APPENDIX D

Groundwater assessment (Part A)

Cobbora Holding Company Pty Limited

EMM EMGA Mitchell McLennan

Cobbora Holding Company Pty Limited

Cobbora Coal Project Groundwater Assessment

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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 (^2H)	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 (^2H) 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 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 have been estimated based on the numerical modelling results. The peak groundwater inflows are 1,775 ML/a, at year 2031. If aquifer permeability is more than doubled to test model sensitivity, the peak inflow is an additional 47%. CHC has commenced the process of acquiring sufficient water access licences from the water trading market to account for the 1,775 ML/a. This will consist of 280ML/a from the Talbragar River, with the remaining 1,495 ML/a coming from the Gunnedah-Oxley Basin MBD Groundwater Source. As of August 2012, CHC holds two groundwater access licences with a combined associated volumetric entitlement of 538 ML for the Gunnedah-Oxley Basin MDB Groundwater Source. The availability of licences to trade from within the Gunnedah-Oxley Basin MDB Groundwater Source is high, with an additional 15,659 ML across approximately 115 Water Access Licences with which to source the remaining 957 ML. In addition, the approximate volume of unassigned water in the Gunnedah-Oxley Basin MBD Groundwater Source is high, at approximately 177,806 ML/a. At this stage no licence entitlements for the extraction of water from the main stream of the Lower Talbragar River have been purchased. However, there is a combined 1,279 ML held across approximately 23 WALs in the Lower Talbragar River Water Source and the Upper Talbragar River Water Source. The CHC licensing requirement from the Talbragar River will consist of up to 280 ML/a which is approximately 22% of the total entitlement. The trading markets associated with the respective Talbragar River water sources have historically been limited. CHC intends to enact a strategy of direct engagement with WAL holders to ensure the required licences are obtained.

Modelled groundwater inflows to the mining areas are expected to lead to maximum lowering of the water table of up to 85 m in mining area B. The 1 m drawdown contour is predicted to extend up to 5 km to the south of the mining areas and nearly 4 km to the west. Drawdown to the north and east is far less extensive, with the 1 m drawdown contour predicted to lie within 3 km of the mining areas.

The predicted cumulative storage losses within the alluvium could reach a maximum value of approximately 300 megalitres (ML), which constitutes only 0.1% of the estimated 220,000 ML (220 gigalitres (GL)) of available groundwater storage in the alluvium aquifer within the model domain.

Drawdown is predicted to extend over a greater area in the Ulan Coal Seams than in the water table aquifer. The 1 m drawdown contour is predicted to lie approximately 5 km to the west of mining areas A and B. The extent of drawdown 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 six private groundwater bores that will experience drawdown greater than 2.5 m during mining. Five of these six bores are owned by CHC, the other private bore shows a maximum drawdown of 2.9 m. Therefore impacts to third-party bores are considered negligible. 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 of approximately 280 ML/a, which occurs towards the end of mining. The impact is considered small in relation to flows in the Talbragar River, representing only 0.5% 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.

Modelling has indicated that post mining, the hydraulic gradient will be towards the alluvium to the west and north-west of the mining areas. Mitigation measures include rehabilitating the final landform to reduce the potential for groundwater and surface water salinisation by limiting the accumulation of surface water and managing waste material to avoid potential acid mine drainage. The final landform includes a lake in the southern area of Pit B, and groundwater in the vicinity flows towards the Pit B Lake over the longer term.

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.

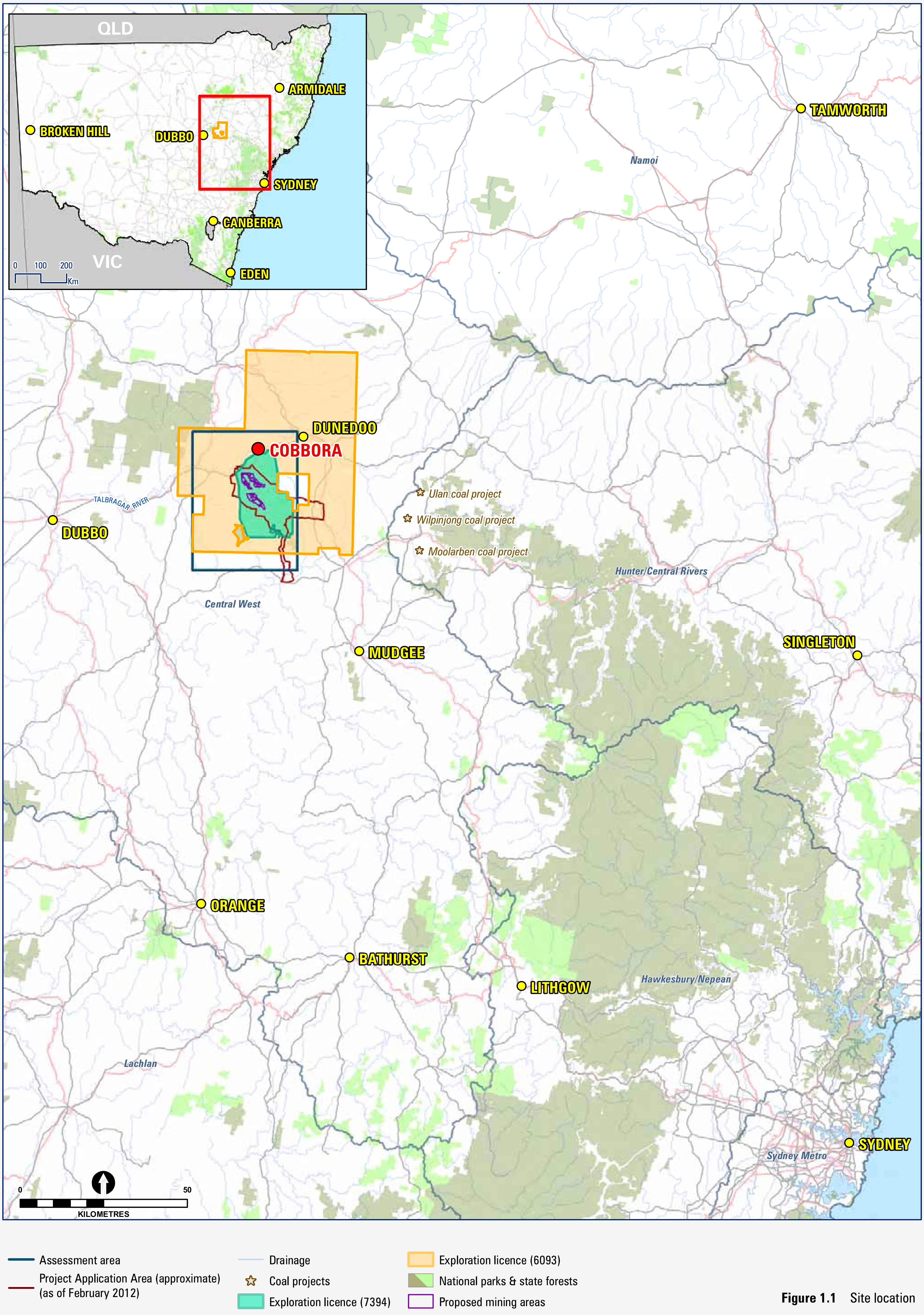


Figure 1.1 Site location

1.1.2 Open-cut mine

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

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

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

- AC-OOP between mining areas A and C
- B-OOP E adjacent to mining area B on the east side of Laheys Creek
- 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:

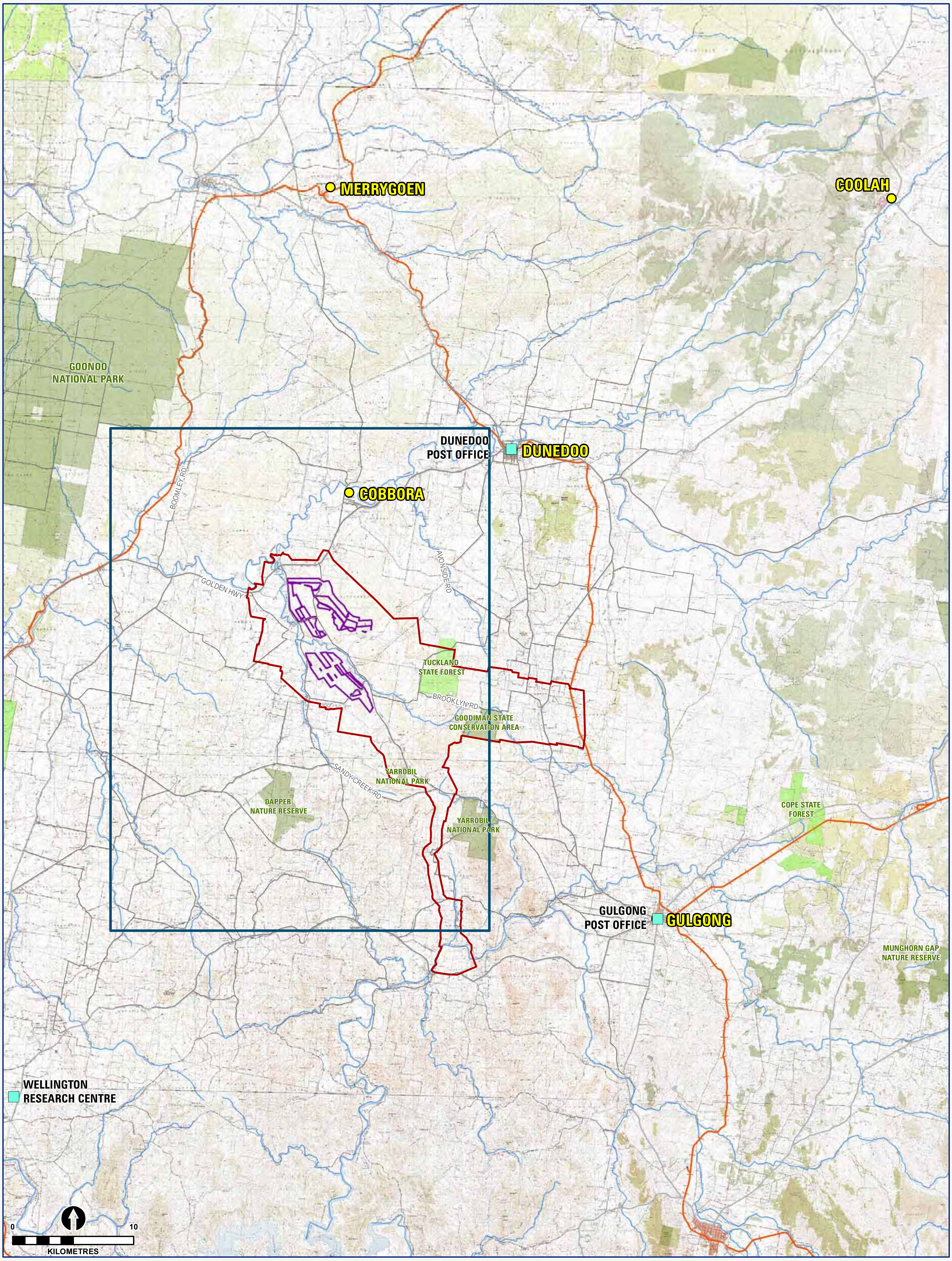
- to identify and assess potential impacts on groundwater from the development of the Project
- to satisfy the DGRs relevant to groundwater impacts
- to inform the wider community about the project and its potential impacts on the local and regional groundwater environment.

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.



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

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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)	5,778
Native title	0
Aquifer access licences	16,197
Total water requirements[1]	22,087
Unallocated water[2]	177,806 (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:

- NSW State Groundwater Quantity Management Policy (DLWC 2001 (Unpublished)).
- NSW State Groundwater Quality Protection Policy (DLWC 1998).
- 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.

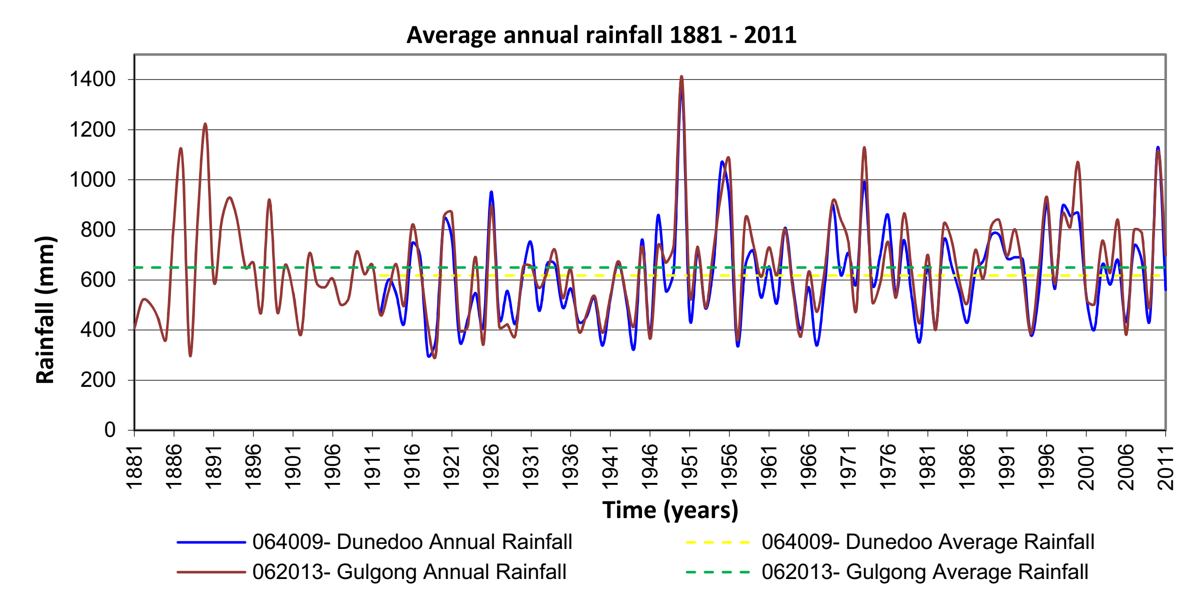
The Talbragar River, Sandy and Laheys Creek are naturally ephemeral waterways and cease to flow during dry periods. There are no headwater storages to regulate flows and therefore all flows are a direct reflection of rain events, groundwater baseflows and evapotranspiration processes.

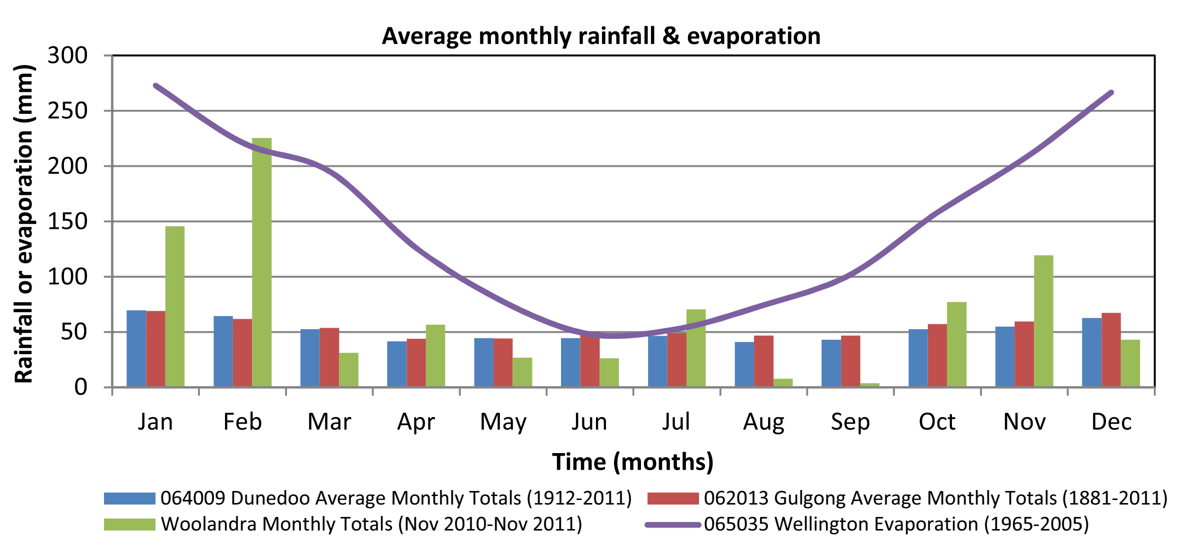
Laheys Creek is a small, densely vegetated channel over most of its length. Upstream of its confluence with Laheys Creek, Sandy Creek is a sandy, grassed channel with evidence of bank erosion. Downstream of the confluence Sandy Creek widens to become a broad, flat channel that is heavily vegetated with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





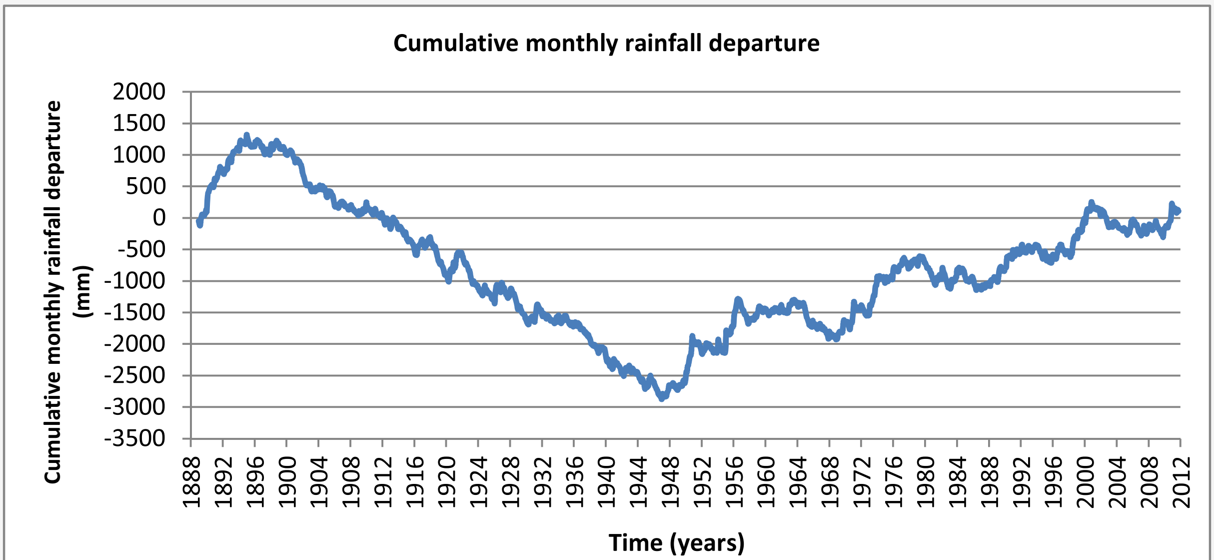


Figure 3.1 Climate information

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

The Salinity Risk Assessment of the Central West Catchment (Humphries 2000) describes the salinity hazard rating of the Lower Talbragar catchment as ‘very high’. The Project is located within a subcatchment of the Lower Talbragar, but has relatively low salinity 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 Lower Talbragar 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 only the Triassic and Permian rocks within the Sandy and Lahey’s Creeks subcatchments and not the Lachlan Orogen metasediments and therefore the salinity risk is considered much lower in this particular area of the Lower Talbragar catchment.

3.6 Geology

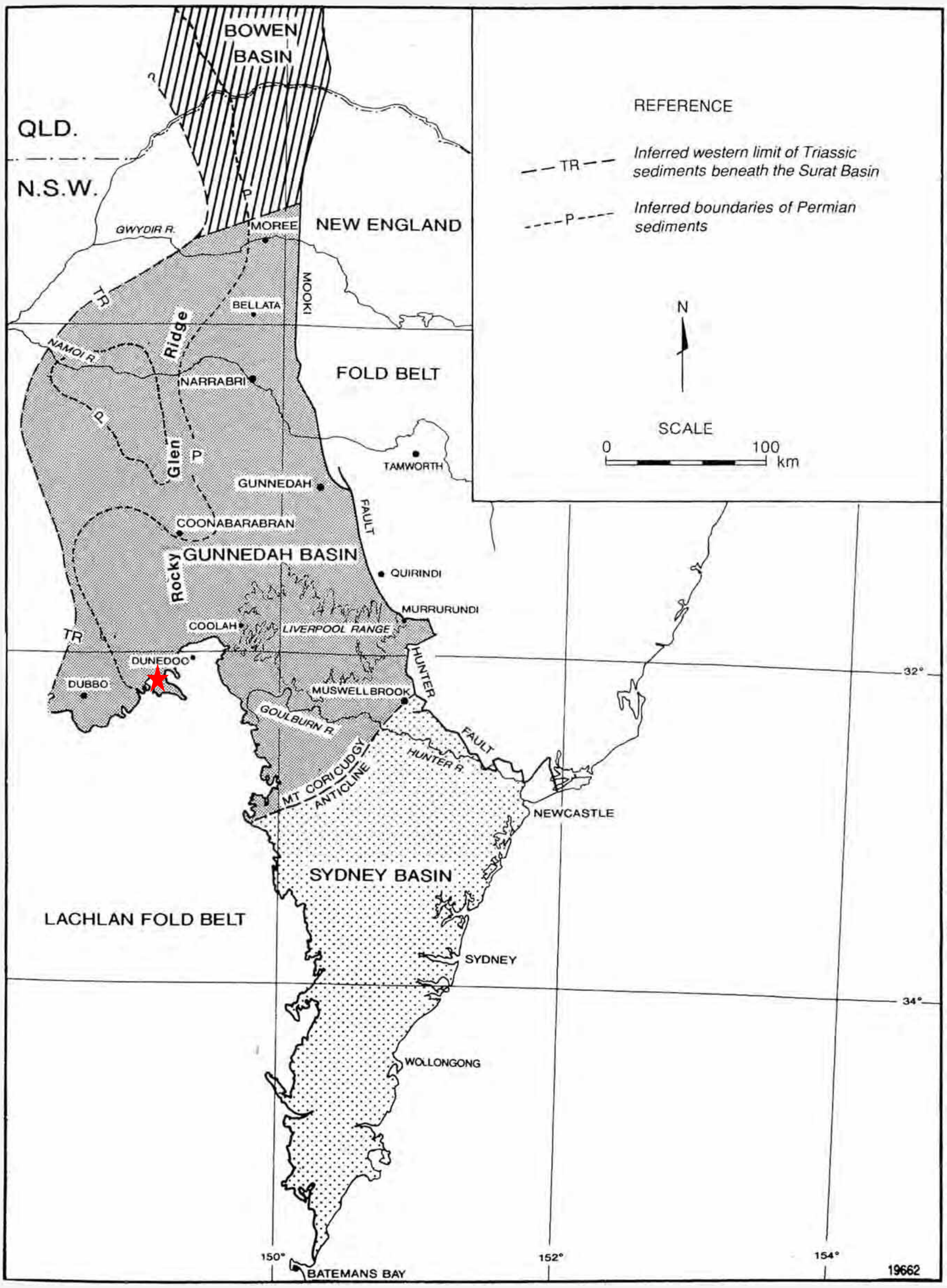
3.6.1 Regional geology

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 3.2.

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 3.2 Regional geology

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
Devonian		Basalt	Mafic to intermediate intrusions	unknown	Basalt

Period	Group	Formation	Description	Thickness	Gunnedah Basin nomenclature
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 3.3.

3.6.3 Geological structure

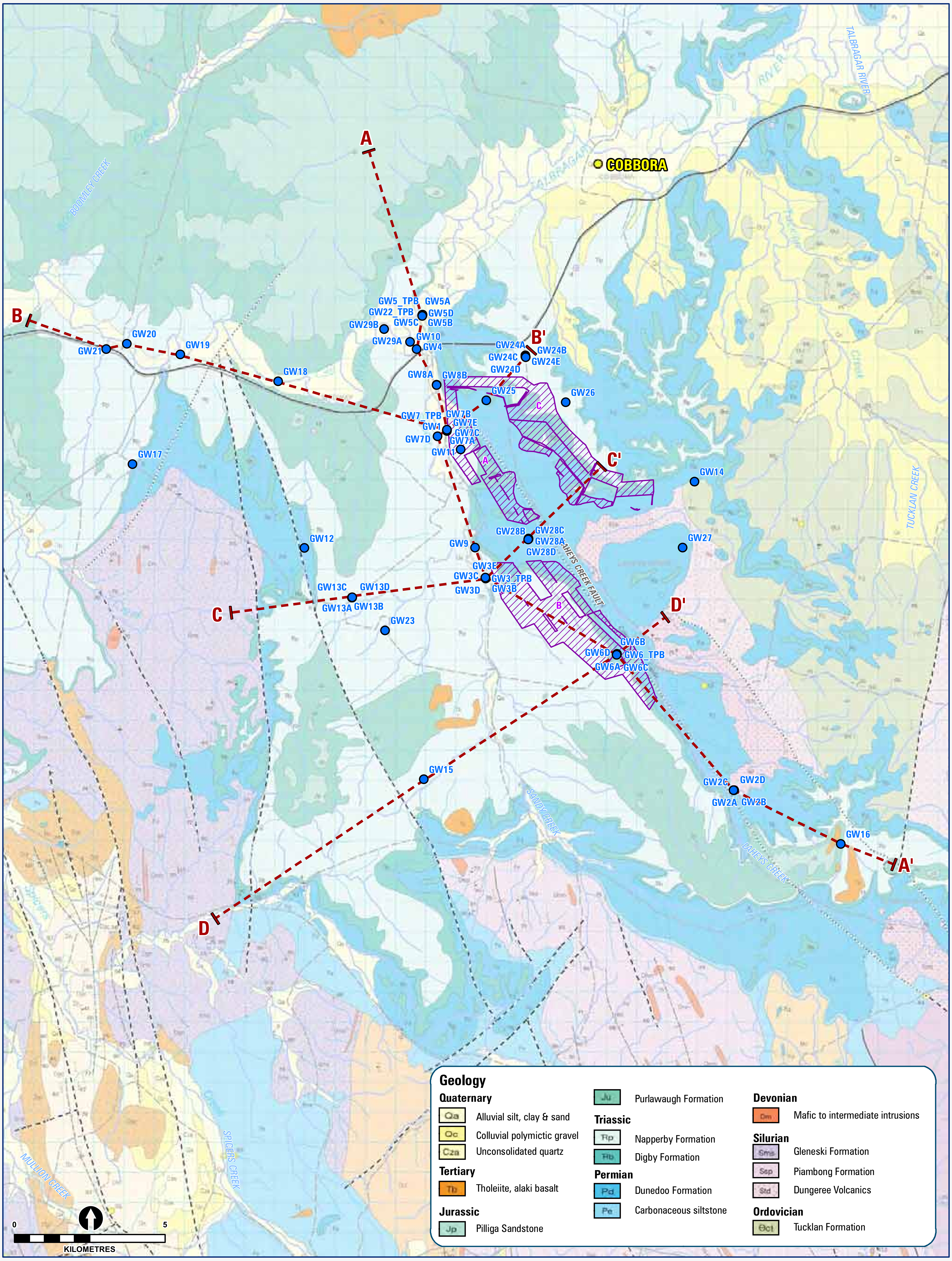
The basement rocks of the Lachlan Fold Belt are located within the Hill End Synclinal Zone, between the Cowra and Capertee Zones (Meakin & Morgan 1999). The strata of the Hill End Zone are characterised by open south-plunging, north to north-northwest trending folds and faults.

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

Figure 3.3 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:

- 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.

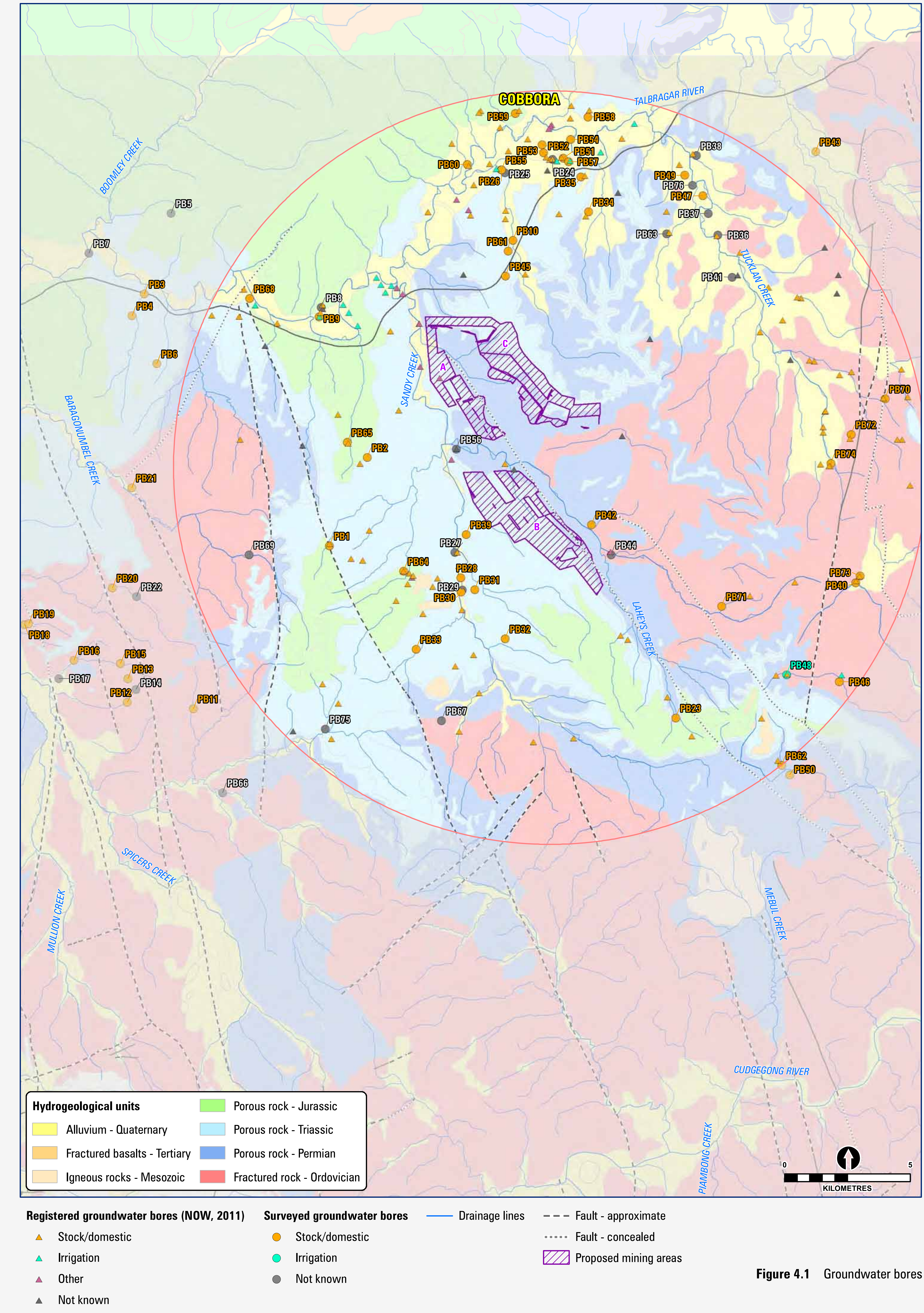

Figure 4.1 Groundwater bores

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5. Hydrogeology

5.1 Overview

The geological units and provinces that occur in the Project area and surrounds underpin the understanding of the hydrogeology in the assessment area. This section of the report:

- Identifies and discusses New South Wales Office of Water (NOW) groundwater sources and the hydrogeological units (Figure 5.1) within these categories, and discusses the more detailed aspects of the hydrogeology within these broad categories.
- Details the methods for acquiring hydrogeological data and the results and analysis of the data.
- Provides an assemblage of the data and hydrogeological principles to present the conceptual hydrogeological model for the assessment area.

5.2 NOW — Groundwater sources

NOW has categorised the groundwater sources in NSW based on a combination of large scale geological and hydrogeological mapping and geological descriptions. The water source boundary map is presented in Figure 5.1 for the assessment area. The water source boundaries are described in detail within three separate water sharing plans: Water Sharing Plan for the NSW MDB Porous Rock Groundwater Sources (NOW 2011b), the Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources (NOW 2008) and the Water Sharing Plan for the NSW MDB Fractured Rock Groundwater Sources (NOW 2011c).

Within the immediate vicinity of the Project area the groundwater source areas defined by NOW are:

- **Gunnedah-Oxley Basin MDB Groundwater Source**. This water source includes the Permian, Triassic, Jurassic, Cretaceous and Tertiary rocks within the boundary presented in Figure 5.1 as outlined in Part 1, clause 4, subclause 3 (a) in the Water Sharing Plan for the MDB Porous Rock Groundwater Source (NOW 2011b).
  The boundary illustrated in Figure 5. is indicative and all Permian, Triassic and outlier Jurassic rocks south of the Talbragar River are considered to be within the Gunnedah–Oxley Basin water source for the purpose of water management and licensing. It should be noted that the Gunnedah-Oxley Basin water source also includes the alluvium within the assessment area Part 1, clause 4, subclause 3 (b).
- **Talbragar Alluvial Groundwater Source**. The Talbragar River alluvium approximately 5 km upstream of the assessment area is managed as an independent groundwater source. The Talbragar Alluvial Groundwater Source is detailed in the Draft Water Sharing Plan for the Macquarie Bogan Unregulated and Alluvial Water Sources (NOW 2011a). The alluvium within this groundwater source is managed separately to the alluvium immediately adjacent to the Project area. NOW incorporates the alluvium associated with the Sandy Creek, Laheys Creek and the Talbragar River adjacent to the proposed mine site as part of the Gunnedah-Oxley Basin Groundwater Source (see dot point above).
- **Great Artesian Basin Groundwater Sources**. The NOW boundary for the GAB includes the significant areas of Jurassic rocks to the north of the Talbragar River. The isolated deposits of Jurassic rocks occurring south of the Talbragar River are included in the Gunnedah-Oxley Basin Groundwater Source (see first dot point).

- **Lachlan Fold Belt MDB Groundwater Source**. In the vicinity of the Project area the Lachlan Fold Belt Groundwater Sources include groundwater associated with the Devonian, Silurian and Ordovician rocks surrounding and underlying the Gunnedah-Oxley Basin.

