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Bioregional assessment project: Sydney Metropolitan, Southern Rivers and Hawkesbury-Nepean Catchments: data collation phase to study the impact of mining activity and coal seam gas on environmental assets

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Bioregional assessment project: Sydney Metropolitan, Southern Rivers and Hawkesbury-Nepean Catchments: data collation phase to study the impact of mining activity and coal seam gas on environmental assets

Abstract

This study was commissioned by the Hawkesbury-Nepean (HNCMA), Sydney Metropolitan (SMCMA) and Southern Rivers (SRCMA) Catchment Management Authorities and undertaken by the University of Wollongong to collate existing data and to provide a preliminary assessment of the potential impacts of coal seam gas (CSG) and coal mining activities on environmental assets within the three CMA regions, where environmental assets were defined under three broad themes; water, land and biodiversity. This study formed part of the Australian Federal Government's Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) Bioregional Assessment initiative within regions potentially affected by CSG and coal mining activities. The key components of this study included:

Creating a database (using on the SEWPaC supplied template) identifying key environmental assets (groundwater, surface water, wetlands, land use, soils, vegetation and threatened species) within each of the three CMA regions.

Providing a list of the key GIS datasets used to compile the database and their sources.

Providing this report which outlines findings in relation to potential impacts and hazards of coal seam gas and mining activity on these environmental assets.

Identifying knowledge and data gaps, and providing recommendations for future research.

Keywords

bioregional, project, sydney, metropolitan, southern, rivers, hawkesbury, nepean, catchments, data, collation, phase, study, impact, mining, activity, coal, seam, gas, environmental, assets, assessment, GeoQuest

Disciplines

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WOLLONGONG**

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**Data Collation Phase to study the Impact of Mining Activity and Coal Seam
Gas on Environmental Assets**

November 2012

**Prepared for Hawkesbury-Nepean, Sydney Metropolitan and Southern Rivers
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EXECUTIVE SUMMARY

This study was commissioned by the Hawkesbury-Nepean (HNCMA), Sydney Metropolitan (SMCMA) and Southern Rivers (SRCMA) Catchment Management Authorities and undertaken by the University of Wollongong to collate existing data and to provide a preliminary assessment of the potential impacts of coal seam gas (CSG) and coal mining activities on environmental assets within the three CMA regions, where environmental assets were defined under three broad themes; water, land and biodiversity. This study formed part of the Australian Federal Government's Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) Bioregional Assessment initiative within regions potentially affected by CSG and coal mining activities. The key components of this study included:

- Creating a database (using on the SEWPaC supplied template) identifying key environmental assets (groundwater, surface water, wetlands, land use, soils, vegetation and threatened species) within each of the three CMA regions.
- Providing a list of the key GIS datasets used to compile the database and their sources.
- Providing this report which outlines findings in relation to potential impacts and hazards of coal seam gas and mining activity on these environmental assets.
- Identifying knowledge and data gaps, and providing recommendations for future research.

The potential impacts of CSG and coal mining activities on environmental assets were the key focus of this study. Data collation and analysis concentrated on gathering information that linked environmental assets to underlying coal lithology in the three CMA regions. For this study, lithology was used as the key factor underpinning potential impacts of CSG and coal mining. Consequently potential impact to environmental assets was assessed by overlaying environmental spatial datasets with lithological and structural (fault and fracture) geology datasets in a Geographical Information Systems (GIS). The potential risk of CSG to environmental assets was assigned using risk matrices which classified the potential impacts as high, medium or low. Environmental assets deemed to be potentially at risk from coal mining were those underlain by coal seams within 500 m of the surface and where the lithology contained a high fracture density. Similarly, environmental assets thought to be at greatest risk of impact from CSG activities were those underlain by coal seams occurring at depths >500 m and where the lithology was highly fractured.

The likely impacts on groundwater, surface water and wetland assets were found to vary according to the type of mining, the proximity to mining, the amount of groundwater extraction and the extent

of the aquifer connection. Potential direct impacts of CSG and coal mining activities on water assets were found to include:

- The level of water supply needed for CSG drilling and mining processes.
- Groundwater quantity (groundwater drawdown). Groundwater quality (contamination risk).
- Surface water quality (produced water storage and containment).
- Surface water quantity (compressive failure fracturing).

Based on the GIS analysis, the groundwater assets most at risk from both current and potential operations were 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 water yields for agricultural and domestic use, as well as in some cases irrigation for agriculture. Subsequently, groundwater assets deemed to have high potential impacts from CSG and coal mining activities were found to occur throughout most of the Hawkesbury-Nepean CMA (HNCMA) and Sydney Metropolitan CMA (SMCMA) and in the northern area of the Southern Rivers CMA (SRCMA).

Hazard analysis for the surface water assets demonstrated that both existing and potential impacts classed as medium to high hazard occurred widely within the HNCMA and SMCMA regions. Seven sub-catchments within the SRCMA were determined to have potential impacts including the Kangaroo River, Minnamurra River, Bungonia, Bugong Creek, Bomaderry Creek, Broughten Creek and Broughten Mill Creek. Sub-catchments draining to Lake Illawarra, along with the small Wollongong sub-catchments draining the Illawarra escarpment all contained existing hazards associated with current coal extraction.

A significant portion of the central HNCMA was classified as having high potential impact with regards to CSG operations. This included the major drinking water supply reservoirs (the Nepean, Avon, Cordeaux, Cataract and Woronora, and Wingecarribee Reservoirs) supplying the Sydney region. The sub-catchments of these reservoirs correspondingly were classified as having high potential impacts. Lake Woronora and Prospect Reservoir were found to be medium potential impact, though the headwaters of the Lake Woronora catchment were considered to be of high potential impact. The majority of Lake Burragorang was classed as low impact, although the outflow to the Nepean River has potential high hazard potential. The eastern portion of the HNCMA and much of the SMCMA have a medium impact ranking.

In terms of potential hazards from coal mining much of the central and western portions of the HNCMA were classified as having high likely impact. However, areas east and downstream of the Hawkesbury River, South Creek and Webbs Creek sub-catchments have a low likely impact associated, owing to the depths of the coal sequences in this part of the basin.

There were a number of factors which limited the degree to which the potential impacts of CSG and coal mining could be determined in this study. These included gaps in data and knowledge gaps in hydrogeological processes and the degree of scientific understanding of how CSG or coal mining may affect environmental assets.

Key data gaps identified in this study included:

- Lack of spatial data for threatened species in the study area.
- Lack of spatial data for wetlands in the study area.
- Lack of spatial data for vegetation within the study area.
- Lack of gauge records for a large number of sub-catchments.
- Lack of ground water data, particularly in high risk areas and in vertical profiles.
- Lack of data quality assurance.

Critical knowledge gaps with regard to hydrogeological processes identified included.

- Lack of knowledge of groundwater flow. Lack of specific knowledge of aquifer storage and behaviour parameters
- Lack of knowledge in the degree of connectivity between aquifer systems.
- A lack of understanding of vertical groundwater conditions
- A lack of knowledge of fracturing and jointing patterns within the rocks containing aquifers.
- Knowledge gaps in groundwater and surface water connectivity.
- Knowledge gaps in existing ground water extent and behaviour driven by poor quality data collection.
- Lack of groundwater data sharing between CSG operators and water resource and environmental managers compounding existing knowledge gaps.

Several key knowledge gaps regarding the potential effects of CSG and coal extraction on environmental assets were identified. These include:

- A lack of understanding of flow-on effects, indirect impacts and cumulative effects of CSG and coal extraction. ..

- Lack of knowledge about the contribution of CSG derived methane to greenhouse gas concentrations. ..
- Lack of publically available data which could contribute to closing knowledge gaps..
- Lack of understanding of potential effects of CSG or coal mining operations on groundwater dependent ecosystems. T.
- Gaps in knowledge on likely impacts of CSG development in the study area on bush fire hazard. Knowledge gaps surrounding habitat destruction and fragmentation during development of coal or CSG operations (.
- Potential effects of groundwater contamination on the wider environment.

Based on the findings of this report a number of key recommendations were suggested for future research. These included:

- Collection of agreed standardised baseline monitoring data, particularly for groundwater resources from aquifer systems in vertical profiles. .
- Comprehensive research and modelling of potential fracture networks in aquifers..
- Development of a cumulative risk assessment framework to determine the long-term environmental effects of CSG exploration and extraction.
- Environmental asset sensitivity analysis.
- Development of an integrated GIS and environmental database system that can be used to characterise risk and potential impacts.

Recommendations are suggested for future research based on key knowledge and data gaps identified and can be summarised as follows:

- Collection of agreed standardised baseline monitoring data, particularly for groundwater resources from aquifer systems in vertical profiles. This should include scientifically valid installation of bores, water level and quality sampling, and pumping tests on aquifers and aquitards to characterise vertical geological profiles. A more comprehensive surface water testing that analyses water quality, flow rate, discharge and recharge, and ecosystem health in catchments identified as high risk. This should be conducted in spatially strategic areas.
- Comprehensive research and modelling into potential fracture networks and aquifer parameter characteristics in these systems. This should include sensitivity analysis of environmental assets on the modelling results.
- Developing a cumulative risk assessment framework associated with long-term environmental effects of CSG exploration and extraction.

- Development of an integrated GIS and environmental database system that can be used to characterise risk and potential impacts.

The development of a method to assess the flow-on, cumulative and long-term effects of CGS exploration and extraction which considers impacts on both the adjacent and wider environment. This could include the development of a cumulative risk assessment framework.

1. INTRODUCTION

This report has been compiled as part of the Federal government's Bioregional Assessment Projects on the potential impacts of coal seam gas (CSG) and coal mining on water resources, and funded through key Catchment Management Authorities (CMAs) where these potential impacts were most likely to occur. An Interim Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining was setup by the Federal Minister for Sustainability, Environment, Water, Population and Communities (SEWPaC) to oversee research on identified knowledge gaps in scientific understanding about the potential water-related impacts of CSG and/large coal mining developments to assist in regulatory decisions made at the State level.

In June 2012, the Hawkesbury-Nepean, Sydney Metropolitan, and Southern Rivers CMAs commissioned the University of Wollongong's School of Earth and Environmental Sciences to collate the water/environmental asset datasets available, and to propose potential impacts and hazards of mining activity and CSG on these environmental assets, as part of the federal initiative. The study area for this report will be focused on these three CMA regions, and will be referred to as the "study area" henceforth. The study area is endowed with rich natural resources with a growing population. This places pressure on land, water and ecological assets, creating a need for a better understanding of the natural system and the sustainable management of those natural resources.

In the past number of years in Australia, and specifically within the study area, the development of CSG has emerged as an extremely contentious environmental issue. Although there are genuine concerns about the potential social impacts of this rapidly evolving industry, the main concerns raised by the community groups tend to concentrate on the possible environmental impacts of CSG development, particularly local and regional impacts on groundwater, water catchments and agricultural land. Independent researchers and numerous government agencies have also expressed concern, particularly at the apparent lack of independent scientific research and baseline data with which to make informed decisions (NSW Inquiry into CSG, 2012).

Significant environmental challenges remain however, particularly in regions such as the Illawarra in NSW, where CSG is planned for relatively pristine bushland in an important water catchment for the Sydney Basin. However, the economy of the Illawarra region has been closely tied to coal mining that has powered industries such as Port Kembla Steel works and provided important export revenue to the state for the past 150 years. Concerns about water are of particular importance in

the Illawarra, as the Southern Coalfields forms part of an important water catchment for the Sydney Basin, supplying drinking water to over four million people.

This report aims to address the need for collating baseline data with a view to identifying knowledge gaps for future research activities and to provide a preliminary assessment of the potential impacts and hazards of coal mining and CSG activities within the study area. Specifically, the objectives of this report are to:

- Review existing water assets map of the three CMA regions by SEWPac;
- Identify additional existing water asset data sets within the study area;
- Identify other relevant environmental asset data sets;
- Collate the above information into a database provided by SEWPac (presented separately to this report);
- Identify potential impacts and possible hazards of CSG and coal mining on identified environmental assets and discuss why they are perceived impacts and hazards;
- Identify knowledge gaps and/or caveats in the data sets.

2. STUDY AREA

The study area (*Figure 1*) has been defined as three Catchment Management Authority areas; the Hawkesbury-Nepean, Sydney Metropolitan and the Southern Rivers. Currently, the Hawkesbury-Nepean and the Sydney Metropolitan CMAs are in the process of merging.

2.1 Catchment Management Areas

Hawkesbury-Nepean Catchment Management Authority (HNCMA) Area

The Hawkesbury-Nepean catchment is defined by the drainage of the Hawkesbury and Nepean river systems. The catchment cradles Sydney, supplying the city and surrounding regions with food, water and other resources. The Hawkesbury River starts near Lake Bathurst, south of Goulburn and flows 470 km to its outlet at Broken Bay. The river drains 21,400 km² and covers 2.14 million hectares of land.

Sydney Metropolitan Catchment Management Authority (SMCMA) Area

The Sydney Metropolitan catchment is a highly urbanised region centred on Sydney and its surrounds. The region consists of the Woronora Plateau, coastal and estuarine landscapes of the Georges, Woronora and Cooks Rivers, drowned river valleys and ridgelines of the Parramatta River, Middle Harbour and Sydney Harbour, sheer coastal cliffs of Manly and Watson's Bay, the entrance of Sydney Harbour, coastal bays, beaches and sand dune systems such as Botany Bay, and the broad plains and low hills of the Cumberland woodlands. Sydney's natural environment has been extensively degraded with 90% of riparian vegetation cleared.

Southern Rivers Catchment Management Authority (SRCMA) Area

The Southern Rivers catchment covers a 32,000 km² area of the south-east of NSW – from Stanwell Park in the north, to the Victorian border in the south, and includes the major river systems of the Shoalhaven, Snowy and Genoa. The Southern Rivers region is home to approximately half a million people and supports a variety of landuses including agriculture, urban and expanding urban areas, industrial areas and rural lifestyle residential development. The SRCMA covers all or part of 12 local government areas: Wollongong, Shellharbour, Kiama, Shoalhaven, Eurobodalla, Bega Valley, Bombala, Snowy River, Cooma-Monaro, Palerang, Goulburn-Mulwaree and Wingecarribee.

The Hawkesbury-Nepean and Sydney Metropolitan catchments completely lie within the Sydney Geological Basin. Only the northern area of the Southern Rivers Catchments form part of the Sydney Basin. This is important because the Southern Coalfields and Western Coalfields lie within the Sydney Basin. The Southern Coalfields affect all three CMA regions and the Western Coalfields (around Lithgow) affect the HNCMA region. The southern section of the Southern Rivers Catchment area are included in the study area for completion but are not affected by coal mining or CSG activity due to the lack of coal present.

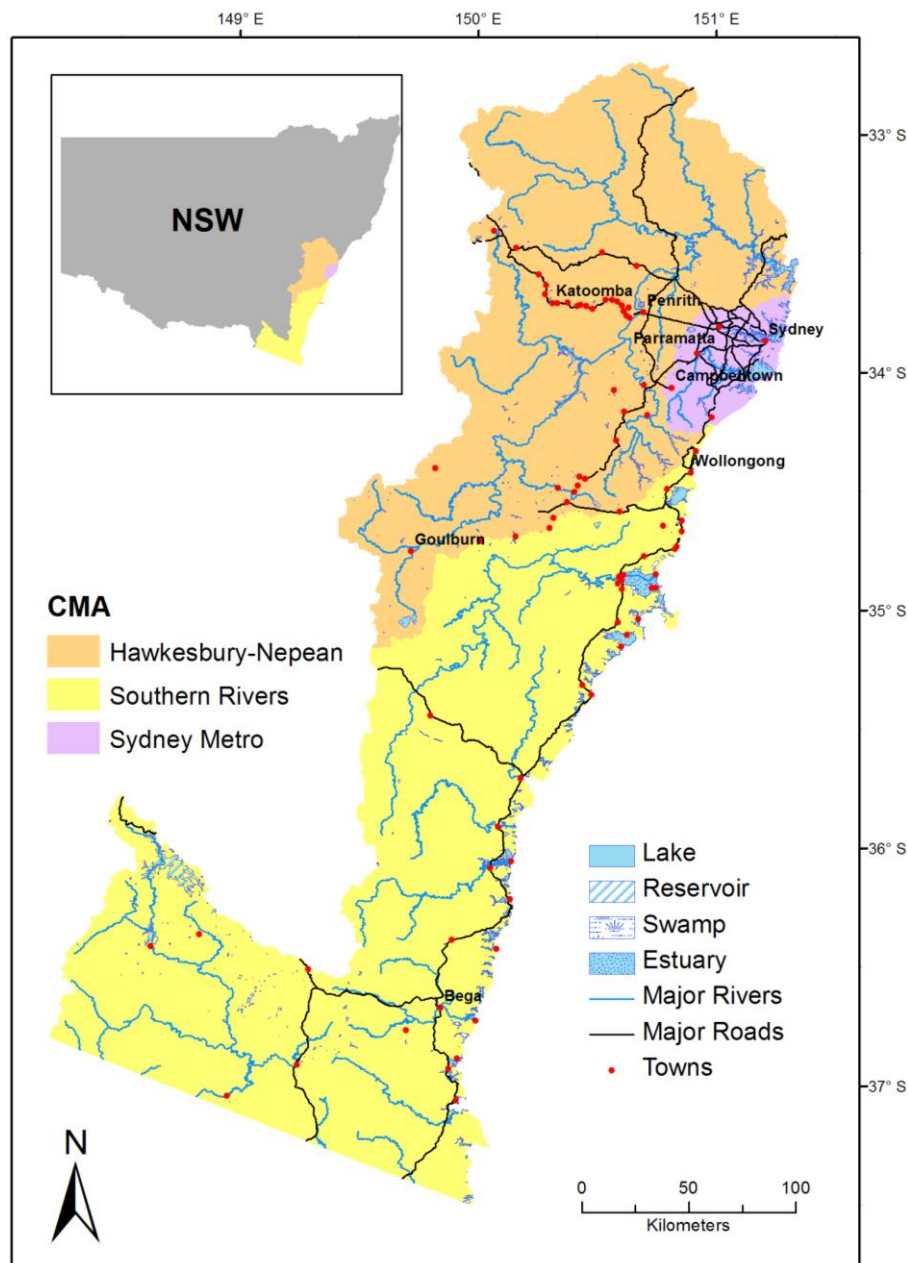


Figure 1: Location of the three CMA areas that form the study area

2.2. Geology

The geology of the study area consists of the Sydney Basin, Lachlan fold belt and the Bega Batholith. There are five major coalfields located within the study area: the Hunter, Southern, Western, Central and Newcastle coalfields (*Figure 2*). The coalfields occur exclusively within the Sydney-Gunnedah-Bowen Basin system. For the purposes of this report the Lachlan fold belt and the Bega Batholith will not be considered in further detail, as no associated hazards or impacts from coal mining and CSG activities occur within these regions. Within the study area, coal titles occur primarily in the Southern Coalfields, covering both Hawkesbury-Nepean and Southern Rivers CMA regions, while coal titles to the west of the Hawkesbury-Nepean CMA lie within the Western coalfields. Since there are no coal titles existing in the Central, Hunter or Newcastle coalfields, these will not be discussed further.

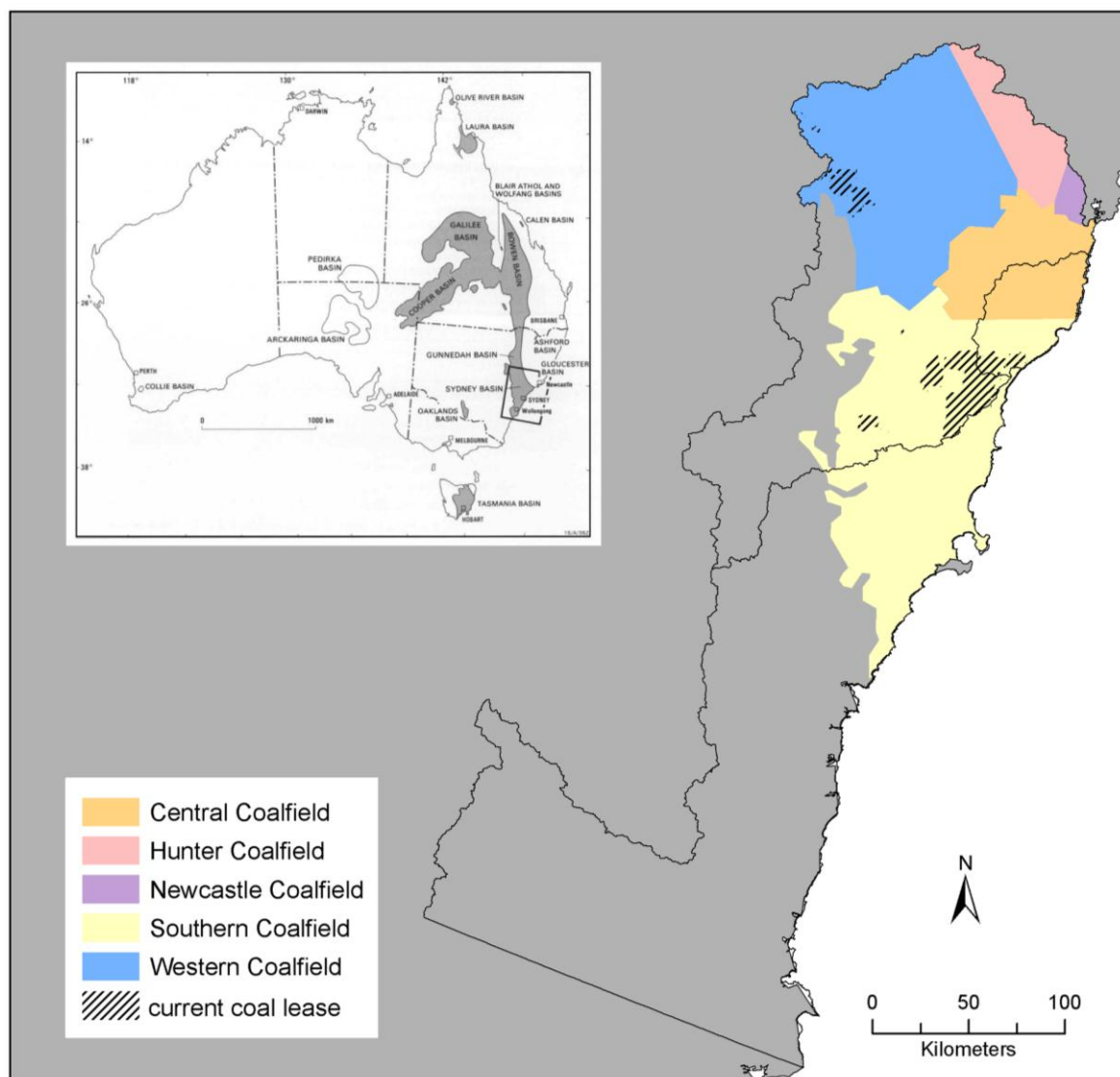


Figure 2: Major coal resources and mining leases within the study area

2.2.1. Sydney Basin

The Sydney Basin is a large sedimentary basin on the east coast of Australia covering almost 50,000 km², whereby approximately 44,000 km² is located onshore and another 5,000 km² located offshore extending to the edge of the continental shelf (*Figure 2*). The basin forms part of the larger Sydney-Gunnedah-Bowen Basin system (*Figure 2* inset) which extends 1,700 km north from coastal southern NSW to Townsville.

Stratigraphy

The stratigraphy of the Sydney Basin is dominated by six major units that gradually thin from the centre of the basin to the margins, shown as a N-S cross section in *Figure 3* and a stratigraphic column in *Figure 4*. 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. The Shoalhaven Group consists of lithic sandstones interbedded with shale and mudstone, which were deposited in a marine or marine-influenced environment. The group consists of the basal Pebbly Beach Formation, the Snapper Point Formation, the Wandrawandian Siltstone, the fluvially deposited Nowra Sandstone, the Berry Siltstone, and capping the sequence - the Budgong Sandstone (Bowman, 1973; Runnegar, 1973; Eyles *et al.*, 1998).

On the western margins of the southern Sydney Basin, where the basin meets the Lachlan Fold Belt, the Talaterang Group and Pebbly Beach Formation are not present; the basal outcrop is the Snapper Point Formation. 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 (Bembrick *et al.*, 1980; Carr and Jones, 2001).

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 (Bowman, 1973; Hutton *et al.*, 1990; Hutton, 2009).

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 (Haworth, 2003).

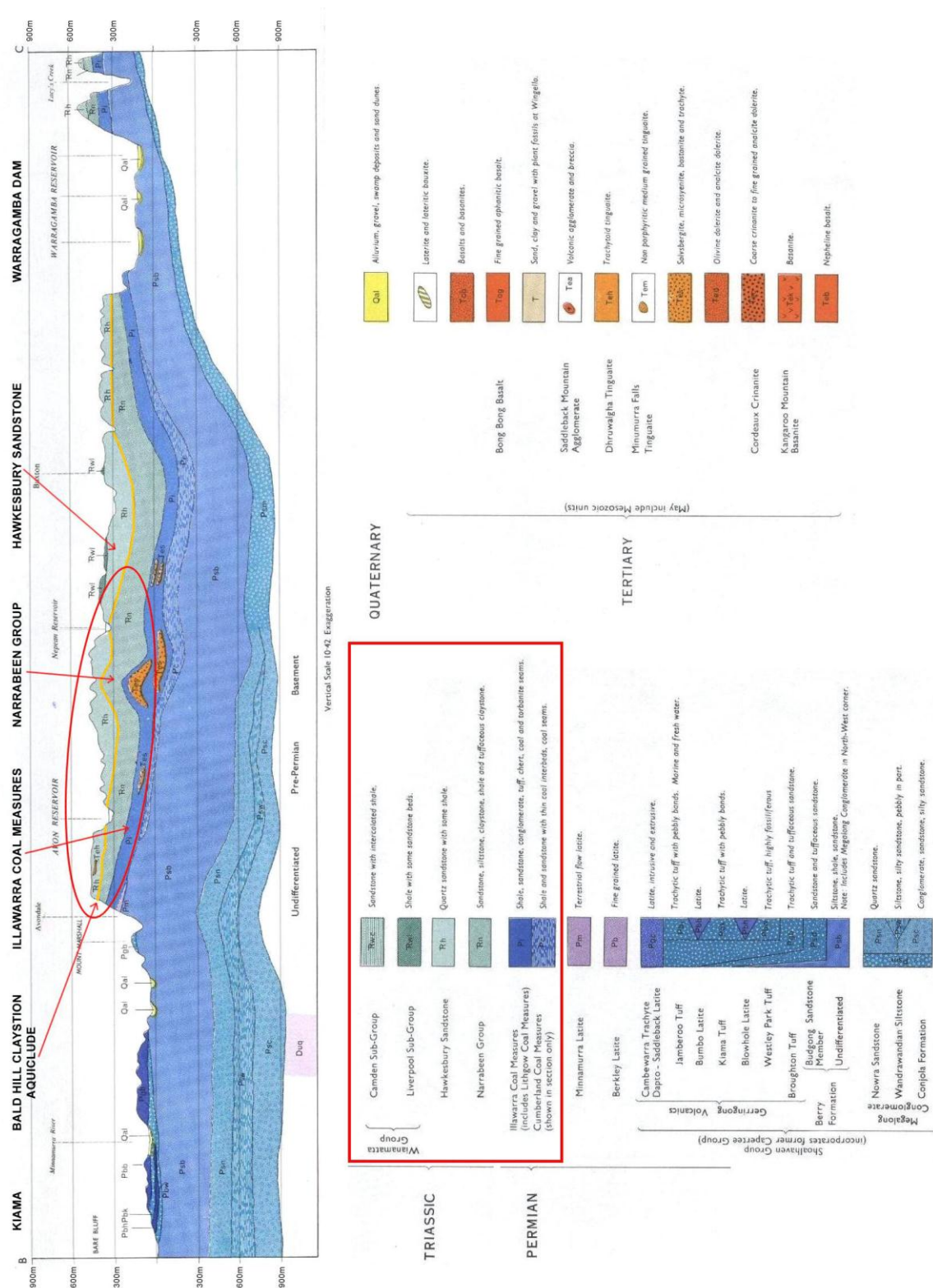


Figure 3: Stratigraphic cross-section of the Sydney Basin (Source: Geological Survey of NSW)

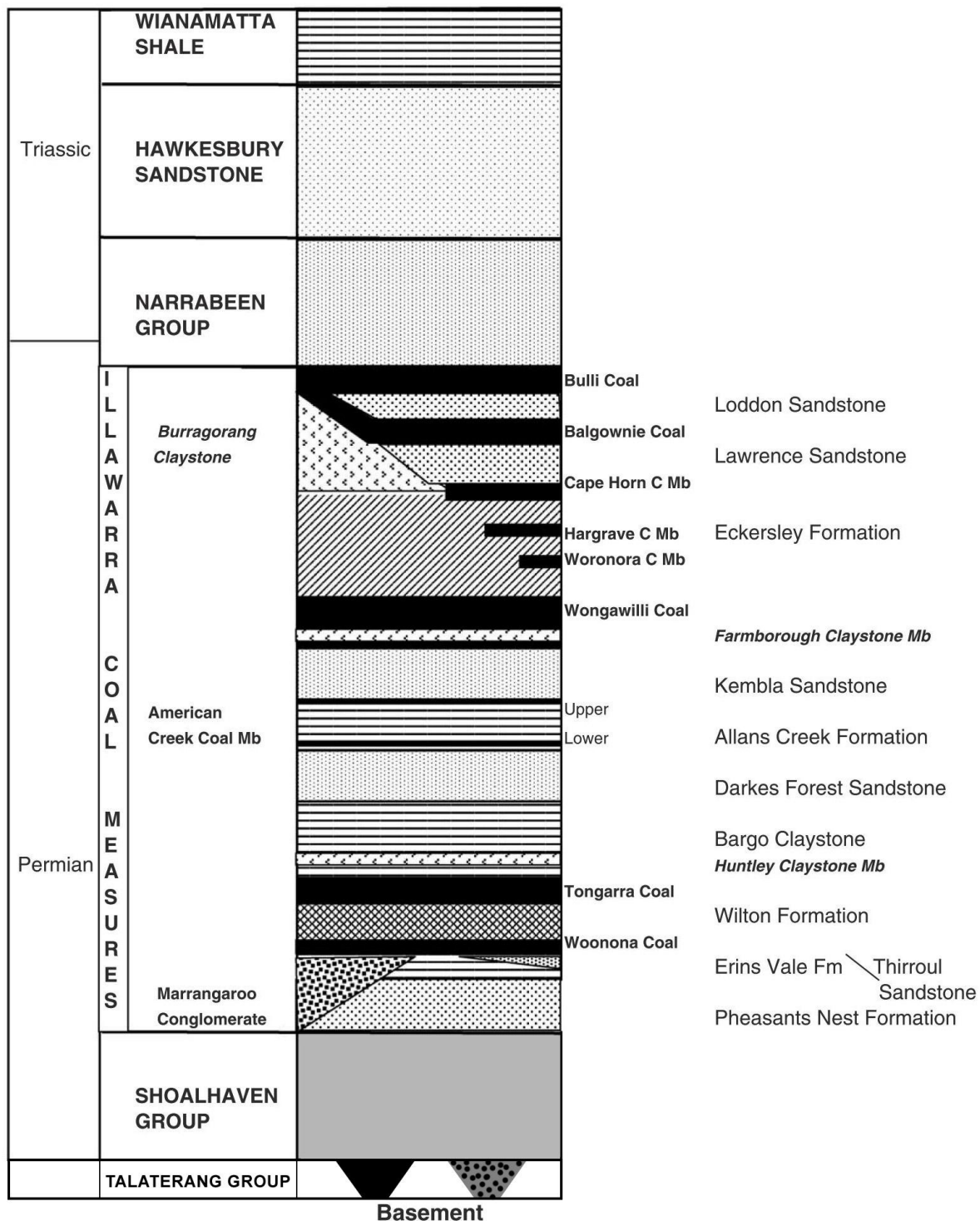


Figure 4: Stratigraphy of the Sydney Basin (not to scale) (Source: Grevenitz et al., 2003; Geological Survey of NSW, 2012; NSW Geological Survey, 1985)

Historically, the top of the Illawarra Coal Measures (i.e. the Permian geology) has been defined as the uppermost coal-bearing horizon. This has also been considered as the upper limit of the Permian system in the Sydney Basin (Bembrick, 1980). It is useful to illustrate the relationship between the spatial distribution of surface geological units relative to the depth to the Permian coal seams. This is presented in *Figure 5*.

