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By email
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Dear Nicola

Update on the Camden North Phase 2 Groundwater Program - Denham Court Road

AGL Energy Ltd (AGL) is planning to expand the Camden gas production wellfield from Permian coal measures in the Camden North area, within PEL 2 and PPL5 areas. The target coal seams are typically within the Illawarra coal measures at depths of approximately 700 m below ground level (mbgl). Parsons Brinckerhoff was engaged to investigate the hydrogeological environment to characterise the groundwater systems, and to assess the value of the groundwater resources and the possible connectivity between Triassic aquifers and Permian coal seams targeted for coal seam gas (CSG) extraction in the Camden North area.

1. Phase 1 Groundwater Assessment and Conceptual Hydrogeological Model

The Phase 1 Groundwater Assessment and Conceptual Hydrogeological Model for the Northern Expansion of the Camden Gas Project (Parsons Brinckerhoff 2011), was a desktop study summarising information from a number of sources including the NSW Office of Water (NOW) groundwater database and the DIGS geological database, and previous reports and detailed drill logs supplied by AGL. The main conclusions from the Phase 1 investigation are:

- Groundwater is rarely used for consumptive uses across the area given the urbanisation and the availability of reticulated water supplies from Sydney Water.
- The available hydrogeological data for the region suggest that the groundwater systems of the project area are:
  - Alluvial aquifer system
  - Hawkesbury Sandstone aquifer system
  - Narrabeen Group aquifer system
  - Illawarra coal measures.

- The Hawkesbury Sandstone is the main aquifer across the expansion area, with minor aquifers in the Narrabeen Group sandstones. The coal seams are low permeability water bearing zones and are not useful aquifers for supply purposes.
- Available water quality data suggests distinct differences in water chemistry and isolation of each of these aquifer zones. The groundwater quality in aquifer systems in the study area is highly variable, ranging from fresh (below 300 mg/L TDS) to slightly salty (up to 7,500 mg/L TDS). Groundwater quality is generally brackish to salty in the shallow Wianamatta Group shales, while the most saline groundwater generally occurs in the deeper Permian coal seams.
- Groundwater resources are characterised by low yields from the Hawkesbury Sandstone and alluvial aquifers. Negligible yields characterise the Ashfield Shale and coal measures.
- It is anticipated that the presence of extensive and thick claystone formations in the stratigraphic sequence that overlies the Illawarra coal measures in the project area will impede the vertical flow of groundwater such that overlying aquifer zones will be hydraulically isolated, experiencing little, if any drawdown impact related to depressurisation of the coal measures. However the possibility cannot be ruled out that major fault zones could provide a hydraulic pathway through claystone horizons and that some shallow groundwater impacts may be observed close to those structures.

The Phase 1 assessment also facilitated the development of a conceptual model that provided a characterisation of the groundwater systems in the Camden North area (Figure 1).

