Camden Gas Project
Proposed Expansion of Stage 2

Report

on

The Potential for
Coal Seam Methane Gas Extraction
to result in Subsidence at the Surface

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Executive Summary

AGL Gas Production (Camden) Pty Limited (AGL) intends to apply for approval under Part 3A of the *Environmental Planning & Assessment Act 1979* (EP&A Act) to expand the Camden Gas Project through the development of additional well fields, including wells and supporting infrastructure.

The Concept Plan for the extension of Stage 2 of the Camden Gas Project extends from the suburbs of Narellan and Currans Hill in the north, to south of Menangle, extending across to Glen Alpine and Ambervale in the east, and Camden in the west. The Stage 2 Concept Application Area is shown in Figure 1, in Appendix C.

In addition, concurrent Project approval will be sought for the development of new well fields in Spring Farm and Menangle Park involving the development of well surface locations, gas gathering lines and access roads.

Four new well surface locations are proposed within the Spring Farm Project Area and twelve new well surface locations are proposed within the Menangle Park Project Area as shown in Figures 2 and 3, in Appendix C.

The proposed well surface locations will comprise a mix of vertical, directional and horizontal Surface to In-Seam (SIS) well heads. The wells will initially target coal seam methane in the Bulli Seam, though additional gas resources are believed to exist in the subsequent lower formations.

An Environmental Assessment Scoping Report (EASR) has already been submitted to the Department of Planning for review. The EASR is the first step in the application process and as part of this process a number of consultations have been held to canvass the views of stakeholders and the general public.

During the early consultations with members of the general public, a number of issues were raised including the potential for subsidence to occur at the surface as a result of coal seam methane extraction below ground.

AGL therefore commissioned Mine Subsidence Engineering Consultants Pty Ltd (MSEC), in February 2007, to study the proposals for coal seam methane extraction in the Camden area and to consider the potential for the coal seam methane extraction to result in subsidence at the surface. This report was prepared on completion of that study.

Chapter 2 of this report has addressed the methods of extraction that are proposed in the Spring Farm and Menangle Park areas. Sixteen new well surface locations are proposed (each comprising up to 6 individual wells), which will involve the drilling of boreholes up to 180 mm diameter from the surface into the coal seam or seams. The subterranean spacing of the bores will generally be more than 350 metres. Some of the vertical bores may be reamed out to 2 metres diameter within the seam. Other bores will use hydraulic fracturing techniques to facilitate the extraction of the gas.

Chapter 3 of this report has addressed the major causes of surface subsidence and has indicated that there are a number of activities and mechanisms that can cause subsidence. These have been provided to illustrate the general conditions that are necessary for subsidence to occur. Surface subsidence will not occur unless:

- Large voids are created in the strata by the mining or extractive activity, leading to subsequent collapse, consolidation and subsidence of the overlying strata.
- Large voids are created in the strata by the mining or extractive activity, leading to subsequent failure of remnant pillars and subsidence of the overlying strata.
- Unconsolidated beds of strata are present, which can subsequently be consolidated by the weight of the overburden, following the removal of interstitial fluids.

The proposed extraction of coal seam methane at Camden will not create large voids in the strata, nor leave remnant pillars. The strata within the coal measures are not unconsolidated and in fact are hard and well consolidated rocks. The conditions for significant subsidence to occur are not therefore present and it is concluded that the potential for subsidence to occur as the gas is extracted is almost negligible.

When coal waste gas is extracted by coal mining companies prior to mining, this is achieved by drilling horizontal gas drainage bores into the coal seam from the adjacent development headings, or roadways underground. The bores are generally 90 mm diameter and are drilled at very close centres. This is a much more invasive method than the method of gas extraction proposed within the Camden Gas Project and results in the creation of a considerably greater number of voids in the coal seam. It does not, however, result in any measurable subsidence at the surface, which provides further support to the above conclusion.

According to Gray, 1986, coal has been shown to shrink on desorption of gas and to expand again on resorption. It is possible therefore that there could be some shrinkage of the coal seam due to the extraction of the methane, but any shrinkage would be a matter of a few millimetres. Any subsidence that might occur at the surface, due to shrinkage of the coal seam, would, therefore, be negligible.

Contents

Chapter 1 Background

1.1 Coal Seam Methane Gas

Coal Seam Methane (CSM) is a natural gas, which was formed as a by-product during the process by which organic matter was turned into coal. The Sydney Basin, covering Sydney, Wollongong and Newcastle, holds vast coal resources and, therefore, very large amounts of CSM. The exploration for CSM resources and the subsequent extraction of the resources are controlled by the Department of Primary Industries, by the issue of exploration licences and production leases under the Petroleum (Onshore) Act, 1991.

1.2 The AGL and Sydney Gas Joint Venture

In November 2005, AGL entered into a joint venture agreement with Sydney Gas Limited (SGL) to participate in the development and production of coal seam methane gas.

The joint venture holds Petroleum Exploration Licences (PELs) 2, 4, 5 and 267 stretching from the Upper Hunter to the Southern Highlands of NSW. The joint venture also holds Petroleum Production Leases (PPLs) 1, 2, 4 and 5 in the Camden and Campbelltown area.

The boundaries of the PELs and PPLs are shown in Figure 1.1, below.

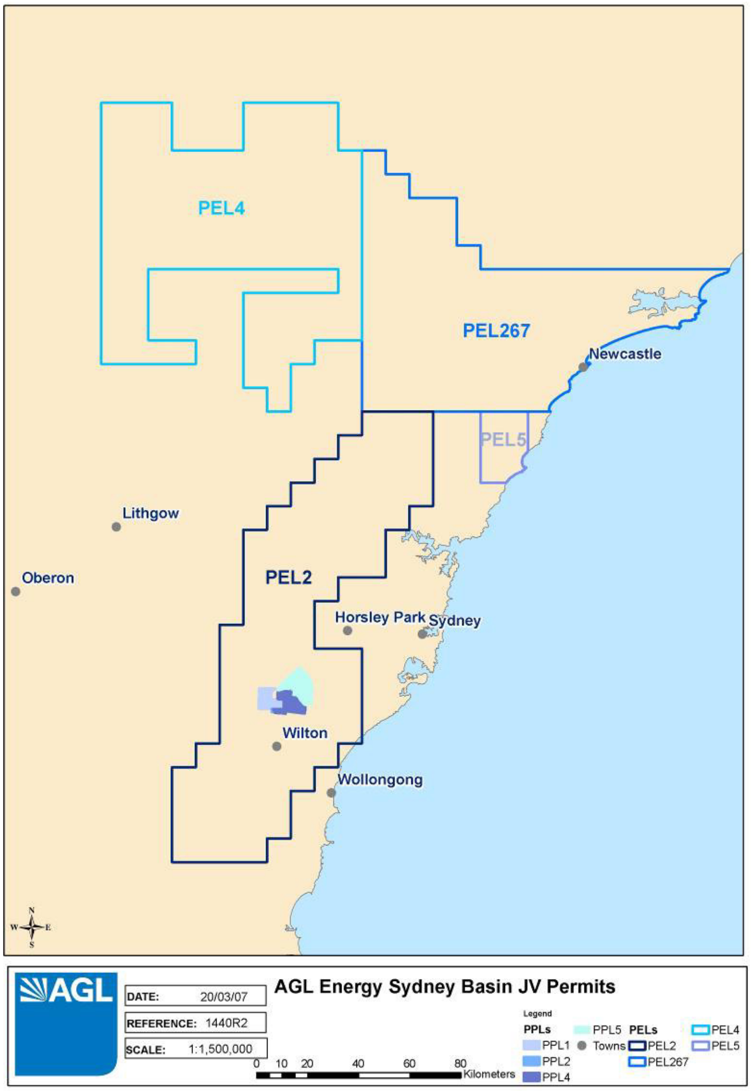

Figure 1.1 Petroleum Exploration Licence Areas in NSW

1.3 The Camden Gas Project

The Camden Gas Project is located 65 km southwest of Sydney, as shown in Figure 1.1, and involves the exploration for gas under Petroleum Exploration Licence 2 (PEL 2) and the production of gas from Petroleum Production Leases (PPLs) 1, 2, 4 and 5.

