Appendix H

Groundwater Assessment, Volume One Data Analysis

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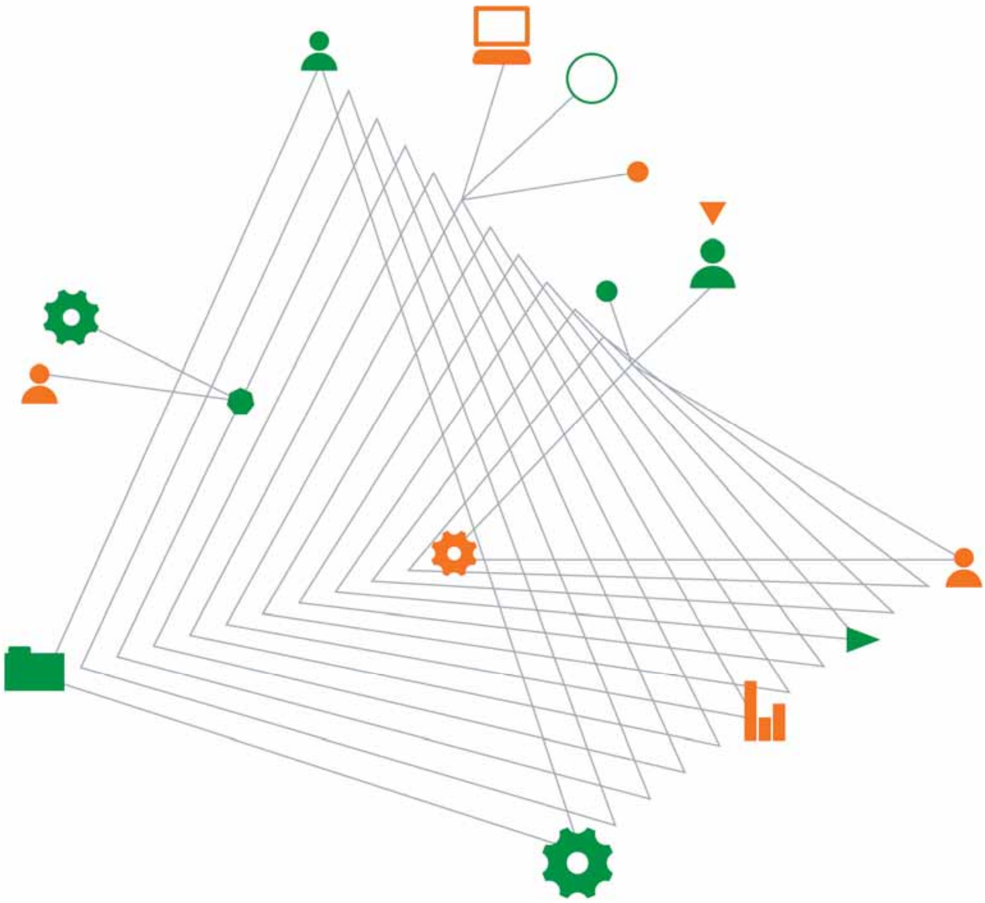
Hume Coal Pty Limited

Hume Coal Project

Groundwater Assessment Volume 1: Data Analysis

17 November 2016



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Hume Coal Project

Prepared for
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For and on behalf of Coffey

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Table of Contents

Tables

Figures

Drawings

Appendices

Executive Summary

A large groundwater database has been collated for the Hume Coal Project. The purpose of the database was to support the development of a regional numerical groundwater flow model for the project. Results of the data analysis were used to develop a hydrogeological conceptual model, and to reduce uncertainty in model parameters using the large number of observations available for these parameters. Numerical model development, calibration, and predictive simulations and results, are reported separately. The database, and results interpreted therefrom, are as follows:

- Long-term rainfall observations from 20 regional stations, providing coverage of the regional area, and several years of observations from Hume's on-site rain gauge. The average long-term annual rainfall for the mine lease was estimated as 957 mm.
- Streamflow observations from four gauges on the Hume mine lease monitored by Hume (SW01, SW03, SW04, and SW08) and seven government gauges in the regional area. These were subjected to baseflow analysis. For the lease area the estimated baseflow to drainage channels is about 1.5% to 2% of annual rainfall.
- A database of hydraulic conductivity (K) measurements comprising 28 packer tests on the Hume lease, two long-term pumping tests undertaken by Hume on the lease in 2014 (pumping bores HU0098 and GW108194 (Wongonbra) with multiple observation piezometers monitored), six long-term pumping tests from private bores in the wider area, 129 estimates of hydraulic conductivity from specific capacity data in government records for private water bores, and laboratory tests on 39 cores of Hawkesbury Sandstone and Farmborough Claystone retrieved from five boreholes. Hydraulic conductivity and storativity decrease with depth. The K field for the Hume area has greater magnitudes than seen elsewhere in the Southern Coalfield, and is believed to result from significant tectonic disturbance and associated intrusive activity.
- An extensive groundwater level and quality monitoring network operated by Hume in the lease area, comprising vibrating wire piezometer (VWP) and standpipe piezometer (SP) installations. The network comprises 46 SPs at 19 locations, 11 VWPs at 3 locations, and 2 private water bores. This provides 59 subsurface measurement points at 24 locations. Monitoring commenced in late 2011 when the first piezometers were installed, and has continued to the present. Useful monitoring information is also available from the Berrima Mine monitoring network (VWPs and bores), and a government monitoring network in the regional area. The combination of highland topography and contrasting outcrop lithologies produces a hydraulic head field which is elevated along the western Hawkesbury Sandstone outcrop and at Wingecaribbee Reservoir to the southeast, and decreases towards the south and northeast. Wingecarribee Reservoir and rainfall recharge at sandstone outcrop areas form the main upper hydraulic controls in the subsurface, for the hydraulic head field. Increased vertical hydraulic head gradients can be identified in proximity to the Berrima mine workings.
- Observations of discharge from the Berrima mine workings, providing vital calibration targets for deep groundwater discharges.

The database also contains large amounts of water quality measurements, bore lithology logs, and other observations (such as stress measurements and mining-related documentation for the Hume area available on the NSW Department of Primary Industries internet data portal).

A hydrogeological conceptual model was developed based on the observations in the database. The presence of a large number of hydraulic conductivity and hydraulic head measurements (including for evolution of drawdown from mining, at the Berrima mine), in conjunction with a large number of baseflow estimates (shallow discharge of groundwater from the system), and observed discharge from the Berrima mine (deep discharge of groundwater from the system) provided a stringent observation dataset for large-scale reliable estimation of Kv down the profile, an important parameter for simulation of deep discharges such as mine inflows. Pumping tests undertaken by Hume at HU0098 and GW108194 provided highly useful independent estimates of large-scale Kv for sandstone, providing strong calibration targets.

The objective of model calibration was to simultaneously replicate the following crucial observation datasets:

- Hydraulic conductivity.
- Hydraulic heads.
- Shallow groundwater discharge (baseflow to streams).
- Deep groundwater discharge (discharge to mine voids).

This is the optimal set of data for calibration of a numerical groundwater flow model, and provided a suitable basis for predictive simulation of the proposed Hume mining operations.

1. Introduction

This is the first of two reports that present the results of a groundwater assessment for the Hume Coal Project. The assessment was undertaken by Coffey Geotechnics Pty Ltd (Coffey) for Hume Coal Pty Limited (Hume). The purpose of the assessment was to assess impacts on the groundwater system and dependent users from proposed mining. Results of the assessment will be used to support an application for development consent.

Approval for the Hume Coal Project is being sought under Part 4, Division 4.1 of the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) and the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). An environmental impact statement (EIS) is a requirement of the approval processes. This groundwater assessment forms part of the EIS. It documents the groundwater assessment methods and results, and outlines initiatives built into the project design to avoid and minimise impacts on the groundwater system.

The assessment comprised compilation and analysis of a groundwater database, development of a hydrogeological conceptual model, and development of a groundwater flow numerical model to simulate drawdown of the groundwater system due to mining and any consequent drawdown interference in private bores in the region, and any effects on surface water hydrology. A substantial database of observations was compiled from data provided by Hume, and data obtained from published sources. Database analysis was undertaken to support development of the hydrogeological conceptual model (and subsequent numerical model development and calibration).

This volume presents the results of compilation and analysis of the groundwater database, and development of the hydrogeological conceptual model. Numerical model development, calibration, predictive simulations, and predictive drawdown and inflow assessment, are reported in Volume 2 (Numerical Simulation). This volume should be read in conjunction with Volume 2.

1.1. Background

Hume proposes to develop and operate an underground coal mine and associated mine infrastructure (the Hume Coal Project) in the Southern Coalfield of NSW. Hume is a wholly owned subsidiary of POSCO Australia. Hume holds exploration Authorisation 349 (A349), which covers an area of 89 km^2 to the west of Moss Vale, in the Wingecarribee local government area (LGA). A349 adjoins the southern boundary of the Berrima Colliery lease (CCL748). The underground mine will be developed within A349 and associated surface infrastructure facilities will be developed within and north of A349. The project area and its regional setting are shown in Drawing 1. Drawing 1 shows the interrelationship between A349, the mining lease application area, the proposed workings, and the model domain boundary; the latter two features are further discussed in this report and the numerical simulation report.

The project has been developed following several years of technical investigations to identify and address potential environmental, social and economic constraints. This has allowed for the development of a well-considered, practical and economic project design that will enable effective resource recovery, while minimising adverse impacts to the environment and community.

Hume will undertake a non-caving first workings mining layout and method, which is a low impact method having negligible subsidence effects, and offering a significant amount of protection to overlying hydrostratigraphic media and surface features. The mining target is the Wongawilli Coal Seam of the Permian Illawarra Coal Measures.

Mining is to be carried out in separate compartments known as panels. A panel consists of a number of plunges (parallel tunnels driven into the seam with unmined coal between plunges) connected by gate roads driven along the long dimension of the panel. A panel of the Hume first workings method is dissimilar to a panel in longwall mining with respect to post-mining deformation. All tunnels in a panel occur within the seam. A group of panels forms a mining block, where each panel in the block is connected by a set of main headings that allow access for workers, equipment, and ventilation, and also provide mined coal during their development. The set of headings remains open until mining of the last panel in the block is finished.

Figure 1.1 is a detail of two panels for reference in the following discussion. A mining height of 3.5 m has been adopted. Where the coal seam is thinner than 3.5 m, a cutoff height of 1.8 m has been assumed. All panels are initially developed with gate roads (and associated cut-throughs) that are driven off the main headings in a direction parallel to the panel long dimension. Gate roads are positioned down the centre of the panel. Additional workings comprising plunges (tunnels) are driven off the gate roads. These openings are separated by pillars that are designed not to fail post-mining.

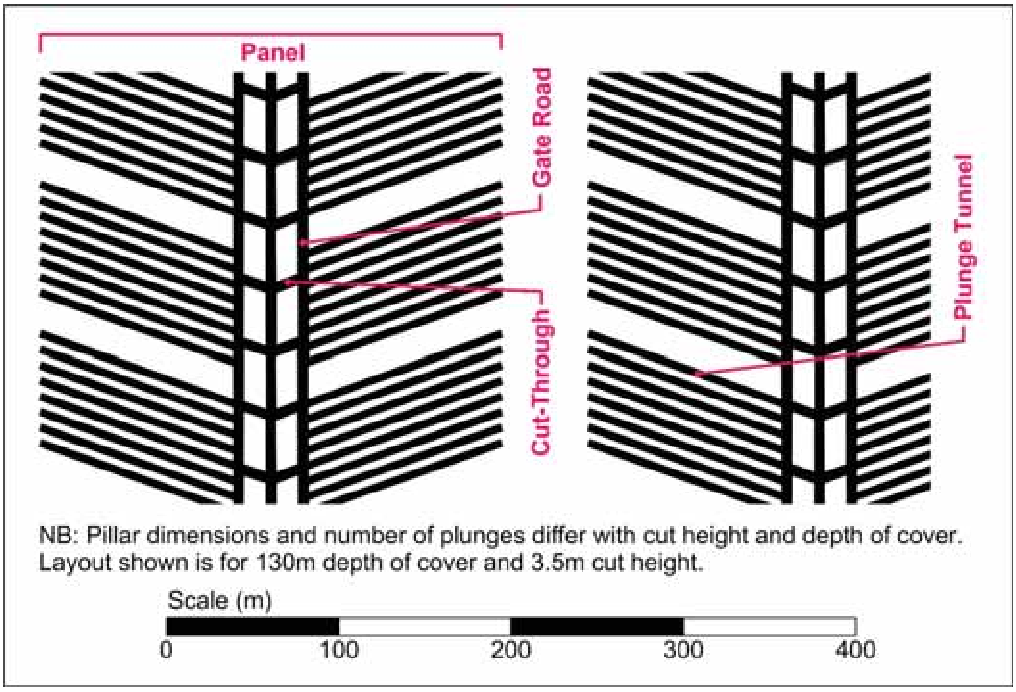


Figure 1.1. Detail of mine openings for the first workings mining method. Black areas indicate removed coal.

The mining method is non-caving, which results in openings remaining open post-mining, without caving (goaf is not created). Overburden deformation would occur as relaxation in the immediate roof over the openings, generally limited to less than 3 m into the overlying roof.

1.1.1. Project description

The project involves developing and operating an underground coal mine and associated infrastructure over a total estimated project life of 23 years. A full description of the project, as assessed in this report, is provided in Chapter 2 of the main EIS (EMM 2016). In summary, the project involves:

- Ongoing resource definition activities, along with geotechnical and engineering testing, and other low impact fieldwork to facilitate detailed design.
- Establishment of a temporary construction accommodation village.

- Development and operation of an underground coal mine, consisting of approximately two years of construction and 19 years of mining, followed by a closure and rehabilitation phase of up to two years, leading to a total project life of 23 years. Some coal extraction will commence during the second year of construction during installation of the drifts, and hence there will be some overlap between the construction and operational phases.
- Extraction of approximately 50 million tonnes (Mt) of run-of-mine (ROM) coal from the Wongawilli Seam, at a rate of up to 3.5 million tonnes per annum (Mtpa). Low impact mining methods will be used, which will have negligible subsidence impacts.
- Following processing of ROM coal in the coal preparation plant (CPP), production of up to 3 Mtpa of metallurgical and thermal coal for sale to international and domestic markets.
- Construction and operation of associated mine infrastructure, mostly on cleared land, including:
  - One personnel and materials drift access and one conveyor drift access from the surface to the coal seam.
  - Ventilation shafts, comprising one upcast ventilation shaft and fans, and up to two downcast shafts installed over the life of the mine, depending on ventilation requirements as the mine progresses.
  - A surface infrastructure area, including administration, bathhouse, washdown and workshop facilities, fuel and lubrication storage, warehouses, laydown areas, and other facilities. The surface infrastructure area will also comprise the CPP and ROM coal, product coal and emergency reject stockpiles.
  - Surface and groundwater management and treatment facilities, including storages, pipelines, pumps and associated infrastructure.
  - Overland conveyors.
  - Rail load-out facilities.
  - Explosives magazine.
  - Ancillary facilities, including fences, access roads, car parking areas, helipad and communications infrastructure.
  - Environmental management and monitoring equipment.
- Establishment of site access from Mereworth Road, and minor internal road modifications and relocation of some existing utilities.
- Coal reject emplacement underground, in the mined-out voids.
- Peak workforces of approximately 414 full-time equivalent employees during construction and approximately 300 full-time equivalent employees during operations.
- Decommissioning of mine infrastructure and rehabilitation of the area once mining is complete, so that it can support land uses similar to current land uses.

The project area, shown in Figure 1.2, is approximately 5,051 hectares (ha). Surface disturbance will mainly be restricted to the surface infrastructure areas shown in Figure 1.3, though will include some other areas above the underground mine, such as drill pads and access tracks. The project area generally comprises direct surface disturbance areas of up to approximately 117 ha, and an underground mining area of approximately 3,472 ha, where negligible subsidence impacts are anticipated.

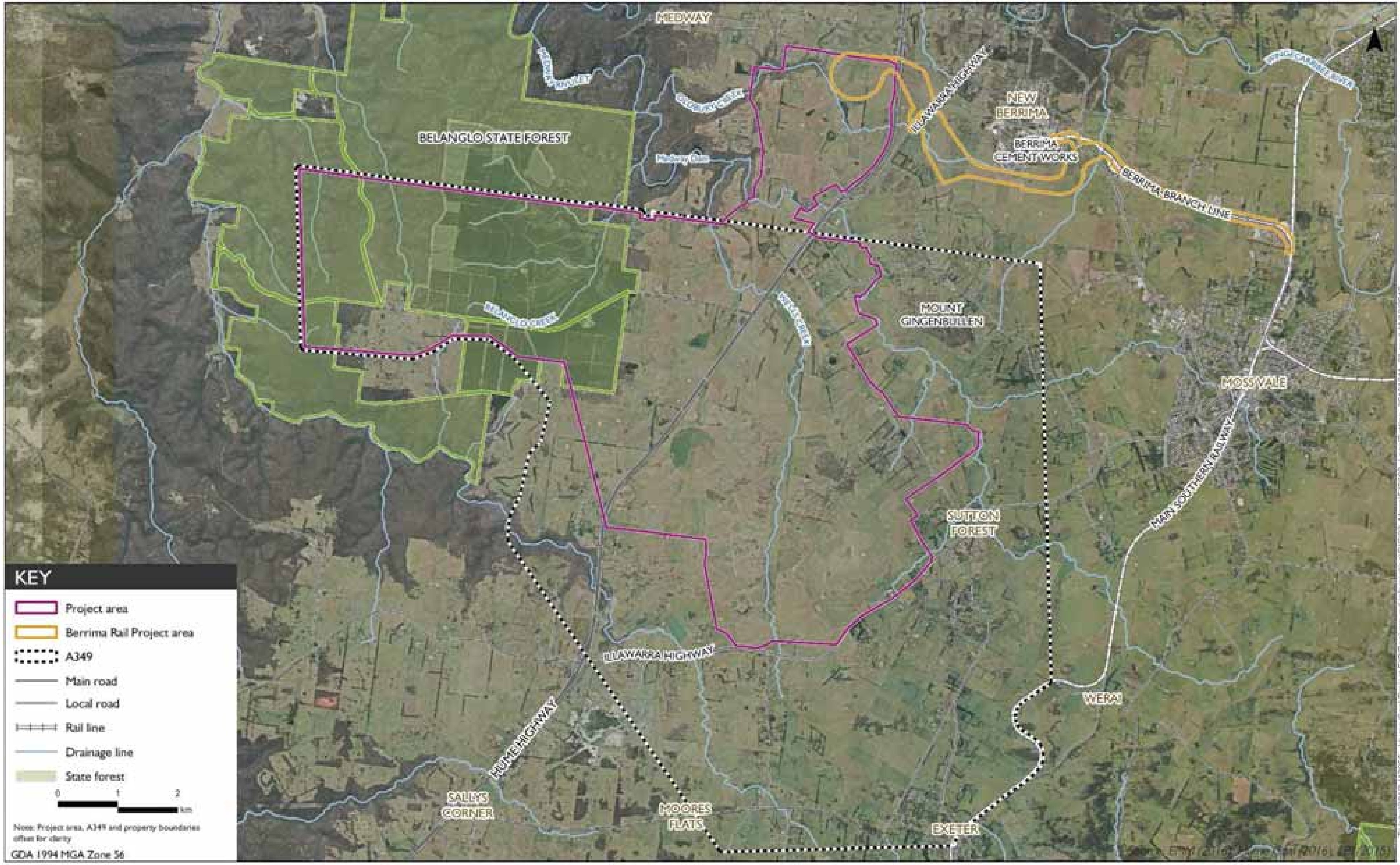


Figure 1.2. Local context

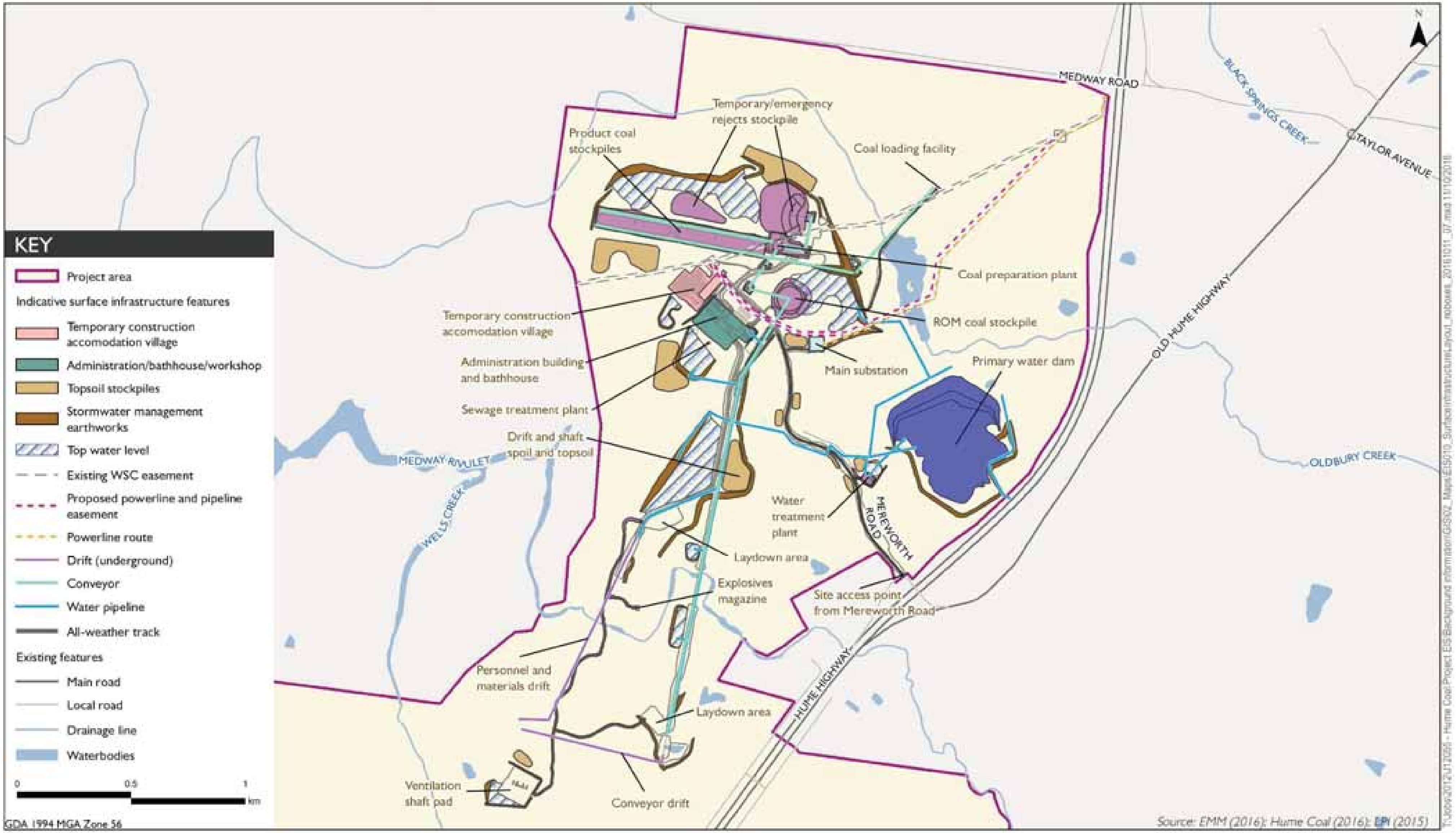


Figure 1.3. Indicative surface infrastructure layout.

A construction buffer zone will be provided around the direct disturbance areas. The buffer zone will provide an area for construction vehicle and equipment movements, minor stockpiling and equipment laydown, as well as allowing for minor realignments of surface infrastructure. Ground disturbance will generally be minor and associated with temporary vehicle tracks and sediment controls as well as minor works such as backfilled trenches associated with realignment of existing services. Notwithstanding, environmental features identified in the relevant technical assessments will be marked as avoidance zones so that activities in this area do not have an environmental impact.

Product coal will be transported by rail, primarily to Port Kembla terminal for the international market, and possibly to the domestic market depending on market demand. Rail works and use are the subject of a separate EIS and State significant development application for the Berrima Rail Project.

General site description

The project area is approximately 100 km southwest of Sydney and 4.5 km west of Moss Vale town centre in the Wingecarribee LGA (refer to Drawing 1 and Figure 1.2). The nearest area of surface disturbance will be associated with the surface infrastructure area, which will be 7.2 km northwest of Moss Vale town centre. It is in the Southern Highlands region of NSW and the Sydney Basin Biogeographic Region.

The project area is in a semi-rural setting, with the wider region characterised by grazing properties, small-scale farm businesses, natural areas, forestry, scattered rural residences, villages and towns, industrial activities such as the Berrima Cement Works and Berrima Feed Mill, and some extractive industry and major transport infrastructure such as the Hume Highway.

Surface infrastructure is proposed to be developed on predominately cleared land owned by Hume Coal or affiliated entities, or for which there are appropriate access agreements in place with the landowner. Over half of the remainder of the project area (principally land above the underground mining area) comprises cleared land that is, and will continue to be, used for livestock grazing and small-scale farm businesses. Belanglo State Forest covers the northwestern portion of the project area and contains introduced pine forest plantations, areas of native vegetation and several creeks that flow through deep sandstone gorges. Native vegetation within the project area is largely restricted to parts of Belanglo State Forest and riparian corridors along some watercourses.

The project area is traversed by several drainage lines including Oldbury Creek, Medway Rivulet, Wells Creek, Wells Creek Tributary, Belanglo Creek and Longacre Creek, all of which ultimately discharge to the Wingecarribee River, at least 5 km downstream of the project area (Figure 1.2). The Wingecarribee River's catchment forms part of the broader Warragamba Dam and Hawkesbury-Nepean catchments. Medway Dam is also adjacent to the northern portion of the project area (Figure 1.2).

Most of the central and eastern parts of the project area have very low rolling hills with occasional elevated ridge lines. However, there are steeper slopes and deep gorges in the west in Belanglo State Forest.

Existing built features across the project area include scattered rural residences and farm improvements such as outbuildings, dams, access tracks, fences, yards and gardens, as well as infrastructure and utilities including roads, electricity lines, communication cables and water and gas pipelines. Key roads that traverse the project area are the Hume Highway and Golden Vale Road. The Illawarra Highway borders the south-east section of the project area.

Industrial and manufacturing facilities adjacent to the project area include the Berrima Cement Works and Berrima Feed Mill on the fringe of New Berrima. Berrima Colliery's mining lease (CCL 748) also adjoins the project area's northern boundary. Berrima colliery is currently not operating with production having ceased in 2013 after almost 100 years of operation. The mine is currently undergoing closure.

1.1.2. Assessment guidelines and requirements

This groundwater assessment has been prepared generally in accordance with the following:

- Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A, and Boronkay A. 2012. Australian groundwater modelling guidelines. Waterlines Report Series, Number 82. National Water Commission, Canberra.
- NSW Department of Primary Industries (Office of Water). 2012. NSW Aquifer Interference Policy: NSW Government policy for the licensing and assessment of aquifer interference activities. September.

1.2. Previous mining

Mining has occurred in the area since the 1800s. All known mines in the area are now abandoned, all believed to be underground, comprising (see Drawing 1):

- Berrima Mine, located to the north of Wingecarribbee River on the Berrima Mine lease. The workings are the most extensive of any mine in the area and comprise 1st workings and pillar extraction in the Wongawilli seam. Mining operations commenced in 1926 and ceased in 2013. Mechanisation (and full extraction) commenced in 1968 (EMGA 2011). Production varied between 0.13 and 0.46 Mt/year and was reported as 0.25 Mt/year in 2009 (EMGA 2011). The workings are currently under care and maintenance, remaining largely empty and draining to the Wingecarribee River. Groundwater drawdown from this mine can be identified in monitoring piezometer hydrographs. The owner is considering sealing the mine to reduce or eliminate drainage to the river. Groundwater and surface water quality, and groundwater levels, around the mine are monitored by Boral.
- The Loch Catherine Mine (abandoned), opened in 1924 with an anticipated maximum possible production of 200 t/day. It is located underneath the current Berrima Colliery stockpile in a localised zone of Hawkesbury Sandstone bounded by Medway Rivulet and the Wingecarribee River. The mine worked the Wongawilli Seam and ceased operation in 1958 (BCSC 1993). It included some mechanised workings utilising shuttle cars. Full extraction is thought to have occurred based on the shape of the mine footprint, and its presence in the Mine Subsidence Compensation Act on the list of compulsory contributors to the compensation fund. The adits are still open, and iron staining is evident in the water pooled at the mine entries.
- Southern Colliery (abandoned), located on Foxgrove Road about 5 km from the Hume lease boundary. Mining appears to have occurred in the Tongarra Seam. This was a small scale mine which ceased operations many years ago.
- Numerous adits at coal seam outcrops along escarpments (see Drawing 1, not all identified) for pre-mechanisation (manual) abandoned workings. Typical examples are Black Bobs, Belanglo (abandoned in the 1950s), Belanglo Extended, and Flying Fox collieries to the west and the north of the Hume lease, and Erith Colliery near Bundanoon. These were likely to be very small operations, probably mining less than 100,000 t in total. Most are not sealed and drain into local watercourses. They typically consist of two headings extending in from outcrop by a few hundred metres. Belanglo was a small operation along Black Bobs Creek, presumed to be on the southern side of the creek, to the west of the Hume Highway. Murrimba Colliery was on the eastern side of Black Bobs Creek in approximately the same location and was abandoned after hitting a full face of stone a few hundred metres from the creek (coincident with a high magnetic anomaly). Belanglo Colliery is located in the Berrima lease in a tributary of Medway Rivulet.

Two adits have also been discovered along Longacre Creek. The workings are of unknown length. They are above one another (in the Tongarra and Wongawilli seams). Historical literature discusses a number of old mines in the area around the Loch Catherine mine, and it is likely that other small scale abandoned mine workings are present along the coal seam outcrop in this area.

2. Climate

The distribution of regional rainfall was assessed from a large number of climate stations whose data are held by the Australian Bureau of Meteorology (ABM). Stations which had more than 30 full years of records, with at least 15 years post 1955, were used. The mean and median annual rainfall for these stations are listed in Table 1.

Table 1. Regional rainfall.

Station Name	Station Number	Latitude	Longitude	Mean Annual Rainfall (mm)	Median Annual Rainfall (mm)	Elevation (mAHD)	Opened
Bannaby (Hillasmount)	70002	34.43°	150.00°	791	770	710	1945
Berrima West (Medway (Wombat Creek))	68186	34.48°	150.29°	783	771	655	1970
Brayton (Longreach)	70143	34.64°	149.95°	701	696	610	1959
Bundanoon (Ballymena)	68008	34.65°	150.31°	1158	1093	688	1902
Burragorang	63016	34.20°	150.30°	858	880	Unknown	1942
Burrawang (Range St)	68009	34.60°	150.52°	1374	1304	758	1891
Burruer (Illaroo)	68031	34.87°	150.45°	867	821	Unknown	1902
Buxton (Amaroo)	68166	34.24°	150.52°	856	882	420	1967
High Range (Wanganderry)	68062	34.34°	150.27°	817	797	740	1921
Joadja (Greenwalk)	68089	34.43°	150.24°	785	772	725	1959
Kangaroo Valley (Main Rd)	68036	34.74°	150.53°	1294	1201	85	1914
Mittagong (Alfred St)	68044	34.45°	150.46°	910	902	635	1886
Mittagong (Kia Ora)	68033	34.46°	150.49°	899	902	610	1902
Moss Vale (Hoskins St)	68045	34.54°	150.38°	962	939	675	1870
Moss Vale (Torokina)	68195	34.64°	150.40°	1110	1074	568	1971
Sutton Forest (Eling Forest)	68093	34.57°	150.26°	899	843	658	1945
Wingello State Forest	68067	34.72°	150.20°	1093	1093	640	1940
Wollondilly (Bullio)	68068	34.35°	150.15°	825	785	675	1941
Wombeyan Caves	63093	34.31°	149.97°	833	861	580	1942
Yerrinbool	68071	34.37°	150.55°	901	903	500	1916
Hume AWS (Wongonbra, Mine Lease)	N/A			938*			

* From correlation with Station 68045 (rainfall is 98% of monthly rainfall at Station 68045 over the period April 2012 to January 2015).

Figure 2.1 shows the interpreted distribution of average annual rainfall over the regional area. The mine lease has an area-weighted average annual rainfall of 957 mm. Given the geography of the area and the long-term average at Station 68045 (Moss Vale), that station is useful for comparison to lease rainfall.

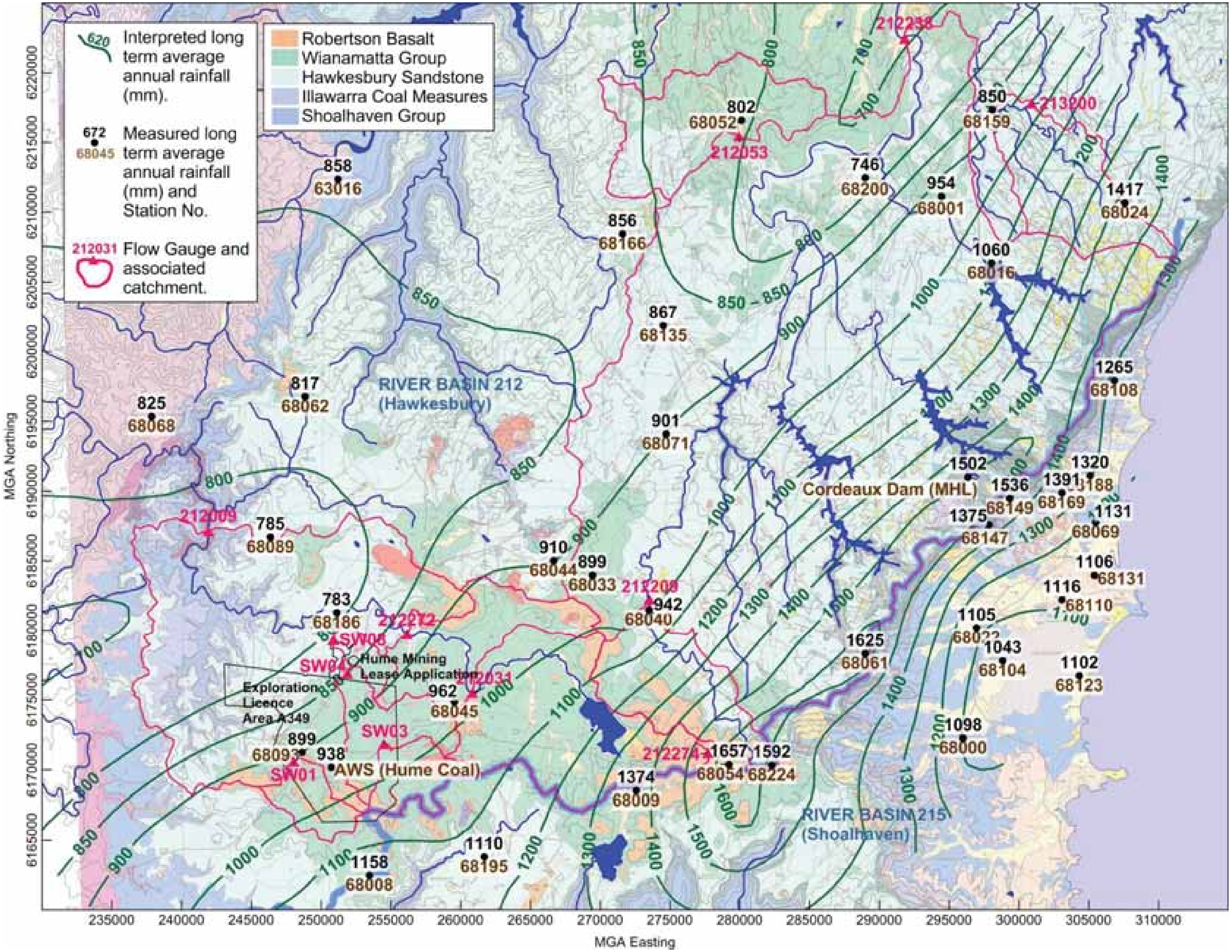


Figure 2.1. Interpreted pattern of average annual rainfall.

Figure 2.2 shows the average monthly rainfall pattern in the vicinity of the mine lease (a combination of monthly averages at Stations 68093 (1945 to 2000) and 68186 (1970 to 2014)), and the average monthly pan evaporation at Goulburn TAFE (Station 70263). Average monthly rainfall ranges between a maximum of 85 mm in February to a minimum of 49 mm in July (the annual average for these stations is 841 mm). Average monthly pan evaporation ranges between a maximum of 198 mm in January to a minimum of 33 mm in June, with an annual average of 1294 mm. A soil moisture deficit is likely to occur between September and April in an average year.

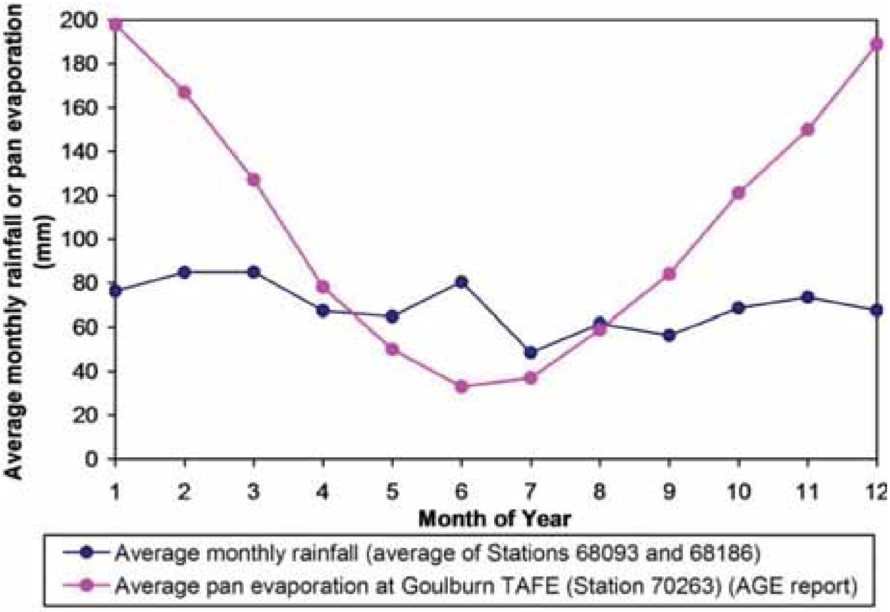


Figure 2.2. Estimated average monthly rainfall in the mine lease and average monthly pan evaporation at Goulburn.

Rainfall has also been measured by Hume at an automatic weather recording station on the mine lease (known as the Wongonbra gauge) from April 2012. Figure 2.3 shows a correlation of monthly rainfall at Wongonbra and Station 68045 for the period April 2012 to January 2015 inclusive. Monthly rainfall for March 2013, June 2013, and July to September 2014 (inclusive) showed poor correlation with their 68045 counterparts, and were removed from the correlation because of known equipment malfunction. The correlation indicates the quality of Wongonbra records appears acceptable.

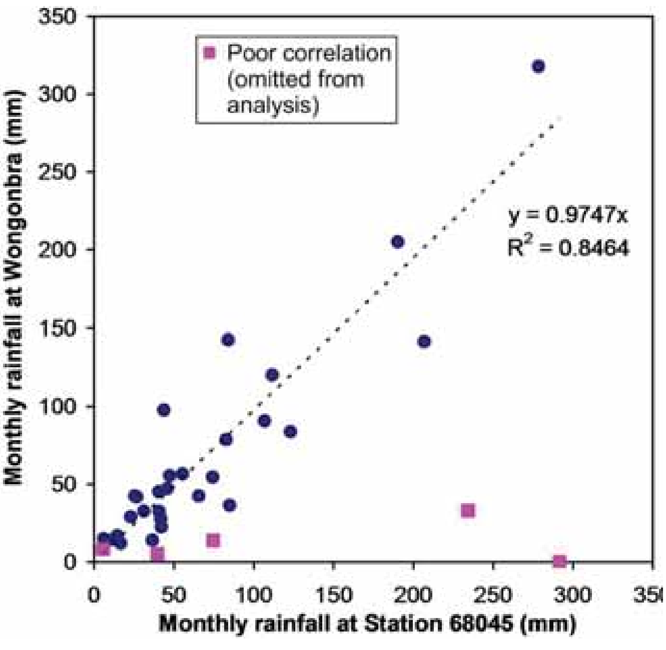


Figure 2.3. Correlation of monthly rainfall between Station 68045 (Moss Vale) and Hume's site gauge at Wongonbra.

3. Surface drainage

The digital topographic elevation dataset used in the current work comprises the 1 arc-second (~30m) gridded smoothed version of the digital elevation model (DEM-S Version 1.0) obtained from the Shuttle Radar Topographic Mission (SRTM) (ANZCW0703013355), available from the Geoscience Australia website.

The mine lease is located on the southern (upstream) limits of the Hawkesbury River Basin (Figure 2.1). This basin is flanked to the south by the Shoalhaven River Basin. Figure 3.1 shows a detail of the surface drainage over the mine lease. Topography in the lease ranges from about 730 m AHD in the southeast to about 660 m AHD in the north. Surface drainage is towards the north/northwest. Beyond the lease, drainage channels become significantly incised where Hawkesbury Sandstone is not overlain by the Wianamatta Group, with elevation of drainage channels falling rapidly near the extremities of the Hawkesbury Sandstone to the northwest.

The main drainage feature is the Wingecarribee River (see Figure 3.1). Wingecarribee River is regulated, mainly by Wingecarribee Reservoir (see Drawing 1), with dam releases common during drought. Its main functions are provision of a potable water supply to the Southern Highlands (approximately 25,000 people), providing a transfer point between the Shoalhaven and Sydney water supply schemes, and maintenance of flows for environmental and Sydney water supply purposes.

Other storages on the Wingecarribee River in the regional area are Medway Dam (on Medway Rivulet; see Figure 3.1) (1300 ML), Bong Bong Weir (500 ML), and Berrima Weir (9000 ML).

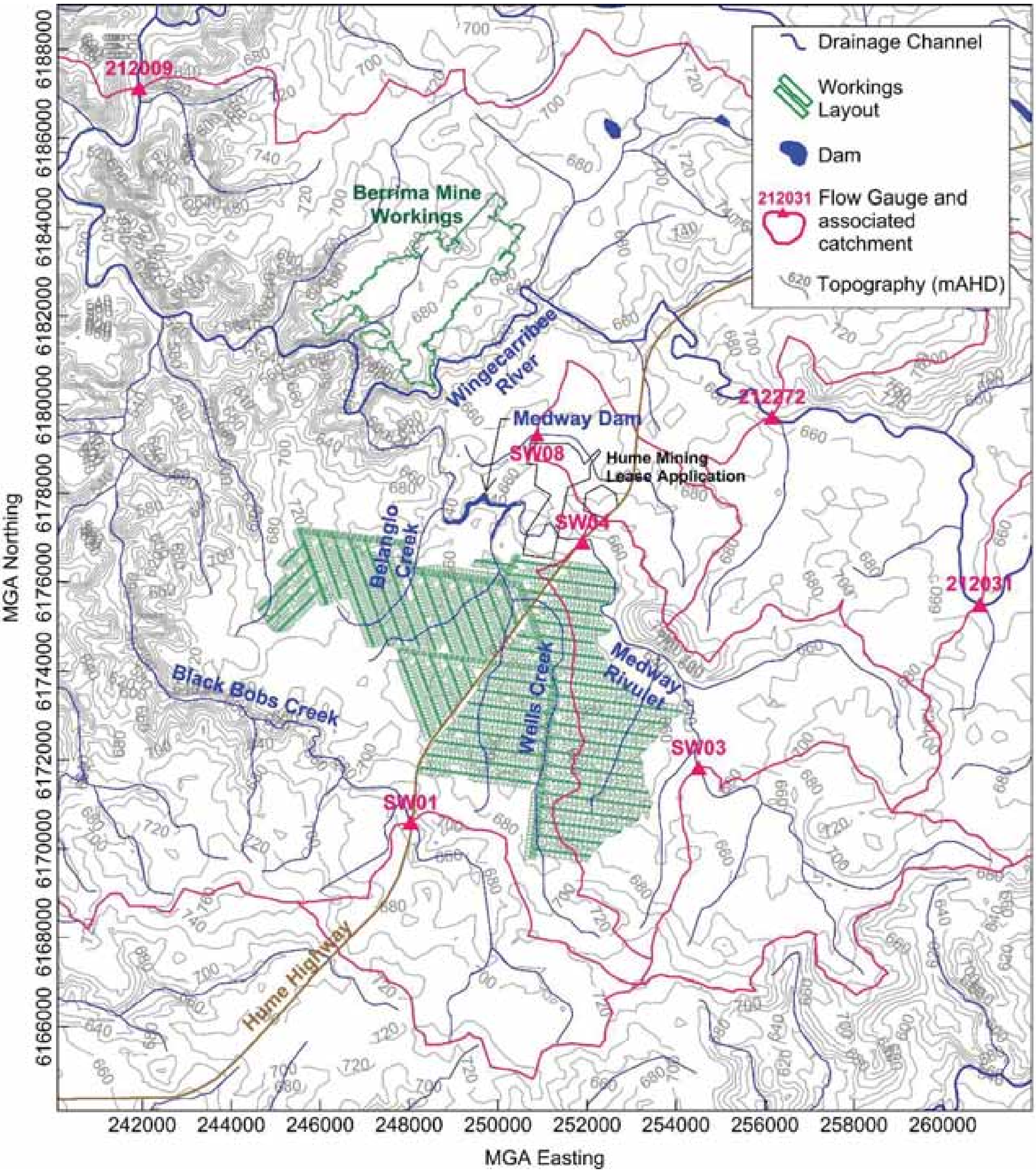


Figure 3.1. Detail of surface drainage over the mine lease.

For the mine lease, stream flow data are available for four gauges monitored by Hume (SW01, SW03, SW04, and SW08, see Figure 3.1) and for three government gauges on the Wingecarribee River (Figure 3.1). Table 2 lists the average daily stream flow measured at these gauges, and the occurrences of nil flow. These flows are resultant flows, after river extraction. Black Bobs Creek and Medway Rivulet are considered ephemeral. Wingecarribee River sustains flow most of the time, assisted by dam regulation in the last few decades, and is considered perennial. The period of monitoring for Oldbury Creek was insufficient to assess its flow sustenance capability.

Table 2. Average daily flow and occurrences of nil flow for streams near the mine lease.

Gauge	Location	Monitoring Period	Monitoring Days	Average Flow (all days) (ML/day)	Nil Flow Days	% of time nil flow
SW01	Black Bobs Creek at the Hume Highway	24 Jan 2012 to 6 Feb 2014	672	19	226	34%
SW03	Medway Rivulet at the Illawarra Highway	23 Jan 2012 to 7 Oct 2015	1354	17.1	315	23%
SW04	Medway Rivulet at the Hume Highway			50.5	371	27%
SW08	Oldbury Creek	15 May 2015 to 8 Oct 2015	147	7.1	0	0%
212031	Wingecarribee River at Bong Bong Weir	1 Jan 1990 to 31 Dec 2002	4748	79	379	8%
212272	Wingecarribee River at Berrima			108	464	10%
212009	Wingecarribee River at Greenstead			185	39	1%

3.1. Rainfall recharge to the water table

Rainfall recharge to the water table was analysed by assessing water level rises in shallow piezometers from rainfall events, using a simple one-dimensional model.

Figure 3.2 shows the interpreted annual recharge to the water table in Hawkesbury Sandstone overlain by residual soil, at five locations in the Southern Highlands, assuming a refillable void space in the short to medium term (days to months) of 0.0125 (based on Tammetta and Hewitt 2004). Of the Hume monitoring network, only H44XB had a combination of a sufficient amount of data and a reasonably shallow screen to allow this type of analysis, and is shown. Vibrating wire piezometer (VWP) response has greater uncertainty than conventional piezometer response. Piezometer screen bases vary from 5 m to 10 m below ground.

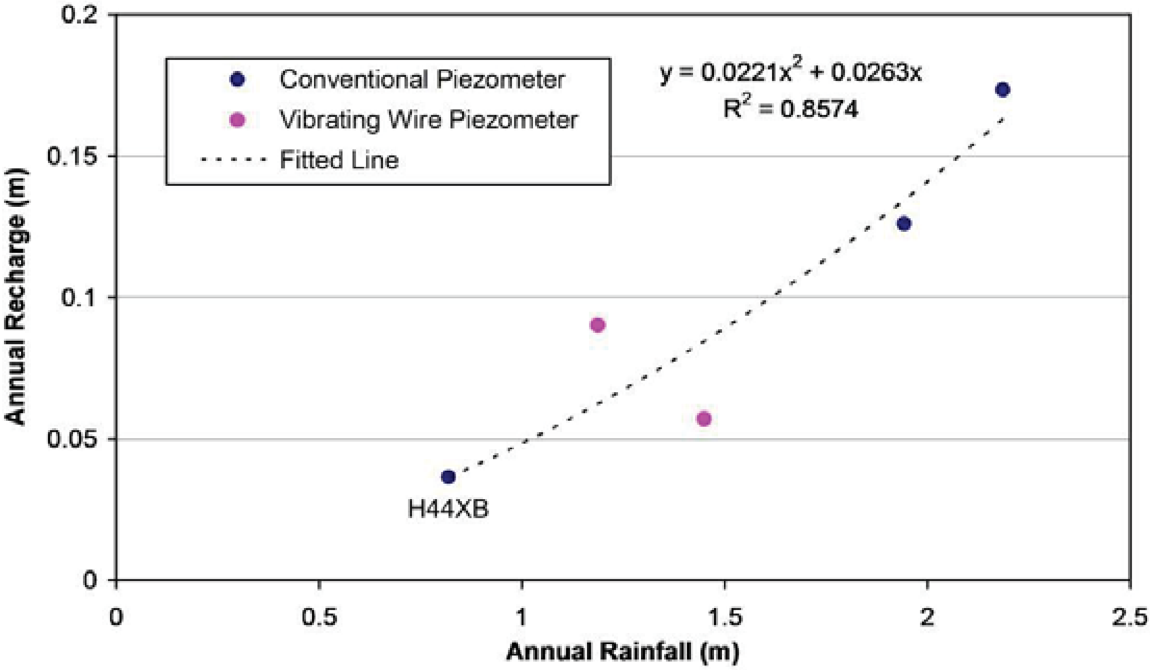


Figure 3.2. Interpreted recharge to the water table for Hawkesbury Sandstone overlain by residual soil, in the Southern Highlands.

Figure 3.3 shows the response at H44XB to rainfall, compared to the daily cumulative rainfall deficit, and indicates that the one-dimensional analytical model is valid, with rise in groundwater levels occurring rapidly following rainfall.

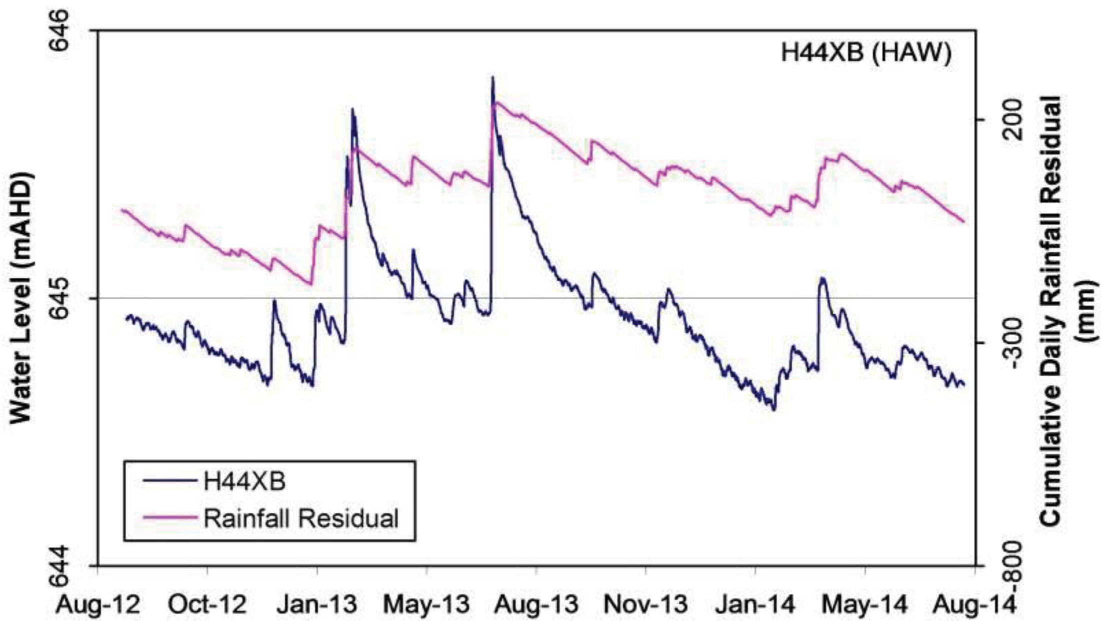


Figure 3.3. Response to rainfall at Hume Monitoring Piezometer H44XB.

No data were available for the Wianamatta Group, however analysis of a piezometer in the Sydney outer metropolitan area, for Ashfield Shale covered by residual soil, returned a recharge rate to the water table of about 1.5% to 2.0% of annual rainfall, assuming a short to medium term refillable void space of 0.01. Recharge to basalt water tables has been observed at greater than 10% in rural areas.

3.2. Stream flow

Stream flow data were obtained for a number of flow gauges in the Hume project area and from the wider Southern Highlands to compare catchments of different outcrop lithologies. Comparison for basalt-dominant catchments was assisted using observations from a basalt catchment in northern coastal NSW. Gauge locations (except for gauge 203012, Byron Creek at Binna Burra, in northern NSW) are shown in Figure 2.1. An analysis of stream baseflow was undertaken for these gauges. Gauging by Hume at SW03 and SW04 provided several years of daily flow observations.

For the Hume Coal Project, baseflow analysis has been undertaken using the local minimum method, implemented using the program BFI and the procedure of Wahl and Wahl (1995). Appendix A provides a discussion of the comparison between baseflow analysis methods, and the method used in this work.

The Nepean and Wingecarribee Rivers are regulated. This has been taken into account in the baseflow analysis (see Appendix A). The baseflow analysis also incorporates removal of river flow through licensed river extraction, using the catchment for gauge 212238 as a guide, in conjunction with licensing information for the Hume area. The analysis also accounts for evaporation from major dams (Wingecarribee Reservoir for gauges 212009, 212031, and 212272), and changes in dam storage.

Results

Catchment 203012 is dominated by basalt and is used for comparison to the Caalang Creek catchment (gauge 212274, located at the head of the Wingecarribee River catchment), also dominated by basalt. Both are microcatchments. Baseflow results are area-averages (for an entire catchment). For large catchments, the effect of flow path length (to a drainage channel) on changes in catchment area is small. The influence of flow path length (and larger hydraulic gradients for basalt systems) is accentuated in micro-catchments.

Baseflow analysis results are listed in Table 3. Baseflow appears highly sensitive to the proportion of basalt terrain (interpreted from results for gauges 212209, 212031, and the basalt microcatchments). Baseflows calculated for gauge 212209 (30% basalt terrain) were conspicuously higher than other gauges. Basalt has significantly enhanced baseflow capability compared to typical sedimentary media.

For Hawkesbury Sandstone terrain, baseflow is about 3% of annual rainfall. For Wianamatta Group terrain, baseflow is about 1% to 1.5%.

The catchment over the lease has about 15% basalt terrain (see Drawing 1 and Figure 2.1). The average baseflow for average rainfall conditions for the Hume mine lease and surrounding area is estimated to be about 1.5% of annual rainfall. This takes into account the contribution from basalt.

Table 3. Results of baseflow analysis.