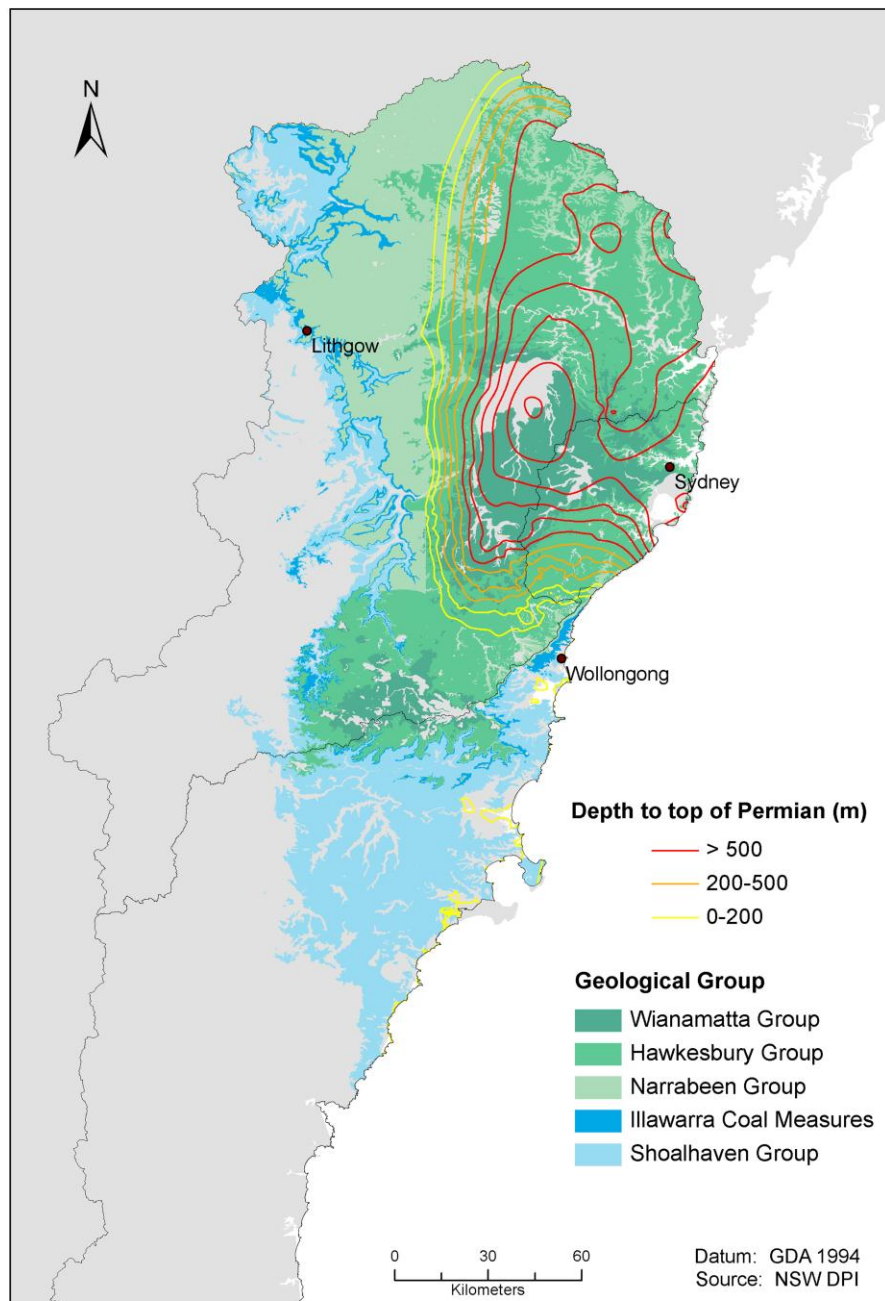


Figure 5: Contours showing the depth to the top of Permian stratigraphic unit, which is the depth to the major coal seams of the Sydney Basin illustrated as the five geological groups

2.2.2 Southern Coalfield

The Southern Coalfield comprises the southern portion of the Sydney Basin, covering an area south of Sydney almost to Batemans Bay, bounded in the west by the towns of Camden and Mittagong, and Helensburgh and Wollongong in the east. The present areas of active longwall coal mining and CSG development are typically located near the Hume Highway to the west and the Illawarra escarpment to the east (McNally and Evans, 2007; NSW Dept. Trade and Investment, 2012).

The first coal mining operation began in the region at Mt Keira in 1848, with more than 60 mines established in the region since that time. The high quality coking coal became one of the key drivers for economic development in the region, more recently leading to the development of a vibrant local steel industry, port facilities, and railway lines linking Wollongong to Sydney. Although industries such as tourism and education have helped diversify the mix of commercial enterprise in the region, coal mining continues to play an important role in the Illawarra economy (ERMA, 2007).

The topography of the region is a rugged sandstone plateau intersected by steep V-shaped gorges, which in some sections exhibit a rectilinear drainage pattern characterised by dominant joints and lineaments. These lineaments, which can be the exposed surface of igneous dykes or clusters of 'master' joints and can sometimes be greater than one kilometre in length, are occasionally linked with regions of sub-surface rock mass permeability and lateral stress. The soils on the sandstone plateau surface are generally thin, with bare rock shelves frequently exposed in creek beds. The combination of thin soils, exposed rock shelves and relatively wide-spaced jointing, tends to intensify surface strains and cause noticeable vertical fractures in areas that have been undermined (Bunny, 1972; Sherwin and Holmes, 1986; McNally and Evans, 2007).

The major sequences of the Southern Coalfield requiring further discussion in this study are the Illawarra Coal Measures, and the Triassic sequence of the Narrabeen Group and Hawkesbury Sandstone. It is these geological sequences that have the potential to impact environmental assets due to CSG and coal mining activity.

Illawarra Coal Measures

The geological units of major economic significance in the Southern Coalfield are the late Permian Illawarra Coal Measures, a 240 m thick deltaic sequence that occurs above the Shoalhaven Group and beneath the Hawkesbury Sandstone and Narrabeen Group. The Illawarra Coal Measures (*Figure 4*) are divided into two subgroups, the basal Cumberland Subgroup, containing both the Pheasants Nest Formation and Erins Vale Formation, and the Sydney Subgroup which contains the economic coal seams (Bulli, Balgownie, Wongawilli, and Tongarra seams). The coal measures outcrop above

sea level approximately 20 km to the north of Wollongong. The Illawarra Coal Measures dip at approximately four degrees to the NW in the Illawarra that creates the outcrop pattern that extends from sea level about 20 km north of Wollongong before turning westward to track the northern side of the Shoalhaven River valleys (Bowman, 1973; Hutton *et al.*, 1990; Hutton, 2009).

The Bulli seam, in particular, has become the main target for CSG exploration and development in the region, with greenfield CSG production near the Camden region and goaf methane generators at the Appin and Tower collieries operating for 10 years and 16 years respectively. Nearer to Wollongong, in the Helensburgh/Darkes Forest region, Apex Energy has submitted plans to develop CSG from the collapsed coal workings (goaf) of the Metropolitan Colliery.

The Bulli seam is stratigraphically the top seam in the Illawarra Coal Measures and represents the majority of the coal reserves. The seam is generally two to three metres thick, apart from the northern section of the coalfield where it increases to five metres. It comprises interbanded dull and bright coal plies, with sub-bands of siderite and claystone. The seam is medium ash (8 to 9% in the east, and increasing westward), medium volatile matter (21.5 to 27.5%, air dry) and has a relatively low sulphur content.

In terms of potential for CSG development, the Sydney Basin and Illawarra Coal Measures represent an enormous reservoir for methane, with gas contents in many areas in excess of 18 m³ per tonne, with the gas consisting predominantly of methane (up to 95%), with ethane concentrations up to 5% at greater depth (Faiz and Hutton, 1995).

The Triassic Sequence

The Triassic sequence of the Southern Coalfield (i.e. the Narrabeen Group and Hawkesbury Sandstone) is mainly sandstone, with finer-grained rocks at depth. The combined sequence varies in thickness from 100 m at the Illawarra Escarpment to 400 to 500 m at the longwall mines to the west, dipping to the north-west at a very low angle. Both major groups are intruded in places by basaltic and syenitic plugs, sills and dykes. These intrusions in the sequence may act as channels for surface water to migrate down to seam level, and depending on the intensity of weathering and fracturing, can act as groundwater stores, or vertical conduits and connectivity for aquifers. It is generally accepted that although natural fractures are present, they do not have a great impact on groundwater (Bunny, 1972; Sherwin and Holmes, 1986; McNally and Evans, 2007).

Narrabeen Group

The overall thickness of the Narrabeen Group in the Southern Coalfield is approximately 300 m, of which 200 m is the Bulgo Sandstone and 24 m is the overlying Bald Hill Claystone. The Bald Hill Claystone is generally thought to act as a confining or sealing layer (aquiclude) between the Bulgo and overlying Hawkesbury Sandstone (see *Figure 3*). Assessments of both groups show that the Narrabeen Group differs from the Hawkesbury Sandstone in the following ways:

- Bedding in the Narrabeen Group is typically more continuous (shale beds often extend horizontally further than 100 m).
- The Narrabeen Group displays minimal cross bedding.
- Cliff lines in the Narrabeen Group are less visible (McKibben and Smith, 2000; McNally and Evans, 2007).

The Narrabeen Group is also characterised by its petrological features:

- Grains of the sandstones are a mix of quartz and lithic fragments, rather than quartz. The sand-sized lithic fragments make up 20 to 30% of the clastic part of the unit, and are not as well sorted as in the Hawkesbury Sandstone.
- Unweathered sandstones are typically more cemented, denser and less porous than those of the Hawkesbury Sandstone, and the cement is principally carbonate (more siderite than calcite).
- Unweathered rocks are light to dark grey in colour due to a fine siderite cement and can be found one to two metres below the surface. Hawkesbury Sandstone is by contrast often weathered and orange-brown to depths of 30 m and greater (McKibben and Smith, 2000; McNally and Evans, 2007).

Hawkesbury Sandstone

The Hawkesbury Sandstone is a quartz sandstone unit composed of very thick beds of heavily compacted sand, with a small quantity (about 5%) of shale in discontinuous beds one to three metres thick. The thickness of the Hawkesbury Sandstone in the Southern Coalfield varies depending on the amount of erosion, but is typically 100 to 200 m thick, with some sections up to 300 m thick. The individual sandstone beds are generally one to 10 m thick, but continue laterally for only 100 to 300 m. For this reason, the sandstone beds are described as being 'lenticular'. The joints in the Hawkesbury Sandstone are sub-vertical and normally spaced slightly wider than the bedding planes (Bunny, 1972; Conaghan, 1977; Miall, 2006; McNally and Evans, 2007)

Groundwater flow is generally down joints and laterally across the bedding planes, creating numerous perched water tables after rain. There is also a certain amount of variability in the degree of cementation between layers, resulting in some beds outcropping more than others. This is also likely to lead to variations in the distribution of perched water tables and differences in hydraulic conductivity (permeability) between layers (McNally and Evans, 2007).

2.2.3 Western Coalfield

The Western Coalfield lies on the western portion of the Sydney Basin, west of the Blue Mountains National Park and centres on the township of Lithgow. It lies partially in the Hawkesbury-Nepean CMA region. Coal mining activity has taken place in the Western Coalfield since about 1880. Major coal mining areas occur further to the north and west, in the vicinity of Lithgow.

The coal seams are part of the Illawarra Coal Measures (described under Southern Coalfields) and have been divided into two sub-groups, the Nile Sub-Group and the Charbon Sub-Group (Bembrick, 1980). The major economic seam, the Katoomba seam, is at the top of the sequence. A useful account of the coalfield geology is found in Branagan (1960).

A stratigraphic column that summarises the correlation between all five coalfields of the Sydney Basin is found in *Figure 6*.

AGE		WESTERN (LITHGOW AREA)		SOUTHERN (WOLLONGONG AREA)		NORTHEASTERN (NEWCASTLE AREA)		NORTHWESTERN (MUSWELLBROOK AREA)					
TRIASSIC	LADINIAN			Bringelly Shale Minchinbury Sandstone									
		Ashfield Shale Mittagong Formation		Ashfield Shale Mittagong Formation									
	ANISIAN	Hawkesbury Sandstone		Hawkesbury Sandstone		Hawkesbury Sandstone		Hawkesbury Sandstone					
	SPATHIAN SMITHAN DIENERIAN GRIES- BACHIAN	Burralow Formation Banks Wall Sandstone Mount York Claystone Burra-Moko Head Sandstone Hartley Vale Claystone Govetts Leap Sandstone Victoria Pass Claystone Clwydd Sandstone Beauchamp Falls Shale		Newport Formation Garie Formation Bald Hill Claystone Bulgo Sandstone Stanwell Park Claystone Scarborough Sandstone Wombarra Shale Coal Cliff Sandstone		Terrigal Formation Patonga Claystone Tuggerah Formation Munmorah Conglomerate Dooralong Shale		Terrigal Formation Patonga Claystone Tuggerah Formation Munmorah Conglomerate Dooralong Shale					
PERMIAN	CHANG- SINGIAN	ILLAWARRA COAL MEASURES	ILLAWARRA COAL MEASURES	NEWCASTLE COAL MEASURES	WOLLOMBI COAL MEASURES	Katoomba Coal		Bullis Coal		Vales Point Coal Wallarah Coal		Griegs Creek coal	
						Woodford Coal Middle River Coal		Balgownie Coal		Toukley Coal Buff Point Coal Great Northern Coal		Hillsdale Coal	
								Burragorang Claystone Cape Horn Coal		Awaba Tuff Chain Valley Coal Fassifern Coal		Nalleen Tuff Hebden Gully Coal Eyriebower Coal Rombo Coal	
								Hargrave Coal		Upper Pilot Coal Lower Pilot Coal Hartley Hill Coal Mount Hutton Tuff		Carramere Coal	
								Woronora Coal		Australasian Coal		Alcheringa Coal	
								Wongawilli Coal Farmborough Claystone		Montrose Coal Wave Hill Coal Fern Valley Coal Victoria Tunnel Coal		Stafford Coal	
								American Creek Coal		Nobbys Tuff Nobbys Coal Dudley Coal Yard Coal Borehole Coal		Monkey Place Tuff Abbey Green Coal	
								Huntley Claystone					
								Tongarra Coal		Upper Sandgate Coal Lower Sandgate Coal		Whybrow Coal Redbank Creek Coal Wambo Coal Whynot Coal Blakefield Coal Glen Munro Coal Woodlands Hill Coal Arrowfield Coal Bowfield Coal Warkworth Coal Mt Arthur Coal Piercefield Coal Vaux Coal Broonie Coal Bayswater Coal	
										Upper Buttai Coal Lower Buttai Coal		Bulga Coal Arties Coal Pikes Gully Coal Upper Liddell Coal Lower Liddell Coal Barrett Coal Hebden Coal	

Figure 6: Stratigraphic framework for major regions of the Sydney Basin showing (with gray highlight) coal seams correlated by sequence stratigraphy (From Retallack et al., 2011)

2.3 Hydrogeology of the Sydney Basin

One of the reasons that CSG development has come under intense scrutiny are the potential impacts on groundwater and surface water systems. It is therefore important to discuss these systems as they relate to the Sydney Basin.

As shown in *Figure 7*, the typical representation of the hydrogeologic cycle is described as a sequence of higher permeability units called aquifers, confined by units of lower permeability called aquitards (Reynolds, 1976).

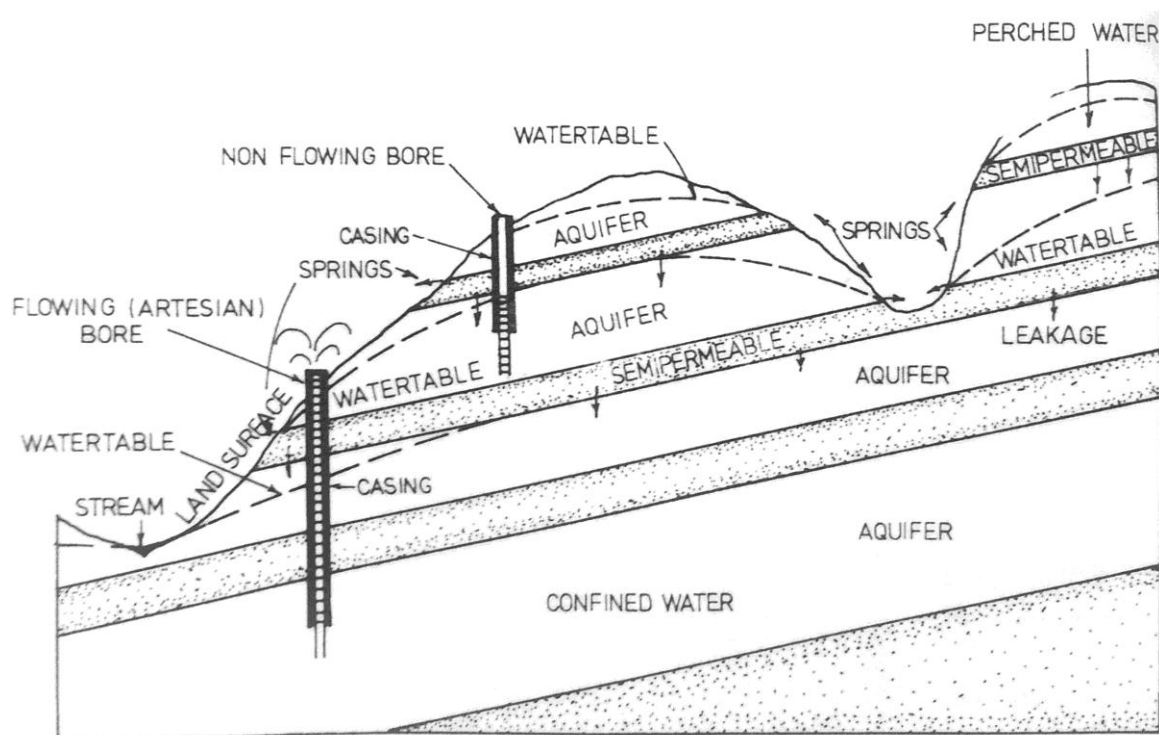


Figure 7: Typical hydrogeologic system (Source: Reynolds, 1976)

There is general consensus that both the natural hydrologic systems and the impacts of coal mining and water storage have created a hydrogeologic cycle in the Sydney Basin more complex than the traditional representation. There is not scope in this report to analyse the system in all its complexity, though a number of the significant characteristics are provided below.

2.3.1 Perched aquifers and vertical groundwater flow

The proposed model of the groundwater system in the Sydney Basin is provided by Reynolds (1976; *Figure 8*) and shows a system of perched aquifers and low permeability layers, with groundwater flowing down joints and horizontally across bedding planes. The system is typically anisotropic,

meaning that horizontal groundwater flow is significantly greater than vertical flow. While vertical flow is typically minimal in the region, it has been suggested by Judell *et al.*, (1984) that subsidence from longwall mining can create fractures that lead to an increase in vertical flow. The overall result is the movement of groundwater stepping downwards through a ladder-like network of numerous semi-isolated aquifers, (some of which may be impacted by the effects of longwall mining) linked by zones of higher permeability such as joints and cleaner sandstones (Reynolds, 1976; Judell *et al.*, 1984; Soliman *et al.*, 1997; Stone, 1999; Nonner, 2003; NSW Government, 2008). The variability of cementation between layers also results in some beds outcropping more than others, thereby leading to further variations in the distribution of perched water tables and permeability, particularly within the Hawkesbury Sandstone (McNally and Evans, 2007).

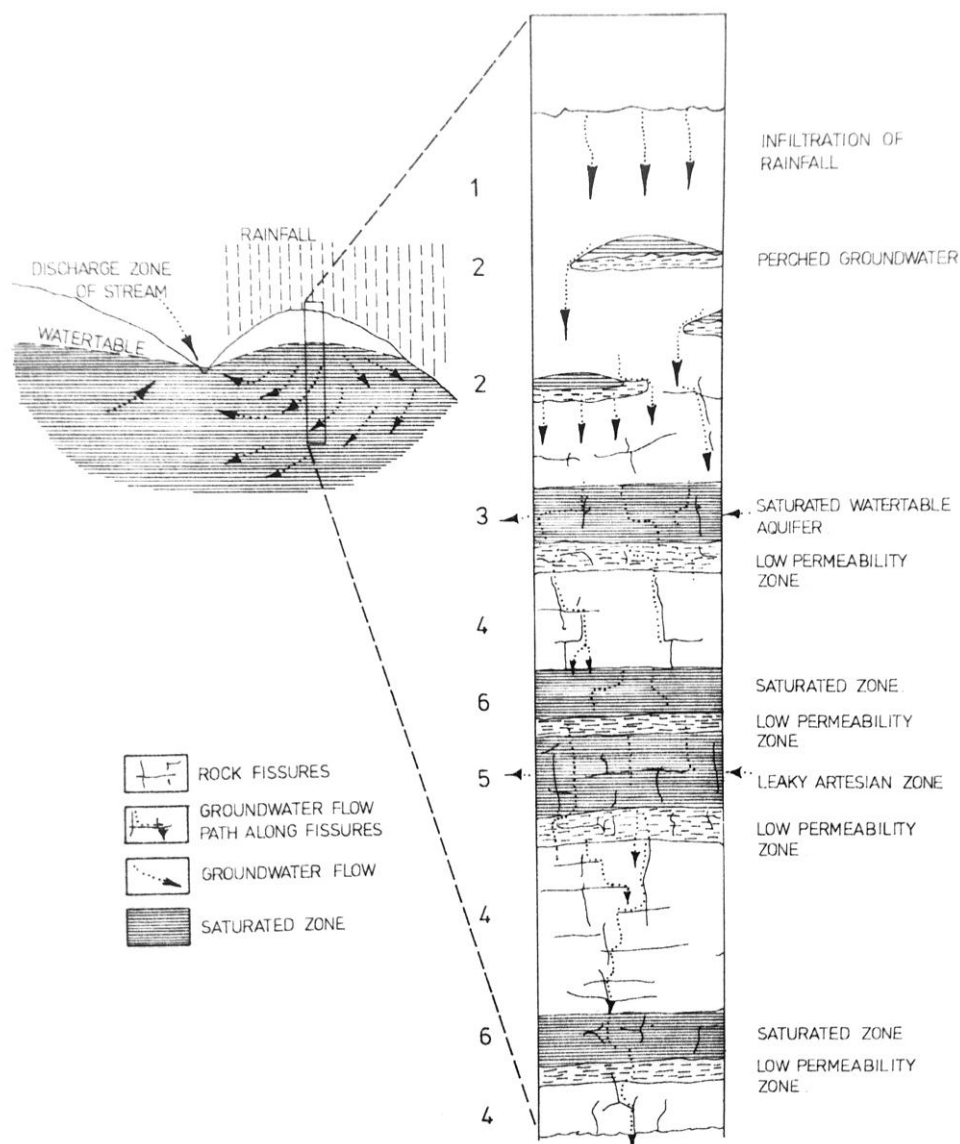


Figure 8: Proposed hydrogeological model of the Sydney Basin (Source: Reynolds, 1976)

2.3.2 Significant differences in permeability between surface sediments and deeper rocks

The permeability of the shallow unconsolidated, soils, swamps and alluvial deposits (with moderate to high permeability) is significantly higher than the permeability of the deeper consolidated rocks such as the Hawkesbury Sandstone and Narrabeen Group (low permeability). Consequently, groundwater flows through the soils and regolith much faster than it flows through the consolidated rocks. It therefore follows that the contributions of groundwater flow into the creeks and rivers within the region are significantly greater from the swamps and regolith than from the deeper rocks such as the Hawkesbury Sandstone and Narrabeen Group. Accordingly, the age of the groundwater that originates from the surficial sediment is quite young, while groundwater that comes from the deeper rocks is typically extremely old, typically in the range of 5,000 to 10,000 years in parts of the Hawkesbury Sandstone (McKibben and Smith, 2000; NSW Government, 2008).

2.3.3 The Hawkesbury Sandstone - Aquifer characteristics

The basic chemistry of groundwater is essentially the consequence of interactions between groundwater and rock over geologic time. Normally, natural uncontaminated groundwater will exhibit chemical stability within a narrow and predictable range, typically attributable to recharge processes. However, changes in groundwater flow paths, or reductions in recharge rates possibly caused by natural or induced fracturing of sandstone aquifers, may cause new rock/water reactions to take place. This can lead to short-term changes in groundwater chemistry, although it would be expected that conditions will tend towards stabilisation over time, with the groundwater chemistry tending towards that before conditions were altered (NSW Government, 2008; Karsten *et al.*, 2008; Nonner, 2003; Stone, 1999).

In the Sydney Basin, the Hawkesbury Sandstone is of great significance to groundwater, surface water and topography. The unit is highly resistant to weathering, and therefore the dominant topographical features of valleys and cliffs are influenced by naturally occurring fractures and joints in the unit. It also hosts a multi-layered system of sub- aquifers (perched water tables), connected by vertical joints and discontinuities in horizontal bedding planes (McKibben and Smith, 2000; McNally and Evans, 2007). As an aquifer, it is typically only exploited for its water in a few areas such as the Southern Highlands where well yields can be as high as 40 litres per second, although typical yields are usually 0.2 to 2 litres per second (Sydney Catchment Authority, 2006).

The water quality of the Hawkesbury Sandstone is generally potable close to recharge areas with total dissolved salts (TDS) less than 500 milligrams per litre, but salinity increases towards the centre

of the Sydney Basin with TDS often greater than 10,000 milligrams per litre. The unit porosity and hydraulic conductivity are typically secondary in origin, principally as a result of jointing and solution cavities (sandstone karsts). Permeability for the Hawkesbury Sandstone tends to be highly variable, especially in areas that have experienced subsidence from longwall mining, and therefore it is difficult to make general associations across the whole Sydney Basin, although transmissivities of 2.8m^2 per day are typical (McKibben and Smith, 2000; McNally and Evans, 2007; Hammond, 2007; Moore and Nawrocki, 1980).

2.3.4 The Bald Hill Claystone

The Sydney Basin contains a number of claystone and siltstone aquitards that restrict the movement of groundwater and gas between adjacent strata. The Bald Hill Claystone is possibly one of the more important aquitards in the Southern Coalfield because it occurs below the main aquifer in the region, the Hawkesbury Sandstone. It is generally accepted that the presence of the claystone restricts the exchange of groundwater and gas between the Hawkesbury Sandstone and the underlying Bulgo Sandstone (NSW Government, 2008; McKibben and Smith, 2000). This is significant for CSG development since wells are drilled through the both the Hawkesbury Sandstone aquifer and Bald Hill Claystone aquitard to reach the coal seams below. Migration of gas and fluids may occur if for example, well integrity was not maintained, or if the claystone was to be significantly fractured (Faiz and Hutton, 1995).

























AGE	GROUP	STRATIGRAPHIC UNIT ¹	GRAPHIC	INDICATIVE DEPTH ² (m)	GEOLOGICAL DESCRIPTION ³	HYDROGEOLOGY ⁴
MIDDLE TRIASSIC (210→200 x10 ⁶ years BP)	WIANAMATTA GROUP	BRINGELLY SHALE (AQUITARD)		60	Shale, carbonaceous claystone, claystone, laminite, fine to medium grained lithic sandstone, rare coal and tuff.	TDS >3000mg/L
		MINCHINBURY SANDSTONE		70	Fine to medium grained lithic sandstone.	
		ASHFIELD SHALE (AQUITARD)		110	Dark grey to black claystone-siltstone and fine sandstone-siltstone laminite.	Transmissivity ≈ 4m ² /day (weathered) TDS >3000mg/L
		MITTAGONG FORMATION		120	Interbedded shale, laminite and medium grained quartz sandstone	
		HAWKESBURY SANDSTONE (AQUIFER)		300	Medium to very coarse grained quartz sandstone, very minor laminated mudstone, shale, claystone and siltstone lenses.	TDS <500mg/L Yields: 0.2 to 2L/sec Transmissivity ≈ 2.8m ² /day
		NEWPORT FORMATION		320	Interbedded shale, laminite and quartz to quartz-lithic sandstone.	Transmissivity ≈ 0.1 m ² /day
EARLY TRIASSIC (230→210x10 ⁶ years BP)	NARRABEEN GROUP	GARIE FORMATION		340	Clay-pellet sandstone.	
		BALD HILL CLAYSTONE (AQUITARD)		360	Dominantly red-brown claystone and red shale with fine to medium grained sandstone.	
		BULGO SANDSTONE (AQUIFER)		610	Fine to medium grained quartz-lithic sandstone with lenticular shale interbeds.	TDS <1500mg/L, pH ≈ 7.9 Transmissivity ≈ 0.11m ² /day
		STANWELL PARK CLAYSTONE		640	Red, green and grey shale and quartz-lithic sandstone.	
		SCARBOROUGH SANDSTONE		660	Quartz-lithic sandstone, pebbly in parts.	Transmissivity ≈ 0.2m ² /day
		WOMBARRA CLAYSTONE		670	Grey shale and minor quartz-lithic sandstone.	
LATE PERMIAN (260→230x10 ⁶ years BP)	ILLAWARRA COAL MEASURES	COAL CLIFF SANDSTONE			Fine to medium grained quartz-lithic sandstone.	Transmissivity ≈ 0.34m ² /day
		BULLI COAL		690		
		LODDON SANDSTONE				
		BALGOWNIE COAL MEMBER				
		LAWRENCE SANDSTONE				
		ECKERSLEY FORMATION				
		WONGAWILLI COAL		750	Interbedded quartz-lithic sandstone, grey siltstone and claystone, carbonaceous claystone, clay, laminite and coal.	TDS <5000mg/L, pH ≈ 8.7
		KEMBLA SANDSTONE		760		
		ALLANS CREEK FORMATION		770		
		DARKES FOREST SANDSTONE		790		
		BARGO CLAYSTONE		820		
		TONGARRA COAL		850		

Figure 9: Simplified stratigraphy of the Southern Coalfield showing typical hydrogeological characteristics (Source: Sydney Catchment Authority, 2007a)

2.3.5 Rivers, rainfall, recharge and runoff

Rivers and streams of the Sydney Basin tend to flow in a north-west direction away from the coast, typically following the bedding plane of the underlying sandstone bedrock. Rainfall that occurs in the region drains into to the network of creeks, streams and rivers, and recharge to any unconsolidated materials and underlying consolidated sandstone strata. This drainage network also acts on a

regional level to relieve groundwater pressures and limit the elevation of the groundwater table to stream levels within the valleys and gorges. In areas away from the valleys and gorges, rainfall continues to recharge the system by creating an elevated water table and sustaining groundwater flows toward the creeks and rivers (McNally and Evans, 2007; Sydney Catchment Authority, 2007b).

