AGL Energy Ltd

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PHASE 1 GROUNDWATER ASSESSMENT AND CONCEPTUAL HYDROGEOLOGICAL MODEL NORTHERN EXPANSION OF CAMDEN GAS PROJECT

PARSONS BRINCKERHOFF

Phase 1 Groundwater Assessment and Conceptual Hydrogeological Model – Northern Expansion of Camden Gas Project

December 2010

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PARSONS BRINCKERHOFF

Parsons Brinckerhoff Australia Pty Limited
ABN 80 078 004 798

Level 27, Ernst & Young Centre
680 George Street
SYDNEY NSW 2000
GPO Box 5394
SYDNEY NSW 2001
Australia
Telephone +61 2 9272 5100
Facsimile +61 2 9272 5101
Email sydney@pb.com.au

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Author: .... Sarah Scarff, Ellen Kwantes, Stuart Brown

Signed: ....

Reviewer: .... James Duggleby, Graham Hawkes

Signed: ....

Approved by: .... Liz Webb

Signed: ....

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Glossary

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.
Alluvial aquifer	Groundwater stored within unconsolidated alluvial sediments. Shallow alluvial aquifers are generally unconfined.
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 or phreatic **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 **aquifer** to another. Aquitards retard but do not prevent the movement of water to or from an adjacent **aquifer**.
Australian Height Datum (AHD)	The reference point (very close to mean sea level) for all elevation measurements, and used for correlating depths of **aquifer**s and water levels in bores.
Bedding plane	In sedimentary or stratified rocks, the division plane which separates the individual layers, beds or strata.
Bore	A structure drilled below the surface to obtain water from an **aquifer** or series of **aquifer**s.
Claystone	A non-fissile rock of sedimentary origin composed primarily of clay-sized particles (less than 0004 mm).

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.

Discharge The volume of water flowing in a stream or through an **aquifer** past a specific point in a given period of time.

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.

Fault A fracture in rock along which there has been an observable amount of displacement. Faults are rarely single planar units; normally they occur as parallel to sub-parallel sets of planes along which movement has taken place to a greater or lesser extent. Such sets are called fault or fracture zones.

Fracture Breakage in a rock or mineral along a direction or directions that are not cleavage or fissility directions.

Groundwater The water contained in interconnected pores located below the water table in an unconfined **aquifer** or located at depth in a confined **aquifer**.

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).

Hydrogeology The study of the interrelationships of geologic materials and processes with water, especially groundwater.

Infiltration The flow of water downward from the land surface into and through the upper soil layers.

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.

Monitoring bore A non-pumping bore, is 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.
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.
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 **aquifer**s. The addition of water to an **aquifer**.
RL	Reduced level or height, usually in metres above or below an arbitrary or standard datum.
Screen	A type of bore lining or casing of special construction, with apertures designed to permit the flow of water into a bore while preventing the entry of **aquifer** or filter pack material.
Shale	A laminated sediment in which the constituent particles are predominantly of clay size.
Siderite	A mineral composed of iron carbonate $FeCO_3$.
Siltstone	A fine-grained rock of sedimentary origin composed mainly of silt-sized particles (0.004 to 0.06 mm).
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.
Unconfined aquifer	Where the groundwater surface (water table) is at atmospheric pressure and the **aquifer** is recharged by direct rainfall infiltration from the ground surface.
Water quality	Term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Well	Pertaining to a gas exploration well or gas production well

List of abbreviations

AGL	AGL Energy Ltd
BoM	Bureau of Meteorology
CGP	Camden Gas Project
CSG	Coal seam gas
EC	Electrical conductivity
GDE	Groundwater dependent ecosystem
NOW	NSW Office of Water
PB	Parsons Brinckerhoff
PEL	Petroleum Exploration Licence
PPL	Petroleum Production Lease
RPGP	Rosalind Park Gas Plant
SCA	Sydney Catchment Authority
TDS	Total dissolved solids

List of units

°C	degrees Celsius
L/s	litres per second
m	metres
mAHD	metres Australian Height Datum
m bgl	metres below ground level
m/day	metres per day
m^2/day	square metres per day
ML	megalitres
µS/cm	microSiemens per centimetre
mg/L	milligrams per litre

Executive summary

Parsons Brinckerhoff (PB) was commissioned by AGL Energy Ltd. (AGL) to undertake a Phase 1 groundwater assessment (and hydrogeological conceptual model) for the new coal seam gas (CSG) development area associated with the Camden Gas Project (CGP). The Northern Expansion Area of the CGP is located near Narellan, approximately 60 km south west of Sydney, New South Wales. The project is situated within the Petroleum Exploration Licence (PEL) 2 and also Petroleum Production Lease (PPL) 5 areas, issued under the Petroleum (Onshore) Act 1991.

The primary objectives of this desktop study are to characterise the groundwater systems in the Camden North area, assess the value of groundwater resources in the area, and assess the likely connectivity between Triassic sandstone aquifers and Permian coal seams targeted for CSG extraction. This study also provides information on regulatory requirements for groundwater management and requirements for groundwater monitoring.

The groundwater resources of this area are of limited beneficial use as yields to bores are low and water quality is typically poor. There is very little consumptive use of groundwater and increased development in the future is unlikely given the depth of drilling and the availability of reticulated supplies for domestic, commercial and industrial purposes.

This review concludes that the presence of extensive and thick claystone formations in the stratigraphic sequence that overlies the Illawarra coal measures in the project area will impede the vertical flow of groundwater such that overlying aquifer zones will be hydraulically isolated, experiencing little, if any drawdown impact related to depressurisation of the coal measures. However the possibility cannot be ruled out that major fault zones could provide a hydraulic pathway through claystone horizons and that some shallow groundwater impacts may be observed close to those structures.

Phase 2 groundwater investigations should be carried out in the Northern Expansion area and a suitable groundwater monitoring network should be installed to monitor water levels and water quality in the major aquifer zones.

1. Introduction

1.1 Project background

Parsons Brinckerhoff (PB) was commissioned by AGL Energy Ltd. (AGL) to complete a Phase 1 groundwater assessment (and hydrogeological conceptual model) for the new coal seam gas (CSG) development area associated with the northern expansion of the Camden Gas Project (CGP).

1.1.1 The Camden Gas Project

The current CGP operations consist of 130 existing CSG wells, underground gas gathering lines, a high pressure pipeline, the Rosalind Park Gas Plant (RPGP) and access roads located within the Camden and Campbelltown Local Government Areas in south-western Sydney, NSW. The current CGP involves the extraction of gas from the Illawarra Coal Measures within the Southern Coalfields of the Sydney Basin, at an average depth of approximately 700 m below ground level.

The CGP is located on land subject to Petroleum Production Leases PPL1, PPL2, PPL4 and PPL5, issued under the Petroleum (Onshore) Act 1991. AGL is responsible for the delivery of the CGP in accordance with all regulatory requirements.

The current CGP has been delivered in two stages (the locations of which are shown on Figure 1-1):

- Stage 1 was approved in 2002 and initially comprised 22 wells, the Ray Beddoe Treatment Plant, and a gas gathering system in the Cawdor area.
- Stage 2 was approved in 2004 and comprised 43 wells, the RPGP and gas lines around Menangle. Sixteen additional wells were approved in 2008 under Stage 2, some are already producing gas and the remainder are scheduled for completion and/or commencement of production in 2010 and 2011.

1.1.2 The Northern Expansion

The next stage involves a new gas development area, incorporating additional wells and associated infrastructure, to the north-east of the existing development area (Figure 1-2), and extends from the suburb of Glen Alpine to the south to Leppington in the north bound by the Hume Highway in the east and the Camden Valley Way in the west.

The Northern Expansion involves the construction and operation of 12 additional well locations (with up to six well heads each), the construction and operation of gas gathering and water lines and the construction of roads and additional infrastructure, including storage facilities.

1.2 Objectives and scope

The primary objective of this desktop study is to characterise the groundwater systems in the Camden North area, assess the value of groundwater resources in the area and assess the likely connectivity between Triassic sandstone aquifers and Permian coal seams targeted for CSG extraction. This study also provides information on regulatory requirements for groundwater management and requirements for groundwater monitoring.

The groundwater assessment includes the area surrounding the Northern Expansion (approximately 20 km by 20 km), and includes a review of geology, hydrogeology, hydrogeological conceptual model, groundwater management and gap analysis, and recommendations for Phase 2.

1.3 Report structure

Chapter 1 provides a brief introduction to the Camden Gas Project (CGP) and the Northern Expansion of the CGP, including proprietor and operational information. It also provides an outline of the objective, scope and structure of this report.

Chapter 2 describes the location, topography, surface hydrology, climate and land use of the Northern Expansion Area.

Chapter 3 and **Chapter 4** present the results of a literature review and data collation on the geology and hydrogeology, respectively, of the Sydney Basin region and on a local scale, the Northern Expansion Area.

Chapter 5 presents the hydrogeological conceptual model for the Northern Expansion Area.

Chapter 6 discusses the groundwater management requirements, including water policy and legislation.

Chapter 7 presents the conclusions for the Phase 1 study.

2. Site description

The Northern Expansion Area of the Camden Gas Project is located near Narellan, approximately 60 km south west of Sydney, New South Wales. The project is situated within PEL 2 and also PPL5 areas, issued under the Petroleum (Onshore) Act 1991.

2.1 Topography and surface hydrology

The Northern Expansion Area straddles two catchment areas: the Hawkesbury Nepean Catchment and the Sydney Metropolitan Catchment.

The major surface hydrology features near the Northern Expansion are the Nepean River, which meanders in a south to north direction, to the west of the project area and the Georges River, which flows north-east, to the south-east of the project area. Other surface water features include Narellan Creek and Kenny Creek (tributaries of the Nepean River) to the south-west of the project area and the headwaters of South Creek (tributary of the Hawkesbury River) which occurs 4 km north-east of Narellan, in the east of the project area. Rileys Creek a tributary of South Creek occurs in the north-eastern area of the Northern Expansion.

The Northern Expansion Area is located on the south-eastern margin of the Cumberland Plain and has a flat to undulating, low lying topography. Elevations within the Northern Expansion Area range from 47 m AHD in the north-east, near Denham Court, to 196 m AHD at Badgally Hill in the south of the Northern Expansion Area. Elevations within the Northern Expansion Area generally decrease to the east and west with a slight ridgeline running generally north to south.

An open gravity water supply canal, part of the Upper Canal system, runs across the centre of the northern CGP area. The Upper Canal is a system of canals, aqueducts and tunnels built between 1880 and 1888 to transfer up to 680 megalitres per day (ML/day) from the Metropolitan Dams to the Prospect Reservoir, supplying several localities en route. It is lined for the most part by dry rubble masonry, concrete or rubble cement and remains in good condition. The canal system is currently operated by the Sydney Catchment Authority (SCA) and remains an important component of the Sydney bulk water supply. A groundwater resource drilling investigation carried out adjacent to the Upper Canal just west of Appin by the SCA (SCA, 2005) identified minor seepage at shallow depths due to leakage from the canal system.

Small farm dams are common in the non urban areas to provide water for stock, and limited garden and irrigation purposes on rural lands. Dams are replenished by rainfall and runoff, although some seepage flow through weathered soil profiles occurs after long wet periods. Dams and seepage flows are not related to the regional groundwater systems. There are no known springs in the project area.

2.2 Climate

The nearest Bureau of Meteorology (BoM, 2010) weather station, with consistent climate measurements, is located at Camden Airport (BoM site number 68192), approximately 4 km south west of the Northern Expansion Area. Mean temperatures at Camden Airport range from 17.2°C in July to 29.4°C in January (based on records from 1971 to 2010). The average annual rainfall is 783.7 mm (based on records from 1943-2010). On average September receives the least rain, with a mean rainfall of 39.5 mm, while February receives the most rain, with a mean of 104.2 mm.

2.3 Land use

The majority of the land holdings in the Northern Expansion Area are privately owned. The private holding land uses within the expansion area are predominantly rural and agricultural, with grazing activities dominant. Land use for recreational and public service purposes is also present in the Northern Expansion Area, with three golf courses and two schools, including sports fields, located in the area.

Some lands within the Northern Expansion Area are designated for future urban (residential, commercial and industrial) development as part of the NSW Government's *Sydney Metropolitan Strategy (2005)*.

3. Geological setting

3.1 Literature review and data collation

A review and collation of Sydney Basin geology references and exploration wells occurring in the Northern Expansion and the surrounding Camden region was undertaken. The relevant geological and hydrogeological data are presented in this report.

Six AGL CSG exploration wells, Currans Hill 1, Currans Hill 18, Denham Court 1, Elderslie 1, Raby 1 and Raby 2, have been constructed within the Northern Expansion Area since 2006. Three other exploration wells have been drilled in the Northern Expansion Area prior to AGL establishment of the CGP. The exploration wells with completion reports are listed in Table 3-1.

DM Varroville DDH1 and DDH2 were drilled within the Northern Expansion in 1993 and 1994, respectively, as part of the West Campbelltown Drilling Programme. This was a joint venture between the Department of Mineral Resources and Amoco Australian Petroleum Company (AAPC). DM Varroville DDH1 extends to just below the Cape Horn Coal Seam and DM Varroville DDH2 extends to just below the Tongarra Coal Seam. The third pre-existing exploration well in the Northern Expansion Area, AOG Badgelly No. 1, was drilled in 1964, for the exploration of shallow natural gas by the Australian Oil and Gas Corporation Limited (AOG). AOG Badgelly No. 1 terminates within the Narrabeen Group.

A further 41 exploration wells that intersect the Illawarra Coal Measures in the Camden region, have been identified through the NSW Department of Primary Industries DIGS Database, and are listed in Table 3-1.

