Hydrogeological Summary of the Camden Gas Project area

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Glossary

Alluvial aquifer	Permeable zones that store and produce groundwater from unconsolidated alluvial sediments. Shallow alluvial aquifers are generally unconfined aquifers.
Alluvium	Unconsolidated sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on river beds, floodplains, and alluvial fans.
API	American Petroleum Institute
Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water.
Aquifer properties	The characteristics of an aquifer that determine its hydraulic behaviour and its response to abstraction.
Aquifer, confined	An aquifer that is overlain by low permeability strata. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.
Aquifer, semi-confined	An aquifer overlain by a low-permeability layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the confining layer – also known as a leaky artesian or leaky confined aquifer.
Aquifer, unconfined	Also known as a water table aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of an unconfined aquifer.
Aquitard	A low-permeability unit that can store groundwater and also transmit it slowly from one formation to another. Aquitards retard but do not prevent the movement of water to or from adjacent aquifers.
Baseline	The natural situation.
Beneficial aquifer	An aquifer that can produce water at a sufficient rate and quality for an identified consumptive use.
Bore	A structure drilled below the surface to obtain water from an aquifer/reservoir or series of aquifers.
bgl	Below ground level
Ca / Mg-HCO_3	Calcium / Magnesium, Bicarbonate
Casing	Steel pipe cemented in place during the construction process to stabilize the wellbore.
CGP	Camden Gas Project
Coal	A sedimentary rock derived from the compaction and consolidation of vegetation or swamp deposits to form a fossilised carbonaceous rock.

Coal seam	A layer of coal within a sedimentary rock sequence.
Coal seam gas (CSG)	Coal seam gas is a form of natural gas (predominantly methane) that is extracted from coal seams.
Confining layer	Low permeability strata that may be saturated but will not allow water to move through it under ordinary hydraulic gradients.
CSG	Coal seam gas
Dewatering	The process of removing formation water from a targeted coal seam. Dewatering is required to reduce pressure in the coal so gas can desorb and produce.
Drawdown	A lowering of the water table in an unconfined aquifer or the pressure surface of a confined aquifer caused by pumping of groundwater from bores and wells.
Electrical conductivity (EC)	A measure of a fluid's ability to conduct an electrical current and is an estimation of the total ions dissolved. It is often used as a measure of water salinity.
EPL	Environment Protection Licence
Fracture stimulation	See hydraulic fracturing.
Groundwater	The water contained in interconnected pores or fractures located below the water table in the saturated zone.
Groundwater system	A system that is hydrogeologically more similar than different in regard to geological province, hydraulic characteristics and water quality, and may consist of one or more geological formations.
GWSP	Groundwater Sharing Plan
Head (hydraulic head)	A specific measurement of water pressure above a geodetic datum.
Hydraulic conductivity	The rate at which water of a specified density and kinematic viscosity can move through a permeable medium (notionally equivalent to the permeability of an aquifer to fresh water).
Hydraulic fracturing	A fracture stimulation technique that increases a gas well's productivity by creating a pathway into the targeted coal seam by injecting sand and fluids through the perforated interval directly into the coal seam under high pressure.
Hydrostratigraphic unit	A collection of stratigraphy considered, for the purpose of building a conceptual or numerical model, to contain the same hydraulic properties.
km	Kilometre
L/s	Litres per second
m	Meters
m/s	Meters per second

m / d	Meters per day
m^2 / day	Meters squared per day
mg / L	Milligrams per litre
microSiemens per centimetre (µS / cm)	A measure of water salinity commonly referred to as EC (see also Electrical Conductivity). Most commonly measured in the field with calibrated field meters.
ML	Megalitres
Monitoring bore	A non-pumping bore generally of small diameter that is used to measure the elevation of the water table and/or water quality. Bores generally have a short well screen against a single aquifer through which water can enter.
Na-HCO_3	Sodium, Bicarbonate
NATA	National Association of Testing Authorities
NOW	New South Wales Office of Water
PEL	Petroleum Exploration Licence
Permeability	A measure of the ability of a porous material (e.g. a rock or unconsolidated material) to allow fluids to pass through it.
pH	Potential of Hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, greater than 7 is alkaline and less than 7 is acidic).
Piezometer	See monitoring bore or vibrating wire piezometer (as appropriate).
Potentiometric surface	The potential level to which water will rise above the water level in an aquifer in a bore that penetrates a confined aquifer; if the potential level is higher than the land surface, the bore will overflow and is referred to as artesian.
PPL	Petroleum Production Lease
Pressure cement	Cement that is pressure inserted around casings of a well built to withstand a required pressure and to ensure that there are no pathways for water or gas to leak or migrate.
Produced water	Groundwater generated from coal seams during flow testing and production dewatering.
Production well	A well used to retrieve gas from the underground reservoir.
Recharge	The process which replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water reaching the water table or exposed aquifers. The addition of water to an aquifer.
Sandstone	Sandstone is a sedimentary rock composed mainly of sand-sized minerals or rock grains (predominantly quartz).

Sandstone aquifer	Permeable sandstone that allows percolation of water and other fluids, and is porous enough to store large quantities of groundwater.
Sedimentary rock aquifer	These occur in consolidated sediments such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. These aquifers are generally located in sedimentary basins that are continuous over large areas and may be tens or hundreds of metres thick. In terms of quantity, they contain the largest volumes of groundwater.
SIS	Surface to In-Seam
Standing water level (SWL)	The height to which groundwater rises in a bore after it is drilled and completed, and after a period of pumping when levels return to natural atmospheric or confined pressure levels.
Stratigraphy	The depositional order of sedimentary rocks in layers.
TDS	Total Dissolved Solids, measured in milligrams/litre (mg/L)
Water bearing zone	Geological strata that are saturated with groundwater but not of sufficient permeability to be called an aquifer.
Water quality	Term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Water table	The top of an unconfined aquifer. It is at atmospheric pressure and indicates the level below which soil and rock are saturated with water.
Well	Pertaining to a gas exploration well or gas production well.
Wellhead	The surface termination of a wellbore.
Workover	The process of performing major maintenance or remedial treatments on an oil or gas well.

1. Introduction

This report provides a summary of the hydrogeological environment within the Camden Gas Project (CGP) area. It has been compiled from available data including publicly available reports and data collected from AGL Upstream Investments Pty Ltd's (AGL) activities in recent years.

It focuses on the geology, hydrogeology and groundwater use of the CGP area. There is also a brief explanation of the potential (but unlikely) risks to groundwater resources across the CGP, and the management and mitigation measures that AGL has adopted to provide a high level of confidence in water resource protection.

All groundwater in the CGP area is located within two groundwater sources: the Sydney Basin Nepean Groundwater Source (south of the Nepean River) and the Sydney Basin Central Groundwater Source (north of the Nepean River). These are two of 13 groundwater sources gazetted under the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011* (NSW) (GWSP) under the *Water Management Act 2000* (NSW).

1.1. Camden Gas Project

The CGP is owned and operated by AGL, and is located in the Macarthur region 65 km southwest of Sydney, in the Wollondilly, Camden and Campbelltown Local Government Areas (Figure 1). The CGP has been producing gas for the Sydney region since 2001 and currently consists of 144 gas wells, low-pressure underground gas gathering pipes and a gas plant facility. Not all production wells are currently operational. Most were licensed under the *Water Act (1912)* (NSW) except for a few that are suspended and planned to be plugged and abandoned. In FY2013, all the production bore licences transitioned to Water Access Licences, Works Approvals and Use Approvals under the *Water Management Act 2000* (NSW), including an allocation of 30 ML per year for the existing CGP and associated dewatering activities from the coal seams.

AGL holds five Petroleum Production Leases (PPLs) (which are PPLs 1, 2, 4, 5, and 6) and a Petroleum Exploration Licence (PEL 2) in the CGP area issued under the *Petroleum (Onshore) Act 1991*(NSW) (Petroleum Act) enabling exploration and the production, gathering and sale of coal seam methane gas.

The well surface locations, or well sites, are scattered throughout the PPLs and have been determined following extensive geological exploration and analysis.

Once the preferred geological target areas have been identified, the well site selection process then considers the environmental and social constraints of the area. These include land use (existing and future), topography, subsurface geology, flora and fauna, archaeology and noise. This detailed design information becomes part of the environmental assessment and approvals process for new gas fields and facilities.

A gas well generally has the following four main stages in its life cycle:

1. drilling (construction and fracture stimulation (where required), includes associated civil construction);
2. commissioning (flowback, includes initial rehabilitation of the surplus construction area);
3. production (dewatering, operation and maintenance); and
4. well closure, abandonment and final rehabilitation.

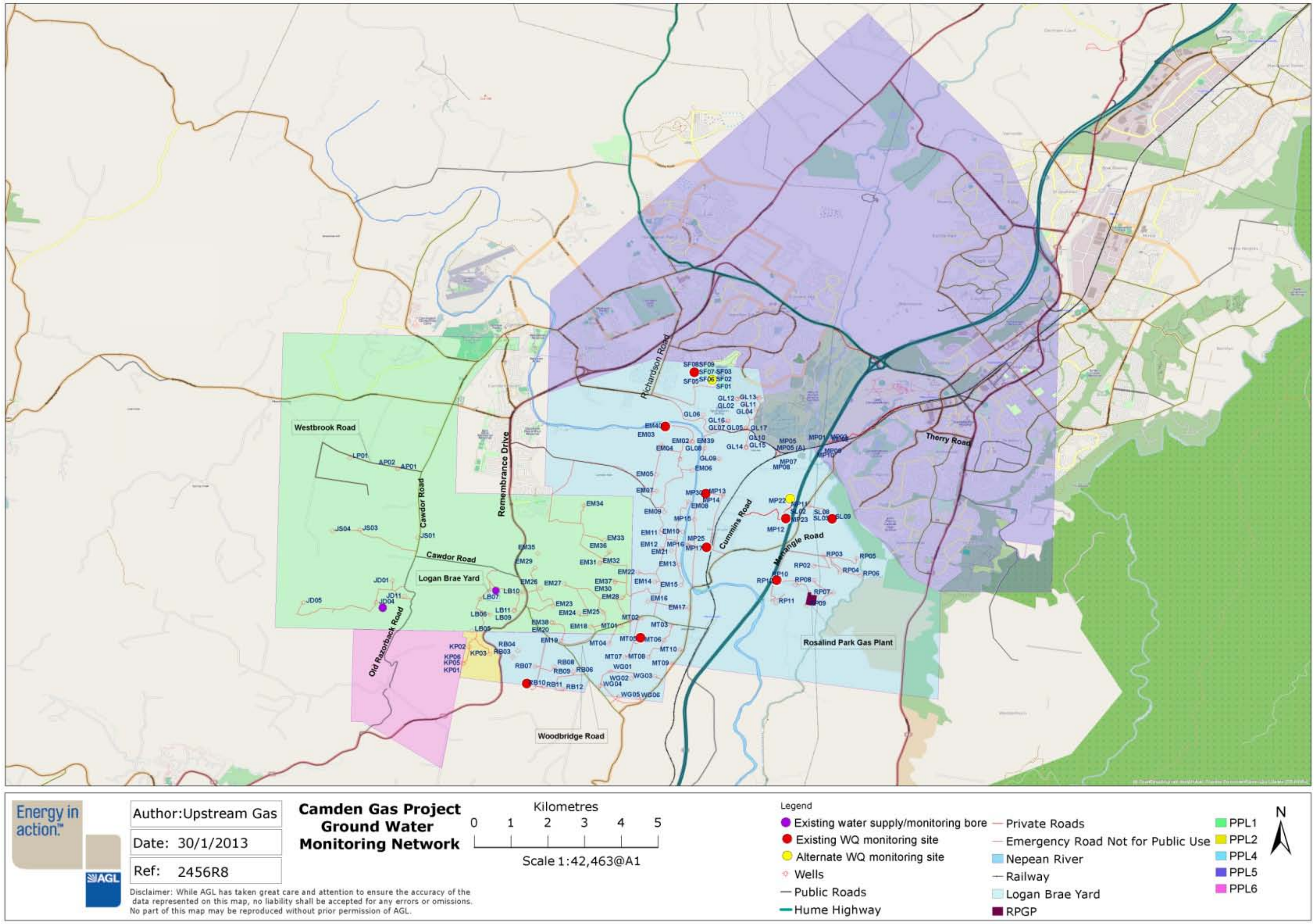

Figure 1: Location of CGP and PPLs and locations within the groundwater monitoring network **(not including dedicated groundwater monitoring bores located north of the current project area).**

1.1.1. Well Construction

The production wells within the CGP area comprise a mixture of vertical, deviated and horizontal wells. The production wells drilled since 2009 have been entirely horizontal wells with multiple wellheads on single pads so as to minimise the land use impacts. The two well types are:

- Vertical and Deviated Drilling: Vertical and deviated wells (all of which have been fracture stimulated) are the majority gas well type in the CGP area. Wells are drilled vertically or at a deviation to a maximum of 45° (for deviated wells) to intercept the Bulli and Balgownie Coal Seams. Wells have multiple casings with a conductor casing near surface (6-30m depending on the shallow sedimentary environment) to support surface formations and avoid any cave ins near surface during drilling operations, a surface casing to around 120 -140 m (depending on the location) to exclude shallow aquifers and a production casing to full depth. All casings are pressure cemented in place.
- Horizontal Drilling / Surface to In-Seam (SIS): Horizontal wells are used to increase the drainage area of a reservoir and provide a means of stimulating the reservoir through the drilling process. Like vertical wells, horizontal wells also have steel conductor and surface casing which is pressure cemented in place to exclude shallow aquifers. The well is drilled vertically from the surface and gradually builds angle so as to intersect the seam near parallel with the seam dip angle. Once intersected, this portion of the well bore is cased, cemented and a smaller hole is subsequently drilled through the seam anywhere from about 1300 to 2500m. It allows a significant reduction in the number of surface locations along with the ability to access previously sterilised gas reserves.

Shallow beneficial aquifers (which in this area are mostly less than 150m from surface in the alluvium and shallow sandstone, but occasionally up to 300m from surface in the Hawkesbury Sandstone) are protected by up to four barriers within the well construction: two steel and two cement barriers. The well construction design incorporates numerous contingencies to ensure zonal isolation between coal seams and other formations including the shallow aquifers. Aside from the important environmental considerations, zonal isolation is important for gas production, as water migration from any other source will hinder gas production, so all precautions are taken during well construction to ensure no communication between other formations can exist with respect to the well bore.

Gas production is maximised once the coal seam is dewatered and there is minimal or no ongoing water contributions from the coal seam and adjacent formations.

1.1.2. Previous Approvals

Exploration drilling and production well completions have historically been approved under the Petroleum Act and the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act), while the dewatering and produced water disposal activities were approved under the *Water Act (1912)* (NSW) and the *Protection of the Environment Operations Act 1997* (NSW) (POEO Act). The subsequent approvals and licences issued under these Acts for the CGP cover all drilling, maintenance activities, workovers, and fracture stimulation programs.

AGL's historical programs to protect shallow beneficial aquifers include:

- Designing and constructing gas wells with multiple casings, pressure cemented to ensure long life and to exclude shallow groundwater.
- Monitoring the integrity of gas wells constructed throughout the field to ensure that steel casings are cemented to full depth and that the pressure cementing of casing strings is to surface so as to isolate all aquifers.

- Containment of all drilling/fracturing fluids in lined pits and tanks, tanking of fluids away for disposal at licensed wastewater facilities thereby minimising the potential for impacts to surface water or groundwater.
- Monitoring and recording of produced water flows from gas wells.
- Water sampling of selected gas wells and water supply bores and dedicated water monitoring bores to characterise the deep groundwater quality.
- Monitoring of water pressure in shallow beneficial aquifers at dedicated water monitoring bores.

This information is presented in numerous well completion reports, environmental compliance reports, annual reports and sustainability reports. Water legislation requirements are now covered under *Water Management Act 2000* (NSW) as the area has transitioned to Water Access Licences and Works/Use Approvals under the GWSP.

1.1.3. Northern Expansion

AGL has lodged an application with the Department of Planning and Infrastructure for the expansion of the CGP to a new gas development area, incorporating additional wells and associated infrastructure. The expansion is towards the north-east of the existing development area, and extends from the suburb of Currans Hill to the south to Denham Court in the north bound by the Hume Highway in the east and the Camden Valley Way in the west.

The northern expansion area (the application was transitioned from a Part 3A project under the EP& Act to a State significant development project towards the end of 2012) involves the construction and operation of 11 additional well surface locations (with up to six well heads each), the construction and operation of gas gathering and water lines and the construction of access roads. Most of the proposed gas wells are expected to be horizontal well completions.

2. Geology

2.1. Regional and local geological and structural setting

The whole of the CGP is located within the Southern Coalfield of the Sydney Geological Basin. The Sydney Basin is sedimentary in origin, with deposition of sediments occurring from the early Permian (290 million years ago) through to the latter part of the Triassic (200 million years ago). The Sydney Basin on-laps the Lachlan Fold Belt to the west and south, with basin depth increasing to the north and east. Surface geology and locations of major structures are shown in Figure 2. Appendix B illustrates a schematic model for the stratigraphy of the CGP area (PB, 2011b).