Gauge	Catchment Area (km^2)	Time Period		Average flows over period (ML/day)		Average annual rainfall over period (mm)	Average flows as a proportion of rainfall	
		From	To	Baseflow	Total Flow		Baseflow	Total Flow
SW03 (Medway Rivulet at the Illawarra Highway)	24.3	1-Mar-12	11-Sep-15	0.4	17.8	1053	0.002	0.100
SW04 (Medway Rivulet at the Hume Highway)	61.7	1-Mar-12	11-Sep-15	3.3	51.8	1053	0.019	0.291
212009 (Wingecarribee River at Greenstead)	599.0	1-Jan-90	31-Dec-02	25.2	139.2	710	0.021	0.113
212031 (Wingecarribee River at Bong Bong Weir)	136.9	1-Jan-90	31-Dec-02	11.5	73.5	874	0.033	0.213
212272 (Wingecarribee River at Berrima)	200.6	1-Jan-90	31-Dec-02	12.4	95.9	831	0.026	0.199
212274 (Caalang Creek)	6.1	1-Jan-88	31-Dec-02	8.1	14.2	1476	0.328	0.571
212238 (Nepean River at Menangle Weir)	1311.5	1-Jan-91	31-Dec-06	30.0	341.0	864	0.010	0.110
213200 (O'Hares Creek at Wedderburn)	73.1	1-Jan-62	31-Dec-01	7.0	81.1	1269	0.028	0.319
212209 (Nepean River at Maguires Crossing)	69.3	1-Jan-72	31-Dec-01	28.5	110.1	1552	0.097	0.374
212053 (Stonequarry Creek at Picton)	87.9	1-Jan-91	31-Dec-01	1.1	14.9	754	0.006	0.082
203012 (Byron Creek at Binna Burra)	39	1-Jan-53	31-Dec-02	37.6	114.3	1870	0.188	0.572

Gauge	Dominant Lithologies					
	Alluvium	Basalt	WG	HAW	Permian	Lake
SW03 (Medway Rivulet at the Illawarra Highway)	0.0%	15.0%	85.0%	0.0%	0.0%	0.0%
SW04 (Medway Rivulet at the Hume Highway)	0.0%	16.7%	83.3%	0.0%	0.0%	0.0%
212009 (Wingecarribee River at Greenstead)	2.4%	12.1%	42.1%	28.8%	13.6%	1.0%
212031 (Wingecarribee River at Bong Bong Weir)	9.5%	19.4%	66.8%	0.0%	0.0%	4.3%
212272 (Wingecarribee River at Berrima)	7.2%	19.1%	68.7%	2.0%	0.0%	2.9%
212274 (Caalang Creek)	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
212238 (Nepean River at Menangle Weir)	1.3%	1.7%	17.2%	72.7%	4.7%	2.4%
213200 (O'Hares Creek at Wedderburn)	4.1%	0.0%	0.0%	95.9%	0.0%	0.0%
212209 (Nepean River at Maguires Crossing)	2.2%	28.4%	29.1%	40.3%	0.0%	0.0%
212053 (Stonequarry Creek at Picton)	4.5%	0.0%	57.6%	37.9%	0.0%	0.0%
203012 (Byron Creek at Binna Burra)	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%

NB: WG denotes Wianamatta Group, HAW denotes Hawkesbury Sandstone.

Figure 3.4 shows the results of the baseflow analysis as baseflow height (baseflow volume divided by catchment area) versus annual catchment rainfall. Appendix A shows these results separately.

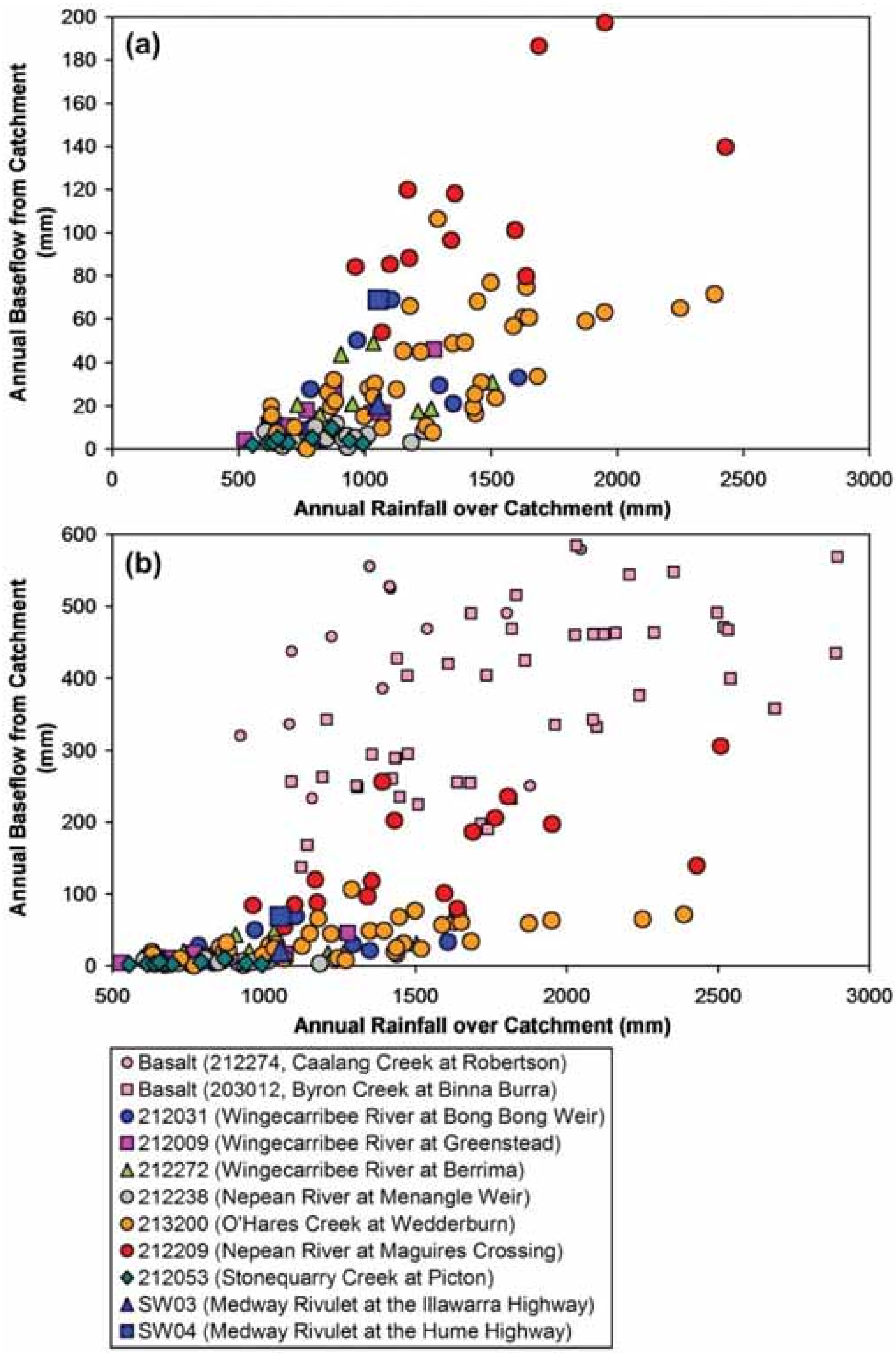


Figure 3.4. Annual estimated baseflow for (a) catchments not dominated by basalt, and (b) all analysed catchments.

According to the published geology map, alluvium occurs only along the upper reach of the Wingecarribee River (see Drawing 1). Its extent is limited to close proximity to the river channel, and is a small proportion of the total recharge area encompassed by the mine capture zone. While it may afford greater rainfall recharge, most of the recharge is considered to be in intimate connection with the river channel. Its extent is considered minor. Borehole logs identifying the strata between the alluvium and rock were unavailable. However, alluvial sequences such as this one commonly overlie a layer of residual soil, present at the start of the depositional phase, which may compact with increasing alluvial thickness. For this case, any compacted residual soil would be of Wianamatta Group origin and be clay-dominant. On an area basis, recharge to underlying fractured media from the alluvium is considered a negligible component of the total recharge to these media.

4. Geology

4.1. Stratigraphy

The Hume Coal exploration area is located on the southwest margin of the Sydney Basin. The geological sequence in this area is shown in Drawing 1 and Figure 2.1. The sequence is (in stratigraphic order of increasing age):

- Robertson Basalt (Tertiary basalt, dolerite and volcanic breccia).
- Wianamatta Group (Bringelly Shale, Minchinbury Sandstone, and Ashfield Shale) and Mittagong Formation (Triassic).
- Hawkesbury Sandstone (Triassic).
- Narrabeen Group (present only in parts) (Triassic).
- Illawarra Coal Measures (Permian).
- Shoalhaven Group (Permian)

Minor alluvium is present along the upstream reach of the Wingecarribee River.

Bulletin 26 issued by the Geological Survey of NSW (1980) provides detailed geological descriptions of the fractured media lithologies. The regional occurrence of these lithologies (Drawing 1 and Figure 2.1) is taken from the 1:100,000 Southern Coalfield geology map and the 1:100,000 Wollongong/Port Hacking and Kiama geology maps, with further descriptions of the lithologies given in the notes that accompany these maps.

The Triassic Wianamatta Group (WG) comprises black shale interbedded with lithic sandstones. The shale consists mainly of sulphide-rich claystones and siltstones containing abundant plant debris and some lenses of coal. The Minchinbury Sandstone is a persistent sandstone horizon which separates the Ashfield and Bringelly Shales of the WG.

The Triassic Hawkesbury Sandstone is a quartz arenite, containing grains of sub-angular quartz and graphite, with a smaller proportion of feldspar, clay, and iron compounds such as siderite. It ranges in thickness from less than 100 m on the southwest edge of the Sydney Basin to around 250 m in the Sydney metropolitan area. In the Hume area it is around 120 m thick where fully developed. It is composed of the following three facies:

- Sheet facies (cross-bedded strata bounded by planar sub-horizontal surfaces).
- Massive facies (nearly, but not wholly, structureless poorly sorted sandstone, containing higher proportions of clay and less chemical cement and quartz overgrowth than the sheet facies).
- Claystone facies (thin dark grey to black mudstone units with a characteristic thickness of between 0.3 m and 3 m).

The Narrabeen Group has been almost completely eroded in the south western marginal zone of the Sydney Basin. It is absent over a large part of the study area, reaching a maximum thickness of around 6 m in the Berrima mine area, north of A349. Where it is not present, the Hawkesbury Sandstone unconformably overlies the Illawarra Coal Measures (ICM).

The ICM are a freshwater sequence comprising alternating layers of conglomerate, quartz-lithic sandstone, grey shale, carbonaceous shale and coal seams. These rock types occur in a cyclic pattern up the profile, with each cycle consisting of a basal sandstone layer overlain by shale or mudstone (seat soil), then by a coal seam. The ICM host the Wongawilli Seam (the mining target), located at the top of the ICM in the Hume area. Their thickness ranges from about 50 m in the Southern Highlands to more than 250 m near Wollongong.

The ICM are underlain by the Shoalhaven Group, which comprises sandstones deposited under marine conditions interbedded with latite flows (intermediate potassic volcanic extrusives). In the project area the Group unconformably overlies the strongly folded Palaeozoic basement.

Figure 4.1 shows the stratigraphy for bore HU0016CH (located in the southern part of the exploration lease), typical for the lease area, showing downhole density measurements and gamma ray emissions recorded during the geophysical survey. Figure 4.1 also shows a detail of the Wongawilli Seam using average thicknesses calculated from logs within the Hume lease.

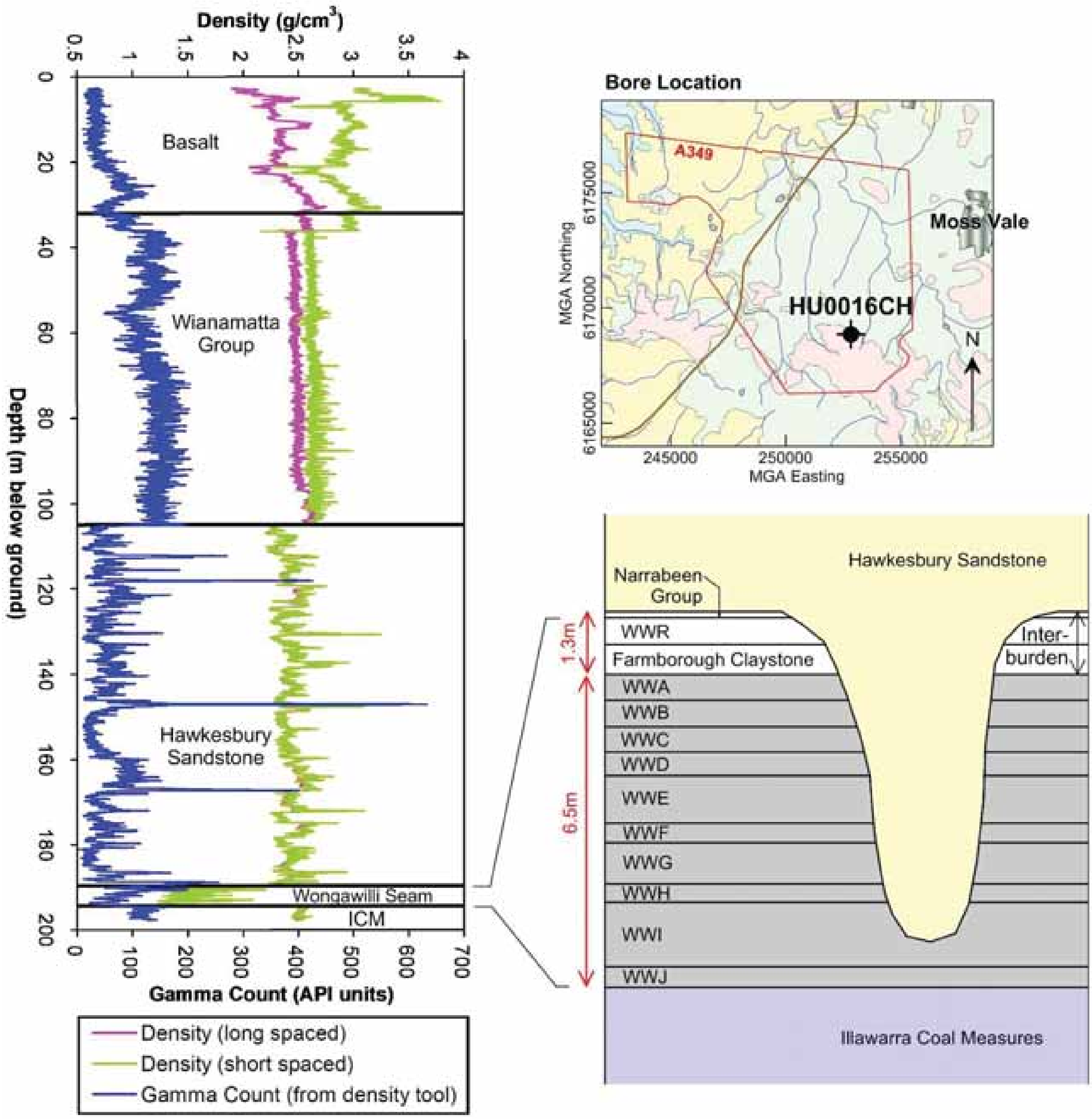


Figure 4.1. Stratigraphy and geophysical measurements for bore HU0016CH (left). The seam detail is shown to the right (colouring denotes adopted hydrostratigraphic subdivisons). Thicknesses are averages over the mine lease.

Geophysical results indicate higher clay mineral content in the WG compared to the overlying basalt and the Hawkesbury sandstone. The Wongawilli Coal seam comprises plies WWR to WWJ. The WWR ply is a carbonaceous claystone. The Farmborough Claystone Member is a tuffaceous claystone (Bamberry 1991). The Narrabeen Group, WWR ply, and Farmborough Claystone are combined into a single, sediment-dominant unit (referred to as the interburden). It has contrasting hydraulic properties to the underlying remainder of the Wongawilli seam (low density, coal-dominated), and overlying Hawkesbury Sandstone (medium to fine quartz arenite). The interburden is not present over part of the lease (see Figure 4.3). The Wongawilli Seam can be incised by the Hawkesbury Sandstone down as far as the WWI ply.

4.2. Structure contours

Structure contours for the most critical geological horizons in the Hume and Berrima leases were compiled from data provided by Hume. These data were complemented with information in Bamberry (1991), McElroy Brian and Associates (MBA) (1980), and the Government Southern Coalfield Geology map to obtain structure contours covering the larger model domain, for six fundamental surfaces. These were the base elevations of the Tertiary Basalt, Wianamatta Group, Hawkesbury Sandstone, Wongawilli Seam, Illawarra Coal Measures, and Shoalhaven Group. For the purpose of modelling, other surfaces (for example, subdivision of the Hawkesbury Sandstone) were developed from these six fundamental surfaces using constant offsets or proportioned thicknesses.

Figure 4.2 shows the structure contour surface for the base of the Wongawilli seam. In A349 the general dip of the seam (and most other strata) is easterly. A conspicuous large-scale palaeochannel is present east of A349, suggesting palaeodrainage to the northeast. Figure 4.2 also shows faults interpreted by others to be present in the area.

Figure 4.3 shows the interburden thickness. The interburden is largely absent over the southwestern half of the A349, but thickens to the north. The interburden forms an important sequence with respect to relaxation above the seam following mining.

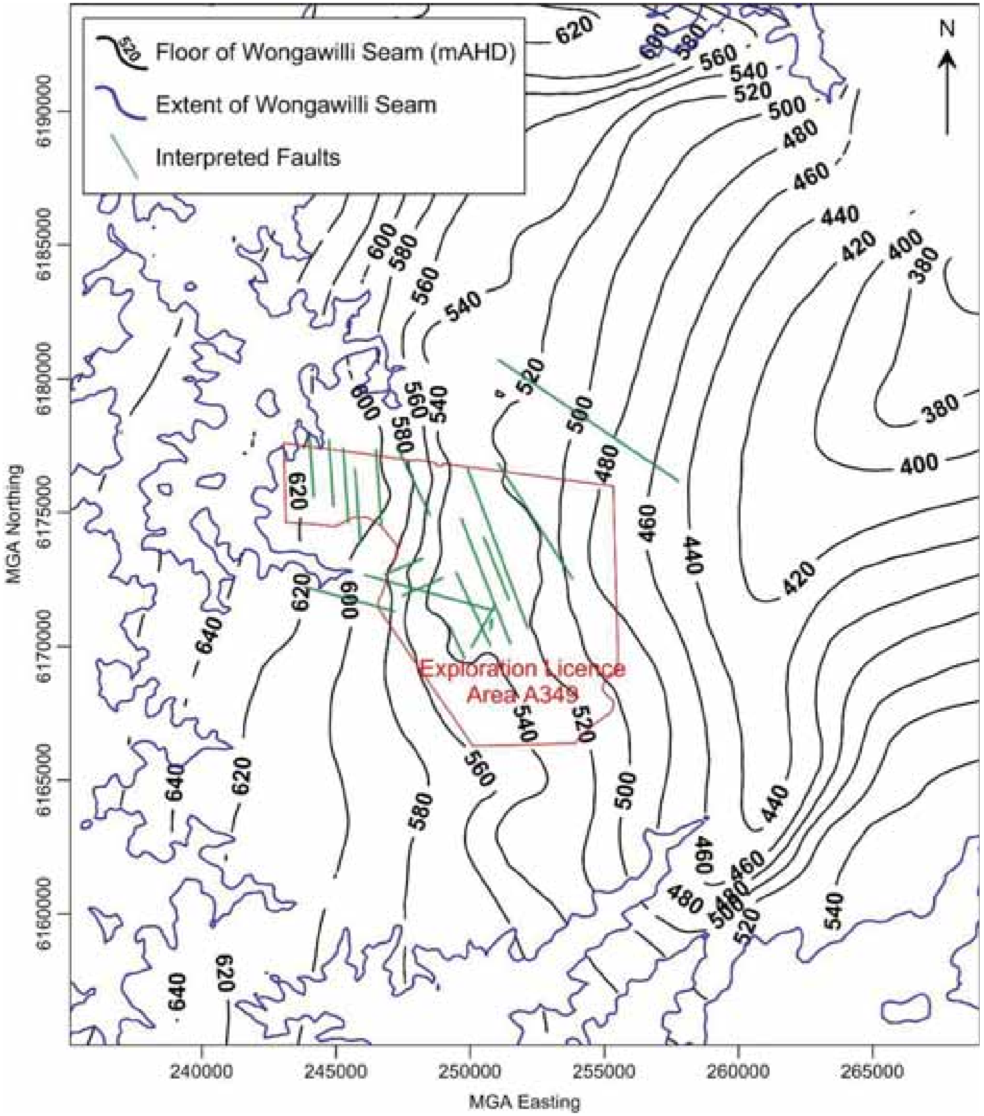


Figure 4.2 (left). Structure contours for the base of the Wongawilli Seam, and interpreted faults.

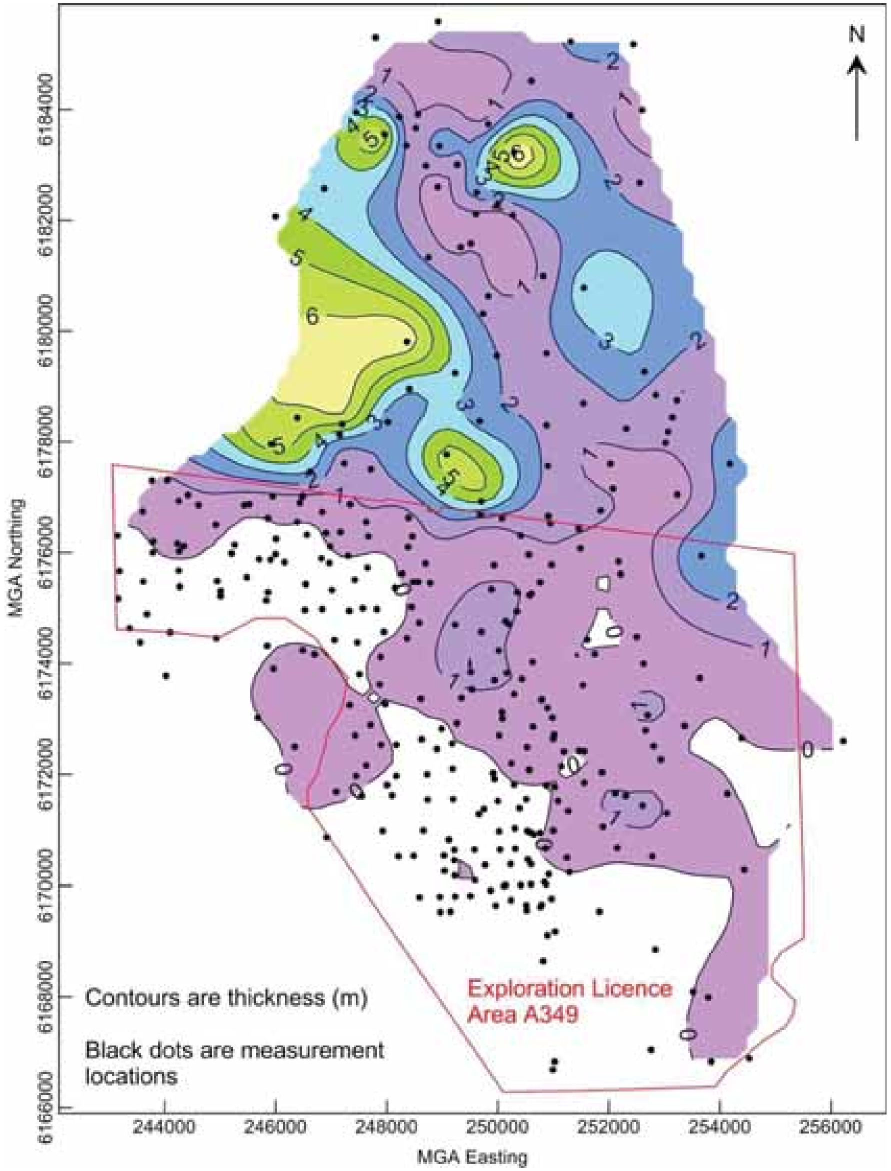


Figure 4.3 (right). Interburden thickness.

During quality control of surfaces, the Narrabeen Group thickness (Figure 4.4) was found to change markedly when traversing the Mount Murray Monocline. The thickness is relatively constant in the Hume area (southwest of the Mount Murray Monocline) but increases considerably northeast of the monocline, moving towards the Sydney urban area. This relationship coincides with the predominance of intrusive activity southwest of the monocline, and the pattern of registered bore airlift yields (where higher yields are generally recorded in areas of greater intrusive activity; see the discussion on media hydraulic properties below).

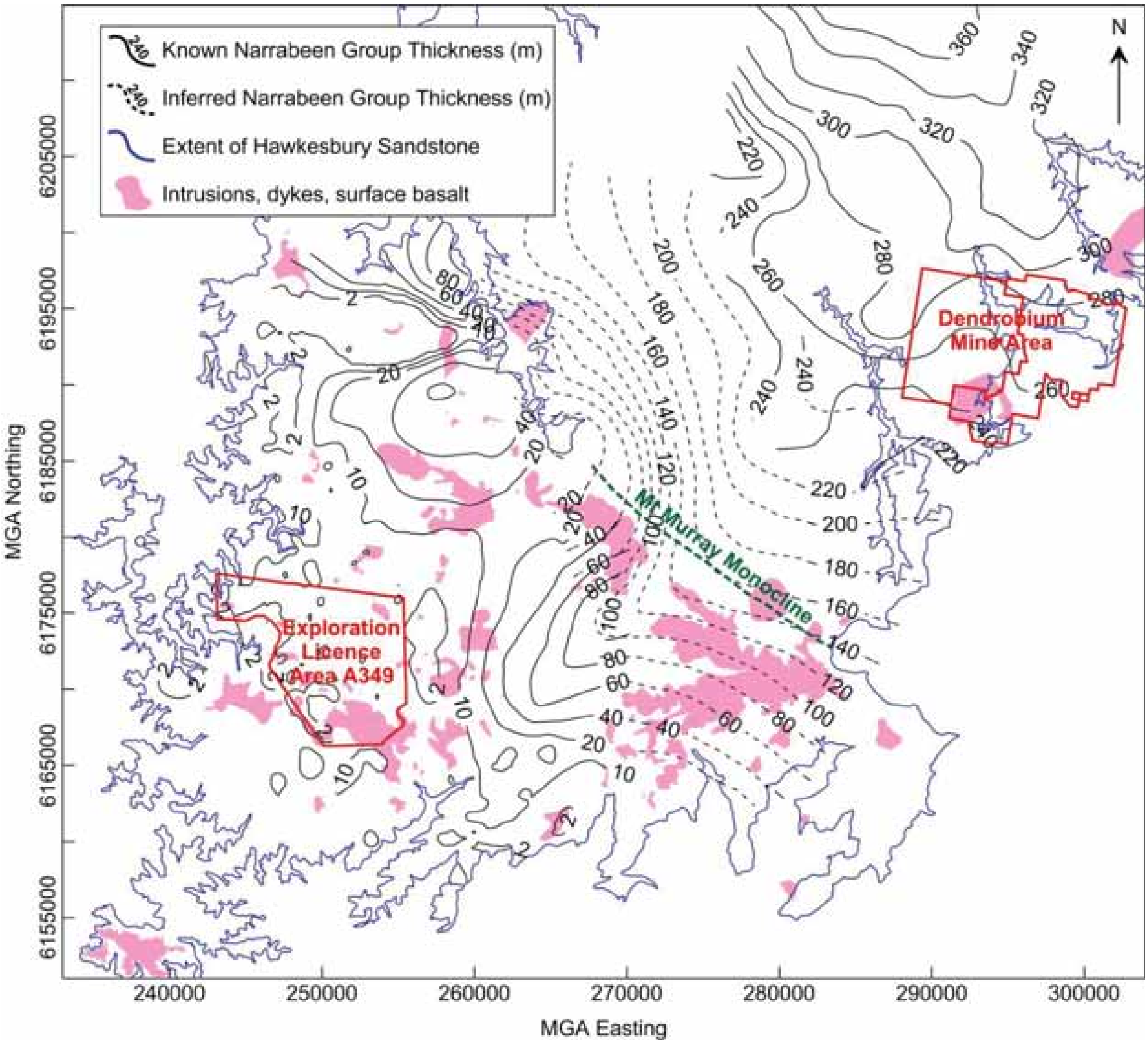


Figure 4.4. Interpreted regional thickness of the Narrabeen Group, from the quality control assessment.

4.3. Faults and Intrusions

Blue Circle Southern Cement (BCSC) (1993) identified two main structural features in the area:

- The Cement Works Fault (Figure 4.5), located southeast of the Wingecarribee River, with an estimated displacement of 65 m near the Berrima Cement Works. The fault strikes approximately WNW-ESE. The degree of displacement diminishes moving westwards towards the Wingecarribee River. It is thought that a number of volcanic intrusions may be associated with this fault. Anecdotal information from more recent years indicates displacement from this fault was not explicitly identified at Berrima colliery. International Environmental Consultants (IEC) (2008) reports that borehole information and surface inspection of the (Wingecarribee) riverbed suggested that the fault displacement probably reduced to nil before reaching (that is, to the east of) the river. The fault has not been mapped beyond the Wingecarribee River.
- A major dome structure located near Berrima township. Its presence was interpreted from aeromagnetic survey data, coal seam floor structure contours, and a dolerite sill intersected by boreholes (see Figure 4.6), thought to be a southwesterly manifestation of the dome.

Figure 4.5 shows the Cement Works Fault and faults in the Hume mining area interpreted by Hume. Also shown are subsurface barriers to groundwater flow that were required to achieve a reasonable model calibration to observed hydraulic heads. These barriers are discussed in greater detail in Volume 2.

The large change in displacement of the Cement Works Fault over such a relatively small distance would suggest the fault plane is not an extensive subvertical plane with consistent displacement. Figure 4.6 shows magnetic field intensity over the area. Also shown are four diatremes (D1 to D4) interpreted by BCSC (1993); these are discussed further below. East of the Hume Highway, a magnetic anomaly is associated with the fault where the fault's displacement is largest. The anomaly indicates a linear igneous media feature associated with the fault damage zone, or remagnetisation of the fault zone from severe movement or thermal change. The absence of an anomaly associated with the fault west of the Hume Highway, and the limited strike of the published fault, suggest the width of the fault zone is smaller there, possibly associated with a smaller displacement. Paul et al (2009) provide results from various authors indicating a direct relationship between fault strike length and fault damage zone width. Three parallel lineaments in the NNE-SSW direction are qualitatively interpreted as part of the current work. These lineaments support the interpreted trend in the K field (see Section 5).

Exploration efforts in the Berrima lease also identified a large syenite plug formed as a result of Tertiary Period volcanic activity, located at Mt Misery, northwest of Berrima township. Seam floor contours indicate that this structure has had a significant impact on the coal seam in its vicinity. However, the structure is distant from the Hume mining area.

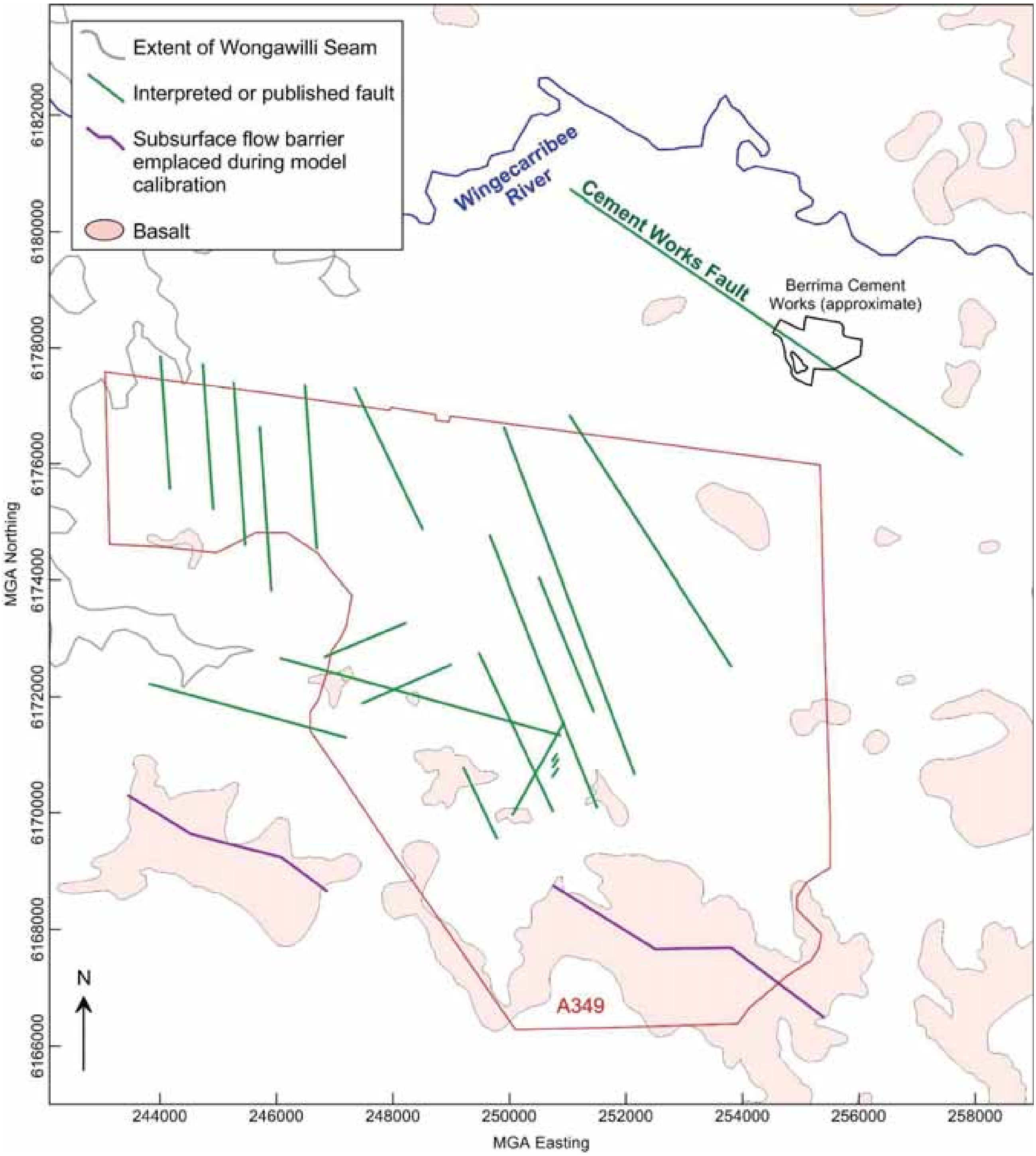


Figure 4.5. Interpreted and published faults in the Hume area, and subsurface barriers to groundwater flow interpreted during model calibration.

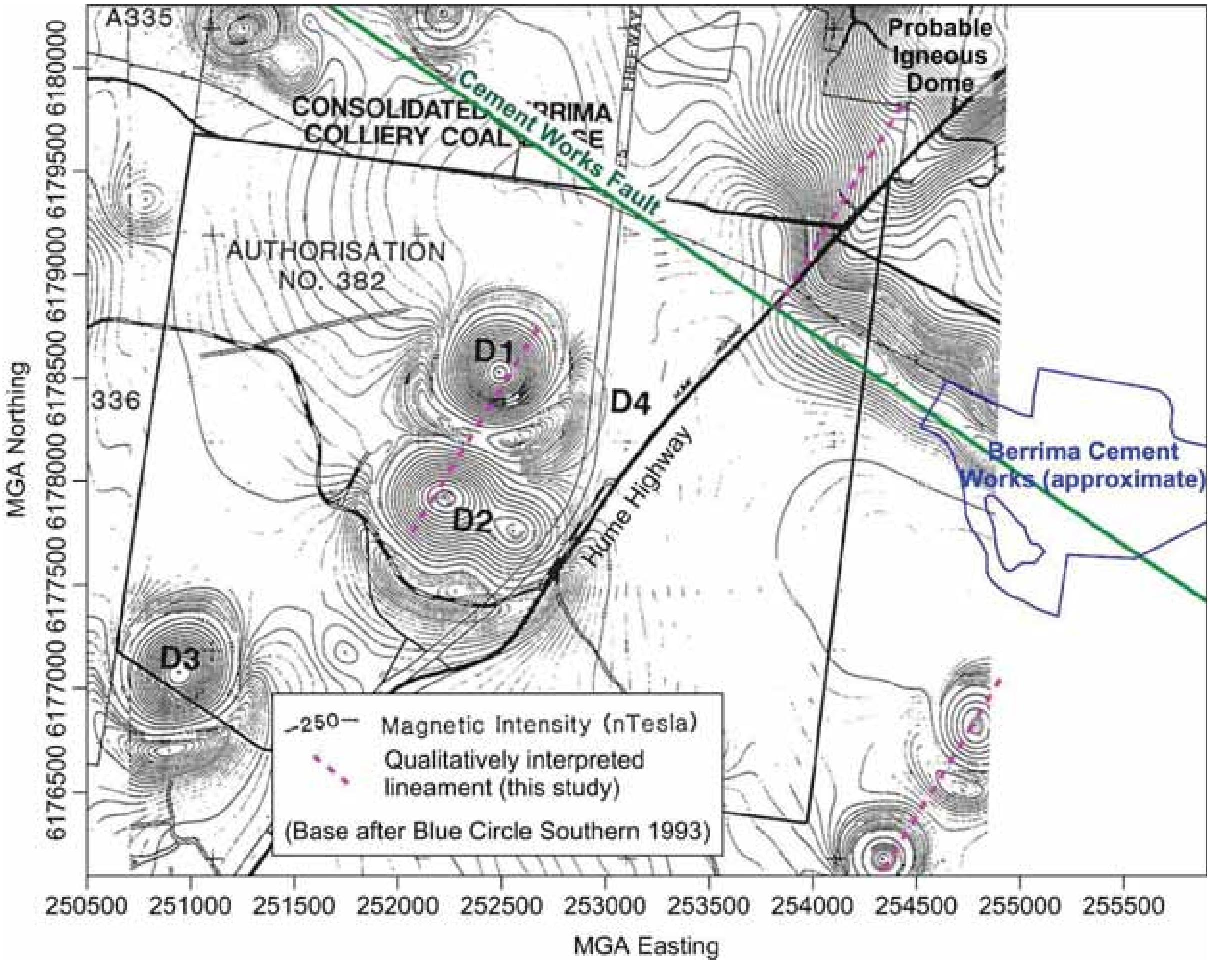


Figure 4.6. Magnetic field intensity compared to the Cement Works Fault (base after BCSC 1993).

The regional area has a higher density of igneous intrusions than elsewhere in the Sydney Basin (refer to the discussion on sub-surface hydraulic properties below). The closest known intrusions to the proposed Hume mine workings layout are shown in Figure 4.7 (after BCSC 1993), comprising intrusions D1 to D4 (interpreted in BCSC 1993) and the Mount Gingenbullen intrusion.

BCSC (1993) undertook a detailed interpretation of intrusions D1 to D4 using borehole logs, aeromagnetic survey data, and ground-based magnetic survey data. These intrusions were classified as diatremes, generally consisting of analcime or olivine basalt, or basalt breccia. Each plug is encircled by a disturbed zone of sedimentary and volcanic breccia. Disturbed zones vary in thickness between 20 m and 60 m. Plug boundaries were reported to be mapped with an accuracy of 5 m while the disturbed zone to an accuracy of 10 m. For mining purposes, BCSC (1993) made allowance for a 20 m safety zone around diatreme boundaries. Observations made at Ulan coal mine, where numerous igneous plugs and sills are present, indicate that increases in inflows to the workings generally occur within about 100 m, or less, of the edge of such a feature (after intersection of the disturbed zone). At Ulan mine, wherever mining has occurred in proximity to, but outside, the disturbed zone, the effects of the intrusive feature on the observed hydraulic head field, and on inflows at the working face, appear to have been absent. Perturbation in the hydraulic head field due to the properties of the feature is thus assessed as being likely to occur only with intersection of the disturbed zone.

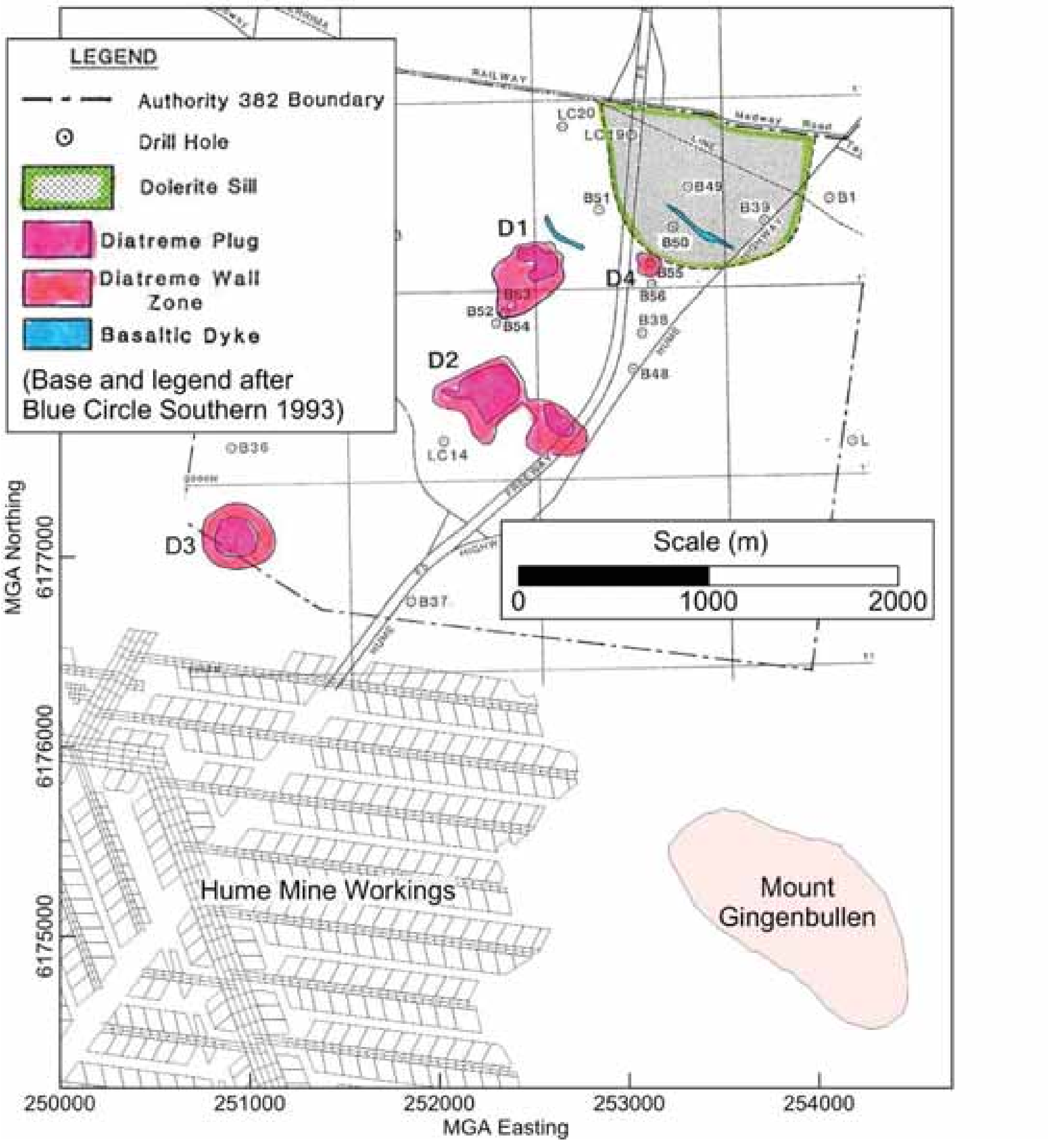


Figure 4.7. Known intrusions close to the proposed Hume mine workings (base and legend after BCSC 1993).

4.3.1. Mount Gingenbullen

The Mount Gingenbullen intrusion (see Drawing 1) is located in the northeastern corner of A349, forming a steep hill. Thomas et al (2000) describe the intrusion as a horizontal sill 80 m thick and composed of crudely columnar quartz dolerite that intruded the Wianamatta Group shales and sandstones. Its overburden has been removed by weathering. In surface expression the intrusion is approximately 1200 m long and an average of about 350 m wide. The published extent of the intrusion (see Figure 4.7 and Drawing 1) is a minimum of 600 m from the proposed workings. Figure 4.8 shows the intrusion as a shadow image using topographic elevations obtained from LIDAR (Laser Imaging Detection and Ranging) surveying undertaken by Hume. A quarry was worked on the north eastern flank of the intrusion but is now abandoned. Sedimentary media surrounding the intrusion can be identified on the southern slope of the mountain. The interpreted extent from LIDAR surveying is similar to the published extent.

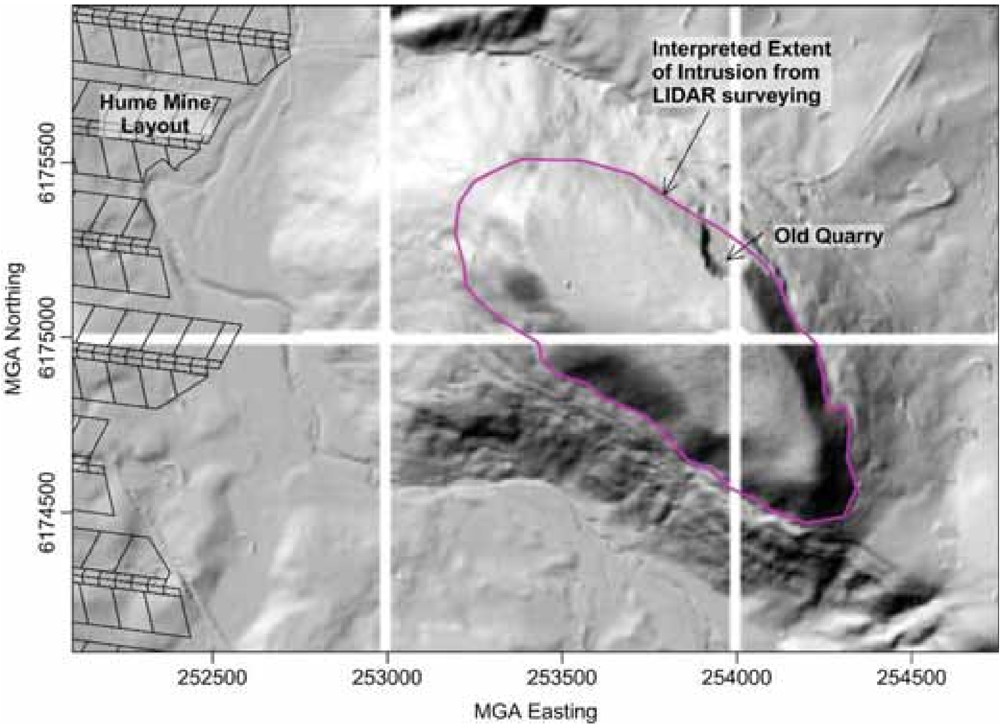


Figure 4.8. The Mt Gingenbullen intrusion as revealed by LIDAR topographic survey.

Allowing for a disturbed zone of 100 m thickness (based on preceding observations and interpretations), it is estimated that at least 500 m of sedimentary media separate the Hume workings from the intrusion. This is supported by drilling information from an exploration bore drilled about 400 m to the north of the intrusion, where a full sequence of the Wongawilli seam was present. Due to its isolated circular nature, the presence of the intrusion is therefore expected to have minimal impact on the evolution of the hydraulic head field during Hume mining operations. Thomas et al (2000) report that the intrusion is a sill, in which case the access gallery for the intrusion (the space defined by the pathway linking the source to the point of intrusion), at the level of the workings, may be smaller in lateral extent than the sill, and the thickness of sedimentary media (between it and the mine) greater.

Intrusions of this type usually locally warp the stress field, and, together with their usually different hydraulic characteristics, may show a contrast in groundwater response (compared to their host rock) when the disturbed zone is intersected. When intersected, groundwater impacts mainly take the form of short-term increased inflows while the storage of the intrusion is depleted, and localised drawdown at the intrusion. After this, impacts mitigate significantly. At reasonable distances these bodies provide imperceptible perturbation to the flow field and groundwater retained in storage by them remains unchanged. For this reason the intrusion is not explicitly modelled.

4.3.2. Berrima Mine

A series of dykes was intersected in the Berrima underground workings. They occur mainly as sub-vertical sheet-like single features and as sub-parallel swarms, generally trending west-northwest, and appear to have intruded minor faulting and joints. They vary in thickness between 0.2 m and 10 m at seam level. They are altered, highly weathered, and relatively soft, with cindered zones on each side. Dyke swarms are generally spaced an average of 400 m apart, ranging from 150 m to 620 m. Some mining panels in the 10 years before the end of mining were truncated to avoid known zones of significant igneous intrusions. The reported average distance between dyke swarms compares favourably with the orthogonal distance between the qualitatively interpreted lineaments in Figure 4.6.

5. Subsurface hydraulic properties

5.1. Hydraulic conductivity

A large database has been compiled of K measurements from insitu hydraulic testing (Parsons Brinckerhoff 2015). The database consists of the following:

- 28 packer tests on the Hume lease.
- Two long-term pumping tests undertaken by Hume on the lease in 2014 (pumping bores HU0098 and GW108194 (Wongonbra) with multiple observation piezometers monitored).
- Six long-term pumping tests from private bores in the area.
- 129 estimates of hydraulic conductivity from specific capacity data in government records for private water bores, for basalt, WG, Hawkesbury Sandstone, and the ICM. Appendix B shows the method used to obtain K from specific capacity.
- Laboratory tests on 39 cores of Hawkesbury Sandstone and Farmborough Claystone, retrieved from five boreholes.

Figure 5.1 shows the K database developed from these measurements. Results indicate decreasing K with depth, but elevated magnitudes in comparison to other areas in the Southern Coalfield. Laboratory results for cores have been approximately corrected for gas slippage but not for overburden pressure; no correction for overburden pressure will bias the results toward higher values.

Figure 5.2 shows packer test results for the regional Southern Coalfield and for the Dendrobium mine leases (all northeast of the mount Murray Monocline; see Figure 4.4), with Hume packer tests (to maintain comparison between consistent observation scales). Salient features of this figure are:

- The Dendrobium area K distribution is similar to the regional Southern Coalfield K distribution.
- The Hume area K distribution is laterally offset from the Southern Coalfield K distribution by about one decade (towards higher values), but has approximately the same rate of decrease with depth.

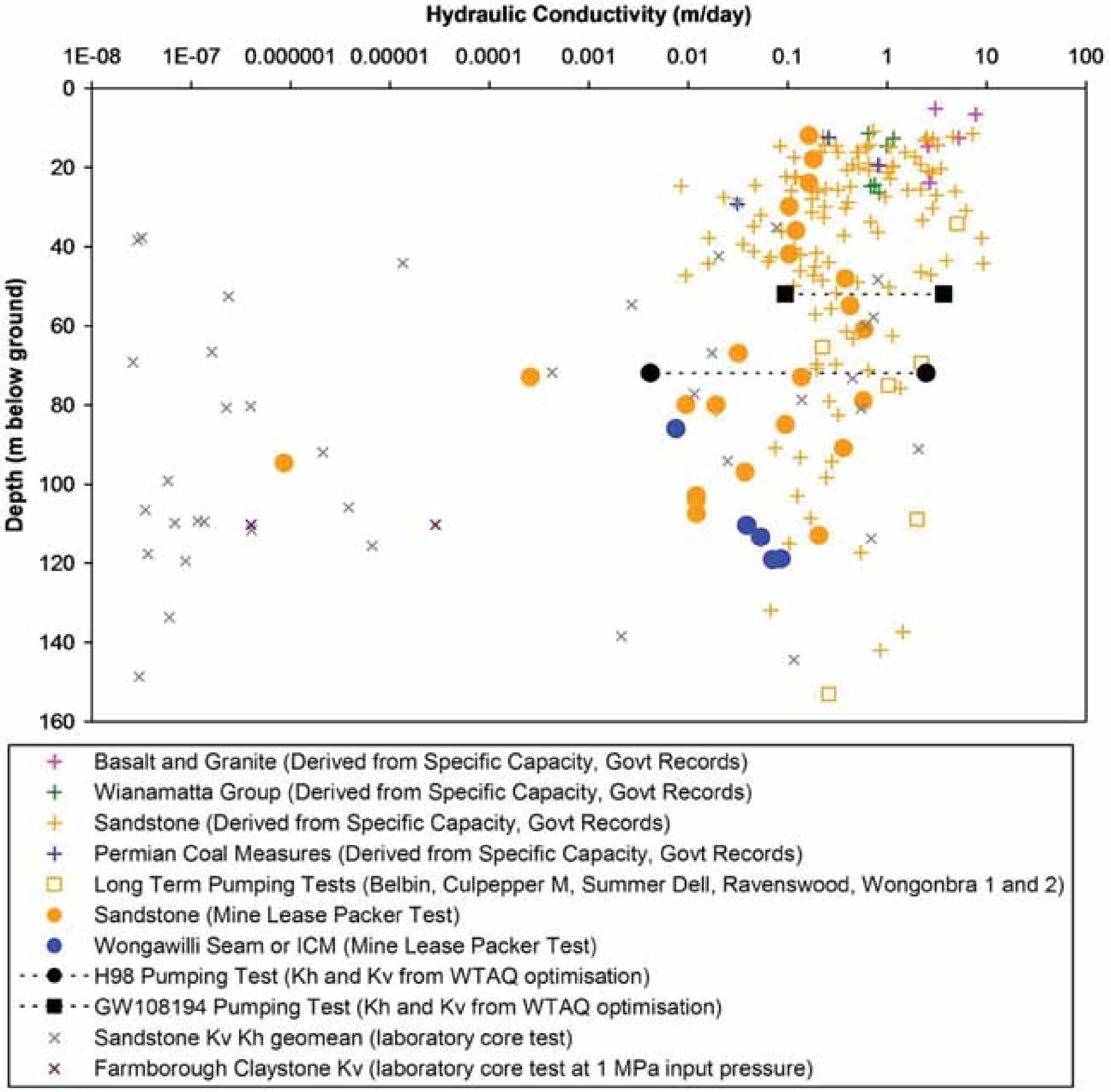


Figure 5.1. K database for the Hume area.

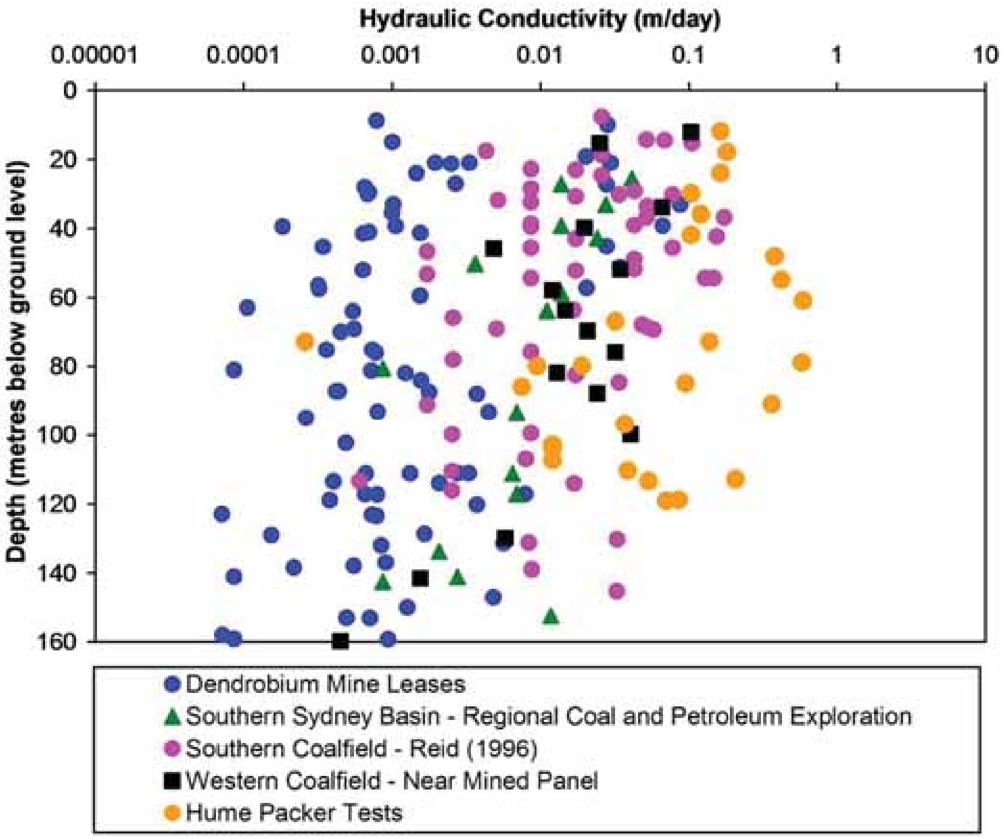


Figure 5.2. Packer test K distributions for the regional Southern Coalfield and the Dendrobium mine leases, compared to Hume area packer tests.