The project is a joint venture between AGL and Sydney Gas (Camden) Operations Pty Limited (SGL). SGL is responsible for the exploration component of the joint venture, while AGL is responsible for the development and production of the gas assets.

The Project currently consists of approximately 80 wells and the Rosalind Park Gas Plant south of Campbelltown where the gas is treated and compressed before it is sold into the Moomba – Sydney gas pipeline.

1.4 Proposed Expansion of Stage 2 of the Camden Gas Project

AGL has applied for Concept approval under Part 3A of the EP&A Act for the development of additional well fields, including wells and supporting infrastructure, as an expansion of Stage 2 of the Camden Gas Project.

In addition, concurrent Project approval will be sought for the development of new well fields in Spring Farm and Menangle Park involving the development of well surface locations, gas gathering lines and access roads.

An Environmental Assessment Scoping Report (EASR) was submitted to the Department of Planning in October 2006 for review. The EASR is the first step in the application process and as part of this process a number of consultations have been held to canvass the views of stakeholders and the general public.

1.5 Stage 2 Concept Approval

The concept plan, for the extension of Stage 2 of the Camden Gas Project extends from the suburbs of Narellan and Currans Hill in the north, to south of Menangle, extending across to Glen Alpine and Ambervale in the east, and Camden in the west. The Concept Plan area includes the proposed new well fields identified as Spring Farm, Menangle Park, Mount Gilead and Kay Park Stage II (see Figure 1 in Appendix C).

1.6 Spring Farm and Menangle Park Project Approval

Concurrent Project approval is also being sought at this stage for the construction of wells and the installation of gas gathering lines within the Spring Farm and Menangle Park well fields.

The area known as Spring Farm is located within the Camden LGA, approximately 65 km south west of Sydney, to the north of the existing well fields of Glenlee and EMAI Stages I and 2 (see Figure 1 in Appendix C). Up to four new well surface locations are proposed within the Spring Farm Project Area, as shown in Figure 2, in Appendix C.

The Menangle Park area falls within the Campbelltown LGA. The land is situated south of the proposed Spring Farm Project Area and is surrounded by the existing well fields of EMAI Stage 1, Menangle Park Stage 1, Glenlee, Sugarloaf Farm and Rosalind Park as shown in Figure 1, in Appendix C. Up to twelve new surface well locations are proposed within the Menangle Park Project Area, as shown in Figure 3, in Appendix C.

Each well surface location may contain up to six wells depending upon resources and environmental constraints. The proposed well surface locations will comprise a mix of vertical, directional and horizontal surface to inseam (SIS) well heads. The wells will initially target coal seam methane in the Bulli Seam, though additional gas resources are believed to exist in the subsequent lower formations.

1.7 The Geological Setting

Camden lies in the Southern Coalfield, which is located in the southern part of the Permo-Triassic Sydney Basin, within which the main coal bearing sequence is the Illawarra Coal Measures, of Late Permian age. The Illawarra Coal Measures contain a number of workable seams throughout the area, the uppermost of which is the Bulli Seam, which contains valuable coking coal resources and reserves of coal seam methane gas. Below the Bulli Seam are the Balgownie, Wongawilli, American Creek, Tongarra and Woonona Seams, which are also believed to contain reserves of coal seam methane resources. A typical stratigraphic section for the Southern Coalfield is shown in Figure 1.2.

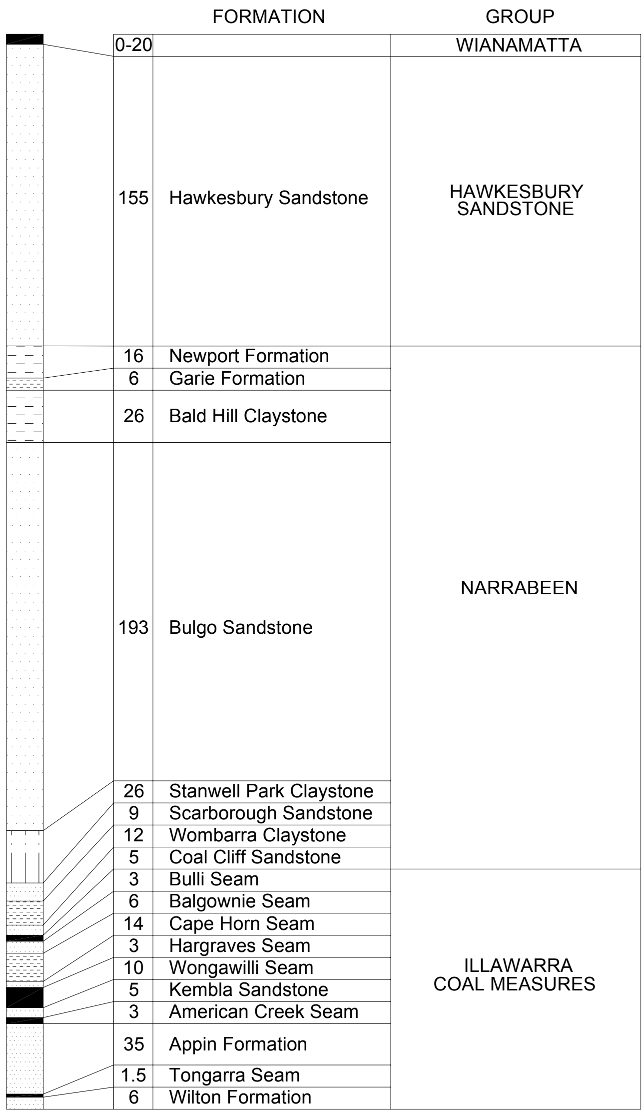

Figure 1.2 Typical Stratigraphic Section – Southern Coalfield

All of the sediments that form the overburden to the Bulli Seam belong to the Hawkesbury Tectonic Stage, which comprises three stratigraphic divisions. The lowest division is the Narrabeen Group, which is subdivided into a series of interbedded sandstone and claystone units. It ranges in age from Lower to Middle Triassic and varies in thickness up to 450 metres.

Overlying the Narrabeen Group is the Hawkesbury Sandstone Group, which is a series of bedded sandstone units which dates from the Middle Triassic and has a thickness of up to 185 metres.