The geological strata of the Sydney Basin are shown in Table 2 and can also be summarised (from youngest to oldest) as following:

› Unconsolidated alluvial deposits along the major rivers and dune/beach deposits along the coast (Tertiary and Quaternary in age).

› Fractured volcanic intrusive and flows (and associate dyke swarms and occasional sills) within the Sydney Basin (Jurassic and Tertiary in age).

› Sedimentary rocks (including substantial coal measures at depth) of the Sydney Basin (Permian and Triassic age).

› Fractured basement rocks below the Sydney Basin (Palaeozoic age).

Locally the stratigraphy of the CGP area (from youngest to oldest) can be summarised as:

- Alluvial sediments (sand, gravel, silt and clay) overlie the Wianamatta Shales and Hawkesbury Sandstone along the major rivers and creeks. These sediments are rarely more than 20 m thick.
- Wianamatta Group: where alluvial deposits are not present, the Triassic Wianamatta Group comprises the surficial geology over most of the CGP area. It can be very thin to more than 100m thick in some of the more elevated areas. The Wianamatta Group primarily comprises shales, with occasional calcareous claystone, laminate and coal. The Ashfield Shale is the most widespread rock type, at surface, across the area.
- Mittagong Formation: separates the Ashfield Shale from the underlying Hawkesbury Sandstone. It is a thin layer (generally less than 10 m thick) comprising dark grey to grey alternating beds of shale laminate, siltstone and quartzose sandstone.
- Hawkesbury Sandstone: alluvial in origin, with a thickness of approximately 170 m in the region. Sandstone thicknesses increase to the north. The Triassic Hawkesbury Sandstone is generally medium to coarse grained quartz sandstone, with interbedded siltstone, finer grained sandstone and shale lenses. Shale lenses are common within this formation.
- Narrabeen Group: the total thickness of these Triassic rocks is approximately 450 m across the CGP area.
    - Gosford Sub-group: the Newport Formation is medium grained, light to dark grey, quartzose sandstone interbedded with siltstone. The Garie Formation is a thin, cream kaolinite claystone, which grades upwards to grey.
    - Clifton Sub-group: Bald Hill Claystone is grey to red/brown claystones and mudstones, occasional siderite nodules and generally softer than the overlying Garie Formation. Bulgo Sandstone is white to grey coarse grained sandstone, fining upwards to coarse pebbly sandstone, with interbedded siltstone. Stanwell Park Claystone comprises alternating light grey/green to brown sandstone and claystone intervals, with minor conglomerate. Scarborough Sandstone is fine to very coarse grained, white to grey sandstone, with occasional siltstone and conglomerate laminae. Wombarra Claystone consists of light grey/green to dark grey claystone, siltstone, mudstone with minor quartz lithic sandstone and conglomerate.
- Illawarra Coal Measures: the sedimentary thickness is approximately 300 m in the central area of the Southern Coalfield. The upper sections of the Permian Illawarra Coal Measures (Sydney Sub-group) contain the major coal seams including the Bulli and Balgownie Coal seams. The underlying Cumberland Sub-group generally contains thin coal seam development.
- Shoalhaven Group: The Permian Budgong Sandstone is shallow marine to littoral, typically comprising fine and course grained sandstone.
- Basement geology: The Southern Sydney Basin Permian and Triassic rocks have been deposited upon early to middle Palaeozoic basement rocks, of the Lachlan Fold Belt. These rocks consist of intensely folded and faulted slates, phyllites, quartzite sandstones and minor limestones of Ordovician to Silurian age.

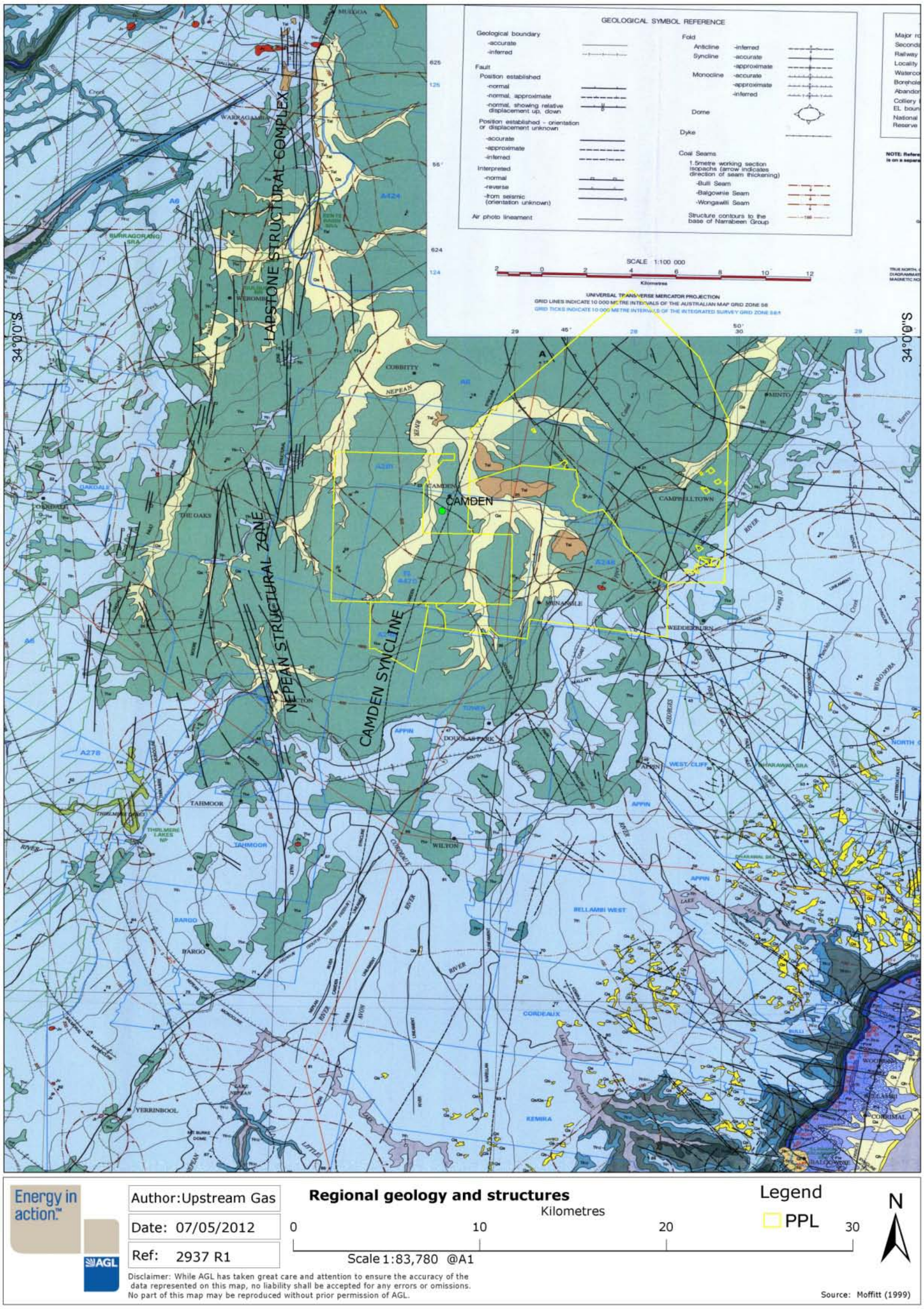

Figure 2: Geological map of the regional CGP area, showing significant structures (Moffitt, 1999). Map legend shown in Appendix C.

Table 1: Stratigraphy of the CGP area

Age	Unit			Lithology*	Average Thickness # (m)	Average depth to top# (m bgl)
Quaternary	Alluvium			Quartz and lithic "fluvial" sand, silt and clay	<20	0
Tertiary	Alluvium			High- level alluvium		
Triassic	Wianamatta Group		Bringelly Shale	Shale, carbonaceous claystone, laminite, lithic sandstone, rare coal	80 (top eroded)	0 -20
			Michinbury Sandstone	Sandy barrier island complex. Fine to medium-grained lithic sandstone.		
			Ashfield Shale	Black to light grey shale and laminite.		
	Mittagong Formation			Interbedded shale, laminite and medium-grained quartz sandstone.	11	113
	Hawkesbury Sandstone			Medium to coarse-grained quartz sandstone with minor shale and laminite lenses.	173	114
	Narrabeen Group	Gosford Subgroup	Newport Formation	Lower part contains quartzose sandstones which are top-sealed by the shaly laminite at the top of the unit.	35	274
			Garie Formation	Clay pellet sandstone.	8	308
		Clifton Subgroup	Bald Hill Claystone	Dominantly red shale and fine to medium-grained sandstone.	34	292
			Bulgo Sandstone	Fine to medium-grained quartz-lithic sandstone with lenticular shale interbeds.	251	331
			Stanwell Park Claystone	Red, green and grey shale and quartz-lithic sandstone.	36	574
			Scarborough Sandstone	Quartz-lithic sandstone, pebbly in parts.	20	621
			Wombarra Claystone	Grey shale, minor quartz-lithic sandstone.	32	636
Permian	Illawarra Coal Measures	Sydney Sub-group	Bulli Coal	Shale, quartz-lithic sandstone, conglomerate, chert, sporadically carbonaceous mudstone, coal and torbanite seams.	4	667
			Loddon Sandstone		12	684
			Balmain Coal Member		24	737
			Balgownie Coal		2	684
			(Remaining Sydney Sub-group)		?	699
		Cumberland Sub-group			-	-
	Shoalhaven Group			Sandstone, siltstone, shale, polymictic conglomerate, claystone; rare tuff, carbonate, evaporite.	-	-
Paleozoic	Lachlan Fold Belt			Intensely folded and faulted slates, phyllites, quartzite sandstones and minor limestones of Ordovician to Silurian age (PB, 2011a)	-	-

Key: * From Geoscience Australia's Stratigraphic Units Database (http://dbforms.ga.gov.au/www/geodx.strat_units.int); #average thickness and depth to top taken from available information on all wells within CGP

2.2. Structural nature and identified faults

Structurally, the CGP area, and surrounds, is dominated by the north, north-east plunging Camden Syncline, which is a broad and gentle warp structure (Alder et al, 1991; Bray et al, 2010, *in* PB, 2011a). The Camden Syncline is bounded in the west and truncated in the southwest by the north-south trending Nepean Structural Zone, part of the Lapstone Structural Complex.

Towards the east of the CGP, a set of north-west trending faults aligned with the more deformed Lapstone Structural Complex to the west are present. There may be some relationship between the structural domains defined by this fault set and the coal quality of the Bulli and Balgownie coal seams (Alder et al, 1991, *in* PB, 2011a). Interpretation of seismic profiles by Herbert (1989, *in* PB, 2011a) indicated that in cross section, these major regional faults comprise complex bifurcating "flower" structures dominated by high-angle reverse faulting with relatively minor individual vertical offsets.

Figure 2 shows the structure of the region, as identified by Moffitt (1999).

2.3. Target coal seam gas formations

The principal coal seam gas targets for the CGP are the late Permian Bulli and Balgownie Coal Seams within the Sydney Sub-group of the Illawarra Coal Measures (ICM). The ICM are composed of shale, quartz-lithic sandstone, conglomerate, chert, sporadically carbonaceous mudstone, coal and torbanite seams[1] mostly deposited in a deltaic plain environment (Herbert and Helby, 1980).

The Bulli and the Balgownie Coal Seams are approximately 2 - 5 m and 1 - 3 m thick, respectively, within the CGP area, and are, on average, 666 m and 683 m deep across the CGP area.

The ICM overlies early Permian marine Shoalhaven Group and is conformably overlain by the Wombarra Claystone of the Narrabeen Group.

3. Hydrogeology

3.1. Beneficial aquifers

The primary beneficial aquifers (used for water supply) across the CGP area are the shallow alluvial aquifers (where present) and the porous and fractured rock aquifers within the Hawkesbury Sandstone. There is minor use of groundwater in the Wianamatta Group at a local level. Groundwater in these aquifers is used for stock, domestic, recreation and minor irrigation uses and is not used as a drinking water source. It should be noted that the coal seams are not beneficial aquifers (but are rather water bearing zones) and are not used as a water supply source. Even though the coal seams are depressurised and dewatered over the project area, based on previous studies (for example, Jewell, 2001; KBR, 2008; PB, 2008; SCA, 2005b) it is concluded that the presence of extensive and thick claystone formations in the stratigraphic sequence that overlies the Permian coal measures in the area protects shallower aquifers in the Triassic sandstones and prevents vertical leakage, hence, there are no noticeable impacts on beneficial shallow aquifers or surface water within this area.

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[1] Australian Stratigraphic Names Database, http://dbforms.ga.gov.au/pls/www/geodx.strat_units.sch_full?wher=stratno=27802, accessed on 16 April 2012

3.2. Regional hydrogeological setting

The hydrogeology in the Southern Coalfield is controlled by sub-horizontal sedimentary aquifers and aquitards (confining layers). Typically, the sandstone units behave as aquifers and the claystones and shales behave as aquitards.

The groundwater in the regional area is characterised by low yields from the Hawkesbury Sandstone, Bulgo Sandstone, and alluvium, with generally variable water quality. It is predicted that any future groundwater exploitation will be from the shallower sandstone aquifers on a relatively minor scale and that nearby urban developments will be serviced by reticulated water supplies.

Figure 3 shows the mapped location at surface of each of the identified beneficial aquifers at a regional (basin wide) scale on. Due to the shape of the basin, the outside edge of the surface location of each aquifer system would likely represent the outermost edge of the hydrostratigraphic unit; the unit would be present underneath the younger units within this boundary.

Figure 4 shows the mapped location at surface of each of the identified beneficial aquifers at the PPL scale. The Hawkesbury Sandstone, Narrabeen Group, and Illawarra Coal Measures are interpreted to exist across the entirety of this area, subsurface. The Quaternary and Tertiary alluvial aquifers are located along the floodplain of the Nepean and Paleo-Nepean River. There is no surface expression of any of the deeper groundwater systems within this area and consequently there are no groundwater dependent ecosystems associated with any of the sedimentary rock groundwater systems.

Table 3 lists some hydrogeological properties for the stratigraphic units within the Southern Coalfield where available. Due to limited available data, some data has been obtained from areas relatively distant to the CGP, and may not necessarily represent the hydrogeological properties of the stratigraphic units within the CGP.

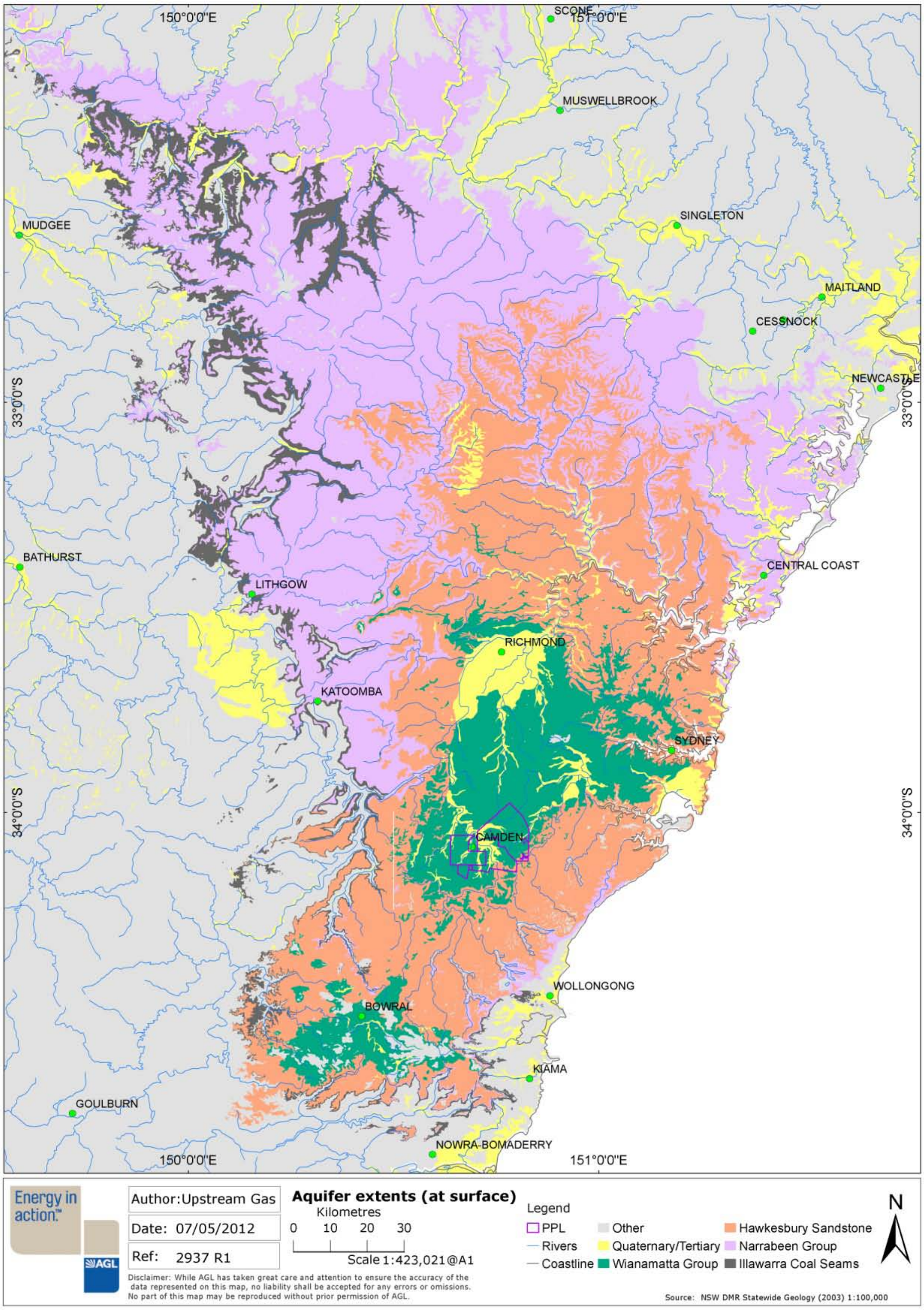

Figure 3: Regional map outlining aquifer extents (at surface). The Newport and Garie Formations are included in Narrabeen Group in this map. Some alluvium outside Sydney Basin is also shown.

