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Caroona Coal Project
Application for Gateway Certificate

Appendix C
Preliminary Groundwater Assessment

CAROONA COAL PROJECT:

GATEWAY APPLICATION PRELIMINARY GROUNDWATER ASSESSMENT

FOR

BHP BILLITON

By

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Report: HC2013/25

Date: March 2014

EXECUTIVE SUMMARY

HydroSimulations has been engaged by Coal Mines Australia Pty Ltd (CMAL), a wholly owned subsidiary of BHP Billiton, to undertake a Preliminary Groundwater Assessment for the proposed Caroona Coal Project (the Project), for the purposes of assessment under the New South Wales (NSW) Government's Gateway Application Process. A further groundwater assessment will be undertaken for the Environmental Impact Statement (EIS).

The Project is a proposed underground (longwall) coal mining operation targeting the Hoskissons Coal seam, with an operational life of approximately 30 years. The Project is located in the New England North West Region, approximately 40 kilometres (km) south east of Gunnedah in NSW. The Project area is located within Exploration Licence (EL) 6505.

Consistent with the requirements of the *Strategic Regional Land Use Policy Guideline for Gateway Applicants* (NSW Government, 2013) (Gateway Application Guidelines), the assessment relies on numerical modelling of potential risks of mine development in terms of the NSW Aquifer Interference (AI) Policy and Gateway Application requirements. This modelling was undertaken in consideration of the Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline (MDBC, 2001) and the relatively new National Guidelines, sponsored by the National Water Commission (Barnett et al., 2012).

A review of the data, literature and conceptual hydrogeology associated with other studies from the area and surrounds was carried out as a basis for model development. This was supported by a review of currently available information on geology, rock mass hydraulic properties, and strata geometry in the vicinity of the Project.

The complexity of the numerical groundwater model developed as part of this study is appropriate for this preliminary groundwater assessment by simulating contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the proposed development.

The AI Policy framework has been developed by the NSW Government to assist with the assessment and management of activities with potential to affect groundwater resources. The AI Policy framework has been developed by the NSW Office of Water (NOW) which identifies two Levels of minimal impact considerations, as described below:

- Level 1 impact, which is considered acceptable.
- Level 2 impact, which requires further studies to assess whether a project will prevent the long-term viability of a dependent ecosystem or significant site, or needs other arrangements to mitigate the impacts.

Consistent with the Gateway Application Guidelines, this report assesses impacts on groundwater designated as 'highly productive' groundwater.

The key findings of the preliminary groundwater assessment with respect to NOW's AI Policy are as follows:

- The Project meets the Level 1 Minimal Impact Considerations of the AI Policy for 'highly productive' groundwater associated with the Namoi Alluvium (i.e. Upper and Lower Namoi Groundwater Sources), and with the Liverpool Range Basalts (i.e. NSW Murray Darling Basin Fractured Rock Groundwater Sources [Liverpool Ranges Basalt MDB]).

- The Project triggers the Level 2 Minimal Impact Considerations of the AI Policy for the 'highly productive' Jurassic NSW Murray Darling Basin Porous Rock Groundwater Sources (Gunnedah-Oxley Basin MDB [Spring Ridge]). This is due to a model estimation of more than 2 metres (m) cumulative drawdown at 27 water supply works.

Consistent with the findings of the Namoi Catchment Water Study, BHP Billiton has committed to "make good" provisions for any groundwater users adversely affected by mine operations and associated impacts – i.e. provision of alternative water supply or remedial works (e.g. deepening of existing wells or bores). A Groundwater Management Plan will be developed prior to the commencement of longwall mining to define groundwater level triggers, including a Trigger Action Response Plan, and appropriate management responses and mitigation measures.

The impact assessment presented in this preliminary groundwater assessment will be refined as part of the groundwater assessment to accompany the Project EIS. As part of the Gateway Assessment, a number of bores were inspected to confirm their location, hydrogeological characteristics and usage (i.e. a bore census). BHP Billiton will conduct a second stage of the bore census in consultation with relevant landholders to confirm the status, location and details of the bores not yet inspected in order to inform further impact assessment work planned for the EIS.

DOCUMENT REGISTER

Revision	Description	Date
1	Preliminary draft. Data analysis section only.	05/12/2013
2	Draft for internal and external review. Completed Sections 3 through 8 (model build, calibration and predictions).	12/01/2014
3	Draft for external review. Completed Section 2, added predictive sensitivity, revised sections 4 through 8 (model predictions).	24/01/2014
4	Incorporated BHP/Resource Strategies/preliminary Frans Kalf comments.	16/02/2014
5	Final Draft. Incorporated BHP/Resource Strategies/Frans Kalf comments.	03/03/2014
6	Final. Incorporated BHP/Resource Strategies comments.	18/03/2014

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1 INTRODUCTION

HydroSimulations has been engaged by Coal Mines Australia Pty Ltd (CMAL), a wholly owned subsidiary of BHP Billiton, to undertake a Preliminary Groundwater Assessment for the proposed Caroona Coal Project (the Project), for the purposes of assessment under the New South Wales (NSW) Government's Gateway Process.

The Gateway Process requires a preliminary assessment of risks of the Project on groundwater resources. A broader groundwater assessment will be included in the Project Environmental Impact Statement (EIS). Given that this Gateway Application will be referred to the Independent Expert Scientific Committee (IESC), Attachment A provides a tabulation of where each of the IESC's information requirements is addressed.

The Project is a proposed underground coal mining operation with an operational life of approximately 30 years. The Project is located in the New England North West Region, approximately 40 kilometres (km) south east of Gunnedah in NSW (refer to Figure 1). The Project is located within Exploration Licence (EL) 6505.

BHP Billiton plans to seek Development Consent from the NSW Minister for Planning and Infrastructure under Division 4.1 of Part 4 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

1.1 NATURE OF THE PROJECT

The key components of the proposed Project comprise:

- an underground mining operation within EL 6505 involving a single longwall in the Hoskissons Seam on Doona Ridge and a second longwall in the Hoskissons Seam on Nicholas Ridge;
- production of approximately 260 million tonnes (Mt) of run-of-mine (ROM) coal over the life of the mine;
- production of up to approximately 10 Mtpa (million tonnes per annum) of saleable thermal coal;
- a mine life of approximately 30 years;
- development and operation of a pit top mine infrastructure area comprising administration offices, bathhouse, workshop, store, coal stockpile areas, coal handling infrastructure, bunded hydrocarbon tanks, laydown areas, car parking, electrical substation, muster area, associated linear infrastructure and access road on Doona Ridge;
- development and operation of a separate men and materials shaft on Doona Ridge;
- construction and operation of an event Coal Preparation Plant (CPP) (1 Mtpa ROM coal capacity) on Doona Ridge for washing of occasional high-ash ROM coal;

- construction and operation of a coal unloading facility on Doona Ridge to allow transportation of Nicholas Ridge ROM coal to Doona Ridge via rail for washing;
- co-disposal of fine and coarse rejects in an emplacement on Doona Ridge, with rejects to be transported within an infrastructure corridor;
- development and operation of a separate pit top mine infrastructure area comprising coal handling infrastructure, coal stockpiles, an access road, car parking, administration offices, muster area, electrical substation and associated linear infrastructure on Nicholas Ridge;
- relocation of Rossmar Park Road;
- construction and operation of separate rail loops and spurs to connect to the Binnaway-Werris Creek Railway from Doona Ridge and Nicholas Ridge;
- employment of up to approximately 400 operational personnel at peak production;
- employment of an average number of construction employees of approximately 400 and up to 600 at peak construction;
- emplacement of overburden excavated during the construction of access drifts and shafts;
- progressive development of sumps, pumps, pipelines, water storages and other water management equipment and structures (including dewatering infrastructure);
- development and operation of ventilation surface infrastructure and gas drainage infrastructure;
- development and operation of water and gas pipelines to connect the Nicholas Ridge infrastructure area to the Doona Ridge infrastructure area;
- ongoing exploration activities within EL 6505;
- ongoing surface monitoring and rehabilitation (including rehabilitation of mine related infrastructure areas that are no longer required) and remediation of subsidence effects; and
- other associated minor infrastructure, plant, equipment and activities.

1.2 SCOPE OF WORK

The key tasks for this assessment are:

- data analysis and conceptualisation of the groundwater system, including assessment of hydrostratigraphic units (HSU) and their properties, and groundwater recharge and discharge;
- development of a lower resolution regional-scale 3-dimensional numerical groundwater flow model based on data analysis and conceptual model development;
- steady state model calibration to observed groundwater level data, using a single zone of uniform parameters for each hydrostratigraphic unit;
- transient model verification against observed groundwater level data;
- transient prediction for the 30 year mine plan using lower temporal resolution of the extraction schedule, followed by simulation of the post-mining recovery period; and
- preparation of this Preliminary Groundwater Assessment report for inclusion in the Gateway Application documents that includes assessment of potential groundwater impacts of the Project and, where applicable, cumulative impacts with other existing and approved mines in the area associated with the development.

This assessment will focus on the criteria specified by the NSW Aquifer Interference (AI) Policy and the requirements of the *Strategic Regional Land Use Policy Guideline for Gateway Applicants* (NSW Government, 2013) outlined in Table 1.

Table 1 Gateway Process Requirements

Requirement	Section Reference
Estimates of all quantities of water that are likely to be taken from any water source on an annual basis during and following cessation of the activity;	Section 7
A strategy for obtaining appropriate water licence/s for maximum predicted annual take;	Section 7
Establishment of baseline groundwater conditions including groundwater depth, quality and flow based on sampling of all existing bores in the area potentially affected by the activity, any existing monitoring bores and any new monitoring bores that may be required under an authorization under the Mining Act 1992 or the Petroleum (Onshore) Act 1991;	Section 2
A strategy for complying with any water access rules applying to relevant categories of water access licences, as specified in relevant water sharing plans;	Section 7
Estimates of potential water quality, level, or pressure drawdown impacts on nearby water users who are exercising their right to take water under a basic landholder right;	Section 5.5
Estimates of potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources;	Section 5.5 and 5.2
Estimates of potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems;	Section 5.6
Estimates of potential for increased saline or contaminated water inflows to aquifers and highly connected river systems;	Section 5.7
Estimates of the potential to cause or enhance hydraulic connection between aquifers;	Sections 2.7, 4.1.1, 5.4, 5.7 and 7
Estimates of the potential for river bank instability, or high wall instability or failure to occur;	Refer to MSEC (2014)
Outline of the method for disposing of extracted water (in the case of coal seam gas activities).	Not Applicable
Assess the project against the criteria specified in 'Table 1 – Minimal Impact Considerations for Aquifer Interference Activities' in the Aquifer Interference Policy.	Section 5.9

Source: NSW Government (2013)

1.3 WATER REGULATION

The NSW Office of Water (NOW) implements water regulation according to the *Water Management Act 2000*, a primary objective of which is to facilitate the sustainable management and use of water resources, balancing environmental, social and economic considerations.

NOW is in the process of developing Water Sharing Plans (WSPs) throughout the State, which establish rules for sharing and trading both groundwater and surface water between competing needs and users.

The relevant WSPs and the associated water sources for the Project are outlined in Table 2 and shown in Figure 2. The NSW AI Policy is designed to provide a framework for the assessment of impacts of the taking of water under a proposed development. The AI Policy divides groundwater sources into "highly productive" and "less productive" categories based on salinity and groundwater yield, which are also shown in Table 2.

Table 2 Relevant Water Sharing Plans and Water Sources

Water Sharing Plan	Water Source	Productivity
Upper and Lower Namoi Groundwater Sources 2003	Namoi alluvium (Narrabri Fm and Gunnedah Fm)	Highly Productive
NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011	Liverpool Ranges Basalt	Highly Productive
NSW Murray Darling Basin Porous Rock Groundwater Sources 2011, Gunnedah-Oxley Basin MDB (Spring Ridge) Management Zone	Jurassic units (Pilliga Sandstone, Purlawaugh Fm , Garrawilla Volcanics)	Highly Productive
NSW Murray Darling Basin Porous Rock Groundwater Sources 2011, Gunnedah-Oxley Basin MDB (Other) Management Zone	Triassic to Permian units (Napperby Fm, Digby Fm, Blackjack Group and Permian strata)	Less Productive

Note: The Gunnedah–Oxley Basin MDB (Spring Ridge) Management Zone is also separated vertically from the Gunnedah–Oxley Basin MDB (Other) Management Zone, which is not displayed on the Plan Map (refer to Figure 2). Fm: Formation

The AI Policy also specifies 'minimal impact considerations' for both highly productive and less productive groundwater zones (Figure 4); these comprise thresholds for watertable and groundwater pressure drawdown, and changes in groundwater and surface water quality. Different minimal impact considerations are specified for highly productive and less productive groundwater zones for:

- Water supply works;
- Listed Groundwater Dependent Ecosystems (GDEs); and
- Culturally significant sites.

The AI Policy framework identifies two levels of minimal impact considerations, as described below:

- Level 1 impact, which is considered acceptable.
- Level 2 impact, which requires further studies to assess whether a project will prevent the long-term viability of a dependent ecosystem or significant site, or needs other arrangements to mitigate the impacts.

1.4 Approach to the Gateway Process

Under the Gateway process, the AI Policy requires estimation of all water takes and impacts during and following cessation of the proposed activity based on a "simple modelling platform" that the Minister determines to be "fit-for-purpose", based on appropriate baseline data. In this report the model is referred as a ‘lower resolution model’ that uses well established numerical simulation procedures.

It is clear from the AI Policy that a *risk management* approach should be adopted. That is to say, the level of effort in the assessment should be proportional to the *likelihood* of impacts and the potential *consequences* of those impacts.

However, some of the other reasons why the groundwater assessment for the Gateway process is only intended to be preliminary include:

- The preliminary groundwater assessment will not have the benefit of information usually provided by associated disciplines (especially surface water hydrology, geochemistry and ecology studies). However it should be noted that some analysis of surface water hydrology has been conducted for this study, primarily in the context of groundwater-surface water interaction.

- Often the available data for hydrogeological conceptualisation and model calibration would be limited; although in this case there is, generally, an extensive dataset.

- There is a limited 90 day period for assessment by the Gateway Panel, who must obtain the advice of the Minister for Primary Industries and the IESC within that period of time.

- There is to be no public consultation or exhibition of submitted documents.

In combination, the above constraints lead to the conclusion that it would be inappropriate to offer the same level of detail and effort that is normally expended in an EIS. Nevertheless, and fortunately for this project, there is already a considerable amount of surface water and geochemical data that is normally only available for an EIS. This was included in the assessment presented herein. Our approach to the modelling for this preliminary groundwater assessment for the Gateway Process is outlined in Table 3.

Consultation with the NOW with regard to the level of detail proposed for the Preliminary Groundwater Assessment has been undertaken. NOW indicated that they were generally satisfied with the proposed approach.

Biophysical Strategic Agricultural Land mapped by the NSW Government and highly productive groundwater is shown on Figures 3 and 4, respectively.