Above the Hawkesbury is the Wianamatta Group, which consists dominantly of shales and siltstones with occasional sandstone interbeds. These sediments vary up to 90 metres thickness over the project area.

The major sandstone units are interbedded with other rocks and, though shales and claystones are quite extensive in places, the sandstone predominates. The major sandstone units are the Scarborough, the Bulgo and the Hawkesbury Sandstones and these units vary in thickness from a few metres to as much as 200 metres. The rocks exposed in the river gorges and creek alignments belong to the Hawkesbury Group.

The other rocks generally exist in discreet but thinner beds of less than 15 metres thickness, or are interbedded as thin bands within the sandstone.

1.8 The Basis of this Study

During the early consultations with members of the general public a number of issues were raised including the potential for subsidence to occur at the surface as a result of coal seam methane extraction below ground.

AGL therefore commissioned Mine Subsidence Engineering Consultants Pty Ltd (MSEC), in February 2007, to study the joint venture proposals for coal seam methane extraction in the Camden area and to consider the potential for the coal seam methane extraction to result in subsidence at the surface. This report was prepared on completion of that study.

As background to the project, MSEC was provided with a copy of a report entitled, "Environmental Assessment Scoping Report - Expansion of Stage 2 of the Camden Gas Project" (EASR), dated 19th October 2006, which was prepared by HLA-Envirosciences Pty Limited for AGL. Some of the background information given in the EASR has been relied on in the preparation of this report.

Further information regarding the Camden Gas Project has been obtained from the AGL website.

Chapter 2 The Extraction of Coal Seam Methane

2.1 Coal Seam Methane

As indicated in Chapter 1, Coal Seam Methane (CSM) is a natural gas, which was formed as a by-product during the process by which organic matter was turned into coal. CSM is also referred to as coal bed methane or coal seam gas.

If the gas is removed directly from underground coal mines as part of the mining process, it is called mine waste gas or coal mine methane. CSM is used in the same way as any other gas to power such things as barbecues, stoves, heaters and water heaters in homes and businesses and is also used as a direct source of power for industry and as a fuel for electricity generation.

Unlike conventional natural gas reservoirs, where gas is trapped in the pores or void spaces of a rock such as sandstone, shale or limestone, methane trapped in coal is adsorbed onto the coal surface (cleats and joints) or micropores and is held in place by reservoir (water) pressure. Hence the coal is both the source and the reservoir for the methane.

Because the micropore surface area is very large, coal can potentially hold significantly more methane per unit volume than most conventional reservoirs, making the Sydney Basin's coal seams an excellent source of fuel and energy. Coal generally has lower permeability, however, than conventional reservoirs and the rates of production are usually lower. In order to achieve optimal production rates, it is generally necessary to stimulate the coal reservoirs by fracture stimulation.

A photograph of a typical rehabilitated wellhead is shown in Plate 1.

Plate 1. Typical Rehabilitated Wellhead

2.2 Drilling Activities

There are a variety of technologies used for the drilling of wells, taking into consideration land access constraints, aboriginal/heritage and other environmental issues and geological technical issues. A summary of the different methods that are available for drilling wells in Stage 2 of the Camden Gas Project is provided, below.

Underbalanced Vertical Drilling

- This is the traditional method used in the Camden programme and currently represents 95% of wells drilled;
- Penetration rates are maximised through shallow abrasive sands of medium hardness by underbalanced percussion drilling;
- Drilling rates of 300 metres per day or more can be achieved;
- Requires a drilling rig equipped with 2 air compressors and booster package for fluid circulation. Drilling action employed uses a percussion air hammer, button bit and drill collars to provide the impacts to break up formations.

Overbalanced Vertical Drilling

- Allows drilling of wells where land access constraints or environmental features limit the use of drill pits.
- Improvements are being made to the rate of penetration to a level which is comparable with underbalanced drilling.
- Equipment includes a drilling rig and equipment required to focus on drill fluid circulation and solid control systems with an operating capacity of 1800 litres per minute. The drilling relies on applied weight on bit and rotation to penetrate and remove formations. Weight is provided by running drill collars behind the bit with rotation provided by the rig's top drive or a downhole motor.

Directional Drilling

- The major advantage of directional drilling is that bottom hole locations can be located up to 400 metres away from the surface location, depending on the vertical depth of the seam. Therefore, wells can be drilled into areas that do not permit a vertical well intersecting a desired target.
- Multiple wells can be drilled from a single location and gas reserves that are stranded by surface developments can be accessed from outside the developed areas.
- Similar surface equipment is required to that used for overbalanced drilling, however directional equipment is added to the downhole equipment to allow control of drilling angle and direction.

Surface to Inseam (SIS) or Horizontal Drilling

- The well is drilled vertically from the surface and gradually builds angle so as to intersect the seam near parallel with the seam dip angle. Once intersected, this portion of the well bore is cased, cemented and a smaller hole is subsequently drilled through the seam for up to some 2000 metres.
- Horizontal wells are used to increase the drainage area of a reservoir and provide a means of stimulating the reservoir through the drilling process.
- If this technique is successful in Camden (3 trial wells have been established), the number of surface locations would potentially be reduced along with the ability to extract inaccessible gas reserves more than 1500 metres away from the well site location.
- This technique is more complex and requires drilling operations to be conducted 24 hours a day, 7 days a week for certain sections of the well.

2.3 Fracture Stimulation

Upon completion of drilling, the well is cased off with steel casing which is pressure cemented in place to ensure zonal isolation behind the pipe. The well is then perforated across the selected coal seam intervals and is subsequently fracture stimulated (known as 'fracing') through the injection of a slurry of sand and water at sufficient pressure to create a conductive pathway into the coal reservoir.

This process mechanically stimulates the gas-bearing zone to facilitate the mobility of the gas and water from the coal seam, allowing the gas and water to flow up the well bore to the surface.

Following fracing, the waters are removed from the coal seam either to future drilling and fracing campaigns or are transported to licensed disposal facilities due to the saline nature of the formation waters mixed with the fracing water.

Dewatering pumps are used in approximately 20% of wells to remove the injected fracture stimulation water and the formation water, which reduces reservoir pressure and allows gas desorption of the coal seam methane wells.

Chapter 3 Surface Subsidence

3.1 The Major Causes of Surface Subsidence

Surface subsidence can be caused by a number of activities and mechanisms, the most common being:

- Underground coal extraction.
- Underground mineral extraction.
- Pumping of oil and gas from underground reservoirs.
- Dewatering of sandy or fissured subsoils.
- Withdrawal of geothermal fluid.
- Erosion or leaching of fine particles in the surface soils and underlying rocks.
- Swelling and Shrinkage of cohesive subsoils due to changes in moisture content.

Surface subsidence occurs due to the removal or displacement of solid or liquid materials below ground and the consequential creation of voids or change in hydrostatic pressure, which result in subsidence of the overlying strata. The amount of subsidence that is likely to develop is dependent upon the nature of the surface soils and underlying strata and the extent of the underground voids that are created by mining and other activities.

Generally, when coal or other minerals are extracted below ground, as the volume of extraction increases the amount of subsidence also increases. The extent of the subsidence is, however, dependent upon the sizes and distribution of the voids that are left and the capacity of the overlying strata to bridge the voids.

