# (Draft) Report on Hydrogeological Investigations Dooralong & Yarramalong Valleys Wyong, Central Coast, NSW

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Northern Geoscience

Submitted to:

Tony Davis & Associates
Australian Gas Alliance
Dooralong NSW 2259

## EXECUTIVE SUMMARY

Hydrogeological investigations have been conducted in the Dooralong and Yarramalong Valleys, which form the headwaters and recharge zones for the central coast Wyong catchment. These investigations have resulted in:

i. a more detailed hydrogeological characterisation of the valleys surface and groundwater;

ii. a more detailed understanding of geological structures present in the valleys;

iii. greater confidence in the prediction of potential impacts associated with coal seam methane production by Sydney Gas Ltd; and

iv. development of a conceptual groundwater flow model.

The main issues of environmental significance is the possibility of dewatering groundwater aquifer systems, impacting on stream flow and water quality, land subsidence, damage to riverine ecosystem and leaching of gas during methane gas production.

Investigations indicate groundwater in the Yarramalong and Dooralong Valleys is encountered within four distinct weathered and fresh geological profiles. The near surface shallow colluvium and alluvial aquifers, sandstone aquifers, and deeper rock units, which include Newcastle Coal Measures. It has been concluded that there is a complex hydrogeological system, which nevertheless can be modelled using average and known aquifer hydraulic properties for the purposes of estimating likely impacts through dewatering.

Groundwater is interpreted as moving in a south easterly direction towards the valley lows, here it discharges into incised streams being the Wyong River in the Yarramalong Valley and Jilliby Creek in the Dooralong Valley. The water table is shallow with surface water and groundwater considered a single system that migrates towards the lowlands and lakes district of the central coast.

Water quality in shallow and near surface aquifers is high and of potable quality, as is the surface flows of Jilliby Creek and Wyong River which contribute approximately 50% of the central coast drinking water supply. The water quality of the coal seams is considered saline, highly mineralised and considered of low quality with analytes above the Australian Drinking Water Standard. Any cross contamination from the coal seams to overlying aquifers will impact on the availability and quality of potable domestic supplies for the central coast.

Conceptual hydraulic modelling has shown that dewatering of underlying coal seams in the valleys will impact on the overlying groundwater resource, which in turn has the potential to reduce stream flow and impact on the environmental ecosystem. Geological structures and high permeability values for near surface aquifer systems results in a possibility of higher groundwater velocities within discrete fracture zones within the aquifers, and high volumetric rates of groundwater movement. Modelling confirms the creation of a groundwater void in coal seams will result in waters migrating downwards towards the voids via regional and localised faults, fractures and joints sets. This water will then be pumped along with the low quality coal seam water effectively dewatering the valleys over time. This is particularly true during periods of low flow or during drought conditions.

The lowering of the groundwater table through coal seam dewatering will result in significant impacts to groundwater domestic supply bores, within the zone of influence of the commercial gas wells, through a reduction in the quantity of available groundwater and the drying up of many wells for potable supplies. Commercial irrigation wells will also be impacted causing significant economic losses in agricultural production.

Environmental impacts to streams through the loss of surface flow caused by lowering of groundwater aquifers have the potential to kill off and reduce stream bank vegetation, trees and the associated loss of species. This impact will be further magnified through methane gas migration away from the well into overlying formations.

As coal seam methane production progresses it is anticipated that the coal will effectively shrink or slump as the hydrostatic pressures are reduced through dewatering. This can result in land subsidence and is highly probable as the Wyong area is a declared coalmine subsidence zone.

The final recommendation to be drawn from this report is that strong scientific fact exists that coal seam methane production in the Yarramalong and Dooralong Valleys, at the scale being proposed by Sydney Gas Ltd, will result in an unacceptable level of social, economic and environmental impact.

A halt to mining is recommended and no further licences issued in the valleys to allow for a full and comprehensive environmental impact study that incorporates a geological, hydrogeological and geophysical investigation to expand on this study. A key requirement of such a study would be long-term water monitoring of between four to ten years to collect an appropriate level of time series groundwater data prior to any further mining licence assessment by government.

# TABLE OF CONTENTS

**SECTION** **PAGE**

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF APPENDICES

## 1. INTRODUCTION

This report presents the results of hydrogeological investigations conducted in the Dooralong and Yarramalong Valleys (study area), which form the headwaters and recharge zones for the central coast Wyong catchment. The study area covers an approximate area of 252 $km^2$ and is located within the Wyong Shire, approximately 100 km north of Sydney, midway between the Hawkesbury River and Lake Macquarie on the New South Wales central coast (Figure 1). Tim Jones was retained by the Australian Gas Alliance to undertake these hydrogeological investigations and provide an unbiased and independent study on the hydrogeology of the study area and relate the findings to the possible impacts caused through commercial methane gas production proposed by Sydney Gas Ltd (SGL).

The objectives of the programme were to:

- undertake a detailed hydrogeological characterisation of the Dooralong and Yarramalong Valleys which form the headwaters and recharge zones for a significant portion of the central coast Wyong catchments (Figure 2);
- undertake a detailed geological and geotechnical characterisation of the study area to identify groundwater migration pathways and geological effects from dewatering for coal seam methane production; and
- undertake a detailed environmental characterisation of the study area to obtain greater confidence in the prediction of potential environmental impacts associated with coal seam methane production.

## 2. SCOPE OF WORK

The scope of the investigation has been previously provided by Tim Jones in a letter to Mr Tony Davis (Australian Gas Alliance) dated 12 December 2004.

The main issues identified of environmental significance to this investigation are:

- Water residing in coal seams typically has a different chemistry and is of a poor quality to the overlying high quality shallower aquifers. Drilling and dewatering can allow for cross contamination and overhead leakage;
- dewatering the coal seams will cause overhead leakage through faults or fracture zones and can lower water tables significantly during periods of low flow or drought;
- percolation of methane into the overlying formations has the potential to impact on the aquatic ecosystem and riparian vegetation;
- land slumping or subsidence following coal shrinkage through gas production;

- disposal of waters pumped from the production wells, as it is of a low quality cannot be allowed to mix with streams or rivers, which form the central coast drinking water catchment; and
- impacts to other registered bores by lowering of water tables within the zone of influence of any production wells, and impacts on stream flows.

During the conceptual design phase of this investigation, it was found that very little information on groundwater conditions in the Wyong catchment and no groundwater studies have been completed in the study area. Although little had been done in relation to groundwater studies in the Wyong catchment, hydrology and geological studies have been completed for infrastructure e.g. roads, pipelines, water storage and treatment works. This information along with registered bore logs, pump tests, water quality analysis, stream gauge data and geophysical data was combined with a field study.

In summary, the programme requires:

- an assessment of the geological and hydrogeological conditions, requiring data collection and interpretation, review of available geological, geophysical and hydrogeological data;
- field environmental, geological and hydrogeological investigations, including site visit, water sampling and permeability testing;
- analysis of field results, groundwater analyses and refinement of the conceptual groundwater model; and
- reporting of investigations.