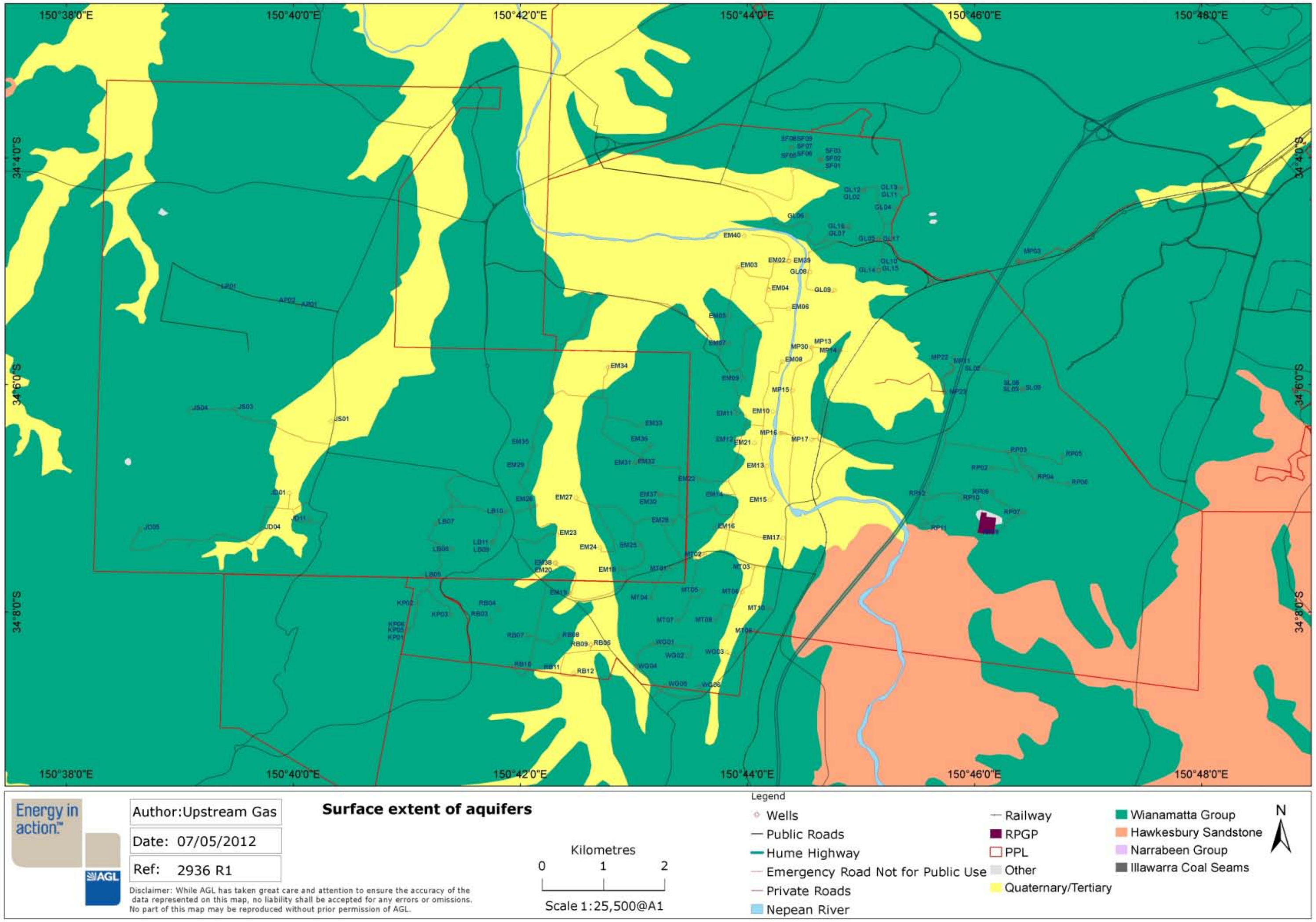

Figure 4: Surface extent of aquifers within the PPL area.

Table 2: Hydrogeological properties for stratigraphic units where available (after SCA (2005b), Broadstock (2011), and PB (2011a))

Age	Stratigraphic unit	Average thickness* (m)	Type of hydrogeological unit	Hydraulic conductivity - Horizontal (m/d)	Hydraulic conductivity - Vertical (m/d)	Transmissivity (m^2/day)	Permeability (m/s)#	Quality
Quaternary / Tertiary	Alluvial deposits	<20	Unconfined aquifer	1 - 10		>20		
Triassic	Wianamatta Group	80 (top eroded)	Aquitard -Unconfined / perched	0.01	0.05	<1 (Ashfield Shale)		TDS>3000 mg/L
	Hawkesbury Sandstone (including the Newport and Garie Formations)	217	Unconfined / semi-confined aquifer	0.1	0.05 – 6 x 10^{-4} (SCA, 2005)	1 – 5 (0.016 – 9.2, mean of 2.8 (McKibbon and Smith, 2000))	3x10^{-8}	TDS <500-10,000 mg/L
	Bald Hill Claystone	34	Aquitard	1.0 x10^{-5}	2.0 x10^{-6}		5x10^{-9}	
	Bulgo Sandstone	251	Minor confined aquifer	5.50x10^{-4}	1.10 x10^{-4}	0.1 – 0.5	6x10^{-8}	TDS 1500 – 5000 mg/L
	Stanwell Park Claystone	36	Aquitard	3.00x10^{-5}	6.00x10^{-6}		3x10^{-9}	
	Scarborough Sandstone	20	Minor confined aquifer	0.01	5.00x10^{-3}	0.1 - 0.5	2x10^{-7}	
	Wombarra Claystone	32	Aquitard	3.00x10^{-5}	6.00x10^{-6}		1x10^{-9}	
Permian	Illawarra Coal Measures	200	Confined water bearing zones	5.00x10^{-2} (Bulli)	2.50x10^{-2} (Bulli)	0.005 – 0.1	1x10^{-5} (Bulli)	TDS >5000 mg/L

Key: * - inferred from information from all wells across CGP

- from GHD (2007), and is applicable to the Dendrobium mine area, about 30 km south of the CGP area

3.3. Groundwater sources/aquifers

As shown in Table 3, the aquifers/water bearing zones within the area are:

- Unconfined Quaternary and Tertiary alluvial/sediment aquifers (minor beneficial);
- Late Triassic Wianamatta Group rocks (minor aquifer or aquitard);
- Middle Triassic Hawkesbury Sandstone (major beneficial) (including Newport and Garie Formations);
- Lower Triassic Narrabeen Group sandstone aquifers; and
- Permian water bearing zones (Illawarra Coal Measures).

These are summarised in more detail in the following sections. The hydraulic properties for each aquifer, where possible, are defined, including permeability, quality, and quantity (in the form of bore yields).

3.3.1. Quaternary and Tertiary alluvial aquifers

Thin Tertiary and Quaternary alluvial deposits occur in valleys, creeks and river beds across the region. The alluvial deposits are generally shallow, discontinuous and relatively permeable, and typically have transmissivities in excess of 20 m^2/day. Alluvial aquifers are responsive to rainfall and stream flow, and are a localised beneficial aquifer across the region.

There are 33 bores that have been interpreted to tap into the alluvial aquifers in the PPL area, within the Pinneena database (refer to Section 4 and Appendix A). Of these bores, the average yield recorded is 2.6 L/s, and the average standing water level is 5.6 m below ground level (bgl). Salinity, where recorded, is listed as being “good” or “excellent”, whereas values recorded numerically have an average of 2142 mg/L TDS, which is considered brackish.

3.3.2. Wianamatta Group aquifers

The youngest of the three Triassic strata, the Wianamatta Group, consists mostly of shale with some sandstone layers. Water is usually brackish to saline, especially in low relief areas of western Sydney (due to the marine depositional environment of the shales (PB, 2011a)); because of this, the tributary streams draining from formations in that part of the catchment also have high salinity levels (Jewell, 2001). The Wianamatta Group Shales are considered aquitards although small aquifers are sometimes present (PB, 2011a). Groundwater in shales typically exceed 3000 mg/L TDS and the Ashfield Shale has an approximate transmissivity of 4 m^2/day (SCA, 2007, in PB, 2011a).

There are 12 bores that have been interpreted to tap into the Wianamatta Group in the PPL area, within the Pinneena database (refer to Section 4 and Appendix A).Of these bores, the average yield recorded is 1.3 L/s, and the average standing water level is 3.5 mbgl. Salinity, where recorded, is listed as being “fresh”, “brackish”, “v.salty”, whereas values recoded numerically have an average of 2529 mg/L TDS, which is considered brackish.

3.3.3. Hawkesbury Sandstone aquifer system

The Hawkesbury Sandstone is often grouped with the Newport and Garie Formations of the Narrabeen Group, and labelled the Sydney Sandstone aquifer system (McKibbon and Smith, 2000). The Sydney Sandstone aquifer system is a dual porosity aquifer system that occurs across the whole of the Sydney Basin (McKibbon and Smith, 2000). The Hawkesbury Sandstone is the major aquifer across this region. Groundwater flow is variable throughout the sandstone, and is generally dominated by secondary porosity and fracture flow.

The Hawkesbury Sandstone is interpreted as a layered aquifer system, with groundwater occurring in vertically discrete horizons that have little downward movement between them; groundwater movement is interpreted to be variable, with both primary granular flow and secondary fracture flow along joints/shear zones (PB, 2003). Groundwater movement is controlled by elevation of the potentiometric surface, which is a muted expression of the topography, and generally flows towards the direction of nearby creeks and rivers (McKibbon and Smith, 2000; SCA, 2005a).

Recharge, on a regional scale, is by direct infiltration of rainfall on outcrop areas, from infiltrating run-off in upland areas, and by minor inter-aquifer leakage (McKibbon and Smith, 2000). Recharge to this aquifer system occurs to the south and east of the main CGP area where sandstone sub-crops or is exposed at surface.

The primary porosity of the rock matrix is low, and a bore that does not intercept major fractures or fissures is likely to yield less than 2 litres per second (L/s) in this area, but can be considerably higher (up to 40 L/s). Transmissivity for the Hawkesbury Sandstone is typically 1 to 5 m^2/day.

Water quality within the Hawkesbury Sandstone varies significantly spatially and can be fresh to slightly saline, generally Na-Cl type water, slightly acidic to slightly alkaline, and high in iron (SCA, 2005b). Water quality within the upper sections of the Hawkesbury Sandstone is often poorer than the lower sections due to leakage from the overlying shale formations. In areas, the sandstone groundwater is commonly acidic with some pH values recorded below 5; as a result, elevated iron concentrations are also reported and in places exceed the Australian Drinking Water Guidelines (McKibbon and Smith, 2000; SCA, 2005a).

There are 45 bores that have been interpreted to tap into the Hawkesbury Sandstone aquifer in the PPL area, within the Pinneena database (refer to Section 4). Of these bores, the average yield recorded is 1.5 L/s, and the average standing water level is 43 mbgl. Salinity, where recorded, is listed as being “fresh”, “fair”, “good” or “brackish”, and values recorded numerically have an average of 738 mg/L, which is considered fresh. Groundwater salinity increases to the north where the sandstone is buried under more than 60m of Wianamatta Group shales. North of the CGP, however, the salinity of the water in the Hawkesbury Sandstone is typically around 3760 mg/L TDS within the basal zone of the aquifer, and is saltier (6190 mg/L TDS) within shallower parts of the aquifer (PB, 2012).

Results of the Phase 2 Groundwater Assessment to August 2012 (PB, 2012) characterize the quality of water sampled from groundwater monitoring bores that access the Hawkesbury Sandstone aquifer north of the CGP as poor and salty, with electrical conductivity of >5700 µS/cm. Water of this salinity is generally too saline to be used for irrigation and only some stock could potentially tolerate it as a water source. Isotopic and surface water results also indicate that the aquifers in the region contain old water (>30,000 years) and the sampled surface water sites are not linked to deeper groundwater systems.

3.3.4. Narrabeen Group sandstone aquifers

The sandstone formations within the Narrabeen Group below the Bald Hill Claystone (predominantly the Bulgo Sandstone and the Scarborough Sandstone) are considered to be minor aquifers and are not considered beneficial. These formations are generally considered to have minimal resource potential and are much lower yielding and of poorer water quality then the overlying Hawkesbury Sandstone (Madden, 2010). Yields are typically low, from 0.2 to 2 L/s (Jewell et al, 2001). Recharge to the Narrabeen Group aquifers is likely to occur where the formations are outcropping, which is at some distance from the CGP.

The Scarborough Sandstone is expected to be a dual porosity aquifer with most flow in secondary features such as joints (Madden, 2010).

Transmissivities of thin sandstone aquifers within the Bulgo Sandstone of the Narrabeen Group are low and expected to be around 0.1 to 0.5 m^2/day.

Water quality is poorer than in the overlying Hawkesbury Sandstone. There is only limited data available but salinity is typically ranges from <1500 – 5000 mg/L TDS (PB, 2011a; SCA, 2005b).

No bores are interpreted to tap into the Narrabeen Group aquifers in the PPL area, within the Pinneena database (refer to Section 4).

3.3.5. Permian water bearing zones

The coal seams present in the Illawarra Coal Measures are minor water bearing zones. Groundwater associated with coal seams is generally poor in quality, with moderate salinities. Negligible yields and poor water quality characterise the coal measures; therefore, it is not regarded as a beneficial aquifer.

The permeability of the coal seams within the Illawarra Coal Measures is quite low. The Bulli seam has a permeability range of between 1 to 30 millidarcies (approximately equivalent to a hydraulic conductivity of 0.001 to 0.03 m/day), with an average of 10 millidarcies (0.01 metre/day), whilst the Balgownie and Wongawilli seams both have permeabilities of less than 1 millidarcy (Jewell et al, 2001). Recharge to the Permian water bearing zones is likely to occur where the formations are outcropping, which is remote from the CGP.

Water quality in these coal seams is the poorest of any of the sedimentary rock units, in terms of salinity. Typically salinities are slightly to moderately salty and are mostly between 5,000 – 10,000 mg/L TDS.

No bores are interpreted to tap into the Permian water bearing zones in the PPL area, within the Pinneena database (refer to Section 4), although some of the coal seams within the Permian strata are the target formations for the gas wells (refer to Section 2.3).

3.4. Confining layers

All aquifer systems are separated by low permeability aquitards. The sedimentary rocks and the claystone aquitards in particular, are not compromised by longwall coal mining in this area. All Southern Coalfield mining operations occur south of the CGP area. The following claystones and shales act as confining layers and separate/isolate the aquifers mentioned in Section 3.3.

- Ashfield Shale and Mittagong Formation (located above the Hawkesbury Sandstone and below the Minchinbury Sandstone (part of the Wianamatta Group) and alluvium) – in this area these formations separate the alluvial aquifers from the deeper sandstone aquifers
- Bald Hill Claystone (located below the Hawkesbury Sandstone and above the Bulgo Sandstone of the Narrabeen Group) – in this area, this formation separates the Hawkesbury Sandstone from any sandstone aquifers in the Bulgo Sandstone
- Stanwell Park Claystone (located below the Bulgo Sandstone and above the Scarborough Sandstone, both within the Narrabeen Group)
- Wombarra Claystone (located below the Scarborough Sandstone of the Narrabeen Group, and above the Illawarra Coal Measures)

Based on previous studies (for example, Jewell, 2001; KBR, 2008; PB, 2008; SCA, 2005b) it is concluded that the presence of extensive and thick claystone formations in the stratigraphic sequence that overlies the Permian coal measures in the area will protect shallower aquifers in the Triassic sandstones. These very low permeability layers are likely to 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.

The Narrabeen Group confining layers form an effective hydraulic barrier between the Hawkesbury Sandstone aquifers and the Illawarra Coal Measures (Jewell et al, 2001). The presence of this barrier is one reason why the coal seam gas wells produce so little water; the other is the inherently low horizontal permeability of the coal measure rocks themselves (Jewell, 2001).