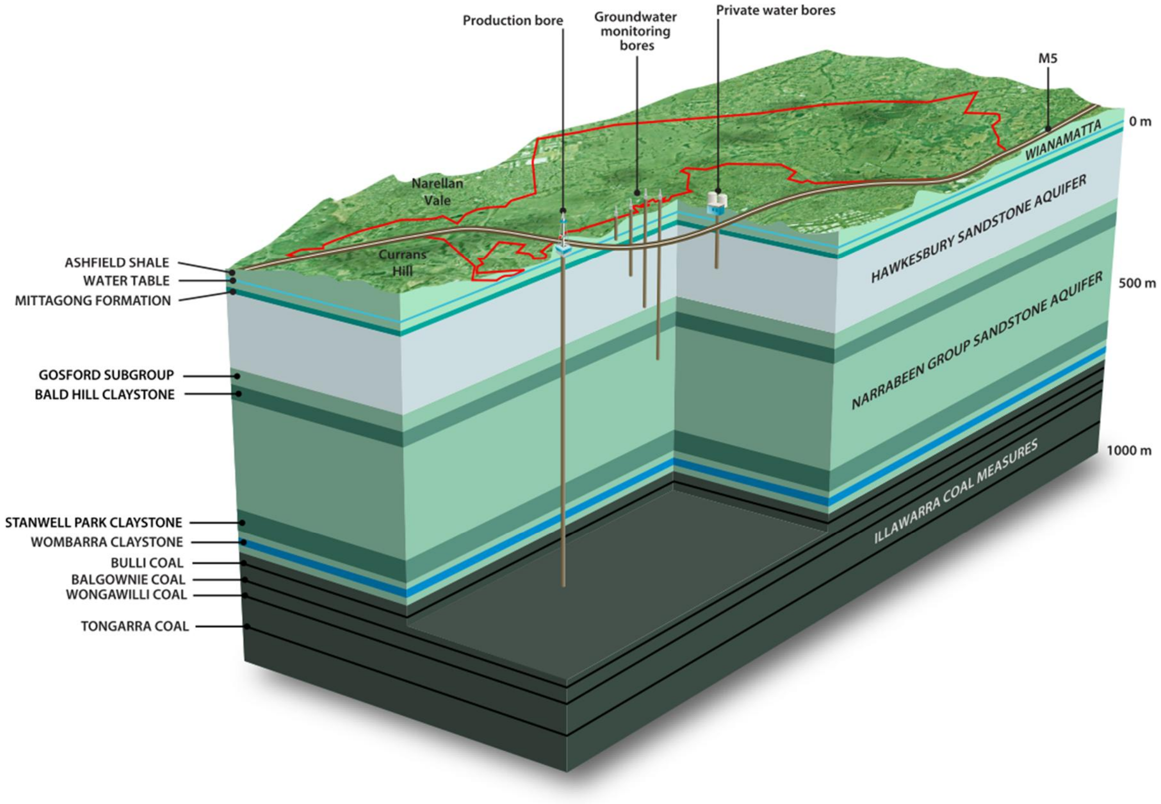

Figure 1 Schematic of the Camden Northern Expansion area showing the key components of the project

2. Phase 2 Groundwater Investigations

The Phase 2 Groundwater Investigations currently comprise the installation of a groundwater monitoring network of three bores, and subsequent groundwater quality and level monitoring at AGL's Raby Site, Denham Court Road, Denham Court. The objective of the drilling was to establish dedicated monitoring bores in the shallowest aquifer (Ashfield Shale) and the main water supply aquifers (Hawkesbury Sandstone) so as to obtain baseline water level and water quality prior to any coal seam gas development.

Environmental and radiogenic isotope sampling has been carried out to verify and enhance the understanding of aquifer characteristics and the hydrogeological conceptual model. The Phase 2 Groundwater Investigations were undertaken during October and November 2011, and the preliminary findings from this investigation are detailed below.

2.1 Bore completions

The groundwater monitoring bore installation program was undertaken between 4 October and 19 October 2011. The drilling of the groundwater monitoring bores was undertaken by Highland Drilling using an air rotary drilling rig supervised by Parsons Brinckerhoff hydrogeologists. The drilling and construction of the groundwater monitoring bores was carried out in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (ARMCANZ 2003). Figure 2 details the bore locations and Table 1 and Figure 3 summarise the bore construction details.

Table 1 Groundwater monitoring bore construction details

Monitoring Bore	Location	Total depth (m)	Screened interval (mbgl)	Lithology	Casing material	Formation
RMB01	Raby Site	84	69 – 81 (12 m)	Siltstone	50 mm, class 18 u PVC, screwed casing	Wianamatta Group, Ashfield Shale
RMB02	Raby Site	150	135 – 147 (12 m)	Sandstone	50 mm, class 18 u PVC, screwed casing	Upper Hawkesbury Sandstone
RMB03	Raby Site	300	290 – 299 (9 m)	Sandstone	50 mm, galvanised / stainless steel, screwed casing	Lower Hawkesbury Sandstone

The groundwater monitoring bores were drilled through the following Triassic formations within the Sydney Basin: Ashfield Shale, Mittagong Formation and Hawkesbury Sandstone. Some shale lenses, up to 7 metres thick, were observed in the Hawkesbury Sandstone.