Table 3-1 Identified exploration well references

Document	No. wells	Location
AGL Exploration Well Completion Report, Currans Hill 1	1	Northern Expansion
AGL Exploration Well Completion Report, Denham Court 1	1	Northern Expansion
AGL Exploration Well Completion Report, Raby 1	1	Northern Expansion
Borehole Completion Report, West Campbelltown Drilling Program, DM Varroville DDH 1	1	Northern Expansion
Borehole Completion Report, West Campbelltown Drilling Program, DM Varroville DDH 2	1	Northern Expansion
AOG Badgelly No. 1, Sydney Basin, NSW, Well Completion Report	1	Northern Expansion
Programme Completion Report - Camden Drilling Programme	39	Camden region
AMOCO Well completion report, Narellan No 1, PEL 260 Sydney Basin	1	Camden region
Sydney Gas Ltd Well Completion Report for Glenlee #8	1	Camden region

3.2 Regional geological setting

The Northern Expansion Area is part of the Southern Coalfield of the Sydney Geological Basin (see Figure 3-1). The Sydney Basin is sedimentary in origin and the deposition of sediments has occurred from the early Carboniferous (290 million years ago) through to the latter part of the Triassic (200 million years ago) (Pells, 1985). The Sydney Basin on-laps the Lachlan Fold Belt to the west and south, with basin depth increasing to the north and east.

The geological strata of the Sydney Basin can be summarised as:

- 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 of the Sydney Basin (Permian and Triassic age)
- Fractured basement rocks below the Sydney Basin (Palaeozoic age)

3.3 Local geology

3.3.1 Stratigraphy

The stratigraphy of the Northern Expansion Area in the Camden-Campbelltown area is summarised in Table 3-2 and is as follows:

- Tertiary and Quaternary alluvial sediments overlie the Wianamatta Shales along river and creek beds in the local region. Unconsolidated quartz and lithic alluvium material, comprising clay, silt, sand and gravel is deposited adjacent to South Creek (Clark & Jones, 1991), which originates in the north of the Northern Expansion Area.
- Wianamatta Group: where alluvial deposits are not present the Triassic Wianamatta Group comprises the surficial geology in the Northern Expansion Area. The Wianamatta Group primarily comprises shales, with occasional calcareous claystone, laminate and coal. The Bringelly Shale is shown to outcrop in the west of the Northern Expansion Area and the Ashfield Shale outcrops in the east of the Northern Expansion Area on the Wollongong 1:100,000 Geological Map (Stroud *et al*, 1985). The Minchinbury Sandstone is a thin quartz lithic sandstone strata overlying the Ashfield Shale. The Ashfield Shale is a sequence of dark grey to black sideritic claystone – siltstone which grades upwards to a fine sandstone siltstone laminate (Bembrick *et al*, 1987).
- Mittagong Formation: a thin layer comprising dark grey to grey alternating beds of shale laminate, siltstone and quartzose sandstone. The sandstone is often siderite cemented in the upper part of the formation (Alder *et al*, 1991).
- Hawkesbury Sandstone: alluvial in origin, with a thickness of approximately 200 m in the Camden area (Alder *et al*, 1991). 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. The shale lenses commonly range between 2-4 m in the Western Sydney area.

- Narrabeen Group:
  - Gosford Sub-group (Triassic): Newport Formation is medium grained, light to dark grey, quartzose sandstone interbedded with siltstone. Garie Formation is a thin, cream kaolinite claystone, which grades upwards to grey. Reddish or chocolate colour (hematite stained) kaolinite is common in both formations (Sherwin & Holmes, 1986).
  - Clifton Sub-group (Triassic): 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, but exploration holes have not penetrated the base of the coal measures in the Northern Expansion area. The upper sections of the Permian Illawarra Coal Measures (Sydney Sub-group) contain the major coal seams: Bulli, Balgownie, Wongawilli, Tongarra and Woonona. 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, which is often so bioturbated that bedding is destroyed (Alder *et al*, 1991).
- Basement geology: The Southern Sydney Basin Permian and Triassic rocks have been deposited upon early to middle Palaeozoic basement rocks (Moffitt, 1999). The undifferentiated Palaeozoic basement consists of intensely folded and faulted slates, phyllites, quartzite sandstones and minor limestones of Ordovician to Silurian age (Moffitt, 2000).

Table 3-2 Summary of hard rock stratigraphy – Camden-Campbelltown region

Period	Group	Sub-group	Formation	Approx. thickness (m)
Triassic	Wianamatta Group		Ashfield Shale	75 (top eroded)
			Mittagong Formation	4 - 6
			Hawkesbury Sandstone	196 - 223
	Narrabeen Group	Gosford Sub-group	Newport Formation	19 - 27
			Garie Formation	1 - 3
		Clifton Sub-group	Bald Hill Claystone	26 - 61
			Bulgo Sandstone	266 - 309
			Stanwell Park Claystone	53 - 70
			Scarborough Sandstone	17-23
Permian			Wombarra Claystone	19 - 33
	Illawarra Coal Measures	Sydney Sub-group	Bulli Coal	2-5
			Loddon Sandstone	12-30
			Balmain Coal Member	1 - 8
			Balgownie Coal	1 - 3
			Lawerence Sandstone	8 - 20
			Eckersley Formation	0.5 - 55
			Cape Horn Coal	0.5 - 1
			Wongawilli Coal	5 - 15
			Farmborough Claystone	1
			Kembla Sandstone	15 - 25
			Allans Creek Formation	20 - 27
			Upper American Creek Coal	2 - 3.5
			Lower American Creek Coal	1 - 6
			Darkes Forest Sandstone	7 - 10
			Bargo Claystone	30 - 31
			Huntley Claystone	1 - 3
			Tongarra Coal	1 - 4
			Wilton Formation	78 - 104
			Woonoona Coal	3
			Marangarroo Conglomerate	10 - 11
		Cumberland sub-group	Erins Vale Formation	?
			Pheasants Nest Formation	?
	Shoalhaven Group		Budgong Sandstone	?
			Berry Siltstone	?

Note: thicknesses from AGL exploration wells CU01, DC01 and RA01, and DM Varroville DDH1 and DDH2

3.3.2 Structural controls in the study area

Structurally, the Camden area 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). 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 Camden area, including the Northern Expansion Area, a set of north-west trending faults associated with the Lapstone Structural Complex 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). Interpretation of seismic profiles by Herbert (1988) 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.

Mauger *et al* (1984) identify a number of lineaments from air photo and satellite images for the Wollongong – Port Hacking 1:100,000 map sheet which covers the southern half of the project area. These traces have been plotted on Figure 3-1. The dominant trends for lineaments tend to be in the WNW-NW and NNE-NE sectors. While it is not often possible to relate these lineaments to specific geological structures such as mapped faults, the general spatial trends identified are consistent with the trends of regional faults and may also reflect the dominant joint orientations which have the potential to influence groundwater flow, at a local scale. The major cross cutting faults may provide pathways for groundwater to flow between formations.

4. Hydrogeological setting

4.1 Literature review and data collation

A search of the NSW Office of Water (NOW) groundwater database within the regional area (approximately 30 km x 30 km) identified 298 registered water bores. A further search of the registered bores in order to gather a smaller, more representative data set (using an area of approximately 20 km x 20 km) identified 133 bores. There are only 12 water bores registered within the Northern Expansion Area. A summary of the data from the NOW database is presented in Appendix A.

The deepest registered bore (GW073533) in the area surrounding the Northern Expansion, had a depth of 330 m which is equivalent to some of the sandstone units in the upper Narrabeen Group. Deeper exploration is required to determine hydrogeological characteristics of formations deeper than the Hawkesbury Sandstone in the Camden region.

The three pre-existing exploration wells in the Northern Expansion Area had groundwater quality analyses undertaken. The DM Varroville DDH1 groundwater sample was a composite sample from several formations and is not used in this assessment. DM Varroville DDH2 and AOG Badgelly No. 1 had water quality analysis undertaken for the Hawkesbury Sandstone aquifer. The results are discussed in Section 4.5.

The three AGL CSG production wells to the south and south-west of the Northern Expansion (Spring Farm 09, Sugarloaf 03 and Glenlee 07) had water quality analyses undertaken in September 2010 and the results are presented in Section 4.7.

Three exploration wells and one production well in the Camden region, with groundwater analyses, were identified. These were: AOG Camden No. 1, AOG Camden No. 6, AOG Mt. Hunter No. 1 and AGL Razorback 10, and are discussed in the following sections.

The locations of the registered water bores, coal exploration bores from DIGS with hydrogeological data, and the six AGL wells (Currans Hill 1, Raby 1, Denham Court 1, Spring Farm 09, Sugarloaf 03 and Glenlee 07) are shown in Figure 3-1.

4.2 Regional hydrogeological setting

Thin alluvial deposits occur in valleys, creeks and river beds across the region. The alluvial deposits are generally shallow, discontinuous and relatively permeable. They are likely to be responsive to rainfall and stream flow and not considered a significant aquifer in the region.

The Wianamatta Group Shales are characterised by saline groundwater due to the marine deposition environment, and are generally not considered aquifers. The Wianamatta Shales are generally low permeability and mostly behave as aquitards. The underlying Mittagong Formation is low permeability and is not considered an aquifer.

The Hawkesbury Sandstone is a dual porosity regional aquifer system that occurs across the whole of the Sydney Basin. Groundwater flow is variable throughout the Hawkesbury Sandstone, and is generally dominated by secondary porosity and fracture flow associated with structures such as faults and fracture zones. 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 litre per second (L/s) in this area. 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.

The sandstone formations within the Narrabeen Group are considered minor aquifers. If fractured these formations may be useful aquifers on a regional scale. These formations are generally considered to be lower yielding and of poorer water quality then the overlying Hawkesbury Sandstone.

Coal seams, such as those present in the Illawarra Coal Measures, generally form minor water bearing zones. Groundwater associated with coal seams is generally poor in quality, with moderate to high salinities.

Three conceptual hydrogeological cross-sections that summarise the groundwater conditions in the Northern Expansion Area are presented in Figures 4-1 to 4-3. The cross-section lines are indicated on Figure 3-1.

4.3 Alluvial aquifers

Ten water bores registered on the NOW groundwater database were found to intercept alluvial aquifers in the region surrounding the Northern Expansion Area (approximately 20 km x 20 km). Two water bores (GW016682 and GW058697) were located to the north-east of the Northern Expansion, near Liverpool South, and eight (GW026239, GW026469, GW026472, GW026473, GW026474, GW026533, GW026545 and GW026557) were located to the south-west, near Menangle Park. None are located within the Northern Expansion Area.

Only one of the ten registered water bores identified, GW058697, recorded a standing water level (SWL) and yield, which were 8.5 m below ground level (bgl) and 0.125 litres per second (L/s) respectively.

4.4 Wianamatta Group

The Wianamatta Group Shales are considered aquitards. In the Southern Sydney Basin groundwater within the Wianamatta Shales typically exceeds 3000 mg/L total dissolved solids (TDS) and the Ashfield Shale has an approximate transmissivity of 4 m^2/day (SCA, 2007).

Two exploration bores in the Camden region, intersecting groundwater from the Wianamatta Group, were identified from the DIGS database to contain water quality analyses and water level data. These technical details are presented in Table 4-1.

During drilling at AOG Camden No. 1, located to the south-west of the Northern Expansion, water seeped at 11 m bgl, in the upper weathered clays (most likely the Bringelly Shale) of the Wianamatta Group. During drilling of AOG Camden No. 6, located to the north of the Northern Expansion, seepage from the Wianamatta Formation was also identified.

Table 4-1 Details of water analyses for the Wianamatta Group

Bore	WBZ depth (m bgl)	Water level (m bgl)	Yield (L/s)	pH	EC (µS/cm)	Water type
AOG Camden No. 1	11	1.2	na	4.7	477	na
AOG Camden No. 6	9-21	na	0.01	na	na	na
AOG Camden No. 6	43	30.5	0.2	na	na	na

Notes: WBZ – water bearing zone, bgl – below ground level, na – not available

The water quality analysis of AOG Camden No. 1 suggests the upper weathered clays of the Wianamatta group contain fresh and acidic water quality. These water quality results appear anomalous as other water quality data within the Wianamatta Group indicates groundwater to be typically brackish to saline (SCA, 2005; SCA, 2007; Woolley, 1991).

4.5 Hawkesbury Sandstone

The Hawkesbury Sandstone is the primary aquifer in the Southern Sydney Basin and typically has yields of 0.2 to 2 L/s, transmissivity of approximately 2.8 m^2/day and water quality is typically below 500 mg/L Total Dissolved Solids (TDS) (SCA, 2007), although in this area where most of the sandstone is not exposed at surface, poorer water quality is expected. Results from drought investigation drilling near the Upper Canal and located west of Appin in 2005 (SCA, 2005) indicated generally poor groundwater quality in the Hawkesbury Sandstone aquifer with TDS between 1600 mg/L and 5500 mg/L. The groundwater yields in the Southern Sydney Basin are lower than those found elsewhere in the Basin for the Hawkesbury Sandstone.

Three exploration bores in the Camden region were identified from the DIGS database to have water analyses undertaken for the Hawkesbury Sandstone. Water levels were only available for one bore, as was yield, and water quality was available for the three bores. The details of water analyses are presented in Table 4-2.

During the drilling of AOG Badgelly No. 1 and DM Varroville DDH2, within the Northern Expansion Area, and AOG Mt Hunter No. 1, located west of Camden, the Hawkesbury Sandstone aquifer was intercepted and water quality analysis was undertaken.

Groundwater level, yield, water quality as pH, electrical conductivity (EC) and water type are presented for the Hawkesbury Sandstone aquifer in the Camden region in Table 4-2.

Table 4-2 Summary of water analyses for the Hawkesbury Sandstone aquifer

Bore (m bgl)	WBZ depth (m bgl)	Water level (m bgl)	Yield (L/s)	pH	EC (µS/cm)	Water type
AOG Badgally No. 1	152	60.96	na	7.45	7,740	Na-Cl
DM Varroville DDH2	155-180	na	na	8.90	10,910	Na-Cl
AOG Mt. Hunter No. 1	59	na	0.001	7.2	2,220	Na-Cl-HCO_3
AOG Mt. Hunter No. 1	76	na	0.003	7.9	900	Na-HCO_3-Cl
AOG Mt. Hunter No. 1	81	na	>0.8	7.9	738	Na-Mg-HCO_3-Cl
AOG Mt. Hunter No. 1	226	na	na	7.4	2,376	Na-Ca-Mg-Cl-HCO_3

Notes: WBZ – water bearing zone, bgl – below ground level, na – not available

EC for the Hawkesbury Sandstone surrounding the Northern Expansion is more brackish than encountered in other areas of the Sydney Basin. This is due to infiltration of groundwater from the overlying Ashfield Shales which are known to have high salinities (Woolley, 1991; SCA, 2005).