3.2 Underground Coal Extraction

In underground mines, coal has generally been extracted using bord and pillar mining methods, employing continuous miners, or longwall mining methods, which require very expensive longwall face equipment. Most modern coal mines today use longwall mining techniques, which allow greater efficiency in the extraction of the coal resources. These methods of coal mining are described below.

Bord and Pillar Mining

Fig. 3.1 shows an idealised layout of a mine using the bord and pillar method of extraction.

In this method, a series of parallel tunnels, referred to as headings, is driven into the coal seam from the mine entrance using mining machines, known as continuous miners. As the coal is removed it is transferred by shuttle cars to belt conveyors, which carry the coal out of the mine.

This leaves the strata in the roof above the seam supported on a regular distribution of coal pillars, though in some mines the sizes and shapes of the pillars were in fact quite irregular.

The extent to which the coal in these districts is removed is dependent upon the amount of mine subsidence that is permitted above the extracted area. Figure 3.1 shows three alternative options in this regard. If no subsidence is permitted, then all of the pillars are left in place. If a small amount of subsidence is permitted, then alternate rows of pillars can be removed. If a greater amount of subsidence is permitted, then, wide panels of coal can be extracted by removing several rows of pillars.

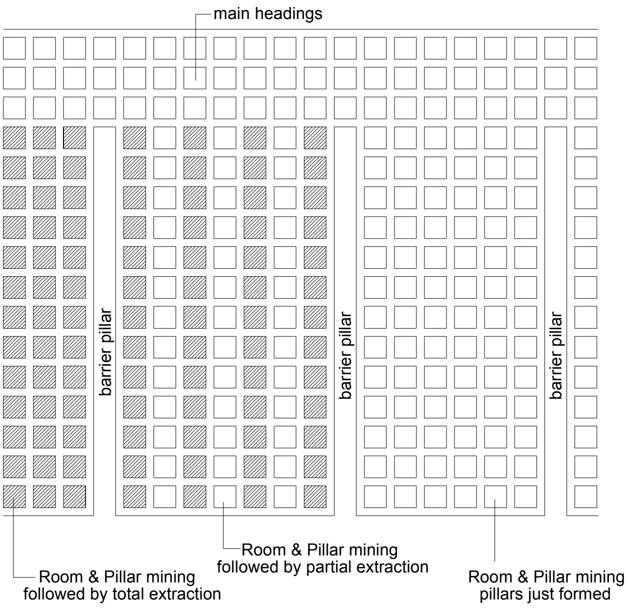

Figure 3.1 Typical Layout of a Bord and Pillar Mine

Longwall Mining

In longwall mining, a panel of coal, typically around 150 to 400 metres wide, 1000 to 4000 metres long and 2 to 5 metres thick, is totally removed by longwall shearing machinery, which travels back and forth across the coalface.

The area immediately in front of the coalface is supported by a series of hydraulic roof supports, which temporarily hold up the strata in the roof above the seam and provide a working space for the shearer and face conveyor. A typical section through coal face is shown in Figure 3.2.

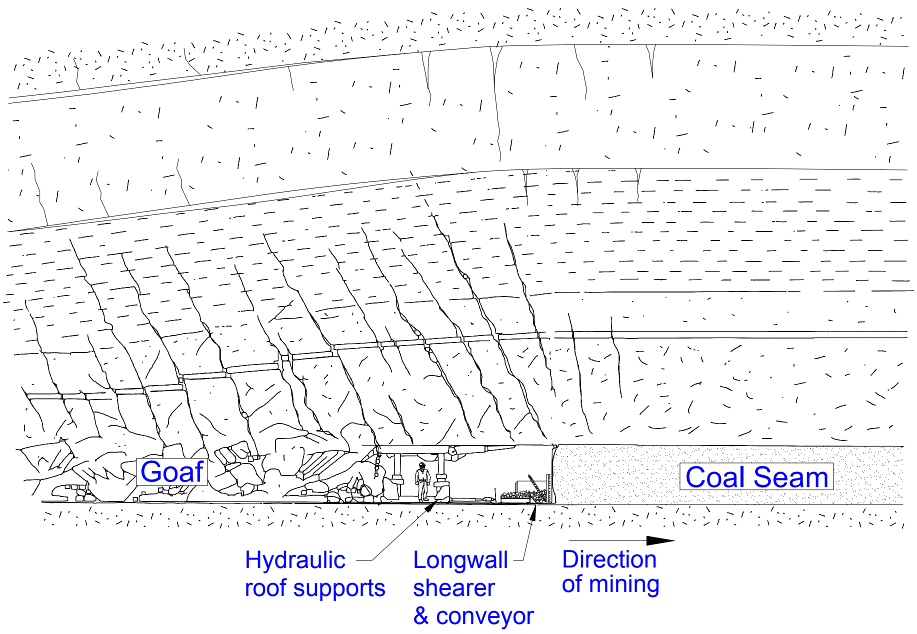

Figure 3.2 Cross Section of a Typical Longwall Face

The shearer cuts a slice of coal from the coalface each time it passes and this falls onto an armoured plate conveyor, which runs along the full length of the coalface. At the end of the coalface, the armoured plate conveyor discharges onto a belt conveyor that carries the coal out of the mine.

When coal is extracted using this method, the roof immediately above the seam is allowed to collapse into the void that is left as the face retreats. This void is referred to as the goaf. Miners working along the coalface, operating the machinery, are shielded from the collapsing strata by the canopy of the hydraulic roof supports.

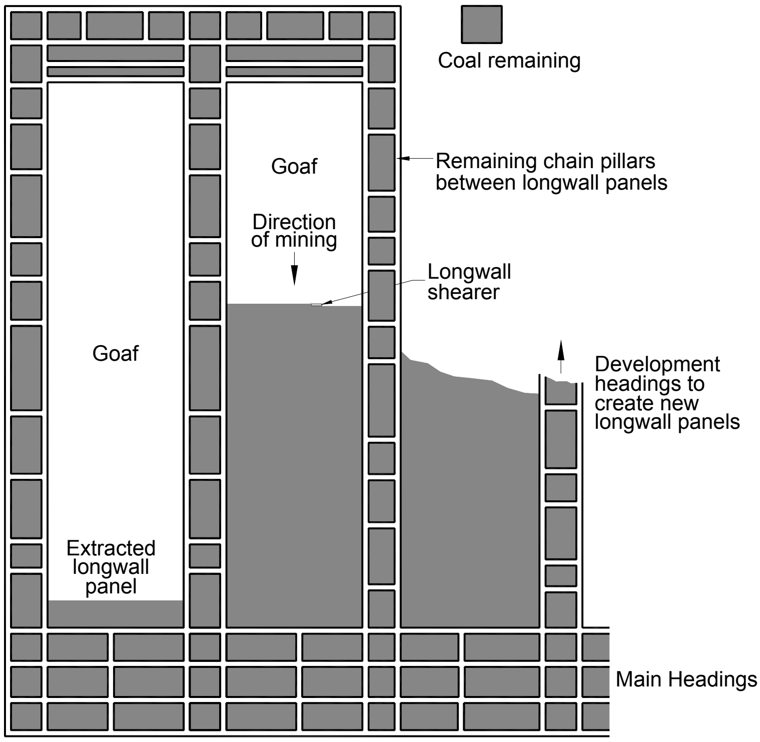

Figure 3.3. Typical Plan View of a Series of Longwall Panels

Figure 3.3 shows a typical layout of a group of longwalls. Before the extraction of a longwall panel commences, continuous mining equipment extracts coal to form roadways, which are known as headings, around the longwall panel. These roadways form the mine ventilation passages and provide access for people, machinery, electrical supply, communication systems, water pump out lines, compressed air lines and gas drainage lines.