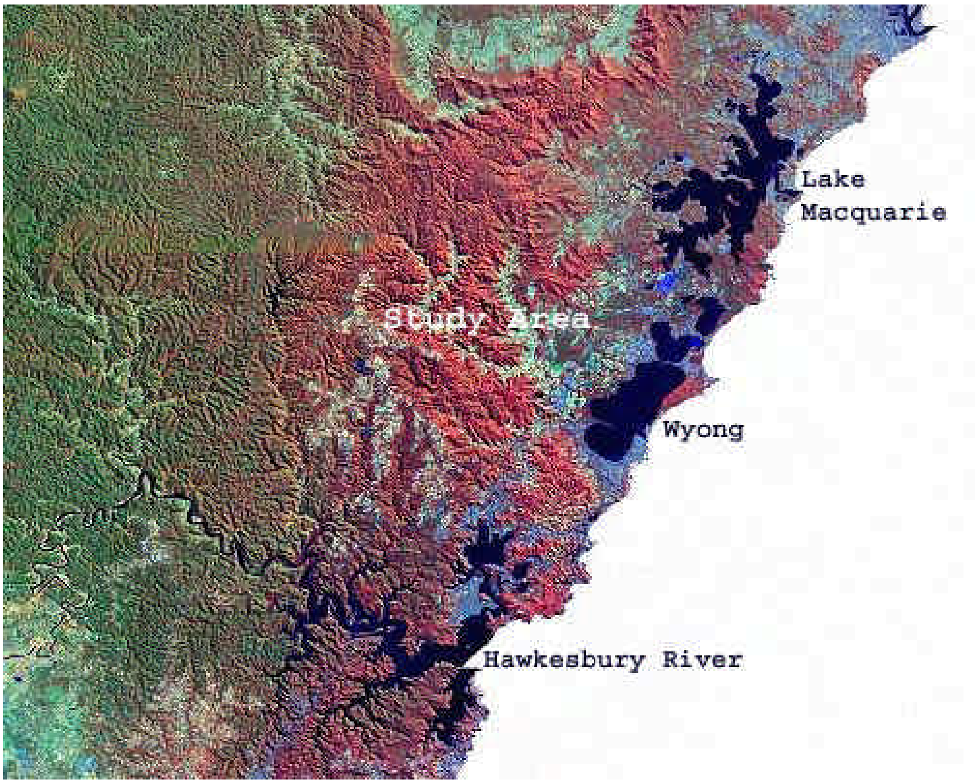


**Figure 1 – Location of Study Area**

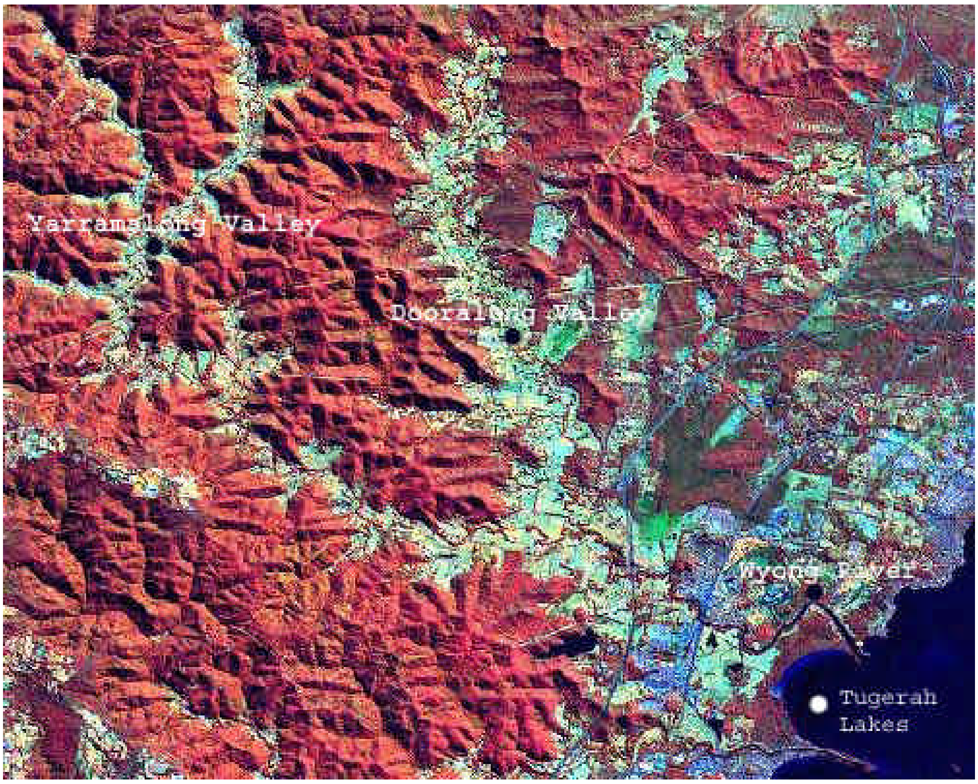


**Figure 2 – Location of Dooralong and Yarramalong Valleys**

Source: Landsat 7 satellite image (year 2000)

## 3. BACKGROUND

### 3.1 Methane Gas Production

Coal bed methane gas trapped in the coal seam is held in by hydrostatic (water) pressure. Lowering the hydrostatic pressure on the coal allows gas to flow from the lattice into the cleats and fractures in the coal. It then bubbles out of the water to be produced as methane gas at the surface. The hydrostatic pressure on the coal is lowered by pumping out water in the coal in a process called dewatering. Typically, the higher the permeability within the coal seams, the quicker the dewatering and the higher the expected gas flow rates after dewatering.

The amount of gas contained in the coal seams can be directly proportional to the depth of the seam whereupon deeper coal seams can contain more gas per tonne than shallower seams. If permeabilities are low, coal seams will take longer to dewater, may produce at lower rates and generally will require costly reservoir stimulation (eg. Fraccing to increase the gas flow out, and underreaming to increase the hole diameter gas can flow into).

Sydney Gas Ltd is an Australian energy company listed on the Australian Stock Exchange Ltd (ASX). Its ASX code is SGL. Operating under the Onshore Petroleum Act, Sydney Gas Ltd Wyong Project is a coal seam methane project, proposed over a wide area of operations. The company announced at the 2004 annual general meeting to shareholders it proposes to drill up to 200 production wells into the Dooralong and Yarramalong Valleys.

In mid 2004 Sydney Gas Ltd (SGL) drilled two production wells, Jilliby 1B (Figure 3) and Jilliby 2A (Figure 4) to assess the gas potential of the Wyong area. The wells are targeting the Great Northern Coal seam within the Upper Permian Newcastle Coal Measures at an approximate depth of 410 m – 417 m. Prior to production testing of these wells, SGL carried out hydraulic fracturing of the coal seams in an attempt to increase permeability.

At the time of this investigation the Jilliby 2A well was operating and dewatering the underlying coal seam at an approximate rate of 100,000 litres per week. The Jilliby 2A well is located in the Little Jilliby Creek gully 80 m from the creek line at and approximately 2 km upstream from Jilliby Creek. The Jilliby 1B is 50 m from Jilliby Creek.

**Figure 3 – SGL’s Jilliby 1B Methane Well**

Location: 33°15’26S / 151°23’10E

**Figure 4 – SGL’s Jilliby 2A Methane Well**

Location: 33°14’17S / 151°22’15E

### 3.2 Available Information

The following information is considered relevant to this study:

- preliminary geological and hydrogeological investigations
- borelogs, water levels and quality provided by NSW Government (GW Database)
- surface and groundwater chemical analysis provided by NSW University
- stream gauging station datasets provided by NSW Government (HITS Database)
- a geology plan provided by NSW Government (DLWC)
- geophysical aeromagnetic data provided by Geoscience Australia
- various published geological and hydrogeological plans and publications
- field study conducted by Tim Jones (2005).

### 3.3 Climate

The Wyong area falls within a warm temperate climatic zone, with a maritime influence near the coast. It experiences warm wet summers and cool dry winters. Rainfall generally peaks in late Summer and early Autumn, although local variations due to topography are evident. Annual average rainfall ranges from 1,207mm at Kulnura to 1,589mm in Olney State Forest. The long-term average annual rainfall in the catchment is approximately 1200 mm, March being the wettest month (140 mm) and August the driest (70 mm). Statistical data on evaporation for the years 1981 to 2002 were taken from (Clark, 2003). The total annual evaporation across this period was noted to vary between 1087 to 1462 mm.

