APPENDIX E

Groundwater assessment (Part A)

Cobbora Coal Project - Groundwater Assessment

January 2013

Cobbora Holding Company Pty Limited

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Glossary

Acidity	Base neutralising capacity.
Alkalinity	Acid neutralising capacity.
Alluvium	Unconsolidated sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on river beds, floodplains and alluvial fans.
Aquiclude	Low permeability unit that forms either the upper or lower boundary of a groundwater flow system.
Aquifer	Rock or sediment in a formation, group of formations or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to bores, wells and springs.
Aquifer properties	Characteristics of an aquifer that determine its hydraulic behaviour and its response to abstraction.
Aquifer, confined	Aquifer that is overlain by a confining, low-permeability layer. The hydraulic conductivity of the confining bed is significantly lower than that of the aquifer.
Aquifer, semi-confined	Aquifer confined by a low-permeability layer that permits water to slowly flow through it. During pumping, recharge to the aquifer can occur across the confining layer; also known as a leaky artesian or leaky confined aquifer.
Aquifer, unconfined	Also known as a water table or phreatic aquifer. An aquifer in which there are no confining beds between the zone of saturation and the surface. The water table is the upper boundary of unconfined aquifers.
Aquitard	Low-permeability unit that can store groundwater and also transmit it slowly from one aquifer to another. Aquitards retard but do not prevent the movement of water to or from an adjacent aquifer.
Artesian water	Groundwater that is under pressure when tapped by a bore and is able to rise above the level at which it is first encountered. It may or may not flow out at ground level. The pressure in such an aquifer is commonly called artesian pressure, and the formation containing artesian water is called an artesian aquifer or confined aquifer.
Australian Height Datum (AHD)	Reference point (very close to mean sea level) for all elevation measurements, and used for correlating depths of aquifers and water levels in bores.
Baseflow	Part of stream discharge that originates from groundwater seeping into the stream.
Beneficial use	Groundwater use that depends on water quality present and the potential values of the water in the long term.
Bore	Structure drilled below the surface to obtain water from an aquifer system.
Boundary	Lateral discontinuity or change in the aquifer resulting in a significant change in hydraulic conductivity, storability or recharge.
Brackish	See salinity classification.

Confining layer	Body of relatively impermeable material that is stratigraphically adjacent to one or more aquifers; it may lie above or below the aquifer.
Deuterium (^{2}H)	Also called heavy hydrogen, a stable isotope of hydrogen with a natural abundance of one atom in 6,500 of hydrogen. The nucleus of deuterium, called a deuteron, contains one proton and one neutron, where a normal hydrogen nucleus has just one proton.
Discharge	Volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.
Discharge area	Area in which there are upward or lateral components of flow in an aquifer.
Drawdown	Lowering of the water table in an unconfined aquifer or the potentiometric surface of a confined aquifer.
Electrical conductivity	A measure of a fluid's ability to conduct an electrical current and is an estimation of the total ions dissolved. It is often used as a measure of water salinity.
Environmental isotopes	Also known as stable isotopes, they act as 'groundwater signatures' and can be used as natural groundwater tracers.
Fissility	The property of rocks that causes them to split down planes of weakness.
Fracture	Breakage in a rock or mineral along a direction or directions that is not due to cleavage or fissility.
Fractured rock aquifer	Occur in sedimentary, igneous and metamorphosed rocks that have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding plains and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvium and porous sedimentary aquifers.
Global meteoric water line (GMWL)	Line that defines the relationship between oxygen-18 (^{18}O) and deuterium (^{2}H) in fresh surface waters and precipitation from a number of global reference sites.
Groundwater	Water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.
Groundwater-dependent ecosystems (GDEs)	Communities of plants, animals and other organisms whose extent and life processes depend on groundwater.
Groundwater flow	The movement of water through openings in sediment and rock; occurs in the zone of saturation.
Groundwater flow system	Regional aquifer or aquifers within the same geological unit that are likely to have similar recharge, flow, yield and water quality attributes.
Hydraulic conductivity	The rate at which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation.
Hydraulic gradient	Change in total hydraulic head with a change in distance in a given direction, which yields a maximum rate of decrease in head.

Hydraulic head	Specific measurement of water pressure or total energy per unit weight above a datum. It is usually measured as a water surface elevation, expressed in units of length. The hydraulic head can be used to determine a hydraulic gradient between two or more points.
Hydrogeology	Study of the interrelationships of geological materials and processes with water, especially groundwater.
Hydrology	Study of the occurrence, distribution and chemistry of all waters of the earth.
Hydrostatic pressure	Gravitational pressure exerted by a fluid at equilibrium.
Infiltration	Flow of water downward from the land surface into and through the upper soil layers.
Interfluves	Region of higher land between two rivers that are in the same drainage system.
Isotope	One of multiple forms of an element that has a different number of neutrons than other atoms of that element. Some elements have isotopes that are unstable or radioactive, while others have 'stable isotopes'.
Major ions	Constituents commonly present in concentrations exceeding 10 mg/L. Dissolved cations generally are calcium, magnesium, sodium and potassium; the major anions are sulfate, chloride, fluoride and nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.
Metalloid	Metalloid refers to a subset of elements, which are neither metals nor non-metals, as they contain characteristics of both. Boron, silicon, germanium, arsenic, antimony, tellurium and polonium are generally classified as metalloids.
Monitoring bore	A non-pumping bore is generally of small diameter and is used to measure the elevation of the water table and/or water quality. Bores generally have a short well screen against a single aquifer through which water can enter.
Oxygen-18 (^{18}O)	A natural, stable isotope of oxygen and one of the environmental isotopes. It makes up about 0.2% of all naturally occurring oxygen on earth.
Perched water	Unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone and supported by an aquitard or aquiclude.
Permeability	Property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. It is a measure of the relative ease of fluid flow under unequal pressure. The hydraulic conductivity is the permeability of a material for water at the prevailing temperature.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
pH	Potential of hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral, greater than 7 is alkaline and less than 7 is acidic).

Piezometer (monitoring well)	A non-pumping monitoring well, generally of small diameter, which is used to measure the elevation of the water table and/or water quality. A piezometer generally has a short well screen through which water can enter.
Porosity	Proportion of interconnected open space within an aquifer, made up of intergranular space, pores, vesicles and fractures.
Porosity, primary	Porosity that represents the original pore openings when a rock or sediment is formed.
Porosity, secondary	Porosity caused by fractures or weathering in a rock or sediment after it has been formed.
Potentiometric surface	Surface to which water in an aquifer would rise by hydrostatic pressure.
Precipitation	(1) in meteorology and hydrology, rain, snow and other forms of water falling from the sky.
	(2) the formation of a suspension of an insoluble compound by mixing two solutions. Positive values of saturation index (SI) indicate super saturation and the tendency of the water to precipitate that mineral.
Pumping test	Test made by pumping a bore for a period of time and observing the change in hydraulic head in the aquifer. It may be used to determine the bore's capacity and the aquifer's hydraulic characteristics.
Recharge	Process that replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and river water entering the water table or exposed aquifers; addition of water to an aquifer.
Recharge area	Area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area.
Recovery	Difference between the observed water level during the recovery period after pumping stops and the water level measured immediately before pumping stopped.
Redox potential (ORP or Eh)	The redox potential is a measure (in volts) of the affinity of a substance for electrons — its electronegativity — compared with hydrogen (which is set at 0). Substances more strongly electronegative than (i.e. capable of oxidising) hydrogen have positive redox potentials. Substances less electronegative than (i.e. capable of reducing) hydrogen have negative redox potentials. Also known as oxidation-reduction potential and Eh.
Residence time	Time that a water source spends in storage before moving to a different part of the hydrological cycle (i.e. it could be argued it is a rate of replenishment).
Salinity	The concentration of dissolved salts in water, usually expressed in electrical conductivity units or milligrams of total dissolved solids per litre (mg/L TDS).

Salinity classification (adapted from AWRC, 1988)	The following classifications use electrical conductivity (EC) at 25°C and assume EC=TDS(mg/L)/0.64. Fresh — water with a salinity <781 µS/cm. Marginal — water that is more saline than fresh and generally waters between 781 and 2,343 µS/cm. Brackish — water that is more saline than fresh and generally waters between 2,343 and 4,688 µS/cm. Saline — water that is more saline than brackish with a salinity between 4,688 and 21,875 µS/cm. Saline to hypersaline — water that is almost as saline as seawater with a salinity greater than 21,875 µS/cm.
Saturated zone	Zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.
Sedimentary aquifers	Aquifers in consolidated sediments (such as porous sandstones and conglomerates, in which water is stored in the intergranular pores) and limestone (in which water is stored in solution cavities and joints). They are generally located in sedimentary basins that are continuous over large areas. Up to tens or hundreds of metres thick, they contain the largest groundwater resources.
Specific yield	Ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take many months to occur.
Spring	Location where groundwater emerges on to the ground surface. Water may be free-flowing or slowly seeping.
Storativity	Volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to specific yield.
Stratigraphy	The study of stratified rocks (sediments and volcanics), including their sequence in time, the character of the rocks and the correlation of beds in different localities.
Surface water – groundwater interaction	Occurs in two ways: (1) streams gain water from groundwater through the streambed when the elevation of the water table next to the streambed is greater than the water level in the stream; and (2) streams lose water to groundwater by outflow through streambeds when the elevation of the water table is lower than the water level in the stream.
Transmissivity	Rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.
Unconfined aquifer	Where the groundwater surface (water table) is at atmospheric pressure and the aquifer is recharged by direct rainfall infiltration from the ground surface.
Unsaturated zone	That part of an aquifer between the land surface and water table. It includes the root zone, intermediate zone and capillary fringe.

Water table	Surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a metre or so into the zone of saturation and then measuring the water level in those wells.
Well	Any structure, deeper than it is wide, that is bored, drilled driven or dug into the ground to reach groundwater.

Executive summary

This report provides an assessment of the potential groundwater impacts associated with the proposed operation of the Cobbora Coal Project (the Project). Parsons Brinckerhoff prepared the report for Cobbora Holding Company Pty Limited (CHC) for the purpose of informing the environmental assessment.

The Project is a new open-cut coal mine that will be developed near Dunedoo in the central west of New South Wales (NSW). The Project Application Area is approximately 274 square kilometres (km^2). The primary purpose of the Project is to provide coal for five major NSW power stations.

In accordance with the Director General's requirements, the key objectives of the groundwater assessment are to assess the existing hydrogeological environment within the Project area and immediate surrounds, provide baseline data on the groundwater conditions within the assessment area, identify and quantify the potential impacts of the Project on current groundwater conditions and groundwater users, propose mitigation and contingency measures for identified impacts, and assess the water licensing requirements in accordance with the relevant legislation.

A program of field investigations was undertaken to establish site-specific and regional baseline hydrogeological conditions. The program comprised drilling and installing 56 piezometers and five test production bores, geophysical logging of test production bores, hydraulic testing of piezometers and test production bores, groundwater quality and groundwater level monitoring, investigating groundwater – surface water interactions, assessing the potential impacts on potential groundwater availability to ecosystems, surveying existing groundwater users in the assessment area, and carrying out a transient electromagnetic (TEM) groundwater investigation.

The field investigations and assessment of the groundwater regime indicate that the main hydrogeological units in the assessment area are:

- quaternary alluvium associated with the unconsolidated sediments of the Talbragar River, Sandy Creek and Laheys Creek
- minor tertiary fractured basalt caps occurring on some higher relief areas
- Jurassic sandstone porous rock to the north west of the assessment area with some isolated areas of Jurassic sandstone to the west and south of the main Project area. To the north of the Talbragar River these Jurassic rocks form part of the Great Artesian Basin
- minor intrusions of Mesozoic igneous rock to the south of the Project area
- porous rocks of Permian and Triassic (Permo-Triassic) sandstone, coal and claystone associated with the Gunnedah Basin
- fractured rocks of the Lachlan Fold Belt, which underlay and surround the porous Permo-Triassic rocks.

Of these hydrogeological units the two main aquifers across the assessment area are the Quaternary alluvium aquifer associated with the unconsolidated sediments of the Talbragar River, and the porous rock aquifer associated with the Permo-Triassic units. Both units form part of the Gunnedah-Oxley Basin water source and are managed within the Water Sharing Plan for the Murray Darling Basin (MDB) Porous Rock Groundwater Source (NSW Office of Water 2012b). Other hydrogeological units that are present in the assessment area are not considered hydrogeologically connected to the two main aquifer systems, and are therefore not expected to be impacted.

The alluvium aquifer is characterised by sandy gravel, interspersed with high clay content, and is of low permeability. There is minimal alluvium in the assessment area other than around the Talbragar River, where it appears to be hydrogeologically and compositionally very similar to the weathered rock with which it is in contact. Groundwater quality in the alluvium aquifer is mostly brackish to saline and generally varies with depth and clay content.

The primary water-bearing zones within the Permo-Triassic porous rock aquifer are the Dapper Formation and the Upper and Lower Ulan coal seams within the Dunedoo Formation Group. The Dapper Formation and the Upper and Lower Ulan seams have low to moderate permeability. Connectivity between the units is generally limited by confining or semi-confining units of shale, claystone, siltstone or other lower permeable materials. Leakage may occur between the confining layers, especially in highly fractured areas near faults and in areas where the confining layers have low clay content. Artesian pressures are present in the deeper units generally along the alignment of Sandy Creek.

Analysis of long-term (21-day) pumping tests indicates there is a poor hydraulic connection between the alluvium aquifer and underlying Permo-Triassic porous rock aquifer, and subsequently the Talbragar River. This is confirmed by the strong vertical hydraulic gradients across the alluvium interface and distinct isotopic composition and radiocarbon ages.

Surface water and groundwater are connected across the assessment area in a variety of forms, including springs/seeps, baseflow and semi-permanent pools within the Talbragar River and tributaries, and flood flow recharge to groundwater.

A numerical groundwater model was developed using data collected during the field investigation program to provide a quantitative assessment of the impacts of the Project, in particular the groundwater inflows to the pit voids, the extent of drawdown of the water table and depressurisation of the underlying aquifer.