Natural recharge in the region is complex, with aquifer systems recharged by rainfall over geologic time, and groundwater in the upper surfaces typically responding quicker than the deeper aquifers. Rates of recharge in the system are also affected by the local permeability of the rocks (including induced fractures from subsidence), in addition to natural evaporation and evapotranspiration. Recharge rates will also vary depending on local site characteristics. For example, in the upland areas where swamps exist, runoff may be restricted. These upland swamps also act as water stores and provide a base flow component to creeks and streams.

During rainfall events, perching of the water table can be expected particularly in the upland swamps and the regolith, as rainwater infiltrates slowly through the profile. Groundwater flow can be enhanced along structural defects and are often observed as hanging swamps in many of the steep gorges, and are important in supporting groundwater dependent ecosystems. Areas that have rock outcrops or thin regolith profiles will normally experience fast runoff, unless natural or induced fractures allow permeability and porosity to increase. These regions of fast runoff will typically not contribute significantly to groundwater recharge (McNally and Evans, 2007; Sydney Catchment Authority, 2007b; Hammond, 2007).

3. EXISTING SURFACE WATER ASSETS IN THE STUDY AREA

The surface water assets within the study area include the drinking water supply reservoirs for the majority of the population of NSW, including the Sydney Metropolitan Area, the Blue Mountains, the Illawarra, the Southern Highlands and Lithgow Valley. Significant supply reservoirs within the study area include Lake Burragorang (Warragamba Dam), Prospect Reservoir in Western Sydney, Mangrove Creek Dam to the north and Nepean, Avon, Cordeaux, Cataract, Woronora dams to the south along with Wingecarribee Reservoir and Fitzroy Falls Reservoir (*Figure 10*). The surface water assets within the study area fall under the following NSW water sharing plans:

- Greater Metropolitan Region Unregulated River Water Sources - commenced 1 July 2011
- Greater Metropolitan Region Groundwater Sources - commenced 1 July 2011
- Kangaroo Water Sharing Plan - commenced 1 July 2004
- Bega and Brogo Rivers Area Unregulated, Regulated and Alluvial - commenced 1 April 2011

Existing water assets have been identified by SEWPaC for the study area (*Appendix I*). These draft water asset maps show major and minor watercourses as water assets along with major waterbodies, RAMSAR wetlands and Nationally Important Wetlands. Water bores, dams, pipelines and other hydrological points (gamma hole, native well, pool, rock hole, soak, spring and waterhole) are depicted in each of the CMA regions (*Appendix I*). These water asset maps provide a useful inventory of important environmental assets in the study area, however it is unclear for the watercourses or dams what size or contributing area resulted in their inclusion as an asset. The issue of the relevant spatial scale is an aspect that limits many components of the identified water assets.

Major rivers/water assets in the HNCMA include the Hawkesbury, Nepean, Wollondilly, Mulwaree, Tarlo, Wingecarribee, Nattai, Coxs, Kowmung, Grose, Capertee, Colo and Macdonald. Major lakes, swamps and reservoirs are all depicted in *Appendix I*. In the SRCMA region, the Shoalhaven, the Tuross, the Clyde, the Bega, the upper Snowy and upper Genoa rivers form the major watercourses. A number of nationally important and coastal wetlands are identified in the SEWPaC water assets map. Within the SMCMA region, most catchments feed into Sydney Harbour, Botany Bay and Port Hacking, including the Parramatta River, Lane Cove River, Georges River, Woronora River, Cooks River, Alexandra Canal, Hacking River or are small coastal draining catchments such as Manly, Dee Why, Curl Curl and Narrabeen lagoons. The Sydney Metropolitan region features the only RAMSAR wetland relevant to CSG exploration, Towra Point Nature Reserve in Botany Bay. The SMCMA also

includes a small area of wetlands identified as nationally important in the Newington Wetlands Bi-Centennial Park.

Despite multiple water monitoring programmes throughout the study area, no systematically consistent and comprehensive data set exists for either water quality or quantity. Currently, individual site data exists but is dispersed among several reports, including annual SCA water quality reports, a quarterly drinking water quality report published by Sydney Water, local government authorities' State of the Environment (SOE) reports and gauge records from the NSW Office of Water. Other privately collected and managed data from mining companies, government agencies and local government is not publicly available. In order to query data from a specific site, it is necessary to search for that site within a corresponding report. A clear, easily accessible and comprehensive database covering the region is non-existent.

A significant proportion of the region remains ungauged, with many of the sub-catchments lacking any discharge record. Within these catchments, discharge baselines and variability cannot be established and therefore no comparative data is provided for future monitoring of surface water assets and potential impacts of mining may not be detectable.

Regional water quality monitoring has been similarly deficient. Water quality monitoring has generally been limited to broad catchment assessments from limited, individual monitoring sites. Many sub-catchments have few, if any, ongoing monitoring sites. These are generally coupled with stream gauges and provide continuous salinity, temperature, and turbidity data as indicators of water quality. The 2010 State of the Catchments (SOC) reports provide the most comprehensive current assessment for the Hawkesbury-Nepean, Southern Rivers, and Sydney Metropolitan region. The reports provide mapped locations for all water quality sites, though minimal data is presented, with only information on the trends of water temperature, electrical conductivity and turbidity, and the percentage of time exceeding ANZECC guideline values for phosphorus and turbidity. No precise data used to generate these trends is outlined. No systematic, ongoing nor comprehensive water quality data is available for the range of physical, chemical and biological indicators of water quality (*Table 1*).

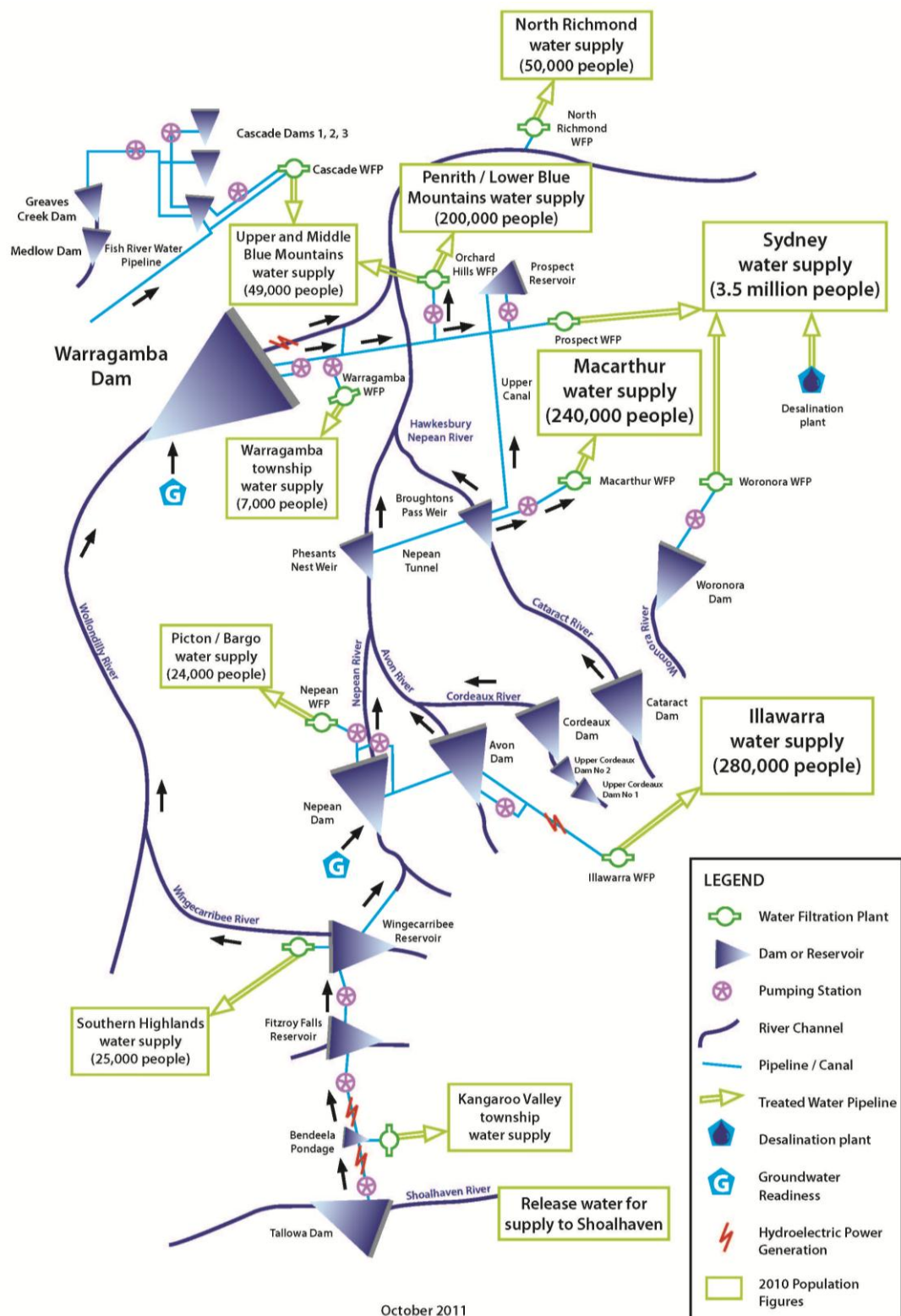


Figure 10: Greater Sydney Water Supply system (Source: Sydney Catchment Authority)

Table 1: Properties of a water body indicative of water quality

Category	Indicators
Biological	Bacteria, algae
Physical	Temperature, turbidity, colour, electrical conductivity (salinity) suspended solids, dissolved solids
Chemical	pH, dissolved oxygen, biological oxygen demand, nutrients (including nitrogen and phosphorus), organic and inorganic compounds (including toxicants)
Aesthetic	Odours, taints, colour, floating matter
Radioactive	Alpha, beta and gamma radiation emitters

4. EXISTING COAL MINING IN THE STUDY AREA

There are several types of mining being undertaken within the study area. For the purpose of this report, we have identified all black coal mining within the regions. In 2008, it was estimated that the Southern Coal field (in which all three CMAs are located) contained 786Mt of recoverable coal, valued at \$45.7 billion and representing 14.7% of the total recoverable coal in NSW (DPI, 2009).

Table 2 identifies all coal mining actives within the Sydney Basin. Mines have been identified through current mining leases. This information has been used within the database to examine the current vulnerability of a region. *Table 2* lists the current mining leases, their location and the company that holds the lease within the CMA regions. This information has been provided by NSW Government Resources and Energy.

Table 2: Summary of current coal leases within the study area

Mine Location	Company	Title Ref No.	Expiry Date	Title Area
5 km ENE of CAMDEN	Director General Nsw Department Of Tiris On Behalf Of The Crown	AUTH5	01 May 2013	727 KM2
14 km NNW of DAPTO	Dendrobium Coal Pty Ltd	AUTH143	07 Nov 2013	5396 HA
2 km NNW of APPIN	Endeavour Coal Pty Limited	AUTH199	27 Jun 2014	1072 HA
2 km SSW of APPIN	Endeavour Coal Pty Limited	AUTH201	27 Jun 2014	484 HA
27 km SSE of KANDOS	Centennial Airly Pty. Limited	AUTH232	20 Oct 2014	3054 HA
3 km WSW of CAMDEN	Director General Nsw Department Of Tiris On Behalf Of The Crown	AUTH281	01 May 2013	8925 HA
11 km NW of DAPTO	Gujarat Nre Fcgl Pty Ltd	AUTH295	27 Oct 2014	1150 HA
10 km SE of APPIN	Endeavour Coal Pty Limited	AUTH306	27 Jun 2014	1477 HA
8 km E of LITHGOW	Hartley Valley Coal Company Pty Ltd	AUTH307	24 Aug 2014	2430 HA
5 km W of APPIN	Endeavour Coal Pty Limited	AUTH312	10 Aug 2013	2910 HA
14 km SSW of APPIN	Endeavour Coal Pty Limited	AUTH338	08 Oct 2014	3564 HA
3 km E of PORTLAND	Ivanhoe Coal Pty Limited	AUTH359	24 Jun 2014	464 HA
23 km SE of KANDOS	Director General Nsw Department Of Tiris On Behalf Of The Crown	AUTH360	30 Aug 2013	647 KM2
5 km S of APPIN	Endeavour Coal Pty Limited	AUTH370	27 Jun 2014	3129 HA
7 km WSW of APPIN	Endeavour Coal Pty Limited	AUTH395	10 Aug 2013	571 HA
7 km WNW of APPIN	Endeavour Coal Pty Limited	AUTH396	27 Jun 2014	7225 HA
0 km SSE of APPIN	Endeavour Coal Pty Limited	AUTH397	27 Jun 2014	407 HA
13 km SSW of KANDOS	Charbon Coal Pty Limited	AUTH414	30 Jun 2013	3047 HA
14 km ENE of LITHGOW	Coalex Pty Ltd	AUTH416	24 Aug 2014	1639 HA
13 km NNE of CAMDEN	Director General Nsw Department Of Tiris On Behalf Of The Crown	AUTH424	01 May 2014	172 KM2
7 km E of APPIN	Endeavour Coal Pty Limited	AUTH432	31 Aug 2013	3312 HA
16 km NE of LITHGOW	Coalex Pty Ltd	AUTH451	24 Aug 2014	699.7 HA
9 km W of DAPTO	Htt Huntley Heritage Pty Limited	CCL700	09 Oct 2015	1859 HA
10 km ENE of PORTLAND	Coalpac Pty Limited	CCL702	24 Nov 2024	1840 HA

Mine Location	Company	Title Ref No.	Expiry Date	Title Area
1 km WSW of HELENSBURGH	Metropolitan Collieries Pty. Ltd.	CCL703	26 Jan 2024	5195 HA
12 km E of PORTLAND	Centennial Springvale Pty Limited	CCL704	14 Jan 2023	2541 HA
13 km ENE of LITHGOW	Coalex Pty Ltd	CCL705	20 Dec 2026	3210 HA
7 km SSW of PICTON	Tahmoor Coal Pty Ltd	CCL716	13 Mar 2021	4080 HA
3 km E of KANDOS	Kandos Collieries Pty Ltd	CCL726	18 Nov 2028	1608 HA
6 km SSE of KANDOS	Charbon Coal Pty Limited	CCL732	02 Dec 2025	1024 HA
7 km ESE of PORTLAND	Centennial Springvale Pty Limited	CCL733	03 Jul 2027	723.5 HA
13 km SSE of APPIN	Gujarat Nre Coking Coal Limited	CCL745	30 Dec 2023	6001 HA
13 km SSW of PICTON	Bargo Collieries Pty Ltd	CCL747	06 Nov 2025	4769 HA
12 km NE of PORTLAND	The Wallerawang Collieries Limited	CCL749	11 Mar 2030	3706 HA
7 km E of PORTLAND	Centennial Springvale Pty Limited	CCL756	06 Dec 2024	101 HA
9 km WSW of DAPTO	Gujarat Nre Fcgl Pty Ltd	CCL766	09 Oct 2015	514 HA
8 km E of PORTLAND	The Wallerawang Collieries Limited	CCL770	11 Dec 2024	199.6 HA
9 km ESE of PORTLAND	Centennial Springvale Pty Limited	CL361	16 Jul 2032	14.26 HA
9 km NNE of LITHGOW	Centennial Springvale Pty Limited	CL377	09 Mar 2025	1105 HA
3 km WNW of APPIN	Endeavour Coal Pty Limited	CL388	22 Jan 2013	47.2 HA
8 km ESE of PORTLAND	Centennial Springvale Pty Limited	CL394	27 May 2013	17 HA
6 km E of PORTLAND	Boulder Mining Pty Ltd	EL5899	23 Oct 2013	62 HA
10 km E of PORTLAND	Centennial Springvale Pty Limited	EL5293	16 Sep 2014	485 HA
7 km E of PORTLAND	Centennial Springvale Pty Limited	EL5294	16 Sep 2014	105 HA
11 km NNE of LITHGOW	Centennial Springvale Pty Limited	EL5974	13 Dec 2012	4381 HA
11 km NNW of LITHGOW	Centennial Springvale Pty Limited	EL7415	20 Oct 2014	169.6 HA
16 km SW of KANDOS	Centennial Inglenook Pty Limited	EL7431	18 Dec 2014	3850 HA
22 km S of KANDOS	Centennial Inglenook Pty Limited	EL7442	12 Jan 2015	1815 HA
6 km NE of LITHGOW	Biogas Energy Pty Ltd	EL7543	11 May 2014	1263 HA
13 km WNW of MOSS VALE	Boral Limited	EL7603	19 Aug 2015	6135 HA
9 km ESE of PORTLAND	Centennial Springvale Pty Limited	ML564	02 May 2023	19.75 HA
5 km E of PORTLAND	Ivanhoe Coal Pty Limited	ML1301	29 Sep 2013	5.131 HA
9 km NNW of LITHGOW	Centennial Springvale Pty Limited	ML1303	15 Dec 2013	713 HA
8 km SW of PICTON	Tahmoor Coal Pty Ltd	ML1308	02 Mar 2014	13.16 HA
8 km S of KANDOS	Charbon Coal Pty Limited	ML1318	29 Jun 2014	983 HA
7 km E of PORTLAND	Centennial Springvale Pty Limited	ML1319	05 Jul 2014	5.69 HA
10 km NNW of LITHGOW	Centennial Springvale Pty Limited	ML1323	03 Aug 2014	30.24 HA
11.52 NNE of LITHGOW	Centennial Springvale Pty Limited	ML1326	18 Aug 2024	2157 HA
27 km NNE of PORTLAND	Centennial Airly Pty. Limited	ML1331	12 Oct 2014	2745 HA
5 km ESE of PORTLAND	Centennial Springvale Pty Limited	ML1352	23 Jun 2015	7.6 HA
16 km NE of LITHGOW	Coalex Pty Ltd	ML1353	21 Jul 2015	1075 HA
14 km NE of LITHGOW	Coalex Pty Ltd	ML1354	21 Jul 2015	155.3 HA
4 km WSW of PICTON	Tahmoor Coal Pty Ltd	ML1376	28 Aug 2016	2095 HA
4 km W of APPIN	Endeavour Coal Pty Limited	ML1382	19 Dec 2016	1.184 HA
8 km ESE of PORTLAND	Enhance Place Pty Limited	ML1422	03 Dec 2018	6.992 HA
17.34 E of PORTLAND	Centennial Springvale Pty Limited	ML1424	18 Aug 2024	7735 HA

Mine Location	Company	Title Ref No.	Expiry Date	Title Area
1 km WNW of APPIN	Endeavour Coal Pty Limited	ML1433	23 Jul 2019	65 HA
6 km ESE of PORTLAND	Centennial Springvale Pty Limited	ML1448	30 May 2020	95.16 HA
7 km E of LITHGOW	Hartley Valley Coal Company Pty Ltd	ML1457	03 Nov 2020	185.1 HA
8 km ESE of PORTLAND	Enhance Place Pty Limited	ML1458	28 Nov 2020	13.98 HA
6 km SE of APPIN	Endeavour Coal Pty Limited	ML1473	19 Nov 2021	1082 M2
6 km W of WOLLONGONG	Dendrobium Coal Pty Ltd	ML1510	23 Apr 2023	44.03 HA
8 km ESE of PORTLAND	Enhance Place Pty Limited	ML1520	28 Aug 2023	9.636 HA
10 km NNE of LITHGOW	Centennial Springvale Pty Limited	ML1537	15 Jun 2024	4.125 HA
3 km WSW of PICTON	Tahmoor Coal Pty Ltd	ML1539	15 Jun 2024	547 HA
7 km SSE of KANDOS	Charbon Coal Pty Limited	ML1545	08 Jan 2025	204.7 HA
13 km W of DAPTO	Gujarat Nre Fcgl Pty Ltd	ML1565	09 Oct 2015	3177 HA
12 km WNW of WOLLONGONG	Dendrobium Coal Pty Ltd	ML1566	06 Sep 2026	5.262 HA
8 km E of PORTLAND	Enhance Place Pty Limited	ML1569	11 Dec 2024	161 HA
7 km SSW of APPIN	Endeavour Coal Pty Limited	ML1574	30 Dec 2023	419.4 HA
12 km S of APPIN	Gujarat Nre Coking Coal Limited	ML1575	07 Oct 2029	544.4 HA
9 km E of PORTLAND	Enhance Place Pty Limited	ML1578	14 Mar 2027	69.4 HA
12 km ENE of LITHGOW	Coalex Pty Ltd	ML1583	08 Jul 2027	3331 HA
14 km NE of LITHGOW	Centennial Springvale Pty Limited	ML1588	18 Oct 2027	976 HA
9 km NW of DAPTO	Gujarat Nre Fcgl Pty Ltd	ML1596	07 Oct 2029	11074 HA
14 km NE of PORTLAND	The Wallerawang Collieries Limited	ML1607	08 Jan 2018	2503 M2
8 km SSW of PICTON	Tahmoor Coal Pty Ltd	ML1642	27 Aug 2031	206.4 HA
7 km S of KANDOS	Charbon Coal Pty Limited	ML1647	17 Dec 2031	570.9 HA
7 km E of PORTLAND	Enhance Place Pty Limited	ML1664	10 Jan 2033	4.1 HA
13 km ENE of WALLERAWANG	Centennial Springvale Pty Limited	ML1670	17 Feb 2033	3000 M2
10.87 ESE of APPIN	Endeavour Coal Pty Limited	MPL200	13 Jan 2024	5706 M2
10.85 ESE of APPIN	Endeavour Coal Pty Limited	MPL201	13 Jan 2024	2498 M2
9 km SSW of APPIN	Gujarat Nre Coking Coal Limited	MPL271	09 May 2033	8.75 HA
9 km NNW of LITHGOW	Centennial Springvale Pty Limited	MPL314	03 Aug 2014	96 HA
1 km ESE of HELENSBURGH	Metropolitan Collieries Pty. Ltd.	MPL320	09 Dec 2014	7 HA
4.28 E of PORTLAND	Ivanhoe Coal Pty Limited	MPL348	23 May 2025	9.45 HA
4 km NNW of MOSS VALE	Boral Limited	MPL503	12 Mar 2023	1.998 HA
4 km NNW of MOSS VALE	Boral Limited	MPL504	12 Mar 2023	1.84 HA
8.89 ESE of PORTLAND	Centennial Springvale Pty Limited	PLL133	10 Aug 2024	16.51 HA

5. REVIEW OF DIRECT IMPACTS OF MINING ON WATER

This chapter provides a review of the potential major impacts on water and associated environmental assets associated with CSG extraction and longwall mining that have been highlighted within the literature. The *Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield: Strategic Review* (2008) stated that the single most important land use in the Southern Coalfield is as a water catchment, with the region supplying over four million people in Sydney, the Illawarra and Southern Highlands with approximately 1.4 GL of drinking water each day.

Figure 11 shows the Upper Nepean River system along with mining holdings, current petroleum exploration applications, and the Sydney Catchment Authority (SCA) supply assets and special areas. The 'Special Areas' surrounding SCA dams and storages (shown in Figure 11 by the red and lime green hatched regions) are lands declared under the *Sydney Water Catchment Management Act 1998* for their ecological integrity and value in protecting the quality of the raw water. The Special Areas basically function as a filtration system for inflowing water entering storage sites by reducing the nutrient and sediment load (SCA, 2007b).

It is important to recognise that mining is currently undertaken within much of the catchment, including SCA Special Areas. Petroleum exploration (PEL 444) is currently planned for parts of the Woronora Catchment, with some wells falling within SCA Special Areas. With such a considerable amount of underground mining in the region, it is not unreasonable to assume that future CSG development will likely involve the drilling and construction of gas wells in SCA Special Areas.

In its submission to the 2008 Southern Coalfield Inquiry, the SCA suggested that due to the lack of scientific data and baseline monitoring in the region, it was difficult to assess with any confidence the full range of potential impacts of mining on water resources in the Southern Coalfield, particularly groundwater resources. The SCA further advocated in its submission that it favoured a precautionary approach to any future mining in the region, "*Until the reports from the science and research program become available, a risk management approach must be taken to applications for future mining in the most sensitive areas with the Metropolitan, O'Hares and Woronora Special Areas*" (SCA, 2007b).

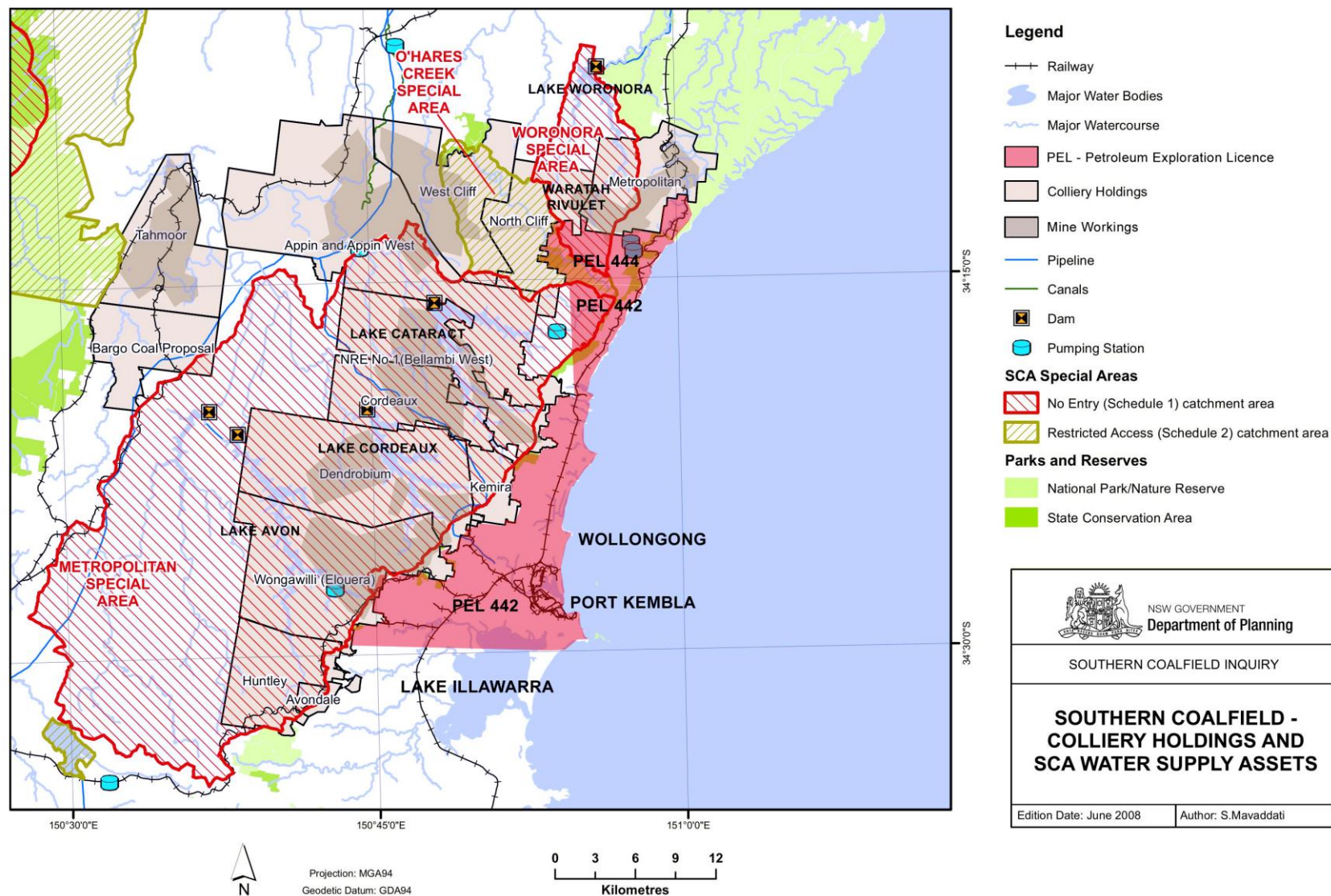


Figure 11: Southern Coalfield - Petroleum exploration, SCA supply assets, colliery holdings and workings (adapted from Southern Coalfield Inquiry Report, 2008)

5.2. Coal Seam Gas

CSG is a naturally occurring gas found within the pores and fractures of all subsurface coal seams typically at a depth of 300 to 1000 m (Strapoć *et al.*, 2008; CSIRO, 2012; Freij-Ayoub, 2012). CSG is formed by the same chemical and physical processes that generate coal and oil, that being the microbial (biogenic) or thermal (thermogenic) alteration of organic matter in oxygen-depleted environments over millions of years (Rutovicz *et al.*, 2011; Moore, 2012; Freij-Ayoub, 2012). In the study area, CSG reserves are located in high volatile to medium volatile bituminous Permian coals of the Sydney Basin (Faiz, 2008). The gas is normally composed of more than 95% methane, and can also contain other hydrocarbons such as ethane, propane and butane, as well as carbon dioxide, carbon monoxide and nitrogen (CSIRO, 2012).

Recent technological developments provide the ability to extract CSG from the surrounding geological strata without the removal of the rock in which it is contained (CSIRO, 2012). Approximately 90% of the gas is stored in a near-liquid state mainly within the matrix of the coal, with the remainder held within the fractures, or cleats, of the coal seams (U.S. EPA, 2009). Cleats refer to the natural fractures created by localised geological forces and the contraction of the buried organic matter under increasing heat and pressure.

The concepts of permeability and porosity are of fundamental importance in understanding and assessing CSG. Essentially, porosity refers to the amount of void space in the coal, while permeability is the degree to which these void spaces are interconnected. In terms of CSG development, permeability is important for determining the capacity for water and gas to flow through a reservoir and is generally determined by the number and width of the cleats and their continuity (Dabbous *et al.*, 1974; Lingard *et al.*, 1982). Typically, as overburden pressure increases with depth, the permeability of the coal can become restricted by closing the natural fractures in the rock (Somerton *et al.*, 1975; Enever *et al.*, 1999).

5.2.1 Extraction techniques

Molecules of methane in a coal seam are held tightly within the large internal surface area of the coal by a combination of pressure from the overlaying rock, water in the seam, and adsorption of the gas molecules to the surface of the coal (Milewska-Duda *et al.*, 2000). 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. A number of CSG extraction techniques are available to gas operators, with the primary

methods including vertical wells, horizontal drilling (including directional and multilateral drilling), dewatering and hydraulic fracturing, summarised in Table 3.