During winter, the prevailing wind direction is from the south-west, whilst south-east winds prevail during spring and early summer. In late summer, north-easterly sea breezes prevail.

### 3.4 Regional Geology

The geology of the Sydney Basin is best described by Herbert, (1983). It is predominantly the result of sedimentation and phases of earth movements. The underlying structure of the Basin was laid down during the Permian and earlier geological periods under marine and marshy conditions which, with major earth movements, produced the sandstone and siltstone formations and intervening coal measures lying at considerable depths under Sydney.

The geological formations that outcrop in the study area are mainly Triassic sediments which were deposited in lakes in the unfolded parts of the geosyncline of the Sydney Basin that had developed by the end of the Permian. The first group of sediments, which is common in the study area, was the Narrabeen Group, which has a wide range of sediments. This was followed by the Hawkesbury Sandstone and lastly the Wianamatta Group containing shales, which were deposited in a series of isolated depressions. Since Triassic times the surface of the Sydney basin has been above sea level and consequently any further deposition of sediments have been terrestrial. During the Jurassic period the sediments of the Sydney Basin were intruded by small bodies of magma.

Erosion and transportation of tertiary freshwater sediments by drainages has lead to the deposition of valley-fill and superficial deposits which now cover much of the underlying strata. The tertiary deposits were typically a coarse gravely layer up to eight metres in thickness underlying silt and sand of an average depth of about six to ten metres. Subsequent weathering has turned much of the sandy silt into siliceous clay. At the close of the Tertiary period earth movements occurred which produced an uplift of 600 metres in a large area of eastern Australia.

These movements produced the Blue Mountains and Hornsby Plateaux, with the lagging behind of part of the peneplain becoming the Cumberland Plain. This movement produced the entrenching of existing rivers including the Hawkesbury-Nepean and the development of new rivers of which the Wyong is one.

The Quaternary period saw a rise in sea level of about 60 metres, which drowned the lower Hawkesbury River together with the great part of the eastern Australian coast. It is thought that the barrier lake systems of Tuggerah, Budgewoi, Munmorah and Macquarie were formed during this period, (see Figure 1).

The Quaternary deposits were formed by flood or wind and are well in evidence in the study area, and in the flood plain of the Hawkesbury River and its tributaries. These deposits consist of varying depths of estuarine and river sands and gravels, typically six to eight metres of gravel overlaid by about six metres of sandy silt.

### 3.5 Local Geology

Wyong Shire falls within the Hornsby Plateau subdivision of the Sydney Basin, and is comprised of consolidated sediments of the Triassic Hawkesbury and Narrabeen series. Hawkesbury sandstone outcrops along the Kulnura Plateau, while sediments from the Narrabeen sandstone series occur across the majority of the Shire. Extensive areas of unconsolidated alluvial soils also occur along major valleys and streams, and large deposits of Quaternary marine and aeolian sands occur along the coastline.

The dominant rock formation outcropping in the study area is Triassic age Hawkesbury Sandstone and Gosford Formation. The sandstone units are composed of mainly medium-coarse quartz grains bound by a secondary quartz-siderite cement with a clay matrix of variable proportion which unweathered can completely infill the intergranular pore space. Standard (1969) estimated an average clay matrix of 20% and considers that rock fragments made up about 2% of the sandstone based on a thorough study of the petrology of the Hawkesbury Sandstone throughout the outcrop area.

Both massive and strongly crossbedded units of individual thickness in the range of 1.5 to 3m are a common feature of the formation (Figure 5). Crossbedding, ripple marks and brecciated zones are all important structures in the sandstone of the area.

Several sets of high angle (near vertical) well developed joints are apparent in the area. These joint sets are parallel and perpendicular to the main regional fold axes, and are thus probably tensional features resulting from stress release after folding (Sherwin, 1986).

The sandstones have been subject to laterisation and the depth of weathering can be highly variable. Weathering effects vary from superficial colour changes due to the presence of siderite oxidation, with no measurable effects on rock strength or other physical properties to complete loss of strength and disaggregation to sand. The degree of weathering experienced at a particular location is controlled by a number of factors, including the degree of silicification of the original sandstone, unit thickness and joint development.

| **Figure 5 – Hawkesbury Sandstone** | **Figure 6 – Narrabeen Formation** |
|---|---|
|  |  |
| Source: SG Lane Collection/Australian Museum | Crushed and sheared Gosford Sandstone |

Enhanced water access is provided by zones of closely spaced, well developed jointing, leading to deeper weathering. Weathering can extend to depths of up to 30 m and may take the form of pronounced “weathering troughs” (Douglas, 1992).

Geophysical evidence and field mapping has identified areas of faults and fractures in both valleys. The resultant crush zones in the sandstone create transient pathways for vertical and horizontal movement of waters.

Figure 6 presents an example of a fault crush zone found in outcrop of the Gosford Sandstone in the Dooralong Valley. The feature has a strike 270$^{o}$ and dip 82$^{o}$ and can be traced across the valley. Features such as this represent conclusive evidence of transient migration pathways for vertical groundwater movement.

A simplified stratigraphy of the local geology is presented in Table 1.

**Table 1- Stratigraphy of the study area**

| Age | Unit | Group | Formation |
|---|---|---|---|
| Quaternary | Unconsolidated riverine alluvium | | |
| | Unconsolidated aeolian sands | | |
| | Unconsolidated marine sands | | |
| Triassic | Hawkesbury Sandstone | | |
| | Narrabeen Sandstone | Gosford sub-group | Terrigal Formation |
| | | Clifton sub-group | Patonga claystone |
| | | | Tuggerah Formation |
| | | | Munmorah Conglomerate |
| | | Undifferentiated sediments | |
| Permian | Illawarra Coal Measures | | Newcastle Coal Measures |
| | | | Tomago Coal Measures |

## 3.6 Physiography & Soils

Wyong Shire occupies approximately 82,700 hectares on the central coast of New South Wales, and occurs midway between the major metropolitan areas of Sydney and Newcastle.

The Shire lies within the Sydney Basin bioregion of Thackway and Cresswell (1995). It extends from Munmorah in the north, to Forresters Beach in the south, and from the Pacific Ocean west to Kulnura. Existing conservation reserves within this area include Munmorah SRA, parts of Lake Macquarie SRA and Wyrrabalong NP, together with sections of Olney, Ourimbah and Wyong State Forests, and Little Jilliby Creek and Bar Flora Reserves.

The study area is characterised by topography comprising two narrow lenticular valleys where no part terrain is far removed from a natural drainage channel in the adjacent terrain. Murphy, (1993) described the valleys as level to gently undulating dissected alluvial plain on Quaternary sediments derived from the Wattagan Mountains and Erina Hills. The principle surface stream in the Dooralong Valley is the Jilliby Creek and for the Yarramalong Valley the Wyong River. A series of steep strike ridges and deep gullies fringe the valleys that are considered groundwater recharge areas and form part of the Wyong catchment boundary. The highest point within the study area is Mount Yambo 264 m above sea level. Topographic gradients in the study area vary considerably from about 1 in 1 to 1 in 50.

