville property	390380	6531030
G76		Mann Drain West	Greville property	390340	6531000
G77	6171257	Gingin Sth Drain	Shane Ray property south diversion	389121	6531191
G78		Gingin Bk Main	Greville property	390400	6531220
G79		Gingin Bk Bypass	Greville property	390340	6531360
G80	6171263	Boonanarring Bk	Upper 1	396355	6542320
G81	6171264	Boonanarring Bk	Upper 2	393780	6541600
G82	6171265	Boonanarring Bk	Brand Hwy	389750	6539685
G83	6171266	Wallering Brook	Brand Hwy	392360	6537040
G84	6171267	Werribee Creek	Brand Hwy	392335	6535425
G85	6171270		Mann property Nth	390018	6531489
G86	6171271		Mann property South	389958	6531348
G87	6171285		Mann property - SE corner flowing out of Grevilles	*391223*	*6529801*
G88	6171288		Mann property - SE corner flowing out of Grevilles	*390007*	*6531499*
G89		Gingin Bk	Extra branch sth channel Cockram property	391336	6529766
G00	617015	Moore River	Waterville Rd	366138	6540217
G85		Field Duplicate	Duplicate of G40		
G86		Gingin Bk	2nd channel of G39 (northern branch)		
G87			Mann Property Sth Branch	389955	6531343
G88			Mann Property Nth Branch	390007	6531499

Site data

Site no.	AWRC	Stream	Name	Easting	Northing
G89		Field Blank	Field Blank at G77		
LO1	6171286		LO1 – North-east corner flowing out of Grevilles	389532	6531078
LO2	6171287		LO2 – South-east corner flowing out of Grevilles	389507	6529281

Gingin Brook spot flows

L/s

Site no.	2/2007	5/2007	10/2007	19/11/2007	3/12/2007	17/12/2007	3/01/2008
G01	2.00	102	252	86	59	147	10
G03	27.00	89	254	no DM	no DM	no DM	no DM
G05	25.64	61.8	296				
G06	11.60	35.6	193	40	35	56	14
G07	1.85	10	161				
G08	0	0	38	no DM	no DM	no DM	no DM
G09	0.65	3	98	no DM	no DM	no DM	no DM
G10	0	0	11				
G11	no access	0	0	no DM	no DM	no DM	no DM
G12	no access	10	31	no DM	no DM	no DM	no DM
G13	0	0	24				
G14	0	4.5	25	Dry	Dry	1	Dry
G15	0	32	72	no DM	12	5	Dry
G16	0	35	58/36	no DM	no DM	no DM	Dry
G19	64.61	133(in doubt)	148	no DM	no DM	no DM	no DM
G20	16.37	31	36	17	15	22	6
G21	48.24	131	167	81	94	130	58
G22	32.00	119	133	no DM	no DM	no DM	no DM

Gingin Brook spot flows
L/s

Site no.	2/2007	5/2007	10/2007	19/11/2007	3/12/2007	17/12/2007	3/01/2008
G23	61.23	155	163/132	no DM	no DM	no DM	no DM
G24	38.43	117	148/121	88	77	134	38
G25	10.84	56	64				
G26	128.30	220	210	no DM	no DM	no DM	no DM
G27	43.50	99	119	no DM	no DM	no DM	no DM
G28		85	94				
G29		44	50				
G30	0	0	28				
G31	0	0	62				
G32	0	47	62	24	19	24	0.5
G33	0	54	58				
G34	0	0	0				
G35	0	0	0				
G36	3.82	15	6				
G39	62.02	156 / 158	150	no DM	no DM	no DM	65
G39D	40.00	no access	no access				
G39E		no access	no access				
G40	62.81	198	208/159	no DM	no DM	no DM	73
G44		15	13				
G45	144.38	212	182	no DM	187	220	143
G46	114.44	125	132	no DM	109	135	113
G51	0	10	13				
G52	0	17	14	Dry	Dry	Dry	Dry
G53	0	0	<10				
G54	0	0	0	no DM	6	13	Dry
G55	0	21	27				
G56N		0	0				