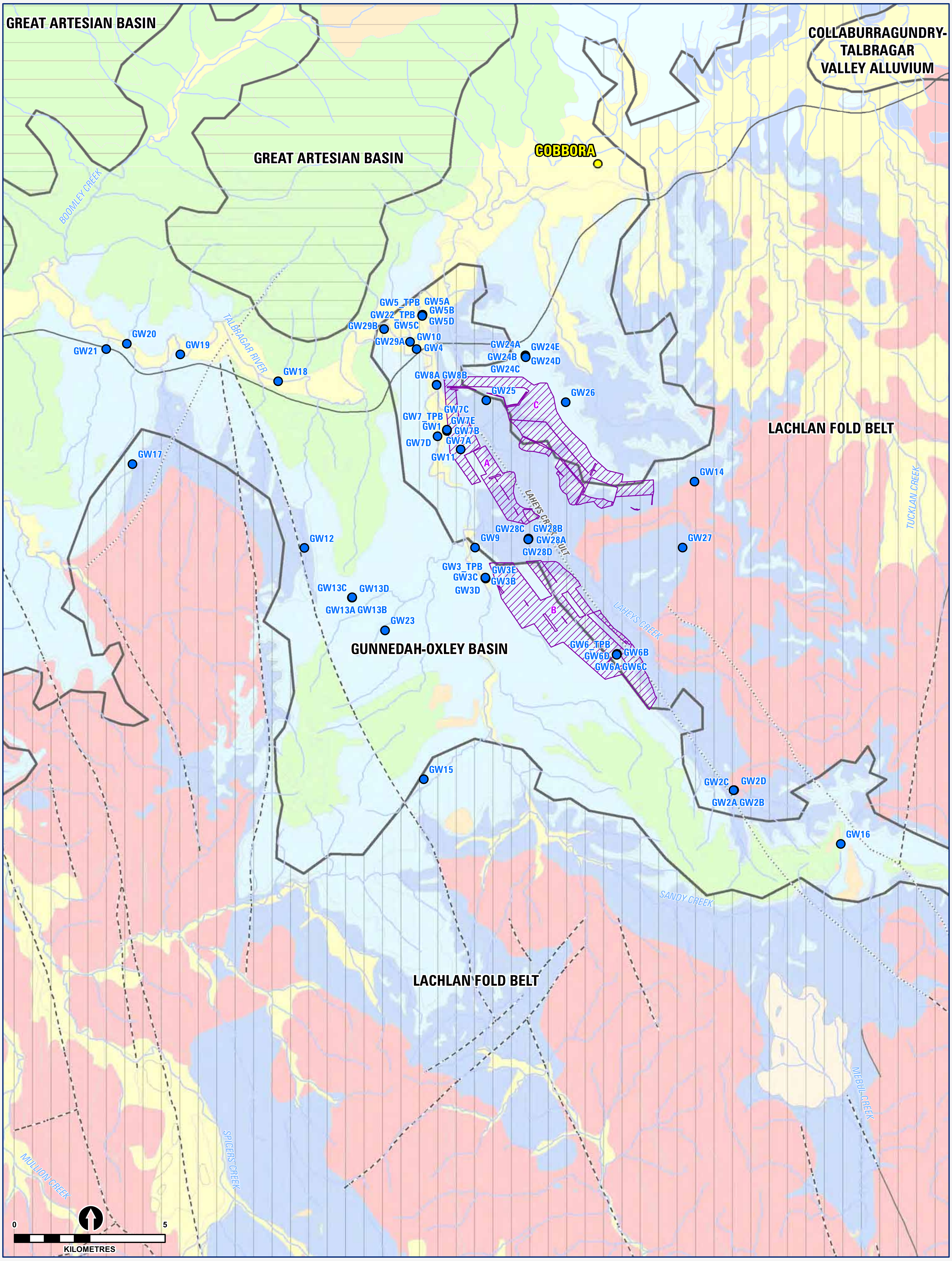
It should be noted that the NOW groundwater source boundary map does not define the Lachlan Fold Belt and Gunnedah-Oxley Basin boundary at the same scale as the geological mapping, as can be seen by the underlying geological boundaries in Figure 5.1.
As discussed previously the Project site lies within the Gunnedah-Oxley Basin.

5.3 Hydrogeological units

The main hydrogeological units across the assessment area comprise:

- quaternary alluvium aquifer 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 occurs mainly to the north-west of the assessment area with some isolated areas of Jurassic sandstone also occurring 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 sandstone, coal and claystone associated with the Gunnedah Basin
- the fractured rocks of the Lachlan Fold Belt (Devonian, Silurian and Ordovician metasediments) which underlay and surround the porous Permo-Triassic rocks.

The hydrogeological units and water source boundaries are presented in Figure 5.1. Conceptual hydrogeological cross-sections are presented in Figure 5.2 to Figure 5.5, with cross-section lines shown on Figure 5.3.



- Piezometer sites
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas
- Water source boundaries as per the NSW Office of Water as at February 2012

Hydrogeological units

- Alluvium - Quaternary
- Fractured basalts - Tertiary
- Igneous rock - Mesozoic
- Porous rock - Jurassic
- Porous rock - Triassic
- Porous rock - Permian
- Fractured rock - Ordovician

Figure 5.1 Hydrogeological units

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

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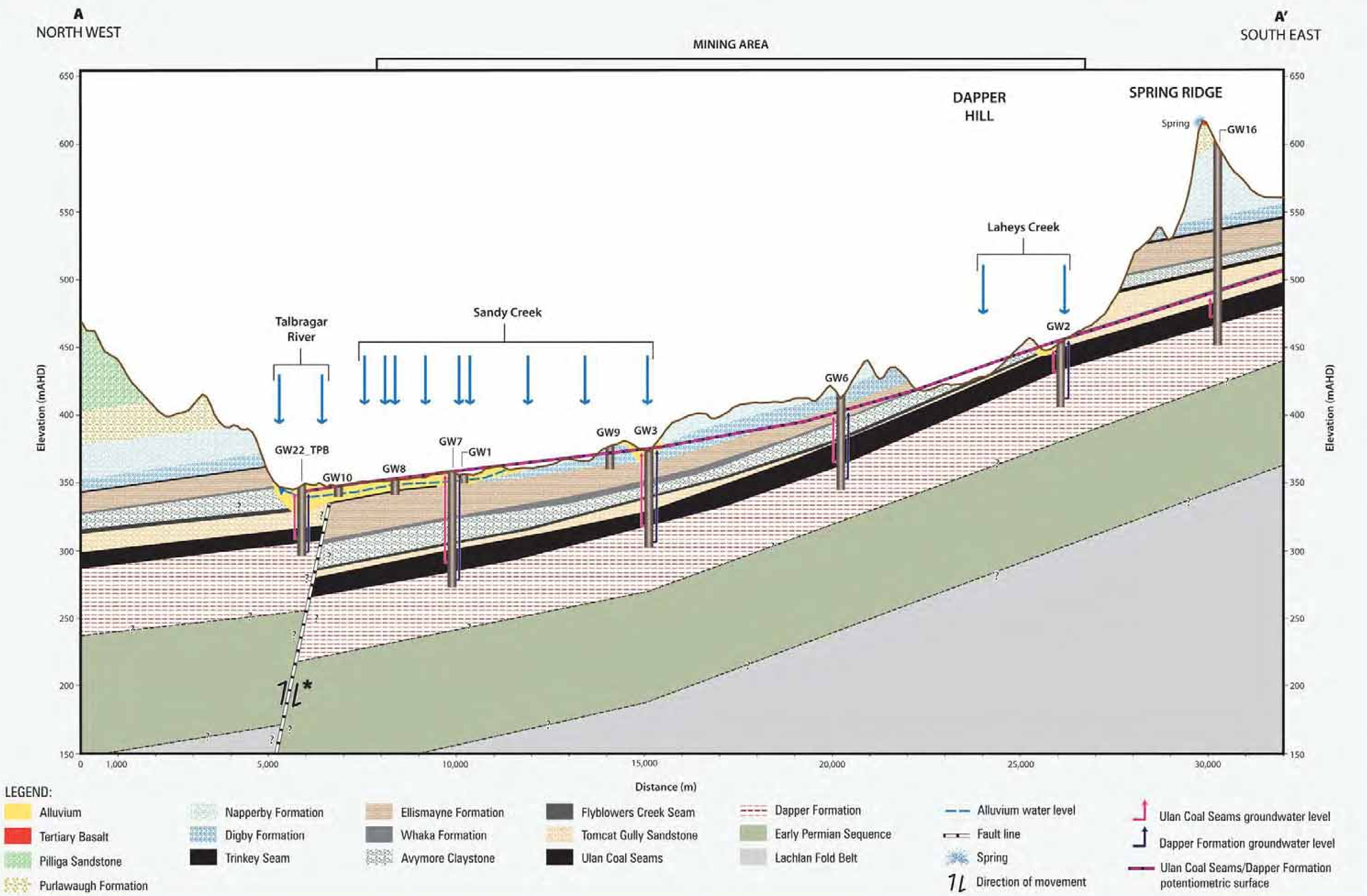
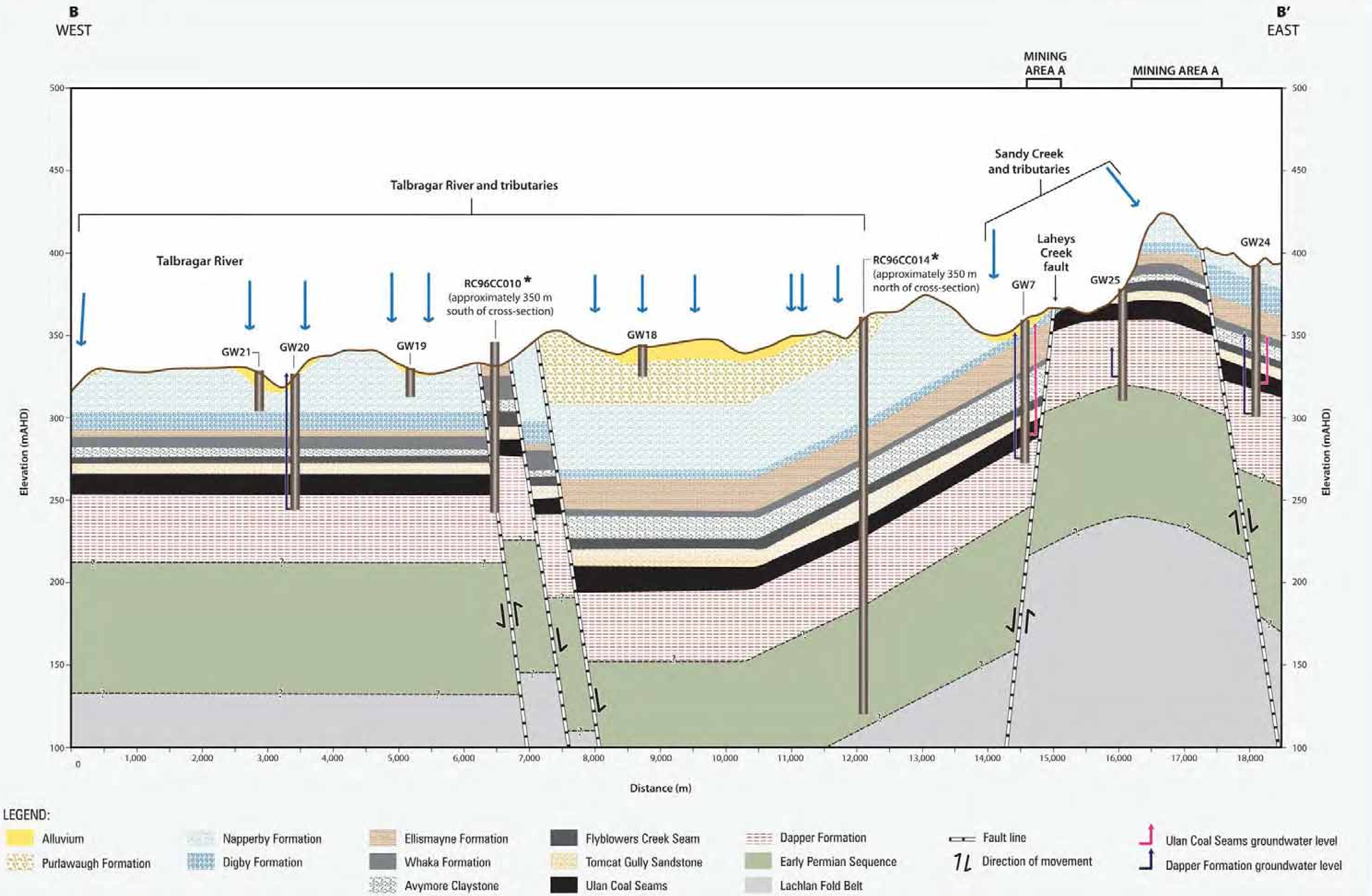
PARSONS BRINCKERHOFF

COBBORA COAL PROJECT
CHC PTY LTD



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

Figure 5.2 Conceptual hydrogeological cross-section A - A'

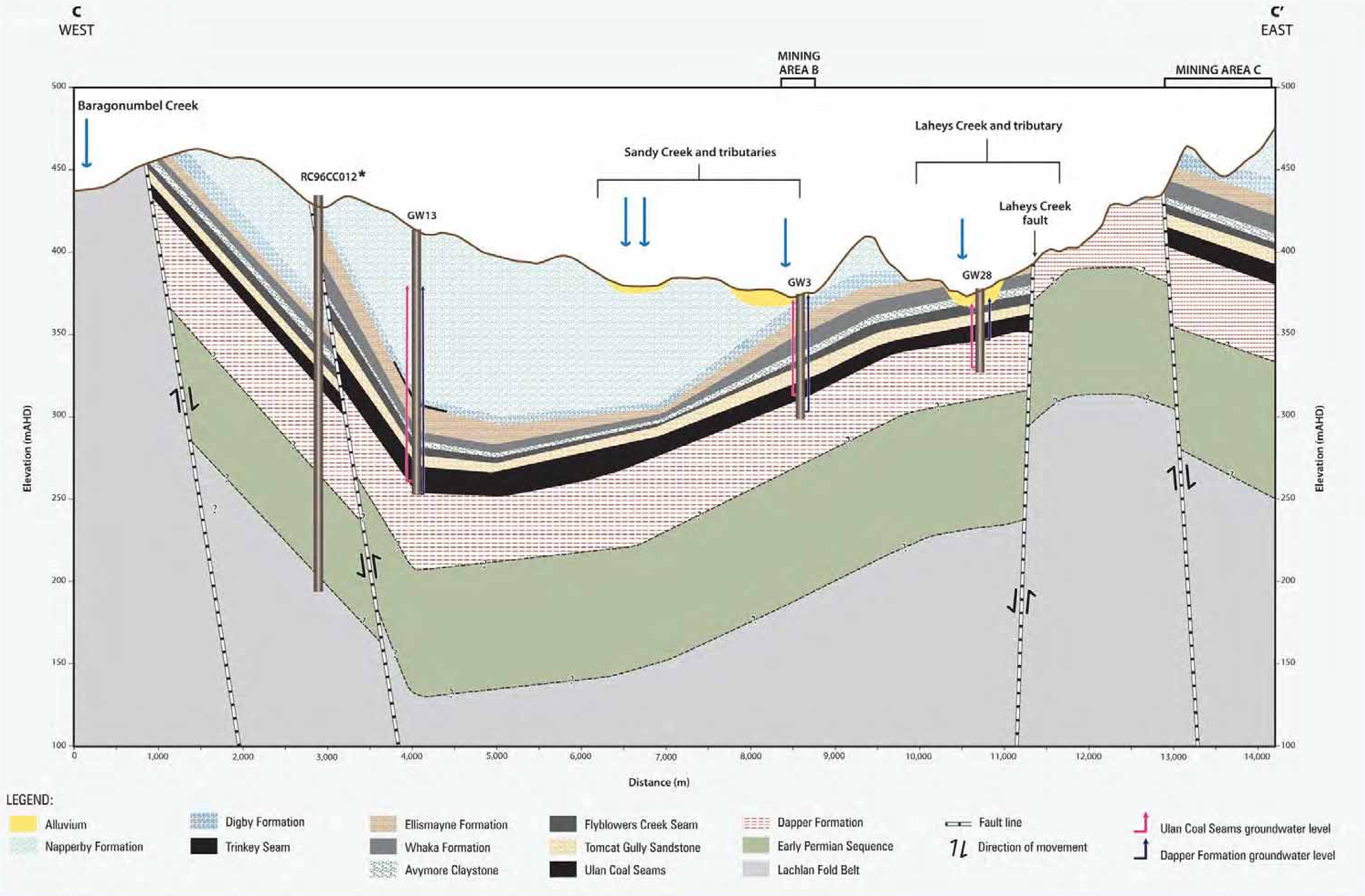


Note: * *RC96CC0** bores were drilled as part of the CRA exploration program (Menpes, 1997)*

Figure 5.3 Conceptual hydrogeological cross-section B - B'

PARSONS BRINCKERHOFF

COBBORA COAL PROJECT
CHC PTY LTD

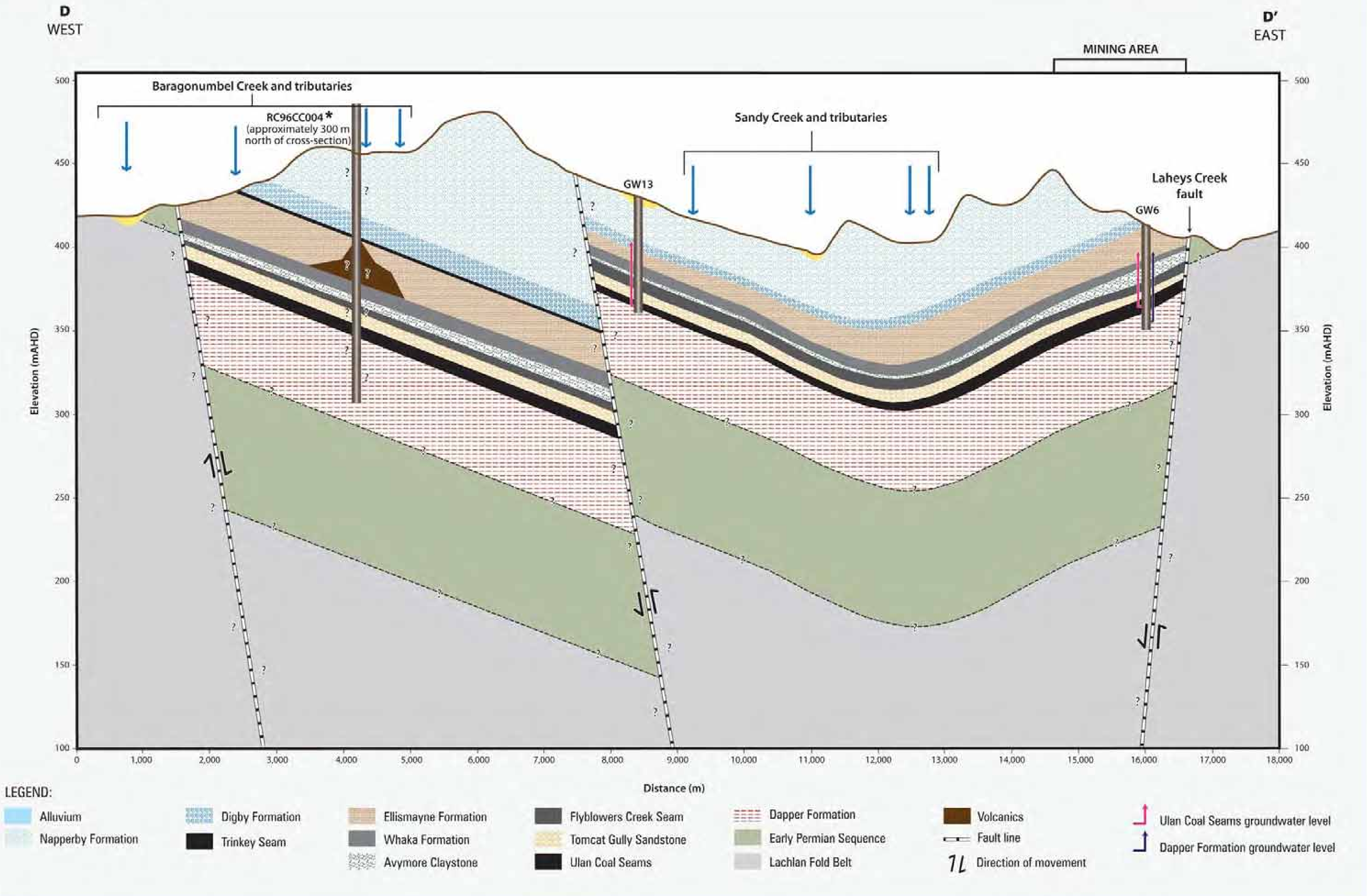


Note: **RC96CC0** bores were drilled as part of the CRA exploration program (Menpes, 1997)*

Figure 5.4 Conceptual hydrogeological cross-section C - C'

PARSONS BRINCKERHOFF

COBBORA COAL PROJECT
CHC PTY LTD



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

Figure 5.5 Conceptual hydrogeological cross-section D - D′

5.3.1 Alluvium aquifers

The alluvium aquifer is present in the assessment area along the course of the Talbragar River, and Sandy Creek downstream of the Laheys Creek and Sandy Creek junction where it widens to become a broad flat channel and joins the Talbragar River. The alluvium aquifer is characterised by sandy gravel, interspersed with clay, and is of low permeability due to the high clay content.

Based on the geology intersected during drilling programs, the maximum depth of alluvium recorded was 23.5 m along the Talbragar River (GW5A). About 10 km upstream of the assessment area, the floodplain is much greater in extent both vertically and horizontally. As a result the alluvium aquifer in this upstream location is highly developed and used for primary production and town water supply (Dunedoo). This upstream area is managed as the Talbragar Alluvial Groundwater Source (NOW 2011).

Alluvial and colluvial sediments are also present in areas along Sandy Creek, Laheys Creek and Tucklan Creek. These are generally discontinuous and do not constitute a useful aquifer.

5.3.2 Tertiary fractured basalt

Tertiary basalt deposits are isolated outliers to the south and west of the assessment area. The deposits are of limited extent and form local hydrogeological systems overlying the broader regional systems. Rainfall provides direct recharge to the basalt, while groundwater within the basalt is likely to discharge in the form of seeps and springs at the contact with the underlying Jurassic, Triassic and Permian strata.

5.3.3 Porous rock — Jurassic sandstone

To the north-west of the assessment area lie the Jurassic Pilliga Sandstone and Purlawaugh Formation. These are the sandstone sediments of the Surat Basin. To the north of the Talbragar River these units form part of the larger Great Artesian Basin with the Pilliga sandstone forming part of the NSW southern recharge zone of the Great Artesian Basin.

The Purlawaugh Formation, which underlies the Pilliga Sandstone, comprises shales and interbedded sandstones, and forms a basal confining layer for the Pilliga Sandstone. The Jurassic units are therefore not considered to be hydraulically connected to the Permo-Triassic aquifers of the Gunnedah-Oxley Basin. Isolated deposits of the Purlawaugh Formation and Pilliga Sandstone are present within the assessment area; however, these outliers are considered part of the Oxley Basin (Australian Government 2009), and are managed and licensed as Gunnedah-Oxley Basin (NOW 2011b).

5.3.4 Porous rock — Permo-Triassic

The Triassic and Permian formations comprise a sequence of geological units, all of which have varying capacities to transmit water. Table 5.1 lists each unit within the sequence and their relative capacity to transmit water.

Table 5.1 Hydrogeological properties of porous rock units

Geological units		Hydrogeological properties
Triassic	Napperby Formation	water-bearing zone
	Digby Formation	water-bearing zone
Permian (Dunedoo formation)	Trinkey Seam	water-bearing zone
	Ellismayne Formation	water-bearing zone
	Whaka Formation	water-bearing zone
	Avymore Claystone	aquitard
	Flyblowers Creek Seam	water-bearing zone
	Tomcat Gully Sandstone	water-bearing zone
	Upper Ulan Seam	water-bearing zone
	C-Marker Claystone	aquitard
	Lower Ulan Seam	water-bearing zone
	Dapper Formation	water-bearing zone

The Dunedoo Formation consists of interbedded shales, claystones, coals, tuffaceous units and sandstones. The Dapper Formation and the Upper and Lower Ulan coal seams are recognised as the main water-bearing units, with low to moderate permeability. Anecdotally, the Tomcat Gully Sandstone can be locally quite transmissive and high yielding.

The Tomcat Gully Sandstone overlies the Ulan Upper seam and is separated from the Ulan Lower seam by a confining unit (aquitard), the C-Marker Claystone. Overlying the Tomcat Gully Sandstone is the Flyblowers Creek Seam, which is a minor water-bearing zone of higher clay content than the Ulan Coal Seams. The Dapper Formation underlies the Ulan Lower Seam.

Connectivity between the units is generally limited by confining or semi-confining units comprising shale, claystone, siltstone or other lower permeable materials. There is potential for leakage between confining layers, especially in highly fractured areas near faults and in areas where the confining layers have low clay content.

5.3.5 Fractured rocks of the Lachlan Fold Belt — Devonian, Silurian and Ordovician

Within the assessment area, the Lachlan Fold Belt fractured groundwater system underlies the porous rock aquifer of the Gunnedah-Oxley Basin. It comprises Devonian, Silurian and Ordovician aged rocks, which are characterised by metamorphosed sedimentary, volcanic and intrusive fractured rock of very low permeability. Outcropping basement rocks of the Lachlan Fold Belt occur to the west, east, south and south-east of the assessment area (Figure 5.1). As mining will not intersect the basement Lachlan Orogen units, this aquifer system will not be impacted by mining.

5.4 Recharge and discharge

Groundwater in the alluvium aquifer is unconfined. Recharge is via direct infiltration of rainfall and stream and riverbank recharge during flood events, with discharge affected by leakage to underlying aquifers or direct to springs and surface water.

Results of the TEM survey (Appendix G) indicate that adjacent to the Talbragar River and the lowest part of Sandy Creek are numerous conductive, near-surface, roughly meander-shaped features. It is likely that these are saline saturated (or at least moistened) alluvium. Flood events which occurred prior to the survey (2011), likely created a zone of resistive alluvium along the river itself.

The Permo-Triassic porous rock aquifers are primarily recharged by direct infiltration of rainfall into aquifer outcrop areas. Recharge may also occur to the porous rock aquifers by downward leakage from the overlying alluvium particularly in the upper sections of Sandy Creek and Laheys Creek. Discharges from the Permo-Triassic porous rocks may take place where aquifer units within the bedrock sediments outcrop, typically as springs on hillsides or baseflow to creeks and gullies. In the down gradient areas at nested groundwater monitoring sites where an alluvium bore is present (GW5 and GW7), the hydrographs (Appendix E) indicate groundwater pressures in the Permian deeper units are generally higher than those measured in the alluvium.

Based on groundwater elevations, the typical magnitude of head difference between the alluvium and Permian units was 0.5–1 m at site GW5 and 4–5 m at site GW7. This indicates an upward pressure gradient and potential groundwater flow from the Permo-Triassic units into the alluvium.

5.5 Groundwater levels and flow direction

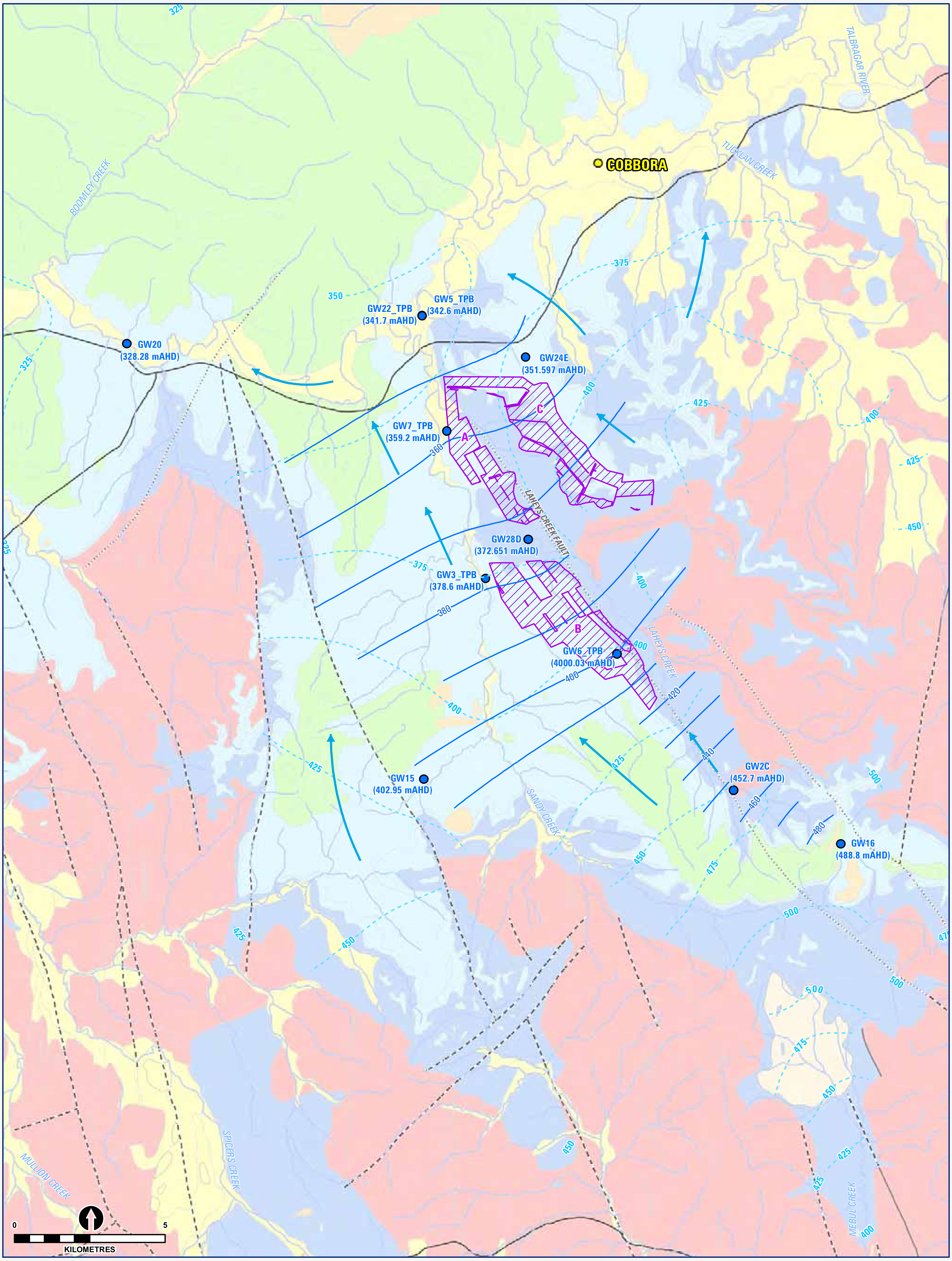
Groundwater flow direction appears to mimic the topography with a flow direction for the alluvium down valley, consistent with surface water flows. Available groundwater level data in the unconfined alluvium aquifer indicates an inferred groundwater flow direction north towards the Talbragar River. Levels range from 353 m AHD up-gradient on Sandy Creek to around 341.5 m AHD at the Talbragar River.

Groundwater flow in the semi-confined to confined porous rock aquifer is influenced by stratigraphic dip and depth to aquifer, with influence also from geological structures. Groundwater level data indicates a high degree of connectivity between the Permian and Triassic units with groundwater levels measured at nested sites generally within 1 m in all porous rock aquifer bores.

The groundwater levels in the porous rock aquifer range from a high of approximately 452 m AHD in the elevated south east area (site GW2) of the assessment area, to a low of approximately 342 m AHD at the Talbragar River (site GW5). Groundwater flow is generally to the north, north-west. Groundwater level contours and flow direction are depicted in Figure 5.6.

Artesian pressures have been measured in the porous rock aquifers at sites GW3 and GW7 along Sandy Creek. The TEM survey (Appendix G) of this area strongly depicts various lithologies with a clear boundary extending approximately along the same line (i.e. Sandy Creek). The lithologies are deformed in some places, indicating evidence of faulting. Furthermore exploration drilling highlights a similar lineament along Sandy Creek, where the highest groundwater yields were encountered during drilling and artesian pressures observed (Figure 5.7).

Another interesting trend observed from the exploration drilling water-make data, is the depth of maximum water cut which increased westwards in the direction of dip and is consistent with the Dapper Formation hosting the main water bearing zone (Figure 5.8).
This demonstrates that, at least locally, groundwater flow may be influenced by the dip and faulting of strata.



