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# A methodology for the rapid assessment of the potential impact and hazard of coal seam gas mining on aquifers and the environment

## Abstract

The potential environmental impacts and hazards of coal seam gas mining in Australia are highly contentious and poorly understood. Concerns have been raised by communities, and the Australian government has incorporated management tools and strategies to address these concerns. The primary environmental issue associated with coal seam gas mining would be on the aquifers above the target coal seam. If the upper aquifers are affected in terms of quantity and quality, then there are cumulative impacts to the surface environment such as groundwater dependent ecosystems and surface waters. This paper will examine the Australian situation with regard to coal seam gas mining and present a methodology for rapid assessment of the potential impacts and hazards of coal seam gas extraction on aquifers and surface environments. A GIS analysis method for developing broad scale potential impact and hazard criterion for aquifers above the target coal zone are discussed. Current investigations and future research and development opportunities are explored.

## Keywords

aquifers, potential, impact, coal, seam, environment, gas, mining, methodology, rapid, assessment, hazard, GeoQuest

## Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

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## **A Methodology for the Rapid Assessment of the Potential Impact and Hazard of Coal Seam Gas Mining on Aquifers and the Environment**

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### **ABSTRACT**

The potential environmental impacts and hazards of coal seam gas mining in Australia are highly contentious and poorly understood. Concerns have been raised by communities, and the Australian government has incorporated management tools and strategies to address these concerns. The primary environmental issue associated with coal seam gas mining would be on the aquifers above the target coal seam. If the upper aquifers are affected in terms of quantity and quality, then there are cumulative impacts to the surface environment such as groundwater dependent ecosystems and surface waters. This paper will examine the Australian situation with regard to coal seam gas mining and present a methodology for rapid assessment of the potential impacts and hazards of coal seam gas extraction on aquifers and surface environments. A GIS analysis method for developing broad scale potential impact and hazard criterion for aquifers above the target coal zone are discussed. Current investigations and future research and development opportunities are explored.

### **1. INTRODUCTION**

Coal Seam Gas (CSG) extraction is a thriving industry as an alternative source of non-renewable energy, particularly in eastern Australia where there are large coal reserves. There are indeed significant challenges for this industry as governments and community aim to keep the industry accountable for any potential impacts extracting this energy resource may have on the sub-surface (aquifers) and surface (land-vegetation-water) environments. To address the issues related to potential environmental impacts of CSG, the Australian Government are using a regulatory framework involving legislative and policy instruments that assist in managing the fine balance between economic, environmental and social issues.

Recently, the New South Wales (NSW) government launched the NSW Aquifer Interference Policy and Strategic Land Use Policy. The NSW Aquifer Interference Policy defines the protection of NSW aquifers, balancing the water use requirements of towns, farmers, industry and the environment. It details how potential impacts to aquifers should be assessed, and how this information is provided to the relevant planning process. As part of the Strategic Land Use Policy, all new major projects for mining or petroleum which have the potential to affect agricultural resources or industries must submit an Agriculture Impact Statement. Whilst these government regulatory instruments provide the framework for companies to be responsible for any potential impacts their CSG mining activities may have on the environment, each assessment should be underpinned by good scientific investigation on a case by case basis.

The objectives of this study were to provide a preliminary assessment of the potential impacts and hazards of CSG mining activities at a regional scale, and devise a rapid assessment methodology to determine basic criteria for estimating the potential impacts and hazards of CSG activities on the environment using the Sydney Basin as a case study.

## **2 SITE DESCRIPTION**

The study area has been defined as three New South Wales Catchment Management Authority (CMA) areas; the Hawkesbury-Nepean, Sydney Metropolitan and the Southern Rivers (Figure 1), based on federal government funding initiatives. The Hawkesbury-Nepean and Sydney Metropolitan catchments completely lie within the Sydney Basin. Only the northern area of the Southern Rivers Catchments form part of the Sydney Basin. The Sydney Basin is a large sedimentary basin on the east coast of Australia covering almost 50,000 km<sup>2</sup>. The Southern Coalfields and Western Coalfields lie within this basin. The Southern Coalfields affect all three CMA regions and the Western Coalfields affect the western section of Hawkesbury-Nepean region. The southern section of the Southern Rivers Catchment area is not affected by coal mining or CSG activity due to the lack of coal present.