Table 3 Summary of common CSG extraction techniques (Source: Rutovicz et al., 2011)

VERTICAL WELLS	<ul style="list-style-type: none"> • Typically the cheapest method. The well is cased with steel pipe and cemented to the surface, isolating the well from surrounding geological layers • Each well requires one surface well-pad to be constructed, therefore projects using only vertical drilling typically require multiple surface sites • Likely to require fracturing to stimulate gas production. • Drainage radius of 200 to 400 m • Drilling and completion is usually 7 to 10 days
HORIZONTAL DRILLING	<ul style="list-style-type: none"> • Includes directional and multilateral drilling • Less likely to require hydraulic fracturing than vertical drilling • Allows for a sub-surface network (or ‘web’) of as many as six wells per location. This enables the extraction of gas in multiple directions along the target coal seam • The web of underground wells can be constructed from one drill pad. Therefore, horizontal drilling can be less surface-intensive than vertical drilling • Drainage radius of 1500 to 2500 m • Drilling and completion is usually 3 to 4 weeks
DEWATERING	<ul style="list-style-type: none"> • Allows the seam to depressurise allowing the gas to move through the natural cleats in the coal • The ratio of water to gas will vary depending on the site and age of the well. Typically volumes of water decrease gradually over the life of the well
HYDRAULIC FRACTURING	<ul style="list-style-type: none"> • ‘Fracking’ or ‘stimulation’ aids the extraction of gas by increasing the permeability of the coal • The most common technique is hydraulic fracturing which uses water and sand, a viscofying agent such as guar gel, and other chemicals • The use of fracking is not always required - dependent on geology • Other types of fracking include using petroleum gels and gases such as air and carbon dioxide

A *Code of Practice for Coal Seam Gas Well Integrity* was released by the NSW Government in September 2012 and stipulates that well design and construction “*must ensure that no leaks occur through or between any casing strings. The fluids produced from the well must travel directly from the production zone to the surface inside the well conduit, without contamination of groundwater or other aquifer resources, and avoiding leakage*” (NSW Government, 2012d). One of the major

concerns raised in regards to drilling is the possibility of cross-aquifer contamination. In NSW, wells are cased with steel and cemented to the surface, isolating the well from surrounding geological layers (AGL Energy Limited, 2012a). Figure 12 illustrates current well construction requirements in NSW (November 2012). The actual technique used in each well may involve one or a combination of methods may be used and will depend on the geology, physical constraints and economic viability of the site.

Vertical wells have been the most common extraction technique used to date due to similarities with conventional oil and gas exploration and is typically the cheapest method (Kimber and Moran, 2004). Vertical wells often require hydraulic fracturing to stimulate water and gas production, and require individual well pads for each well. Vertical well gas projects can result in a mosaic of closely-spaced well pads located only a few hundred metres apart (Moore, 2012; Freij-Ayoub, 2012). 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. Each well site is generally contained by a one hectare exclusion area, which is cleared to enable well operation (Queensland Curtis LNG, 2009). 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. Hydraulic fracturing has been used extensively throughout the world to increase production in oil and gas wells (ALL Consulting, 2012). The technique has recently come under intense scrutiny from governments, the public and non-governmental organisations due to potential environmental and human health impacts (Lloyd-Smith and Senjen, 2011). Some of these concerns include the volume of water consumed; the composition of fracture fluid chemical additives and its disclosure; possible surface and groundwater contamination from vertical fracture propagation; the treatment, recycling and disposal of produced water; onsite storage and handling of chemicals and wastes; and increased truck movements (ALL Consulting, 2012).

The use of hydraulic fracturing in coal formations depends on the natural permeability of the formation. The process of hydraulic fracturing involves pumping large volumes of a fluid at high pressure down the well into the coal 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 (Rutovic *et al.*, 2011). 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 (Colmenares and Zoback, 2007). The typical constituents of fracking fluid and their common uses are outlined in *Table 4*. In NSW, the use of potentially toxic BTEX chemicals (benzene, toluene, ethylbenzene, and xylene) in hydraulic fracturing has been prohibited.

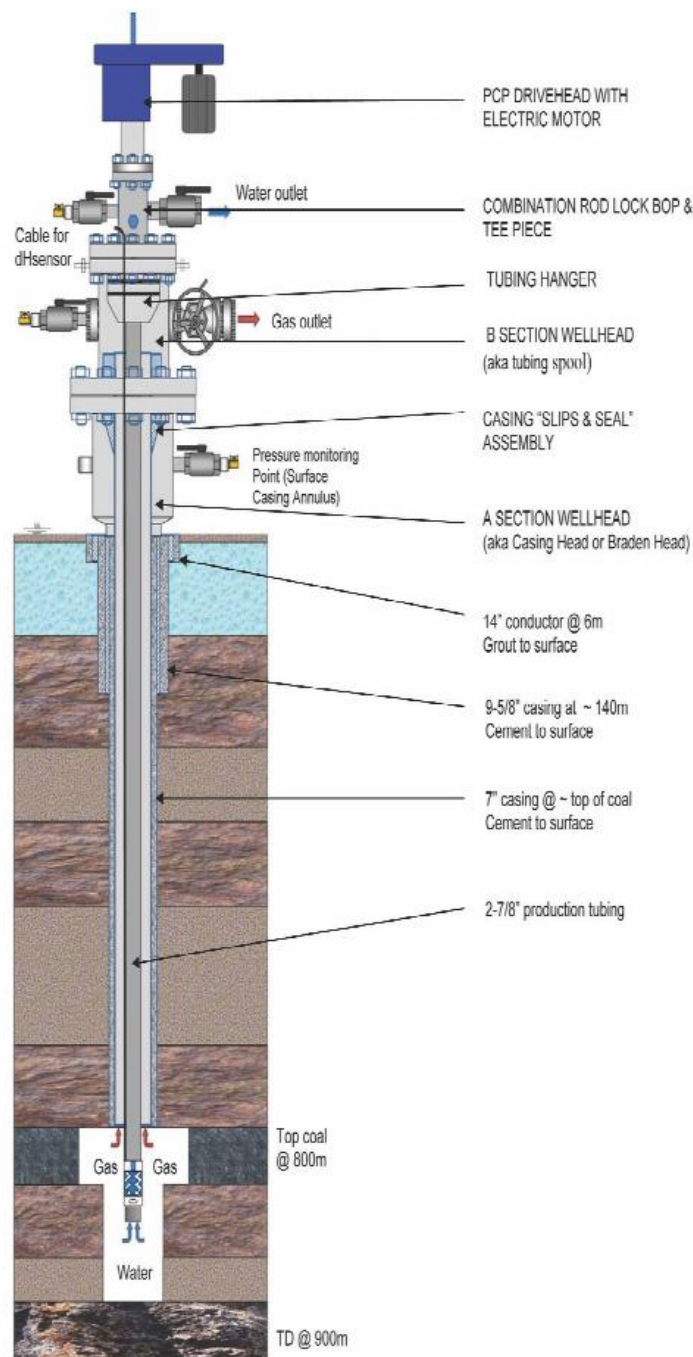


Figure 12: Typical vertical well. Note: 'A Section Wellhead' would normally be set below ground level but is shown above ground level for illustration purposes only (Source: New South Wales Parliament Legislative Council, 2012; Karsten et al., 2008; Beavis, 1976)

A typical hydraulic fracturing operation on a vertical CSG well will consume between 200,000 to 600,000 litres of water and additives (Rutovicz *et al.*, 2011; AGL Energy Limited, 2012a). The site will also require preparation similar to that used for a normal drilling operation, but may also require the construction of a storage dam depending on the volume of water produced by the well. The sand used for the operation is typically 20 to 40 mesh sand which is able to withstand the crush pressures and hold open the fractures for the gas to flow (AGL Energy Limited, 2012a).

Table 4: Categories and uses of typical hydraulic fracturing chemicals (Adapted from QLD DEHP, 2012; Independent Petroleum Association of America (IPAA), 2012)

Type	Main Compound(S)	Purpose	Common Uses
Proppant	Sand	Used to hold the fractures open while the gas is released into the well.	Used in filtration, play sand.
Diluted acid	Hydrochloric acid or muriatic acid	Helps dissolve minerals and initiate cracks in the rock.	Swimming pool cleaner and chemical.
Biocides	<u>Glutaraldehyde</u>	Kills bacteria in the water that produce corrosive byproducts, and reduces risk of fouling	Disinfectant, sterilizer for medical and dental equipment
Breakers	Ammonium persulfate, Peroxodisulfate	Allows delayed breakdown of gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics.
Corrosion inhibitor	N,n-dimethyl formamide	Prevents well corrosion	Used in pharmaceuticals, acrylic fibres and plastics.
Clay stabilizer	salts, ie tetramethyl ammonium chloride	Reduces clay swelling around the well and enhance pre-fracture conditions.	
Crosslinker	Borate salts	Maintains fluid viscosity as temperatures increase.	Used in laundry detergents, hand soaps and cosmetics.
Friction reducer	Polyacrylimide	Minimises friction between fluid and pipe, by 'slickening' the water.	Water treatment, soil conditioning.
	Mineral oil		Make-up remover, laxatives and sugar sweets.
Gelling agents	Guar gum or hydroxyethyl cellulose	Increases thickness/ viscosity of the fluid to make it more 'gel-like'. Helps hold sand in suspension and allow more of it to be carried into the fractures.	Food-grade thickener used in cosmetics, ice cream, toothpaste, and sauces.
Iron control	Citric acid	pH control - prevents precipitation of metal oxides.	Food additive, flavouring in food and beverages, eg: lemon juice ~7% Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid.	Low sodium table salt substitute.
Oxygen scavenger	Ammonium bisulfite	De-oxygenates water to protect pipes from corrosion.	Cosmetics, food and beverage processing, water treatment.
pH adjusting agent	Sodium or potassium carbonate	Maintains effectiveness of other components such as crosslinkers.	Washing soda, detergents, water softener, glass, soap, ceramics.
Scale inhibitor	Ethylene glycol	Prevents scale deposits and precipitation in pipe.	Automotive antifreeze, household cleansers, deicing and caulk.
Surfactants	Isopropanol	Increases viscosity of fracture fluid.	Glass cleaner, antiperspirant, hair colouring.
Note: the specific compounds used in a given fracturing operation will depend on company preference and site-specific characteristics of the target formation.			

Improvements in drilling technology have allowed horizontal drilling techniques, principally including directional and multilateral drilling (Figure 13) are becoming more commonly used in CSG extraction (Rutovicz *et al.*, 2011). These techniques provide the gas operator with the ability to operate multiple wells from one drill pad, enabling the extraction of gas in multiple directions along the target coal seam (AGL Energy Limited, 2012a). Horizontal wells significantly increase contact with the coal seam, with bore lengths extending up to 2000 m out from the well pad. This allows gas extraction rates to be significantly increased compared to vertical wells restricted to a drainage radius of just 200 to 400 m (Rutovicz *et al.*, 2011).

Horizontal drilling may provide the advantage of reducing the need for hydraulic fracturing, since the simple action of drilling along the seam can increase permeability and stimulate gas and water extraction (Final Report NSW Inquiry into CSG, 2012). Although horizontal wells are initially more expensive to construct than vertical wells, they typically allow for more sustained production of methane (U.S. Department of Energy, 1999), reduced number of wells, reduced landuse on the surface, and improvements to the economic viability of the CSG extraction.

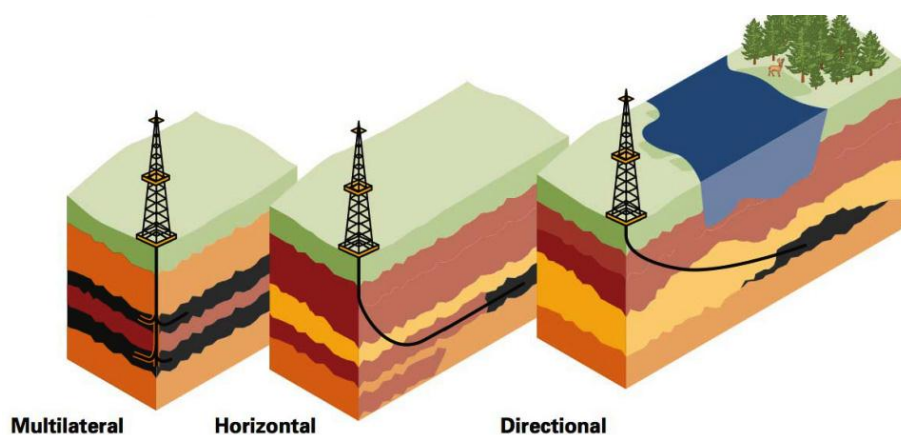


Figure 13: Representation of various CSG drilling techniques (Source: U.S. Department of Energy, 1999)

5.2.2 Impacts of Coal Seam Gas Development on Water

Water is an important consideration in CSG development as the coal seam needs to be depressurized by removing the water (Flores, 1998). Once the pressure in the coal seam is reduced, the gas is desorbed from the surface of the coal matrix and diffused into the cleats (Rice, 1993; Flores, 1998). Consideration must also be given to the typical changes in water and gas production over the life of a CSG project. For vertical wells, the volumes of water produced will typically decline gradually over time, until the methane production rate reaches a peak value (Figure 14). The

dewatering curves for horizontal wells will often differ significantly to vertical wells, with the horizontal method dewatering the system at a more rapid rate (Maracic *et al.*, 2005).

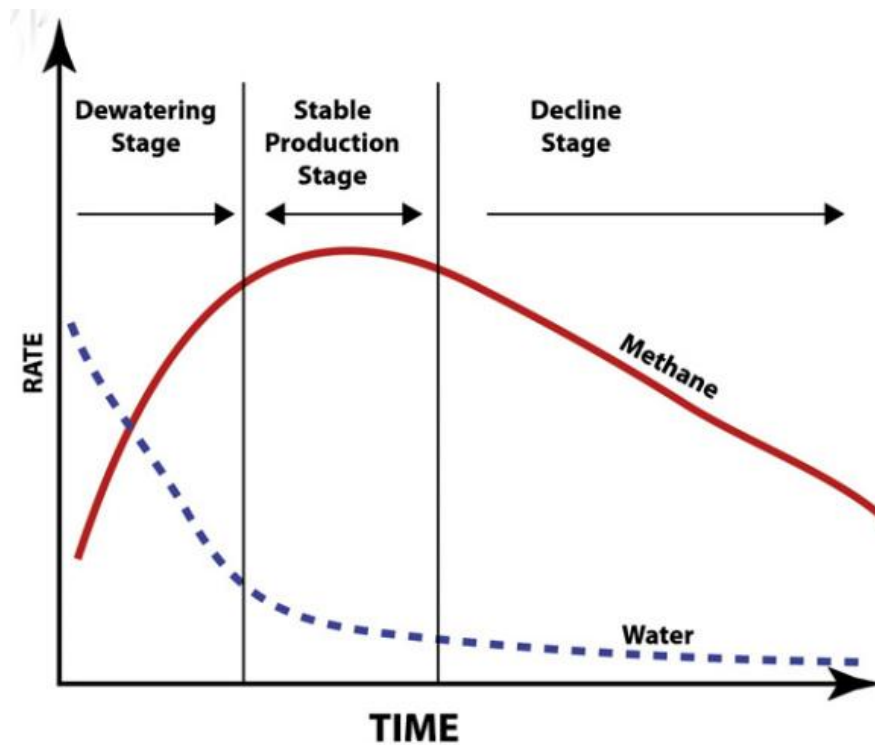


Figure 14: Typical CSG production profile of a vertical well, showing gas and water production rates (Source: Moore, 2012)

In Australia, it has been suggested that CSG is as much a water business as it is a gas business (Athanasiadis, 2012). The main concerns relating to water and CSG development have tended to focus on issues relating to aquifer depletion, aquifer contamination, and disposal of produced water (Nghiem *et al.*, 2010; Freij-Ayoub, 2012; ALL Consulting, 2003; Chalmers *et al.*, 2010). It is important to recognise that potential environmental impacts, especially those impacts relating to groundwater, are very often site-specific and typically determined by the hydrologic and geologic physiognomies of the target seam, the techniques used to extract the resource, the use or otherwise of procedures designed to mitigate potential environmental impacts, and the adherence to the legislative framework regulating CSG development.

Aquifer Depletion

In order to extract CSG from a coal seam, the hydrostatic pressure of the stratum needs to be reduced by pumping out groundwater from the coal seam (Moran and Vink, 2010). Large amounts of water are removed from the underground aquifers over the life of the gas field, mainly from the coal seam. The cumulative effects of dewatering a coal seam depend on the surface-groundwater recharge regime and the degree of hydraulic connectivity between the target coal seam and the overlying and underlying aquifers. The process of dewatering can have the following impacts:

- Drawdown, or lowering of the water table on a regional scale (*Figure 15*).
- As extraction typically involves many wells across a large area, dewatering and depressurisation may lead to the inflow of water from surrounding strata, possibly resulting in a major cumulative effects on surrounding aquifers (Holla and Barclay, 2000; Helmuth, 2008).
- Development of steep hydraulic gradients between the coal seam and the adjacent water-bearing formations (QGC, 2009). This may induce seepage of groundwater between the formations.
- Alteration of hydraulic relationships between alluvium and the underlying strata (US Committee on Produced Water, 2010).
- A reduction or loss of surface water contribution, with potential follow-on effects on aquatic ecology of surface water ecosystems.

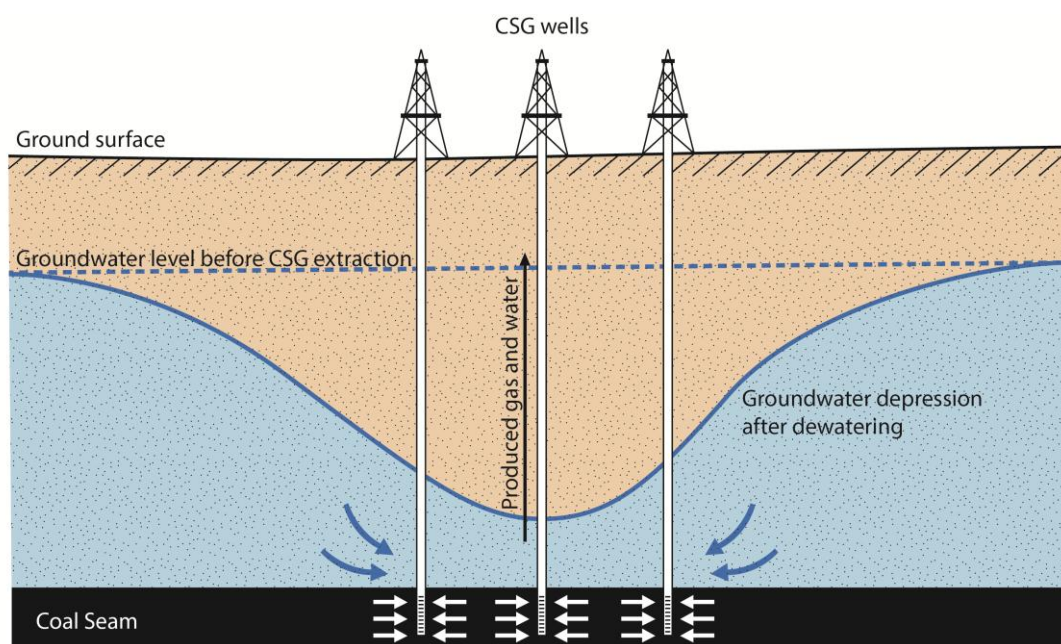


Figure 15: Dewatering and drawdown associated with CSG operations

Surface Water and Aquifer Contamination

Aquifer contamination can occur due to CSG development and extraction. Though mitigation practices are carried out during production, aquifer contamination can occur during the drilling and dewatering processes. Possible routes of contamination include:

- Contamination through aquifers may occur from pressure loss and artificially connecting the coal seam and overlying aquifers (Rutovicz *et al.*, 2011; McKibben and Smith, 2000).
- Loss of containment of drilling fluids, which can occur from inadequate well design and drilling technique (QGC, 2009).
- The lowering of the water table by dewatering exposes minerals to an oxygen rich environment, which may affect solubility and mobility. This process could therefore lead to increased salinity of sub surface water, oxidation of subsurface minerals or stimulate bacterial growth.
- Alluvial aquifer bore water quality may be affected by local re-distribution of water in response to drawdown or upwelling of lower quality water from deep within an aquifer (USEPA, 2011).

Furthermore, contamination of aquifers can occur through hydraulic fracturing. This process generates new fractures or enlarges existing ones, increasing the connectivity of the fracture system and can lead to contamination due to:

- Propagation of fractures outside of the target coal seams and migration of fracking fluids and methane into overlying formations and aquifers (Osborn *et al.*, 2011; Davies *et al.*, 2012). If uncontrolled, fracking fluids may expend 70% of the injected volume during hydraulic fracturing (Glenn *et al.*, 2011).
- Reduced pressure following hydraulic fracturing increases the solubility of coal seam methane in solution (Osborn *et al.*, 2011). Potential for methane to migrate vertically through the fracture system and contaminate groundwater systems is substantially increased.

Produced Water

Significant volumes of waste water, known as ‘produced water’, are extracted in the CSG process. The volume of produced water can vary significantly, producing between 150 L/day to 20,000 L/day, depending on site specific characteristics. The produced water is often saline, requiring specific handling, treatment and disposal (Van Voast, 2003; Jackson and Reddy, 2007; Dahm *et al.*, 2011). Produced water is dominated by sodium and bicarbonate and devoid of calcium, magnesium and sulphate (Van Voast, 2003), with the specific chemical composition determined principally by the geological characteristics of the particular coal seam (ALL Consulting, 2003). Together, water quality, volumes, treatment and disposal of produced water have emerged as one of the major environmental concerns in CSG development. Environmental impacts of produced water include:

- Alterations of natural flow regimes if released to surface water system. This can have significant impacts on water quality in rivers, wetlands, and reservoirs (ALL Consulting, 2003).
- Incorrect disposal, or seepage of produced water stored in water storage ponds would increase the potential for contamination of surface and groundwater. The high concentration of dissolved salts other the primary contaminants, with other possible pollutants including crude oil released by coal-bearing strata.

One of the major issues in CSG development is the treatment and disposal of saline produced water. Electrical Conductivity (EC) measurements of the produced water from the Camden Gas Project normally range between 7,000 and 15,000 $\mu\text{S}/\text{cm}$, which is too high for domestic or agricultural use. Therefore, produced water must be transported off site and treated at a water processing facility. Other characteristics of the produced water from the Camden Gas Project include:

- A pH level of about 7 to 8.5.
- Typically low levels of heavy metals.
- Approximately 50,000 years of age (AGL Energy Limited, 2012b).

The treatment of the produced water to an acceptable level removes the salts from the water. Considerable issues remain as to the storage and disposal of the removed salts and concentrated brine. This remains one of the significant challenges to CSG development where large volumes of produced water are extracted (Freij-Ayoub, 2012; Nghiem *et al.*, 2010; Athanasiadis, 2012).

5.3. Longwall Mining

Retreat longwall mining is the principal method of coal extraction in the study area due to the thickness of overburden, the potential for high efficiency and improved safety conditions (Sidle *et al.*, 2000). Land subsidence, the vertical or horizontal displacement of the ground surface and subsurface, is an unavoidable consequence of longwall mining, dependent on the thickness of the coal seam removed and the depth of mining (Holla and Bailey, 1990; NSWMC, 2007). When coal is extracted the overlaying strata collapse to fill the void created, with fractures propagating vertically for approximately 20 times the thickness of the seam (Figure 16; Booth, 2005; Ward, 1984). Severe fracturing within this zone considerably increases the permeability of the strata and drainage rates of groundwater. Above the fracture zone, readjustment of the strata tends to occur as bending into the subsidence trough, with limited cracking (Figure 16). Fractures may be induced in the near surface as strata are less influenced by confining pressure, as high horizontal stress causes shearing and cracking in the bedrock (Booth, 2005; Krogh, 2007; Ward, 1984), putting groundwater-dependent ecosystems and bedrock streams at risk of drainage.

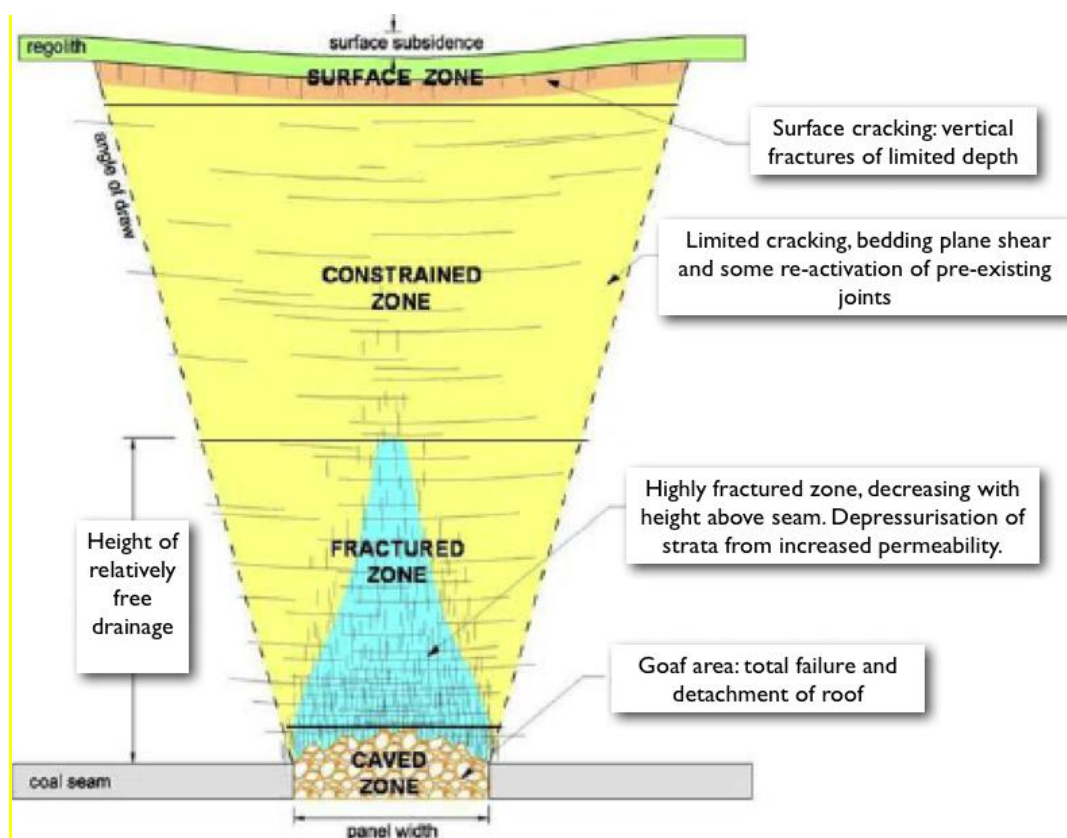


Figure 16 Typical zones of a subsidence trough associated with longwall mining (Source: DOP, 2008)

5.3.1. Subsidence Prediction

Prior to mining extraction, a number of empirical values are used to predict the degree and rate of conventional subsidence found in flat lying areas (*Figure 17*), with a 15% degree of accuracy to that observed in the environment post mining (NSWMC, 2007). However, the geology and geomorphology of the Sydney Basin make it prone to non-conventional subsidence, with unexpected subsidence phenomena documented throughout the region (McNally and Evans, 2007). Empirical methods lose validity when predicting non-conventional subsidence as complex variables are introduced from horizontal stress planes present in the valley floor. Horizontal stress can induce brittle fracturing of creek beds, causing upsidence (upward buckling) of the strata. Predictive models for valley closure and upsidence are less advanced and for this reason subsidence estimations are cautiously used during environmental planning (DOP, 2008; NSWMC, 2007).

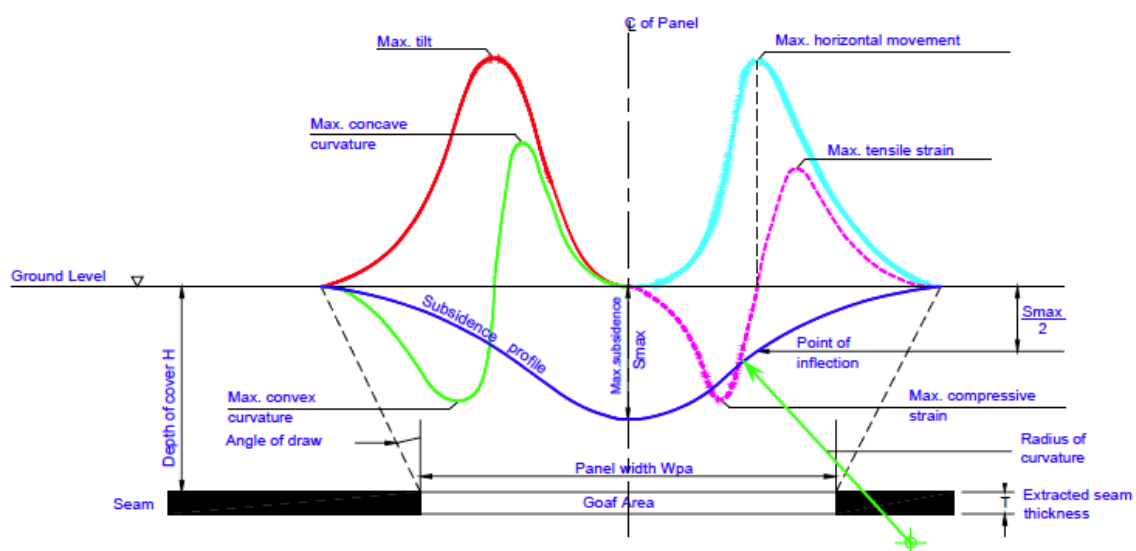


Figure 17: Typical subsidence profile exaggerated on the vertical scale (Source: MSEC, 2007)

Figure 17 shows the primary subsidence characteristics of conventional subsidence used in subsidence modeling and prediction, including:

- *Tilt*: calculated by the change in subsidence between two points divided by the distance between both points.
- *Horizontal movement*: the horizontal component of subsidence. It reaches its greatest value when tilt is at its maximum.
- *Curvature*: either convex (hogging) over the goaf edges or concave (sagging) toward the bottom of the trough.
- *Strain*: calculated from the horizontal change in length of a subsidence profile divided by the original pre mining profile length.

5.3.2. Primary impacts of longwall mining

Accurate mapping of mining-induced subsidence within the Woronora Plateau has demonstrated up to 3 m subsidence (Palamara *et al.* 2007) and 0.5 m of upsidence (Jankowski *et al.*, 2008) in the surface profile as a direct result of long wall mining. Subsidence and upsidence result in a range of associated hydrogeological impacts, outlined below. Alterations to habitat, ecosystems and surface processes caused by subsidence have the potential to threaten flora and fauna (*Threatened Species Conservation Act 1995*) and damage infrastructure (Holla and Bailey, 1990). Limited peer reviewed evidence of the degree to which threaten species are impacted by longwall mining exists throughout the study area (Krogh, 2007).

Surface Water

Increased tensile and compressive strains resulting from subsidence (*Figure 17*) induce increased fracturing and separation of bedding planes in the surface bedrock (Jankowski and Knights, 2010), particularly evident in bedrock-controlled stream beds. This results in a net loss of surface water flow to the subsurface (Jankowski *et al.*, 2008; McNally and Evans, 2007). Hydrological analysis in the Southern Coalfield upstream and downstream of longwall panels indicates increased surface water-groundwater connectivity with increased infiltration, reduced runoff and base flow discharge (Jankowski and Knights, 2010). This has been observed at Cataract River Gorge (Everett *et al.* 1998), Waratah Rivulet (Galvin 2005; Jankowski *et al.*, 2008) Upper Georges River and Bargo River (Kay *et al.*, 2006). The volume of water loss and the extent of system recovery in the study area have not been quantified.

