Appendix

H

Groundwater Model Technical Report

PRC_5714C_2162570A_Appendix H

Cobbora Coal Project Groundwater Model

Technical Report

September 2012

Cobbora Holding Company Pty Limited

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A+ GRI Rating: Sustainability Report 2010

Revision	Details	Date	Amended By
00	Draft for EMM/CHC review	4 May 2012	Malcolm Graham
A	Final draft for adequacy	28 June 2012	Leah Gleeson
B	Final for public exhibition	14 September 2012	Liz Webb

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Approved by: Stuart Brown..

Signed: ....

Date: 18 September 2012..

Distribution: ....

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Glossary

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.
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, storativity or recharge.
Drawdown	Lowering of the water table in an unconfined aquifer or the potentiometric surface of a confined aquifer.
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.
Groundwater	Water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.

Groundwater age	The amount of time which has passed since groundwater was recharged to an aquifer as rainfall or via infiltration from surface water bodies.
Groundwater flow	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.
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.
Parameterisation	The process of defining the parameters necessary for the specification of a model.
Permeability	Property or capacity of a porous rock, sediment, clay or soil to transmit a fluid. Measures the relative ease of fluid flow under unequal pressure. Hydraulic conductivity is a material's permeability to water at the prevailing temperature.
Permeable material	Material that permits water to move through it at perceptible rates under the hydraulic gradients normally present.
Piezometer (monitoring well)	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.
Potentiometric surface	Surface to which water in an aquifer would rise by hydrostatic pressure.
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 capacity of the bore and the hydraulic characteristics of the aquifer.
Recharge	Process that replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water entering the water table or exposed aquifers; addition of water to an aquifer.
Recovery	Difference between the observed water level during the recovery period after pumping stops and the water level measured immediately before pumping stopped.

Saturated zone	Zone in which the voids in the rock or soil are filled with water at a greater pressure 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.
Slug test	A hydraulic test in which a small volume (or slug) of water is suddenly removed from a well, or a small volume of water or material is added to the water column in the well. The water level response in the well over time is used to estimate the transmissivity or hydraulic conductivity of the aquifer.
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 and 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; (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 few feet 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

Parsons Brinckerhoff was commissioned to undertake a groundwater assessment for the proposed Cobbora Coal Project (the Project). The objective of the groundwater assessment is to identify and quantify the potential impacts of the proposed mining operation on the groundwater regime, and to propose mitigation and contingency measures, where applicable, for those impacts that are likely to be unacceptable.

A numerical model was developed to provide a quantitative assessment of impacts from the proposed mining operation. The three-dimensional finite difference model was created using the Groundwater Vistas pre-processor. MODFLOW (McDonald & Harbaugh 1988) was used in conjunction with MODFLOW-SURFACT^{TM} (version 3) to allow for saturated and unsaturated flow conditions. The model is of moderate complexity and is suitable for predicting the impacts of the proposed operations and post-mining recovery, consistent with the 'impact assessment' class described by the Murray Darling Basin Commission (MDBC 2001), and is consistent with the national guideline (Barnett et al, 2012). The main aspects of model development are summarised below:

- The numerical groundwater model was based on the conceptual model Parsons Brinckerhoff (2012a) developed for the assessment area. The conceptual model builds on work by Parsons Brinckerhoff and others, and includes data collected during 2010–2011 as part of an extensive groundwater monitoring and testing program.

- The model was calibrated to baseline groundwater conditions using available groundwater monitoring information. Calibration was carried out in two stages with the assistance of automated parameter estimation software. First, a steady state model was developed to simulate average long-term conditions within the assessment area. Second, a transient calibration was carried out to further refine key model parameters, particularly in respect of the model's ability to simulate the effects of changes in groundwater flows arising from variations in rainfall between March 2010 and August 2011. Calibration of the model achieved a normalised root mean square error of 2.65% and 2.43% respectively for the steady state and transient runs. This is well within the target value of 5% agreed with the independent reviewer, Dr Noel Merrick.

- Sensitivity analyses carried out on both the steady state and transient models indicate that model calibrations are relatively insensitive to the majority of the input parameters. The model is most sensitive to the horizontal conductivity of the Digby Formation, Whaka Formation, Ulan Coal Seams and Dapper Formation and also storage and recharge in the Digby Formation. The results were used to make further refinements to estimates of model input parameters.

The calibrated model was developed further, to allow a predictive simulation of mine inflow rates and changes in groundwater level over time. The proposed mine plan, provided by Cobbora Holding Company Pty Limited (CHC), was represented in the model by drain cells, which were active only during the period of excavations in that area of the mine and for one year afterwards, prior to backfilling. The recharge and hydraulic properties assigned to the backfill material were based on work by Mackie (2009), using the transient material properties capability in MODFLOW-SURFACT. Following the cessation of proposed mining activities, the model simulates the residual mine void. In all other excavated areas, backfill material has been simulated. The model records simulated flows and groundwater levels four times each year during the life of the mine, and at yearly intervals for a further 50 years after cessation of the proposed mining operations.