The Sydney Basin is dominated by six major stratigraphic units that gradually thin from the centre of the basin to the margins. Overlying the intensely folded Palaeozoic basement lie the marine sediments and coal measures of the Talaterang and Shoalhaven Groups, which progressively thin from 1,000 m at the coast (near Nowra) to approximately 45 m thick at Tallong (50 km further west). The Talaterang Group is made up of the Clyde Coal Measures and the shallow marine Wasp Head Formation. Overlying the Talaterang Group is the 300 to 900 m thick Shoalhaven Group. Bowman, [1] and Eyles et al., [2] state that the Shoalhaven Group consists of lithic sandstones interbedded with shale and mudstone, which were deposited in a marine or marine-influenced environment.

At the top of the Shoalhaven Group, alternating layers of sandstones and siltstones are capped by volcanic rocks, and are interbedded with the upper Budgong Sandstone and the base of the Illawarra Coal Measures as detailed by Carr and Jones [3]. Above the Shoalhaven Group is the economically significant Illawarra Coal Measures. This 240m thick deltaic sequence consists of lithic sandstone units interbedded with thinner units of coal, sediments and shale. The maximum thickness of the coal

measures is 520m in the northern section of the coalfield according to Hutton [4].

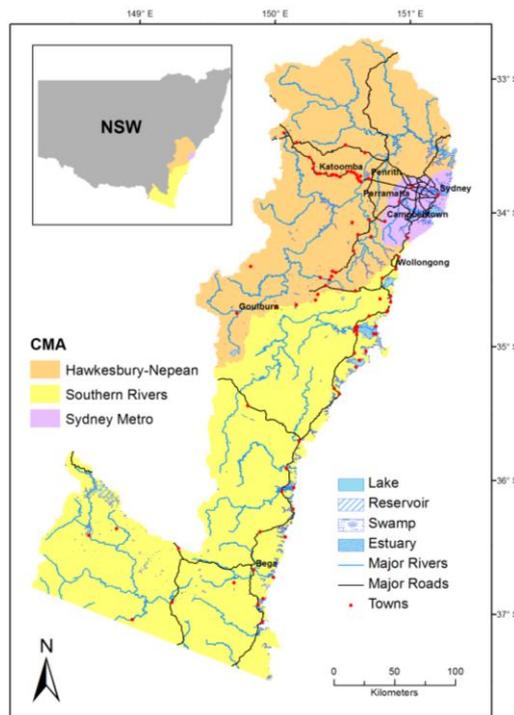


Figure 1. Investigation area highlighting the three catchment management areas.

The erosional surface at the top of the Bulli coal is overlain by the Triassic sequence, namely the Narrabeen Group and Hawkesbury Sandstone. The Narrabeen Group comprises lithic to quartz lithic sandstones, shales and claystones and has a thickness ranging from 300 to 500 m. This group also contains the Bald Hill Claystone unit, a largely continuous aquitard/aquiclude, capping the Narrabeen Group. The Bald Hill Claystone unit has been identified as an important impermeable unit in restricting the migration of water and gas into adjoining aquifer systems as discussed by Haworth [5].

### 3 COAL SEAM GAS EXTRACTION AND ANTICIPATED ENVIRONMENTAL IMPACTS

Evaluation of the aquifer and surface environment characteristics of the study area is possible by understanding the extraction process. In order to extract the gas from the coal seam, the pressure in the seam is reduced by pumping the groundwater from the coal seam. This dewatering process causes the vertical hydraulic gradient between lithologies to be potentially affected, depending on the degree of hydraulic connectivity (leakage coefficient) between lithological units. Hydrogeological characterisation of a CSG site, in particular the properties of permeability and porosity, are of fundamental importance in understanding and assessing potential impacts of CSG.

To release the gas, water must be extracted by drilling a well into the target coal seam, reducing the pressure and allowing the gas to flow. One of the major concerns raised in regards to drilling is the possibility of cross-aquifer contamination.