Mine inflow rates (or theoretical dewatering rates) have been estimated based on the numerical modelling results. Mine inflow rates are predicted to peak at approximately 2,800 megalitres per annum (ML/a) after 14 years of mining. Net groundwater usage (for the purpose of licensing) during the proposed mine life is predicted to average 2,100 ML/a between 2021 and 2030, reaching a maximum value of 2,202 ML/a in 2028. The induced river losses (469 ML/a) and enhanced in-pit recharge (330 ML/a) combine to peak at 799 ML/a in 2034.

CHC has commenced the process of acquiring sufficient aquifer access licences from the water trading market to account for groundwater usage. By utilising the account management provisions of the Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources in respect to Available Water Determinations, carryover and account limits, required aquifer access licence entitlement is 1,924 unit shares. As of January 2013, CHC holds three aquifer access licences with a combined associated volumetric entitlement of 1,024 unit shares for the Gunnedah-Oxley Basin MDB Groundwater Source. Purchase of a further 150 unit shares is currently pending. The volume of entitlement to trade from within the Gunnedah-Oxley Basin MDB Groundwater Source is high, with an additional 15,496 unit shares across approximately 113 AALs with which to source the remaining 750 unit shares. In addition, the approximate volume of unassigned water in the Gunnedah-Oxley Basin MBD Groundwater Source is high, at approximately 177,806 ML/a.

CHC has completed acquisition of water access licences from the Lower Talbragar River Water Source to account for surface water usage. CHC holds two water access licences with a combined 1,780 unit shares in the Lower Talbragar River Water Source. The licences are associated with three existing licensed dams which historically stored water for irrigation and stock watering. In accordance with the Water Sharing Plan for the Macquarie Bogan Unregulated and Alluvial Water Sources, CHC will consult with NOW to establish changes to licensing arrangements, including change of use for mining purposes. Modelled groundwater inflows to the mining areas are expected to lead to maximum lowering of the water table of up to 90 m in mining area B. The 1 m drawdown contour is predicted to extend up to 5.5 km to the south of the mining areas and nearly 6 km to the west. Drawdown to the north and east is less extensive, with the 1 m drawdown contour predicted to lie within 4 km of the mining areas.

The predicted cumulative storage losses within the alluvium could reach a maximum value of approximately 720 megalitres (ML), which constitutes only 0.3% of the estimated 220,000 ML (220 gigalitres (GL)) of available groundwater storage in the alluvium within the model domain.

Depressurisation of groundwater in the Ulan Coal Seams is predicted to extend over a greater area in the Ulan Coal Seams than in the water table aquifer. The 1 m depressurisation contour is predicted to lie approximately 6 km to the west of mining areas A and B. The extent of depressurisation to the south, north and east of the mining areas is similar to that predicted for the water table aquifer.

The potential impact the Project will have on the local groundwater systems is a result of the drawdown in the alluvium and Permo-Triassic porous rock aquifers, which locally reduces the groundwater levels for nearby extractive users and the environment.

The groundwater model predicts there are 13 private groundwater bores that will experience drawdown greater than 2 m during mining. Ten of these 13 bores are owned by CHC; the other private bores show maximum drawdown values of 2.2 m, 2.4 m and 5.1 m. Therefore impacts to third-party bores are considered minor. Where future impacts to third-party bores are assessed to be directly related to mining operations, CHC will take corrective actions at its own expense.

The lowering of groundwater levels will result in some reduction in baseflow of the Talbragar River. The model results indicate a likely maximum reduction in river flows of approximately 480 ML/a, which occurs in 2036 following the end of mining operations. The impact is considered small in relation to flows in the Talbragar River, representing only 0.9% of the average annual flow. Existing water access licences on the Lower Talbragar River will be purchased by CHC via the water trading market to account for the water, therefore the overall impact is considered low.

Ecosystems potentially relying on groundwater in the Project area can be classified into three systems: springs/seeps, semi-permanent pools and shallow groundwater in the alluvium. The springs/seeps that have been identified in the assessment area represent local perched systems, independent of the regional aquifer system. Flow rate and water quality of the springs/seeps are therefore unlikely to be impacted by the Project.

The depressurisation likely to occur in the Permo-Triassic units to the west of mining areas A and B is likely to induce leakage from the alluvium and could cause a decline in groundwater seepage in semi-permanent pools that are reliant on groundwater discharges. Subsequently, the availability of groundwater to ecosystems potentially relying on shallow groundwater in the alluvium or semi-permanent pools within the creeks and river may be reduced. Rainfall and flood recharge will likely sustain the local alluvium aquifers for several months following rainfall and flood recharge events and during mining changes in the surface water regime will result in an increased frequency of low flows in creeks. Therefore the overall impact to semipermanent pools is considered moderate. Monitoring via strategically located alluvium monitoring bores will be undertaken to mitigate the potential impact.

A lake will form within the final void of mining area B due to accumulation of groundwater inflow and surface water runoff. The water levels in the lake are expected to increase over time following the cessation of mining as groundwater levels recover and reach an equilibrium level of approximately 373.9 m AHD after approximately 100 years. At this elevation, the lake will continue to act as a groundwater sink causing continued drawdown in the immediately surrounding area. The hydraulic gradient will be toward the pit lake and therefore groundwater flow will be from Sandy Creek towards the pit. As a consequence it is not expected that the pit lake will degrade water quality in the adjacent Sandy Creek.

While the groundwater assessment has identified a number of potential impacts to the groundwater system, these impacts are generally considered transient and low to moderate with respect to downstream users and the environment. CHC is committed to implementing mitigation and management measures to monitor and manage these potential impacts throughout the life of the mine and post mining through the development of a groundwater management plan. The Plan will be prepared in consultation with NOW, and will assist the mine in operating in accordance with contemporary environmental standards, to ensure that CHC can comply with its anticipated licensing and statutory obligations.

1. Introduction

The Cobbora Coal Project (the Project) is a new open-cut coal mine proposed by Cobbora Holding Company Pty Limited (CHC). The Project is located approximately 5 kilometres (km) south of Cobbora, 22 km south-west of Dunedoo, 64 km north-west of Mudgee and 60 km east of Dubbo in the central west of NSW (see Figure 1.1).

A Major Project application under Part 3A of the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) was submitted to the NSW Department of Planning in January 2010. The Director General's Environmental Assessment Requirements (DGRs) for the Project were issued in March 2010 and revised requirements were subsequently provided that responded to project changes and altered Government policies.

This report describes the groundwater assessment that Parsons Brinckerhoff undertook for the Project's environmental assessment (EA) report.

1.1 Cobbora Coal Project

1.1.1 General overview of Project

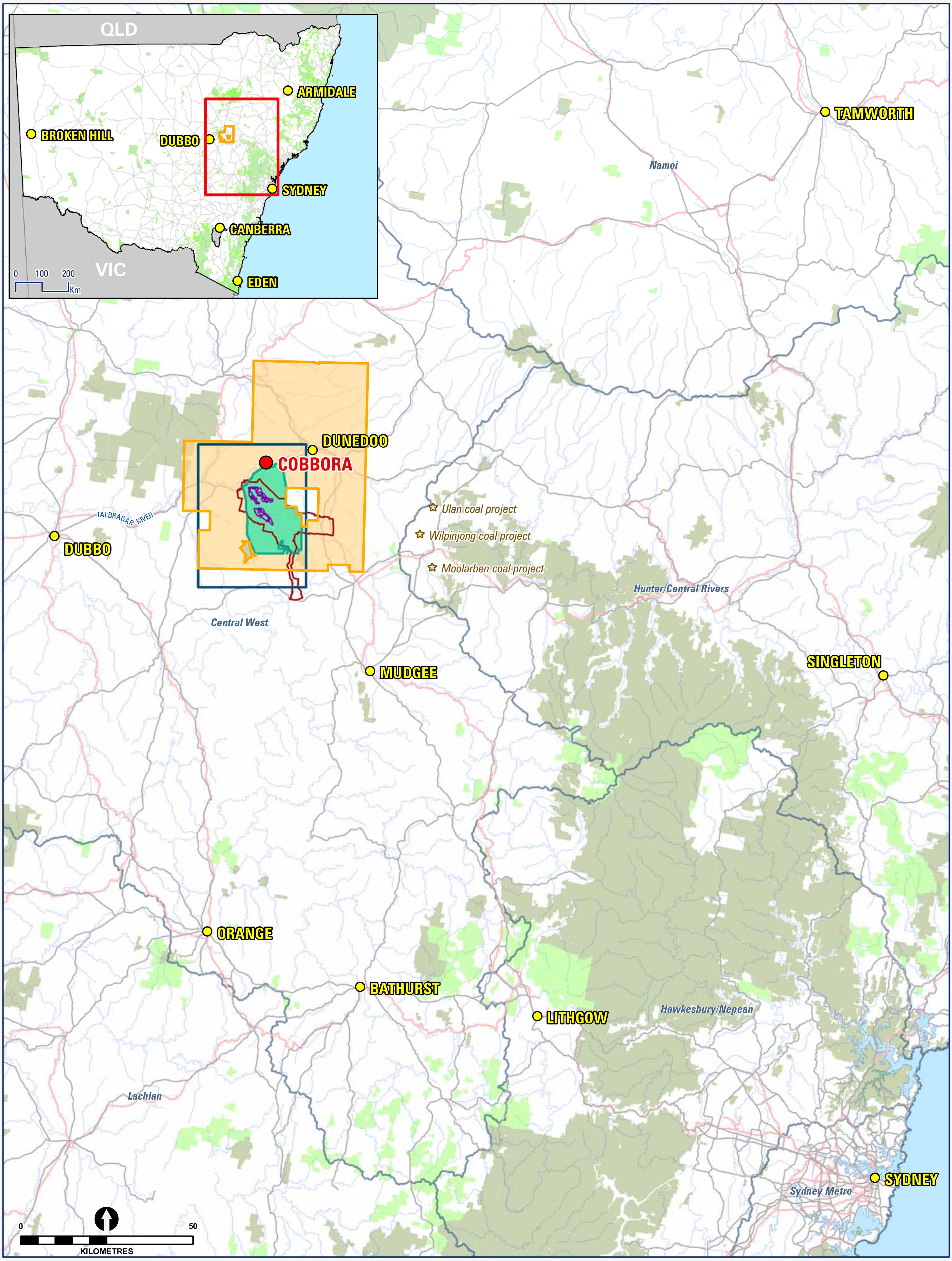
The Project will be developed near Dunedoo in the central west of New South Wales (NSW). The Project Application Area is approximately 274 square kilometres (km^2). The primary purpose of the Project is to provide coal for five major NSW power stations.

The mine will extract around 20 million tonnes per annum (Mt/a) of run-of-mine (ROM) coal. From this, approximately 9.5 Mt/a of product coal will be sold to Macquarie Generation, Origin Energy and Delta Electricity under long-term contract. In addition, approximately 2.5 Mt/a will be produced for export or the spot domestic market.

The Project's key elements are:

- an open-cut mine
- a coal-handling and preparation plant (CHPP)
- a train-loading facility and rail spur
- a mine infrastructure area
- supporting infrastructure, including access roads, water supply and storage, and electricity supply.

Construction is expected to commence in mid-2013, with coal being supplied to customers from the first half of 2015. The mine life will be 21 years.



Assessment area
Project Application Area (approximate) (as of February 2012)
Drainage
Coal projects
Exploration licence (7394)
Exploration licence (6093)
National parks & state forests
Proposed mining areas

Figure 1.1 Site location

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1.1.2 Open-cut mine

Multiple open-cut mining pits will be developed in three mining areas:

1. mining area A north of the infrastructure area
2. mining area B south of the infrastructure area
3. mining area C north-east of the infrastructure area.

There will be three out-of-pit waste rock emplacements:

1. AC-OOP between mining areas A and C
2. B-OOP E adjacent to mining area B on the east side of Laheys Creek
3. B-OOP W adjacent to mining area B on the west side of Laheys Creek.

Over the mine life, operations will encompass approximately 4,350 hectares (ha), including associated infrastructure (e.g. haul roads), out-of-pit waste rock emplacements and rehabilitated areas. The mining areas and out-of-pit waste rock emplacements have been designed and placed to maximise the efficient extraction of the coal resource, while avoiding or minimising impacts on creeks and ecologically significant vegetation.

1.1.3 Coal-handling and preparation plant

The CHPP will treat ROM coal so that product coal meets customers' sizing and coal quality requirements. Subject to the level of impurities (rejects) in the coal and washability characteristics the ROM will be either crushed and bypassed, or treated (washed) in the preparation plant. The rejects will typically include waste rock from above, below and within the coal seam, as well as mineral matter dispersed throughout the coal.

The CHPP will be typical of those used by most coal mines in NSW and will be capable of treating up to 20 Mt/a of ROM coal. The CHPP will separate washed product coal from rejects in a series of coal-cleaning circuits (including heavy media separation). The CHPP will include a truck dump station, crushing plants, coal stockpiles and infrastructure to move and stockpile coal. Rejects from the CHPP will be returned back to the operating mine.

1.1.4 Train-loading facility and rail spur

Coal will be transported by rail to the Project's customers, including Bayswater and Liddell power stations in the Upper Hunter Valley, and Eraring, Vales Point and Munmorah power stations on the NSW Central Coast. Coal will also be transported to other domestic customers or to a ship-loading facility in Newcastle for export.

Product coal will be loaded onto trains from an overhead train-loading bin located on a rail spur balloon loop. Approximately four trains will be loaded each day. The rail spur will be approximately 28 km long (including the loop) and will join the Dunedoo-Gulgong rail line near Tallawang. A locomotive-provisioning facility will be located adjacent to the balloon loop.

1.1.5 Mine infrastructure area

An infrastructure area will be located adjacent to the mining areas. It will include workshops, hardstand and lay-down areas, bulk storage buildings, bulk fuel storage and a fuelling station, office buildings, an operations building and change-house, parking, an explosives magazine and vehicle washdown bays.