Further assurance on the effectiveness of the confining layers is given by the successful dewatering of existing wells throughout the CGP area, which demonstrates the isolation of the targeted water bearing zone from other water bearing zones and aquifers in the vicinity. More than 80% of the operating wells at the CGP in the 2011-2012 financial year produced negligible or no water (<50 kL per well during the whole year).

3.5. Water quality

The groundwater quality in aquifer systems underlying the CGP area is highly variable, with salinities ranging from fresh (below 500 µS/cm) to slightly salty (up to 10000 µS/cm), with the most saline groundwater generally occurring in the deeper Permian coal seams. While it is typical for groundwater quality to decline with depth reflecting increasing residence time of the groundwater, the available data does not show a clear systematic depth-quality relationship in this area (most probably due to the marine origin of the Wianamatta shales and residual connate salts at shallow depth). In particular there is a wide range in reported salinity in the Hawkesbury Sandstone aquifer and it tends to be more brackish than encountered in other areas of the Sydney Basin. A basin wide salinity map (adapted from Russell, 2007) for the groundwater residing in the Hawkesbury Sandstone (Figure 5) indicates that the CGP is located in an area of much poorer quality water than other areas in the basin.

The quality of the water in the Hawkesbury Sandstone within the central and southwestern part of the CGP area is generally fresh, around 600 - 800 µS/cm[2]. However, the quality degrades to brackish to the northwest, as observed at the dedicated monitoring bores located to the northeast of PPL5 (5500 – 9500 µS/cm).

The quality of the water within the coal seams is considered poor and is generally salty typically with values typically between 7,000 and 15,000 µS/cm.

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[2] As observed at water supply bores that are part of the Groundwater Monitoring Network located south of the Nepean River.

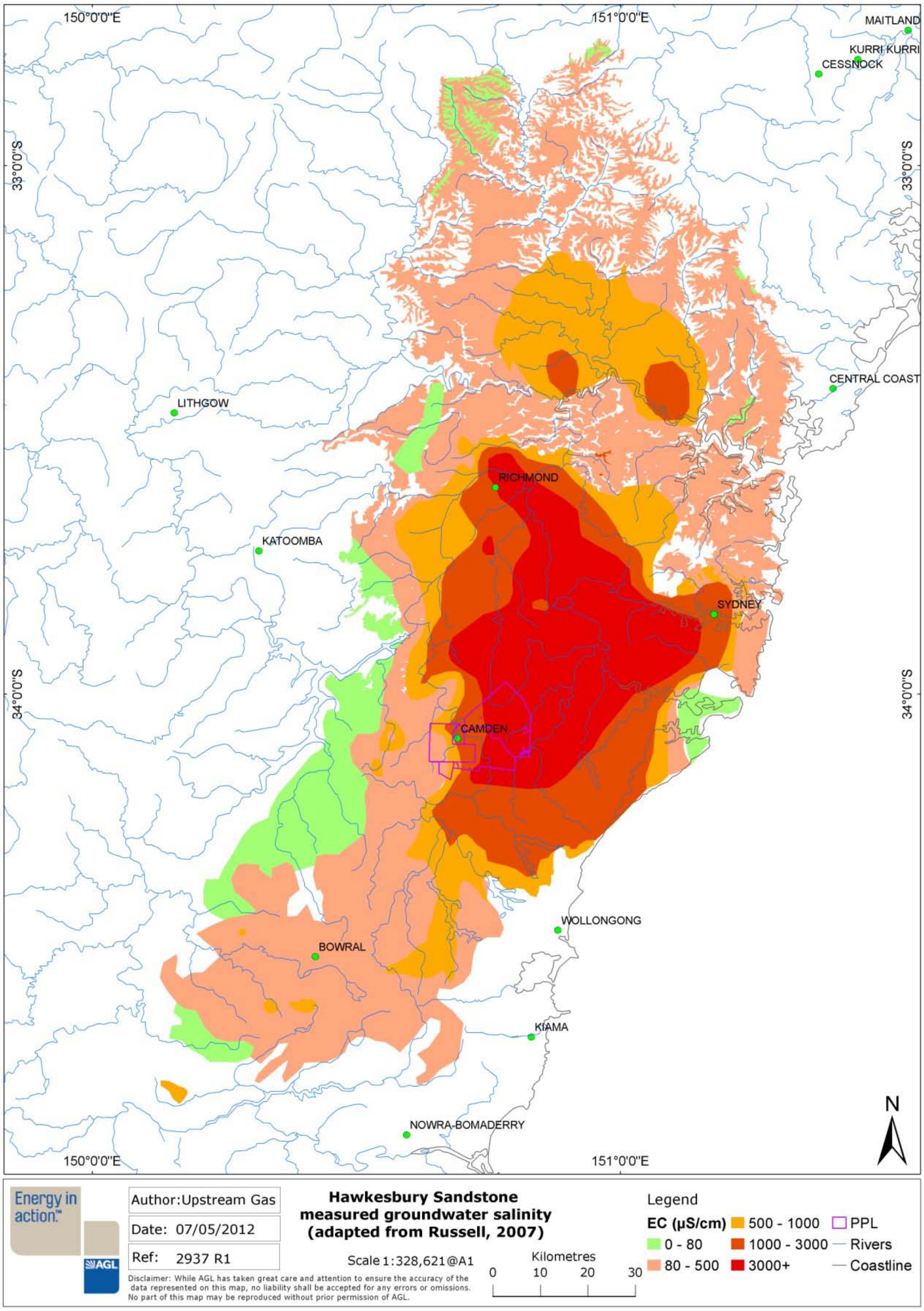

Figure 5: Basin wide salinity map for Hawkesbury Sandstone (adapted from Russell, 2007).

3.5.1. Monitoring network

A groundwater monitoring network for the CGP is defined within the Groundwater Management Plan (Section 5.2.5) and has been endorsed by the NSW Office of Water and the EPA. The groundwater monitoring network includes:

- monitoring produced water volumes from all operating gas wells (monthly);
- water quality sampling from a selection of operational gas wells and water supply bores and dedicated groundwater monitoring bores (various); and
- water levels at dedicated groundwater monitoring bores (continuously)

The water quality samples are analysed by an external NATA certified laboratory. Water levels (hydraulic heads) are rarely monitored in gas production wells because of the nature of the internal tubing, pumping equipment, and API wellhead configuration.

Within the northern expansion area, there is currently one location which consists of three nested monitoring bores with dedicated continuous dataloggers monitoring water levels in three aquifer systems. It is planned to construct two more nested sites within the region in the coming year, which will provide data both within the CGP wellfield area and distal to, and down gradient (in terms of groundwater flow) of, the wellfield.

3.5.2. Water quality for monitored zones

Typical ranges from recent analyses of the produced water are shown in Table 4. Electrical conductivity varies significantly within the water produced from the Permian Illawarra Coal Measures, with a typical conductivity of 12,112 µS/cm; compared with a less varying value of 587 µS/cm for samples taken from the Hawkesbury Sandstone. The produced water from the coal measures is typically strongly Na-HCO_3 type waters, whereas the water sampled from bores tapping the Hawkesbury Sandstone is typically more Ca/Mg-HCO_3 type, as shown in Figure 6.

The distinct water signature of the produced water compared with the beneficial aquifer water signature is a strong piece of evidence to support the model that there is isolation of the aquifer systems, and that the water being produced during CSG extraction is only sourced from the coal seam water bearing zones and is not being contributed to from the beneficial aquifers.

Water quality trends over time for the Hawkesbury Sandstone aquifer sampled from the two water supply bores within the CGP area follows natural variation and do not show any indication that the water quality is being altered as a result of CSG activity. For example, salinity data for the two bores fluctuates between 570 and 640 µS/cm for a 12 month period; this is considered variation within a natural range. A similar trend is observed for all the other analytes. As shown in Table 4, within the water sampled from the Hawkesbury Sandstone there are no analytes that are unexpectedly high. Iron concentrations, although low, do fluctuate, which is likely due to the natural higher levels of iron in the Hawkesbury Sandstone.

In terms of heavy metals, water samples from the Illawarra Coal Measures in almost all cases are below the levels classified in the Australian and New Zealand drinking water guidelines (NHMRC, 2011), with the exception of arsenic, copper, lead, barium and molybdenum – all which only slightly exceed these guidelines. It should be emphasised, however, that the water contained within the Illawarra Coal Measures is not fresh (in terms of salinity) water and is NOT classified as drinking water, so this comparison with drinking water guidelines is for a reference only.

pH of the produced water from the Permian coal measures is typically around 8 – 9, whereas pH for the Hawkesbury Sandstone aquifer is typically less than 7.

Table 3: Typical produced water characterisation profile from samples taken from CGP producing gas wells and water bores (including data from 2010-2012).

Unit of measurement = mg/L unless stated	Illawarra Coal Measures			Hawkesbury Sandstone		
	Sample number		36	Sample number		8
	Average	Minimum	Maximum	Average	Minimum	Maximum
Electrical Conductivity (µS/cm @25°C)	12599	6130	36100	611	578	639
Salinity	7380	3330	14300	297	280	310
Suspended solids	4104	2	136000	9	<5	13
Hydroxide Alkalinity as $CaCO_3$	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	930	<1	3050	7	<1	7
Bicarbonate Alkalinity as $CaCO_3$	7331	3360	16400	268	237	293
Total Alkalinity as $CaCO_3$	7809	3500	16400	269	237	293
Sulfate as SO_4 - Turbidimetric	21	<1	202	<1	<1	<1
Chloride	440	93	1240	29	23	34
Calcium	12	2	38	58	38	68
Magnesium	8	2	36	17	15	19
Sodium	3690	1540	8000	40	27	54
Potassium	33	11	208	6	4	8
Aluminium	<0.01	<0.01	0.07	<0.01	<0.01	<0.01
Arsenic	<0.001	<0.001	0.03	0.006	<0.001	0.008
Beryllium	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001
Barium	10.3	0.45	35.5	1.28	0.76	1.89
Cadmium	<0.0001	<0.0001	0.0003	0.0003	<0.0001	0.0003
Chromium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
Copper	0.01	<0.001	0.03	<0.001	<0.001	<0.001

Unit of measurement = mg/L unless stated	Illawarra Coal Measures			Hawkesbury Sandstone		
	Sample number		36	Sample number		8
	Average	Minimum	Maximum	Average	Minimum	Maximum
Lead	0.01	<0.001	0.03	<0.001	<0.001	<0.001
Manganese	0.02	<0.001	0.13	0.025	0.001	0.076
Molybdenum	0.02	<0.001	0.10	<0.001	<0.001	<0.001
Nickel	0.01	<0.001	0.02	<0.001	<0.001	0.001
Selenium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium	3.27	0.15	10.2	0.3	0.2	0.4
Uranium	0.001	<0.001	0.002	<0.001	<0.001	<0.001
Vanadium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	0.02	<0.005	0.07	0.01	<0.005	0.014
Boron	0.13	<0.05	0.26	<0.05	<0.05	<0.05
Iron	0.99	<0.05	15.4	3.39	<0.05	10.3
Bromine	1.21	<0.1	5.7	0.15	<0.1	0.2
Iodine	0.33	<0.1	0.80	<0.1	<0.1	<0.1

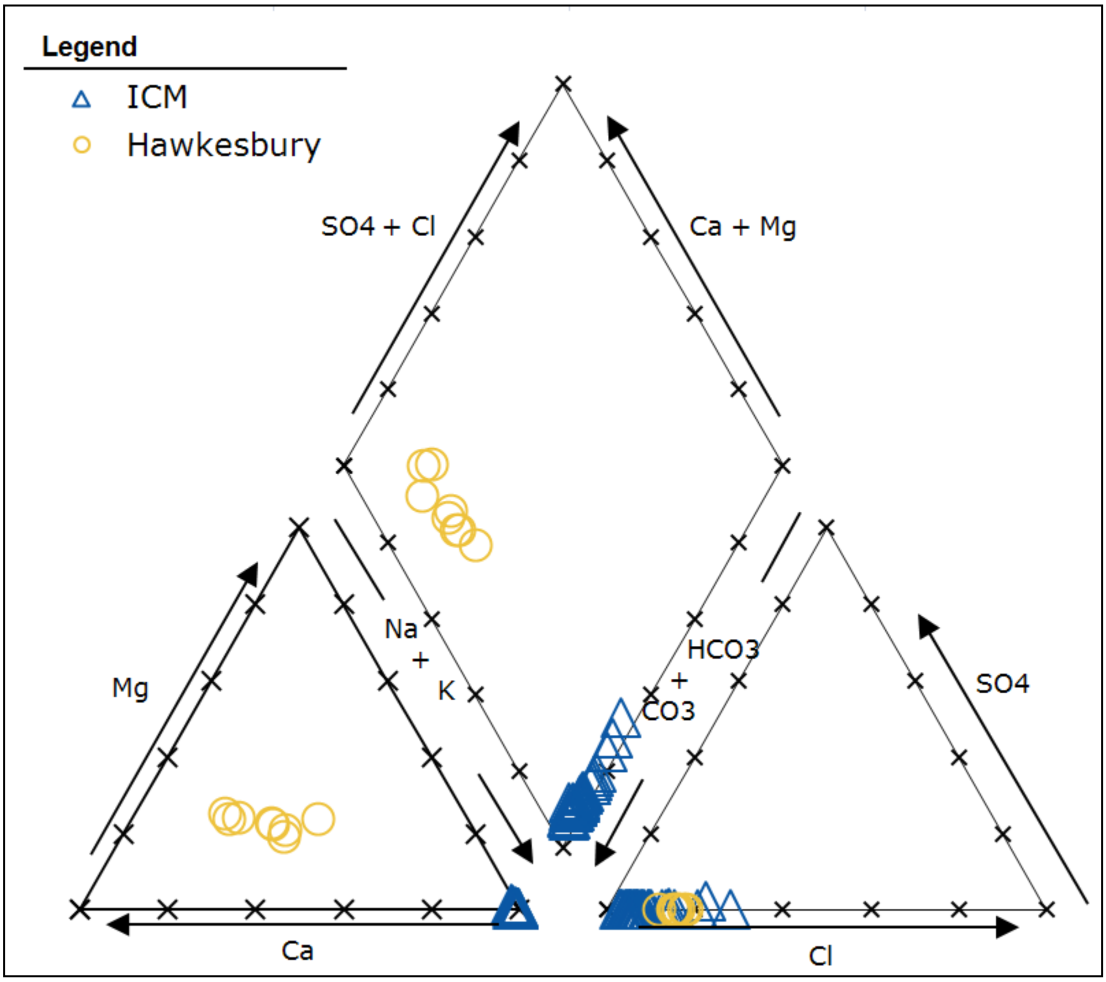

Figure 6: Trilinear plot for groundwater chemistry of the Triassic Hawkesbury Sandstone and Permian Illawarra Coal Measures (ICM) showing distinct water signatures for the beneficial aquifer and the coal seams, from AGL data (including data from 2010 – 2012)

3.6. Conceptual model

On a regional scale groundwater levels and flows are largely controlled by the basin geometry, topography and major hydraulic boundaries. In the southern Sydney Basin, groundwater flow in all the sedimentary basin rocks (except for the uppermost Wianamatta Group rocks) is predominantly towards the north or north-east, eventually discharging via the Georges and Hawkesbury River systems, and ultimately also off shore to the east. On a basin wide scale, recharge is via rainfall infiltration on rock outcrop areas, infiltration of stream runoff water in upper catchments and also by inter-aquifer leakage (PB, 2011a).

The conceptual model for groundwater flow within the Camden area is described within PB (2011a). Within the local area there is rainfall and river recharge to the alluvial sediments associated with the Nepean River, with very limited rainfall recharge to the Wianamatta Group shales with most rainfall generating stormwater runoff. There is some minor leakage through the Wianamatta Group into the Hawkesbury Sandstone aquifer, however most recharge to the sandstone aquifers is expected to occur via lateral groundwater through-flow from upgradient and updip areas to the south.

Flow occurs within the individual aquifers and there does not appear to be any interaction between the Hawkesbury Sandstone aquifers and the deeper water bearing zones in the Narrabeen Group and the Illawarra Coal Measures. Groundwater flow is variable throughout the Hawkesbury Sandstone, and is generally dominated by secondary porosity and fracture flow.

Madden (2010) reported evidence of some vertical connectivity between the lower units of the Narrabeen Group (the Bulgo Sandstone, Stanwell Park Claystone, Scarborough Sandstone and Wombarra Claystone), however, this observation was in relation to the effects of longwall mining in the Southern Coalfields to the south and is unlikely to be the case in the CGP area.

Within the CGP area, discharge via groundwater pumping is likely to be a relatively minor component of the overall water balance with most groundwater users being domestic or rural. There may be a small base flow or interflow discharge component from the alluvium to local stream headwaters during wet periods. Surface water – groundwater interactions in the wider area, however are not well defined.

Carbon dating from Hawkesbury Sandstone monitoring bores (PB, 2012) confirms long residence times greater than 30,000 years (dated from AGLs dedicated monitoring bores, located 12km northeast of the existing Camden Gas Project wellfield). It is expected that the age of the groundwater in the deeper coal seam water bearing zones will be significantly older again; however this work has not been completed at this time.