The roadways, which provide access from the mine entrance to the longwalls, are referred to as the main headings. Once the main headings have been established additional roadways, known as development headings, are driven on both sides of the longwall panel and are connected together across the end of the longwall.

As the coal is extracted, the overlying strata are allowed to collapse into the void behind the face. Miners working along the coalface, operating the machinery, are shielded from the collapsing strata by the canopy of the hydraulic roof supports. As the roof collapses into the goaf behind the roof supports, the fracturing and settlement of the rocks progresses through the overlying strata and results in sagging and bending of the near surface rocks and subsidence of the ground above, as illustrated in Figure 3.2.

If the width of an extracted panel of coal is small and the rocks above the seam are sufficiently strong, it is possible that the overlying strata will not collapse and hence no appreciable subsidence will occur at the surface. However, to maximise the utilisation of coal resources and for other economic reasons, wide panels of coal are generally extracted and, in most cases, the roof is unable to support itself.

As the immediate roof strata, i.e. the rocks immediately above the seam, collapse into the goaf, the rocks above them lose support and sag to fill the void beneath them. The mechanism progresses towards the surface and the affected width increases so that at the surface, an area somewhat larger than the extracted panel of coal undergoes settlement.

The subsidence of the surface is considerably less than the thickness of coal removed, due to the voids that are left within the collapsed strata. The extent of the settlement at the surface is therefore dependent upon the strength and nature of the rocks overlying the coal seam and is a direct function of their capacity to bridge over the voids.

Subsidence impacts at the surface are determined by the relationships between the subsidence to seam thickness ratio (S/M) and the width to depth of cover ratio (w/h) and vary from coalfield to coalfield. The subsidence in each case is determined by the strengths of the rocks in the overburden to the coal seams. Where the overburden is strong, the rocks are able to span further before subsidence is initiated and the amount of subsidence is reduced. In all cases, where the width of extraction is small, the subsidence is generally negligible.

The methods of coal extraction described above are generally used in New South Wales where the coal seams are relatively flat. Not all coal deposits, however, occur in flat seams and in some countries, such as Spain and Korea the coal seams are so steeply folded and undulating in nature that normal methods of extraction cannot be employed. In those circumstances the methods used are similar to those used in extracting other mineral deposits.

In the Southern Coalfield of New South Wales, the extracted thickness of the coal seams generally varies from 2 metres to 3.5 metres. The depth of cover varies from approximately 400 metres to 650 metres and the longwall widths vary from approximately 250 metres to 320 metres. The maximum subsidence at the surface therefore varies from 600 mm to 1500 mm, depending on the mining geometry.

This subsidence occurs because large quantities of coal are extracted using the longwall mining process, leaving large voids into which the strata above the seam is allowed to collapse, with consequential sagging of the strata that are closer to the surface.

Quite clearly, there is no comparison between the surface subsidence impacts of the longwall mining operation, which extracts the coal seam and the coal seam methane extraction operation, which simply releases the gas from the coal seam.

3.3 Underground Mineral Extraction

The extraction of minerals underground is dependent upon the form and distribution of the mineral body. Some minerals such as rock salt and phosphate are present in sedimentary deposits and occur in relatively flat seams similar to coal seams. The effect of mining these can be compared directly with the effects of coal mining.

Rock salt in the United Kingdom was generally mined using bord and pillar methods, leaving the pillars in place as permanent roof supports and this did not result in any significant subsidence, even though large voids were left in the strata. In some cases, however, solution mining has been used for the extraction of rock salt, with the consequential development of sinkholes.

In other cases ground water movements have affected the long-tern stability of rock salt pillars causing pillar failure and consequential subsidence.

Phosphate mining has also generally been carried out using bord and pillar or longwall techniques, with limited subsidence in some cases. Mining at Boulby Phosphate Mine, near Whitby in North Yorkshire, UK, was carried out using solution mining techniques and large voids were formed by removal of the phosphate, resulting in surface subsidence. This can be equated to longwall mining or the removal of pillars in bord and pillar mining.

Metaliferous mining generally uses different techniques to remove bodies of ore which are of irregular form within igneous rocks. In these circumstances the ore is generally extracted using sublevel caving techniques. In this method, intermediate levels divide a deposit into horizontal slices, which are then blasted down from the bottom up on an angled front.

Two other methods which belong in this category are open-stope caving and block caving, both of which have been used in ore mining. The first of these, adopted in steep dipping deposits, having a certain minimum strength of wall rock, provides for an underground excavation, or open stope, over 15 metres high, from which the mineral is worked laterally by caving at several sub-levels, to be collected at a lower level for hauling to the surface.

In block caving, a massive ore body of considerable height is freed from the host rock surrounding its vertical sides, is undercut across its entire base, and is then brought down in sections from lower levels by shot firing and gravity.

This is similar to the procedure followed, with comparatively thin horizontal slices, in sublevel caving. In the latter method, as caving progresses upwards to the roof the waste rock and the main body of overlying strata follow the collapsing ore down forming subsidence troughs or trenches at the surface, which can be several metres deep.

3.4 Pumping of Oil and Gas from Underground Reservoirs

The pumping of oil and gas from conventional underground deposits, usually sandstone, shale or limestone, can result in subsidence of the ground surface if the nature of the strata is such that support of the overburden is reduced by the process. This depends upon the nature of the oil and gas reservoir and the surrounding and overlying strata. Subsidence of this type is generally greatest at the oil well and spreads laterally for a considerable distance.

By way of example, the maximum subsidence at the Wilmington Oil Field, which is the third largest oil field in the USA, was reported to be almost 9 metres. Similarly the maximum subsidence at the Ekofisk Oil Field in the North Sea was reported in 1985 to be 2.6 metres.

The subsidence depression was indicated to be approximately 6km long and 4km wide, which resembles the size and shape of the underlying reservoir 3km below. This type of subsidence can be reduced by replacing the extracted oil with water.

The extraction of coal seam methane gas is, however, quite different, because unlike conventional natural oil and gas reservoirs, where the oil and gas are trapped in the pores or void spaces of a rock such as sandstone, shale or limestone, methane trapped in coal is adsorbed onto the coal surface and is released without significant change in the volume of the coal seam.

3.5 Dewatering of Sandy or Fissured Subsoils

The pumping of water from competent sandstone beds beneath the surface does not normally result in subsidence movement at the surface.

The pumping of water from unconsolidated sandy and fissured subsoils, however, can result in significant subsidence at the surface due to drawdown of the water table.

For example, Mexico City is founded on water bearing alluvial deposits, which have provided a supply of water to the city for many years. The extraction of water from the underlying aquifer, however, has resulted in considerable subsidence of the surface.