1.1.6 Supporting infrastructure

1.1.6.1 Access road

The main access to the mine will be from the Golden Highway to the north of the operations, via a road diversion that will replace an existing section of Spring Ridge Road. There will be limited light vehicle access from the south via Spring Ridge Road. Internal roads will connect the mine entrance to the workshop, administration buildings and the mine infrastructure area. Internal roads will also connect the various mine areas.

1.1.6.2 Water supply

The Project will require water, primarily for the CHPP and for dust suppression. Water will be sourced by extracting surface water, by pumping groundwater that enters the mine area, and by harvesting and re-using water on site in accordance with the relevant permits and licences. The primary source of external water will be the Cudgegong River. Water will be supplied via approximately 26 km of pipeline from a pump station on the Cudgegong River to a primary raw-water dam south-east of the mining area. Pre-existing high-security water access licences have been purchased to allow up to 3.311 gigalitres (GL) of water to be extracted from the river.

1.1.6.3 Electricity supply

The Project will require 20 megawatts (MW) of electrical power. The mine will be connected to the grid at a small switching yard adjacent to the Castlereagh Highway. A power line, generally running parallel to the rail spur, will deliver electricity to a substation in the mine infrastructure area. An 11 kV powerline will supply the Cudgegong River pump station from the existing grid approximately 2 km south of the pump station site.

1.1.7 Workforce and operating hours

The proposed mine construction workforce will average approximately 350 persons, peaking at approximately 550 persons between the third quarter of 2013 and the second quarter of 2016.

The operational workforce is estimated to be 300 persons during the first two years of full production in 2016 and 2017. This will increase steadily over the next 10 years to peak at approximately 590 persons between 2027 and 2030.

Mine construction is expected to occur up to 10 hours a day. However, construction may occur up to 24 hours a day at times, such as during major concrete pours. Mining will occur up to 24 hours a day, 7 days a week, 52 weeks a year.

1.2 Scope of assessment

Parsons Brinckerhoff was commissioned by CHC to assess potential groundwater impacts from the construction and operation of the Project, as described in Section 1.1 of this report.

The key objectives of the assessment were:

- to identify and assess potential impacts on groundwater from the development of the Project
- to satisfy the DGRs relevant to groundwater impacts
- to inform the wider community about the project and its potential impacts on the local and regional groundwater environment.

To achieve these objectives, the groundwater impact assessment had to:

- assess the existing hydrogeological environment within the Project area and immediate surrounds (assessment area) (Figure 1.2)
- provide baseline data on the groundwater conditions within the assessment area
- identify and quantify the potential impacts of the Project on current groundwater conditions and groundwater users (including cumulative impacts where applicable)
- propose mitigation and contingency measures for those impacts where they are likely to be unacceptable
- assess water licensing requirements in accordance with the relevant legislation.

To achieve these objectives Parsons Brinckerhoff undertook the following scope of works:

- describe the groundwater environment in the assessment area
- identify the local users of the groundwater resources through a survey of groundwater users in the assessment area
- describe any connectivity of groundwater with surface water. Pumping tests, surveying of the Talbragar River bed, surveying groundwater users and interpretation of regional geology were used to assess the potential connectivity between surface water and groundwater
- assess the Project's potential impacts on the existing hydrogeologic regime on a local and regional scale using numerical groundwater modelling to simulate the impacts that open-cut mining would have on the regional aquifer system
- develop a proposed groundwater monitoring program
- develop mitigation measures and response plans to reduce potential impacts.

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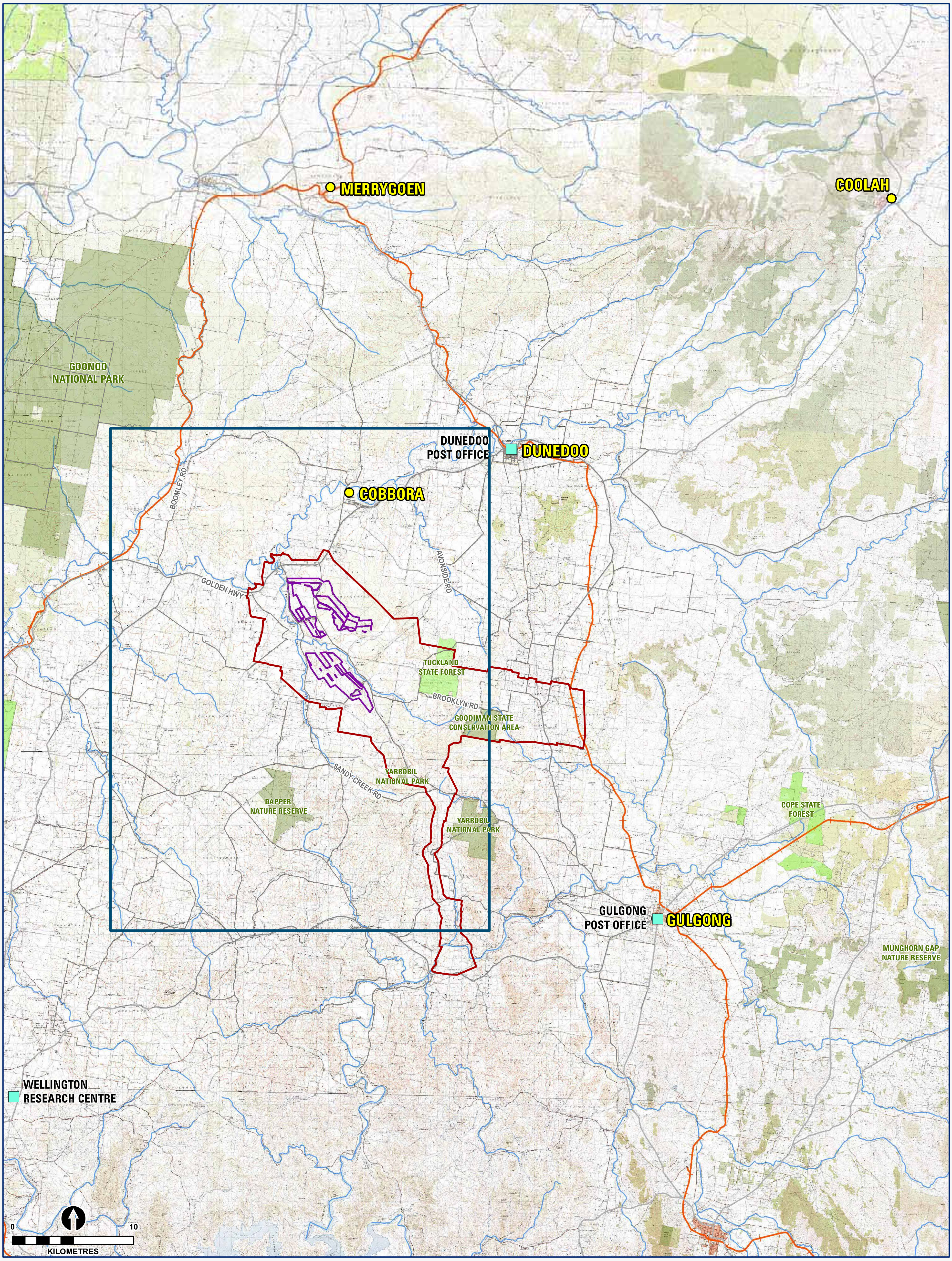

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- Bureau of Meteorology station
- Assessment area
- Project Application Area (approximate) (as of February 2012)
- Drainage lines
- National parks & state forests
- Proposed mining areas

Figure 1.2 Site plan

Topographic map source: NSW Department of Lands, 1989

1.3 Report structure

The structure of this report is as follows:

- **Section 1** provides an introduction to the groundwater assessment report, including an overview of the Project, and the purpose and scope of the groundwater assessment report.
- **Section 2** provides the DGRs relating to groundwater for the Project and the relevant legislation, policies and guidelines.
- **Section 3** describes the regional setting of the assessment area including topography, land use, climate, hydrology, geology, soils, surface water – groundwater connectivity and potential groundwater availability to ecosystems.
- **Section 4** details the groundwater investigations undertaken as part of this assessment, including drilling and testing programs, groundwater quality monitoring and groundwater level monitoring.
- **Section 5** describes the hydrogeology of the assessment area, including assessment of hydraulic properties; groundwater levels; groundwater flow directions and groundwater quality. It also presents surface water – groundwater connectivity, potential groundwater availability to ecosystems and the hydrogeological conceptual model.
- **Section 6** summarises the groundwater modelling undertaken, including model setup, design, calibration and predictive simulations.
- **Section 7** discusses the Project's potential impacts on local and regional groundwater resources, groundwater users and potential groundwater availability to ecosystems.
- **Section 8** discusses the future monitoring and management of groundwater, including monitoring requirements, recommendations, and a groundwater management plan.
- **Section 9** describes the potential groundwater mitigation measures and response plans for the Project.
- **Section 10** provides the conclusions of the groundwater assessment.
- **Section 11** provides the list of references used in the assessment.

1.4 Terms of engagement

This commission was carried out under the contract between Parsons Brinckerhoff and Cobbora Holding Company. It assesses existing conditions and proposes measures to mitigate impacts from the proposed mine on groundwater. As further information becomes available and detailed designs are carried out, those mitigation measures can be optimised.

The investigations had the benefit of two years of site-specific monitoring data, together with more than a century of nearby weather information. The nature and extent of that monitoring are described in this report. The monitoring and measurements of site conditions are believed to be representative of conditions during those two years and were performed in a professional manner, in accordance with generally accepted practices and using a degree of skill and care ordinarily exercised by reputable environmental consultants under similar circumstances.

The recommended monitoring program will add further information that will increase the understanding of groundwater at the site.

In preparing this report, Parsons Brinckerhoff received information from a variety of reputable sources, including CHC, other specialist consultants, published papers and other environmental assessments. While Parsons Brinckerhoff reviewed the data before using it, the information was accepted in good faith and it was not verified in detail for accuracy or completeness.

The report is for the use of CHC and regulators in the determination of a development application for the Project and no responsibility will be taken for its use by other parties.
If any other party seeks to rely on this report, they should seek their own independent advice to ensure that it is relevant to their own needs. Any losses or damage that they suffer as a result of failing to make their own enquiries will not be the responsibility of Parsons Brinckerhoff.

2. Planning and legislation

2.1 Director General's requirements

On 14 October 2011, in accordance with the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act), the Director General of the NSW Department of Planning and Infrastructure (DP&I) issued a set of requirements for the Project. The Director General Requirements (DGRs) include specific requirements from the NSW Office of Water (NOW).

The DGRs relating to groundwater are listed in Table 2.1 and include the section of this report where they are addressed.

Table 2.1 Director General's requirements

Director General's requirements	Relevant sections
A description of the existing environment, including sufficient baseline data.	Sections 3, 4 & 5
An assessment of the potential impacts of the Project, including any cumulative impacts, taking into consideration any relevant guidelines, policies, plans and statutory provisions.	Section 7
Description of the measures that would be implemented to avoid, minimise and if necessary, offset potential impacts of the Project, including detailed contingency plans for managing any significant risks to the environment.	Section 8 & 9
Detailed modelling of the potential groundwater impacts of the Project.	Section 6
A detailed assessment of the potential impacts on: ▪ the quality and quantity of existing groundwater resources ▪ affected licence water users and basic landholder rights ▪ groundwater availability to ecosystems.	Section 7
Identification of licensing requirements under the Water Act 1912 (and) or Water Management Act 2000, and NSW Inland Groundwater Shortage Zones Order Numbers 1 and 2.	Section 2

2.2 Relevant legislation

2.2.1 Water Act 1912

The *Water Act 1912* (WA 1912) has historically been the main legislation for the management of NSW water resources. However, the WA 1912 is being progressively phased out and replaced by the *Water Management Act 2000* (WMA 2000). Water sharing plans are statutory plans under the WMA 2000 that apply to individual water source areas and which contain the rules for sharing and managing the water resources of NSW. These plans are progressively being developed for all water source areas across NSW.

The Project site is located within the Gunnedah-Oxley Basin Murray Darling Basin (MDB) Groundwater Source, and this groundwater source is part of the Water Sharing Plan for the MDB Porous Rock Groundwater Sources (NOW 2011b). This water sharing plan commenced on 16 January 2012, and groundwater within the porous rock groundwater source is now managed under this plan.

The WA 1912 however still applies for the licensing of groundwater monitoring bores required for the Project.

2.2.1.1 Groundwater licensing

Under Part 5 of the WA 1912, groundwater licences were obtained for all monitoring bores installed and tested during the investigation process. The licences are listed in Section 4.1. The monitoring provisions under the WA 1912 remain in place and the WA 1912 licences for these groundwater monitoring bores remain current.

2.2.2 Water Management Act 2000

Once a water sharing plan has commenced, the WA 1912 is repealed for that water source and existing licences are converted to new consents under the WMA 2000. For the purpose of this Project the WMA 2000 requires any development taking or using water to:

- assess whether there is an adverse impact from the development to the river or aquifer and its dependent ecosystems
- protect basic landholder rights.

The WMA 2000 outlines the requirements for the taking and trading of water through water access licences, water supply works and water use approvals.

The Water Sharing Plan for the MDB Basin Porous Rock Groundwater Sources commenced on 16 January 2012 and at this time the WMA 2000 became the overriding legislation for the management of groundwater within the Gunnedah-Oxley Basin. Dewatering of the Triassic and Permian strata of the Gunnedah-Oxley Basin is required for the removal of coal resources within the mining area. Groundwater access licences will be required for the dewatering process which is regulated under the WMA 2000.

A Water Sharing Plan for the MDB Fractured Rock Groundwater Sources (NOW 2011c) which covers the surrounding Lachlan Fold Belt is not relevant for this Project (see Section 5). Impacts to the Lachlan Fold Belt MDB Groundwater Source have been assessed as negligible.

2.2.2.1 Groundwater licensing

Cobbora Holding Company Pty Ltd held 13 stock and domestic groundwater licences and three groundwater production bore licences in August 2012. These licences have transitioned over to the new WMA 2000 as basic right work and use approvals, and groundwater access licences and associated approvals.