Piezometer sites
Drainage lines
Main roads
Mine pit area
Fault - approximate
Fault - concealed
Groundwater contours
Potentiometric level in the deep Ulan Coal Seam (mAHD)
Groundwater flow direction

Aquifer systems

Alluvium
Tertiary fractured basalts
Great Artesian Basin
Mesozoic igneous rocks
Porous rock - Triassic
Porous rock - Permian
Lachlan Fold Belt

Figure 5.6 Groundwater level contours

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

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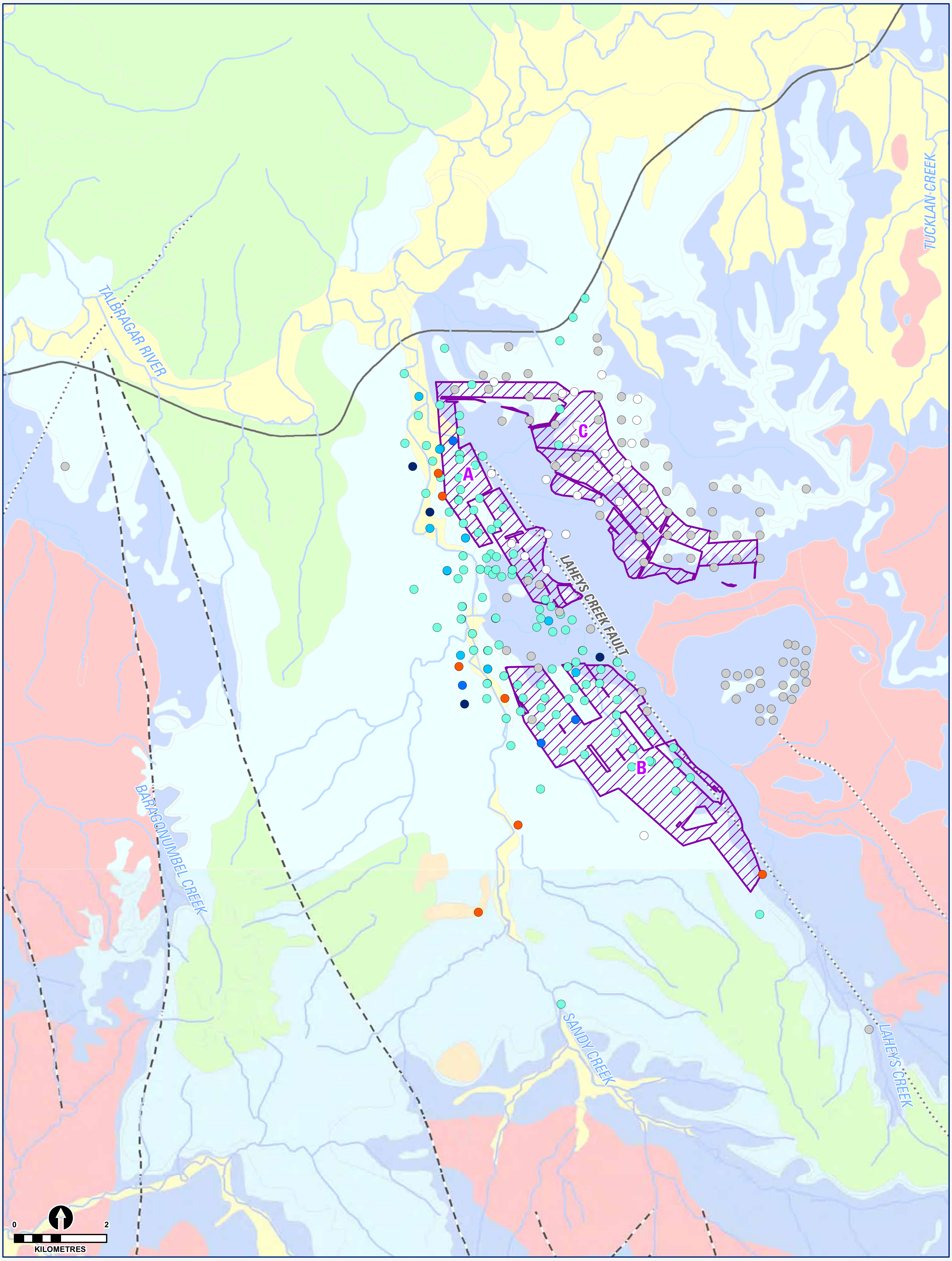


Maximum water rate (L/s)

- Negligible water and <0.1
- 0.1 – 2.5
- 2.5 – 5.0
- 5.0 – 7.5
- >10
- Artesian
- Dry

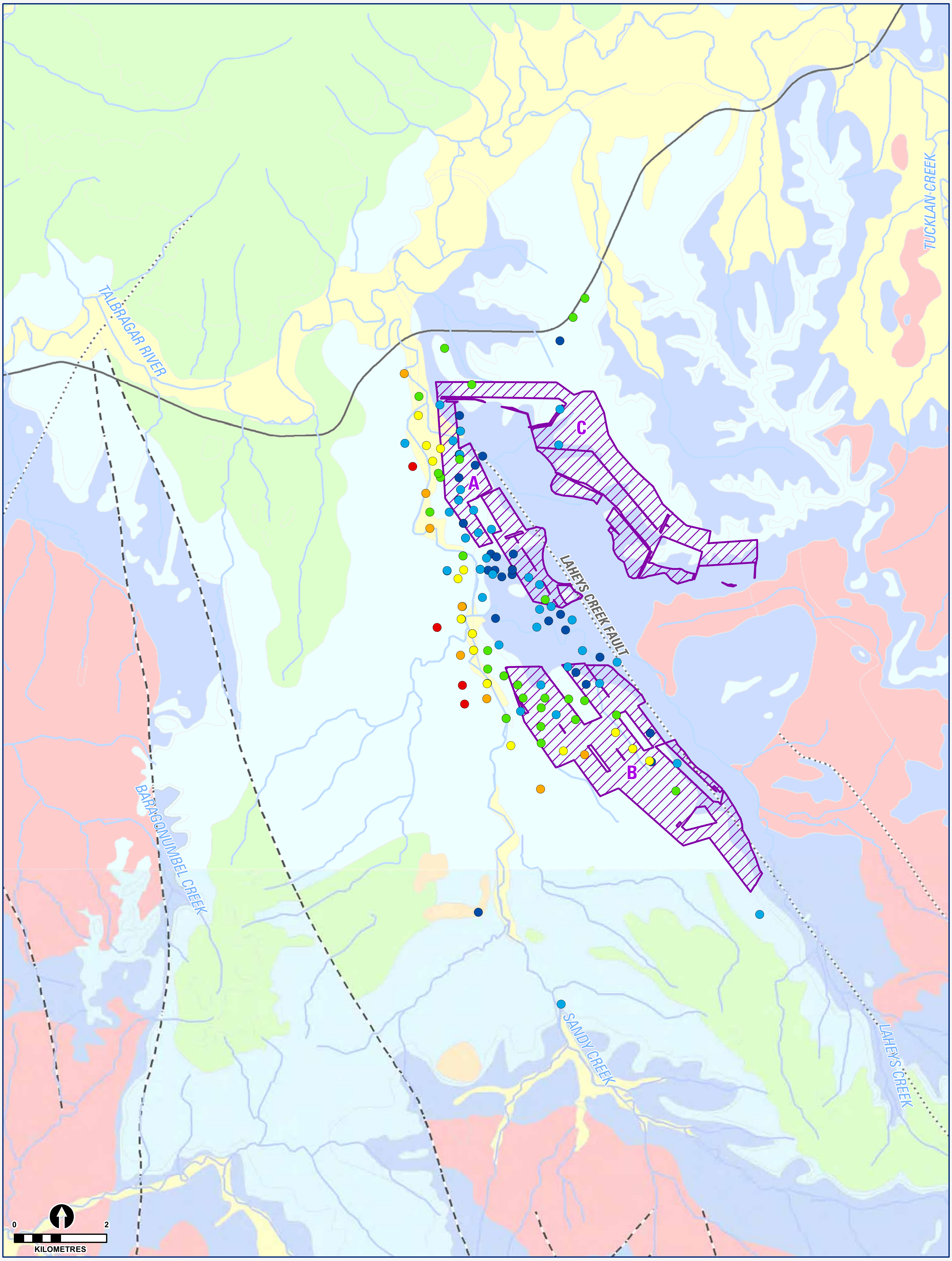
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas

Hydrogeological units

- Alluvium - Quaternary
- Fractured basalts - Tertiary
- Igneous rocks - Mesozoic
- Porous rock - Jurassic
- Porous rock - Triassic
- Porous rock - Permian
- Fractured rock - Ordovician

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

Figure 5.7 Water make in exploration holes - maximum flow rate



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Depth of maximum water cut (m)
- 10-40
- 40-60
- 60-80
- 80-100
- 100-120
- 120-140

- Drainage lines
- Fault - approximate
- Fault - concealed

Hydrogeological units
- Alluvium - Quaternary
- Fractured basalts - Tertiary
- Igneous rocks - Mesozoic
- Porous rock - Jurassic
- Porous rock - Triassic
- Porous rock - Permian
- Fractured rock - Ordovician

- Proposed mining areas

Figure 5.8 Water make in exploration holes - depth of maximum water cut

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

5.5.1 Hydrographs

Available groundwater level data has been plotted as potentiometric pressure (m AHD) versus time (days), along with the long-term (1889–2011) cumulative deviation from mean rainfall (CDM) trend (Appendix E) to assess trends in recharge.

Analysis of the hydrographs indicates three primary trends:

- There is an overall rising trend in water levels over the assessment area which corresponds to the CDM rainfall trend. Site GW7 is the exception; groundwater levels have continued to decline unlike at other sites which have plateaued despite the occurrence of high rainfall events at the end of 2010. This trend may indicate potential groundwater extraction from a nearby private bore.

- Groundwater bores monitoring the alluvial and shallow weathered rock groundwater levels, located within close proximity to a creek or river, exhibit a rapid response to large and sustained rainfall events. Following the high rainfall events in December 2010, the following peak water level rises were recorded within 2 to 3 weeks; GW5A – 3 m, GW6A – 4 m, GW7A – 3 m, GW8A – 2.5 m, GW8B – 1 m, GW18 – 3.5 m and GW21 – 6 m. The most rapid groundwater level responses (rises) were generally identified in the bores nearest to a creek or river, indicating rapid flood recharge to these alluvial areas.

- Groundwater bores monitoring the deeper confined units display a more muted response in water level changes. Rises observed over approximately 6 months were between 1 and 3 m. They were continual and sustained over a longer period (sites GW2A-D, GW3B-E, and GW6B-D), indicating slower leakage rates from the overlying units.

5.6 Hydraulic testing

5.6.1 Aquifer responses

Constant rate pumping tests were carried out to assess regional and local impacts of stressing the aquifer, and also the transmissivity and storage values of the aquifer. Tests were for periods of 24 hours, 14 days or 21 days. Continuous monitoring of the water levels at the test production bore and nearby piezometers was undertaken.

Although aquifer hydraulic parameters can be (and were) derived from the tests, the main aim of the tests was to assess drawdown and rates of leakage between aquifers. It is noted later in this report that aquifer testing in multi-layered systems can yield erroneously high permeability values due to the violation of several assumptions in the Theis (1935) solution (Cook 2003).

5.6.1.1 Short-term tests

Short-term 24-hour pumping tests were undertaken to determine the most productive bore for a longer term test. Pumping tests were carried out as follows: GW3_TPB at 4.4 litres per second (L/s), GW5_TPB at 3.5 L/s and GW7_TPB at 4.4 L/s. Water level drawdown and recovery data was also used to assess hydraulic parameters.

Total drawdowns were measured in the test production bores at the completion of each test as follows:

- GW3_TPB at 42.7 m
- GW5_TPB at 13.3 m
- GW7_TPB at 36.9 m.

At the cessation of pumping the recovery of water levels was measured in each test production bore. At 10 minutes the following recoveries were observed:

- GW3_TPB at 95%
- GW5_TPB at 90%
- GW7_TPB at 65%.

For each test the porous rock aquifer piezometers showed a rapid and similar response to pumping in the associated test production bore. Where present at each site observation bores screened across the alluvium (GW5A and GW7B), and weathered rock (GW9), each showed minimal drawdown as a result of pumping at the associated test production bores.

5.6.1.2 Long-term tests

GW3_TPB 14-day test

GW3_TPB was pumped at 4.4 L/s for 14 days, with a total drawdown of 47 m.
Initial recovery in GW3_TPB was rapid, with 85% recovery after 10 minutes.

All piezometers showed a rapid response to pumping in the associated test production bore, with the exception of the observation bore screened across the weathered rock (GW9), which showed minimal drawdown as a result of pumping. This suggests poor hydraulic connection between the shallow weathered rock and the deeper porous rock aquifer.

Total drawdowns at each piezometer were GW3C: 5.7 m; GW3D: 7.4 m and GW3E: 13 m. The varying magnitudes of drawdown observed at each site indicate heterogeneity between the Permo-Triassic units.

Analysis of the recovery data during the 14-day test in the piezometers screening the Dapper Formation (GW3E) indicates that the cone of drawdown intersected a recharge boundary after approximately 800 minutes. The recharge boundary is likely to represent where the Dapper Formation is truncated as it outcrops at ground surface to the east, intersecting Laheys Creek (see Figure 5.4). Conversely, drawdown at GW3B, which screens a series of units in the Permian sequence, indicates a barrier boundary was intersected. This is likely due to the Permian sequence being truncated at ground level (see Figure 5.5). In this case the truncation provides a barrier because there is no recharge from surface water.

GW7_TPB 21-day test

GW7_TPB was pumped at 2.5 L/s for 21 days, with a total drawdown of 24.13 m. Similar to the 24-hour test, recovery was slower than experienced at the other sites with 85% reached after 810 mins (or 13.5 hours).

Drawdown trends in the porous rock aquifer piezometers GW7C, GW7D and GW7E each showed rapid responses to pumping, while the magnitude of drawdowns varied. Total drawdown recorded at each bore was GW7C: 9.4 m; GW7D: 9.5 m and GW7E: 11.3 m. While drawdown at GW7C and GW7D were comparable, the drawdown in GW7E was almost 2 m greater, which indicates heterogeneity between the Permo-Triassic units.

Drawdown in the alluvial bore (GW7A) was slight and estimated at between 0.1 m and 0.2 m after the effects of rainfall and barometric pressure variations were removed. It is noted that these effects almost overwhelmed the drawdown response.

GW22_TPB 21-day test

GW22_TPB was pumped at 2 L/s for 21 days, with a total drawdown of 22.2 m. Recovery of 85% was reached 6 minutes after pumping ceased.

Drawdown trends in the porous rock aquifer piezometers GW5B, GW5C, and GW5D showed a rapid and similar response to pumping. Total drawdowns recorded at each bore were GW5B: 2.3 m; GW5C: 2.5 m and GW5D: 2.7 m. The magnitude of drawdown in each monitoring bore was within 0.4 m of each other, indicating good hydraulic connection.

The groundwater level monitored at the alluvium aquifer bore GW5A showed an overall declining trend over the 21-day period. Interference due to rainfall events (105 mm total) and pump stoppages over the course of the test attributed to both positive and negative displacement of the water level; however, an estimated overall drawdown of between 0.1 and 0.15 m was observed.

The minimal drawdown observed suggests a poor hydraulic connection to the porous rock aquifer, and that rainfall and stream bank flood recharge is significant. Leakage rates were analysed further using a local-scale numerical groundwater model (see Section 5.6.2.1, below).

5.6.2 Aquifer hydraulic parameters

A summary of the results of the estimation of the hydraulic parameters for the alluvium and porous rock aquifers is provided in Table 5.2. It should be noted that while the reported values for hydraulic conductivity are a range, and the higher values are indicative of the presence of some localised higher permeability zones within the porous rock aquifer, that are not necessarily representative of the regional aquifer system. Table 5.5 details all parameter estimates from aquifer tests.

Table 5.2 Calculated aquifer hydraulic parameters

Aquifer	Test method	Hydraulic conductivity (m/d)	Storativity
Alluvium	Slug test	0.06–3.8	
Tomcat Gully Sandstone	Pumping test	3.7–19.4	7.1×10^{-4} –3.1×10^{-2}
	Slug test	0.012–0.7	
Ulan Coal Seam	Pumping test	2.3–10.2	2.2×10^{-5} –2.9×10^{-3}
	Slug test	0.3–0.8	
	Packer test	8.5×10^{-3}–6.9×10^{-2}	
Dapper Formation	Pumping test	1.4–10.2	7.3×10^{-7} –4.7×10^{-3}
	Slug test	0.03–0.4	

5.6.2.1 Alluvium aquifer

Based on the rising head test results, the hydraulic conductivity of the alluvium aquifer is estimated to be within the range of 0.06 to 3.8 m/d.

More detailed analysis has been carried out to further assess the hydraulic conductivity of the alluvium aquifer using data obtained from the 21-day pumping test at GW22_TPB.

A local-scale numerical model was constructed using MODFLOW to estimate hydraulic parameters in each of the units at site GW5/GW22, in particular, the parameters that control leakage from the alluvium to the Permian aquifers when they are depressurised. To do this, the rainfall and barometric pressure corrected, drawdown data for the 21-day test was used with PEST to calibrate the modelled drawdown to the observed drawdown. Horizontal (K_h) and vertical (K_v) hydraulic conductivity and storage were allowed to vary. The results of the PEST run in which the best fit was obtained for the alluvium are listed below in Table 5.3.

K_h and K_v for the alluvium were estimated at approximately 1 m/d and 0.001 m/day respectively. The ratio of K_h to K_v is about 1000. The parameters for the other units, while valid for this location are not considered to reflect conditions for the regional aquifer system.

Table 5.3 Estimates of vertical and horizontal hydraulic conductivity at site GW5

Zone	Unit	K_h (m/d)	K_v (m/d)	K_v/K_h (m/d)	S_s	S_y
1	Alluvium	1.09	1.1×10^{-3}	1.0×10^{-3}	1.00×10^{-6}	3.37×10^{-2}
2	Tomcat	0.16	0.07	0.45	1.47×10^{-6}	
3	Ulan	3.87	0.22	0.06	2.00×10^{-6}	
4	Dapper	0.05	2.0×10^{-3}	0.05	5.48×10^{-5}	

K_h — horizontal hydraulic conductivity; K_v — vertical hydraulic conductivity; K_h/K_v — ratio of horizontal/vertical hydraulic conductivity; S_s — specific storage; S_y — Specific yield

5.6.2.2 Porous rock aquifer

The transmissivity, hydraulic conductivity and storativity of the porous rock aquifers have been estimated from data obtained during pumping tests, rising head 'slug' tests and packer tests. Hydraulic parameters discussed in this section include those for the Tomcat Gully Sandstone, Ulan Seams and the Dapper Formation. Hydraulic parameters have also been estimated for bores screened across several units, and are provided in Table 5.5.

Estimates of hydraulic conductivity in the porous rock aquifers ranged over five orders of magnitude, indicating significant heterogeneity within the porous rock. Table 5.12 shows hydraulic conductivity estimates from pumping tests to be significantly higher than those estimated through slug tests, packer tests or groundwater age dating.

Estimates of slug and packer testing for individual units are typically one or two orders of magnitude lower than estimates derived from test pumping. This is commonly observed and reflects the scale-dependent nature of permeability testing (especially in fractured or dual porosity aquifers), and also the inherent bias of each particular testing method (e.g. test pumping is not possible in formations of very low permeability). In addition, the standard Cooper-Jacob and Theis recovery approach were used to estimate hydraulic conductivity from piezometers screened in sub-units.

This approach is known to yield overestimates of permeability in monitored subunits when the pumping bore is screened across multiple units (Cook 2003). For these reasons, the hydraulic parameters estimated using data from the slug tests and packer tests are considered more representative of the formations, while the test pumping data is best used to determine leakage between units, and assess regional groundwater impacts.

The geometric means of slug test and packer test data are in the order of 10^{-1} and 10^{-2} m/d (see Table 5.4).

Groundwater age (^{14}C) provides an approximate upper limit to the subregional hydraulic conductivity; groundwater ages of approximately 40,000 years are observed at GW6 which, if we assume that groundwater recharged at the basin margin (t_0), implies a hydraulic conductivity of less than approximately 0.02 m/d (based on the observed hydraulic gradients).

There is little field test evidence for significant differences in hydraulic conductivity between the sandstone and siltstone units, although anecdotally the Ulan and the Tomcat can be locally quite transmissive and high yielding as noted during exploration drilling.

Table 5.4 Average horizontal hydraulic conductivity values from field testing (m/day)

Test	Geometric mean	Arithmetic mean	Notes
Slug tests	0.117	0.374	Bouwer-Rice method
Packer tests	0.012	0.017	
Slug + packer	0.049	0.235	
14C age	0.017	0.019	Seepage rate from Darcy's Law
Test pumping	3.6	5.6	Cooper-Jacob and Theis recovery analysis

Estimates of hydraulic conductivity (K) in coal seams and interburden from other studies (e.g. Bulli Seam Operations Groundwater Assessment (Merrick 2009); Hunter Valley Mackie 2009)) show similar large ranges, but typically average 10^{-1} to 10^{-2} m/d (partly weathered coal at shallow depths) and 10^{-2} to 10^{-4} m/d or less (weathered interburden).

Hydraulic conductivity also tends to decrease with depth, due to increasing lithostatic pressure and closing of joints and fractures, and so lower values of hydraulic conductivity may be more typical of deeper coal measures such as those in the Southern Coalfields. It is noted that within the assessment area the coal measures are relatively shallow (or outcropping) and are variably weathered and fractured which may justify slightly higher estimates of hydraulic conductivity.

Figure 5.9 Estimated hydraulic conductivity

5.7 Groundwater quality

Groundwater quality for the alluvium and porous rock aquifers is discussed in the following sections. Groundwater quality results are compared to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000). The ANZECC (2000) freshwater guidelines (95% level of protection) were selected as the area is moderately disturbed. The ANZECC (2000) guidelines for upland rivers in south-east Australia were also referred to because the site location is >150 m altitude and in NSW.

Major ion chemistry can be used to interpret the sources of natural waters. A Piper diagram can be used to graphically show the relative concentrations of major ions (Ca, Mg, Na, K, Cl, HCO_3 and SO_4). A Piper diagram for groundwater in the assessment area is presented in Figure 5.10. Evolution of groundwater chemistry along the direction of groundwater flow is shown on the north-south cross-section in Figure 5.11. The variability in groundwater salinity is shown on Figure 5.12.

Selected samples were analysed for stable isotopes of water (^{18}O and ^{2}H) and radiocarbon to assess origins of water and groundwater residence times. Stable isotopes for groundwater are compared to surface water, springs and the Global Meteoric Water Line ($\delta^2H = 8.\ \delta^{18}O + 10$ (Craig 1961)) and a Local Meteoric Water Line ($\delta^2H = 7.89\ \delta^{18}O + 14.18$ (Timms et al. 2009)) in Figure 5.13. The change in groundwater age along the direction of groundwater flow is shown on the north-south cross-section in Figure 5.14.

Table 5.5 Summary of hydraulic testing results

Bore	Screened unit	Estimation method	Transmissivity (T) (m^2/d)	Hydraulic conductivity (K) (m/d)	Storativity* (S)
GW5A	Alluvium	Rising head test (Bouwer-Rice 1976)		3.8	
GW28A	Alluvium	Rising head test (Bouwer-Rice 1976)		0.06	
GW28B	Alluvium	Rising head test (Bouwer-Rice 1976)		2.8	
GW29B	Digby Formation	Rising head test (Bouwer-Rice 1976)		0.05	
GW3C	Tomcat Gully Sandstone	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	49.7 DD 77.3 REC	8.3 DD 12.9 REC	4.7×10^{-3}
		14-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	30.3 DD 38.7 REC	5.0 DD 6.4 REC	7.4×10^{-3}
GW5B	Tomcat Gully Sandstone	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	52.7 DD 69.2 REC	17.6 DD 23.1 REC	3.1×10^{-2}
		3-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	55.8 DD	18.6 DD	2.7×10^{-3}
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	39.6 DD	13.2 DD	1.6×10^{-3}
		Rising head test (Bouwer-Rice 1976)		0.7	
GW6B	Tomcat Gully Sandstone	Rising head test (Bouwer-Rice 1976)		0.02	
GW7C	Tomcat Gully Sandstone	24-hour pump test (Cooper-Jacob, 1946 (DD); Theis 1935 (REC))	11.2	3.7	1.8×10^{-4}
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	12.2	4.0	9.5×10^{-5}
GW24C	Tomcat Gully Sandstone	Rising head test (Bouwer-Rice 1976)		0.012	
GW3D	Ulan Coal Seams	14-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	33.2 DD 31.6 REC	2.8 DD 2.6 REC	5.4×10^{-4}
GW5C	Ulan Coal Seams	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	34.6 DD 69.2 REC	5.8 DD 11.5 REC	2.9×10^{-3}
		3-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	60.6 DD 57.0 REC	10.1 DD 9.5 REC	1.6×10^{-3}
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	39.6 DD	6.6 DD	3.2×10^{-4}

Bore	Screened unit	Estimation method	Transmissivity (T) (m^2/d)	Hydraulic conductivity (K) (m/d)	Storativity* (S)
		Rising head test (Bouwer-Rice 1976)		0.8	
GW6C	Ulan Coal Seams	Rising head test (Bouwer-Rice 1976)		0.3	
GW7D	Lower Ulan Seam	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	17.4	5.8	6.5×10^{-5}
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	14.1	4.7	1.8×10^{-5}
GW24D	Ulan Seams	Rising head test (Bouwer-Rice 1976)		1.1	
GW28C	Ulan Seams	Rising head test (Bouwer-Rice 1976)		0.7	
GW3E	Dapper Formation	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	18.3 DD 16.9 REC	3.1 DD 2.8 REC	6.6×10^{-3}
		14-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	16.6 DD 26.3 REC	2.8 DD 4.4 REC	6.0×10^{-4}
GW5D	Dapper Formation	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	41.0 DD 55.4 REC	6.8 DD 9.2 REC	1.1×10^{-3}
		3-day pump test (Cooper-Jacob 1946 (DD)	51.7 DD	8.6 DD	1.4×10^{-3}
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	45.2 DD	2.5 DD	6.6×10^{-4}
		Rising head test (Bouwer-Rice 1976)		44.7	
GW6D	Dapper Formation	Rising head test (Bouwer-Rice 1976)		0.4	
GW7E	Dapper Formation	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	12.2	4.0	3.0 x 10-4
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	12.4 DD 8.9 REC	2.1DD 1.5 REC	3×10^{-5}
GW24E	Dapper Formation	Rising head test (Bouwer-Rice 1976)		0.03	
GW28D	Dapper Formation	Rising head test (Bouwer-Rice 1976)		0.05	
GW3_TPB	Whaka Formation, Avymore Claystone, Ulan Seams, Dapper Formation	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	15.5 DD 27.8 REC	1.2 DD 2.2 REC	
		14-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	13.9 DD 36.6 REC	0.9 DD 2.9 REC	
GW3B	Whaka Formation, Avymore Claystone, Flyblowers Creek Seam, Tomcat Gully	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	154.6 DD 131.4 REC	12.4 DD 10.5 REC	5.7×10^{-3}

Bore	Screened unit	Estimation method	Transmissivity (T) (m^2/d)	Hydraulic conductivity (K) (m/d)	Storativity* (S)
	Sandstone	14-day pump test (Theis 1935 (REC))	43.5 REC	3.5 REC	
GW22_TPB	Ulan Coal Seams, Dapper Formation	3-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	28.5 DD 31.6 REC	1.9 DD 2.1 REC	
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	14.1 DD	0.94 DD	
GW5_TPB	Tomcat Gully Sandstone, Ulan Coal Seams, Dapper Formation	24-hour pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	44.3 DD 85.2 REC	2.5 DD 4.7 REC	
		3-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	53.7 DD 76.9 REC	3.0 DD 4.3 REC	1.3 x 10^{-2}
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	28.7 DD	1.6 DD	6 x 10^{-3}
GW6_TPB	Whaka Formation	Packer test (Houlsby 1976)		7.52 x 10^{-3}	
	Whaka Formation, Avymore Claystone	Packer test (Houlsby 1976)		3.60 x 10^{-3}	
	Upper Ulan Seam	Packer test (Houlsby 1976)		6.30 x 10^{-3}	
	Lower Ulan Seam	Packer test (Houlsby 1976)		3.45 x 10^{-2}	
GW6A	Ellismayne and Whaka Formations, Avymore Claystone, Flyblowers Creek Seam	Rising head test (Bouwer-Rice 1976)		0.003	
GW7_TPB	Ellismayne and Whaka Formations, Avymore Claystone, Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams, Dapper Formation	24-hour pump test (Cooper-Jacob 1946 (DD); Theis, 1935 (REC))	8.5 DD 15.5 REC	0.2 DD 0.3 REC	
		21-day pump test (Cooper-Jacob 1946 (DD); Theis 1935 (REC))	27.9 DD 23.2 REC	0.5 DD 0.4 REC	
	Whaka Formation	Packer test (Houlsby 1976)		9.80 x 10^{-3}	
	Flyblowers Creek Seam	Packer test (Houlsby 1976)		2.60 x 10^{-2}	
	Upper Ulan Seam	Packer test (Houlsby 1976)		3.11 x 10^{-2}	

Note: DD = drawdown; REC = recovery; * Storativity is only calculated for drawdown

5.7.1 Alluvium aquifer

Groundwater quality is marginal to saline in the alluvium aquifer. The variable salinity may be associated with the depth of the piezometer and the clay content of the alluvium at each location. The highest salinities are found at monitoring piezometers screened across clayey gravels (GW1, GW10 and GW7A). Salinity in the alluvium aquifers is similar to surface water in the surrounding area (Section 5.6).

Groundwater in the alluvium aquifers is generally dominated by sodium and chloride, while in some locations magnesium and bicarbonate are dominant. Dissolved iron, copper and zinc concentrations are elevated in the alluvium aquifers. Total iron concentrations are higher than dissolved iron concentrations, indicating insoluble iron is naturally elevated in the alluvium aquifers. Elevated dissolved metal concentrations are considered to reflect natural background concentrations.

In 2009 and early 2010, concentrations of ammonia and nitrate were typically low in the alluvium aquifers, whereas total nitrogen and total phosphorus concentrations were elevated and generally exceeded the ANZECC (2000) guidelines. This may be reflective of natural processes or land practices in the area, with downward percolation of rainfall sourced water from overlying layers.

A summary of the water quality in the alluvium aquifers is presented in Table 5.6.

Table 5.6 Water quality summary for alluvium aquifers

Parameter	Units	ANZECC (2000)	No. samples	Min	Max	Mean[3]
EC	µS/cm	30–350[1]	48	**1,850**	**6,949**	**3,648**
pH	pH units	6.5–7.5[1]	48	6.21	**8.01**	7.06
Al	mg/L	0.055[2]	48	<0.01	**0.77**	0.04
Ba	mg/L	na	48	0.03	0.48	0.14
Co	mg/L	ID	48	<0.001	0.056	0.007
Cu	mg/L	0.0014	15	<0.001	**0.011**	**0.004**
Fe	mg/L	ID	48	<0.05	3.20	0.43
Pb	mg/L	0.0034[2]	48	<0.001	0.003	<0.001
Mn	mg/L	1.9[2]	48	0.016	**5.70**	0.981
Ni	mg/L	0.011[2]	15	0.001	**0.012**	0.005
Zn	mg/L	0.008[2]	48	<0.005	**0.194**	**0.028**

Note: Metals are dissolved metal species.
1 trigger values for upland rivers in south-east Australia (ANZECC 2000)
2 95% trigger values (ANZECC 2000)
3 mean calculated by halving values below detection limits
4 **Bold** — value outside ANZECC guidelines
5 na — no trigger value available
6 ID — insufficient data to determine trigger value

Apparent groundwater ages in the alluvium aquifers, determined by radiocarbon dating, were modern (i.e. less than 100 years).

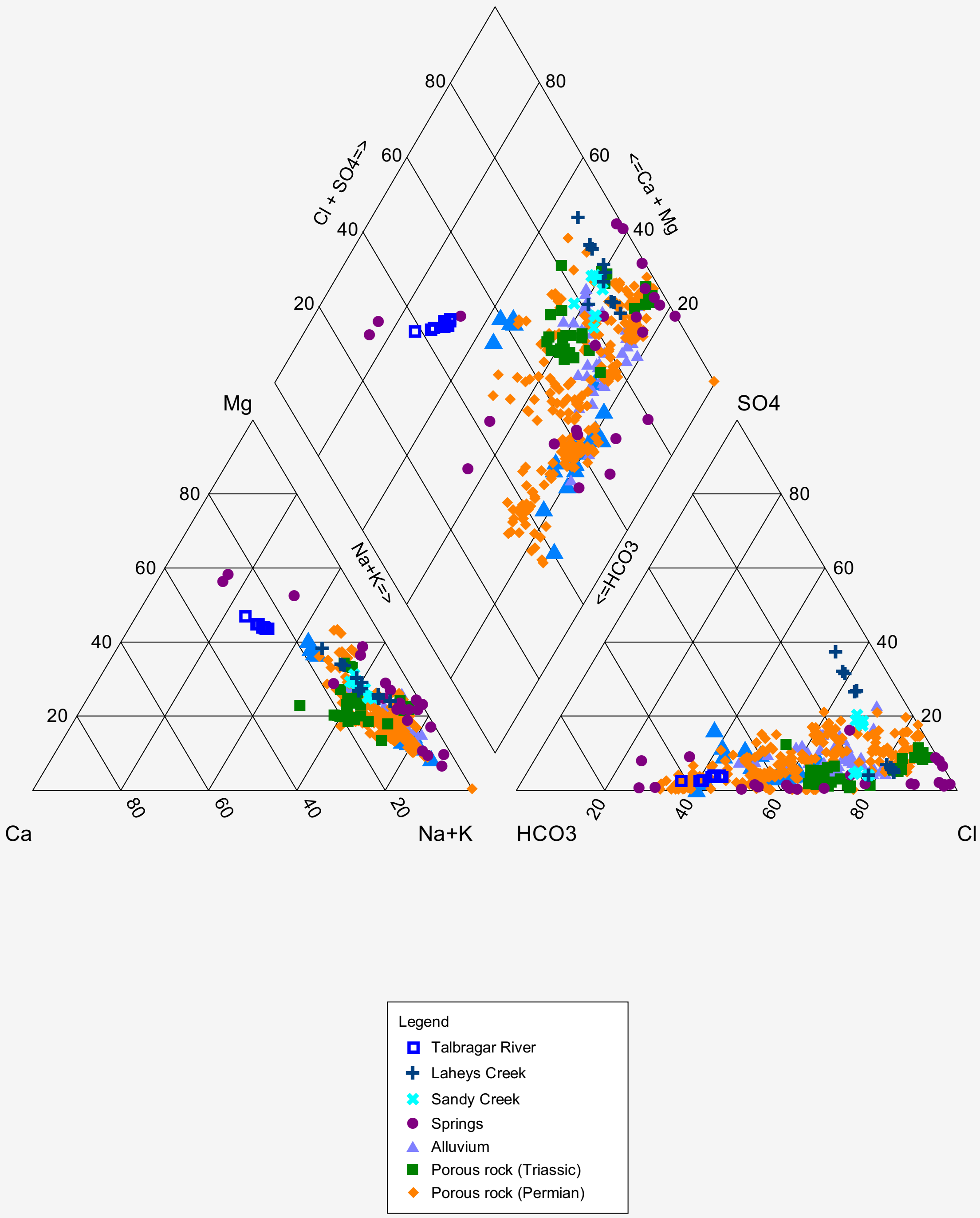
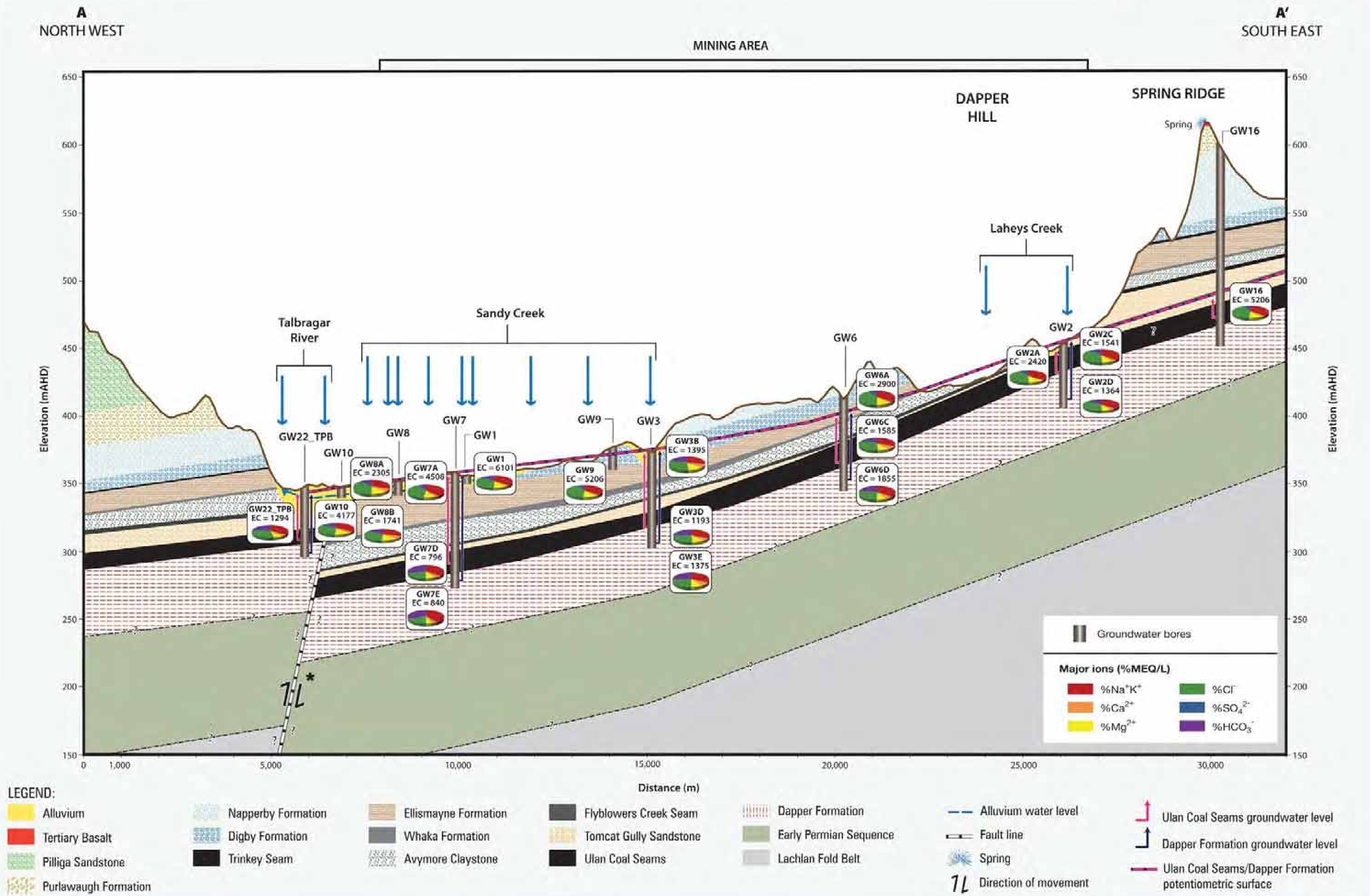


Figure 5.10 Piper diagram for groundwater, surface water and springs



Note: *Interpreted extension to Laheys Creek fault.