Ground Water

Fractured strata and bedding separation alters permeability, porosity, hydraulic gradient, aquifer interconnectivity and groundwater levels. This in turn impacts local hydrogeological patterns (Booth, 2005) and groundwater supplies in nearby communities (Karaman *et al.*, 2001; Hill and Price, 1983). Recent increases in groundwater subsurface permeability have been highlighted at Dendrobium Colliery, with up to 8 ML/d leaking into the longwall panel (McNally and Evans, 2007). Surface water loss in the Thirlmere Lakes National Park has been a recent concern to community groups, with an independent enquiry into possible impacts from the nearby Tahmoor colliery currently under review (November 2012). This enquiry has found that this is not due to a breach of the underlying strata, but likely due to over-extraction of groundwater and subsidence, resulting in an increase of the hydraulic gradient and, therefore, groundwater flow (Riley *et al.*, 2012).

Wetlands

Wetland swamps occur on the sandstone plateau throughout the study area as groundwater dependent ecosystems, with water supplied via perched water tables. These swamps are exceptionally species rich and are of particular conservation value (DECC, 2007). As discussed above, subsidence has the potential to redirect groundwater flow, significantly altering the wetland's water balance (DECC, 2007). Cumulative impacts on groundwater patterns result in follow-on affects to groundwater dependent wetlands, including desiccation, changes to vegetation and ecological regimes, and increased susceptibility to fire (Gibbins, 2003). There are currently no methods to remediate wetlands found to be dewatered following subsidence (Department of Land and Water Conservation, 2002). Few mining induced impacts have been reported in the study area (NSWMC, 2007).

Chemical Alteration

In cases where flows from surface and groundwater systems become inherently mixed, the prevailing chemical properties may be altered. Increased iron-oxide precipitate and in turn the growth rate of iron-oxidising bacteria may potentially deteriorate water quality and stream habitat (Everett *et al.*, 1998). Water reemerging downstream of the subsidence trough is often of a degraded quality, as reported by Galvin (2005) along Waratah Rivulet. Discharge emerges as de-oxygenated, more acidic, saline and iron-oxide and manganese rich water (NSWMC, 2007). Fracturing of the roof strata during coal extraction liberates carbon dioxide, methane and other gases. Though ventilation systems are used to remove these gases, some remains and may permeate up through the overlaying strata to reduce localised groundwater and surface water quality (Everett *et al.*, 1998) and soil health (DECC, 2007).

Geomorphology and Habitat

Mining induced subsidence can result in differential movement, exacerbating natural instabilities along cliffs. Rock benches and weathered cliff overhangs are common geomorphic characteristics of the Hawkesbury Sandstone and subsidence induced landscape changes have been evident at a number of locations within the study area (Holla and Bailey, 1990; Kay *et al.*, 2006; Zahiri *et al.*, 2006). Overhangs and benches provide habitat for bats and nesting birds, with subsequent collapse may impact cliff ecology (Total Environment Centre, 2007). Though it is difficult to determine the degree to which longwall mining affects such features beyond natural erosive processes (NSWMC, 2007; Total Environment Centre, 2007), spatial analysis of rock falls on the Woronora plateau

exemplify that rock fall sites have not occurred beyond the extent of extracted longwall panels (Kay *et al.* 2006; Zahiri *et al.* 2006).

5.3.2. Secondary impacts of longwall mining

Assets may also be affected by activities associated with the construction of mine site infrastructure, including:

- The construction of heavy vehicle access roads and coal processing facilities can lead to habitat fragmentation, degradation and loss as vegetation is cleared for infrastructure development (Carroll *et al.*, 2000; Lindenmayer and Burgman, 2005). This development has the potential to place additional pressures on threatened species and communities (Bottrill *et al.* 2011)
- Polluted mine water discharged into swamps and streams from storage ponds due to spillage, leakage or overflow can lead to a loss of water quality, impacting stream and wetland ecology and drinking water (Krogh, 2007).

6. HAZARD AND IMPACT IDENTIFICATION

6.1. Background

This section recommends a framework to assess the hazard and impact of coal extraction and CSG to environmental assets in the study area. The framework is based on the spatial extent of coal measures and location of the environmental assets in the study area.

6.2. Input Data

A number of geospatial datasets were used to spatially define assets and input information into the database (*Table 5*). These data sets were chosen based on their spatial coverage and their existence in the public domain. Datasets have been identified as either primary or secondary. Primary datasets are asset specific and are utilised to spatially define a given asset. For example, groundwater assets were spatially grouped into groundwater management areas. The purpose of secondary datasets is to provide the additional information required to populate the various fields in the database. In the case of groundwater, for example, the NSW landuse dataset was used to document the different categories of landuse present within each groundwater management area.

Table 5: Primary and secondary datasets used for each environmental asset

Asset	Primary Datasets	Secondary Datasets
Groundwater	GW management areas; water boreholes	NSW landuse; 100kMapNames; NSW statewide geology; sub-catchment boundaries; GW dependent ecosystems
Wetlands	NSW wetlands; wetlands important; sub-catchment boundaries	NSW landuse; 100kMapNames; NSW geology; NPWS Parks
Landuse	NSW Landuse; physiographic regions	NSW landuse; 100kMapNames; NSW statewide geology
Soil	soil atlas; physiographic regions; land capability	NSW landuse; 100kMapNames; NSW statewide geology;
Surface Water	Riverstyles (HNCMA/SRCMA); waterway health (SMCMA); sub-catchment boundaries	NSW landuse; 100kMapNames; NSW statewide geology; NPWS Parks; NSW wetlands
Threatened	threatened flora and fauna; sub-catchments	boundaries;

Asset	Primary Datasets	Secondary Datasets
Species	sub-catchment boundaries	100kMapNames
Vegetation	*** Data Incomplete ***	*** Data Incomplete ***

Table 6: Description of datasets compiled for this study. Detailed metadata for each dataset can be found in the provided metadata database using the metadata reference number.

Dataset	Description	Metadata Reference Number
NSW Statewide Geology	NSW statewide geology formed from 250k geological map sheets.	6142D3F8-37C4-4263-9D58-2948875DA8A0
100kMapNames	Topographic map index of Australia 1:100,000	n/a
Sub-catchment Boundaries	Boundaries of sub-catchments in NSW	611A88A6-8462-49F0-AA82-A05D63AA3412
NSW Landuse	Dataset of NSW landuse compiled between June 2000 and June 2007 using three classification schemes: NSW Landuse Mapping Program, NSW Standard Classification for Attributes of Land; Australian Landuse and Management Classification.	A941FAEE-46E8-4F79-AD53-4292B9A735D3
NPWS Parks	Boundaries of areas in NSW which are under the management of the NSW NPWS.	F2B66279-9037-40F8-A6A9-D554761324BB
Physiographic Regions	Regolith terrains of Australia. Regolith terrain units divided based on dominant topography, geology and regolith.	8D5E5465-99B4-4912-A396-E0A0B25767D9
Soil Atlas	The digital version of the Atlas of Australian Soils created by the National Resource Information Centre in 1991.	20DB6342-A2AE-454B-88D6-9F11D04F2FDB
Riverstyles/waterway health	Assessment of waterway health using the River Condition Index (RCI) which is a long-term reporting tool for changes in riverine condition and associated input attributes, for use in State of the Catchment and State of the Environment reporting.	3EA652E2-19F1-40BD-AE07-121D469BDF4E
Land Capability	The standard eight-class classification was used based on an assessment of the biophysical characteristics of the land, the extent to which these will limit a particular type of landuse and the technology available for land management.	4BC73D43-82BA-4D78-87EC-41DE6E3A73A4
Threatened Flora and Fauna	Point locations of rare and threatened Australian flora and fauna. This data is not comprehensive and should not be considered a complete inventory.	13B8237E-5A55-4766-B3BD-F2B89D528F75
Ground water (GW) management areas	Assessment maps of the expected and dominant groundwater resources for specified areas. They provide a plan of the spatial distribution, expected yields and quality of the dominant groundwater system.	32B4EA06-DFC3-4E0D-ADF4-4A6FBB184556
GW dependent ecosystems	Point locations of ecosystems dependent on groundwater resources.	F37BBE44-A416-4785-A462-0DE3BE4EBD3B
Water boreholes	Data includes borehole logs, name of major lithology, colour, form, grain size, borehole geometry, pump test results, use, construction and casing details. It also includes depth to groundwater, aquifer depth and artesian flow (as found, intermediate and as left).	3BDAFC80-5BEC-4FF7-94F6-9D418566D8E1

Dataset	Description	Metadata Reference Number
Triassic Sediment Thickness	Grid of Triassic sediment thickness (m). The Triassic isopach map has been calculated by subtracting the top Permian surface from the top Triassic surface.	15986656-980A-4A7B-AEA6-43A9C6008E73
Fault lines	Interpreted faults from various data sources: DEM, Magnetics, Gravity, Landsat, Seismic and existing Map data.	856C107B-5B2E-4AC8-9534-F89D11A24B8D
Coal titles	Locations of current coal leases in New South Wales.	4C311608-624E-43A7-A9E9-8DC529799BFF
Coal boreholes	The database contains summary information about each borehole such as location, total depth, completion date, etc and references.	2A0271D7-7CD7-4F23-BE67-9CF6460F9C13
Wetlands Important	Locations of wetlands cited in the "A Directory of Important Wetlands in Australia" Third Edition (EA, 2001), plus various additions for wetlands listed after 2001.	70507904-DD4B-4D9E-AC6A-79F8BED15E5C
Wetlands NSW	Locations of wetlands in New South Wales.	6754FEBE-639A-4830-A672-D2E632268F31

6.3. Vulnerability Criteria

The vulnerability template in the database was completed based on a defined objective criterion for assessing impact and hazard. The field 'impact' required the asset to be assessed into one of three categories; low, medium and high. The 'hazard' field in the database was divided by three categories: existing, existing and potential expansion and potential. For the purpose of this report a hazard is any source of potential damage, harm or adverse effect on an environmental asset by existing or potential coal mining and CSG activity (based on existing coal titles). Therefore hazard can only occur if there is a likely source (i.e. coal titles). Impact in this report is the predicted (i.e. likelihood or potential) level of effect on an environmental asset if CSG or coal mining activity 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.

6.3.1. Impact Assessment

The impact assessment of coal mining extraction was performed using the matrix shown in *Table 7*. This matrix was established using the depth to the Triassic units as a proxy for existing and future coal mining extraction. This proxy was chosen as the coal measures located in the study region are of the Permian age, which precedes the Triassic. Therefore the depth from the ground surface to the base of the Triassic is a surrogate for the distance to the youngest coal seam, thus providing a minimum depth for coal extraction. One of the primary factors affecting the degree of subsidence from coal mining is the depth to the extracted coal seam from the surface, whereby the deeper the extracted coal seam the less obvious the effects of subsidence are at the surface. This relationship is reflected in the impact classification matrix shown in *Table 7*. Furthermore, coal measures in the study area are typically being extracted at depths of 200 to 500 m below the ground surface (Pells & Pells, 2012). Consequently, coal extraction at depths greater than 500 m from the surface were classified as low impact as mining is currently not occurring at such depths.

The impact assessment of CSG was performed using the matrix shown in

Table 8. This matrix was established on the depth to the base of the Triassic units and the density of natural fractures. The depth to Triassic units was again used as a proxy for the depth to the shallowest coal seam. Fractures act to increase the permeability and connectivity of the bedrock overlying the coal measures. Consequently, increased fracture density in an area has the potential to increase the impact of CSG, as it can facilitate its release to the ground surface. As previously discussed, coal seam gas is typically extracted from coal seams at depths of 300 to 1000 m (CSIRO,

2012). Generally at shallower depths CSG would be expected to have naturally vented from the coal seam to the surface through permeable overlaying bedrock fractures and faults. Therefore, this report assumes a low CSG impact when the depth to the coal seam is 0 - 200 m, as it has previously been released to the environment. Coal extraction results in subsidence and has the potential to release CSG through the increased connectivity of fractures and by the decline of water level in an aquifer. Mining operations are currently only operated to depths of less than 500 m, and therefore subsidence-induced CSG release can potentially occur to this depth. This theory is reflected in the impact classification matrix, whereby CSG impact is low at depths deeper than 500 m from the ground surface and highest between 200 and 500 m. In the study region, coal measures are predominately located below the Triassic units. Areas where there is no Triassic unit were therefore classified as low risk due to the absence of coal measures.

Table 7: Decision rules for impact of coal mining extraction based on the thickness of Triassic formation

Triassic Thickness (m)			
0 -200	200-500	>500	No Triassic
High	Medium	Low	Low

Table 8: Decision matrix for CSG impact based on the thickness of the Triassic formation and the fault density

Fault Density	Triassic Thickness (m)			
	0 -200	200-500	>500	No Triassic
High	Low	High	High	Low
Medium	Low	High	Medium	Low
Low	Low	Medium	Medium	low

6.3.2. Hazard Assessment

The hazard assessments of environmental assets for coal mining extraction and CSG activities were based on 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 hazard when it fell within the boundary of the Permian coal measures but did not contain a current coal mining title. Assets classified as Existing and Potential Expansion hazard refer to assets that fall into areas containing both existing and potential hazards. These can be considered areas

where expansion of a current lease is possible. Finally, the hazard field in the database was left blank (no hazard) for environmental assets that did not overlay Permian coal measures as CSG and coal mining extraction would not occur in these areas.

Table 9: CSG and coal mining extraction hazard identification matrix based on the presence of Permian lithology and the existence of current coal titles

Coal Title	Permian Coal Measures	
	Present	Not Present
Present	Existing	Left blank
Not Present	Potential	Left blank

6.4. GIS Methodology

The hazard and impact vulnerability assessment was performed using GIS analysis based on the decision rules in *Table 7*,

Table 8 and *Table 9*. For the impact assessment (*Figure 18*), 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 using natural breaks, which is a method based on natural groupings of data values and is determined statistically by finding adjacent feature pairs, between which there is a relatively large difference in data values.

A GIS hazard layer was created based on the classification matrix shown in *Table 9* by overlaying the coal titles with the spatial extent of the Permian coal measures (*Figure 19*). 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).

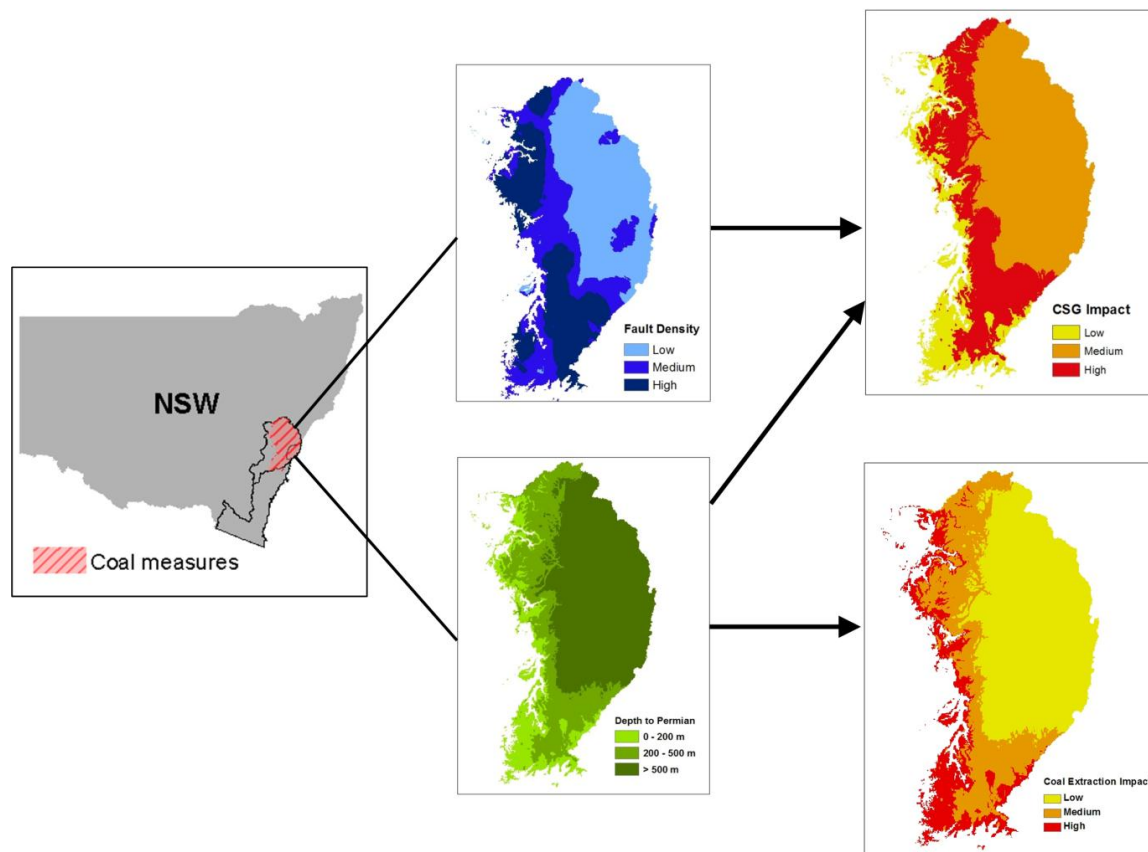


Figure 18: The resulting GIS impact layers for CSG and coal extraction. CSG impacts were derived from fault line density and depth to Permian coal measures. Impact levels for coal extraction were derived from depth to Permian coal measures only. Any area beyond the coal measures boundary was assumed to be low impact

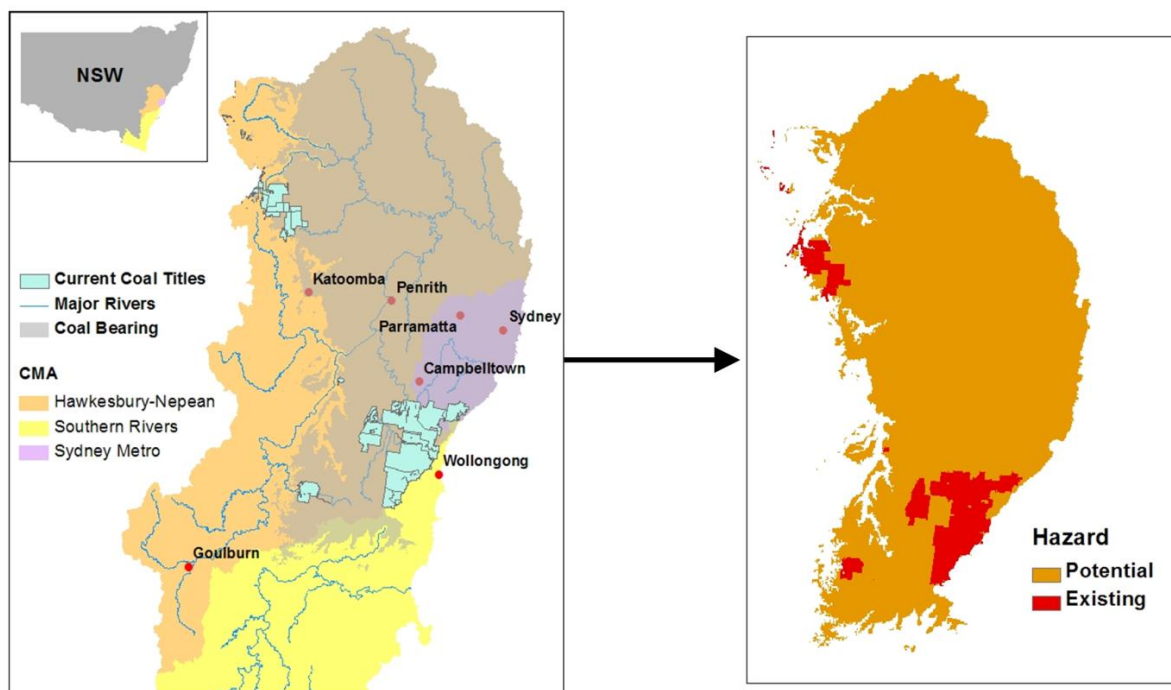


Figure 19: The resulting GIS hazard layer developed from locations of current coal titles and the extent of Permian coal measures. Assets that do not fall within the limits of potential or existing hazards are classified as 'No Hazard.'

7. ENVIRONMENTAL ASSETS IN THE STUDY AREA

This study identifies three environmental areas of concern in regards to CSG mining; water, land and biodiversity. Within the database these three areas have been broken down even further to identify environmental assets at risk. Environmental assets can be defined as specific areas of environmental value. The assets identified within the database include groundwater, surface water, wetlands, landuse, soil, threatened species and vegetation (*Table 10*)

Table 10: Environmental assets suitable for risk assessment

Theme	Asset	No. of Datasets (see Chapter 6.2)
Water	Groundwater	8
	Surface Water	6
	Wetlands	5
Land & Agriculture	Landuse	6
	Soil Type	7
Biodiversity	Threatened Species	5
	Vegetation	-

7.1. Water

For the purposes of this report, water assets have been divided as groundwater, surface water and wetlands. These assets have been defined below, though the associated hazards, impacts and knowledge gaps have been integrated due to the interconnectivity of these assets.

Groundwater is a resource for many activities including agriculture, industry, fire fighting, mining, recreation and domestic uses and supports natural resources such as wetlands and rivers. Surface water assets include all major watercourses, lakes and dams/reservoirs. The surface water assets within the study area include the drinking water supply reservoirs for the majority of the population of NSW, including the Sydney Metropolitan Area, the Blue Mountains, the Illawarra, the Southern Highlands and Lithgow Valley. Surface water is also used for the purposes of recreational, agricultural and industrial activities and provides important ecological services to the natural environment. Pressures and impacts on surface water assets from regional mining in the Southern Coalfield already exist (*see Chapter 5*).

Wetlands were identified as significant environmental assets due to their ability to provide habitat, and directly influence water quality. They rely on natural patterns of groundwater flow and range from RAMSAR coastal wetlands to freshwater swamps and lakes. Changes to the groundwater levels and quality from contamination may have adverse impacts on wetlands (Department of Land and Water Conservation, 2002) and therefore, it is important to develop a dataset for wetlands that are likely to be impacted by CSG and coal mining activities that can be managed accordingly.

7.1.2. Methodology

Groundwater

Three data sources were used to define groundwater assets.

1. GW Macro Plans; Pinneena Groundwater Data v3.2:

The extent of the Groundwater Management Areas (GWMA) were used to map the assets. GWMAs were assigned by the then Department of Infrastructure, Planning and Natural Resources (DIPNR) and were sourced from Pinneena. The administrative boundaries are currently used to manage groundwater and are therefore relevant when identifying and mapping water assets. GWMAs vary in surface area greatly. Assets identified as alluvial sand deposits, despite being restricted spatially, are significant ground water resources and are generally heavily developed. Although point data from

boreholes were used, the assets are defined as polygons with multiple assets sharing the same extent. These extents were used in overlay with other data sets including those used for the vulnerability.

2. Groundwater Level Data and Groundwater Bore data; Pinneena Groundwater Data v3.2:

Data from licenced bore holes in NSW from Pinneena GW were used to define the types of aquifers that occur in each GWMA zone. Pinneena GW is the leading source of historical ground water resources data in NSW (<http://waterinfo.nsw.gov.au/pinneena>). Data for deepest recorded aquifer for each borehole were used along with the single entry data. GMA_NAME field was used to determine water body type and to define what the aquifer types were for the asset area. Details of Pinneena GW data is used in other fields of the water asset database as provided in the methodology table (*Appendix II*).

3. NSW Office of Water Website:

This website was used for descriptions of the aquifer management areas used to define groundwater assets.

Surface Water

Surface water assets include all major watercourses, lakes and dams/reservoirs. However, for the purpose of this report surface water assets have been defined using sub-catchments as the base unit, which includes all surface water resources within each sub-catchment. This methodological approach was used to allow systematic classification of water surface assets across the three CMA regions at a scale that matched available data.

The surface water assets have been classified using differing methods for each CMA region, dependent on the extent of available datasets. The HNCMA region and SRCMA region have been derived from a consistent methodology. However, the lack of systematically continuous data has required the use of additional datasets for the Sydney Metropolitan region. Additional data has been obtained from individual CMA websites. *Appendix III* identifies the source data for each field for surface water assets.

River style provides a useful base description for the geomorphology of the rivers (surface water assets) and whilst it may not be applicable across the entire sub-catchment it provides a consistent fluvial landscape description. The value 'Permanent rivers/streams/creeks' in Waterbody was defined by the sub-catchment boundaries layer of the NSW stressed rivers dataset. The Wetlands

NSW data set was used to spatially identify which other water body types are present within the bounds of the surface water assets. The translation of waterbody types identified in Wetlands NSW to the Waterbody types used in the database is detailed in *Table 11*.

Whilst limited based on the age of the data, the environmental stress category of the NSW stressed rivers is spatially consistent and includes indicators of the extent of riparian vegetation, geomorphological health, barriers to fish passage, catchment landuse, presence of major dams, presence of acid sulphate soils and water quality. Where two-thirds of these environmental indicators returned a high classification for a particular sub-catchment, the overall environmental stress was to be assessed to be *high stress*. Where two-thirds of these environmental indicators returned a low classification for a particular sub-catchment, the overall environmental stress was to be assessed to be *low stress*. Remaining sub-catchments in the stressed rivers assessment were classified as being of *medium stress* environmental stress. Environmental values were assumed to be the inverse of stress, and sites of natural significance within each sub-catchment were further identified and are listed within Environmental Value. The hydrologic stress of a sub-catchment was calculated as the estimated proportion of daily flow that has been made available for extraction under existing (1999) licenses. In the NSW stressed rivers assessment each sub-catchment was classified as being low (0 to 30% extraction of flow), medium (40 to 60% extraction) or high (70 to 100% extraction) hydrologic stress.

A determination of the condition was made based on how densely an area was afflicted with high salinity, high risk of sulphate acidification and degraded vegetation. For both SRCMA and HNCMA condition had already been tabulated within 'Stream_con' layer, in many circumstances the sub-catchment had several different conditions within it. In these cases we have identified the worst condition present.

Table 11: Translation of waterbody types identified in Wetlands NSW to the Waterbody types used in the database

NSW Wetlands Sub Group	WaterBody Type
Canal	Permanent rivers/streams/creeks
Coastal vegetation	Estuarine waters
Dam	Permanent freshwater lakes
Estuarine water body	Estuarine waters
Estuarine water body	Intertidal marshes
Estuarine water body	Intertidal mud/ sand or salt flats
Floodplain water body	Seasonal/intermittent/irregular rivers/streams/creeks
Floodplain water body	Seasonal/intermittent freshwater lakes
Floodplain water body	Seasonal/intermittent saline/brackish/alkaline lakes and flats

NSW Wetlands Sub Group	WaterBody Type
Named coastal lagoons and lakes	Coastal brackish/saline lagoons
Named coastal lagoons and lakes	Coastal freshwater lagoons
Named coastal lagoons and lakes	Intertidal marshes
Named coastal lagoons and lakes	Intertidal mud/ sand or salt flats
Named freshwater lake	Permanent freshwater lakes
Non-Wetland	Permanent rivers/streams/creeks
Non-Wetland	Permanent freshwater lakes
Reservoir	Permanent freshwater lakes
Unnamed coastal lagoons and lakes	Coastal brackish/saline lagoons
Unnamed coastal lagoons and lakes	Coastal freshwater lagoons
Unnamed freshwater lake	Permanent freshwater lakes

Wetlands

Wetlands are grouped into assets by the sub-catchment or sub-catchments they are found within. Wetlands from the Wetlands NSW and Wetlands Important datasets that are present within sub-catchments that share the same extents as Surface Water assets also share many of the same physical descriptors, see methodology table (*Appendix II*). Vulnerability of entire sub-catchments containing wetlands is considered due to the potential flow on effects within that sub-catchment from coal mining and CSG extraction. Wetlands are considered separately from other water assets because of their ecological importance and due to their interaction with and dependence on groundwater, as well as surface water. *Wetlands NSW* and *Wetlands important* were used to identify the location and presence of wetlands within sub-catchments due to their up to date nature, and spatial consistency within and across CMAs. Wetlands NSW is a regularly updated dataset based on classification of satellite imagery and previously mapped data. It identifies both known and named wetlands and also many unnamed remotely classified wetlands.

7.1.3. Hazards and Likely Impacts

The likely impacts on groundwater, surface water and wetland assets vary according to the type of mining, the proximity to mining, the amount of groundwater extraction and the extent of the aquifer connection. Direct impacts of CSG and coal mining activities on water assets include the high level of water supply needs for the CSG drilling and mining processes, with further potential impacts on:

- Groundwater quantity (groundwater drawdown).
- Groundwater quality (contamination risk).

- Surface water quality (produced water storage and containment).
- Surface water quantity (compressive failure fracturing).

Groundwater

Figure 20 shows the impact and hazard associated with coal mining and coal seam gas on groundwater assets based on 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. For example, a high coal extraction impact area will be associated with coal lithology above 500 m depth with high fracture density, while 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 and coal extraction, the analysis was based on current coal titles. Thus, 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 to the maps produced is really a scale and dataset issue more than anything.

Based on the specified GIS analysis described in *Chapter 6*, the groundwater assets most at risk 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, groundwater assets have a high existing and potential hazard due to coal mining and CSG operations.