Two groundwater access licences 80BL112584 and 80BL238690 have entitlements of 188 ML and 82 ML per year respectively for extraction purposes, and are assigned to the Lachlan Fold Belt MDB Groundwater Source. However, 80BL112584 is incorrectly assigned as, according to the database driller's logs and groundwater bore location, it should be assigned to the Gunnedah-Oxley Basin MDB Groundwater Source. One groundwater access licence 80AL707460) has an entitlement of 350 ML for extraction purposes and is assigned to the Gunnedah-Oxley Basin MDB Groundwater Source. Therefore, the total volume of groundwater CHC currently hold in the Gunnedah-Oxley Basin MDB Groundwater Source is 538ML/a.

2.3 NSW water policies, guidelines and plans

2.3.1 Water Sharing Plan for the Murray Darling Basin Porous Rock Groundwater Sources

The Water Sharing Plan for the MDB Porous Rock Groundwater Sources (NOW 2011b) sets the annual groundwater recharge volumes for each identified groundwater source and the volumes of water available for sharing (the long-term average annual extraction limit).

Provisions are made for environmental water allocations, basic landholder rights, domestic and stock rights and native title rights. The statistics for the Gunnedah-Oxley Basin MDB Groundwater Source availability are presented in Table 2.2.

Table 2.2 Requirements for water sharing (Gunnedah-Oxley Basin)

Use	Share component (ML/a)
Recharge	399,786 (not high environmental value) 14,773 (high environmental value)
Environmental water	199,893 (50% of recharge for not high environmental value) 14,773 (100% of recharge for high environmental value) Yet to be defined in ML (99.998% of the long-term groundwater storage)
Long-term average annual extraction limit (LTAAEL)	199,893
Town water supply	112
Basic rights (domestic and stock)	5,779
Native title	0
Aquifer access licences	16,309
Total water requirements[1]	22,200
Unallocated water[2]	177,693 (recharge component) Yet to be defined in ML (one-off storage component)

1. This number is not listed in the water sharing plan, but is calculated by summing all requirements for water under Part 5 of the plan for the Gunnedah-Oxley Basin.
2. This number is not listed in the water sharing plan, but is calculated as the difference between the long-term average annual extraction limit, minus the total water requirements.

The Project will require dewatering of the Triassic and Permian strata of the Gunnedah-Oxley Basin during mining to allow for the removal of coal resources within the mining area. There will also be some indirect dewatering of the overlying alluvium adjacent to the pit as a result of dewatering the Triassic and Permian strata. The water sharing plan states that the Gunnedah-Oxley Basin MDB Groundwater Source includes all rocks of Permian, Jurassic, Cretaceous and Tertiary age within the outcropped areas, and all alluvium within the outcropped areas (not including existing marked alluvial groundwater sources). Therefore, all groundwater dewatering by this Project (including alluvial) is within the Gunnedah-Oxley Basin MDB Groundwater Source.

The Aquifer Interference Policy (DTIRIS 2012) requires the take of water to be licenced in accordance with predicted impacted volumes from each individual groundwater source and a licence held for each water source (Section 2.4.8). The take of groundwater will therefore need to be licenced within the Gunnedah-Oxley Basin MDB Groundwater Source and will need to be obtained either by the purchase of existing entitlement or via a future controlled allocation policy.

The current market pool for trading of existing entitlement is equivalent to the 16,197 ML/a share components outlined in Table 2.2. The Long Term Average Annual Extraction Limit (LTAAEL) for the Gunnedah-Oxley Basin MDB Groundwater Source is 199,893 ML, and of this volume 177,806 ML, plus a one off storage component, is classed as unassigned water and will potentially become available in the future via a controlled allocation policy. These numbers indicate that the Project is looking to obtain groundwater (an additional 957 ML) from within a large groundwater source with both a legitimate trading market (of 16,179ML) and with a large volume of currently unassigned water (177,806ML). At this time a controlled allocation policy for the release of unallocated water within this water source has not been made and CHC are looking to the trading market to secure this water.

2.3.2 NSW State Groundwater Policy Framework Document

The NSW State Groundwater Policy Framework Document (DLWC 1997) comprises a set of three policy documents:

1. NSW State Groundwater Quantity Management Policy (DLWC 2001 (Unpublished)).
2. NSW State Groundwater Quality Protection Policy (DLWC 1998).
3. NSW State Groundwater Dependent Ecosystem Policy (DLWC 2002).

The NSW groundwater policies aim to slow, halt or reverse degradation in groundwater resources, ensure long-term sustainability of the biophysical characteristics of the groundwater system, maintain the full range of beneficial uses of these resources, and maximise the economic benefit to the region and state.

In undertaking this Project the NSW State Groundwater Policy Framework Document (DLWC 1997) will be used in the development of the groundwater management plan for the Project.

2.3.3 Murray Darling Basin Commission groundwater flow modelling guideline

Murray Darling Basin Commission groundwater flow modelling guideline (MDBC 2001) describes general guidelines for groundwater flow modelling that are designed to reduce the level of uncertainty for model study clientele. The guideline promotes transparency in modelling methodologies, and encourages consistency and best practice. Guidance is provided to non-specialist clientele to outline the steps involved in scoping, managing and evaluating the results of groundwater modelling studies. Guidance is also provided to modelling specialists to indicate the technical standards expected to be achieved for a range of modelling Project scopes.

The guidelines were used in the development of the groundwater numerical model developed for the Project (Section 6). New national guidelines for modelling were released in July 2012 (Barnett et al, 2101) and are largely based on the previous MDBC modelling guidelines (MDBC 2001). The assessment, modelling and reporting for this project remains consistent with the new national guideline.

2.3.4 Australian and New Zealand guidelines for fresh and marine water quality

The Australian and New Zealand guidelines for fresh and marine water quality (ANZECC/ARMCANZ 2000) set out the framework for the application of the water quality guidelines. These guidelines describe requirements over a variety of marine and freshwater environments — aquatic ecosystems, primary industries, recreational water, drinking water and monitoring and assessment. The guidelines provide an authoritative guide for setting water quality objectives required to sustain current or likely future environmental values (uses) for natural and semi-natural water resources in Australia and New Zealand.

The guidelines were used when assessing the baseline groundwater quality for the Project (Section 5.7).

2.3.5 Guidelines for the assessment and management of groundwater contamination

The Guidelines for the assessment and management of groundwater contamination (DEC 2007) outline the best practice framework for assessing and managing contaminated groundwater in NSW. The guidelines assist consultants and industry to devise groundwater assessment and management strategies that are consistent with the Department of Environment and Conservation's expectations.

The guidelines will be used in the development of the groundwater management plan for the Project.

2.3.6 Murray Darling Basin groundwater quality sampling guidelines, technical report no. 3

The Murray Darling Basin groundwater quality sampling guidelines (MDBC 1997) provide a set of guidelines for groundwater quality sampling with an emphasis on regional monitoring networks. A uniform, accurate and reliable set of sampling procedures will ensure that comparable data of a known standard is collected throughout the Murray Darling Basin, and will allow for greater confidence in the interpretation of any basin wide data.

The guidelines have been used for the groundwater monitoring program and will also be used to develop the groundwater management plan.

2.3.7 National water quality management strategy guidelines for groundwater protection in Australia

The National water quality management strategy guidelines for groundwater protection in Australia (ARMCANZ/ANZECC 1995) provide a framework for protecting groundwater from contamination in Australia. The protection framework involves the identification of specific beneficial uses and values for the major aquifers, and a number of protection strategies which can emerge to protect each aquifer, including monitoring for all aquifers.

The guidelines will be incorporated into the management and mitigation measures recommended for the Project.

2.3.8 NSW aquifer interference policy

The NSW Department of Trade and Investment, Regional Infrastructure and Services have published the aquifer interference policy that includes the regulation of mining and coal seam gas extraction in regard to groundwater. The policy outlines the NSW Government's approach to assessing approvals.

Approvals for aquifer interference activities will be based on an 'avoid, prevent, mitigate' approach to ensure impacts on groundwater and surface water systems are minimised.

The policy requires the dewatering volumes for the Project to be licenced in accordance with predicted impacted volumes from each individual water source and a licence held for each water source.

2.4 Commonwealth legislation

2.4.1 The draft Basin Plan

The Commonwealth Government has developed the Basin Plan, which establishes 'sustainable diversion limits' for groundwater within the MDB. The limits have been set to ensure the level of use is environmentally sustainable in the long term and:

- maintains the contribution groundwater makes to rivers
- supports groundwater dependent ecosystems
- maintains groundwater systems for productive use
- protects against salinity.

While the draft Basin Plan sets the limits, it remains the responsibility of the relevant state agencies to decide how the water is used.

2.5 Stakeholder engagement

Stakeholder engagement has been undertaken throughout the life of the Project to ameliorate the concerns of neighbouring land owners and regulatory authorities, specifically NOW. A number of meetings have taken place with NOW in relation to the Project's impact on the groundwater system and groundwater users.

Table 2.3 lists the main issues raised by NOW since consultations were initiated in 2009, and where the issues have been addressed or resolved within the groundwater assessment report.

Table 2.3 Groundwater related issues raised by NOW

Issue	Detail	Relevant sections
Groundwater source and groundwater licensing requirements.	Initial advice from NOW indicated that the Project was located within the Lachlan Fold Belt MDB groundwater source, when it is in fact within the Gunnedah-Oxley Basin groundwater source.	Sections 2.4.1 & 5.2
Potential hydrogeological connection between the Permo-Triassic strata and the Talbragar River and associated alluvium aquifer.	Pumping tests, numerical groundwater modelling, and river surveys were carried out.	Sections 5.6.2.1, 5.8.4
Groundwater-dependent ecosystems.	The presence of potential groundwater dependent ecosystems, and the potential impact.	Section 5.8.5

3. Existing environment

The Project is located within the Central West Catchment Management Authority (CMA), within the CMA subregions of Talbragar Valley and Upper Slopes. Two creeks, Sandy Creek and Laheys Creek occur within the assessment area and discharge into the Talbragar River to the north. The Sandy Creek and Laheys Creek catchments cover an area of approximately 280 km^2. The Cudgegong River is located just to the south of the assessment area within the Cudgegong River catchment.

3.1 Topography and land use

The topography of the site is gently undulating to hilly with elevations of approximately 320 m Australian Height Datum (AHD) around the Talbragar River extending to about 620 m AHD in the south-east around Spring Ridge. The site is drained by the northerly flowing Sandy Creek and Laheys Creek. The creeks converge within the assessment area and flow north to the Talbragar River, which forms the northern extent of EL7394.

The assessment area is mostly cleared and used for agricultural purposes, including grazing sheep and cattle, cultivating cereal crops and forestry.

3.2 Climate

There are no Bureau of Meteorology weather stations with complete long-term data sets within the assessment area. The nearest weather stations with a complete set of long-term observation data are:

- Bureau of Meteorology Station 064009: Dunedoo Post Office (BoM 2011a), approximately 20 km north-east of the Project and in operation since 1912.
- Bureau of Meteorology Station 062013: Gulgong Post Office (BoM 2011b), approximately 20 km south-east of the Project and in operation since 1881.

Rainfall data from these sites has been analysed to understand local weather patterns.

An operational Bureau of Meteorology Station 064026 is located at Cobbora (Ellismayne); however, the data set is incomplete. The closest station to the assessment area with long-term evaporation observations is located at Wellington Research Centre (BoM Station 065035) about 60 km to the south-west of the assessment area.

Two additional meteorological gauging stations were installed by CHC in the assessment area between 2009 and 2011. These have been used to supplement long-term records obtained from the BoM stations, and provide rainfall information specific to the assessment area. The locations of these weather stations are shown in Figure 1.2.

Annual rainfall follows very similar patterns at each Bureau of Meteorology station. However, the historical average annual rainfall was slightly higher at Gulgong station than at Dunedoo station.

The average annual rainfall at Gulgong station, measured between 1881 and 2011, was 651.6 mm/a. Average annual rainfall at the Dunedoo station, measured between 1912 and 2011, was 616.4 mm/a, a difference of approximately 35 mm/a.

This may be mainly attributed to 14 years of above-average rainfall that occurred between 1881 and 1912, before the Dunedoo station operated. A comparison of annual rainfall at each station is shown in Figure 3.1.

Average monthly rainfall and evaporation data is shown in Figure 3.1. Generally the average monthly rainfall recorded at Gulgong and Dunedoo stations is very similar. In the period of record from November 2010 to November 2011 (inclusive), rainfall recorded at the Woolandra station was for half of the year well above the average monthly rainfall for the Dunedoo and Gulgong stations. This is the result of above-average rainfall, which was also experienced at Dunedoo and Gulgong.

The long-term (1889–2011) cumulative mean deviation (CMD) was calculated using rainfall data sourced from the Data Drill database to show the long-term trends in rainfall patterns (Figure 3.1). Data Drill accesses grids of data derived by interpolating the Bureau of Meteorology‘s station records. The CMD graph shows a negative gradient after the start of 2000 up to the end of 2009, indicating the area had below-average rainfall during this period. Since the beginning of 2010 the graph shows a positive trend, indicating above-average rainfall conditions.

The average annual evaporation from 1965 to 2005 (inclusive) recorded at the Wellington station was approximately 1,800 mm (BoM 2006) (which is reduced to 1,440 mm after applying the pan correction factor of 0.8 for surface water bodies in the central west region).

Overall, the records indicate that rainfall is generally greater in the summer months than in the winter months and there is a high level of evaporation in comparison to rainfall. The winter months of June and July are the exception, where rainfall and evaporation are relatively equal.

3.3 Surface water

Rivers in the greater Cobbora area include the Talbragar River and Cudgegong River, which are tributaries of the Macquarie River. The assessment area lies within the catchment of Sandy Creek, a tributary of the Talbragar River. Sandy Creek, Laheys Creek (a tributary of Sandy Creek) and a number of minor tributaries flow through the proposed mine area.

The Talbragar River, Sandy and Laheys Creek are naturally ephemeral waterways and cease to flow during dry periods. Other than the existing dams on the tributary of Laheys Creek, there are no headwater storages to regulate flows and therefore, generally, all flows are a direct reflection of rain events, groundwater baseflows and evapotranspiration processes.