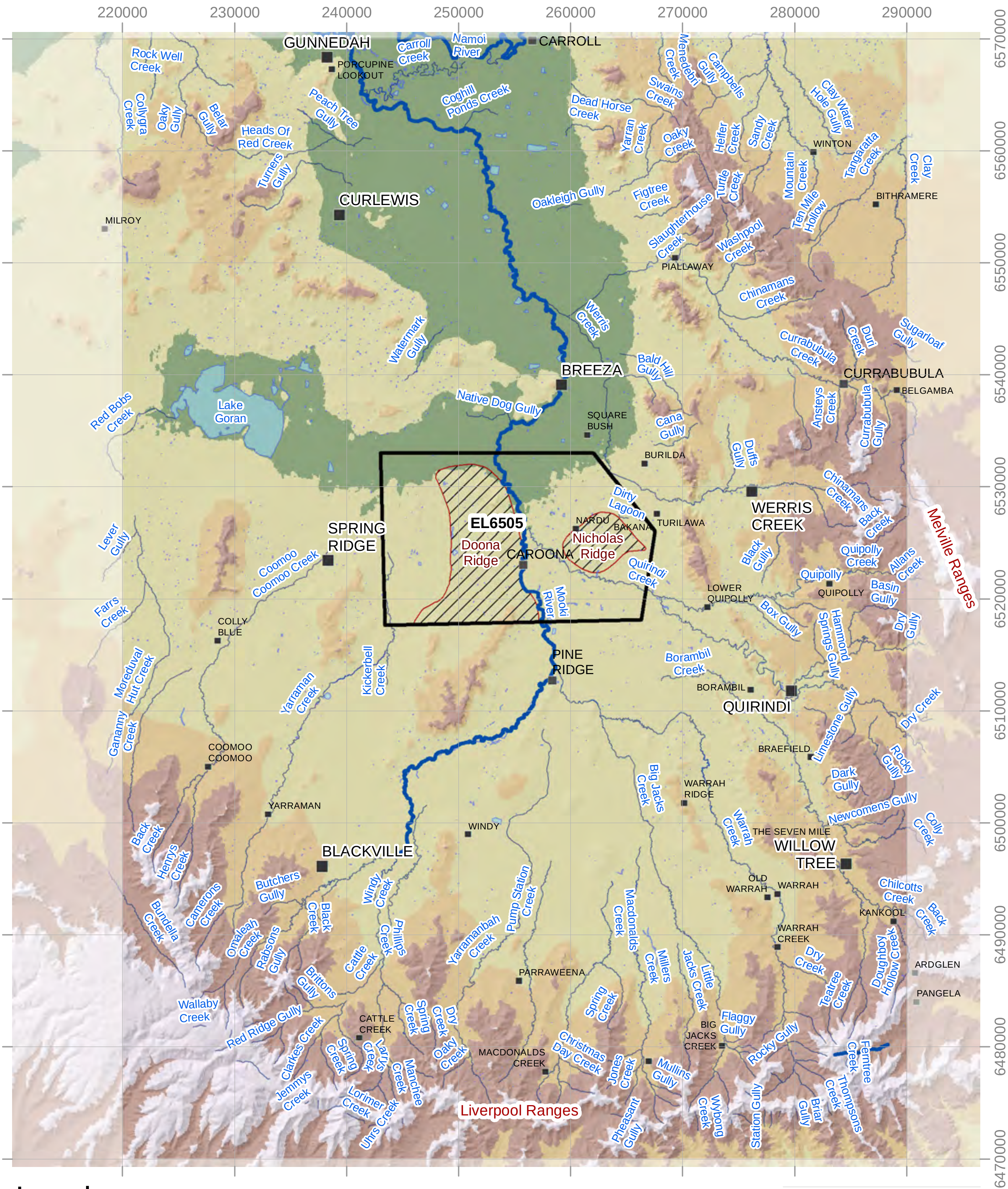
Table 3 Gateway Process Preliminary Groundwater Assessment - Modelling Approach

MODEL FEATURE	APPROACH
Spatial Scale	Coarse (uniform 400 m grid cell size)
Temporal Scale	Coarse (annual or greater stress period durations in the predictive model)
Model Extent	70 km x 97.6 km
Stratigraphy	9 Layers
Spatial Parameter Variability	No
Steady-State Calibration	Yes
Transient Calibration	No (verification only)
Prediction	30 years
Fractured Zone	Yes
Tracking of Headings	Limited to none
Sensitivity Analysis	Limited
Uncertainty Analysis	No
Recovery Analysis	Yes
Cumulative Assessment	Law of Superposition
Climate Change	No
Mitigation Measures	If required
Monitoring Program	Yes
Outputs	Focused on AI Policy
Licensing Volumes	Provisional
Software	MODFLOW-SURFACT
Report	Condensed

1.5 NAMOI CATCHMENT WATER STUDY

The Namoi Catchment Water Study was undertaken between 2008 and 2012 by Schlumberger Water Services (SWS) (2012). The Minister for Mineral Resources appointed a Ministerial Oversight Committee to steer the water study. The study involved the development of numerical models which were used to review risks on key water resources in the Namoi Catchment associated with coal mining and coal seam gas extraction (Namoi Catchment Water Study, 2014).

The study consisted of a series of interim reports (Phase reports) and a final report in 2012. The study is considered to be a key reference for the Project groundwater assessment, and consistent with BHP Billiton's commitment to incorporate the findings of the report, has been frequently referred to during the production of this report.



Legend

■ Town
■ Village
▪ Locality
River
Creek
Waterbody

Topography
mAHD
221.9 - 300
300.1 - 400
400.1 - 500
500.1 - 750
750.1 - 1,494.6

Targeted Exploration Area
Exploration Licence

BHP Billiton
Caroona Coal Project

Figure 1

Project Location

DrawingNo: CAR001-001
Rev: C.
Created by: CNicol
Date: 10/02/2014.

Scale: 480,000 @A4
GDA 1994 MGA Zone 56

0 2.75 5.5 11 16.5 22
km

HYDRO SIMULATIONS

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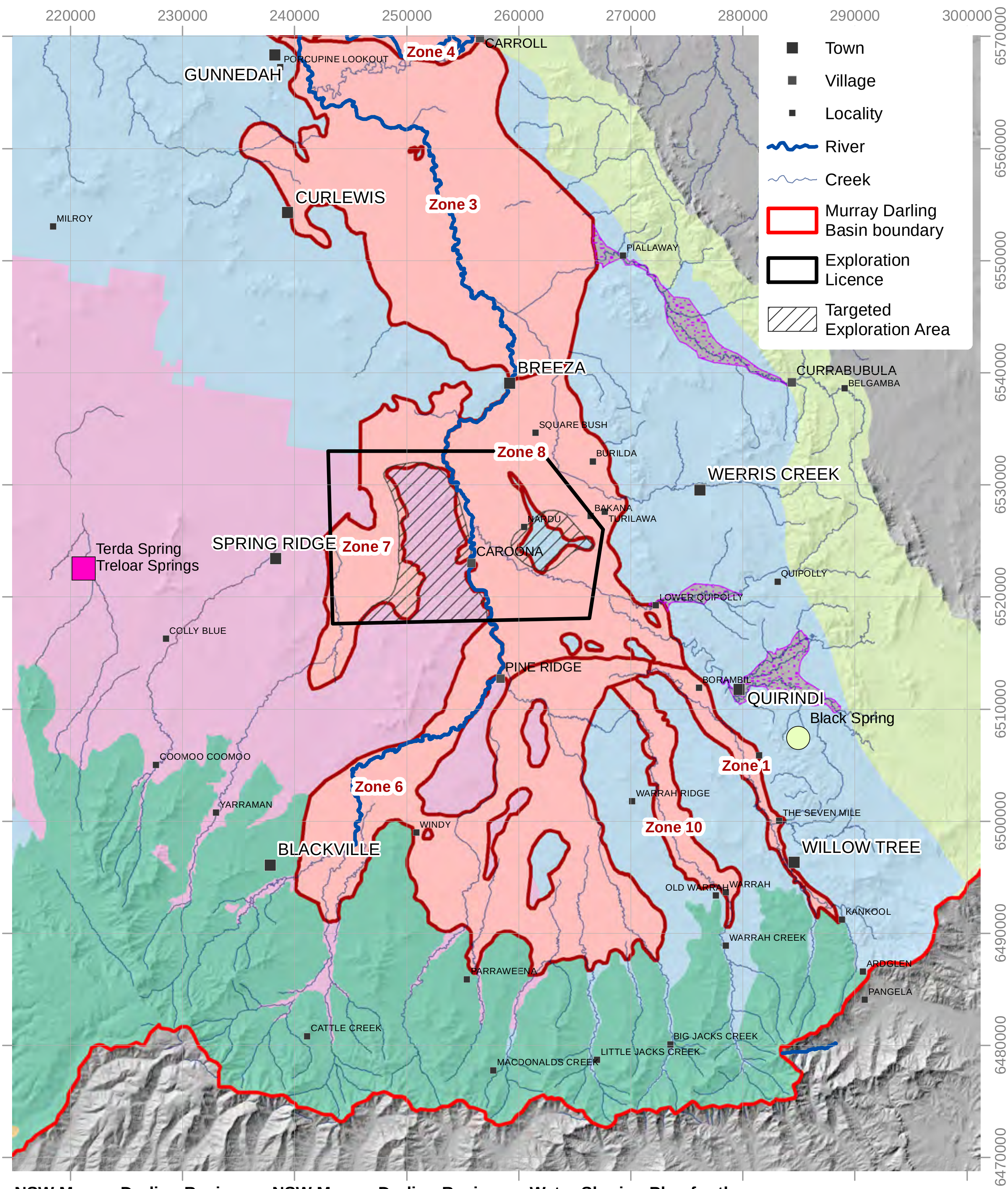

NSW Murray Darling Basin Porous Rock Groundwater Sources 2011

- Gunnedah-Oxley Basin MDB (Other)
- Gunnedah-Oxley Basin MDB (Spring Ridge)
- Sydney Basin MDB (Macquarie Oxley)
- High Priority GDEs (Porous Rocks)

NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011

- Liverpool Ranges Basalt MDB
- New England Fold Belt MDB
- High Priority GDEs (Fractured Rocks)

Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003

- Groundwater Management Zones
- Excluded Alluvial

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Caroona Coal Project

Figure 2

Relevant Water Sharing Plans

DrawingNo: CAR001-002
Rev: C.
Created by: CNicol
Date: 10/02/2014.

Scale: 480,000 @A4
GDA 1994 MGA Zone 56

0 2.5 5 10 15 20 km

HYDROSIMULATIONS

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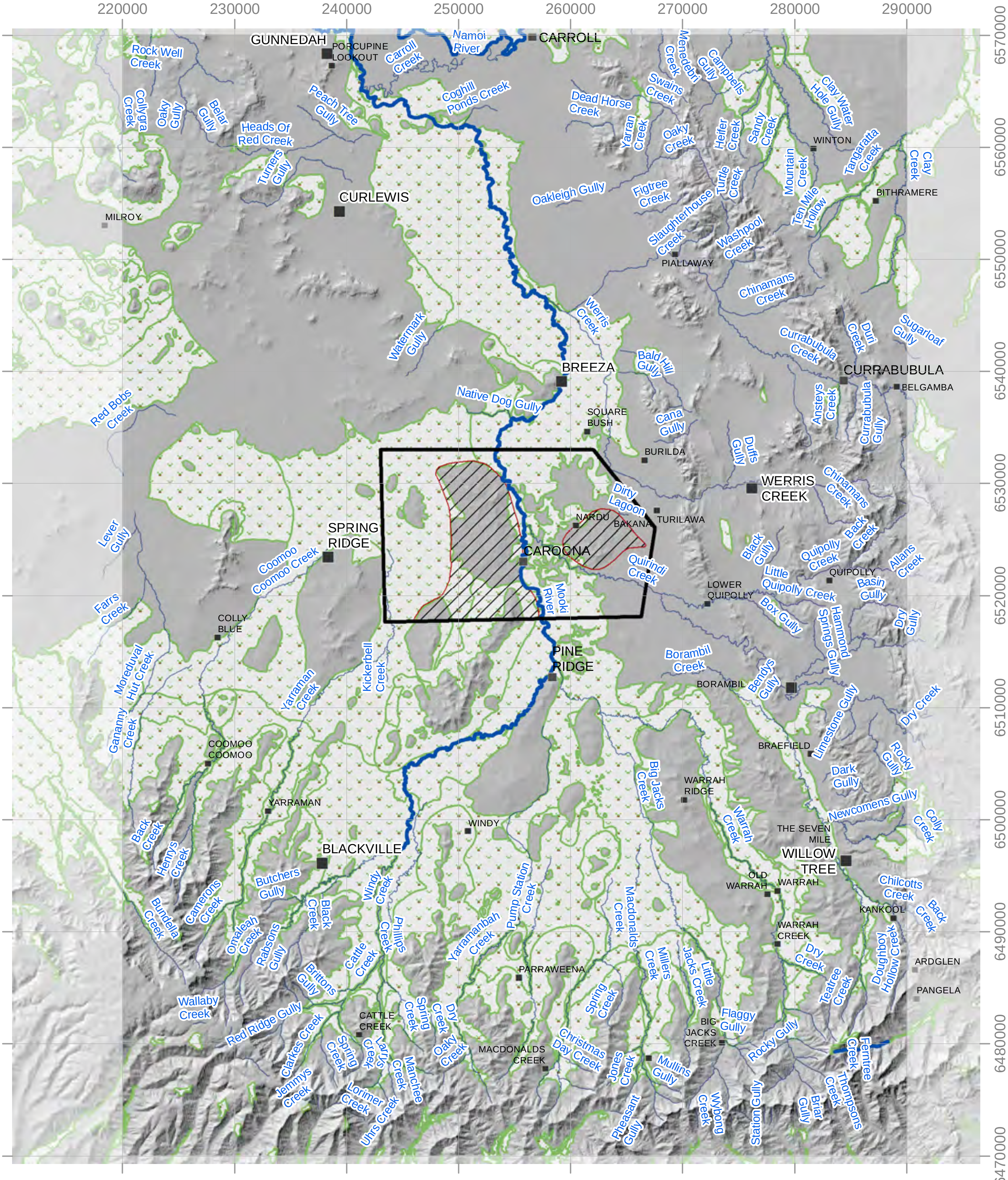

Legend

- Town
- Village
- Locality
- River
- Creek
- Targeted Exploration
- Exploration Licence
- Biophysical Strategic Agricultural Land as shown in the New England North-West SRLUP

BHP Billiton
Caroona Coal Project

Figure 3

Biophysical Strategic Agricultural Land

Scale: 480,000 @ A4
GDA 1994 MGA Zone 56

0 2.75 5.5 11 16.5 22 km

DrawingNo: CAR001-010
Rev: B.
Created by: CNicol
Date: 10/02/2014.

HYDROSIMULATIONS

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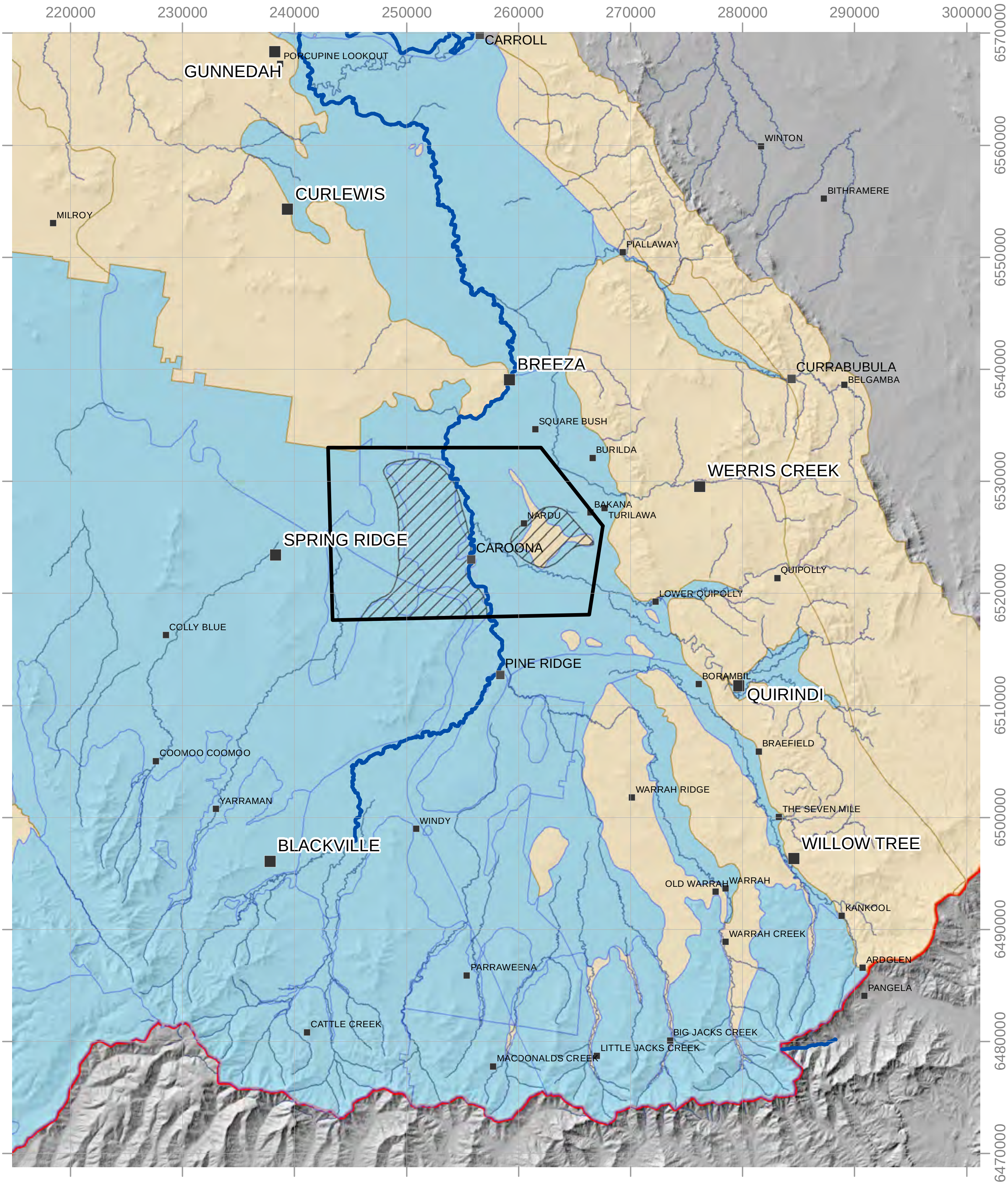

Legend

- Town
- Village
- Locality
- River
- Creek
- Murray Darling Basin boundary
- Exploration Licence
- Targeted Exploration Area

Groundwater Productivity

- Highly Productive
- Less Productive

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Caroona Coal Project

Figure 4

Highly Productive Groundwater

DrawingNo: CAR001-011
Rev: B.
Created by: CNicol
Date: 10/02/2014.

Scale: 480,000 @A4
GDA 1994 MGA Zone 56

0 2.5 5 10 15 20 km

HydroSimulations

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2 HYDROGEOLOGICAL SETTING AND CONCEPTUALISATION

2.1 TOPOGRAPHY

The Project EL6505 lies within the upper Namoi Catchment of the Liverpool Plains. Land surface elevation ranges from 1,500 mAHD (metres above Australian Height Datum) on the Liverpool Ranges in the south down to approximately 265 mAHD near Gunnedah in the north (Figure 1). Drainage is broadly from south to north, with alluvial plains becoming significantly broader to the north as topography flattens out.

Within EL6505, elevation ranges from 300 to 350 mAHD in the south and decreases to around 270 mAHD in the north (Figure 1). Topography in the lease is characterised by Doona Ridge, a north-south trending area of elevated and gently sloping land, which is surrounded by flat to undulating areas of alluvial plain. To the east, the flat topography is disrupted by Nicholas Ridge, a small area of elevated and gently sloping land. Another north-south trending ridge, Spring Ridge, defines the western lease margin. Elevated land also occurs to the south of the lease, which covers a much broader regional area.