The clearing of surface vegetation to enable infrastructure development, such as access roads, can lead to a modification of surface water hydrology and a reduction in habitat. The clearing of vegetation is likely to increase the extent of erosion and

therefore has the potential to enhance stream sedimentation rates, resulting in degradation of water quality.

Hydraulic fracturing, or ‘fracking’, is the process by which a coal seam (or any other hydrocarbon-bearing deposit) can be ‘stimulated’ by forcing fluids at high pressure into the reservoir unit to create an artificial network of fractures and increase the permeability of a seam. The fluid is normally composed of water, a ‘proppant’ (typically sand) to hold the fractures open, and a chemical solution that will vary depending on the geology of the site (Rutovicz *et al.*, [6]). The consequences of fractures extending beyond the target coal seam include the possibility of fracking fluids entering overlying strata, possible cross contamination of aquifers, excess water production, and inefficient depressurisation of the coal seam according to Colmenares and Zoback [7].

## **4 A METHODOLOGY FOR RAPID ASSESSMENT OF POTENTIAL IMPACTS AND HAZARDS**

### **4.1 Definitions and rationale**

For the purposes of this study, ‘impact’ is defined as the likely level of effect on the environment if CSG is to occur based on pre-determined criteria. In this case, the predetermined criteria are based on the location of coal geology and geological fault density. ‘Hazard’ is defined as any source of potential damage, harm or adverse effect on the environment by existing or potential CSG activity (based on existing coal titles and current CSG activity). Based on this definition, hazard can only occur if there is a likely source (i.e. coal titles).

A defined objective criterion for assessing potential impact and hazard was used. Impact was divided into three basic categories of ‘low’, ‘medium’ and ‘high’. Hazard was divided into three categories: ‘existing’, ‘existing and potential expansion’, and ‘potential’. Existing refers to where current CSG activity is occurring, potential expansion refers to where there is a coal title but no current activity is occurring, and potential refers to areas where coal reserves exist but no titles are held.

Fractures form part of the potential impact criteria since fractures act to increase the permeability and connectivity of the strata overlying the target coal seam. Consequently, increased fracture density in an area has the potential to increase the impact of CSG. According to CSIRO [8], coal seam gas is typically extracted from coal seams at depths of 300 to 1000 m. Generally at shallower depths CSG would be expected to have naturally vented from the coal seam to the surface through permeable overlying bedrock fractures and faults. It is therefore reasonable to assign a low CSG potential impact when the depth to the coal seam is 0 - 200 m, as it has previously been released to the environment.

### **4.2 Data**

Geospatial datasets for the study area were obtained from government agencies including primary and derived Geographical Information Systems (GIS) layers. NSW Statewide Geology data based on the 1:250 000 geological map sheets, was the primary dataset for determining the spatial distribution of geological units, particularly coal. Coal depth was determined from the Department of Primary Industries geological contour maps expressing depth to each geological unit. In

addition, fault and fracture GIS data was used in the analysis of potential impacts also.

Aquifer data was collated from both borehole data and derived GIS layers including Groundwater Management Areas (GWMAs). The boredata was collated from the NSW Office of Water’s “Pinneena” dataset. GWMAs were also based on the geology primary dataset. Since geology is the key data for the assessment, a description of the geology and hydrogeology is presented below.

### 4.3 GIS Analysis Methodology

The impact assessment was performed using GIS analysis based on the criteria described previously for the decision rules. For the potential impact assessment, the Triassic sediment thickness was used as a proxy for the depth to the top of the Permian coal measures and reclassified into the three depth categories: 0 - 200, 200 - 500 and >500 m. Fault density was determined using the ArcMap tool ‘Line Density’, which calculates the density of linear features in the neighbourhood of each unit area. Here, a large radius parameter was chosen to produce a more generalised fault density map. The fault density was then classified into areas of high, medium and low density. This was a method based on natural groupings of data values and was determined statistically by finding adjacent feature pairs, between which there was a relatively large difference in data values. The decision matrix for CSG potential impact is presented in Table 1.