Soil types relate to parent geological material and subsequent weathering. The soils derived from the sandstones are generally poor but the repeating ridge-slope-gully formations produce a number of types ranging from barely structured sandy soils on the ridges and steep slopes to deep, strongly structured sandy clays in the gullies. The rolling terrain of the lower valley areas with slopes rarely exceeding 20 per cent produces heavy textured podsolic soils on upper and mid slopes and yellow podsolics on lower slopes and flat drainage depressions. On the alluvials the soil type depends on the age of the sediment. The tertiary related soils cover a wide range from sand deposits to gravel, silt soils and, at their most developed, duplex soils with distinct clay subsoils. The soils on the younger alluvials range from sandy loams to clays and often show little structure.

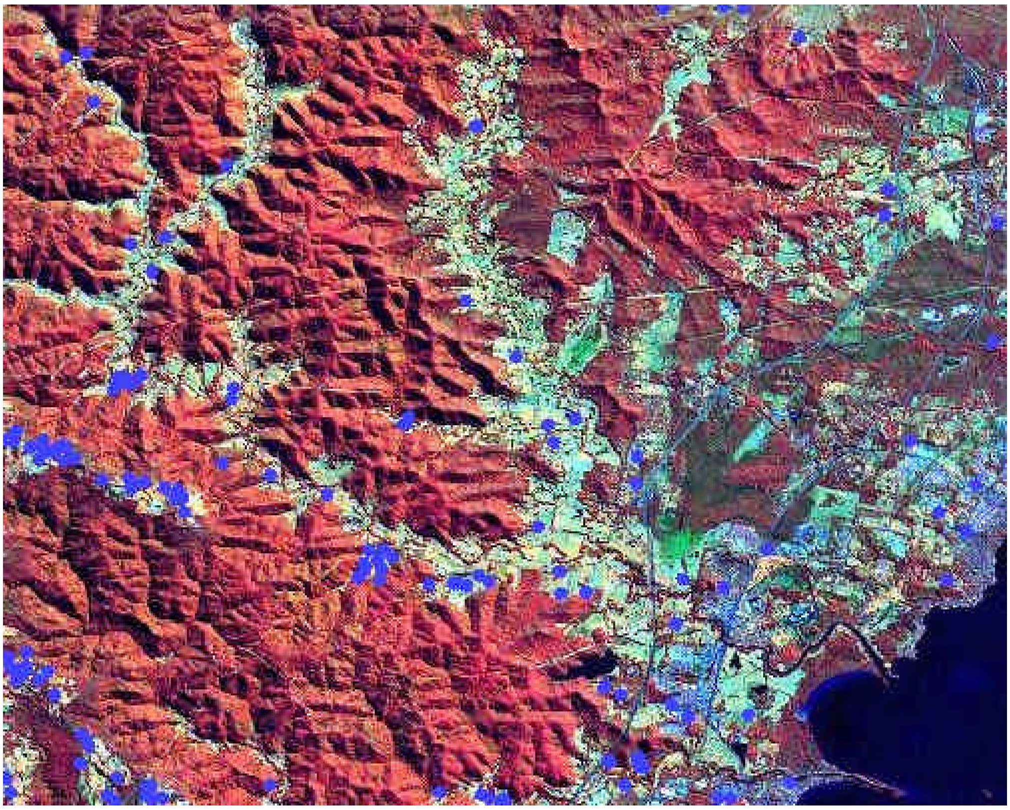
## 3.7 Hydrogeology

Geophysical and hydrogeological investigations have been completed in the study area. The geophysical study was undertaken to provide information on the subsurface conditions and any structures that may influence groundwater in the area.

The hydrogeological study comprised an assessment of 10 registered bores, lithological logs, groundwater sampling, water analysis and hydraulic parameter testing at 10 locations. This information provided for permeability and groundwater flow velocity studies. The basic findings were that the dewatering of the underlying coal seam at the scale proposed by Sydney Gas Ltd in the study area, will adversely impact on the local and regional groundwater regime.

Groundwater occurs in the study area throughout the geological profile. Data from Department of Infrastructure, Planning & Natural Resources groundwater database identifies there are approximately 52 registered groundwater bores in the Yarramalong and Dooralong Valleys. The locations of registered groundwater bores in the study area is presented in Figure 7.

**Figure 7 – Location of Registered Groundwater Bores**



Because shallow bores did not have to be registered prior to 1955, there could be others in the area, which are not listed because the Department of Infrastructure, Planning & Natural Resources do not know them.

Groundwater originates from direct rainfall recharge over outcropping rock units and from direct infiltration of rainfall and runoff. Groundwater gradients of the central and lower study area are low. During periods of very high rainfall, some locations with low hydraulic gradients saturate and form flood plain. Gradients of the upper reaches of the valleys are high. Groundwater velocity and permeability is high to moderate throughout.

Measurements made across the study area reveal a shallow groundwater zone between (2 m and 10 m) a weathered zone between (10 m and 30 m) a deeper sandstone zone and saturated conditions to the underlying Permian coal seams >400 m below the surface. The shallow aquifer zone is regarded as flowing towards the valley topographic lows and then generally in a south-easterly direction eventually discharging into the drainages of Jilliby Creek and Wyong River.

The deeper groundwater zone is assessed to flow in a south-easterly direction also. Groundwater yields can be high in large, well-connected fracture networks or low when occurring in tight, infilled or poorly connected joint systems. Registered bore drill logs show aquifer zones often exhibit features such as iron staining on drill cuttings, and may be identified by a sudden increase in air lift flow during drilling.

The deeper aquifer system is interpreted to provide important base-flow to the shallower overlying aquifer, a significant environmental flow to deep rooted vegetation and recharge mechanism for the downstream lakes district, the most important being Tuggerah lakes. The NSW State Government conducted an estuary management study (Wyong Shire 2004), which concluded that groundwater in the catchment provided important stream base-flow and was environmentally significant in Tuggerah lakes flushing.

The principle water transmitting capacity of the sandstones is dependent on the presence of secondary features such as faults, joints and bedding planes. Depending upon localised hydrogeological conditions in the study area the deeper aquifers may be activated in apparently confined, unconfined or intermediate conditions, and water levels measured in boreholes may reflect local conditions and may not give a true indication of regional hydraulic gradients. Generally, the groundwater flow is characterised by the local topography.

Rain falling on the grassed and sparsely vegetated portion of the study area is absorbed into the soil. In the days following heavy rain, water seeps from the soil into the top of the gullies surrounding the catchment. Discharge via the soil into the top of the gullies ceases after a few days. Discharge via a deeper groundwater path over a much slower time regime lower in the gullies ultimately forms the base flow of the Jilliby Creek and Wyong River. A rough comparison of the volumetric flow in the Wyong River and Jilliby Creek a few days after rain compared to base-flow shows groundwater discharge to be dominated by discharge from a thin upper moist soil-regolith layer.

The basic hydrogeological structure suggested from the investigation consists of:

a) a near surface soil and regolith layer, typically , 2 - 10 m;

b) a weathered sandstone layer of variable thickness and degree of weathering, <1 m - < 30 m;

c) unweathered sandstone, shale, conglomerate, tuff, chert layers, 30 m - < 400 m; and

d) Newcastle Coal Measures > 400 m

Drill logs from registered bores in the study area shows the degree of variability for these layers, both in their thickness and also their degree of definition. In places there is no clear distinction between these layers. This can result in an exaggerated pattern of hydraulic conductivity because of mineral aggregation or cementation by authigenic mineral growth for these layers.

Deeper standing water levels in the sandstone aquifer are measured on the valley fringes and highs with shallower water levels towards the valley lows and central drainage lines. Hydraulic conductivity has been measured for 10 bores in the shallow aquifer, 2 bores in the deeper weathered and unweathered aquifer. The shallower aquifer has a higher conductivity than the deeper aquifer, by 1-2 orders of magnitude.