2.2 RAINFALL AND EVAPORATION

Climatic data are or have historically been collected by the Bureau of Meteorology (BoM) at a number of monitoring stations throughout the Project area and surrounds (Figure 5). The BoM have interpolated average annual rainfall throughout the area, which is presented in Figure 5. Useful stations near or within the lease are at Spring Ridge (Station No. 055039; 5 km from EL6505), Pine Ridge (Mooki Springs) (Station No. 055037; 6.5 km from EL6505), and Pine Ridge (Billabong) (Station No. 055046; 8.5 km from EL6505). Long-term average annual rainfall at these gauges is approximately 600 millimetres (mm) (Table 4).

The BoM mapping suggests a strong topographic control on average annual rainfall, with up to 1,000 millimetres (mm)/year rainfall in the Liverpool Ranges to the south, and less than 650 mm/year along the lower parts of the catchment and valleys (Figure 5).

Table 4 Average and median annual rainfall at Australian Bureau of Meteorology stations in the regional area.

Station Name	Station Number	Period of Record	Average Annual Rainfall (mm)	Median Annual Rainfall (mm)	Easting (mMGA zone 56)	Northing (mMGA zone 56)	Elevation (mAHD)
Spring Ridge	055039	1922 to current	599	493.5	238496.6	6523905	314
Pine Ridge (Mooki Springs)	055037	1886 to 2012	595	484.5	253080.3	6510946	335
Pine Ridge (Billabong)	055046	1921 to current	594.5	474.9	256932.1	6508817	340

The range of annual rainfall percentiles for Spring Ridge is shown in Table 5 and Figure 6. The median (50th percentile) of 589 mm is close to the long-term average (599 mm).

Table 5 Annual Rainfall Statistics at Spring Ridge (Station No. 055039) from 1922 to 2013

Percentile	10	20	25	50	75	80	90
Annual Rain(mm)	366	448	481	589	701	786	834

Average monthly rainfall and cumulative deviation from mean rainfall (i.e. the ‘residual mass curve’) for Spring Ridge station 055039 from 1922 to 2013, are shown in Figure 7. Rainfall is highest between the months of October and February (60-80 mm/month), and remain relatively constant between March and September, hovering around 40 mm/month.

The residual mass curve of Figure 7 indicates when rainfall is generally above or below average, with a rising trend indicating an extended period of above average rainfall (when groundwater recharge is likely to be higher) while a downward trend indicates a period of below average rainfall accumulation (when recharge is likely to be lower). Figure 7 indicates the first extended dry period from 1922 to 1948 followed by wet and dry cycles that have occurred between 1948 and 1968. Since 1968 the area has generally observed above average rainfalls, with only a few periods of below average rainfall, such as around 1978-84, 1995-1997, and in the early to mid-2000s.

A meteorological monitoring station was installed at the Project in 2007 (located at easting 254494 / northing 6525314 (GDA94 zone 56)), which uses both a traditional tipping bucket gauge (1/7/2007 to current), and, more recently, a Vasala sensor (20/6/2013 to current). The Vasala sensor’s period of record is currently too short for meaningful analysis, however monthly averages from the tipping bucket gauge between December 2008 and May 2013 are provided in Table 6 and compared to the corresponding average monthly rainfall for BoM Spring Ridge station 055039.

Table 6 Project Rainfall Gauge Data

Month	Average Monthly Rainfall Project (mm)	Spring Ridge (mm)
January	72	58
February	76	91
March	36	68
April	28	29
May	31	36
June	28	26
July	22	40
August	11	13
September	41	53
October	27	36
November	92	88
December	69	42

The closest BoM climate monitoring station to the Project area that collects evaporation data is the Gunnedah Resource Centre (Station No. 055024), located approximately 40 km north-west of the Project. Data collected between 1948 and 2013 indicates an average annual potential evaporation of approximately 1752 mm for the area. Spatially interpolated BoM average annual and monthly pan evaporation data have been used to estimate pan evaporation for the Project lease, which is presented in Table 7.

Table 7 Average pan evaporation

Month	Average Monthly Pan Evaporation (mm)	
	BoM Mapping (EL6505)	Gunnedah Resource Centre (Station 055024)
January	300	238.7
February	250	187.6
March	300	186
April	150	129
May	100	83.7
June	60	57
July	80	58.9
August	100	86.8
September	150	120
October	200	164.3
November	250	198
December	300	238.7
ANNUAL	2,000	1,752
Number of Years	10 (minimum)	66
Start Year	1,975	1,948
End Year	2,005	2,013
Elevation (mAHD)	313	307

Note: Annual values are not the same as the sum of the monthly values.

The actual evapotranspiration (ET) in EL6505 is about 580-600 mm per annum according to BoM (2013). The definition for actual ET is: "*... the ET that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average. For example, this represents the evapotranspiration which would occur over a large area of land under existing (mean) rainfall conditions.*"

A comparison between average monthly rainfall at Spring Ridge (Station 055039) and average monthly potential evaporation at Gunnedah Resource Centre (Station 055024) shows that, on average, the area has an excess evaporative capacity over rainfall in all months (Figure 7).

2.3 SURFACE DRAINAGE

The Project area is located in the upper Namoi River catchment of the Murray Darling Basin. The primary drainage channel in the Project area is the Mooki River, which flows from south to north within EL6505, and joins the Namoi River to the north, at Gunnedah (Figure 1). The Mooki River's headwaters originate from the Liverpool Ranges situated some 45 km south of EL6505 near the Project area southern boundary (Figure 1). Major tributaries that enter east of the Mooki River, from south to north include: Warrah Creek, Quirindi Creek and Werris Creek. The latter two streams originate in the Melville Ranges (Figure 1).

Tributaries flowing from the west are few, and are chacterised by sheet wash (overland flow) with limited channel definition in their lower reaches (Figure 1). This overland flow drains to the Mooki River via Lake Goran and / or Native Dog Gully, which runs west to east along the northern EL6505 boundary. This suggests that their stream flow is ephemeral. Yarraman Creek channel is one of these poorly defined western tributary channels, which enters and extends along the western edge of EL6505.

The Australian Government's Directory of Important Wetlands (http://www.environment.gov.au/cgi-bin/wetlands/report.pl?smode=DOIW;doiw refcodelist=NSW005) states that Lake Goran is an internally draining system that has been modified since the 1970s. Yarraman Creek and Coomoo Coomoo Creek have been artificially diverted into the lake, whereas they once ultimately discharged via sheet flow into the Mooki River. The directory also states that less than 10% of the lake area is regularly waterlogged, and that much of the lake bed is used for cropping most of the time.

Figure 8 shows the locations of five relevant NOW stream gauging stations. Gauging station details are shown in Table 8. Stream flow exceedance statistics for the May 1979 through August 2013 period for the Mooki River gauges are presented in Figure 9. This figure indicates that when Mooki River flows are in the higher range (greater than approximately 50 ML/day) the flows in the river at the Breeza gauge are greater than at the Caroona gauge. Conversely when the Mooki River flows are in the lower range (less than approximately 7 ML/day), the flows at Caroona gauge are greater than at the Breeza gauge. The higher flows at Breeza during higher flow periods is due to the inclusion of stream flows that drain a larger catchment area, including stream flow contribution from Quirindi Creek. This is discussed further in Section 2.6.6. The difference in stream flow rate at Breeza and Caroona at low river flows is significant, with no flow periods occurring 20% of the time at Breeza, and 10% of the time at Caroona. Low flows (beyond the 60th percentile) indicate higher, more persistent flows at Caroona than at Breeza. These low flow differences are a response of stream flow to extended dry climatic periods and/or natural losses from surface water to the underlying alluvium, and/or groundwater and surface water usage.

Table 8 Stream Flow Gauging Stations

Gauge Number	419034	419027	419098	419106	419093
Gauge Name	Mooki River at Caroona	Mooki River at Breeza	Quirindi Creek at Greenacres	Quirindi Creek at Dury Bridge	Yarraman Creek near Spring Ridge
Catchment Area (km^2)	2540	3630	-	-	-
Easting (MGA)	255749.10	258307.32	261004.00	273895.16	243860.54
Northing (MGA)	6522402.73	6537317.15	6522291.31	6516297.86	6523693.54
Distance from site centre (km)	1.5	13	4	18	13
Record Start	23/05/1979	26/09/1971	22/05/2003	12/04/2011	3/03/1999
Record End	05/09/2013	5/09/2013	8/09/2013	8/09/2013	8/09/2013
Average Flow (over period of record) (ML/day)	209.5	325.48	26.8	17.39	-
Zero gauge elevation (mAHD)	300.87	282.58	307.32	340.26	308.43
Average river stage (over period of record) (m)	0.856	0.69	0.88	0.77	0.6
Average river stage elevation (over period of record) (mAHD)	301.72	283.27	308.20	341.03	309.03

Note: - means not been recorded; km^2 – square kilometres; ML/day – megalitres per day.

2.4 GEOLOGY

The Project area lies in the geological Gunnedah Basin that is a sub-basin of the central part of the more extensive regional geological Sydney-Bowen Basin (Figure 10). This regional Basin extends 1,700 km from central Queensland to offshore southern New South Wales. All three basins are infilled with a sequence of coal-bearing rocks of Permian to Triassic age (Figure 11 and Figure 12).

Tadros (1993) describes the tectonic evolution of the Gunnedah Basin, which is very briefly outlined here. The basin comprises a series of linearly-arranged troughs and adjacent highs, which formed in a volcanic rift system. Hence basal late Carboniferous to early Permian units comprise volcanics (Boggabri Volcanics and Werrie Basalt). A period of basin-wide subsidence and marine transgression occurred in the mid-Permian, depositing a thick sequence of sediments interleaved with pyroclastic deposits (the Porcupine and Watermark Formations). The eastern part of the Gunnedah Basin experienced a final phase of subsidence in the mid-to late

Permian, with further, primarily fluvial and lacustrine, deposition (Blackjack Group; Figure 12). Similar periods of subsidence and deposition recurred in the Triassic, depositing the Digby and Napperby Formations.

A period of uplift beginning in the late Triassic in the eastern part of the basin activated extensive volcanism, depositing the Jurassic Garrawilla Volcanics, which were then overlain by the fluvial deposits of the Purlawaugh and Pilliga Formations (NSW Department of Mineral Resources [DMR], 2002). In the Tertiary, the last period of active volcanism occurred, depositing basalts of the Liverpool Range Beds. These basalts and the preceding period of uplift in the eastern basin define the current geometry of the Gunnedah Basin.

Quaternary alluvial deposits cover parts of the basin along the alluvial plains of current and palaeo-drainage systems (Figure 11). These deposits have been subdivided into the basal Gunnedah Formation, which is overlain by the Narrabri Formation (Broughton, 1994; Lavitt, 1999). The distinction between these two units has been made based upon clay content versus coarser components like sand and gravel, which is thought to have resulted from changes in the climate and depositional environment around the Pliocene-Pleistocene boundary (Lavitt, 1999). Lavitt (1999) termed the collective alluvial units in the vicinity of the Project area as 'Mooki Alluvium', which are lateral equivalents of the 'Namoi Alluvium', occurring to the north of Breeza and Gunnedah, along the Namoi River. The term 'Namoi Alluvium' has been used throughout this report for simplicity. There are two main alluvial plains, which are broken by Permo-Triassic outcrop on Doona Ridge and Nicholas Ridge (Figure 11). The alluvial plain to the east of the Doona Ridge is called the Mooki alluvial plain, which is associated with the Mooki River and Quirindi Creek. The Mooki alluvial plain covers a large area (150 km^2 from north-east to south-east, and is up 100 m thick. The alluvial plain to the south-west of Doona Ridge is termed the 'Yarraman alluvial plain', and is associated with Yarraman Creek. It covers an area of around 92 km^2 (Australian Groundwater & Environmental Consultants [AGE], 2013).

Of note is the narrow constriction in the alluvium around Breeza (Figure 11), which is the result of a bedrock high (the 'Breeza Shelf' [DMR, 2002]), to the south of which lies the 'Murrurrundi Trough', within which the deepest sections of alluvium are found in the vicinity of the project area. Lavitt (1999), and other earlier studies, note the Breeza Shelf's controlling influence on the distribution of Pliocene alluvial facies within the basin, with a south to north change from alluvial fans through to (coarse) bedload stream deposits 'backing up' behind the Breeza Shelf. Over the Breeza Shelf, only clayey overbank deposits are found, to the north of which, along the Namoi River, bedload stream deposits are again found.

The Permian coal measures within EL6505 comprise an interbedded sequence of sandstone, conglomerate, siltstone and claystone with coal seams, minor tuff and tuffaceous sediments (AGE, 2013). These sedimentary units unconformably on-lap the Late Permian and strike in a northwest direction with dips of 2 degrees to the south-west. The coal seams of interest belong to the Black Jack Group, which include four main coal seams: Clift Seam, Howes Hill Seam, Caroona Seam and Hoskissons Seam (Figure 12).

The Hoskissons Seam is the most important seam in the Caroona area, containing over half the total coal resource, and hence is the subject of the proposed underground mining at Caroona. The coal seam thickness ranges from approximately 8 m to 16 m within the Project area (Mine Subsidence Engineering Consultants, 2014).

2.5 NEARBY MINES AND PROJECTS

The Watermark Project is a neighbouring proposed coal mine in EL7223, immediately north of the Project's EL6505 (AGE, 2012). The Watermark Project proposes three open cut coal mining areas down to 195 mAHD in its southern mining area, and 225 mAHD in the eastern mining area. The proposed mine has a 30-year operational lifespan. The open cut areas will be progressively backfilled and rehabilitated. The target coal seams are the Hoskissons and Melvilles seams. At the time of writing, the EIS had been lodged and the Project was under assessment by the NSW Government.

Whitehaven Coal Limited (Whitehaven Coal) operates an existing open cut coal mine 4 km south of Werris Creek, east of EL6505 (Werris Creek Coal Mine - Figure 1). This mine extracts coal from the Greta Coal Measures (of early Permian age, older than the basal Werrie Basalt of Figure 11 and Figure 12).

Whitehaven Coal had until late 2012 operated the Sunnyside Coal Mine, located 15 km west of Gunnedah (Figure 1). It excavated coal from the Hoskissons seam using open cut methods down to a proposed elevation of 295 mAHD. The Sunnyside Coal Mine is currently under care and maintenance. Historically (until 2000), the Hoskissons seam was mined to the immediate south of this area, in the Gunnedah Colliery, using underground (bord and pillar methods) (Geoterra, 2008).

Whitehaven Coal also operates the Narrabri Coal Mine, located some 80 km north-west of the Project. This is an underground (longwall) operation which extracts coal from the Hoskissons seam (Aquaterra, 2009). The minimum mine floor elevation is approximately -50 mAHD. Longwall mining at Narrabri commenced in June 2012 (Whitehaven Coal, 2013).

Other regional mining operations and Projects include Whitehaven's Tarrawonga Coal Mine, Rocglen Coal Mine, Vickery Coal Project and Maules Creek Coal Project and Idemitsu Australia Resources Pty Ltd's Boggabri Coal Mine.

2.6 GROUNDWATER OCCURRENCE AND FLOW SYSTEMS

There are three groundwater-bearing geological units of varying water quality, yield and therefore of variable utility as water resources in the Caroona area (Table 9):

- Groundwater within the Mooki and Yarraman alluvial plains. The Mooki alluvial plain includes the deeper Gunnedah Formation and the overlying Narrabri Formation. The deeper Gunnedah Formation consists of sands, gravels and associated silts and clay. This formation is the most productive and is the source of groundwater from bores used for irrigation throughout the region. The overlying Narrabri Formation has a much lower yield potential and its use is restricted particularly for irrigation purposes because it contains brackish to saline groundwater. The Yarraman alluvial plain further west has much less groundwater potential as the sediments are less productive and contain generally poorer quality groundwater.

- Porous (and fractured) rock groundwater system belonging to the Jurassic to Permian sedimentary and volcanic formations. The coal seams and some sandstone beds within these strata form the main water-bearing strata. These geological units, particularly the coal seams, generally produce much lower yields of poor quality groundwater. The NOW classifies the Jurassic geological units (Pilliga Sandstone, Purlawaugh Formation, Garrawilla Volcanics) as having highly productive groundwater, whilst the older units (Triassic to Permian age) are classified as having less productive groundwater.

- The fractured basalt of the Liverpool Range Beds. This rock type can provide moderate yields of groundwater of generally good quality, but which is largely restricted to an area some considerable distance south of the Project area, in the Liverpool Ranges.

The surficial regolith (weathered rock) water bearing strata yields very small quantities of groundwater in ridge areas, which is of variable quality (AGE, 2013).

Figure 13 shows the interpolated watertable elevation for February 2010. This is a snapshot of the watertable for illustrative purposes (i.e. it will vary due to climatic conditions and localised extraction/use of groundwater). Groundwater flow is generally from south to north with the Liverpool Ranges in the south being a prime recharge area. The watertable contours rely on observed groundwater levels from the Project groundwater monitoring bores and shallow auger holes, from NOW monitoring bores, and from time of drilling water levels stored within NOW's Pinneena database. The interpolated watertable elevation is useful for determining regional depths and interpreted groundwater flow directions.