Minor seeps were only encountered in the Ashfield Shale at depth. Groundwater was encountered in the Hawkesbury Sandstone (starting at approximately 108 – 114 mbgl) and minimal flows were recorded throughout (a maximum value of 0.9 litres per second when airlifting). No fractures were encountered during drilling and therefore groundwater flow is assumed to be via primary permeability. There are no major fault zones in this area.

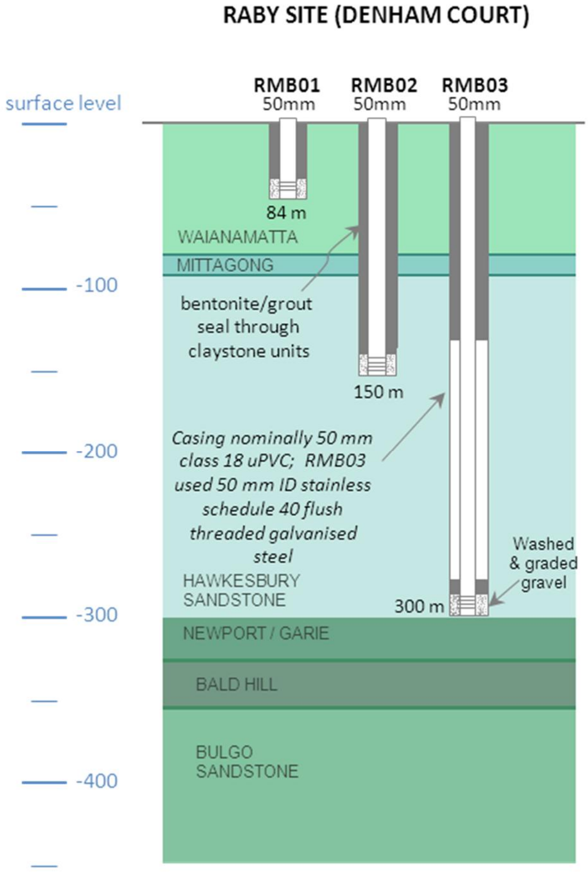

Figure 3 Nested groundwater monitoring bores at Denham Court

2.2 Survey

The groundwater monitoring bore locations were surveyed by registered surveys (SMEC Pty Ltd) to MGA, a grid coordinate system based on the Geocentric Datum of Australia 1994. The bores were also surveyed for surface elevation to Australian Height Datum (AHD). The survey results are detailed in Table 2.

Table 2 Monitoring bore coordinates and elevations

Monitoring Bore	Easting	Northing	Ground level (mAHD)	Top of casing (mAHD)
RMB01	300465.86	6237305.08	72.42	72.94
RMB02	300474.93	6237308.70	72.80	73.34
RMB03	300481.29	6237310.92	73.00	73.54

2.3 Groundwater levels

Solinst Levelogger (M30) dataloggers are installed in each monitoring bore, programmed to record water levels at 6 hourly intervals. A hydrographs showing fluctuations in groundwater level from November 2011 to June 2012 within each bore is shown in Figure 4. Individual hydrographs are attached in Appendix A.