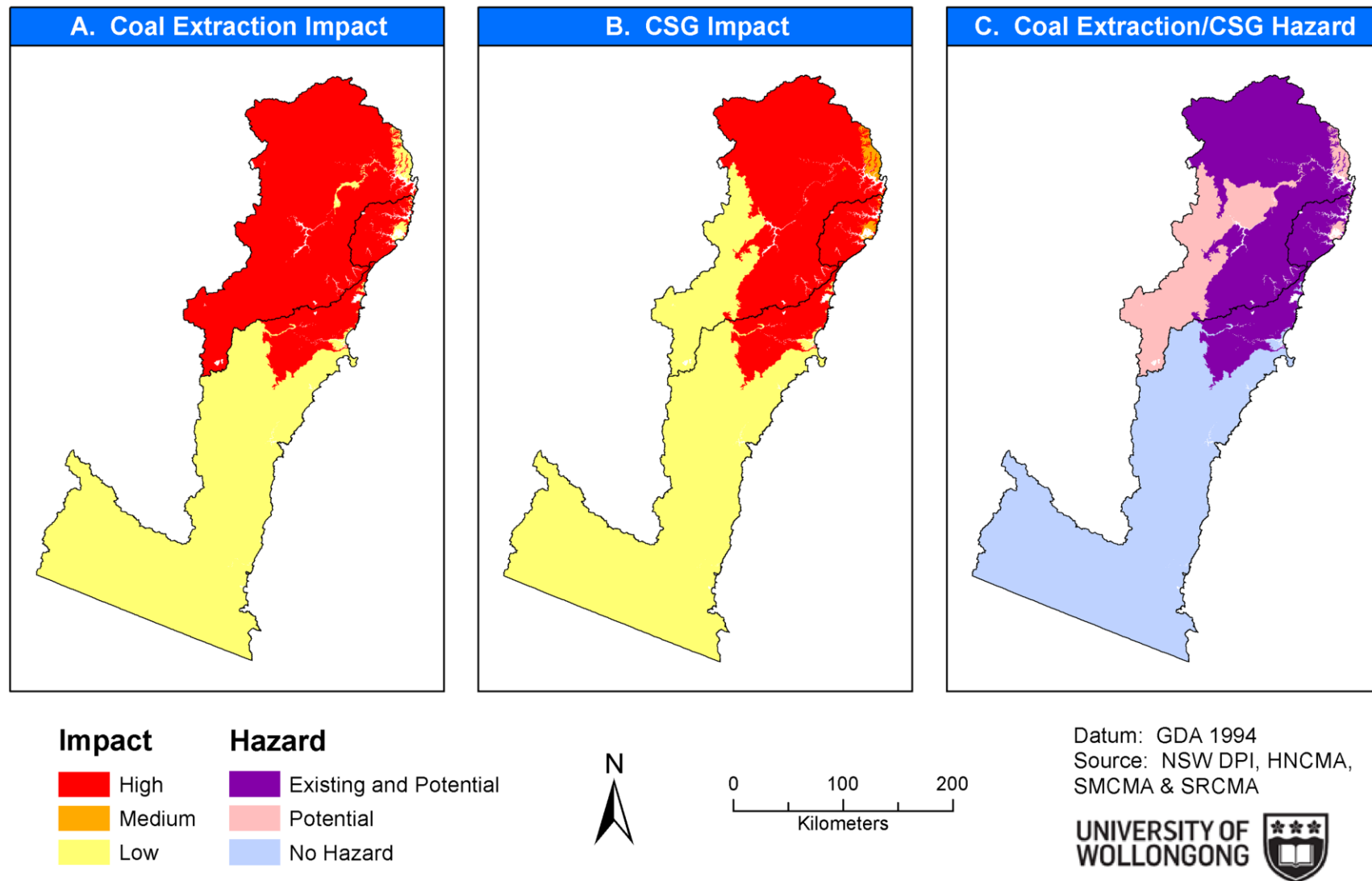


Figure 20: Hazards (c) and impacts (a & b) associated with the extents of Groundwater assets

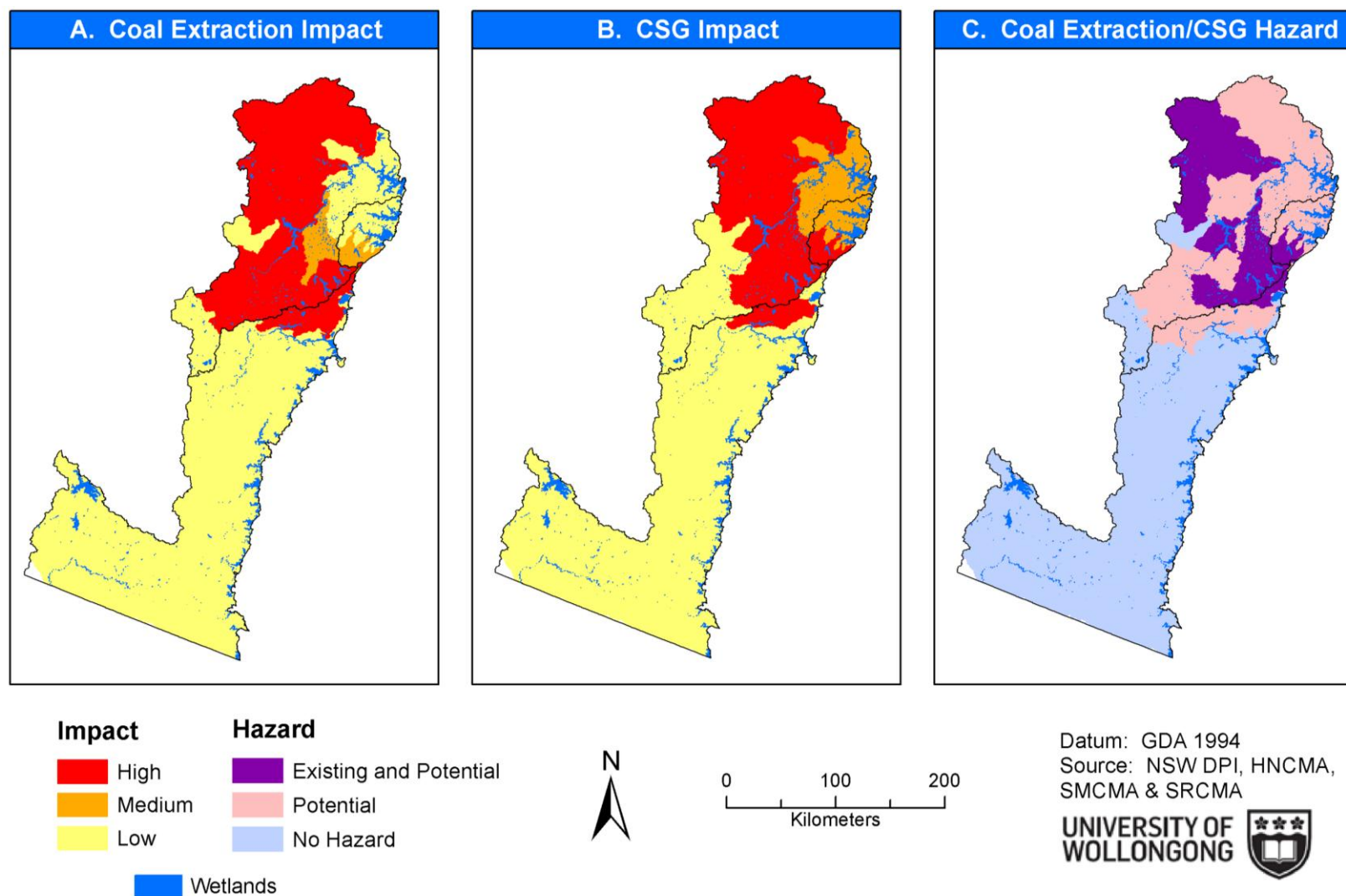


Figure 21: Impacts (A-B) and hazards (C) of sub-catchments in the three CMAs. Extents of sub-catchments are used to assess the vulnerability of Surface Water, Wetlands and Threatened Species assets. Where multiple vulnerability values occurred the worst case scenario was selected.

Figure 20 demonstrates that many of the highest risk areas fall within Sydney's water catchment. This is relevant as changes to the quality and/or quantity of groundwater as a function of mining and extraction industries could affect Sydney's drinking water, through its connectivity with surface water.

Surface Water

Figure 21 shows the hazards for the surface water assets and the likely impacts on water assets from CSG and coal extraction. This figure demonstrates firstly that both existing and potential hazards, along with medium to high risk impacts mostly occur in the Sydney Basin; falling within HNCMA and SMCMA regions. However, seven sub-catchments within the SRCMA have a potential hazard rating and these include the Kangaroo River, Minnamurra River, Bungonia, Bugong Creek, Bomaderry Creek, Broughten Creek and Broughten Mill Creek. Sub-catchments draining to Lake Illawarra, along with the small Wollongong sub-catchments draining the Illawarra escarpment have existing hazards associated with current coal extraction (*Figure 21c*).

Figure 21b shows that a large central portion of the HNCMA is in the category of high impact with regards to CSG operations. This portion includes major drinking water supply reservoirs within the region and includes Nepean, Avon, Cordeaux, Cataract and Woronora, and Wingecarribee Reservoir. The surrounding sub-catchments of these reservoirs have also been found to be high risk areas. Lake Woronora and Prospect Reservoir are at a medium risk, though headwaters of the Lake Woronora catchment are considered high risk. The majority of Lake Burragorang is at a low risk from coal seam gas mining impacts, though outflow to the Nepean River is over high risk geology. *Figure 21b* highlights that the eastern portion of the HNCMA and much of the SMCMA have a medium impact ranking.

Figure 21a-b highlights similar trends to the CSG likely impacts with much of the central and western portions of the HNCMA having a high likely impact associated with coal extraction. The notable difference is that areas east and downstream of the Hawkesbury River, South Creek and Webbs Creek sub-catchments have a low likely impact associated with coal extraction, reflecting the depths to the coal sequences in this part of the basin.

Wetlands

As the vulnerability assessment of wetlands has been assessed at a sub-catchment scale, the results are synonymous with the Surface Water vulnerability assessment (*Figure 21*). This scale was considered appropriate due to the comparative risk of impact from CSG and mining activities

between wetlands and surface water. The Sydney Metropolitan region features the only RAMSAR wetland in the study area relevant to coal extraction, Towra Point Nature Reserve in the Botany Bay Sub-catchment (Catchment ID 213_01). This and Botany Bay wetlands have very high conservation value and the sub-catchment has been identified as at a medium risk of impact from CSG activities and a potential hazard from Coal extraction/CSG.

7.1.4. Knowledge and Data Gaps

Many knowledge and data gaps exist for the water assets in the study area. These can be broken into data input limitations and research knowledge gaps. Data input limitations include:

- Accurate and accessible spatial groundwater data, including specific characteristics of groundwater extent, volume, quality, productivity, depth, primary and secondary porosity, and connectivity to the surface and other aquifers.
- Data used in environmental value and hydrology is over a decade old and is most likely outdated.
- Sub-catchment environmental condition unknown in many instances.
- Hydrological characteristics unknown in many instances. Of the 350 sub-catchments in the three CMA regions 50% are completely ungauged. This is a fundamental problem for determining the future impacts of either coal extraction and CSG operations. This is exemplified in *Table 12* which highlights 29 sub-catchments that are classed as high likely impact from either CSG or coal extraction which are completely ungauged.
- Lack of continuous water quality data other than electrical conductivity and temperature at existing gauges.
- Data not publicly available (privately collected and managed data from mining companies, government agencies and local government).

The most critical aspect with regards to surface water assets is the lack of information on linkages (e.g. recharge and exchange) between surface water and sub-surface aquifers. This bears further relevance to wetland ecosystems, in which the degree of groundwater dependence in the three CMA regions is largely unknown. Knowledge gaps regarding groundwater are detailed in *Chapter 8* of this report, and include:

- Boreholes used to monitor groundwater hydraulic heads, or used to determine aquifer characteristics, were not drilled for scientific purposes but often for water supply information or water level monitoring at a given aquifer zone rather than looking at vertical aquifers.

- An understanding of aquifer and aquitard characteristics and depths in vertical profiles is critical to impact and risk analysis but real data is lacking to input into models that can assess this adequately.
- Using correct models with data available and the collection of meaningful data.
- Lack of understanding of modelling fracture networks and aquifer parameter estimates in geological systems where CSG and longwall mining are undertaken.
- Lack of understanding regarding the calibration and validation of models existing, given that there are many assumptions and poor monitoring networks and inadequate bores.

Table 12: Ungauged catchments within the Sydney Basin Coalfields

Asset ID	CMA	Catchment ID	Coal extraction impact	CSG impact	Hazard
Cowan/Pittwater_Hawkesburry Nepean_249	HNCMA	212_01	low	med	potential
Berowra Creek_Hawkesburry Nepean_250	HNCMA	212_03	low	med	potential
Webbs Creek_Hawkesburry Nepean_255	HNCMA	212_06	low	med	potential
Hawkesbury River_Hawkesburry Nepean_232	HNCMA	212_08	low	med	potential
Erskine Ck/Sassafras River_Hawkesburry Nepean_234	HNCMA	212_12	high	high	potential
Monkey Creek_Hawkesburry Nepean_227	HNCMA	212_17	med	high	potential
Little River_Hawkesburry Nepean_224	HNCMA	212_18	high	high	potential
Lower Coxs River_Hawkesburry Nepean_264	HNCMA	212_20	high	high	potential
Wollemi Creek_Hawkesburry Nepean_260	HNCMA	212_23	high	high	potential
Georges_River_Sub-catchment_02	SMCMA	213_03	low	med	potential
Georges_River_Sub-catchment_09	SMCMA	213_04	low	med	potential
Georges_River_Sub-catchment_08	SMCMA	213_05	low	med	potential
Georges_River_Sub-catchment_07	SMCMA	213_10	med	high	existing
Cooks_River_Sub-catchment	SMCMA	213_13	low	med	potential
Port_Jackson_Sub-catchment_01	SMCMA	213_14	low	med	potential
Middle_Harbour_Sub-catchment	SMCMA	213_15	low	med	potential
Lane_Cove_River_Sub-catchment	SMCMA	213_16	low	med	potential
Parramatta_River_Sub-catchment_02	SMCMA	213_17	low	med	potential
Duck_River_Sub-catchment	SMCMA	213_18	low	med	potential
Parramatta_River_Sub-catchment_04	SMCMA	213_19	low	med	potential
Northern_Beaches_Sub-catchment_04	SMCMA	213_21	low	med	potential
Northern_Beaches_Sub-catchment_03	SMCMA	213_22	low	med	potential
Northern_Beaches_Sub-catchment_02	SMCMA	213_23	low	med	potential
Northern_Beaches_Sub-catchment_01	SMCMA	213_24	low	med	potential
Bundeena Gully_Sub-catchment	SMCMA	214_24	low	med	potential

Asset ID	CMA	Catchment ID	Coal extraction impact	CSG impact	Hazard
Cabbage Tree Creek (Hacking)_Sub-catchment	SMCMA	214_25	low	med	potential
South West Arm Creek_Sub-catchment	SMCMA	214_26	low	med	potential
Muddy Creek_Sub-catchment	SMCMA	214_27	low	med	potential
Lower Hacking River_Sub-catchment	SMCMA	214_28	med	high	existing
Engadine Creek_Sub-catchment	SMCMA	214_29	low	med	potential
Kangaroo Creek_Sub-catchment	SMCMA	214_30	low	med	potential
Waterfall Creek_Sub-catchment	SMCMA	214_31	med	high	existing
Frews Gully_Sub-catchment	SMCMA	214_32	med	high	existing
Cawleys Creek_Sub-catchment	SMCMA	214_33	med	high	existing
Wilsons Creek_Sub-catchment	SMCMA	214_34	med	high	existing
Mid Hacking River_Sub-catchment	SMCMA	214_35	med	high	existing
Camp Gully_Sub-catchment	SMCMA	214_36	med	high	existing
Cedar Gully_Sub-catchment	SMCMA	214_37	med	high	existing
Herbert Gully_Sub-catchment	SMCMA	214_38	med	high	existing
Upper Hacking_Sub-catchment	SMCMA	214_39	med	high	existing
Gills Gully_Sub-catchment	SMCMA	214_40	med	high	existing
Dents Creek_Sub-catchment	SMCMA	214_41	low	med	potential
North Hacking Urban Area_Sub-catchment	SMCMA	214_42	low	med	potential
Royal National Park (coastal)_Sub-catchment	SMCMA	214_43	low	med	potential
Macquarie Rivulet sub-catchment_Southern Rivers_24	SRCMA	214_06	high	high	existing
Duck Creek sub-catchment_Southern Rivers_23	SRCMA	214_08	high	low	existing
Mullet Creek sub-catchment_Southern Rivers_20	SRCMA	214_11	high	low	existing
Fairy Creek sub-catchment_Southern Rivers_19	SRCMA	214_13	high	low	existing
Towradgi Creek sub-catchment_Southern Rivers_18	SRCMA	214_14	high	low	existing
Bellambi Gully sub-catchment_Southern Rivers_10	SRCMA	214_15	high	low	existing
Bulli sub-catchment_Southern Rivers_17	SRCMA	214_16	high	low	existing
Thirroul sub-catchment_Southern Rivers_16	SRCMA	214_17	high	high	existing
Coledale sub-catchment_Southern Rivers_15	SRCMA	214_19	med	high	potential
Wombarra sub-catchment_Southern Rivers_14	SRCMA	214_20	med	high	potential
Clifton_Southern Rivers_189	SRCMA	214_21	high	high	potential
Stoney Creek sub-catchment_Southern Rivers_13	SRCMA	214_22	high	high	potential
Stanwell Creek sub-catchment_Southern Rivers_12	SRCMA	214_23	high	high	existing
Bugong Creek sub-catchment_Southern Rivers_39	SRCMA	215_07	high	low	potential

7.2 Land & Agriculture

Soil and landuse assets have been identified within the study area as important environmental assets. Whilst interconnected for the purpose of this study landuse and soils (land capability) are presented independently. The vulnerability of such assets is the focus of this study as soil health and landscape productivity is reliant on both water quantity and quality. Impacts to land and agriculture assets in the study area may vary in relation to the style of farming practise, the intensity of water use, the dependence on water assets and the nature of the impacts.

7.2.2. Methodology

Landuse

Landuse assets for this study have been classified using the Australian Landuse and Management classification (ALUM Version 7). This classification method identifies five primary landuse classes by their increasing levels of intervention or potential impact to the natural landscape. Water is included as a sixth class due to its importance for natural resource management and protection. The six classes are summarised below:

1. Conservation and natural environments: landused primarily for conservation purposes, based on maintaining the essentially natural ecosystems present.
2. Production from relatively natural environments: landused mainly for primary production with limited change to the native vegetation.
3. Production from dryland agriculture and plantations: landused mainly for primary production based on dryland farming systems.
4. Production from irrigated agriculture and plantations: landused mostly for primary production based on irrigated farming.
5. Intensive uses: land subject to extensive modification, generally in association with closer residential settlement, commercial or industrial uses.
6. Water: water features (water is regarded as an essential aspect of the classification, but it is primarily a cover type).

Condition and value data were calculated based on an adapted risk matrix which can be seen in *Table 13*. A classification of existing ALUM landusetypes was devised and ranged from minimal impact to high environmental impact from existing landuses (*Table 13*). Environmental impact was determined based on descriptions from within the original landuse data (*Table 13*). Conservation

and natural environments yielded minimal impact (good condition), in contrast to intensive landuses which yielded a high impact classification (very poor to extremely poor condition; *Table 13*).

Table 13: Risk matrix for determining landuse asset condition based on potential environmental impact

		Environmental Impact		
		Min impact from landuse	Med impact from landuse	High impact from landuse
ALUM 7 Landuseclassification	Conservation and natural environments	Good	Moderate	Poor
	Production from relatively agriculture and plantations	Moderate	Poor	Poor
	Production from dryland agriculture and plantations	Poor	Poor	Very Poor
	Water	Poor	Very Poor	Very Poor
	Production from Irrigated agriculture and plantations	Very Poor	Very Poor	Extremely Poor
	Intensive uses	Very Poor	Extremely Poor	Extremely Poor

Table 14: Summary of determined Asset ID condition based on ALUM 7 landuse characteristics

Asset ID	Landuse	Impact on land	Outcome
Conservation and natural environments	Conservation and natural environments	Min - med impact	Good/Moderate
Production from relatively agriculture and plantations	Production from relatively agriculture and plantations	Med - high	Poor
Production from dryland agriculture and plantations	Production from dryland agriculture and plantations	Med - high impact	Poor/Very poor
Water	Water	Min impact	Poor
Production from irrigated agriculture and plantations	Production from Irrigated agriculture and plantations	Med impact	Very poor
Intensive uses	Intensive uses	Med - High impact	Extremely poor

Soil

Soils assets in the study area have been assessed via land capability classes. The study area was initially divided into broad physiographic regions based on an existing CSIRO classification (*Appendix IV*). For each of the physiographic regions land capability polygons were defined with each of the eleven land capability classes to reduce the number of soil assets per physiographic region (*Figure 22, Appendix IV*). Multiple soil types were assigned to each of the eleven asset classes and were allocated based on the assets geographic locations throughout the catchment. Soil type data was obtained from a digital version of the Atlas of the Australian Soils (*Appendix IV*).

A condition assessment of soil assets was developed using the same protocol for landuse based on an adapted risk matrix (*Table 15 and Table 16*). For example, soil assets with high impact from landuse (e.g. suitable for regular cultivation) were rated as having an extremely poor condition in contrast to soil assets in conservation areas which were rated as in good condition (*Table 16*). In order to assess hazard and likely impact the same vulnerability criteria has been used for surface and groundwater as presented in *Chapter 6*, however physiographic regions have been used as the base unit for both the landuse and soil assets.

Table 15 Risk matrix table for determining soil asset condition based on potential clearing and landuse impact

		Landuse		
		No impact from landuse	Med impact from landuse	High impact from landuse
Vegetation clearing	No clearing	Good	Moderate	Poor
	Minimal clearing	Moderate	Poor	Very Poor
	Moderate clearing	Poor	Very Poor	Extremely poor
	High Clearing	Very Poor	Extremely Poor	Extremely Poor
	Mining	Very Poor	Extremely Poor	Extremely Poor

Table 16: Summary of determined Asset ID condition

Soil Asset (land capability)	Landuse	Vegetation clearing	Outcome
MINING AND QUARRYING AREAS	High impact from landuse	High clearing	Extremely poor
NATIONAL PARK	No impact from landuse	No clearing	Good
NATURE RESERVE	Med impact from landuse	No clearing	Moderate
OTHER	No impact from landuse	No clearing	Good
STATE FOREST	No impact from landuse	No clearing	Good
RECREATION AREA	No impact from landuse	Minimal clearing	Moderate
SUITABLE FOR GRAZING WITH NO CULTIVATION	Med impact from landuse	Minimal clearing	Poor
SUITABLE FOR GRAZING WITH OCCASIONAL CULTIVATION	Med impact from landuse	Moderate clearing	Very poor
SUITABLE FOR REGULAR CULTIVATION	High impact from landuse	High clearing	Extremely poor
URBAN AREA	High impact from landuse	High clearing	Extremely poor
TIMBER RESERVE	High impact from landuse	High clearing	Extremely poor

7.2.3 Hazards and Likely Impacts

A number of hazards from CSG and coal mining have been identified that have the potential to negatively impact soil and landuse assets and by association affect land capability. This assessment focuses on the likelihood of an asset being affected based on its proximity to coal bearing geological sequences. *Figure 22* shows the hazards for the physiographic regions and the likely impacts on soil and landuse assets from CSG and coal extraction. It should be noted that the predicted impacts and associated hazards are identical for both assets.

Figure 22 a – b shows that most physiographic regions within the HNCMA receive a high likely impact status for both coal extraction and CSG. The exception to this is the Canberra, Crookwell, Abercrombie and the Blue Mountain (coastal margin only) physiographic regions. This figure also demonstrates that all physiographic regions within the entire SMCMA are classed as high likely impact for both coal extraction and CSG. In the SRCMA the northern physiographic regions of the CMA (Illawarra, Braidwood and Ettrema) are classed as high likely impact for both coal extraction and CSG (*Figure 22a- b*). It should be noted that the estimation of impact from coal extraction and

CSG differs marginally with the Macquarie Range being classed as low impact from CSG. This is a reflection of the depth to the coal measures in this region.

The prediction of existing and potential hazard mirrors that of predicted impacts for both coal extraction and CSG. In order to examine the potential hazard associated with coal extraction and CSG *Figure 22c* presents the study area with non-agricultural areas masked and agricultural areas identified as potential and existing hazard versus no hazard. This figure highlights some important aspects with regards to potential hazards on agricultural land in the study area. A high concentration of agricultural lands and their associated soil types occur in the following physiographic regions and these have been identified as having existing and potential hazard associated with coal extraction and CSG: Braidwood, Cumberland, Macquarie Range, Bathurst, Mossvale and Illawarra. This is particularly relevant for areas such as the Cumberland Plain, Braidwood, Moss Vale where market gardens, cropping and grazing are primary agricultural industries. The Macquarie Range and Bathurst regions are also agricultural regions where existing and potential hazard has been identified in the HNCMA (*Figure 22c*). In the SMCMA small areas of existing and potential hazard have been identified potentially impacting market garden production in this area. In the SRCMA, the Illawarra and Braidwood physiographic regions are the two areas with identified existing and potential hazards. Whilst this latter assessment has focussed on agricultural soils it must be acknowledged that soils in non-agricultural areas in regions deemed as existing or potential hazards are equally at risk.

7.2.4 Knowledge and Data Gaps

The NSW statewide landuse data set was incomplete throughout the duration of this study and the data set used lacked the Sydney 100k tile, limiting the extent to which the Sydney Metropolitan and Hawkesbury-Nepean CMA could be assessed. Future revision of the database to include this data will further enhance vulnerability assessment in these regions.

Classifying soil and landuse assets in the manner presented has ultimately reduced the ability of the database to identify location specific assets and assess their vulnerability. The value of soil and landuse assets is subjective and may vary depending on the user group or activity utilising the resource at any one time. One of the key gaps in knowledge with regards to soil and landuse assets is the uncertainty with regards to the role of groundwater and surface water on soil health and landuse capability.

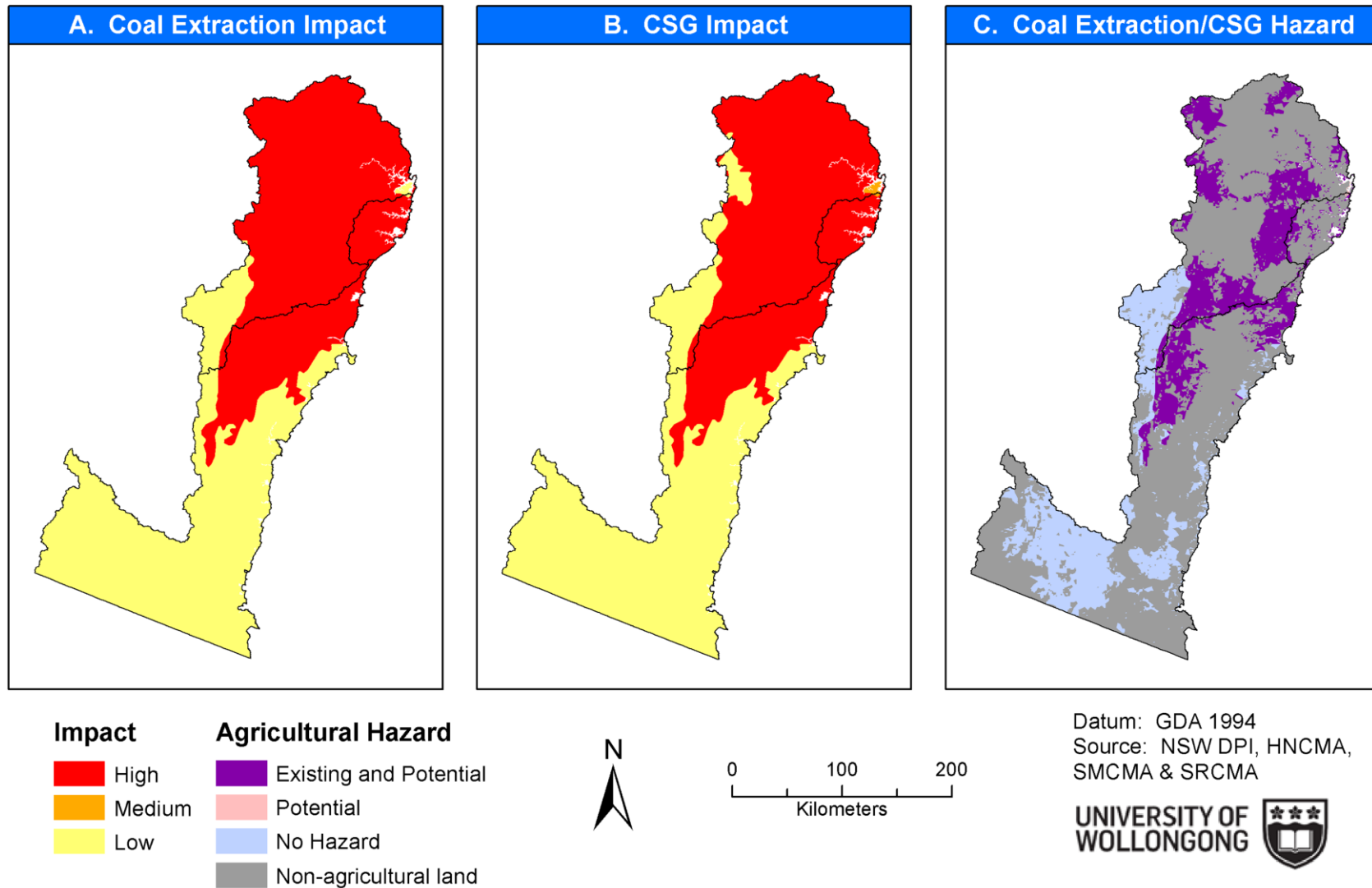


Figure 22. Predicted impacts (A-B) and hazards (C) on physiographic regions – used as the base unit for soils and landuse. Note, predicted impacts and hazards on soil assets are identical for landuse assets; (C) Masked areas of non-agricultural areas with identified zones of hazard

7.3. Biodiversity

As surface and ground water play critical roles in the water cycle; the limiting factor of ecosystem biodiversity, is changes to either of these water systems (changes such as water quantity, water quality and flow patterns). Empirical analysis shows that decreases in water table levels have had heavy impacts on biodiversity and on ecosystems that harbour notoriously high levels of biodiversity. For example it has been shown that altered flow regimes have caused the loss of 90% of floodplain wetlands within the Murray-Darling Basin (SEWPaC, 2009). The NSW Threatened Species Conservation (TSC) Act lists 'alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands' as one of the major 'key threatening processes' that cause extinction of threatened species (OEH (a), 2012). As the species and communities that are in the poorest state (endangered and critically endangered) often are also the most sensitive to change there is real risk that changing ground and surface water flows could lead to the extinction of endangered species or communities (Araujo and New, 2007).

Vegetation

Vegetation includes all forms of plant species. In Australia, it is common for vegetation to be broadly defined according to formation classification systems which primarily take into consideration the dominant species present, such as those developed by Keith (2002).

Threatened Species

Threatened species are both flora and fauna species that have been identified by either the State or Federal Government as being under threat. Government agencies have implemented projects that aim to reduce threats, restore habitats and rebuild populations of threatened species. Most of the species that are identified as threatened are endemic to Australia and form part of our national identity. Development of new mine sites creates a risk that a population of a threatened species could decline further, possibly to the point of extinction in that area, as the development would require disturbance or removal of habitat.

7.3.1. Methodology

Vegetation

To complete the template for vegetation assets, a desktop analysis and evaluation of current Australian vegetation sub-formation information was initially undertaken. The OEH website was recognised to provide a comprehensive foundation for the assessment of vegetation assets within

the study area. Each vegetation asset was described based on the classification features of the sub-formation. It was decided that particular aspects of the template were not directly applicable to vegetation assets and were therefore excluded (*Appendix II*).

In order to determine current condition of vegetation assets within the study area a risk matrix table based on conservation status (as outlined by the NSW Threatened Species Conservation [TSC] Act) was developed. This can be seen in *Table 17* which identifies the relationship between the conservation status of individual species and the overall condition of the asset. Vegetation assets listed to be in either a very poor or extremely poor condition have high levels of endangered and critically endangered species, populations or ecological communities within them. It is important to note that this assessment was based only on the listings of threatened species for NSW (within the TSC Act) and intentionally excluded any species which were considered to be ‘predicted’ within the vegetation asset. As the assessment is only taking into account the conservation status the role of urbanisation and degree of land clearing of vegetation are not considered as part of the condition rating.

Table 17: Risk matrix table for determining vegetation asset condition based on biodiversity values.
Conservation status is based on TSC Act

		Conservation Status (NSW)			
		Not listed	Vulnerable	Endangered	Critically Endangered
No of Spp.	>15	Good	Very Poor	Extremely Poor	Extremely Poor
	10-15	Good	Very Poor	Extremely Poor	Extremely Poor
	5-9	Good	Poor	Very Poor	Extremely Poor
	2-4	Good	Poor	Very Poor	Extremely Poor
	≤1	Good	Moderate	Poor	Extremely Poor

Unlike ground and surface water, soil and land assets there has been no vulnerability assessment undertaken on vegetation. This is due to a lack of baseline data required for a vulnerability assessment

Threatened Species

To determine a condition assessment of threatened species any species listed as critically endangered received a very poor condition status (*Table 18*). Detailed methods for the creation of each dataset within the database have been outlined in a work flow diagram within *Appendix II*. Data used to define assets was sourced from OEH. Information sourced from OEH was used as it identified all known threatened species present within each sub-catchment; however the data has a note that it is not a complete atlas of all existing threatened species (this level of detail does not exist in any

databases). Fields that were identified as relevant to threatened assets were populated using both geospatial data and information obtained from the OEH and CMA websites. The population of some fields have been limited to specific assets due to limited geospatial and metadata.