Close to the Jilliby Creek and Wyong River, registered bores show the ground water levels fluctuate sympathetically with the level of water in the drainages. This sympathetic variation extends up to 100 m from the centre of the drainages into the weathered, jointed and faulted sandstone.

No saturated hydraulic conductivity measurements of the soil layer were attempted because of the expected wide range of values of the soils in the study area, unsaturated flow for most soils and the difficulty in relating laboratory or field measurements of a single point to a wider representative area. However, text book figures for saturated hydraulic conductivity in sandy soils show a likely range from $10^{-6}$ to $10^{-9}$ cm/sec and $10^{1}$ to $10^{-1}$ m/day.

A conceptual model of the study area hydrogeological structure is one in which a thin highly permeable soil layer absorbs rain. Most of this water then rapidly drains laterally to the topographic lows at the heads of the valleys. Rainwater can, in localised areas, flow downward due to the high hydraulic conductivity into the sandstone groundwater system.

Preferential groundwater flow paths along fractures and joints, also occurs within the upper sandstone layers. Geophysical imaging for the study area has detected many discontinuities, faults and discrete fractures in the underlying rock.

There is a significant case to be made for the occurrence and connection between shallow zones and deeper aquifers. A direct relationship between groundwater flow in fractures and groundwater flow in the porous sections of the sandstones can be made. Ultimately all groundwater in the study area is thought to discharge to either the Jilliby Creek, Wyong River or continue as base-flow to discharge into Tuggerah Lakes.

## 3.8 Hydrology

The study area is dominated by two main drainages. In the Dooralong Valley the Jilliby Creek drains south-eastward as a meander from the valley high around Lemon Tree eventually converging with the Wyong River approximately 14 km downstream. A major geological feature of the Jilliby Creek is that it follows a fault zone approximately 1.3 km west of Mount Alison. The drainage runs along the fault in almost a direct line to the south for approximately 1.5 kilometres from 151°23’20E / 33°14’10S to 151°23’20E / 33°14’30S. Midway along this feature the Little Jilliby Creek converges into Jilliby Creek. The whole of the Little Jilliby Creek gully is at right angles from the Jilliby Creek and is interpreted as a conjugate fault zone, which the Little Jilliby Creek has incised. Geophysics and air photo interpretation confirm this assumption. The significance of the feature is that it provides a significant transient pathway to groundwater movement and discharge into the surface stream flow regime.

The Jilliby 2A well is located in the Little Jilliby Creek gully 80 m from the creek line and approximately 2 km upstream from Jilliby Creek. At the time of this investigation the Jilliby 2A well was operating and dewatering the underlying coal seam at an approximate rate of 100,000 litres per week.

The upper Yarramalong Valley is dominated by Cedar Brush Creek which drains south-eastward from a valley high of 300 m above Kingtree Point. Cedar Brush Creek meanders approximately 6 km where it joins the Wyong River and flows, through the township of Yarramalong before turning eastward for 3 km and then meandering south-east and eastward where the Jilliby Creek converges approximately 9 km downstream.

The Wyong Shire pumps from the Wyong River at Woodburys Bridge Pumping Station to the Mardi Dam. The river contributes approximately 50% of the central coast drinking water supplies. The Gosford-Wyong Councils Water Supply Report states for the year 2001, the serviced population of 285,000 drinking water demand was 34,300 ML/a, with peak demands averaging 254 ML/d (Wyong Shire, 2004).

Both the Jilliby Creek and Wyong River flow continually with sharp flow responses following heavy rainfall events. The Department of Infrastructure, Planning & Natural Resources (2004) has stream gauging stations on Jilliby Creek at Wyong River (station 21101), and the Wyong River at Yarramalong (station 211014). Data from the stream flow (HITS) database was assessed in this study. Daily average recorded stream flows for both stations is presented in Figures 8 and 9 and Appendix A.

The average daily flow for Jilliby Creek for the period 1 January 2000 to 1 January 2005 is 34.15 ML/day with an average annual flow recorded as 12,481 ML/year. The average daily flow for the same period in the Wyong River is 46.0 ML/day with an average annual flow recorded as 17,045 ML/year. The combined average annual flow over a five-year period from the study area is recorded as 29,526 ML.

Both the Jilliby Creek and Wyong River trend line show a significant decline in average daily stream flow over the five-year period. The reasons for this are estimated to be a combination of evaporation losses, evapotranspiration, periods of low rainfall and groundwater abstractions for domestic and agricultural purposes.

The total average annual flow for the Wyong River at the pumping station to Mardi Dam is reported at 94,080 ML (Wyong Shire, 2004). An assessment of stream flow from the study area reveals that the Jilliby Creek and the upper reaches of the Wyong River contribute approximately 32% of the surface flow recorded downstream at the pumping station. A significant portion of downstream flow in the Wyong River, calculated at 64,554 ML per annum, derives from groundwater discharge into the river system between the gauges and the pumping station. The high number of springs, wetlands and variability in water quality confirms this assumption.

Permanent barrier lake systems exist to the east, being Tuggerah Lake, Lake Munmorah and Lake Macquarie. The Wyong River eventually flows into Tuggerah Lake at Tacoma. Environmental flows are the stream flows that are required to maintain natural stream conditions and these flows are thought to be essential for the health of instream biota. The Tuggerah Lakes estuary relies on inflows from its tributary rivers and creeks to provide freshwater input and brackish/freshwater habitat. It is thought that the instream ecology of the Wyong River is under stress from reduced flow and/or increased salinity. The salinity and electrical conductivity of the waters are important to aquatic organisms because many are stenohaline which means that they are tolerant only to small variations in salinity (NSW Gov 2003).

Figure 8 - Stream Flow Jilliby Creek Gauge 21101

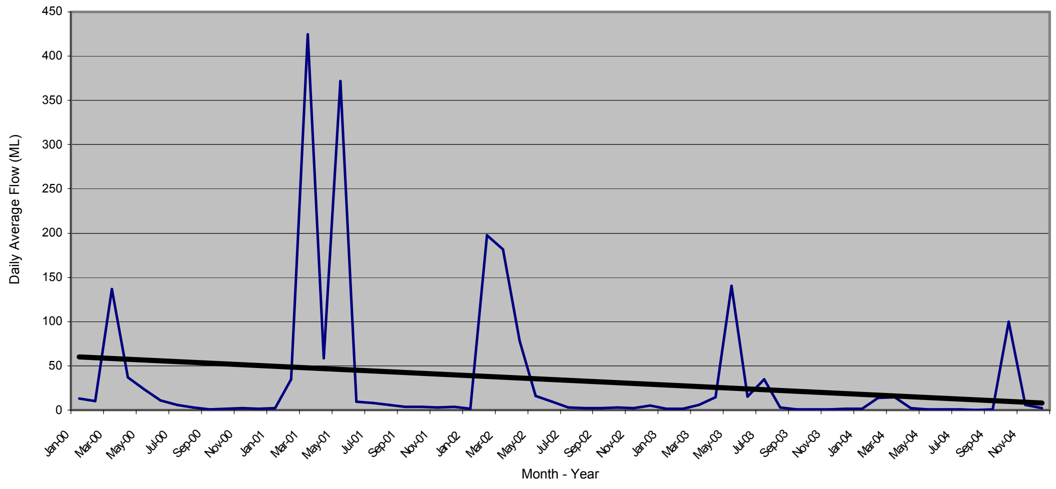
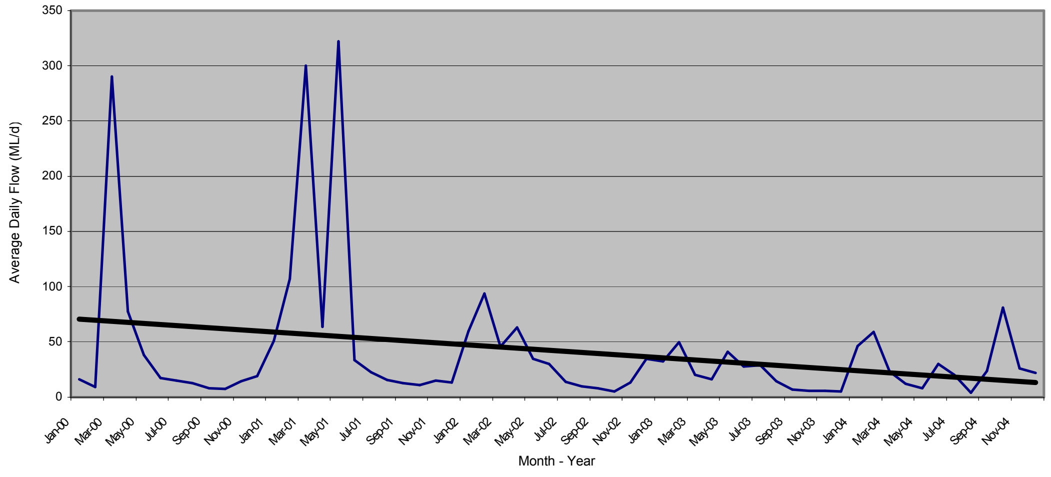