The results of the predictive modelling are summarised as follows:

- Mine inflow rates are predicted to peak at 1,775 megalitres per annum (ML/a) after 16 years of mining, with dewatering rates of approximately 1,000 ML/a or more between 6 and 16 years after mining commences. Approximately half of all mine inflows are expected to occur in mining area B.
- The Ulan and Dapper formations (Permian-Triassic porous rock aquifer) are expected to provide the greatest volume of water to the mine pit, with predicted cumulative storage losses of up to 2,000 ML in each by the end of mining (2035).
- Predicted cumulative storage losses within the alluvium reach a maximum value of nearly 300 ML. This constitutes 0.1% of the estimated 220,000 ML (220 GL) of available groundwater storage in the alluvium aquifer within the model domain.
- The model results indicate a maximum reduction in river flows of approximately 280 ML/a, which occurs towards the end of mining operations. This constitutes 0.5% of the average annual flow in the Talbragar River.
- Of the private bores assessed in the assessment area (Parsons Brinckerhoff 2012a) only six private bores are expected to experience drawdown of more than 2.5 m during the life of the mine, five of which are on CHC owned land. CHC will continue to model and monitor groundwater during and after the life of the mine. If a bore not owned by CHC is significantly affected, CHC will address the issue at its own cost.

Sensitivity analysis was conducted on the model to assess the effects of uncertainties in aquifer properties on model predictions. As the Ulan Formation is expected to be the biggest contributor of inflows to the pit, a sensitivity analysis was run based on the horizontal hydraulic conductivity of this unit being increased from 0.3 m/d to 0.8 m/d (vertical hydraulic conductivity increased from 0.003 m/d to 0.008 m/d). Under this scenario, the predicted mine inflow rates may be higher over the period of peak groundwater inflow between 2021 and 2031.

The groundwater model and draft Groundwater Model Technical Report were externally reviewed by Dr Merrick (Heritage Computing) in February 2012. Comments from the review were addressed in the final model and incorporated into this report.

1. Introduction

Parsons Brinckerhoff was commissioned by Cobbora Holding Company Pty Limited (CHC) to undertake a groundwater assessment for the proposed Cobbora Coal Project (the Project).

Parsons Brinckerhoff developed a groundwater numerical model to provide a qualitative assessment of impacts from the proposed mining operation. The model and draft report were externally reviewed by Noel Merrick (Heritage Computing) in February 2012. Comments from the review are provided in Appendix I of *Cobbora Coal Project - Groundwater Assessment* (Parsons Brinckerhoff 2012a) and were addressed in the final model. The results from the final model are reported in this document.

A summary of the hydrogeological conceptual model developed for the assessment area is presented in this document. A more detailed description of the conceptual model is provided in the main body of the *Cobbora Coal Project - Groundwater Assessment* (Parsons Brinckerhoff 2012a).

2. Data analysis and hydrogeological setting

2.1 Setting

A map of the assessment area and the extent of the groundwater model are shown in Figure 2.1. A detailed description of the hydrological, geological and hydrogeological features of the assessment area is provided in the *Cobbora Coal Project - Groundwater Assessment* (Parsons Brinckerhoff 2012a). A summary of these features is presented in Figure 2.3.

2.1.1 Hydrological catchment

The assessment area is located within the Sandy Creek and Laheys Creek catchments, which are subcatchments of the Talbragar River, which in turn is a subcatchment of the larger Macquarie–Bogan River catchment. The Sandy Creek and Laheys Creek catchments cover an area of 282 km^2.

2.1.2 Topography and land use

The topography of the site is undulating to hilly, with elevations of approximately 320 m Australian Height Datum (AHD) to the north-west of the assessment area, rising to approximately 660 m AHD at the south-eastern end of the assessment area. The site is drained by the northerly flowing Sandy Creek and Laheys Creek. The creeks converge within the Project footprint and flow north to the Talbragar River, which forms the northern extent of EL7394.