Alluvial groundwater flows along the line of the Mooki River from the south-west to the north, and the Yarraman alluvial plain exhibits the same broad flow direction. The low hydraulic gradients within the alluvial plains reflect the higher transmissivity and overall relatively smaller elevation differences of these deposits, compared to the much higher hydraulic gradients seen in bedrock areas that are the result of much lower transmissivity and steep topography.

Table 9 Groundwater Yield and Salinity Summary

Management Zone	YIELD (L/sec)					SALINITY (EC; uS/cm)				
	Count	Min	Max	Average	Median	Count	Min	Max	Average	Median
Gunnedah–Oxley Basin MDB (Other) Management Zone (Permo-Triassic strata)	241	0.001	38	0.8	0.5	36	2,950	8,948	773	824
Gunnedah–Oxley Basin MDB (Spring Ridge) Management Zone (Jurassic strata)	177	0.006	83	6.1	0.8	0	n/a	n/a	n/a	n/a
NSW MDB Fractured Rock Groundwater Sources (Liverpool Range Basalts)	94	0.03	21	1.7	0.9	0	n/a	n/a	n/a	n/a
Upper and Lower Namoi Groundwater Sources (and Namoi unregulated alluvial) (Upper Namoi Alluvium)	1292	0.01	200	14	1.5	2,451	1,180	4,873	420	683

Source: NOW Pinneena database. D:\HydroSim\CAR001\GWModel\CARv2TR\Processing\Prediction\MaxDDN\CARv2TR023\CARv2TR023_MaxDDNs_Bores_V2.xlsx

Interpolated depth to watertable is shown in Figure 14. Consistent with Figure 13, this is a snapshot of the watertable for illustrative purposes. Interpolated watertable depths in the alluvials in the west and south are relatively shallow, ranging from 2 to 10 m. The shallow areas to the west, particularly around Lake Goran, agree with other information (Directory of Important Wetlands) which reports shallow saline watertable issues in these areas. The alluvials around the Mooki River exhibits a contrastingly deep watertable, ranging from 10 to 25 m over broad areas. A shallower watertable is observed over the Breeza Shelf, where the alluvials thin out and become clay-dominated (see Section 2.4). This area acts as a 'choke' point on the alluvial groundwater system, as outlined by Lavitt (1999).

On the regolith areas of the Doona and Nicholas Ridges, estimated watertable depths are much greater, ranging from 10 to 100 m. This suggests low recharge rates to outcropping bedrock given that the rock hydraulic conductivity is low to very low.

North-south and west-east potentiometric head cross sections for September 2009 through the targeted exploration area are presented in Figure 15. This figure is a snapshot, however is broadly indicative of the pattern of potentiometric head cross sections across other periods, given no evidence for vertical gradients changing over time. These were generated using vibrating wire piezometer (VWP) data and deep standpipe piezometer data (see Section 2.6.1). They indicate discharge from the Permo-Triassic geological strata to the alluvium from depths as great as 350 m. The sections are dominated by downward hydraulic gradients, with limited areas of upward gradient to the valley floors. This suggests that local land surface topography is the primary control on the flow system, with little to no evidence of down-geologic basin groundwater flow to the west as suggested by regional data (Lavitt, 1999).

2.6.1 Groundwater Monitoring

A significant groundwater monitoring network was installed by BHP Billiton across EL6505 during the period 2007 to 2012. Data loggers have also been installed in 13 existing NOW alluvial aquifer monitoring bores for the Project (see Table 10). A total of 68 monitoring boreholes has been drilled at 32 sites. These consist of 52 standpipe piezometers installed at 26 sites, 18 VWPs with 113 sensors at varying depths, with up to 8 VWPs installed at various depths in the one borehole. 43 bores have been equipped with data loggers set to automated recording of groundwater levels at 6 or 12 hour intervals. Construction details of the standpipe piezometers and VWPs are summarised in Table 11 and Table 12, respectively.

Figure 16 presents the locations of existing groundwater monitoring bores. It shows 47 bores monitoring the alluvial aquifer at 21 sites - 35 holes on Mooki Alluvial Plain located on 15 sites and 12 holes on Yarraman Alluvial Plain located on six sites. It also shows three boreholes drilled in Nicholas Ridge at three locations and the remaining 18 boreholes drilled in Doona Ridge at eight sites.

Table 10 Bore Construction Details – NOW bores

NOW Monitoring Bores	MGA Coordinates		Top of Casing Elevation	Depth Drilled	Aquifer/Strata Screened	Screen Interval	Water Quality January 2012		Water Level Feb 2010
	Easting (m)	Northing (m)	(mAHD)	(m)		(m below GL)	TDS (mg/L)	pH	(mAHD)
Mooki Alluvial Plain									
GW030010/1	258212	6530642	298.788	29	Alluvium - Gunnedah Formation	22.9 - 29.0	553	7.28	280.85
GW030010/2	258212	6530646	298.786	50.6	Alluvium - Gunnedah Formation	44.5 - 50.6	377.2	7.36	280.26
GW030012/1	257793	6527757	300.827	15.2	Alluvium - Narrabri Formation	9.1 - 15.2	bore is dry		
GW030012/2	257792	6527762	300.886	44.2	Alluvium - Gunnedah Formation	38.1 - 44.2	757	7.11	282.33
GW030078	257413	6524637	304.147	39.6	Alluvium - Gunnedah Formation	33.5 - 39.6	891	7.1	285.35
GW030380	257418	6524644	304.094	82.3	Alluvium - Gunnedah Formation	73.2 - 76.2	1,032	7.05	284.64
GW030083/1	261259	6520883	314.744	29	Alluvium - Narrabri Formation	26.8 - 28.9	2,593	6.95	291.5
GW030083/2	261251	6520886	315.220	41.1	Alluvium - Gunnedah Formation	35.7 - 41.8	764	7.18	-
GW030063/1	265040	6519781	321.490	33.5	Alluvium - Gunnedah Formation	24.4 - 27.4	604	6.88	296.04
GW030063/2	265048	6519778	322.119	53.3	Alluvium - Gunnedah Formation	50.3 - 53.3	604	6.88	295.87
Yarraman Alluvial Plain									
GW965576/1	247317	6523457	NA	7.2	Alluvium - Narrabri Formation	5.2 - 7.2	6,600	7.91	127.09
GW965576/2			NA	27.8	Alluvium - Gunnedah Formation	25.8 - 27.8	7,839	7.82	298.54
GW965576/3			NA	37.8	Alluvium - Gunnedah Formation	35.8 - 37.8	6,968	7.65	297.56

Notes: (i) Co-ordinates in MGA 56 (ii) Total Dissolved Solids (TDS) was calculated by multiplying electrical conductivity (µS/cm) by a conversion factor of 0.67 (iii) NA – means not available. (iv) GL – means ground level.

Table 11 Bore Construction Details - Piezometer bores

Site No.	Borehole No.	MGA Coordinates		Top of Casing Elevation	Ground Level	Depth Drilled	Aquifer/Strata Screened	Screen Interval	Water Quality February 2012		Groundwater Level July 2011
		Easting (m)	Northing (m)	(mAHD)	(mAHD)	(m)		(m below GL)	TDS (mg/L)	pH	(mAHD)
Mooki Alluvial Plain											
C011	CCP0061A	260181.4	6519438	312.33	311.43	74	Alluvium - Gunnedah Formation	68-74	376	6.81	292.26
C050	CCP0046A	260062.1	6523063	310.78	310.08	37.23	Alluvium - Gunnedah Formation	27.75-33.75	620	6.96	290.4
C076	CCP0051A	256549.8	6524064	305.08	303.98	34.5	Alluvium - Gunnedah Formation	27.7-33.7	710	7.2	285.96
C089A	CCP0063A	258929	6526611	304.54	303.64	63	Alluvium - Gunnedah Formation	54-60	421	7.42	284.84
C102A	CCP0067A	256711	6527225	301.61	300.25	37	Alluvium - Gunnedah Formation	33-36	515	7.07	283.94
C102B	CCP0066A	256712	6527224	301.35	300.2	21	Alluvium - Narrabri Formation	17-20	683	6.44	284.04
C102C	CCP0065	256711	6527223	301.26	300.26	155	Clift Seam	148-154	724	7.75	284.64
C102D	CCP0064A	256712	6527223	301.2	300.2	96	Alluvium - Base of	89-95	412	6.96	283.97
C199A-1	CCP0163A	258176	6530161	299.83	299.05	27	Alluvium - Narrabri Formation	20-26	2425	12	282
C199A-2	CCP0161A	258175	6530157	300.01	299.14	58.5	Alluvium - Gunnedah Formation	51-57	416	7.36	282.03
C199A-3	CCP0160N	258174	6530147	300.1	299.08	75.63	Clare Sandstone	68-74	336	7.53	282.004
C199A-4	CCP0159N	258174	6530151	300.09	299.07	90	Howes Hill Seam	84-90	287	7.57	281.9
C199A-5	CCP0158	258175	6530154	300.14	299.09	187.3	Hoskissons Seam	106-112	556	7.45	284.93
C265	CCP0151A	260518	6526559	304.67	303.87	30	Alluvium - Gunnedah Formation	20-26	864	7.61	291.94
C268-3	CCP0335N	264250	6526549	NA	308.27	21	Alluvium - Narrabri Formation	12-21	No data logger		

Site No.	Borehole No.	MGA Coordinates		Top of Casing Elevation	Ground Level	Depth Drilled	Aquifer/Strata Screened	Screen Interval	Water Quality February 2012		Groundwater Level July 2011
		Easting (m)	Northing (m)	(mAHD)	(mAHD)	(m)		(m below GL)	TDS (mg/L)	pH	(mAHD)
C282A	CCP0153A	257325	6526402	302.03	301.17	76.3	Alluvium - Gunnedah Formation	67-73	406	7.46	284.67
C285	CCP0155A	256155	6526331	300.87	300.01	93.4	Alluvium - Gunnedah Formation	43-49	557	7.94	284.43
Nicholas Ridge											
C078A	CCP0124A	260941	6524822	318.11	317.28	20	Regolith	13.3-19.3	2955	6.92	308.16
C162	CCP0148A	262505	6524592	353.84	353.04	45	Regolith	25.5-31.5, 37.6-43.5	4650	6.31	317.57
C153A	CCP0123A	261501	6523496	336.79	335.79	24	Regolith	16.4-22.4	2874	6.33	317.48
Doona Ridge											
C017	CCP0174A	252730	6519793	343.91	342.57	43	Regolith	37-43	2425	6.77	317.8
C037	CCP0142A	253291.1	6522150	338.13	337.13	35	Regolith	26.3-32.3	1367	7.15	321.9
C119A	CCP0146A	251301	6528797	357.68	356.97	50	Regolith	28.5-34.5, 40.5-46.5	-	-	311.22
C168B	CCP0147A	253664	6525326	349.66	348.81	46	Regolith	28-34, 40-46	-	-	304.58
C182-1	CCP0138A	252692	6527567	351.15	349.88	40	Regolith	30.5-33.5, 36.5-39.5	No access		Bore is dry
C182-2	CCP0131	252691.3	6527564	350.78	349.87	247.4	Clare Sandstone	211-217, 223-229, 235-241	750	8.61	310.96
C188-1	CCP0157A	235506	6528396	344.71	343.73	45	Regolith	39-45	-	-	301.07
C188-2	CCP0145	235506	6528396	343.58	343.14	241	Hoskissons Seam	225-241	No data logger		
C193A-1	CCP0141A	253865	6529477	318.76	317.53	226	Clare Sandstone	169-175, 181-187, 193-199	-	-	286.78
C193A-2	CCP0139	253859	6529478	319	317.84	18.5	Regolith	12-18	750	8.3	Bore is dry

Site No.	Borehole No.	MGA Coordinates		Top of Casing Elevation	Ground Level	Depth Drilled	Aquifer/Strata Screened	Screen Interval	Water Quality February 2012		Groundwater Level July 2011
		Easting (m)	Northing (m)	(mAHD)	(mAHD)	(m)		(m below GL)	TDS (mg/L)	pH	(mAHD)
C243	CCP0187	250907	6522948	311.47	310.55	18	Regolith	12-18	15142	6.31	307.95
Yarraman Alluvial Plain											
C023	CCP0102A	248203	6520811	311.95	310.88	35	Alluvium - Gunnedah Formation	29-32	2144	7.82	309.3
C043	CCP0079A	247309.9	6523279	309.17	308.15	106	Alluvium - Base of	94.5-100.5	1802	6.05	308.7
C113	CCP0039	245733	6531232	298.63	297.53	223	Hoskissons Seam	209-215	7772	6.81	288.28
C151	CCP0127A	249208	6524941	306.13	305.2	31.6	Alluvium - Narrabri Formation	25-28	15209	5.98	303.24
C180A	CCP0110A	249967.8	6527530	304.24	303.26	47	Alluvium - Gunnedah Formation	39.8-45.8	14740	6.27	301.61
C137-1	CCP0362	254010.73	6530956.05		295.87	186.58	Alluvium – Hoskissons Seam	163- 172	No data logged		
C137-2	CCP0363N	254010.43	6530954.12		295.84	42.2	Alluvium – Hoskissons Seam	36 – 42	No data logged		
C137-3	CCP0364A	254010.33	6530952.19		295.86	21.46	Alluvium – Hoskissons Seam	12 -21	No data logged		

Note: (i) Co-ordinates in MGA 56 (ii) TDS was calculated by multiplying electrical conductivity (µS/cm) by a conversion factor of 0.67(iii) "-" means Insufficient water to sample on February2012.

Table 12 Bore Construction Details - Vibrating Wire Piezometers

Site No.	Borehole No.	MGA Coordinates		RL Collar	Depth Drilled	Depth of Vibrating Wire Completions	Target Aquifer/Strata of VWP (in descending depth order)	Groundwater Level July 2011
		Easting (m)	Northing (m)	(mAHD)	(m)	(m below GL)		(mAHD)
Mooki Alluvial Plain								
C011	CCP0060	260182.29	6519440.34	311.61	592.24	105	Below Base of Alluvials	293.88
						195	Sandstone/Conglomerate	297.88
						424	Clift Seam	289.97
						530	Hoskissons Seam	287.31
C050	CCP0017	260062.13	6523062.94	310.11	433.28	90	Base of weathering	283.06
						155	Mooki/Springfield Seams Interburden	290.73
						217.94	Clift Seam B	292.10
						256	Goran Conglomerate C	445.93
						283.98	Lower Breeza Seam	286.43
						340	Howes Hill/Caroona A Seams Interburden	288.51
						372.5	Hoskisson Sesam	284.30
						425.57	Lower Melville Seam	509.82
C076	CCP0050	256549.8	6524063.8	304.03	330.78	80	Below Base of Alluvials	284.10
						103.5	Yarraman/Doona Interburden2	282.76
						207	Springfield/Clift Seams Interburden	287.29
						299	Caroona Seam/Hoskissons Seams Interburden	288.62
C089A	CCP0062	258929.4	6526611	303.64	301.12	73.75	Springfield Seam B	282.11
						110	Clift Seam	281.10
						150	Goran Conglomerate C	285.14

Site No.	Borehole No.	MGA Coordinates		RL Collar	Depth Drilled	Depth of Vibrating Wire Completions	Target Aquifer/Strata of VWP (in descending depth order)	Groundwater Level July 2011
		Easting (m)	Northing (m)	(mAHD)	(m)	(m below GL)		(mAHD)
						217.75	Howes Hill Seam	282.60
						236.5	Caroona Seam/Hoskissons Seams Interburden	281.84
						247	Hoskissons Seam	284.00
						270	Hoskissons/Melville Seams Interburden	282.34
						288.5	Melville Seam	282.18
C265	CCP0135	260521.5	6526558.37	303.85	247.27	56	Base of Alluvium+30m	287.62
						105	Clift Seam	287.53
C282A	CCP0152N	257321.13	6526401.31	301.17	169.06	130	Base of Alluvium+30m	278.22
						160	Base of Alluvium+60m	281.02
C285	CCP154N	256155.52	6526327.03	300.07	279.68	124	Springfield Seam/Waverly Conglomerate Interburden	279.09
						150	Waverly Conglomerate	280.44
						265	Hoskissons Seam	279.82
Doona Ridge								
C017	CCP0156	252734.25	6519792.31	342.57	590.2	335	Doona Seam	367.08
						436	Clift Seam	212.20
						487	Clare Sandstone B	290.64
						537	Hoskissons Seam	277.03
C037	CCP0144	253291.07	6522150	337.13	428.4	100	Conglomerate	316.62
						226	Doona Seam	291.15
						285	Intrusive	285.48

Site No.	Borehole No.	MGA Coordinates		RL Collar	Depth Drilled	Depth of Vibrating Wire Completions	Target Aquifer/Strata of VWP (in descending depth order)	Groundwater Level July 2011
		Easting (m)	Northing (m)	(mAHD)	(m)	(m below GL)		(mAHD)
						338	Clift Seam	283.42
						370	Clare Sandstone B	290.72
						413	Hoskissons Seam	325.53
C168A	CCP0095	253663.99	6525325.63	348.81	385.22	181.5	Doona Seam	287.71
						275	Clift Seam	285.54
						311	Clare Sandstone B	284.03
						363	Hoskissons Seam	284.29
C188-3	CCP0128	253514.23	6528391.63	342.84	255.02	73	Doona Seam Roof	284.43
						87	Doona Seam	283.00
						120	Clift Seam Roof2	288.70
						132.5	Clift Seam Roof1	284.96
						145	Clift Seam	283.42
						215	Clare Sandstone C	286.08
						225	Hoskissons Roof	283.15
						236	Hoskissons Seam	281.56
C188-4	CCP0140	253523.88	6528416.2	343.58	255.76	75	Doona Seam Roof	287.19
						91	Doona Seam	282.10
						120.5	Clift Seam Roof2	282.40
						129.5	Clift Seam Roof1	280.53
						145	Clift Seam	281.18
						215	Clare Sandstone C	283.08
						224	Hoskissons Roof	285.08