4.6 Narrabeen Group

The Narrabeen Group is quartz lithic sandstone, similar to the Hawkesbury Sandstone, although less porous and hence has a lower yield than the Hawkesbury Sandstone.

Three exploration bores in the Camden region were identified from the DIGS database contained groundwater analyses from the Narrabeen Group. Water levels from these bores are unavailable. The details of water analyses are presented in Table 4-3.

The primary aquifer in the Narrabeen Group is the Bulgo Sandstone, which is at a depth of approximately 360 to 610 m and typically has transmissivity of approximately 0.11 m^2/day, water quality less than 1500 mg/L TDS and a neutral pH, in the Southern Coalfields (SCA, 2007). Poorer water quality can be expected in this northern area and locally where impacted by mining activities.

Aquitards with low yields are formed by the Bald Hill Claystone and the claystones, underlying the Bulgo Sandstone in the Narrabeen Group (SCA, 2007).

During the drilling of AOG Camden No. 1, AOG Camden No. 6 and AOG Mt Hunter No. 1 groundwater from the Narrabeen Formation was intercepted and analysed, the results are presented in Table 4-3.

Table 4-3 Summary of water analyses for the Narrabeen Group aquifers

Bore (m bgl)	WBZ depth (m bgl)	Water level (m bgl)	Yield (L/s)	pH	EC (µS/cm)	Water type
AOG Camden No. 1	354	na	0.003	8.3	5,600	na
AOG Camden No. 6	518-604	na	na	8.2	10,800	na
AOG Mt. Hunter No. 1	325	na	na	7.7	1,019	Ca-Na-Mg-HCO_3-Cl
AOG Mt. Hunter No. 1	347-350	na	0.02	7.8	547	Na-Ca-Mg-HCO_3
AOG Mt. Hunter No. 1	526	na	na	7.75	530	Na-Ca-HCO_3

Notes: WBZ – water bearing zone, bgl – below ground level, na – not available

4.7 Illawarra coal measures

The Permian Illawarra coal measures typically have low yields in the Camden region. In the Southern Coalfields the water quality of the Permian coal measures is typically below 5000 mg/L TDS and alkaline pH of approximately 8.7 (SCA, 2007). Higher salinities are known from the Camden-Campbelltown area. Groundwater quality is typically poorer in the Illawarra coal measures than the overlying aquifers.

One exploration bore, AOG Mt. Hunter No. 1, in the Camden region was identified from the DIGS database to have water analyses (yield and water quality) recorded for the Illawarra coal measures. Four AGL CSG wells had water quality analyses undertaken for the Illawarra coal measures. Details of these water analyses are presented in Table 4-4.

Water analysis was undertaken at AOG Mt. Hunter No. 1 during drilling in 1962, in the upper Illawarra Coal Measures (depth of 680 m). AOG Mt. Hunter No. 1 is located to the west of the Northern Expansion.

The production well AGL Razorback 10, located to the south of the Northern expansion, was drilled in 2007 and is screened in the Bulli Coal seam (624.1 - 627.1 m). Water sampling and analysis was completed for AGL Razorback 10 in June 2008.

The production wells AGL Spring Farm 09 and AGL Glen Lee 07 are located to the south west of the Northern Expansion area and were sampled and analysed in September 2010 for this desktop assessment. AGL Spring Farm 09 and AGL Glen Lee 07 are screened in the Bulli and Balgownie coal seams.

The production well AGL Sugarloaf 02, located to the south of the Northern Expansion, is also screened across the Bulli and Balgownie coal seams and was analysed for water chemistry in September 2010. Detailed laboratory reports for these three water samples are provided in Appendix B.

Table 4-4 Summary of water analyses for the Illawarra coal measures

Bore (m bgl)	WBZ depth (m bgl)	Water level (m bgl)	Yield (L/s)	pH	EC (µS/cm	Water type
AOG Mt. Hunter No. 1	680	na	0.006	7.75	530	Na-HCO_3
AGL Razorback 10	624.1-627.1	na	na	8.05	8,920	Na-HCO_3
AGL Spring Farm 09 #	1,053-2,602 1,975-2,524	na	na		11,800	Na-HCO_3
AGL Sugarloaf 02	648-651 666-668	na	na		12,300	Na-HCO_3
AGL Glen Lee 07	772.7-775.7 792.3-794.3	na	na		10,400	Na-HCO_3-Cl

Notes: WBZ – water bearing zone, bgl – below ground level, na – not available, # - this is an "in seam" well so the depths quoted are a combination of vertical depth and lateral distances

4.8 Groundwater dependent ecosystems

No groundwater dependent ecosystems (GDE's) have been identified within the Northern Expansion area or the area directly surrounding the Northern Expansion Area of the CGP.

Three GDE's have been identified within the wider Southern Sydney Basin region and their details are provided in Table 4-5. The three GDE's presented in Table 4-5 are over 20 km from the Northern Expansion and have no association with groundwater systems that occur in the Camden-Campbelltown area.

Table 4-5 Summary of the Southern Sydney region GDE's (NOW, 2010)

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, which 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:	627

GDE Name	Latitude (GDA 94)	Longitude (GDA 94)	Location	Area (ha)
			Gandangarra, Werri-Berri, Couridjah, Baraba and Nerrigorang Lakes.	

4.9 Groundwater use

A total of 133 water bores are registered with NOW within an approximate 20 km x 20 km area surrounding and including the Northern Expansion. A summary of the data from the NOW database is presented in Appendix A. Of the 133 water bores, 44 are used for monitoring purposes, 16 are used for irrigation, 9 are used for domestic purposes, 4 for stock watering and 4 for general use. The remaining bores were constructed for the purpose of monitoring, testing, industrial, exploration or waste disposal. It is noted that the waste disposal bores are all shallow holes completed to a depth of 2.4 m, presumably for infiltration of waste water effluent or stormwater. For 32 bores the purpose is unknown.

The deepest registered bore (GW073533) in the area surrounding the Northern Expansion is 330 m, although the majority of bores are less than 50 m deep. The bores are generally screened in alluvium, sandstone and shale units. Bore yields are variable ranging from 0.03 to 6.3 L/s and groundwater levels range from 0.7 to 80 m bgl.

Specifically within the Northern Expansion Area there are 12 registered water bores. Of these, eight bores are exploration wells/bores and five are private abstraction bores. The abstraction bores range in total depth between 60.9 m and 297 m and are assumed to intersect water bearing zones within the Ashfield Shale and upper Hawkesbury Sandstone. According to the NOW database, these private water bores are used for stock, domestic and irrigation purposes (although their current status is unknown). Locations are shown on Figure 1-2 and highlighted in Appendix A.

The majority of the bore search area is urbanised and groundwater use is low with the main groundwater purpose being monitoring. There is very little consumptive use of groundwater. The area is reticulated with potable water from Sydney Water and consequently the use of groundwater for domestic and industrial use is low. It is anticipated that new urban development in the project area will include an extension of reticulated water supplies and will not lead to any increase in groundwater use.

5. Conceptual hydrogeological model

5.1 Introduction

A conceptual model for the aquifer systems underlying the project area is presented below based on the review and synthesis of the following information:

- Geological maps and explanatory notes for the Sydney Basin (1:100,000 scale mapping)
- Borehole logs and associated information derived from the NOW and DIGS databases
- Borehole logs for AGL exploration wells
- Previous published and unpublished reports relating to the hydrogeology of the Sydney Basin and groundwater impacts of coal mining in the Southern Coalfield, as referenced below.

Although no numerical modelling has been carried out during this desk-top phase study, the following conceptual framework and parameter estimates is intended to provide the basis for initial numerical modelling, if and when required.

5.2 Aquifer systems

The following aquifer systems are identified in the general vicinity of the project area:

- Alluvial aquifer system
- Hawkesbury Sandstone aquifer system
- Narrabeen Group aquifer system
- Illawarra coal measures

A summary of these aquifer systems and groundwater quality have been included in earlier sections of this report. All aquifer systems are separated by low permeability aquitards. The following sections describe the aquifer systems underlying the project area, recharge-discharge relationships and possible pathways for groundwater impacts related to CSG development. The main hydrogeological features are summarised in the cross sections in Figures 4-1, 4-2 and 4-3.

Alluvial deposits typically comprise unconsolidated sand, clay and minor gravel of variable permeability within river and stream valley systems that are incised into the Wianamatta group shales and locally into the underlying Hawkesbury Sandstone, where the Wianamatta Shale has been eroded. The project area is dominated by the low ridge line of the Gregory Hills and therefore alluvial deposits are largely absent from the northern expansion area. However alluvial deposits are associated with the upper reaches of the Narellan and Bow Bowing creeks immediately to the west and east of the site, respectively.

The Hawkesbury Sandstone and Narrabeen Group form part of an extensive confined to partially confined regional aquifer system within the Sydney Basin sequence. The Hawkesbury Sandstone is more widely exploited for groundwater, being of generally higher yield, better quality and either outcropping or buried to shallow depths over large parts of the

Sydney and surrounding areas. The units have a combined thickness of approximately 670 m beneath the northern expansion area. While there are expected to be minor fault offsets, the total thickness is relatively consistent, but thickens slightly to the north, towards the depositional centre of the Sydney Basin.

Both units are characterised by dual porosity whereby the *primary porosity* is imparted by connected void space between sand grains and the *secondary porosity* is due to interconnected rock defects such as joints, fractures, faults and bedding plane partings. Groundwater flow within the sandstone aquifers is largely focussed on coarse-grained sandstone units with high permeability and also areas where there is a higher density of interconnected rock defects. Superior bore yield in the sandstone aquifers is often associated with major fractures or a high fracture density.

Thick claystone units such as the Bald Hill Claystone are typically very low permeability and act as aquitards on local and regional scales. These horizons impede the vertical flow of groundwater such that they commonly cause confinement of underlying aquifer zones. Logs of boreholes drilled in the CGP area show a number of major claystone aquitards, the thickest being the Bald Hill Claystone, Stanwell Park Claystone and the Wombarra Claystone. There are also numerous minor aquitards comprising thinner claystone or fine-grained sandstone horizons. These give rise to a distinctly layered and hydraulically complex aquifer system. It is likely that any drawdown in hydraulic head within the Illawarra Coal Measures associated with gas extraction will be strongly attenuated in these aquitards such there may be no noticeable impacts on groundwater levels in overlying aquifers. Potential impacts are discussed further in Section 5.6 below.

The Illawarra Coal Measures comprise interbedded quartz-lithic sandstone, siltstone, claystone, carbonaceous shale and coal seams. As with the sandstone lithologies, aquifer zones are likely to be associated with rock defects such as bedding plane partings, joints and shear zones. Due to the greater depth of burial of the coal measures and fine-grained nature of the sedimentary rocks, the permeability is generally low compared with the overlying sandstone aquifers. Individual coal seams can have higher fracture related permeability (compared to surrounding rocks) and are sometimes termed *coal seam aquifers,* although they are in fact mostly low permeability water bearing zones and not useful aquifers for supply purposes.

5.3 Groundwater recharge and discharge

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. Within the project area there is limited rainfall recharge to the Wianamatta Groups shales with most rainfall generating stormwater runoff. There is expected to be some leakage through the Wianamatta Group into the Hawkesbury Sandstone aquifer where there is adequate fracture spacing, however it is anticipated that most recharge to the sandstone aquifers occurs via lateral groundwater through-flow from upgradient and updip areas to the south. Outside of the project area, the dominant recharge mechanism is likely to be infiltration of rainfall and runoff though alluvial deposits in valleys, particularly where they are incised into weathered Hawkesbury Sandstone.

The water bore database searches carried out in this investigation yielded insufficient reliable groundwater level information across the project and surrounding area to generate a realistic piezometric (water level) contour map, or to assess vertical hydraulic gradients. However on a regional scale groundwater levels and flows will be largely controlled by the Basin geometry, topography and major hydraulic boundaries. In the southern Sydney basin, groundwater flow 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.

Within the Northern Expansion 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 to local stream headwaters during wet periods. Surface water – groundwater interactions in the wider area, however are not well defined.

5.4 Groundwater quality

Review of available groundwater quality information in Section 4 of this report indicates that groundwater quality in aquifer systems underlying the CGP area is highly variable, ranging from fresh (below 300 mg/L TDS) to slightly salty (up to 7500 mg/L TDS), 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 do not show a clear systematic depth-quality relationship. 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. This is due to infiltration of groundwater from the overlying Ashfield Shales which are known to have high salinities (SCA, 2005; Woolley, 1991).

In summary, the groundwater resource in the project area is characterised by low yields from the Hawkesbury Sandstone, Bulgo Sandstone, Wianamatta Shale and alluvium, with generally variable water quality. Negligible yields and poor water quality characterise the coal measures. It is predicted that any future groundwater exploitation will be from the shallower sandstone aquifers on a relatively minor scale and that urban developments will be serviced by reticulated water supply.

5.5 Estimates of permeability

With the exception of measurements carried out in the target coal seams by AGL, there are no available permeability data for aquifer units specifically within the project area. However given the lateral extent and lack of structural complexity of water bearing units in the Sydney Basin it is valid to base estimates of aquifer parameters on tests carried out elsewhere in the basin. Table 5-1 summarises typical ranges in permeability from a number of investigations including KBR (2008), SCA (2005), PB (2008), SWB (1990) and the summary in Merrick (2009).