Figure 5.11 Cross-section (A - A') showing groundwater chemistry and salinity

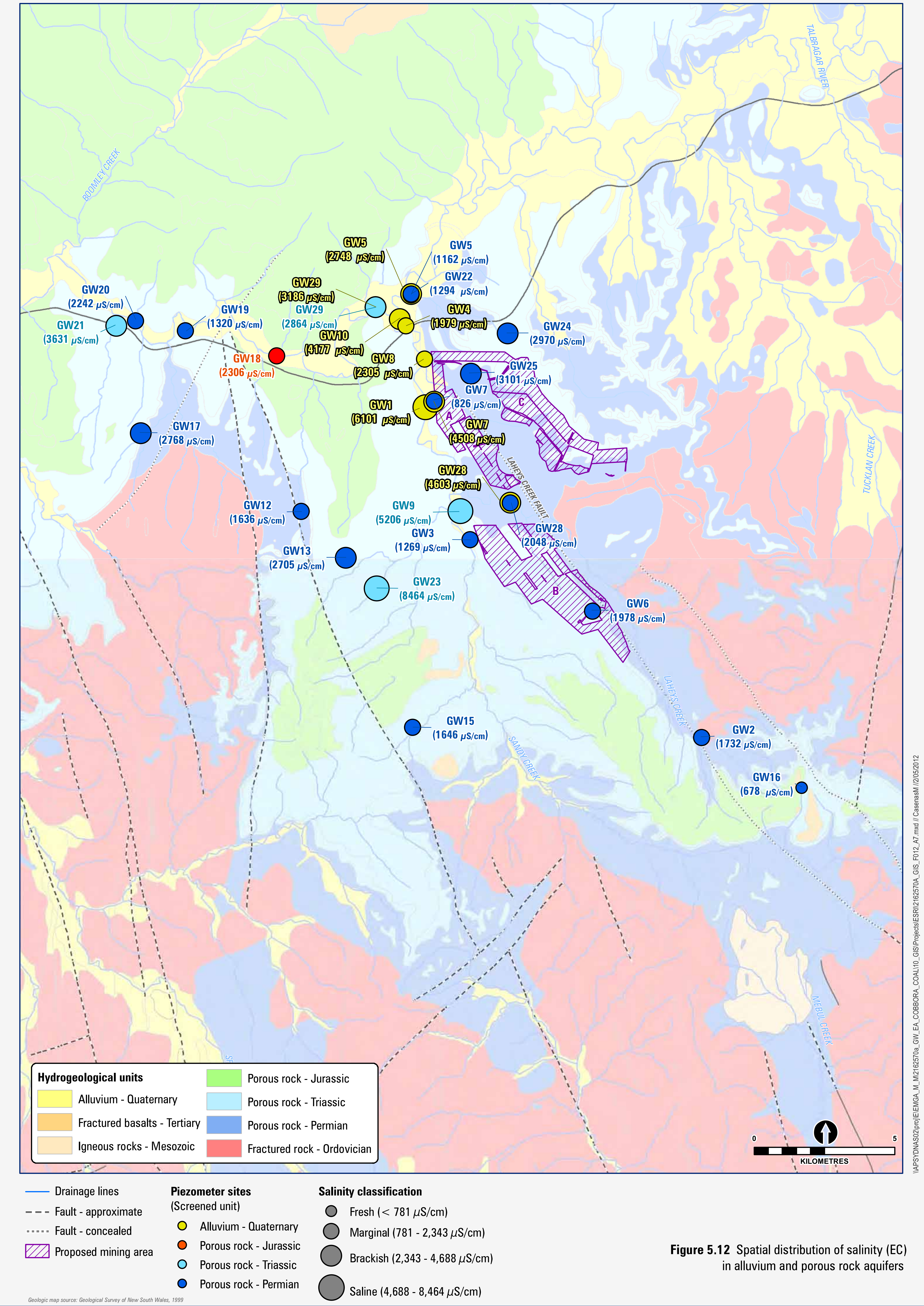


Figure 5.12 Spatial distribution of salinity (EC) in alluvium and porous rock aquifers

\\APSYDNAS02\proj\E\EMGA_M_M2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F012_A7.mxd // CasenasM // 2/05/2012

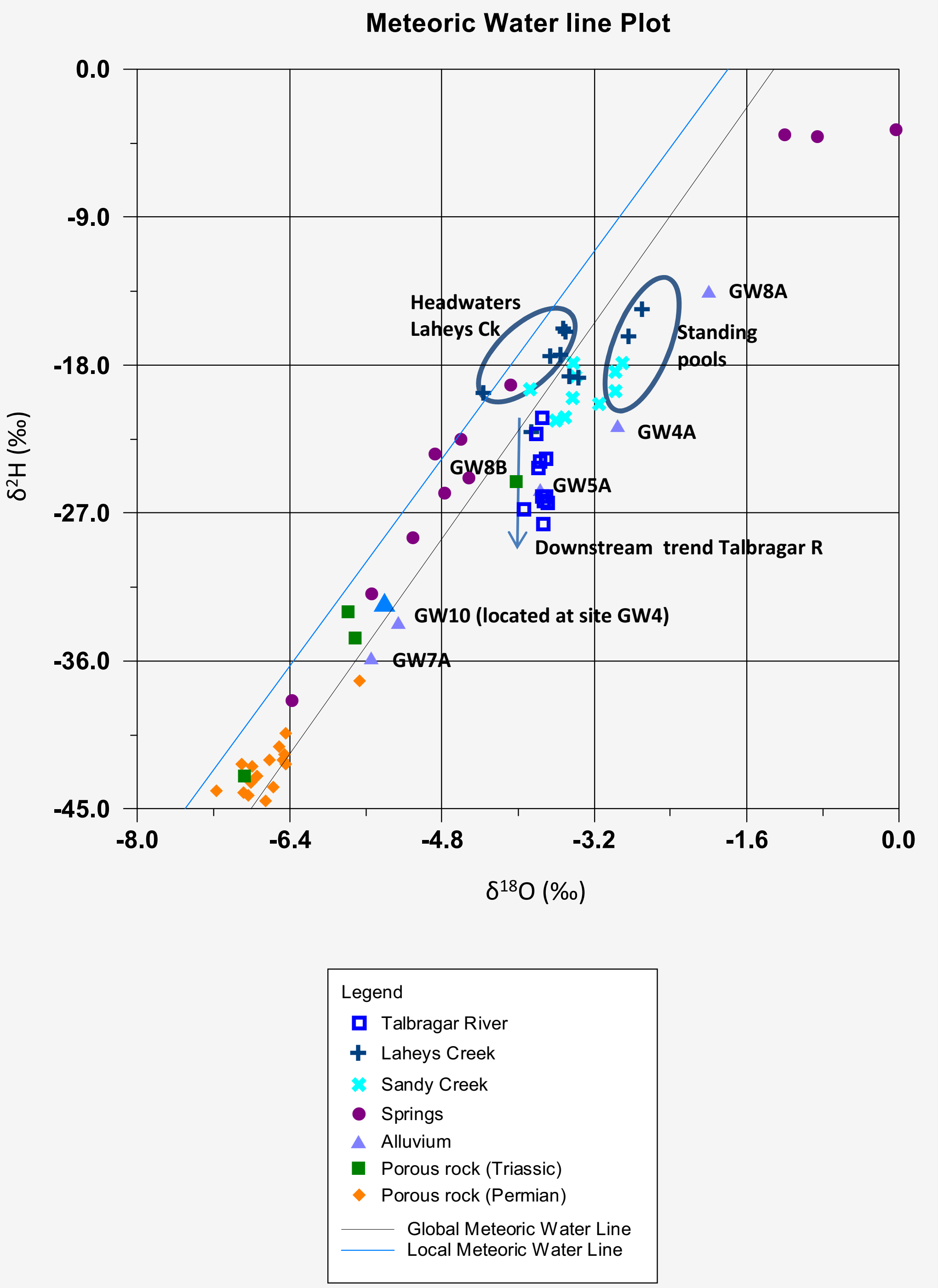
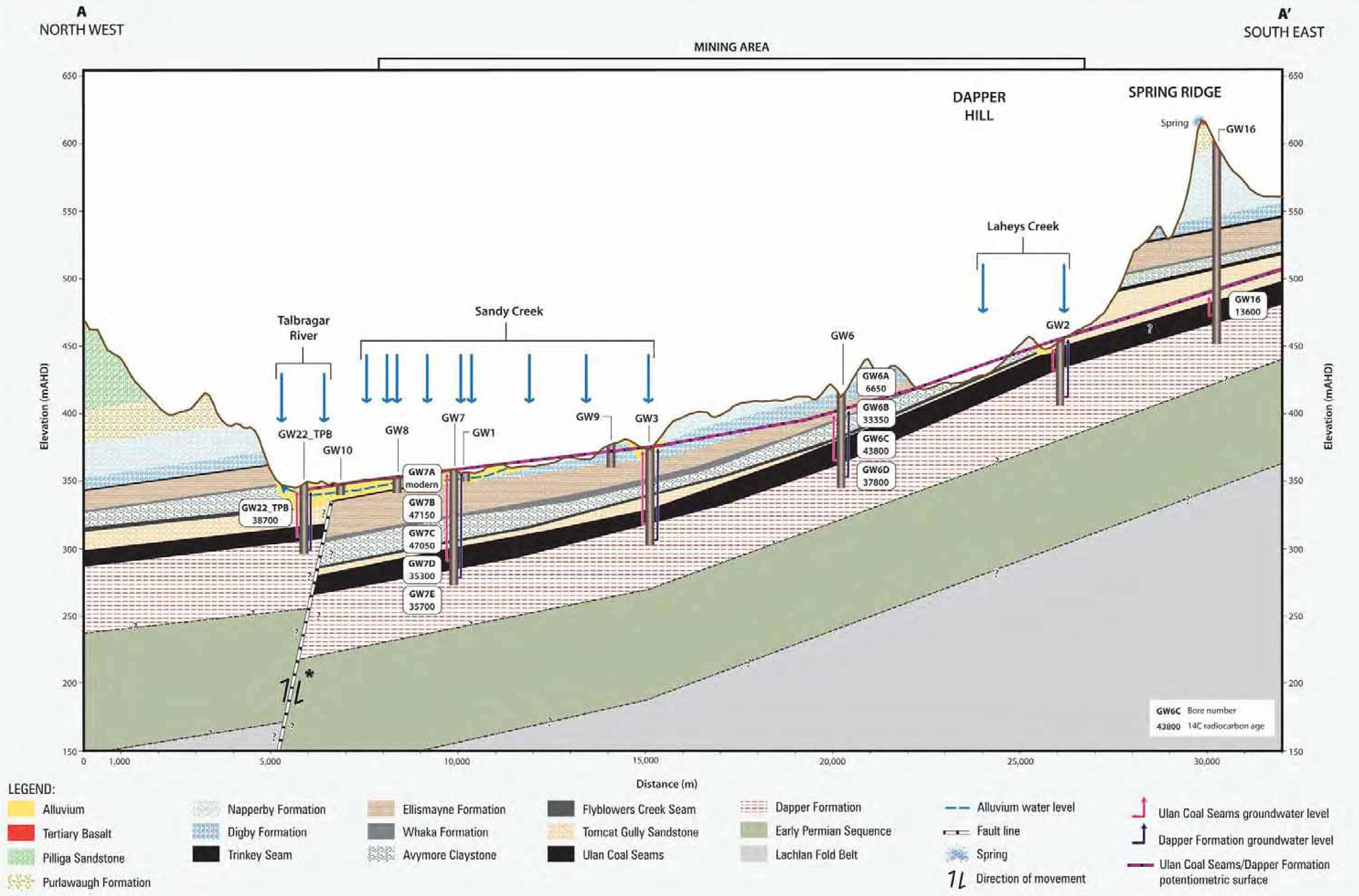


Figure 5.13 Bivariate plot of δ^2H v $\delta^{18}O$ results plotted against the GMWL



Note: * Interpreted extension to Laheys Creek fault.

Figure 5.14 Cross-section (A - A') showing groundwater age

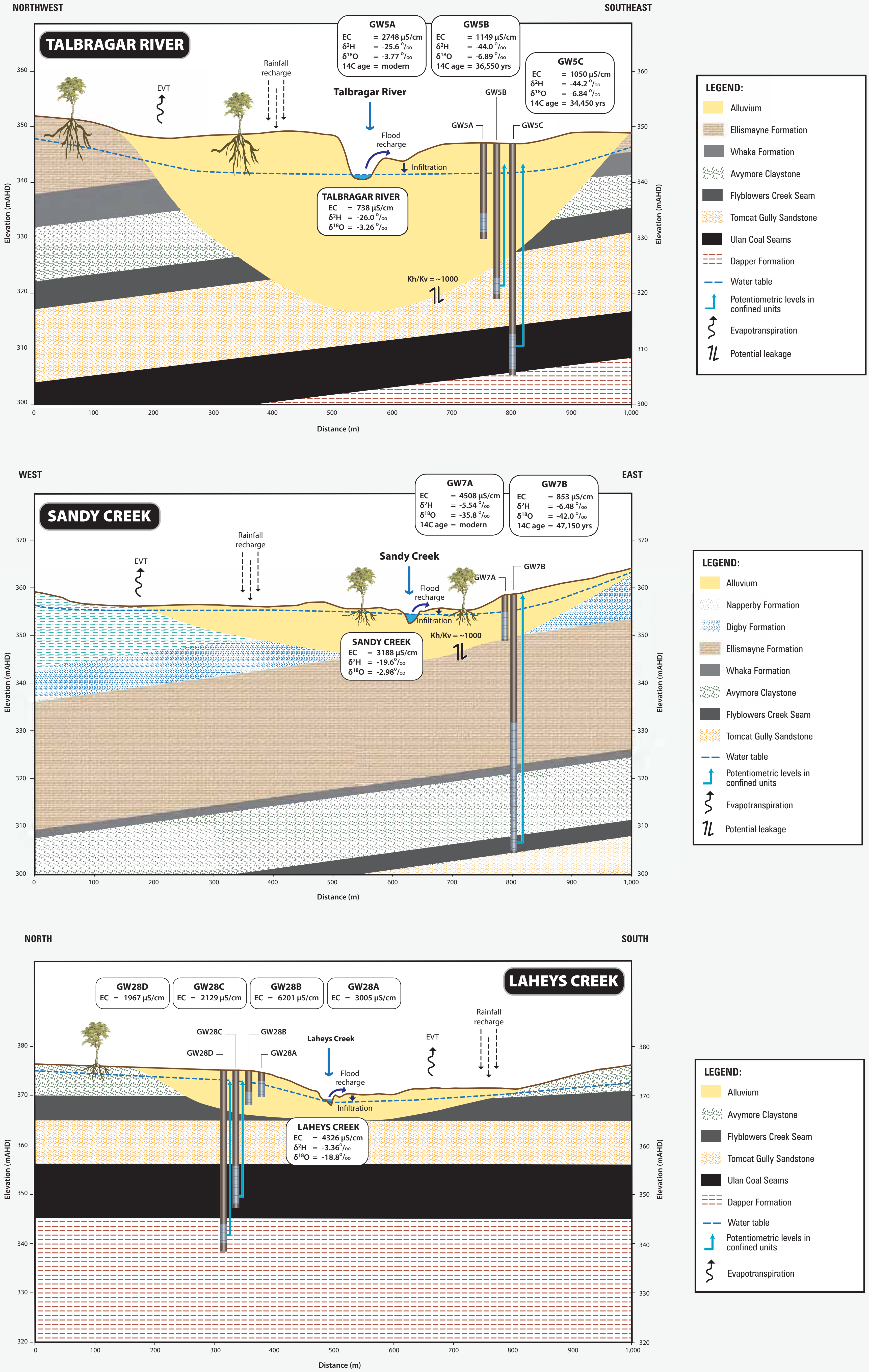


Figure 5.15 Conceptual hydrogeological cross-sections for Talbragar River, Sandy Creek and Laheys Creek

5.7.2 Porous rock — Permo-Triassic

The Permo-Triassic porous rock aquifers typically contains brackish, slightly acidic and sodium-chloride type waters. Although some differences in water quality occur between the Triassic and Permian aquifers, they are characteristically similar.

5.7.2.1 Triassic aquifers

The Triassic aquifers are marginal to saline with a higher average salinity than other units in the assessment area. The pH is slightly acidic to slightly alkaline and was often within the ANZECC (2000) guideline range of pH 6.5 to pH 7.5.

The Triassic aquifers are dominated by chloride and sodium ions, and at some locations bicarbonate and magnesium ions. Dissolved copper, zinc and manganese concentrations often exceeded the ANZECC (2000) guidelines; however, this is likely to be representative of natural background concentrations within the Triassic aquifers.

In 2009 and early 2010, concentrations of ammonia and nitrate were low in the Triassic aquifers, whereas, total nitrogen and total phosphorus concentrations were elevated and generally exceeded the ANZECC (2000) guidelines. Elevated total phosphorus and total nitrogen concentrations can be attributed to land practices or natural processes.

A summary of the water quality in the Triassic aquifers is presented in Table 5.7.

Table 5.7 Water quality summary for Triassic aquifers

Parameter	Units	ANZECC (2000)	No. samples	Min	Max	Mean[3]
EC	µS/cm	30–350[1]	31	**827**	**9,060**	**3,993**
pH	pH units	6.5–7.5[1]	31	**5.83**	**7.67**	6.51
Al	mg/L	0.055[2]	31	<0.01	**0.09**	0.015
Ba	mg/L	na	31	<0.001	0.8	0.257
Be	mg/L	ID	31	<0.001	0.094	0.004
Co	mg/L	ID	31	<0.001	0.044	0.009
Cu	mg/L	0.0014	5	<0.001	0.011	0.003
Fe	mg/L	ID	31	<0.05	7.16	2.02
Pb	mg/L	0.0034[2]	31	<0.001	**0.008**	<0.001
Mn	mg/L	1.9[2]	31	0.05	**6.27**	1.00
Ni	mg/L	0.011[2]	5	<0.001	**0.031**	**0.014**
Zn	mg/L	0.008[2]	31	<0.005	**0.126**	**0.033**

Note: Metals are dissolved metal species.
1 trigger values for upland rivers in south-east Australia (ANZECC 2000)
2 95% trigger values (ANZECC 2000)
3 mean calculated by halving values below detection limits
4 **Bold** — value outside ANZECC guidelines
5 na — no trigger value available
6 ID — insufficient data to determine trigger value

5.7.2.2 Permian aquifers

The Permian aquifers are fresh to saline. The Whaka Formation and Flyblowers Creek Seam have the highest salinities. The Dapper Formation and the Lower Ulan Coal Seam have the lowest salinities in the Permian aquifers.

The pH of the Permian aquifers range from acidic to alkaline and are generally below the ANZECC (2000) guideline range of pH 6.5 to pH 7.5.

The Permian aquifers are dominated by sodium, magnesium, chloride and bicarbonate ions, with the exception of monitoring bore GW24C. The groundwater measured at GW24C was found to be sodium and potassium dominated. Water types varied with location in the assessment area. Different Permian formation aquifers are often found to be more similar at nested monitoring sites, than within the same Permian units at separate sites. This may indicate vertical connection between the Permian units.

Dissolved metal concentrations are generally below ANZECC (2000) guideline values in the Permian units, with the exception of dissolved nickel and zinc. Concentrations of dissolved iron were elevated and total iron concentrations were higher, indicating insoluble iron is in higher concentrations in the Permian aquifers. The elevated metal concentrations are considered representative of natural background conditions.

In 2009 and early 2010, concentrations of ammonia and nitrate were typically below the ANZECC (2000) guidelines in the Permian aquifers. Total nitrogen and total phosphorus concentrations typically exceeded the ANZECC (2000) guidelines. This can be attributed to land practices or natural processes.

A summary of the water quality in the Permian aquifers is presented in Table 5.8.

Table 5.8 Water quality summary for Permian aquifers

Parameter	Units	ANZECC (2000)	No. samples	Min	Max	Mean[3]
EC	µS/cm	30–350[1]	222	**556**	**9,030**	**1,618**
pH	pH units	6.5–7.5[1]	222	**5.27**	**12.24**	**6.46**
Al	mg/L	0.055[2]	222	<0.01	**7.92**	**0.08**
Ba	mg/L	na	222	0.029	0.949	0.157
Be	mg/L	ID	222	<0.001	0.002	<0.001
Co	mg/L	ID	222	<0.001	0.126	0.006
Cu	mg/L	0.0014	57	<0.001	0.011	0.001
Fe	mg/L	ID	222	<0.05	91.1	14.50
Pb	mg/L	0.0034[2]	222	<0.001	**0.093**	0.001
Mn	mg/L	1.9[2]	222	0.009	**3.56**	0.56
Ni	mg/L	0.011[2]	57	<0.001	**0.156**	**0.011**
Zn	mg/L	0.008[2]	222	<0.005	**1.08**	**0.05**

Note: Metals are dissolved metal species.
1 trigger values for upland rivers in south-east Australia (ANZECC 2000)
2 95% trigger values (ANZECC 2000)
3 mean calculated by halving values below detection limits
4 **Bold** — value outside ANZECC guidelines
5 na — no trigger value available
6 ID — insufficient data to determine trigger value

Apparent groundwater ages in the Permian aquifers, determined by radiocarbon dating, range from 6,650 to 47,150 years.

5.8 Surface water – groundwater connectivity

Surface water and groundwater connectivity exists across the assessment area in a variety of forms, including springs/seeps (discussed in Section 5.8.5.3), baseflow and semi-permanent pools within the Talbragar River and tributaries, and flood flow recharge to groundwater. Conceptual cross sections through alluvium in Talbragar River, Sandy Creek and Laheys Creek are shown in Figure 5.15 to illustrate the following discussion.

5.8.1 Talbragar River

5.8.1.1 Hydraulic gradient

Groundwater levels at the alluvium piezometers GW4, GW10 and GW5A were compared with the river stage elevations in the Talbragar River at each location (Table 5.9). The higher groundwater levels compared to the Talbragar River stages confirms that the Talbragar River, in that location, at that time was potentially a gaining stream. Photos 5.1 and 5.2 show the Talbragar River at the time of the survey near GW4 and GW5A.

The longer-term monitoring at these sites indicates the groundwater levels used for the comparison are not temporarily high as a result of recent rainfall but instead are close to average conditions (see Appendix E). The groundwater flow direction at these sites is established to be towards the Talbragar River.

Table 5.9 Comparison of Talbragar River and alluvium groundwater levels

Piezometer	Talbragar River level (mAHD) 29 April 2010	Groundwater level (mAHD) 29 April 2010
GW4	339.3	342.7
GW10	339.3	339.8
GW5A	339.7	341.1

(Photos by Boardman and Peasley (2010))

Photo 5.1 Talbragar River near GW4

Photo 5.2 Talbragar River near GW5A

In August 2011, Parsons Brinckerhoff completed a survey of the Talbragar River in the assessment area to identify potential locations of groundwater baseflow discharge. Samples were collected at 10 locations for chemical and isotopic analysis (Table 5.10). At the time of the survey, there was continuous flow the entire length of the survey area and there were no obvious visual signs of groundwater discharge.

During the survey of the Talbragar River salinity and pH increased along the flow path. Major ion chemistry was dominated by Mg-Na-Ca-HCO_3-Cl and was distinctly different from surface water from Laheys and Sandy creeks, and groundwater from the alluvium or porous rock aquifers (Figure 5.10). Dissolved metals concentrations were generally low and did not exceed the ANZECC (2000) guidelines.

Based on hydrogeochemical evidence, the contribution of groundwater baseflow within the study area must be low and this is further investigated in Section 5.8.4.

Table 5.10 Water quality summary for Talbragar River (10 samples)

Parameter	Units	ANZECC (2000)	Min	Max	Mean[3]
EC	µS/cm	30–350[1]	**732**	**1,146**	**941**
pH	pH units	6.5–7.5[1]	7.4	**8.65**	**8.43**
Al	mg/L	0.055[2]	<0.01	**0.24**	0.03
Ba	mg/L	na	0.049	0.061	0.057
Fe	mg/L	ID	<0.05	0.30	0.05
Mn	mg/L	1.9[2]	0.021	0.100	0.037
Zn	mg/L	0.008[2]	<0.005	**0.047**	**0.013**

Note: Metals are dissolved metal species.
1 trigger values for upland rivers in south-east Australia (ANZECC 2000)
2 95% trigger values (ANZECC 2000)
3 mean calculated by halving values below detection limits
4 **Bold** — value outside ANZECC guidelines
5 na — no trigger value available
6 ID — insufficient data to determine trigger value

5.8.2 Sandy Creek

In August 2011, Parsons Brinckerhoff completed a survey of Sandy Creek in the assessment area to identify potential locations of groundwater baseflow discharge. Samples were collected at 10 locations for chemical and isotopic analysis (Table 5.11). At the time of the survey, surface water was present in a series of disconnected semi-permanent pools.

Table 5.11 Water quality summary for Sandy Creek (10 samples)

Parameter	Units	ANZECC (2000)	Min	Max	Mean[3]
EC	µS/cm	30–350[1]	**1903**	**3280**	**2690**
pH	pH units	6.5–7.5[1]	6.88	**8.46**	**8.06**
Al	mg/L	0.055[2]	<0.01	0.03	0.01
Ba	mg/L	na	0.156	0.27	0.23
Co	mg/L	ID	<0.001	0.001	<0.001
Fe	mg/L	ID	<0.05	0.26	0.06
Mn	mg/L	1.9[2]	0.213	0.734	0.478
Zn	mg/L	0.008[2]	<0.005	0.007	<0.005

Note: Metals are dissolved metal species.
1 trigger values for upland rivers in south-east Australia (ANZECC 2000)
2 95% trigger values (ANZECC 2000)
3 mean calculated by halving values below detection limits
4 **Bold** — value outside ANZECC guidelines
5 na — no trigger value available
6 ID — insufficient data to determine trigger value

The survey at Sandy Creek found salinity increased along the flow path. pH ranged from near-neutral to alkaline, however, there was no correlation between pH and distance along flow path. The major ion chemistry of Sandy Creek was generally dominated by Na-Mg-Cl (Figure 5.10), with the exception of samples collected at the headwaters and the confluence with the Talbragar River, which were dominated by Na-Mg-Cl-HCO_3. Dissolved metals concentrations were generally low and did not exceed the ANZECC (2000) guidelines.

Major ion chemistry of Sandy Creek is similar to the alluvium in the vicinity of the confluence with the Talbragar River (GW8A, GW10 and GW7A), although there are some differences in salinity between groundwater from the alluvium and surface water.

5.8.3 Laheys Creek

In August 2011, Parsons Brinckerhoff undertook a survey of Laheys Creek within the assessment area to identify potential locations of groundwater baseflow discharge. Samples were collected at 10 locations for chemical and isotopic analysis (Table 5.12). At the time of the survey, surface water was present in a series of disconnected semi-permanent pools.

The survey at Laheys Creek found salinity typically increased from the headwaters in the south-east of the assessment area along the flow path to the confluence with Sandy Creek. The pH was neutral to alkaline, however, there was no correlation between pH and distance along flow path. Surface water evolved from Na-Mg-Cl in the headwaters to Na-Mg-Cl-SO_4 type water in the lower reaches.

Table 5.12 Water quality summary for Laheys Creek (10 samples)

Parameter	Units	ANZECC (2000)	Min	Max	Mean[3]
EC	µS/cm	30–350[1]	**853**	**4676**	**2742**
pH	pH units	6.5–7.5[1]	7.03	**8.50**	**7.92**
Al	mg/L	0.055[2]	<0.01	**0.18**	0.04
Ba	mg/L	na	0.049	0.196	0.110
Co	mg/L	ID	<0.001	0.002	0.001
Fe	mg/L	ID	<0.05	1.83	0.28
Mn	mg/L	1.9[2]	0.031	1.16	0.49
Zn	mg/L	0.008[2]	<0.005	**0.032**	**0.009**

Note: Metals are dissolved metal species.
1 trigger values for upland rivers in south-east Australia (ANZECC 2000)
2 95% trigger values (ANZECC 2000)
3 mean calculated by halving values below detection limits
4 **Bold** — value outside ANZECC guidelines
5 na — no trigger value available
6 ID — insufficient data to determine trigger value

5.8.4 Environmental isotopes

A meteoric water line plot presents the stable isotope results for groundwater, surface water and springs in the assessment area in Figure 5.13. Isotope results for alluvium, porous rock aquifers and surface water are summarised in Table 5.13. Stable isotopes were analysed to assist with assessing:

- connection between the alluvium groundwater and surface water
- connection between porous rock aquifers and alluvium groundwater and/or surface water.

Table 5.13 Stable isotope summary for alluvium, porous rock and surface water

Unit	$\delta^{18}O$ (‰)			$\delta^{2}H$ (‰)		
	Min	**Max**	**Mean***	**Min**	**Max**	**Mean**
Alluvium Aquifer	-5.5	-2.0	**-3.9**	-35.8	-13.5	**-26.1**
Porous rock (Triassic)	-6.9	-4.0	**-5.6**	-43.0	-25.1	**-33.9**
Porous rock (Permian)	-7.2	-5.7	**-6.5**	-44.5	-37.2	**-42.2**
Talbragar River	-3.8	-3.7	**-3.8**	-27.7	-21.2	**-24.8**
Sandy Creek	-3.9	-2.9	**-3.3**	-21.4	-17.9	**-19.5**
Laheys Creek	-4.4	-0.9	**-3.3**	-22.1	-4.1	**-16.5**

The major findings from stable isotopes are:

- The isotopic values of surface water from the Talbragar River plot near the GMWL at the western boundary of the assessment area, and show a general trend of ^{2}H depletion along the flow path, with isotopic values merging towards those of the alluvium in the vicinity of GW5. The isotopic signatures suggest that there is some connection between alluvium groundwater and surface water along the Talbragar River in the vicinity of its confluence with Sandy Creek. These results support the hydrograph data for GW5A, which shows sharp rises in level in response to rainfall and relatively steep recession curves which is indicative of direct riverbank recharge by flood waters.

- Stable isotope values from Sandy Creek plot to the right of the GMWL, indicating surface water has undergone evaporative enrichment. This is consistent with the condition of surface water at time of sampling (standing water in a series of disconnected semi-permanent pools).

- The isotopic signatures of Sandy Creek are distinctly different from the isotopic signature of the Permian aquifers, suggesting that even in those locations where Permian rocks outcrop, the connection between groundwater and surface water is limited.

- The isotopic signatures of Laheys Creek headwaters plot close to GMWL, and are distinctly different to the isotopic signature of the Permian aquifers. These results are consistent with the headwaters of Laheys Creek being located in a groundwater recharge zone.

- Surface water samples collected from shallow standing pools in mid-reaches of Laheys Creek show an evaporative signature (plot right to the GMWL). These isotopic signatures appear to be similar to those of the Laheys Creek headwaters, but with an isotopic enrichment in 18O by evaporation.

- The isotopic signatures of the alluvium at GW4A and GW8A are isotopically enriched (plotting to the right of the GMWL), and appear to represent an evaporated surface water signature. The channel of Sandy Creek in the vicinity of these monitoring bores is less confined than further upstream and the U-shaped geometry of the channel indicates that overbank flooding occurs. These isotopic findings are consistent with recharge of evaporated floodwaters.

- There are distinct isotopic differences between GW8A (shallow alluvium) and GW8B (deep alluvium/top of the Triassic) indicating very limited connection between Triassic aquifers and deep alluvium.

- There are distinct isotopic differences between GW4 (shallow alluvium) and GW10 (deep alluvium/top of the Triassic) (bores are located at the same site located adjacent to Sandy Creek), indicating very limited connection between Triassic aquifers and deep alluvium.
- The isotopic signature of groundwater in the alluvium at GW7A is isotopically similar to those of groundwater samples from Triassic aquifers indicating a limited hydraulic connection between the Triassic aquifers and alluvium at this location. The isotopic data supports the hydraulic data, which indicates a strong upward gradient (but weak hydraulic connection (low conductivity) across the alluvium interface).

5.8.5 Potential groundwater availability to ecosystems

Groundwater is potentially available to ecosystems in the following environments:

- shallow groundwater in alluvium
- semi-permanent pools (non-flowing) within the creeks
- springs/seeps (including Naran Springs).

5.8.5.1 Shallow groundwater in the alluvium

Figure 5.17 indicates areas where groundwater is inferred from monitoring and modelling to occur within 3 m of the ground surface (the assumed maximum rooting depth for trees). The 3 metres represents an appropriate depth for the limit of evapotranspiration across the area due to the likely maximum depth of the capillary fringe, and the prevalence of shallow rooted vegetation. These alluvial areas tend to be restricted to a narrow zone close to the creek and river channels. Where groundwater is inferred to be shallow, there is potential for groundwater to discharge to semi-permanent pools.

5.8.5.2 Semi-permanent pools

The Project ecologist has identified six semi-permanent pools that potentially provide a refuge function to aquatic ecology. These are shown in Figure 5.17. Water quality at these aquatic ecology sites and in the shallow alluvium is discussed in the preceding sections. A more detailed discussion on semi-permanent pools is provided in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012).

5.8.5.3 Springs

Seventeen springs were identified in this study, a number of which were dammed and could therefore not be conclusively shown to be spring-fed. The springs identified generally occurred at the contact between permeable Jurassic sandstone and underlying Triassic shales or between the Tertiary basalts and underlying strata. These are located in upland areas to the south and south-east of the mining area, or on the northern side of the Talbragar River (Figure 5.16). The two springs located north of the Talbragar River are associated with discharges from Jurassic strata and one of these springs contributes to baseflow of a nearby creek (a tributary of Boomley Creek).

Naran Springs is designated a high-priority groundwater dependent ecosystem (GDE) identified in the Water Sharing Plan for the MDB Porous Rock Groundwater Source (NOW 2011b). It is located approximately 5.25 km to the west of the proposed mining area A (Figure 5.17). The location of Naran Springs was identified in the field during a site visit in March 2012. The ‘spring’ was found to be dammed and was not in a natural condition.

A water sample was collected from the spring and was analysed. The stable isotope result indicated an evaporated rainfall signature, similar to other spring water samples collected in the area.

Identified springs generally ranged from fresh to brackish, with the exception of the springs associated with the Jurassic strata, which were saline. The lower salinity springs to the south and south-east of the mining area are rainfall-fed, while the brackish springs were either rainfall-fed springs (or seeps) affected by evaporation, or springs associated with shallow groundwater systems.

The pH was generally slightly acidic and was often below the ANZECC (2000) guideline range of pH 6.5 to pH 7.5. Higher pH values were found to the west of the mining area.

Springs are generally Na-Mg-Cl dominant (Figure 5.10), with increasing HCO_3^- in springs associated with Tertiary basalts in the south-east of the assessment area.

Dissolved metals were detected at most spring locations but were below the ANZECC (2000) guideline range, except for aluminium.

In 2009, concentrations of ammonia and nitrate were low and typically below the ANZECC (2000) guidelines. Reactive phosphorus concentrations occasionally exceeded the ANZECC (2000) guidelines.

A summary of the water quality in the identified springs is presented in Table 5.14.