The condition field was completed based on the most extreme conservation status of either the NSW TSC Act or the Commonwealth EPBC Act. For example if the TSC Act lists a species as critically endangered but the EPBC Act does not mention the species then the rating was based on the TSC Act's listing.

Table 18: Summary of condition rating based on Conservation Status from TSC Act or EPBC Act

Condition Rating	Conservation Status
Very poor	Critically endangered
Poor	Endangered
Moderate	Vulnerable

For threatened species a vulnerability assessment was performed in a different manner than those performed for ground and surface water, soil and land assets. The vulnerability assessment gives a hazard and potential impact rating. Due to the nature of threatened species' large distribution area and the vast numbers of threatened species present within the study area, the vulnerability assessment was conducted by breaking presence/absence of a species into the same sub-catchment boundaries as were used for surface water and wetlands (refer to *Figure 21*). Within each of the CMAs the species was given the worst-case risk and hazard rating specific to each of the sub-catchment areas. These ratings that are specific to the sub-catchment areas are the same used for the surface water vulnerability assessment.

7.3.2. Hazards and Likely Impacts

A number of hazards from CSG and coal mining have been identified that have the potential to negatively impact biodiversity. Direct and indirect hazards have been identified with indirect hazards defined according to 'key threatening processes'. 'Key threatening processes' have been compiled by the NSW government and are defined as *'processes that if left unchecked will inevitably cause the extinction of native plants and animals, especially those that are already at risk such as threatened species'* (OEH (a), 2012). Six key threatening processes may directly result from the construction of new mine sites. These are:

- Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands.

- Bushrock removal.
- Clearing of native vegetation.
- Alteration of habitat following subsidence due to longwall mining.
- Loss of hollow-bearing trees.
- Removal of dead wood and dead trees.

Other key threatening processes may be exacerbated as secondary impacts of new mine site construction, including an increase in opportunistic invasive or weed species presence due to habitat loss/change.

In relation to threatened species, certain areas are at greater risk than others within the study area. *Figure 23* shows the presence of threatened species of fauna and flora based on the number of species present in the sub-catchment area.

As can be seen from *Figure 23*, the areas of highest numbers of threatened species are most commonly found in the areas where CSG mining is possible (excluding the Far South-Coast sub-catchment region). These regions are Upper Nepean River, Hawkesbury River, Shoalhaven Estuary and Kurnell for Fauna and the Hawkesbury River for Flora. Some more well known species found in this area include the Koala, Booroolong Frog, Powerful Owl, Gang-gang Cockatoo and Camden White Gum. The high risk sub-catchment regions in terms of fauna contain between 51 to 60 different species. In terms of flora 41 to 50 different threatened species are found in the Hawkesbury River sub-catchment region. Another trend that can be observed in terms of number of threatened species of fauna is that sub-catchment areas with higher numbers of threatened species are found closer to the coast (except for the region surrounding Sydney) (*Figure 23*).

The vegetation types found most densely around the Sydney region where coal and CSG mining is likely to take place is wet and dry sclerophyll forests. *Figure 23* shows the number of different threatened species of fauna around the Sydney region as ranging from 21 to 60 depending on which sub-catchment is being examined. This is in comparison to the southern portion of NSW which shows threatened species counts mainly in the 0 to 40 categories. Around Sydney the mode value for threatened species counts is 31 to 40 species compared to the southern portion of NSW where the mode score for a sub-catchment is 11 to 20 different threatened species of fauna. This greater diversity of threatened species around Sydney means that threatened species in that area are at greater risk of damage due to coal and CSG mining disturbance.

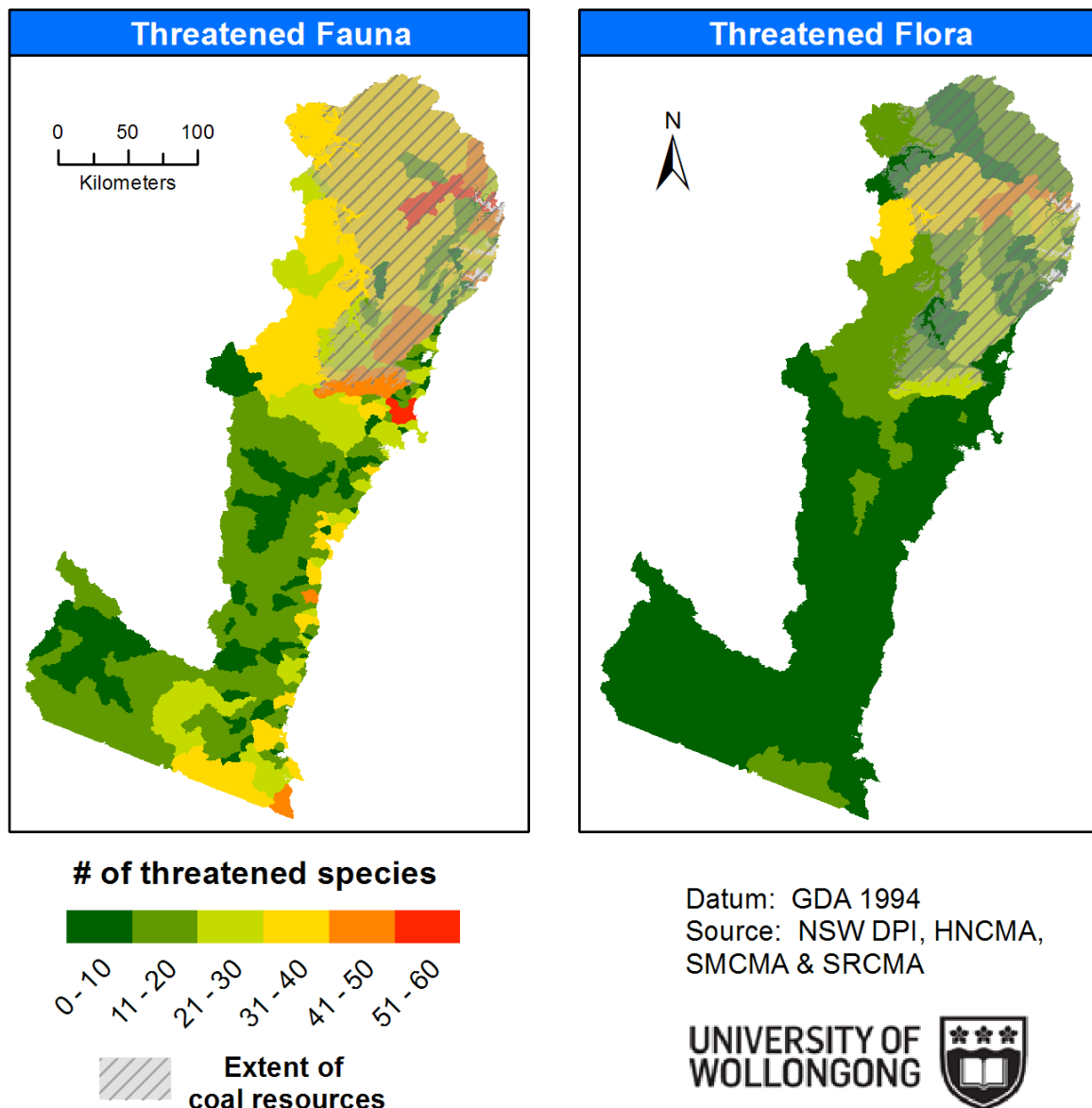


Figure 23: The presence of threatened species of fauna and flora (TSC Act and EPBC Act) based on the number of species present in the sub-catchment area

7.3.3. Knowledge and Data Gaps

A number of data gaps were found for biodiversity. The main data gap was found to be the availability and resolution of spatial data. The resolution of data for threatened species and vegetation were limited by licensing conditions, and a set of wetland data was limited by point data. This limited the output of the GIS analyses.

Other knowledge gaps were found when determining the social/cultural values, economic values, hydrology and condition. There also remain several other asset specific knowledge gaps that need to be considered:

- Relationship between habitat destruction and extension of threshold of endangered species (Fahrig, 2002; Robinson *et al.*, 1992).
- Not all species within the vegetation sub-formations are known.
- It is unclear what vegetation habitats are present in areas already impacted by both current and future mining projects.
- Unknown current stressors already affecting vegetation.
- Consistent and uniform approach to vegetation mapping within Australia (Sun *et al.*, 1997).

8. KNOWLEDGE GAPS AND DATA LIMITATIONS

The report has identified potential hazards associated with CSG extraction and coal mining for environmental assets within the study area. There are however significant knowledge gaps and data deficiencies that have limited the effectiveness of hazard identification. These limitations are outlined in this chapter. In this context, limitations can be grouped into four categories. These are:

1. Limitations in the structure and format of the database.
2. Limitations in the availability and quality of environmental asset data.
3. Gaps in knowledge of hydrogeological processes, both specifically within groundwater systems in the study area and more generally.
4. Gaps in knowledge in the specific impacts of CSG and coal mining on environmental assets both in the study area and more broadly.

The limitations of the environmental assets and vulnerability database affected the factors which could be considered and specificity and accuracy at which hazard risk could be classified, as did the availability and quality of existing data for the study area. In addition, gaps in knowledge in physical and biological processes and their interaction limited the extent to which the risks of coal and CSG mining operations on environmental assets could be determined. Combined, these limitations contribute to the degree of unknown or unquantifiable risk in the study area and consequently impact upon degree of confidence with which the likely impacts of CSG and coal extraction could be ascertained.

8.1. Database limitations

The framework of the supplied environmental assets and vulnerability assessment database controlled the degree and type of hazard impact which could be assessed. Key limitations of the database included:

- The inability of the database to represent environmental assets or vulnerability spatially limited the specificity at which the potential hazard impact could be determined. Many environmental assets are spatially complex, consequently environmental impacts for spatially complex environmental assets could only be considered at an aggregate level.
- The lack of true spatial representation in the database meant relationships between environmental assets and CSG and coal mining operations could not be considered. The

vulnerability of environmental assets is in part a function of its spatial relationship to coal mining and CSG operations. The database allowed for point location data only. Many environmental assets are interdependent where the degree a hazard posed to one asset will influence effect another. This aspect of hazard assessment was not able to be captured in the database.

- Lack of capacity to identify indirect impacts and potential long-term and cumulative effects of coal mining and CSG extraction. The database only allowed for direct impacts to be assessed, i.e. site specific impacts. Consequently, factors including downstream impacts, or impacts of prolonged groundwater drawdown or long-term aquifer contamination could not be considered.
- Lack of capacity to capture the risk posed by different mining approaches, including, for example, factors such as mine size and the number of wells and CSG extraction methods. These influence the degree of hazard posed by coal and CSG mining.
- The database did not allow vulnerability be ranked for any given environmental asset, e.g. rivers. Consequently, the specific assets, e.g. a particular river, most at risk could not be identified.
- Critical characteristics of the coal seams and groundwater systems which influence potential risk to environmental assets, such as depth to surface of seam and vertical distribution and thickness of aquifers and aquitards, were not taken into account within the database. This limited the ability to ascribe risk specifically.

8.2. Limitations in data availability and quality

Chapter 8 outlined existing environmental asset data and data gaps for the study area. Data gaps limit both the ability to identify environmental assets, where for example the presence of a threatened species or a ground water dependant ecosystem in an area is unknown, and to classify vulnerability when the physical extent, quantity and quality of an environmental asset is unknown. The key data gaps identified as affecting this study include:

- Lack of spatial data for threatened species in the study area.
- Lack of spatial data for wetlands in the study area.
- Lack of spatial data for vegetation within the study area.
- Lack of gauge records for a large number of sub-catchments.
- Lack of ground water data.
- Lack of data quality assurance.

8.3. Gaps in knowledge of hydrogeological processes and groundwater extent

Knowledge gaps in hydrogeological processes generally, and in the study area, affect the ability to identify risks from changes to water quality and quantity as a result of, for example, groundwater drawdown during CSG extraction, or with regard to the degree of connectivity between surface water and ground water. Specific limitations include:

- Lack of knowledge of groundwater flow. The mathematical algorithms that underpin groundwater flow models are based on assumptions, for example, fully-penetrating wells, porous media with homogeneity and isotropic conditions, which rarely occur in real world situations.
- Lack of specific knowledge of aquifer storage and behaviour parameters including storage coefficients (for unconfined aquifers), storativity (for confined aquifers) and transmissivity both in the study area and more generally.
- Lack of knowledge in the degree of connectivity between aquifer systems which limit the ability to predict cross contamination and wide spread groundwater drawdown.
- A lack of understanding of vertical groundwater conditions with regard to aquifer and aquitard characteristics which is required to assess cross-contamination potential.
- Knowledge gaps in the degree of heterogeneity in aquifers (Mares *et al.*, 2009).
- A lack of knowledge of fracturing and jointing patterns within the rocks containing aquifers, which may for example influence aquifer cross contamination.
- Knowledge gaps in groundwater and surface water connectivity (Osborn *et al.*, 2011) and the long-term effects of CSG development on the water balance as has been highlighted by recent CSG operations in the Murray-Darling Basin (Moran & Vink, 2010); This has implications for groundwater extraction on surface water dependant ecosystems and uses.
- Knowledge gaps in existing ground water extent and behaviour driven by poor quality data collection.
- Lack of groundwater data sharing between CSG operators and water resource and environmental management authorities and organisations compounding existing knowledge gaps.

8.4. Gaps in knowledge about impacts of CSG and coal extract extraction

Several key knowledge gaps regarding the potential effects of CSG and coal extraction on environmental assets have been identified. These include:

- A lack of understanding of flow-on effects, indirect impacts and cumulative effects of CSG and coal extraction (Helmuth, 2008; Habermehl, 2010). These include downstream effects, cumulative effects of long-term operations or the impact of multiple CSG operations on for example tipping points in groundwater dependant ecosystem, or the impacts prolonged CSG extraction on environmental assets.
- Lack of knowledge about the contribution of CSG derived methane to greenhouse gas concentrations. There are currently no published data on the emissions of methane from CSG activities in Australia, and no systematic emission monitoring is being undertaken (Saddler, 2012). Losses of methane from individual CSG wells is highly variable (Helmuth, 2008), consequently the relative contribution of greenhouse gases from CSG extraction maybe higher than that of coal (Osborn *et al.*, 2011).
- Lack of publically available data which could contribute to closing knowledge gaps. CSG companies often collect data which could contribute to closing knowledge gaps which is not made widely available to scientists (Helmuth, 2008).
- Lack of understanding of potential effects of CSG or coal mining operations on groundwater dependent ecosystems. This includes broad knowledge gaps in which groundwater influences and maintains ecosystems across Australia including in the study area (Hatton & Evans, 1998), and more specific knowledge gaps with regard to individual species or species assemblages, e.g. fish (Davis *et al.*, 2006) to changes in groundwater discharge or water quality.
- Gaps in knowledge on likely impacts of CSG development in the study area on bush fire hazard. Much of the land on which CSG development may occur in the study area is highly prone to bushfire or ember attack (Stammers, 2012). The potential impacts of CSG exploration and extraction on potential fire regimes, have however not been explored.
- Knowledge gaps surrounding habitat destruction and fragmentation during development of coal or CSG operations (Bottrill *et al.*, 2011).
- Potential occurrence of groundwater contamination on the wider environment (Rutovitz *et al.*, 2011).

- Limitations in current regulation related to CSG production have been suggested as an additional knowledge gap (Rutovitz *et al.*, 2011). Regulation is currently limited by existing knowledge gaps with increased monitoring and planning required to close knowledge gaps limiting current regulation deficiencies (Osborn *et al.*, 2011; Rutovitz *et al.*, 2011). In addition, the structure of legislation and policy may in some circumstances contribute to other knowledge gaps by proscribing a particular scope of monitoring, for example, thereby limiting the nature of data being collected.

9. RECOMMENDATIONS

Based on the knowledge and data gaps identified throughout the report, a number of recommendations are suggested for future research and development. These are:

- The development of a method to assess the flow-on, cumulative and long-term effects of CGS exploration and extraction which considers impacts on both the adjacent and wider environment. This could include the development of a cumulative risk assessment framework.
- Converting the existing database to an advanced spatial analysis database (GIS) in order to better capture the interdependent and spatially complex character of environmental assets allowing for improved characterisation of risk.
- Development of a modelling framework based on specific mining scenarios and the different effects which each scenario could potentially have on the environment. For example, this should include the consideration of mine size, number of wells and extraction methods used.
- Development of a system for ranking the vulnerability of each asset so that future research and monitoring programs are aware of the areas which are potentially most at risk.
- Further research into the relationships between different asset types, as well as the identification of asset specific hazards.
- Development of a standardised monitoring technique for hydraulic heads in vertical profiles.
- The development of compulsory standardised aquifer parameter testing.
- Comprehensive research and modelling into potential fracture networks and aquifer parameter estimates.
- More comprehensive surface water monitoring that analyses water quantity, quality, discharge and recharge volumes, and ecosystem health in catchments identified as high risk.
- Further research and analysis of models to prove validity and provide adequate understanding of the hydrological principles within the study area.
- Comprehensive research into the distribution and thickness of aquifer and aquitard systems the study area.
- Scenario modelling of the potential impacts to agricultural production and other land uses, e.g. conservation, of CSG development.

- Undertaking sensitivity analysis in regard to the potential impacts of coal and CSG extraction on ecosystem services and species specific response, in particular in relation to threatened species.
- Improved environmental asset data collection within the study area both in terms of data quality and integrity and the spatial extent over which monitoring data are collected, e.g. stream gauges and water quality data. It is recommended that groundwater data and data pertaining to groundwater dependant ecosystems should be a particular focus in this regard.

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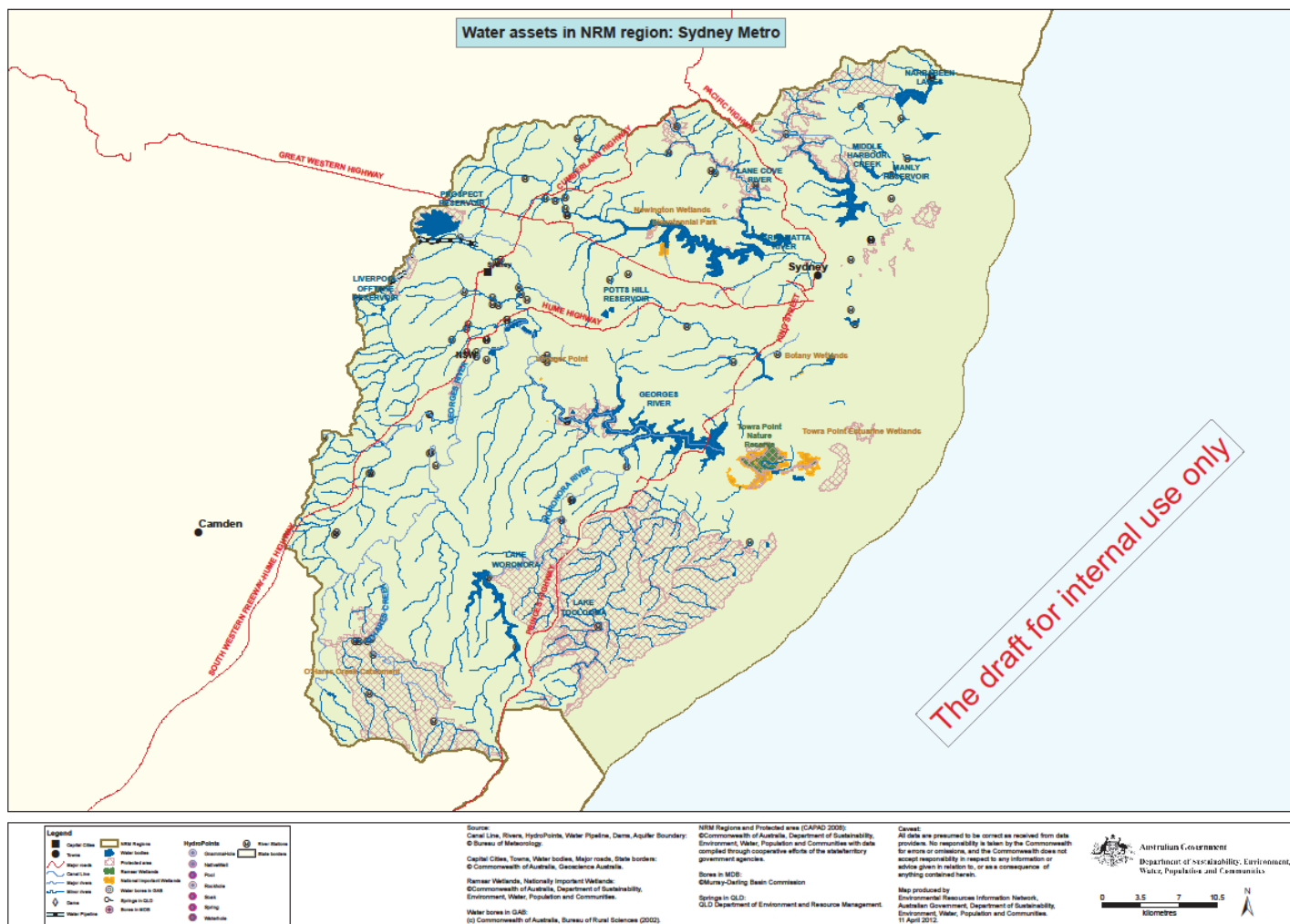
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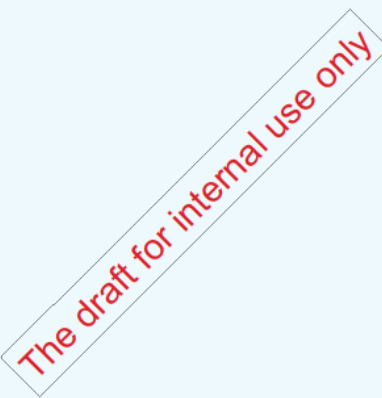
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APPENDIX I: TEMPLATES







APPENDIX II: METHODOLOGY TABLE (REFER TO APPENDIX III FOR EXPLANATION OF DATA SET USAGE)

Asset	Description	WaterBody_Type	Coordinates_latitude_longitude	NWQMS_Values	coordinates_define	Nearest_Town
Groundwater	Asset descriptions were written using information from: http://www.water.nsw.gov.au/	Pinneena, GMA Zone Defines all assets as aquifers	Co-ordinates of the assets can be defined spatially using the data sources; see metadata.	Pinneena GW, Purpose description field used.	All spatial data in the primary datasets are defined by the polygons of the GWMA's.	Pinneena GW, 'county' field used as the often large spatial extents of the assets encompass a great number of towns.
Surface water	For Sydney Metro data was taken from SMC_Waterway_Health – 'Style' column in attribute table. For both Southern Rivers and Hawkesbury Nepean data was taken from the 'RIVER_STYL' and 'RIVER_ST1'.	Sub-catchmentsStressedRivers Identifies all assets as including permanent water courses. Wetlands NSW classifications used to identify water body types as per Table 11 (Chapter 7.1.2).	Co-ordinates of the assets can be defined spatially using the data sources recorded in the metadata	Field populated based on presumptions that surface water assets contained aquatic ecosystems, drinking water, industrial water, recreation and aesthetics.	All spatial data in the primary datasets are defined by using the 'Sub-catchmentsStressedRivers' layer which identified the sub-catchments	Field not populated as the relationship between surface water and nearest town is undefined
Wetlands	Indicates wetlands within the sub-catchment based on Wetlands NSW and Wetlands Important data sets.	Wetlands NSW classifications used to identify water body types as per Table 11 (Chapter 7.1.2).	Co-ordinates of the assets can be defined spatially using the data sources recorded in the metadata	Values determined based on asset value to the environment	All spatial data in the primary datasets are defined by using the 'Sub-catchmentsStressedRivers' layer which identified the sub-catchments	Field not populated as the relationship between surface water and nearest town is undefined
Landuse	Defined by a combination of the columns LU_NSWMAJO and the LU_NSWDETA found in NSW landuse dataset.	Based on the classifications of the landuse layer	Asset co-ordinates defined as the central point of the physiographic regions.	Defined based on the framework found at http://www.environment.gov.au/water/publications/quality/pubs/nwqms-guidelines-4-vol1.pdf Section 2.1.3. More research into location specific value is needed.	All spatial data in the primary datasets are defined by polygons	Field not populated as the relationship between Landuse and nearest town is undefined. Landuse assets occur spatially across each physiographic region and intersected many townships.
Soils	The Terrain attribute out of Physiographic regions layer (regold.shp) was used to populate the Description field of the database.	Field not populated as the relationship between soil and water body type is undefined. More research into location specific data is needed	Asset co-ordinates defined as the central point of the physiographic regions.	Field not populated as the relationship between soil and NWQMS is undefined. More research into location specific value is needed.	All spatial data in the primary datasets are defined by polygons.	Field not populated as the relationship between soil and nearest town is undefined. Soil assets occur spatially across each physiographic region and intersected many townships.
Vegetation	Primarily determined based on description provide on each asset by OEH website	Field not populated as the relationship between vegetation and water body type is undefined. More research into location specific data is needed	Was not defined due to lack of spatial data	Field not populated as the relationship between vegetation and NWQMS is undefined. More research into location specific value is needed.	Was not defined due to lack of spatial data	Based on information provided by OEH website
Threatened species	Primarily determined based on description provide on each asset by OEH website	Field not populated as the relationship between threatened species and water body type is undefined. More research into location specific data is needed	Threatened species co-ordinate data cannot be defined due to legal issues	Field not populated as the relationship between threatened species and NWQMS is undefined. More research into location specific value is needed.	All spatial data in the primary datasets are defined by point data	Based on information provided by OEH website

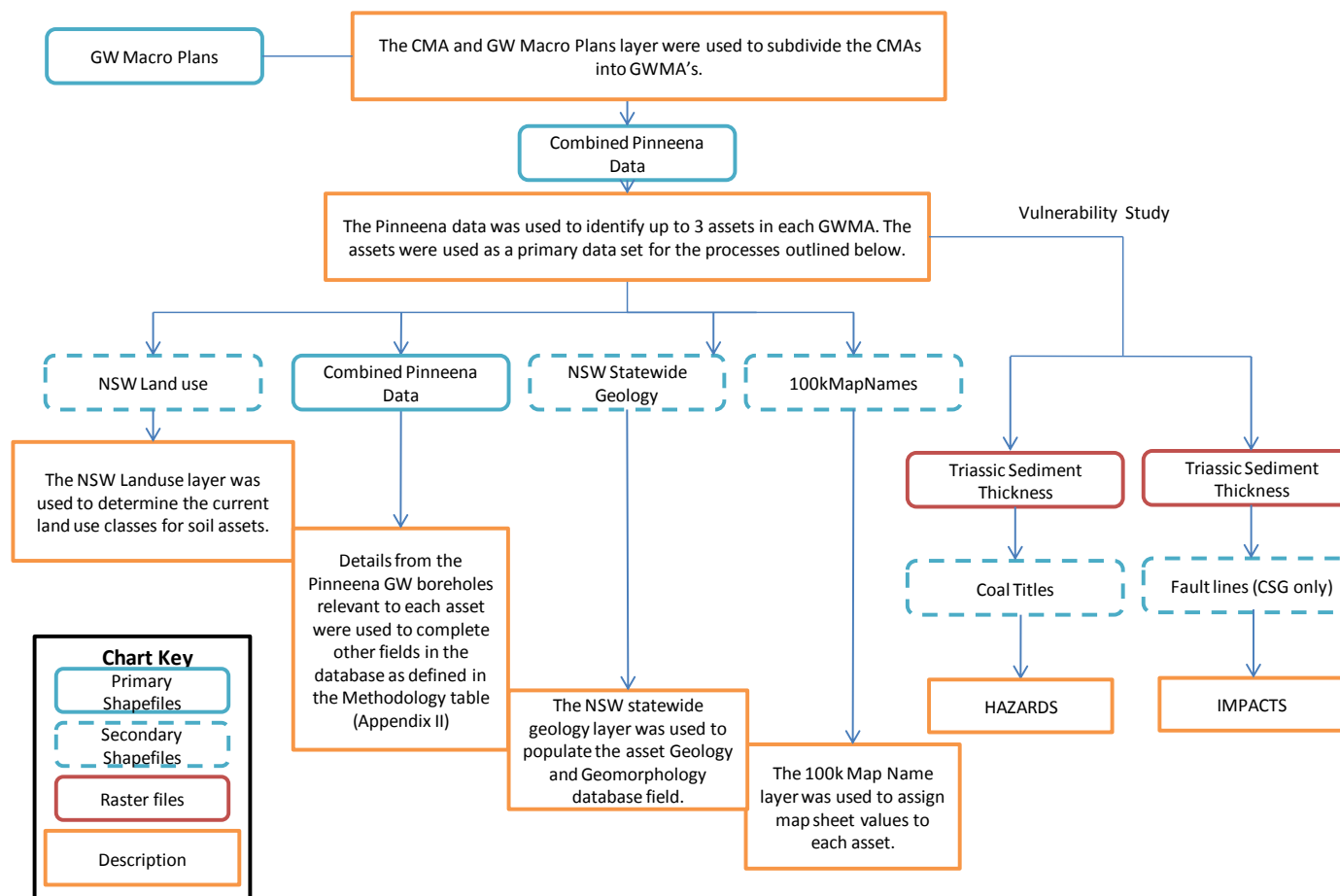
Asset	Mapsheet_100k_name	Environmental Value	EconomicValue	SocialCulturalValue
Groundwater	Defined using secondary data: 100kMapNames name in overlay with GWMAs from GW Macro Plans.	GW Macro Plans overlayed with GW Dependant ecosystems and Sub-catchments to identify which groundwater assets are related to surface water and wetland assets.	Pinneena GW 'Licensed purposes' field used to identify activities that are economically reliant on the use of groundwater from that GWMA and aquifer type.	Pinneena GW 'Licensed purposes' where recreational uses are identified.
Surface water	Defined using secondary data: 100kMapNames	Determined based on 'Ecological Stress' from Sub-catchmentsStressedRivers layer. Environmental value assumed as the inverse of 'ecological stress'. NPWS parks layer used to define any NPWS managed areas Within the sub-catchments.	Determined based on information provided on each CMA website	Determined based on information provided on each CMA website
Wetlands	Defined using secondary data: 100kMapNames	Determined based on 'Ecological Stress' from Sub-catchmentsStressedRivers layer. Environmental value assumed as the inverse of 'ecological stress'. NPWS parks layer used to define any NPWS managed areas Within the sub-catchments.	Determined based on information provided on each CMA website	Determined based on information provided on each CMA website
Landuse	Defined using secondary data: 100kMapNames	Assets were divided into 4 classes based on the assets environmental worth to the community. Environmental value classes were defined be the definitions for the assets current and potential Landuse outlined in the guidelines (Guidelines for landuse mapping in Australia: principles, procedures and definitions, 4th edition, 2011). Some assets were assigned multiple classes. 1: National Park 2: National Park/conservation land 3: Developed land 4: Agricultural land	Was divided into 4 classes based on the function defined by the asset name. Some assets were assigned multiple values. 1: Natural Resources 2: Recreation and tourism 3: Infrastructure 4: Agricultural. More research into location specific value is needed	Was divided into 4 classes based on the function and definition asset name and definitions defined in the (Guidelines for landuse mapping in Australia: principles, procedures and definitions, 4th edition, 2011).1: Recreational
Soils	Defined using secondary data: 100kMapNames	Assets were divided into 4 classes based on the assets environmental worth to the community. Environmental value class data was firstly defined by the potential function of the land derived from the LAND_CAP_D column and secondly by definition found in the SOILCON_PR column of LandCapability.shp layer. Some assets were assigned multiple classes. 1: National Park 2: National Park/conservation land 3: Developed land 4: Agricultural land	Was divided into 4 classes based on the function defined by the asset name. Some assets were assigned multiple values. More research into location specific value is needed. 1: Natural Resources 2: Tourism 3: Recreation 4: Agricultural	Was divided into 5 classes based on the function and definition asset name. More research into location specific value is needed. 1: Recreational 2: Cultural 3: Resource 4: Community 5: Industrial
Vegetation	Was not defined due to lack of spatial data	Primarily determined based on vulnerable, endangered and critically endangered species, populations and ecological communities known to the present within them. More research into specific environmental value is needed.	Primarily determined based on vulnerable, endangered and critically endangered species, populations and ecological communities known to the present within them. More research into specific economic value is needed.	Primarily determined based on vulnerable, endangered and critically endangered species, populations and ecological communities known to the present within them. More research into specific social and cultural value is needed.
Threatened species	Defined using secondary data: 100kMapNames	Is the conservation status of the particular species based on the NSW Threatened Species Act 1995 and the Environment Protection and Biodiversity Act 1999	Primarily determined based on vulnerable, endangered and critically endangered species, populations and ecological communities known to the present within them. More research into specific economic value is needed.	Primarily determined based on vulnerable, endangered and critically endangered species, populations and ecological communities known to the present within them. More research into specific social and cultural value is needed.