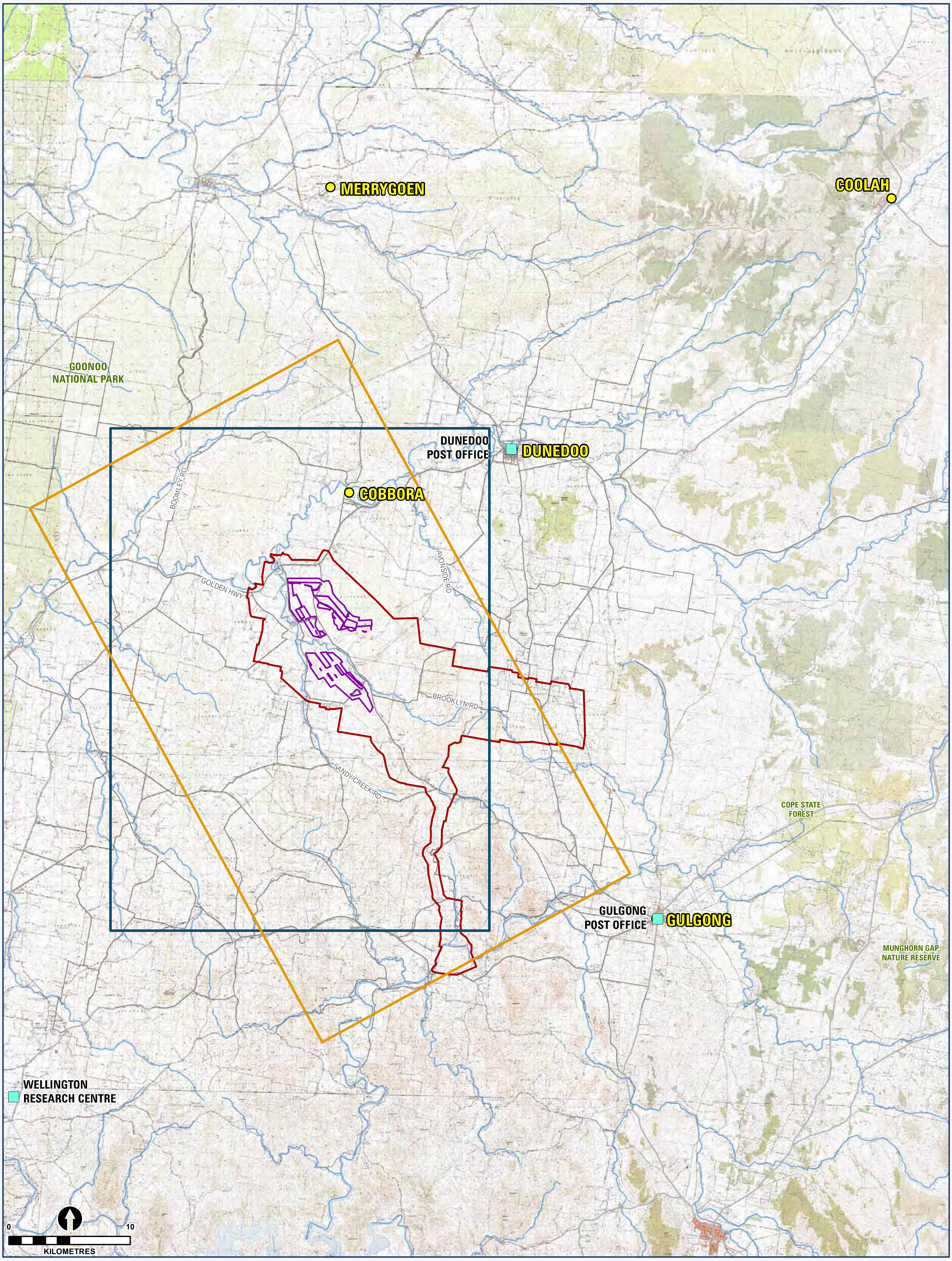
The assessment area is mostly cleared and used for agricultural purposes, including grazing sheep and cattle, and cultivating cereal crops. Only 6% of the total area contains areas of conservation, state forest and national park (ERM 2009), including the Goodiman State Conservation Area, Dapper Nature Reserve, Tuckland State Forest and the Yarrobil National Park (M Branson, pers. comm. 28 May 2010).

2.1.3 Geology

The assessment area is located within the south-western portion of the Gunnedah Basin, in the Gilgandra Trough, to the west of the Western Coalfield. The Gunnedah Basin contains a sequence of marine and non-marine Permian and Triassic sediments, and is an important Permian coal-bearing basin. The Project's target geology is the coal-bearing sequences of the Late Permian Dunedoo Formation. The Gunnedah Basin units within the assessment area are underlain by Silurian and Devonian units of the Lachlan Orogen.

Jurassic sandstone units of the Surat Basin overlie the Gunnedah Basin and occur on the northern periphery of the assessment area. Quaternary alluvium is present around river floodplains and some larger creeks. A summary table of the stratigraphy, predominantly based on Marston (2009), is shown in Table 2.1. A more detailed representative stratigraphic column for the assessment area is presented in Figure 2.2.

The outcropping geology is presented in Figure 2.3, along with the locations of cross-sections shown in Figure 2.4 to Figure 2.7.



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

Figure 2.1 Site plan and model extent

Topographic map source: NSW Department of Lands, 1989

\\APSYDNAS02\proj\E\EMGA_M_M2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F015_A3.mxd.mxd // CasenasM //23/04/2012