Table 5-1 Estimates of permeability

Stratigraphic unit	Hydrogeological unit	Hydraulic conductivity (m/d)	K_h/K_v
Alluvial deposits	Unconfined aquifer	1 - 10	~10
Wianamatta Group	Unconfined / perched	0.01 – 0.1	5 - 10
Hawkesbury Sandstone	Unconfined / semi-confined aquifer	10^{-3} – 70	2 - 20
Bald Hill Claystone	Aquitard	10^{-5} – 10^{-4}	5 - 10
Stanwell Park Claystone	Aquitard	10^{-5} – 10^{-4}	5 - 10

Stratigraphic unit	Hydrogeological unit	Hydraulic conductivity (m/d)	K_h/K_v
Narrabeen Group	Confined / semi-confined aquifer	10^{-4} – 10^{-1}	2 - 5
Wombarra Claystone	Aquitard	10^{-5} – 10^{-4}	5 - 10
Illawarra Coal Seams	Confined aquifer [1]	10^{-3} – 10^{-2}	5 - 10

Key: [1] – typically water bearing zones rather than aquifers

Hydraulic conductivity testing by AGL indicates that the inherent permeability of coal seams ranges between 3 and 5 millidarcys (relating to a range in hydraulic conductivity of between 0.002 and 0.004 m/day), and rarely exceeds 10 millidarcys (~0.01 m/day). They are therefore of low permeability and do not constitute productive aquifers as such, but are likely to be one or two orders of magnitude more permeable than the claystone aquitards of the overlying Narrabeen Group.

5.6 Connection between aquifer systems

Extraction of coal seam gas and associated groundwater will lead to the depressurisation of the coal seam water bearing zones at depth for the duration of the extraction operations. Of key relevance to understanding the potential impacts to shallow groundwater resources, groundwater dependent ecosystems 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.

There are no specific test pumping data that demonstrates the degree of vertical connection between the Illawarra coal measures and the overlying sandstone aquifers at the project site, however 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 groundwater resource investigations (e.g. KBR, 2008; PB, 2008; SCA, 2005).

In the Southern Coalfields, groundwater levels in shallow aquifers show a wide range in responses to the progression of long wall coal mining past a monitoring point, from no noticeable impact to significant but generally transient drawdown responses (Merrick, 2009). At some locations (e.g. bore DDH34 at Dendrobium Colliery, 2007) there were no discernable drawdown impacts observed in the shallow aquifer zones due to depressurisation of the underlying coal seams suggesting that, in the absence of natural or mining induced fracture pathways, shallower aquifers are largely isolated by multiple aquitards in the stratigraphic succession.

In other locations (e.g. bore NGW10 near Longwall 702, Appin Colliery, BHP Billiton, 2005 – 2006), there are clear and significant drawdown impacts. It was noted by Merrick (2009) that these impacts do not correlate well between bores and the hydraulic pathways must be complex, involving faults, joint networks and mining induced fracturing which can be extensive.

Long term test pumping of the Hawkesbury Sandstone aquifers was carried out at Stockyard Swamp and Butlers Swamp in the Southern Highlands between 2007 and 2008 as part of a feasibility and environmental impact assessment by the SCA for the planned Kangaloon Borefield near Robertson (KBR, 2008). In both cases, no drawdown response was noted in the swamps or adjacent permanent streams after more than three months of pumping, indicating that these perched swamp systems are hydraulically isolated from the underlying sandstone aquifer. Furthermore the study by KBR (2008) concluded that the Ashfield Shale and Mittagong Formation act as aquitards where they are present in the geological sequence.

The drilling and test pumping programme carried out just west of Appin by the SCA (2005) indicated that the vertical permeability of the Hawkesbury Sandstone is very low in this location and at least an order of magnitude less than the horizontal permeability (Kv/Kh = 0.04).

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 project area will protect shallow 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. However the possibility cannot be ruled out that major fault zones could provide a hydraulic pathway through claystone horizons and that some shallow groundwater impacts may be observed close to those structures. Minor fault zones and fault zones that have been infilled with clay are unlikely to be conduits for groundwater migration.

Figure 3-1 shows known and inferred faults and lineaments that cross the project area as vertical faults which intersect the entire geological sequence, however the actual subsurface geometry of these structures and their potential to transmit groundwater is poorly known. Herbert (1989) described the subsurface geometry of faults within the Lapstone Complex by interpreting data from the 1987 Camden Seismic Survey conducted by AGL. That study showed that in cross section this major fault zone is not a single continuous normal fault, but comprises flower-like bifurcating structures consisting of dominant high-angle reverse faults with minor high-angle reverse and normal faults bifurcating upwards. Many of these minor faults are not vertically extensive and do not reach the surface. Similarly, faults in the project area are likely to have complex geometries and will not be vertically and laterally continuous as depicted in Figure 3-1. It is recommended that the role of faults in groundwater flow and their potential for transmitting groundwater be given further consideration in Phase 2 studies.

6. Groundwater management

6.1 Plans and policies

The project area is governed by local plans, state government policies, legislation and plans, and federal government strategic initiatives. These include:

- The Camden Local Environmental Plan 2010
- The Campbelltown Local Environmental Plan 2002
- The NSW State Groundwater Policy Framework (Department of Land and Water Conservation (DLWC) 1997). The NSW State Groundwater Policy Framework introduces three policy documents:
  - NSW Groundwater Quality Protection Policy (DLWC 1998)
  - NSW Groundwater Quantity Management Policy (draft) (DLWC n.d.)
  - NSW Groundwater Dependent Ecosystem Policy (DLWC 2002). Updated NSW Wetlands Policy 2010

  The NSW State Groundwater Policy Framework aims to slow, halt or reverse degradation in groundwater resources, ensure long-term sustainability of the biophysical characteristics of the groundwater system, maintain the full range of beneficial uses of these resources and maximise the economic benefit to the region and state.
- NSW Water Sharing Plans
- The National Water Initiative was signed by the Council of Australian Governments (CoAG) in June 2004. The aim of the National Water Initiative is to promote productive and efficient use of water, to service rural and urban communities, and ensure sustainable and healthy river and groundwater systems.

NSW legislation and water sharing plan initiatives are discussed below.

6.2 Water legislation

The access, taking and use of groundwater in NSW is currently managed and implemented under two primary legal instruments — the *Water Management Act 2000* and the *Water Act 1912*. All groundwater in the project area is within the Sydney Basin Central Groundwater Source which is one of 13 groundwater sources under the proposed Greater Metropolitan Region Groundwater Sharing Plan. Groundwater within this water source is currently managed under the *Water Act 1912* and will be until such time as a water sharing plan commences for this water source.

The *Water Act 2007* is Commonwealth legislation and applies at national level. It is high level legislation that is designed to implement the objectives of the National Water Initiative at a State jurisdictional and catchment level – and it not aimed at the management of individual licence holders. It has no direct application within the project area.

6.2.1 Water Act 1912

The *Water Act 1912* came into force at the turn of the last century and since 2003 has been progressively phased out (repealed) and replaced by the *Water Management Act 2000.* The Water Management Act requires a Water Sharing Plan to be established and commence prior to repealing that section or area of the old Water Act 1912. Licence applications for dewatering and water supply for the Sydney Basin Central Groundwater Source are currently managed under Part V of the *Water Act 1912*. However, when the new Greater Metropolitan Region Groundwater Sharing Plan is gazetted, the *Water Management Act 2000* licences granted under Part V of the *Water Act* will be converted to access licences and works and use approvals.

6.2.2 Water Management Act 2000

The *Water Management Act 2000* is gradually being introduced across NSW. Once a water sharing plan commences, the *Water Act 1912* is repealed for that water source and existing licences are converted to new consents under the *Water Management Act 2000*. Within the *Water Management Act 2000*, Section 20 requires that a water sharing plan be developed and “establish rules according to which access licences are to be granted”.

The water sharing plans must firstly determine the water source boundaries and management zones. The Plan then needs to establish the average annual groundwater recharge volume for each identified groundwater source and the volumes (or percentage) required for environmental water requirements, basic landholder rights, domestic and stock rights and native title rights. The remaining volume forms the Long Term Average Annual Extraction Limit (LTAAEL) for sharing between licence holders. If there the sum of the current licensed volume is less than the LTAAEL, then this ‘unassigned water’ may be made available through a controlled allocation order. The Plans also establish accounting provisions for carryover, trading rules and distance conditions for work and use approvals for access licences,

The requirement for a licence may be exempted under Clause.18 of the *Water Management (General) Regulation 2004.* Clause 19 of this same Regulation prescribes a number of different types of these ‘specific purpose’ access licences for which applications may be made under S.61 of the *Water Management Act 2000* irrespective of whether or not an embargo on further licence applications is in place. Water Sharing Plans may also specify additional specific purpose access licences for which applications may be made. This section of the Regulation is significant for mining and Coal Seam Gas operations with the thought that ‘aquifer interference approvals’ for dewatering or similar activities that are not permanent may potentially be regulated under this section of the *Water Management Act 2000*.

There are three NSW groundwater policies currently under development that may have a bearing on the granting of access licences across the Sydney Basin, and the licensing of groundwater extraction for Coal Seam Gas activities. These are the Aquifer Interference Guideline, the Stacked Water Source Policy and the Controlled Allocation Policy.

6.3 Draft Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2010

The Draft Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2010 was placed on public exhibition from 7 June until 30 July 2010. This plan is still in a draft form and the final plan is yet to be released. Commencement of the final plan is likely to occur in accordance with the start of a water year.

The draft plan covers 13 groundwater sources. The Greater Metropolitan Region groundwater sources are located on the east coast of NSW, covering an area of approximately 32,500 km^2. The region spans from Broken Bay in the north, to Shoalhaven Heads in the south, and Lithgow and Goulburn to the west.

The project area is located in the proposed 'Sydney Basin Central Groundwater Source' in the Draft Water Sharing Plan for the Greater Metropolitan Region groundwater sources (2010). The Sydney Basin Central Groundwater Source is bounded by the Hawkesbury River to the north and by the Nepean River to the west and south. A large proportion of Sydney's population resides within this groundwater source area and relatively few bores are distributed across the area. The total area of the Sydney Basin Central Groundwater Source is approximately 3,750 km^2.

6.4 Groundwater licensing

Groundwater abstraction within the project area is currently managed under the *Water Act 1912*. Groundwater licences are obtained under the *Water Act 1912*, but licences granted will need to transition across to the *Water Management Act 2000* with the introduction of the new water sharing plan. All production gas wells in AGLs Camden Gas Project have a combined allocation of 30 ML per year and are licensed for industrial purposes. The CGP is located across two groundwater source areas: the Sydney Basin Nepean Groundwater Source area and the Sydney Basin Central Groundwater Source area.

Where water sharing plans have commenced the *Water Management Act 2000* governs the issue of new water licences and the trade of water access licences and allocations in NSW. Water access licences under the *Water Management Act 2000* differ from licences under the *Water Act 1912*. *Water Management Act 2000* licences:

- provide a share of water, in a particular water source, that can be sustainably extracted
- provide an entitlement that is separate from land ownership
- separate the entitlement to access water from the approvals associated with supply and use of the water
- in the case of 'continuing' water access licences (licences granted in perpetuity), allow for the licence and water allocation available to be bought and sold, subdivided, consolidated and changed (eg for category, zone, water source)
- are listed on a public Water Access Licence Register.

The current *Water Act 1912* licences for 30 ML will transition over to new Aquifer Access Licences under the *Water Management Act 2000* once Water Sharing Plan for these water sources commences. The 30 ML licence will then become a share of 30 units within the overall pool of available water (the LTAAEL), and yearly announcements of available water will credit water into the licence account. These aquifer sources are not over-allocated, and therefore it can be assumed that the announcements each year will be 100% and that the 30 share components will equal 30 ML under this new plan. This will allow AGL's Camden Gas project to continue its operations seamlessly upon commencement of the Plan.

7. Conclusions

This Phase 1 report summarises information from a number of sources including the NOW groundwater database and the DIGS geological database, reviews of previous reports and detailed drill logs supplied by AGL. These provide a detailed understanding of the geology underlying the project area and the region. Previous groundwater investigations to the south and west provide good estimates of the hydraulic properties that could be expected and some indication of groundwater flow and potential for vertical hydraulic continuity between aquifers. In addition this report provides an overview of the current and future groundwater use and an overview of the regulatory and groundwater licensing framework.

Groundwater is rarely used for consumptive uses across the area given the urbanisation and the availability of reticulated water supplies from Sydney Water. There are only 12 registered bores in the Northern Expansion area of the Camden Gas Project (CGP) however their current status is unknown.

The available hydrogeological data for the region suggest that the groundwater systems of the project area are:

- Alluvial aquifer system
- Hawkesbury Sandstone aquifer system
- Narrabeen Group aquifer system
- Illawarra coal measures

Minor groundwater is sometimes located in the shallow Wianamatta Group shales however yields to bores are low and water quality is generally brackish to salty (and hence it is not considered a useful aquifer). The three primary aquifer systems are separated by low permeability claystone aquitards. Available water quality data suggests distinct differences in water chemistry and isolation of each of these aquifer zones. The Illawarra Coal Measures have higher fracture related permeability (compared to surrounding rocks) and are sometimes termed *coal seam aquifers,* although they are in fact mostly low permeability water bearing zones and not useful aquifers for supply purposes.

This review concludes that the presence of extensive and thick claystone formations in the stratigraphic sequence that overlies the Illawarra coal measures in the project area will impede the vertical flow of groundwater such that overlying aquifer zones will be hydraulically isolated, experiencing little, if any drawdown impact related to depressurisation of the coal measures. However the possibility cannot be ruled out that major fault zones could provide a hydraulic pathway through claystone horizons and that some shallow groundwater impacts may be observed close to those structures.

Phase 2 groundwater investigations should be carried out in the Northern Expansion area and a suitable groundwater monitoring network should be installed to monitor water levels and water quality in the major aquifer zones.