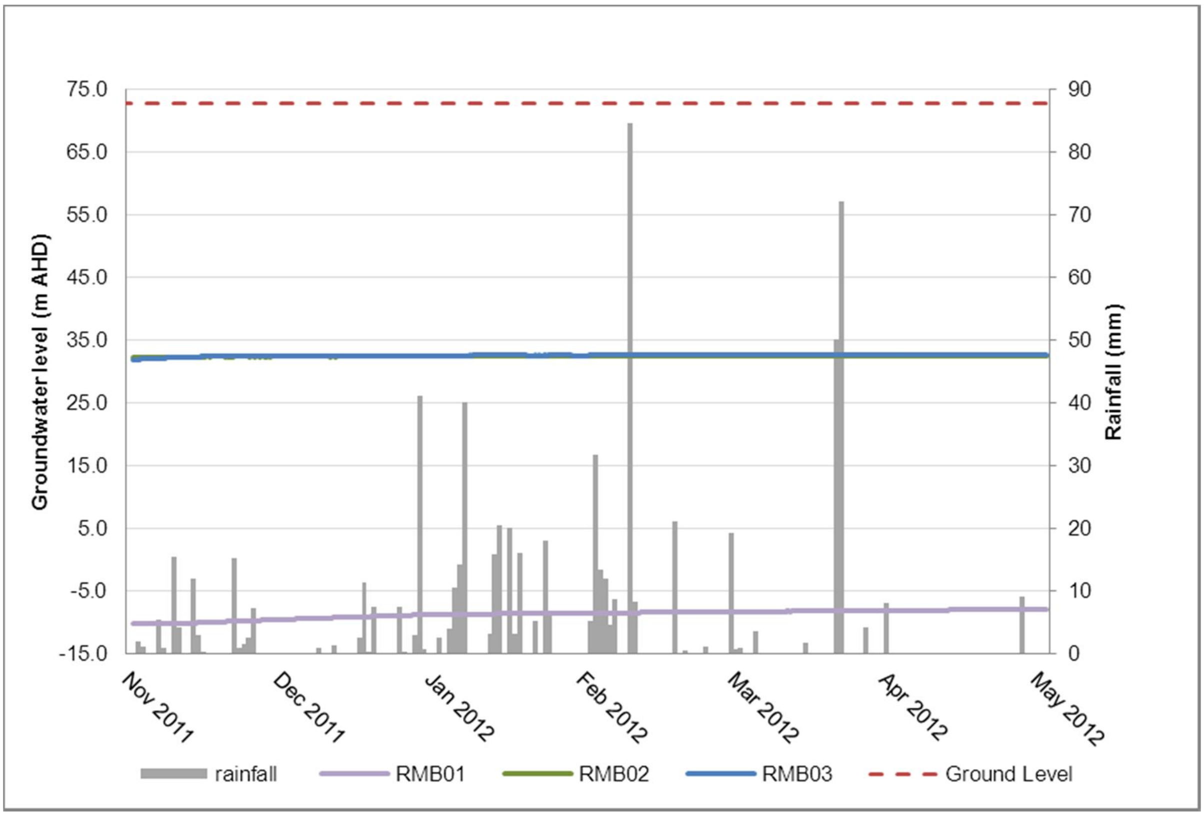

Figure 4 Groundwater levels in the Denham Court monitoring bores.

2.4 Groundwater quality

The monitoring bores were sampled between 3 and 7 November 2011. (Note that RMB01 was not sampled as there was insufficient groundwater in the bore to obtain a representative sample).

A micro-purge™ low flow sampling system was deployed allowing a representative groundwater sample to be drawn into the pump intake directly from the screened portion of the sandstone aquifer. Water levels and water quality parameters were monitored with a calibrated YSI water quality meter during the micro-purge™ pumping to ensure that a representative groundwater sample was collected. Samples were sent to Australian Laboratory Service (ALS) Environmental Pty Ltd for laboratory testing. ALS is certified by the National Association of Testing Authorities (NATA) for all analytes tested.

Isotope sampling was also undertaken to enhance the hydrogeological conceptual model. The isotope testing laboratories; Rafter Radiocarbon Laboratory and GNS Science Stable Isotope Laboratory are located overseas and are not NATA certified but have been principal isotope laboratories for over three decades.

Table 4 details the analytical results from the groundwater quality sampling event.

Table 4 Groundwater and farm dam quality (October and November 2011)