Figure C1 in Appendix C shows the data of Figure 5.2 (without the Hume packer tests, for improved clarity) to greater depths, illustrating measurements obtained in coal seams where natural K has increased due to shrinkage from degasification and reduction in coal seam stresses from proximal full extraction mining and associated caving. These measurements are used as a guide for the Hume area.

Russell (2007) analysed airlift yields in Hawkesbury Sandstone over the Sydney Basin from government records of registered bores and identified lower yields at greater burial depths underneath shale in the Cumberland Basin and higher yields in the southern areas (Figure 5.3). He interpreted the higher yields to the south as being influenced by stress relief, tectonic uplift, and possible solution enhancement of defect and matrix voids. The region southwest of the Mount Murray monocline has also undergone prolific igneous activity. Intrusions are known to permanently alter the natural stress field, due to their emplacement as fluids. The results of Russell (2007) indicate the conspicuous nature of the K field southwest of the monocline. These support the contrast in Narrabeen Group thickness (Figure 4.4).

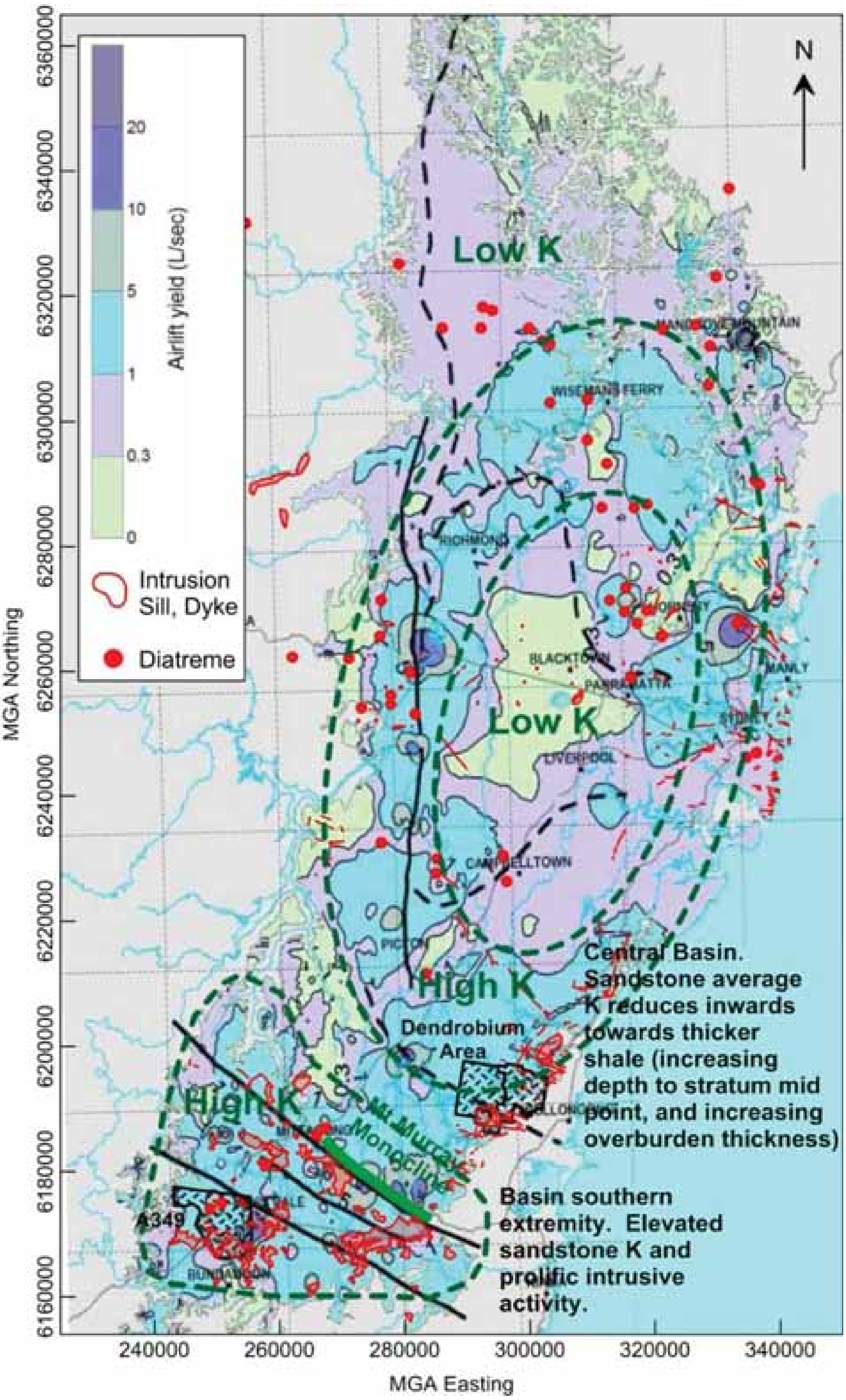


Figure 5.3. Airlift yields for the Hawkesbury Sandstone from government records (after Russell 2007), overlain with igneous structures, mine leases, and interpreted regional trends.

The relationship between the K field and principal horizontal stress magnitude was explored by considering only the stiffer media within the profile. This included general interburden (mostly sandstone) only, and excludes coal seams. Figure 5.4 shows the running 10-point log-average K down the depth profile for Permian Coal Measures (excluding coal seams) at a site in Kentucky (Hutcheson et al 2000a, 2000b), the Southern Coalfield (Reid 1996), the Hunter Valley, and the Bowen Basin, compared to the Hume area. Figure 5.4 also shows the measured principal horizontal stress in the Southern Sydney Basin (Hillis et al 1999) and three measurements undertaken on the Hume lease. All five datasets identify a reducing K with depth, caused by increasing overburden pressure. Average horizontal stress magnitudes for a depth of 100 m as estimated from field measurements are labelled at the average K for each K distribution.

Each distribution has approximately the same rate of decrease in K with depth, mostly caused by increasing overburden pressure (with media densities being similar between areas). Excluding the Hume area, a clear relationship in lateral position of each K distribution and the magnitude of horizontal stress is also apparent, where increasing horizontal stress displaces the lateral position of a K profile to the left (smaller magnitudes).

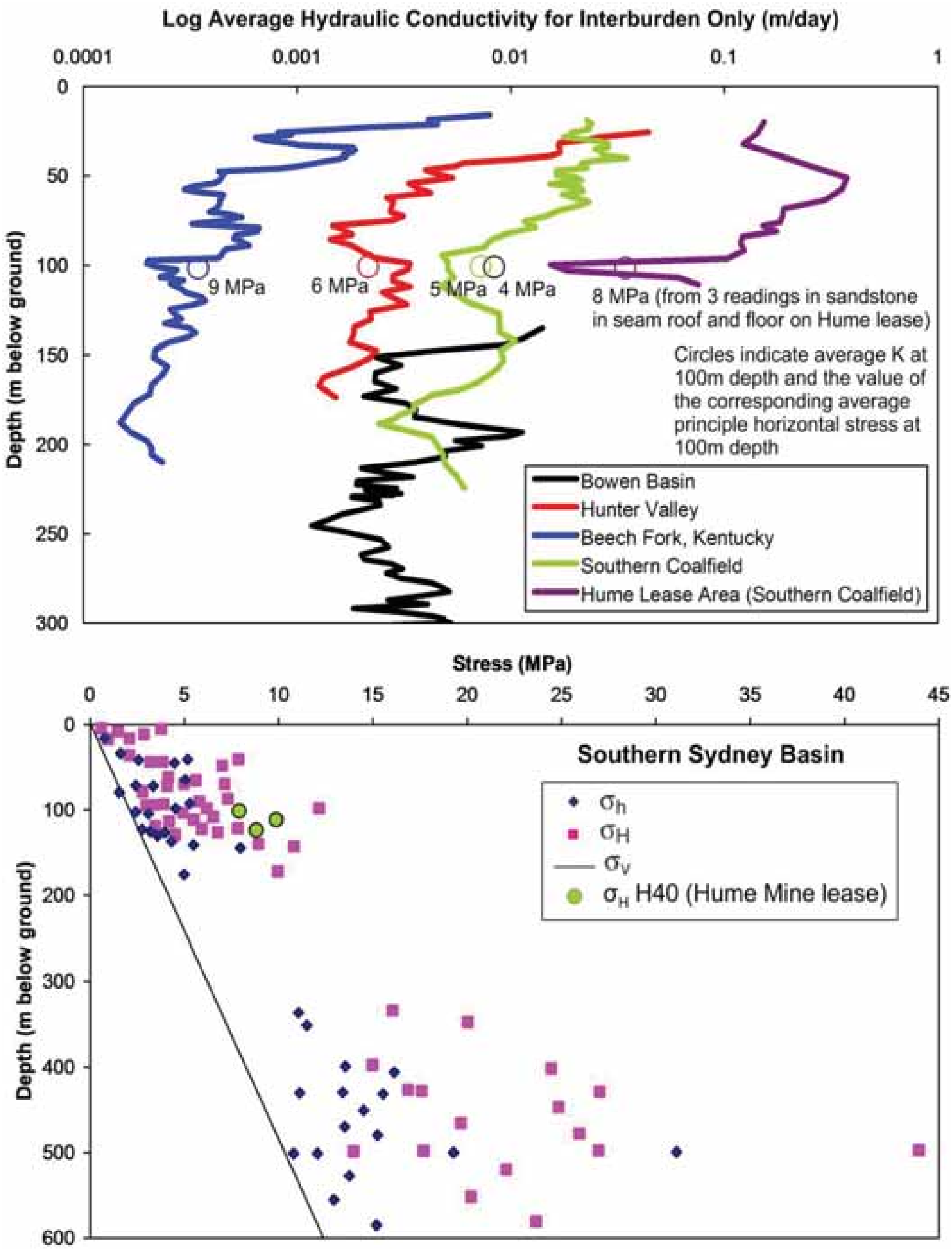


Figure 5.4. Comparison of stress and hydraulic conductivity (K). The upper chart shows K and regional stress magnitude for Permian Coal Measures (excluding coal seams) at four locations in Australia and one in the USA. The lower chart shows actual stress measurements unsegregated by media stiffness, for the southern Sydney Basin (base from Hillis et al 1999). σ_H and σ_h are the maximum and minimum horizontal stresses respectively; σ_v is the vertical stress.

Three stress measurements were undertaken in the Hume area, in bore HU0040CH (Sigra 2012) in the roof and floor of the Wongawilli Seam. One of the roof measurements was reported as having reduced reliability (Sigra 2012). Field measurements returned a principal horizontal stress ranging between 7.9 and 9.9 MPa, oriented just east of magnetic north. Shallow breakout at HU0031CH indicates the potential for locally elevated horizontal stress, typically associated with faults, dykes, and intrusives (SCT 2014). The tectonic factor (excess tectonic lateral stress normalised to rock stiffness) calculated from the measurements ranges between 0.0003 and 0.0006; results are shown in Figure 5.5 (after Figure 6 from Nemcik et al. 2006), indicating average tectonic conditions compared to other coal mines (other data are from SCT measurements only; Nemcik et al. 2006).

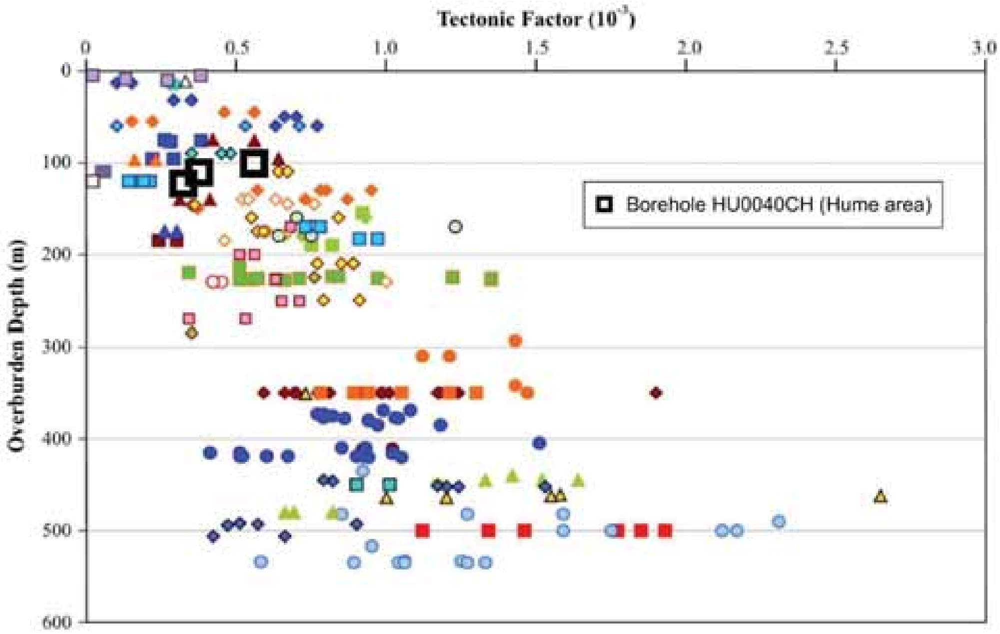


Figure 5.5. Tectonic factor calculated from results from borehole HU0040CH plotted on Figure 6 of Nemcik et al. (2006). Other data (coloured) are from SCT measurements only (Nemcik et al. 2006).

The Hume area is unique amongst the group of areas in Figure 5.4 for the proliferation of igneous activity. Based on the limited stress measurements, it also does not appear to accord with the relationship between K magnitude (at some depth) and magnitude of horizontal stress as seen for the other four areas. Large differences in Young's modulus for the various media may be influencing this. In contrast to the Hume area, the Dendrobium area (also being classified in the Southern Coalfield) has not suffered the same level of igneous activity, and hosts lower K magnitudes. It is believed that the K field in the Hume area results from increased tectonic disturbance and changes induced in the stress field from subsequent intrusive activity.

The large number of K measurements for the Hume lease was used to estimate the spatial variation in K for the Hawkesbury Sandstone for an interval between 14 m and 44 m above its base, with a minimum overburden thickness of 40 m (Figure 5.6). Despite the northwest/southeast trending structures, the K field appears to align with the major horizontal stress direction (just east of magnetic north), but is perturbed by warping of the stress field by igneous intrusions. Figures C2 to C4 in Appendix C present additional information supporting this conclusion.

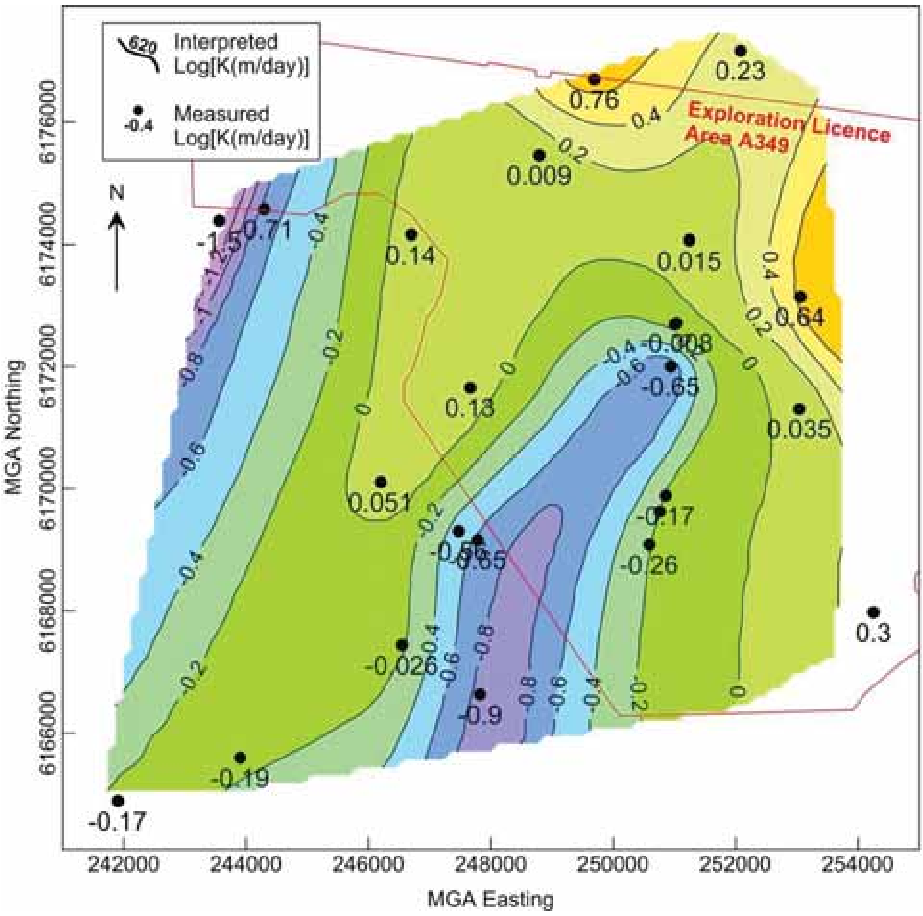


Figure 5.6. Log[K(m/day)] for Hawkesbury Sandstone between 14 m and 44 m above its base.

5.1.1. Pumping tests

Two long-term, single-rate pumping tests were carried out by Hume at bores HU0098 (duration 1 day) and GW108194 (duration 7 days) on the mine lease, with monitoring at multiple observation piezometers for each test (Parsons Brinckerhoff 2015). Pumping bore locations are shown in Figure D1 in Appendix D. Drawdown observations from these tests (observation piezometer nest H96 for pumping at HU0098, and H73 for pumping at GW108194) were subjected to automated parameter estimation using the WTAQ algorithm (Barlow and Moench 1999) for unconfined media, which allows partial penetration and vertical anisotropy. Drawdown records from two monitoring piezometers for each test were simultaneously optimised. The match between calculated and observed drawdowns is shown in Figure 5.7. Optimised K values are shown in Figure 5.1. The optimised average specific yield was 0.015, and specific storage 3×10^{-6} m^{-1}. The ratio of vertical K (Kv) to horizontal K (Kh), Kv/Kh, was 0.0017 and 0.026 for the H98 and GW108194 tests respectively.

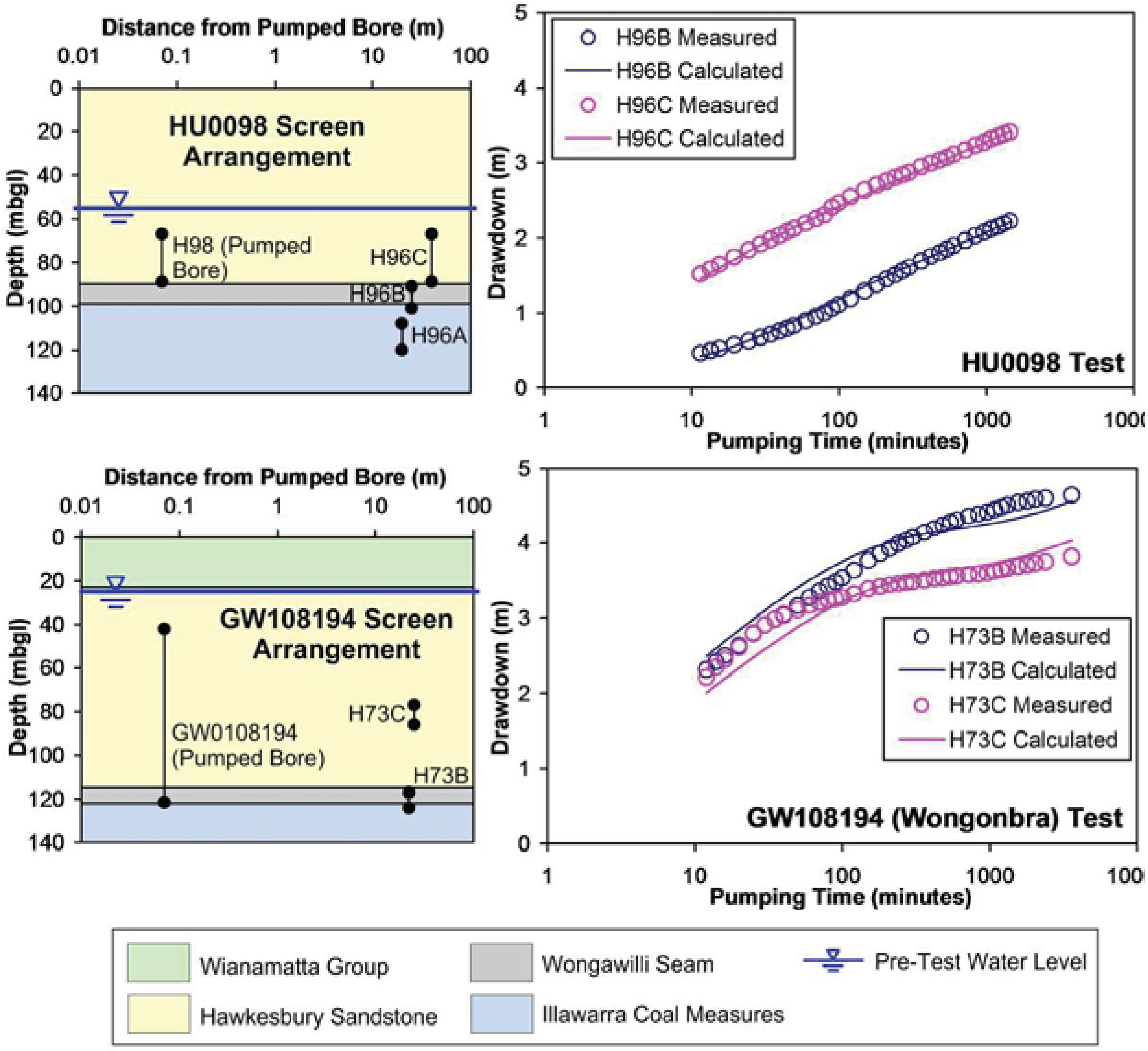


Figure 5.7. Calculated and observed drawdowns using the WTAQ algorithm in an optimisation capacity, for pumping tests at HU0098 and GW108194 on the Hume lease.

5.2. Storativity

5.2.1. Specific yield

Typical coal measures media have a void distribution composed of pores and defects. The pore distribution is created during sedimentation and diagenesis, and individual entities are closely spaced and very small. Defects (existing fractures, joints, and partings, and those introduced by caving) are created during failure of the rock mass (from a changing stress field) and their geometry is completely different to pores. Drainage occurs quickly from defects and slowly from pores. The majority of the total void space is contained in the pores (typically 10% to 20% of the medium) however observations demonstrate that this void space contributes negligibly to specific yield (Sy) in the medium term. This is due to the moisture retention characteristics of the matrix. It can withstand much higher suction (compared to defects) prior to pore drainage. This is amplified by the absence of solar radiation in underground voids.

If the time rate of water table change in defects is rapid compared to matrix K then overall Sy may approach defect Sy. Conversely, where the time rate of water table change is slow compared to matrix K, overall Sy may have a non-negligible matrix component.

Specific yield, void space, and specific storage usually decrease with depth. Sy for coal measures rocks is rarely more than a few percent, ranging from less than 0.01 for claystones to around 0.02 to 0.03 for highly fractured sandstone. Typical published estimates are 0.013 for Devonian siltstone (Risser et al. 2005) and 0.012 for laminated shale (Woods and Wright 2003). Unpublished results from Australia are an Sy of between 0.005 and 0.007 (over 5 years) for Permian coal measures (claystone, sandstone, and interbedded coal) in the Western Coalfield, and an Sy of between 0.004 and 0.008 (over 3 years) for Permian coal measures in the Hunter Coalfield. Studies conducted in the Sydney metropolitan area and elsewhere indicate a specific yield of between 0.01 and 0.02 is reasonable for typical, undeformed Hawkesbury Sandstone (Tammetta and Hewitt 2004). The transient aspect of Sy is important.

5.2.2. Specific storage

The dominant component of specific storage is media compression, mostly via contraction of defect apertures. The specific storage of Hawkesbury Sandstone in the Blue Mountains west of Sydney has been estimated to be about 1 x 10^{-6} m^{-1} (Kelly et al. 2005) in the upper zones where fracture flow is dominant. Results of long duration pump testing in Hawkesbury Sandstone in western Sydney (Tammetta and Hawkes 2009) indicated an average specific storage of 1.5 x 10^{-6} m^{-1} for depths between ground surface and 300 m.

Assuming that the total primary and secondary porosity that allows fluid flow ranges between 10% at the surface and 5% at depth, and assuming that the medium is incompressible, then the specific storage ranges between 4.5 x 10^{-7} m^{-1} at the surface to 2.3 x 10^{-7} m^{-1} at depth (field measurements of specific storage show its depth variability; see for example Heywood, 1997). Greater media compression is possible at shallower depths, where flow through defects predominates, than at deeper depths.

5.2.3. Defect distributions

A Coffey in-house borehole imaging database for the Hawkesbury Sandstone (from a number of large infrastructure projects in the Sydney metropolitan area) provides 5671 defects in 89 bores which has been analysed to assess defect spacing and aperture (Figure 5.8). Defect spacing is an average of about 1 m to 2 m at depth. Spacing distribution occurs in cycles, with the recurring pattern for a group of defects rarely extending more than 20 m along the profile.

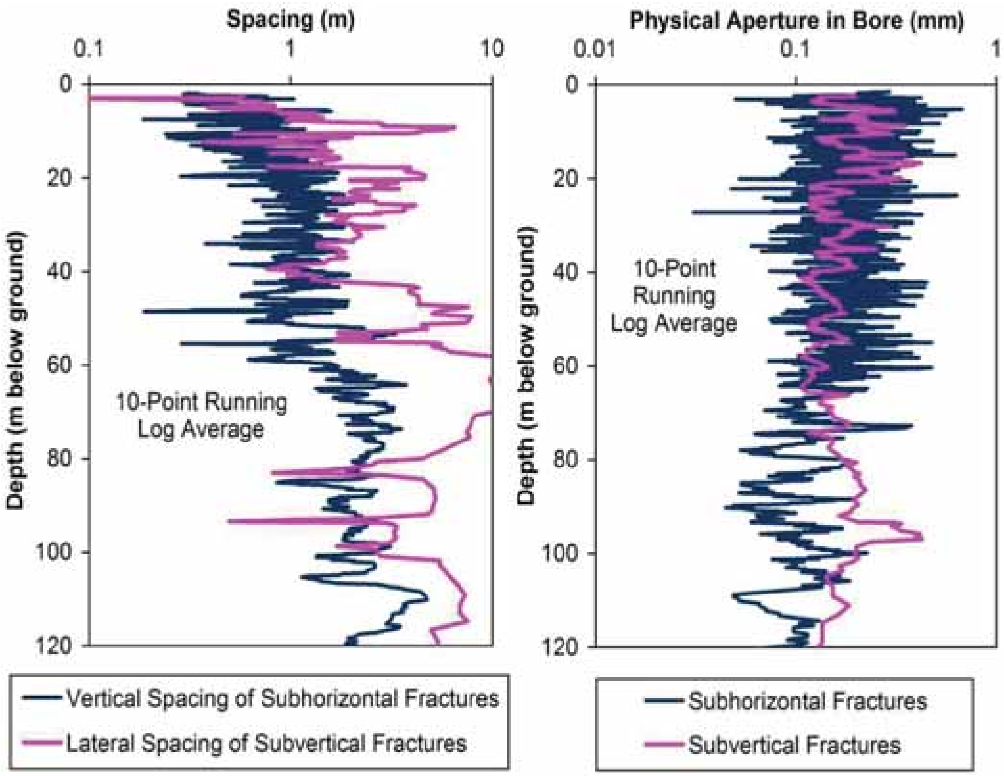


Figure 5.8. Defect spacing and aperture estimated from acoustic imaging of Hawkesbury Sandstone in the Sydney metropolitan area.

For typical claystones, inclined defects of non-zero aperture are recorded at depths up to 500 m (see for example Risser et al 2013). Kv can be controlled by defects and also open boreholes. The Hume area has a high density of such boreholes, mostly in sandstone. Numerical simulation of a regional shale sequence (the Maquoketa Formation) by Hart et al (2006) suggested a large scale Kv of 1.6 x 10^{-6} m/day. Matrix measurements of Kv ranged between 1.6 x 10^{-9} to 3.5 x 10^{-7} m/day. Based on bore logs, erosional windows or high-conductivity zones were considered unlikely. Defects penetrating the entire thickness of shale, spaced 5 km apart with an aperture of 50 microns, were estimated to provide sufficient flow across the sequence to match that provided by an equivalent bulk Kv of 1.6 x 10^{-6} m/day. Alternatively, 50 bores of 0.1 m radius open across the sequence, evenly spaced 10 km apart, could also match the model Kv. This case study illustrates a requirement to characterise large-scale Kv for regional simulation, and the inapplicability of using matrix measurements.

5.3. Summary

Hydraulic conductivity and storativity in the Hume area decrease with depth. The K field for the Hume area has greater magnitudes than seen elsewhere in the Southern Coalfield. This is believed to be the result of significant tectonic disturbance and associated intrusive activity. At the scale of packer tests, Kh ranges from about 1 m/day near the surface to about 0.1 m/day at 100 m depth. For measurements in the same depth interval, the Kh distribution is log-normal, with a standard deviation of between 0.5 and 0.8 decades around the geometric mean.

Kv/Kh is approximately 0.01. Kv has also been enhanced by the large number of open private water bores present in the area. Storativities for the Hawkesbury Sandstone calculated from pumping tests are in agreement with published values.

6. Groundwater levels

Groundwater levels in the Hume area are monitored by Hume using an extensive network of vibrating wire piezometer (VWP) and standpipe piezometer (SP) installations. The network comprises 46 SPs at 19 locations, 11 VWPs at 3 locations, and 2 private water bores. This provides 59 subsurface measurement points at 24 locations. Typically, a monitoring site comprises several SPs in separate boreholes. The Hawkesbury Sandstone and Wongawilli Seam are screened at most of these locations. Several monitoring sites comprise a single borehole with several VWPs fixed at various depths down the borehole in grout. Monitoring commenced in late 2011 when the first piezometers were installed, and has continued to the present. Useful monitoring information is also available from the Berrima Mine monitoring network (VWPs and bores), and a government monitoring network in the regional area.

These data were combined into a database which allows identification of natural and human processes, in preparation for conceptual model development. Appendix D presents a register of monitoring piezometers and bores forming the three monitoring networks, maps showing their locations (the regional area and a detail around the Berrima mine), and water level hydrographs. For numerical simulation, piezometers where no saturation was ever recorded, or where the screen interval is unknown, or where the screen interval or hydraulic interval is excessively large compared to model layer thicknesses, have not been used.

Government records for registered bores indicate that three private bores (GW043849, GW106337, and GW059975) occur over existing Berrima mine workings (see Appendix D). These provide useful historical information regarding impacts from mining.

6.1. Hydrographs

Water levels are relatively stable in the Hume lease area, except for periodic drawdown induced by pumping at private bores close by. Small long-term decreases in hydraulic heads are apparent at some locations; numerical simulation suggests this is depressurisation occurring from private pumping and drainage from existing mines. Significant vertical hydraulic head gradients generated by full extraction mining at Berrima are clearly seen at B62 and B63, which are alongside the last portion of workings (full extraction) to have been undertaken at the mine over the period 2011 to 2013.

Slow recovery from sampling events is seen at sites HU37 and HU38. Periodic drawdown in monitoring piezometers greater than 5 m, interpreted to be caused by periodic groundwater pumping from nearby private bores, is present at HU32LD, HU35, HU88, GW075034, and GW075036. Periodic drawdown smaller than 5 m amplitude, caused by private pumping, is interpreted to be present at HU40, HU72, HU73, GW075032, and GW075033. This provides useful information on the presence of private pumping bores, and is further discussed below. The location of GW075033 is shown in Figure 6.3 below; it is far to the east of the Hume area (near Wingecarribee Swamp) and not considered further, except for hydraulic head surface compilation. Water levels at GW075033 may be partly controlled by variations in the Reservoir water level. Observations made in 2015 at HU118 are to be confirmed. HU136B appears to have failed in late 2014 and Hume is currently in the process of decommissioning it.

Hydraulic head observations in the vicinity of the Berrima mine provide vital calibration targets and conceptual information. Details of the monitoring piezometers and bores around the mine are provided in Appendix D. Monitoring bore C Mon (Culpepper Monitoring) was converted from an old coal exploration bore (believed to be B28). It penetrated the Wongawilli Seam and shows little variation in water level except during approach of the Berrima Mine working area in mid-2012 when the bore failed and was reported blocked at a depth of about 40 m below ground. The water level fell to below the blockage at around the same time. This behaviour was caused by large depressurisation in the Wongawilli seam at the bore location, and penetration of the Wongawilli seam by the bore. Other bores in the vicinity, completed to shallower depths (C Prod and DeBeaujeu), maintained measurable water levels at the same time.

Private bore GW059975 was installed in 1983 over Berrima mine 1st workings that were mined prior to 1982 (and probably prior to 1977). It had a recorded water level of 37 m below ground. The bore was 92 m deep and the top of the Wongawilli seam is at an approximate depth of 125 m at that location. This indicates saturation above 1st workings areas, consistent with Tammetta (2013). Neither the current bore status nor water level is known.

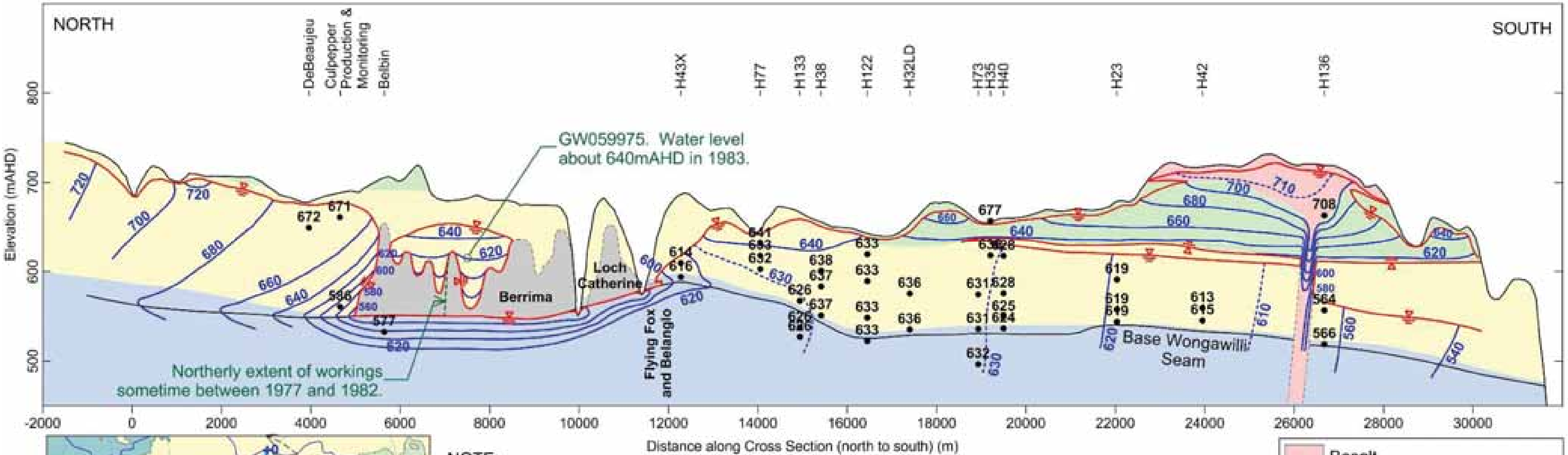
Bore GW106337 was installed in 2002, to a depth of 122 m, probably having intersected the Wongawilli Seam, in another portion of the 1st workings area mined prior to 1982. No measured water level is recorded at its installation, however it appears to have sustained a water level at installation since it was reported as going dry in 2005 and subsequently abandoned. It may have penetrated a pillar instead of a roadway, which probably provided a reasonable seal at the base while hydraulic heads were not drawn down below some threshold (below which pillar drying would occur).

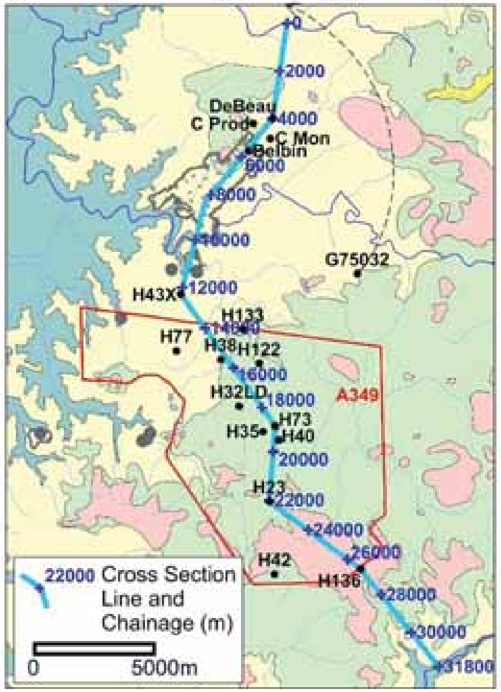
The current Belbin bore is a deeper replacement for a previous bore in the same location (overlying full extraction workings) which went dry after undermining. The previous bore was drilled in May 2004 to 115 m depth; it dried up and the replacement bore was drilled in April 2008 to 186 m depth. The replacement bore was screened in saturated media below the mined seam, harnessing the pressures and reasonable water quality present there. The C Prod (Culpepper Production) and DeBeajeu bores show drawdown accompanying the approach of the full extraction working area in the northern part of the Berrima mine.

6.2. Vertical hydraulic head gradients

To assess the hydraulic head field in three dimensions, hydraulic heads were first assessed by developing a hydraulic head cross-section for late 2013 / early 2014 through the mine lease (Figure 6.1). Results suggest a high probability of a desaturated zone beneath the shale in the southern part of the lease. Other salient features are:

- Hydraulic heads in the sandstone near the Berrima and Loch Catherine mines are largely controlled by the Wongawilli seam deformation processes resulting from full extraction, creating moderate to strong vertical gradients. The effect from Berrima has migrated northwards in a normal way, but has only migrated slightly to the south, influenced by barriers caused by incision of the sandstone by drainage courses.
- Vertical hydraulic head gradients are very small in the central area over the lease (overlain by WG), due to its distance from mining and escarpments. This suggests minimal recharge from above. On approach to escarpments, vertical gradients are generated by the discharge (and associated decrease in hydraulic head) at escarpment seepage faces (usually consumed by vegetation), and rainfall recharge vertically above (direct to the sandstone).
- Hydraulic heads and structure contour surfaces taken in tandem indicate a very high probability of a major sub-vertical structural feature present in the southern part of the lease, running approximately ENE-WSW, underneath the basalt body. The structure was likely an access gallery for the basalt extrusion, and appears to exhibit the classical behaviour of increased K along its plane, but decreased K in a direction normal to its plane.
- The hydraulic effect of the small bord and pillar operations in the escarpments (Flying Fox and Belanglo on the section) is to contract the water table further in towards the main body, and main recharge area, of the hydrostratigraphic unit.





NOTE:

1. The vertical hydraulic head gradient at chainage -1000 was estimated using the gradient at GW075032, since the radial depressurisation, and topography, are similar at both locations. This nest indicates a a hydraulic head difference of 16m between 147m and 110m above the base of the Hawkesbury Sandstone.
2. Zones in the southern (old) part of the Berrima Colliery workings where the extraction type is unknown are assumed to have undergone full extraction.
3. Flying Fox and Belanglo Collieries are assumed to have undergone 1st workings only.
4. The estimated height of desaturation over existing workings is calculated using Tammetta (2013). The height is representative for the plane of the cross-section, and is not necessarily the maximum height.
5. The position of the water table was estimated using the hydraulic head, pressure head, and pressure head gradient.
6. The hydraulic head for the Culpepper Monitoring bore is taken as midway between the reported blockage in 2012 (40m below ground), and the base of the bore (143m below ground).
7. The hydraulic head in the Wianamatta Group at H35 does not correlate with the section because there is a 15m difference in topography between it and the section. It demonstrates the curvature of the water table and the vertical gradients that are typically present in the Wianamatta Group, there being a difference of about 15m between H35 and the section line, in a direction normal to the section line (about the same difference as the fall in ground level). H35 Wianamatta Group has a pressure head of 20m at 24.5m below ground level.

Basalt
Wianamatta Group
Hawkesbury Sandstone
Narrabeen Group (where present) and Permian Coal Measures
Estimated desaturated zone caused by mining
620 Interpreted hydraulic head contour (mAHD). 20m interval. Half interval (10m) shown as dashed line.
Interpreted water table
672 Observed Hydraulic Head for late 2013 / early 2014 (mAHD)

Figure 6.1. Interpreted hydraulic head cross-section for late 2013 / early 2014 through the Berrima and Hume mine leases.

Vertical hydraulic head gradients were also assessed by analysing the vertical pressure head distribution at each piezometer nest for late 2013 / early 2014 (Figure 6.2). The distributions support the hydraulic head cross-section, with the majority of sites indicating negligible vertical hydraulic head gradients. These are located in and around the mine lease, underneath WG. Strong vertical gradients due to depressurisation from the Berrima mine can be identified at piezometer nests B62 and B63. The lateral position of GW075032 suggests the vertical gradient at that location has been created by the existing mines. Drawdown from mining is not conspicuously observable in hydrographs for piezometers at H43X, the nearest Hume site to the existing mines; this site shows a negligible gradient in sandstone, probably due to insulation from the mined area via incision by drainage courses. H77 shows a moderate gradient at shallow depths, highly typical for outcropping Hawkesbury Sandstone in the Southern Highlands. The results suggest the drawdown from the Berrima mine has migrated mainly northwards and eastwards.

Sites H136 and H35 are interpreted to have potential unsaturated zones (of unknown vertical thickness) below the base of the basalt and WG respectively.

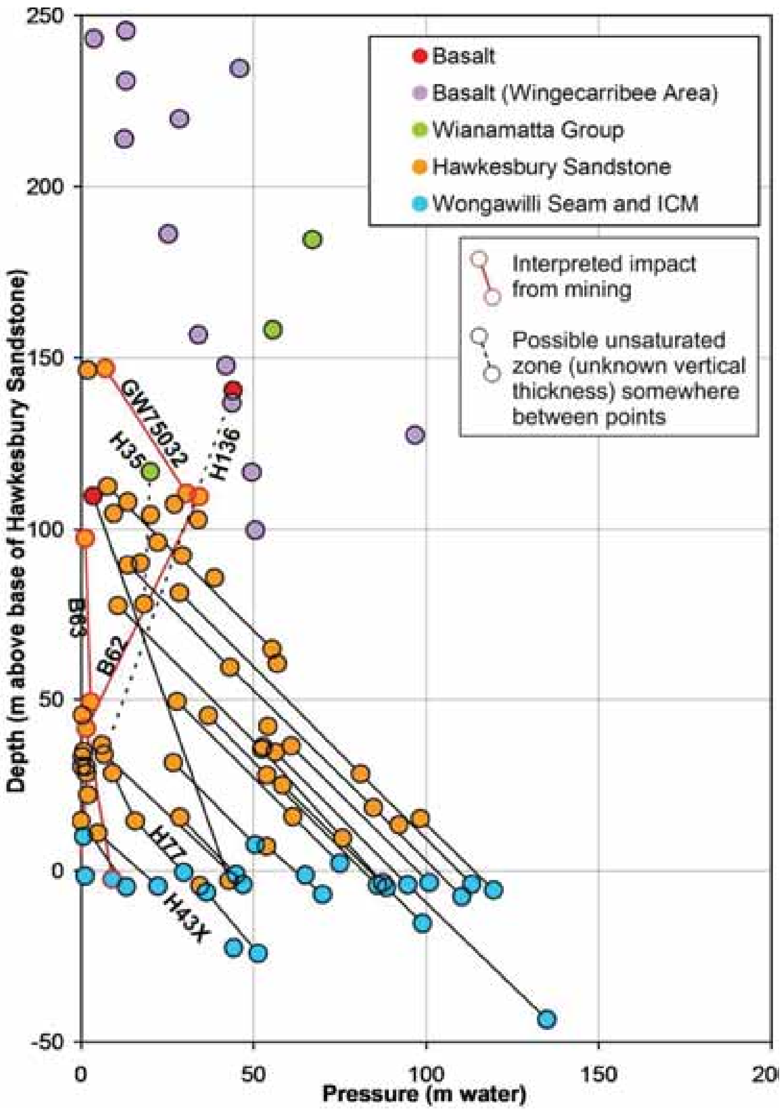


Figure 6.2. Vertical pressure head distributions for late 2013 / early 2014.

6.3. Hydraulic head surfaces for late 2013 / early 2014

Where vertical hydraulic head gradients are present, it is necessary to consider the vertical position of a piezometer in the profile when assessing hydraulic head surfaces. Surfaces are usually only useful if observations for a surface are located at the same stratigraphic horizon, since the K field is controlled by the structure of the medium. Horizons that are a given distance above or below an important depositional marker (such as the base of the Hawkesbury Sandstone) are generally required, however an element of variability from changing overburden thickness is present.

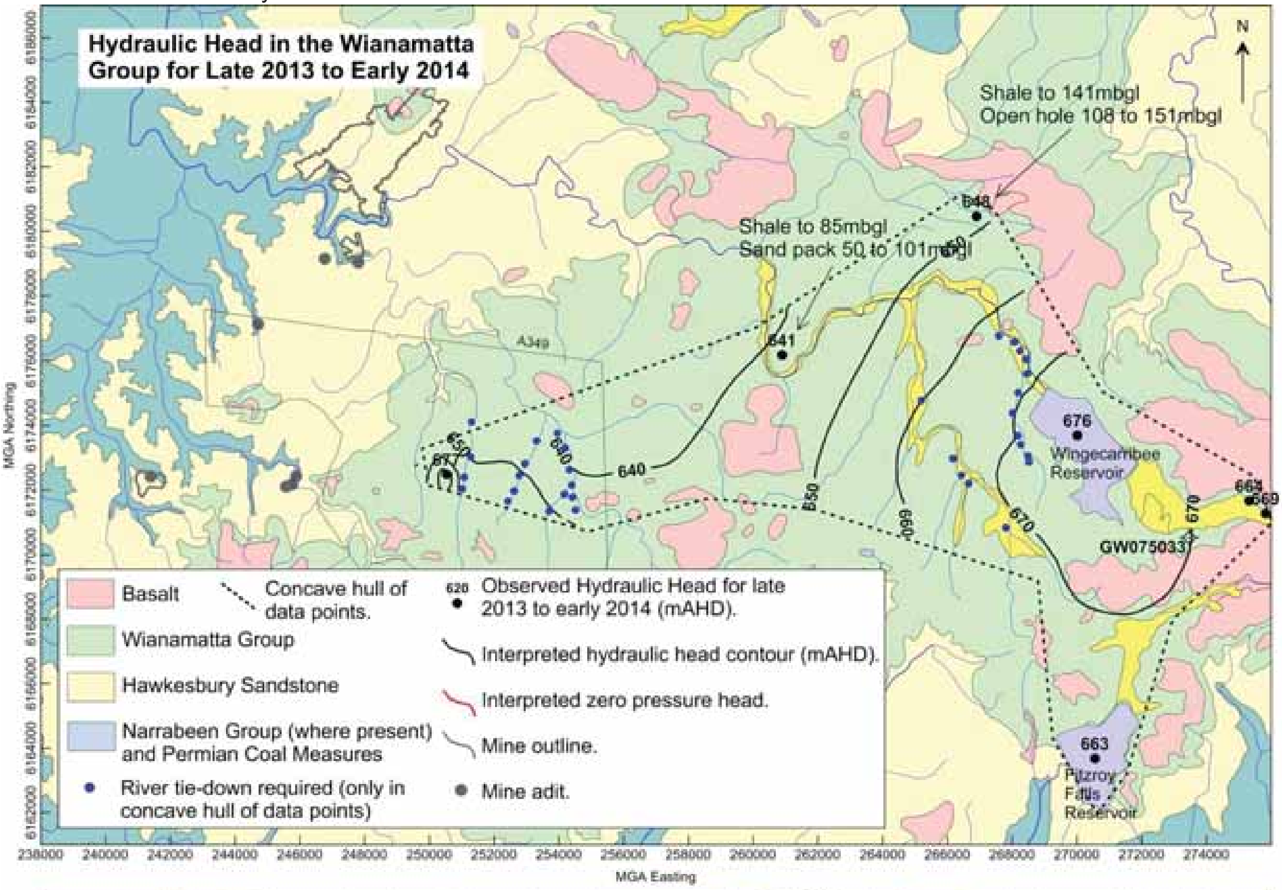
Hydraulic head surfaces for late 2013 / early 2014 (the period with the greatest overall lateral coverage in observations at the time of reporting) were compiled for the following horizons, to achieve a reasonable representation of the three-dimensional variation of hydraulic head over the area and at the same time using horizons where a sufficient number of observations were available to provide a meaningful surface:

- WG (7 observations, of which two are long-term elevations of water levels in Wingecarribee and Fitzroy Falls Rservoirs).
- Shallow Hawkesbury Sandstone (19 observations between 77 m and 108 m above the base of the Hawkesbury Sandstone, and application of zero pressure head at appropriate locations on the Berrima and Loch Catherine mine boundaries).
- Deep Hawkesbury Sandstone (23 observations between 22 m and 45 m above the base of the Hawkesbury Sandstone, and application of zero pressure head at appropriate locations on the Berrima and Loch Catherine mine boundaries).
- Wongawilli Seam and ICM (21 observations between 0 m and -24 m above the base of the Hawkesbury Sandstone, and application of zero pressure head at appropriate locations on the Berrima and Loch Catherine mine boundaries).

Figure 6.3 shows the hydraulic head surfaces for the WG and shallow Hawkesbury Sandstone. Appendix E has hydraulic head surfaces for deep Hawkesbury Sandstone and the Wongawilli Seam / ICM. The combination of highland topography and contrasting outcrop lithologies produces a hydraulic head field which is elevated along the western Hawkesbury Sandstone outcrop and at Wingecarribee Reservoir to the southeast, and decreases towards the south and northeast. Wingecarribee Reservoir and rainfall recharge at sandstone outcrop areas form the main upper hydraulic controls in the subsurface, for the hydraulic head field.

Surfaces obtained from initial contouring of data were tied down with ground elevations wherever these initial surfaces intersected ground surface (mainly at drainage channels). Points where tie-down was undertaken are shown, and provide an approximation for the areas where baseflow to drainage channels occurs (recognising that the extent of tie-down zones are a function of data density, and that the actual hydraulic head in these zones, for the particular horizon, is not necessarily at ground surface).

The water table is difficult to locate, especially where vertical hydraulic head gradients are present. An approximation can be made by extrapolating the pressure head distributions in Figure 6.2 to obtain the y axis intercept (the depth where pressure head is zero) and taking the elevation of that point. However this is not possible where hydraulic head gradients are greater than 1, such as for B62.



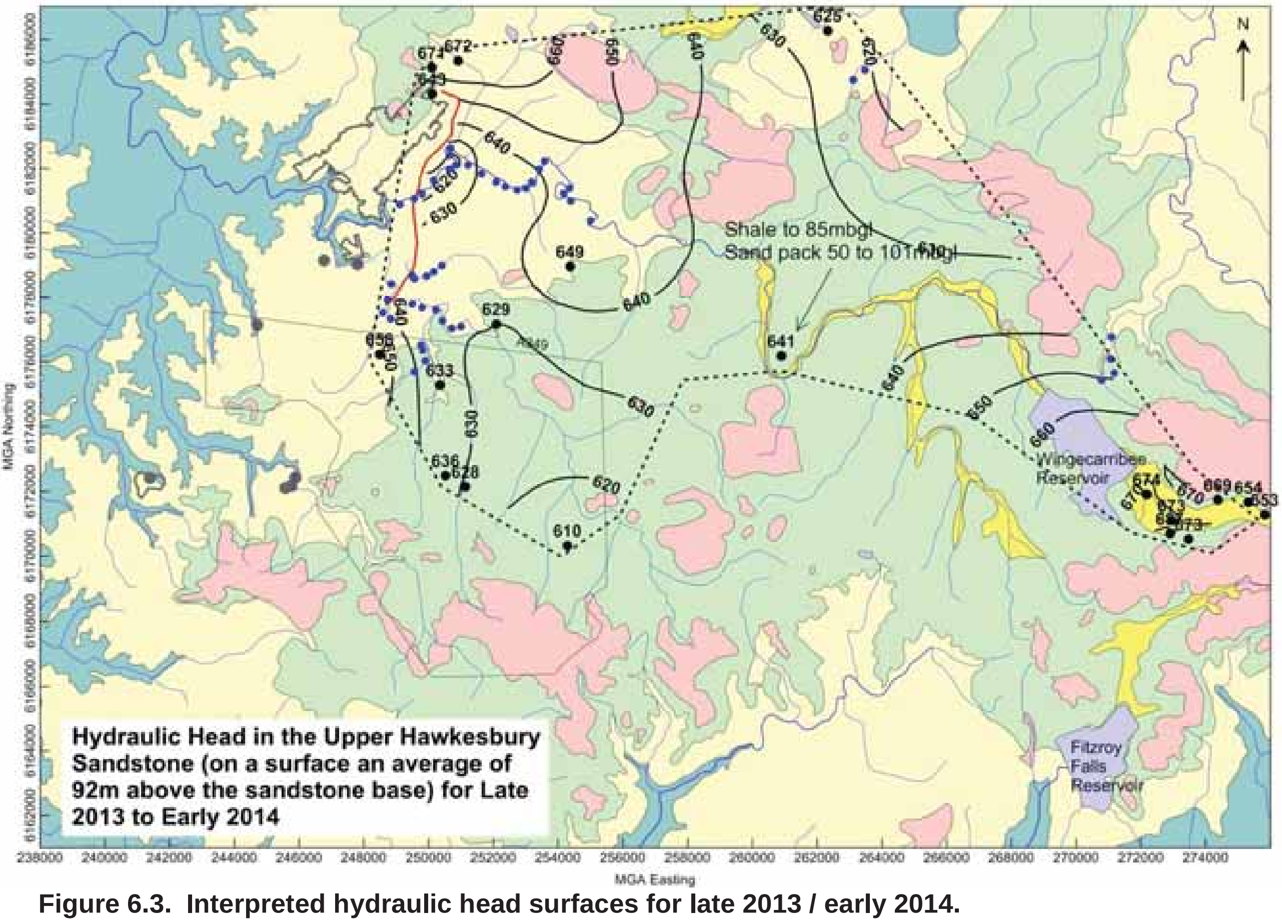


Figure 6.3. Interpreted hydraulic head surfaces for late 2013 / early 2014.

6.4. Hydraulic heads in basalt

The interpreted unsaturated zone below the Wianamatta Group (WG) over a large part of the study area (Figure 6.1) prompted a detailed assessment of the hydraulic relationship between basalt and underlying strata. This comprised assessment of the hydraulic head field present in the southeastern basalt body (see Figure 6.4), and underlying WG. The purpose of the assessment was to characterise the probable behaviour of hydraulic heads in the basalt groundwater system due to drawdown in underlying media, given the large number of private bores utilising the basalt groundwater system.

The southeastern basalt body is as shown in Figure 6.4. Most other basalt bodies in proximity to the proposed mine footprint are very small. Another large body is located just west of the southeastern basalt body however it likely hosts a smaller groundwater system, and also hosts fewer private bores.