Gingin Brook spot flows

L/s

Site no.	2/2007	5/2007	10/2007	19/11/2007	3/12/2007	17/12/2007	3/01/2008
G56S		35	30/24				
G57N		0	0				
G57C		0	0				
G57S		20	26/21				
G58	141.00	276 / 330	296				
G59	0	4.2	6				
G60	0	0	0				
G61	0	0	0				
G62	0	0	0				
G63	0	0	0				
G64	61.00	145	177				
G65	87.70	169	207	no DM	no DM	no DM	no DM
G66		no access	no access				
G70	0	0	0				
G74		256	247				
G75		no access	no access				
G76		no access	no access				
G77		43	30				
G78		no access	no access				
G79		no access	no access				
G80		no access	no access				
G81		0	0				
G82		0	0				
G83		0	0				
G84		<1	<1				
G85		12	G88=26				
G86		25.9	G87=23				

Gingin Brook spot flows
L/s

Site no.	2/2007	5/2007	10/2007	19/11/2007	3/12/2007	17/12/2007	3/01/2008
G87		na	23	no DM	25	Dry	Dry
G88		na	26	no DM	Dry	30	Dry
G89		19.3	G86=47				
G00		227	356				
G85		was G87	0				
G86		was G89	47	no DM	no DM	no DM	Dry
G87		was G86	23				
G88		was G85	26				
G89		was G88	0				

Appendix D — Surface water hydrochemistry data

Site no.	Date	Time	Easting	Northing	pH	Temp ºc	Cond µs/cm	DO mg/L	DO %
G01	8/02/2007	09:25	367499	6536027	7.66	23.1	1391	4.46	48
G03	8/02/2007	10:30	369355	6534184	7.48	23.9	1361	3.21	38
G05	8/02/2007	12:50	373490	6532357	7.55	23.7	1596	6.58	78
G06	8/02/2007	11:45	375989	6534933	7.08	23.1	1797	2.84	34
G07	8/02/2007	13:50	380071	6535591	7.10	22.7	2130	2.61	31
G09	9/02/2007	09:00	381501	6536384	7.82	22.4	2970	3.30	36
G19	8/02/2007	09:50	393390	6530287	6.79	22.1	450	7.61	88
G20	8/02/2007	09:58	392968	6530299	7.05	22.5	456	5.29	67
G21	8/02/2007	10:11	393185	6530186	7.14	22.5	453	7.48	89
G22	8/02/2007	10:54	393169	6530123	7.03	24.9	476	8.15	99
G23	8/02/2007	08:30	393870	6530445	6.79	25.6	448	7.11	83
G24	8/02/2007	09:20	393925	6530350	6.80	22.3	451	8.50	96
G25	9/02/2007	14:15	395457	6531141	6.52	23.1	471	4.46	51
G26	9/02/2007	10:30	397990	6532210	7.44	21.2	393	7.40	84
G27	9/02/2007	10:30	398211	6532332	8.25	25.3	603	11.50	137
G36	9/02/2007	14:40	395474	6530990	6.30	24.3	481	7.37	89
G39	8/02/2007	12:28	391155	6529580	7.22	24.9	485	8.62	100
G40	8/02/2007	11:32	392190	6529790	7.05	24.2	474	7.68	92
G45	9/02/2007	09:27	397536	6535270	6.47	20.2	379	6.52	70
G46	9/02/2007	08:21	400286	6539527	6.12	19.1	348	6.15	68
G58	9/02/2007	12:45	397040	6531700	6.69	21.9	454	6.54	74
G64	9/02/2007	13:22	396086	6526117	7.05	22.0	795	8.66	98
G65	8/02/2007	17:00	396905	6528000	7.24	23.2	826	7.04	83
G74	9/02/2007	13:50	395503	6531077	6.75	23.1	471	7.45	88
G77	8/02/2007	14:50	389140	6531195	8.38	34.0	717	10.73	152
G01	9/05/2007	13:22	367499	6536027	8.02	16.5	1573	7.10	73
G03	9/05/2007	13:56	369355	6534184	7.87	15.5	1533	7.20	71
G05	9/05/2007	15:52	373490	6532357	8.03	15.9	1768	8.40	84
G06	9/05/2007	09:06	375989	6534933	7.60	14.2	1865	4.40	43
G07	9/05/2007	07:56	379953	6535566	7.60	12.7	2520	4.30	41
G09	8/05/2007	14:26	381501	6536384	7.96	20.0	3300	6.50	73
G12	9/05/2007	10:09	387240	6536580	6.94	14.9	780	4.70	47
G14	8/05/2007	09:31	388874	6532939	6.60	12.8	571	7.40	70
G15	10/05/2007	14:00	391211	6330696	6.38	19.0	591	7.64	81
G16	10/05/2007	13:00	392179	6529956	6.23	17.4	553	8.37	86
G19	9/05/2007	11:30	393390	6530287	6.44	14.0	498	9.99	95
G20	9/05/2007	12:45	392963	6530289	6.45	14.5	506	9.20	90
G21	9/05/2007	13:30	393185	6530186	6.48	14.5	506	9.91	98
G22	9/05/2007	14:15	393175	6530100	6.85	17.3	540	10.20	106
G23	9/05/2007	10:50	393870	6530445	6.64	13.9	495	9.74	94
G25	9/05/2007	08:55	395457	6531141	6.65	13.3	492	6.76	69
G26	8/05/2007	14:00	397865	6532305	6.06	14.4	444	6.41	63