According to the Mexico Valley Water Authority, the net subsidence over the last 100 years has lowered the central, urbanized area of the city by an average of 7.5 meters. The result has been extensive damage to the city's infrastructure, including building foundations and the sewer system.

In this case, the subsidence is caused by the loss of support to the unconsolidated water-bearing strata, which was provided by the hydrostatic pressure of the groundwater.

The extraction of coal bed methane gas is, however, quite different, because it is extracted from the relatively hard and consolidated coal seam and the process does not significantly affect the water table.

3.6 Withdrawal of Geothermal Fluid

It was reported in 1975 that the withdrawal of fluid from the geothermal field at Wairakei on the North Island of New Zealand had resulted in subsidence of 4.5 metres, with accompanying horizontal ground displacements of up to 0.5 metres.

The area affected was apparently approximately 3 square kilometres and was located essentially over the main geothermal reservoir, which had a thickness of 370 metres to 790 metres.

The cause of subsidence was attributed to volume changes in the reservoir undergoing depletion of geothermal fluid storage, coupled with thermal contraction.

The extraction of coal bed methane gas is, however, quite different, because it is extracted from the relatively hard and consolidated coal seam, the volume of which is not significantly reduced as the methane is desorbed.

3.7 Drainage of Organic Soils

Subsidence can occur due to the drainage of organic soils such as peat beds, which have a naturally high void ratio and high water content, when submerged. Subsidence rates are determined by the nature of the peat, the depth to the water table and the temperature. Subsidence tends to occur at a faster rate in warmer regions when compared to similar deposits in cooler climates.

Drainage of some of the fen lands in England has resulted in almost 3.5 metres of subsidence since drainage began in the 17^{th} century. The extent of the subsidence is dictated by the nature of the peat and its ability to consolidate as the water is removed from the voids within it.

3.8 Erosion or Leaching of Fine Particles in the Surface Soils and Underlying Rocks

In many cases the flow of water through the ground results in the leaching and erosion of soil and rock particles and the formation over time of underground water paths, tunnels and caves. This often occurs in limestone rocks creating large and extensive cave systems. In some case the caves expand in size, by scouring to the point where the overlying rocks can no longer span the voids and sinkholes develop through to the surface. There are many examples of this type of subsidence, which results in sinkholes that are many metres in depth. The major reason for the subsidence is the presence of large voids in the strata as the materials from the voids are washed away downstream.

The extraction of coal bed methane gas is, however, quite different, because it does not result in the extraction of solid particles from the coal seam or the formation of significant voids.

3.9 Swelling and Shrinkage of Cohesive Subsoils due to Changes in Moisture Content

It is well known that certain reactive clays swell and shrink in response to moisture changes. These effects are greatest close to the surface, where the clay is less confined by overburden and where the moisture can be more quickly reduced by evaporation.

Reduction in the moisture content of the clay results in subsidence at the surface. As an example, a clay bed 1.5 metres thick at Beaudesert in South Queensland was calculated to swell or shrink by up to 100mm due to seasonal drying and wetting.

This problem is often exacerbated by the presence of tree roots, which absorb the moisture from the clay, causing ground movement. This is one of the primary causes of damage to building foundations in urban environments.

3.10 Conclusion

Conventional reservoirs have oil and/ or gas trapped within sandstones, shales or limestones. Some formations such as friable or unconsolidated sands and high porosity vugular limestones rely on the presence of fluids or gas pressurising the formation to stop compaction of the weak rocks. As coal stores gas differently to conventional reservoirs, sandstones, shales or limestones, it does not rely on the presence of gas to provide support to the strata, thus any removal of gas will not alter the competency of the rock to cause large scale compaction. Coal seam gas is also referred to as unconventional gas as it is not found in a conventional reservoir.

Chapter 4 The Potential for Coal Seam Methane Gas Extraction to result in Subsidence at the Surface

4.1 The Project

Chapter 1 of this report has outlined the proposal to extend Stage 2 of the Camden Gas Project and has identified that the proposal involves the installation of additional gas wells in the Spring Farm and Menangle Park areas for the extraction of coal seam methane. The proposed wells will comprise a mix of vertical, directional and surface to inseam (SIS) or horizontal drilled wells, and the well surface locations that are illustrated in HLA Figures 5 and 6 in Appendix C are only indicative. The wells will initially target coal seam methane in the Bulli Seam, though additional gas resources are believed to exist in the subsequent lower formations.

4.2 The Gas Wells

Chapter 2 of this report has addressed the methods of extraction that are proposed in the Spring Farm and Menangle Park areas as an extension to Stage 2 of the Camden Gas Project. Up to sixteen new well surface locations are proposed (each of which may contain up to 6 individual wells), which will involve the drilling of boreholes up to 180 mm diameter from the surface into the coal seam or seams. The subterranean spacing of the wells will generally be more than 350 metres. Some of the vertical wells may be reamed out to 2 metres diameter within the seam. Other wells may use fracture stimulation techniques to facilitate the extraction of the gas.

The well bores will be cased and sealed, particularly through aquifers closer to the surface to prevent hydraulic linkage between aquifers at different levels in the strata. It should also be noted that coal seams are confined aquifers and that dewatering has little effect on the surrounding aquifers.

4.3 Surface Subsidence

Chapter 3 of this report has addressed the major causes of surface subsidence and has indicated that there are a number of activities and mechanisms that can cause subsidence. These have been provided to illustrate the general conditions that are necessary for subsidence to occur. Surface subsidence will not occur unless:

- Large voids are created in the strata by the mining or extractive activity, leading to subsequent collapse, consolidation and subsidence of the overlying strata.
- Large voids are created in the strata by the mining or extractive activity, leading to subsequent failure of remnant pillars and subsidence of the overlying strata.
- Unconsolidated beds of strata are present, which can subsequently be consolidated by the weight of the overburden, following the removal of interstitial fluids.

4.4 The Potential Surface Impacts of the Coal Seam Methane Extraction at Camden

The proposed extraction of coal seam methane at Camden will not create large voids in the strata, nor leave remnant pillars. The strata within the coal measures are not unconsolidated and in fact are hard and well consolidated rocks. The conditions for significant subsidence to occur are not therefore present and it is concluded that the potential for subsidence to occur as the gas is extracted is almost negligible.

When coal waste gas is extracted by coal mining companies prior to mining, this is achieved by drilling horizontal gas drainage bores into the coal seam from the adjacent development headings, or roadways. These bores are generally 90 mm diameter and are drilled at very close centres, which is a much more invasive method than the method of gas extraction proposed within the Camden Gas Project and results in the creation of a considerably greater number of voids in the coal seam. It does not, however, result in any measurable subsidence at the surface, which provides further support to the above conclusion.

It should be noted that coal mine degasification works are regularly undertaken beneath established urban areas and result in negligible subsidence impact on the existing surface infrastructure.

According to Gray, 1986, coal has been shown to shrink on desorption of gas and to expand again on resorption. Gray noted that Hargraves, 1963, had conducted a series of tests on coal from Metropolitan Colliery, New South Wales, Australia, which showed an average linear strain of 0.00182, per MPa change in equivalent sorption pressure, using CO_2 as the gas. Japanese workers showed a similar but lesser effect using methane on coal from the northern Ishikari coal field in Hokkaido. Their average value was 0.000125 linear strain, per MPa, which is more than an order of magnitude less.