Table 5.14 Water quality summary for private springs

Parameter	Units	ANZECC (2000)	No. samples	Min	Max	Mean[3]
EC	µS/cm	30–350[1]	23	48	**8,830**	**1,362**
pH	pH units	6.5–7.5[1]	23	**4.53**	**8.98**	**6.20**
Al	mg/L	0.055[2]	17	<0.01	**4.43**	**0.55**
Ba	mg/L	na	17	0.009	0.446	0.116
Co	mg/L	ID	17	<0.001	0.063	0.006
Fe	mg/L	ID	17	<0.05	10.80	1.29
Pb	mg/L	0.0034[2]	17	<0.001	**0.006**	<0.001
Mn	mg/L	1.9[2]	16	0.014	0.643	0.230
Zn	mg/L	0.008[2]	17	0.006	**0.126**	**0.030**

Note: Metals are dissolved metal species.
1 trigger values for upland rivers in south-east Australia (ANZECC 2000)
2 95% trigger values (ANZECC 2000)
3 mean calculated by halving values below detection limits
4 **Bold** — value outside ANZECC guidelines
5 na — no trigger value available
6 ID — insufficient data to determine trigger value

Stable isotopic ratios for spring samples generally plot on the GMWL indicating springs are of meteoric origin (rainfall recharge (Figure 5.13)). A number of samples plot to the right of the GMWL; it is important to note these samples were collected from shallow pools/dams and isotopic signatures are the result of isotopic fractionation by evaporation.

One spring located south-west of the mining area (LS41) had an isotopic signature similar to older, more isotopically depleted signatures of groundwater. The groundwater level within the Permo-Triassic rocks at this location is estimated at approximately 50 m below the surface.

Therefore, the water supplying this spring is likely to be associated with slow groundwater flow through the low hydraulically conductive units of the Purlawaugh Formation, which consist of sandstones, siltstones and mudstones. This spring has anecdotally being flowing continuously since agricultural development commenced in the area and is located on the contact between the Jurassic and Permo-Triassic units.

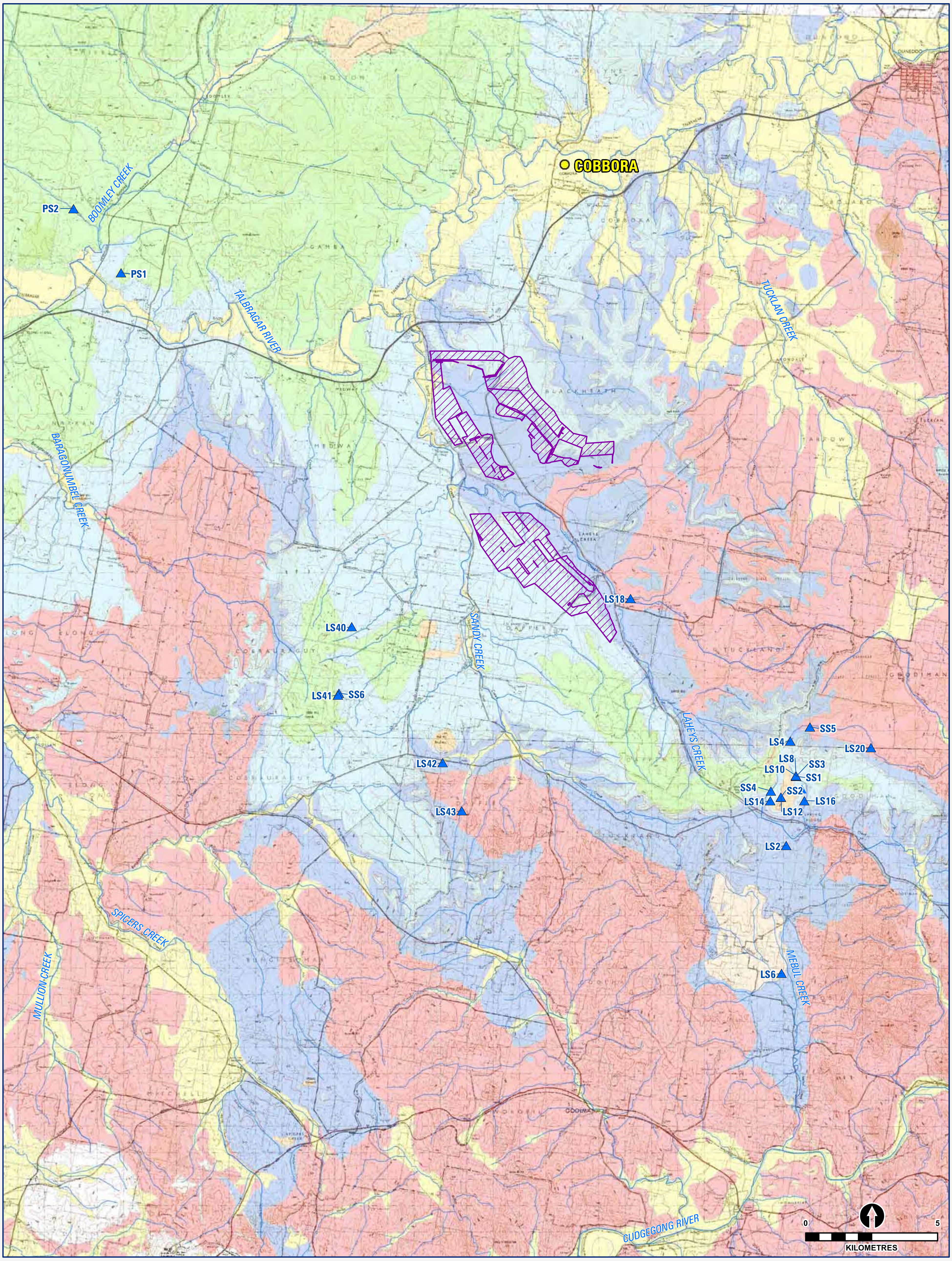
Apparent spring water ages, determined by radiocarbon dating, were modern to less than 400 years.

Based on the geochemical and isotopic evidence, springs are rainfall recharge fed, and occur due to the relatively short flow paths within the basalt system and limited connectivity between the basalt and underlying formation. Springs appear to be typically associated with isolated (local) hydrogeological systems overlying the more regional systems.

5.9 Conceptual model

A hydrogeological conceptual model is a summary, accompanied by a graphical representation, of the key processes considered to control groundwater levels and flow within a groundwater system. The conceptual model describes how water enters, exits, is stored, and moves within a hydrogeological system and how groundwater interacts with surface water systems and potentially dependent ecosystems. Ultimately the conceptual model informs the development of a numerical predictive groundwater model which is used to assess impacts on hydrologic systems from activities such as mining and groundwater extraction.

The conceptual model for groundwater systems in the assessment area is based on the cumulative results from an extensive groundwater investigation program carried out over three years. While our conceptual understanding is always evolving as new data comes to light, there is now a strong scientific basis for the following conceptual framework.
The current conceptual understanding of the groundwater system in the assessment area is depicted on the hydrogeological cross sections in Figure 5.15.



Springs

Proposed mining areas

Hydrogeological units

- Alluvium - Quaternary
- Fractured basalts - Tertiary
- Igneous rocks - Mesozoic
- Porous rock - Jurassic
- Porous rock - Triassic
- Porous rock - Permian
- Fractured rock - Ordovician

Figure 5.16 Spring survey

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

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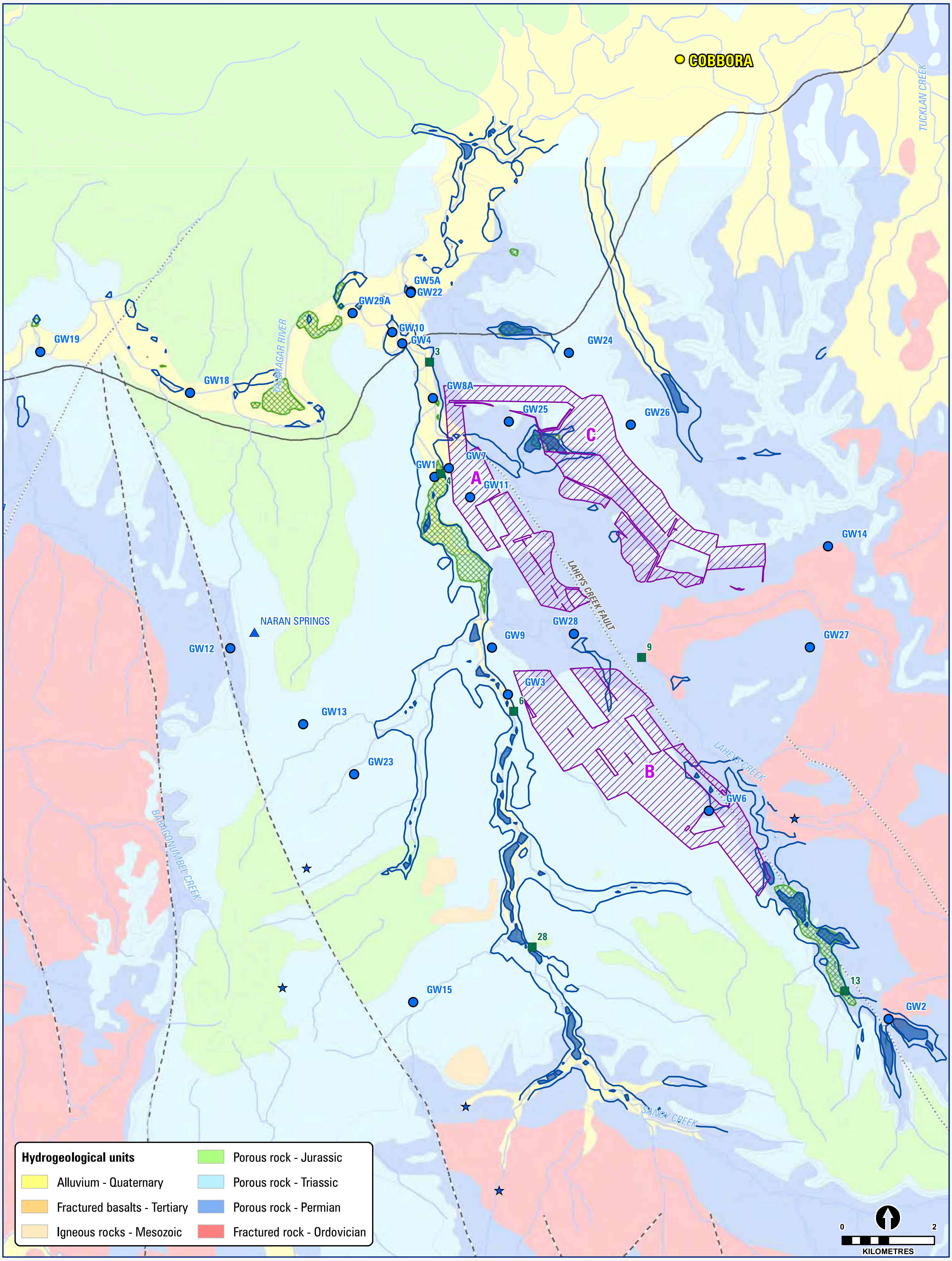

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- Piezometer sites
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas

Potential GDE

- Springs (identified in spring survey)
- High priority GDE*
- Aquatic ecology sites

Potential groundwater available to ecosystems

(Based on model)

- 0 - 3 m below ground level in alluvium
- 3 - 5 m below ground level in alluvium
- Artesian heads in Dapper Formation

Figure 5.17 Modelled potential groundwater availability to ecosystems

*Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011, NSW Office of Water 2011

5.9.1 The groundwater systems

Within the assessment area and immediate surrounds groundwater occurs within four regionally significant aquifer systems:

- the alluvium aquifer associated with unconsolidated sediments of the Talbragar River, and also minor alluvium associated with the tributaries to the Talbragar River (Sandy Creek and Laheys Creek)
- the porous rock aquifer within the Permo-Triassic sediments of the Gunnedah-Oxley Basin
- porous rock aquifers of Jurassic age
- fractured rock aquifers within the metamorphic basement rocks of the Lachlan Fold Belt.

Of these, the first two aquifer systems are by far the most important in the assessment area with regard to groundwater and surface water impacts.

The Lachlan Fold Belt fractured aquifer is of very low permeability, does not host a significant groundwater resource and will not be intersected by mining. Jurassic rocks associated with the GAB occur to the north of the Talbragar River. However, much of the Jurassic rocks in the assessment area are disconnected outliers and are considered part of the Gunnedah-Oxley basin for water management purposes.

The basal unit of the Jurassic rocks (Purlawaugh Formation) comprises shales and interbedded sandstones and therefore the aquifer units of the Jurassic formations are considered not to be hydraulically connected to the underlying Permo-Triassic aquifers. Groundwater modelling carried out as part of this investigation supports the conclusion that the porous Jurassic aquifers will experience negligible impact from the proposed operations.

The Permo-Triassic coal measures and sandstone units form an open folded and faulted sequence of porous rocks that unconformably overlie the low permeability basement rocks of the Lachlan Fold Belt. Groundwater monitoring indicates that the Permo-Triassic rocks act essentially as a single (but heterogeneous) porous aquifer unit of low to moderate permeability. Within the major river and stream valleys, alluvial deposits comprising mostly sandy and gravelly clays form minor aquifers.

Although the alluvium directly overlies the Permo-Triassic rocks, the alluvium aquifers are distinct systems that are locally recharged and hydraulically poorly connected to the regional Permo-Triassic aquifer.

The dominant surface water features in the assessment area are the Talbragar River and its main tributary streams, along which groundwater discharges via evapotranspiration and, locally, by minor direct seepage. For the most part the stream and river channels are within Quaternary alluvial deposits of low permeability, but at several locations, Permo-Triassic rocks are exposed in the stream bed and banks.

The Talbragar River and its tributaries are ephemeral systems in the assessment area, i.e. there is no sustained baseflow during dry periods, despite artesian groundwater pressures in adjacent and underlying rocks.

Within this aquifer framework, groundwater storage and flow is largely driven by the following key processes:

- rainfall recharge (inflow)
- evapotranspiration (outflow)
- baseflow discharge to streams and the Talbragar River (outflow)
- inter-aquifer connectivity (inflow/outflow)
- regional through flow (inflow/outflow).

A more detailed discussion of the current understanding of these processes along with supporting rationale is provided in the following subsections.

5.9.2 Groundwater flow

Groundwater levels and flow direction are mainly influenced by geology and topography with the latter mainly controlling the location of major hydraulic boundaries: areas of recharge at outcrop along ridges and interfluves, and areas of discharge along major streams and rivers. Groundwater flow is also controlled locally by geology, stratigraphic dip, faulting and episodic flooding.

Interpreted groundwater level contour plots are shown in Figure 5.6 based on observed groundwater elevations and output from the calibrated numerical model.
Groundwater elevations define a piezometric surface which is a subdued reflection of the topography; groundwater movement is perpendicular to groundwater contours such that groundwater flow in the assessment area is generally in a northerly direction (towards the Talbragar River) in all units.

In detail, groundwater levels in each unit are slightly different reflecting the local hydraulic controls and aquifer heterogeneity. In addition observations from exploration drilling and transient electromagnetic (TEM) imaging indicate that dipping strata and faulting can influence groundwater flow and yield on a local scale.

It should be noted that actual groundwater flow velocities are limited by the generally low permeability of the Permo-Triassic aquifer and are likely to be in the order of 10 to 20 cm per year under natural conditions (assuming an average hydraulic conductivity of 10^{-1} to 10^{-2} m/d). Such velocities are consistent with radiocarbon dating that indicates groundwater residence times of 40,000 to 50,000 years in Permo-Triassic rocks in the lower Sandy Creek catchment.

Groundwater within the alluvium flows in a downstream direction and is convergent on the river channel. Groundwater within the Permo-Triassic aquifer flows in a generally northerly direction, but also converges on major drainages where discharge occurs mainly via evapotranspiration.

Nested piezometers show that there is a strong downward hydraulic gradient along ridges and interfluves (indicating a recharge area (e.g. GW24A-E)), whereas there is typically an upward hydraulic gradient along the major creeks and the Talbragar River (e.g. GW7A-E), suggestive of discharge zones. The piezometer nest near Laheys Creek (GW28A-D) indicates a slight downward gradient suggesting that streams are recharge features (losing streams) in their upper reaches.

Depth to the water table varies with topography. Along the ridges and upper slopes, groundwater is encountered typically 25 m to 35 m below the ground surface. Near the stream and river channels, groundwater is encountered at shallow depths — typically less than 3 m below the surface.

Artesian pressures (where groundwater levels in the aquifer are higher than the ground surface) have been noted at two locations along Sandy Creek (GW3B-E and GW7B-E) within the Permo-Triassic units indicating that those aquifer units become confined below the Quaternary alluvium. Groundwater levels within the alluvium at the same locations (GW3A, GW7A) are several metres lower, indicating both a strong upward gradient and a very weak hydraulic connection (low conductivity) across the alluvium interface.

On a regional scale the Surat Basin sedimentary units dip into the basin to the north and north-west. The underlying Lachlan Orogen units are trending to the north. Structurally the graben block within the valley has been tilted in a northerly direction and groundwater flow is likely to follow this regional structural fabric.

5.9.3 Recharge

Groundwater recharge is defined as the component of rainfall or surface water that infiltrates to the water table and therefore contributes to groundwater storage. In arid and semi-arid parts of Australia recharge to the groundwater systems is typically low as a proportion of total rainfall (<5%) with most rainfall lost to surface runoff and evapotranspiration.

Within the assessment area, groundwater recharge occurs through the following main mechanisms:

- direct rainfall infiltration in areas of sedimentary and fractured rock outcrop (along the ridges and mid-slopes); fractures provide preferential paths for infiltration in these areas
- infiltration of surface runoff from headwater creeks, gullies and ponds that incise sedimentary or fractured rocks
- direct rainfall recharge of unconsolidated alluvium and weathered rock in the lower slope and valley floor areas
- stream and riverbank recharge during flood events.

Recharge from direct rainfall over the entire assessment area, but particularly areas of sandstone outcrop is supported by monitoring bore hydrographs. Almost all hydrographs show a trend of increasing groundwater levels that correlate well with the cumulative deviation from mean monthly rainfall (CDM) trend.

As noted elsewhere, this investigation has shown that the most significant recharge occurs during large and sustained rainfall events (e.g. December 2010) when evaporative losses are low relative to precipitation and streams and rivers are in flood.

By contrast, low intensity rainfall events during dry spells typically do not lead to significant groundwater recharge due to high evaporative losses and resaturation of the shallow soil profile.

During the period of high rainfall in late 2010, groundwater levels rose between 1 m and 3 m and remained elevated (relative to early 2010) for more than 6 months after the wet period. The rate of recharge can be very high in mid-slope areas where water gathers in hollows or creek beds (e.g. GW6A-D — up to 5 m rise in groundwater level).

Groundwater level rise in deeper units of the Permo-Triassic sequence (e.g. Dapper Formation) tend to be more subdued indicating that recharge to those units is by somewhat delayed leakage from overlying units.

Hydrographs for monitoring bores installed adjacent to stream channels tend to show sharp rises in groundwater level and relatively steep recession curves, indicative of direct riverbank recharge by flood waters. This phenomenon is noted both in the alluvium aquifers (GW8A; GW5A) and in Permo-Triassic sandstones adjacent to the river channels (e.g. GW18; GW21). Infiltration during flood events is therefore an important recharge mechanism, despite the typical (long-term average) hydraulic gradient towards the creek and river channels.

Isotopic data and radiocarbon dating provide the most compelling evidence for sources of recharge and groundwater residence times. Corrected radiocarbon ages for groundwater within the Permo-Triassic sequence tend to increase in age from the groundwater basin margin (approximately 14,000 years at GW16) down-gradient towards the major discharge areas (e.g. 38,000 to 40,000 years at GW6). The groundwater contains distinctly lighter isotopic ratios of hydrogen and oxygen (lower $\delta^{2}H$ and $\delta^{18}O$ values) suggesting recharge during a cooler climate, consistent with the inferred age and travel times.

By contrast, groundwater in the alluvium aquifers tends to be modern (<100 years — GW5A, GW7A) and has typically higher values of $\delta^{2}H$ and $\delta^{18}O$, similar to surface water samples. The radiocarbon and stable isotope data are therefore consistent with relatively recent recharge of water to the alluvial system via rainfall and/or surface water infiltration. Upward leakage and mixing of older groundwater from the Permo-Triassic rocks appears to be minor where the alluvium is well developed.

Results of the TEM survey indicate that around the Talbragar River and the lowest part of Sandy Creek, there are numerous conductive, near-surface, roughly meander-shaped features (Appendix G). It is likely that these are sinuous abandoned channels that are saturated with saline groundwater derived from evaporated rainwater and flood waters. A zone of slightly more resistive material along the river itself is likely due to riverbank recharge from recent flood events.

5.9.4 Discharge

Groundwater discharge refers to any net loss from the aquifer system. Typically discharge from aquifers occurs via seepage into streams (providing baseflow), springs, evaporative losses where groundwater is shallow, transpiration of plants and abstraction for human activities. Evapotranspiration is a term used to describe the sum of evaporation and plant transpiration from the earth's land surface to atmosphere.

Within the assessment area, groundwater discharge from springs and stream baseflow is considered to be a relatively minor component of the overall water budget. Baseflow in the Talbragar River and Sandy Creek is essentially zero during periods of low rainfall. It is assumed that many of the non-flowing semi-permanent pools along the creeks and rivers are sustained in part by some seepage from the alluvium and also the Permo-Triassic aquifer where exposed in the stream bed.

However, groundwater contours and vertical hydraulic gradients near streams indicate that significant discharge must be occurring along the valley axes. Groundwater levels in the alluvium are typically several metres lower than the underlying sedimentary aquifer implying discharge from the alluvium aquifer but relatively limited leakage into the alluvium from the underlying formations.

It is assumed that the discharge is mainly via evapotranspiration, both as direct evaporation from the soil profile where groundwater is shallow, and transpiration by vegetation.

Evapotranspiration only occurs within a certain depth below the ground surface and the rate decreases with depth to until an ‘extinction depth’ is reached, where essentially no loss to evapotranspiration occurs. The actual depth of influence for evapotranspiration depends on numerous factors including plant type and root zone depth, soil compaction, and soil or rock type. On a local scale it is assumed that evapotranspiration could occur to depths of up to 5 m but may be up to 10 m where deep-rooted trees grow. However, over the study area 3 metres would represent an appropriate depth for the limit of evapotranspiration due to the likely maximum depth of the capillary fringe, and the prevalence of shallow rooted vegetation. Given that evapotranspiration rates are greater than average annual rainfall rates, and groundwater is relatively shallow in low-lying areas, evapotranspiration is considered a major process by which water is removed from the groundwater system on a catchment-wide scale.

5.9.5 Surface water – groundwater connectivity

Interaction between surface water and groundwater systems occurs though a variety of mechanisms, including:

- baseflow to streams and semi-permanent pools
- flood flow recharge to groundwater
- discharge at springs/seeps.

A large component of the groundwater investigation was aimed at gaining an understanding of surface water – groundwater connectivity. It is clear that surface water – groundwater interactions are complex, variable over time, and also variable across the assessment area depending on the nature of the stream bed, alluvium and underlying aquifer. The following general conclusions are drawn from the investigations.

5.9.5.1 Baseflow to streams and semi-permanent pools, and flood flow

- Surveys of stream bed elevations and groundwater levels show that over lower stretches of the Sandy Creek, Laheys Creek and the Talbragar River, hydraulic gradients are towards the channel, indicating a potential for groundwater discharge to streams. In contrast, upper reaches of creeks are likely to be disconnected losing systems.
- Semi-permanent pools along Sandy Creek, Laheys Creek and the Talbragar River appear to be sustained by some seepage from the alluvium aquifers, and potentially also the Permo-Triassic aquifer where they outcrop in the stream beds. However, surface water samples from these pools tend to have stable isotopic signatures that are distinct from groundwater derived from the Permo-Triassic units.
- All surface water channels cease to flow (including the Talbragar River) for periods of time when rainfall is low (there is no significant baseflow component).
Baseflow recession curves for the tributary creeks are steep (typically days) while recession curves for the Talbragar are longer (weeks), but ultimately reduce to zero baseflow over time. This indicates that groundwater discharge from the main regional aquifer (Permo-Triassic units) is not a major contributor to surface water flows and the rapid recessions may instead indicate temporary storage in alluvium proximal to the channel.

- Where alluvial deposits are developed along the stream and river courses, the connection between the Permo-Triassic aquifer and the alluvium aquifer is weak and the alluvium aquifers form distinct local aquifer systems. This is evidenced by the strong vertical hydraulic gradients across the alluvium interface and distinct isotopic composition and radiocarbon ages, as discussed in the recharge subsection (5.8.3).

- Long-term (21-day) pumping tests were carried out at two locations (GW5 and GW7) in an attempt to induce leakage across the alluvium interface and assess the vertical conductivity of the alluvium. In both cases, drawdown in the order of 10–20 cm was noted towards the end of the tests, implying very low leakage rates and a horizontal to vertical permeability ratio in the order of 1,000 or more. Moderate rainfall that fell during both tests generated enough recharge to almost negate the induced drawdown. This is consistent with other lines of evidence that suggest that induced leakage rates due to depressurisation of the coal measures would be very low and probably less than the long-term rate of recharge to the alluvial systems via rainfall and floods.

- Hydrographs from monitoring bores adjacent to creek and river channels show sharp ‘flashy’ responses to high rainfall and flood events indicative of direct recharge from flood waters. The surface water recharge signatures are noted mainly in the alluvium, but also the Permo-Triassic aquifer where the alluvium deposits are thin or absent.

- Groundwater levels in the alluvium appear to take approximately 6 to 8 months after a major flood event to approach the pre-flood groundwater levels. This suggests that semi-permanent pools may be sustained for a similar length of time between high flow events.

In summary, groundwater elevations indicate that lower stretches of stream and river reaches are potentially gaining systems. Groundwater discharge to the creeks is sufficient to sustain the semi-permanent pools throughout most of the year (although some are known to dry out), but insufficient to produce permanent flow. In addition the alluvial systems are poorly connected such that depressurisation of the coal measures due to mining is likely to induce only minimal leakage from alluvium aquifers and surface water where alluvium occurs. Rainfall and flood recharge will likely be sufficient to sustain the local alluvium aquifers and semi-permanent pools where they are poorly connected to the Permo-Triassic aquifer. However there is potential for leakage to be induced from surface water where alluvium is thin or absent.

5.9.5.2 Discharge at springs and seeps

A number of springs occur at the contact between permeable Jurassic sandstone and underlying Triassic shales or between the Tertiary basalts and underlying strata. These are located in upland areas to the south and south-east of the mining area, or on the northern side of the Talbragar River. Two springs located north of the Talbragar River are associated with discharges from Jurassic strata and one of these springs contributes to baseflow of a nearby creek (a tributary of Boomley Creek).

Hydrogeochemical and isotopic evidence indicates that most of the springs are derived from recent (<400 years) recharge waters and are associated with isolated (local) hydrogeological systems overlying regional systems (i.e. perched or interflow systems). They are also in areas where the groundwater levels for the Permo-Triassic units are generally deep below the surface (in many places > 50 m below ground). Therefore, springs and seeps in the area are considered to be independent of the regional Permo-Triassic groundwater system.

6. Groundwater modelling

A numerical groundwater model was developed to provide a quantitative assessment of impacts from the proposed mining operation. The groundwater model and a draft version of the *Groundwater Model Technical Report* were externally peer reviewed by Dr Merrick (Heritage Computing) in February 2012. Comments from the peer review were addressed in the final model and technical report and a second peer review was undertaken by Dr Noel Merrick. The final version of the *Groundwater Model Technical Report* is included in Appendix H. The peer reviews and responses to peer reviews are included in Appendix I.

The model incorporates the mine plan and is based on the current conceptual understanding of the groundwater system within the assessment area. Aquifer properties and groundwater level data collected in the period up to September 2011 have been used in model development.

The model was created using the Groundwater Vistas user interface. MODFLOW (McDonald & Harbaugh 1988), in conjunction with MODFLOW-SURFACT (version 3) were used to allow for saturated and unsaturated flow conditions.

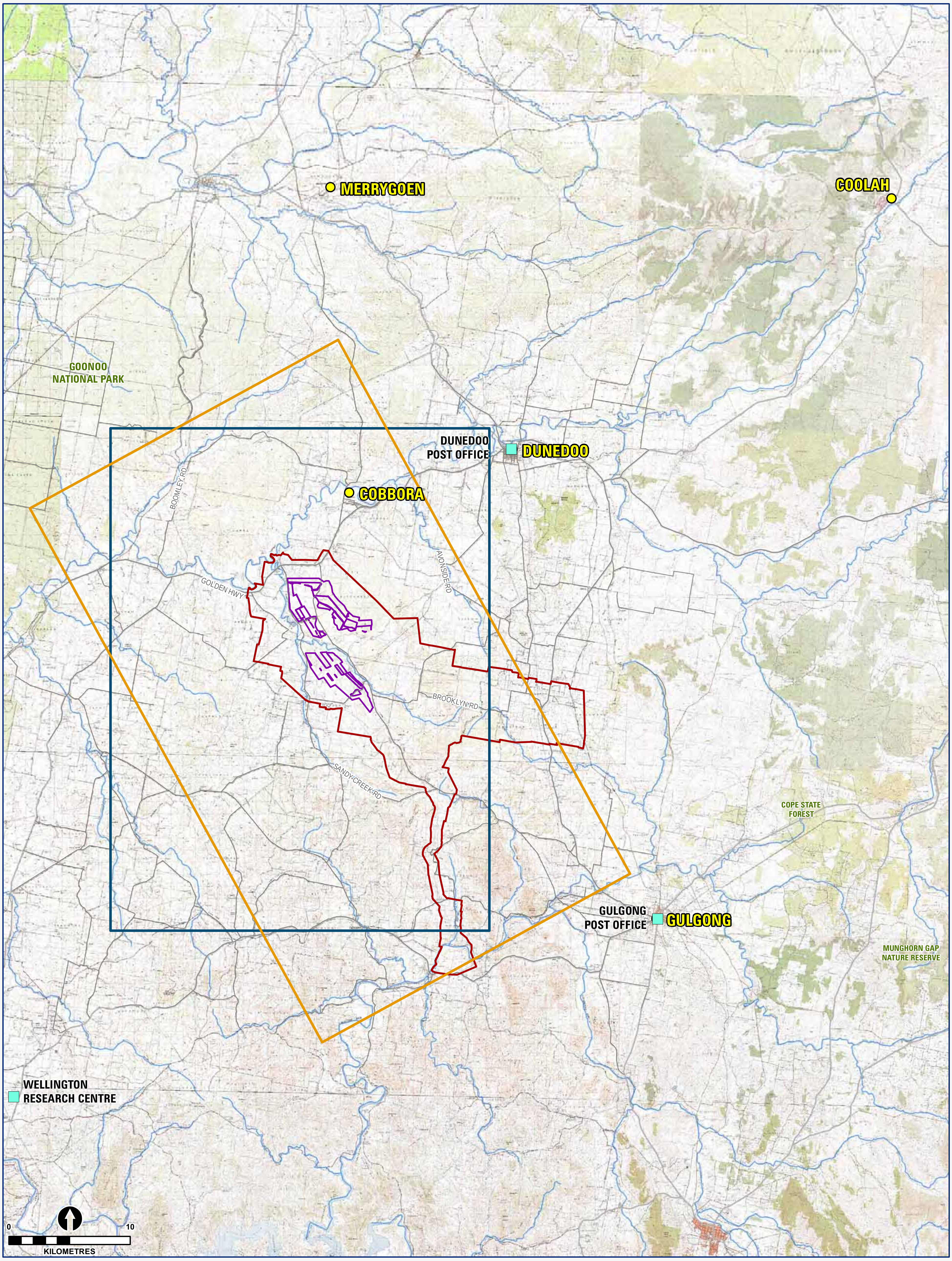
The complexity of the groundwater model is consistent with the 'impact assessment' class described by the Murray Darling Basin Commission guidelines for groundwater flow modelling (MDBC 2001). New national guidelines for modelling were released in July 2012 (Barnett et al, 2101) and are largely based on the previous MDBC modelling guidelines (MDBC 2001). The modelling for this project is consistent with the new national guideline. It has moderate complexity and is suitable for predicting the impacts of the proposed operations and post-mining recovery. A detailed description of the development and results of the groundwater model is provided in the *Cobbora Coal Project – Groundwater Model Technical Report* (Appendix H). A summary of this report is presented below.

6.1 Model development

A map of the assessment area, including the extent of the groundwater model, is shown in Figure 6.1. The model domain has an extent of 29 km x 50 km (1,458 km^2). The active mine area is located within the centre of the model domain and covers approximately 30 km^2. The model grid is orientated to the north-west to align the conceptualised primary groundwater flow direction in the Project catchment (north-west) with the model columns, which would simplify the numerical solutions.

The numerical groundwater model is based on the conceptual model described in this document (Section 5.9) and includes data collected during 2009–2011, as part of an extensive groundwater monitoring and testing program. The hydrogeological units of relevance to the assessment area have been simplified for incorporation into the groundwater model as discrete model layers (see Table 6.1). The simplification aims to combine formations assumed to the have similar hydraulic characteristics.

A process of model calibration was undertaken to refine estimates of aquifer properties for these units and to develop suitable boundary conditions for the model. Figure 6.2 shows the model domain and assigned boundary conditions, including the three mining areas in the proposed mine plan (mining areas A, B and C). Inactive cells have been assigned only at topographic divides and in areas where very low permeability geological units outcrop. The hydrostratigraphic units assigned to the top layer of the model are also shown in Figure 6.2.