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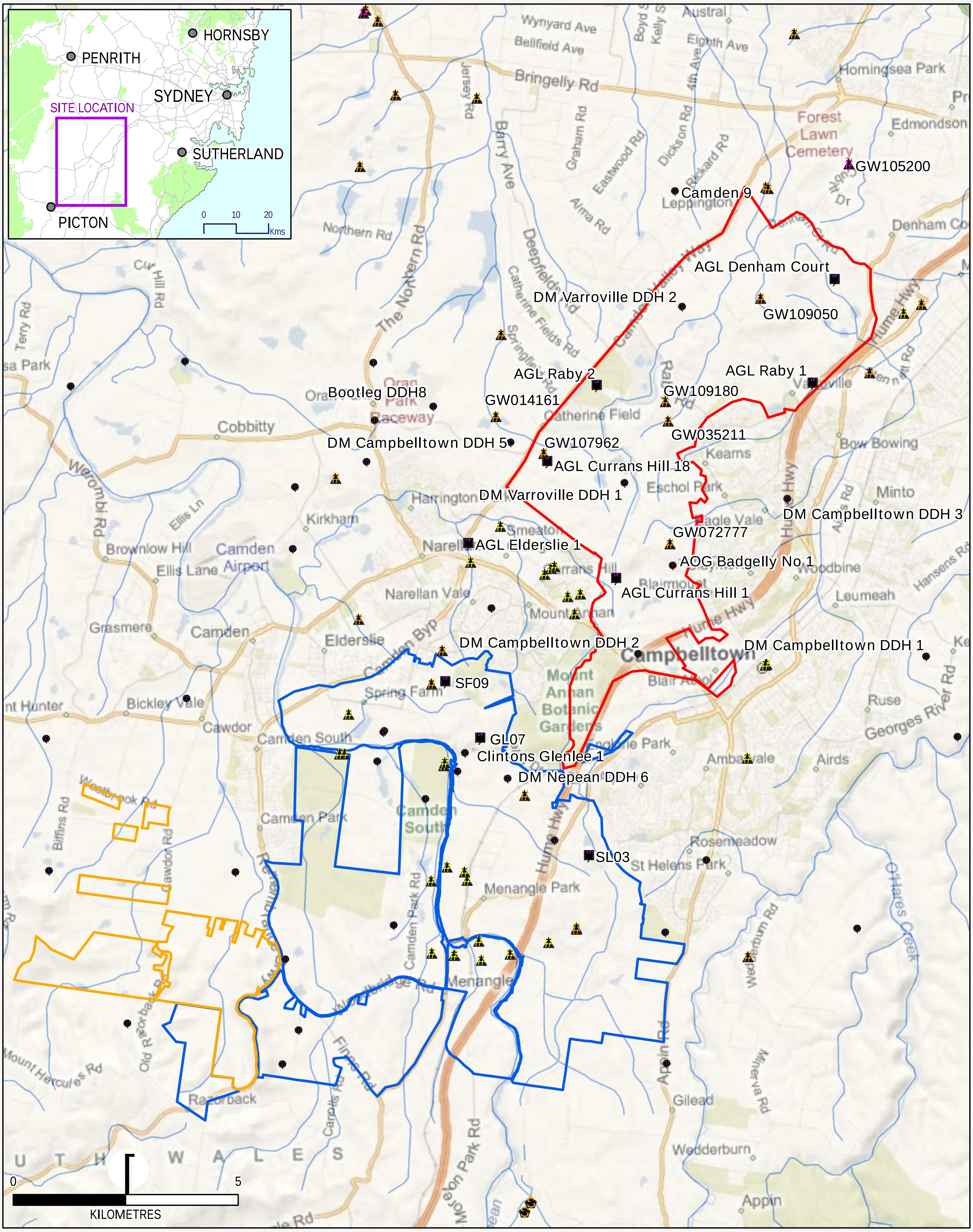

Drilling areas

- Northern expansion
- Stage 1
- Stage 2

Registered bore

- AGL
- DIGS
- NOW
- SCA

Depth (m)

- < 50
- 50 - 300
- 300 - 700
- > 700

Figure 1-1: Site location

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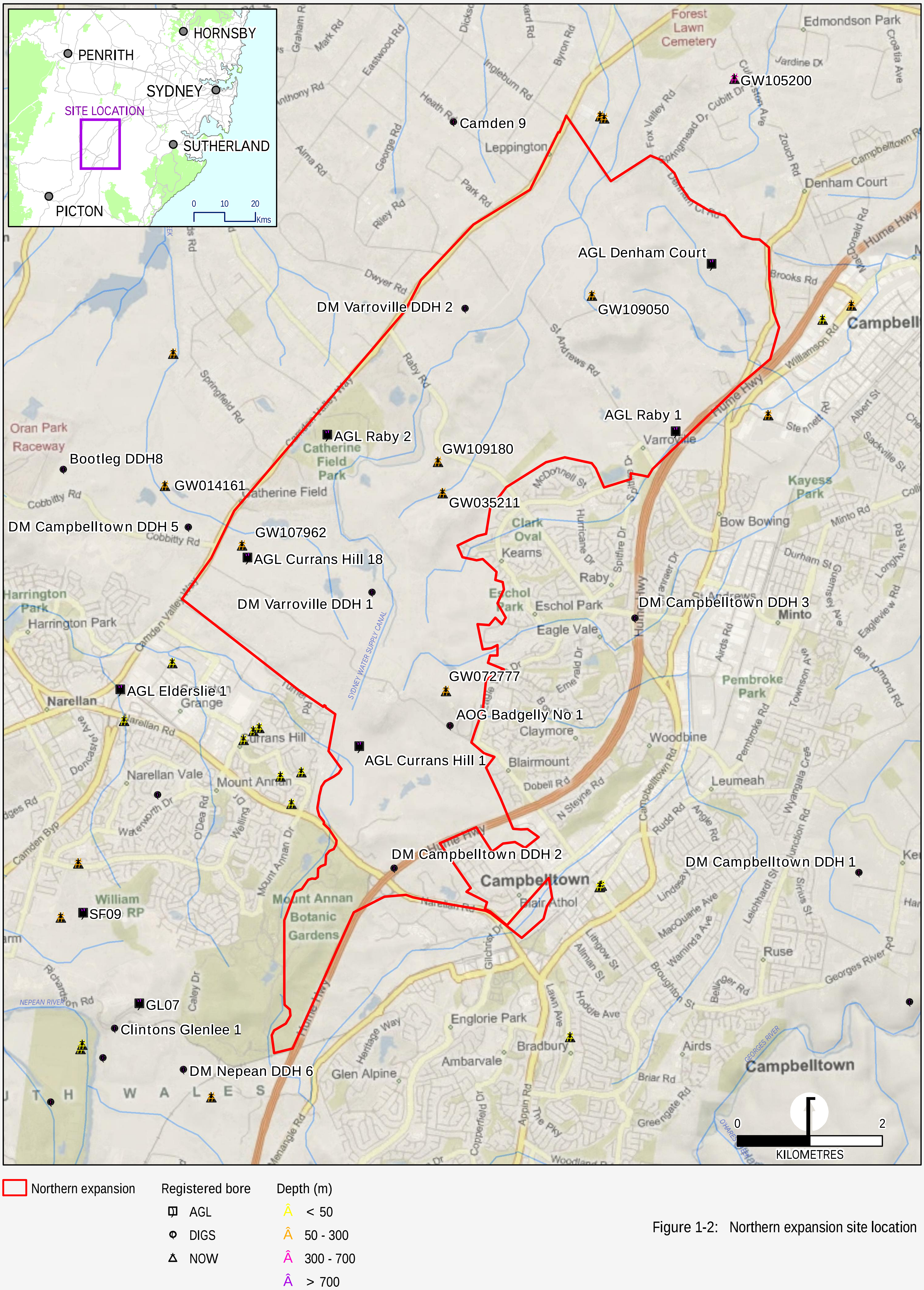

Figure 1-2: Northern expansion site location

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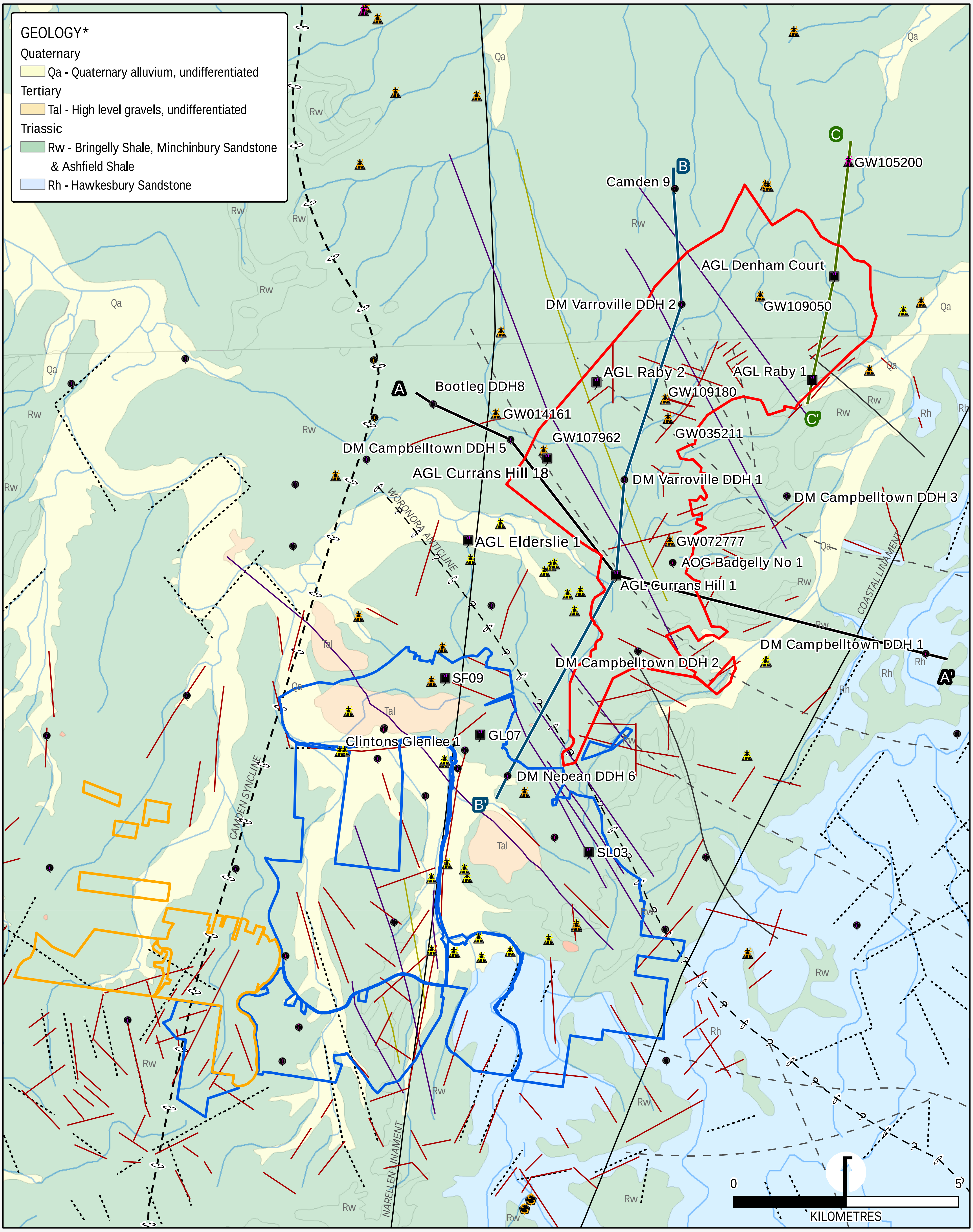
PARSONS BRINCKERHOFF

NORTHERN EXPANSION OF CAMDEN GAS PROJECT
AGL ENERGY



Drilling areas	Registered bore	Depth (m)	Geological structure		Faults ***
Northern expansion	AGL	< 50	Fold - Camden syncline *	Fault *	Certain fault
Stage 1	DIGS	50 - 300	Fold - anticline *	Fault - interpreted *	Possible fault
Stage 2	NOW	300 - 700		Lineaments - Landsat interpreted (CSIRO) **	
Cross sections	SCA	> 700		Lineaments - air photo interpreted (CSIRO) **	

Figure 3-1: Geology and structure

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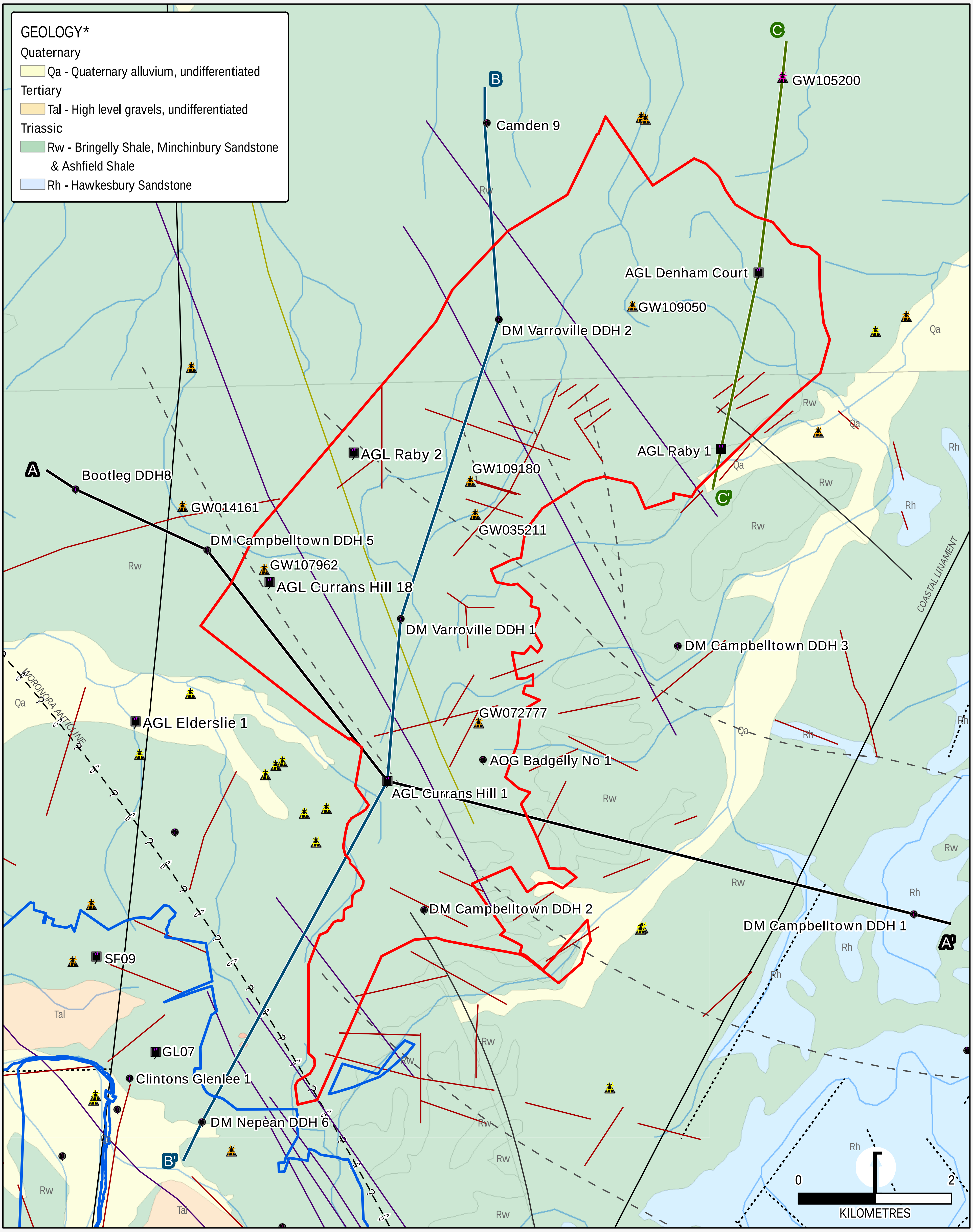
PARSONS BRINCKERHOFF