Parameters	Units	ANZECC (2000) guidelines[a]	RMB02	RMB03	SW1	SW2
Date			**3/11/11**	**7/11/11**	**20/10/2011**	**20/10/2011**
Field water quality parameters						
EC	µS/cm	125-2200*	**9517**	**5713**	182	151
pH	pH units	6.0 – 8.0*	6.52	7.42	7.78	**8.93**
Temperature	^{0}C	-	27.55	na	24.82	25.02
Dissolved oxygen	% sat	80-110*	**5.8**	**5.6**	**111.6**	**112.5**
Redox	mV	-	-10	-136	-5.8	-71.4
Laboratory water quality parameters						
Major ions						
Calcium	mg/L	-	121	385	9	5
Magnesium	mg/L	-	40	95	6	5
Sodium	mg/L	-	1580	2090	27	17
Potassium	mg/L	-	25	35	2	9
Chloride	mg/L	-	2350	3980	20	18
Sulfate	mg/L	-	39	86	2	2
Total alkalinity as $CaCO_3$	mg/L	-	606	743	72	47
Silica	mg/L	-	10	15.6	na	na
Water type			Na-Cl	Na-Cl		
Metals[c]						
Aluminium	mg/L	0.055	<0.01	<0.01	na	na
Arsenic	mg/L	0.013	0.006	0.009	<0.001	0.001
Beryllium	mg/L	ID	<0.001	<0.001	na	na
Barium	mg/L	-	5.44	1.18	na	na
Cadmium	mg/L	0.37	<0.0001	<0.001	<0.0001	<0.0001
Cobalt	mg/L	ID	0.006	0.004	na	na
Copper	mg/L	0.0014	**0.005**	**0.003**	**0.003**	**0.004**
Lead	mg/L	0.0034	<0.001	<0.001	<0.001	<0.001
Manganese	mg/L	1.9	0.085	0.116	0.007	0.044
Mercury	mg/L	0.0006	na	na	<0.0001	<0.0001
Molybdenum	mg/L	ID	0.014	0.001	na	na
Nickel	mg/L	0.011	**0.018**	0.009	0.001	0.002
Selenium	mg/L	0.011	<0.01	<0.01	na	na
Strontium	mg/L	-	5.78	10.8	na	na
Uranium	mg/L	ID	<0.001	0.016	na	na
Vanadium	mg/L	ID	<0.01	<0.01	na	na

Parameters	Units	ANZECC (2000) guidelines[a]	RMB02	RMB03	SW1	SW2
Zinc	mg/L	0.008	**12**	**0.624**	**0.027**	**0.058**
Boron	mg/L	0.37	0.08	0.06	na	na
Iron	mg/L	ID	0.62	0.029	0.18	0.35
Bromine	mg/L	ID	4.9	7.9	na	na
Nutrients[c]						
Ammonia as N	mg/L	0.02*	**2.77**	**4.51**	na	na
Nitrite as N	mg/L		<0.01	<0.01	na	na
Nitrate as N	mg/L	0.7	0.02	<0.01	na	na
Total Phosphorus	mg/L	0.05*	<0.01	<0.01	na	na
Reactive phosphorus	mg/L	0.02*	<0.01	<0.01	na	na
Total Organic Carbon	mg/L	-	17	9	na	na
Gases						
Methane	µg/L	-	18200	10100	na	na
Phenolic compounds						
Phenol	µg/L		1.1	<1.0	na	na
Polycyclic aromatic compounds	µg/L		<LOR	<LOR	na	na
BTEX compounds	µg/L		<LORs	<LORs	<LORs	<LORs
Total petroleum hydrocarbons						
C_6-C_9	µg/L		<20	<20	<20	<20
C_{10}-C_{14}	µg/L		<50	<50	<50	<50
C_{15}-C_{28}	µg/L		210	460	<100	<100
C_{29}-C_{36}	µg/L		<50	<50	<50	<50
Isotopes						
Oxygen-18	‰	-	-6.06	-6.03	na	na
Deuterium	‰	-	-36.1	-36.4	na	na
Carbon-13	‰		5.4	8.4	na	na
$a^{14}C$	pMC		1.18±0.05	1.87±0.06	na	na
Carbon-14	Yrs BP	-	35620±370	31900±240	na	na

ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: 95% protection levels (trigger values).

[a] ANZECC (2000) guidelines for the protection of freshwater aquatic ecosystems: trigger values for lowland rivers in south-east Australia.

Bold indicates exceedance of guideline value.

The groundwater is characterised as slightly saline, with sodium (Na^+) and chloride (Cl^-) the dominant ions. pH conditions are circum-neutral. Dissolved metals concentrations are generally low and do not exceed ANZECC (2000) criteria with the exception of copper, nickel and zinc. Ammonia (as N) concentrations exceed ANZECC (2000) guideline criterion and dissolved methane concentrations are also elevated. Phenol was detected at concentrations just above the laboratory limit of reporting (LOR) in RMB02. No BTEX compounds or PAHs were detected. Total petroleum hydrocarbon (TPH) $C_{15}C_{29}$ were detected in both monitoring bores.