Site no.	Date	Time	Easting	Northing	pH	Temp ºc	Cond µs/cm	DO mg/L	DO %
G27	8/05/2007	13:00	398346	6532233	7.46	18.4	606	11.70	126
G28	8/05/2007	11:45	400211	6532854	7.29	15.9	597	9.82	99
G29	8/05/2007	09:15	402071	6533573	7.02	17.0	707	7.51	78
G32	8/05/2007	08:54	387844	6533610	6.60	13.8	737	4.80	47
G33	9/05/2007	16:50	388070	6530791	6.25	17.1	695	7.57	79
G36	9/05/2007	09:48	395474	6530990	6.40	13.5	483	8.07	77
G39	10/05/2007	09:20	391155	6529580	6.68	13.9	498	9.10	88
G40	10/05/2007	13:20	391997	6529787	6.38	16.3	521	8.57	89
G44	8/05/2007	10:53	401000	6531057	7.19	16.4	169	6.84	69
G45	8/05/2007	15:55	397555	6535187	7.40	14.8	375	11.50	114
G46	0/01/1900	14:50	400286	6539527	6.59	17.6	364	8.62	90
G51	8/05/2007	11:55	388295	6534820	6.60	16.9	683	5.80	60
G52	8/05/2007	10:35	390756	6533021	6.56	17.1	616	7.20	74
G55	10/05/2007	10:05	391225	6531280	6.97	16.7	533	9.87	100
G56S	10/05/2007	11:35	392159	6530582	6.50	16.5	526	8.70	90
G57S	10/05/2007	11:10	391760	6530697	6.93	16.5	526	10.80	110
G58	8/05/2007	17:00	397040	6531700	7.21	15.5	496	7.68	77
G59	9/05/2007	11:15	376485	6534175	6.49	13.2	1780	1.20	12
G64	10/05/2007	08:15	396086	6526117	7.84	14.2	727	6.80	68
G65	10/05/2007	10:06	396905	6528000	7.70	14.8	740	6.30	64
G74	9/05/2007	09:28	395503	6531077	6.50	13.2	479	8.75	82
G77	9/05/2007	17:15	389121	6531191	6.71	21.8	680	8.98	96
G84	10/05/2007	12:35			7.96	16.9	2040	7.00	73
G85	9/05/2007	15:15	390018	6531489	6.90	21.7	659	9.10	104
G86	9/05/2007	15:35	389958	6531348	7.20	21.9	636	10.40	100
G00	9/05/2007	12:16			7.48	18.4	2200	8.80	92
G01	22/10/2007	15:30	367499	6536027	7.20	18.3	1385	7.90	81
G03	22/10/2007	14:50	369355	6534184	7.25	17.9	1387	6.40	68
G05	22/10/2007	13:00	373490	6532357	6.80	18.0	1510	6.70	70
G06	23/10/2007	13:00	375989	6534933	7.27	17.3	1533	5.22	54
G07	23/10/2007	08:40	379953	6535566	6.9	15.5	1474	6.03	60
G08	23/10/2007	12:20	381250	6536530	7.00	17.9	2930	7.20	79
G09	23/10/2007	11:25	381501	6536384	7.10	18.5	846	7.50	76
G10	23/10/2007	14:20	381125	6541860	6.90	16.8	3040	4.60	50
G12	23/10/2007	09:45	387240	6536580	7.70	18.5	512	8.50	86
G13	23/10/2007	14:00	388250	6534600	7.50	22.2	563	9.57	109
G14	23/10/2007	11:45	388874	6532939	7.31	24.0	56.6	8.41	93
G15	22/10/2007	16:25	391211	6330696	6.67	19.8	493	6.15	68
G16	22/10/2007	17:00	392179	6529956	6.63	17.9	470	5.81	69
G19	22/10/2007	11:10	393390	6530287	6.85	15.5	434	9.01	89
G20	22/10/2007	12:50	392963	6530289	6.88	16.3	442	8.10	82
G21	22/10/2007	11:46	393185	6530186	7.05	15.8	408	8.20	82