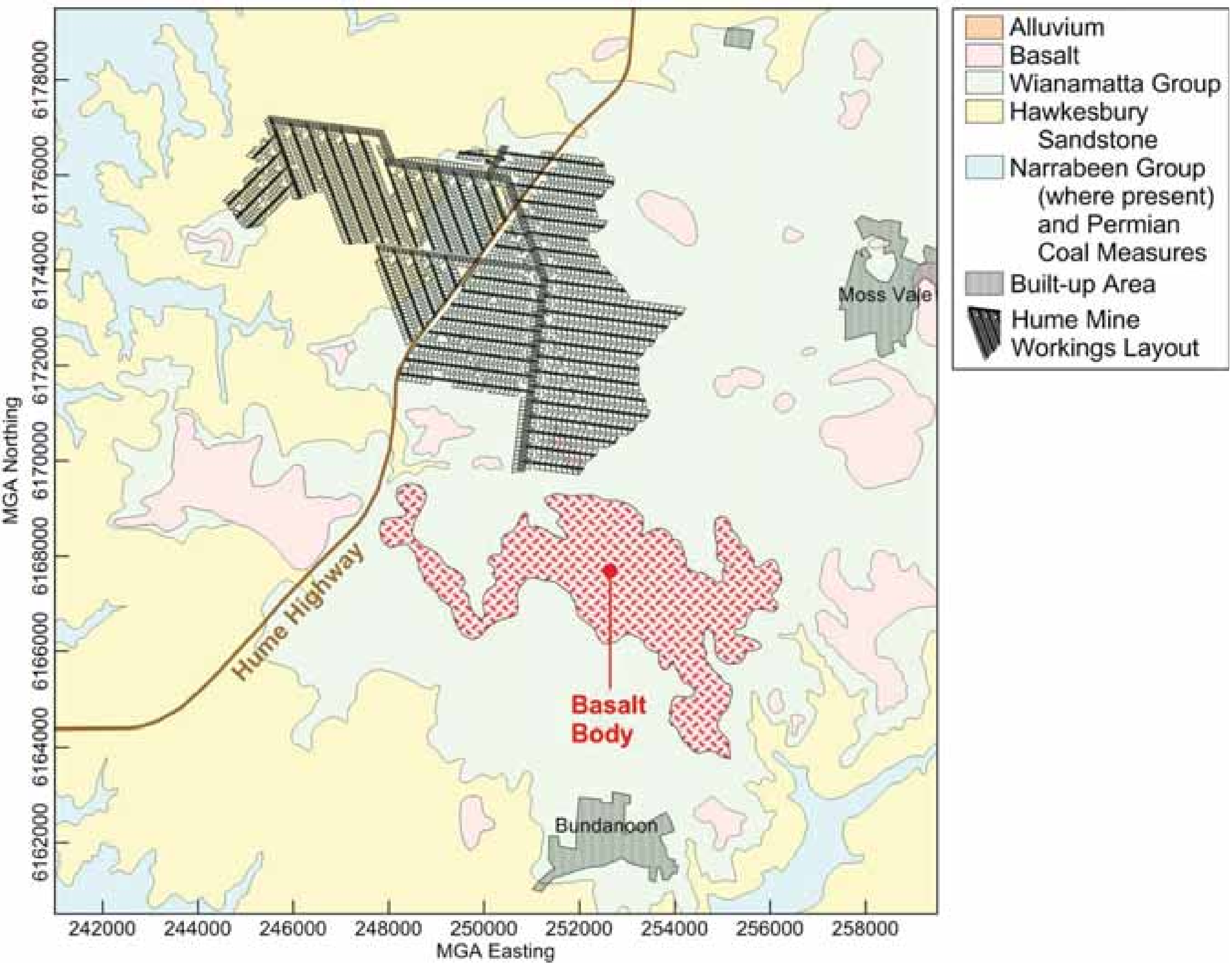


Figure 6.4. The southeastern basalt body.

A database of hydraulic head measurements, specifically for the basalt body and underlying media, was compiled from registered private bores penetrating this subsurface volume (DPI Water database extraction 2015). The analysis is more three-dimensional in nature than is possible using observations from monitoring networks alone.

Bore completions and measured water levels were obtained for 40 water bores, in hydraulic communication with the following media in and around the basalt body (see Figure 6.5):

- 30 in basalt only.
- 7 in Hawkesbury Sandstone (HAW) underlying basalt.
- 3 in HAW on the fringes of the basalt body.

Figure 6.5 shows private bores present in the area, and the 40 private bores for which the hydraulic connection has been interpreted from construction records and measured water levels. Data are provided in Appendix F. Lithologies recorded in bore logs may not agree with published geology maps. No measurements of hydraulic head for the WG were available for this volume. Measured water levels cover a period mainly between 1990 and 2010. Hydraulic heads were calculated for each bore. Observations from monitoring piezometer nests H136 (three piezometers in basalt, HAW, and ICM) and H42 (two piezometers in HAW and ICM), located at the basalt body, were added to the observation dataset to create a database of 45 hydraulic head observations in the subsurface volume.

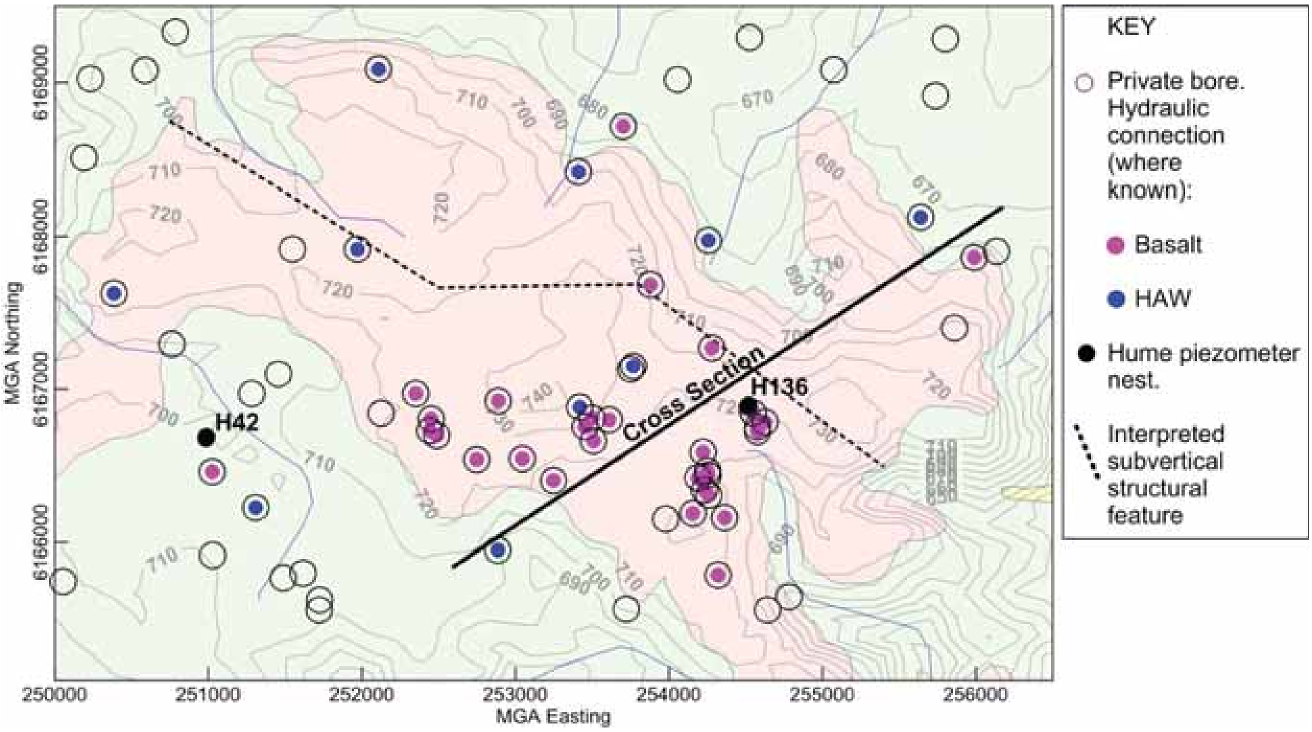


Figure 6.5. Private bores located in and around the southeastern basalt body. Those used for analysis are coloured (identified hydraulic connection).

The database was initially used to assess vertical pressure head gradients. This distribution is shown in Figure 6.6, and includes observations from piezometers in the wider lease area to assist with assessing gradients. Only one observation was available for the WG (H35B, in the centre of the Hume lease).

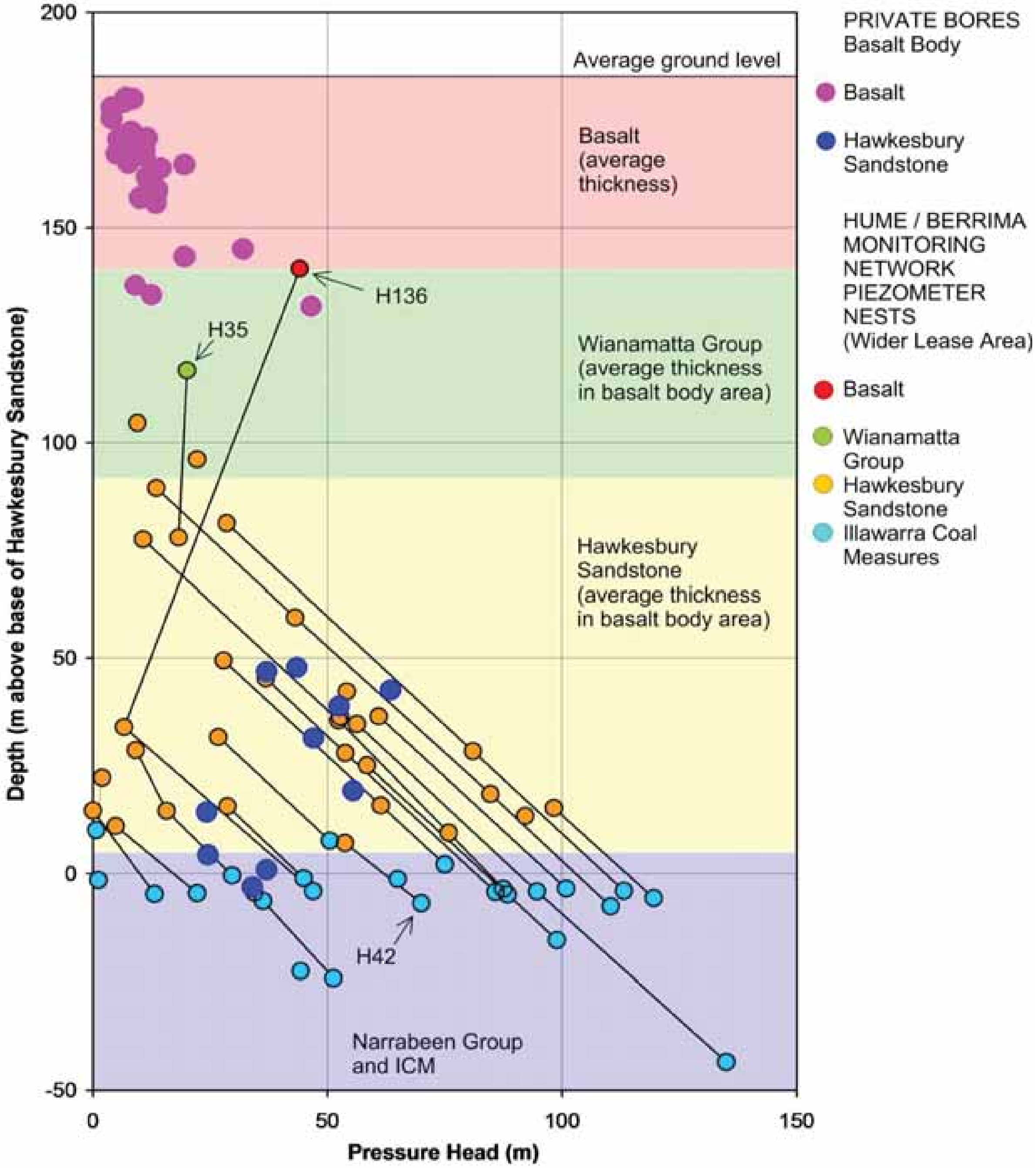


Figure 6.6. Pressure head versus depth distribution for the basalt body volume (mainly from private bores), and for the wider lease area (from monitoring piezometer networks).

Figure 6.6 (and Figure 6.7, see below) indicates that vertical hydraulic head gradients are small in the basalt and HAW, but likely to be significant (and downward) in the intervening WG. The pattern emerging from the large number of observations strongly indicates a largely unsaturated zone below the WG, in the basalt area. This was further investigated by compiling a hydraulic head cross section for the basalt body (see Figure 6.5 for section location). Observations made in basalt within 500 m (laterally) of the cross section were included for plotting.

Figure 6.7 shows the interpreted hydraulic head cross section. An unsaturated zone occurs below the WG south of the subvertical structural feature. North of the structural feature, the hydraulic head difference between the top of the HAW and the base of the basalt is about 80 m. The overall hydraulic gradient is about -1 downward. North of the structural feature, the pressure head at the top of the sandstone is an average of about 10 m.

The analysis indicates the following:

- Drawdown in the HAW south of the structural feature will not cause any change to the saturated flow regime in the basalt in the same area. The majority of private bores in the basalt are located here.
- North of the structural feature, the top of the sandstone can undergo a drawdown of about 10 m before desaturation occurs between the sandstone and WG, at which point any further drawdown will not impact the saturated flow regime in the overlying basalt. This is an increase in the magnitude of the vertical hydraulic head gradient of about 13%. This assumes saturation is maintained from the base of the WG (moving upwards); this is considered reasonable given the strong vertical anisotropy exhibited by the WG.
- It is estimated that of the recharge to the basalt, less than 10% drains vertically into the WG, with the remainder consumed by surface processes and baseflow. The realisation of drawdown greater than 10 m at the top of the HAW is therefore likely to increase the vertical drainage from the basalt by about 1% of the recharge to the basalt, or less.
- If maximum drawdown were to occur at the top of the HAW, drawdown in the basalt would initially be non-zero but negligible, as drainage from storage occurs. With time, drainage from storage ceases and water levels would re-establish (during mining), with the increased vertical drainage satisfied by decreased baseflow to streams.

No direct evidence (from bores) is available for the structural feature. Its presence is interpreted from hydraulic heads, regional lineaments, and structure contour surfaces considered in unison. The feature is considered major, running approximately ENE-WSW, underneath the basalt body. The structure was likely an access gallery for the basalt extrusion, and appears to exhibit the classical behaviour of increased K along its plane, but decreased K in a direction normal to its plane.

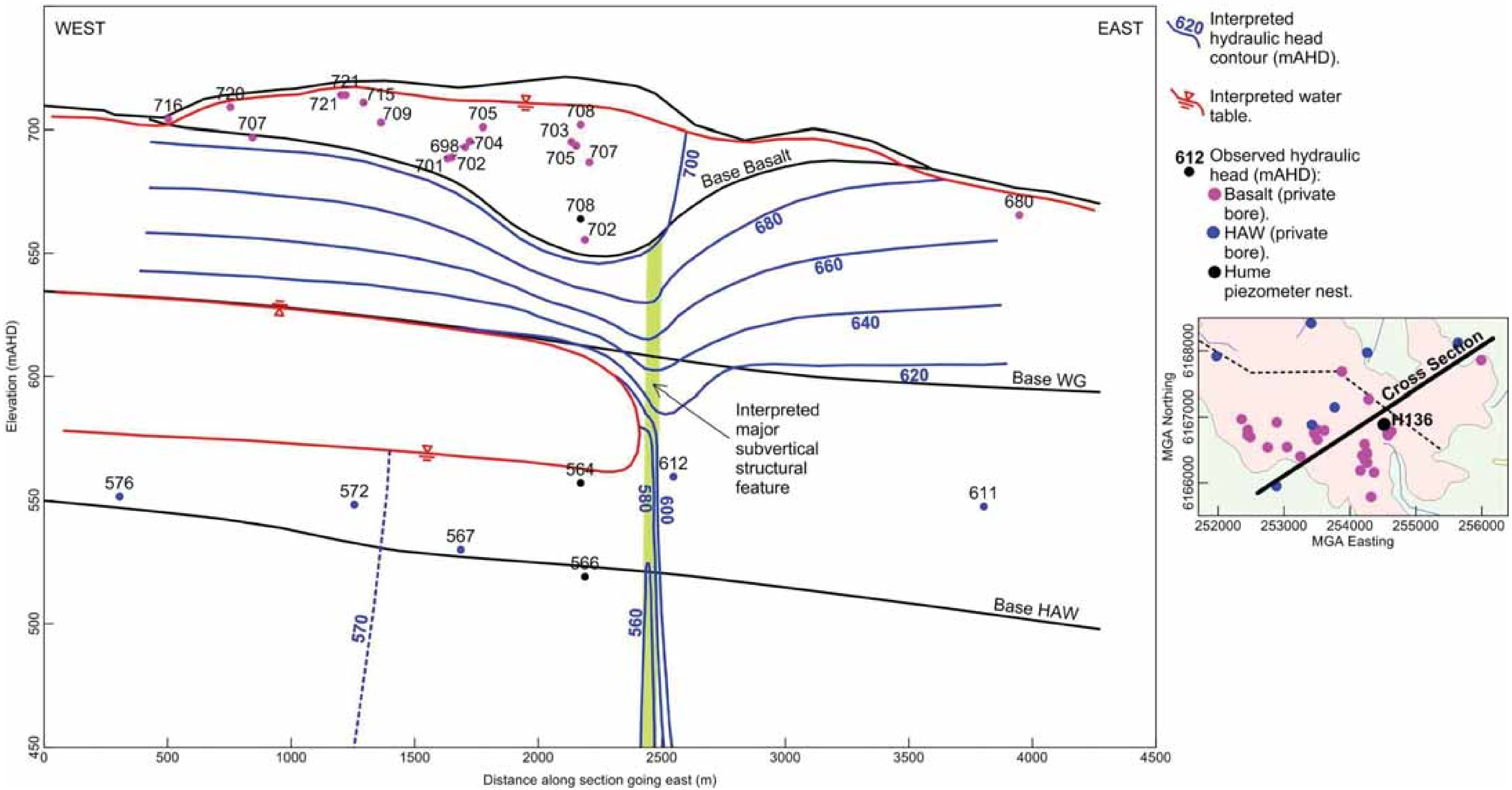


Figure 6.7. Hydraulic head cross section along the basalt body.

6.5. Reliability of Hydraulic Head Measurements

The reliability of a hydraulic head measurement is a necessary consideration for model calibration. Standpipe piezometers (SPs) provide the most reliable hydraulic head observations, however practical considerations limit the number of piezometers in the vertical profile at a single location. Vibrating wire piezometers (VWPs) provide hydraulic head measurements of lower accuracy than SPs, but practical considerations allow significantly greater coverage of the vertical profile with VWPs at a single location (up to five in the Hume network) than is possible with SPs. The Hume monitoring network contains a combination of SPs, VWPs, and private water bores for acquisition of hydraulic head observations and provides a substantial database for characterisation of the groundwater system in the Hume area.

An estimate of the resolution of VWPs was previously made for another project in the Southern Coalfield using measurements from VWPs located at two sites on a mine lease. It was found that simultaneous water level measurements from coincident VWPs varied. Results indicated that, 50% of the time, a VWP measurement at that site would have been within 7.8 m of the measurement from a coincident VWP. The ability of a VWP to provide the true hydraulic head adds an additional uncertainty to the measurement. This accuracy is considered not better than ±10 m most of the time. This accuracy may be acceptable in areas with a high vertical hydraulic head gradient (for example, for depressurisation due to underground mining, as at B62 and B63), but may be less suitable in areas with smaller vertical hydraulic head gradients.

The lower accuracy of VWP measurements has been taken into consideration when comparing model output to hydraulic head observations. The hydraulic head calibration dataset includes observations from VWPs at locations B62 and B63 in the Berrima monitoring network.

7. Groundwater inflows to the Berrima mine void

Measured discharge from the Berrima mine void provides an invaluable calibration aid for numerical modelling. When used in conjunction with hydraulic heads, the mine inflows are able to significantly reduce the uncertainty associated with the correlation between rainfall and K. Coupled with reliable a-priori estimates of rainfall recharge and the Kh distribution, deep discharges (mine inflows in this case) provide vital information in estimating the Kv distribution between the surface and the mining zone.

Mine operators have monitored discharge from the Berrima workings for several years, with discharge measurements available from 2005. Water is pumped from various points within the workings to the main sump where it flows through an old roadway to the Wingecarribee River where it is discharged through an adit under EPA Licence conditions (EMGA 2011). Water was previously pumped from the workings to storage tanks in the northern corner of the Berrima pit top, from where it was used for dust suppression, equipment washdown, bathhouse and ablutions, and piped under gravity to the township of Medway for non-potable water use (EMGA 2011). During the recent active mine life (2012/2013) these consumptions (plus an estimate for ventilation loss) are estimated to have been about 0.05 ML/day. At present, the consumption is estimated to be about 0.02 ML/day. These consumptions were or are taken from void inflow, with the remainder discharged to the Wingecarribee River.

Existing groundwater removed in coal moisture (during mining) is conservatively estimated to have been about 0.1 ML/day (about 2% existing groundwater, at 0.25 Mt/y). Coal removal is assumed to have ceased on 31 March 2013.

When the mine was active, mine workers observed that the void inflow rate appeared to be approximately proportional to the area of seam roof exposed, with no obvious lateral inflow from the Wongawilli seam. Anecdotal information indicates the following:

- Panels driven beneath basalt experienced higher inflows.
- Wet weather sometimes resulted in large volumes of water flowing down along the contact zones of dykes. There appeared to be a strong correlation between the occurrence (and distribution) of subvertical dykes and increases in inflow during 2008.

Monitoring of void discharge at the licensed discharge point up to October 2012 was undertaken using a v-notch weir. In October 2012 a more accurate cut throat weir outfitted with an automatic recorder was installed. Void discharge observations have the following limitations:

- Prior to 2009, it is understood that measurements may only have been made when discharge pumps were active, with resulting measurements excluding periods of no pumping. If pump on/off times were available, averages over periods larger than the pumping frequency would be useful, since void inflow during pump off times would report to void storages for future pumping. However, it is not clear if observations published prior to 2009 were averaged over large periods (compared to the pumping frequency). The data points present in published information would suggest this was not the case.
- It is understood that the original v-notch weir had a lower accuracy than the cut throat weir installed in 2012.
- The coincident installation of an automatic recorder with the cut throat weir suggests observations between 2009 and 2012 may also have suffered from biased sampling.

These limitations mean observation reliability is reasonable only after October 2012. Prior observations may be overestimates. Figure 7.1 shows the recorded discharge. Also shown is the monthly cumulative rainfall residual for the period 2000 to the present (incorporating an entire southern oscillation cycle with the major drought in the middle of last decade).

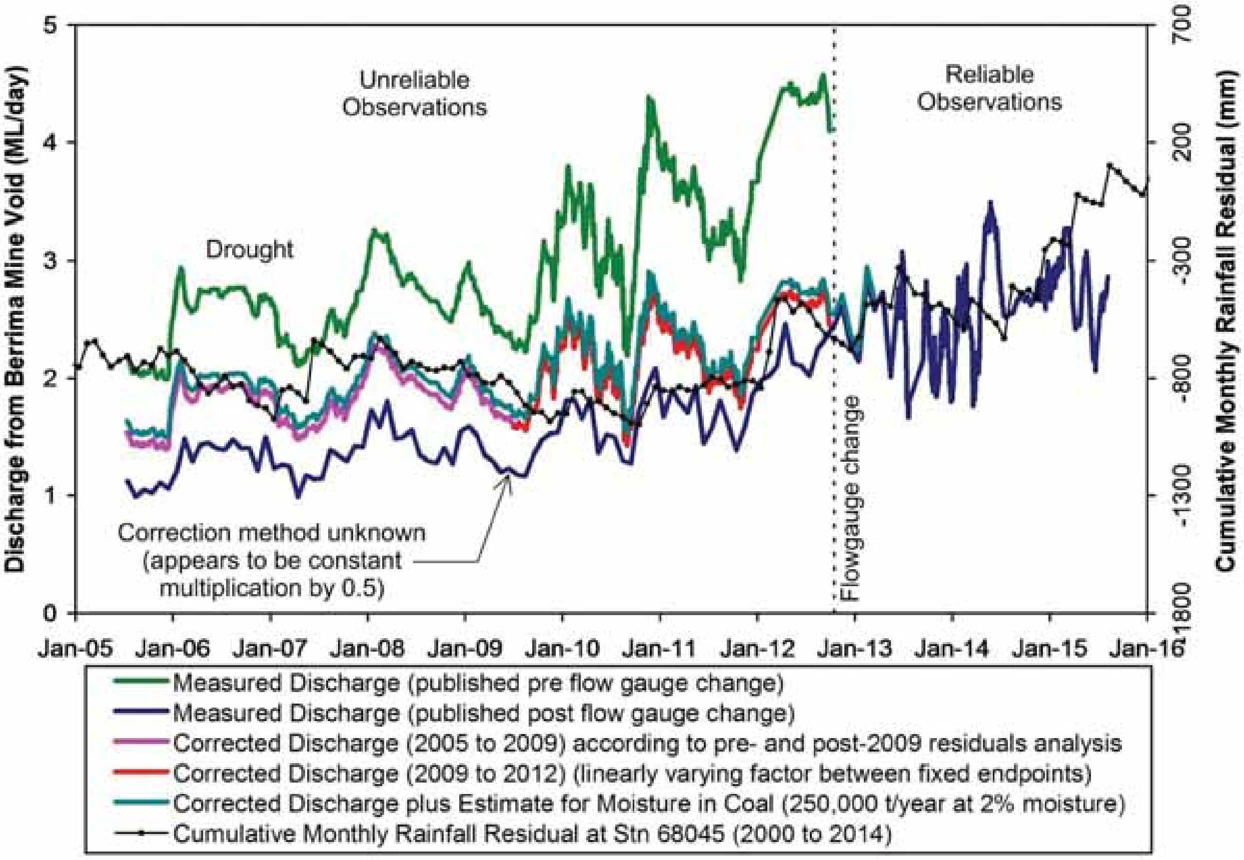


Figure 7.1. Measured discharge from the Berrima mine.

Observations take no account of changes in void storage or evaporation, however it is understood that in the last few years the void was kept virtually empty, and changes in the small underground sump storages are considered to negligibly affect average monthly flow volumes. Also, the void is not known to be artificially ventilated. The majority of the inflow to the void is discharged to the river, with the consumptions listed above accounting for about 2% (during mining) or 1% (post mining) of the total inflow.

Observations are considered reliable following the flow gauge change in October 2012. Observations prior to the change do not appear reliable. Pre-gauge-change observations published in 2014 appear to have been multiplied by 0.5 to obtain corrected observations. Uncorrected pre-gauge-change observations appear to begin increasing from 2009. Pre-gauge-change observations may also have been affected by drought conditions between 2005 and 2009.

Published corrected observations were assessed for any relationship with rainfall by correlating the departure of the rainfall and inflow patterns from their respective long-term trends. These departures are known as residuals and were calculated by first plotting the cumulative value of these variables over time, then fitting a polynomial trend line to the cumulative curves and finding the residuals via the difference between observations and the fitted polynomials.

Figure 7.2 shows discharge and rainfall residuals, and indicates the clear relationship between rainfall and inflow. The highest degree of correlation was for a 12-month lag between rainfall and inflow. The ratio of inflow to rainfall residuals prior to 2009 suggests the potentially applied reduction factor (50%), to obtain corrected observations, might be too large.

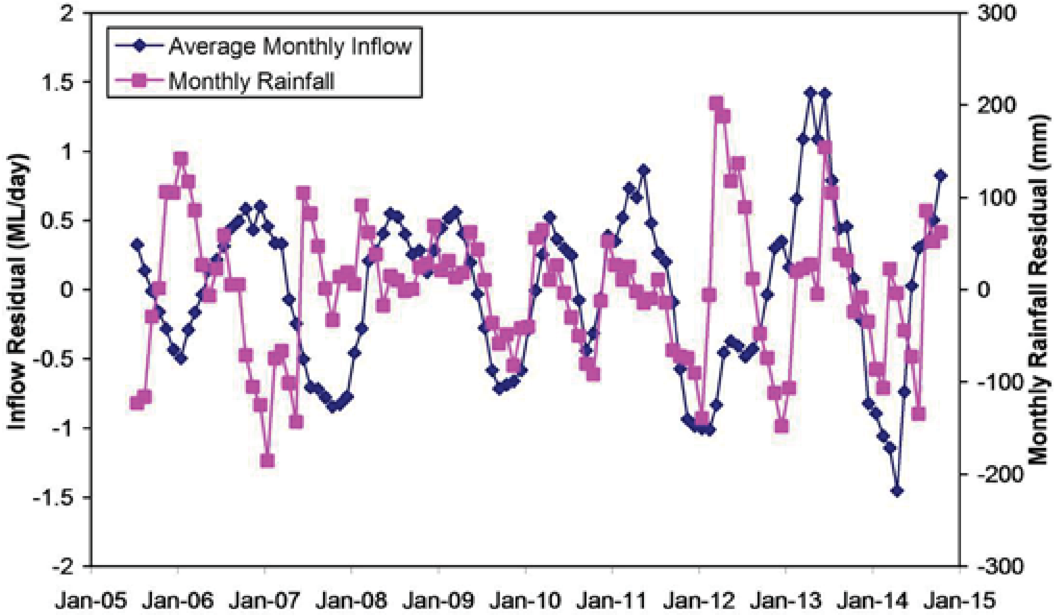


Figure 7.2. Departures of rainfall and Berrima mine discharge from their long-term trends.

Comparing pre- and post-2009 residuals ratios, the reduction to obtain corrected discharge is calculated to be a maximum of about 30%. This correction is based on residuals only, not magnitudes. Corrected discharge using a 30% reduction, for the period 2005 to 2009, is shown in Figure 7.1. Observations obtained after the gauge change are considered to be reliable. For observations made between 2009 and the gauge change, a correction has been applied comprising a linearly varying correction factor of 30% at 2009 to 41% at the gauge change (to obtain compliance in observations at that point); this dataset is also shown in Figure 7.1. The adopted observation dataset used for calibration therefore comprises the following three components:

- 2005 to mid-2009: Uncorrected observations reduced by 30%.
- Mid-2009 to October 2012: Reduction by 30% at mid-2009, increasing linearly to reduction by 41% at October 2012 (to obtain compliance in observations at that point).
- Post October 2012: Observations as published.

A nominal consumption of 0.1 ML/day is added to account for groundwater removed in mined coal (assumed to have ceased on 31 March 2013). The adopted dataset appears to accord more reasonably with the cumulative annual rainfall deficit than other datasets.

8. Groundwater character

Water quality monitoring has been undertaken at the Hume groundwater monitoring network (Parsons Brinckerhoff 2015). These data have been subjected to statistical analysis to assess groundwater character in the various hydrostratigraphic units. Table 4 lists statistics for these units, for electrical conductivity (EC) and sulphate.

Table 4. Electrical conductivity and sulphate of groundwater from the Hume monitoring network.

Analyte	Hydrostratigraphic Unit			
	Basalt	Wianamatta Group	Hawkesbury Sandstone	Wongawilli Seam and Illawarra Coal Measures
Electrical Conductivity				
Average (uS/cm)	748	2477	295	392
Standard Dev. (uS/cm)	13	158	243	261
Sulphate				
Average (mg/L)	64	80	7	17
Standard Dev. (mg/L)	27	9	9	26
Sample Information				
Number of Samples	2	2	69	56
Sampling Date Interval	Average interval 17 October 2011 to 23 May 2014			

In the Hume lease area, the Hawkesbury Sandstone (HAW) has the lowest average EC of the units, comparable to the Illawarra Coal Measures. EC of the Wianamatta group is more than 8 times larger than the HAW. This is also observed in the Sydney metropolitan area. Sulphate concentrations for the units follow similar proportions.

8.1. Stream flow and electrical conductivity

Concurrent streamflow and stream EC measurements are useful as an independent indicator of the flow range where groundwater seepage to the stream is a large proportion of the total flow.

Intermittent EC measurements for WaterNSW station E332 and concurrent daily flow measurements for the adjacent flow gauge (212272: Wingecarribee River at Berrima Weir) for the period 1991 to 2014 were correlated. Multiple EC readings taken on the same day were volume-averaged (where more frequent flow measurements were available), or time-averaged.

A strong inverse correlation is apparent when viewing flow and EC time series (see Figure 8.1). Figure 8.1 shows daily flow and EC correlated for two periods:

- 1991 to 2001 inclusive (weak regulation).
- 2002 to 2014 inclusive (strong regulation).

Stream regulation is conspicuous in the latter dataset, resulting mainly from the severe drought of the 2000s. Reservoir water has a large component of surface runoff and its EC will be lower than groundwater EC. Artificial discharges wash away high EC water at prevailing low flow, and replace it with lower EC water at moderate flows. In extreme cases, where streamflow ceases, a small artificial discharge reaching the gauge will have significantly lower EC than would be expected naturally.

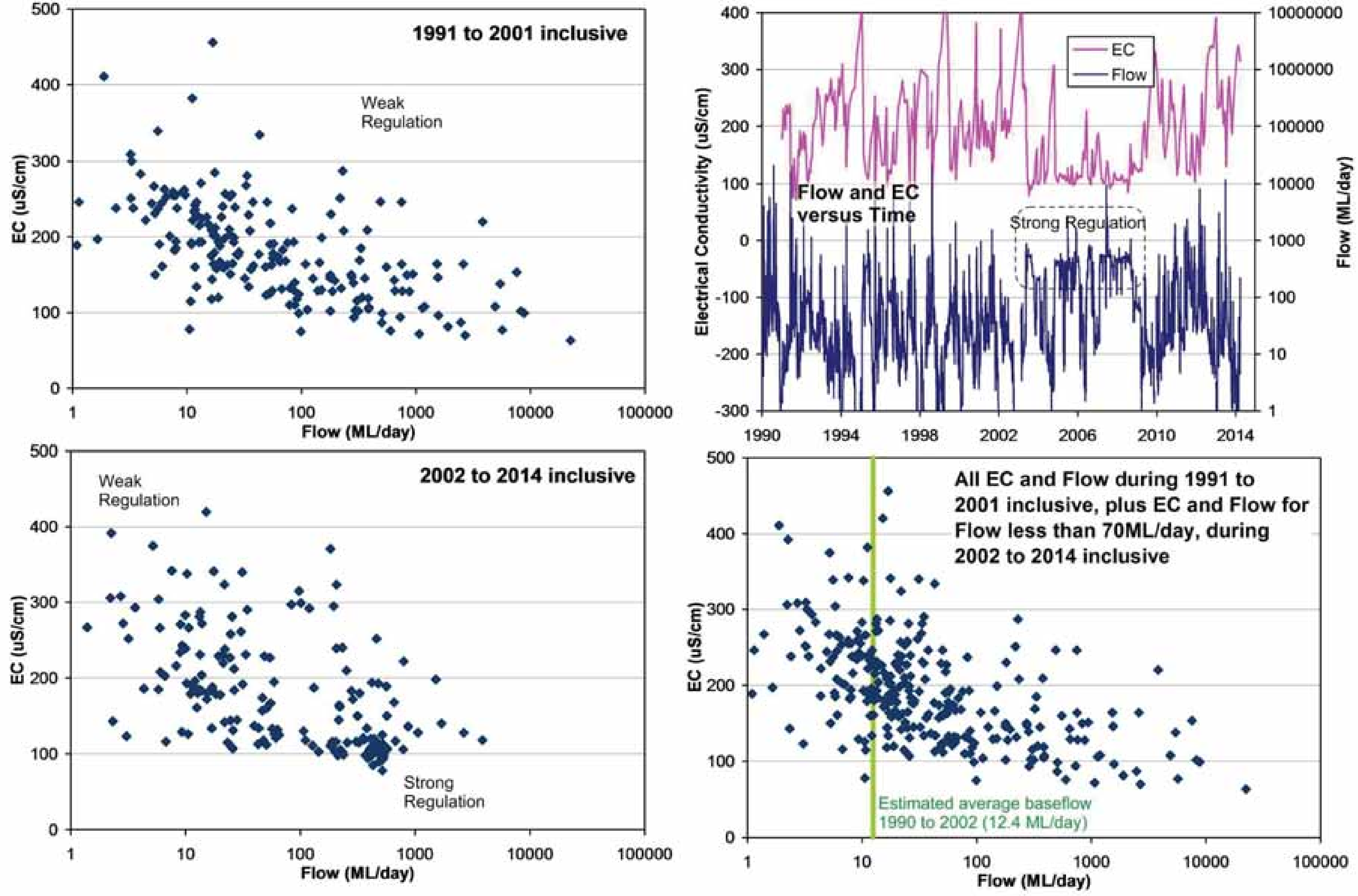


Figure 8.1. Flow at stream gauge 212272 and measured stream EC. Anticlockwise from top right: comparison of time series; correlation for 1991 to 2001; correlation for 2002 to 2014; selected dataset estimated to have reduced impact from regulation.

Considering only measurements occurring during weakly regulated times, a reasonable hyperbolic relationship is apparent between log[flow] and EC.

The baseflow at gauge 212272 calculated using the local minimum method (see above) is in reasonable agreement with the flow versus EC distribution, being located in the likely zone of major change of the distribution.

9. Groundwater use

9.1. Private bore use

Registered private water supply bores from the NSW State Government database are shown in Figure 9.1. A drawdown impact assessment for private water bores in the Hume area is reported in Volume 2. Over the mine lease, the majority of bores are reportedly deeper than 100 m, in an attempt to harness water supplies in the Hawkesbury Sandstone underneath reasonable thicknesses of WG. This trend continues north-eastwards, along the WG body (see Figure 9.1 and Drawing 1).

A search of private water bore access licences within 9 km of the Hume mine area centroid returned 83 known water access licences with a combined level of entitlement of 14.5 ML/day (5300 ML/year). It is understood that a significant number of unregistered bores also exists. No metering of usage is undertaken by regulatory agencies for the area, therefore actual usage from registered bores is not known.

The vast majority of private bores extract groundwater from the Hawkesbury Sandstone. A number of basic rights bores (registered for stock and domestic use) also exist; there is no volumetric entitlement associated with these bores. The total usage of basic rights bores within 9 km of the mine centroid is estimated to be about 2.6 ML/day. The total level of entitlement for the model area is likely to be in excess of 20 ML/day. Basic rights bores are estimated to have a combined usage of up to approximately 5 ML/day.

A search of surface water access licences in the regional area returned 173 licences with a combined entitlement of 26 ML/day (9495 ML/year). Table 5 lists the total entitlement by management area. Actual usage is estimated using published information for the catchment of gauge 212238 as a corollary, based on land use (and assuming 10% of intensive urban use areas are irrigated with water to maintain grass).

Table 5. Surface water entitlement by management zone.

Management Zone	Total Entitlement (ML/year)
Bundanoon Creek	1108
Lower Wingecarribee River	1135
Lower Wollondilly River	5411
Medway Rivulet	1027
Nattai River	124
Upper Wingecarribee River	690
Total	9495

Figure 9.2 shows the following:

- Monitoring piezometers where drawdown from pumping at proximal private bores is evident.
- Irrigation and intensive urban land uses according to government databases.

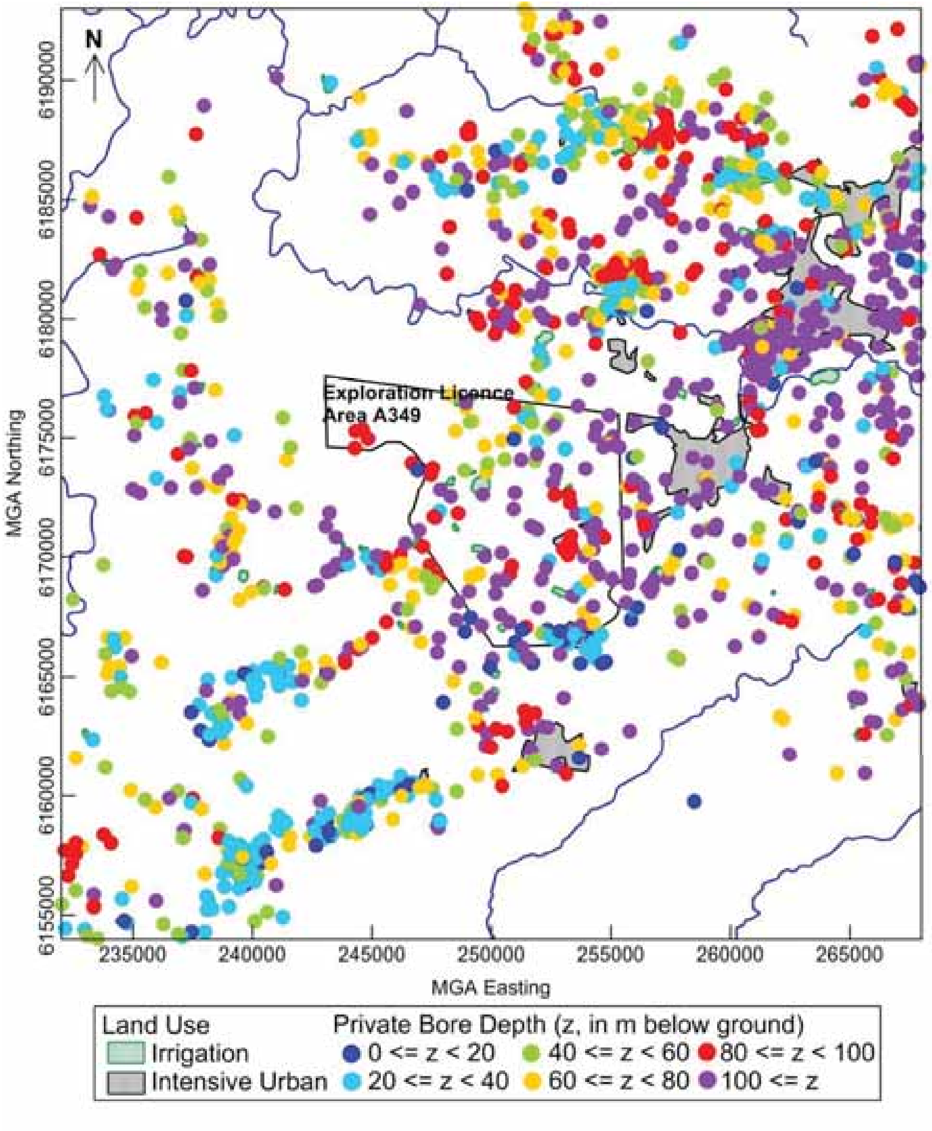


Figure 9.1. Registered private water bore locations, according to completed depth.

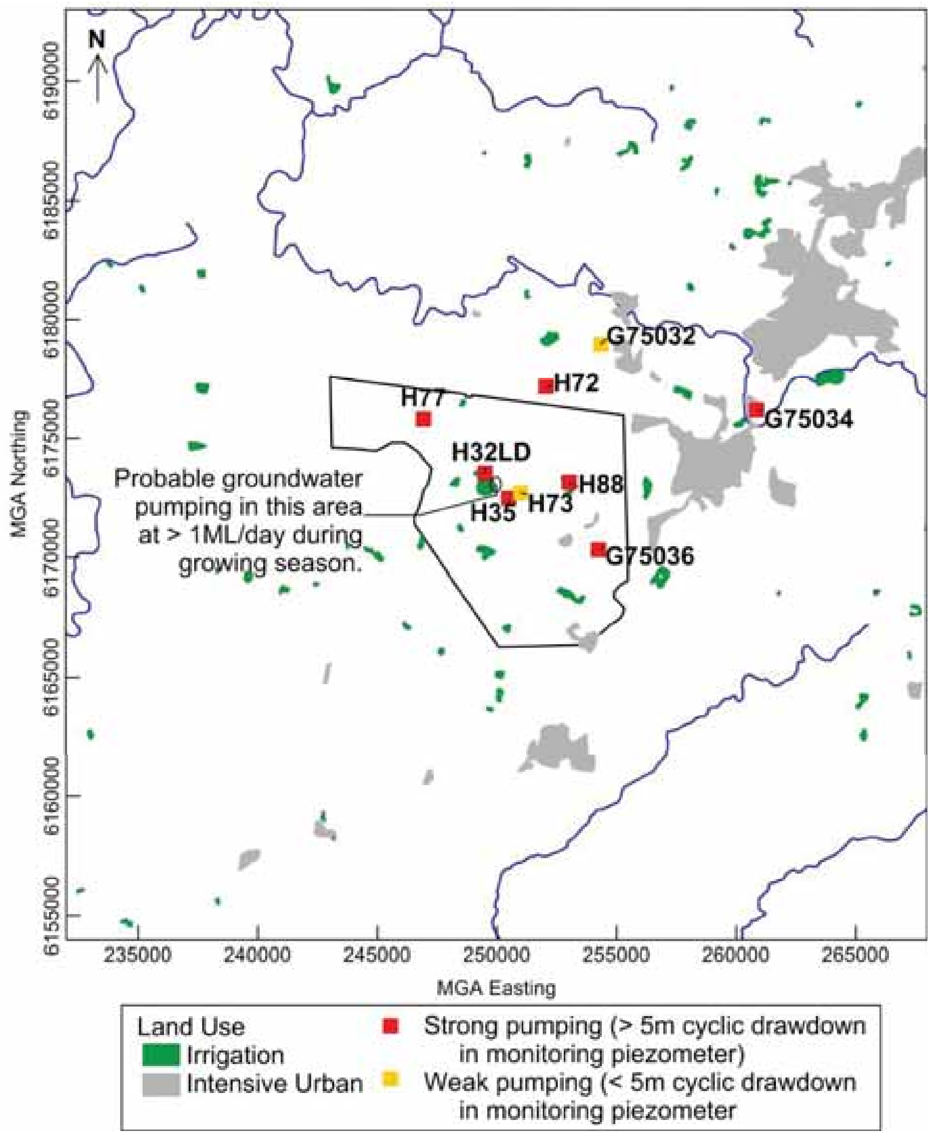


Figure 9.2. Land use and interpreted private pumping effects in monitoring hydrographs.

Drawdown seen at Hume monitoring piezometer locations H32, H35, and H73 between October 2013 and January 2014 is potentially related to pumping from the same private bore. At that location there is what appears to be an irrigated circular agricultural field of about 700 m diameter. Depending on the crop, and southern oscillation cycles, the additional water required (above rainfall) over the growing season, for this field, may be in excess of 1.0 ML/day. An approximate calculation using observed maximum drawdowns at the monitoring piezometers, an assumed transmissivity of 100 m^2/day, and a bore located on the northeast perimeter of the field, was undertaken using the Jacob equation, with results indicating a pumping rate in excess of 1.5 ML/day over the period October 2013 to January 2014.

10. Hydrogeological conceptual model

A hydrogeological conceptual model has been developed based on the data analysis conducted in the preceding sections. A large database of observations for Kh, hydraulic head, and fluxes provides a reliable platform for development of a numerical groundwater flow model for numerical simulation of the proposed Hume mining operations. In conjunction with a large number of baseflow estimates (shallow discharge of groundwater from the system), observed discharge from the Berrima mine (deep discharge of groundwater from the system) provides a vital observation dataset for large-scale reliable estimation of Kv down the media profile, an important parameter for simulation of deep discharges such as mine inflows, and vertical propagation of drawdown. Pumping tests undertaken by Hume at HU0098 and GW108194 provide useful independent estimates of large-scale Kv for sandstone, providing additional calibration targets.

10.1. Recharge

Recharge to the groundwater system occurs mainly by rainfall infiltration. Recharge may also occur from drainage channels wherever the stream stage is higher than the water table. Annual recharge to the water table is estimated to be about 2% of annual rainfall for the Hume area. Annual baseflow to drainage channels is estimated to be about 1.5% of rainfall from baseflow analysis.

10.2. Key hydraulic properties

Hydraulic conductivity and storativity decrease with depth. The K field for the Hume area has greater magnitudes than seen elsewhere in the Southern Coalfield, and is believed to result from significant tectonic disturbance and associated intrusive activity. For Kh measurements in the same depth interval, the Kh distribution is log-normal, with a standard deviation of between 0.5 and 0.8 decades around the geometric mean.

Vertical anisotropy is also believed to decrease with depth, given the greater proportion of matrix flow at depth. Kv/Kh is estimated to be around 0.01 at the depths monitored during the pumping tests.

10.3. Discharge

Groundwater discharge or consumption occurs as follows:

- Baseflow discharge to drainage channels.
- Evapotranspiration in the unsaturated zone, in zones with shallow water tables, at escarpments, and at forested areas.
- Groundwater pumping or discharge to mined voids.

Discharge to the Berrima and Loch Catherine mine voids ultimately reports to drainage channels so that this term forms part of the baseflow to drainage channels.

10.4. Approximate water balance

Table 6 lists an approximate water balance for the model area (say 800 km^2), to the nearest 5 ML/day, for average rainfall conditions. The estimate for reservoir leakage considers only the proportion that would be surface runoff into the reservoir. Baseflow to streams includes discharge from mine voids in the area.

Table 6. Approximate water balance for the model area for average rainfall conditions.

IN (ML/day)		OUT (ML/day)	
Rainfall Recharge (just over 2% of annual rainfall)	45	Baseflow to streams (about 1.5% of annual rainfall)	30
Leakage from Reservoirs and release from groundwater storage.	5	Groundwater pumping	10
		Surface water pumping	5
		Evapotranspiration	5
TOTAL	50	TOTAL	50

10.5.Ground deformation

Hume will use the PF mining method which comprises a non-caving system where ground response is similar to conventional 1st workings mining methods. These methods were extensively practised prior to the advent of mechanisation but are rarely undertaken now. The PF method is the preferred mining method for the Hume project as it significantly minimises groundwater impacts compared to full extraction mining. Deformation (dilation) from 1st workings is limited to minor movement in the roof above roadways, extending upwards a maximum of about 3 m, depending on road width, horizontal stress magnitudes, roof rock strength, and rock bolting (or other support) strategy. Dilation typically extends about 2 m into the roof for common 1st workings mine plans. Extensional strains in the overburden are significantly smaller, and extend a shorter vertical distance, than for full extraction mining. Deformation in the dilated zone comprises enlargement of defect apertures and minor cracking. The dilated zone undergoes a marked increase in K, and is usually completely drained. Above the dilated zone, negligible deformation occurs and saturation is maintained.

Anecdotal information from the Berrima mine indicates the roof was extremely competent except in areas mined towards the end of the mine life (to the north), where a significant structural zone was encountered.

For the Hume project, intervening pillars are designed to remain intact and receive the overburden weight shed from over the roadways.

The dilated zone and coal seam are surrounded by a compressional zone (the pressure arch and abutments) (Booth 1986) within which K decreases. In numerical simulation, the compressional zone is described using a drain conductance. In a 1st workings operation where the workings are a network of headings, rooms, and pillars, a multicellular hydraulic head pattern will be induced in the lower strata around the mine openings (Booth 1986). Higher in the profile, the cellularity diminishes and hydraulic head contours flatten (Booth 1986), inducing more diffuse effects in the hydraulic head field. Figure 10.1 presents a typical hydraulic head field generated around square mine openings for a 1st workings operation (after Figure 3 of Booth 1986).

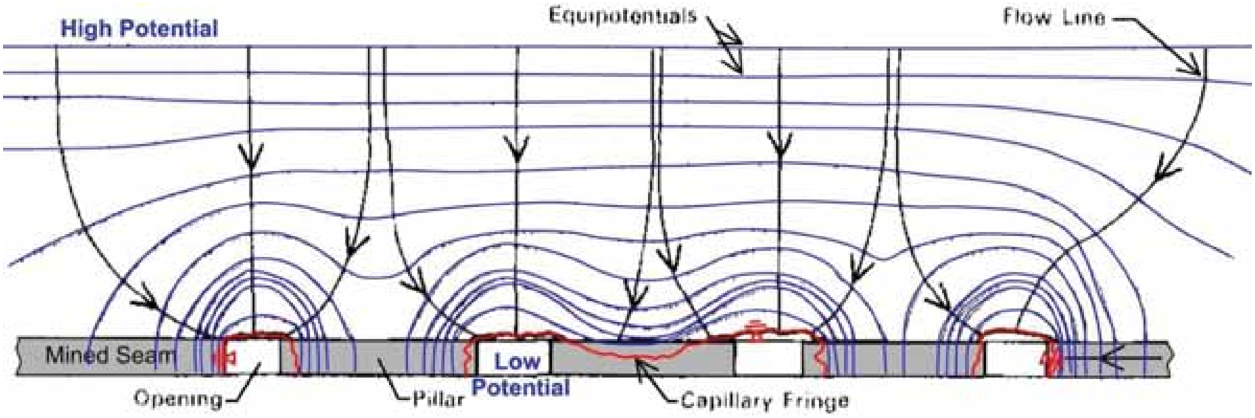


Figure 10.1. A typical hydraulic head field generated around a 1st workings network of openings (after Booth 1986).

10.5.1. Full extraction

Full extraction (longwalls or pillar removal) is not proposed at Hume, but was practiced at the Berrima mine (as pillar extraction). This method creates deformation which extends significantly higher into the overburden than for non-caving methods. Caving from full extraction results in the creation of two distinct zones above a panel (Tammetta 2013): the Collapsed Zone and the Disturbed Zone (Figure 10.2, after Tammetta 2016). The Collapsed Zone is severely disturbed and is completely drained of groundwater during caving, and is subsequently unable to maintain a positive pressure head. Groundwater flow is not laminar and Darcy's law is unlikely to be obeyed. The Disturbed Zone overlies the Collapsed Zone, and maintains positive groundwater pressure heads. Mine-induced desaturation in the Disturbed Zone occurs above the chain pillars. Results from Tammetta (2013) indicate the height of desaturation (H) for pillar extraction panels is between 50% and 60% of their longwall counterparts. This is caused by the differing patterns of caving between these types.

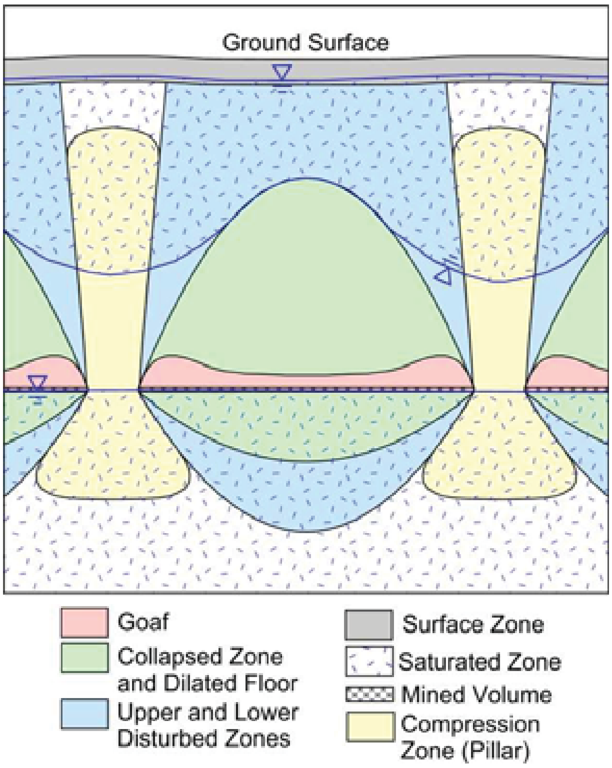


Figure 10.2. Adopted conceptual model for desaturation above full extraction workings (after Tammetta 2016). The subsurface is shown as a cross-section normal to the panel long dimension.

In the study area, the Berrima mine practiced full extraction (pillar extraction). H for mined pillar extraction panels is calculated using the equation in Tammetta (2013) for longwall panels, with pillar extraction H taken as 60% of longwall H for the same panel geometry.