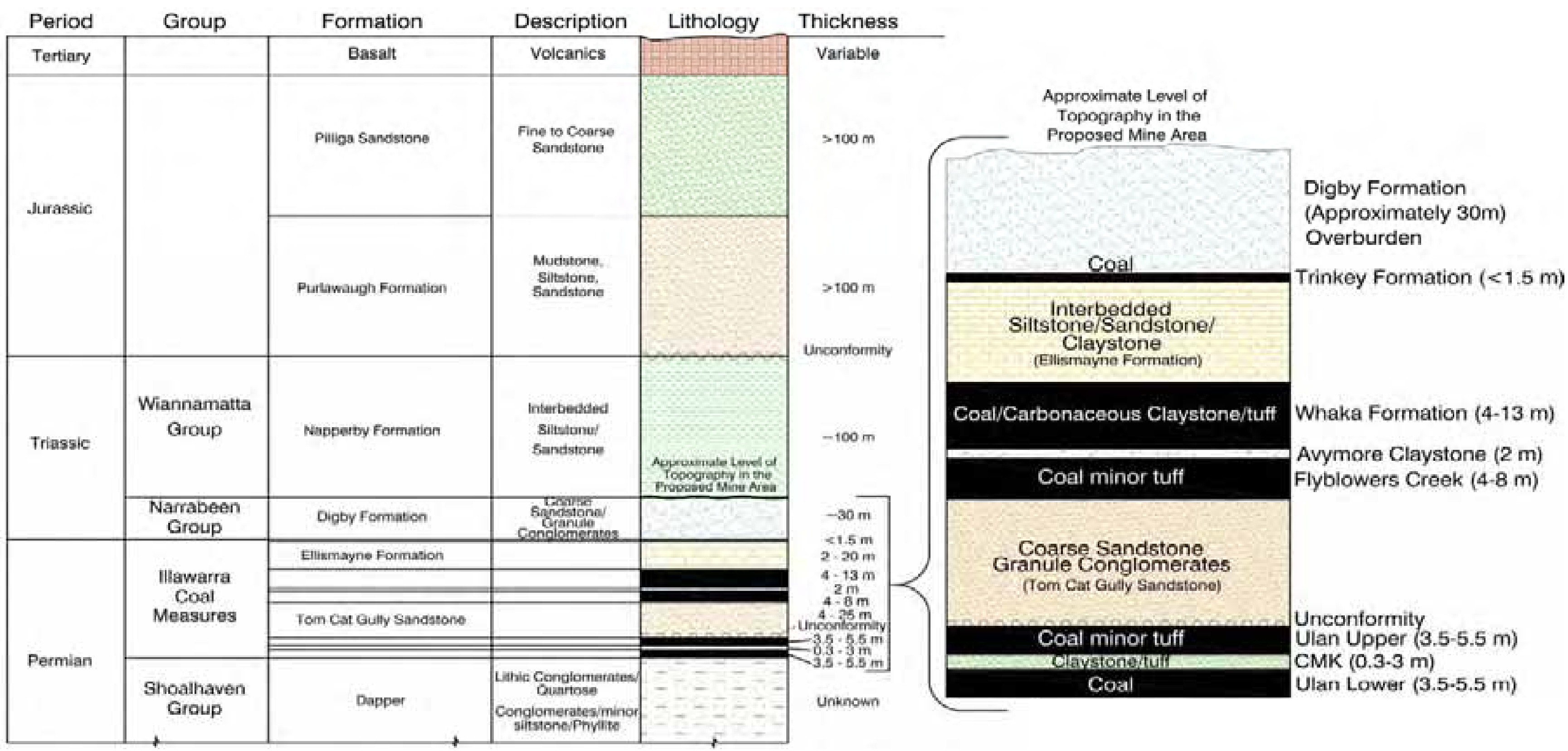


Figure 2-2: Representative stratigraphic column for the Project area (Marston, 2009)