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 6.1 Site plan and model extent

Topographic map source: NSW Department of Lands, 1989

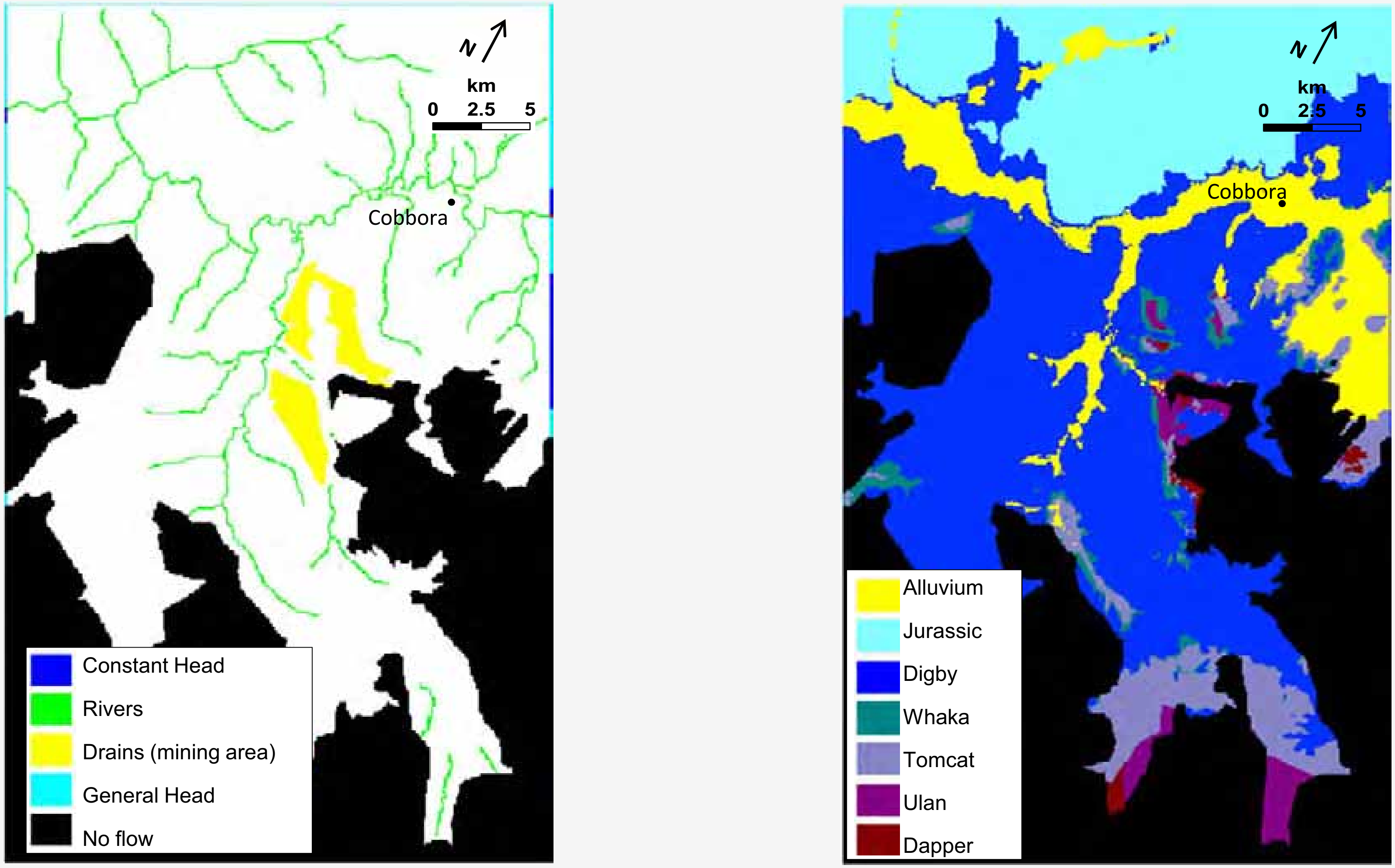


Figure 6.2 Model domain showing a) assigned boundary conditions and b) hydrostratigraphic units in layer 1

Table 6.1 Hydrostratigraphic units assigned to the groundwater model

Hydrostratigraphic unit	Geological formations
Alluvium	Alluvium
Jurassic	Pilliga Formation, Purlawaugh Formation
Digby	Napperby Formation, Digby Formation, Ellismayne Formation
Whaka	Whaka Formation, Avymore Claystone, Flyblowers Creek Seam
Tomcat	Tomcat Gully Sandstone
Ulan	Upper Ulan Seam, C-Marker Clay, Lower Ulan Seam
Dapper	Dapper Formation

6.1.1 Model calibration

Calibration is the process by which the independent variables (parameters and boundary conditions) of a model are adjusted, within realistic limits, to produce the best match between simulated and measured data. Calibration of the model to observed groundwater levels was used to refine the values of the model input parameters, including aquifer properties data and recharge to the groundwater system.

6.1.1.1 Steady state model

A steady state model was developed to simulate average long-term conditions within the assessment area. The model was calibrated to groundwater level data collected in March 2010, near the beginning of the groundwater monitoring program. A cumulative rainfall residual curve for the assessment area (Figure 6.3) indicates negligible net surplus or deficit of rainfall at this time and suggests that groundwater levels are likely to be close to their long-term average values

Calibration of the steady state model achieved a normalised root mean square (NRMS) error of 2.53%. This is well within the target value of 5% agreed with the independent reviewer, Dr Noel Merrick.

Sensitivity analysis indicates that the steady state model is not sensitive to the majority of input parameters. The model is sensitive to the horizontal conductivity of the Digby Formation, Ulan Coal Seams and Dapper Formation, with improved calibration arising from increased values of these parameters. The model was also found to be sensitive to recharge and vertical hydraulic conductivity in the Digby Formation and evapotranspiration extinction depth.

The results of sensitivity analysis were used to refine estimates of model input parameters, while ensuring that these estimates agree with the available range of data and conceptual model. Further details on the sensitivity analysis carried out are provided in Appendix H of this document.

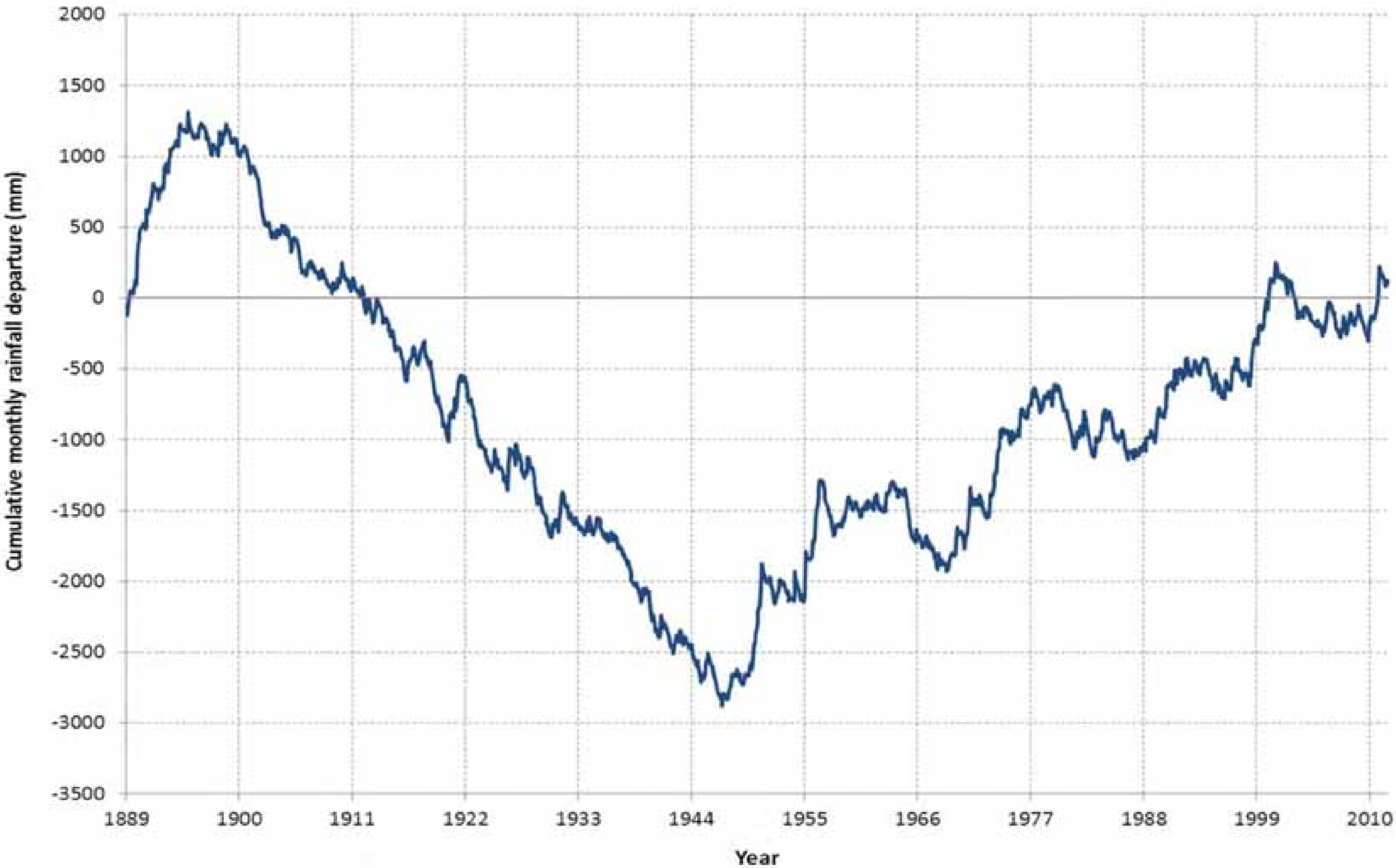


Figure 6.3 Cumulative monthly rainfall residual curve for the Project area since January 1889

6.1.1.2 Transient model

A transient model was developed to simulate the effects of changes in groundwater flows arising from variations in rainfall. The model was calibrated to groundwater level data collected between March 2010 and August 2011, as part of the groundwater monitoring program.

Calibration of the transient model achieved an NRMS error of 2.59%, which is well within the target value of 5%.

Sensitivity analysis indicates that the transient model is not sensitive to the majority of input parameters. The model was found to be most sensitive to vertical hydraulic conductivity in the Whaka Formation and vertical hydraulic conductivity, specific yield and recharge in the Digby Formation. The results were used to make further refinements to estimates of model input parameters. Further details on the transient sensitivity analysis are provided in Appendix H of this document.

The parameter values assigned to the model following completion of sensitivity analyses for both the steady state and transient models are presented in Table 6.2. For transient and predictive simulations, a long-term average rainfall of 636 mm/a was applied. The assigned evapotranspiration rate is 600 mm/a and is based on the available data (Bureau of Meteorology 2005). The depth below surface to which evapotranspiration is active in the model (i.e. evapotranspiration extinction depth) was set at 5 m, following model calibration.

Table 6.2 Summary of model input parameters

Layer(s)	Hydrogeological unit	K_h (m/d)	K_z (m/d)	S_y	S	Recharge (% of rainfall)
1	Alluvium	1	0.001	0.2	$5x10^{-4}$	2.9%
2	Jurassic	0.04	0.004	0.1	$3x10^{-4}$	0.46%
3	Digby	0.1	0.003	0.01	$5x10^{-5}$	0.64%
4	Whaka	0.004	$6x10^{-5}$	0.1	$5x10^{-4}$	0.46%
5	Tomcat Gully	0.008	$8x10^{-5}$	0.1	$5x10^{-4}$	0.46%
6	Ulan	0.3	0.003	0.1	$8x10^{-4}$	0.58%
7	Dapper	0.1	0.01	0.1	$8x10^{-4}$	0.46%

6.1.2 Predictions of mine inflows

The calibrated model was developed further, to allow a predictive simulation of mine inflow rates and changes in groundwater level over time. The following refinements were made in implementing the predictive simulation:

- The proposed mine plan 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 1 year afterwards, prior to backfilling taking place. The proposed mine plan comprises the mining areas A, B and C. The drain cells ensured that groundwater levels within all three mining areas were maintained at the base of the excavated area.
- The recharge and hydraulic properties assigned to the backfill material were assigned, based on work by Mackie (2009), which indicates a geometric mean hydraulic conductivity value for spoil material of 3.2 m/d and an average recharge value of 3.3% of rainfall. This was achieved using the time-varying material properties package (TMP1) in MODFLOW-SURFACT.

- The model recorded 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 the proposed mining operations ceased.

6.2 Model results

6.2.1 Predicted mine inflow rates

An initial model simulation was run to provide best estimates of mine inflow rates and to investigate the potential effects on groundwater levels and river flows in the area.

Predicted inflow rates during the proposed period of mining (2015 to 2035) are presented in Table 6.3 (and in Figure 6.4) for the three proposed mining areas: A, B and C. Mining area B accounts for approximately half of all inflows to the mine. The largest inflow rates occur between 2020 and 2031, with total flows typically between 1,000 and 1,775 ML/a during this period.

Table 6.3 Summary of estimated mine inflow rates

Year	Inflow rates (ML/a)			
	Mining area A	**Mining area B**	**Mining area C**	**Total**
2015	1	37	0	38
2016	124	277	4	404
2017	309	372	20	701
2018	283	524	79	886
2019	258	615	4	878
2020	282	611	129	1,022
2021	454	611	226	1,291
2022	281	626	122	1,030
2023	456	642	130	1,227
2024	611	679	246	1,537
2025	607	968	79	1,654
2026	180	1,120	249	1,550
2027	276	970	304	1,550
2028	20	989	357	1,366
2029	94	569	313	976
2030	281	734	326	1,340
2031	491	962	322	1,775
2032	219	242	374	835
2033	109	*	166	275
2034	184	*	64	248
2035	186	*	162	348

* This table illustrates mine inflow during active mining only. Following the end of mining in area B (at year 2033) the process of groundwater recovery commences and inflow rate calculations for the recovery is presented and discussed in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012).

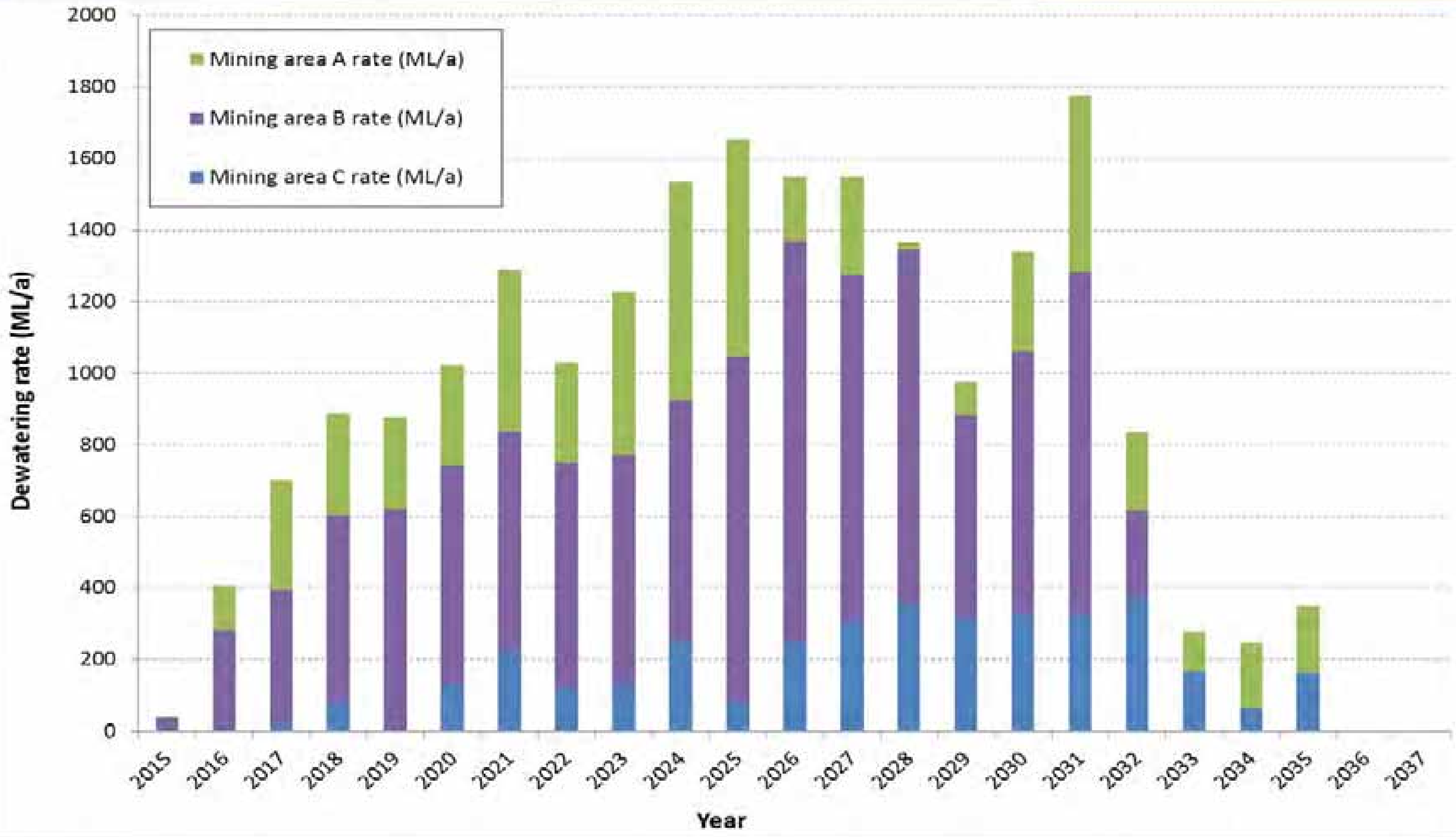


Figure 6.4 Predicted dewatering rates in each mining area

6.2.1.1 Sources of inflows

The sources of groundwater inflows to the mine have been inferred based on changes in storage within each of the seven main hydrostratigraphic units in the model (not including material within the proposed mine pit voids) and the estimated reduction in river flows (the results are presented in Figure 6.5). The river flow in Figure 6.5 is portrayed by the dashed line, and is read off the secondary y-axis, and the cumulative storage loss is portrayed by the solid fill colours and is read off the primary y-axis. The Ulan and Dapper hydrostratigraphic units are the biggest contributors to mine inflows in the model, with predicted cumulative storage losses of up to 2,000 ML in each by the end of mining in 2035.

Predicted cumulative storage losses within the alluvium reach a maximum value of nearly 300 ML over the total 21 years. This constitutes 0.1% of the estimated 220,000 ML (220 GL) of available groundwater storage in the alluvium aquifer within the model domain (ignoring stagnant water stored in ‘dead-end’ pores).

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 54,427 ML/a.

6.2.2 Predicted drawdown

The maximum drawdown extent in the water table aquifer (which includes the alluvium) and Ulan Coal Seams is shown in Figure 6.6 and Figure 6.7 respectively, along with the locations of privately owned groundwater bores in the assessment area. This represents the maximum predicted drawdown in the water table at each location within the model domain and has been derived by combining predicted drawdown values across a range of time steps within the model.

Groundwater inflows to the mining areas are expected to lead to maximum lowering of the water table of up to 85 m in mining area B (with maximum lowering of the water table in mining areas A and C of 49 m and 35 m respectively). The 1 m drawdown contour is predicted to extend up to 5 km to the south of the mine and nearly 4 km to the west. Drawdown to the north and east is far less extensive, with the 1 m drawdown contour predicted to lie within 3 km of the mining areas.

As the greatest lowering of water levels is expected to occur within mining area B, the largest drawdown is expected to be focused around this area. Lower values of drawdown are predicted in the vicinity of mining areas A and C as a result of lower inflow volumes.

Drawdown is predicted to extend over a greater area in the Ulan Coal Seams than in the water table aquifer (which includes the alluvium). The 1 m drawdown contour is predicted to lie approximately 5 km to the west of mining areas A and B. The extent of drawdown to the south, north and east of the mining areas is similar to that predicted for the water table aquifer.

The model predicts that, 20 years after the cessation of mining activity, groundwater will have largely recovered over much of the model domain, but there will be some residual drawdown within approximately 2 km of the Pit B lake based on the current mine plan and this will reach equilibrium following approximately 50 years from the cessation of mining.

The recovery of groundwater levels after mining ceases is largely due to the following:

- The recovery is modelled using enhanced recharge for areas that are backfilled in accordance with the recommendations in Mackie 2009.
- Some reaches of the creeks are defined as net recharge areas over the longer term, and this is consistent with the isotopic signatures obtained during the field investigations. It also corresponds with the rapid recharge response in the alluvium following rainfall and high flow events. The model uses this information for these sections of creeks.
- All other parameters used in the model are based on thorough field investigations, and published literature.

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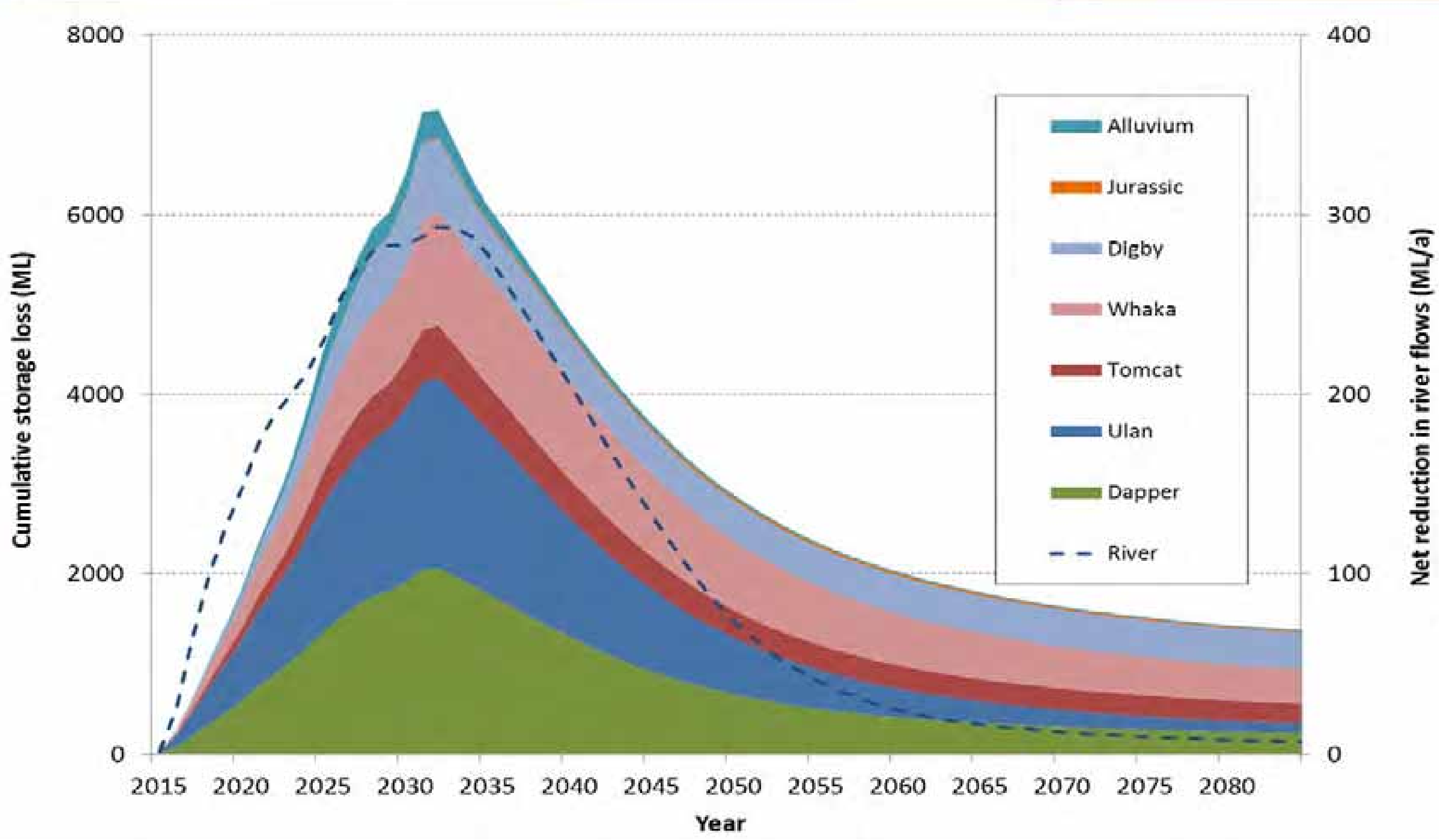
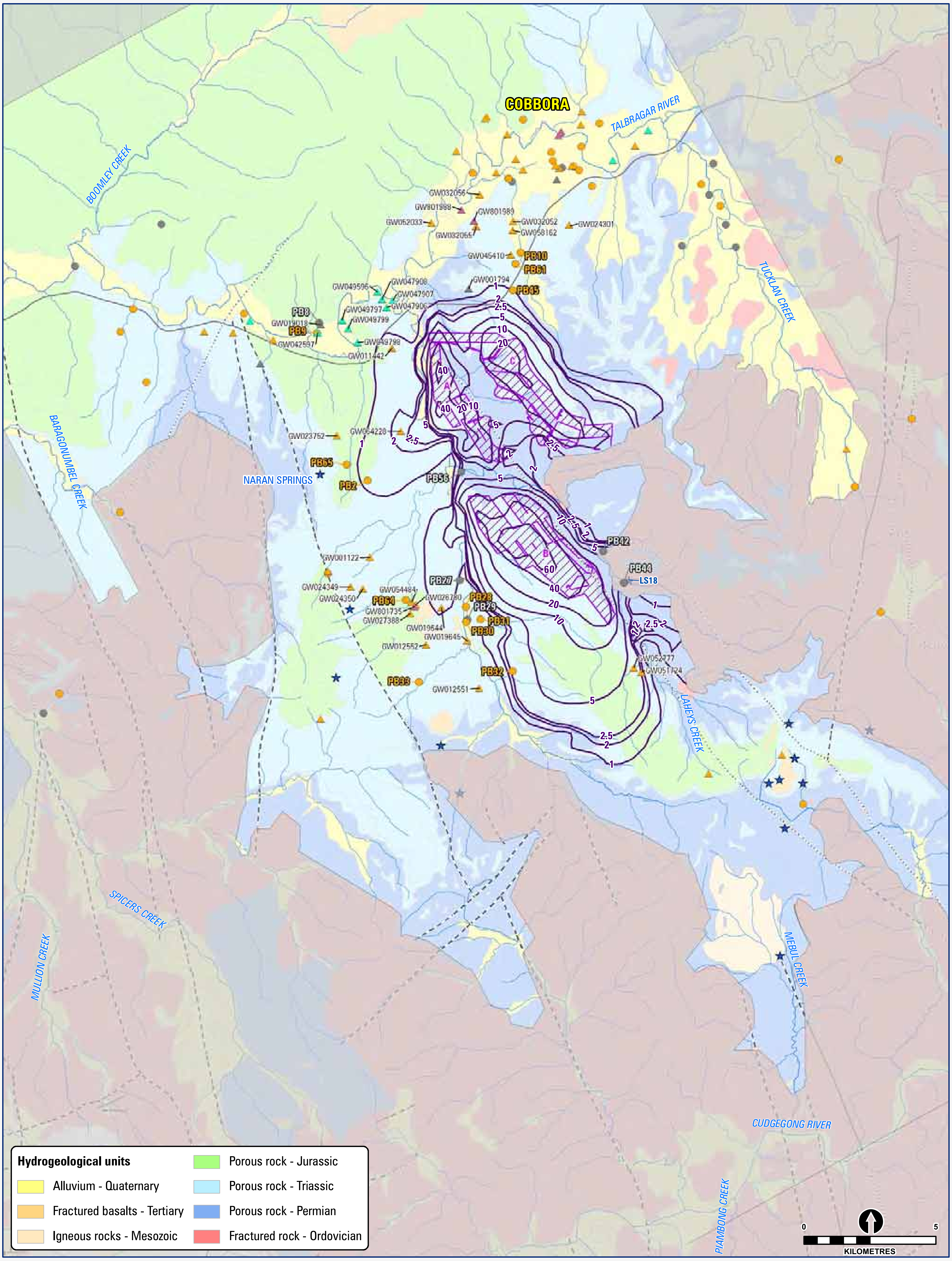


Figure 6.5 Predicted storage and river losses from mine dewatering



Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed

- Proposed mining areas
- No flow boundary of numerical groundwater model

- Maximum predicted drawdown (m)

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

Figure 6.6 Maximum predicted drawdown in water table aquifer

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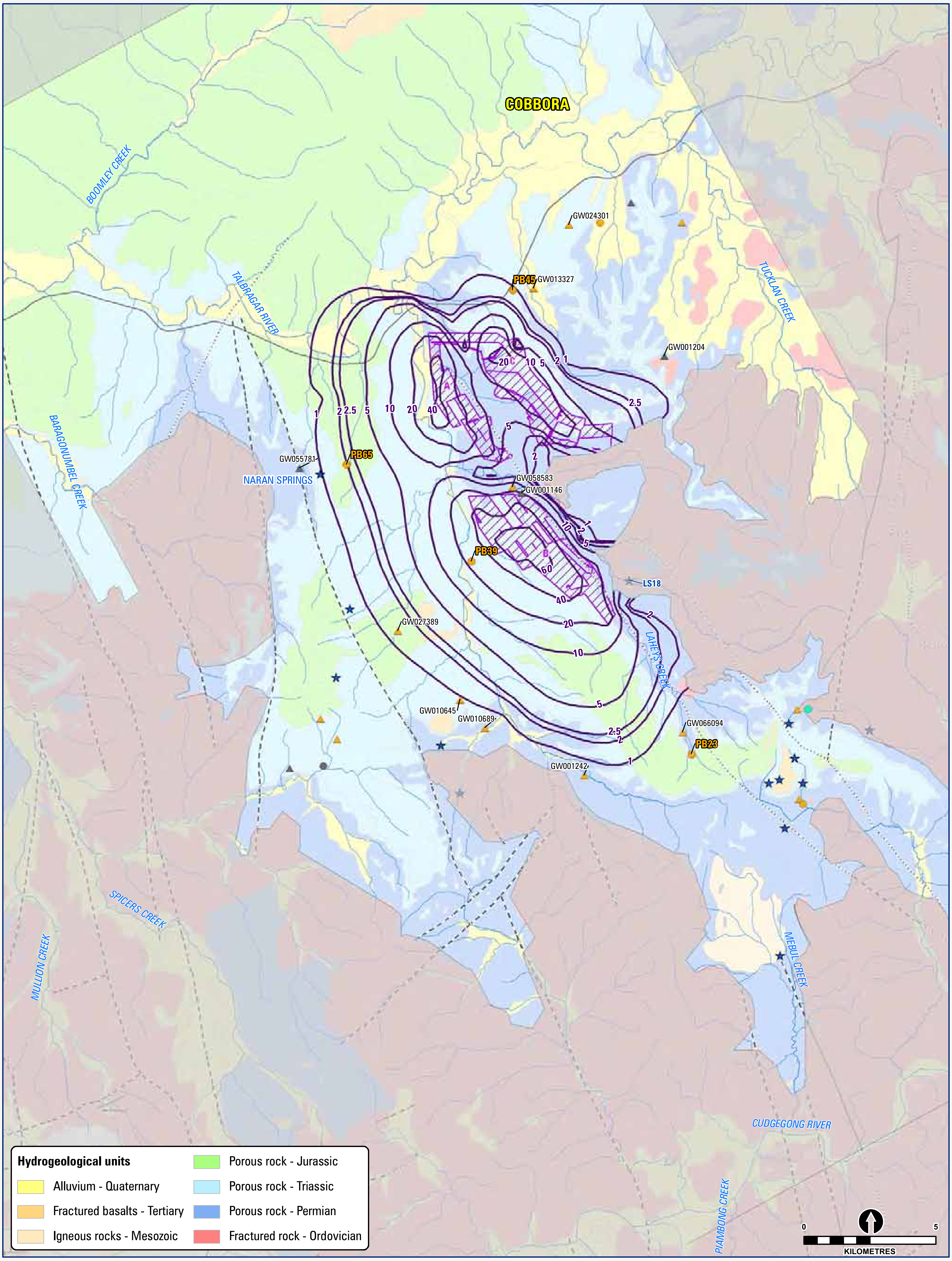


Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Irrigation
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Maximum predicted depressurisation (m)

Figure 6.7 Maximum predicted depressurisation in the Ulan Coal Seams

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

6.2.2.1 Predicted impacts on local groundwater bores

Existing groundwater bores identified as part of a hydrocensus in the assessment area are shown in Figure 4.1, along with the locations of other privately owned registered bores. A threshold of > 2.5 m drawdown has been applied for assessment purposes, as it has been calculated to represent the likely natural range of groundwater levels in the Project area. Groundwater levels in the piezometers/test production bores, used during transient calibration of the model, varied by an average of 2.3 m during the 74-week monitoring period, which had slightly more rainfall than the Project area's long-term average.

Model hydrographs for surveyed bores with a maximum predicted drawdown of more than 2.5 m as a result of mine dewatering are shown in Figure 6.8, with further details on these bores in Table 6.4 below. The privately owned registered bores (not surveyed) likely to experience drawdown > 2.5 m are also included in Table 6.4.

Table 6.4 List of potentially impacted groundwater bores

Bore	Ownership	Coordinates (MGA Zone 55)		Predicted maximum drawdown (m)	Approximate bore depth (mBGL)	Likely screened unit
		Easting (m)	Northing (m)			
PB32*	Private	710912	6431760	2.9	44.7	Triassic
PB39*	CHC	709354	6435914	23	100	Permian
GW001146	CHC	711270	6438510	25.8	18.8	Permian
GW058583	CHC	710907	6438733	15	53.3	Permian
GW051724	CHC	715790	6431728	4.1	77.5	Triassic
GW052777	CHC	715506	6431888	4.9	77.5	Triassic

* registered bore number unknown
MGA = Map Grid Australia

Five of the six bores with predicted drawdowns > 2.5 m are owned by Cobbora Holding Company Pty Ltd, the one bore not owned (PB32) shows a maximum drawdown of 2.9 m.

Most private registered bores and bores identified during the hydrocensus show predicted drawdown values of less than 2.5 m throughout the period of mining activities and beyond.

6.2.3 Sensitivity analysis of mine inflows

Because of the inherent uncertainty in estimating representative aquifer properties from a finite number of data points, Parsons Brinckerhoff conducted a sensitivity analysis on the predictive model to obtain give a high-end estimate of inflow rates. As the largest component of mine inflows in the model comes from the Ulan unit, a sensitivity analysis was based on an increase in the horizontal hydraulic conductivity from 0.3 m/d to 0.8 m/d and vertical hydraulic conductivity from 0.003 m/d to 0.008 m/d. Under this scenario, the predicted mine inflow rates may be higher by approximately 47% over the period of peak groundwater inflow between 2021 and 2031.

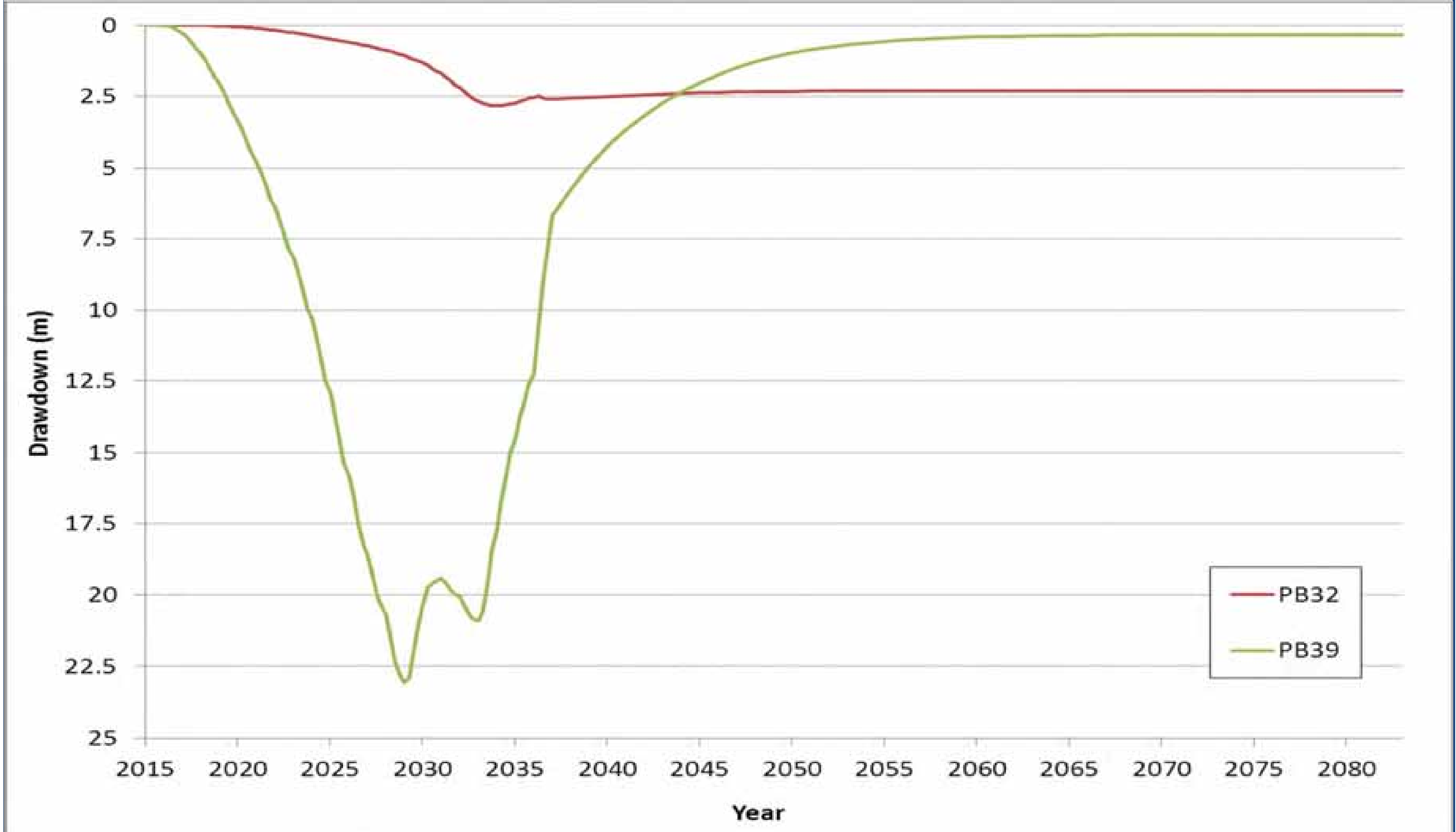


Figure 6.8 Hydrographs of groundwater bores with >2.5 m drawdown

6.2.4 Areas of potential groundwater availability to ecosystems

Groundwater is potentially available to ecosystems in the following environments:

- springs/seeps
- semi-permanent pools (non-flowing) within the creeks supporting aquatic species
- shallow groundwater in alluvium.