Figure 9 Stream Flow Wyong River @ Yarramalong Gauge 211014



## 4. FIELD INVESTIGATIONS

The objectives of the field investigations were to:

- confirm the geological and hydrogeological data including, mapping, sampling and data collection;
- assess available bores, map the groundwater profile, flow direction and water levels;
- conduct hydraulic testing; collect water samples; and

- refinement of the conceptual groundwater model

Field investigations were carried out over the period 4 to 7 January, 2005, conducted by Principal Hydrogeologist, Tim Jones.

Field investigations comprised the following:

i. collection of water samples and measurement of field hydrochemistry;

ii. field permeability testing;

iii. geological and hydrogeological mapping;

iv. assess registered bores; and

v. assess stream hydrology.

## 4.1 Field Hydrochemistry and Water Sampling

Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were recorded at various sites up stream and downstream of the exploration methane gas wells and in registered bores in the study area.

Groundwater samples were collected using a bailer from registered bores in the shallow and deep aquifer zones. A duplicate sample was also taken from each bore, field-filtered and analysed for major ions. Samples were taken from the Jilliby Creek and Wyong River up stream and downstream from the two Sydney Gas Ltd exploration methane wells and two samples were provided from each of the exploration gas wells. Each sample was kept under refrigeration until delivery to New South Wales University, Water Testing Laboratory. Table 2 presents the locations sampled in the study area

**Table 2 – Location of sample sites**

| Sample Number | Latitude (S) | Longitude (E) | Location | Description |
|---|---|---|---|---|
| 1 | 33°15’00 | 151°23’00 | Test location | bottled water calibrated sample |
| 2 | 33°15’26 | 151°23’10 | Jilliby 1 well* | deep bore water |
| 3 | 33°14’17 | 151°22’15 | Jilliby 2A well* | deep bore water |
| 4 | 33° 10’37 | 151°21’33 | Jilliby Creek | stream sample, Hitchcocks Lane |
| 5 | 33°13’13 | 151°22’31 | Dooralong Turf Farm | shallow bore water |
| 6 | 33°13’07 | 151°22’23 | Dooralong Turf Farm | stream sample over control weir |

| | | | | |
|---|---|---|---|---|
| 7 | 33°13’11 | 151°22’31 | Wyong River | stream sample, Kidmans Lane |
| 8 | 33°18’01 | 151°23’37 | Mardi Reservoir | surface sample, main dam wall |
| 9 | 33°16’42 | 151°23’58 | Wyong River | Mardi Rd pump station |
| 10 | 33°15’40 | 151°23’24 | Jilliby Creek | upstream confluence of Wyong River |

* Sydney Gas Ltd methane gas wells, Dooralong Valley.

## 4.2 Field Permeability Testing

The hydraulic conductivity and storage coefficient of the study area aquifers have been estimated by an assessment of pumping tests, granulometric analysis and slug tests. The slug test method requires that a known volume of water is added instantaneously to the bore and water levels are monitored at regular time intervals. The rate at which water levels in the bore recover to their original ‘static’ level provides an indication of the permeability of the materials being tested. As part of this study, slug-injection and slug-recovery test were carried out in 2 bores within the shallow alluvial and deeper sandstone aquifers to determine hydraulic conductivities of these aquifers.

The hydraulic conductivities derived from pumping tests and the granulometric analysis are generally an order higher than the values determined using slug tests. Results of pumping tests may be more accurate as the tests are performed over a much longer period of time and as a result the pumping bore is more developed. Pump tests completed by C.O.A.L Australia on seams of the Newcastle Coal Measures estimated a storage co-efficient for the coal where confined was generally in the order of $10^{-3}$ to $10^{-4}$.

Hydraulic conductivity of the deeper sandstone aquifer has been derived using a groundwater flow rate of 0.5 m/year, is about 0.25 m/d, and is similar to the hydraulic conductivity estimated from slug tests.

The hydraulic conductivity is more likely to progressively decrease with depth due to compaction and consolidation of sediments and increase in zones of fracturing and faulting.

Table 3 presents a summary of aquifer parameters identified in this study.

**Table 3. Summary of Aquifer Parameters**

| **Aquifer** | **Pump Tests** | | **Grain size Distribution** | **Slug Tests** |
|---|---|---|---|---|
| | **Hydraulic Conductivity (m/day)** | **Storage Co-efficient** | **Hydraulic Conductivity (m/day)** | **Hydraulic Conductivity (m/day)** |

| | | | | |
|---|---|---|---|---|
| Shallow<br>0 - 30 m | 4.0 | - | 1.0 | 0.24 |
| Weathered Sandstone<br>30 - 100 m | 2.8 | $4 \times 10^{-4}$ | - | 0.28 |
| Sandstone<br>100 m - < 400 | 2.0 | $2 \times 10^{-3}$ | - | 0.15 |
| Coal > 400 | 0.6 | $3 \times 10^{-4}$ | - | 0.49 |

## 4.3 Geological Mapping

The New England Fold Belt was the dominant source of sediment for the Sydney Basin throughout the Permian. Deformation and uplift of the New England Fold Belt in the Early

Permian led to the transformation of the Sydney Basin into a foreland basin. The large volume of sediments eroding from the topographically active New England Fold Belt led to a prolonged regressive sequence of deposition forming the Newcastle Coal Measures.

An attempt was made in this investigation to delineate many of the geological structures present in the study area. Geological mapping was conducted at rock outcrops in the study area, through bore lithological logs and from stratigraphic hole drill logs. This information was cross-referenced to the 1:250,000, 1:100,000 Geological map series, geophysical data and air photos to confirm the regional and localised structure which includes known faults and fracture zones. A series of major folds, thrust and fault zones exist in the study and have been widely mapped by Geoscience Australia, Figure 10.

A series of deformation events added structural complexity to the Newcastle Coal Measures. These include:

- propagation of thrust faults during the Middle Triassic;
- intrusion of sills and dykes in the Mid-Cretaceous;
- uplift and joint formation in the Late Cretaceous; and
- major volcanic activity during the Tertiary.