Table 1: Decision matrix for CSG impact using thickness of the Triassic formation and fault density

	<b>Triassic Sediment Thickness (m)</b>			
<b>Fault Density</b>	<i>0-200</i>	<i>200-500</i>	<i>&gt;500</i>	<i>No Triassic strata found in area</i>
<i>High</i>	Low	High	High	Low
<i>Medium</i>	Low	High	Medium	Low
<i>Low</i>	Low	Medium	Medium	Low

A GIS hazard layer was created based on the classification matrix shown in Table 2 by overlaying the coal titles with the spatial extent of the Permian coal measures. This simple analysis resulted in a layer defining areas which contained current coal titles (existing hazard), Permian coal measures (potential hazard), both (existing and potential expansion) or none (no hazard).

Table 2: CSG and coal mining extraction hazard identification matrix based on the presence of Permian lithology and the existence of current coal titles (currently mined or not mined)

	<b>Permian Coal Measures</b>	
<b>Coal Title</b>	<i>Present</i>	<i>Not Present</i>
<i>Present + current mining</i>	Existing	No hazard
<i>Present + not mined currently</i>	Potential Expansion	No hazard

<i>Not present</i>	Potential	No hazard
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The hazard assessment of CSG mining on aquifer and surface environments was based on location of current coal mining titles and the location of the Permian coal measures. An existing hazard was defined as an area that contained a current coal mining title. An area was classified as a “potential expansion” hazard when it fell within the boundary of the Permian coal measures but did not contain a current coal mining title. GWMA’s classified as “existing” and “Potential” hazard refer to GWMA’s that fall into areas containing both existing and potential hazards. These can be considered areas where expansion of a current lease is possible. It was considered that there is no hazard for aquifers and surface environmental features where Permian coal measures and thus no coal titles existed.

## 5 RESULTS AND DISCUSSION

The likely impacts on groundwater, surface water and ecosystems vary according to the hydrogeological characteristics, the proximity to CSG mining, the amount of groundwater extraction and the extent of the aquifer connection. Figure 2 shows the potential impact associated with CSG mining on groundwater based on the scale of groundwater management areas. At this scale of data analysis, the level of impact on groundwater management areas is spatially broad since analysis is based on lithological information associated with coal depth and geological fault/fracture density. A high CSG impact will be associated with coal lithology below 500 m depth and high fracture density. This will mean that the total spatial extent of a groundwater management area will be shown as a high impact area even if only part of the area has those particular lithology and fracture density characteristics. In regard to hazard to coal seam gas extraction, the analysis was based on current coal titles and presented in Figure 3. If a coal title was found to lie within a groundwater management area, the whole groundwater management area would be indicated as having a high hazard. This limitation is based on the scale issue of regional datasets.

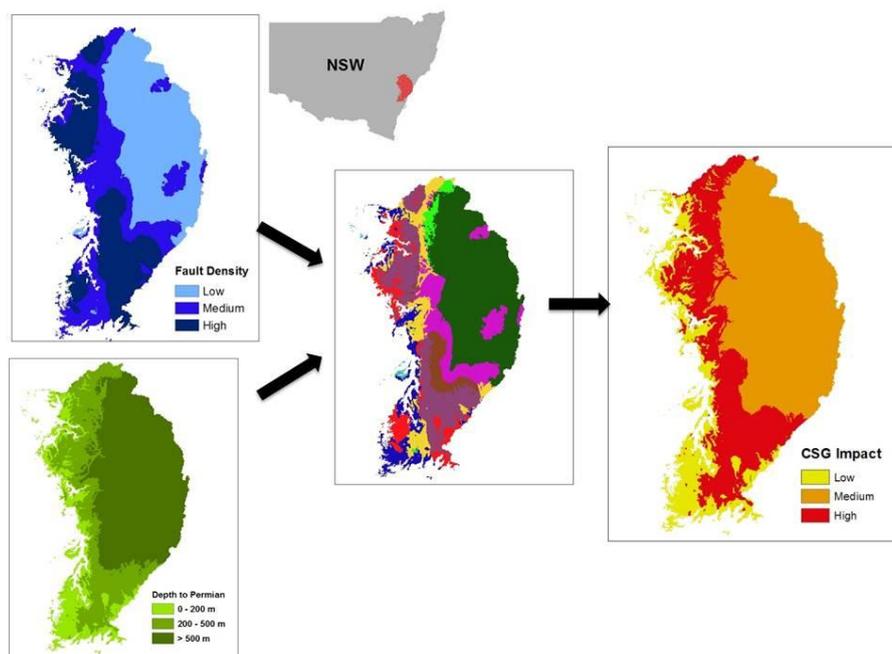


Figure 2: An illustration of the GIS analysis process and the resulting GIS potential impact layers for Coal Seam Gas within the Sydney Basin. The full study area has not been included since that any area beyond the coal measures boundary was assumed to be low impact.