Site No.	Borehole No.	MGA Coordinates		RL Collar	Depth Drilled	Depth of Vibrating Wire Completions	Target Aquifer/Strata of VWP (in descending depth order)	Groundwater Level July 2011
		Easting (m)	Northing (m)	(mAHD)	(m)	(m below GL)		(mAHD)
						235	Hoskissons Seam	281.45
C188-5	CCP0132	253479.91	6528386.68	345.24	255.75	77	Doona Seam Roof	283.26
						90.5	Doona Seam	286.81
						122	Clift Seam Roof2	283.54
						135.5	Clift Seam Roof1	282.79
						149	Clift Seam	284.74
						217	Clare Sandstone C	282.75
						228	Hoskissons Roof	282.26
						239	Hoskissons Seam	281.64
C188-6	CCP0136	253541.93	6528366.69	340.92	249.65	72	Doona Seam Roof	293.46
						86	Doona Seam	289.05
						117	Clift Seam Roof2	286.02
						133	Clift Seam Roof1	286.34
						145	Clift Seam	286.98
						212	Clare Sandstone C	292.81
						222	Hoskissons Roof	283.80
						233	Hoskissons Seam	284.71
Yarraman Alluvial Plain								
C023	CCP089	248202.22	6520806.61	310.85	523	150	Intrusion	302.09
						302.25	Doona Seam	291.62
						433	Clift Seam	284.88
						502.5	Combined Caroona & Hoskissons Seam	276.82

Site No.	Borehole No.	MGA Coordinates		RL Collar	Depth Drilled	Depth of Vibrating Wire Completions	Target Aquifer/Strata of VWP (in descending depth order)	Groundwater Level July 2011
		Easting (m)	Northing (m)	(mAHD)	(m)	(m below GL)		(mAHD)
C043	CCP0073	247309.9	6523279	307.92	487.02	110	Below Base Alluvials	306.84
						193	BHAL/Doona Seam Interburden	305.39
						271	Doona Seam	293.93
						358	Clift Seam	283.32
						396	Clare Sandstone C	286.74
						424.4	Hoskissons Seam	285.01
						444	Hoskissons/Melville Seams Interburden	262.02
						461	Melville Seam	257.22
C151	CCP0116	249207.6	6524941.76	305.2	355.3	160	Doona Seam	289.60
						289	Clift Seam	282.92
						327	Clare Sandstone C	280.63
						350	Hoskissons Seam	281.19
C180A	CCP0100	249967.7825	6527529.878	303.29	283.12	68.8	Yarraman Seam	298.90
						114	Mooki Seam	294.89
						127	Springfield Seam	289.68
						176	Clift Seam	287.31
						199	Clare Sandstone B	284.71
						232	Hoskissons Seam	282.90
						261.5	Melville Seam	284.09

Note: (i) Co-ordinates in MGA 56.

2.6.2 Groundwater Recharge

Recharge to the alluvial groundwater system is derived from a range of sources: diffuse rainfall recharge and irrigation recharge primarily on the Mooki alluvial plain. There is also runoff-recharge at the alluvial margins, horizontal and vertical discharge from adjacent (ridgeline) and underlying bedrock, and leakage from streams – during normal flow conditions and during overbank flood events (Merrick, 2001). Recharge to the bedrock units is likely to be significantly lower than to the alluvium, given the bedrock's comparatively much lower hydraulic conductivity (see Section 2.6.6) and hence its limited capacity to receive and transmit sub-surface water.

Ringrose-Voase et al. (2003) applied the crop-soil-water model APSIM to assess deep drainage throughout the Liverpool Plains under a variety of different cropping regimes and soil types. They estimated long-term average deep drainage rates under current land use in the range of:

- 45 mm/year on the alluvial plains;
- 39 to 78 mm/year on the basalts; and
- 23 to 91 mm/year on the Permo-Triassic rock units.

It must be noted that these estimates do not account for interflow, or soil moisture storage below the modelled soil profile (4 m in the case of Ringrose-Voase et al., 2003), and as such actual recharge to the groundwater system is likely to be lower. This is particularly so in the steeper (Permo-Triassic and basaltic) slopes, where a significant proportion of the modelled deep drainage is likely to be shed laterally as interflow (see Rassam and Littleboy, 2003).

Similar modelling conducted under the Australian Water Availability Project (AWAP) estimated a long-term (1958-2012) average annual recharge rate to the alluvials in the Mooki River catchment of around 20 mm/year. This modelling was used to parameterise NOW's Upper Namoi groundwater flow model, and included the effects of rainfall, irrigation and flood recharge (C. McNeilage, pers. comm. 2013).

Other investigators estimate very low rates of rainfall recharge on the plains (e.g. Lavitt, 1999; Cox and Raiber, 2011), as indicated by the higher salinity of the Narrabri Formation, compared to the relatively low salinity of the underlying Gunnedah Formation. The comparatively low salinity of the Gunnedah Formation suggests that recharge primarily occurs up-catchment, probably around the margins of the alluvial plain. Young et al. (1996) estimated recharge rates to the alluvium in the Mooki catchment of 20-30 mm/year, but noted that there were a number of samples analysed with no tritium, which suggests old groundwater and very low rates of recharge.

AGE (2012) reported that investigations conducted by the University of New South Wales at their research station at Breeza suggest very low recharge rates, in the order of 0.2% of rainfall (around 1 mm/year) on the black soils of the plains. Higher estimates have been made however, using the chloride mass balance and hydrograph fluctuation methods, in the order of 58 mm/year (Berhane, 2001).

SWS (2012) (i.e. the Namoi Catchment Water Study) collated a range of recharge models' and groundwater flow models' recharge estimations and parameterisations for the area. These generally range from 0.5 to 5% of average annual rainfall.

Section 3.3.2 provides a description of recharge rates applied to the model for the Project.

2.6.3 Groundwater Use

The Gunnedah Formation within the Mooki alluvium is the primary (highest yielding, most utilised) aquifer system in the region. Groundwater from the Gunnedah Formation in this region is used extensively for irrigation, stock and domestic use and for the town water supply at Gunnedah, Breeza, Curlewis, Quirindi and also Caroona (Groundwater Exploration Services, 2014; AGE, 2012). But the same formation in the Yarraman alluvial plain is less productive with much poorer quality groundwater available that limits its usage.

A search of the NOW groundwater bore database identified 5279 registered bores and wells within an area 70 km by 97 km centred EL6505. Based on the NOW Pineena database, 72 bores are owned by mines; 201 bores belong to NOW; 4188 bores are privately owned; 106 bores are owned by local or other government; 11 are owned by schools; 2 are owned by trusts; and 699 have unknown owners. The identified bores are shown in Figure 16, whilst the estimated development of groundwater use over time is presented in Figure 17; these data were extracted from NOW's upper Namoi groundwater flow model (C. McNeilage, pers. comm. 2013). They show a significant increase in Namoi Alluvium groundwater usage from the early 1970s through to 2002-2003, beyond which time rates of usage decrease significantly, in line with stricter regulation of abstraction.

2.6.4 Groundwater Quality

A summary of groundwater chemistry based on sampling from bores in each of the main hydrogeological units is shown in Table 13. The data are derived from 42 monitoring bores – data from 23 bores in the period from June 2008 to August 2012, and data from 15 bores in the period from October 2010 to August 2012. Therefore the data are considered representative of medium term conditions. Total Dissolved Solids (TDS) estimates are summarised in Figure 18; TDS was calculated by multiplying electrical conductivity (µS/cm) by a conversion factor of 0.67.

2.6.4.1 ***Salinity***

Table 10 and Table 11 present field sampling salinity data from the Mooki alluvial plain in January-February 2012. The groundwater samples were collected from the alluvium. Narrabri Formation bores exhibit a low to moderate salinity, ranging from 553 to 2,593 mg/L, and as such most groundwater within the formation in this area can be classified as fresh to brackish. These salinities are fresher than those observed in the Narrabri Formation of the Yarraman alluvial plain, which has distinctly higher salinities, with a range of 6,600 to 15,209 mg/L. The same situation is observed in the Gunnedah Formation: lower salinities ranging from 376 to 1,032 mg/L in the Mooki alluvial plain, and higher salinities ranging from 2,144 to 14,740 mg/L in the Yarraman alluvial plain.

Table 13 Summary of Groundwater Chemistry - Groundwater Monitoring Piezometers

Aquifer Screened	Water Quality						Number of Monitoring Bores	Number of Laboratory Samples Collected
	TDS (mg/L)			pH				
	Range	Average	Median	Range	Average	Median		
Alluvium - Narrabri Formation	296-22579	4623	1755	6.0-12.9	7.6	7.3	9	124
Alluvium - Gunnedah Formation	369-19966	1636	727	5.7-8.7	7.4	7.4	19	260
Regolith	625-17755	4235	2821	6.3-8.6	7.1	6.9	8	74
Clift Seam	710-6559	1708	804	7.9-9.7	8.8	8.9	1	11
Clare Sandstone	336-1149	682	750	7.5-8.7	8.0	8.0	2	21
Howes Hill Seam	287-374	326	332	7.3-8.0	7.7	7.8	1	10
Hoskissons Seam	551-11189	4954	7203	6.7-8.1	7.3	7.2	2	24

Table 13 shows that the Narrabri Formation exhibits a generally higher salinity (TDS; median of 1,755 mg/L) than the underlying Gunnedah Formation (median of 727 mg/L). Variability is however similar between the two formations: Narrabri Formation salinity varies from 296 to 22,579 mg/L, whilst that of the deeper Gunnedah Formation is 369 to 19,966 mg/L.

Table 11 presents field sampled groundwater salinity data from regolith monitoring bores on Doona Ridge and Nicholas Ridge. These bores screen between 13.3 m and 45 m depth into the weathered material. The data from the three monitoring bores on Nicholas Ridge indicate that groundwater in the regolith is moderately saline from 2,343 mg/L to 4,183 mg/L. Beneath Doona Ridge, data from four monitoring bores in the regolith indicates a brackish to saline water quality varying from 1,266 mg/L to 15,232 mg/L. The wider salinity range on Doona Ridge could simply reflect the much larger area of Doona Ridge compared to Nicholas Ridge, which would provide greater opportunity for a wider range of groundwater flow path lengths from hillcrest to plain, and hence a wider range of groundwater salinities.

One site which monitors the Clift Seam beneath the Mooki alluvial plain has been sampled (Table 13). Groundwater salinity in this bore is brackish, with an average of 1,708 mg/L TDS.

From the east (shallow subcrop recharge area) to the deep down-dip (discharge) area, groundwater in the Clare Sandstone changes from fresh to slightly brackish (Figure 18), with an average TDS of 378 mg/L on the Mooki alluvial plain and 958 mg/L beneath Doona Ridge.

Groundwater from the Howes Hill Seam has been sampled at one site. This site is located on the Mooki alluvial plain, and the data indicate that groundwater is fresh, with an average salinity of 326 mg/L (Table 13).

Samples were collected from two sites monitoring the Hoskissons Seam, one on the Mooki Alluvial Plain and another on the Yarraman Alluvial Plain. Groundwater is fresh on the Mooki alluvial plain (average 622 mg/L TDS), and saline on the Yarraman alluvial plain (average TDS of 8,358 mg/L). This is the same pattern as observed in the Clare Sandstone: an increase in groundwater salinity in a down-geologic basin direction (from east to west, from shallow subcrop to deep burial).

2.6.4.2 ***pH***

Measured groundwater pH data indicate slightly acidic to highly alkaline conditions, with pH ranging between 5.7 and 12.9 (Table 13). Water from the alluvium has the widest pH range, between 5.96 and 12.9 in the Narrabri Formation and between 5.7 and 8.7 in Gunnedah Formation. Groundwater in the regolith and Hoskissons seam is typically slightly acidic to alkaline. Howes Hill seam pH is generally neutral, varying from 7.3 to 7.97. Groundwater in the Clift seam and Clare Sandstone is mildly alkaline, with average pH values of 8.8 and 8.0 respectively.

2.6.5 Hydraulic Properties

Five hydraulic conductivity test methods have been applied to selected exploration holes for the Project to investigate the rock/alluvial system pore space conductivity and the rock fracture network conductivity (Table 14; AGE, 2013 and SCT, 2012). Figure 19 shows the testing sites and the type of testing undertaken at each site. Details of the hydraulic conductivity test methods follow:

- Packer (Lugeon) Tests: Single-hole in-situ test of formation hydraulic conductivity performed by measuring the volume of water taken in a section of test hole when the interval is pressurised. A total of 377 tests were undertaken at nine sites located on both the alluvium and ridge areas. All packer testing programs have been undertaken by SCT to investigate the conductivity of the pores and fractures.

- Slug/falling head tests: Inserting or removing a slug of water and measuring the rate of recovery back to static level. 16 sites provided 46 tests, all bar two tested the alluvium. These works were completed by AGE.

- Pumping Tests: AGE conducted 24 and 48-hour constant rate pumping tests. A total of four tests were completed at four sites, within the Gunnedah formation, Clare Sandstone and Caroona/Hoskissons seam. The work investigated both pore space and fractured rock mass hydraulic conductivity, and attempted to characterise the degree of hydraulic connection between the alluvium and underlying rock units.

- Core sample hydraulic conductivity tests: SCT analysed 23 core samples in a laboratory to assess pore space hydraulic conductivity of the rock mass.

- Multi-hole interference tests and multi-phase tests: 38 tests were completed by SCT and Multiple Technologies to investigate the borehole horizontal conductivity and reservoir properties in the coal seams and in the Clare Sandstone.

Table 14 Summary of Hydraulic Property Testing

Strata	Packer (SCT)	Multi-hole / Multi-Phase (SCT and Multiple Technologies)	Slug/Falling Head (AGE)	Pump Out (AGE)	Core Samples (SCT)	Total
Alluvium	-	-	19	2	-	21
Interburden -Below Base of Alluvium	36	-	-	-	-	36
Interburden -Below Base of Weathering	14	-	-	-	-	14
Digby Conglomerate	6	-	-	-	1	7
Goran Conglomerate	17	-	-	-	-	17
Conglomerate	14	-	-	-	-	14
Springfield Seam	9	-	-	-	-	9
Doona Seam	7	3	-	-	-	10
Nicholas Seam	4	-	-	-	-	4
Mooki Seam	5	-	-	-	-	5
Clift Seam	21	9	-	-	-	30
Breeza Seam	14	2	-	-	-	16
Clare Sandstone	57	8	1	1	21	88
Howes Hill Seam	3	3	-	-	-	6
Caroona/Hoskissons Seam	35	9	1	1	-	46
Melvilles Seam	10	4	-	-	-	14
Interburden	125	-	-	-	-	125
Unknown	-	-	-	-	1	1
TOTALS	**377**	**38**	**21**	**4**	**23**	**463**

Source: AGE (2013)

2.6.5.1 ***Hydraulic Conductivity (K)***

Figure 20 presents the hydraulic conductivity of the Hoskissons and Clift Seams at Caroona and testing at other mining and coal seam gas projects in the Gunnedah Basin. The results of the packer testing, interference testing and multiphase testing are sourced from SCT (2012). The interference- and multi-phase test data for the Project estimates high hydraulic conductivities relative to other regional test work, specifically the Project packer testing results, and the regional Watermark and coal seam gas testing data.

Figure 20 shows packer test Clift and multiphase Clift testing data mostly fit in the coal hydraulic conductivity range determined by AGC (1984) and Mackie (2009), however, Hoskissons Seam interference testing data are outside of Mackie's range. Hence, the high conductivities seen in the Project data are likely a reflection of the test method, which appears to be biased towards higher hydraulic conductivity. All hydraulic conductivity testing values decrease with depth below ground surface due to the increase in overburden pressure (Figure 20).

Testing work at Maules Creek in the Gunnedah Basin estimated a coal seam hydraulic conductivity range between 1E-2 and 1E-1 m/day (AGE, 2011). The Namoi Water Study indicates a hydraulic conductivity range for the Black Jack Group of between 2E-3 and 3E-2 m/day (SWS, 2010). The Watermark Project to the north of Caroona reported coal seam hydraulic conductivity values from 9.6E-5 to 1.1E-1 m/day, similar to the Caroona Project, based on packer tests and slug tests (AGE, 2012).

It must be noted that the data collected for this Project are all skewed towards measurements of horizontal hydraulic conductivity, with only three interburden core sample tests (at site CCP009), and inverse modelling of head propagation through the interburden providing data on vertical conductivity (discussed below). Accordingly, vertical hydraulic conductivity has been estimated from horizontal measurements using recognised relationships between the two.

As there are no available measurements of coal seam vertical hydraulic conductivity. AGE (2013) estimated that the vertical conductivity is potentially the same as horizontal.