Stable isotopes indicate groundwater is of meteoric (rainfall) origin, and enriched carbon-13 values are indicative of methanogenesis. Uncorrected radiocarbon ages are >30,000 years BP are at the limits of the dating technique.

2.5 Surface water

A survey of two minor creeks adjacent to the monitoring site was undertaken on 20 October 2011. The creeks were traced from their upstream reaches to the confluence at the site boundary. Both creeks were dry with only minor standing water at the confluence. There were no spring zones evident along the creeks. The creeks are incised by a couple of metres and there is evidence of high run-off flows with tree debris along the dry gullies.

The two farm dams on the Raby site were also sampled on 20 October 2011. Water quality measurements were taken using a calibrated YSI water quality meter on site. The water quality field and some laboratory results are provided in Table 4.

The water quality is low salinity and pH conditions are alkaline. Geochemically the farm dam water is classified as mixed cation-chloride-bicarbonate type water. Dissolved metals concentrations are low and do not exceed ANZECC (2000) criteria with the exception of copper and zinc. The distinct geochemical differences between farm dams and groundwater from the Hawkesbury Sandstone suggest groundwater baseflow discharge into dams does not occur.

3. Initial conclusions and future works

The preliminary results of the Phase 2 groundwater investigation support the conceptual model presented in the Phase 1 report (PB 2011). In brief summary:

- Groundwater quality in all aquifers and water bearing zones is poor and of limited beneficial use
- Yields are low in all aquifers and do not constitute useful water supply sources
- Water levels are deep and there is no apparent interaction with the surface environment
- Groundwater quality in the Hawkesbury Sandstone is very different to the surface water quality in nearby farm dams indicating farm dams are not groundwater fed.
- No major fractures or faulting are present

The field investigation program is ongoing with hydraulic testing to assess the hydraulic conductivity of the aquifer formations, and ongoing water level monitoring.

Yours sincerely

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Parsons Brinckerhoff

References

ANZECC, 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality Volumes 3 and 4.* Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra

Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ), 2003. *Minimum Construction Requirements for Water Bores in Australia*.