Asset	Hydrology	Geology_geomorphology	Other_Relevant_Details	Current_landuse	Tenure	Condition
Groundwater	Pinneena GW, 'maximum bore depth' field' used to identify the maximum depth of interaction with resource. 'standing water level' field used to identify a range of the water levels across the GWMA identified by licensed bores.	Geology defined using Secondary Data: NSW statewide geology. More research into location specific geomorphic process is need.	Pinneena GW, the range of salinity from 'Salinity Description' field. Yield range from 'Yield' field.	Current landuse defined NSW Landuse in overlay with GW Macro Plans	Pinneena GW 'Owner type' field used.	Pinneena GW, The range of salinity from 'Salinity Description' field. Yield range from 'Yield' field.
Surface water	Based on information taken from Hydrological Stress layer from Sub-catchmentsStressedRivers	Geology defined using Secondary Data: NSW statewide geology. More research into location specific geomorphic process is need.	Based on the data base feature list provided and internet searches based on the asset names. More research into location specific data is needed.	Current landuse defined Landuse defined using Secondary Data: NSW Landuse	Based on the data base feature list provided and internet searches based on the asset names. More research into location specific data is needed.	<p>For SMCMA, values determined by the correlation of layers</p> <ul style="list-style-type: none"> SMC_Waterway_Health – “vegetation” SM_salinity – “overall hazard” SMCMA_acidsulphate_risk – “risk” <p>For HNCMA and SRCMA derived from Stream_con layer, in many circumstances the sub-catchment had several different conditions within it. In these cases we have identified the poorest condition present.</p> <p>Determined based on wetland health in the region. For SMCMA, values determined by the correlation of layers</p> <ul style="list-style-type: none"> SMC_Waterway_Health – “vegetation” SM_salinity – “overall hazard” SMCMA_acidsulphate_risk – “risk” <p>For HNCMA and SRCMA derived from Stream_con layer, in many circumstances the sub-catchment had several different conditions within it. In these cases we have identified the poorest condition present.</p>
Wetlands	Based on information taken from Hydrological Stress layer from Sub-catchmentsStressedRivers in regards to wetland assets in the region	Geology defined using Secondary Data: NSW statewide geology. More research into location specific geomorphic process is need.	Based on the data base feature list provided and internet searches based on the asset names. More research into location specific data is needed.	Current landuse defined Landuse defined using Secondary Data: NSW Landuse	Based on the data base feature list provided and internet searches based on the asset names. More research into location specific data is needed.	<p>Determined based on wetland health in the region. For SMCMA, values determined by the correlation of layers</p> <ul style="list-style-type: none"> SMC_Waterway_Health – “vegetation” SM_salinity – “overall hazard” SMCMA_acidsulphate_risk – “risk” <p>For HNCMA and SRCMA derived from Stream_con layer, in many circumstances the sub-catchment had several different conditions within it. In these cases we have identified the poorest condition present.</p>
Landuse	Field not populated as the relationship between Landuse and hydrology type is undefined. More research into location specific value is needed.	Geology defined using Secondary Data: NSW statewide geology. More research into location specific geomorphic process is need.	The Terrain attribute out of Physiographic regions (regold.shp) was used to populate this field of the database.	Current landuse defined Landuse defined using Secondary Data: NSW Landuse	Based on the data base feature list provided and internet searches based on the asset names. More research into location specific data is needed.	Values calculated based on the adapted risk matrix summarised within methodology*
Soils	Field not populated as the relationship between soil and hydrology type is undefined. More research into location specific value is needed.	Geology defined using Secondary Data: NSW statewide geology. More research into location specific geomorphic process is need.	This field was populated using values found in the SOILCON_PR column of the Land Capability layer and the soil atlas(soilAtlas2M.shp)	Current landuse defined Landuse defined using Secondary Data: NSW Landuse	Based on the data base feature list provided and internet searches based on the asset names. More research into location specific data is needed.	Values calculated based on the adapted risk matrix summarised within methodology*
Vegetation	Field not populated as the relationship between vegetation and hydrology type is undefined. More research into location specific value is needed.	Field not populated as the relationship between vegetation and geology type is undefined. More research into location specific value is needed.	Was not defined due to lack of spatial data	Was not defined due to lack of spatial data	Based on the data base feature list provided and internet searches based on the asset names. More research into location specific data is needed.	Values calculated based on the adapted risk matrix summarised within methodology*
Threatened species	Field not populated as the relationship between threatened species and hydrology type is undefined. More research into location specific value is needed.	Field not populated as the relationship between threatened species and geology type is undefined. More research into location specific value is needed.	Was not defined due to lack of spatial data	Was not defined due to lack of spatial data	Based on the data base feature list provided and internet searches based on the asset names. More research into location specific data is needed.	The condition field was completed based on the most extreme conservation status of either the NSW TSC Act or the Commonwealth EPBC Act.

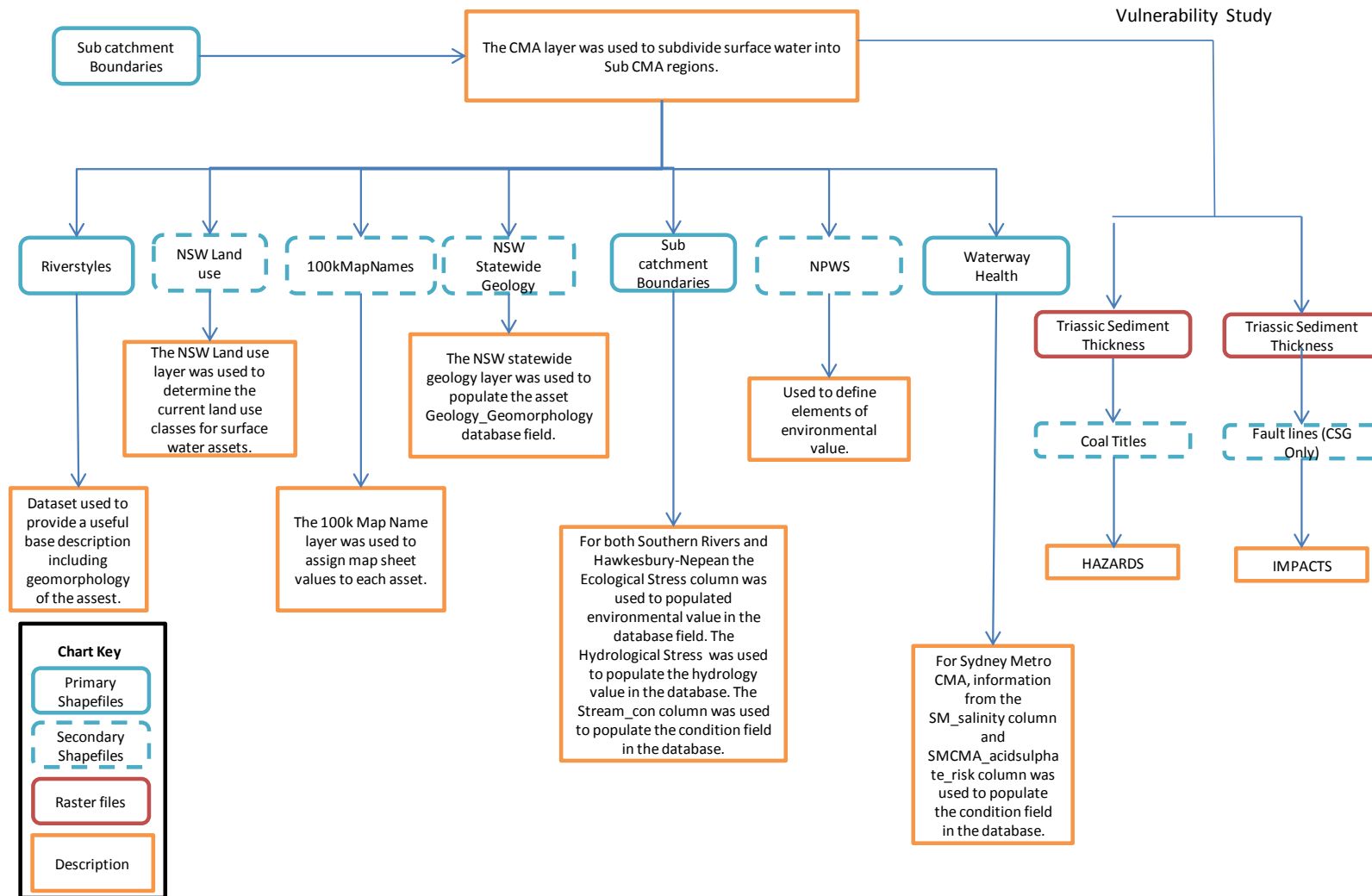
* Please refer to each asset methodology section for a description of risk matrix used

APPENDIX III: WORKFLOW TEMPLATES

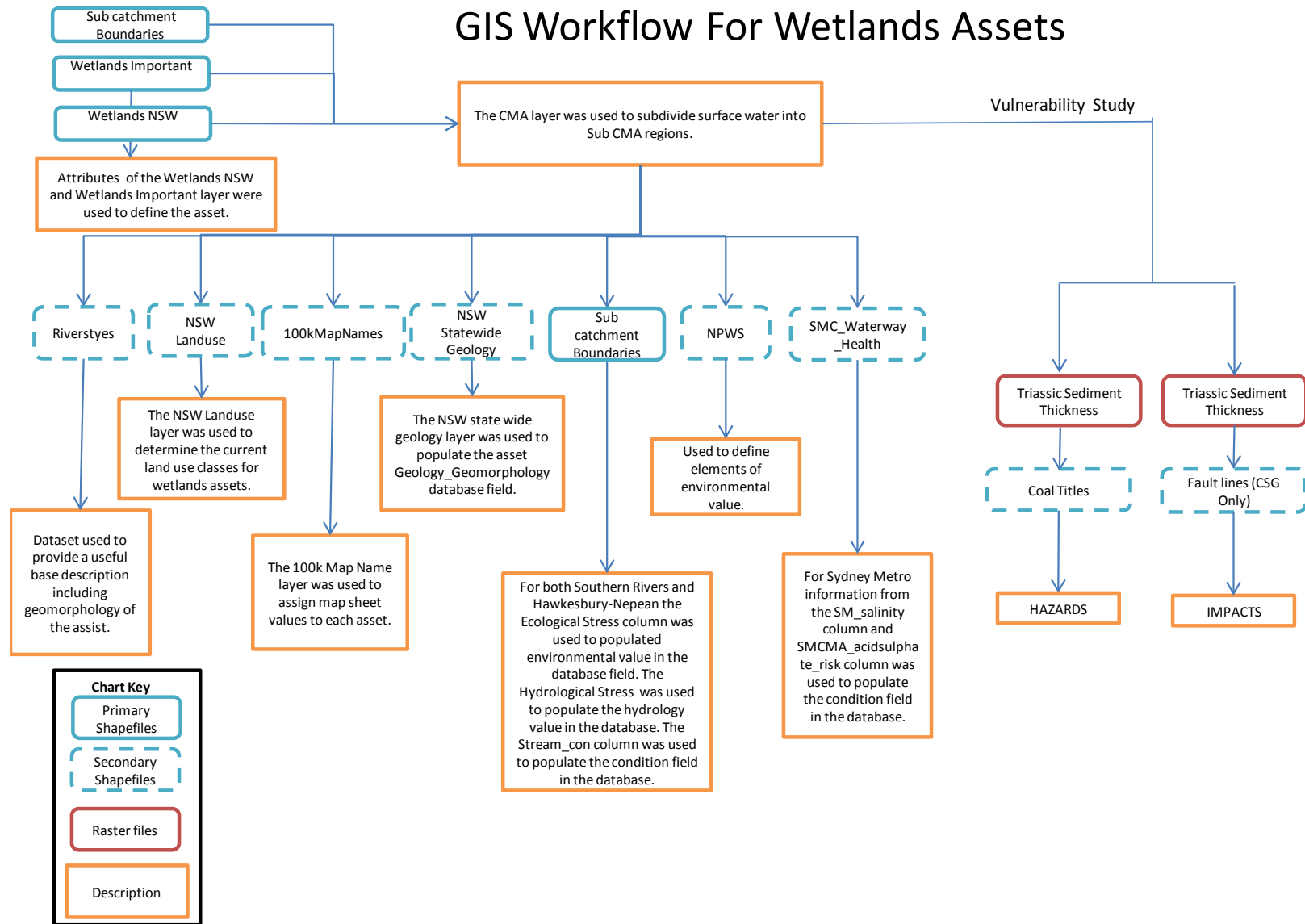
GIS Workflow For Groundwater Assets



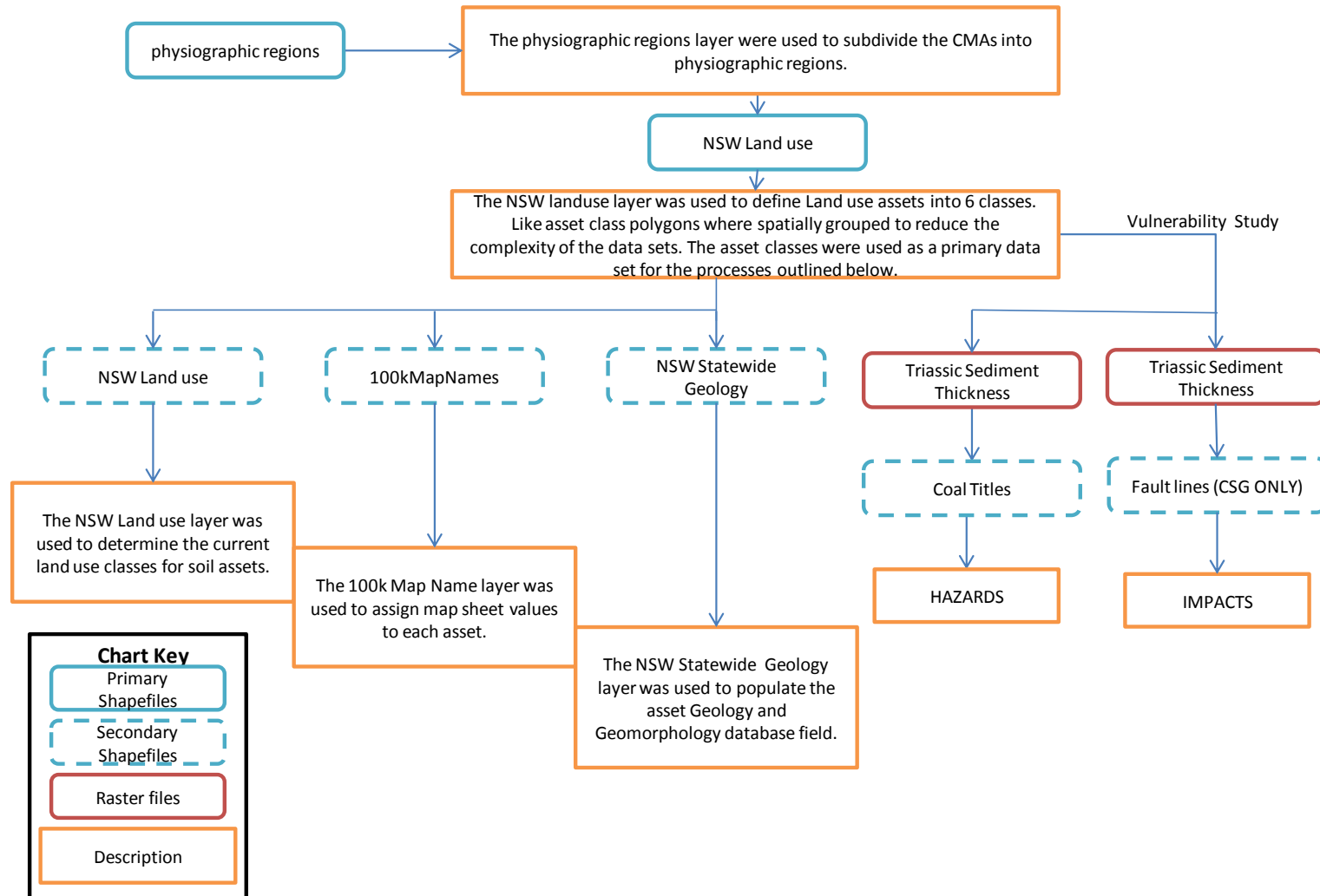
GIS Workflow For Surface Water Assets



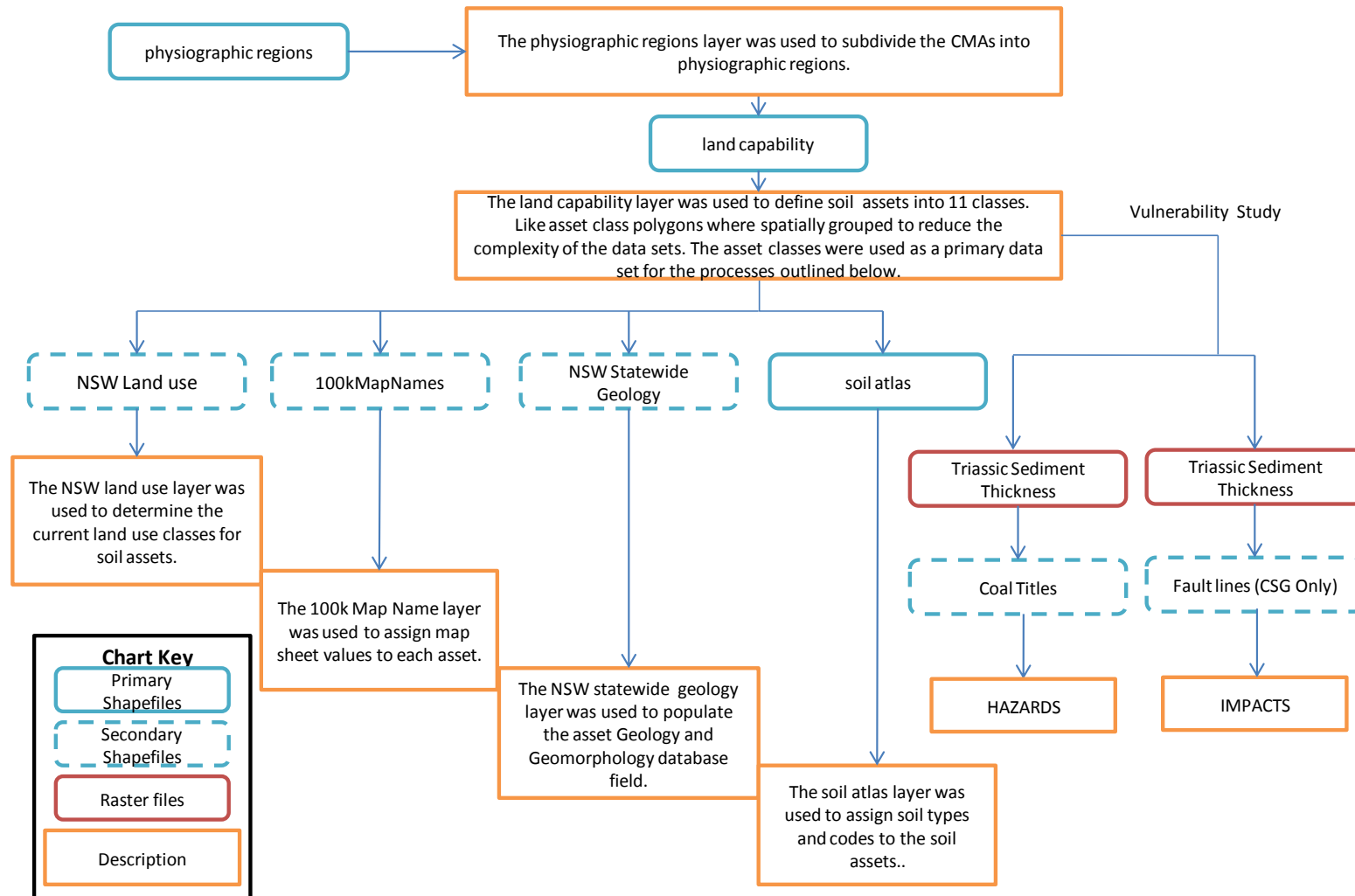
GIS Workflow For Wetlands Assets



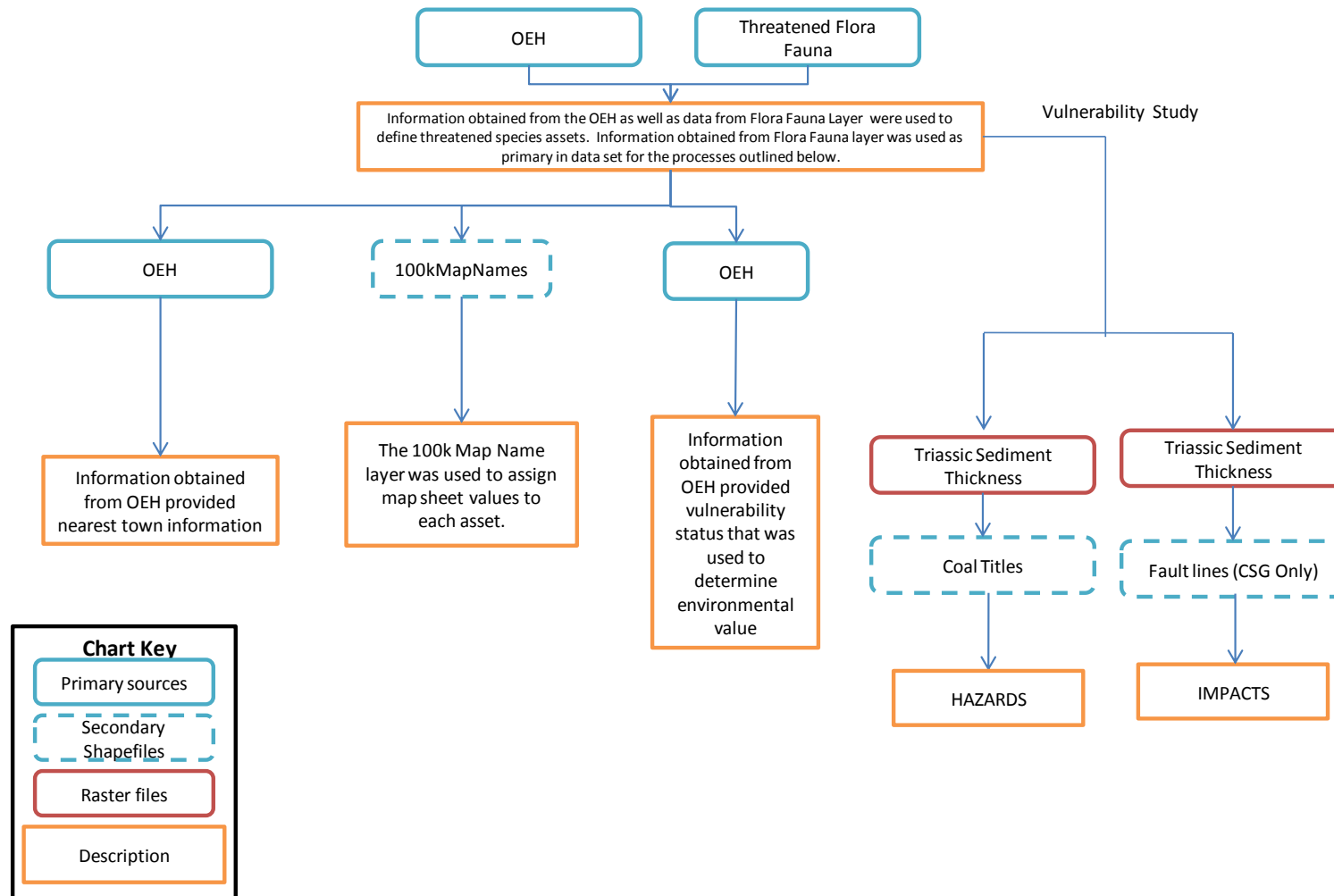
GIS Workflow For Land Use Assets



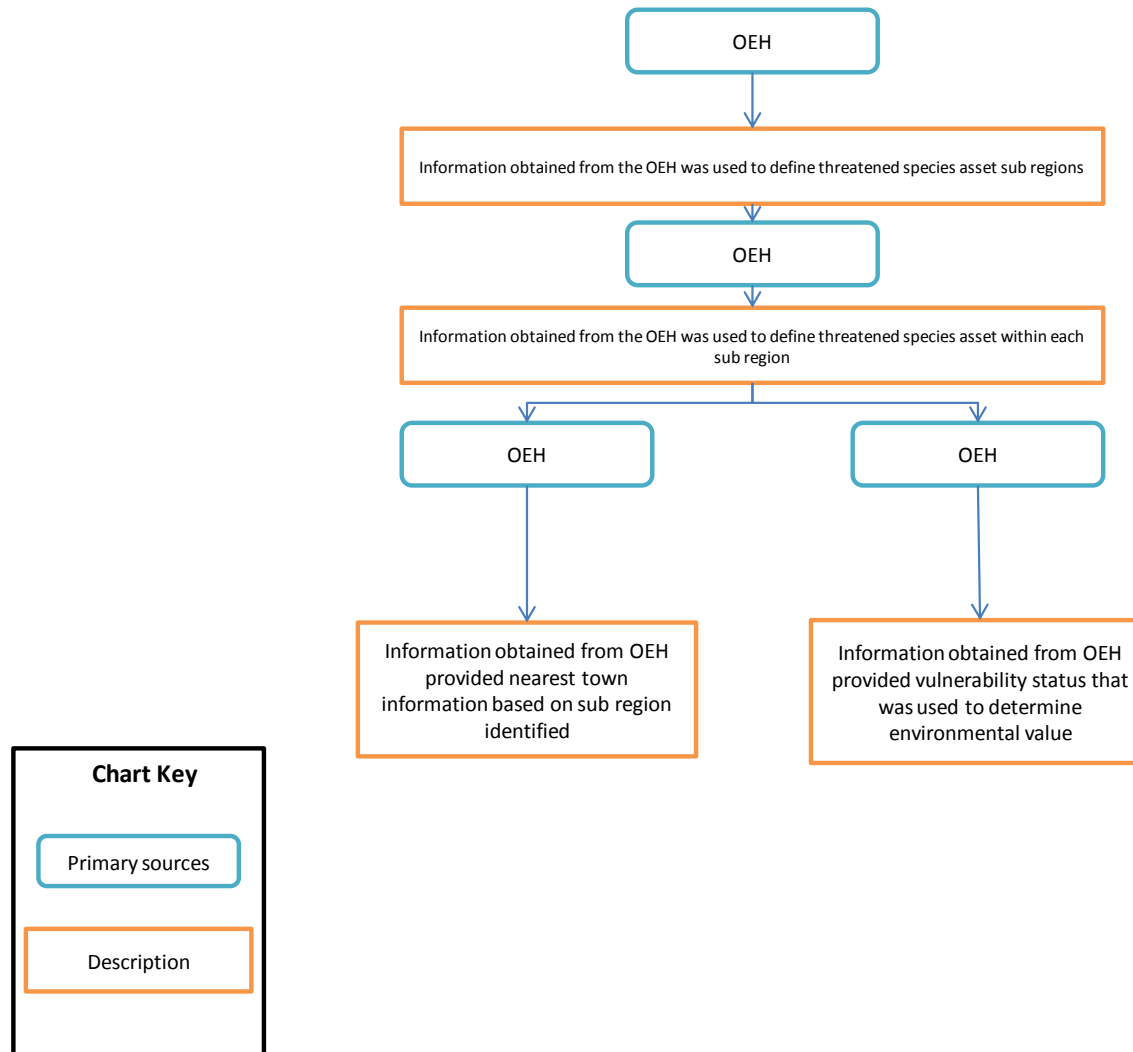
GIS Workflow For Soil Assets



Workflow For Threatened Species Assets



Workflow For Vegetation Assets



APPENDIX IV: SOIL

Soil (Land Capability) Assets

CSIRO Physiographic Region Classification

- regoldd.shp (<http://www.asris.csiro.au/themes/PhysioRegions.html>)

The attribute REGOL_NAME was used to subdivide soil assets into physiographic regions e.g. the Blue Mountains and Cumberland regions for the Sydney Metropolitan CMA.

Soil Assets Classes (Land Capability)

- LandCapability.shp (Data provided by CMAs)

The Land capability layer was used to define soil assets into 11 classes by bio-physical characteristics. Land capability class polygons were spatially grouped into the same asset throughout the physiographic regions. This level of detail was chosen as it represented the best compromise in resolution as the Land Capability data set for the CMAs has many (>9900) unique polygons. The data set excluded detailed mapping in areas designated as National and State Parks, State Forests, restricted water supply catchments, lands set aside for soil conservation management and urban zonings. However these titles were used to define asset classes in this study as their prosperity and function is dependent on soil quality.

Soil Types

- soilAtlas2M.shp (<http://www.asris.csiro.au/themes/Atlas.html>)

The soilAtlas2M layer was joined to asclut.txt file included in the downloadable folder. The soil codes and types found in asclut.txt were used to populate the Other_Relevant_Details field of the database. Definitions of the soil codes can be found in explanatoryNotes.txt also include in the .jZip download.

APPENDIX V: FURTHER READING

The location of theses can be found via the Libraries Australia catalogue

<http://librariesaustralia.nla.gov.au/>

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