Laheys Creek is a small, densely vegetated channel over most of its length. Upstream of its confluence with Laheys Creek, Sandy Creek is a sandy, grassed channel with evidence of bank erosion. Downstream of the confluence Sandy Creek widens to become a broad, flat channel that is heavily vegetated with grasses and reeds.

On the eastern side of the assessment area, two dams have been constructed on Blackheath Creek, a tributary of Laheys Creek. The dams were constructed by the landowner approximately 30 years ago to service the property irrigation needs.

The larger of the two dams has a capacity of 1,470 ML. The upstream smaller dam (referred to as the ‘sausage dam’) has a capacity of approximately 15 ML.

Tucklan Creek flows north from the Project Application Area into the Talbragar, approximately 10 km upstream of the Sandy Creek-Talbragar River confluence. Tucklan Creek has a similar sub-catchment area to Laheys Creek, although only approximately 1 km of headwaters lies within the Project Application Area.

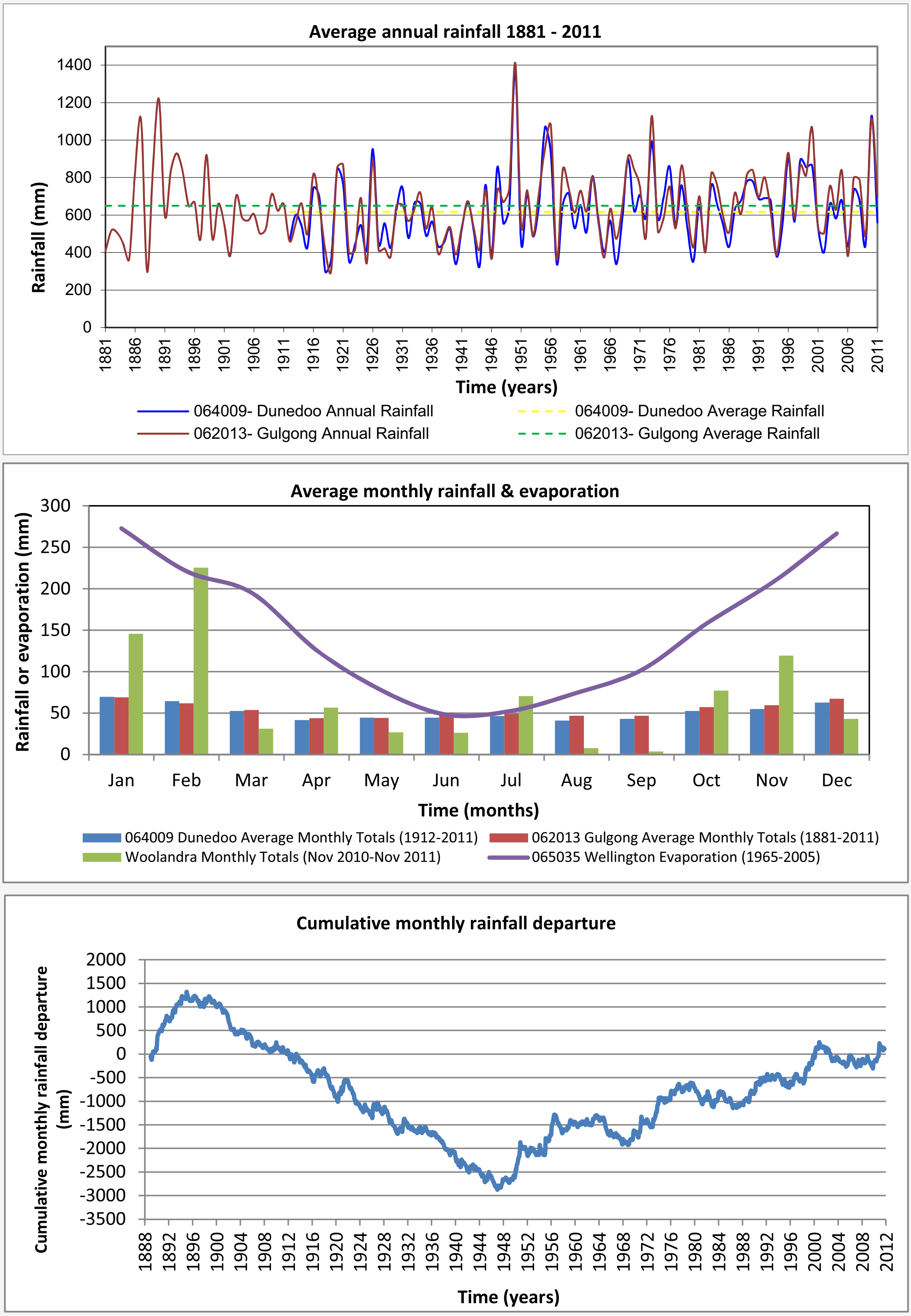


Figure 3.1 Climate information

3.4 Soils

The Australian Soil Resource Information System (ACLEP) (2010) provided information on soils within the assessment area. The predominant soil type is unit Qb17, which occurs in undulating country with gravelly or stony ridges comprising hard and friable neutral red soils.

Along the Talbragar River the soil unit is Gb11, occurring on river terraces and floodplains and comprising dark porous loamy soils with some cracking clays.

3.5 Dryland salinity

Dryland salinity is a product of rising groundwater tables mobilising stored salts toward the ground surface (Science, Engineering and Innovation Council, 1998). Rising groundwater tables are typically caused by the replacement of native deep rooted vegetation with shallow rooted plants (such as crops), which allow more rainfall to leak into groundwater systems, causing them to rise (Walker et al, 1999). The salinisation of landscapes can cause widespread degradation to water supplies, biodiversity, agriculture and infrastructure.

The Australian Dryland Salinity Assessment (ADSA) (National Land and Water Resources Audit, 2001) mapped high risk dryland salinity areas within NSW shown in Figure 3.2.

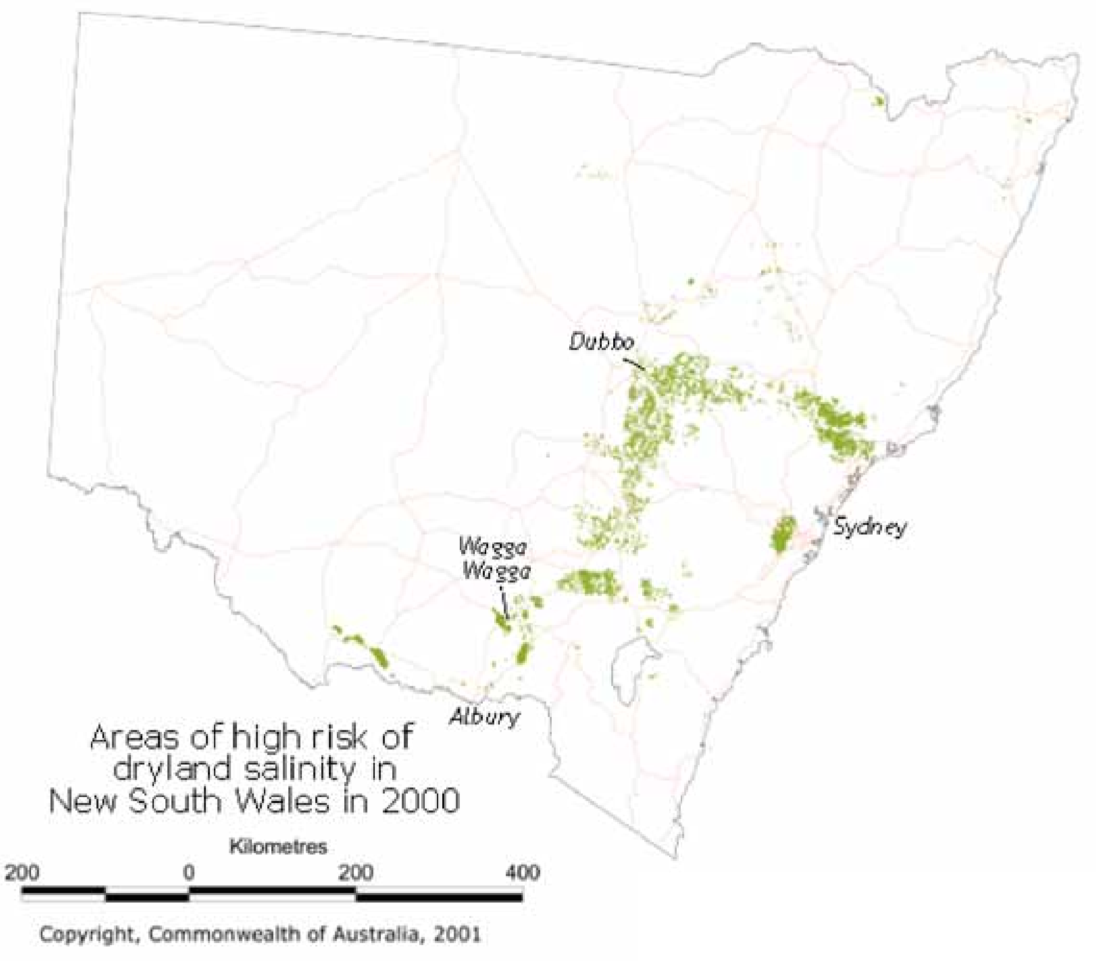


Figure 3.2 Areas of high risk of dryland salinity in NSW in 2000 (National Land and Water Resources Audit, 2001)

The Project area, located east of Dubbo, is considered to be at high risk of dryland salinity according to the ADSA. When considering existing hydrogeological conditions at a more local scale, the existing potential for dryland salinity in the Project area is expected to be moderate to high due to the following factors:

- The potential for dryland salinity is partly determined by the type of soils in the area. Humphries (2000) describes the salinity hazard rating of the Lower Talbragar catchment as ‘very high’. Although the Project area is within the Lower Talbragar, the Project area sub-catchment has relatively low salinity soils compared to the more saline catchments to the west (e.g. Spicers Creek catchment and Snake Gully catchment (Morgan 2005; Smithson & Ackworth 2005)). The Spicers Creek and Snake Gully catchments, to the south-west of the assessment area occur primarily on Lachlan Orogen metasediments, which are generally associated with saline soils. The Project targets the Triassic and Permian rocks within the sub-catchment and not the Lachlan Orogen metasediments and therefore the salinity risk is considered much lower in this particular area of the catchment.
- The risk of rising groundwater levels potentially occurring from the clearing of deep rooted vegetation is expected to be offset by the drawdown predicted to occur as a result of mining (Section 6). In addition, the risk of salinisation of soils is further offset by the moderate to low groundwater salinity observed during the monitoring program (Section 5.7).
- The low-lying areas associated with the drainage lines of the Project area, i.e. Sandy Creek, Laheys Creek and the Talbragar River, are considered to be at relatively higher risk given the potential for water ponding and shallow groundwater. However, salt scalding has not been observed during the field investigations between 2009 and 2012.

Considering these factors the existing dryland salinity risk in the Project area is expected to be moderate to high.

3.6 Geology

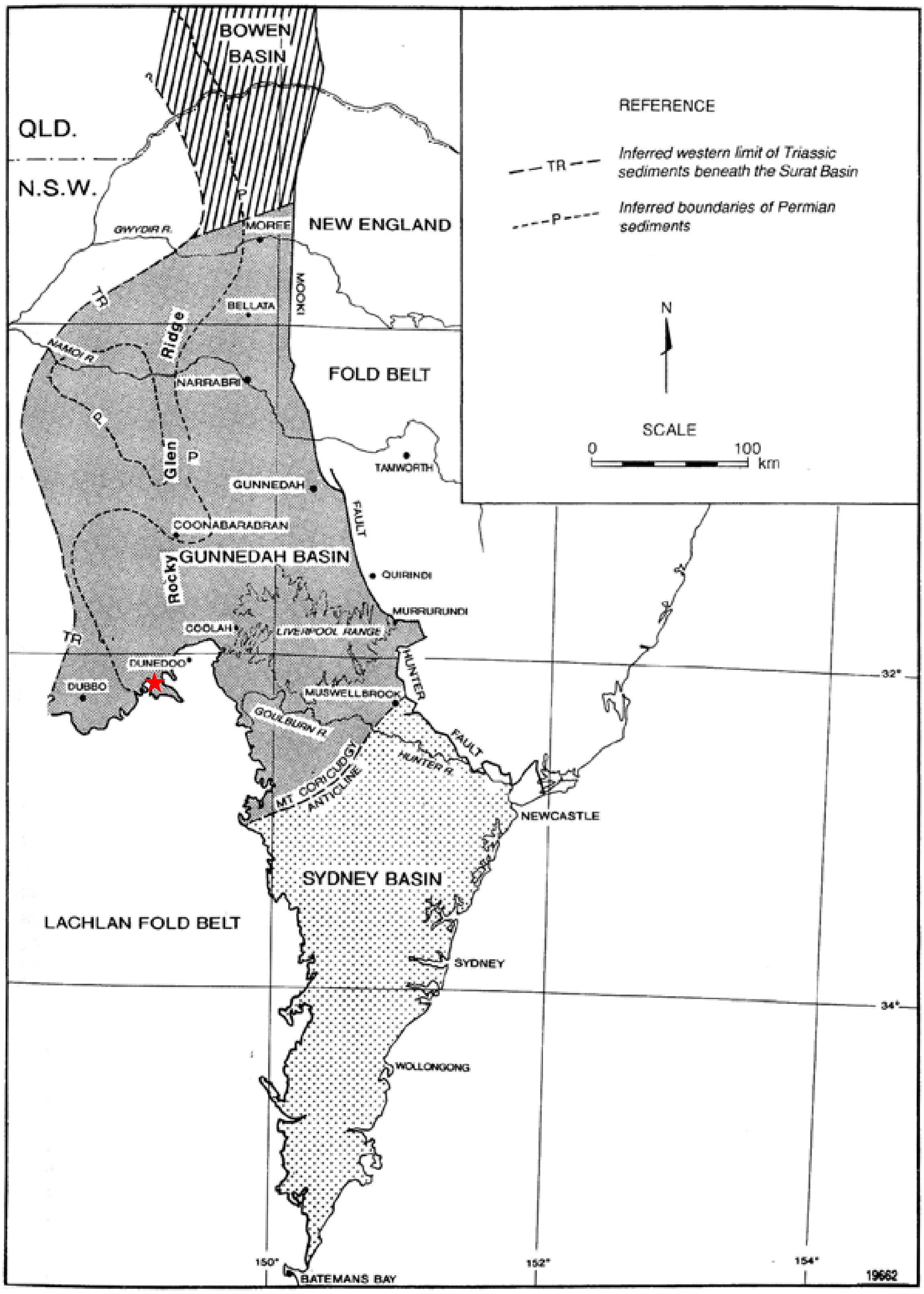
3.6.1 Regional geology

The assessment area is located within the south-western portion of the Gunnedah-Oxley Basin, in the Tooraweenah Trough. The Tooraweenah Trough unconformably overlies Silurian and Devonian units of the Lachlan Fold Belt and comprises late Permian coal-bearing sediments, overlain by Triassic sediments of the Napperby and Digby Formations.