NORTHERN EXPANSION OF CAMDEN GAS PROJECT
AGL ENERGY



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Drilling areas
- Northern expansion
- Stage 2
- Cross sections

Registered bore
- AGL
- DIGS
- NOW

Depth (m)
- < 50
- 50 - 300
- 300 - 700
- > 700

Geological structure
- Fold - syncline *
- Fold - anticline *
- Fault *
- Fault - interpreted *
- Lineaments - Landsat interpreted (CSIRO) **
- Lineaments - air photo interpreted (CSIRO) **

Faults ***
- Certain fault
- Possible fault

Figure 3-2: Geology and structure
Northern expansion site location

Client: AGL Energy
Project: Northern Expansion of Camden Gas Project

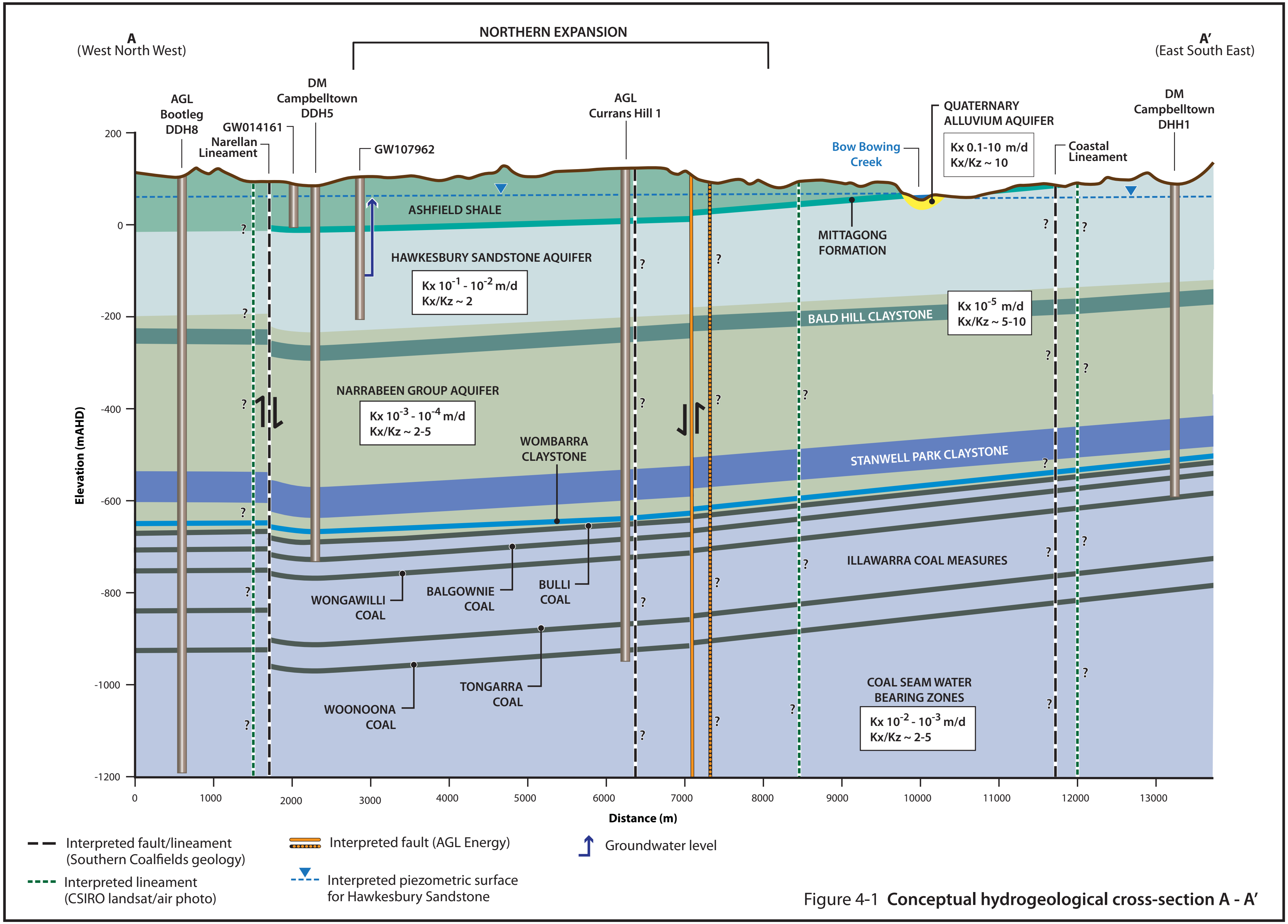

Figure 4-1 **Conceptual hydrogeological cross-section A - A'**

Client: AGL Energy
Project: Northern Expansion of Camden Gas Project

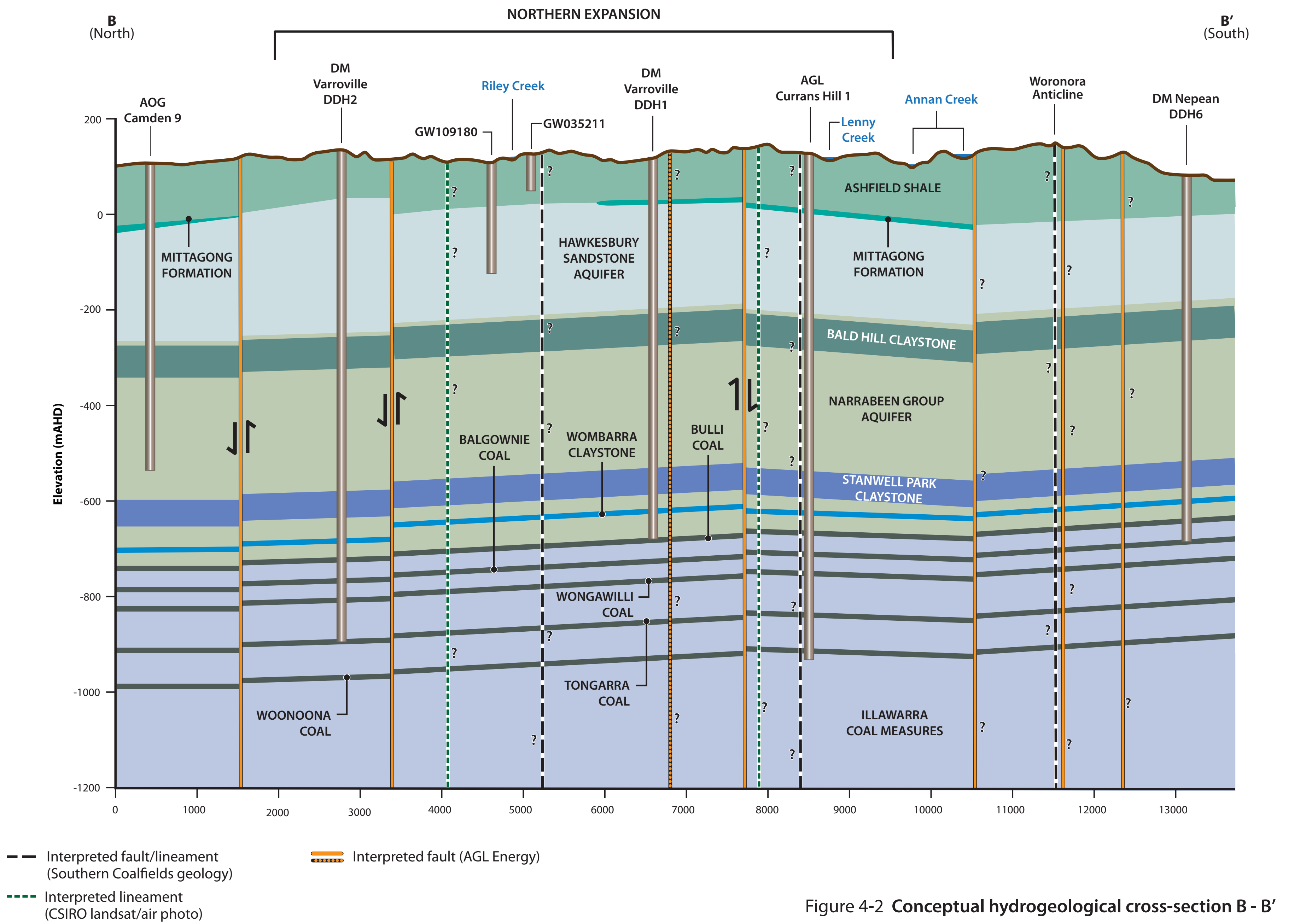

Figure 4-2 **Conceptual hydrogeological cross-section B - B'**

Client: **AGL Energy**
Project: **Northern Expansion of Camden Gas Project**

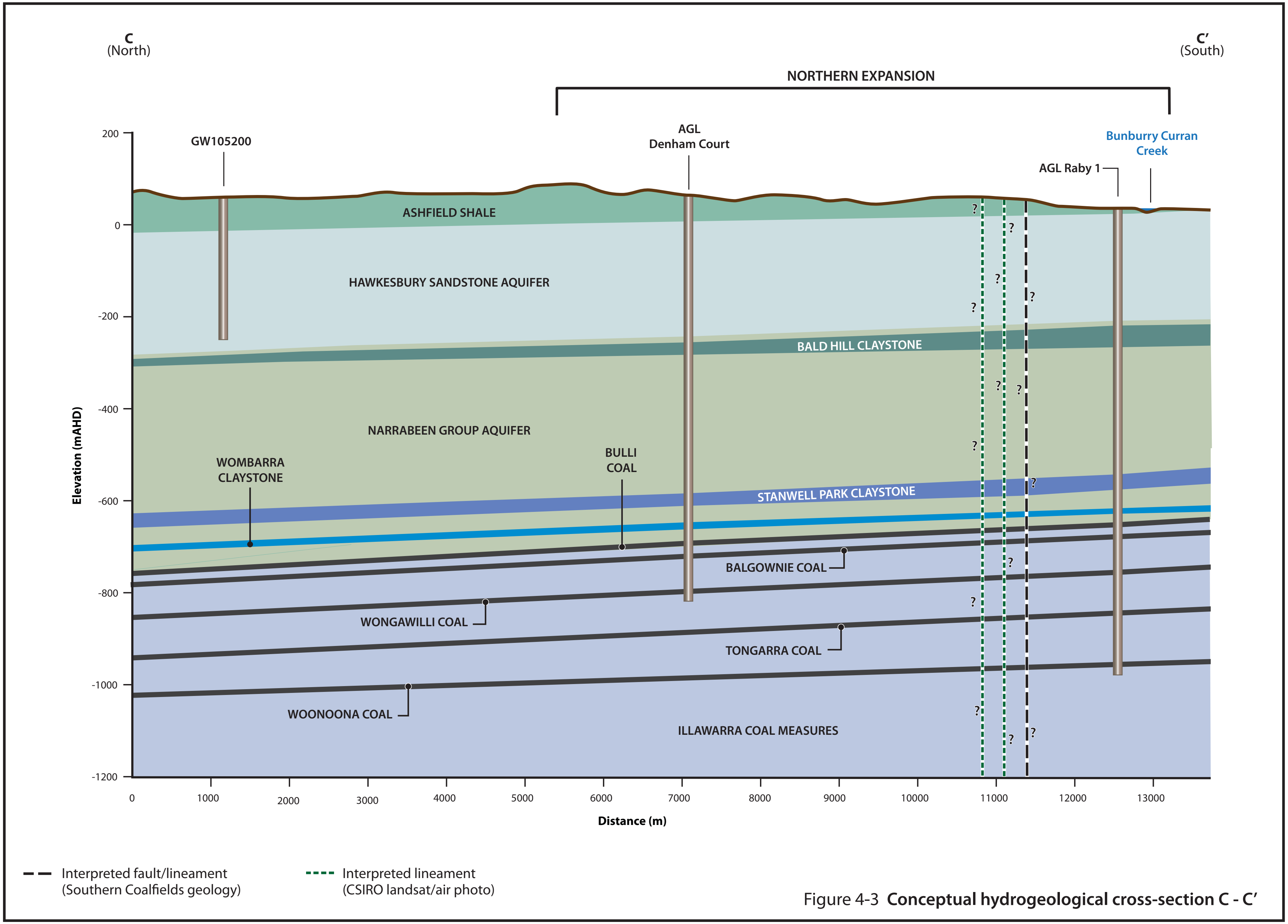

Figure 4-3 **Conceptual hydrogeological cross-section C - C'**

Appendix A

Bore Search Results

Work No	Easting	Northing	Total depth	Date completed	SWL mBGL	WBZ Screen	Screen geology	Purpose description	Salinity	River basin	License	Work type	Owner type
GW014161	292566	6234172	86.6		0.7			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL008245	Bore open thru rock	Private
GW016091	292390	6234045						NOT KNOWN		HAWKESBURY RIVER	10BL008244	(Unknown)	Private
GW016682	308691	6242741	4	1-Sep-61	3.9			WASTE DISPOSAL	(Unknown)	SYDNEY COAST - GEORGES RIVER	10BL011770	Well	Private
GW016829	308350	6243074	5.4	1-Feb-58	3.6			GENERAL USE	(Unknown)	SYDNEY COAST - GEORGES RIVER	10BL007470	Well	Private
GW024351	291921	6223863	21.9	1-May-66	0			NOT KNOWN	(Unknown)	HAWKESBURY RIVER	10BL018771	Bore	Private
GW024353	291479	6224161	24.4	1-May-66	4.5			NOT KNOWN	(Unknown)	HAWKESBURY RIVER	10BL018772	Bore	Private
GW024354	291866	6224047	21.3	1-May-66	0			NOT KNOWN	(Unknown)	HAWKESBURY RIVER	10BL018773	Bore	Private
GW026239	289192	6226669	22.9		0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019653	Bore	Private
GW026469	292182	6222513	20.4	1-Nov-65	0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019648	Bore	Private
GW026470	292880	6222220	2	1-Nov-65				IRRIGATION		HAWKESBURY RIVER	10BL019649	Bore	Private
GW026471	292243	6222082	5.5	1-Nov-65	0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019650	Bore	Private
GW026472	291403	6226410	29		0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019651	Bore	Private
GW026473	291651	6222193	19.2	1-Nov-65	0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019652	Bore	Private
GW026474	291428	6226472	26.2	1-Nov-65	0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019645	Bore	Private
GW026533	289089	6226667	21.3	1-Nov-65	0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019643	Bore	Private
GW026545	291137	6222243	8.5	1-Nov-65	0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019647	Bore	Private
GW026551	291127	6223845	11	1-Nov-65				IRRIGATION		HAWKESBURY RIVER	10BL019646	Bore	Private
GW026557	291625	6222192	28.4	1-May-66	0			IRRIGATION	(Unknown)	HAWKESBURY RIVER	10BL019642	Bore	Private
GW029192	308927	6243794	2.4	1-Nov-68				WASTE DISPOSAL		SYDNEY COAST - GEORGES RIVER	10BL022597	Well	Private
GW029193	309029	6243796	2.4	1-Nov-68				WASTE DISPOSAL		SYDNEY COAST - GEORGES RIVER	10BL022598	Well	Private
GW029194	309004	6243796	2.4	1-Nov-68				WASTE DISPOSAL		SYDNEY COAST - GEORGES RIVER	10BL023674	Well	Private
GW029195	309004	6243796	2.4	1-Nov-68				WASTE DISPOSAL		SYDNEY COAST - GEORGES RIVER	10BL023675	Well	Private
GW029196	308978	6243795	2.4	1-Nov-68				WASTE DISPOSAL		SYDNEY COAST - GEORGES RIVER	10BL023676	Well	Private
GW029197	308952	6243795	2.4	1-Nov-68				WASTE DISPOSAL		SYDNEY COAST - GEORGES RIVER	10BL023677	Well	Private
GW031197	301630	6236463	1.8	1-Jan-67	0			IRRIGATION	invalid code	SYDNEY COAST - GEORGES RIVER	10BL020981	Well	Private
GW031438	289830	6229088		1-Apr-68				GENERAL USE		HAWKESBURY RIVER	10BL023530	Bore	Private
GW032724	289510	6229666	76.2	1-Mar-68	3	12.1 - 63.9 mBGL	Shale	GENERAL USE	(Unknown)	HAWKESBURY RIVER	10BL024430	Bore	Private
GW034351	291132	6228223	182.9	1-Sep-68				IRRIGATION		HAWKESBURY RIVER	10BL026444	Bore	Private
GW034450	291372	6228968	190.5	1-Sep-68	0			NOT KNOWN	Brackish	HAWKESBURY RIVER	10BL026445	Bore	Private
GW035211	296393	6234071	61	1-Sep-68				STOCK		SYDNEY COAST - GEORGES RIVER	10BL027909	Bore open thru rock	Private
GW038092	292680	6235993	258.2	1-Aug-73	29.2			OIL XPLORATION	Fresh	HAWKESBURY RIVER	10BL031418	Bore open thru rock	Private
GW058697	309271	6244541	19.2	1-Jul-84	8.5			G/WATER XPLORE	(Unknown)	SYDNEY COAST - GEORGES RIVER	10BL130184	Bore	Private
GW058698	309117	6244568	19.5	1-Jul-84						SYDNEY COAST - GEORGES RIVER		Bore	Private
GW058734	298567	6239264	191.4	1-Sep-81	91.4				Poor	HAWKESBURY RIVER		Bore	Private
GW058735	298619	6239235	173.7	1-Sep-81	91.4				Poor	HAWKESBURY RIVER		Bore	Private
GW063062	289671	6243201	151	1-Jan-89				INDUSTRIAL		HAWKESBURY RIVER	10BL126198	Bore	Private
GW064814	294354	6222807	48	1-Jan-85						HAWKESBURY RIVER		Bore	Private
GW064815	294355	6222776	64	29-Jan-85	24	42 - 60 mBGL			S.Brackish	HAWKESBURY RIVER		Bore	Private
GW072329	290560	6223453		1-Jan-89						HAWKESBURY RIVER			
GW072372	292136	6241243	228	26-Sep-94	0			STOCK	Good		10BL156018	Bore	
GW072777	296439	6231343	252	9-Mar-95	0				0	SYDNEY COAST - GEORGES RIVER		Bore open thru rock	Private
GW072961	289538	6239727	100	3-Mar-95	0				0	HAWKESBURY RIVER		Bore	Private
GW073533	289618	6243139	330	1-Jan-90						HAWKESBURY RIVER		Bore	Private
GW075051	293652	6230668	10	3-Feb-99	3.6	7 - 10 mBGL	Clay/Gravel		1737	HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075052	293786	6230791	9.5	4-Feb-99	7.7	3.5 - 9.5 mBGL	Weathered Shale		1737	HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075053	293868	6230837	10	4-Feb-99		0.8 - 9.8 mBGL	Weathered Shale			HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075054	294159	6230165	6	4-Feb-99		2.5 - 5.5 mBGL	Clay/Shale			HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075055	294445	6230226	4.6	3-Feb-99		1.6 - 4.6 mBGL	Weathered Shale			HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075056	294312	6229788	11	4-Feb-99	3.2	8 - 11 mBGL	Clay/Weather Gravel		1737	HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075057	292003	6230933	11	3-Sep-98	4.3	8 - 11 mBGL	Clay		1489	HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075058	292667	6231729	5	3-Sep-98	1	2 - 5 mBGL	Blue Metal		1489	HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075064	300221	6247693	4.5	26-Aug-99		1.5 - 4.5 mBGL	Basalt? (Blue Metal)			HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075065	300198	6247702	6	26-Aug-99		3 - 6 mBGL	Weathered Sandstone			HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075066	300170	6247708	6	26-Aug-99		3 - 6 mBGL	Weathered Sandstone					Bore	DWE (Dept of Water & Energy)