Table 3 lists some hydrogeological properties for the local stratigraphic units where available. Appendix B illustrates a schematic model for the stratigraphy of the CGP area (PB, 2011b).

3.6.1. Depressurisation and aquifer interactions

Extraction of coal seam gas and associated groundwater in the deeper Illawarra Coal Measures will lead to the depressurisation of the coal seam water bearing zones at depth for the duration of the gas extraction operations. Of key relevance to understanding the potential impacts to shallow groundwater resources, and surface water, is the degree to which the Illawarra Coal Measures are in vertical connection with overlying aquifer zones within the Narrabeen Group, Hawkesbury Sandstone and thin alluvial deposits.

While there are no specific monitoring or test pumping data that demonstrates this degree of vertical connection or disconnection, inferences can be drawn from studies elsewhere in the southern Sydney Basin, including impacts from long wall coal mining (see review by Merrick, 2009) and nearby groundwater resource investigations (e.g. KBR, 2008; PB, 2008; SCA, 2005b).

Based on these previous studies it is concluded that the presence of extensive and thick claystone formations in the stratigraphic sequence that overlies the Permian coal measures in the area will protect shallower aquifers in the Triassic sandstones. These very low permeability layers are likely to 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.

Further assurance is given by the successful dewatering of existing wells throughout the CGP area, which demonstrates the isolation of the targeted water bearing zone from other water bearing zones and aquifers in the vicinity. More than 80% of the operating wells at the CGP in the 2011-2012 financial year produced negligible or no water (<50 kL per well during the whole year); this is strong evidence to support the conclusion that only water from the coal seams is removed during the CSG extraction process and no water from shallower groundwater systems (such as the shallow beneficial aquifers) is contributing to the overall small volume of produced water.

Additional evidence supporting the conclusion that there is negligible interaction and isolation between the coal seams and the shallow beneficial aquifers is that the water chemistry signatures of samples from both zones are significantly distinct (Figure 6). If there was interaction between the zones, less distinct chemical signatures and changing trends within water chemistry could be expected, which has not been the case.

Further evidence to support the conclusion that there is negligible interaction and isolation between the coal seams and the shallow beneficial aquifers is that the trends observed over a 12 month period at two water supply bores that tap the Hawkesbury Sandstone indicate the water quality has not changed (specifically deteriorated), outside of expected natural variation.

3.6.2. Potential for drilling impacts and contamination

Drilling gas wells is generally completed using an overbalanced mud drilling system. That is, there is a higher head of water and drill fluids in the wellbore compared to the piezometric heads in the different formations. Using this technique there is no potential for natural groundwater systems to leak and be connected during well construction. The natural formations are also low permeability so there is minimal potential for drilling fluids to migrate into the natural formations. Typically, the well is drilled and open against the beneficial aquifers for only 1-2 days prior to the surface casing being installed and pressure cemented in place, and prior to drilling the full depth (i.e., the coal seams at depth). Typically, surface casing in existing wells is installed to around 120-140m below surface for safety and environmental purposes.

A typical vertical well completion at Camden is shown in Figure 9.

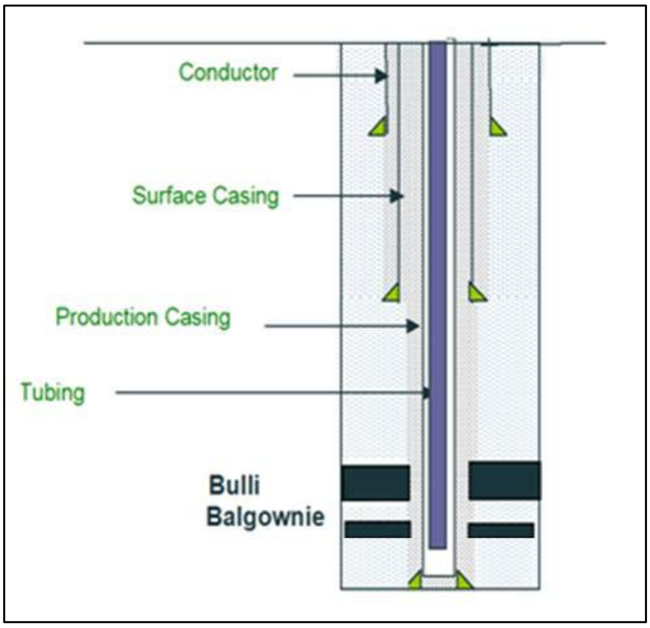

Figure 7: Schematic diagram representing a typical vertical gas well completion for the CGP.

CSG wells in NSW require the isolation of water resource aquifers from hydrocarbon bearing zones. All gas production wells have been or will be completed with multiple casings (and pressure cemented (with cement manufactured to API specifications) in place) to ensure that aquifers remain isolated. Cement bond logs are run downhole to provide a representation of the integrity of the cement job.

Cementing operations in CSG wells are a critical application which must be designed properly to restrict fluid movement between the formations (zonal isolation) and to bond and support the casing. The integrity of the well cement and casing as well as the naturally occurring hydraulic separation of the shallow beneficial aquifers from the Permian Illawarra Coal Measures by the confining layers prevents potential migration paths of the groundwater from the target coal seams through to beneficial aquifers, wells, bores, springs (if present), and watercourses. Although it is acknowledged that groundwater flow may be enhanced within fracture zones within the Hawkesbury Sandstone, lack of large scale fault zones within the area and the low pressures within formations prevents significant interaction between the shallow beneficial aquifers and the target coal seams.

In the past, AGL has carried out hydraulic fracturing to stimulate the CSG reservoir to enhance gas production. All the existing vertical and deviated gas wells within the CGP have been completed using fracture stimulation (hydraulic fracturing). Typically, a well is fracture stimulated only once, at the start of its production life. Hydraulic fracturing consists of pumping a fluid under pressure into a steel cased and cemented wellbore to create enough pressure to fracture, including opening up existing fractures, in the target coal seam. It is only used in association with improving the performance of vertical and deviated gas wells by assisting to enhance or increase the natural permeability of the coal that will not otherwise allow commercial gas flows from the coal seam without stimulation. It is not used as a gas flow improvement technique associated with horizontal wells because there is already a large surface area exposed within the coal seam and the wellbore.

The fluid contains a “proppant” like sand that helps prop the fractures open to allow gas to be produced to surface, up the wellbore. The fracture stimulation fluid recipes can change from site to site and from contractor to contractor but within the CGP fracture stimulation programs have been sand and water with gels to aid viscosity and minor acids and bactericides. Sixty-two (62%) percent of all the 117 fracture stimulation programs on wells in the CGP were performed with just water and sand; no additional chemicals were used. No fracture stimulation programs have been carried out since 2009 and none are planned for new sites at the CGP that involve horizontal completion techniques. It should be noted that fracture stimulation techniques are not used on horizontal wells.

Fracturing occurs within the coal seam (and only targets the coal seam), hundreds of metres below the shallow beneficial aquifers. A typical fracture extends horizontally about 30 – 60 m from the well bore and is, at its widest, approximately a centimetre or two thick. Aside from the important water volume and water quality considerations, zonal isolation is important for gas production, as water migration from any other source will hinder gas production. All precautions are taken during fracture stimulation programs to ensure no new communication is created between targeted coal seams and other formations (such as the beneficial aquifers).

The fluid used is recovered from the well through the “flowback” and dewatering processes. Essentially, what goes down the well comes back up. This is done by using a “breaker” to react with the gel, breaking down its viscosity back to water so that the fluid’s ability to flow is increased so it can be produced back to surface. It is estimated that 100% of the fracturing fluid would be recovered plus coal seam formation water. In order to ensure this, AGL would log, test and dispose of 150% of the volume of fracturing fluid as flowback water, ensuring that all fracturing fluid is recovered. After this volume is recovered AGL’s usual produced water management regime will apply after which time it would revert to produced water.

The flowback fluid is captured into either lined pits or to open top tanks. It is classified as a waste under the POEO Act. The fluid can be recycled for further fracture stimulation, with appropriate treatment if required, or disposed of in accordance with strict environmental regulations set out in AGL's operational licences. This is usually to offsite water recycling plants.

4. Groundwater use

There are 113 licensed water bores contained within the NSW Office of Water Pinneena database (Version 3.2) located within PPLs 1, 2, 4, 5, and 6. These have been mapped (Figure 8) and listed along with their characteristics and distance to nearest wellhead (Appendix A). Some are test bores that appear never to have been converted to water supply bores.

Seventy three (73) bores have active licence status, while 24 have cancelled or abandoned licences. There are 26 bores identified as monitoring bores, and 79 are identified with either domestic, stock and/or irrigation as their intended use. Irrigation bores are mostly associated with the alluvial sediments or the Hawkesbury Sandstone south of the Nepean River.

The average total depth of the bores is 96.7 m. There are 45 bores that are likely to tap the Hawkesbury Sandstone, 12 bores that tap the Wianamatta Group rocks, 33 that tap unconsolidated sediments, and 23 that are dry or the target aquifer is unknown. Of the bores that have records with salinity measured in mg/L, the average is 1295 mg/L: 738 mg/L for Hawkesbury Sandstone, 2529 mg/L for Wianamatta Group rocks, and 2142 mg/L for unconsolidated sediments. The average recorded yield is 1.8 L/s: the average recorded yield for bores tapping the Hawkesbury Sandstone is 1.5 L/s, 1.3 L/s for Wianamatta Group bores, and 2.6 L/s for bores tapping the alluvial unconsolidated sediments.

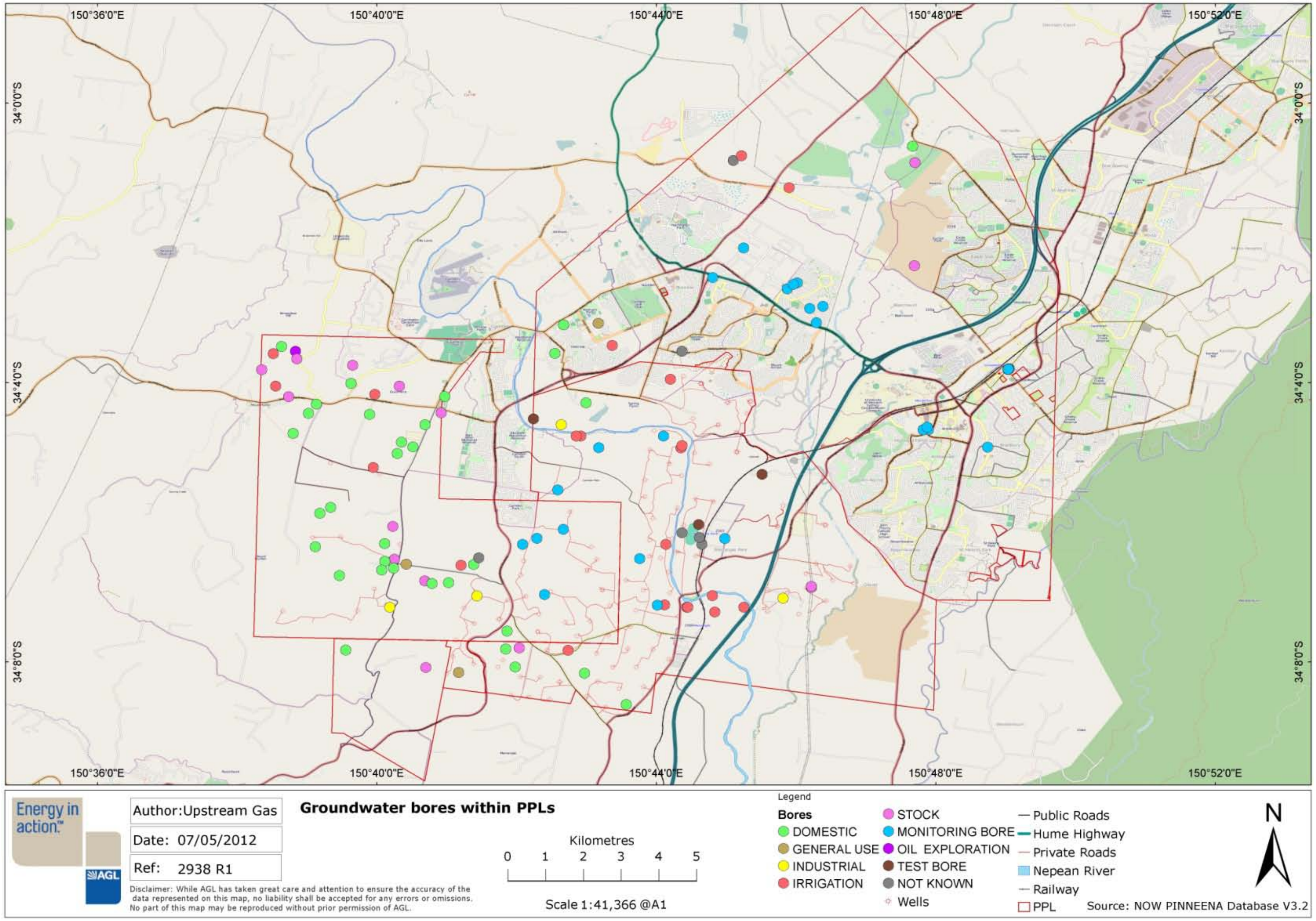

Figure 8: Location of registered bores within PPL 1,2,4,5, and 6, symbolised with respect to intended use.

4.1. Known groundwater uses

The majority of the shallow groundwater being produced from bores within PPLs 1, 2, 4, 5, and 6 is used for domestic, stock, and irrigation purposes (Figure 8). As mentioned in Section 3.5, the water quality of the groundwater extracted within the CGP area is typically more saline than other parts of the Sydney Basin and so beneficial use is limited. Groundwater in this area is not used as a drinking water source.

The deep groundwater being produced from the operational gas wells within the CGP is collected and temporarily stored at each well site in (typically) 10,000 L plastic tanks before being accumulated at the Rosalind Park Gas Plant, where it is filtered, and then delivered to a licensed water recycling facility for approved treatment and beneficial reuse in industrial process, such as brick manufacturing.

4.2. Groundwater dependent ecosystems

NOW (2011) has identified 24 priority groundwater dependent ecosystems (GDEs). No “high priority” groundwater dependent ecosystems (GDEs) have been identified within the CGP or the area directly surrounding the CGP. Four high priority GDEs have been identified within the wider Southern Sydney Basin region, as documented in NOW (2011) (Table 5). The four GDEs presented in Table 5 are over 10 km from the CGP and have no association with any of the groundwater systems that occur in the Camden-Campbelltown area. There are no GDEs identified by NOW in the CGP.

It should be noted the Cumberland Shale Hills/Plains Woodland, which, however, is identified as a “highly probable” groundwater dependant ecosystem, is present within the vicinity of the project area (Serov et al., 2012); however it appears it is dependent on very shallow, localised perched groundwater in soils (derived from Wianamatta Shale) and local colluvium/alluvium rather than the deeper, regional groundwater systems.

Table 4: Summary of the Southern Sydney region GDEs (NOW, 2011)

GDE Name	Latitude (GDA 94)	Longitude (GDA 94)	Location	Area (ha)
Salt Pan Creek	319132	6241847	Estuarine Wetland. Salt Pan Creek, is located in the suburbs of Riverwood and Peakhurst, and flows to the Georges River.	1.077
O’Hares Creek	305027	6211055	Floodplain Wetland. Comprises catchment of O’Hares, Stokes and Four Mile Creeks, downstream to the junction of O’Hares Creek and Stokes Creeks, located between Appin and Bulli on the Woronora Plateau. Elevation: 100-450 m ASL. As much of the upper catchment of this creek is covered by wetlands, absorption, retention and release of water by these wetlands is a major determinant on the hydrology of the catchment.	9000
Thirlmere Lakes	272861	6211256	Freshwater Lakes. The Thirlmere Lakes are located on the edge of the Southern tablelands approximately 10km south west of Picton. The Lakes include: Gandangarra, Werri-Berri, Couridjah, Baraba and Nerrigorang Lakes.	627
Towra	329245	6236488	Located approximately 16 km south of	638

GDE Name	Latitude (GDA 94)	Longitude (GDA 94)	Location	Area (ha)
Point Estuarine Wetlands			Sydney centre. Towra Point adjoins Kurnell Peninsula forming the southern and eastern boundaries of Botany Bay.	

4.3. Volumes of groundwater extracted

There are no known published records of annual abstraction volumes from licensed water bores. Expected volumes of use from the private water bores for domestic and stock use is estimated at approximately 1 ML per annum. Interpolating this for all the private bores with an active licence within the PPL areas (73 bores), this would equate to approximately 73 ML of extraction per year. This water is sourced from a variety of shallow groundwater aquifers including those in shallow alluvium, Wianamatta Group rocks and the underlying Hawkesbury Sandstone.

The CGP is entitled to extract 30 ML per annum under the current Water Access Licence, however, actual volumes of water extracted (produced) are currently much less (<4.8 ML in 2011/12, for example). Shown in Table 6 are recent yearly volumes of produced water for the entire CGP wellfield. Typically, when a new well is constructed higher rates of water are produced from the coal measures in the first few years, and then water production progressively diminishes to very low volumes or no water at all. The actual volume of water produced at each well is dependent on a range of variables including the local permeability of the targeted zones around the wellbore.