The Tooraweenah Trough is separated from the eastern half of the Gunnedah Basin by the north-south trending Rocky Glen Ridge. The southern extent of this ridge is the Dunedoo High, which separates the Cobbora coal deposit from the Western Coalfield.

Overlying the Gunnedah-Oxley Basin are the predominantly sandstone sediments of the Surat Basin. These are marked on the Dubbo 1:250,000 geological sheet (Meakin & Morgan 1999) as part of the Great Artesian Basin. The Pilliga Sandstone and Purlawaugh Formation are present to the north-west and west of the assessment area, with some outliers to the south-west. They are observed as hilly sandstone outcrops. The Surat Basin sediments located in the assessment area are considered part of the Oxley Basin; a sub-basin of the Surat Basin (Australian Government 2009). The broad regional geology is shown in Figure 3.3.

Owing to the closeness of the assessment area to the Western Coalfield, and the discrepancies in the boundary of the Sydney and Gunnedah Basins, the adopted stratigraphic nomenclature used is consistent with the reporting by Marston (2009) and the Sydney Basin nomenclature. The Gunnedah Basin nomenclature is also provided for reference. A summary table of the stratigraphy, predominantly based on Marston (2009), is presented in Table 3.1.



★ Project area location

Reproduced from: Tadros, NZ (1993), The Gunnedah Basin, New South Wales, Geological Survey of New South Wales

Figure 3.3 Regional geology

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Table 3.1 Summary of geological stratigraphy

Period	Group	Formation	Description	Thickness	Gunnedah Basin nomenclature
Quaternary		Alluvium	Gravels and sand with some clay layers associated with stream and river channels and floodplains	Up to 23.5 m (Talbragar River)	Alluvium
Tertiary		Basalts	Topographically inverted tertiary basalt flows forming caps on hills in the assessment area with some intrusive formations	variable	Basalts
Jurassic		Pilliga Sandstone	Fine to coarse sandstone	>100 m	Pilliga Sandstone
		Purlawaugh Formation	Mudstone, siltstone and sandstone	>100 m	Purlawaugh Formation
Triassic		Napperby Formation	Siltstone and sandstone	~100 m (maximum)	Napperby Formation
	Narrabeen Group	Digby Formation	Fluvial lithic and quartz conglomerates, sandstones and minor fine grained sediments	~20 m	Digby Formation
Permian	Dunedoo Formation	Trinkey Seam	Coal	2–5 m	Nea Subgroup
	Dunedoo Formation	Ellismayne Formation	Interbedded siltstone, sandstone and claystone	2–18 m	Nea Subgroup
	Dunedoo Formation	Whaka Formation	Interbedded carbonaceous claystone and tuff with stoney coal seams	2–14 m	Nea Subgroup
	Dunedoo Formation	Avymore Claystone	Claystone	1–13 m	Coogal Subgroup
	Dunedoo Formation	Flyblowers Creek Seam	Coal seam with minor tuff	3–5 m	Coogal Subgroup
	Dunedoo Formation	Tomcat Gully Sandstone	Coarse sandstone and conglomerate, some shale	3–13 m	Coogal Subgroup
	Dunedoo Formation	Upper Ulan Seam	Coal, minor tuff, coal content increases with depth	3–5 m	Coogal Subgroup
	Dunedoo Formation	C-Marker Clay	Claystone	0.1–5 m	Coogal Subgroup
	Dunedoo Formation	Lower Ulan Seam	Coal interbedded with tuff and shale, coal content increases with depth	2–5 m	Coogal Subgroup
	Dunedoo Formation	Dapper Formation	Coarse sandstone and lithic conglomerates	~60 m	Brothers Subgroup
		Early Permian sequence	Interbedded shales, siltstones and fine sandstone	unknown	Watermark, Porcupine and Maules Creek Formations

Period	Group	Formation	Description	Thickness	Gunnedah Basin nomenclature
Devonian		Basalt	Mafic to intermediate intrusions	unknown	Basalt
Silurian	Mumbil Group	Glenski Formation	Felsic to rhyolitic tuff and tuffaceous sedimentary rocks	unknown	
	Chesleigh Group	Piambong Formation	Quartzose to quartz-lithic sandstone and siltstone, tuff and volcaniclastic horizons	unknown	
	Tanabutta Group	Dungeree Volcanics	Rhyolite to dacite lava, limestones, polymictic conglomerate, shale, slate and volcanic-rich sandstone	unknown	
Ordovician	Carbonne Group	Tucklan Formation	Sedimentary rocks of mafic volcanic origin	unknown	

3.6.2 Local geology

Triassic sediments are the predominant surface geology across the assessment area. The Napperby Formation is significantly weathered across the site and is characterised by red brown alluvial plains, which are interspersed by remnant sandy ridges and outlying deposits of the Digby Formation. A narrow zone of discontinuous Quaternary alluvium associated with Sandy Creek is present, becoming more extensive to the north in association with the Talbragar River. To the north-east of the assessment area Quaternary colluvial polymictic gravels are present along drainage lines flowing to the Talbragar River, including Tucklan Creek.

Tertiary basalts outcrop within the assessment area to the south-west and south-east of the mining area. The Tertiary volcanic rocks are both intruded and extruded and mostly lie unconformably over the Jurassic and Triassic strata as capping rocks on the sandstone hilltops.

The Permian Dunedoo Formation unconformably overlies basement rocks of the Lachlan Fold Belt (Devonian, Silurian and Ordovician rocks). The Permian sequence comprises coal measures interspersed with siltstones, sandstones, claystones and conglomerates, and outcrops in low-lying areas. Coal seams are observed to outcrop in eroded creek beds and to the west of Laheys Creek Fault. Structural uplift has raised the coal-bearing sequence along the eastern margin of Laheys Creek Fault resulting in later erosion of the coal seams, while the dip of the Permian sequence trends to the south-west.

A total of five mineable coal seams have been identified within the Dunedoo Formation in EL 7394. In descending order these are the Trinkey Seam, the Whaka Seam, the Flyblowers Creek Seam and the Ulan Upper and Lower Seams. The seams range in thickness from about 2 to 8 m. The deepest seam, Ulan Lower Seam, is underlain by Dapper Formation which is characterised by siltstones, sandstones and quartz lithic conglomerates (Marston 2008).

The basement geology comprises the greater Lachlan Fold Belt, and on the eastern margin locally comprises Silurian aged phyllite rocks that are severely jointed and foliated (Marston 2008). Permian units appear to lap unconformably onto the folded Silurian strata south of the assessment area. To the west the contact is as much fault bound as it is depositional. Silurian bedrock also outcrops east of Laheys Creek Fault. Ordovician basement rocks from the Lachlan Orogen are present to the east.

The Tucklan Formation is generally overlain by the Permian Dunedoo Formation; however, it does outcrop east of the assessment area between Laheys Creek and Tucklan Creek. The Tucklan Formation is predominantly a fine-grained lithology, which is largely undifferentiated. The local geology is shown in Figure 3.4.

3.6.3 Geological structure

The basement rocks of the Lachlan Fold Belt are located within the Hill End Synclinal Zone, between the Cowra and Capertee Zones (Meakin & Morgan 1999). The strata of the Hill End Zone are characterised by open south-plunging, north to north-northwest trending folds and faults.

Laheys Creek Fault, also a north-northwest trending fault and located along the eastern edge of the mining area, is interpreted as a bounding fault to the Hill End Trough (Meakin & Morgan 1999). This fault is considered a northern extension of the Mudgee Fault as interpreted from regional magnetic data (Glen 1999). The Laheys Creek Fault is reported to be a west dipping thrust fault (Glen 1999) associated with convergent tectonism in the mid- Palaeozoic. Borehole data collected by Menpes (1997) shows the latest episode of movement appears to be in the early to mid-Permian with little displacement of late Permian units. Permian reactivation of this fault seems to have resulted in normal movement down to the west, resulting in a graben valley type of geological setting for the assessment area. This agrees with the topography, which exhibits rocky ridges of metamorphosed rock to the west and east of the assessment area; a valley of rolling hills over the outcropping Triassic sandstone strata.

Eight kilometres to the west of Laheys Creek Fault is an unnamed fault that is oriented parallel to Laheys Creek Fault (Figure 5.2 to Figure 5.5). Jurassic units appear to be offset in a sinistral sense along this western fault and movement appears to be down to the east as well as strike slip. This fault block appears to have moved in a rotational fashion with some upwards movement to the east in the southern portion of the fault block.

Another normal fault, located approximately 2 km further west, separates Triassic and Permian sedimentary units from older Lachlan Orogen units. A north-easterly trending lineament towards the north-west of the assessment area potentially represents mid-Palaeozoic thrust movement dipping to the south-east.

Marston (2009) suggested that the dominant structure of the Permian coal sequence was a syncline with its axis to the west of the mining area. Permian coal seams have a dip of up to five degrees to the west in the vicinity of the mining area. It may be that this dip reflects deposition on the underlying basement surface and the influence of pre-existing basement structure rather than a syncline. The geological structure in this area, west of the mining area, is inconclusive.

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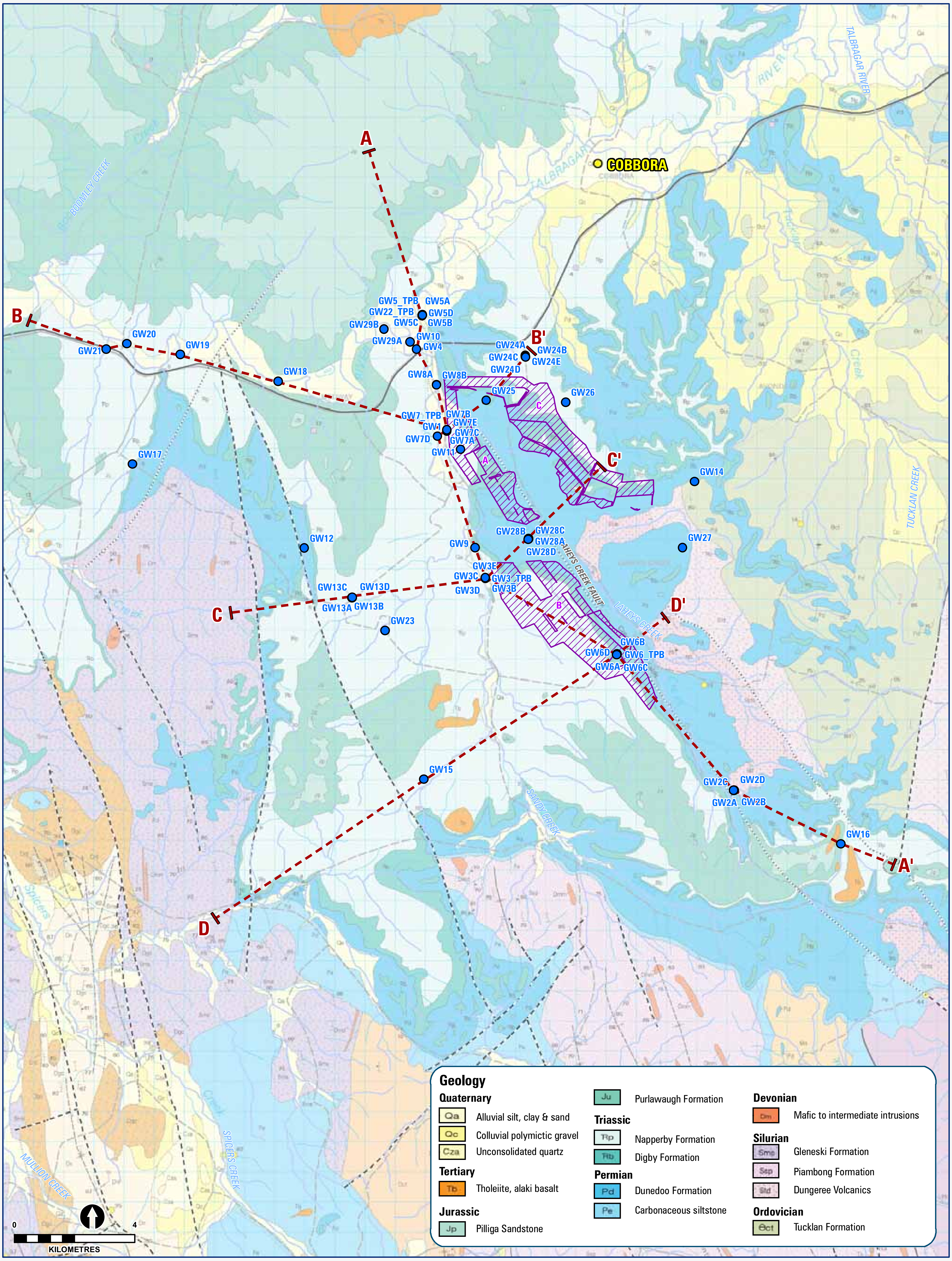

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- Piezometer sites
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas

Figure 3.4 Site geology and geological structures

Geologic map source: Geological Survey of New South Wales, 1999

4. Groundwater investigations

Groundwater investigations commenced in 2009 and have since comprised of:

- drilling and installation of piezometers and test production bores
- geophysical logging of test production bores
- hydraulic testing of piezometers and test production bores
- groundwater quality and groundwater level monitoring
- investigation of groundwater – surface water interactions
- assessment of the impact to potential groundwater availability to ecosystems
- survey of existing groundwater users in the assessment area
- transient electromagnetic (TEM) groundwater investigation.