GW075067	300144	6247717	9	26-Aug-99		6 - 9 mBGL	Sandstone			HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW075068	300118	6247730	10	26-Aug-99		7 - 10 mBGL	Weathered Sandstone			HAWKESBURY RIVER		Bore	DWE (Dept of Water & Energy)
GW100295	302031	6236658	50	15-Jul-94	12			DOMESTIC	Good		10BL154729	Bore	
GW100329	289288	6227553	32.3	26-Mar-93	9	28 - 31.2 mBGL	Sand	DOMESTIC	Good		10BL151638	Bore	
GW100571	298133	6245191	271	4-Feb-97	0			FARMING	Other		10BL157895	Bore	
GW100732	290333	6241317	138	17-Jan-97	0			DOMESTIC	1648		10BL157848	Bore	
GW101062	289934	6242958	220	9-Sep-97	45			DOMESTIC	0		10BL158117	Bore	
GW101106	293207	6225747	280	7-Mar-97	17			TEST BORE	1603		10BL158151	Bore	
GW101280	306840	6245172	6	11-Jun-96	1.34	2.3 - 5.2 mBGL	Gravels And Clay	MONITORING BORE	0		10BL157686	Bore	
GW101281	306840	6245171	3.5	11-Jun-96	1.3	0.5 - 3.5 mBGL	Sandy Clay	MONITORING BORE	0		10BL157686	Bore	
GW101282	306840	6245171	4	11-Jun-96	1.1	0.45 - 3.45 mBGL	Sandy To Gravelly Clay	MONITORING BORE	0		10BL157686	Bore	
GW101283	306840	6245171	4.6	11-Jun-96	1.4	1.2 - 4.5 mBGL	Sandy Clay/Sandy Gravel	MONITORING BORE	0		10BL157686	Bore	
GW102015	303949	6243093	9	1-Mar-96	3			DEWATERING (GROUNDWATER)			10BL157409	Bore	
GW102486	291012	6226710		1-Jan-95				MONITORING BORE			10BL156728	Bore	
GW102488	303708	6231606	30	29-Mar-94	17			DOMESTIC	Fair		10BL154254	Bore	
GW102641	308873	6243885	16.7	1-Jan-98	5.13	13.5 - 16.5 mBGL	Gravels	INDUSTRIAL	1622		10BL158829	Bore	
GW103739	292339	6246890	32.98	6-Apr-01	26.7	16.98 - 31.98 mBGL	Bringelly Shale/Siltstone & Sandst.	TEST BORE	1737		10BL160102	Bore	

Work No	Easting	Northing	Total depth	Date Completed	SWL mBGL	WBZ Screen	Screen Geology	Purpose Description	Salinity	River Basin	License	Work Type	Owner Type
GW103740	292339	6246890	32	11-Apr-01	27.5	16 - 31 mBGL	Shale/Siltstone/Bringelly Shale	TEST BORE	1737		10BL160102	Bore	
GW103741	292339	6246890	27.15	18-Apr-01	22.7	11.15 - 26.15 mBGL	Bringelly Shale/Siltstone/Sandstone	TEST BORE	1737		10BL160102	Bore	
GW103742	292339	6246890	23.93	19-Apr-01	12.7	10.93 - 22.93 mBGL	Sandstone And Shale	TEST BORE	1737		10BL160102	Bore	
GW103743	292339	6246890	27.25	12-Apr-01	23	14.25 - 26.25 mBGL	Shale/Siltstone/Sandstone	TEST BORE	1737		10BL160102	Bore	
GW103744	292339	6246890	32.78	10-Apr-01	24.2	16.78 - 31.78 mBGL	Shale/Siltstone/Sandstone	MONITORING BORE	1737		10BL160102	Bore	
GW103786	309207	6248562	7	13-Jul-90				MONITORING BORE			10BL156593	Bore	
GW103787	309207	6248562	4	6-Jul-01				MONITORING BORE			10BL156593	Bore	
GW103788	309207	6248562	4	13-Jul-90				MONITORING BORE			10BL156593	Bore	
GW103789	309207	6248562	6	10-Apr-91				MONITORING BORE			10BL156593	Bore	
GW103790	309207	6248562	5	10-Apr-91				MONITORING BORE			10BL156593	Bore	
GW103791	309207	6248562	5	24-Mar-95				MONITORING BORE			10BL156593	Bore	
GW103792	309207	6248562	3	25-Mar-95				MONITORING BORE			10BL156593	Bore	
GW103793	309207	6248562	1.7	25-Mar-95				MONITORING BORE			10BL156593	Bore	
GW103794	309207	6248562	2.7	25-Mar-95				MONITORING BORE			10BL156593	Bore	
GW103795	309207	6248562	5	24-Mar-95				MONITORING BORE			10BL156593	Bore	
GW103796	309207	6248562	3.5	24-Mar-95				MONITORING BORE			10BL156593	Bore	
GW103797	309207	6248562	8	24-Mar-95				MONITORING BORE			10BL156593	Bore	
GW103798	309207	6248562	1.7	25-Mar-95				MONITORING BORE			10BL156593	Bore	
GW103799	307325	6244964	3.3	12-Jun-91				MONITORING BORE			10BL156592	Bore	
GW103800	307325	6244964	3	11-Mar-92				MONITORING BORE			10BL156592	Bore	
GW103801	307325	6244964	3	11-Mar-92				MONITORING BORE			10BL156592	Bore	
GW103802	307325	6244964	5	10-Apr-95				MONITORING BORE			10BL156592	Bore	
GW103803	307325	6244964	3	10-Apr-95				MONITORING BORE			10BL156592	Bore	
GW103804	307325	6244964	3	10-Apr-95				MONITORING BORE			10BL156592	Bore	
GW103805	307325	6244964	4	10-Mar-95				MONITORING BORE			10BL156592	Bore	
GW103996	298153	6226575	3.87	13-Aug-98				MONITORING BORE			10BL158732	Bore	
GW104018	303530	6237899	215	12-Oct-00	6			TEST BORE	0		10BL159770	Bore	
GW104078	297614	6248011	30	3-Oct-01		18 - 30 mBGL	Shale	MONITORING BORE			10BL160288	Bore	
GW104079	297649	6248210	30	4-Oct-01		18 - 30 mBGL	Shale	MONITORING BORE			10BL160288	Bore	
GW104080	297677	6248408	30	5-Oct-01		18 - 30 mBGL	Shale	MONITORING BORE			10BL160288	Bore	
GW104081	297710	6248607	30	6-Oct-01		18 - 30 mBGL	Shale	MONITORING BORE			10BL160288	Bore	
GW104212	289000	6232797	188	26-Jan-02	0			IRRIGATION	1771		10BL160361	Bore	Private
GW104349	300880	6235145	60.5	28-Jun-02	1.3			DOMESTIC	1783		10BL160653	Bore	Private
GW105016	292895	6248599	252.5	1-Apr-03	53			STOCK	1489	HAWKESBURY RIVER	10BL161450	Bore	Private
GW105118	298168	6222166	162	26-Feb-96	70			DOMESTIC	0	SYDNEY COAST - GEORGES RIVER	10BL157505	Bore	
GW105200	300414	6239783	303	22-May-03	13			DOMESTIC	1488	SYDNEY COAST - GEORGES RIVER	10BL161684	Bore	Private
GW105305	300098	6244887	240	5-Mar-04	91			TEST BORE	1859	SYDNEY COAST - GEORGES RIVER	10BL162877	Bore	
GW106394	288937	6234148		29-Aug-05						HAWKESBURY RIVER		Bore	
GW106636	292223	6247047		16-Nov-05						HAWKESBURY RIVER		Bore	
GW106735	292192	6247030						INDUSTRIAL			10BL165661	Bore	
GW106942	301163	6236651		30-Mar-06								Bore	
GW107007	299198	6242678	267	23-Nov-04	4			BANK REVEGETATION	Brackish		10BL164442	Bore	
GW107055	303898	6234033		8-May-06								Bore	
GW107912	303445	6248641		8-Mar-07								Bore	
GW107962	293631	6233348	297	30-Jun-05	23			IRRIGATION	Fresh		10BL163388	Bore	
GW108233	303341	6243596	5	22-Nov-05				MONITORING BORE			10BL600117	Bore	
GW108234	303356	6243704	5	22-Nov-05				MONITORING BORE			10BL600117	Bore	
GW108235	303374	6243733	6	22-Jan-05				MONITORING BORE			10BL600117	Bore	
GW108346	306023	6238008	210.3	25-Jan-06	35			TEST BORE	1489		10BL165922	Bore	
GW108678	308024	6248836	11	17-Mar-08				MONITORING BORE			10BL161999	Bore	Private
GW108679	308026	6248818	6	18-Mar-08				MONITORING BORE			10BL161999	Bore	Private
GW108680	308026	6248823	6	18-Mar-08				MONITORING BORE			10BL161999	Bore	Private
GW108802	307099	6239299	23.7	21-Apr-08		14.7 - 23.7 mBGL	Sandstone. L/Grey, Medium Grained	MONITORING BORE			10BL601723	Bore	Private
GW108803	307099	6239304	8	21-Apr-08		3 - 7 mBGL	Sandy Clay	MONITORING BORE			10BL601723	Bore	Private
GW108804	307015	6240274	11	22-Apr-08		5 - 11 mBGL	Sand/Clay/Weathered Shale	MONITORING BORE			10BL601719	Bore	Private
GW108863	293738	6222478	20	8-May-08				INDUSTRIAL - SAND & GRAVEL			10BL601942	Excavation	Private
GW109050	298451	6236794	240	15-Jul-08	70			DOMESTIC			10BL602182	Bore	Private
GW109180	296332	6234503	264	8-Aug-08	80			STOCK			10BL163148	Bore	Private
GW109212	298557	6228642	9	14-Aug-08				MONITORING BORE			10BL602480	Bore	Private
GW109213	298585	6228665	5	14-Aug-08				MONITORING BORE			10BL602480	Bore	Private
GW109214	298571	6228660	7	14-Aug-08				MONITORING BORE			10BL602480	Bore	Private
GW109215	298562	6228650	5	15-Aug-08				MONITORING BORE			10BL602480	Bore	Private