10.6.Conceptual model

The elements of the conceptual model discussed above are presented pictorially in Figure 10.3, based on the hydraulic head cross section of Figure 6.1. It shows a schematic representation of the hydraulic head field that will be created by the PF mining method of the Hume Mine.

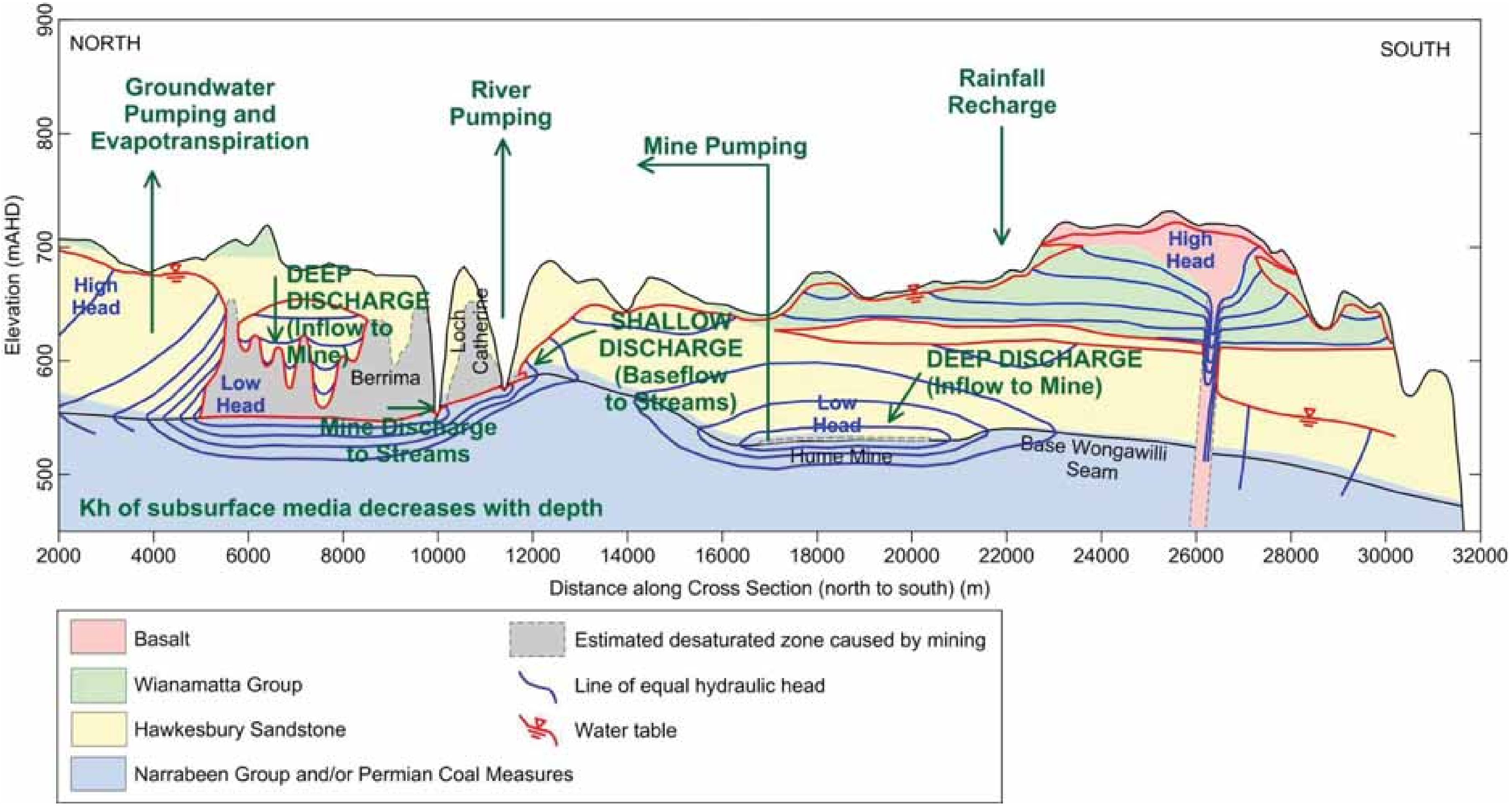


Figure 10.3. Hydrogeological conceptual model.

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Important information about your **Coffey** Report

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man. For example, water levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project.

Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

Your report will only give preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.

Interpretation by other design professionals

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other project design professionals who are affected by the report. Have Coffey explain the report implications to design professionals affected by them and then review plans and specifications produced to see how they incorporate the report findings.

Important information about your **Coffey** Report

Data should not be separated from the report*

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way. Logs, figures, drawings, etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These logs etc. should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment. Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

Rely on Coffey for additional assistance

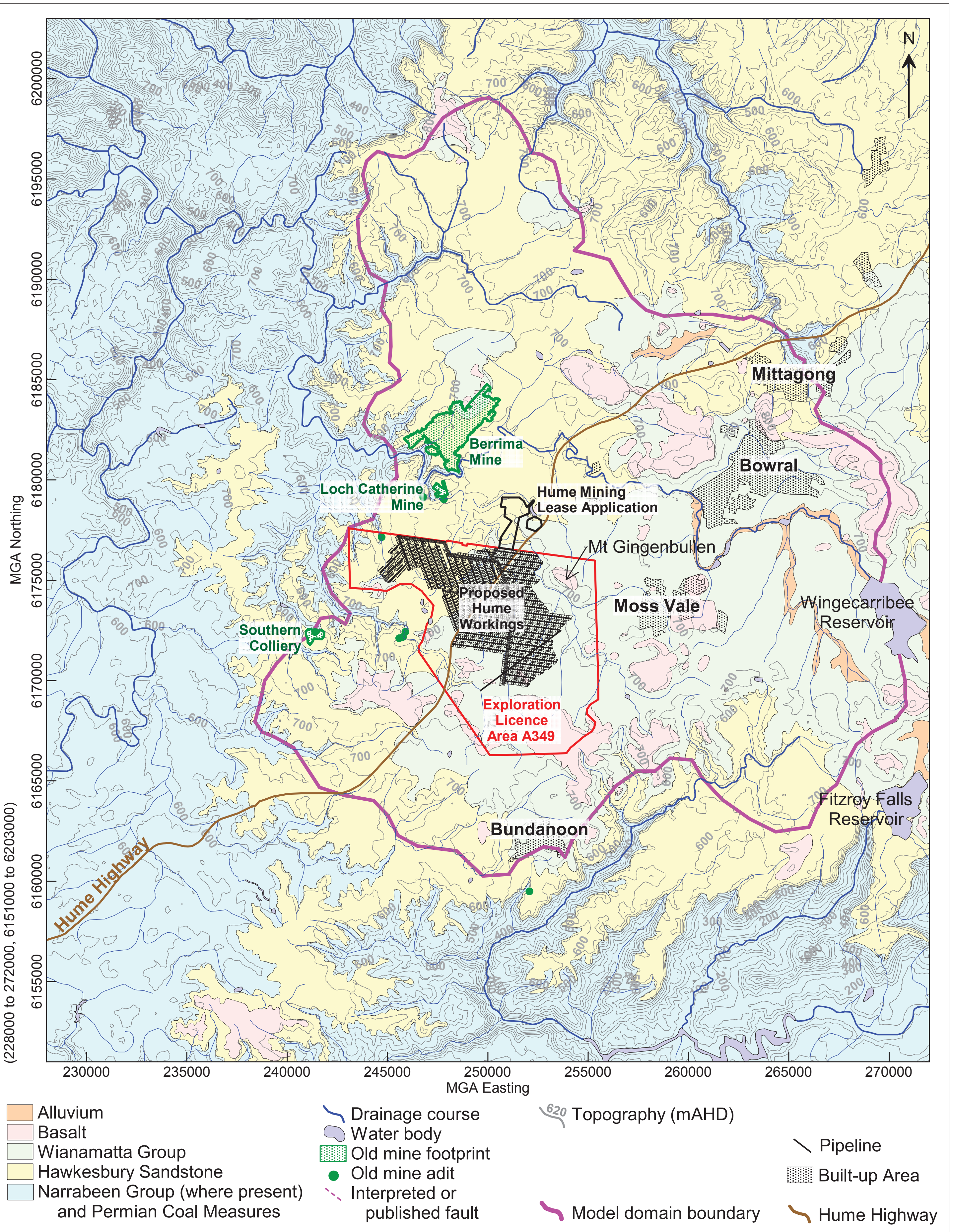
Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As the project progresses through design towards construction, speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

Responsibility

Reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than the design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

* For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical information in Construction Contracts" published by the Institution of Engineers Australia, National headquarters, Canberra, 1987.

Drawings



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approved	RJB	project:	Hume Coal Project Groundwater Assessment
date	30 Jun 2016	title:	**Regional Locality Plan**
scale	1:250,000	project no:	GEOTLCOV25281AB
original size	A4	figure no:	**Drawing 1**

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Appendix A - Baseflow Analysis

1. Baseflow Analysis

The aim of baseflow separation for a streamflow record is to distinguish the following two streamflow components (Eckhardt 2012):

- Baseflow (groundwater discharging into the stream).
- Quick flow (surface runoff and interflow).

The term “runoff” refers to quick flow, or the higher frequency component of the two components extracted from a streamflow series.

Two commonly used methods for baseflow separation are filtering and local minimum searches. For the Hume Coal project the local minimum search is adopted. Both methods are discussed below.

1.1. Filtering method

Eckhardt (2012) provides a useful summary of filtering techniques for baseflow separation. The following text is a summary from that paper.

In the past, many baseflow separation methods have been proposed, amongst them the two parameter recursive digital filter of Eckhardt (2005), which has since been applied in numerous studies, sometimes under the name of “Eckhardt filter”. The equation for the Eckhardt Filter defines a low-pass filter, and represents a whole class of filter algorithms which are based on the widely accepted linear storage model (Eckhardt 2005).

Examples are the algorithms of Chapman and Maxwell (1996) and Boughton (1993). The filter of Chapman and Maxwell (1996) is derived from the Eckhardt Filter by fixing one of the filtering parameters (BFImax) to 0.5 (where BFImax is the maximum value of the baseflow index [the long-term ratio of baseflow to total streamflow] that can be modelled by the algorithm). These methods use only a time-series of streamflow as the observational input.

Filter algorithms which rely more on physics have been presented by Furey and Gupta (2001) and Huyck et al. (2005). In the algorithm of Furey and Gupta (2001), time series of streamflow and precipitation are required, and the following four parameters have to be specified:

- d (the time delay between precipitation and groundwater recharge).
- c1 (the ratio of overland flow to precipitation).
- c3 (the ratio of groundwater recharge to precipitation).
- a (the recession constant).

In the algorithm of Huyck et al. (2005) bk is a function of bk−1, bk−d , bk−d−1, yk−d , and yk−d−1. Twelve parameters have to be specified: d, c1, c3, and nine other parameters describing hydraulic characteristics and the shape of the hydrostratigraphic unit. Required are not only time series of streamflow and precipitation, but also a digital elevation model and information on the drainable porosity of the soil.

Filtering methods are prone to the error where calculated baseflow can be greater than streamflow. This is because a single recession constant is (usually) used, which may perform poorly when confronted with several accumulated recession pulses. When trimming is employed (ensuring baseflow is never larger than total flow), they are useful for analysis of the annual variation in baseflow, when magnitudes are constrained by results from the local minimum method.

1.2. Local minimum method

In the local minimum method, baseflow is estimated by analysing the minima in streamflow time series when partitioned into N-day periods. Unlike filtering methods, the local minimum method cannot calculate baseflows that are greater than streamflow, and makes no assumptions about recession character. Based on experience, and the preferred use of the method by overseas agencies, this method is considered superior to filtering for extraction of baseflow magnitudes. This method was therefore adopted for the current work.

For the Hume Coal Project, the local minimum method is implemented using the program BFI and the procedure of Wahl and Wahl (1995). The BFI program (Wahl and Wahl 1995) is based on a set of procedures developed by the Institute of Hydrology (1980a, b) in which the streamflow record is partitioned into intervals of length N-days.

In the standard method (the one used in the current work), the minimum streamflow during each N-day interval is then identified and compared to adjacent minimums to determine turning points. If 90% of a given minimum (the turning point test factor, f) is less than both adjacent minimums, then that minimum is a turning point. The baseflow hydrograph is completed by connecting the turning points. The current version allows the user to vary the values of N and f to permit tuning the algorithm for different catchments or to match other baseflow separation methods (Wahl and Wahl 1995). In the USGS Toolbox implementation (Barlow et al 2015) (the one used in the current work), turning points are identified continuously throughout the entire period of record, which avoids the creation of artificial turning points at the end of each year. This modification also changes how the daily values are partitioned after a year is completed in which the number of days in the year is not an even multiple of N.

In the modified approach, parameter f is replaced by a daily recession index K′, and the turning-point test considers the exact number of days between turning-point candidates. Results obtained using the modified approach will usually be very similar to those obtained by the standard approach if $K' = f^{1/N}$.

For each year of data, the flow record is analysed for varying values of N. The output is then visually examined on a graph to find the inflection point in the baseflow response. Figure 1 shows the interpretation graph for Gauge 212272 (Wingecarribee River at Berrima). Excluding dam release years, the inflection point is taken as 6 days. 1995 is a conspicuous dam release year. The apparent baseflow versus N function for these years has a more significant convex-up form, at large N.

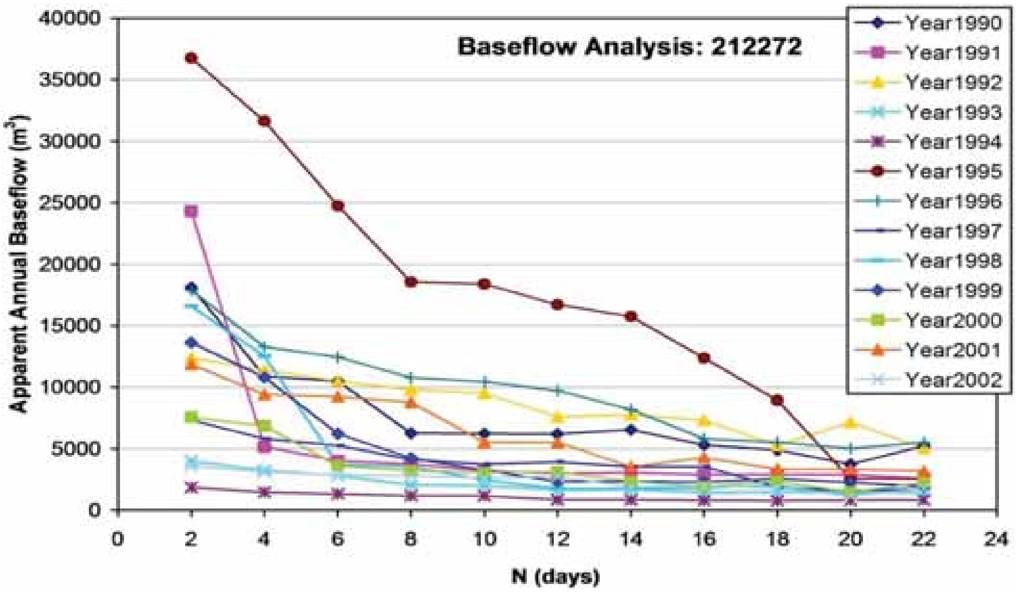


Figure 1. Baseflow analysis for gauge 212272.

The Nepean and Wingecarribee Rivers are regulated. Figure 2 shows the effect of controlled release from Wingecarribee Reservoir on the three Wingecarribee River Gauges (years with conspicuous dam releases are circled). Controlled dam releases do not affect the overall water balance of a drainage channel on a regional basis, except to afford increased consumption by evaporation from the increased surface area of a dam (which would otherwise not exist). However, over small periods and in proximity to such a dam (and depending on the release discharge versus time function), controlled releases can cause a component of surface runoff to masquerade as baseflow. The dam storage acts as a weak to moderate low-pass filter on the response of the drainage channel. However, this effect is attenuated with increasing distance downstream from the dam. Because of the complicating factors associated with dam releases, years with dam releases are removed from the analysis.

The baseflow analysis also incorporates removal of river flow through licensed river extraction, using the catchment for gauge 212238 as a guide, in conjunction with licensing information for the Hume area. The northern part of the 212238 catchment is similar to the central parts of the Wingecarribee River catchment, where Wianamatta Group soils are exploited for horticultural use (with a similar concentration of such enterprises). The analysis also accounts for evaporation from major dams (Wingecarribee Reservoir for gauges 212009, 212031, and 212272), and changes in dam storage.

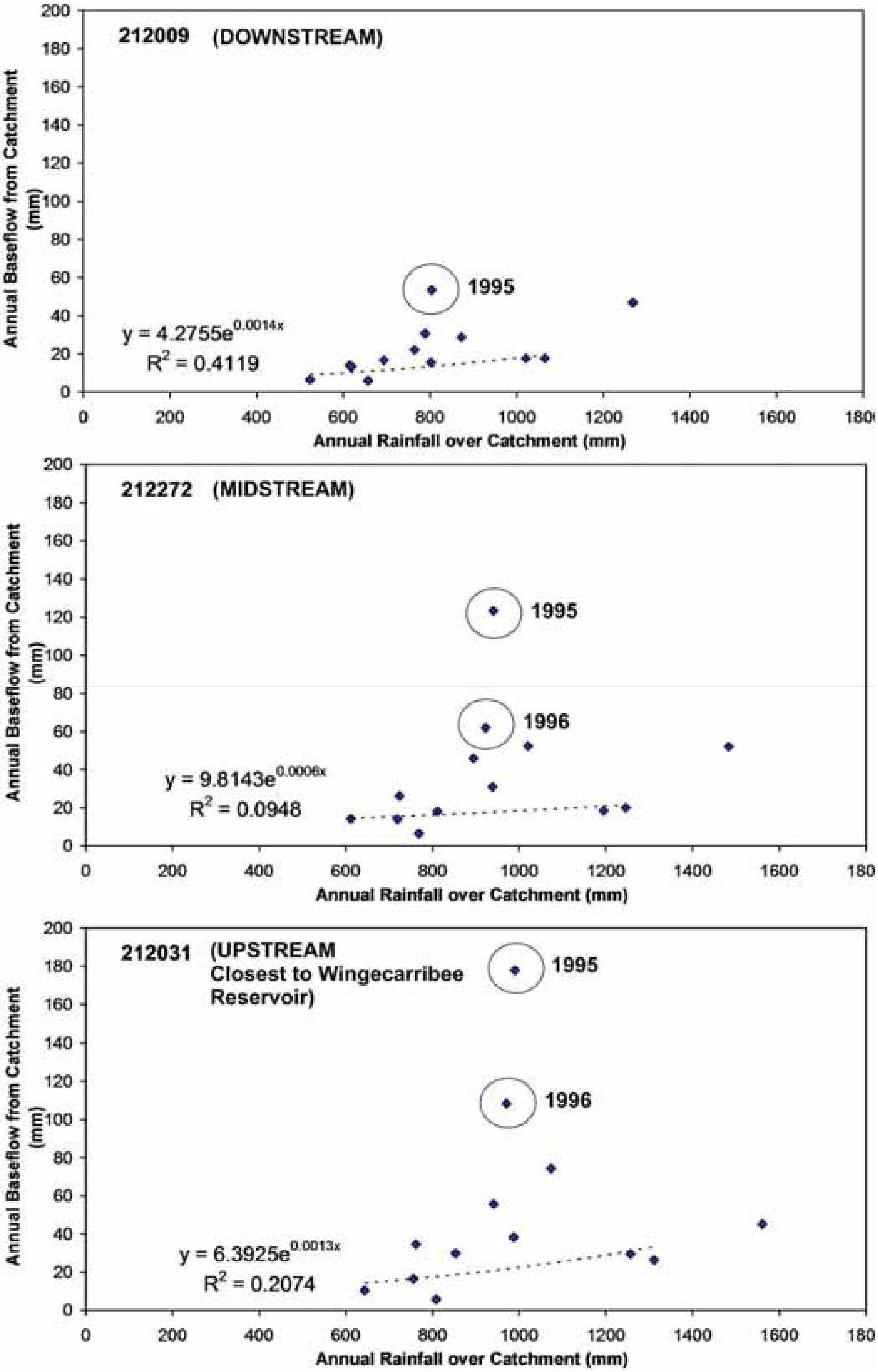
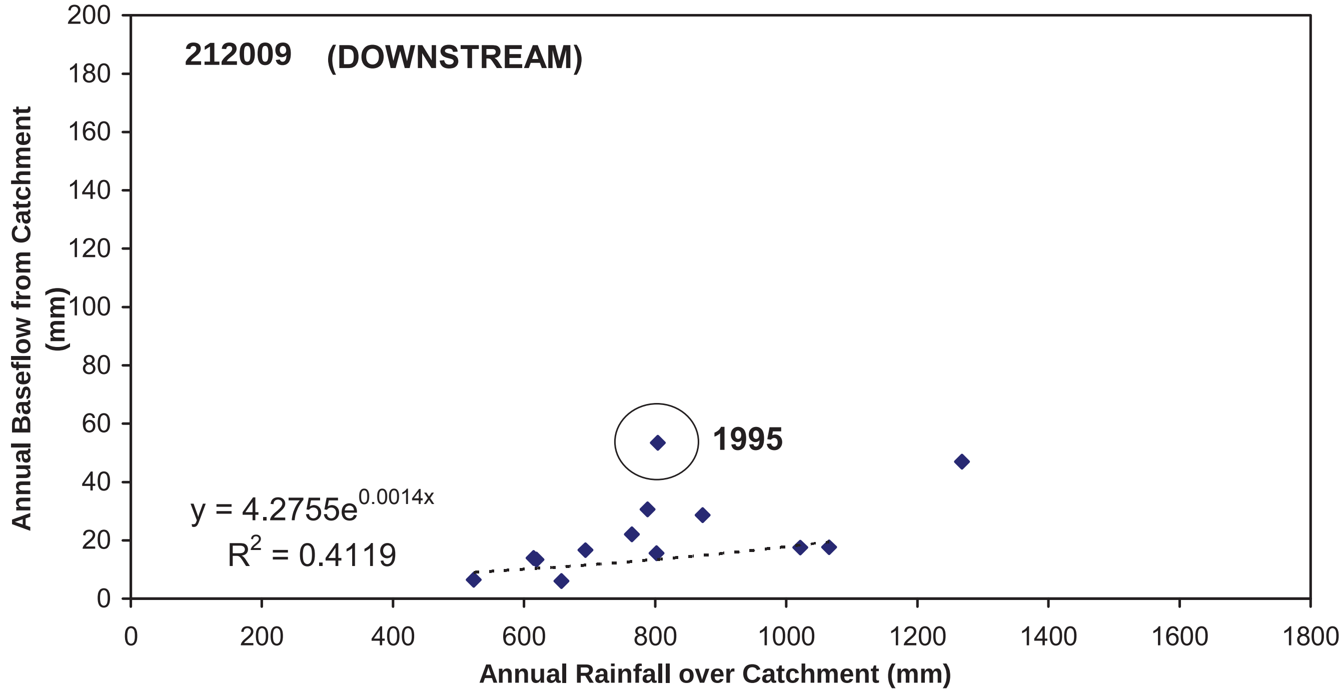
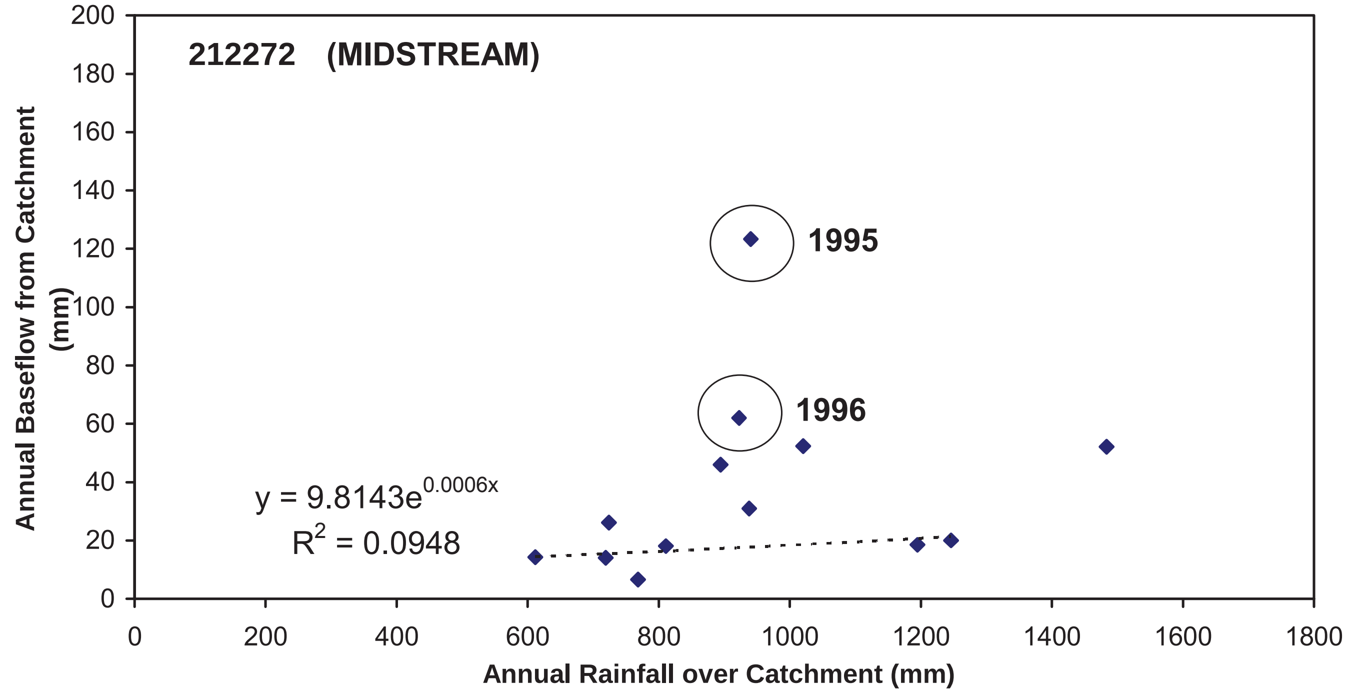


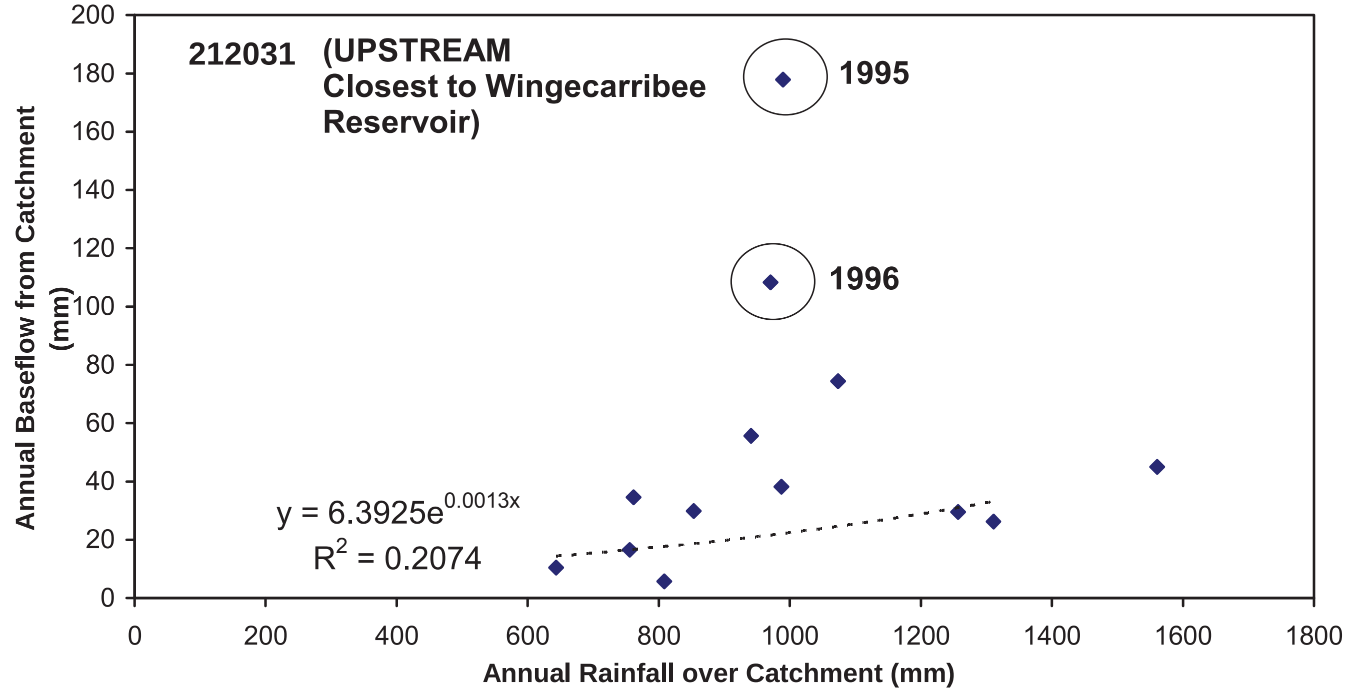
Figure 2. Estimated annual baseflow for the three Wingecarribee River gauges.

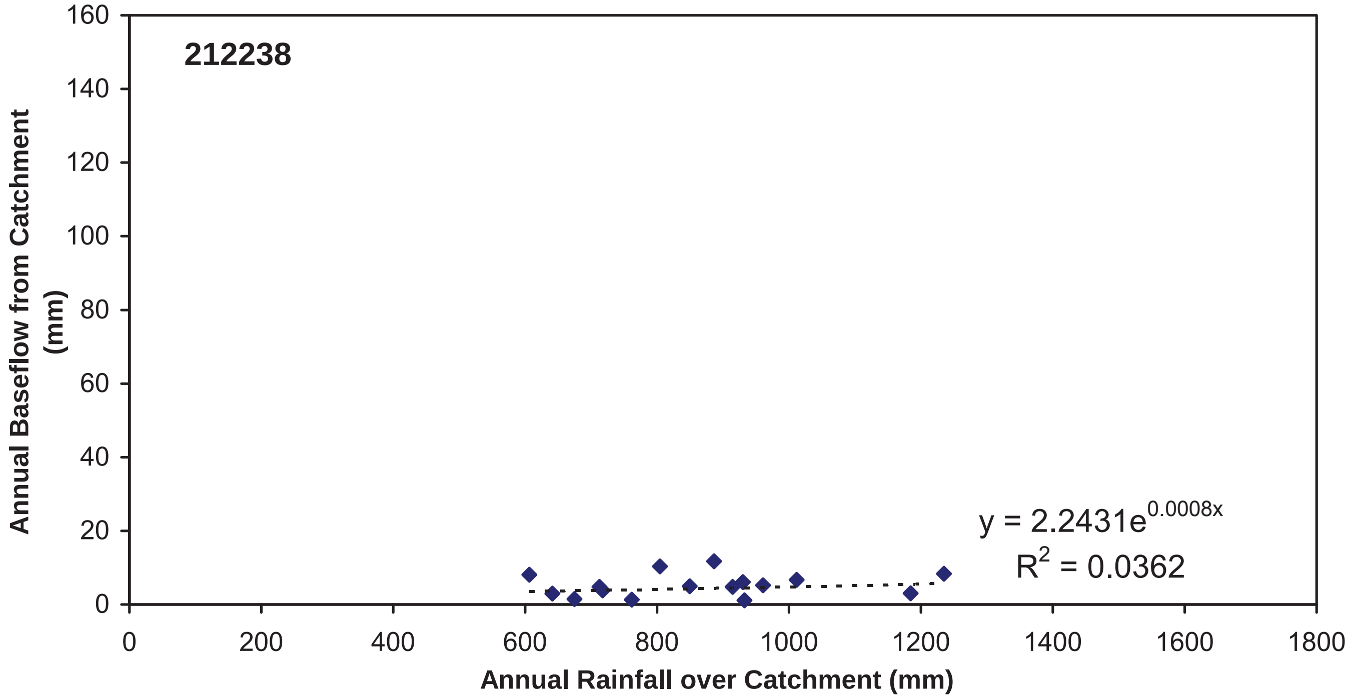
1.3. Results

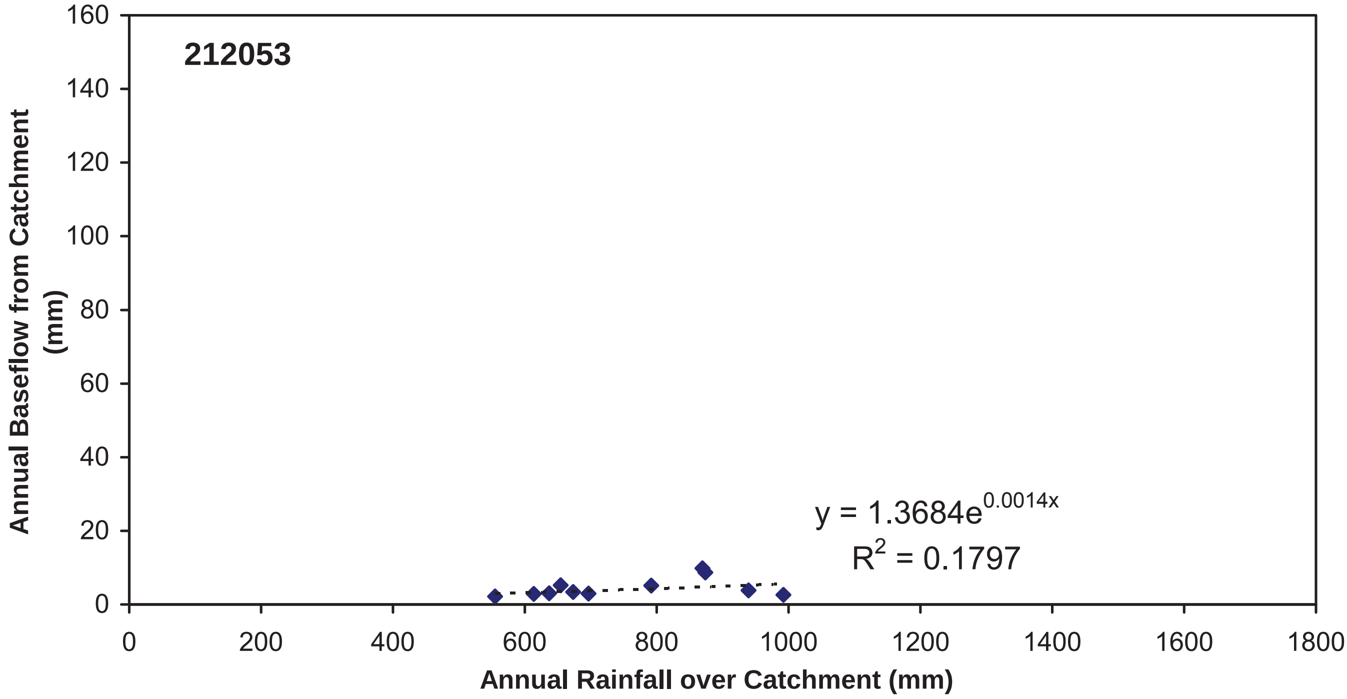
The following pages present additional results of the baseflow analysis undertaken for the Hume project, as charts of baseflow and surface runoff depths over the catchments. See the main report for a summary of the results.

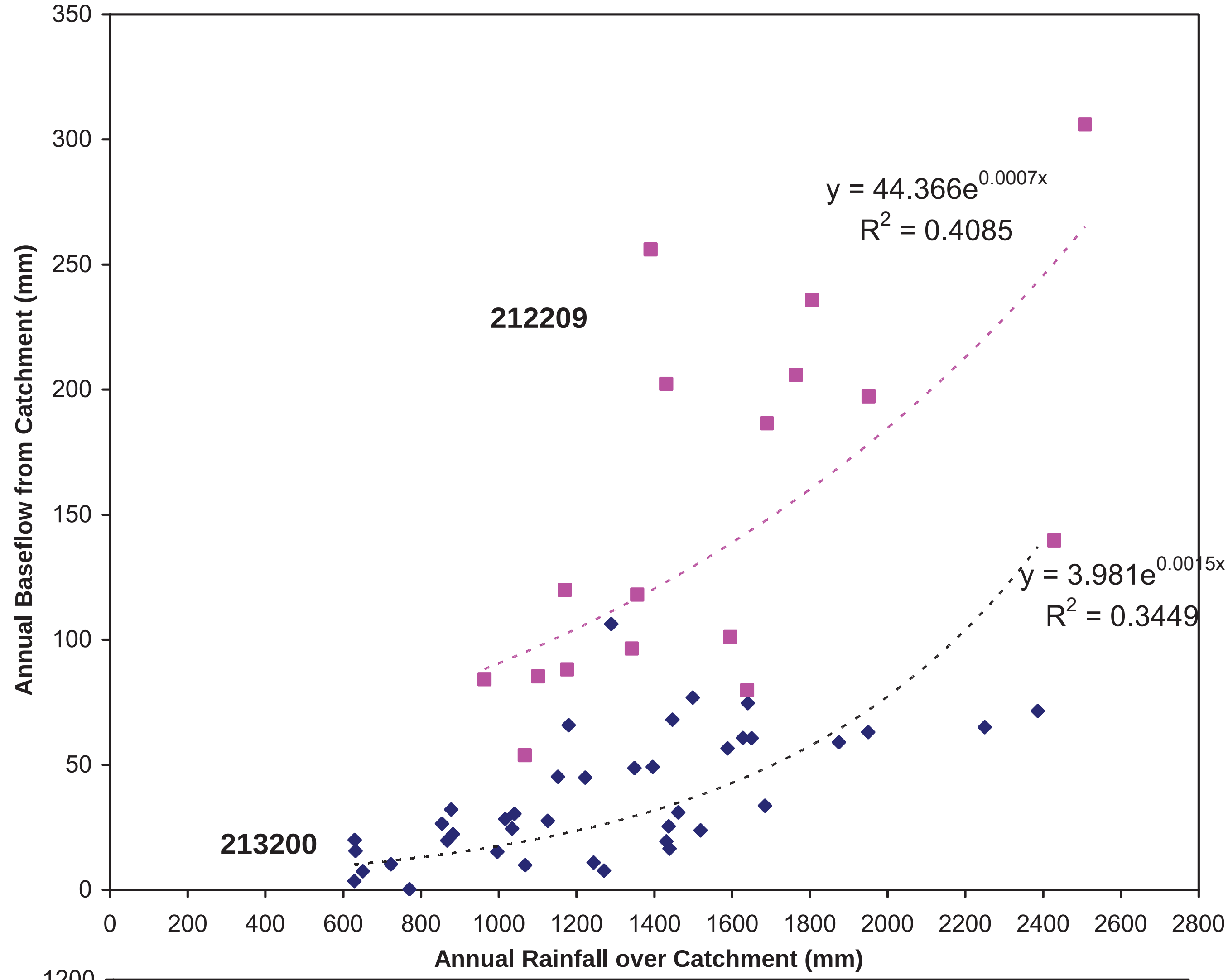

212009 (DOWNSTREAM)
1995
y = 4.2755e^0.0014x
R^2 = 0.4119
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)


212272 (MIDSTREAM)
1995
1996
y = 9.8143e^0.0006x
R^2 = 0.0948
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)

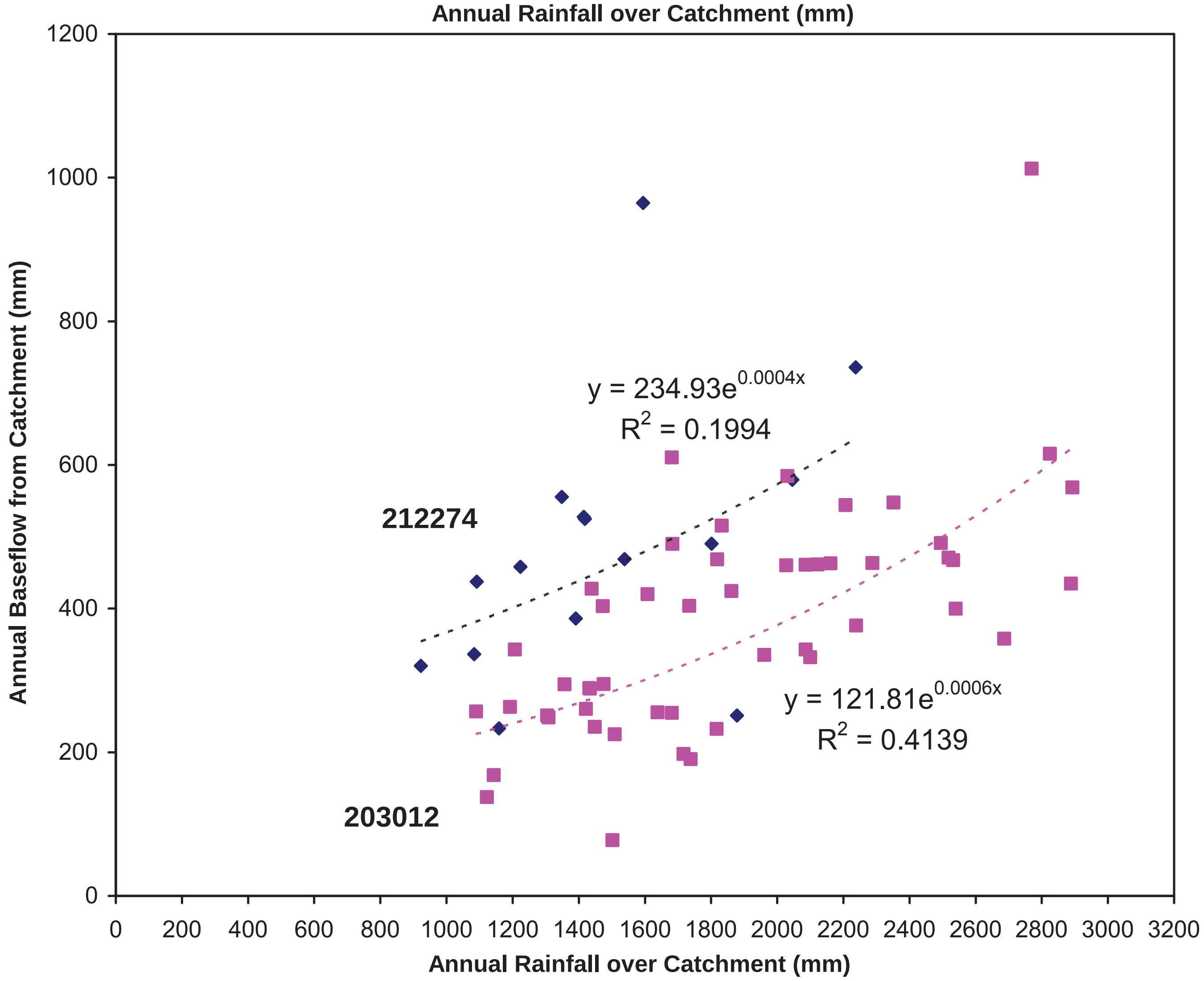

212031 (UPSTREAM
Closest to Wingecarribee
Reservoir)
1995
1996
y = 6.3925e^0.0013x
R^2 = 0.2074
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)


212238
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
y = 2.2431e^0.0008x
R^2 = 0.0362
0
20
40
60
80
100
120
140
160
200
400
600
800
1000
1200
1400
1600
1800

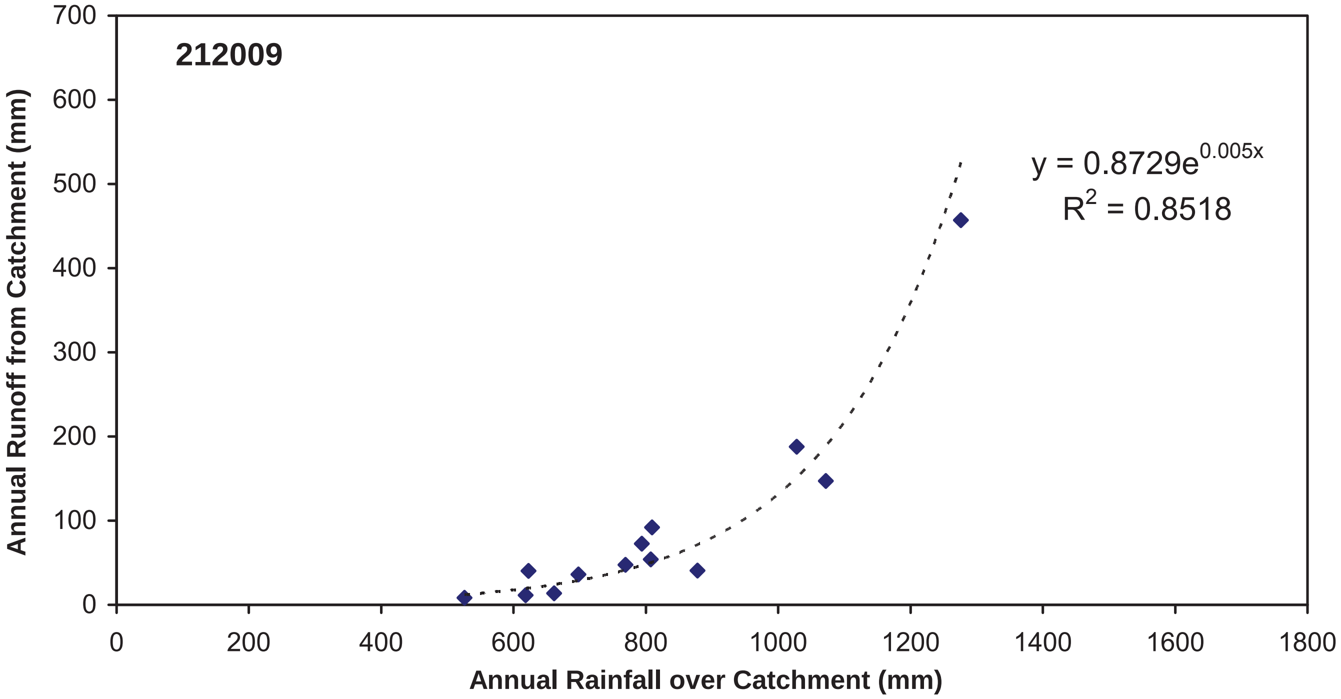

212053
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
y = 1.3684e^0.0014x
R^2 = 0.1797
0
20
40
60
80
100
120
140
160
200
400
600
800
1000
1200
1400
1600
1800



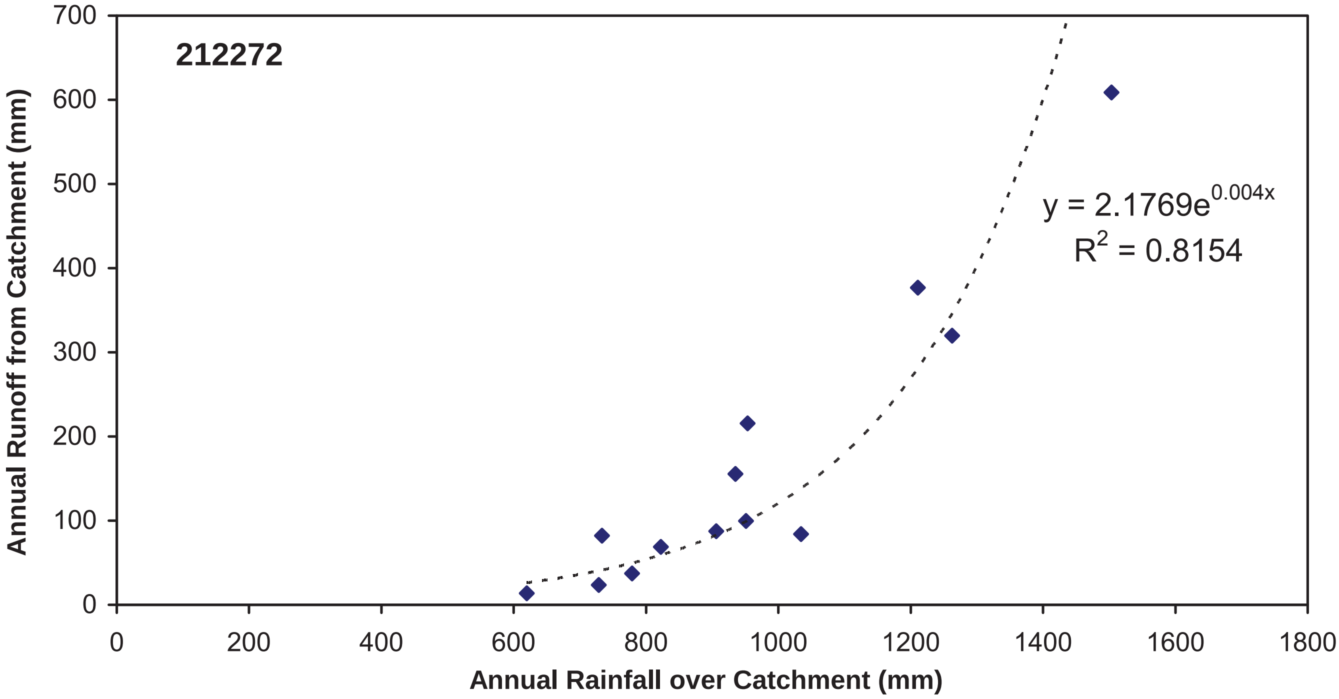
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
212209
213200
y = 44.366e^0.0007x
R^2 = 0.4085
y = 3.981e^0.0015x
R^2 = 0.3449
0
50
100
150
200
250
300
350
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800



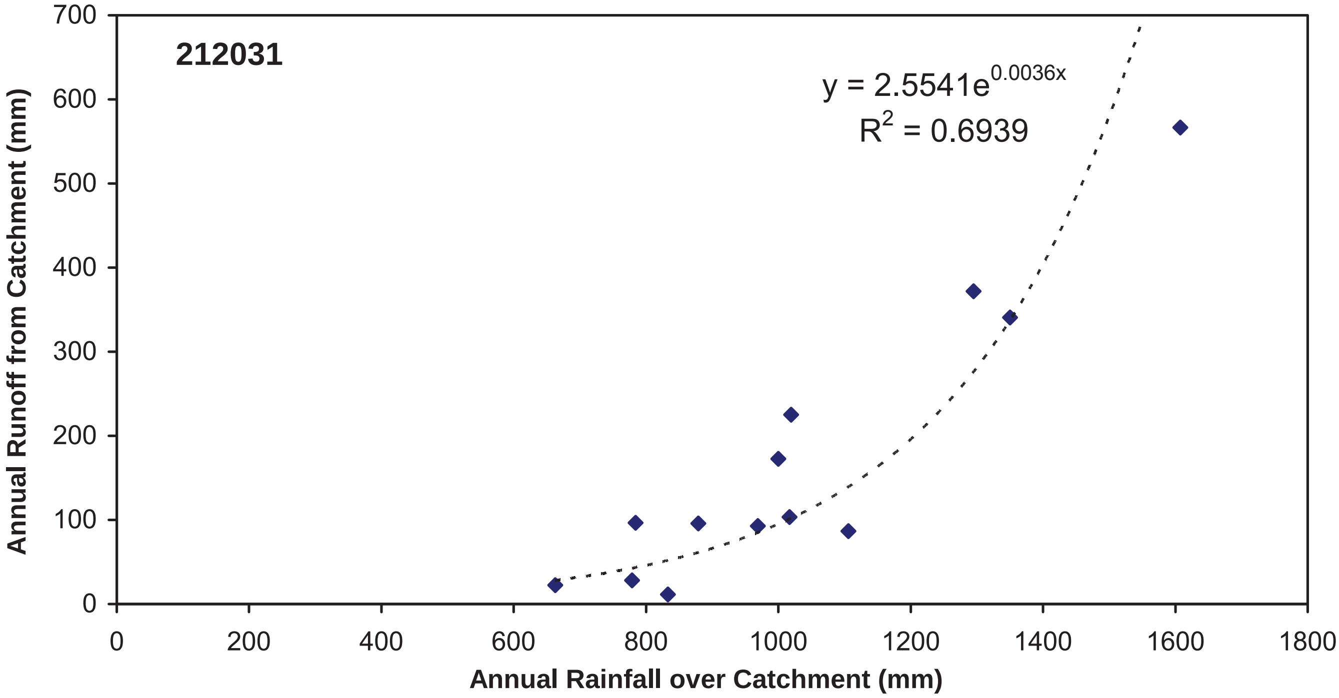
Annual Baseflow from Catchment (mm)
Annual Rainfall over Catchment (mm)
212274
203012
y = 234.93e^0.0004x
R^2 = 0.1994
y = 121.81e^0.0006x
R^2 = 0.4139
0
200
400
600
800
1000
1200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200



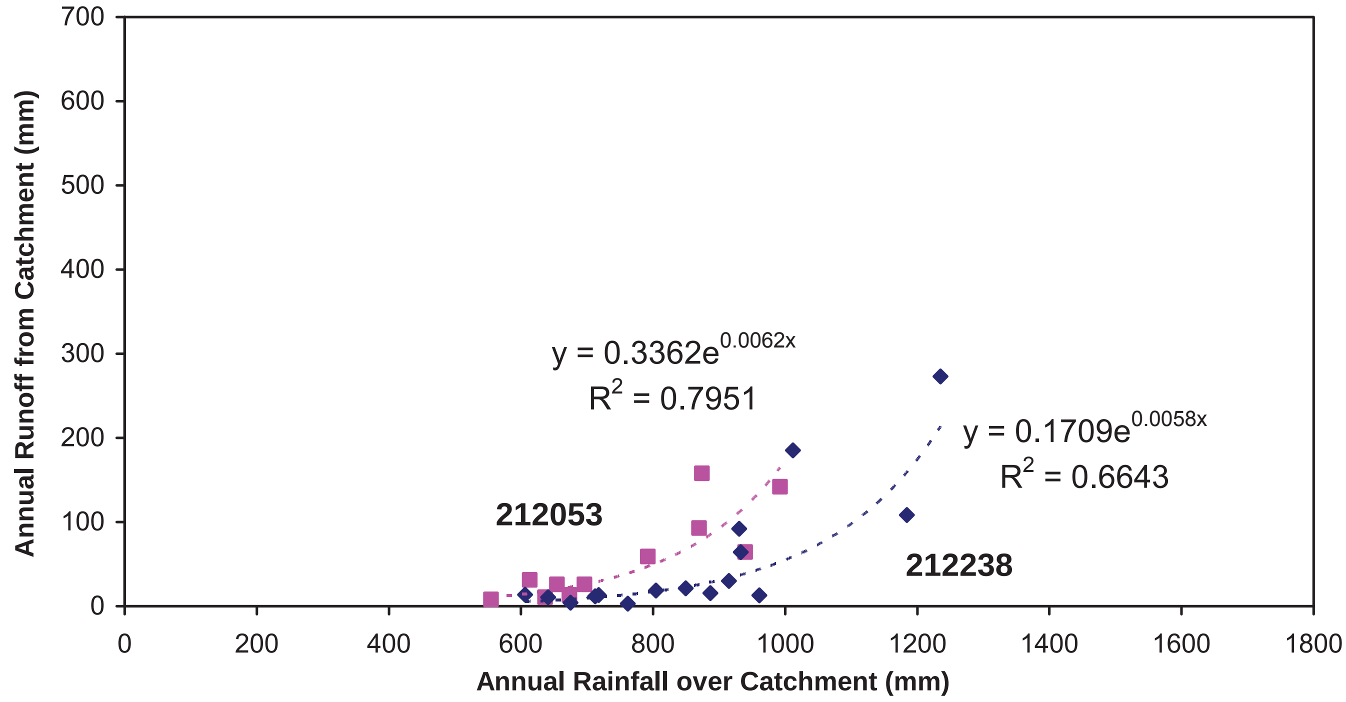
212009
y = 0.8729e^0.005x
R^2 = 0.8518
Annual Runoff from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
100
200
300
400
500
600
700
0
200
400
600
800
1000
1200
1400
1600
1800