Site no.	Date	Time	Easting	Northing	pH	Temp ºc	Cond µs/cm	DO mg/L	DO %
G22	22/10/2007	14:10	393175	6530100	6.95	19.5	477	9.04	98
G23	22/10/2007	09:05	393870	6530445	7.02	14.6	425	9.14	89
G24	22/10/2007	08:17	393925	6530350	6.89	15.3	432	8.70	84
G25	22/10/2007	11:35	395457	6531141	6.24	15.8	435	7.14	72
G26	22/10/2007	14:35	397865	6532305	6.76	17.1	405	7.13	73
G27	23/10/2007	10:00	398346	6532233	6.65	16.4	472	8.21	84
G28	23/10/2007	09:05	400211	6532854	6.40	15.4	492	7.44	74
G29	23/10/2007	08:10	402071	6533573	6.50	17.0	618	7.09	73
G30	23/10/2007	14:45	384350	6537495	6.98	18.5	572	8.32	88
G31	23/10/2007	15:25	384265	6537395	7.24	19.9	730	6.83	75
G32	23/10/2007	12:45	387844	6533610	7.38	17.6	537	8.31	85
G33	23/10/2007	16:20	388070	6530791	6.76	19.1	513	7.15	77
G36	22/10/2007	12:45	395474	6530990	6.58	16.5	439	8.02	82
G39	23/10/2007	09:30	391155	6529580	6.73	14.5	426	8.65	85
G40	22/10/2007	17:40	391997	6529787	6.80	18.3	466	8.15	86
G44	23/10/2007	15:45	401000	6531057	7.60	19.0	180	4.75	51
G45	22/10/2007	16:40	397555	6535187	6.28	16.9	380	7.49	76
G46	22/10/2007	15:45	400286	6539527	6.32	18.6	353	6.39	68
G51	23/10/2007	13:30	388295	6534820	7.37	18.9	513	9.90	106
G52	23/10/2007	11:05	390756	6533021	6.80	17.4	506	7.60	84
G53	22/10/2007	15:40	391225	6531400	6.20	21.8	501	7.30	83
G55	22/10/2007	15:15	391225	6531280	6.72	20.6	488	6.82	76
G56S	25/10/2007	11:25	392159	6530582	6.59	17.5	445	6.70	72
G58	22/10/2007	13:45	397040	6531700	6.65	16.5	437	7.19	73
G59	22/10/2007	10:15	376485	6534175	6.40	14.2	1037	3.50	34
G64	22/10/2007	08:43	396086	6526117	6.10	14.7	660	7.88	77
G65	22/10/2007	09:55	396905	6528000	6.10	15.1	671	6.99	71
G74	22/10/2007	12:05	395503	6531077	6.39	15.8	433	7.84	79
G77	23/10/2007	17:00	389121	6531191	6.85	23.7	603	7.27	84
G84	22/10/2007	17:15			6.66	18.6	1400	8.79	91
G00	22/10/2007	16:45			8.30	24.4	6410	8.69	86
G86	23/10/2007	09:55			6.84	14.4	427	9.16	89
G87	23/10/2007	11:10	389955	6531343	7.32	21.4	515	10.37	116
G88	23/10/2007	11:30	390007	6531499	7.04	20.9	514	9.69	108

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