The Clare Sandstone exhibited significant groundwater yields during drilling of two large diameter bulk sampling holes on Doona Ridge. This unit would be fractured and depressurised by the proposed longwall mining if the height of fracturing (cracking) intercepts this geological unit (AGE, 2013), which was the reason for the hydraulic conductivity testing of this unit. Four different hydraulic conductivity test methods were applied in the Clare Sandstone, the results of which are shown in Figure 21. The lowest hydraulic conductivity values are derived from core sample primary conductivity testing, which indicates a range from 9E-5 m/day to 9E-4 m/day. Results from packer tests are higher, in the range of 9E-4 to 9E-1 m/day for depths less than 200 m. Packer test-derived hydraulic conductivity significantly reduces below 200 m depth, in the range of very low or practically zero flow to 9E-4 m/day. SCT (2012) also report that Clare Sandstone hydraulic conductivity is higher in the north-east, in shallow subcrop, and progressively lower in the south westerly direction as its depth increases.

The multiphase tests and the falling head tests on the Clare Sandstone report the highest hydraulic conductivity values in the range of 5E-3 to 8E-2 m/day. There has been one pumping test conducted in the Clare Sandstone, at site C182 beneath Doona Ridge. This comprised pumping at a constant rate of 2.7 L/second for 24 hours. This test resulted in the highest hydraulic conductivity value estimate of all testing, at 1.7E-1 m/day. SCT (2012) provide the average horizontal conductivity for the Clare Sandstone in the range of 1E-2 m/day for depths less than 200 m, decreasing to 1E-4 m/day at depths greater than 300 m; SCT's report states that these values are biased to the higher end of the hydraulic conductivity range however, as core samples were preferentially selected from higher hydraulic conductivity horizons. They estimate that the vertical conductivity could be half that of the horizontal hydraulic conductivity. Testing for the Watermark Project (AGE, 2012) estimated vertical hydraulic conductivity between 1.2 and 2 times lower than horizontal.

Packer testing was the primary method used for the Project to measure the hydraulic conductivity of the interburden, the results of which are shown in Figure 22. Core samples were also analysed for hydraulic conductivity, and this mostly focussed on the Clare Sandstone (Figure 21), but also included four samples from higher porosity interburden units at site CCP009 (Figure 22). Packer testing between base of alluvium and first underlying coal seam, and below first coal seam, indicate the same range of interburden hydraulic conductivity (about 1E-2 to 1E-5 m/day), with only a very weak declining trend with depth. Figure 22 shows that the Clare Sandstone is more permeable than interburden until it reaches depths below 400 m.

To estimate the vertical hydraulic conductivity of the interburden, SCT (2012) applied inverse modelling of head change propagation and attenuation from the alluvials down into the underlying rock strata, as observed in nested VWPs at a range of locations. This approach estimated a vertical conductivity range of 9E-5 to 9E-4 m/day for depths less than 200 m, and 9E-6 m/day or less for depths greater than 200 m.

Hydrographs at nested bores, located at site 102, were reviewed by AGE (2013). This site contains bores in the Gunnedah and Narrabri formation alluvium, base of alluvium and in the Clift seam. The hydrographs show a consistent response to nearby irrigation pumping in the alluvium, however the Clift seam shows a limited pressure response, indicating that there is a degree of hydraulic separation between the coal seam and the alluvium (AGE, 2013).

The neighbouring Watermark Project collected a significant body of horizontal and vertical core hydraulic conductivity data for the interburden units (AGE, 2012). These data are considered to be relevant to Caroona as the geological units are similar and are summarised and reproduced in Table 15 and Table 16. Freeze and Cherry (1979) recommend that horizontal hydraulic conductivity data are most appropriately summarised using the arithmetic mean, whilst vertical hydraulic conductivity data are best summarised using the harmonic mean. This is because bulk vertical conductivity is dominated by the least permeable medium, whilst horizontal conductivity is dominated by the most permeable medium (Freeze and Cherry, 1979). The corresponding means from the Watermark Project are 4.88E-2 m/day (horizontal), and 5.76E-6 m/day (vertical). Freeze and Cherry (1979) also recommend summarising the ratio of vertical to horizontal hydraulic conductivity data using these same means; in this case, the bulk ratio based upon the Watermark data is 1.18E-4.Falling head tests conducted on the Narrabri Formation yield hydraulic conductivities in the range of 2E-2 m/day to 1 m/day. Two constant rate pumping tests at sites C102 and C199 were undertaken to estimate the hydraulic conductivity of the Gunnedah Formation which yielded values above 100 m/day.

Table 15 Core Hydraulic Conductivity Data Summary from the Watermark Project

Statistic	Hydraulic Conductivity (m/day)		Kz:Kh Ratio
	Horizontal (Kh)	Vertical (Kz)	
Harmonic mean	1.23E-05	5.76E-06^	0.32
Geometric mean	6.64E-04	2.71E-04	0.53
Arithmetic mean	4.88E-02^	2.02E-02	0.64
Median	9.85E-04	4.41E-04	0.66

^ Ratio Kz / Kh = 1.18E-4

Table 16 Core Hydraulic Conductivity Data from the Watermark Project

Bore	Unit	Depth from (m)	Depth to (m)	Length (m)	Kh (m/day)	Kz (m/day)	Kz:Kh
WM0291	Alluvium	67.4	67.6	0.2	6.05 x 10 -3	3.12 x 10 -3	0.52
	Alluvium	72.9	73.1	0.2	2.15 x 10 -2	no data	
	Sandstone	96.14	96.34	0.2	1.30 x 10 -4	1.12 x 10 -4	0.87
	Sandstone	99.2	99.4	0.2	3.80 x 10 -3	2.51 x 10 -3	0.66
	Conglomerate	101.33	101.44	0.11	2.07 x 10 -2	2.03 x 10 -2	0.98
	Sandstone	102.8	103	0.2	5.44 x 10 -5	2.59 x 10 -5	0.48
	Carb Mudstone	105.15	105.3	0.15	8.29 x 10 -3	5.10 x 10 -3	0.61
	Conglomerate	131.7	131.9	0.2	2.56 x 10 -4	3.20 x 10 -4	1.25
	Mudstone/Siltstone	141.18	141.32	0.14	1.72 x 10 -3	8.00 x 10 -7	4.7 x 10 -4
	Sandstone	143.06	143.26	0.2	7.60 x 10 -4	9.68 x 10 -4	1.27
WM0012	Interburden	52	52.2	0.2	no data	<8.64 x 10 -7	
WM0042	Siltstone	32.8	32.92	0.12	8.64 x 10 -7	8.64 x 10 -7	1
	Conglomerate	216.2	216.33	0.13	9.85 x 10 -4	7.43 x 10 -4	0.75
	Sandstone	292.24	292.5	0.26	2.76 x 10 -5	no data	
	Maules Creek	318.46	318.66	0.2	8.99 x 10 -3	6.74 x 10 -3	0.75
WM0255	Siltstone	69	69.15	0.15	2.49 x 10 -3	2.14 x 10 -3	0.86
	Sandstone	153.03	153.2	0.17	1.04 x 10 -4	8.64 x 10 -5	0.83
WM0074 R	Sandstone	42.3	42.4	0.1	1.30 x 10 -4	2.51 x 10 -5	0.19
	Sandstone	103.63	103.83	0.2	8.41 x 10 -1	9.85 x 10 -2	0.12
	Hoskissons U roof	105.4	105.55	0.15	3.34 x 10 -3	9.07 x 10 -4	0.27

Bore	Unit	Depth from (m)	Depth to (m)	Length (m)	Kh (m/day)	Kz (m/day)	Kz:Kh
	Sandstone	140	140.3	0.3	2.07 x 10 -5	1.38 x 10 -5	0.67
	Dolerite	164.4	164.55	0.15	1.73 x 10 -6	8.64 x 10 -7	0.5
WM0066	Conglomerate	45.67	45.87	0.2	5.49 x 10 -1	4.33 x 10 -1	0.79
	Siltstone	116.71	116.91	0.2	1.56 x 10 -4	4.58 x 10 -5	0.29
	Carb Mudstone	151.49	151.69	0.2	1.02 x 10 -3	4.41 x 10 -4	0.43
	Sandstone	158.81	159.01	0.2	5.18 x 10 -5	3.11 x 10 -5	0.6
	Sandstone	185.9	186.05	0.15	8.21 x 10 -3	4.75 x 10 -3	0.58
	Sandstone	225.64	225.8	0.16	3.97 x 10 -5	3.28 x 10 -5	0.83
	Mudstone	240.76	240.96	0.2	1.73 x 10 -6	8.64 x 10 -7	0.5
	Hosk-Mel Interburden	243.24	243.36	0.12	2.71 x 10 -2	7.52 x 10 -4	0.03
WM0239	Sandstone	14	14.2	0.2	4.67 x 10 -5	2.25 x 10 -5	0.48
WM0258	Hosk-Mel Interburden	40.84	40.99	0.15	6.74 x 10 -3	4.84 x 10 -3	0.72

Falling head tests on the Narrabri Formation estimate hydraulic conductivities in the range of 2 x 10^{-2} m/day to 1 m/day. Two constant rate pumping tests at sites C102 and C199 were undertaken to estimate the conductivity of the Gunnedah Formation which provide estimates above 100 m/day.

AGE (2013) reported on test pumping on bore C102, in the Narrabri and Gunnedah Formations. They reported that: *"Alluvial bores C102-B (18 m to 20 m) and C102-A (33 m to 36 m) screened in the Narrabri and Gunnedah Formations respectively and bore C102-D at the base of the alluvium in highly weathered conglomerate, respond <to pumping> in unison showing pressures transmit through the interburden strata. In contrast, the hydrograph of bore C102-C (148 m to 154 m) which is screened in the Clift Seam is relatively flat-lying and only records a pressure response of about 1 m, indicating that there is a degree of hydraulic separation between the coal seam and the alluvium."*

2.6.5.2 ***Specific Yield***

Specific yield (Sy) (together with porosity and specific storage) usually decreases with depth due to increasing overburden pressure. The Watermark model (AGE, 2012) calibrated alluvial Sy in the range of 0.032 to 0.2. Interburden Sy used in that model was in the range of 0.001 to 0.015. Clare Sandstone Sy was estimated to be 0.0012 and Hoskissons Coal Seam 0.0022 in the same model. These are considered to be useful for the Project given the proximity of the projects and similar geology.

2.6.5.3 ***Specific Storage***

Direct testing data are not available for specific storage (Ss) of coal seams or interburden. The Watermark model calibration parameterisations (AGE,2012) suggest that Ss is in the order of 1.7E-5 m^{-1} for the Hoskissons Coal Seam, 1E-5 m^{-1} to 5E-5 m^{-1} for interburden, and 5E-5 m^{-1} for the Clare Sandstone.

2.6.6 Groundwater-Surface Water Interaction

The increase in stream flows in the downstream direction between Caroona and Breeza during higher flow periods noted in Section 2.3 with reference to Figure 9 can be largely attributed to gains from runoff, rather than gains from the groundwater system as baseflow. There is no evidence of baseflow gains along this reach in Figure 9, given that the low flows at Caroona are greater than they are at Breeza. In addition there are more frequent no flow periods at Breeza than there are at Caroona.

The average flow at the Quirindi Creek at Greenacres gauge (419098) over its period of record (2003-2013), which gauges inflows from Quirindi Creek into the Mooki River between Caroona and Breeza, is 26.8 ML/day. The corresponding average flow on the Mooki River at the Caroona gauge is 155 ML/day, and that at Breeza is 175 ML/day; the inflow from Quirindi Creek to the Mooki River explains more than the average increase in flow along the Mooki River between Caroona and Breeza (20 ML/day), and suggests some loss (at least 6.8 ML/day) of flow along this reach, to the underlying alluvial groundwater system, and / or to surface water usage.

The flow gain/loss analysis along the Mooki River between Caroona and Breeza is further explored in Figure 23, which shows estimated flow gains and losses as calculated using the difference in 7-day moving average flows between Caroona and Breeza, with the inflows along the reach comprising the gauged flows on the Mooki River at Breeza, plus those on Quirindi Creek at Greenacres. The moving average is used to account for channel storage and attenuation, and the resultant lags in gauged flows between upstream and downstream gauges.

Figure 23 confirms that this stream reach does, on average and most of the time, lose water to the underlying groundwater system and /or surface water usage. The reach does however switch between flow gaining and flow losing conditions, with gains observed far more consistently during higher flow periods, with a similar but much weaker trend in the timing of flow losses. This tends to confirm that the observed flow gains are primarily runoff, rather than groundwater- (baseflow-) derived.

NOW maintains a nested (i.e. several bores at the one location, screened at different levels) cluster of groundwater monitoring bores adjacent to the lower Quirindi Creek channel (GW030078 / GW030380;Figure 16). Groundwater level data from these bores has been compared to the estimated stream bed elevation and estimated creek water levels in Figure 24, via extrapolation of the Greenacres gauge data downstream (~4.5 km) based on the topographic gradient along the creek as derived from BHP Billiton's high resolution elevation (LIDAR) data. The inference that this area of the Mooki River and Quirindi Creek primarily loses flow is supported by Figure 24, which shows that the groundwater potentiometric surface/watertable lies 10 to 12 m below the creek stage and surface water therefore migrates down into the underlying Namoi Alluvium. The data indicate that there is probably a 10 m thick unsaturated zone between the lower Quirindi Creek and the underlying watertable.

The regional depth to watertable mapping of Figure 14 also confirms that the Mooki River between Caroona and Breeza is a losing stream with estimated groundwater levels at about 10 m below the bed of the river. Many groundwater level hydrographs in the Upper Namoi Alluvium (Attachment D) indicate that levels have dropped by 10-15 m since 1980, which is likely in response to the significantly increasing groundwater usage over that time (Figure 17), rather than climate given that there has been a broadly increasing rainfall trend post-1968 (Figure 7). This effect could have potentially altered the system's state with regard to pre-groundwater development baseflow gains and losses along the Mooki River.

2.7 CONCEPTUAL HYDROGEOLOGICAL MODEL

Figure 25 presents a schematic of the Project's conceptual hydrogeological model, in the pre-mining state. Figure 26 presents the conceptual model of mining impacts on the system.

2.7.1 Hydrostratigraphic Units

The three major hydrostratigraphic units (HSUs)[1] in the vicinity of the Project area are outlined in Section 2.6.

2.7.2 Recharge

Recharge to the alluvial groundwater system is derived from a range of sources including diffuse rainfall recharge runoff-recharge at the alluvial margin, upward discharge from underlying bedrock, horizontal discharge from the bedrock on ridge areas, and leakage from streams into the alluvium. Irrigation recharge occurs only where irrigation occurs on the Mooki and Quirindi alluvial flats. Recharge from stream seepage occurs during normal surface flow conditions, and during overbank flood events. Recharge to the bedrock units and in turn from the alluvial sediments is significantly lower given the Permian strata's comparatively low hydraulic conductivity (see Section 2.6). Estimates of recharge to the alluvium are highly variable, but are typically in the range of 1 to 5% of rainfall for bedrock units (see Section 2.6.2).

2.7.3 Discharge

Groundwater discharge occurs via evapotranspiration from shallow watertables, groundwater pumping (primarily for irrigation and potable water supply), and via

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[1] Kansas Geological Survey (KGS, 1996) defines a hydrostratigraphic unit as follows: a rock **<**or sediment**>** unit distinguished and characterised by its porosity and hydraulic conductivity. Delineation of these units subdivides the geologic framework into relatively more or less permeable portions and thus aids in definition of the flow system.

baseflow to streams, particularly for streams emanating from the Liverpool Range (although as noted previously the Mooki River is considered a predominantly losing stream with only baseflow accession south of Caroona). A minor component of groundwater discharge is likely to occur via the bedrock down-geologic basin to the south-west due to increasing strata thicknesses, and therefore greater transmissivity and greater groundwater flow rates in this direction. Groundwater flow through the Mooki plain alluvial sediments that does not discharge via groundwater pumping, baseflow or evapotranspiration discharges in a northerly direction towards and beyond Gunnedah in the Namoi system.

2.7.4 Hydraulic Properties

Data collected for the Project and other independent studies suggests that the hydraulic conductivity of the Permo-Triassic units decreases with burial depth. This is attributed to fractures (and pore space) being less prevalent at depth due to increasing overburden pressure. The Permo-Triassic groundwater system ranges from unconfined in outcrop areas to semi-confined at greater depths. The alluvium tends to form unconfined to semi-confined zones that are significantly more permeable than the hard rock units, and therefore transmits groundwater at greater flow rates.

2.7.5 Impact of Mining on Overburden

The impact of mining on the hydraulic conductivity of caved overburden has been based on monitoring experience and groundwater modelling conducted in similar mining environments, including research available on free draining heights.

It is generally accepted that there will be a sequence of deformational zones (Figure 26) usually described as:

- the caved zone;
- the fractured zone, consisting of:
  - a lower zone of connective-cracking;
  - an upper zone of disconnected-cracking;
- the constrained zone; and
- the surface cracking zone.

The rocks in the connective-cracking part of the fractured zone will have a substantially higher vertical hydraulic conductivity than the undisturbed (‘host’) rocks. This allows the free draining of groundwater downward towards the goaf. Above that in the disconnected-cracking zone the vertical flow of groundwater is impeded.

Depending on the width of the longwall panels, depth of cover and worked coal seam thickness, there is normally a constrained zone in the overburden that prevents vertical groundwater flow. In this zone, dilation of strata causes an increase in horizontal hydraulic conductivity.

In the near surface zone, fracturing can occur due to tensional forces, but field evidence indicates this is usually restricted to a depth of less than 20 m from the ground surface.

At the base of the fractured zone, groundwater pressures will reduce towards atmospheric pressure, and consequently over a short time the majority of the fractured/disturbed zone would become a free-draining zone.