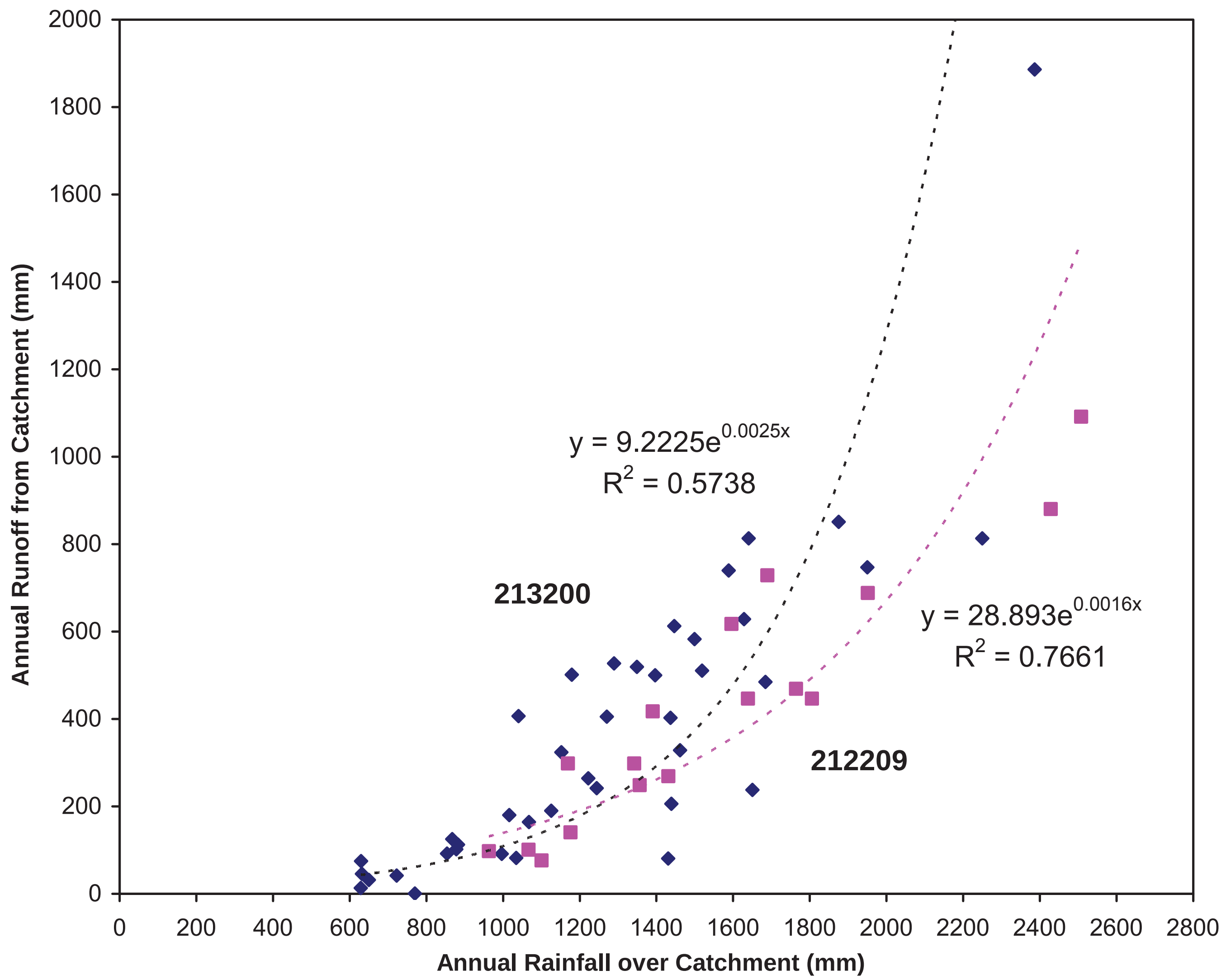
212272
y = 2.1769e^0.004x
R^2 = 0.8154
Annual Runoff from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
100
200
300
400
500
600
700
0
200
400
600
800
1000
1200
1400
1600
1800



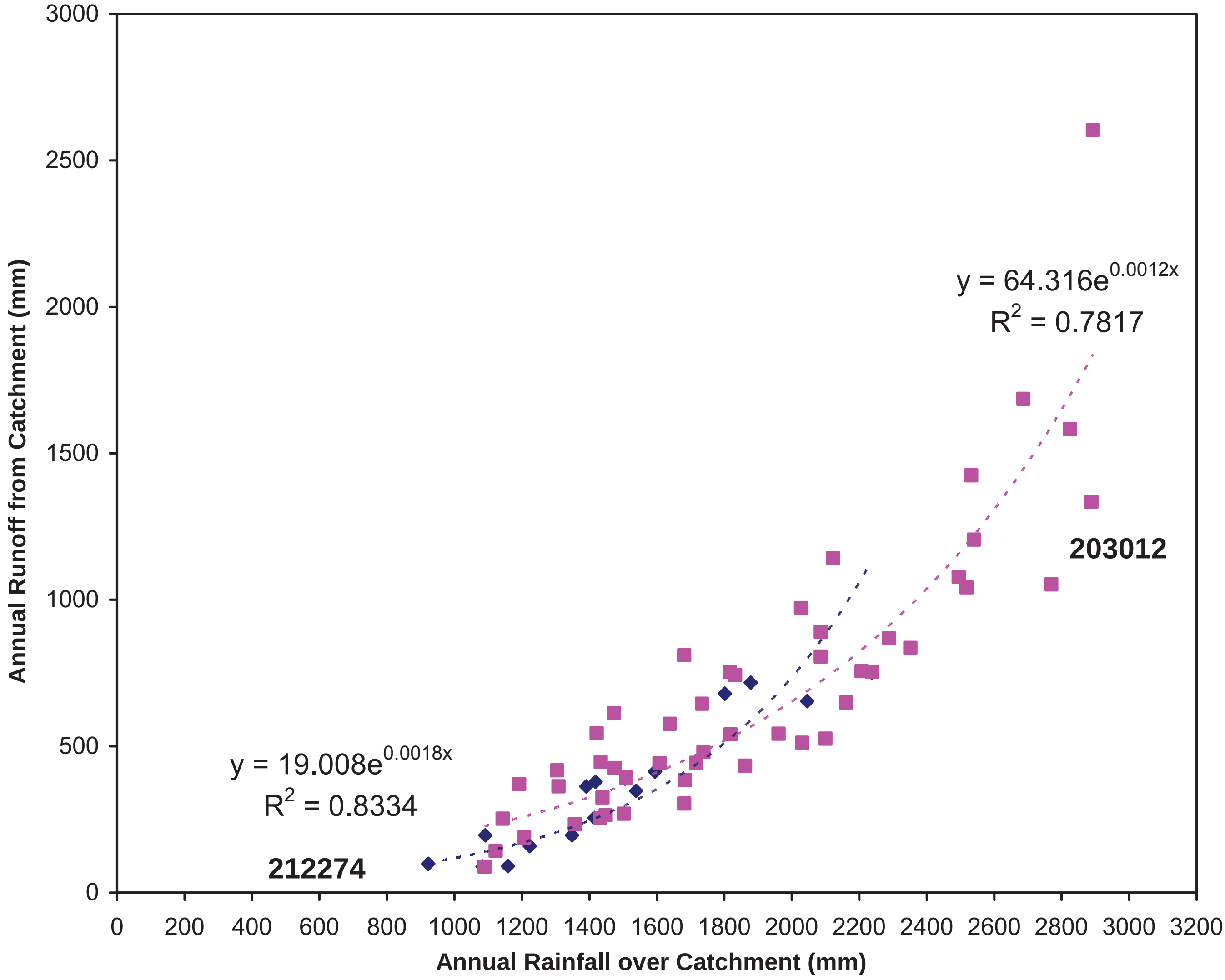
212031
y = 2.5541e^0.0036x
R^2 = 0.6939
Annual Runoff from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
100
200
300
400
500
600
700
0
200
400
600
800
1000
1200
1400
1600
1800



Annual Runoff from Catchment (mm)
0
100
200
300
400
500
600
700
0
200
400
600
800
1000
1200
1400
1600
1800
Annual Rainfall over Catchment (mm)
y = 0.3362e^0.0062x
R^2 = 0.7951
y = 0.1709e^0.0058x
R^2 = 0.6643
212053
212238



Annual Runoff from Catchment (mm)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Annual Rainfall over Catchment (mm)
y = 9.2225e^0.0025x
R^2 = 0.5738
y = 28.893e^0.0016x
R^2 = 0.7661
213200
212209



Annual Runoff from Catchment (mm)
Annual Rainfall over Catchment (mm)
0
500
1000
1500
2000
2500
3000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
y = 64.316e^0.0012x
R^2 = 0.7817
y = 19.008e^0.0018x
R^2 = 0.8334
203012
212274

Appendix B - Specific Capacity Analysis

Specific capacity (Sc) is the pumping rate divided by the drawdown in the pumped bore at a specified time. Most tests in the database were of 1 day duration, so the drawdown at 1 day is selected or estimated.

An analysis is undertaken using tests where temporal drawdown data are available. For each test, Sc is calculated at 1 day. Transmissivity is interpreted from temporal drawdown at the pumped bore using the Jacob method for confined conditions (Tj). The quantity (Tj – Sc)/Tj is then plotted against pumping rate and the relationship approximated with a trendline. This relationship is then used to convert Sc for tests where temporal drawdown is unavailable (the majority of government records).

The method assumes the bores in the database are approximately similar in hydraulic behaviour (well loss component), reasonable for the current database. It also assumes that dissimilarities in screened lithology are minor.

Table B1 lists the eight bores used to find a relationship, and Figure B1 shows the resulting relationship.

Table B1. Bore tests used for specific capacity analysis.

Bore	Registration Number	Hole diameter (mm)	Casing diamete (mm)	Pumping Rate (L/s)	Test Duratio (days)	Tj* (m2/day)	Interpretation	Specific Capacity for Pumping Time = 1 da			
								Pumping Rate (m3	Drawdow (m)	Sc (m2/day)	(Tj - Sc)/Tj
Belbin	GW106150	165	160	0.8	1	14	AGE 2010	69	7.4	9	0.33
Culpepper M	GW066593			0.3	0.07	56	AGE 2010	26	0.58^	45	0.20
H98		165	160	5.2	1	103	This study	449	8.0	56	0.45
Wongonbra	GW108194	200	N/A	20	7	243	This study	1728	34.8	50	0.80
Summer Dell	GW105950	200	N/A	11.4	2	180	This study (dat	985	16.0	62	0.66
Ravenswood	GW110236	200	N/A	9.2	1	56	This study (dat	795	20.5	39	0.31
Wongonbra	GW108194	200	N/A	17.8	2	176	This study (dat	1538	14.6	105	0.40
Wongonbra 2	GW108195	200	N/A	8.3	1.2	20	This study (dat	717	47.0	15	0.24

* Tj = Jacob T
^ Estimated for pumping time of 1 day

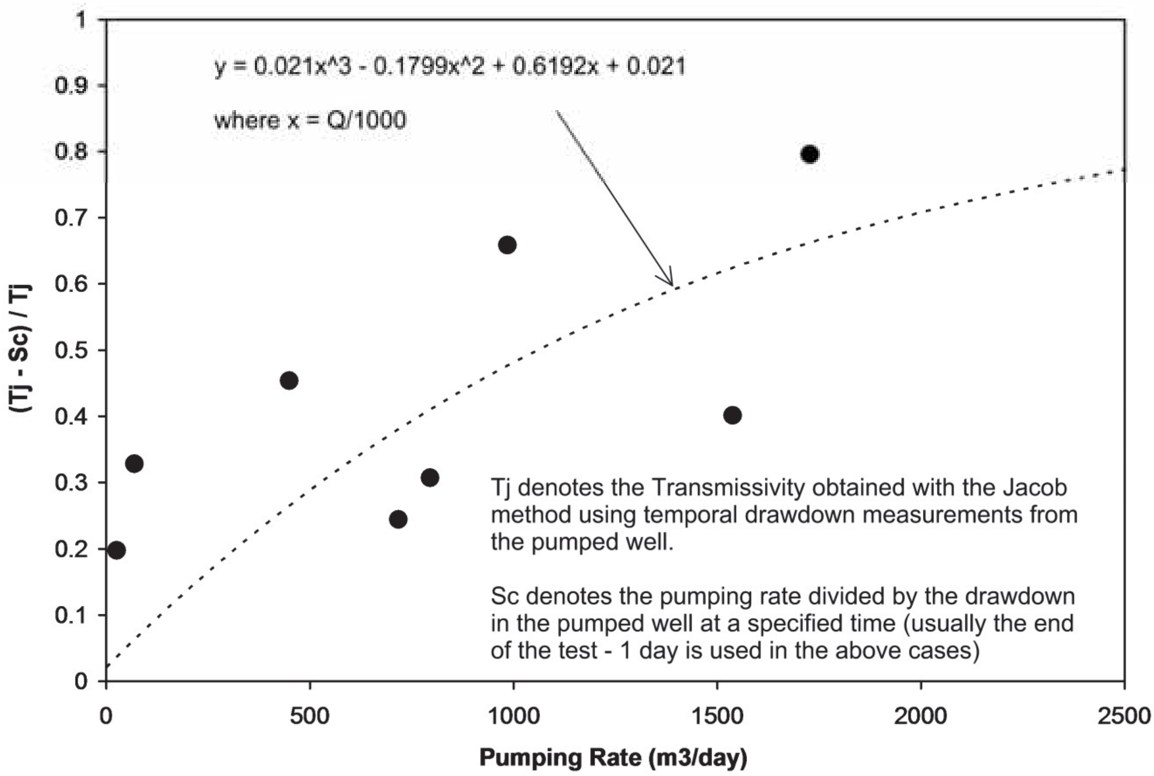


Figure B1. Results of specific capacity analysis for tests in Table B1.

Appendix C - Additional Hydraulic Conductivity Analysis

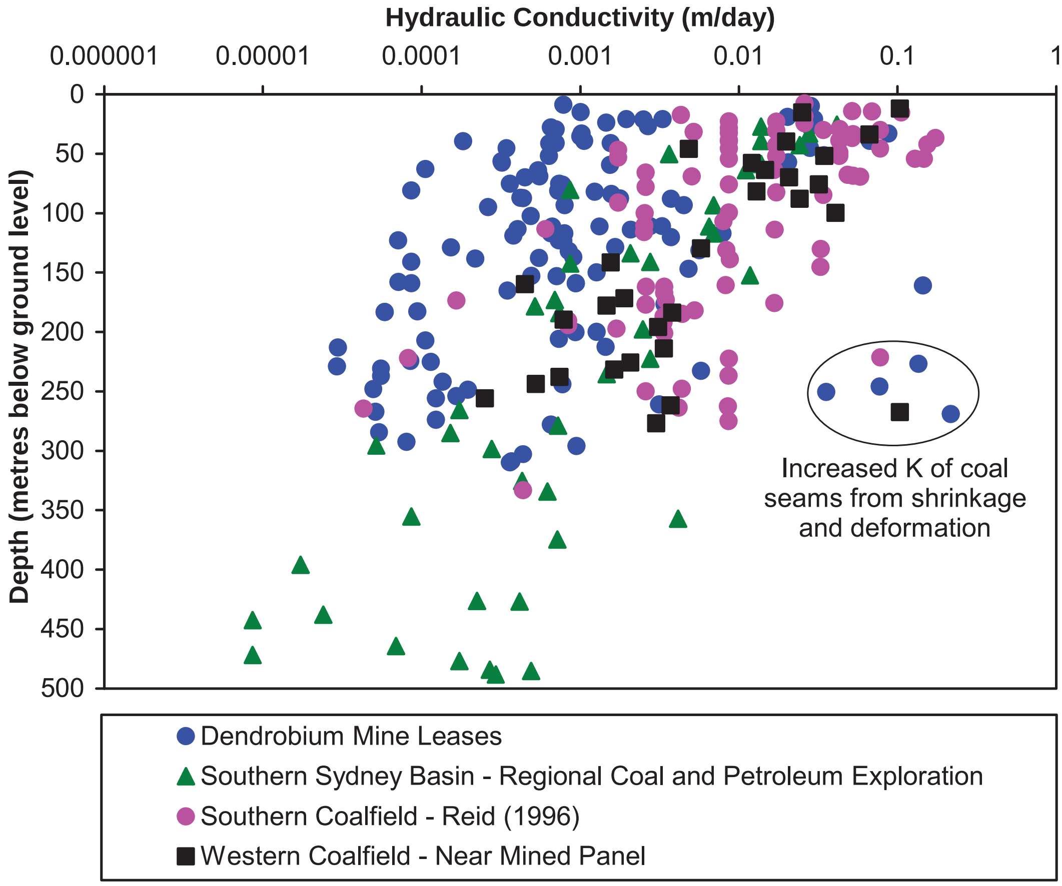
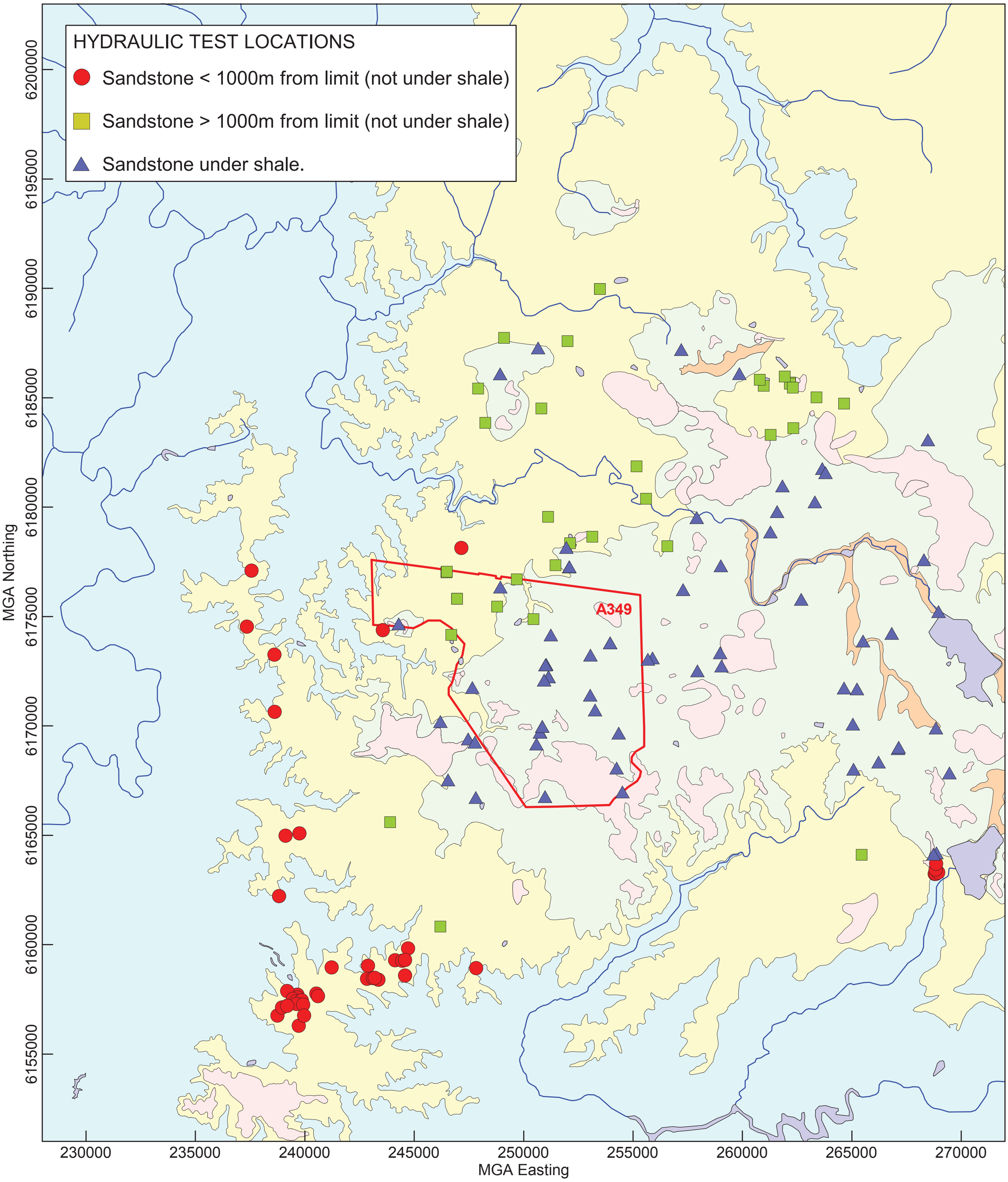
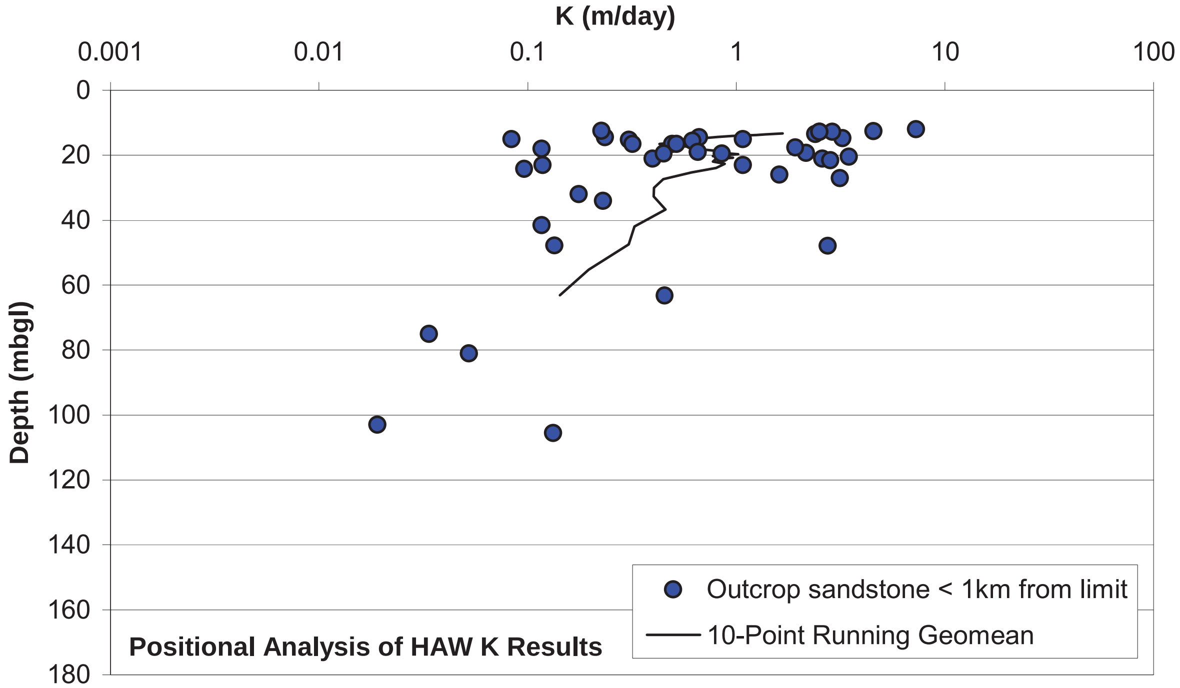
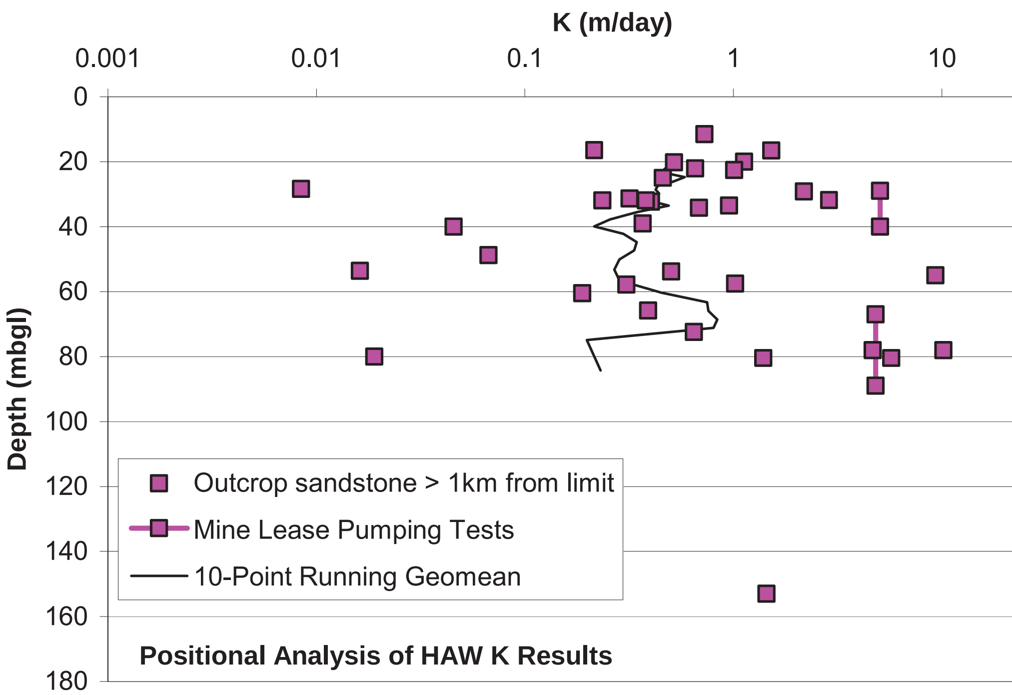


Figure C1. Packer test K distributions for the regional Southern Coalfield and the Dendrobium mine leases, showing measurements obtained in coal seams proximal to full extraction workings, which have been deformed by shrinkage (from degassification) and stress reduction.

Figure C2. Positional analysis of Hawkesbury Sandstone K using specific capacities and pumping test results. The map shows the segregation of data into the following locations:
*** Less than 1km from the lateral sandstone limit.**
*** Greater than 1km from the lateral sandstone limit, but not overlain by the Wianamatta Group.**
*** Wherever overlain by the Wianamatta Group.**
Trends for Sandstone K versus depth for each grouping are shown overleaf.







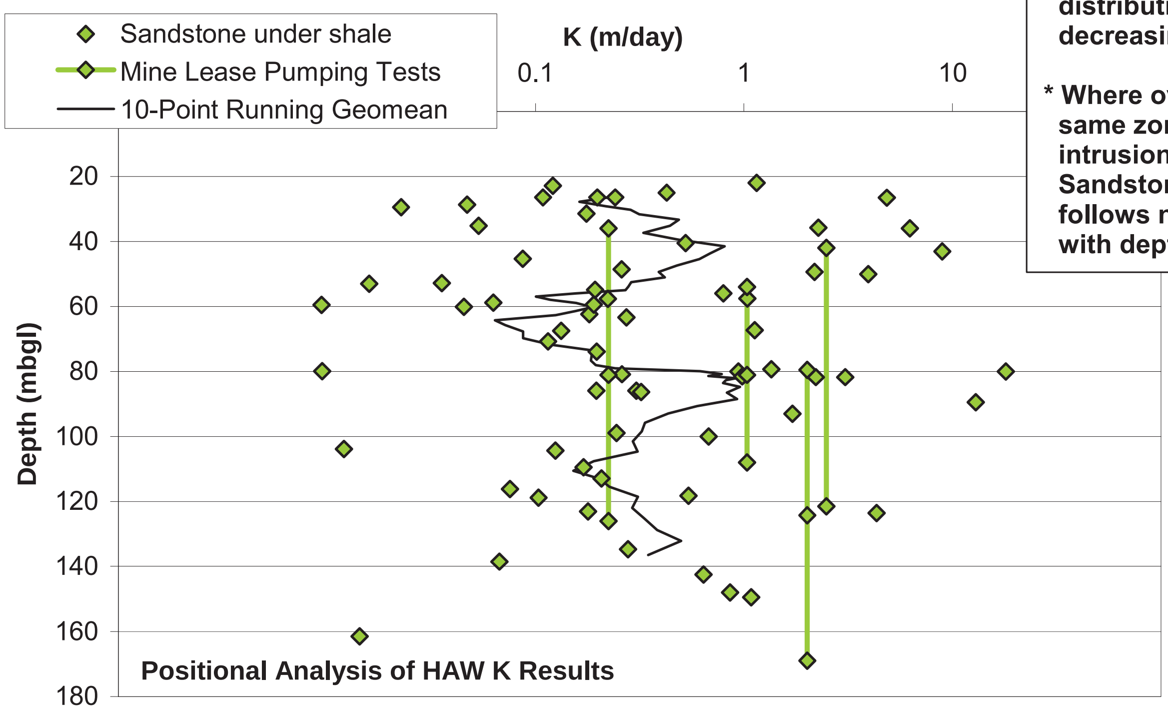


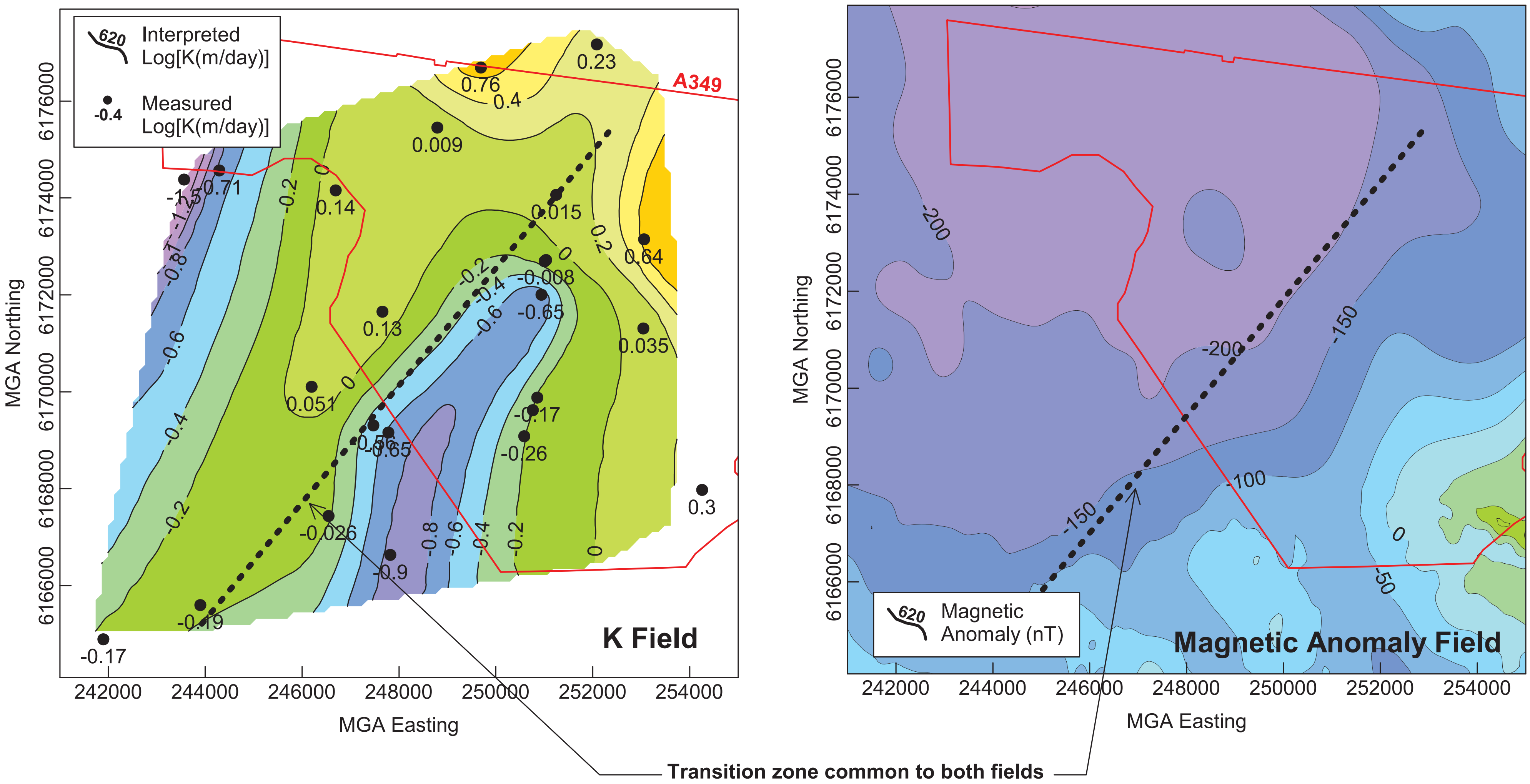
Figure C3. The K versus depth distributions for Hawkesbury Sandstone, for the groupings shown in Figure C2. K is calculated from specific capacities and pumping tests. Interpretation of the results is as follows:

*** At the extremities of the sandstone lateral extent (not overlain by WG), the K distribution follows a typical decreasing trend with depth.**

*** Further into the body of the Sandstone unit, but where no WG is present, the K distribution follows a weaker decreasing trend with depth.**

*** Where overlain by WG (the same zone as where igneous intrusions are present) the Sandstone K distribution follows no discernable trend with depth.**

Figure C4. Comparison of the interpreted K distribution for Hawkesbury Sandstone (over a vertical interval between 14m to 44m above its base) to the regional magnetic anomaly.



Appendix D - Hydraulic Head Database

Piezometer	Easting (MGA)	Northing (MGA)	RL Ground (mAHD)	RL Casing (mAHD)	Drilled Depth (mbgl)	Screen (mbgl)		Sandpack (mbgl)		Screened Stratum	L (m)	Comment
						From	To	From	To			
Hume Coal Monitoring												
H18A	246696	6174166	691.74	691.67	108	96	99	95	99	WW	4	
H18B	246695	6174159	691.97	691.89	114	75	88	73	88	HAW	15	
H19A	243557	6174381	720.65	720.55	108	100	103	100	103	WW	3	
H19B	243562	6174379	720.46	720.36	88	70	81	69	81	HAW	12	
H20A	244258	6176920	703.25	703.18	80	71	77	71	77	HAW	6	Dry (SWL < 626 mAHD)
H20B	244255	6176930	703.67	703.59	114	80	86	78	86	WW	8	
H23A	250769	6169622	680.47	680.38	140	135	138	135	138	WW	3	Decommissioned.
H23B	250763	6169620	680.63	680.55	132	118	130	116	130	HAW	14	Replaced by H142A to
H23C	250755	6169617	680.76	680.69	100	84	97	82	97	HAW	15	H142C
H32LDA	249532	6173533	646.60	646.78	152	108	114	106	117	WW	11	A and B in same hole
H32LDB	249532	6173533	646.60	646.73	152	57	88	54	89	HAW	35	
H35A	250523	6172486	681.43	682.16	152	53	77	50	78	HAW	28	
H35B	250531	6172487	680.84	681.52	35	15	34	14	35	WG	21	
H37A	246551	6167440	703.79	703.70	111	101	105	101	107	ICM	6	WW absent
H37B	246546	6167438	703.77	703.69	90	72	87	70	90	HAW	20	
H38A	248783	6175453	658.53	657.67	117	105	108	103	110	WW	7	
H38B	248788	6175452	658.44	658.33	78	74	77	72	78	HAW	6	
H38C	248793	6175452	658.31	658.17	63	55	62	52	63	HAW	11	
H42A	250988	6166688	702.50	702.43	173	156	159	153	161	WW	8	
H42C	250985	6166678	702.00	701.92	150	142	150	135	150	HAW	15	
H43XA	247147	6178127	692.04	691.96	111	95	101	93	103	WW	10	
H43XB	247152	6178133	691.77	691.69	87	77	86	75	87	HAW	12	
H44XA	242285	6164084	641.94	641.92	12	8	11	7	12	WW	5	
H44XB	242281	6164077	647.00	646.96	5	4	5	3.5	5	HAW	2	
H56XB	245225	6169198	735.45		140	132	140	130	140	HAW	10	
H56XC	245234	6169198	735.51		26	19	25	17	26	Basalt	9	
H72A	252074	6177157	640.12	640.05	129	124	128	121	129	WW	8	
H72B	252083	6177169	640.43	640.36	99	92	98	88	98	HAW	10	
H72C	252091	6177180	640.85	640.77	46	39	45	35	46	HAW	11	
H73A	251015	6172718	656.46	657.00	172	151	169	149	172	ICM Lower	23	
H73B	251029	6172717	655.78	656.35	124	119	123	117	124	WW	7	
H73C	251035	6172717	655.50	656.13	86	79	85	77	86	HAW	9	
H88A	253059	6173144	655.44	655.37	156	143	146	141	148	WW	7	
H88B	253059	6173144	655.33	655.26	150	121	126	119	128	HAW	9	

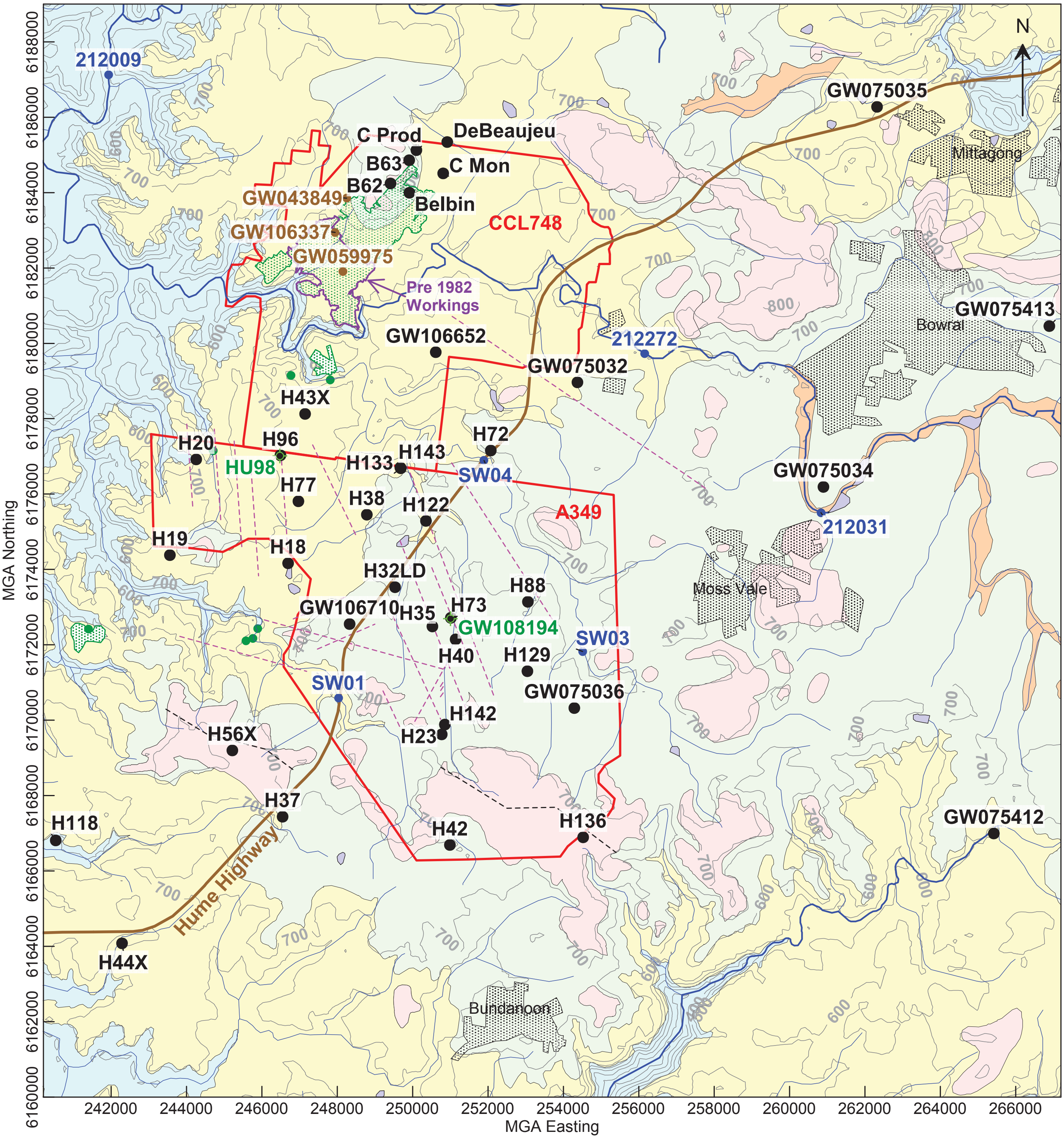
HAW: Hawkesbury Sandstone. WW: Wongawilli Seam. WG: Wianamatta Group. ICM: Illawarra Coal Measures. SS: Sandstone. Sh: Shale.

Piezometer	Easting (MGA)	Northing (MGA)	RL Ground (mAHD)	RL Casing (mAHD)	Drilled Depth (mbgl)	Screen (mbgl)		Sandpack (mbgl)		Screened Stratum	L (m)	Comment
						From	To	From	To			
Hume Coal Monitoring												
H96A	246489	6177025	699.21	699.14	147	111	120	108	120	ICM Lower	12	
H96B	246491	6177029	699.10	699.00	101	92	98	91	101	WW	10	
H96C	246494	6177045	683.00	682.94	89	69	87	67	89	HAW	22	
H118A	240529	6166811	612.50		15.3	7	13	5	15.3	HAW	10	Near swamp (under peat)
H129A	253042	6171301	679.10	679.04	177	166	170	165	171	WW	6	
H129B	253044	6171306	679.20	679.11	177	146	153	146	153	HAW	7	
H133A	249685	6176683	648.15	647.98	141	119	126	115	127	ICM Lower	12	Decommissioned.
H133B	249688	6176688	648.17	648.04	113	108	113	108	113	WW	5	Replaced by H143A to
H133C	249690	6176694	648.03	647.94	84	80	83	77	84	HAW	7	H143C
H136A	254521	6166894	718.49	718.36	216	199	203	196	203	WW	7	
H136B	254517	6166890	718.52	718.40	168	157	168	155	168	HAW	13	
H136C	254513	6166887	718.51	718.40	60	52	59	50	60	Basalt	10	
H142A	250856	6169881	672.43		130.8	127	130	126	131	WW	5	Replacement for H23A
H142B	250855	6169886	672.32		119.8	112	118	110	120	HAW	10	Replacement for H23B
H142C	250855	6169892	672.23		86.8	81	84	79	86.8	HAW	8	Replacement for H23C
H143A	249671	6176708	649.55		125.8	115	125	116	126	ICM Lower	10	Replacement for H133A
H143B	249672	6176703	649.59		113	109	112	107	113	WW	6	Replacement for H133B
H143C	249673	6176697	649.45		95.9	92	95	88	95.9	HAW	8	Replacement for H133C
H40_1	251140	6172143	656.51	656.51	129	120	120	VWP	VWP	WW	Point	Packer testing. Core K.
H40_2	251140	6172143	656.51	656.51	129	107	107	VWP	VWP	HAW	Point	
H40_3	251140	6172143	656.51	656.51	129	81	81	VWP	VWP	HAW	Point	
H40_4	251140	6172143	656.51	656.51	129	39	39	VWP	VWP	HAW	Point	
H77_1	246966	6175811	689.74	689.74	98	87	87	VWP	VWP	WW	Point	Packer testing. Core K.
H77_2	246966	6175811	689.74	689.74	98	72	72	VWP	VWP	HAW	Point	
H77_3	246966	6175811	689.74	689.74	98	58	58	VWP	VWP	HAW	Point	
H122_1	250352	6175286	634.50	634.50	120	112	112	VWP	VWP	WW	Point	Packer testing. Core K.
H122_2	250352	6175286	634.50	634.50	120	86	86	VWP	VWP	HAW	Point	
H122_3	250352	6175286	634.50	634.50	120	45	45	VWP	VWP	HAW	Point	
H122_4	250352	6175286	634.50	634.50	120	15	15	VWP	VWP	HAW	Point	
GW106652	250614	6179763	652.32	652.85	120	25	120	Open hole		HAW	95	Intersects WW seam.
GW106710	248326	6172551	672.39	672.70	115	64	108	Open hole		HAW	44	

HAW: Hawkesbury Sandstone. WW: Wongawilli Seam. WG: Wianamatta Group. ICM: Illawarra Coal Measures. SS: Sandstone. Sh: Shale.

Piezometer	Easting (MGA)	Northing (MGA)	RL Ground (mAHD)	RL Casing (mAHD)	Drilled Depth (mbgl)	Screen (mbgl)		Sandpack (mbgl)		Screened Stratum	L (m)	Comment
						From	To	From	To			
Berrima Mine Monitoring												
Belbin (GW106150)	249914	6183996		691.40	186	132	186	Open hole		HAW	54	
Culpepper P (GW101581)	250100	6185126		693.00	41		41	Open hole		HAW	< 41	
Culpepper M (B28)	250809	6184507		677.90	143		143	Open hole		HAW	> 100	Bore collapsed mid 2012
DeBeaujeu (GW028373)	250915	6185343	678.00	678.00	50	7	50	Open hole		HAW	42	RL estimated from DEM
B62_1	249411	6184243	727.00	727.00	181	58	58	VWP	VWP	HAW	Point	
B62_2	249411	6184243	727.00	727.00	181	126	126	VWP	VWP	HAW	Point	
B62_3	249411	6184243	727.00	727.00	181	170	170	VWP	VWP	WW	Point	
B63_1	249907	6184861	738.00	738.00	185	85	85	VWP	VWP	HAW	Point	
B63_2	249907	6184861	738.00	738.00	185	133	133	VWP	VWP	HAW	Point	
B63_3	249907	6184861	738.00	738.00	185	177	177	VWP	VWP	WW	Point	
Regional Government Monitoring												
G75032_1	254374	6178962	678.23	678.75	91	24	29	1	31	HAW	30	
G75032_2	254374	6178962	678.23	678.65	91	73	88	2	91	HAW	90	
G75033_1	273474	6170523	692.96	693.58	101	30	35	1	36	SS	35	
G75033_2	273474	6170523	692.96	693.04	101	89	99	50	101	SS/Sh	51	
G75034	260898	6176191	660.01	660.73	101	90	100	50	101	WG	51	
G75035	262322	6186276	648.25	648.17	91	74	89	1	91	HAW	90	
G75036	254286	6170323	660.24	660.87	100	73	84	2	85	SS	84	
G75412	265421	6166998	650.07		70	52	64	44	70	SS	26	
G75413	266895	6180460	710.69		151	108	151	Open hole		WG	43	
Private Bores Overlying Berrima Mine Workings												
GW043849	248247	6183852			99	4	99	Open hole				WW top appr. 125mbgl.
Stock. Installed 01.02.1974. Water Level 76.2m below ground. Area mined after 1977.												
GW106337	247940	6182940			122		122					WW top appr. 125mbgl.
Stock / Domestic. Installed 16.11.2002. Intersected coal seams. Went dry 17.08.2005 then backfilled (license cancelled). Area mined before 1977.												
GW059975	248146	6181907			92	3	92	Open hole				WW top appr. 125mbgl.
Stock / Domestic. Installed 01.04.1983. Water Level 36.6m below ground. Area mined before 1977.												

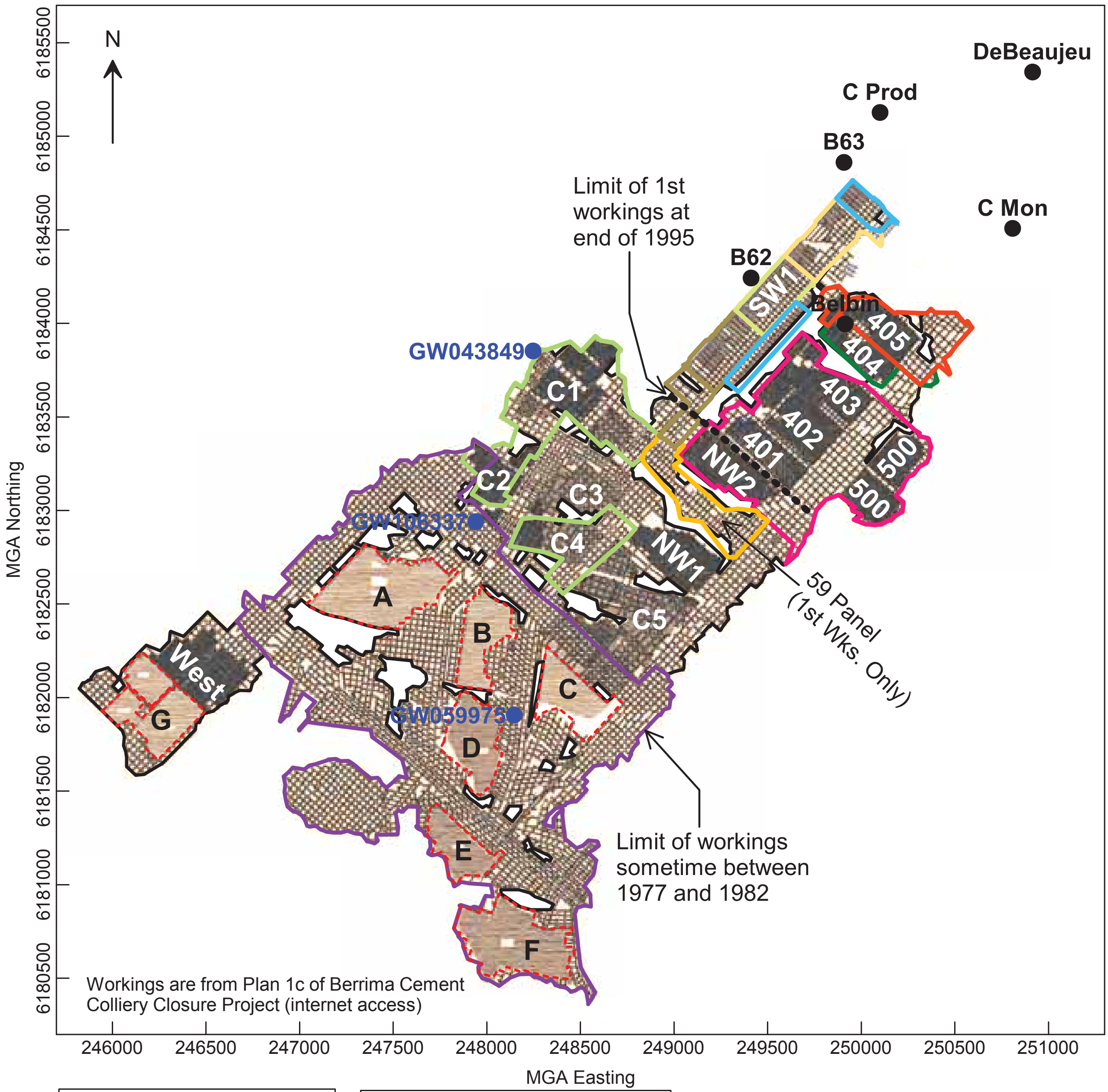
HAW: Hawkesbury Sandstone. WW: Wongawilli Seam. WG: Wianamatta Group. ICM: Illawarra Coal Measures. SS: Sandstone. Sh: Shale.



Subsurface flow barrier emplaced during model calibration.