More than 80% of the operating wells at the CGP in the 2011-2012 financial year produced negligible or no water (<50 kL during the whole year). This is strong evidence to support the conclusion that only water from the coal seams is removed during the CSG extraction process and no water from shallower groundwater systems (such as the shallow beneficial aquifers) is contributing to the overall small volume of produced water.

Table 5: Annual water year volumes of produced water for the CGP wellfield

	2011/12	2010/11	2009/10	2008/09	2007/08
Operational wells	89	81	85	83	87
Average produced water volume per operating well (ML)	0.053	0.043	0.034	0.098	0.094
Total produced water volume for wellfield (ML)	4.73	3.52	2.90	8.16	8.15

5. CSG development risks, and management and mitigation measures

5.1. Risks

As previously mentioned, the only beneficial aquifers (used for water supply) across the CGP area are the shallow alluvial aquifers (where present) and the porous and fractured rock aquifers within the Hawkesbury Sandstone. As explained in Section 3.6, the natural groundwater flow direction is sub-horizontal from approximately south to north within each geological unit, although there is potential for a small component of vertical flow within a unit due to decreasing water levels with depth. However, vertical leakage between groundwater systems under both natural and gas field development scenarios is considered to be negligible based on the available data. There is no potential for changes at depth (e.g. there is no potential mechanism for the injection of fracture stimulation fluids into the coal seams to migrate hundreds of metres vertically and impact the shallow beneficial aquifers).

The volumes of water being removed from the Permian Illawarra Coal Measures are very small (< 4.8 ML for the whole of the CGP area in 2011/12), and so any potential impact would likely be localised.

During coal seam gas operations, a small amount of water is required to be removed from the target coal seams in order to induce gas flow. As a result, the water pressure within the coal seam is reduced. Although confined by the thick impermeable aquitards, which prevent any significant vertical flow between the coal seams and beneficial aquifers, in the unlikely scenario that a connection between the coal seams and beneficial aquifers was induced, the worst case scenario would be that a small amount of water would flow downward, towards the coal seam, due to the pressure gradient. There is no mechanism for coal seam gas water to flow vertically upwards, given the low pressure and the downward gradient. Therefore, there is virtually no risk for contamination of shallow beneficial aquifers by coal seam water away from the well bore.

Although assessed to be low, the primary risks to groundwater are assessed to be:

- The connectivity of shallow beneficial aquifers and the deep water bearing zones resulting in reduction of pressure in shallow beneficial aquifers, and
- The contamination of shallow beneficial aquifers.

Declines in water levels in water supply bores as a result of hydraulic connectivity between the shallow aquifers and the deep coal measure water bearing zones have not been observed. This is due to the thickness (400 – 500 m) and nature of the confining layers that separate the Permian Illawarra Coal Measures and the shallow beneficial aquifers and the fact that many wells have successfully been dewatered (no water is being produced anymore), demonstrating hydraulic isolation of layers.

In addition, water supply bores within the shallow Hawkesbury Sandstone are monitored for changes in water quality. No degradation of water quality has been observed at these bores as a result of CSG activities.

5.2. Management and mitigation measures

5.2.1. Well integrity

Cement and/or casing failure of the wells, which could lead to contamination of shallow aquifers, is also not expected due to integrity of the well construction. In accordance with the *Code of Practice for Coal Seam Gas – Well Integrity* (DTIRIS, 2012a), wells are constructed with multiple casings (conductor casing, surface casing, and production casing) that protect beneficial aquifers and effectively isolate groundwater in each geological formation. During construction, new wells are fully pressure cemented to surface and cement bond logs are run down hole to confirm the integrity of the cement and ensure there is no interaction with any other formation (including the shallow beneficial aquifers). Vertical, deviated and horizontal lateral gas wells only target the Permian Illawarra Coal Measures.

5.2.2. Fracture stimulation

As mentioned previously, fracturing as a result of fracture stimulation occurs within the coal seam (and only targets the coal seam), hundreds of metres below the shallow beneficial aquifers. Aside from the important water volume and water quality considerations, zonal isolation is important for gas production, as water migration from any other source will hinder gas production. The fluid used is recovered from the well through the 'flowback' and dewatering processes. Essentially, what goes down the well comes back up. The fluid is then captured in either lined pits or to open top tanks and disposed of in an appropriate manner. All precautions are taken during fracture stimulation programs to ensure no new communication is created between targeted coal seams and other formations (such as the beneficial aquifers). In the unlikely event that new communications are identified between the targeted coal seams and beneficial aquifers as a result of a fracture stimulation program, it would be possible to cease operations from that well, investigate the integrity of the well, and repair any well or formation issues. In the worst case scenario, the well would be plugged and abandoned, and the area rehabilitated in accordance with best industry standards at the time.

Any hydraulic fracture stimulation will be undertaken in accordance with the *Code of Practice for Coal Seam Gas - Fracture Stimulation Activities* (DTIRIS, 2012b). In particular, the Code of Practice requires:

- the preparation and implementation of an approved fracture stimulation management plan (FSMP);
- that the FSMP:
  - contain a full description of the fracture stimulation process;
  - contain an inventory and characterisation of chemicals used within the fracture stimulation process;
  - address proposed management measures for fracture stimulation fluid; and
  - demonstrate that all risks to the environment, existing land uses, the community and work force, as a result of the fracture stimulation activity, are managed though an effective risk management process that includes identification of hazards, assessment of risks, implementation of control measures and monitoring of the integrity and effectiveness of the control measures.

It should be emphasised that the fracture stimulation technique is not used on horizontal wells.

5.2.3. Regional depressurisation

In the unlikely scenario that an impact was observed within a shallow beneficial aquifer and that CSG depressurisation may be the cause, the situation would be investigated in order to confirm the cause of the impact. If it was determined the impact was due to depressurisation at a specific well, it would be possible to cease production from that well, investigate the integrity of the well, and repair any well or formation issues. In the worst case scenario, the well would be plugged and abandoned, and the area rehabilitated in accordance with best industry standards at the time. Further details regarding management responses are detailed in the Groundwater Management Plan (AGL, 2012).

5.2.4. Plug and abandonment procedures

At the end of the life of each well, the well is plugged with cement and backfilled to surface to prevent any interactions between shallow aquifers and deep water bearing zones in the future. The surface area of the well is reinstated to original site condition, in accordance with best industry standards at the time. All wells must be plugged and abandoned in accordance with *Schedule of Onshore Exploration and Production Safety Requirements* (DMR, 1992).

5.2.5. Groundwater management plan

A Groundwater Management Plan (AGL, 2012) for the whole CGP is currently being implemented. It provides a framework for early assessment of any changes in the groundwater systems beneath the CGP area, particularly to the shallow beneficial aquifers in order to prevent and/or mitigate any adverse impacts.

The objectives of this GMP are to:

- describe the water level and water quality monitoring network across the different groundwater systems located beneath the CGP area;
- build a database of baseline (where possible) and trend information (both water levels and water quality) for shallow beneficial use aquifers;
- identify water level and water quality trends that may suggest connectivity or contamination of aquifers due to dewatering activities;
- provide a monitoring (and an action response) framework for water users and regulators on the groundwater monitoring program at Camden; and
- outline the reporting and review requirements for the monitoring program.

6. References

AGL, 2012. Groundwater Management Plan. AGL document. Last revised November 2012. Available online at http://agk.com.au/camden/assets/pdf/Apr2013/AGL_GMP_Camden_V2-4_20121116.pdf

Broadstock, B., 2011. Impact of groundwater pumping on stacked water sources, NSW Office of Water, Sydney.

Department of Mineral Resources (DMR), 1992. Schedule of Onshore Petroleum Exploration and Production Safety Requirements, NSW. Accessed on 23 May, 2012 via http://www.resources.nsw.gov.au/safety/legislation/petroleum

Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS), 2012a. NSW Code of Practice for Coal Seam Gas Well Integrity, State of New South Wales, NSW Trade and Investment.

Department of Trade and Investment, Regional Infrastructure and Services (DTIRIS), 2012b. NSW Code of Practice for Coal Seam Gas Fracture Stimulation Activities, State of New South Wales, NSW Trade and Investment.

GHD, 2007. Dendrobium Area 3 - predicted hydrogeologic performance, Report for BHP Billiton, Illawarra Coal. Accessed online on 9 May 2012 via http://www.bhpbilliton.com/home/aboutus/regulatory/Documents/Attachment%20F%20-%20Hydrogeology%20Report%20(GHD)-Report%20Only.pdf

Herbert, C. and Helby, R., 1980. A guide to the Sydney Basin, Bulletin 26, Geological Survey of New South Wales, Department of Mineral Resources, Sydney.

Jewell, C. and Associates, 2001. Assessment of groundwater impacts of coal-bed methane development, Cawdor, NSW.

Kellogg Brown and Root (KBR), 2008, Upper Nepean (Kangaloon) Borefield Environmental Assessment. Report for Sydney Catchment Authority, March 2008.

Madden, A., 2010. The Scarborough Sandstone and its connectivity with longwall mining in a water supply catchment. Extended abstract presented at Groundwater 2010, 31 October – 4 November 2010, Canberra. Accessed online 23 April 2012 via http://www.groundwater2010.com/documents/MaddenAndrea_000.pdf

McKibbon, D., and Smith, P.C., 2000. Sandstone hydrogeology of the Sydney region. A paper presented at the 15th Australian Geological Convention: “Sandstone City, Sydney’s Dimension Stone and Other Sandstone Geomaterials”, UTS, Sydney, Department of Infrastructure, Planning and Natural Resources.

Merrick, N., 2009. Bulli Seam Operations Groundwater Assessment: A hydrogeological assessment in support of the Bulli Seam Operations Environmental Assessment. Unpublished report for Illawarra Coal Holdings Pty Ltd by Heritage Computing, July, 2009.

Moffitt, R.S., 1999. Southern Coalfield Regional Geology Map, 1: 100,000, First Edition. Geological Survey of New South Wales, Sydney.

NHMRC, NRMMC, 2011. Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

NOW, 2010. Pinneena, Version 3.2 – Groundwater works, New South Wales groundwater data archive. NSW Office of Water, Department of Environment, Climate Change and Water. Available for purchase via http://waterinfo.nsw.gov.au/pinneena/gw.shtml

NOW, 2011. Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (NSW).

Parsons Brinckerhoff (PB), 2003. Groundwater investigation for contingency drought relief in the Sydney Region – Results of desk study. Unpublished report for Sydney Catchment Authority, Report 2114127A -PR_2984 RevE, December 2003.

Parsons Brinckerhoff (PB), 2008, Leonay – Emu Plains pilot testing program: Hydrogeological analysis of drilling and testing programs. Report for Sydney Catchment Authority, November 2008.

Parsons Brinckerhoff (PB), 2011a, Phase 1 Groundwater Assessment and Conceptual Hydrogeological Model – Northern Expansion of Camden Gas Project. Report for AGL Energy Ltd, February 2011. Available online at http://agk.com.au/camden/assets/pdf/PR5375Camden%20NorthFINAL.pdf

Parsons Brinckerhoff (PB), 2011b. Unpublished schematic stratigraphic diagram of Camden North prepared for AGL.

Parsons Brinckerhoff (PB), 2012. Update on the Phase 2 Groundwater Program – Denham Court Road, Denham Court. Report for AGL Energy Ltd, August 2012. Available online at http://agk.com.au/camden/assets/pdf/Apr2013/2114759B-SCW-LTR-5637_Aug12%20update.pdf

Russell, G., 2007. Hawkesbury Sandstone groundwater attributes and geological influences, poster presentation at UTS/UNSW 20th Anniversary Hydrogeology Symposium, Hydrogeology Over the Years, Friday 20th July, 2007.

Serov, P. Kunginis, L., Williams, J.P., 2012, Risk assessment guidelines for groundwater dependent ecosystems, NSW Department of Primary Industries, Office of Water, Sydney.

Sydney Catchment Authority (SCA), 2005a. Metropolitan Water Plan- priority groundwater investigations for contingency drought relief – Area 2: Upper Nepean Catchment. Report no. 05- GL31A/2.

Sydney Catchment Authority (SCA), 2005b. Metropolitan Water Plan- priority groundwater investigations for contingency drought relief – Area 3: Upper Canal (Appin). Report no.05-GL31A/3

Appendix A: Registered bore information

The information presented in Table 7 and Table 8 has been compiled from the NSW Office of Water Pinneena database – Groundwater Works (Version 3.2, 2010), which is available to order via http://waterinfo.nsw.gov.au/pinneena/gw.shtml. Additional information (marked by '*'), not originally contained in the Pinneena database, has been interpreted or calculated by AGL.

Table 6: Licence and construction information for all registered bores located within CGP PPLs

Work Number	License	Latitude	Longitude	Work Status	Licence Status	Owner Type	Intended Use	Depth (m)	Completion	Distance to closest well head (km)*
GW014161	10BL008245	-34.012594	150.753665	(Unknown)	Cancelled	Private	IRRIGATION	86.5		5.969
GW016091	10BL008244	-34.013705	150.75172	(Unknown)	Cancelled	Private	NOT KNOWN			5.813
GW017315	10BL007993	-34.135928	150.686167	Supply Obtained	Active	Private	GENERAL USE	36.5	1/1/1938	0.253
GW019702	10BL012487	-34.059261	150.647278	(Unknown)	Active	Private	OIL EXPLORATIO N	92.3	1/2/1962	3.047
GW023588	10BL017352	-34.069539	150.666167	(Unknown)	Active	Private	IRRIGATION	91.4	1/1/1965	2.051
GW024351	10BL018771	-34.105372	150.744222	(Unknown)	Cancelled	Private	NOT KNOWN	21.9	1/5/1966	0.322
GW024353	10BL018772	-34.102594	150.739499	Test Hole	Cancelled	Private	NOT KNOWN	24.3	1/5/1966	0.206
GW024354	10BL018773	-34.103705	150.743666	Test hole	Cancelled	Private	NOT KNOWN	21.3	1/5/1966	0.470
GW026239	10BL019653	-34.079539	150.715333	Test Hole	Cancelled	Private	IRRIGATION	22.8		1.571
GW026469	10BL019648	-34.117594	150.746722	Test Hole	Cancelled	Private	IRRIGATION	20.4	1/11/1965	0.923
GW026470	10BL019649	-34.120371	150.754222	Test hole	Cancelled	Private	IRRIGATION	1.9	1/11/1965	0.535
GW026471	10BL019650	-34.121483	150.747277	Test Hole	Cancelled	Private	IRRIGATION	5.4	1/11/1965	0.807
GW026472	10BL019651	-34.082316	150.739221	Test hole	Cancelled	Private	IRRIGATION	28.9		0.062
GW026473	10BL019652	-34.120372	150.740888	Test hole	Cancelled	Private	IRRIGATION	19.2	1/11/1965	0.313
GW026474	10BL019645	-34.08176	150.739499	Test hole	Cancelled	Private	IRRIGATION	26.1	1/11/1965	0.005
GW026516	10BL019654	-34.13065	150.712278	Test hole	Cancelled	Private	IRRIGATION	10	1/11/1965	0.441
GW026529	10BL019644	-34.110372	150.686723	Test hole	Cancelled	Private	IRRIGATION	6.7	1/11/1965	1.110
GW026533	10BL019643	-34.079539	150.714222	Test hole	Cancelled	Private	IRRIGATION	21.3	1/11/1965	1.671
GW026545	10BL019647	-34.119816	150.735333	Test hole	Cancelled	Private	IRRIGATION	8.5	1/11/1965	0.348
GW026551	10BL019646	-34.105372	150.735611	Test hole	Cancelled	Private	IRRIGATION	10.9	1/11/1965	0.215
GW026557	10BL019642	-34.120372	150.740611	Test hole	Cancelled	Private	IRRIGATION	28.3	1/5/1966	0.296