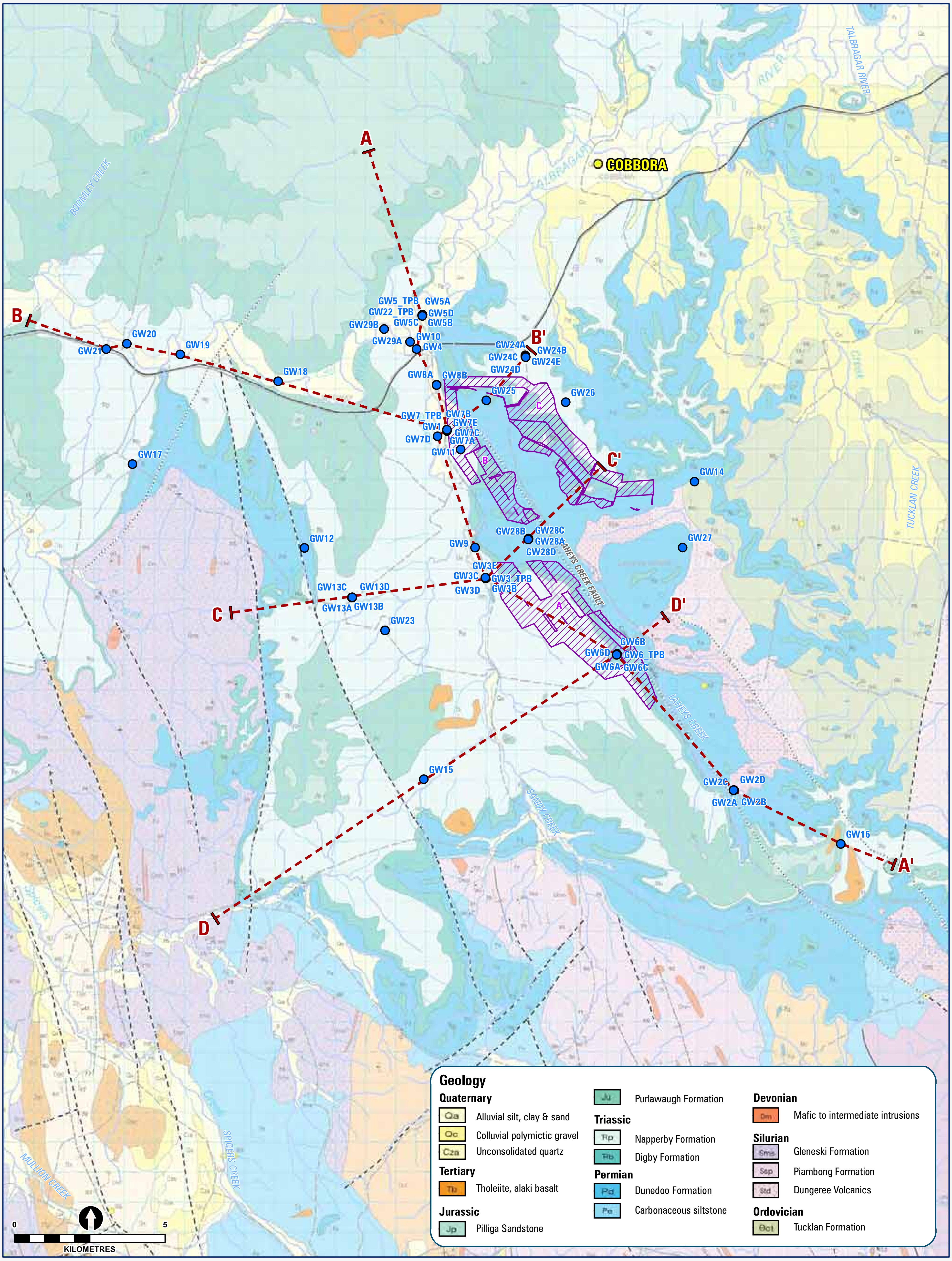
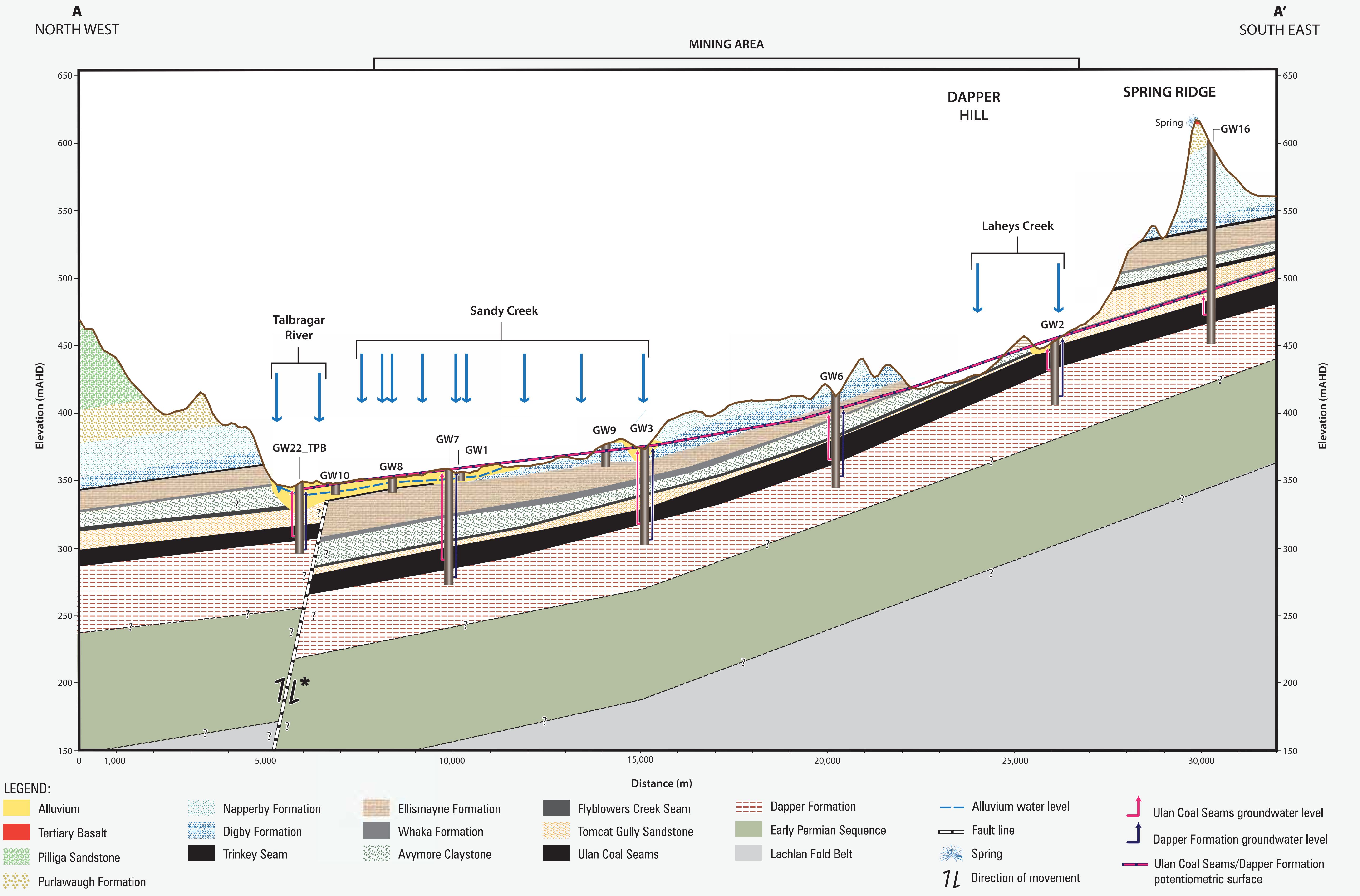