It is possible therefore that there could be some shrinkage of the coal seam due to the extraction of the methane, but at such low strain values any shrinkage would be a matter of a few millimetres. Any subsidence that might occur at the surface due to shrinkage of the coal seam would, therefore, be negligible.

Appendix A Glossary of Terms and Definitions

Glossary of Terms and Definitions

Some of the mining terms used in this report are defined below:

Angle of draw	The angle of inclination from the vertical of the line connecting the goaf edge of the workings and the limit of subsidence (which is usually taken as 20 mm of subsidence).
Chain pillar	A block of coal left unmined between the longwall extraction panels.
Cover depth (H)	The depth from the surface to the top of the seam. Cover depth is normally provided as an average over the area of the panel.
Critical area	The area of extraction at which the maximum possible subsidence of one point on the surface occurs.
Curvature	The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections.
Extracted seam thickness	The thickness of coal that is extracted. The extracted seam thickness is normally given as an average over the area of the panel.
Effective extracted seam thickness (T)	The extracted seam thickness modified to account for the percentage of coal left as pillars within the panel.
Face length	The width of the coalface measured across the longwall panel.
Goaf	The void created by the extraction of the coal into which the immediate roof layers collapse.
Goaf end factor	A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel.
Horizontal displacement	The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.
Inflection point	The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max.
Incremental subsidence	The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel.
Overlap adjustment factor	A factor that defines the ratio between the maximum incremental subsidence of a panel and the maximum incremental subsidence of that panel if it were the first panel in a series.
Panel	The plan area of coal extraction.
Panel length (L)	The longitudinal distance along a panel from the commencing rib to the finishing rib.
Panel width (Wv)	The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.
Panel centre line	An imaginary line drawn down the middle of the panel.
Pillar	A block of coal left unmined.
Pillar width (Wpi)	The shortest dimension of a pillar measured from the vertical edges of the coal pillar, i.e. from rib to rib.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points.
Sub-critical area	An area of panel smaller than the critical area.
Subsidence	The vertical movement of a point on the surface of the ground as it settles above an extracted panel.
Super-critical area	An area of panel greater than the critical area.
Tilt	The difference in subsidence between two points divided by the horizontal distance between the points.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	A reduction in the expected subsidence at a point, being the difference between the predicted subsidence and the subsidence actually measured.