- Alluvium
- Basalt
- Wianamatta Group
- Hawkesbury Sandstone
- Narrabeen Group (where present) and Permian Coal Measures
- Drainage course
- Water body
- Old mine footprint
- Old mine adit
- Interpreted or published fault
- GW106337 Hume pumping test bore
- 620 Topography (mAHD)
- H72 Groundwater monitoring piezometer / well
- GW106337 Private bore over workings
- SW01 Flow gauge
- Pipeline
- Built-up Area
- Hume Highway

drawn	PT	coffey A TETRA TECH COMPANY	client:	Hume Coal Pty Limited
approved	RJB		project:	Hume Coal Project Groundwater Assessment
date	29 Jul 2016			
scale	1:150,000		title:	**Monitoring Piezometer and Well Locations**
original size	A4		project no: GEOTLCOV25281AB	figure no: **Figure D1**



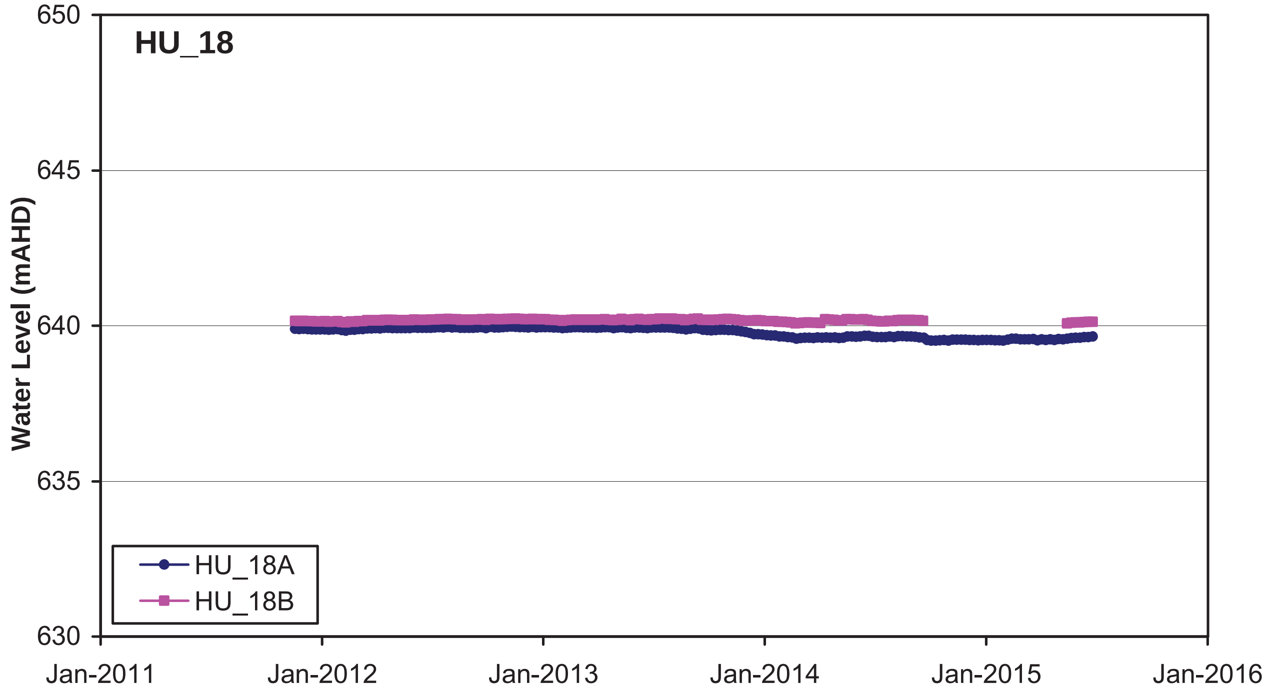
Berrima Mining Schedule:

- 1991 to 1995 (pillar extraction)
- 1996 to 2005 (1st wks. & pill. ext.)
- 2006 to 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013

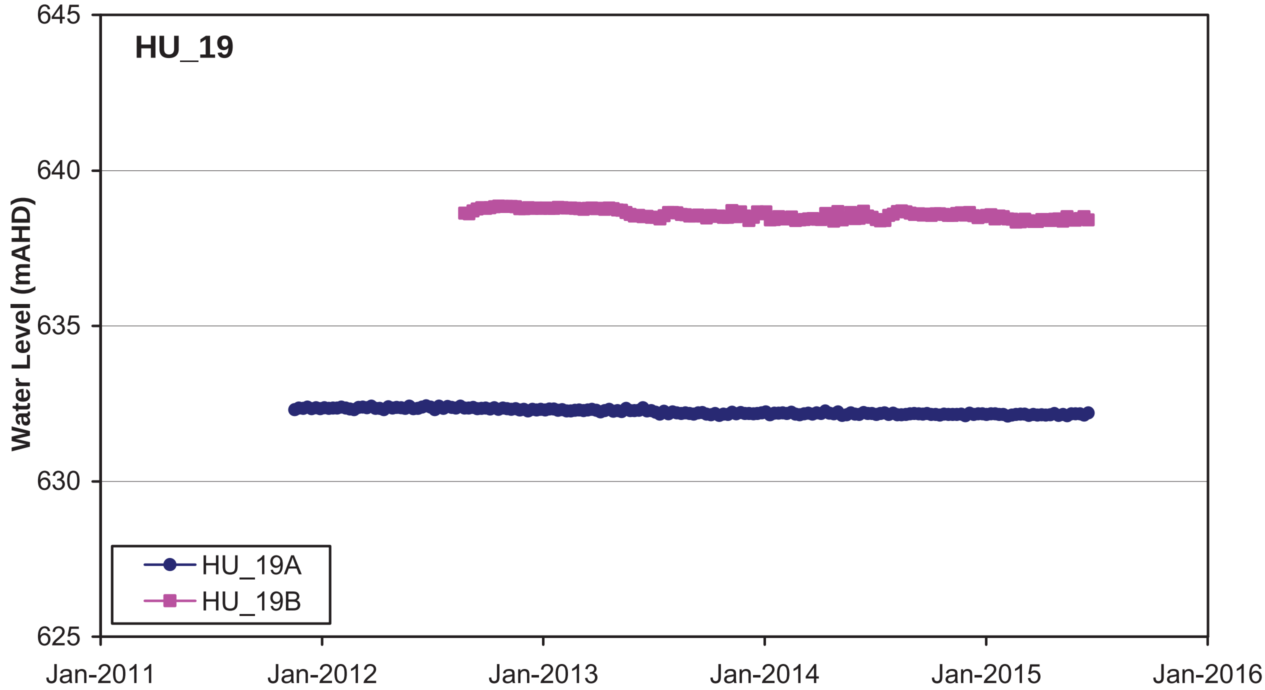
- H72 ● Groundwater monitoring piezometer / well
- GW106337 ● Private bore over workings
- B Unknown workings type. Most likely pillar extraction. Some goaf areas present.
- Mine limit some time between 1977 and 1982.
- 1st Workings
- NW1 Pillar Extraction Panel

drawn	PT	client:	Hume Coal Pty Limited
approved	RJB	project:	Hume Coal Project Groundwater Assessment
date	6 Jun 2016		
scale	1:35,000	title:	**Monitoring Piezometers/Wells (Berrima Mine)**
original size	A4	project no: GEOTLCOV25281AB	figure no: **Figure D2**

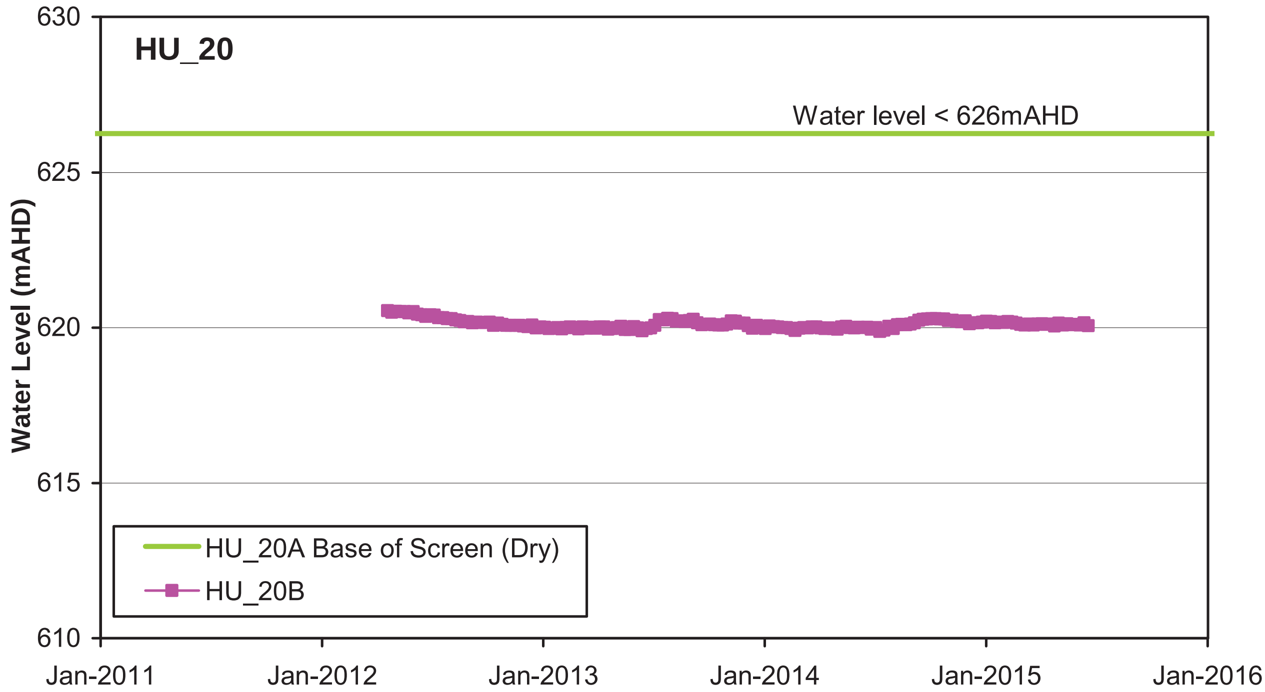
coffey
A TETRA TECH COMPANY



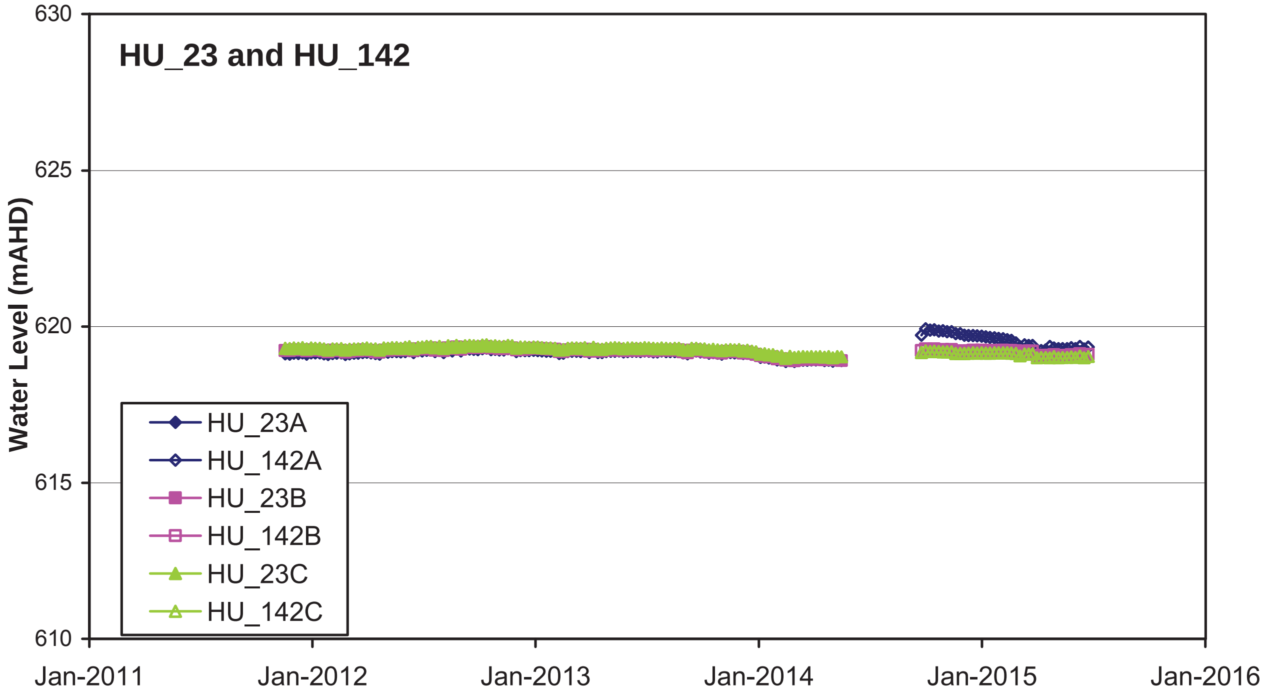
HU_18
Water Level (mAHD)
650
645
640
635
630
HU_18A
HU_18B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016



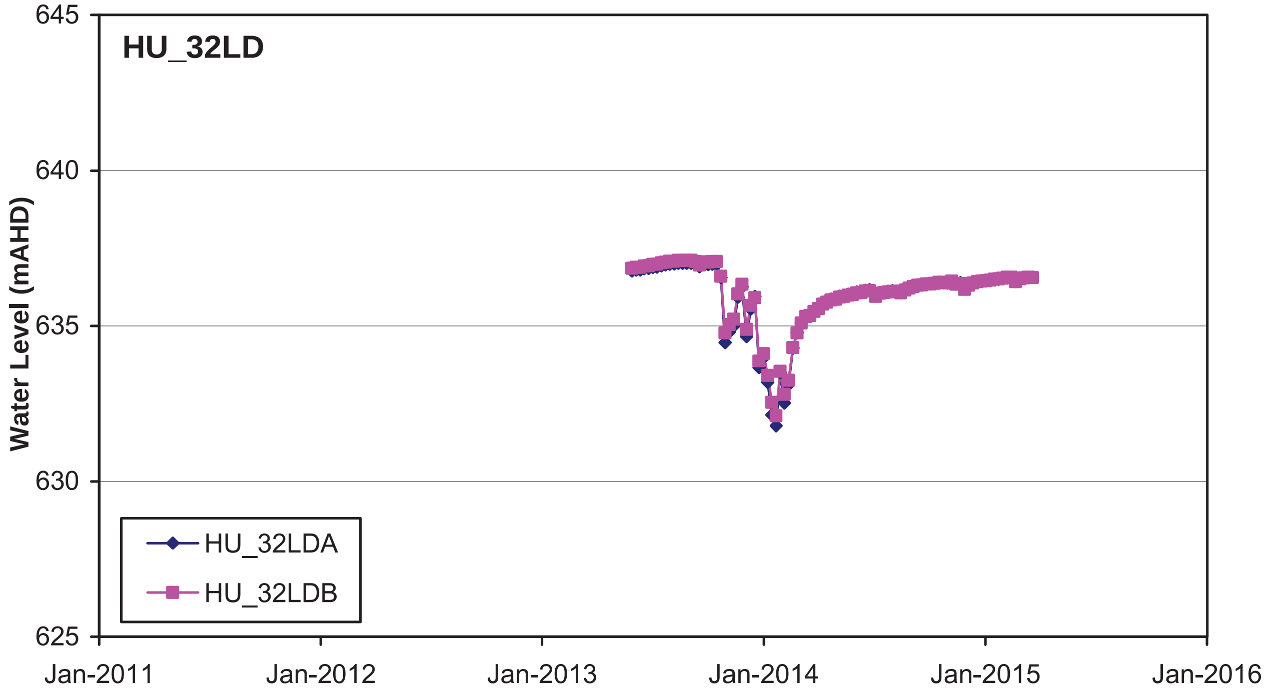
HU_19
Water Level (mAHD)
645
640
635
630
625
HU_19A
HU_19B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016



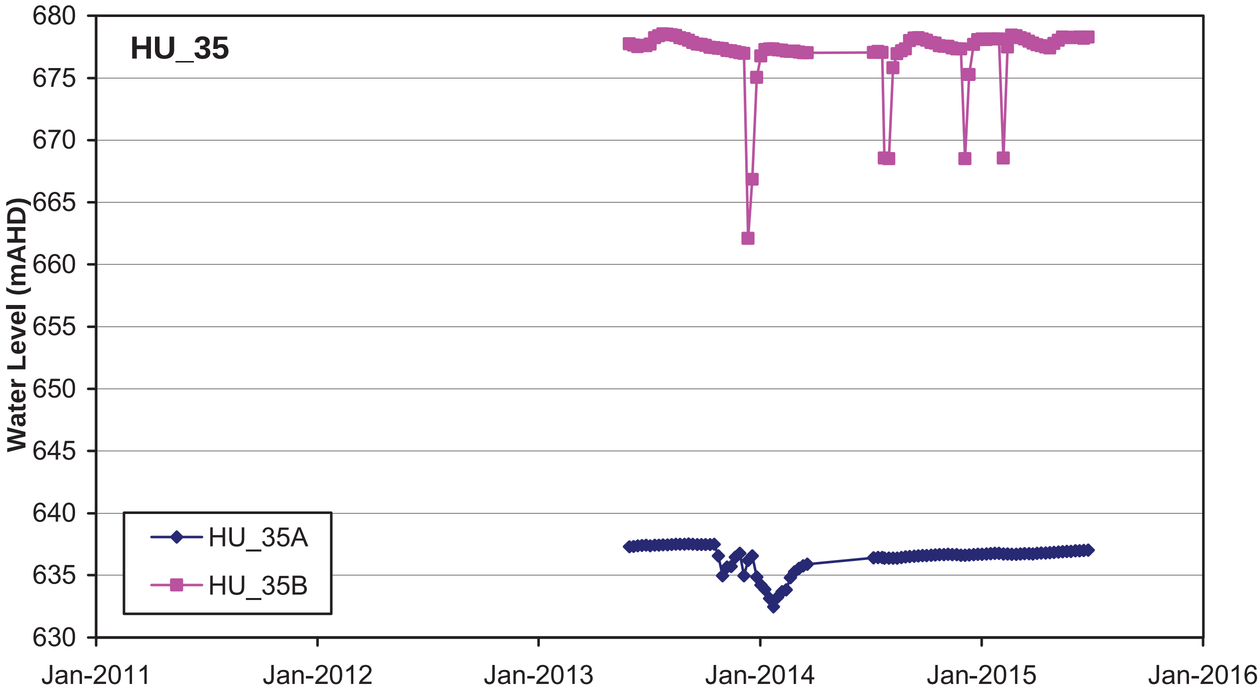
HU_20
Water level < 626mAHD
Water Level (mAHD)
630
625
620
615
610
HU_20A Base of Screen (Dry)
HU_20B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016



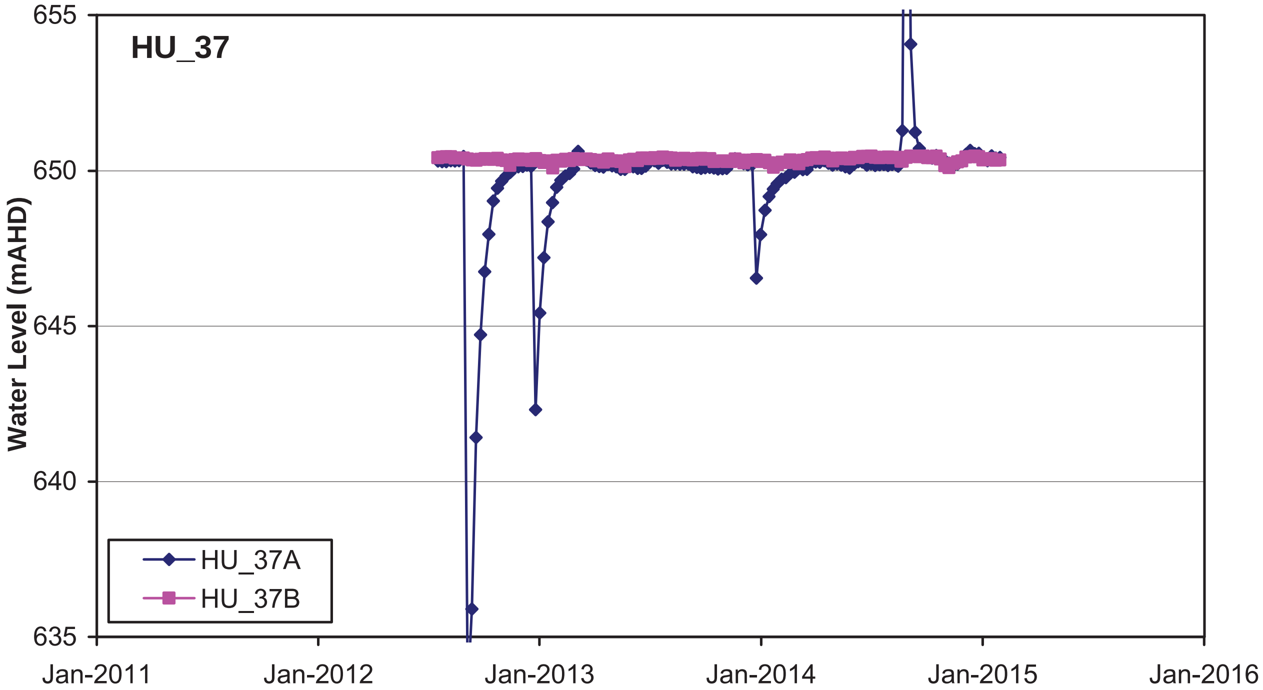
HU_23 and HU_142
Water Level (mAHD)
630
625
620
615
610
HU_23A
HU_142A
HU_23B
HU_142B
HU_23C
HU_142C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

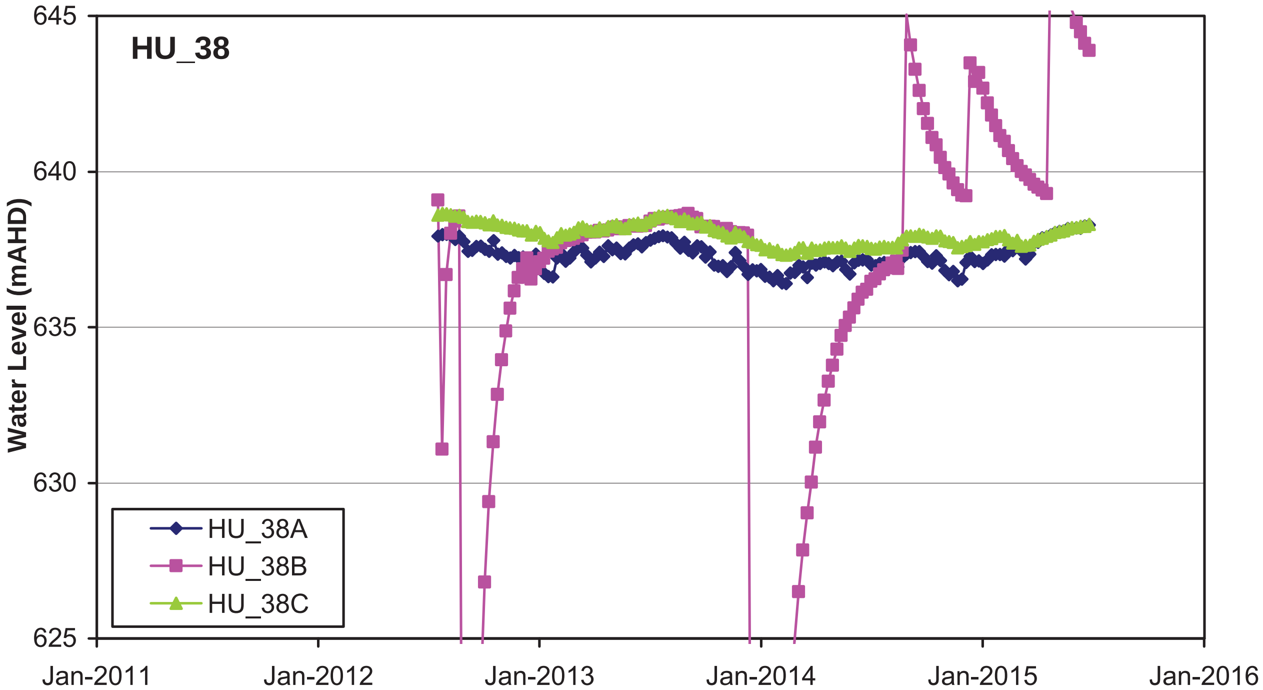


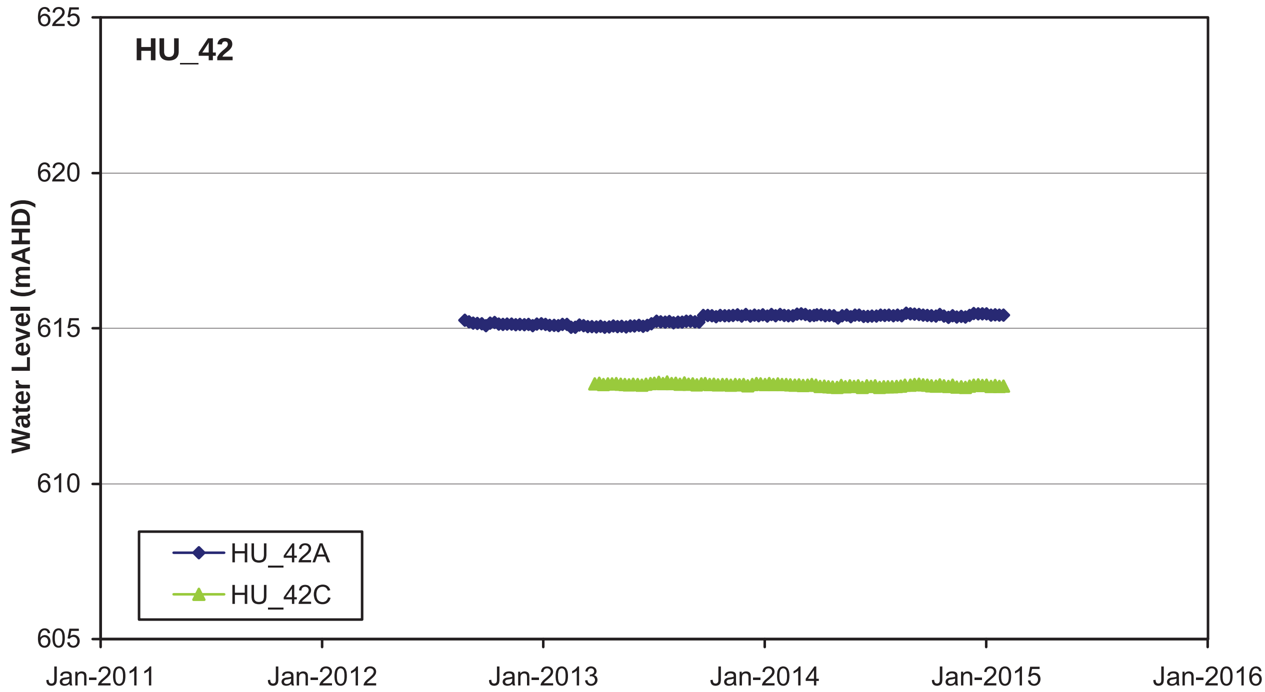
HU_32LD
Water Level (mAHD)
645
640
635
630
625
HU_32LDA
HU_32LDB
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

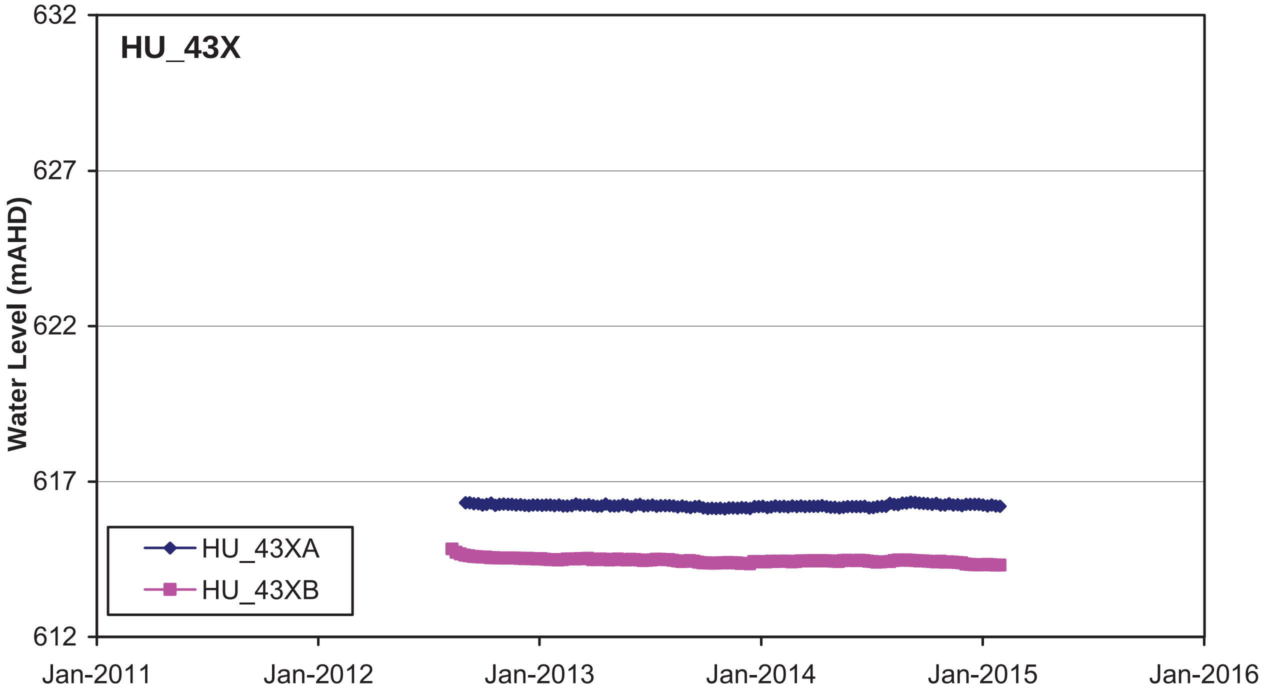


HU_35
Water Level (mAHD)
680
675
670
665
660
655
650
645
640
635
630
HU_35A
HU_35B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

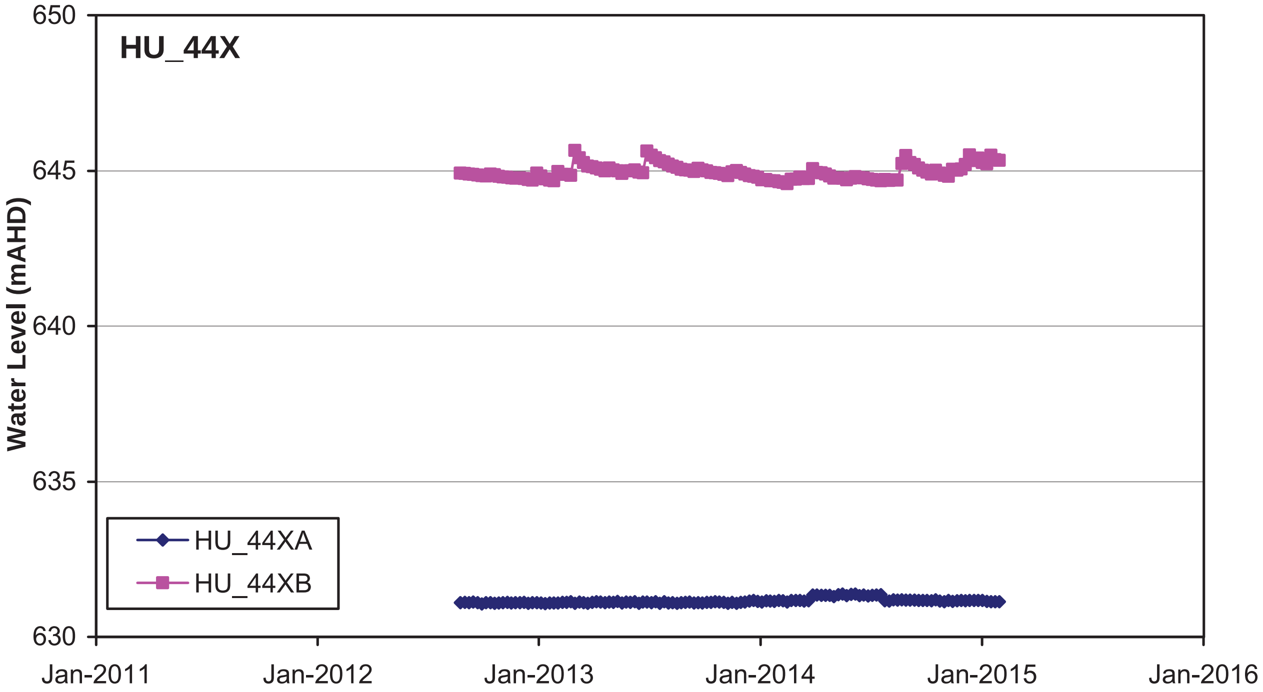

HU_37
Water Level (mAHD)
655
650
645
640
635
HU_37A
HU_37B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016


HU_38
Water Level (mAHD)
645
640
635
630
625
HU_38A
HU_38B
HU_38C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

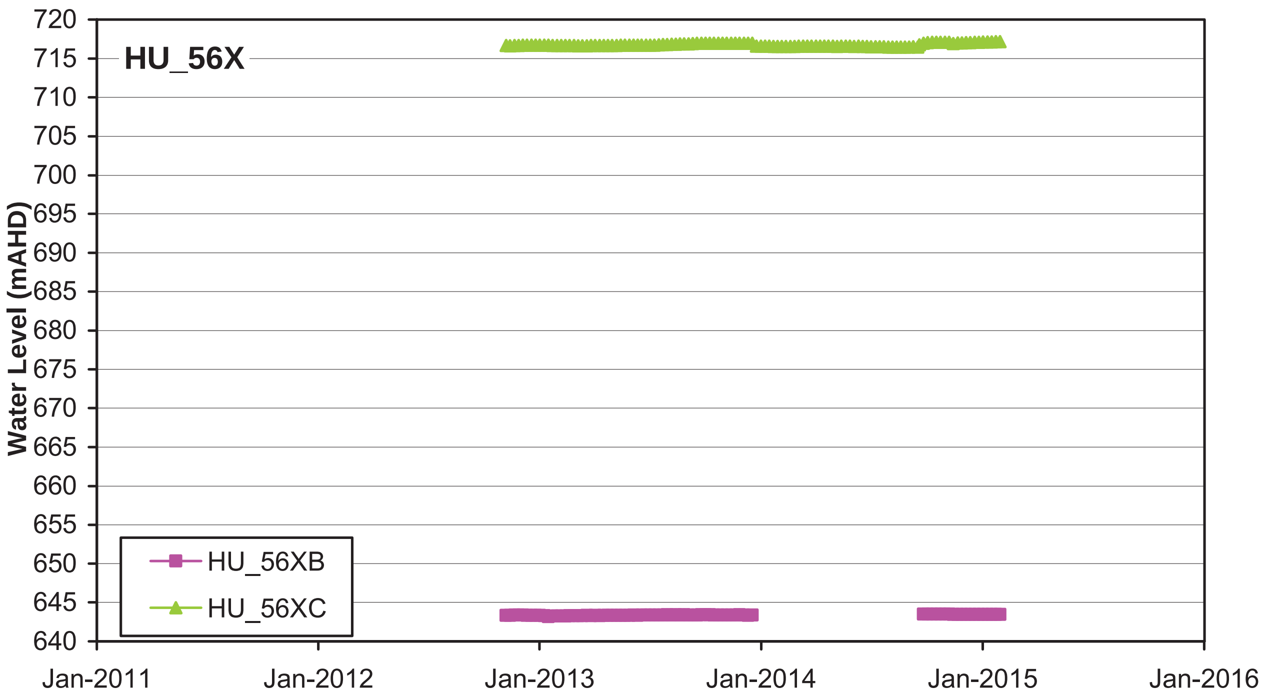

HU_42
Water Level (mAHD)
625
620
615
610
605
HU_42A
HU_42C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016



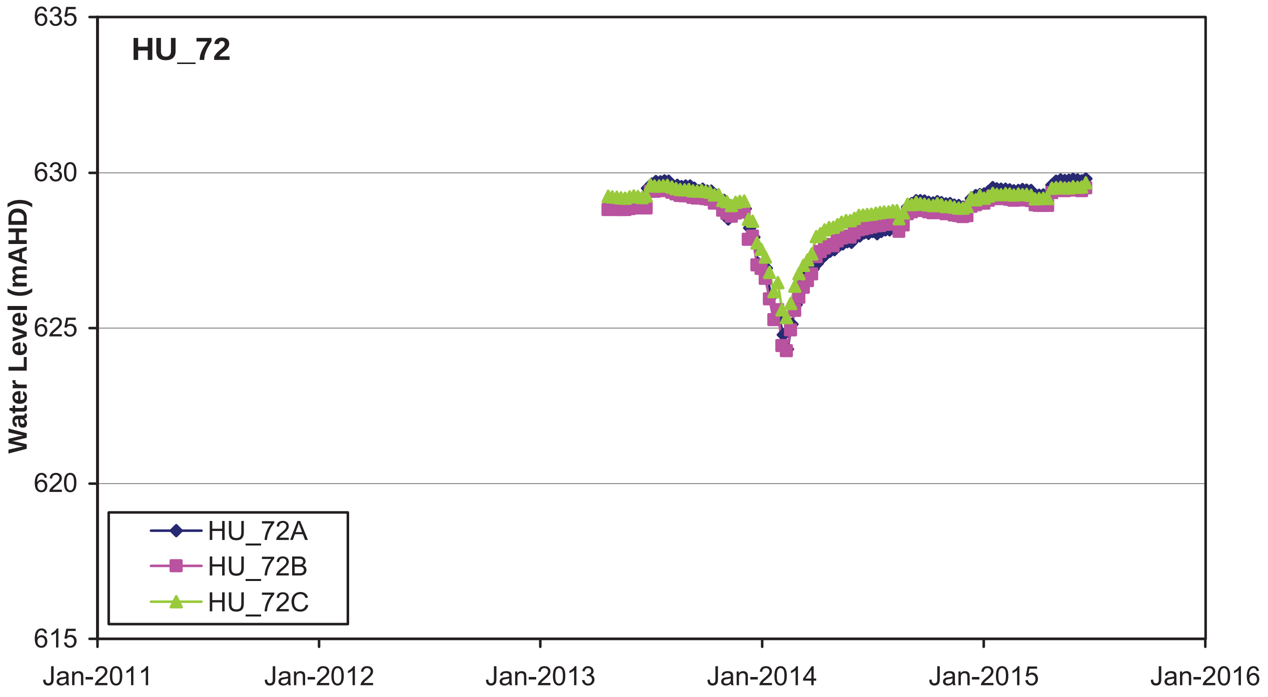
HU_43X
Water Level (mAHD)
632
627
622
617
612
HU_43XA
HU_43XB
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

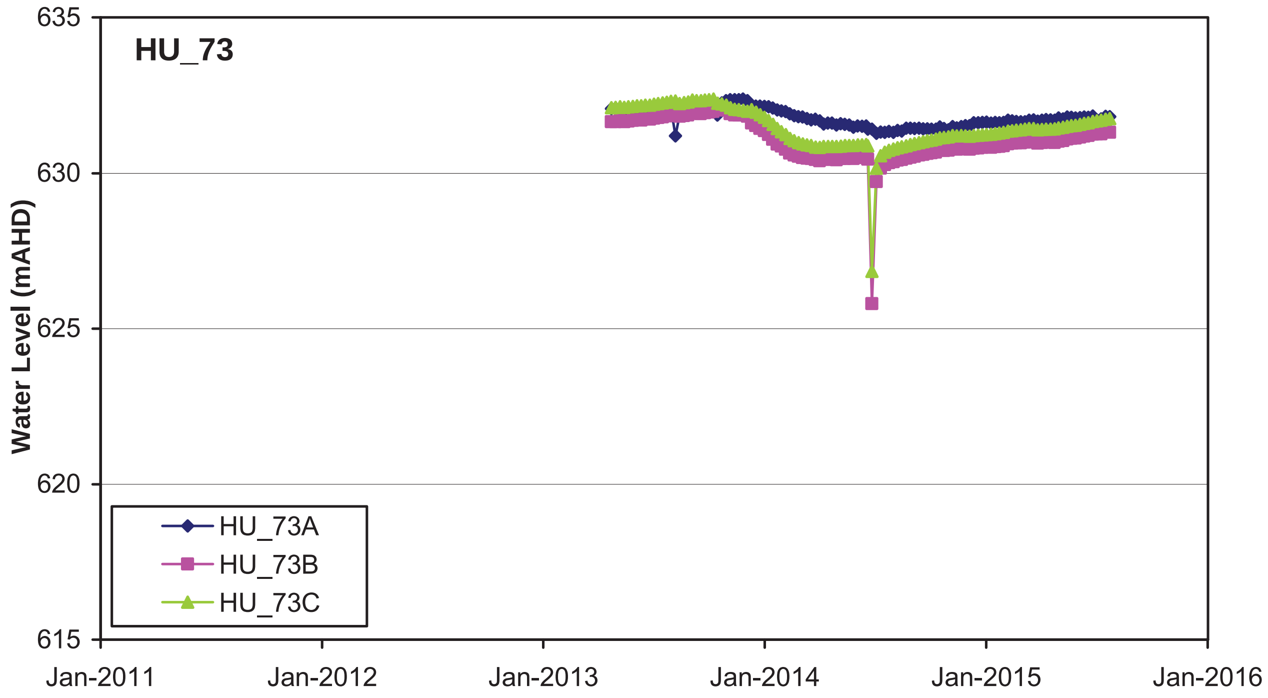


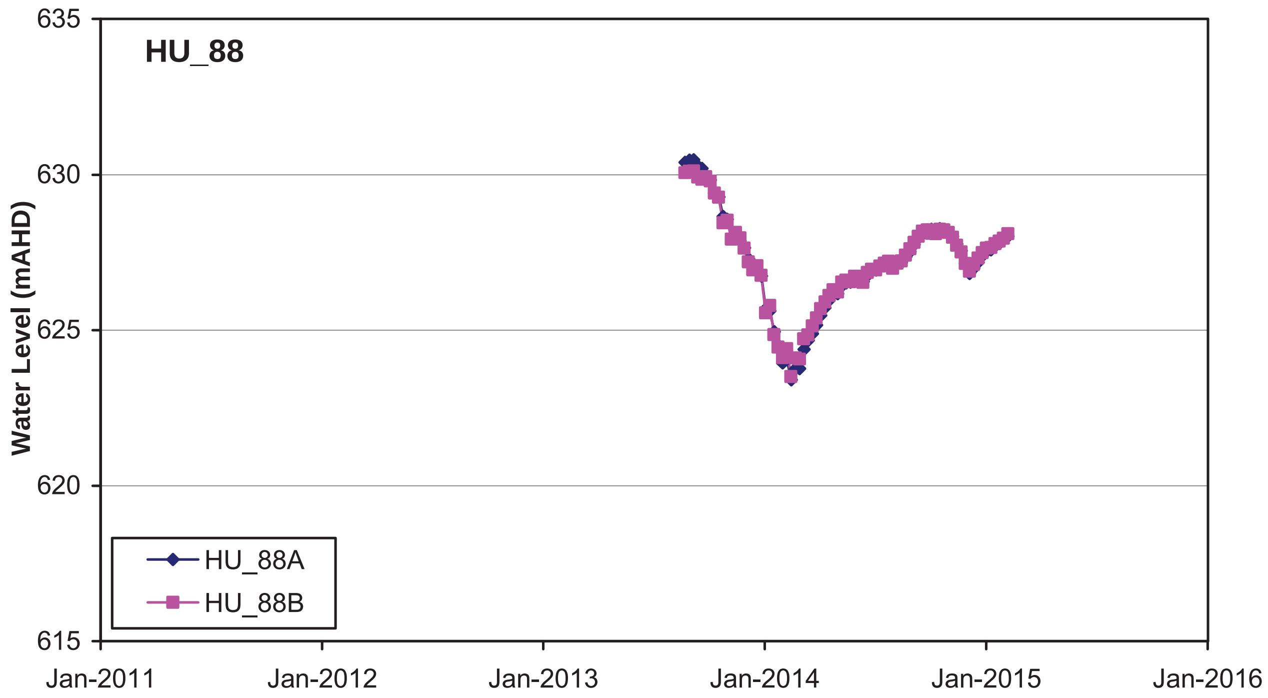
HU_44X
Water Level (mAHD)
650
645
640
635
630
HU_44XA
HU_44XB
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

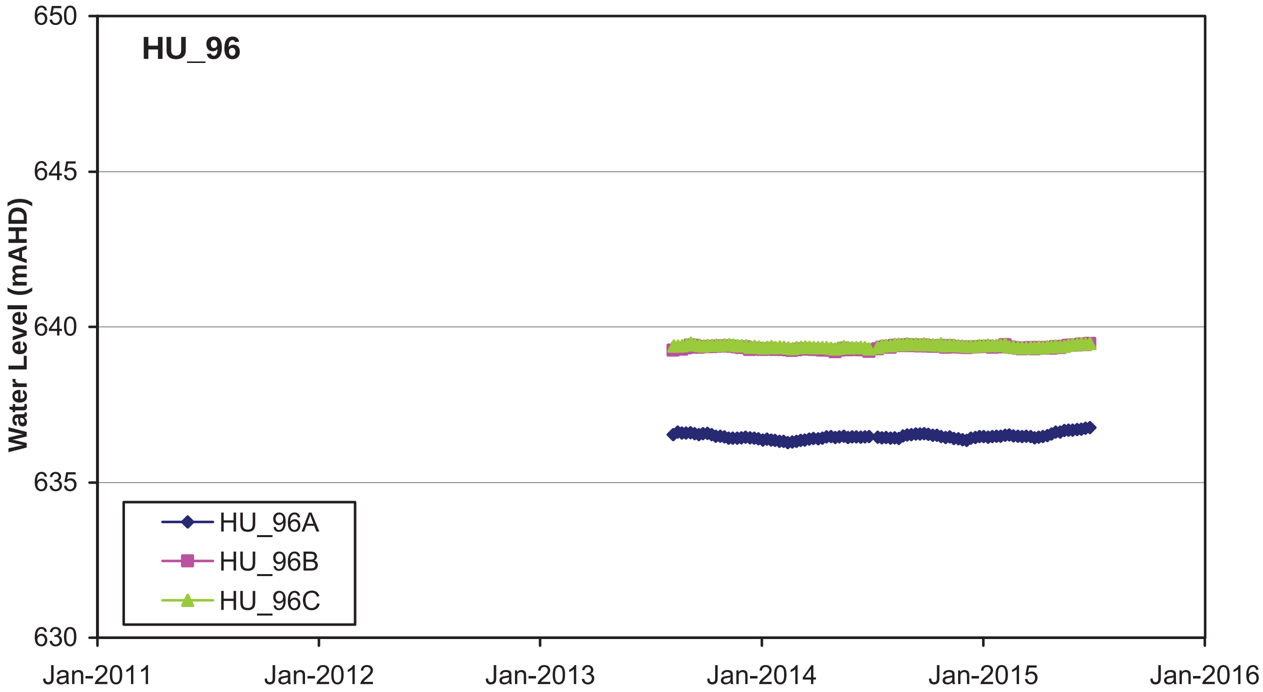


HU_56X
Water Level (mAHD)
720
715
710
705
700
695
690
685
680
675
670
665
660
655
650
645
640
HU_56XB
HU_56XC
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

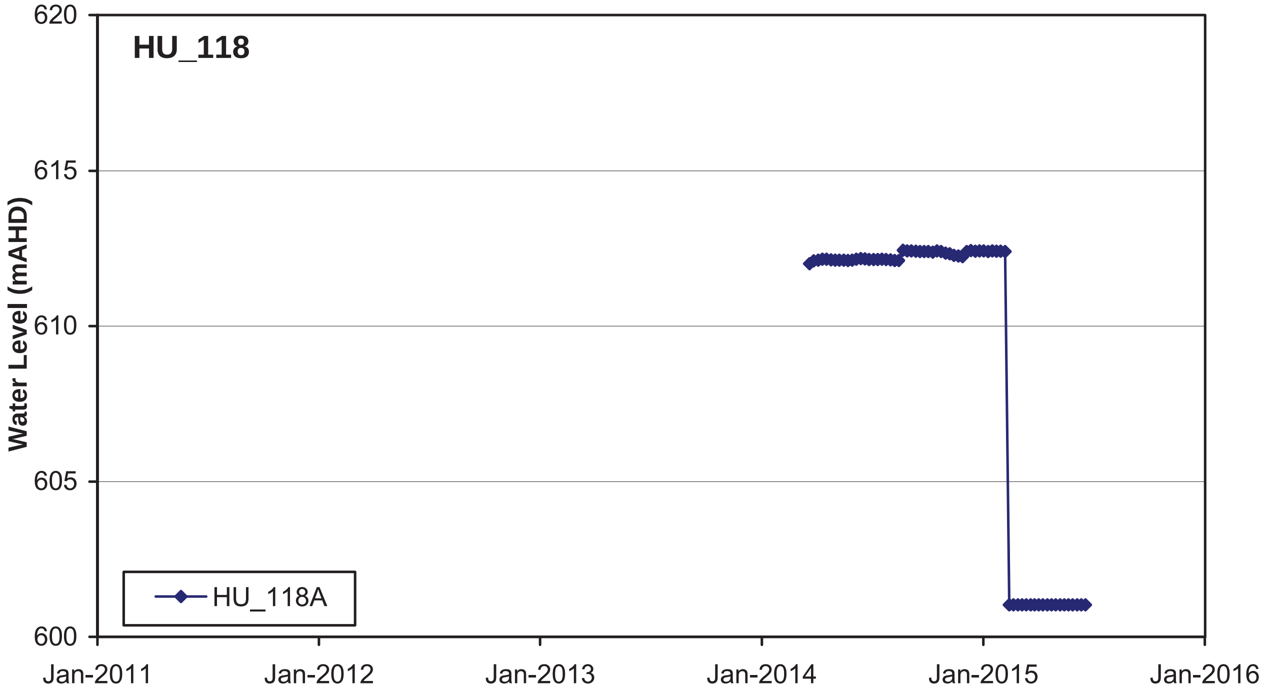

HU_72
Water Level (mAHD)
635
630
625
620
615
HU_72A
HU_72B
HU_72C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016


HU_73
Water Level (mAHD)
635
630
625
620
615
HU_73A
HU_73B
HU_73C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

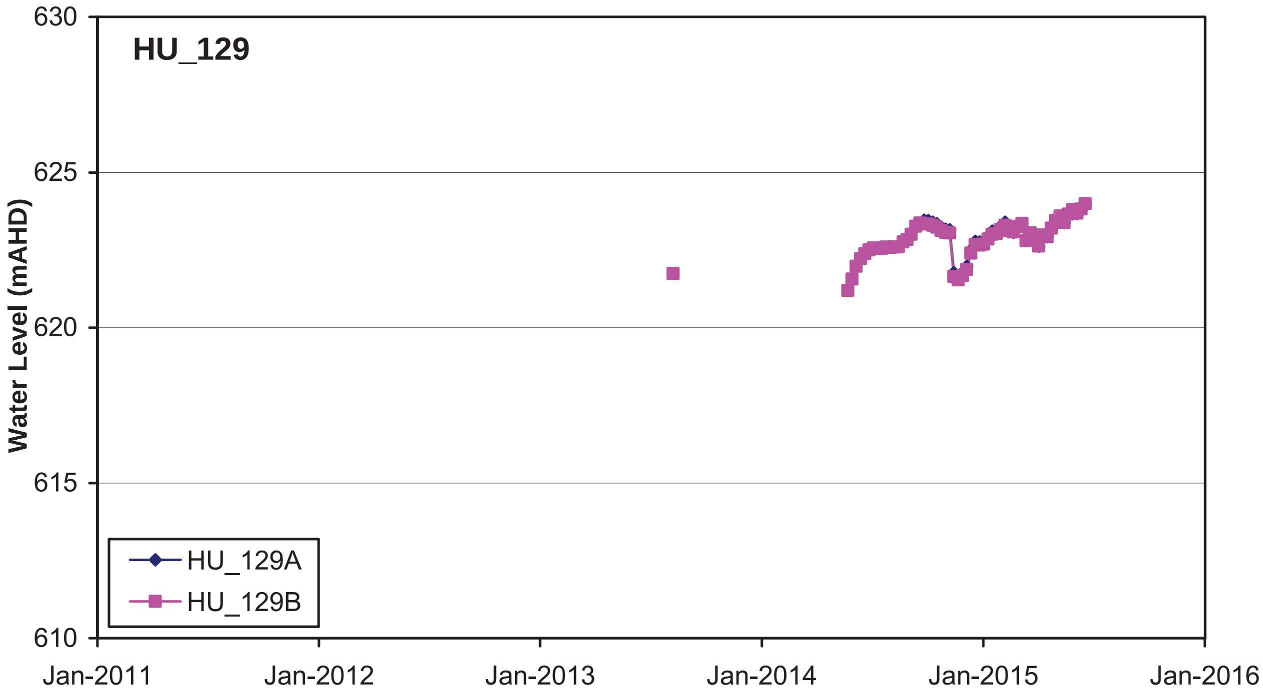

HU_88
Water Level (mAHD)
635
630
625
620
615
HU_88A
HU_88B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016



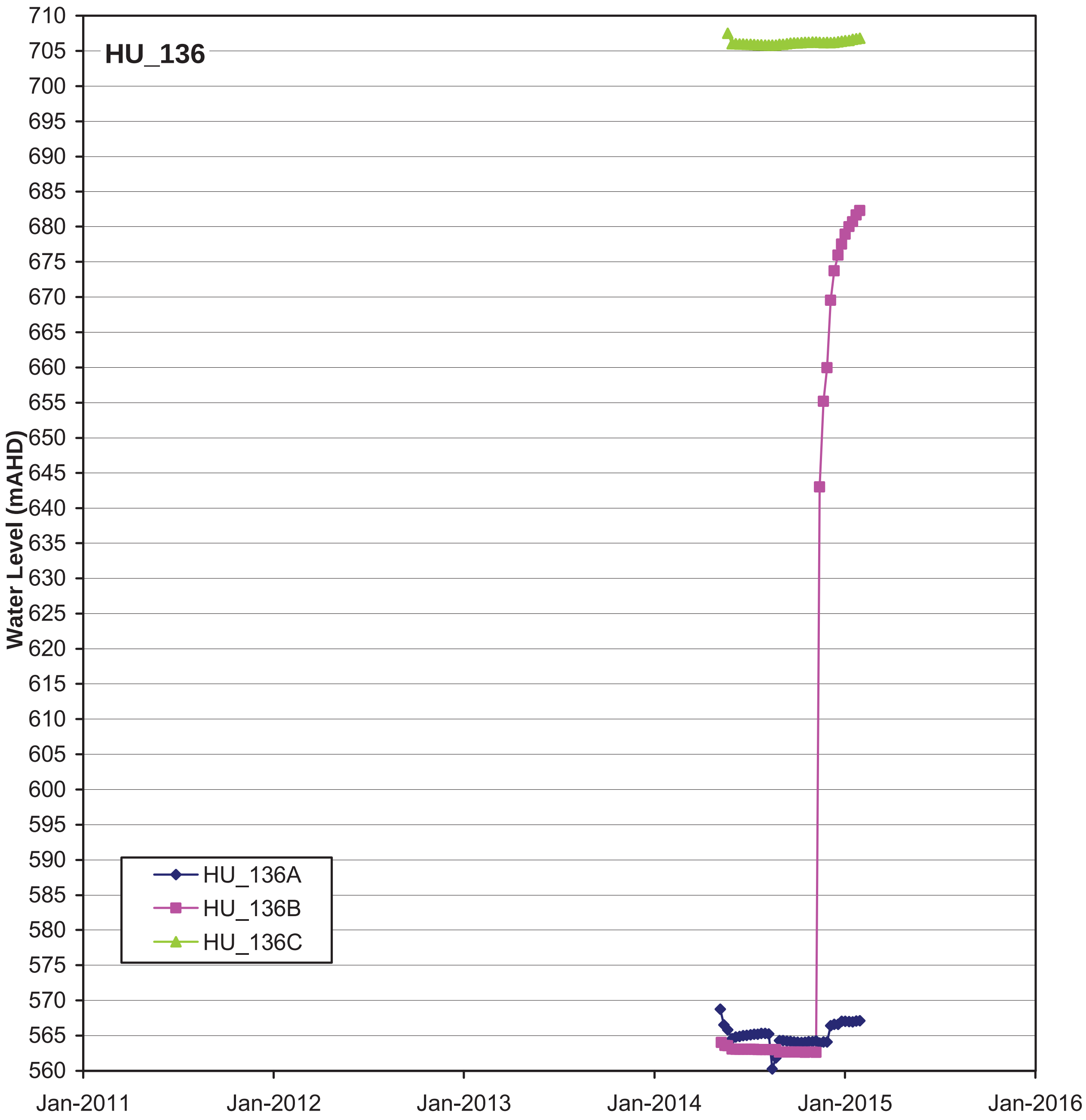
HU_96
Water Level (mAHD)
650
645
640
635
630
HU_96A
HU_96B
HU_96C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

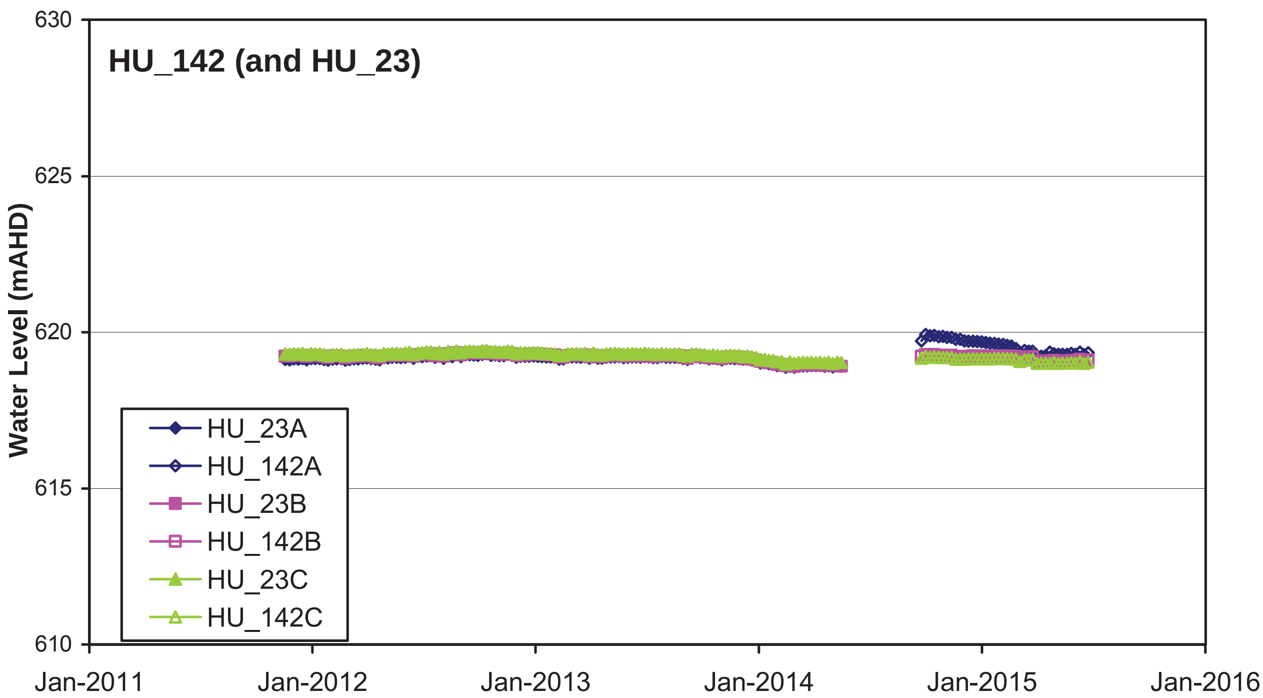


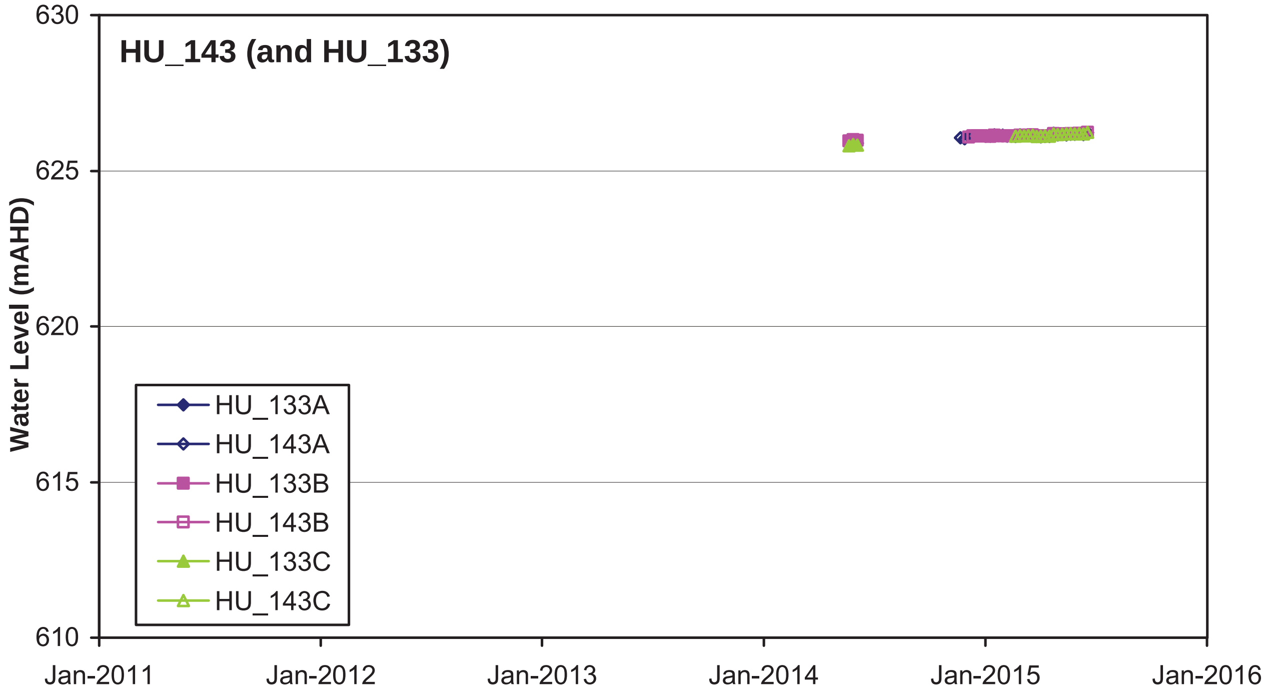
HU_118
Water Level (mAHD)
620
615
610
605
600
HU_118A
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