Registered bores within Northern expansion area

Appendix B

ALS Laboratory Reports

Environmental Division

CERTIFICATE OF ANALYSIS

Work Order	: **ES1017524**	Page	: 1 of 4
Client	: **AGL ENERGY**	Laboratory	: Environmental Division Sydney
Contact	: MR JOHN ROSS	Contact	: Charlie Pierce
Address	: P.O BOX 67 MENANGLE MENANGLE NSW 2568	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
E-mail	: jross@agl.com.au	E-mail	: sydney.enviro.services@alsglobal.com
Telephone	: 4633 5200	Telephone	: +61-2-8784 8555
Facsimile	: ----	Facsimile	: +61-2-8784 8500
Project	: SF PRODUCTION FLOW TESTING PROGRAM	QC Level	: NEPM 1999 Schedule B(3) and ALS QCS3 requirement
Order number	: TL08703		
C-O-C number	: ----	Date Samples Received	: 01-SEP-2010
Sampler	: TL	Issue Date	: 09-SEP-2010
Site	: ----		
		No. of samples received	: 3
Quote number	: SY/456/10	No. of samples analysed	: 3

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

NATA
WORLD RECOGNISED ACCREDITATION

NATA Accredited Laboratory 825

This document is issued in accordance with NATA accreditation requirements.

Accredited for compliance with ISO/IEC 17025.

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Inorganics
Celine Conceicao	Spectroscopist	Inorganics
Hoa Nguyen	Inorganic Chemist	Inorganics
Sarah Millington	Senior Inorganic Chemist	Inorganics

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insuffient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When date(s) and/or time(s) are shown bracketed, these have been assumed by the laboratory for processing purposes. If the sampling time is displayed as 0:00 the information was not provided by client.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting

- **EG020: LOR raised for Chromium due to matrix interference for sample ES1017524 #001, 2 & 3.**
- **EG020: Poor spike recovery was obtained for sample ES1017524 #002. Results have been confirmed by reanalysis.**

Analytical Results

Sub-Matrix: **WATER**

Compound	CAS Number	LOR	Unit	SF09	HB01	HB02	----	----
			Client sample ID	SF09	HB01	HB02	----	----
			Client sampling date / time	01-SEP-2010 08:30	01-SEP-2010 08:30	01-SEP-2010 08:30	----	----
				ES1017524-001	ES1017524-002	ES1017524-003	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	11800	15200	5400	----	----
EA016: Non Marine - Estimated TDS Salinity								
^ Total Dissolved Solids (est.)	----	1	mg/L	7680	9910	3510	----	----
EA025: Suspended Solids								
^ Suspended Solids (SS)	----	1	mg/L	17	52	23	----	----
EA065: Total Hardness as CaCO3								
^ Total Hardness as CaCO3	----	1	mg/L	52	76	19	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	515	128	99	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	6230	8470	905	----	----
Total Alkalinity as CaCO3	----	1	mg/L	6750	8600	1000	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	<1	<1	<1	----	----
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	1	mg/L	571	793	1160	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	11	20	5	----	----
Magnesium	7439-95-4	1	mg/L	6	6	1	----	----
Sodium	7440-23-5	1	mg/L	3220	4040	1200	----	----
Potassium	7440-09-7	1	mg/L	27	76	45	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	0.01	<0.01	0.03	----	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	<0.001	----	----
Boron	7440-42-8	0.05	mg/L	<0.05	<0.05	0.10	----	----
Strontium	7440-24-6	0.001	mg/L	2.71	0.142	0.276	----	----
Barium	7440-39-3	0.001	mg/L	10.5	1.08	0.347	----	----
Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	<0.001	----	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	----	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	<0.001	----	----
Uranium	7440-61-1	0.001	mg/L	<0.001	<0.001	<0.001	----	----
Chromium	7440-47-3	0.001	mg/L	<0.005	<0.005	<0.005	----	----
Copper	7440-50-8	0.001	mg/L	<0.001	<0.001	0.004	----	----
Manganese	7439-96-5	0.001	mg/L	0.008	0.020	0.015	----	----
Molybdenum	7439-98-7	0.001	mg/L	0.015	<0.001	0.007	----	----
Nickel	7440-02-0	0.001	mg/L	<0.001	<0.001	0.004	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	0.002	----	----

Analytical Results

Sub-Matrix: WATER			Client sample ID	SF09	HB01	HB02	----	----
			Client sampling date / time	01-SEP-2010 08:30	01-SEP-2010 08:30	01-SEP-2010 08:30	----	----
Compound	CAS Number	LOR	Unit	ES1017524-001	ES1017524-002	ES1017524-003	----	----
EG020F: Dissolved Metals by ICP-MS - Continued								
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	----	----
Zinc	7440-66-6	0.005	mg/L	<0.005	<0.005	**0.007**	----	----
Iron	7439-89-6	0.05	mg/L	<0.05	<0.05	**1.30**	----	----
Bromine	7726-95-6	0.1	mg/L	**0.5**	<0.1	**2.1**	----	----
Iodine	7553-56-2	0.1	mg/L	<0.1	<0.1	<0.1	----	----
EG035F: Dissolved Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	<0.0001	----	----
EG052F: Dissolved Silica by ICPAES								
^ Silica	7631-86-9	0.1	mg/L	**17.8**	**16.2**	**11.0**	----	----
EN055: Ionic Balance								
^ Total Anions	----	0.01	meq/L	**151**	**194**	**52.9**	----	----
^ Total Cations	----	0.01	meq/L	**142**	**179**	**53.6**	----	----
^ Ionic Balance	----	0.01	%	**3.20**	**4.08**	**0.61**	----	----

CERTIFICATE OF ANALYSIS

Work Order	: **ES1019261**	Page	: 1 of 4
Client	: **AGL ENERGY**	Laboratory	: Environmental Division Sydney
Contact	: MR JOHN ROSS	Contact	: Charlie Pierce
Address	: P.O BOX 67 MENANGLE MENANGLE NSW 2568	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
E-mail	: jross@agl.com.au	E-mail	: sydney.enviro.services@alsglobal.com
Telephone	: 4633 5200	Telephone	: +61-2-8784 8555
Facsimile	: ----	Facsimile	: +61-2-8784 8500
Project	: GL SL PRODUCTION FLOW TESTING PROGRAM	QC Level	: NEPM 1999 Schedule B(3) and ALS QCS3 requirement
Order number	: 4510001195		
C-O-C number	: ----	Date Samples Received	: 24-SEP-2010
Sampler	: TL	Issue Date	: 30-SEP-2010
Site	: ----		
		No. of samples received	: 2
Quote number	: SY/456/10	No. of samples analysed	: 2

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

NATA

WORLD RECOGNISED ACCREDITATION

NATA Accredited Laboratory 825

This document is issued in accordance with NATA accreditation requirements.

Accredited for compliance with ISO/IEC 17025.

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Ankit Joshi	Inorganic Chemist	Inorganics
Celine Conceicao	Spectroscopist	Inorganics
Sarah Millington	Senior Inorganic Chemist	Inorganics

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insuffient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting

- **EG020: LOR raised for Chromium due to matrix interference for sample ES1019261 #001.**

Analytical Results

Sub-Matrix: WATER			Client sample ID	GL7/16-24.9.10 GL16-24.9.10	SL02-24.9.10 SL09-24.9.10	----	----	----
			Client sampling date / time	24-SEP-2010 13:00	24-SEP-2010 13:00	----	----	----
Compound	CAS Number	LOR	Unit	ES1019261-001	ES1019261-002	----	----	----
EA010P: Conductivity by PC Titrator								
Electrical Conductivity @ 25°C	----	1	µS/cm	10400	12300	----	----	----
EA016: Non Marine - Estimated TDS Salinity								
^ Total Dissolved Solids (est.)	----	1	mg/L	6750	8000	----	----	----
EA025: Suspended Solids								
^ Suspended Solids (SS)	----	1	mg/L	36	9	----	----	----
EA065: Total Hardness as CaCO3								
^ Total Hardness as CaCO3	----	1	mg/L	42	118	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	800	840	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	4310	6490	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	5110	7330	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	<1	<1	----	----	----
ED045G: Chloride Discrete analyser								
Chloride	16887-00-6	1	mg/L	851	302	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	8	28	----	----	----
Magnesium	7439-95-4	1	mg/L	5	11	----	----	----
Sodium	7440-23-5	1	mg/L	2640	3230	----	----	----
Potassium	7440-09-7	1	mg/L	14	14	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	<0.01	<0.01	----	----	----
Arsenic	7440-38-2	0.001	mg/L	0.002	<0.001	----	----	----
Boron	7440-42-8	0.05	mg/L	0.12	<0.05	----	----	----
Strontium	7440-24-6	0.001	mg/L	1.73	1.36	----	----	----
Barium	7440-39-3	0.001	mg/L	7.93	3.93	----	----	----
Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	----	----	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	----	----	----
Uranium	7440-61-1	0.001	mg/L	<0.001	<0.001	----	----	----
Chromium	7440-47-3	0.001	mg/L	0.011	0.002	----	----	----
Copper	7440-50-8	0.001	mg/L	0.002	0.020	----	----	----
Manganese	7439-96-5	0.001	mg/L	0.008	<0.001	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	0.006	<0.001	----	----	----
Nickel	7440-02-0	0.001	mg/L	0.011	0.007	----	----	----

Analytical Results

Sub-Matrix: **WATER**			Client sample ID	GL7/16-24.9.10 GL16-24.9.10	SL02-24.9.10 SL09-24.9.10	----	----	----
			Client sampling date / time	24-SEP-2010 13:00	24-SEP-2010 13:00	----	----	----
Compound	CAS Number	LOR	Unit	ES1019261-001	ES1019261-002	----	----	----
EG020F: Dissolved Metals by ICP-MS - Continued								
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.010**	**0.016**	----	----	----
Iron	7439-89-6	0.05	mg/L	**0.32**	<0.05	----	----	----
Bromine	7726-95-6	0.1	mg/L	**1.9**	<0.1	----	----	----
Iodine	7553-56-2	0.1	mg/L	**0.4**	<0.1	----	----	----
EG035F: Dissolved Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	----	----	----
EG052G: Silica by Discete Analyser								
Reactive Silica	----	0.10	mg/L	**23.4**	**10.3**	----	----	----
EN055: Ionic Balance								
^ Total Anions	----	0.01	meq/L	**126**	**155**	----	----	----
^ Total Cations	----	0.01	meq/L	**116**	**143**	----	----	----
^ Ionic Balance	----	0.01	%	**4.22**	**4.02**	----	----	----