These components are discussed in greater detail in the following sections.

4.1 Drilling and installation

The drilling and installation of piezometers and test production bores began in 2009 to establish a baseline database for groundwater levels, flow direction and groundwater quality of the hydrogeological units across the assessment area. In total 56 piezometers and five test production bores have since been installed. A summary of the piezometer and test production bore construction details is provided in Table 4.1, and bore logs in Appendix A.

Drilling was carried out by Highland Drilling, Impax, Intertech Drilling and Gricks Drilling in 2009, 2010 and 2011. Drilling and construction details for all piezometers and test production bores are provided in Appendix A.

The piezometers and test production bores were completed with a padlocked steel monument, and surveyed in reference to the Australian Height Datum (AHD) by certified surveyors. After construction, the piezometers and test production bores were developed by airlifting.

Final bore depth was assessed from observation and geological interpretation of the stone chips samples that were collected for logging at 1 m intervals. The target bore depths were selected on the requirement for adequate information on all formations overlying the target coal seams (Flyblowers Creek and Ulan Coal Seams). The target seams themselves and the underlying Dapper Formation (base of mining).

Groundwater monitoring bore licences were obtained for all piezometers through the New South Wales Office of Water (NOW) prior to drilling. Licence details are provided in Table 4.1. Form As was completed by Highland Drilling, Impax, Intertech Drilling and Gricks Drilling following bore completion, and were returned to NOW.

Table 4.1 Bore construction details

Piezometer or test production bore	Bore licence number	Bore depth (m)	Bore diameter (mm)	Ground surface elevation (m AHD)	Easting (m)	Northing (m)	Screened formation	Screened interval (mBGL)
GW1	80BL245407	10.5	50	355.43	707529.25	6442593.57	Alluvium	7.0–10.0
GW2A	80BL245308	20.6	50	454.66	717366.98	6430846.57	Lower Ulan Seam	16.0–19.0
GW2B	80BL245308	28.3	50	454.61	717360.63	6430846.62	Dapper Formation	23.9–26.9
GW2C	80BL245308	33.3	50	454.52	717354.63	6430846.5	Dapper Formation	28.5–31.5
GW2D	80BL245308	49.1	50	454.42	717348.56	6430846.94	Dapper Formation	42.1–48.1
GW3_TPB	80BL245414	72.6	203	375.31	709120.02	6437874.58	Whaka Formation, Avymore Claystone, Ulan Coal Seams, Dapper Formation	32.0–38.0 56.0–68.0
GW3B	80BL245414	46.1	50	375.24	709117.18	6437880.81	Whaka Formation, Avymore Claystone, Flyblowers Creek Seam, Tomcat Gully Sandstone	29.0–35.0 38.0–44.5
GW3C	80BL245414	53.8	50	375.15	709114.87	6437885.98	Tomcat Gully Sandstone	46.0–52.0
GW3D	80BL245414	64.8	50	375.09	709111.91	6437893.34	Ulan Coal Seams	52.0–64.0
GW3E	80BL245414	73.2	50	375.04	709109.17	6437900.51	Dapper Formation	65.0–71.0
GW4	80BL245488	8.9	50	345.83	706611.66	6445727.53	Alluvium	5.0–8.0
GW5_TPB	80BL245412	54.0	152	349.61	707017.51	6446600.66	Tomcat Gully Sandstone, Ulan Coal Seams, Dapper Formation	30.0–48.0
GW5A	80BL245412	19.8	50	349.58	707019.42	6446611.78	Alluvium	14.8–17.8
GW5B	80BL245412	30.6	50	349.63	707020.52	6446617.82	Tomcat Gully Sandstone	26.6–29.6
GW5C	80BL245412	43.0	50	349.51	707021.80	6446624.40	Ulan Coal Seams	36.0–42.0
GW5D	80BL245412	54.6	50	349.29	707023.18	6446631.55	Dapper Formation	47.0–53.0
GW6_TPB	80BL245409	61.0	203	411.32	713476.75	6435365.20	Ellismayne and Whaka Formations, Avymore Claystone, Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams	13.0–51.0
GW6A	80BL245409	34.5	50	411.42	713475.57	6435359.34	Ellismayne and Whaka Formations, Avymore Claystone, Flyblowers Creek Seam	14.0–34.5
GW6B	80BL245409	38.0	50	411.44	713474.49	6435353.41	Tomcat Gully Sandstone	36.5–38.0

Piezometer or test production bore	Bore licence number	Bore depth (m)	Bore diameter (mm)	Ground surface elevation (m AHD)	Easting (m)	Northing (m)	Screened formation	Screened interval (mBGL)
GW6C	80BL245409	50.0	50	411.45	713473.31	6435347.53	Ulan Coal Seams	41.0–50.0
GW6D	80BL245409	61.0	50	411.44	713472.12	6435341.06	Dapper Formation	55.0–61.0
GW7_TPB	80BL245524	85.0	203	358.47	707836.34	6442769.92	Ellismayne and Whaka Formations, Avymore Claystone, Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams, Dapper Formation	30.0–85.0
GW7A	80BL245524	11.7	50	358.41	707835.22	6442785.11	Alluvium	4.5–11.5
GW7B	80BL245524	53.0	50	358.36	707835.10	6442792.59	Ellismayne and Whaka Formations, Avymore Claystone, Flyblowers Creek Seam	30.0–53.0
GW7C	80BL245524	61.0	50	358.38	707835.98	6442799.39	Tomcat Gully Sandstone	58.0–61.0
GW7D	80BL245524	72.7	50	358.42	707836.34	6442806.20	Lower Ulan Seam	68.0–71.0
GW7E	80BL245524	85.9	50	358.31	707836.65	6442812.96	Dapper Formation	77.5–83.5
GW8A	80BL245405	6.5	50	351.28	707491.38	6444296.65	Alluvium	2.5–5.5
GW8B	80BL245405	10.5	50	351.33	707488.99	6444300.39	Alluvium, Digby Formation	6.0–9.0
GW9	80BL245414	12.9	50	377.48	708772.31	6438896.68	Digby Formation	8.0–11.0
GW10	80BL245488	12.5	50	347.75	706831.36	6445486.72	Alluvium	8.0–11.0
GW11	80BL245524	11.7	50	381.05	708296.82	6442150.75	Digby Formation	7.8–10.8
GW12	80BL245541	122.0	50	393.65	703106.10	6438882.75	Early Permian sequence	114.0–120.0
GW13A	80BL245541	119.0	50	408.33	704679.17	6437233.30	Ellismayne and Whaka Formations	109.0–118.0
GW13B	80BL245541	136.0	50	408.21	704684.63	6437237.27	Tomcat Gully Sandstone	129.0–135.0
GW13C	80BL245541	150.2	50	408.23	704690.17	6437241.12	Ulan Coal Seams	137.0–149.0
GW13D	80BL245541	162.0	50	408.06	704695.92	6437244.88	Dapper Formation	152.0–161.0
GW14	80BL245542	32.0	50	429.01	716052.88	6441091.14	Lachlan Orogen	25.0–31.0
GW15	80BL245739	70.0	50	431.63	707063.06	6431211.79	Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams	56.0–68.0
GW16	80BL245732	132.0	50	601.22	720907.26	6429063.23	Ulan Coal Seams	122.0–131.0
GW17	80BL245733	42.3	50	363.43	697401.60	6441667.07	Tomcat Gully Sandstone	34.0–40.0
GW18	80BL245735	13.0	50	337.89	702230.54	6444415.91	Purlawaugh Formation	9.0–12.0

Piezometer or test production bore	Bore licence number	Bore depth (m)	Bore diameter (mm)	Ground surface elevation (m AHD)	Easting (m)	Northing (m)	Screened formation	Screened interval (mBGL)
GW19	80BL245742	18.3	50	330.12	698984.91	6445305.70	Napperby Formation	14.3–17.3
GW20	80BL245752	78.0	50	326.87	697211.51	6445662.35	Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams, Dapper Formation	54.0–78.0
GW21	80BL245740	20.0	50	328.69	696528.65	6445489.93	Napperby Formation	14.0–19.0
GW22_TPB	80BL245412	52.0	125	349.68	707013.78	6446584.40	Ulan Coal Seams, Dapper Formation	36.0–51.0
GW23	80BL245754	42.0	50	405.92	705786.22	6436148.65	Napperby Formation	35.0–41.0
GW24A	80BL620170	47.5	50	388.96	710440.83	6445279.99	Whaka Formation, Avymore Claystone	31.5–46.5
GW24B	80BL620170	52.7	50	389.13	710441.97	6445268.01	Flyblowers Creek Seam	52.0–52.7
GW24C	80BL620170	57.1	50	389.22	710444.88	6445237.89	Tomcat Gully Sandstone	56.3–57.1
GW24D	80BL620170	70.0	50	389.30	710445.78	6445227.26	Ulan Coal Seams	64.0–67.0
GW24E	80BL620170	88.0	50	389.29	710446.25	6445216.68	Dapper Formation	72.0–87.0
GW25	80BL620170	61.0	50	370.39	709138.98	6443789.37	Dapper Formation	42.1–48.1
GW26	80BL620207	57.0	50	434.95	711780.37	6443721.05	Dapper Formation	50.0–56.0
GW27	80BL620206	29.5	50	436.79	715660.22	6438900.47	Dapper Formation	14.0–29.0
GW28A	80BL620169	6.5	50	376.00	710548.42	6439196.01	Alluvium	2.5–5.5
GW28B	80BL620169	8.43	50	375.93	710545.32	6439185.93	Alluvium, Tomcat Gully Sandstone	4.5–7.5
GW28C	80BL620169	29.5	50	375.88	710542.14	6439176.71	Ulan Coal Seams	20.0–29.0
GW28D	80BL620169	38.5	50	375.80	710538.12	6439165.79	Dapper Formation	33.0–36.0
GW29A	80BL620199	14.0	50	348.31	705751.24	6446145.13	Alluvium	7.5–13.5
GW29B	80BL620199	83.5	50	348.29	705751.25	6446154.55	Digby Formation	66.4–81.4

mAHD – metres Australian Height Datum
mBGL – metres below ground level

4.2 Geophysical logging

Three of the test production bores (GW3_TPB, GW6_TPB and GW7_TPB) were geophysically logged following drilling and construction. A suite of sensors was used to define a number of parameters, including calliper, natural gamma, resistivity, self-potential and induction. The geophysical parameters complemented the geological information provided in the drilling program and helped to identify various information, such as fracture zones and groundwater inflows. The geophysical raw data is presented in the bore logs (Appendix A).

4.3 Hydraulic testing

Field hydraulic testing of the aquifers in the assessment area was carried out through pumping tests, rising head tests and packer tests at several sites. Information on the hydraulic testing carried out is provided in the following sections.

4.3.1 Pumping tests

Pumping tests were carried out at four sites (GW3, GW5/GW22, GW6 and GW7) between October 2009 and December 2011. The aims of the pumping tests were to assess:

- the regional impact on groundwater of the proposed mine
- potential hydraulic connection between the Talbragar River and associated alluvium aquifer, and the Permo-Triassic porous rock aquifer
- potential hydraulic connection between the alluvium and the underlying Permo-Triassic porous rock aquifer.

Drawdown and recovery data collected during the pumping tests were analysed to determine aquifer hydraulic properties. The data were analysed using the Cooper-Jacob method (Cooper & Jacob 1946) and Theis recovery method (Theis 1935) to calculate transmissivity (T), hydraulic conductivity (K) and storativity (S). The results from the pumping tests are summarised in Section 5.6, and the full set of results provided in Appendix B provides a summary of the pumping test programs at each site.

Water samples were collected from the discharge pipe during each pumping test to identify changes in water quality throughout the test. Environmental isotope samples were also taken to characterise the groundwater and determine groundwater age.

All tests were carried out by Ted Wilson and Sons, and were supervised by Parsons Brinckerhoff. Each test was carried out using an electro-submersible pump. Water level drawdown/recovery and flow measurements were recorded throughout the testing using Win-Situ and Solinst data loggers. Manual water levels were also recorded periodically.
In each test production bore, the data logger and manual water level dipper were mounted within a PVC conduit, which was installed in the test production bore alongside the pump. The flow rate was monitored with a MagFlow meter.

Table 4.2 Pumping tests

Test production bore	Date	Pumping test	Pumping rates (L/s)
GW3_TPB	Oct 2009	Step drawdown test 24-hour constant rate test 14-day constant rate test	1.1, 2.4, 3.7, 5.1 4.4 4.4
GW5_TPB	Oct 2009	Step drawdown test 24-hour constant rate test	1.0, 2.5, 5.1 3.5
GW6_TPB	Oct 2009	Step drawdown test	Test abandoned due to insufficient yield
GW7_TPB	Oct 2009	Step drawdown test 24-hour constant rate test	1.0, 2.9, 4.0, 5.0 4.4
	Nov/Dec 2011	Step drawdown test 21-day constant rate test	1.5, 2.5, 3.5, 4.5 2.5
GW22_TPB	Feb/Mar 2010	Step drawdown test 3-day constant rate test 3-day constant rate test	0.5, 1.0, 1.5, 2.0 1.6 1.8
	Sep/Oct 2011	Step drawdown test 21-day constant rate test	0.5, 1.0, 1.5, 2.0, 2.5 2.0

4.3.2 Rising head tests

Rising head 'slug' tests were carried out on 16 piezometers to obtain localised estimates of hydraulic conductivity. The tests were carried out by removing a volume (or 'slug') of water from the piezometer and monitoring the recovery of the water level with an in-hole data logger.