All identified springs, including the priority groundwater dependent ecosystem, Naran Springs, are shown on the maps of maximum drawdown at the water table and depressurisation in the Ulan Coal Seam (Figure 6.6). All identified springs are located well outside the predicted 1 m drawdown. Depressurisation in the Ulan Coal Seam will extend further than the predicted drawdown in the water table such that approximately 1 m head decline may occur in the Permian rocks at Naran Springs, located 5.25 km to the west of the mining areas.

Groundwater investigations (groundwater levels, quality and isotope studies) indicate that springs are not associated with the regional flow systems and do not discharge from the Permo-Triassic aquifer. In addition, all springs are located outside of areas where artesian pressures are observed or predicted to occur. Therefore, our investigations indicate that depressurisation in the Ulan Coal Seam will not impact the identified springs, including Naran Springs.

To assess the potential impacts to shallow groundwater in alluvium and semi-permanent pools along Sandy Creek and Laheys Creek, simulated drawdown hydrographs have been generated for representative aquatic ecology sites (semi-permanent pools). These are shown in Figure 6.9. The site location numbers refer to sites sampled and characterised by the Project ecologist (Figure 5.17). The hydrographs indicate that significant but temporary drawdown will likely occur within the alluvium or exposed Permo-Triassic rocks at some of those locations. In particular, drawdown in the order of 1.5 m to 7 m is predicted to occur at sites 4, 6 and 9. Relatively minor drawdown (<0.5 m) is predicted at sites 3, 13 and 28.

There is potential for drawdown at these locations to cause leakage from the alluvium which may lead to a decline in groundwater seepage in semi-permanent pools that are reliant on groundwater discharge. It is noted that the predicted drawdown is unlikely to lead to permanent loss of semi-permanent pools due to the episodic rapid recharge of the alluvium aquifers during high rainfall and high stream flow events.

Some additional calculations and a more detailed assessment of the overall impacts to semi-permanent pools (to consider the impacts from groundwater dewatering and also the increased low flow frequency for the surface water system) is contained in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012).

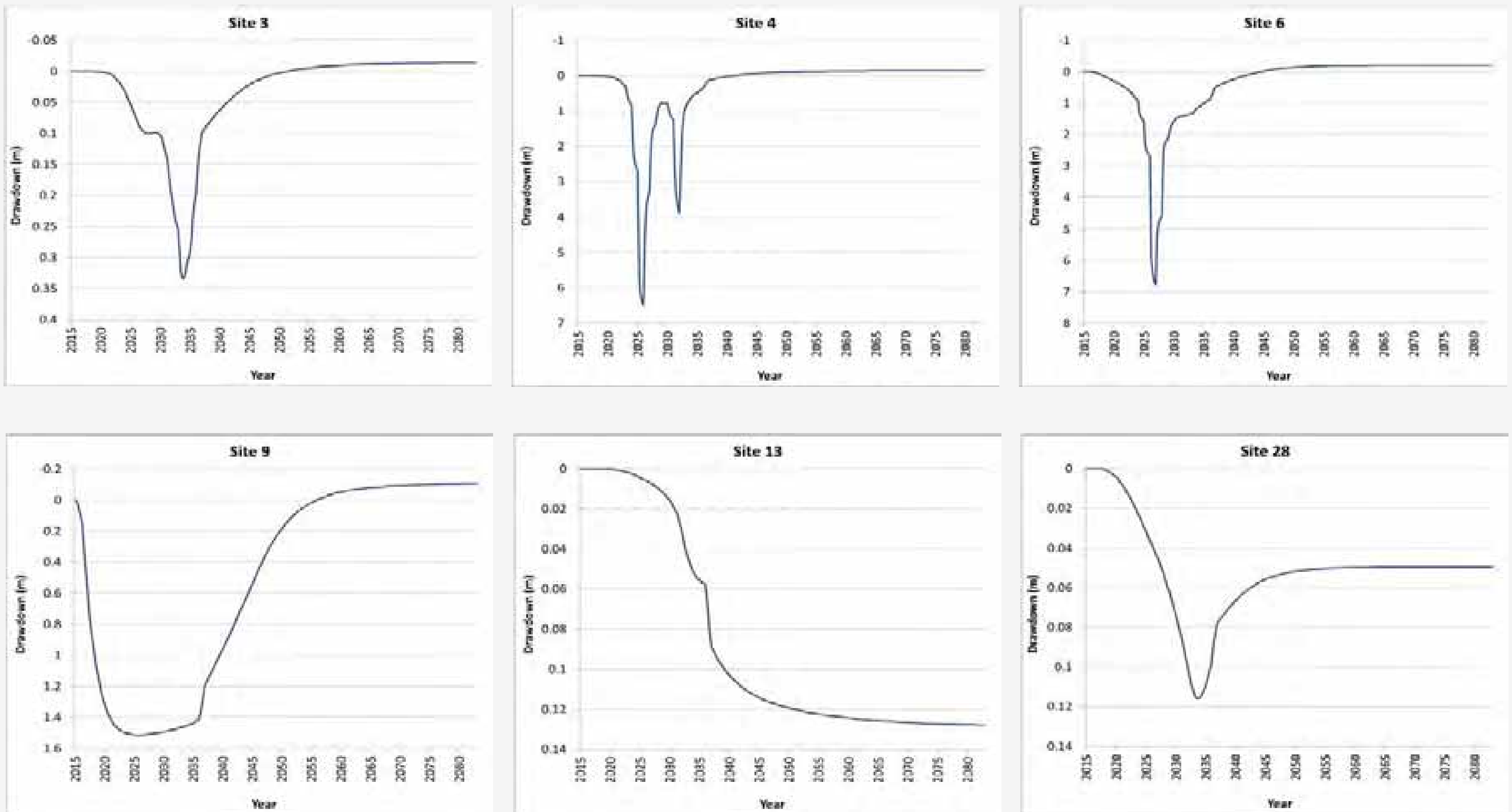


Figure 6.9 Simulated hydrographs at aquatic ecology sites

7. Potential groundwater impacts

Coal mining operations will involve stripping of overburden and interburden units of the Permo-Triassic succession using excavators, and mining of the economic coal seams. Overburden stripping and mining will be carried out in a series of mining strips and blocks which together define three mining areas; A, B and C.

The deepest target seams are the Ulan seams which dip towards the west in the areas designated as mining areas A and B such that those mining areas will reach a total depth of 110 metres below the surface. Mining of those areas will therefore be below the water table and moderate amounts of groundwater inflow will occur. Within mining area C, the Ulan seams occur at shallower depths and the water table is considerably deeper (as it is located along a ridge) such that groundwater inflows will be considerably less than in mining areas A and B.

It is anticipated that in most areas of mining, inflows will be low and dewatering will be achieved through the use of in-pit sumps and pumps. However, active mining blocks, where they are below the water table, may need to be dewatered to allow safe operation of vehicles and machinery where higher inflows are encountered. It may be necessary to install a number of dewatering bores (either inside the proposed pit or just outside the pit perimeter) to depressurise the coal measures prior to and during active mining. A small number of dewatering bores may need to be installed during mining of mining areas A and B. However, mining at mining area C will likely only require minor sump pumping when inflows are encountered or during periods of high rainfall.

All mining areas will receive inflow of surface water runoff from local catchments and direct rainfall during larger rainfall events which will be managed using surface pumping equipment.

Mine inflow and dewatering will result in depressurisation of coal measures in the vicinity of the mining areas, which in turn will cause leakage from overlying units and lowering (drawdown) of the water table in affected areas. Section 6 of this report discusses the likely leakage volumes from surrounding Permo-Triassic and alluvium aquifers within the cone of depressurisation. There is also potential for minor induced leakage from surface water systems which is also discussed in Section 6. The extent of drawdown and potential impacts associated with the Project are assessed further using numerical modelling (Section 6).

Broken waste rock will be back-filled into the mined pit voids. The broken waste rock piles will be more permeable and produce less surface runoff than the pre-existing ground surface, causing significantly higher rates of infiltration and recharge to groundwater in those backfilled areas. This will result in localised groundwater mounding in those areas (to some extent enhancing recovery of the mine induced drawdown) and also some increase in the initial rate of groundwater inflows to mine Pit B.

If waste rock contains acid-forming materials (e.g. sulfides), there is potential for acid mine drainage to develop. Acid mine drainage (AMD) occurs due to the oxidation of sulfide minerals (if present) in the presence of infiltrating water, producing dilute sulphuric acid which, in turn, can leach and mobilise metals in the leachate and groundwater.

In 2012, the consultant Geoterra carried out an AMD assessment as part of this program of investigations and the potential for AMD was assessed to be low at this location. The AMD report is provided in a separate volume of the environmental assessment report and AMD risk is assessed as low for this project.

The final landform has been designed to minimise impacts to groundwater and surface water due to changes to the flow regime and potential salinisation of water that accumulates in the final pit void. The final landform is presented in map and cross section format and Figure 7.1 shows a 3D rendering of the final landform and the location of the cross section lines. Pit A has been backfilled to be 3 metres above the current groundwater table and free draining for surface water, thereby allowing the natural processes of rainfall and groundwater discharge to occur freely (Figure 7.2). Pit B has been designed to minimise impacts to the surface and groundwater systems while also considering the economic feasibility of fully backfilling of this deep narrow pit. The final landform is largely backfilled to 3 metres above the current water table but with a small section of the pit to remain as a lake (Figure 7.3). Pit C will be backfilled to a minimum of 5 metres above the current groundwater table and will also allow surface water to drain freely to the south east into Blackheath Creek a tributary of Laheys Creek (Figures 7.1 and 7.2). Groundwater levels for the current situation, end of mining, and following recovery to equilibrium levels after mining ceases are illustrated on two cross sections (Figures 7.2 and 7.3).

The calculated final equilibrium groundwater levels and the pit void lake quality for Pit B is determined by water and mass balance modelling, as discussed in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012).

The potential impacts the Project will have on the groundwater system include:

- drawdown of groundwater levels and pressures within the alluvium and porous rock aquifers in the assessment area during mining
- reduction in available groundwater for one existing third party groundwater user within the assessment area during mining
- reduced groundwater discharge to creeks and loss of potential groundwater availability to ecosystems during mining
- development of a saline lake that will be isolated from the surrounding environment post mining.

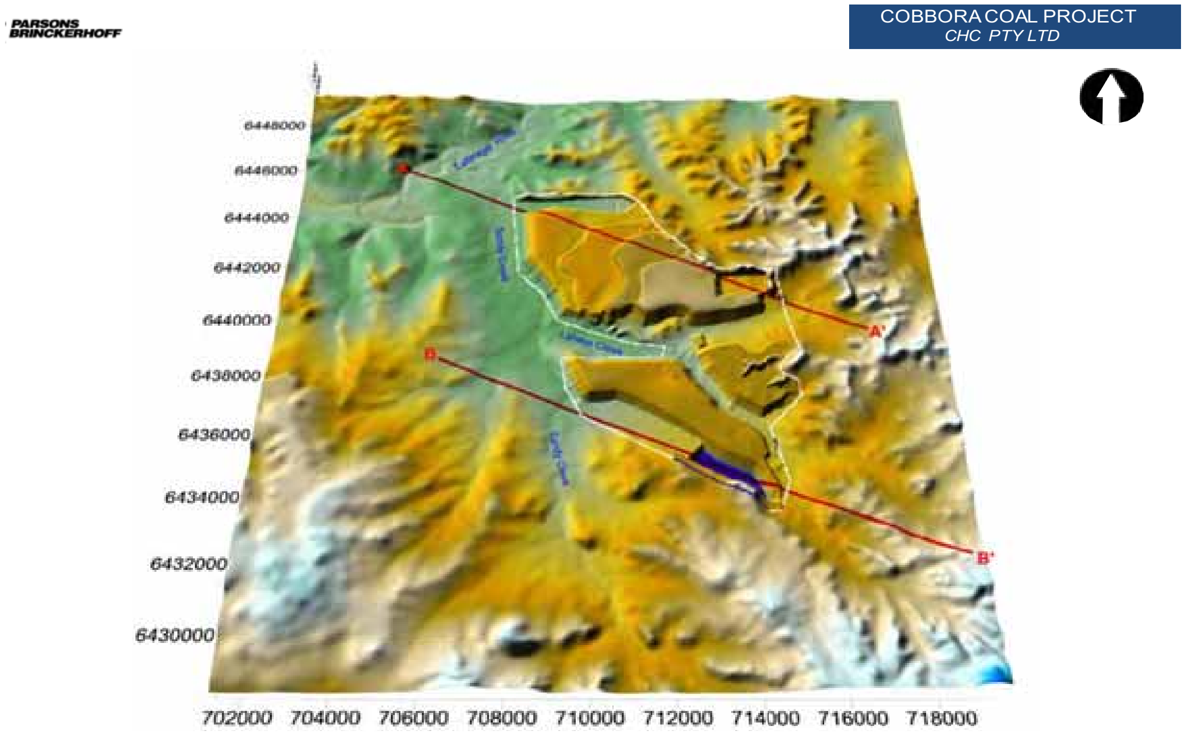


Figure 7.1 Final landform and cross section locations

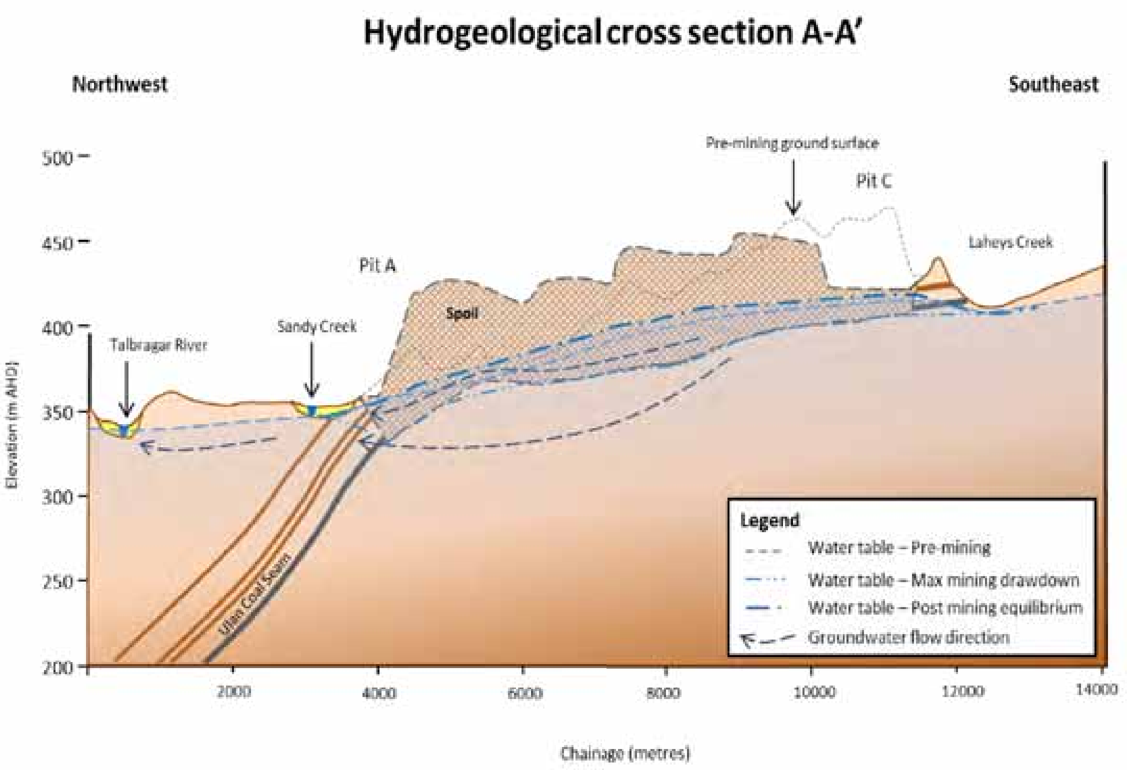


Figure 7.2 Hydrogeological Cross Section - Final landform, Pits A and C

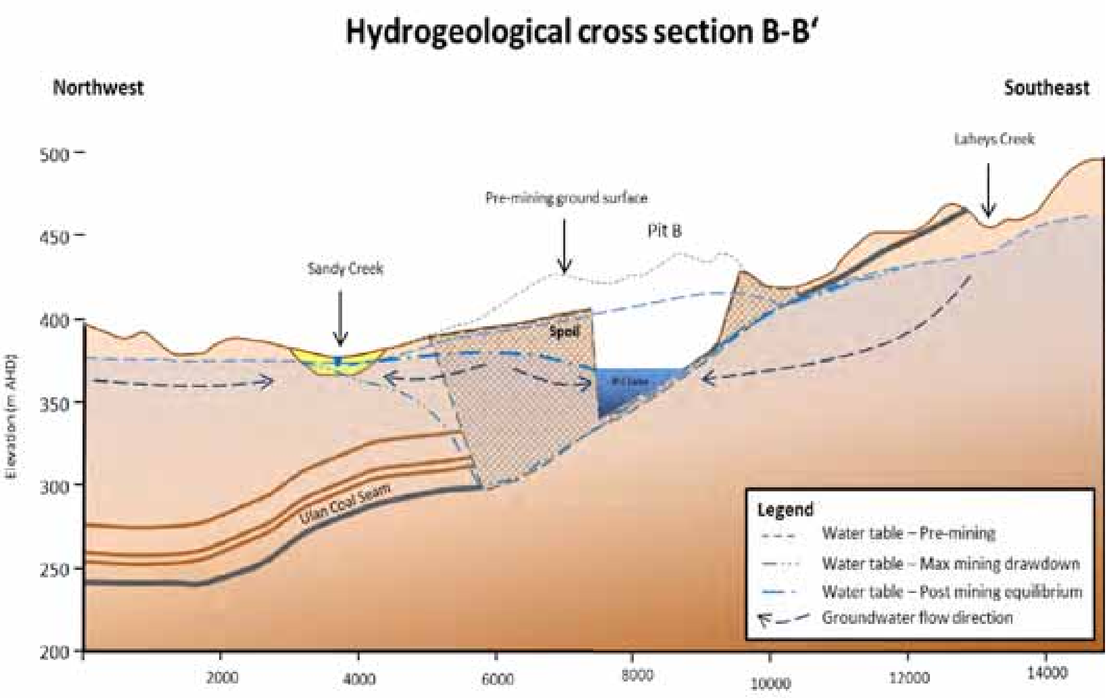


Figure 7.3 Hydrogeological Cross Section - Final landform, Pit B

7.1 Groundwater levels

The numerical model, described in Section 6, has been used to predict changes in groundwater levels as a result of mining. Mine inflow will result in depressurisation of coal measures in the vicinity of the mining areas which, in turn, will cause leakage from overlying units and lowering (drawdown) of the water table in affected areas. The maximum induced drawdown in the porous rock aquifer is predicted to be approximately 85 m. This is expected to occur beneath mining area B, between 10 and 18 years after the commencement of mining activity.

The maximum drawdown adjacent to the alluvium is predicted to be approximately 20 m, enhancing leakage from the alluvium (maps indicating water table drawdown include the alluvium). The location of this maximum drawdown is expected to occur approximately 0.5 km to the west of mining area B within the alluvium associated with Sandy Creek, between 14 and 15 years after the commencement of mining activity. The predicted cumulative storage losses within the alluvium reach a maximum value of approximately 300 ML, which constitutes only 0.1% of the estimated 220,000 ML (220 GL) of available groundwater storage in the alluvium aquifer within the model domain (ignoring stagnant water stored in 'dead-end' pores).

Groundwater drawdown of more than 1 m in the water table is expected to extend up to 5 km to the south of the mining area and nearly 4 km to the west during mining. The 1 m drawdown contour is predicted to remain within 3 km of the mining areas to the north and east. The maximum extent of drawdown is expected to occur at the end of the proposed mining activities. Depressurisation of the Ulan Coal Seam is likely to extend further than drawdown at the water table such that the 1 m drawdown contour in the Ulan Coal Seam may extend up to 5 km to the west of the proposed mining areas.

The maximum drawdown extent in both the water table aquifer and the Ulan Coal Seams is shown in Figure 7.4 and 7.5 respectively, along with locations of privately owned groundwater bores in the assessment area. These figures represent the maximum predicted drawdown at each location within the model domain. Therefore, they accurately represent maximum impact at any location regardless of which year the maximum impact occurs during mining. Water level contours at the end of mining are presented for both the water table aquifer and the Ulan Coal Seam, Figure 7.6.

The model predicts that 20 years after mining ceases, groundwater will have largely recovered over much of the model domain, and following 50 years of recovery a new equilibrium will have occurred. Groundwater levels are presented for both the water table aquifer and the Ulan Coal Seam 20 years after mining in Figure 7.7 and 50 years after mining in Figure 7.8. Groundwater levels near Pit Lake B will remain slightly lower as the lake forms a very localised groundwater sink and groundwater in this area will continue to flow towards the lake over the longer term.

7.2 Groundwater users

Within a 15 km radius of the Project area 143 registered bores were identified. During the two hydrocensus surveys, a total of 74 individual bores were surveyed, with 40 of these able to be correlated with registered bores.

The groundwater model has been used to assess the potential impacts on bores surveyed during the hydrocensus. The model results predict that of the hydrocensus bores, two bores will experience a drawdown of 2.9 m and 23 m respectively as a result of mine dewatering Table 6.4).

Other registered groundwater bores, which could not be accessed during the hydrocensus may also be impacted by mining activities. The screened intervals of these bores have been estimated based on geology information in the NOW groundwater bore database and the geology map. The model results predict that of the registered bores, four bores will experience drawdowns of 4.1, 4.9, 15 and 25.8 m respectively as a result of mining (Table 6.4), and most are located on land now owned by CHC.

The majority of bores show predicted drawdown values of less than 2.5 m throughout the period of mining activities and beyond. A threshold of 2.5 m drawdown has been applied for assessment purposes, as it represents the likely natural range of groundwater levels in the Project area.

Based on these results, the overall impact on groundwater users is considered low and manageable. It is noted that five of the six bores that are predicted to experience drawdown >2.5 m are located on properties owned by Cobbora Holding Company Pty Ltd and therefore impacts to third-party bores is expected to be negligible. Should water supplies from the bore of the single property owner outside the land owned by Cobbora be adversely affected, appropriate remedial measures will be negotiated.

The maximum drawdown groundwater contours during mining are overlain with registered groundwater bore users and the current extent of the land owned by Cobbora Holding Company. The water table drawdown contours and registered bore users who obtain groundwater supply from the water table aquifer are presented in Figure 7.4.
The depressurisation of the Ulan Coal Seam is illustrated in Figure 7.5 and registered bore users who access this deeper groundwater source are illustrated on this map. It should be noted that most users obtain their groundwater supply from the shallower water table aquifer.

7.3 Baseflow to rivers/creeks

The numerical model, described in Section 6, has been used to assess the potential impacts on rivers and creeks in the assessment area as a result of mine dewatering activities.

The model results indicate a likely maximum reduction in river flow of approximately 280 ML/a occurs towards the end of mining operations. This constitutes 0.5% of the average annual flow in the Talbragar River of 54,427 ML/a (Parsons Brinckerhoff 2012).

Many of the creeks and rivers in the assessment area are ephemeral in nature and it is likely that large stretches of the river network receive negligible groundwater flow throughout the year. During dry periods, there remain isolated semi-permanent pools within the creeks. There is no appreciable flow of surface water in these pools and it appears that groundwater inflows to these pools are balanced by evaporative losses. As mining progresses the frequency of low flow events in the surface water systems will increase and this is likely to supplement water to these pools, as further discussed in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012).

The numerical model indicates that, under current pre-mining conditions, surface water bodies are a net source of water to the groundwater system. This is supported by field observations during flooding. This influx of water is expected to occur mainly during periods of high river flow, following heavy rainfall.

The predicted reduction in river flows is expected to mainly comprise increasing recharge of surface water to the underlying aquifers. Reduced flow of groundwater to surface water bodies during mining is expected to make up a much smaller component of the 280 ML/a indicated by the model. The model results predict that approximately 70% of the total reduction in surface water flows is due to increased outflows from rivers to the surrounding groundwater system, with reductions in baseflow accounting for the remaining 30%.

Following the cessation of mining the water table aquifer (which includes the alluvial aquifer) largely recovers within 20 years.

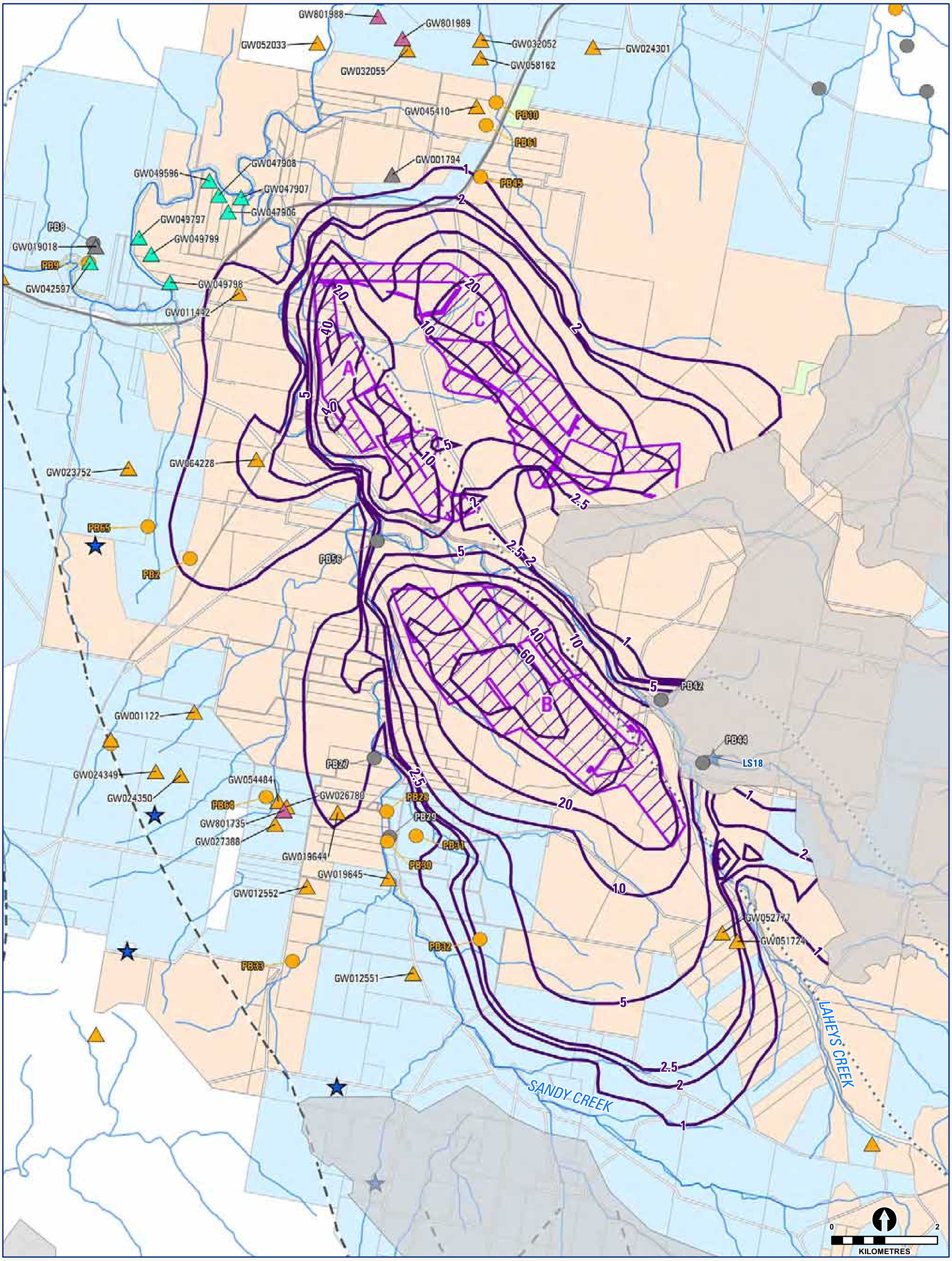
7.4 Potential groundwater availability to ecosystems

Groundwater is potentially available to ecosystems in various environments across the assessment area. Their occurrences, potential impact and impact level are summarised in Table 7.1.

Table 7.1 Potential impacts on groundwater availability to ecosystems

Groundwater environment	Occurrence	Potential impacts	Impact level
Springs/seeps	Seventeen springs or seeps have been identified across the assessment area (Figure 5.17). These are typically associated with localised outcrops of Tertiary basalt or Jurassic sedimentary outliers. The elevations of the springs tend to be significantly higher than the regional water table and piezometric head (confined groundwater pressures).	Hydrogeochemical and isotopic evidence indicates that springs and seeps are derived from recent meteoric recharge and not the Permo-Triassic groundwater system. They represent local perched systems that are independent of the regional aquifer system. In addition the identified springs and seeps are located beyond the area of predicted drawdown. Flow rate and water quality at the springs are therefore unlikely to be impacted by the proposed operations.	Low
Spring*	Naran Springs is identified as a high priority groundwater dependent ecosystem (GDE) in the water sharing plan for porous rock water sources. It is located approximately 5.25 km to the west of the proposed mining areas. It is located in an area where the regional water table (and piezometric surface) is greater than 20 m below the ground surface.	Naran Springs is assumed to be similar to the other springs identified in the study area and associated with outliers of Jurassic sedimentary rocks. Naran Springs is similarly unlikely to be impacted by the proposed operations.	Low
Semi-permanent pools (non-flowing) within the creeks and rivers	Semi-permanent pools occur in a number of locations along Sandy and Laheys Creeks and the Talbragar River. The pools are sustained by episodic stream flow events and minor discharge of groundwater from the alluvium and, locally, the Permo-Triassic system. Groundwater discharge is insufficient to cause permanent base flow in the Talbragar River and tributary streams in the Project area.	Modelling indicates that significant drawdown is likely to occur in the Permo-Triassic units adjacent and to the west of mining areas A and B. This may induce leakage from the alluvium and cause a decline in groundwater seepage in semi-permanent pools that are connected to those groundwater systems along Sandy Creek and Laheys Creek. Despite the predicted drawdown, temporary groundwater storage in the alluvium may continue to sustain these pools for 6 to 8 months following flood recharge events. The increased incidence of low flow events during and post mining from the surface water systems is likely to mitigate the groundwater impact to some degree as further discussed in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012.	Moderate
Shallow groundwater in river and creek alluvium	Groundwater occurs at shallow levels within alluvium and Permo-Triassic units in a narrow (500 m) but discontinuous zone adjacent to creek and river courses in the Project area (Figure 5.17). Where groundwater is shallower than 3 m depth, it is assumed to be available to deeper rooted vegetation.	Significant drawdown is likely to occur in the Permo-Triassic units adjacent and to the west of mining areas A and B. Testing has shown that the alluvium is hydraulically poorly connected to the underlying Permo-Triassic strata and it is expected that depressurisation of the coal measures will cause some drawdown in the alluvium. Modelling suggests that the drawdown may exceed 5 m along stretches of Sandy and Laheys Creek that are adjacent to mining areas A and B. Rainfall and flood recharge will likely be sufficient to sustain the local alluvium aquifers for several months following flood events despite drawdown in the coal measures.	Moderate

* Priority groundwater dependent ecosystem as identified by the Water Sharing Plan for the MDB Porous Rock Groundwater Source (NOW 2011b)



Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known
- Springs

- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Maximum predicted drawdown (m)

Land Ownership
- Private land
- Cobbora Holding Company
- Crown land
- no data

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

Figure 7.4 Land ownership and water table aquifer drawdown extent

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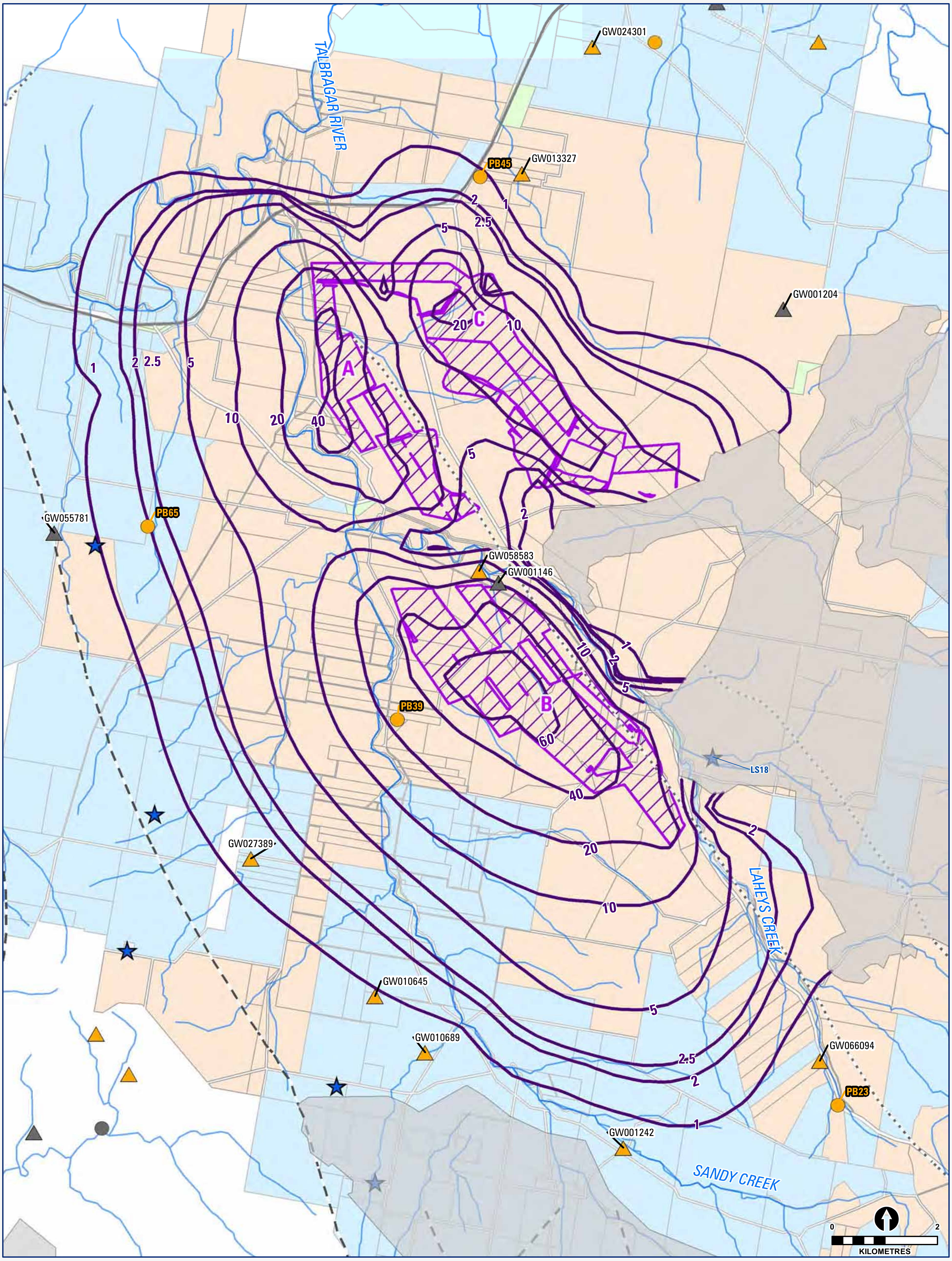


Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Not known

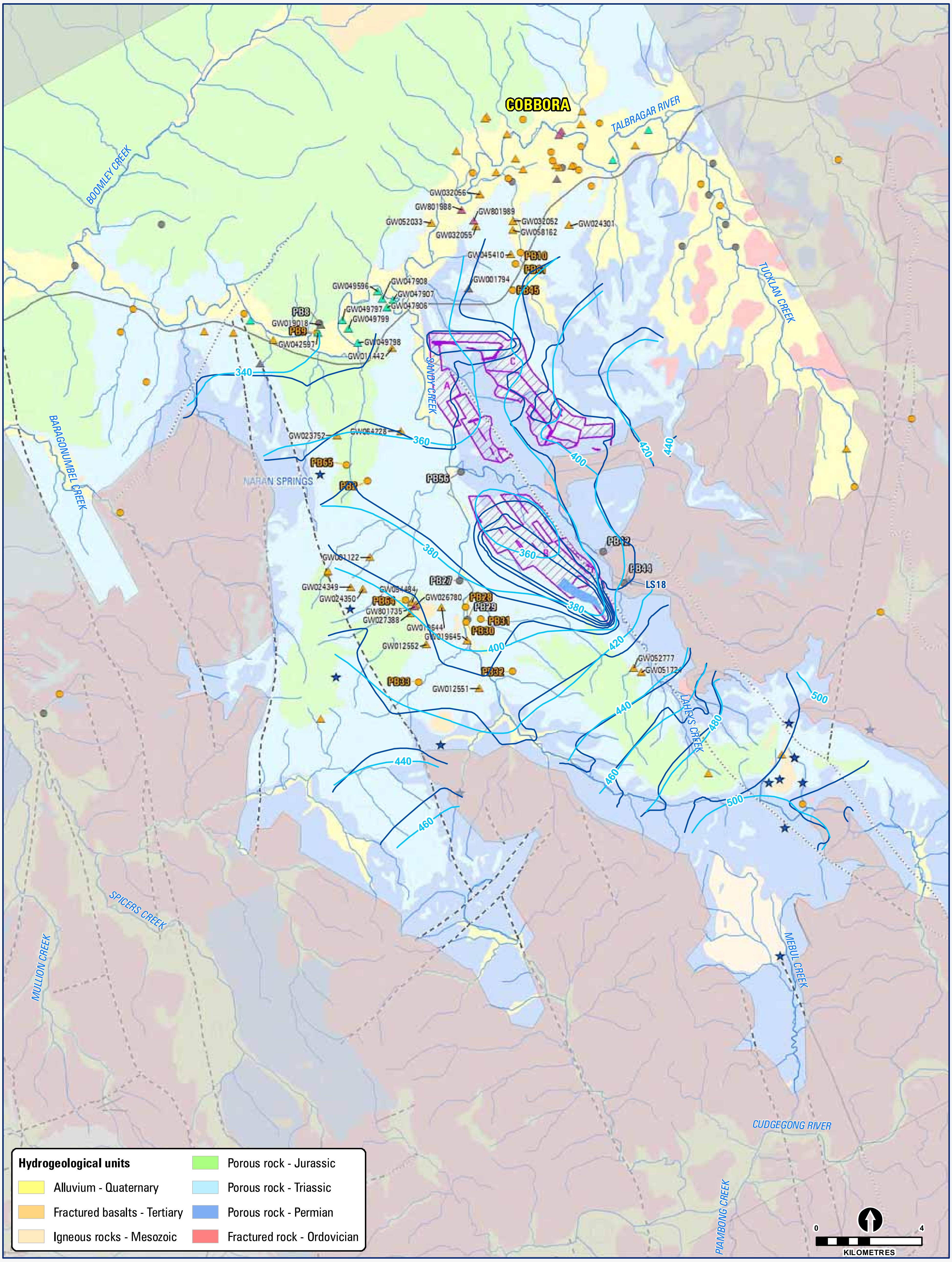
Surveyed Groundwater Users
- Stock/domestic
- Irrigation
- Not known
- Springs

- Maximum predicted depressurisation (m)
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas
- No flow boundary of numerical groundwater model

Land Ownership
- Private land
- Cobbora Holding Company
- Crown land
- no data

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

Figure 7.5 Land ownership and Ulan Coal Seams depressurisation extent



Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed

- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location

- Groundwater elevations: End of mining (Year 21) - Ulan Coal Seam
- Groundwater elevations: End of Mining (Year 21) - Water Table

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

Figure 7.6 Water levels and Ulan Coal Seams pressures at cessation of mining

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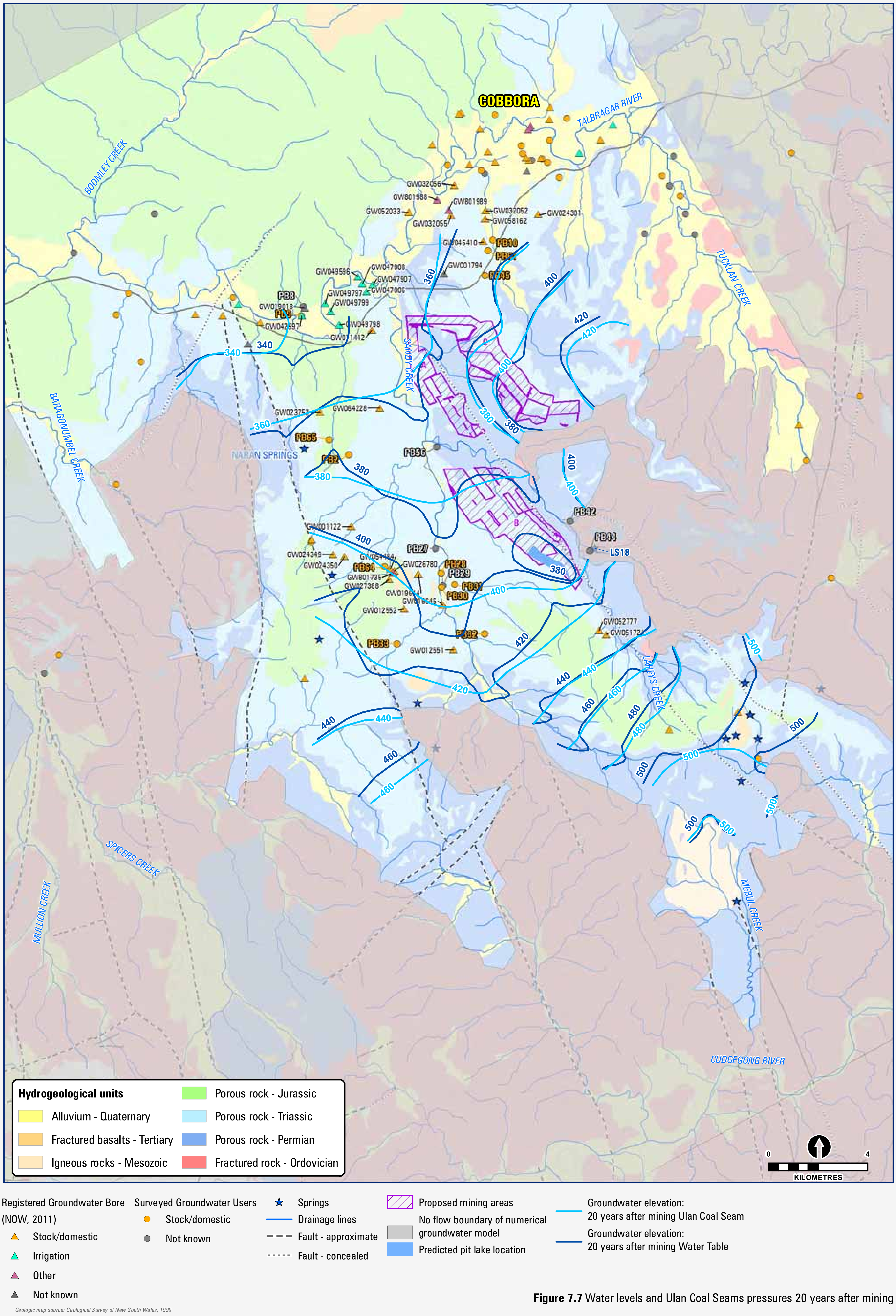

Figure 7.7 Water levels and Ulan Coal Seams pressures 20 years after mining

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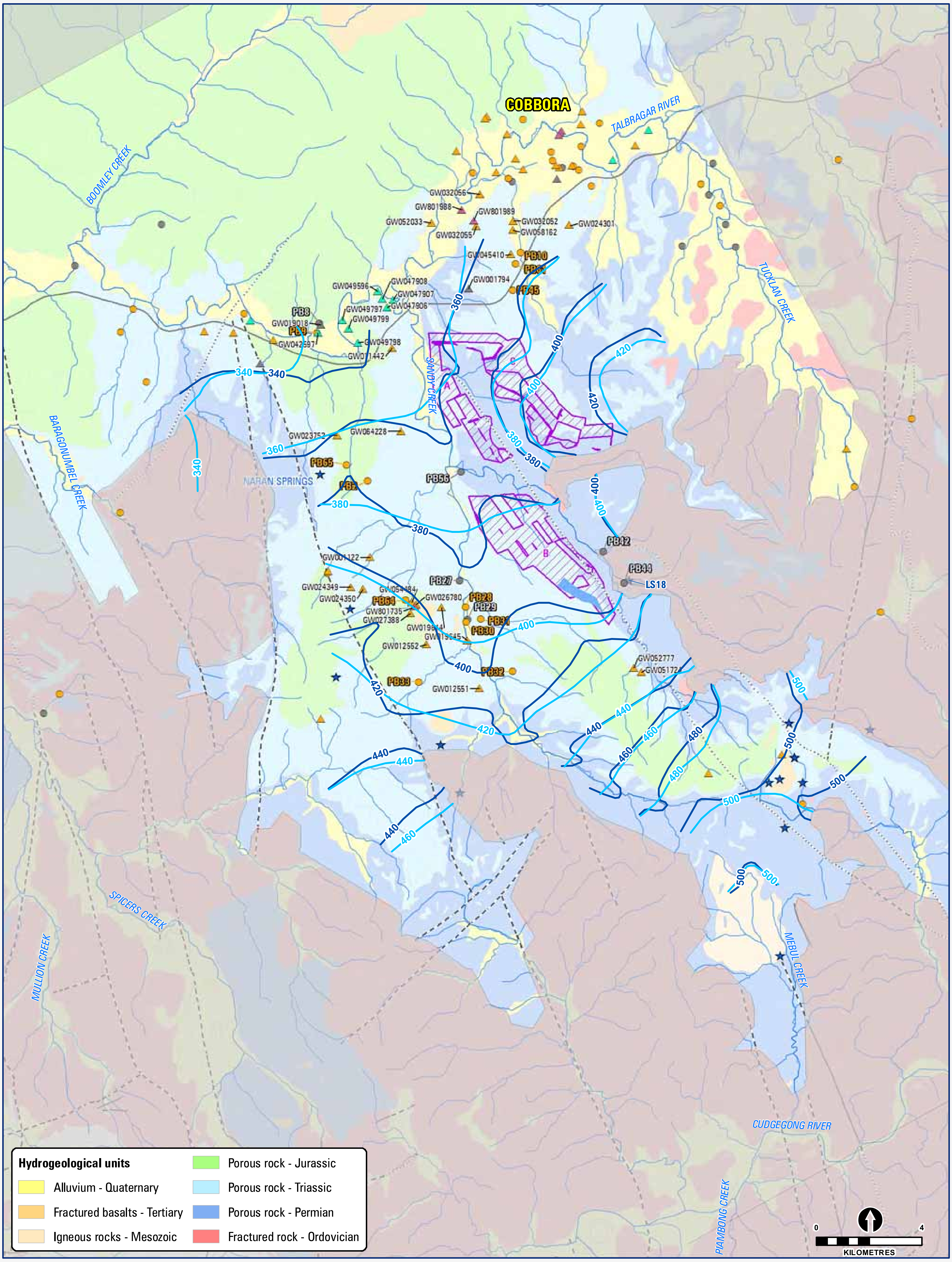

Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed

- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location

- Groundwater elevation: 50 years after mining Ulan Coal Seams
- Groundwater elevation: 50 years after mining Water Table

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

Figure 7.8 Water levels and Ulan Coal Seams pressures 50 years after mining

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7.5 Groundwater quality

Baseline groundwater quality within the alluvium aquifer is marginal to saline (averaging 3,650 µS/cm EC), with salinities generally increasing with depth. Due to the low permeability and isolated nature of the aquifer, the contribution to overall mine inflows and therefore quality is expected to be very low impact.

The western edge of mining area A is the only area planned to intersect alluvial sediments. Therefore the alluvium aquifer groundwater contribution to pit inflows will be very minor. Where leakage of groundwater from the alluvium aquifer to the underlying aquifer occurs, no degradation to the underlying groundwater is expected due to its existing quality.

Groundwater salinity within the Triassic units is 4,000 µS/cm EC, which on average is higher than the Permian units (1,600 µS/cm EC). Therefore there is likely to be some variation in quality of groundwater inflows depending on depth and location of mining. The shallower zones of mining will generally produce more saline waters, while the deeper zones of mining that intersect the fresher groundwater within the Ulan and Dapper seams is likely to improve the quality of overall inflows.

The overall groundwater quality is likely to be similar to that described for those piezometers and test production bores screened across multiple units within the porous rock aquifer (Section 5.7.2). The porous rock aquifer is typically brackish, slightly acidic to slightly alkaline, dominated by chloride and sodium, and contains elevated zinc and iron.

Mining is expected to result in increased connectivity and subsequent mixing of groundwater within the vicinity of the mining areas. However, the anticipated change in water quality as a result of increased interaction between the units will not degrade the measured water quality conditions or beneficial use at most bores.

As mining progresses, mined areas will be backfilled. Active dewatering of the mining area will cease following mining operations and the pore spaces within the backfilled area will gradually become saturated. During this saturation phase, the hydraulic gradient will initially be towards the backfilled material including Pit lake B. Due to the final lake level being lower than the surrounding recovered groundwater levels, over time the Lake in Pit B will become increasingly saline, and potentially hypersaline. This has been calculated analytically and discussed in greater detail in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012). However, groundwater quality outside the lake is likely to be largely un-impacted as hydraulic gradients will continue to be towards the lake over the longer term.

Groundwater flowing through the backfill is likely to undergo slight changes in quality, as groundwater interacts with the backfill material. Minerals present in the backfill material will gradually dissolve into the groundwater until the chemical composition reaches equilibrium. Backfill material will comprise the in situ sedimentary rock removed to access the Ulan Coal Seams, which should minimise the potential for significant changes in resultant groundwater chemistry.

In March 2012, Geoterra carried out a geochemical assessment to assess the acid mine drainage (AMD) potential of the overburden, coal, floor rock and washery wastes anticipated to be produced from development of the Project. The geochemical assessment concluded that:

- overall, overburden and the pit floor are likely to be non-acid forming and should not require any special handling for acid and metalliferous drainage control

- overburden has low salinity and neutral acidity
- mixing mining waste will mitigate isolated AMD leachate.

Based on the samples analysed and interpretation undertaken by Geoterra (2012), the potential for AMD to be considered a risk to groundwater is low.

After mining, groundwater will flow towards the mining areas, and following the recovery of groundwater levels the longer term post mining gradients are expected to be towards the alluvium to the west and north-west across the majority of the landscape.

The neutral acidity and low salinity of the overburden means that longer term impacts to the adjacent groundwater sources, including the alluvium are considered to be low.

Due to the evaporation rates which generally exceed rainfall, evapoconcentration is predicted to reduce water quality in the final Pit B lake over time, as the removal of fresh water by evaporation causes concentrations of dissolved metals and salts to increase. This is discussed in the water balance modelling section of the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012).

7.6 Groundwater licensing

Based on the numerical modelling results the mine inflow rates have been estimated; the peak mine inflows are 1,775 ML/a at year 2031.

Of the 1,775 ML/a peak mine inflow, the model differentiates source inflows to the mine as up to 280 ML/a from the Talbragar River, and the remaining 1,495 ML/a from the Gunnedah-Oxley Basin MDB Groundwater Source. Licences from each individual water source will be required (see Table 7.2).

Table 7.2 Water licensing requirements

Water source	Water licence volume required (ML/a)	Current water licences held (ML/a)
Gunnedah-Oxley Basin MDB Groundwater Source	1,495	538
Talbragar River	280	0
TOTAL	1,775	538

Water access licences on the Talbragar River may be purchased via water trading of existing licences on the River. Further detail is available in Parsons Brinckerhoff (2012) on water availability within this system.

Groundwater within the Gunnedah-Oxley Basin MDB Groundwater Source may be traded from any location within the Gunnedah-Oxley Basin. which extends from the Great Dividing Range in the south east (where it separates from the Sydney Basin) to the north and west where it crosses the NSW-Queensland border.

CHC require a total of 1,495 ML from the Gunnedah Oxley Basin MDB Groundwater Source, and currently have secured 538 ML (36% of the required volume). This leaves 957 ML to be purchased from the remaining 15,659 ML of current available licenced entitlement across approximately 115 Water Access Licences within the Gunnedah-Oxley Basin MDB Groundwater Source.

The 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. A controlled allocation policy will be the mechanism for release of additional unassigned water from the Gunnedah-Oxley Basin MDB Groundwater Source, but this policy is yet to be legislated.

At this stage no licence entitlements for the extraction of water from the main stream of the Lower Talbragar River have been purchased. However, there is a combined 1,279 ML held across approximately 23 WALs in the Lower Talbragar River Water Source and the Upper Talbragar River Water Source. The CHC licensing requirement from the Talbragar River will consist of up to 280 ML/a or approximately 22% of the total entitlement. The trading markets associated with the respective Talbragar River water sources have historically been limited. CHC intends to enact a strategy of direct engagement with WAL holders to ensure the required licences are obtained.

7.7 Final Landform

The final landform has been optimised to minimise impacts to groundwater and surface water over the longer term. Assessments of the impacts post mining consider the final landform and analytical calculations and modelling have been undertaken to assess the impacts.

Mining area A will be backfilled to be 3 metres above the current groundwater table and will also provide a free draining surface profile. This design allows for rainfall to either recharge the underlying groundwater system and or run-off in high rainfall events to the surface water system. The backfill to 3 metres above the water table is considered to be well in excess of the capillary fringe and vegetation on these areas is also likely to be shallow rooted. Therefore this design allows the natural processes of rainfall and groundwater recharge to occur freely (Figure 7.2), and will minimise impacts to the adjacent groundwater and surface water systems.

Mining area B final landform has been designed to minimise impacts to the surface and groundwater systems while also recognising the economic feasibility of fully backfilling this deep narrow pit. The final landform is therefore largely backfilled to 3 metres above the current water table but with a small section of the pit to remain as a deep narrow lake. The backfilled area means that the final surface area of the active mining void is reduced by almost half (Figure 7.3) of the final mining area the end of mining. The backfill to 3 metres above the water table is considered to be well in excess of the capillary fringe and vegetation on these areas is also likely to be shallow rooted. The final shape and location of Pit B lake ultimately minimises the potential for saline water to impact on the surrounding groundwater systems by forming a groundwater sink. Localised groundwater flow over the longer term will be towards this lake, thereby minimising impacts over the longer term.

Pit C will be backfilled to be 3 metres above the current groundwater table and will also provide a free draining surface profile. This design allows for the majority of rainfall on this area to recharge the underlying groundwater system and in high rainfall events to run-off into to the surface water system. Excess surface water will run-off to the south east into Blackheath Creek a tributary of Laheys Creek (Figures 7.1 and 7.2), and will prevent the development of salinity in this small catchment. The backfill to 5 metres above the water table is well in excess of the capillary fringe and vegetation on these areas is also likely to be shallow rooted. Therefore this design allows the natural processes of rainfall and groundwater recharge to occur freely and will minimise impacts to the adjacent groundwater and surface water systems.

8. Monitoring and management

8.1 Groundwater monitoring network

Groundwater quality and groundwater level monitoring has been carried out on the existing network of monitoring bores on an intermittent basis since their installation for the purpose of baseline data collection. It is recommended that nominated bores be used throughout the life of the mine to monitor groundwater level and groundwater quality changes associated with mining.

8.1.1 Replacement monitoring bores

A number of the existing monitoring bores are located within the footprint of the proposed mining area. As mining progresses these bores will be destroyed. To ensure the monitoring network is not compromised, a program to replace the bores will be implemented.
This process will also be applicable to monitoring bores destroyed in the everyday operations of the mine.

All monitoring bores likely to be destroyed based on the current mine plan have been identified. A replacement schedule would be prepared and locations proposed for the bores. Bore locations are preliminary at this stage and in some cases are subject to land access approval. A qualified licensed driller would be required to drill and construct the bores, and bore licences obtained from NOW.

8.1.2 Additional monitoring bores

Additional monitoring bores may be required prior to, during and post mine operations. Based on the predicted impacts (Section 7) the monitoring network will likely need refinement, and additional monitoring bores be installed in strategic locations as follows:

- Drawdown of groundwater levels and pressures within the alluvium and porous rock aquifers in the assessment area:
    - The alluvium aquifer of the Talbragar River to the north east of the project Area. Specifically the monitoring of alluvium between the upstream alluvial irrigators (Collaburragundry-Talbragar Valley Alluvium Water Source) and the area of the alluvium aquifer predicted to be impacted by mining (new monitoring bores).
    - The Talbragar River alluvium aquifer adjacent to the mine site (existing bores GW5A, GW4, GW10).
    - The Talbragar alluvium aquifer downstream of the proposed mine location (new monitoring bore adjacent to one of the existing porous rock bores GW19, 20 or 21).
    - Several additional monitoring bores to the west and south of the mining areas constructed into the Permo-Triassic units between existing private groundwater users and the mining areas (existing GW2, and new monitoring bores).

    - New nested monitoring bores to the west of current Site 6 between Pit B and Sandy Creek to monitor long-term groundwater level and quality changes. This site would provide valuable data during mining and also be critical to monitor the recovery of groundwater levels between Pit lake B and Sandy Creek.

- Reduced groundwater discharge to creeks and loss of potential groundwater availability to ecosystems:

    - Semi-permanent pools along Sandy Creek, Laheys Creek and the Talbragar River which are likely sustained by seepage from the alluvial aquifers, and potentially also the Permo-Triassic aquifer where they outcrop in the stream beds (six new monitoring sites).

    - Naran Springs (one new monitoring bore screened into the base of the Jurassic rock, and one into the underlying Permian Ulan Seam).

- Reduction in available groundwater for identified existing groundwater users within the assessment area:

    - The groundwater assessment indicates six registered groundwater bores may be potentially impacted by the Project, of which five are owned by CHC. To ensure the Project does not result in undue impact on the availability and quality of groundwater supplies to neighbouring landholders, all potentially impacted bores will be fully assessed prior to the commencement of mine operations, and where required, each bore will have trigger levels set for groundwater quality (electrical conductivity) and groundwater availability (water level). These bores will be monitored as part of the overall mine monitoring network.

- Monitoring of mine water dams and general groundwater quality:

    - To ensure early detection of any groundwater contamination, new shallow monitoring bores should be installed adjacent to mine water dams and overburden stockpiles that contain potentially contaminated water or waste rock materials.

    - New monitoring bores (and/or existing where present) should be installed upstream and downstream, and adjacent to the Pit B in the alluvium to monitor groundwater level and quality changes

    - Additional porous rock and alluvium aquifer monitoring bores between the mining area A and the Talbragar River to monitor groundwater levels and quality between the former pit voids and River.

8.1.3 Groundwater level monitoring

All existing monitoring bores are fitted with groundwater level data loggers that record the groundwater level on a continuous basis. The level data is downloaded and the manual levels are recorded on a bi-annual basis.

It is recommended that this practice continues on a bi-annual basis until mining commences. Following the commencement of mining, the frequency of groundwater level monitoring should continue, but additional data downloads from bores closest to the active mining area should be increased to quarterly or monthly downloads to ensure data losses are minimised.

The monitoring frequency and number of bores fitted with data loggers should be reassessed on annual basis as part of the annual monitoring report.

8.1.4 Groundwater dewatering volumes

Rates of seepage to active mine pits during operation should be monitored. Monitoring of groundwater quality and seepage and/or groundwater levels should be undertaken at in-pit sumps and pumps and at dewatering bores if they are constructed as part of the mining operation.

8.1.5 Groundwater quality

A bi-annual groundwater quality monitoring program is ongoing at the site and this should continue until mining commences. As mining progresses, the frequency of monitoring at sites close to active mining areas should be increased to quarterly or monthly to ensure changes in the groundwater chemistry are detected as early as possible. Salinity monitoring in particular is required during mining and following the cessation of mining

The recommended analytical suite for groundwater monitoring, based on the baseline investigations, is as follows:

- field parameters — pH, EC, redox, temperature, DO and CO_2
- laboratory analytes — major ions (calcium, potassium, sodium, magnesium, chloride, bicarbonate and sulfate) and dissolved metals (aluminium, barium, beryllium, cobalt, iron, manganese, lead and zinc).

Sampling should be undertaken by trained personnel to ensure representative samples are collected from each bore. These samples should be submitted for laboratory analysis to a NATA-accredited laboratory.

A program of routine water sampling and testing of washery wastes and overburden and/or interburden materials should also be carried out during active placement to monitor any variation in acid potential and to reconcile the low potential AMD in the overburden.

8.1.6 Existing groundwater users

A number of existing groundwater users have been identified within the predicted 1 m zone of influence. While these groundwater bores remain operational, they will be incorporated into an ongoing groundwater level and quality monitoring program for the Project.

In some situations, additional monitoring bores may need to be specifically constructed to target selected aquifers so that any impacts from the mine on existing users can be more accurately understood. This greater level of understanding can be used to better manage and target practical mitigation options for these users.

8.1.7 Potential groundwater dependent ecosystems

The identification and assessment of groundwater-dependent ecosystems will continue to be undertaken by NOW as stated in Schedule 3 of the Water Sharing Plan for the MDB Porous Rock Groundwater Sources (NOW 2011b). Where additional groundwater-dependent ecosystems are identified during the life of the mine, additional monitoring may be required.

8.2 Data management and reporting

Collation and review of all monitoring data should be undertaken prior to mining commencing. Annual reporting is recommended and should be carried out by an experienced hydrogeologist.

The review of all monitoring datasets should be undertaken annually and focus on identification of trends, overall adequacy of the monitoring program, identification of gaps, and to determine if measured impacts continue to be within reasonable limits of the most recent predictions.

8.2.1 Development of trigger levels

It is proposed that soft trigger levels for groundwater levels and quality be developed immediately prior to the commencement of mining. Trigger levels should not necessarily be fixed for the life of the mine operation, but should be developed in collaboration with nearby groundwater users, NOW and other professionals including ecologists.

Trigger levels should be based on a combination of natural variation in the baseline dataset and the predicted impact from the groundwater model. As mining progresses, the monitoring data may vary (such as over periods of extended wet or dry years) and trigger levels may need to be adjusted annually to ensure they remain relevant and useful tools for environmental management during mine operation.

The update of impact assessment model(s) with the latest datasets and mine operations data (actual mine progression, depths and inflow rates, as well as future mine plans) should be carried out and used to ensure trigger levels are appropriate.

Trigger levels should be designed to ensure that triggers are only activated due to unpredicted impacts occurring, or at key stages of the mine operation to prompt a predetermined action (such as more frequent monitoring or sampling, visits to landholders to ensure their water supplies are being maintained, or inspection of groundwater dependent ecosystems).

The updated models and simulations would be used to review and update the trigger levels and mitigation and response plans, where appropriate.

9. Mitigation measures and response plans

The groundwater assessment has highlighted potential risks associated with mine-induced drawdown for impacts to the groundwater regime and users. These include:

- loss of access to groundwater for some private bores
- mine groundwater inflows
- reduction in baseflow to the Talbragar River and associated tributaries
- reduction in water availability to potential ecosystems
- changes in groundwater quality.

The adoption of a comprehensive mitigation and response plan is required to minimise, if not eliminate, the effects of these potential impacts. A groundwater management plan (Appendix J) will be prepared, which will detail the mitigation measures and response plans.

Based on the modelled potential impacts, the following recommendations should be considered.

9.1 Groundwater levels

A groundwater management plan should be prepared detailing established trigger values for drawdown prior to the commencement of mining. The plan would allow for prompt and appropriate response actions to ensure impacts are mitigated, or responded to.
The framework of the groundwater management plan is provided in Appendix J.

9.1.1 Groundwater users

Groundwater users have been identified as likely to be impacted by mining operations due to a reduction in groundwater levels. At this stage of the assessment the modelled impacts do not require immediate action.

Where groundwater bores have been identified as likely to experience drawdowns they will be included in the routine monitoring program for groundwater levels. Each groundwater user would be assessed on a case by case basis.

Where a groundwater bore is identified as experiencing a loss in availability of water, an assessment will be undertaken investigating the loss of availability, whilst considering any mitigating factors where applicable (e.g. age, bore efficiency/construction, review of climatic conditions, and assessment of current monitoring). If further monitoring information is required, additional monitoring bores may be installed between the landholders bore and the mine site.

Where an assessment deems the impacts are a result of mining and are unacceptable, the options to mitigate the impact could include:

- Replacement bore(s) being drilled deeper on site or at other locations to compensate for the loss in yield or groundwater quality. This could require additional costs for pump replacements (upsizing) and/or expansion or upgrades to the distribution networks and additional power consumption, if any.

- The mine operator providing a replacement water supply, either via surface water licences and/or excess groundwater inflow. This option may require treatment as well as a delivery mechanism.
- Compensation for temporary or permanent retirement of operations requiring water being arranged with private bore users.

9.1.2 Mine groundwater inflows

Groundwater inflows to the mining areas will be routinely monitored and compared to modelled inflows. Where actual inflows exceed modelled inflows under drier than average conditions, a hydrogeologist should carry out a review to establish the nature of the exceedence and the possible reasons for it. An appropriate response action for should be prepared and implemented in consultation with NOW.

Based on the groundwater model, groundwater inflow to the mining areas is likely to be greatest along the western and southern perimeters of the overall mining areas. Artesian groundwater pressures are present on the boundaries of these areas, therefore mitigation measures may include installation of dewatering bores pre mining to depressurise the aquifer in this area, and reduce the inflows to the pit.

9.2 Groundwater quality

To mitigate and manage risks to groundwater quality it is recommended that the following be implemented:

- Any tailing dams to be constructed, managed and rehabilitated to best practice standards to minimise any potential impacts to groundwater sources.
- A water management strategy for end of mining that monitors the chemistry of the water in Pit B.
- A sampling and testing program for monitoring acid potential of the waste rock.
- An emergency spill and clean-up plan upon the notice of a spill or presence of contaminant. Reporting, clean-up and monitoring of all spills are required.
- Collect and store groundwater seepage to the mining areas in small sumps in the pit floor where it can be monitored, and then transfer to environmental dams.

9.3 Communication and reporting plan

Consultation will be undertaken by CHC with stakeholders and government agencies, in particular NOW, when establishing the final mitigation and response plan(s), trigger values, and reporting protocols to be implemented during mine operation. The reporting process will include a clear communications matrix identifying the organisations and personnel to be notified in the event an impact is detected.

10. Conclusions

This report and its associated appendices have been prepared to assess the impacts of the proposed Project on the local and regional groundwater environment. It considered:

- An overview of the Project, and the objectives and scope of the groundwater assessment.
- The DGRs relating to groundwater for the Project and the relevant legislation, policies and guidelines.
- The groundwater investigations undertaken for the assessment.
- The existing groundwater environment of the Project area, including the assessment of hydraulic properties; groundwater levels; groundwater flow and groundwater quality, surface water – groundwater connectivity, and potential groundwater availability to ecosystems.
- The Project's potential impacts on local and regional groundwater resources, groundwater users and potential groundwater availability to ecosystems.
- Mitigation measures and response plans for the Project.
- The future monitoring and management of groundwater for the Project, including monitoring requirements, recommendations and a groundwater management plan.

Through field investigations and assessments, and numerical groundwater modelling it can be concluded that the potential impact the Project will have on the local groundwater system 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.

Modelled groundwater inflows to the mining areas are expected to lead to maximum lowering of the water table of up to 85 m in mining area B. The 1 m drawdown contour is predicted to extend up to 5 km to the south of the mine and nearly 4 km to the west. Drawdown to the north and east is far less extensive, with the 1 m drawdown contour predicted to lie within 3 km of the mining areas.

For the Ulan Coal Seams the 1 m drawdown contour is predicted to lie approximately 5 km to the west of mining areas A and B. The extent of drawdown to the south, north and east of the mining areas is similar to that predicted for the water table aquifer.

The predicted cumulative storage losses within the alluvium could reach a maximum value of approximately 300 megalitres (ML), which constitutes only 0.1% of the estimated 220,000 ML (220 gigalitres (GL)) of available groundwater storage in the alluvium aquifer within the model domain.

Groundwater drawdown levels for nearby users have been assessed and there are six private bores that will experience drawdown greater than 2.5 m. Five of these six bores are owned by CHC and therefore impacts to third-party bores is expected to be negligible. Where the impact to third party bores is 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 of approximately 280 ML/a, which occurs towards the end of mining. The impact is considered small in relation to flows in the Talbragar River, representing only 0.5% of the average annual flow. Existing water access licences will be purchased by Cobbora Holding Company Pty Ltd 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, semi-permanent pools and shallow alluvial groundwater.

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 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 cause a decline in groundwater seepage in semi-permanent pools. Subsequently the availability of groundwater to ecosystems potentially relying on current shallow groundwater and 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 alluvial and Permo-Triassic outcrop monitoring bores will be undertaken to manage and mitigate the impact.

Modelling has indicated that post mining the hydraulic gradient will be towards the alluvium to the west and north-west of the mining areas. Mitigation measures include rehabilitating the final landform to reduce the potential for groundwater and surface water salinisation by limiting the accumulation of surface water in the final pit voids, and managing waste material to avoid potential acid mine drainage.

A groundwater management plan will be prepared prior to the commencement of mining. The Plan will provide details on the monitoring of groundwater levels, mine inflows and groundwater quality, including trigger levels, procedures for review and appropriate response action plans. Mitigation measures would also be included should monitoring indicate impacts are not consistent with modelling results. The staged mine plan allows time to implement mitigation measures should there be inconsistencies with modelled impacts.

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 impact 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 groundwater management plan. The Plan will be prepared in consultation with NOW, and will assist the mine in operating within contemporary environmental standards, to ensure that CHC can comply with its anticipated licensing and statutory obligations.

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