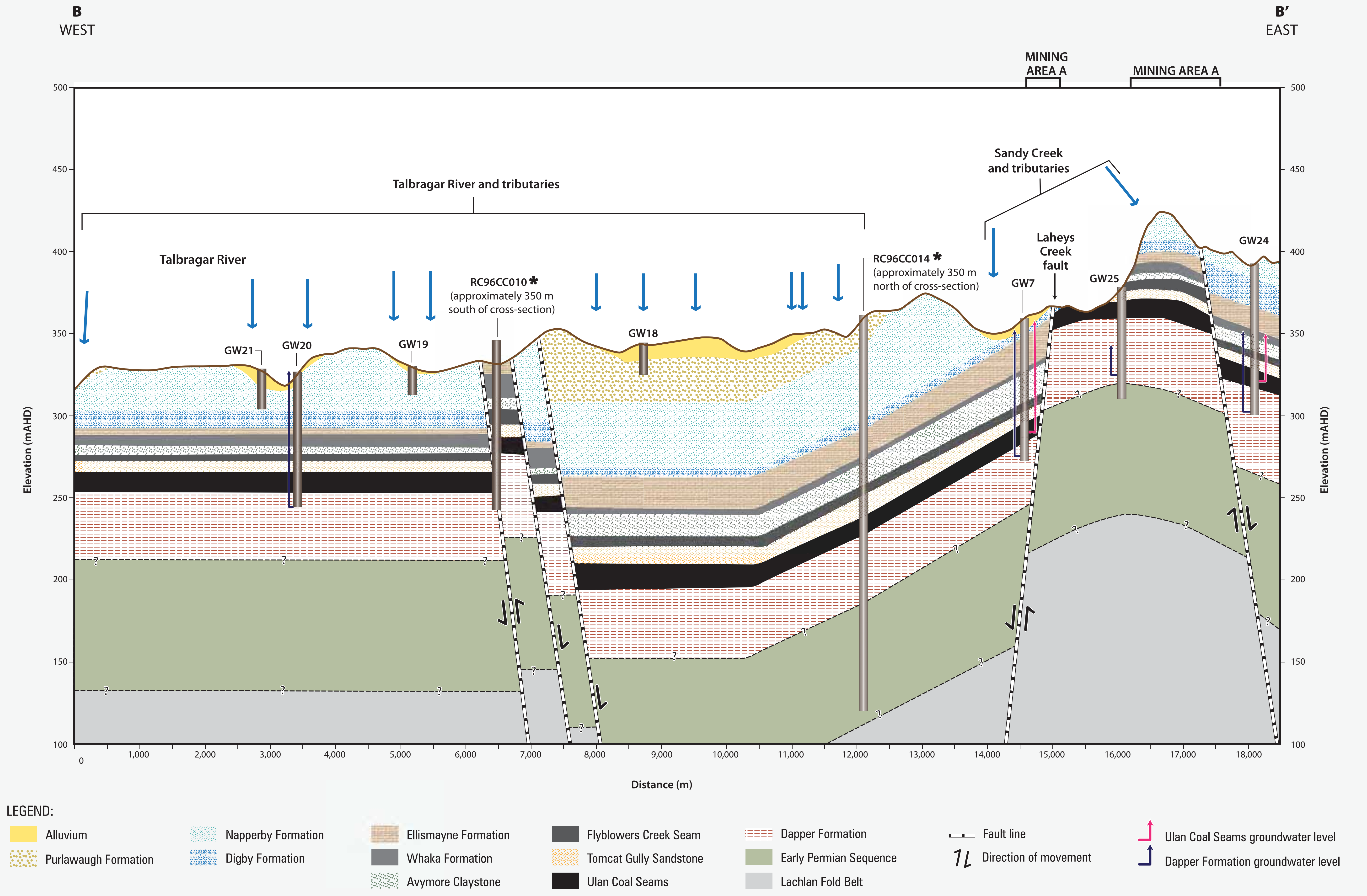
Figure 2.3 Site geology and geological structures