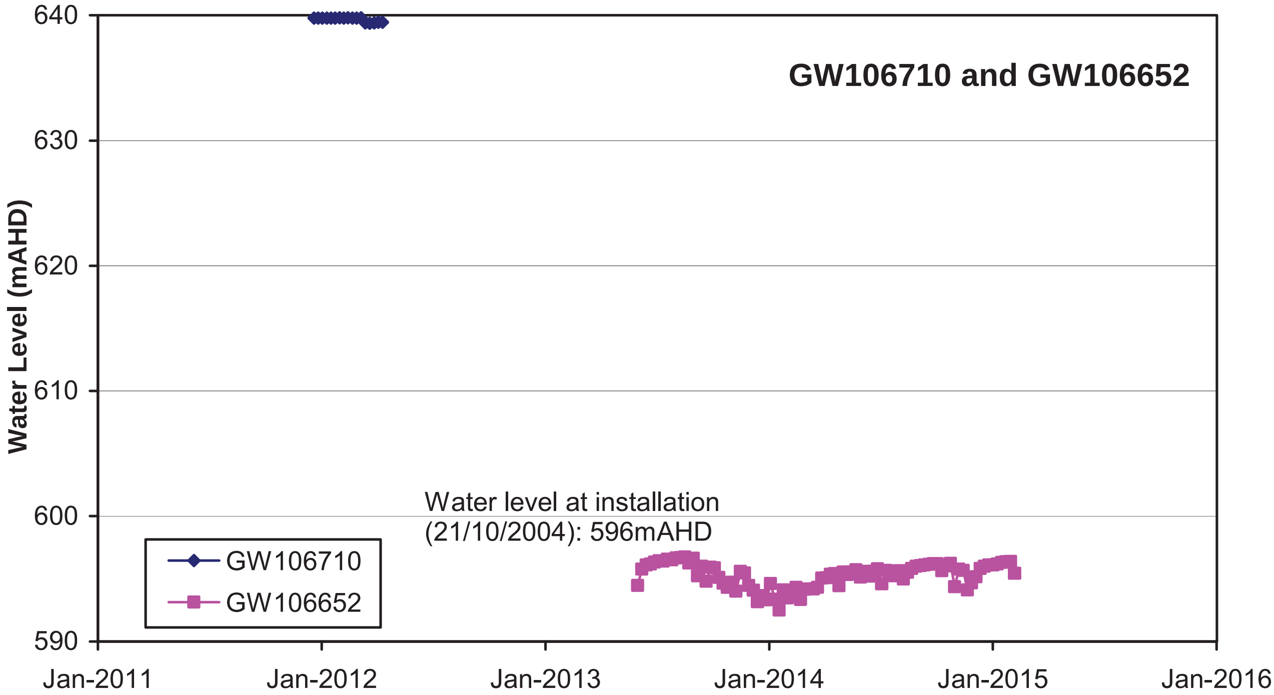


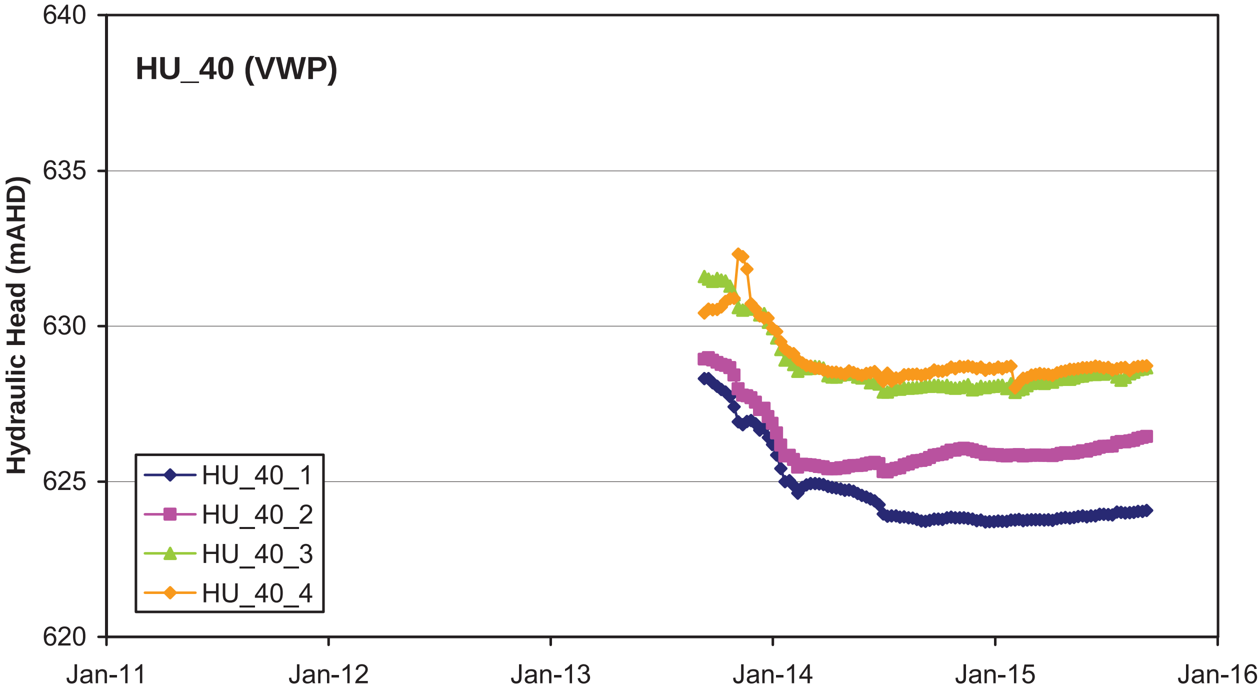
HU_129
Water Level (mAHD)
630
625
620
615
610
HU_129A
HU_129B
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

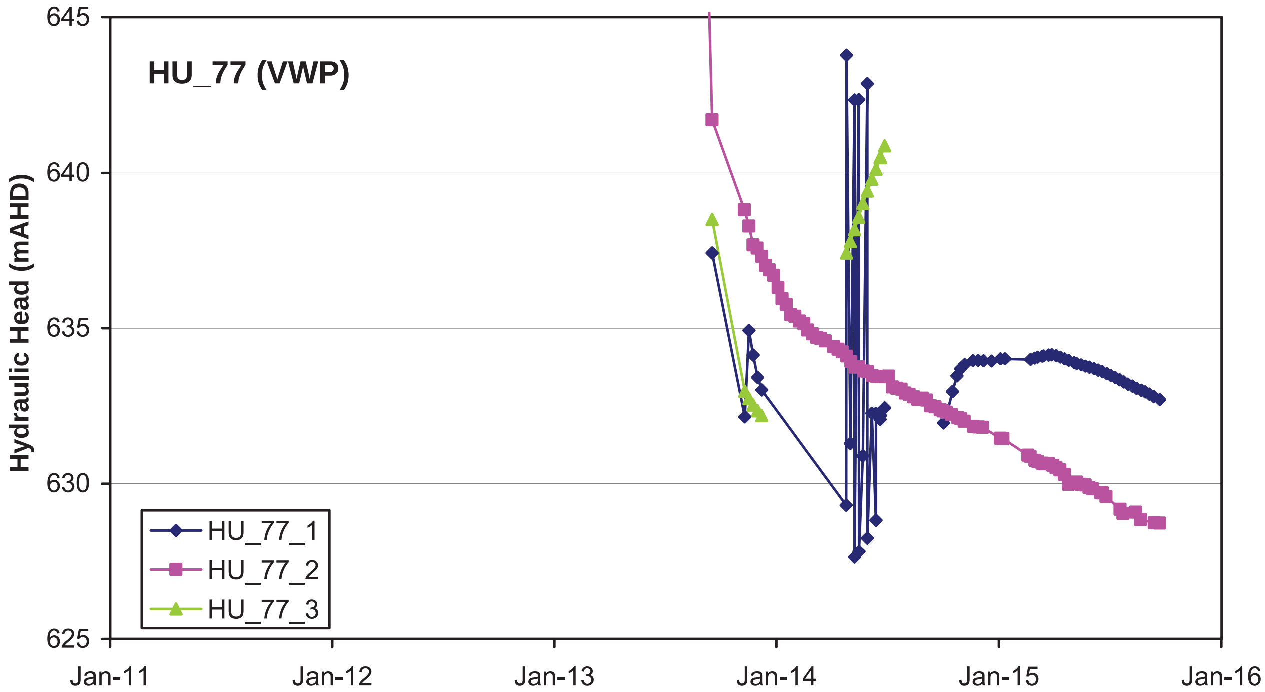

HU_136
Water Level (mAHD)
710
705
700
695
690
685
680
675
670
665
660
655
650
645
640
635
630
625
620
615
610
605
600
595
590
585
580
575
570
565
560
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
HU_136A
HU_136B
HU_136C

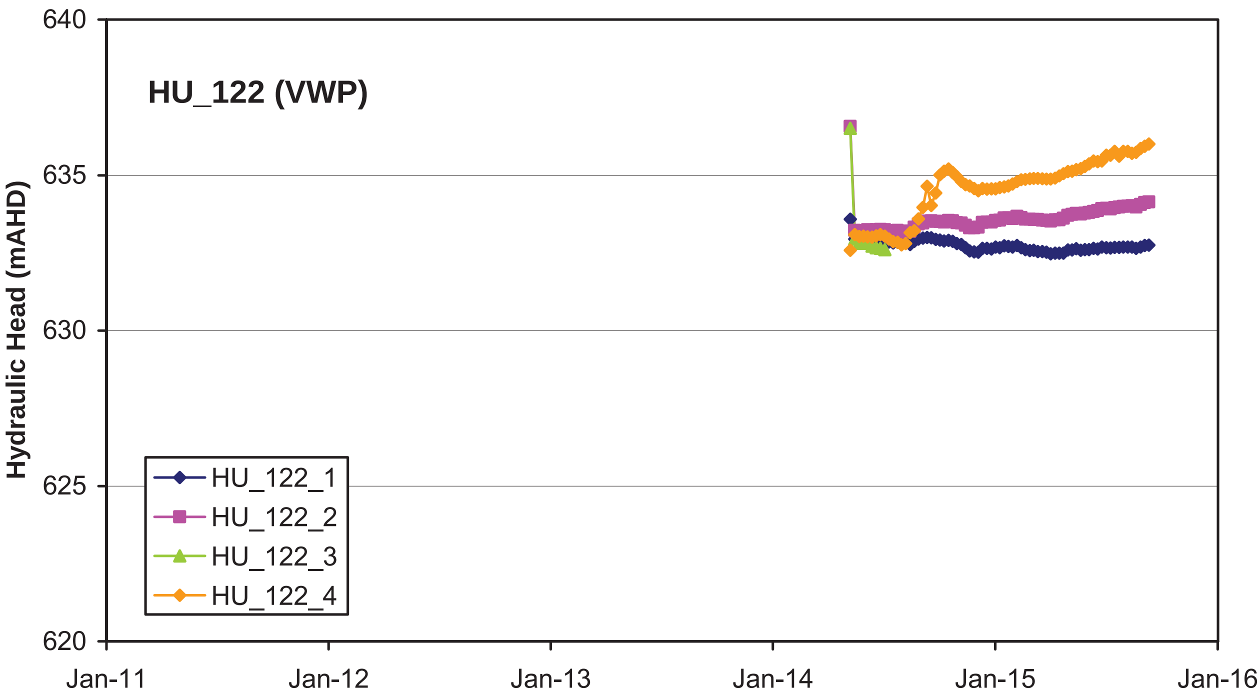

HU_142 (and HU_23)
Water Level (mAHD)
630
625
620
615
610
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016
HU_23A
HU_142A
HU_23B
HU_142B
HU_23C
HU_142C

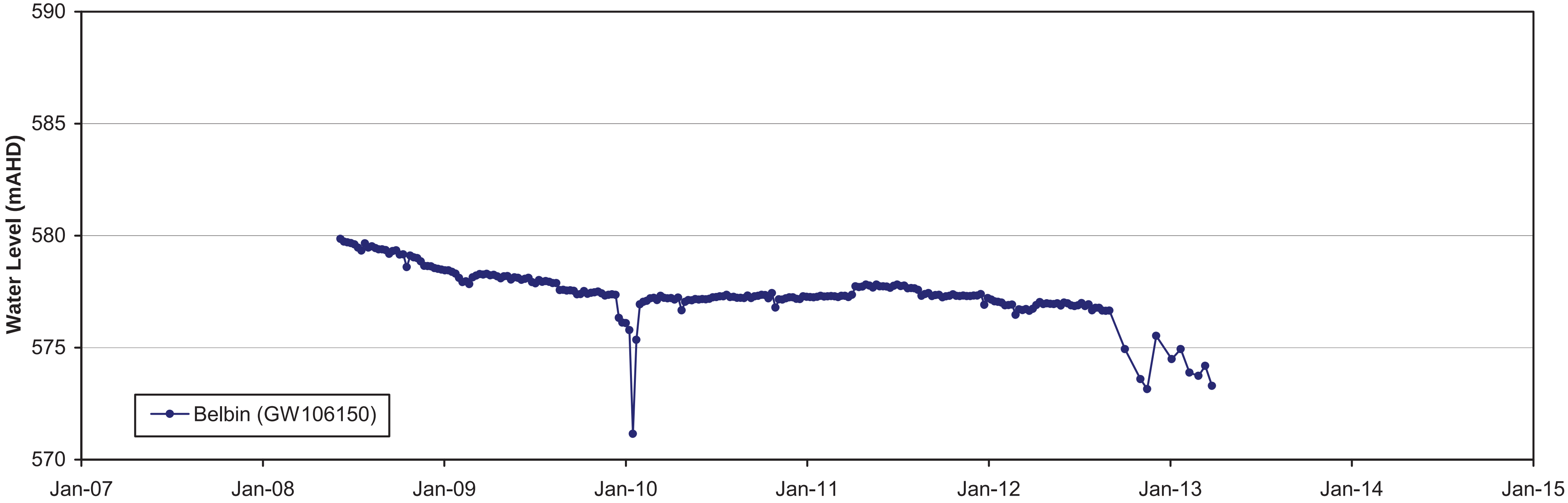

HU_143 (and HU_133)
Water Level (mAHD)
630
625
620
615
610
HU_133A
HU_143A
HU_133B
HU_143B
HU_133C
HU_143C
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016


GW106710 and GW106652
Water Level (mAHD)
640
630
620
610
600
590
Water level at installation
(21/10/2004): 596mAHD
GW106710
GW106652
Jan-2011
Jan-2012
Jan-2013
Jan-2014
Jan-2015
Jan-2016

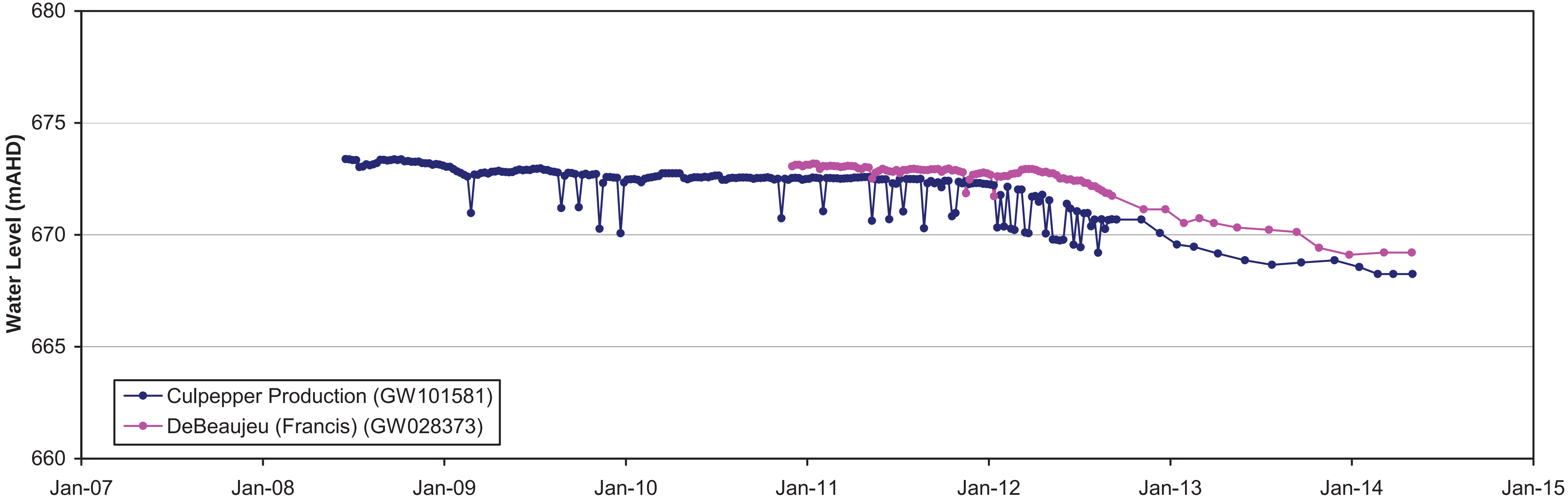

HU_40 (VWP)
Hydraulic Head (mAHD)
640
635
630
625
620
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
HU_40_1
HU_40_2
HU_40_3
HU_40_4


HU_77 (VWP)
Hydraulic Head (mAHD)
645
640
635
630
625
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
HU_77_1
HU_77_2
HU_77_3

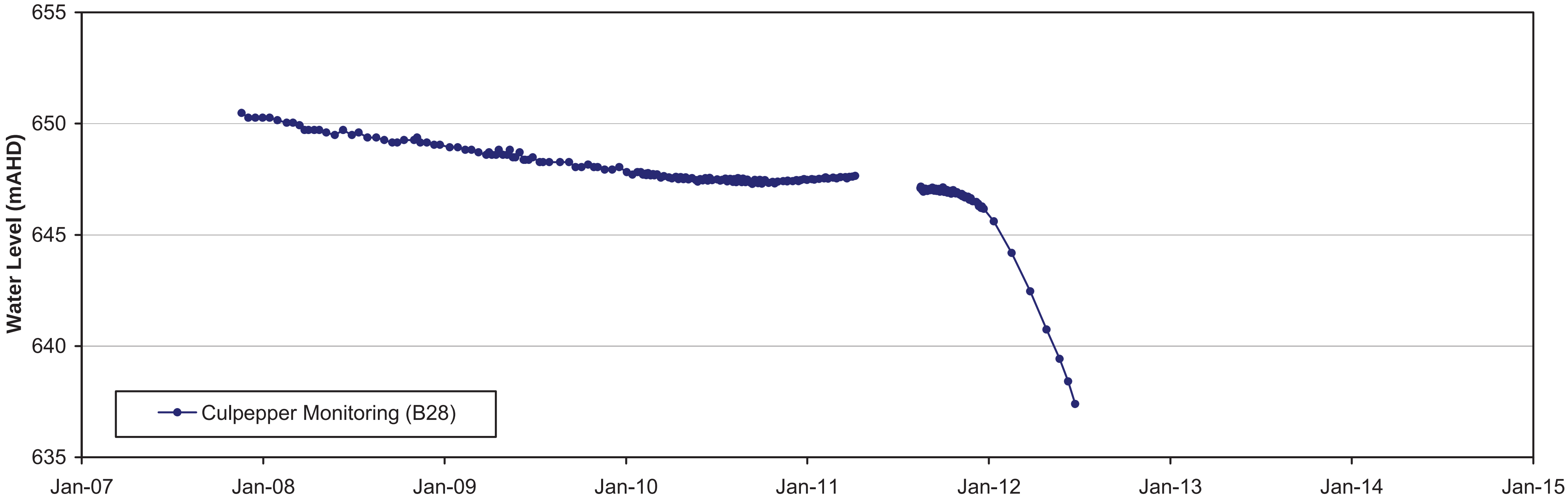

HU_122 (VWP)
Hydraulic Head (mAHD)
640
635
630
625
620
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
HU_122_1
HU_122_2
HU_122_3
HU_122_4



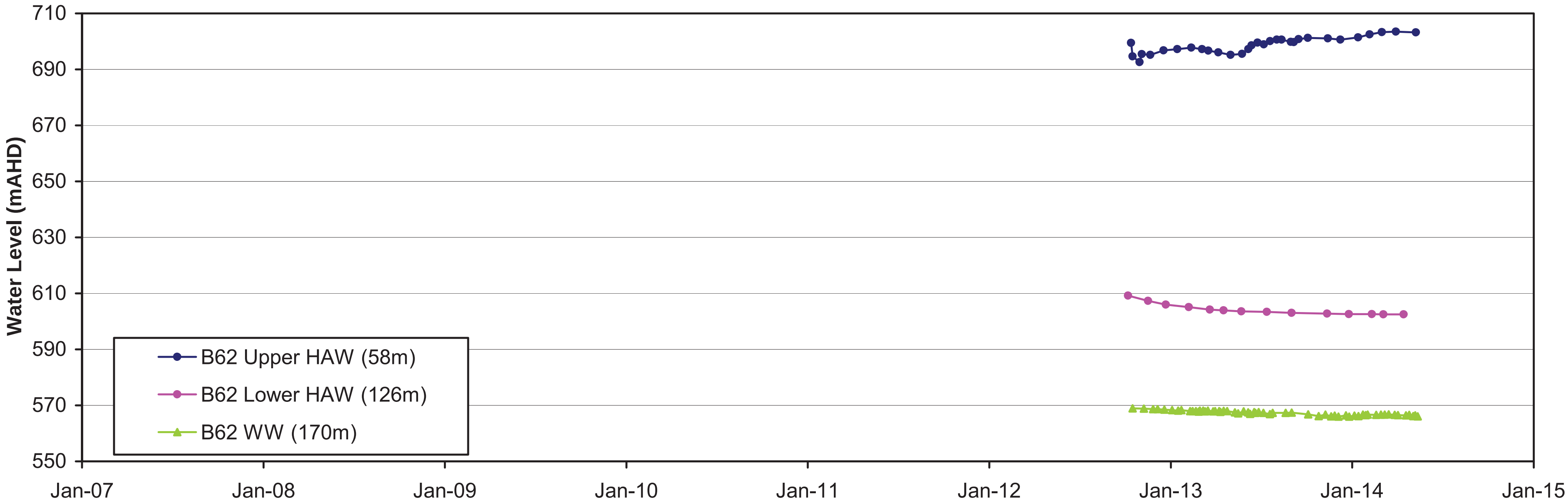
Water Level (mAHD)
590
585
580
575
570
Belbin (GW106150)
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15



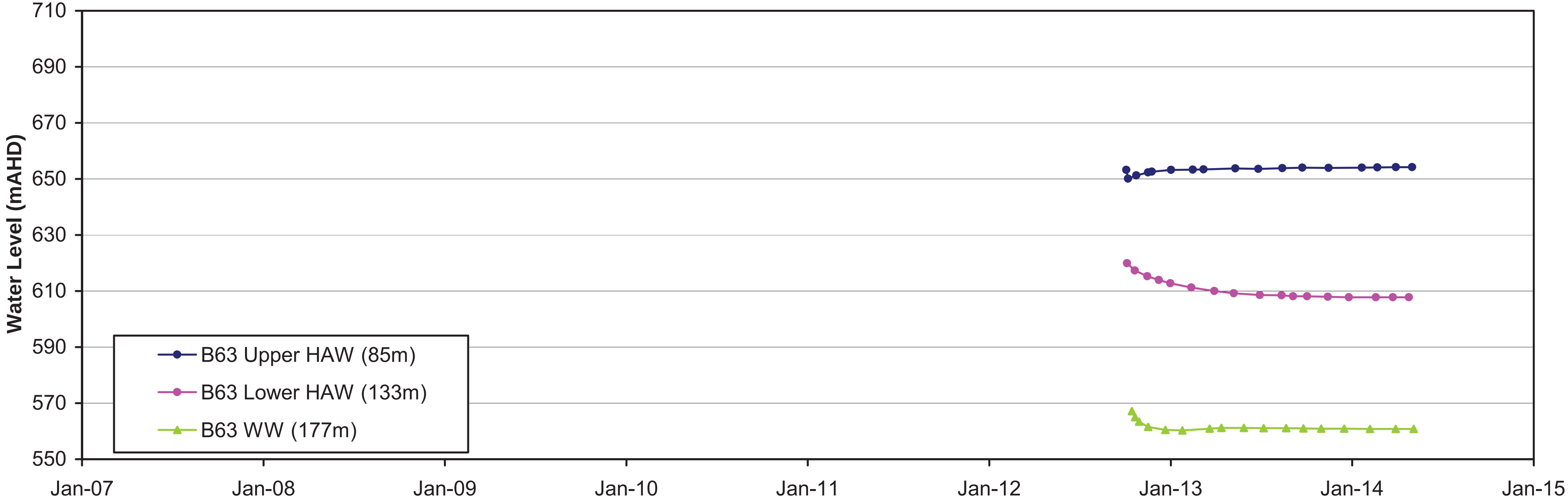
Water Level (mAHD)
680
675
670
665
660
Culpepper Production (GW101581)
DeBeaujeu (Francis) (GW028373)
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15



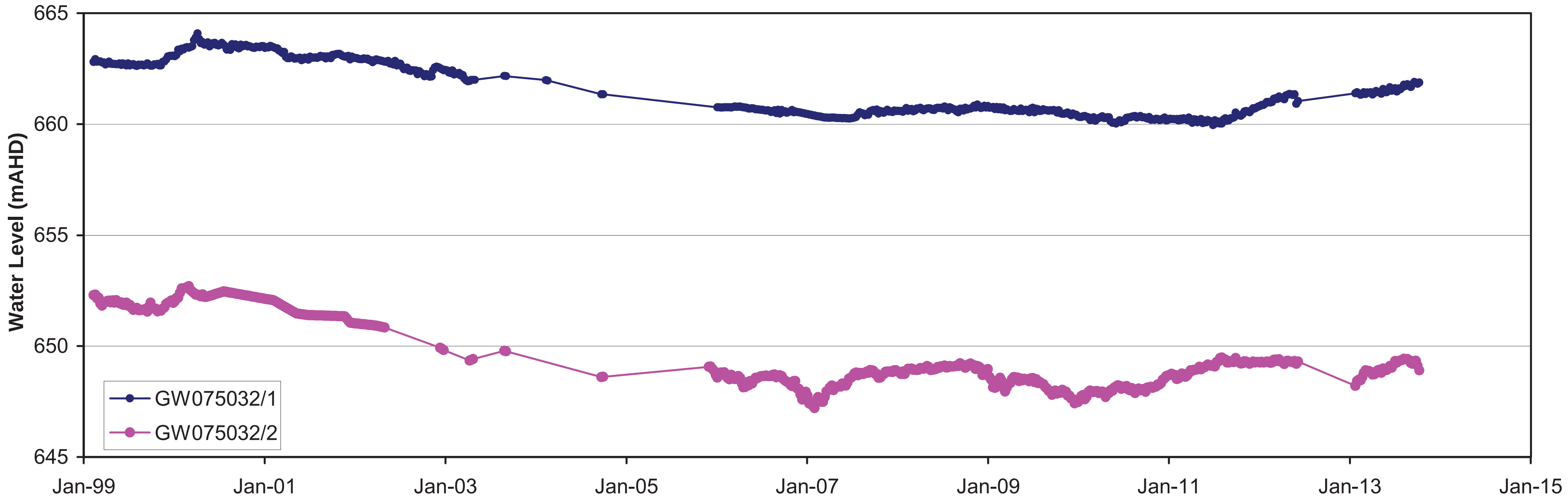
655
650
645
640
635
Water Level (mAHD)
Culpepper Monitoring (B28)
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15



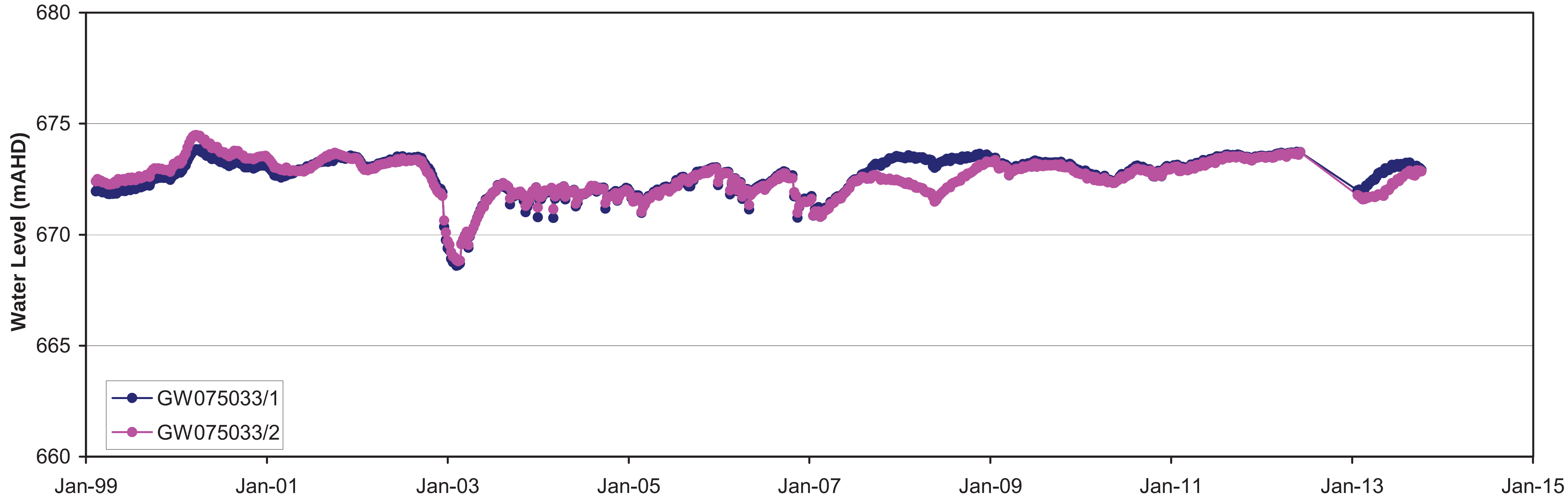
710
690
670
650
630
610
590
570
550
Water Level (mAHD)
B62 Upper HAW (58m)
B62 Lower HAW (126m)
B62 WW (170m)
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15



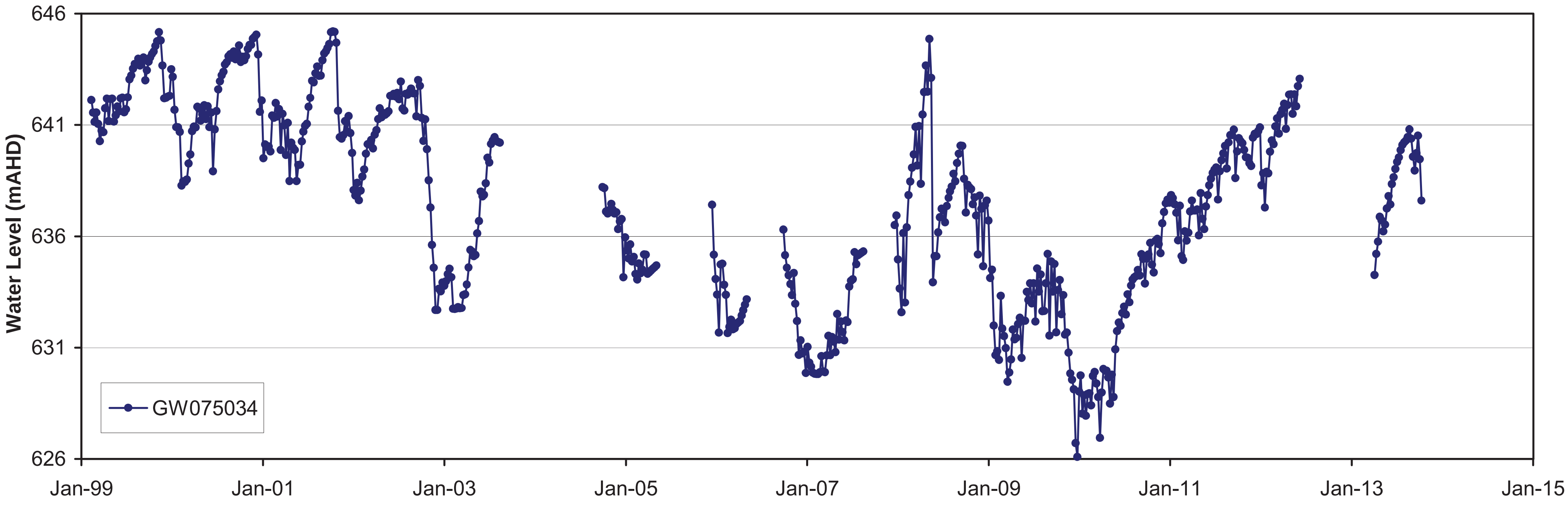
710
690
670
650
630
610
590
570
550
Water Level (mAHD)
B63 Upper HAW (85m)
B63 Lower HAW (133m)
B63 WW (177m)
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15



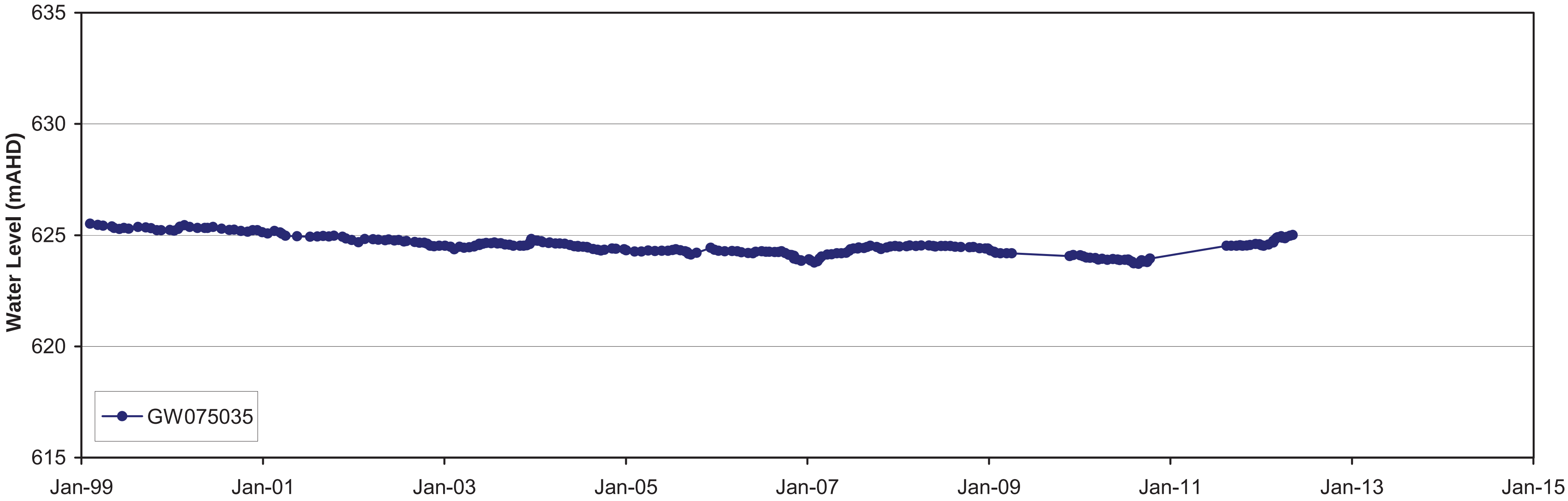
665
660
655
650
645
Water Level (mAHD)
GW075032/1
GW075032/2
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15



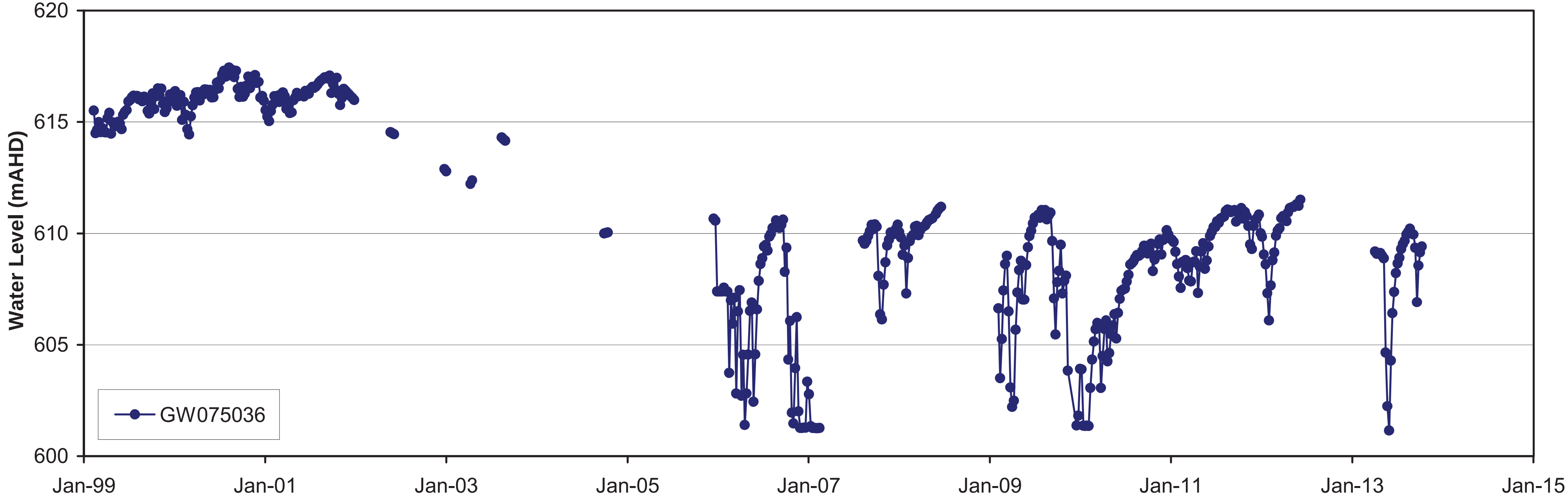
680
675
670
665
660
Water Level (mAHD)
GW075033/1
GW075033/2
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15



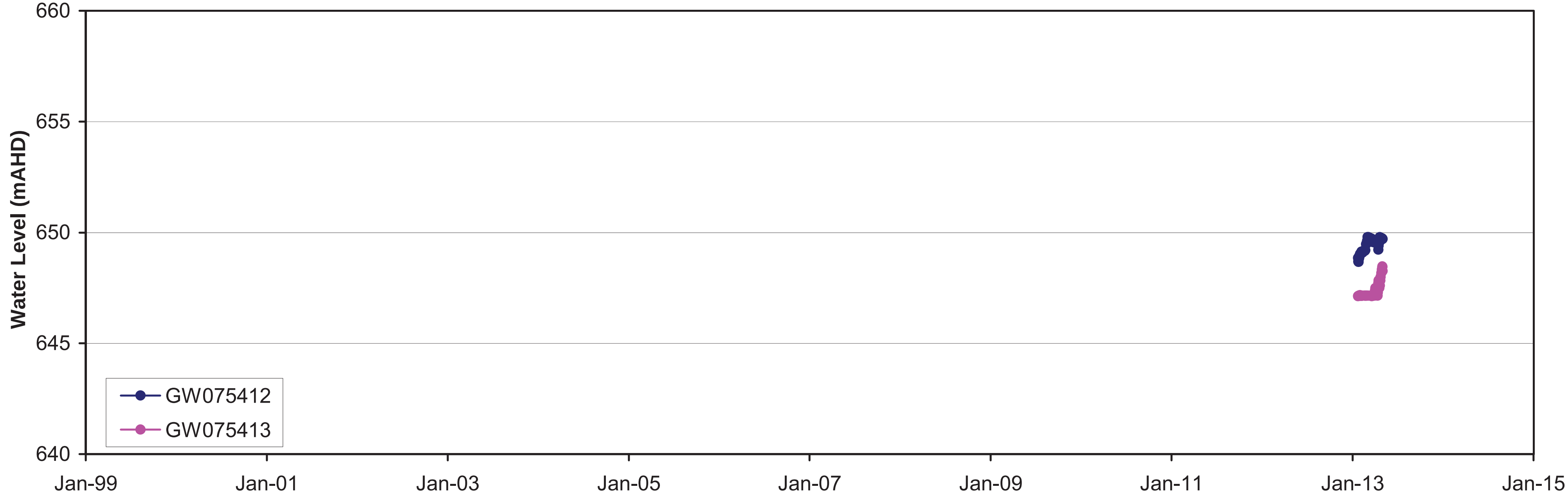
646
641
636
631
626
Water Level (mAHD)
GW075034
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15



635
630
625
620
615
Water Level (mAHD)
GW075035
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15

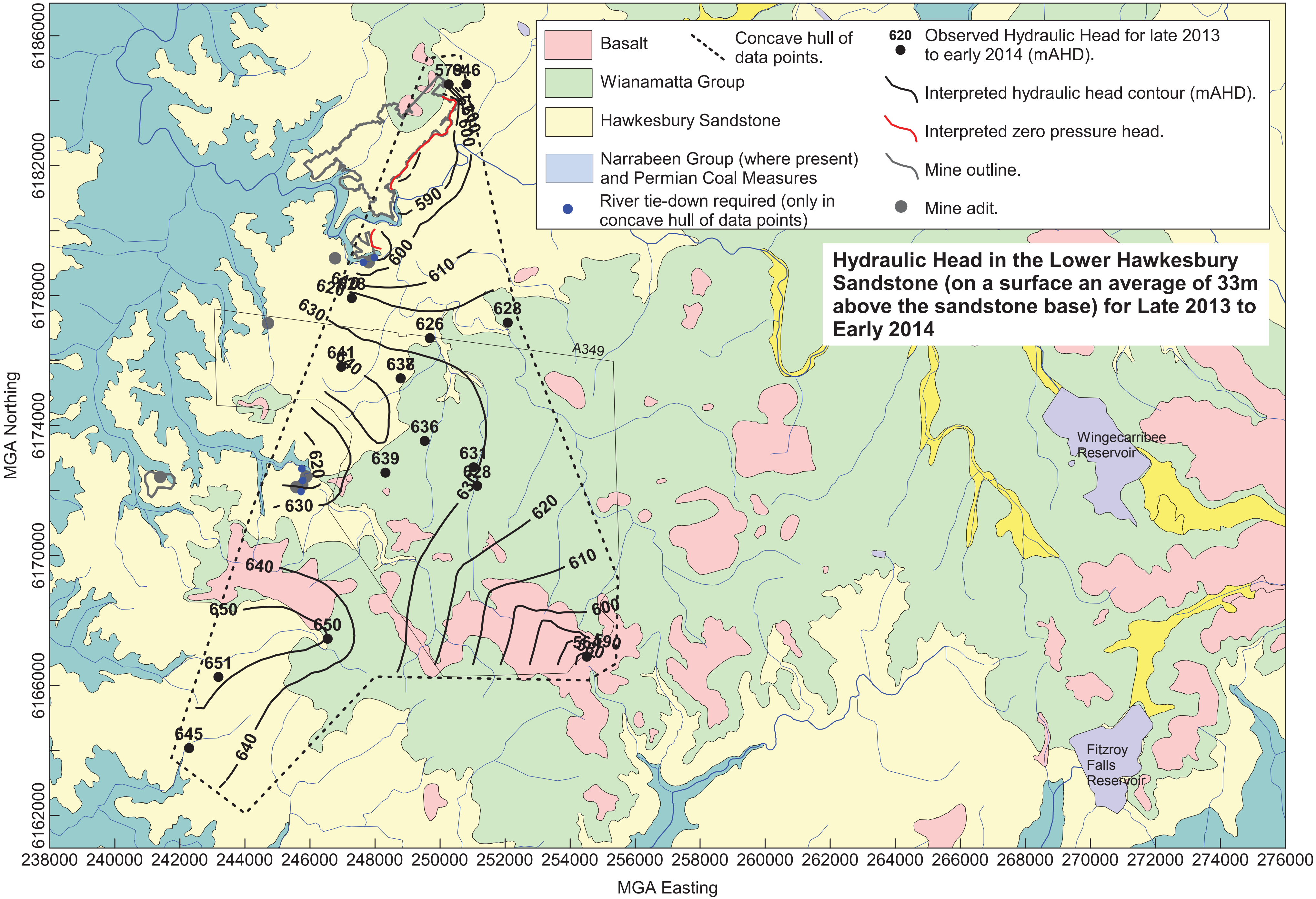


620
615
610
605
600
Water Level (mAHD)
GW075036
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15

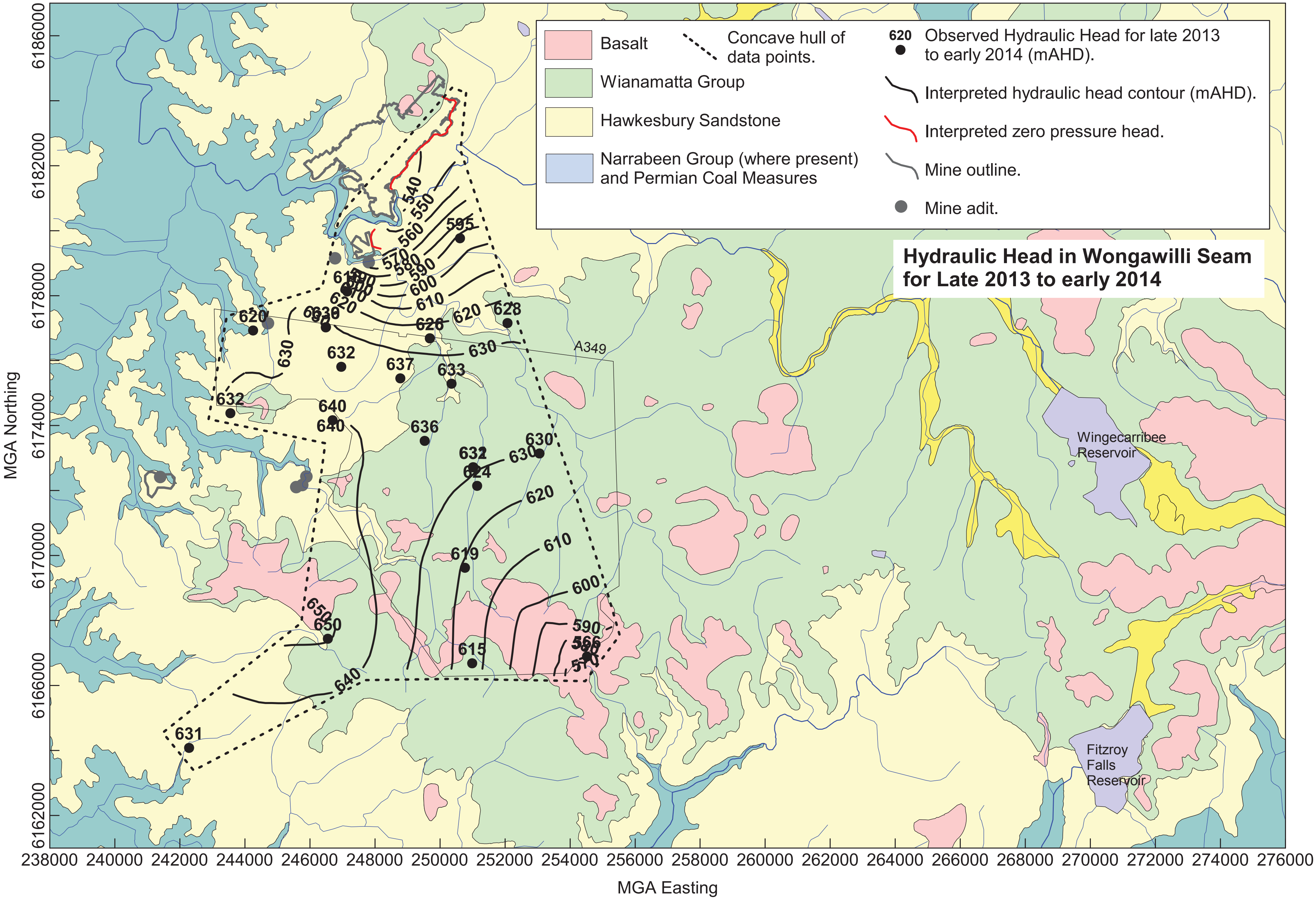


660
655
650
645
640
Water Level (mAHD)
GW075412
GW075413
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Jan-11
Jan-13
Jan-15

Appendix E - Hydraulic Head Surfaces



Basalt
Wianamatta Group
Hawkesbury Sandstone
Narrabeen Group (where present) and Permian Coal Measures
River tie-down required (only in concave hull of data points)
Concave hull of data points.
620 Observed Hydraulic Head for late 2013 to early 2014 (mAHD).
Interpreted hydraulic head contour (mAHD).
Interpreted zero pressure head.
Mine outline.
Mine adit.
Hydraulic Head in the Lower Hawkesbury Sandstone (on a surface an average of 33m above the sandstone base) for Late 2013 to Early 2014
A349
Wingecarribee Reservoir
Fitzroy Falls Reservoir
MGA Northing
MGA Easting
6162000
6166000
6170000
6174000
6178000
6182000
6186000
238000
240000
242000
244000
246000
248000
250000
252000
254000
256000
258000
260000
262000
264000
266000
268000
270000
272000
274000
276000



Hydraulic Head in Wongawilli Seam for Late 2013 to early 2014
Basalt
Wianamatta Group
Hawkesbury Sandstone
Narrabeen Group (where present) and Permian Coal Measures
Concave hull of data points.
620 Observed Hydraulic Head for late 2013 to early 2014 (mAHD).
Interpreted hydraulic head contour (mAHD).
Interpreted zero pressure head.
Mine outline.
Mine adit.
Wingecarribee Reservoir
Fitzroy Falls Reservoir
A349
MGA Northing
MGA Easting
6162000
6166000
6170000
6174000
6178000
6182000
6186000
238000
240000
242000
244000
246000
248000
250000
252000
254000
256000
258000
260000
262000
264000
266000
268000
270000
272000
274000
276000

Appendix F - Hydraulic Head Data for the Southeastern Basalt Body

DATABASE OF WATER LEVELS IN AND AROUND THE SOUTHEASTERN BASALT BODY

Bore	Easting (MGA)	Northing (MGA)	Network	Stratum	Ground Elevation* (mAHD)	Water Level (mAHD)	Probable date of water level measurement	Pressure Head (m)	Height above base of HAW (m)
GW011262	252352	6166970	Private	Basalt	723	719	1-Dec-55	5	170
GW014121	252487	6166696	Private	Basalt	724	716	1-Dec-56	14	158
GW014491	253454	6166753	Private	Basalt	730	721	1-Nov-56	7	180
GW015061	251024	6166459	Private	Basalt	702	701	1-Dec-56	12	134
GW050251	252889	6166923	Private	Basalt top (weathered)	733	728	1-Feb-79	9	180
GW066761	253508	6166662	Private	Basalt	725	721	16-Oct-92	7	180
GW066764	254253	6166435	Private	Basalt	712	698	Unknown	5	167
GW066769	254252	6166466	Private	Basalt	711	704	Unknown	9	170
GW066770	254362	6166160	Private	Basalt	710	700	Unknown	12	162
GW067521	253702	6168715	Private	Basalt	683	665	28-Jan-92	9	137
GW069007	254188	6166419	Private	Basalt	712	702	4-Nov-91	13	163
GW069118	253610	6166800	Private	Basalt	727	709	25-Feb-91	6	171
GW072154	253249	6166401	Private	Basalt	717	707	17-Jan-94	10	157
GW072273	253044	6166546	Private	Basalt (weathered)	724	720	31-Jan-92	11	168
GW072416	252451	6166806	Private	Basalt	723	716	24-Nov-94	8	165
GW100256	254259	6166306	Private	Basalt (weathered)	712	704	10-Aug-93	11	166
GW100257	254231	6166339	Private	Basalt / Sandstone	712	701	12-Aug-93	13	162
GW101324	254223	6166588	Private	Basalt	712	705	26-Sep-95	4	175
GW101421	254321	6165789	Private	Basalt	712	703	13-Mar-96	14	159
GW102401	254158	6166186	Private	Basalt / Shale	719	705	20-Dec-96	32	145
GW102621	254577	6166721	Private	Basalt	716	703	11-Dec-98	8	172
GW102622	254626	6166784	Private	Basalt	719	707	13-Nov-98	20	165
GW102623	254576	6166752	Private	Basalt	716	705	15-Nov-98	12	171
GW102624	254548	6166844	Private	Basalt	719	708	18-Nov-99	6	179
GW102964	253499	6166812	Private	Basalt	730	715	1-Jan-56	4	178
GW104193	255989	6167862	Private	Basalt	686	680	13-Feb-02	15	164
GW104198	252443	6166728	Private	Basalt base	724	713	5-Feb-02	13	156
GW105097	253767	6167150	Private	Basalt / Sandstone	727	567	31-Oct-03	37	1
GW106103	253879	6167685	Private	Basalt base	717	690	27-Feb-04	20	143
GW107625	252749	6166539	Private	Basalt	723	716	15-Nov-05	12	161
GW108271	254281	6167270	Private	Basalt base	717	702	26-Aug-06	47	132
GW100720	253419	6166882	Private	HAW below Basalt	735	572	20-Oct-96	24	14
GW102694	253410	6168417	Private	HAW below Basalt	707	618	1-Sep-99	44	48
GW102757	251971	6167918	Private	HAW below Basalt	716	617	5-May-99	55	19

Bore	Easting (MGA)	Northing (MGA)	Network	Stratum	Ground Elevation* (mAHD)	Water Level (mAHD)	Probable date of water level measurement	Pressure Head (m)	Height above base of HAW (m)
GW104727	252108	6169089	Private	HAW below Basalt	720	619	25-Mar-03	37	47
GW104917	255641	6168126	Private	HAW below Basalt	676	611	28-Nov-02	64	43
GW105093	252884	6165950	Private	HAW Base / Top ICM	702	576	19-Nov-03	25	4
GW105308	250384	6167628	Private	HAW below Basalt	713	630	1-Mar-02	47	31
GW105950	254257	6167973	Private	HAW Base / Top ICM	684	612	1-Jan-04	53	39
GW110529	251309	6166226	Private	HAW Base / Top ICM	705	585	29-Oct-09	34	-3
H136A	254521	6166894	Hume	WW	718	566	22-May-14	47	-4
H136B	254517	6166890	Hume	HAW	718	564	22-May-14	7	34
H136C	254513	6166887	Hume	RB	718	708	22-May-14	44	140
H42A	250988	6166688	Hume	WW	702	615	23-Mar-14	70	-7
H42C	250985	6166678	Hume	HAW	702	613	21-Aug-14	54	7

* Approximate for private bores (estimated from overplotting with digitial elevation model).