2.7.6 Water Balance Changes Due to Mining

These depressurisation impacts, and the resulting mine groundwater inflows, will result in changes to groundwater discharge such as baseflow to streams, down-geologic basin flow, and evapotranspiration. Hydraulic properties will control the spatial (lateral and vertical) and temporal migration of these changes, and ultimately their location, timing and magnitude.

The depressurisation impacts will potentially also take water from groundwater storage, and because mining-induced fracturing of rock strata will alter (increase) groundwater storage properties, in the long term, more water will end up in groundwater storage than was the case pre-mining[2]. This will in turn cause changes to groundwater discharge.

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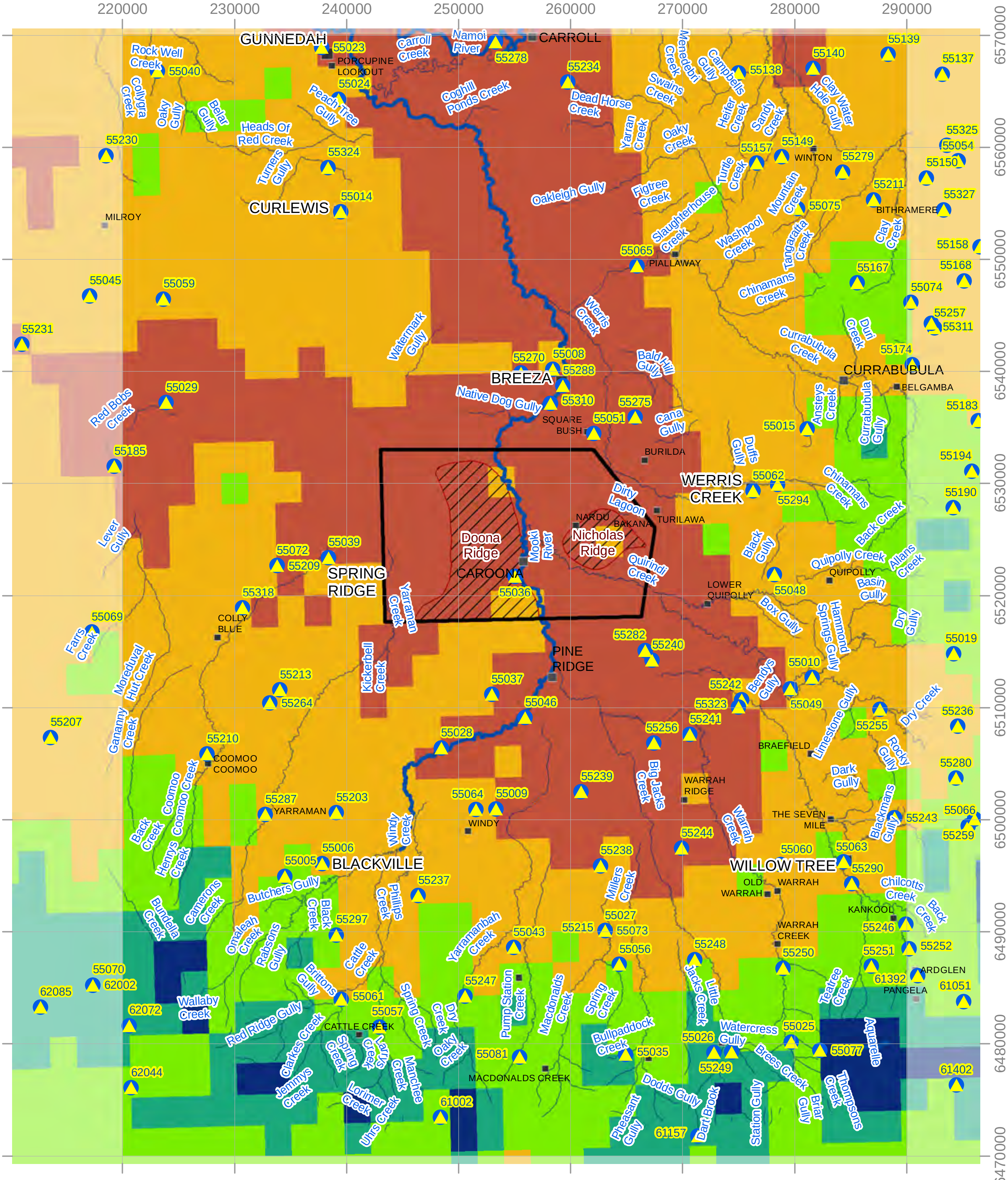
[2] Within the strata portions that remain saturated within the mining footprint. Water is lost from storage overall however due to drawdown.



Legend

- Climate Station
- Town
- Village
- Locality
- River
- Creek

Average Rainfall

mm/year

- <=650
- 650.01 - 750
- 750.01 - 900
- 900.01 - 1,050
- >1,050

- Exploration Licence
- Targeted Exploration Area

Rainfall data source:
Bureau of Meteorology (2013)

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Caroona Coal Project

Figure 5

Average Annual Rainfall 1961-1990

DrawingNo: CAR001-018
Rev: b.
Created by: CNicol
Date: 10/02/2014.

Scale: 480,000 @ A4
GDA 1994 MGA Zone 56

0 2.5 5 10 15 20 km

HYDRO SIMULATIONS

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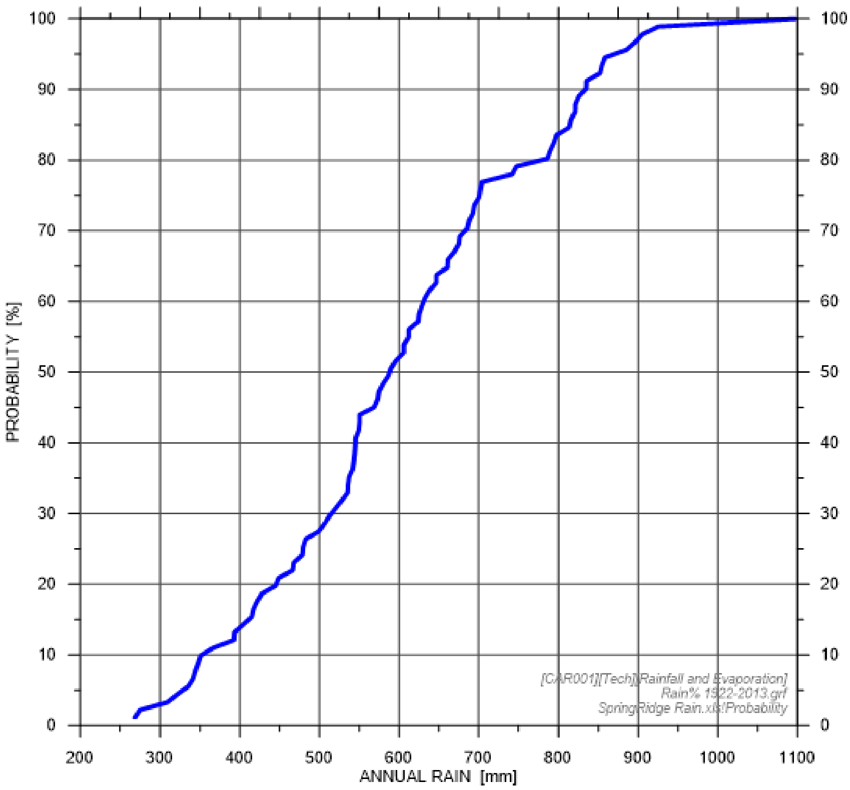
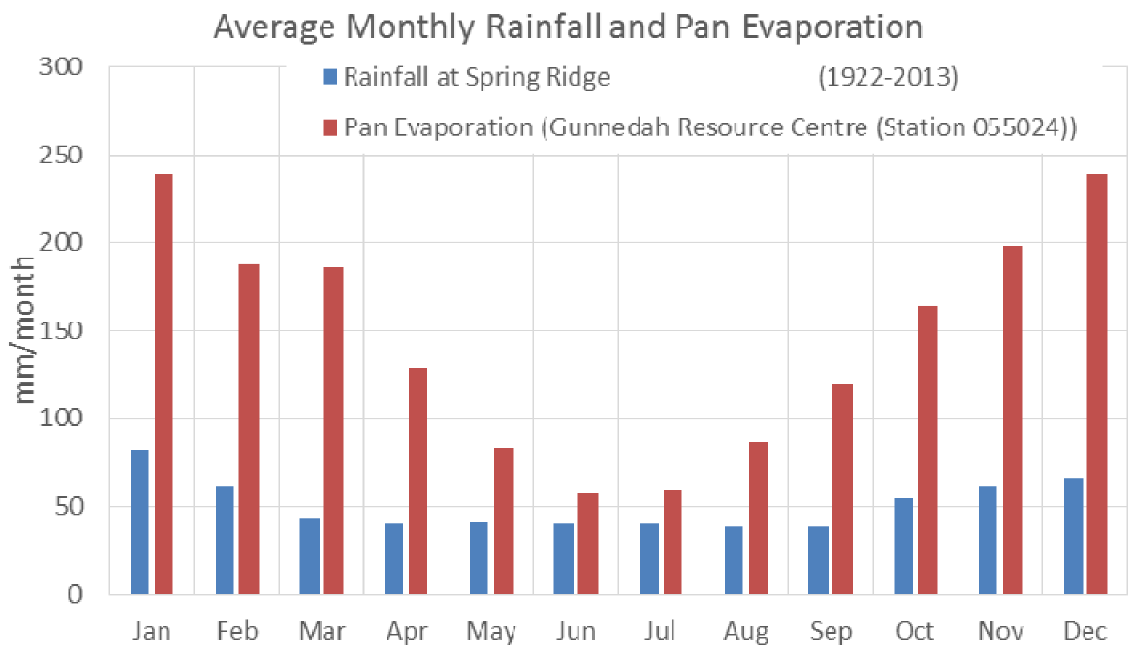


Figure 6 Annual Rainfall Cumulative Distribution Function for Station 055039 at Spring Ridge from 1922 to 2013



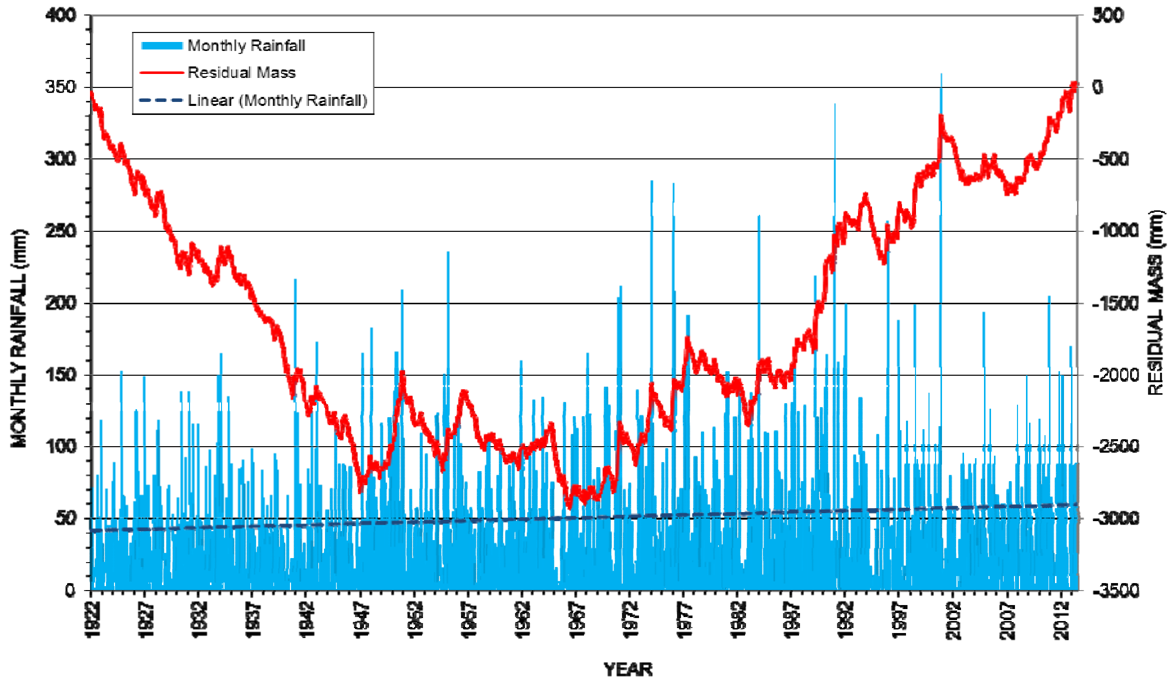
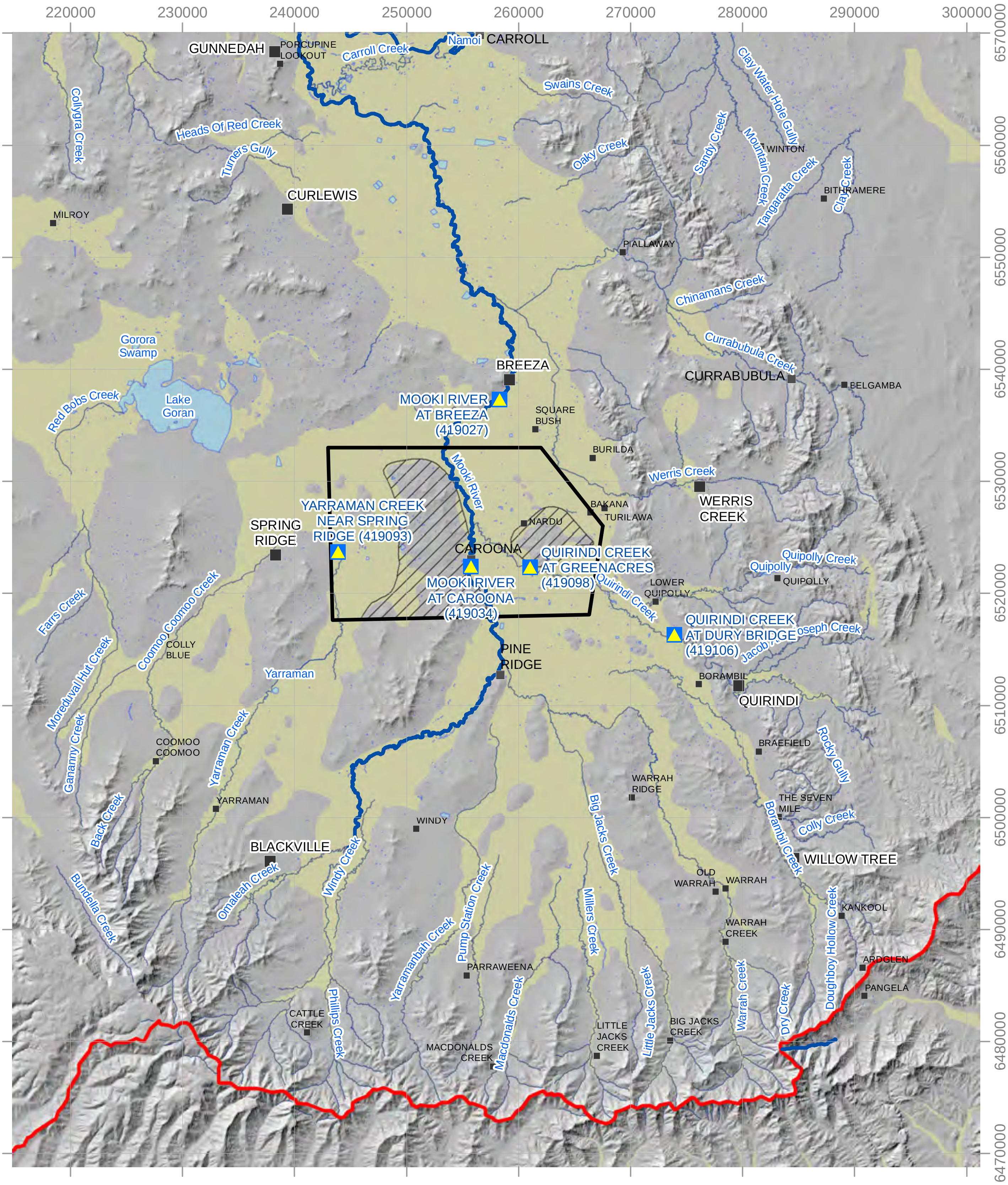


Figure 7 Climate Summary



Legend

▲	Surface Water Gauge		Waterbody
■	Town		Murray Darling Basin boundary
■	Village		Exploration Licence
■	Locality		Targeted Exploration Area
	River		Alluvials
	Creek		

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Figure 8

Stream Gauging Stations

DrawingNo: CAR001-012
Rev: B.
Created by: CNicol
Date: 10/02/2014.