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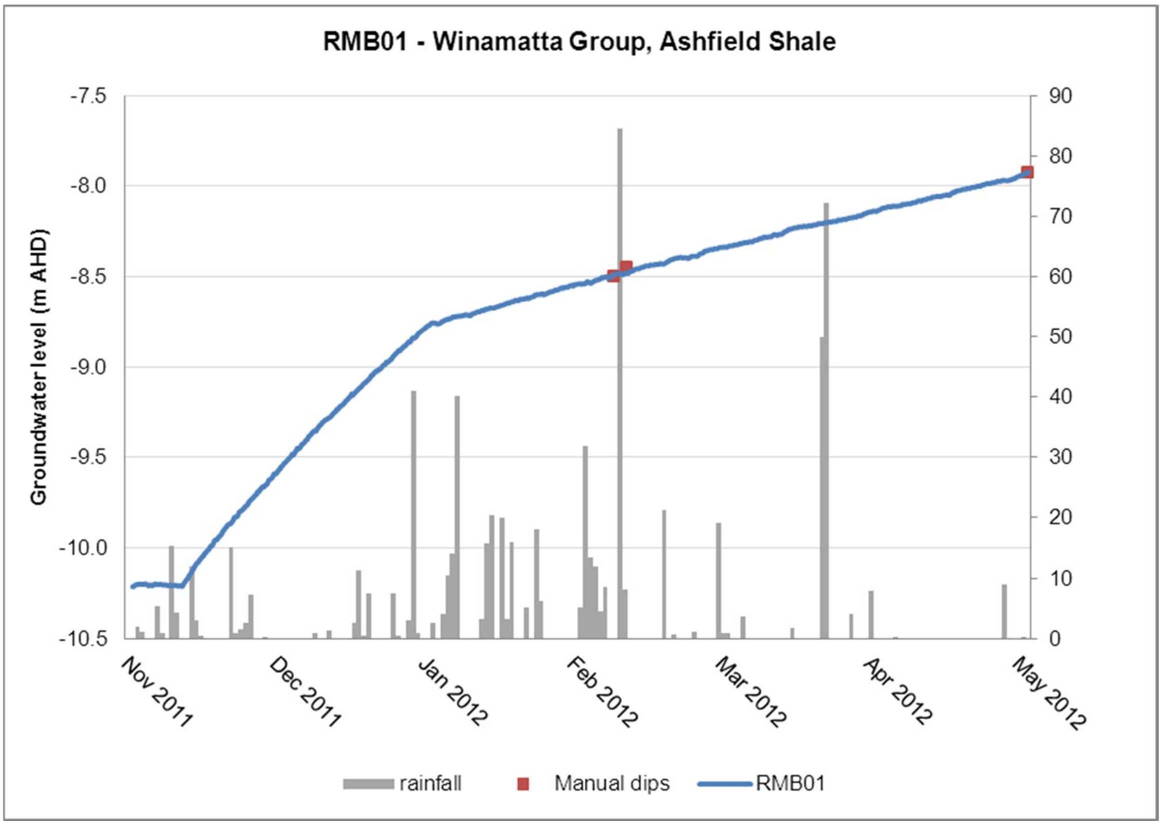
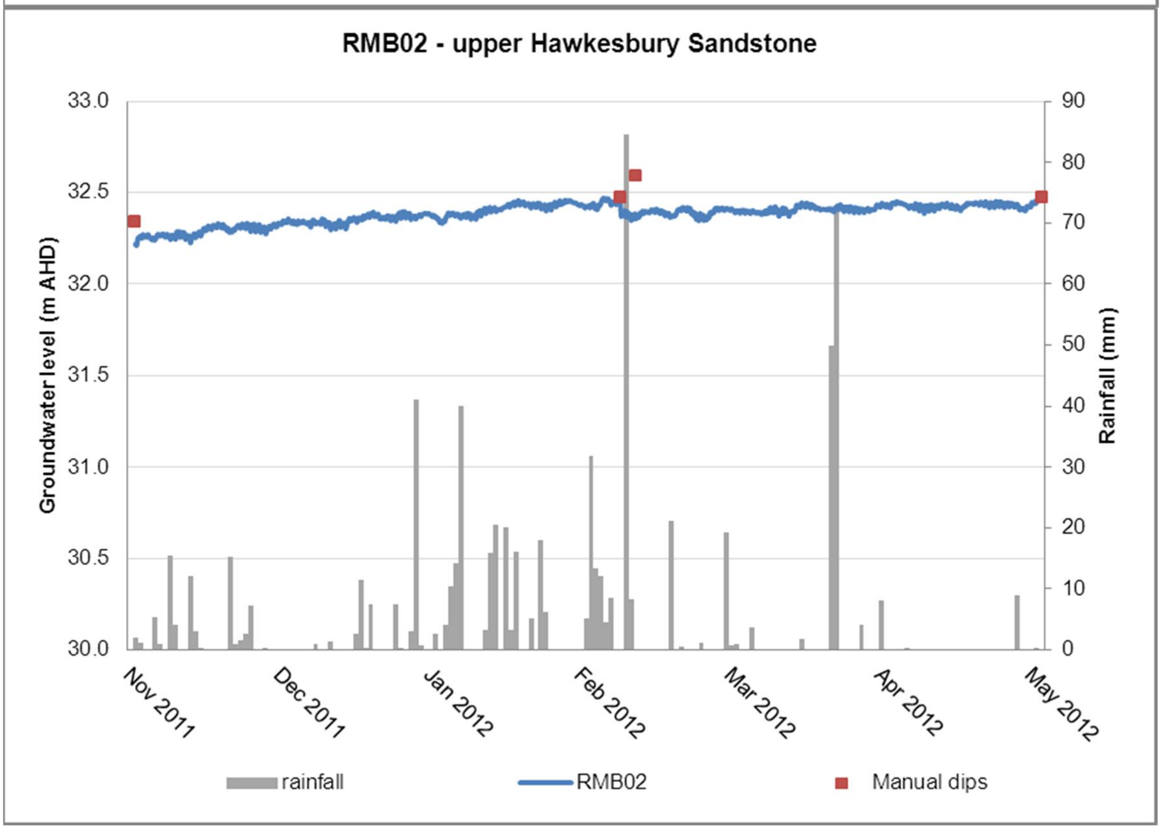
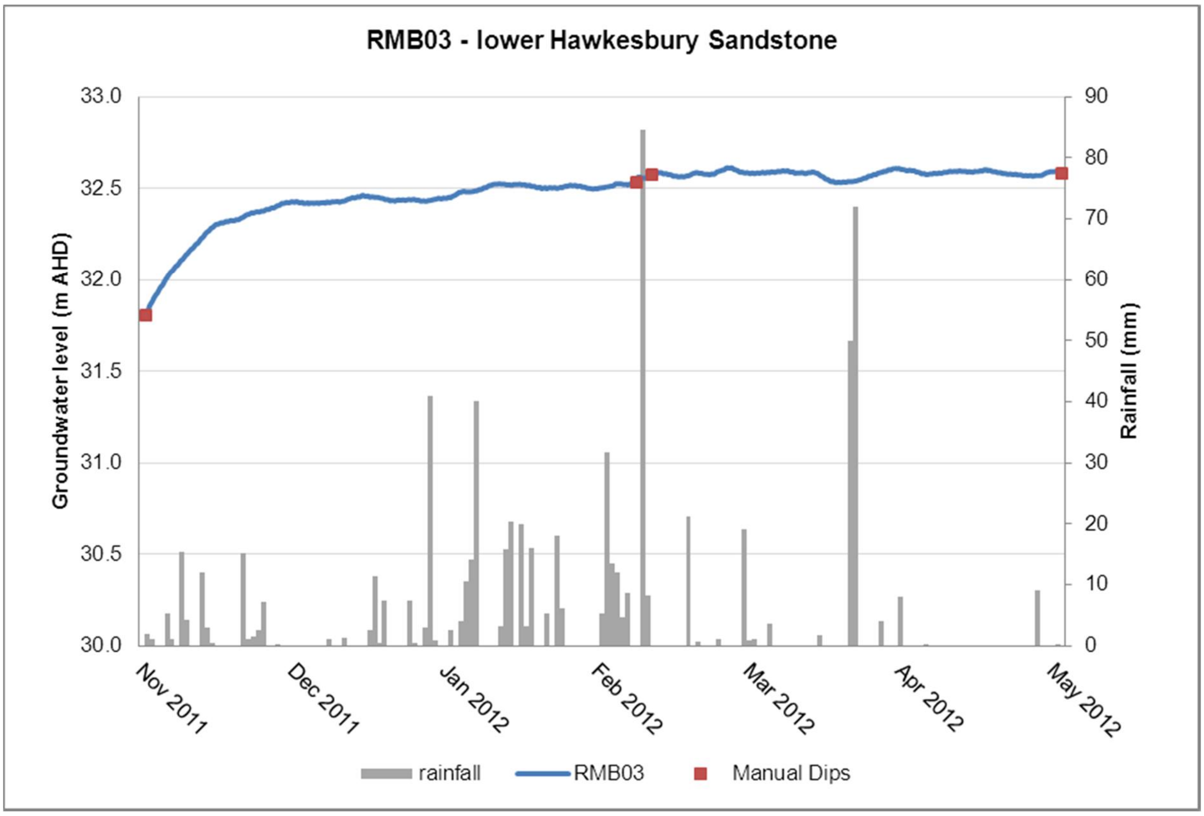
Appendix A – Hydrographs






RMB03 - lower Hawkesbury Sandstone
Groundwater level (m AHD)
Rainfall (mm)
33.0
32.5
32.0
31.5
31.0
30.5
30.0
90
80
70
60
50
40
30
20
10
0
Nov 2011
Dec 2011
Jan 2012
Feb 2012
Mar 2012
Apr 2012
May 2012
rainfall
RMB03
Manual Dips