Based on the specified GIS analysis described previously, the aquifers that have high hazard from both current operations, and from the potential to expand, are the shallow Hawkesbury-Nepean alluvial aquifer associated with the main river systems of the Hawkesbury-Nepean catchment, and the deeper Hawkesbury Sandstone aquifer that lies above the Southern Coalfields. Both aquifer systems provide reliable yields for stock and domestic use as well as in some cases irrigation for agriculture. In the northern area of the Southern Rivers CMA, most of the Hawkesbury-Nepean CMA and Sydney Metropolitan CMA, aquifers have a high existing and potential hazard from CSG extraction.

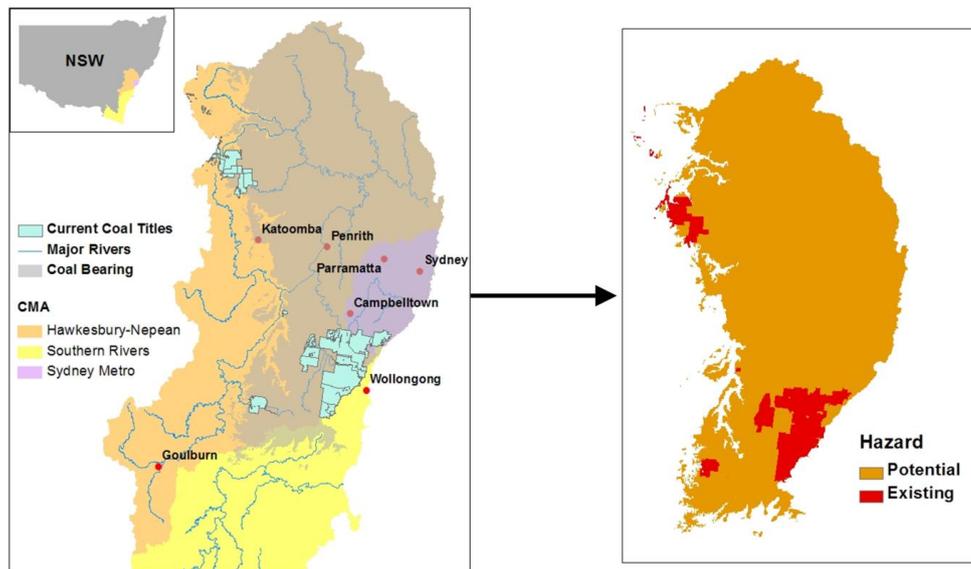


Figure 3: The resulting GIS hazard layer developed from locations of current coal titles and the extent of Permian coal measures. Aquifers and environmental features that do not fall within the limits of potential or existing hazards are classified as ‘No Hazard.’

## 6. CONCLUSION

The results of this initial rapid assessment of potential impacts and hazards of CSG activity on aquifers and the surface environment, and the associated GIS analysis, will provide government a useful tool for implementing environmental management strategies. It is recommended that areas within the study area identified as having a high potential impact should require a more detailed level of environmental impact assessment than an area with medium or low potential impact. These high areas occur where coal seams are at least 200m below ground level and where significant fracture density occurs. Existing hazard areas for CSG relate to where CSG titles (or coal mining titles) currently occur.

It is suggested that future research and development should focus on collecting data on aquifer/aquitard characterisation through pumping test analysis in order to

determine leakage coefficients. This would enable a better understanding of the hydraulic connectivity between aquifers just above the CSG target coal seam and subsequent connection to surface water systems. This would give more confidence in model input parameters which ultimately guide the decision making process for whether a CSG mining activity should go ahead or not.

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