Appendix B References

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Appendix C Drawings

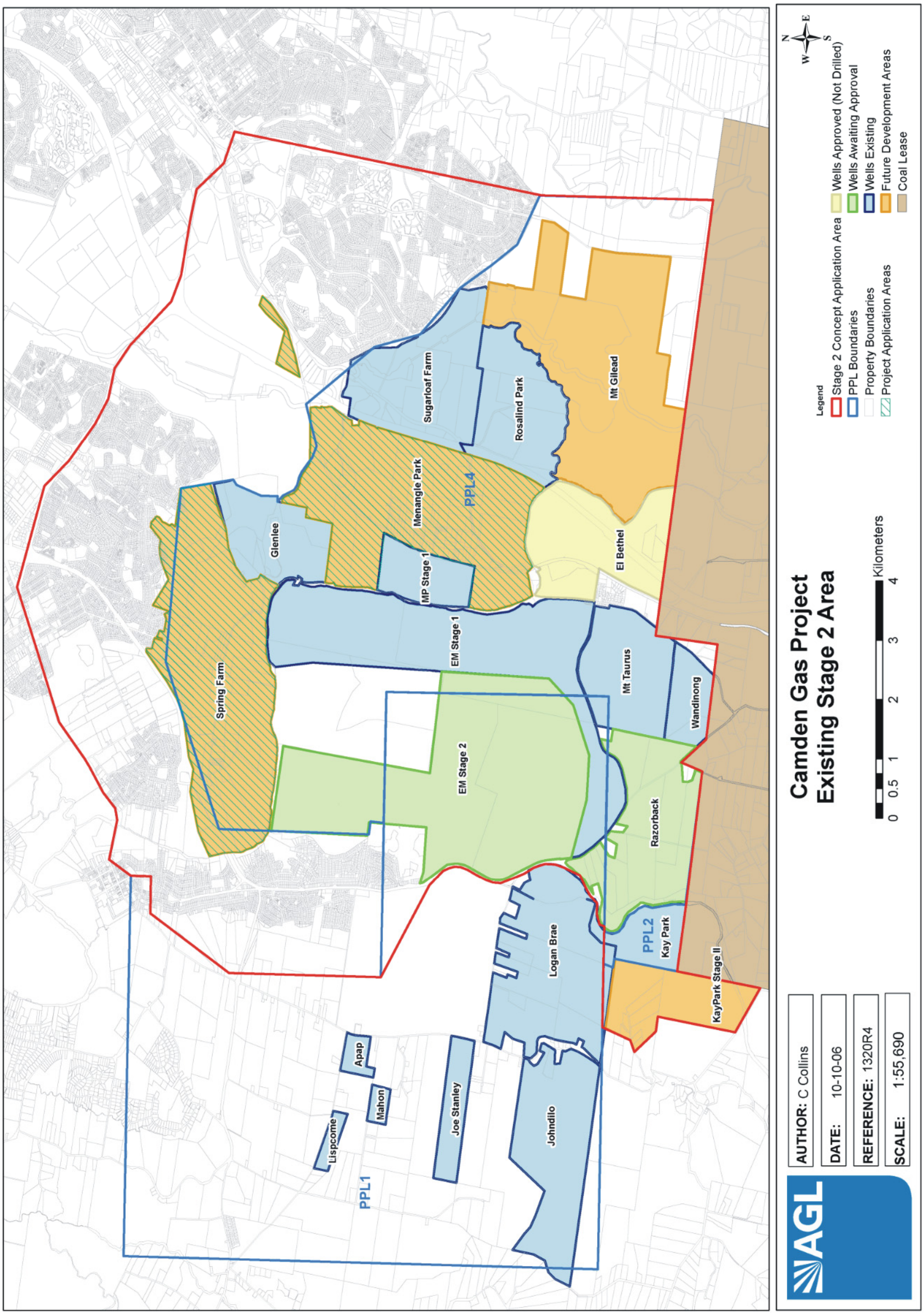

Figure 1. **Camden Gas Project Stage 2 Concept Plan**

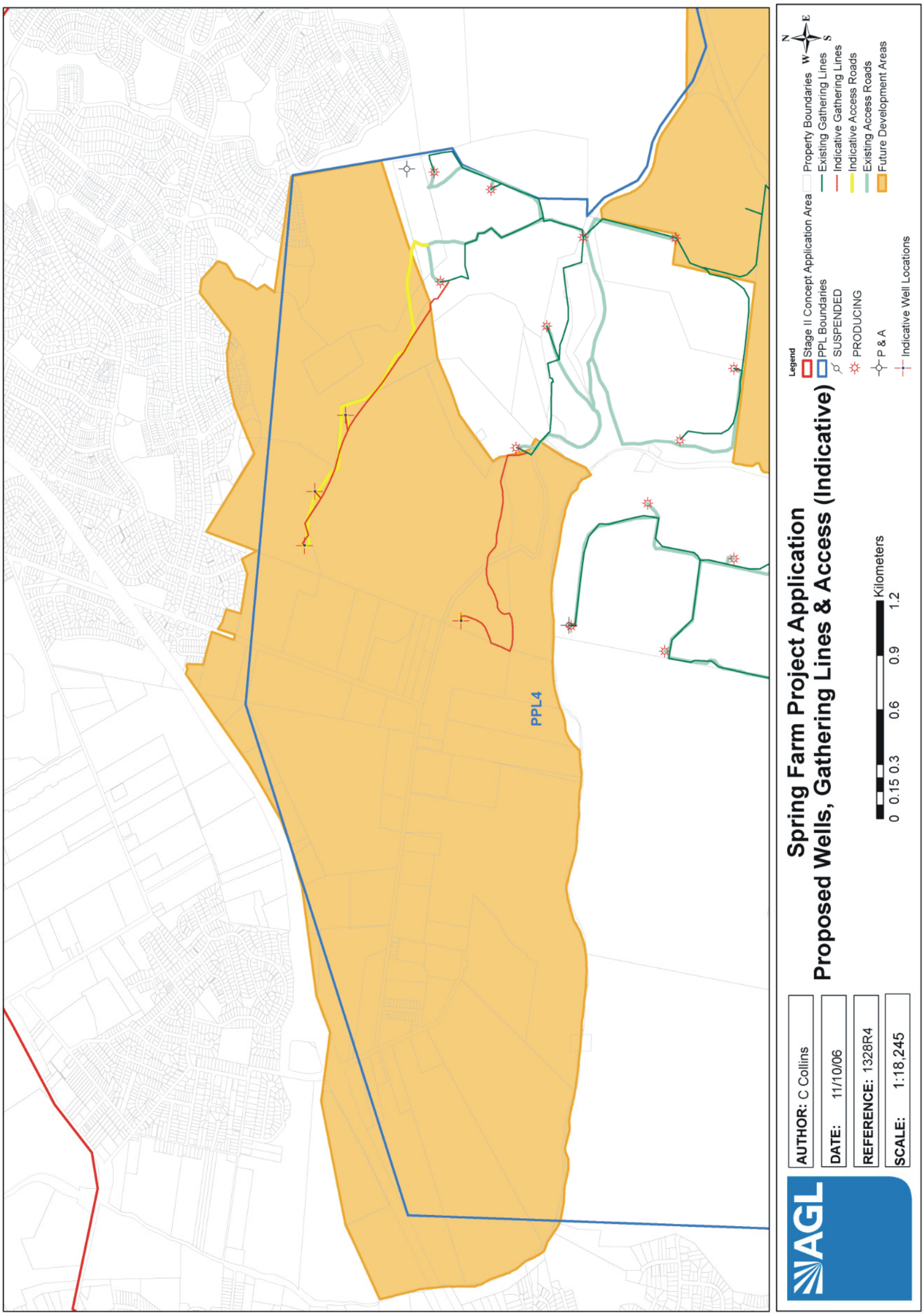

Figure 2. Proposed Gas Wells in the Spring Farm Area

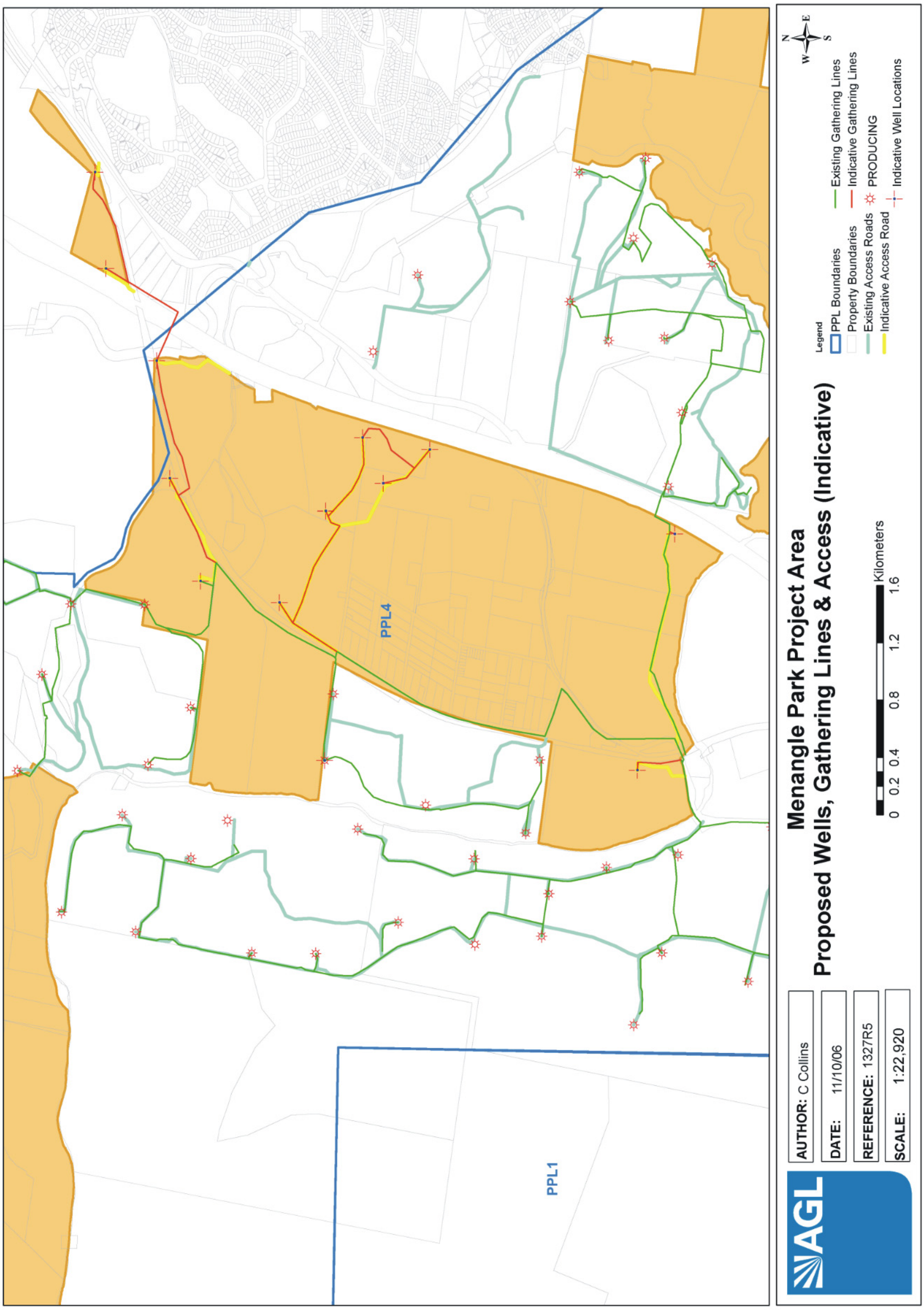

Figure 3. Proposed Gas Wells in the Menangle Park Area