The rising head tests were analysed using the Bouwer-Rice method (Bouwer & Rice 1976) suitable for providing an estimate of hydraulic conductivity near to the piezometer.
The results are summarised in Section 5.6, and the full set of results provided in Appendix B.

4.3.3 Packer tests

Packer tests were carried out at two sites during drilling: GW6 and GW7. The aim of the packer tests was to estimate the bulk field permeability and equivalent hydraulic conductivity of the units tested at each site.

Each packer test was carried out by injecting water under pressure into an uncased section of the borehole, between the bottom of the hole and one upper packer seal, as drilling progressed. The volume of pressurised water injected was measured until steady state conditions were obtained. The procedure was then repeated for five pressure increments for each sealed test section of the borehole.

The packer tests were analysed using the Houlsby (1976) method, where the inflow into jointed rock was calculated in Lugeon units — defined as one litre per minute per metre of test section per ten atmospheres of effective pressure. Lugeon units were then used to obtain approximate values of hydraulic conductivity of each formation tested. The results are provided in Appendix C.

4.4 Groundwater monitoring

4.4.1 Groundwater quality

Groundwater monitoring was conducted at each piezometer after development and on a maximum of seven subsequent monitoring occasions. Groundwater monitoring included the collection of groundwater samples for field analysis of pH, electrical conductivity (EC), oxidation reduction potential (redox), temperature, dissolved oxygen (DO) and carbon dioxide (CO_2), and laboratory analysis of major anions and cations and dissolved metals (aluminium (Al), beryllium (Be), barium (Ba), cobalt (Co), iron (Fe), lead (Pb), manganese (Mn) and zinc (Zn)).

Limited analysis for nutrients (ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), total nitrogen (N), total phosphorus (P), reactive P) and an additional dissolved metal and metalloid suite (arsenic (As), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), selenium (Se), vanadium (V)) was undertaken for selected monitoring piezometers in 2009. ALS Environmental, Sydney, Australia, conducted the laboratory analyses (major ions, dissolved metals and nutrients).

The results from the groundwater quality monitoring are discussed in Section 5.2 and the data is tabulated in Appendix D. Note, monitoring bores GW11, GW26 and GW27 are not included in the tables as they were dry at the time of sampling.

4.4.2 Groundwater levels

Data loggers, which measure groundwater pressure on a continuous basis, were installed in all piezometers and test production bores following construction. Data loggers were downloaded during each monitoring event (approximately quarterly) and the manual water levels were also recorded. Barometric pressure was monitored on-site using a barologger and the data was used to correct the recorded groundwater pressures to a groundwater level.

Groundwater levels are presented in Appendix E. Note: hydrographs for monitoring bores GW11, GW26 and GW27 are not available as they were dry.

4.4.3 Environmental isotopes

Stable isotopes (oxygen-18 (^{18}O), deuterium (^{2}H), and carbon-13 (^{13}C)) and radiogenic isotopes (radiocarbon (^{14}C)) were analysed in selected piezometers to characterise groundwater and determine groundwater age.

Samples were sent to the following laboratories:

- GNS Science Stable Isotope Laboratory, Lower Hutt, New Zealand (^{18}O and ^{2}H).
- Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand (^{13}C and ^{14}C).

4.4.4 Groundwater age dating

Groundwater samples were collected during monitoring events for analysis of groundwater ^{14}C age dating. The information obtained was used to provide an additional estimate of hydraulic conductivity of the porous rock aquifers using the Darcian relationship for seepage velocity (Fetter 1980).

4.5 Groundwater – surface water connectivity

Groundwater – surface water connectivity is observed across the assessment area, in a variety of forms including:

- springs/seeps
- baseflow and semi-permanent pools within the Talbragar River and tributaries
- flood flow recharge to groundwater.

4.5.1 Springs/seeps

Springs and seeps are present in the assessment area, and are typically located in highland areas. Two surveys were undertaken in 2010 and 2011 to record and sample known springs.

The springs identified in the 2010 survey were sampled for:

- field parameters (pH, EC, redox, temperature, DO and CO2)
- major anions and cations
- dissolved metals (Al, Be, Ba, Co, Fe, Pb, Mn, Zn).

In addition to the above suite, spring samples in 2011 were also analysed for stable isotopes (oxygen-18 (^{18}O), deuterium (^{2}H) and carbon-13 (^{13}C)) and radiogenic isotopes (radiocarbon (^{14}C)). These isotopes were analysed to assess whether the springs were groundwater or rainfall dependent.

4.5.2 Stream baseflow

Groundwater discharges occurring as surface water baseflow across the assessment area were considered during surface water surveys and analysis of surface water hydrographs.

In April 2010, registered surveyors Boardman and Peasley (2010) conducted a surface water survey for Parsons Brinckerhoff. The survey involved the measurement of surface water elevations in the Talbragar River.

These elevations were compared with alluvium aquifer groundwater elevations in nearby piezometers to assess whether the river was losing or gaining.

To further assess groundwater – surface water connectivity, surface water quality surveys were conducted by Parsons Brinckerhoff. Parsons Brinckerhoff staff traversed the Talbragar River, Sandy Creek and Laheys Creek, recording field parameters (pH, EC, redox, temperature, DO and CO_2) at potential locations of groundwater baseflow.

Ten samples were collected in each river/creek for analysis of major anions and cations, dissolved metals (Al, Be, Ba, Co, Fe, Pb, Mn, Zn) and stable isotopes (^{18}O and ^{2}H). Sampling locations were photographed and GPS coordinates recorded.

4.5.3 Flood recharge to groundwater

Infiltration of surface water into the alluvium and porous rock aquifers during stream high flow and flood events was assessed by comparing rainfall and stream hydrograph data with monitoring bore hydrographs from locations adjacent to stream channels. Analysis of hydrographs is discussed in Section 5.3.

4.5.4 Potential groundwater availability to ecosystems

The groundwater assessment sought to identify areas and locations where groundwater either discharges at the surface (via springs, seeps or stream base-flow), or exists at shallow depths below the surface. At such locations it is assumed that groundwater is potentially available to plants and associated ecosystems. The Project's ecology consultant, Cardno Ecology Lab, assessed the actual dependence of plant and animal communities on groundwater.

Groundwater dependent ecosystems are communities of flora and fauna that rely partly or entirely on groundwater for their existence and ongoing health. The Water Sharing Plan for the NSW MDB Porous Rock Groundwater Sources (NOW 2011b) lists high-priority groundwater dependent ecosystems within the Gunnedah-Oxley Basin.

Naran Springs is documented as being located approximately 5.25 km to the west of the mining area and is classified as a high-priority groundwater dependent ecosystem in the water sharing plan. High-priority groundwater dependent ecosystems are currently under investigation and some of these may be identified during the term of the plan. The full list of potential groundwater dependent ecosystems will be identified on the NOW GDE Register and as a precautionary approach, will be considered by NOW in the assessment of any application for a water supply work approval within the area of this plan (NOW 2011b).

Surveys were conducted in 2010 and 2011 to locate areas of potential groundwater availability to ecosystems within the assessment area. The surveys aimed to identify the occurrence of baseflow in streams, shallow groundwater in alluvium adjacent to stream channels and wetland areas. Photographs, field notes and GPS coordinates were recorded and provided to the Project consulting ecologist for vegetation species identification and impact assessment.

The results of this survey are discussed further in Section 5.6. Refer to the ecology report (Cardno Ecology Lab 2012) for an assessment of groundwater dependence and impacts.

4.6 Hydrocensus

A search of the NSW state groundwater database managed by NOW was undertaken to obtain information on registered groundwater users in the area. The groundwater database contains records for all registered bores across NSW and information on the database is supplied to NOW by both the landholder and the driller upon construction of the bore. The level of detail in the database and the accuracy of information is not guaranteed, as it depends on the receipt of accurate and informative records from drillers (Form A).

The accuracy of the bore status is also reliant on landholders advising NOW when bores are decommissioned or abandoned.

A hydrocensus was undertaken to locate and survey private groundwater bores in the assessment area on two separate occasions: March 2010 and September 2011. The objective of the hydrocensus was to identify some of the operational bores in the area and collect baseline information such as groundwater level, depth of bore and water quality. Bores surveyed included both registered groundwater bores identified in a NOW database search as well as unregistered bores identified in the field. Not all bores were included due to property access, bore infrastructure or knowledge of operational bore locations. The baseline data provides information which can be used to assist in assessing the potential impacts on existing groundwater users, as a result of the Project. It also provides baseline information that can be referenced when monitoring potential impacts of the Project over time.

The survey covered a wide extent from north of the Talbragar River, to Spicers Creek in the west, and Tucklan Creek in the east. A total of 143 registered bores were identified within a 15 km radius of the Project area (Figure 4.1). The total number of bores surveyed was 74. Of these 74 surveyed bores, 38 were matched to a registered bore, and the remaining 36 were either not registered, or were not located at the same position as provided in the registered bore database. Most bores in the area are used for stock and domestic purposes. The locations and registered purpose of the 143 registered bores, and the 74 bores surveyed in the hydrocensus are illustrated in Figure 4.1.

The bores surveyed as part of the hydrocensus were mainly located near streams, such as the Talbragar River, Sandy Creek, Spicers Creek and Tucklan Creek. Additional anecdotal usage and construction information was collected from the bore owners. Where possible the bore depth and groundwater level was measured, and a water sample collected to record field parameters (EC, total dissolved solids (TDS), pH, redox and temperature) and undertake laboratory analysis of major ions and dissolved metals (Al, Ba, Be, Co, Fe, Mn, Pb and Zn).

Results of the hydrocensus are tabulated in Table F.1 and other registered bores not surveyed are tabulated in Table F.2 in Appendix F.

The potential impacts to groundwater users are assessed in Section 7.

4.7 Transient electromagnetic (TEM) survey

Groundwater Imaging Pty Ltd carried out a transient electromagnetic survey (TEM) in October 2011 around the Talbragar River, Sandy Creek and Laheys Creek in the assessment area. The survey aimed to identify alluvial extent and any other potential groundwater flow paths. The complete TEM report is presented in Appendix G.

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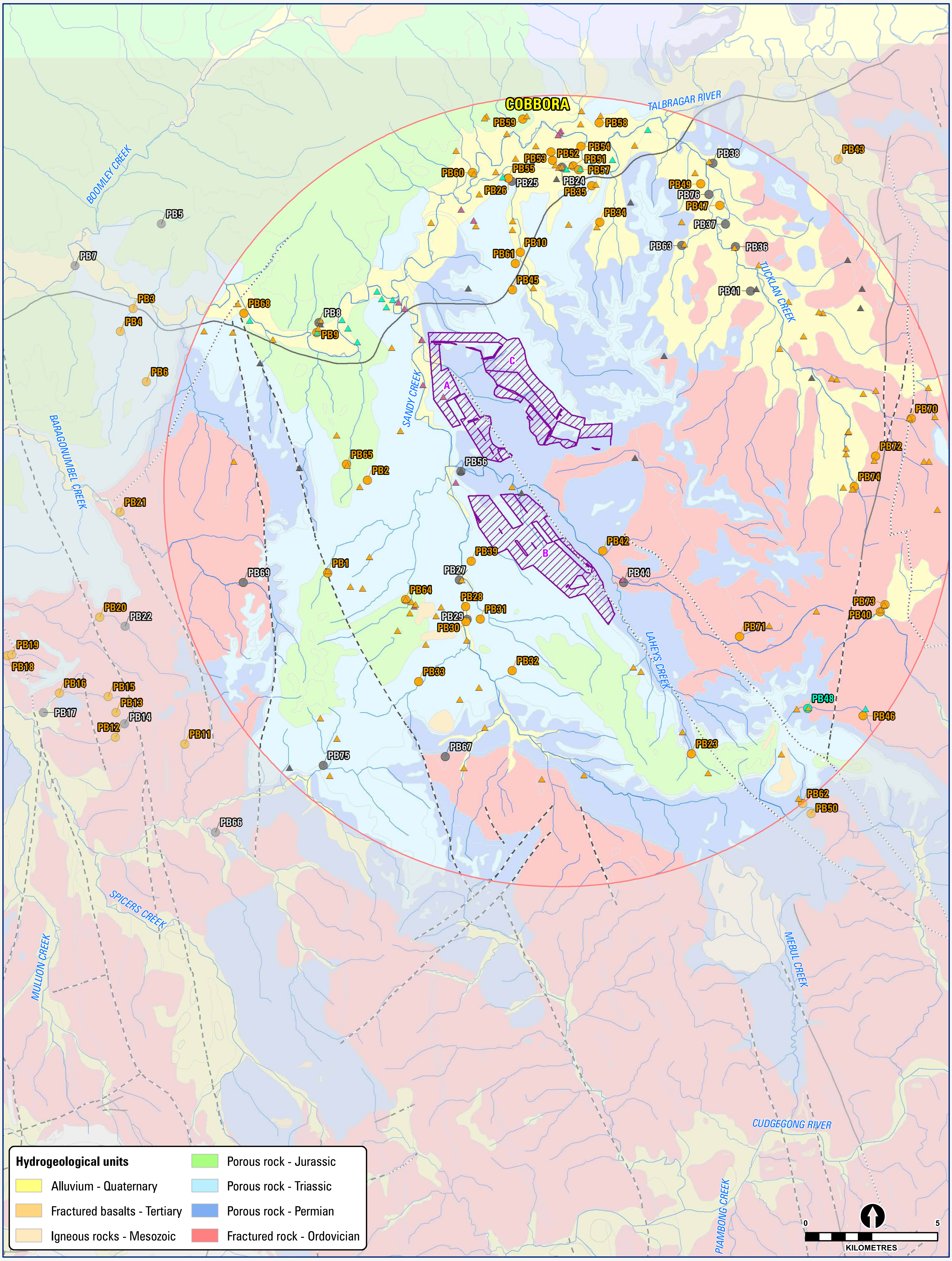

Registered groundwater bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed groundwater bores
- Stock/domestic
- Irrigation
- Not known

- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas

Figure 4.1 Groundwater bores

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