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



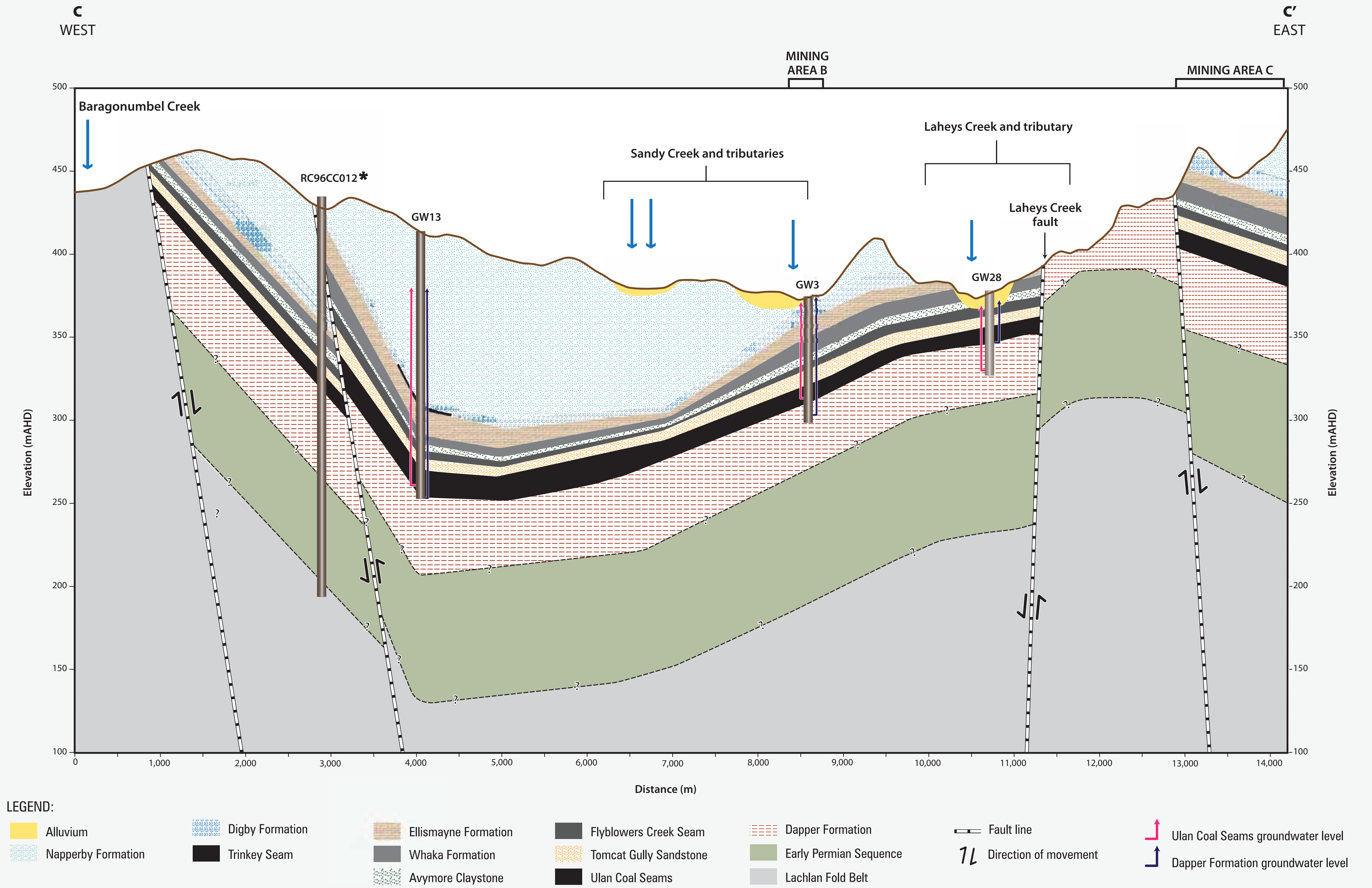
Note: * *Interpreted extension to Laheys Creek fault.*

Figure 2.4 Conceptual hydrogeological cross-section A - A'



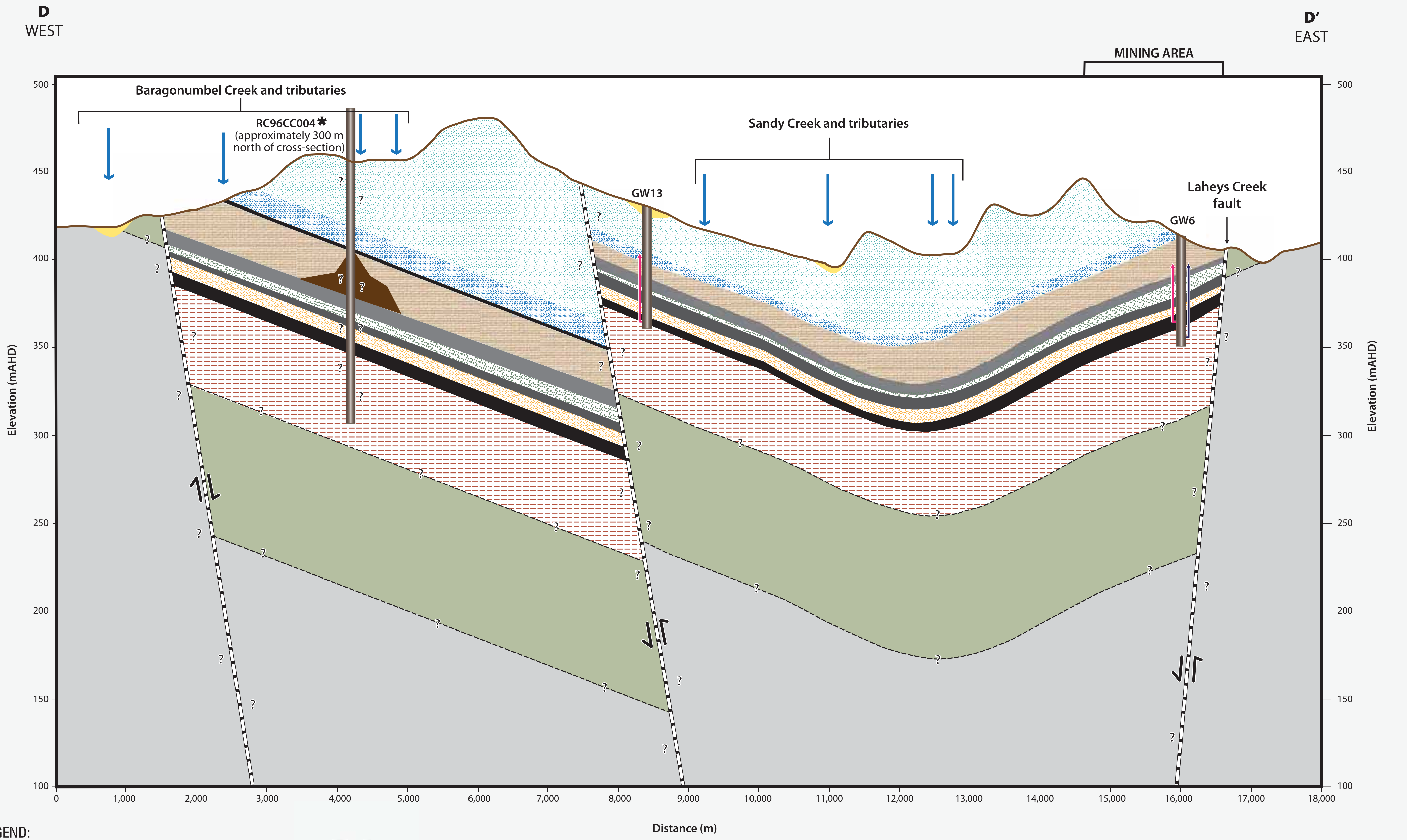
Note: * *RC96CC0** bores were drilled as part of the CRA exploration program (Menpes, 1997)*