Work Number	License	Latitude	Longitude	Work Status	Licence Status	Owner Type	Intended Use	Depth (m)	Completion	Distance to closest well head (km)*
GW031438	10BL023530	-34.057872	150.722832	Supply Obtained	Cancelled	Private	IRRIGATION	23.9	1/4/1968	1.788
GW032724	10BL024430	-34.052594	150.719499	(Unknown)	Active	Private	GENERAL USE	76.2	1/3/1968	2.361
GW034351	10BL026444	-34.065927	150.736721	(Unknown)	Cancelled	Private	IRRIGATION	182.9	1/9/1968	0.315
GW034450	10BL026445	-34.05926	150.739499	(Unknown)	Cancelled	Private	NOT KNOWN	190.5	1/9/1968	0.661
GW035211	10BL027909	-34.01426	150.795053	(Unknown)	Abandoned	Private	STOCK	60.9	1/9/1968	7.264
GW037744	10BL030567	-34.059817	150.642001	(Unknown)	Cancelled	Private	IRRIGATION	56.3	1/3/1969	3.149
GW047444	10BL111085	-34.067595	150.642556	(Unknown)	Active	Private	DOMESTIC, IRRIGATION , STOCK	55	1/12/1979	2.357
GW050754	10BL131334	-34.063706	150.639223	(Unknown)	Active	Private	STOCK	62	1/5/1980	2.886
GW052126	unlisted	-34.110095	150.673667	(Unknown)	Unlisted	Other Govt	GENERAL USE	140	1/12/1981	0.548
GW052159	10BL113840	-34.062595	150.660889	(Unknown)	Active	Private	STOCK	152	1/2/1981	2.622
GW057837	10BL163165	-34.070095	150.645612	(Unknown)	Active	Private	STOCK	78	1/2/1983	1.977
GW059773	10BL602808	-34.073983	150.682	(Unknown)	Active	Private	DOMESTIC, FARMING, INDUSTRIAL , STOCK	121.9	1/9/1983	2.763
GW062945	10BL135102	-34.130094	150.700612	(Unknown)	Active	Private	STOCK	150	1/8/1986	0.606
GW064814	unlisted	-34.115371	150.770332	(Unknown)	Unlisted	Private	STOCK	48	1/1/1985	0.105
GW064815	unlisted	-34.115649	150.770332	(Unknown)	(Unknown)	Private	DOMESTIC, STOCK	64	29/1/1985	0.098
GW072197	unlisted	-34.10109	150.670486	(Unknown)	Unlisted	Private	STOCK	180	7/2/1994	0.494
GW072309	unlisted	-34.067612	150.672082	(Unknown)	(Unknown)	Private	FARMING, STOCK	30	15/7/1994	2.526
GW072329	10BL155242	-34.108797	150.729379	(Unknown)	Active	Private	MONITORIN G BORE	5	1/1/1989	0.235
GW072344	unlisted	-34.108869	150.670886	(Unknown)	(Unknown)	Private	DOMESTIC, STOCK	132.5	7/9/1994	0.416
GW072777	unlisted	-34.038854	150.794915	(Unknown)	(Unknown)	Private	DOMESTIC, STOCK	252	9/3/1995	5.075
GW073364	unlisted	-34.06108	150.64757	(Unknown)	(Unknown)	Private	DOMESTIC, FARMING, STOCK	146	18/1/1993	2.846
GW075051	unlisted	-34.04439	150.764588	New bore	Unlisted	NOW	MONITORIN G BORE	10	3/2/1999	3.064

Work Number	License	Latitude	Longitude	Work Status	Licence Status	Owner Type	Intended Use	Depth (m)	Completion	Distance to closest well head (km)*
GW075052	unlisted	-34.043308	150.766059	New bore	Unlisted	NOW	MONITORING BORE	9.2	4/2/1999	3.217
GW075053	unlisted	-34.042904	150.766961	New bore	Unlisted	NOW	MONITORING BORE	9.8	4/2/1999	3.285
GW075054	unlisted	-34.049024	150.769956	New bore	Unlisted	NOW	MONITORING BORE	5.5	4/2/1999	2.767
GW075055	unlisted	-34.048524	150.773065	New bore	Unlisted	NOW	MONITORING BORE	4.6	3/2/1999	2.960
GW075056	unlisted	-34.05245	150.771518	New bore	Unlisted	NOW	MONITORING BORE	11	4/2/1999	2.518
GW075057	unlisted	-34.041674	150.7468	New bore	Unlisted	NOW	MONITORING BORE	11	3/9/1998	2.682
GW075058	unlisted	-34.034632	150.754178	New bore	Unlisted	NOW	MONITORING BORE	5	3/9/1998	3.632
GW100056	10BL156701	-34.080984	150.672589	(Unknown)	Active		DOMESTIC	144.5	14/6/1995	1.652
GW100088	10BL143717	-34.108592	150.690953	(Unknown)	Active		DOMESTIC, STOCK	150	26/8/1991	1.281
GW100329	10BL151638	-34.071592	150.716584	(Unknown)	Active		DOMESTIC, STOCK	32.3	26/3/1993	1.667
GW100605	10BL157839	-34.108585	150.69096	(Unknown)	Active		DOMESTIC, STOCK	201	31/12/1996	1.281
GW100733	10BL157849	-34.109406	150.668618	(Unknown)	Active		DOMESTIC, STOCK	138	15/1/1997	0.452
GW101031	10BL158264	-34.108583	150.690965	(Unknown)	Active		DOMESTIC, STOCK	36	11/11/1997	1.281
GW101066	10BL158247	-34.083646	150.671554	(Unknown)	Active		DOMESTIC, STOCK	138	18/11/1997	1.486
GW101106	10BL158151	-34.08865	150.758602	(Unknown)	Cancelled		TEST BORE	280	7/3/1997	0.463
GW101314	10BL158377	-34.110141	150.689794	(Unknown)	Active		DOMESTIC, STOCK	192	5/2/1998	1.152
GW101530	10BL158500	-34.05815	150.643945	(Unknown)	Active		DOMESTIC, STOCK	15.2	18/4/1998	3.256
GW101727	10BL158505	-34.076774	150.678158	(Unknown)	Active		DOMESTIC, STOCK	120	17/4/1998	2.307
GW102144	10BL150307	-34.134774	150.678383	Supply Obtained	Active	Private	DOMESTIC, STOCK	182	9/7/1992	0.474
GW102484	10BL156728	-34.105372	150.701445	(Unknown)	Active		MONITORING BORE	17.5	1/1/1995	1.370
GW102485	10BL156728	-34.101761	150.711167	(Unknown)	Active		MONITORING BORE	20.1	1/1/1995	0.500

Work Number	License	Latitude	Longitude	Work Status	Licence Status	Owner Type	Intended Use	Depth (m)	Completion	Distance to closest well head (km)*
GW102486	10BL156728	-34.079538	150.735055	(Unknown)	Active		MONITORIN G BORE		1/1/1995	0.258
GW102507	10BL159415	-34.120372	150.669779	(Unknown)	Active		INDUSTRIAL	165	30/8/1999	0.102
GW102619	10BL158265	-34.134642	150.699698	Supply Obtained	Active	Private	DOMESTIC, FARMING, IRRIGATION , STOCK	224	1/10/1999	0.269
GW103140	10BL159387	-34.096505	150.65569	(Unknown)	Active		DOMESTIC, STOCK	159	22/9/1999	0.438
GW103536	10BL159962	-34.130614	150.659229	(Unknown)	Active		DOMESTIC	220	2/2/2001	0.492
GW103996	10BL158732	-34.082151	150.812366	(Unknown)	Active		MONITORIN G BORE	3.87	13/8/1998	3.615
GW104025	10BL160600	-34.117664	150.690537	Supply Obtained	Active	Private	INDUSTRIAL	305	6/11/2000	0.407
GW104159	10BL159808	-34.114049	150.67812	(Unknown)	Active		DOMESTIC, STOCK	195	19/11/2001	1.038
GW104223	10BL160317	-34.111483	150.667834	Supply Obtained	Active	Private	DOMESTIC, STOCK	231.5	18/1/2002	0.509
GW104224	10BL160403	-34.112806	150.657754	Supply Obtained	Active	Private	DOMESTIC, STOCK	257.5	12/2/2002	0.375
GW104370	10BL158904	-34.082124	150.675287	Supply Obtained	Active	Private	DOMESTIC, STOCK	156	30/7/2002	1.857
GW104383	10BL160618	-34.105928	150.652001	Supply Obtained	Active	Private	DOMESTIC, STOCK	249.5	28/2/2002	0.259
GW104620	10BL161059	-34.066963	150.660495	Supply Obtained	Active	Private	DOMESTIC, STOCK	171.3	18/12/2002	2.140
GW104766	10BL161189	-34.130358	150.697387	Supply Obtained	Active	Private	DOMESTIC, STOCK	192	18/2/2002	0.789
GW105207	10BL161253	-34.111056	150.670649	Supply Obtained	Active	Private	DOMESTIC	250	24/1/2003	0.656
GW105325	10BL163811	-34.126049	150.69774	(Unknown)	Active		DOMESTIC	159	19/12/2001	0.365
GW105737	10BL162818	-34.071901	150.65226	Supply Obtained	Active	Private	DOMESTIC, STOCK	144	14/1/2004	1.577
GW105785	10BL162798	-34.074074	150.650351	Supply Obtained	Active	Private	DOMESTIC, STOCK	174	15/1/2004	1.393
GW106446	10BL162246	-34.059794	150.709131	Supply Obtained	Active	Private	DOMESTIC	140	13/1/2004	2.919
GW107140	10BL165167	-34.097947	150.653053	Supply Obtained	Active	Private	DOMESTIC	198	18/2/2007	0.649
GW107421	10BL163191	-34.114729	150.679819	(Unknown)	Active	Private	DOMESTIC,	297	11/8/2005	0.947

Work Number	License	Latitude	Longitude	Work Status	Licence Status	Owner Type	Intended Use	Depth (m)	Completion	Distance to closest well head (km)*
							STOCK			
GW107608	10BL165804	-34.0789	150.646677	Supply Obtained	Active	Private	DOMESTIC, STOCK	174.4	21/11/2005	1.131
GW107718	10BL160786	-34.105166	150.668537	Test hole	Active	Private	DOMESTIC, STOCK	249.5	28/2/2002	0.343
GW107721	10BL162462	-34.114479	150.683783	Supply Obtained	Active	Private	DOMESTIC, STOCK	277	23/1/2004	0.738
GW107791	10BL161521	-34.136149	150.716229	Supply Obtained	Active	Private	DOMESTIC, STOCK	231	19/3/2003	0.363
GW107962	10BL600017	-34.020231	150.764991	(Unknown)	Active		IRRIGATION, RECREATION	297	30/6/2005	5.493
GW108055	10BL601937	-34.087036	150.665805	(Unknown)	Active	Private	IRRIGATION		27/4/2007	0.945
GW108208	10BL163339	-34.070032	150.682903	Supply Obtained	Active	Private	DOMESTIC	141	7/7/2004	3.065
GW108863	10BL601942	-34.118215	150.763573	(Unknown)	Active	Private	INDUSTRIAL - SAND & GRAVEL	20	8/5/2008	0.180
GW108990	10BL600189	-34.143577	150.726137	(Unknown)	Active	Private	DOMESTIC	150	8/7/2008	0.080
GW109180	10BL163148	-34.010352	150.794494	(Unknown)	Active	Private	DOMESTIC, STOCK	264	8/8/2008	7.619
GW109212	10BL602480	-34.063602	150.817219	(Unknown)	Active	Private	MONITORING BORE	9	14/8/2008	4.530
GW109213	10BL602480	-34.0634	150.817527	(Unknown)	Active	Private	MONITORING BORE	5	14/8/2008	4.566
GW109214	10BL602480	-34.063441	150.817374	(Unknown)	Active	Private	MONITORING BORE	7	14/8/2008	4.551
GW109215	10BL602480	-34.06353	150.817274	(Unknown)	Active	Private	MONITORING BORE	5	15/8/2008	4.538
GW109315	10BL602560	-34.103984	150.749686	(Unknown)	Active	Private	MONITORING BORE	3	9/9/2008	0.778
GW109700	10BL160756	-34.119854	150.733611	(Unknown)	Active	Other Govt	MONITORING BORE	4.8	22/1/2001	0.433
GW109701	10BL160756	-34.11738	150.706685	(Unknown)	Active	Other Govt	MONITORING BORE	6.7	22/1/2001	0.166
GW109702	10BL160756	-34.103939	150.704848	(Unknown)	Active	Other Govt	MONITORING BORE	5	22/1/2001	1.029
GW109703	10BL160756	-34.092401	150.709852	(Unknown)	Active	Other Govt	MONITORING BORE	5.5	22/1/2001	0.628

Work Number	License	Latitude	Longitude	Work Status	Licence Status	Owner Type	Intended Use	Depth (m)	Completion	Distance to closest well head (km)*
GW109704	10BL160756	-34.082313	150.719583	(Unknown)	Active	Other Govt	MONITORING BORE	14.5	22/1/2001	1.140
GW110413	10BL603031	-34.100613	150.743436	(Unknown)	Active	Private	INDUSTRIAL	152	22/8/2009	0.320
GW110491	10BL165971	-34.052954	150.711206	(Unknown)	Active	Private	DOMESTIC	12	7/7/2006	2.993
GW110586	10BL602635	-34.076811	150.710672	(Unknown)	Active	Private	INDUSTRIAL - SAND & GRAVEL, IRRIGATION	20	28/1/2008	2.054
GW110587	10BL600640	-34.075433	150.704036	(Unknown)	Active	Private	TEST BORE	24	12/2/2008	2.578
GW110680	10BL603219	-34.077977	150.798255	(Unknown)	Active	Private	MONITORING BORE	8	13/8/2009	2.348
GW110681	10BL603219	-34.077974	150.796977	(Unknown)	Active	Private	MONITORING BORE	8	13/8/2009	2.232
GW110682	10BL603219	-34.077386	150.797947	(Unknown)	Active	Private	MONITORING BORE	8	13/8/2009	2.333
GW110708	10BL603631	-34.074352	150.66495	(Unknown)	Active	Private	DOMESTIC, STOCK	120	22/1/2010	1.535

Key: *- nearest producing, suspended, plugged, or plugged and abandoned well. Calculated by AGL – not contained in Pinneena database.

Table 7: Hydrogeological information for all registered bores location within PPLs

Work Number	License	Salinity (mg/L unless stated)	Yield (L/s)	SWL (m)	Drawdown (m)	Lithology of Aquifer	Likely aquifer*	Depth to water bearing zone – top (m)#	Depth to water bearing zone - bottom (m)#
GW014161	10BL008245	(Unknown)	6.32	0.7		Sandstone	(Unknown)	79.85	86.56
GW016091	10BL008244	(Unknown)				(Unknown)	(Unknown)	(Unknown)	(Unknown)
GW017315	10BL007993	3001-7000 ppm					(Unknown)		
GW019702	10BL012487	(Unknown)	1.01			(Unknown)	(Unknown)	80.7	80.7
GW023588	10BL017352	v.salty	1.26	3.6		Shale	Wianamatta?	27.4	33.4
GW024351	10BL018771	(Unknown)	0.19	6		Clay	Unconsolidated	14.9	19.4
GW024353	10BL018772	(Unknown)	0.38	4.5		clay sandy	Unconsolidated	4.5	22.4
GW024354	10BL018773	(Unknown)				Clay, Gravel	Unconsolidated	11.1	19.2

Work Number	License	Salinity (mg/L unless stated)	Yield (L/s)	SWL (m)	Drawdown (m)	Lithology of Aquifer	Likely aquifer*	Depth to water bearing zone – top (m)#	Depth to water bearing zone - bottom (m)#
GW026239	10BL019653	(Unknown)	3.16			Clay Light Brown Silty, Gravel, Sand, Shale	Unconsolidated	14.6	22.8
GW026469	10BL019648	(Unknown)				Sand	Unconsolidated	15.8	19.7
GW026470	10BL019649	(Unknown)				Silt, Sand	Unconsolidated		
GW026471	10BL019650	(Unknown)				Silt	Unconsolidated	2.7	4.9
GW026472	10BL019651	(Unknown)				Sand , Shale	Unconsolidated	16.7	28.8
GW026473	10BL019652	(Unknown)				Silt, Sand, Clay	Unconsolidated	11.5	18.2
GW026474	10BL019645	(Unknown)				Silt, Sand	Unconsolidated	13.1	24.6
GW026516	10BL019654	(Unknown)				Clay	Unconsolidated	4.5	4.5
GW026529	10BL019644	(Unknown)	0			Clay	Unconsolidated	3.3	6.3
GW026533	10BL019643	(Unknown)				Silt	Unconsolidated	17.3	21.2
GW026545	10BL019647	(Unknown)				Gravel	Unconsolidated	2.1	3.9
GW026551	10BL019646	(Unknown)				na	(Dry hole)	na	na
GW026557	10BL019642	(Unknown)				Silt, Sand	Unconsolidated	15.8	28.2
GW031438	10BL023530	(Unknown)	0.15	2.4	12.1		(Unknown)		
GW032724	10BL024430	1001-3000 ppm	1.26	3		Shale, Sand	Wianamatta?	57.9	59.4
GW034351	10BL026444	Brackish					Hawkesbury?		
GW034450	10BL026445	Brackish	1.06			Shale grey Black	Wianamatta?	118.9	128
GW035211	10BL027909	S.Brackish					(Unknown)		
GW037744	10BL030567	(Unknown)				Sandstone, Shale Bands		45.72	56.38
GW047444	10BL111085	Fresh	1.8	1.2		Sandstone	Wianamatta?	49.8	51.6
GW050754	10BL131334	Fresh	1.8	3.6		Sandstone	(Unknown)	56.4	57.5
GW052126	unlisted	Fresh				Sandstone	Hawkesbury	134.5	135