**Figure 10 - Regional Geological Structures** **Figure 11 - Great Northern Coal Seam exposed**

Source: Geoscience Australia

Great Northern Coal Seam Exposed in Cliffs at Catherine Hill Bay

Source: Wyong Coal Joint Venture, C.O.A.L.

Relevant to this investigation is the Newcastle Coal Measures, Great Northern coal seam (Figure 11) as that is the target seam penetrated by Sydney Gas Ltd, at Jilliby 1A and 2B wells for methane exploration.

The seam is a high volatile low sulphur medium ash thermal coal, which is used for power generation. The seam is actively mined by Wyong Coal Joint Venture, using longwall mining techniques. The seam is exposed at the coastal fringe forming cliffs at Catherine Hill Bay to the north-east of the study area.

Major fault and fracture zones are evident in drill logs and in seismic surveys completed by Wyong Coal on the seam. Widespread regional faults, thrusts and folds have been mapped by Shepard & Huntington (1981) Geological Survey of New South Wales and others.

Faulting, fracturing and tectonic uplift has resulted in the Great Northern coal seam thickness varying from 0 m – 40 m. In Figure 11 the seam is seen lying beneath the sandstones of the Gosford and Hawkesbury Formations. A major $45^0$ fault separates the sandstone rock units providing evidence that major gas and fluid migration pathways are present.

## 5. RESULTS

### 5.1 Hydrogeological Conditions in the Study Area

Groundwater inflow is mainly from direct infiltration of rainfall and recharge from streams where the watertable is below streambed elevation. Groundwater outflow is from discharge to streams, evapotranspiration from the watertable in areas where the water table is shallow, and groundwater abstraction.

A thick sequence of deeply weathered, gravels alluvial scree, residual clay and sandy soils is encountered in the study area to a depth of approximately 10 – 20 metres overlying fractured and faulted weathered and fresh sandstones of the Hawkesbury and Gosford Formations to a depth of 400 m. A thin lens of shale and silt are recorded in some lithological logs to overlay coal of the Newcastle coal measures, in areas found 400 m below the surface.

Groundwater is encountered throughout the geological profile and provides base flow to the Jilliby Creek and Wyong River. Groundwater recharge by direct infiltration of rainfall as estimated by chloride mass balance is 12%; and by groundwater modelling as 10%. The groundwater flow direction in the near surface aquifer is generally south-east and estimated at 184 $m^3$/day. Standing water levels range from 2 – 3 m to 20 m below ground level with an estimated aquifer saturated thickness of 30m. The hydraulic gradient is estimated to be approximately $1.53 \times 10^{-3}$ m/m. The groundwater of the study area provides a significant portion of the down gradient surface water flow where it discharges into the Wyong River below the stream gauges at Wyong River, Yarramalong and Jilliby Creek upstream of Wyong River. The net groundwater contribution to the surface water supply at the Wyong River pumping station is estimated at approximately 64,554 ML/a or 68% of total annual flow.

Water levels were cross checked with water levels from the NSW Government Department of Infrastructure, Planning & Natural Resources groundwater database.

An assessment of the gradient was completed on the shallow aquifer in the Dooralong Valley, estimated to be $1.53 \times 10^{-3}$ m/m. This was based on a piezometric surface elevation of RL 225m at the valley high and an assumed elevation of about RL 200m on the valley floor.

The cross sectional area is based on an average aquifer thickness of 30m and an average width of the valley of 1km. An estimate of discharge and recharge was made using the Darcy Equation.

$$Q = KiA \text{ m3 / day}$$

Where:
$Q$ = groundwater flow and discharge ($m^3$/day)
$K$ = hydraulic conductivity of the aquifer (4.0 m/day)
$i$ = hydraulic gradient of piezometric surface ($1.53 \times 10^{-3}$)
A = cross sectional area of aquifer across basin (30,000$m^2$)

$$Q = 4.0 \times 1.53 \times 10^{-3} \times 30 \times 1000 \text{m}^3\text{/day}$$
$$= 184 \text{ m}^3\text{/day}$$

## 5.2 Hydrogeochemistry

The results of the groundwater laboratory analyses are summarised in Table 2, with analysis reports presented in Appendix B. The groundwater from the methane exploration wells is of a Calcium/Magnesium Sulphate and Sodium Chloride type. Heavy metals (detection limits in brackets), Arsenic (0.005 mg/L), Cadmium (0.0001 mg/L), Chromium (0.05 mg/L), Copper

(0.017 mg/L), Aluminium (0.218 mg/L), Magnesium (2.95 mg/L) and Mercury (0.0006 mg/L), were detected in the analyses undertaken.

Total dissolved solids (TDS) for each of the SGL methane wells water samples exceeds the Australian Drinking Water Guideline value of 1,000 mg/L (ANZECC, 1996). The results ranged from 3,976 Mg/L to 5,452 Mg/L. In comparison TDS from Jilliby Creek, Wyong River and bores ranged from 212 Mg/L to 768 Mg/L.

Groundwater from the methane wells was highly alkaline with a pH ranging from 8.7 to 9.1, which was outside the guideline standard of 6.5 to 8.5. Analytes such as Iodide, Aluminium, Barium and Chloride far exceed allowable standards resulting in the waters being extracted from the methane wells considered toxic. Under no circumstance should this water be allowed to mix with surface water of Jilliby Creek or Wyong River.

## TABLE 4: Groundwater Chemistry Data

| **Analyte** | **Guideline Value** | 1- Test sample | **2- Jilliby 1A well** | **3- Jilliby 2A well** | 4- Jilliby Creek | 5- Jilliby Ck Hitchcock Lane | 6- Dooralong Turf Farm weir | 7- Mardi Reservoir | 8- Dooralong Turf Farm deep bore | 9- Wyong River Mardi Road Pump | 10- Yarramalong Wyong river |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 6.5 – 8.5 pH units | 6.0 | **9.1** | **8.7** | 7.8 | 5.4 | 6.6 | 6.9 | 7.2 | 4.6 | 4.4 |
| Total Dissolved Solids | 500 mg/L | 370 | **3976** | **5452** | 310 | 364 | 275 | 141 | 768 | 254 | 212 |
| Total Iron | 0.30 mg/L | <0.30 | <0.30 | <0.30 | 0.360 | 5.62 | 4.41 | 0.711 | 0.101 | 3.45 | 3.68 |
| Sodium | 180 mg/L | 13.8 | **1646** | **2232** | 61.9 | 53.9 | 46.2 | 25.8 | 216 | 30.5 | 23.4 |
| Magnesium | 150 mg/L | 3.09 | 2.95 | 4.63 | 13.4 | 11.7 | 11.5 | 5.85 | 13.9 | 6.87 | 6.15 |
| Chloride | 250 mg/L | <20.0 | **590** | **590** | 350 | 115 | 90.0 | 55.0 | 330 | 55.0 | 30.0 |
| Barium | 0.70 mg/L | 0.077 | **1.58** | **3.30** | 0.164 | 0.434 | 0.094 | 0.056 | 0.122 | 0.240 | 0.256 |
| Aluminium | 0.20 mg/L | 0.057 | **0.218** | 0.044 | 0.008 | 0.089 | 0.049 | 0.042 | 0.005 | 0.060 | 0.176 |
| Iodide | 0.10 mg/L | 0.017 | **0.689** | **1.27** | 0.042 | 0.034 | 0.034 | 0.026 | 0.065 | 0.026 | 0.017 |
| Boron | 0.30 mg/L | 0.018 | 0.242 | 0.301 | 0.081 | 0.133 | 0.083 | 0.045 | 0.049 | 0.091 | 0.087 |
| Calcium | 80 mg/L | 1.56 | 4.91 | 8.08 | 7.01 | 6.46 | 6.64 | 3.88 | 28.9 | 4.77 | 7.07 |
| Ammonia | 0.50 mg/L | 2.0 | <0.50 | <0.50 | <0.50 | <0.50 | 2.0 | 0.50 | <0.50 | <0.50 | <0.50 |
| Nitrate | 1.50 mg/L | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 | <5.00 |
| Fluoride | 1.50 mg/L | 0.005 | **2.98** | **2.91** | 0.058 | 0.021 | 0.033 | 0.050 | 0.100 | 0.005 | 0.005 |
| Silver | 0.10 mg/L | 0.057 | 0.002 | 0.003 | 0.008 | 0.010 | 0.011 | 0.005 | 0.008 | 0.003 | 0.009 |
| Chromium | 0.05 mg/L | 0.006 | 0.005 | 0.009 | 0.002 | 0.002 | 0.002 | 0.0007 | 0.004 | 0.002 | 0.011 |
| Copper | 2.0 mg/L | 0.030 | 0.017 | 0.084 | 0.013 | 0.004 | 0.022 | 0.004 | 0.008 | 0.014 | 0.100 |
| Lead | 0.01 mg/L | 0.004 | 0.0005 | 0.0002 | 0.003 | 0.003 | 0.002 | 0.0004 | 0.025 | 0.004 | 0.0001 |
| Nickel | 0.02 mg/L | 0.002 | 0.001 | 0.003 | 0.002 | 0.003 | 0.003 | 0.001 | 0.003 | 0.004 | 0.003 |
| Zinc | 3.0 mg/L | 0.090 | 0.147 | 0.013 | 0.034 | 0.080 | 0.022 | 0.017 | 0.644 | 0.135 | 0.100 |
| Mercury | 0.001 mg/L | 0.0003 | 0.0003 | 0.0001 | 0.0006 | 0.0003 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |

Samples analysed by New South Wales University Chemical Laboratory.

## 5.3 Sydney Gas Ltd Production Concerns

The impact of methane production in the study area and groundwater abstraction from them has been assessed. Jilliby 1B was not operational at the time of this investigation and thought to be flooded. Jilliby 2A was operational and assessed. The initial volume of water taken during dewatering by SGL is not known. Dewatering during methane production at Jilliby 2A was estimated by the discharge into the holding tank on site, and by the removal of water by tankers. SGL remove off-site approximately 100,000 litres a week, by articulated tanker truck, to a disposal facility 2 ½ hours away at Windsor. Trucking water off-site is done because the chemistry of the water is considered toxic and cannot be allowed to enter the natural flow system. The volume extracted equates to approximately 5.2 ML/y being removed at that rate.

SGL has announced at their 2004 AGM it proposes 200 wells for the area, which calculates to an equivalent volume dewatered from the proposed operation at 1040 ML/y. This figure can vary significantly in highly transmissive areas and it does not include initial dewatering volumes.

A simple calculation is to multiply the tanker movements of water per well a week, (approximately 3 X 30,000 liter tankers) by the number of proposed wells (200) = 600. Multiply that by 52 weeks a year = 4,200 tanker movements. The road and bridge infrastructure of the study area does not exist to handle such a load. Such a large volume of tanker movement along one lane roads with blind corners, school zones and single lane light load bridges, should be considered a risk to public safety.

Once coal bed gas is liberated by the withdrawal of water reducing the hydrostatic head, the methane is free to migrate. Geological structures, Inadequately cemented conventional gas wells and extraction of produced water from coal bed methane wells can contribute to natural gas resource losses and to methane migration into surface soils and groundwater.

As methane production progresses, seeps can find there way into domestic water wells, or the presence of gas seeps in pastures, manifested by dead vegetation.

Anoxic environments created in near-surface regimes by a predominance of methane support bacterial generation of hydrogen sulphide gas and promote plant suffocation by precluding soil oxygen. Methane from soil gas vapours can accumulate in confined spaces, such as beneath domestic dwellings, and may pose potential explosion hazards. Escalations in hydrogen sulphide gas will result in seep sites identified by stands of stressed and dying vegetation, trees and habitat.

## 6. DISCUSSION AND CONCLUSIONS

The investigation has shown that the water table is approximately 2 m to 20 m below the ground surface in the study area.

Groundwater was mostly encountered within alluvial soils, highly weathered fractured sandstone, sandstone and coal. Permeable features include porous or vesicular zones, weathered zones and fractures, at least some of which may reasonably be inferred to be continuous over long distances and are probably interconnected with other cross cutting structures.

The groundwater quality at the surface and in streams is high and of potable quality. Groundwater at lower depths below 100 m is brackish and unsuitable for human consumption. Groundwater movement is towards the south-east towards the coast. Although this brackish groundwater is presumed to discharge from the fractured rocks into the potable aquifer system, it does not apparently impair the potable quality of groundwater in the area.

Groundwater modelling has shown that overhead groundwater leakage will occur in the study area during Sydney Gas Ltd dewatering operations and closure. The rate of leakage is, however, unknown and likely to be high in areas of geological features such as faults and fractures. A significant amount of groundwater through flow, estimated as high as 68% is evident from the stream flow gauging data for the Wyong River.

Geological considerations and the significantly higher permeability of overlying sandstone formations both support the expectation that there may be some preferential pathways for groundwater. Some higher velocity seepage pathways exist, where flow rates locally exceed those predicted by modelling (which used “average” properties and could not readily simulate extreme heterogeneity). These preferential pathways may be significantly enhanced by attempts to hydraulically fracture (frac) coal seams in a bid to boost methane production. The volumetric rate of flow along any such preferential flow paths is expected to be problematic to the dewatering of coal for methane gas production.

Dewatering of coal seams will allow for groundwater migration towards coal seam voids. This has a significant potential to effectively dewater sections of the study area. Dewatering of the coal seams will adversely effect the groundwater system and will have a flow on effect of reduced or lost stream flow. The Jilliby Creek and Wyong River have experienced a rapid decline over the last five years in annual daily stream flow. This has probably been caused by drought, climate change and demands by the growing urban population of the central coast. Any further impact to stream flow caused by mining operations has the potential to cause significant impacts to the availability of potable water to the central coast population as an estimated 50% is supplied from the study area.

Riparian vegetation and wetlands are at risk by a lowering of groundwater levels and methane migration into the overlying aquifers during gas production. Regardless of well construction geological features provide transient pathways. The Jilliby Creek has been named by the NSW Government as one of the most pristine systems in the State.

There is a risk of contamination by low quality water mixing with high quality surface aquifers and that discharging into streams. The extent of this is unknown and further study is required.

## 7. RECOMMENDATIONS

The final recommendations to be drawn from this report is that strong scientific fact exists that coal seam methane production in the Yarramalong and Dooralong Valleys, at the scale being proposed by Sydney Gas Ltd, will result in an unacceptable level of social, economic and environmental impact.

A halt to all exploration and/or mining is recommended and no further licences issued in the valleys to allow for a full and comprehensive environmental impact study that incorporates a geological, hydrogeological and geophysical investigation to expand on this study.

A key requirement of such a study would be long-term water monitoring of between four to ten years to collect an appropriate level of time series groundwater data prior to any further mining licence assessment by government.

An assessment should be made into ability of the existing road and bridge infrastructure to cope with the estimated water tanker movements in the study area and the associated risk to public safety.

I would be pleased to answer any questions about this important information.

**TIM JONES (MSc) AIEH**

Tim Jones
Principal Hydrogeologist

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# Appendix A

## Average Daily Stream Flow
## Jilliby Creek
## Wyong River

# Appendix B

# Water Quality Analysis Report