Figure 2.5 Conceptual hydrogeological cross-section B - B'



Note: * RC96CC0** bores were drilled as part of the CRA exploration program (Menpes, 1997)

Figure 2.6 Conceptual hydrogeological cross-section C - C'



LEGEND:

- Alluvium
- Napperby Formation
- Digby Formation
- Trinkey Seam
- Ellismayne Formation
- Whaka Formation
- Avymore Claystone
- Flyblowers Creek Seam
- Tomcat Gully Sandstone
- Ulan Coal Seams
- Dapper Formation
- Early Permian Sequence
- Lachlan Fold Belt
- Volcanics
- Fault line
- Direction of movement
- Ulan Coal Seams groundwater level
- Dapper Formation groundwater level

*Note: * RC96CC0** bores were drilled as part of the CRA exploration program (Menpes, 1997)*

Figure 2.7 Conceptual hydrogeological cross-section D - D′

Table 2.1 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 28 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 stony 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
Silurian	Mumbil Group	Glenski Formation	Felsic to rhyolitic tuff and tuffaceous sedimentary rocks	Unknown	

Period	Group	Formation	Description	Thickness	Gunnedah Basin nomenclature
	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	

The Project is situated in an area of complex geology at the boundary between the Gunnedah Basin and the Lachlan Orogen. The Laheys Creek Fault intersects the assessment area on the eastern side trending north-north-west, with another unnamed fault trending parallel to and about 8–9 km to the west of the Laheys Creek Fault.

2.2 Available data

2.2.1 Pre-existing data

Prior to the commencement of baseline data collection for the current Project, the following data sources were available:

- NSW Office of water (NOW) database, providing borehole logs with lithological data and historical groundwater levels.
- Borehole logs and a digital elevation model of surface topography (20 m resolution) provided by Marston mining consultants.
- Geological maps of the area, produced by the Geological Survey of NSW — 1:100,000 scale (Meakin et al. 1999) and 1:250,000 scale (Meakin & Morgan 1999).
- Bureau of Meteorology weather stations; 062013 Gulgong (BoM 2011a) and 064009 Dunedoo (BoM 2011b) near the assessment area, providing rainfall data from 1881 to the present day. These have been supplemented by data collected at the site since February 2009.
- Bureau of Meteorology weather station 065035 (Wellington), providing evaporation data from 1965 to 2005.

2.2.2 Data collected as part of the current study

The following key information was obtained during the course of the current study and considered during development of the groundwater model:

- proposed mine plan provided by CHC (2011)
- pumping test data from tests carried out between October 2009 and December 2011
- slug test data from tests carried out in November 2011

- lithological and packer test data from drilling conducted between August 2009 and December 2011
- groundwater levels from October 2009 onwards.

A more detailed description of Parsons Brinckerhoff's field program and the data collected is provided in the accompanying *Cobbora Coal Project - Groundwater Assessment* (Parsons Brinckerhoff 2012a).

2.3 Pre-existing conceptual model of the groundwater system

An integrated study of geophysical, geological, hydrogeochemical and hydrogeological data in the Gunnedah Basin, conducted by Schofield and Jankowski (2003), suggests that both regional and local groundwater systems operate in the assessment area. The study suggests that the local groundwater system, which exists within the Permian to recent geological strata, can be divided into deep, intermediate and shallow components.

The deep component is conceptualised as being dominated by fracture flow, and (locally) under artesian pressure, extending from the early Permian units to the base of the Napperby Formation (see Table 2.1).

The intermediate component is conceptualised as a leaky aquitard that acts as a mixing zone between the deep and shallow parts of the system, extending from the Napperby Formation to the top of the Purlawaugh Formation.

The shallow component is present within the Quaternary sediments and Jurassic Pilliga Sandstone. The conceptual model suggests that groundwater within the shallow component is controlled by the influx and lateral migration of surface waters. Groundwater within the regional system, as proposed by Schofield and Jankowski (2003), is controlled by the fabric of Palaeozoic basement rocks, and is inferred to flow towards the north-west.