Work Number	License	Salinity (mg/L unless stated)	Yield (L/s)	SWL (m)	Drawdown (m)	Lithology of Aquifer	Likely aquifer*	Depth to water bearing zone – top (m)#	Depth to water bearing zone - bottom (m)#
GW052159	10BL113840	1001-3000 ppm				Shale, Sandstone	Hawkesbury	73	152
GW057837	10BL163165	(Unknown)	0.6	31.5		sandstone	Hawkesbury?	71.1	72.5
GW059773	10BL602808	Good	0.19			sandstone	Hawkesbury	106.7	107
GW062945	10BL135102	Fresh	0.7	40		Sandstone	Hawkesbury	144.8	145.9
GW064814	unlisted								
GW064815	unlisted	S.Brackish	5.06			(unlisted)	(Unknown)	42	58
GW072197	unlisted	Good	0.3	3		Sandstone	(Unknown)	152	169
GW072309	unlisted					na	(Dry hole)	na	na
GW072329	10BL155242						(Unknown)		
GW072344	unlisted	0-500 ppm	1			Sandstone	Hawkesbury	121.5	121.7
GW072777	unlisted					Shale	Wianamatta	63.7	63.8
GW073364	unlisted	Fresh				Sandstone	Hawkesbury	130.1	131
GW075051	unlisted	1080 mg/L		3.8		Clay, shale, weathered gravel	Unconsolidated	3	10
GW075052	unlisted	1952		7.7		Shale	Wianamatta?	6	9
GW075053	unlisted					Clay, Shale			
GW075054	unlisted					Shale, clay	Unconsolidated		
GW075055	unlisted					Shale	Wianamatta?		
GW075056	unlisted	1800		3.2		Clay	Unconsolidated	4	5
GW075057	unlisted	4063	0.1	4.3		Clay	Unconsolidated	9	11
GW075058	unlisted	416	3	1					
GW100056	10BL156701	230	0.2			sandstone	Hawkesbury	118.1	118.3
GW100088	10BL143717	Good	0.88	50		Sandstone	Hawkesbury	138	138.5
GW100329	10BL151638	Excellent				sand	Unconsolidated	29	31

Work Number	License	Salinity (mg/L unless stated)	Yield (L/s)	SWL (m)	Drawdown (m)	Lithology of Aquifer	Likely aquifer*	Depth to water bearing zone – top (m)#	Depth to water bearing zone - bottom (m)#
GW100605	10BL157839	1000	1.7	105		Sandstone	Hawkesbury	175	195
GW100733	10BL157849	950	0.7			sandstone	Hawkesbury	135.6	135.8
GW101031	10BL158264	Good	0.55	12	24	Gravel, clay	Unconsolidated	18	24
GW101066	10BL158247	480		20		Quartz	Hawkesbury	130	132
GW101106	10BL158151	4080	0.75	17		Sandstone, Shale	(Unknown)	160	163
GW101314	10BL158377	1300	0.59			sandstone	Hawkesbury	143	144
GW101530	10BL158500	460	2	7		Gravel	Unconsolidated	12.2	14.2
GW101727	10BL158505	420	1	58		Sandstone, quartz	Hawkesbury	104	104.5
GW102144	10BL150307	Good	0.38 (cumulative)	6		Sandstone	Hawkesbury	114	168.6
GW102484	10BL156728						(Unknown)		
GW102485	10BL156728						(Unknown)		
GW102486	10BL156728						(Unknown)		
GW102507	10BL159415	Fair		19		Sandstone	Hawkesbury	156	159
GW102619	10BL158265		0.75	95		Sandstone, Shale	Hawkesbury	165	225
GW103140	10BL159387	600	1.8	34		Sandstone	Hawkesbury	149	150
GW103536	10BL159962	440	0.8	39		Sandstone or tonalite	Hawkesbury	217	219
GW103996	10BL158732					(Unknown)	(Unknown)		
GW104025	10BL160600	800	2.9	58	254	Sandstone	Hawkesbury	296	297
GW104159	10BL159808	500	0.6	87		Sandstone	Hawkesbury	183	184
GW104223	10BL160317	Fresh	3	13.7	70	sandstone, bands of shale	Hawkesbury	224	224.6
GW104224	10BL160403	Fresh	1.625	24.6		sandstone, bands of shale	Hawkesbury	238	238.3

Work Number	License	Salinity (mg/L unless stated)	Yield (L/s)	SWL (m)	Drawdown (m)	Lithology of Aquifer	Likely aquifer*	Depth to water bearing zone – top (m)#	Depth to water bearing zone - bottom (m)#
GW104370	10BL158904	710	0.1	32.6		Sandstone	Hawkesbury	142	142.5
GW104383	10BL160618	Fresh	1.35	29		Sandstone, shale	Hawkesbury	233	233.15
GW104620	10BL161059	400	1.2	34		Sandstone/bands of shale	Hawkesbury	154	154.15
GW104766	10BL161189	662	0.15	82		Sandstone	Hawkesbury	184	187
GW105207	10BL161253	300	1.8	24		Sandstone	Hawkesbury	228	228.25
GW105325	10BL163811	1800	0.5		123	sandstone/shale	Hawkesbury	121	122
GW105737	10BL162818	600	1.1	49	144	Sandstone	Hawkesbury	130	131
GW105785	10BL162798	800	1.5	71		sandstone	Hawkesbury	167	168
GW106446	10BL162246	Fresh	10	21		Sandstone	Hawkesbury	132	132.25
GW107140	10BL165167	300	2.2	68		sandstone	Hawkesbury	192	193
GW107421	10BL163191	Fresh	1.5	49		sandstone	Hawkesbury	159	261.1
GW107608	10BL165804	760	0.1	66		sandstone	Hawkesbury	165.1	169.8
GW107718	10BL160786	Fresh		29		Sandstone	Hawkesbury	233	233.1
GW107721	10BL162462	Fresh		38		sandstone	Hawkesbury	260	260.1
GW107791	10BL161521	Fresh	3	37		Sandstone	Hawkesbury	144	231
GW107962	10BL600017	Fresh	0.5	23		sandstone	Hawkesbury	276	276.1
GW108055	10BL601937	Fair	2	24		sandstone	Hawkesbury	180	182
GW108208	10BL163339	400	4.5	11		sandstone	Hawkesbury	96	96.15
GW108863	10BL601942						Unconsolidated ?		
GW108990	10BL600189						(Unknown)		
GW109180	10BL163148	2200	0.16	80		(Unknown)	Hawkesbury?	(Unknown)	(Unknown)
GW109212	10BL602480						Wianamatta		
GW109213	10BL602480						Wianamatta		

Work Number	License	Salinity (mg/L unless stated)	Yield (L/s)	SWL (m)	Drawdown (m)	Lithology of Aquifer	Likely aquifer*	Depth to water bearing zone – top (m)#	Depth to water bearing zone - bottom (m)#
GW109214	10BL602480						Wianamatta		
GW109215	10BL602480						Wianamatta		
GW109315	10BL602560	Good	1	0.6		sand	Unconsolidated	1	3
GW109700	10BL160756	3106		1.84		Shale/Sandstone bedrock	Wianamatta?	4.6	4.8
GW109701	10BL160756	2273		3.27		Sandy clay	Unconsolidated	5	6.7
GW109702	10BL160756	3893		1.67		Gravelly sandtone	Unconsolidated	1.2	5
GW109703	10BL160756	4668		1.83		Monzonite	(Unknown)	4.6	5.5
GW109704	10BL160756	363		9.51		Sandy clay	Unconsolidated	9.2	14.5
GW110413	10BL603031	700	1.4	17		Sandstone	Hawkesbury?	45	46
GW110491	10BL165971		low			sand/clay	Unconsolidated	6	7
GW110586	10BL602635	Good	10	4.13		sand	Unconsolidated	4.13	20
GW110587	10BL600640	Good	9	10.9	14.99	clay, sandy	Unconsolidated	10.9	24
GW110680	10BL603219			6.2		Clay, silt, sand, gravel	Unconsolidated	6	8
GW110681	10BL603219			6.1		Silt, gravel	Unconsolidated	6	8
GW110682	10BL603219			6.2		Sand, clay, gravel	Unconsolidated	6	8
GW110708	10BL603631	620	2	40		sandstone	Hawkesbury	96	102

Key: * - data interpreted, not originally contained in Pinneena database

- data inferred from bore work summary reports within Pinneena database

Appendix B: Schematic model

Shown in the Figure 9 is a schematic representation of the stratigraphy for the CGP area (PB, 2011b). Although the above ground section of the model references the Camden Northern Expansion area, the underground stratigraphy is representative for the entire CGP area.

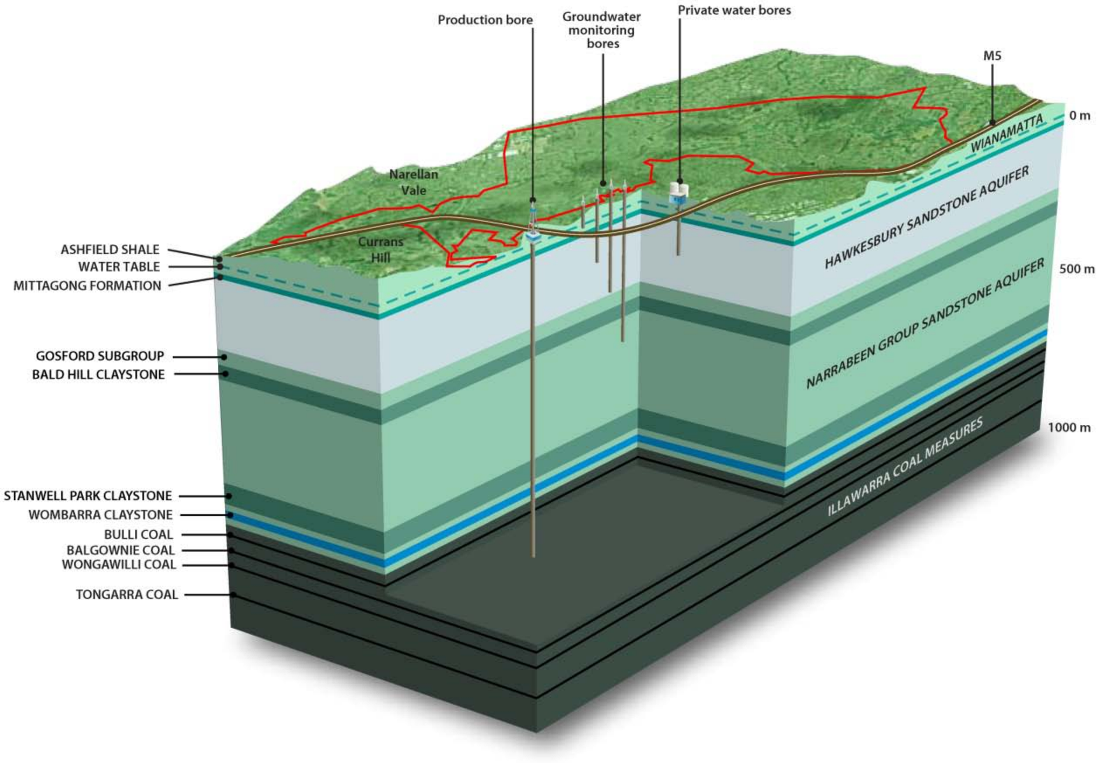

Figure 9: Schematic model that represents the stratigraphy of the CGP area and surrounds (PB, 2011b).

Appendix C: Geological Map Legend

(to accompany Figure 2)

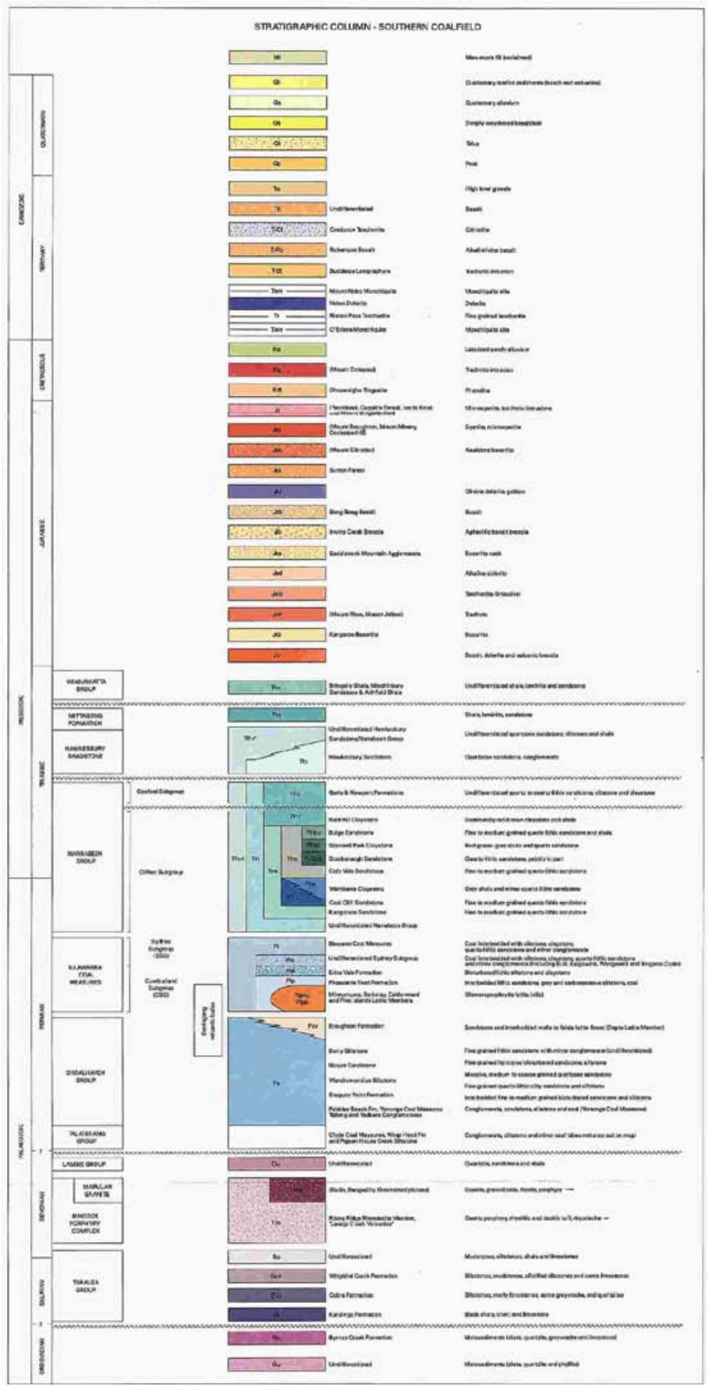

Figure 10: Stratigraphic column and symbology for geological units (Moffitt, 1999).

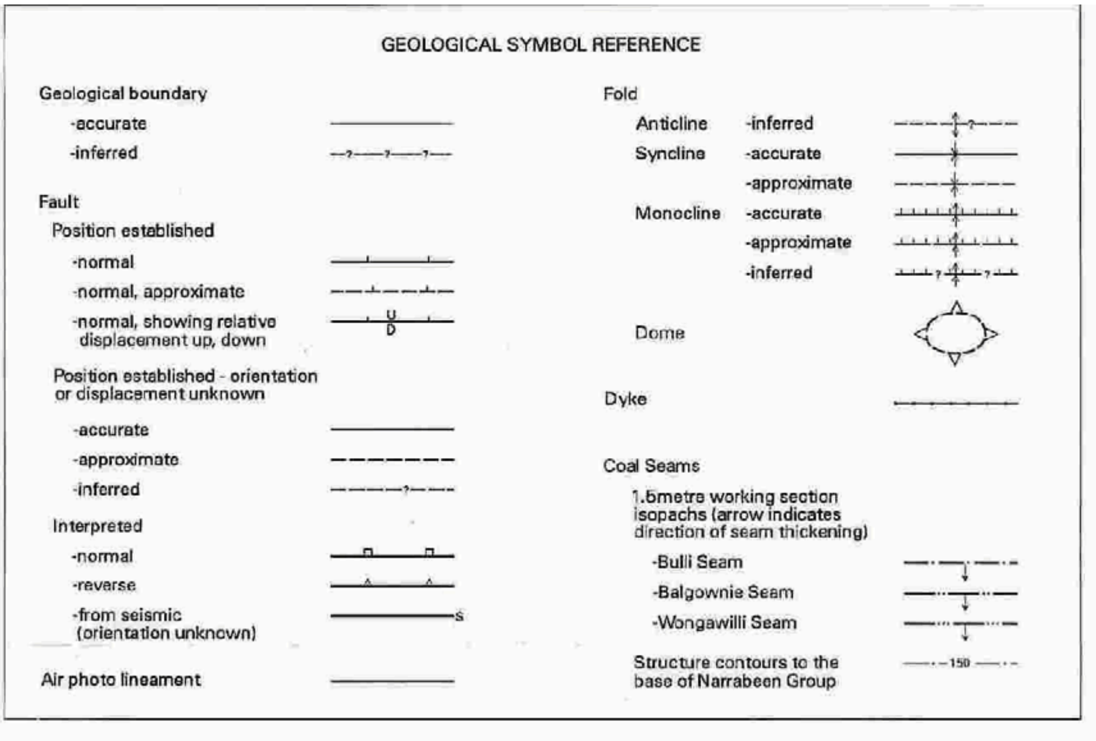

Figure 11: Geological symbol reference (Moffitt, 1999).