Scale: 480,000 @ A4
GDA 1994 MGA Zone 56

0 2.5 5 10 15 20 km

HYDROSIMULATIONS

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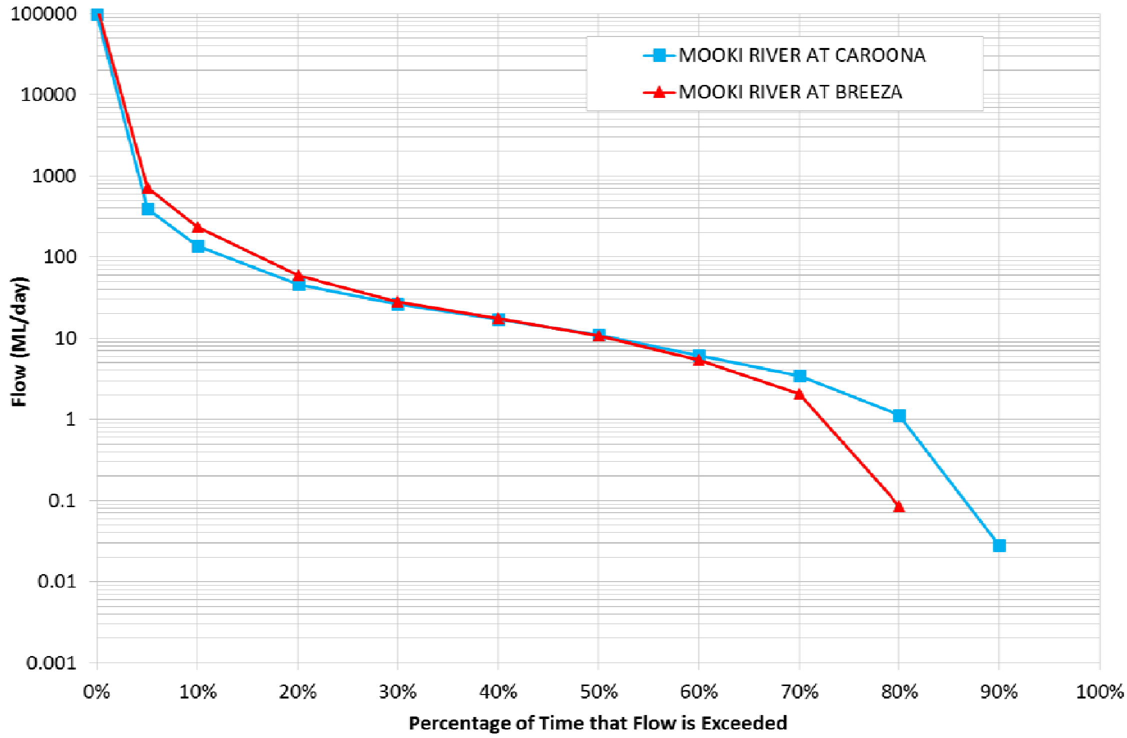
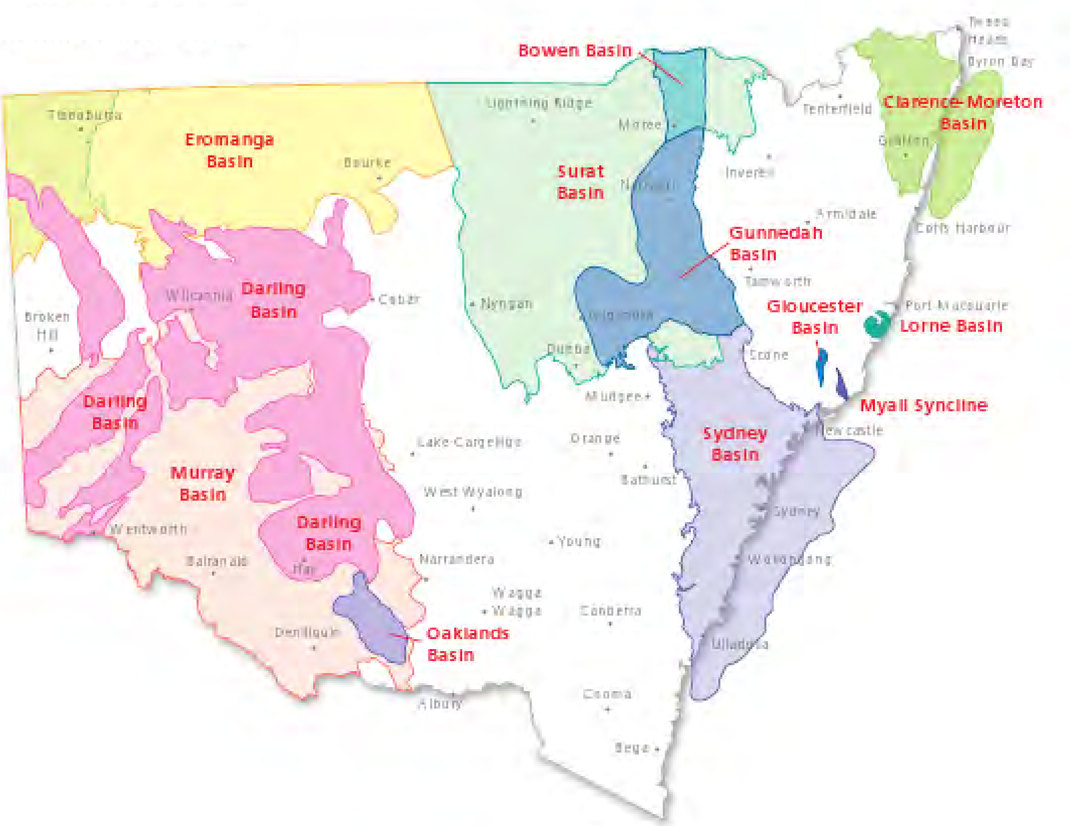


Figure 9 Stream Flow Exceedance Curves for the Mooki River (May 1979-August 2013)



Source: http://atlas.nsw.gov.au/08ba07004524d3c58bf4ff80f0360a0e/Sedimentary%2BBasins.png

Figure 10 Geological Basins of New South Wales

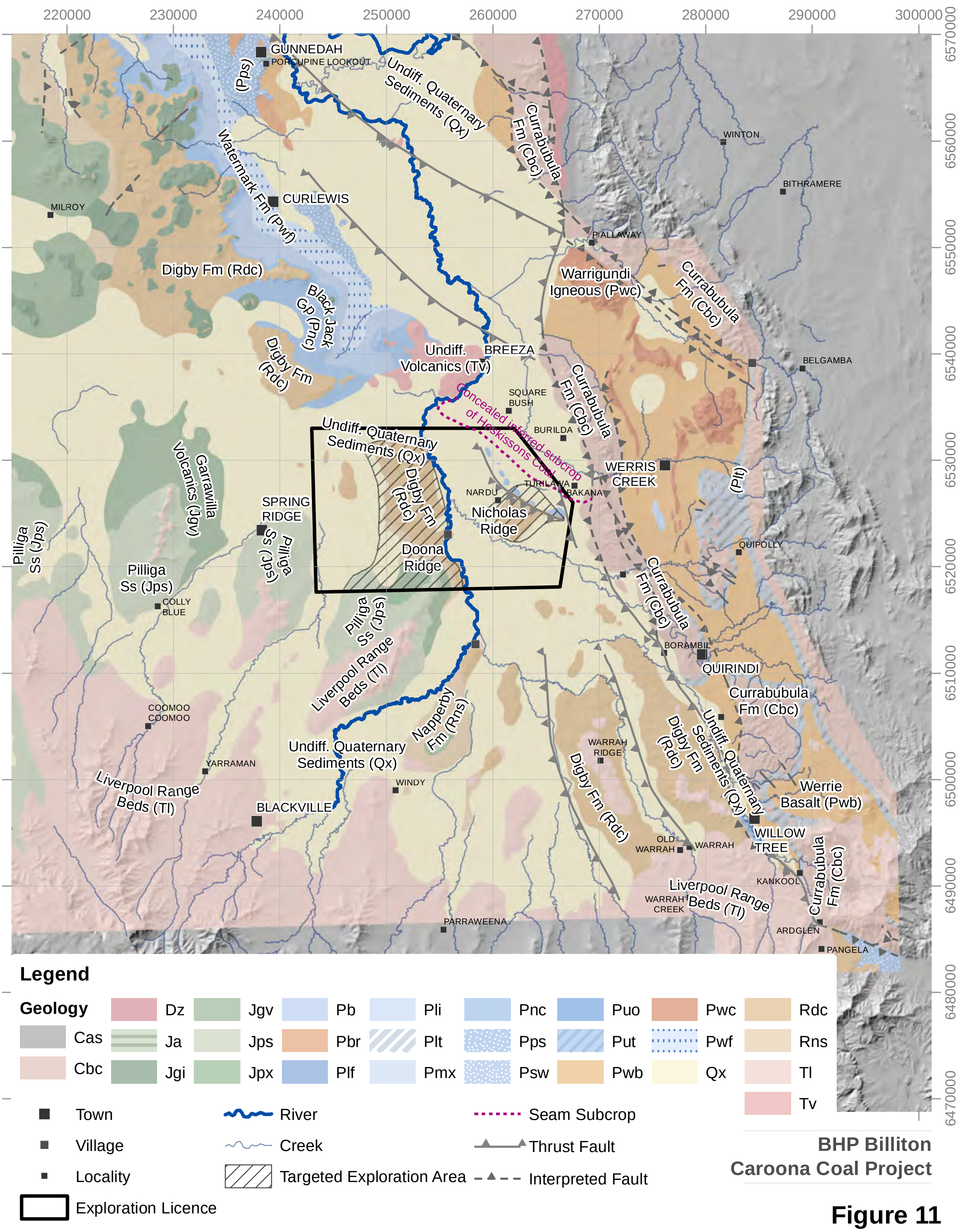


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Figure 11

Geological Outcrop

DrawingNo: CAR001-013
Rev: B.
Created by: CNicol
Date: 13/01/2014.

Scale: 480,000 @ A4
GDA 1994 MGA Zone 56

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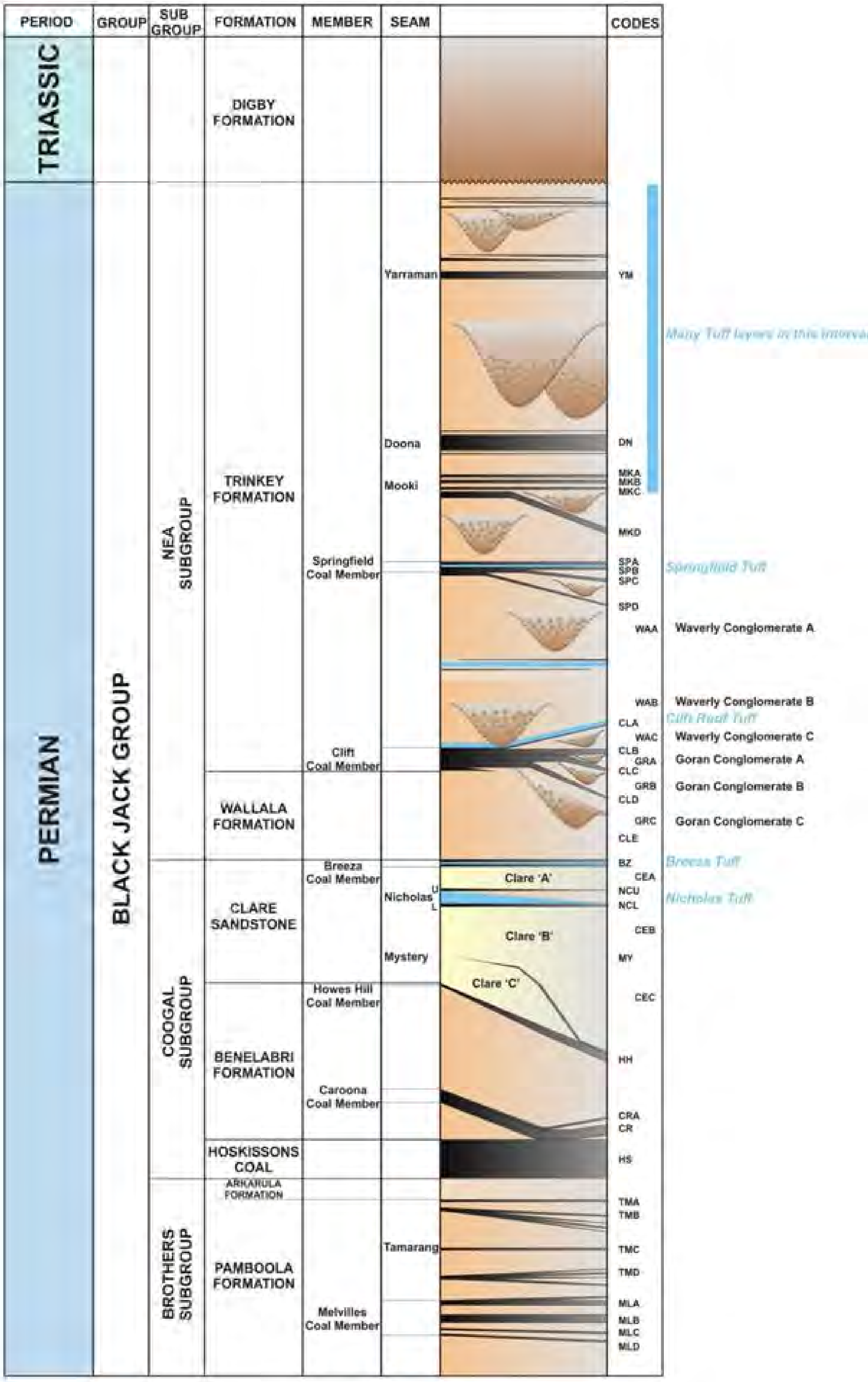
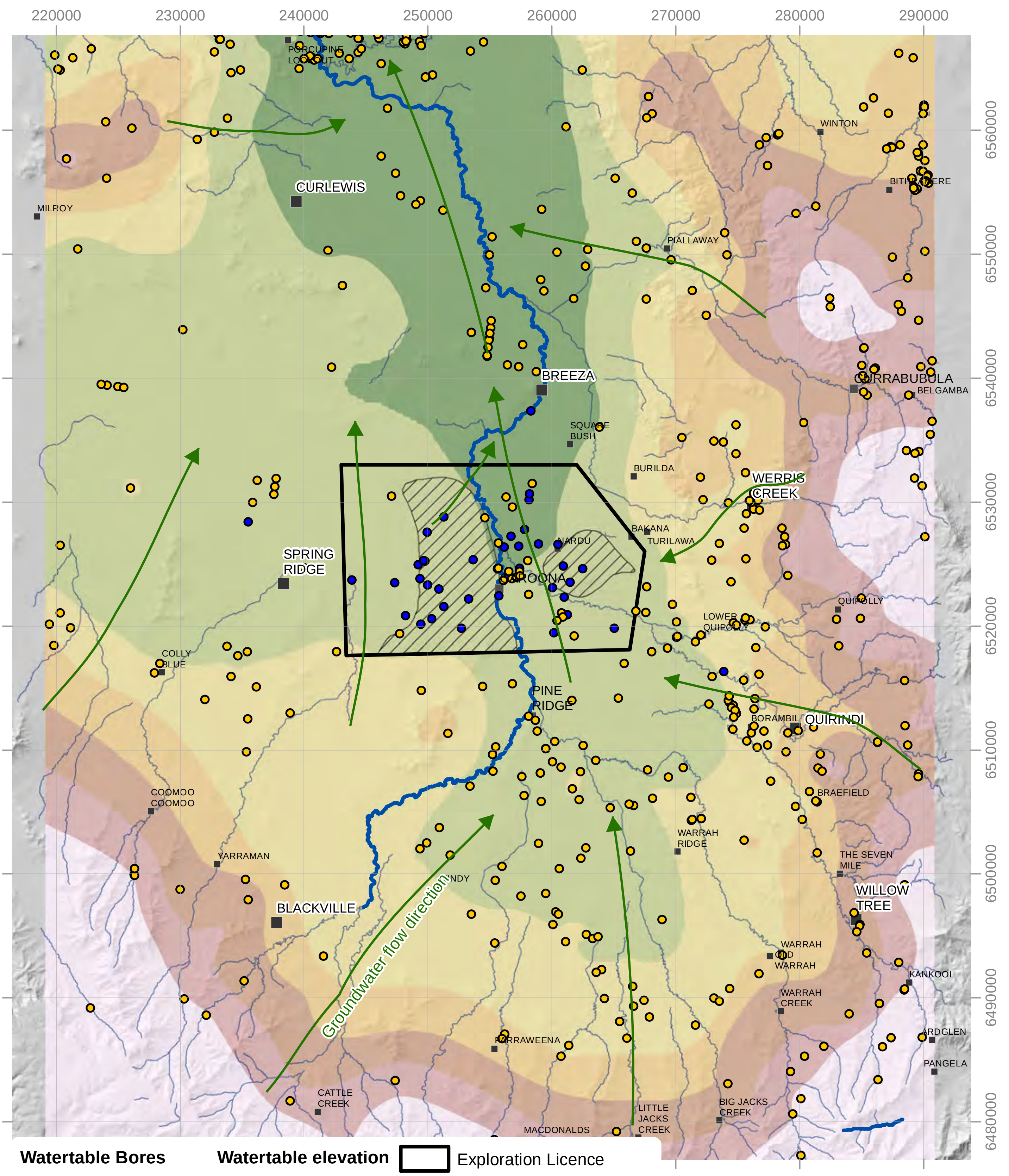


Figure 12 Stratigraphy



Watertable Bores

- Observation Bore
- Time of Drilling
- Town
- Village
- Locality
- River
- Creek

Watertable elevation (mAHD)

- 247.19 - 290
- 290.01 - 330
- 330.01 - 370
- 370.01 - 410
- 410.01 - 450
- 450.01 - 490
- 490.01 - 634.92

- Exploration Licence
- Targeted Exploration Area

BHP Billiton
Caroona Coal Project

Figure 13

Interpolated Watertable Elevation (February 2010)

DrawingNo: CAR001-015
Rev: C.
Created by: CNicol
Date: 10/02/2014.

Scale: 430,000 @ A4
GDA 1994 MGA Zone 56

0 2.25 4.5 9 13.5 18 km

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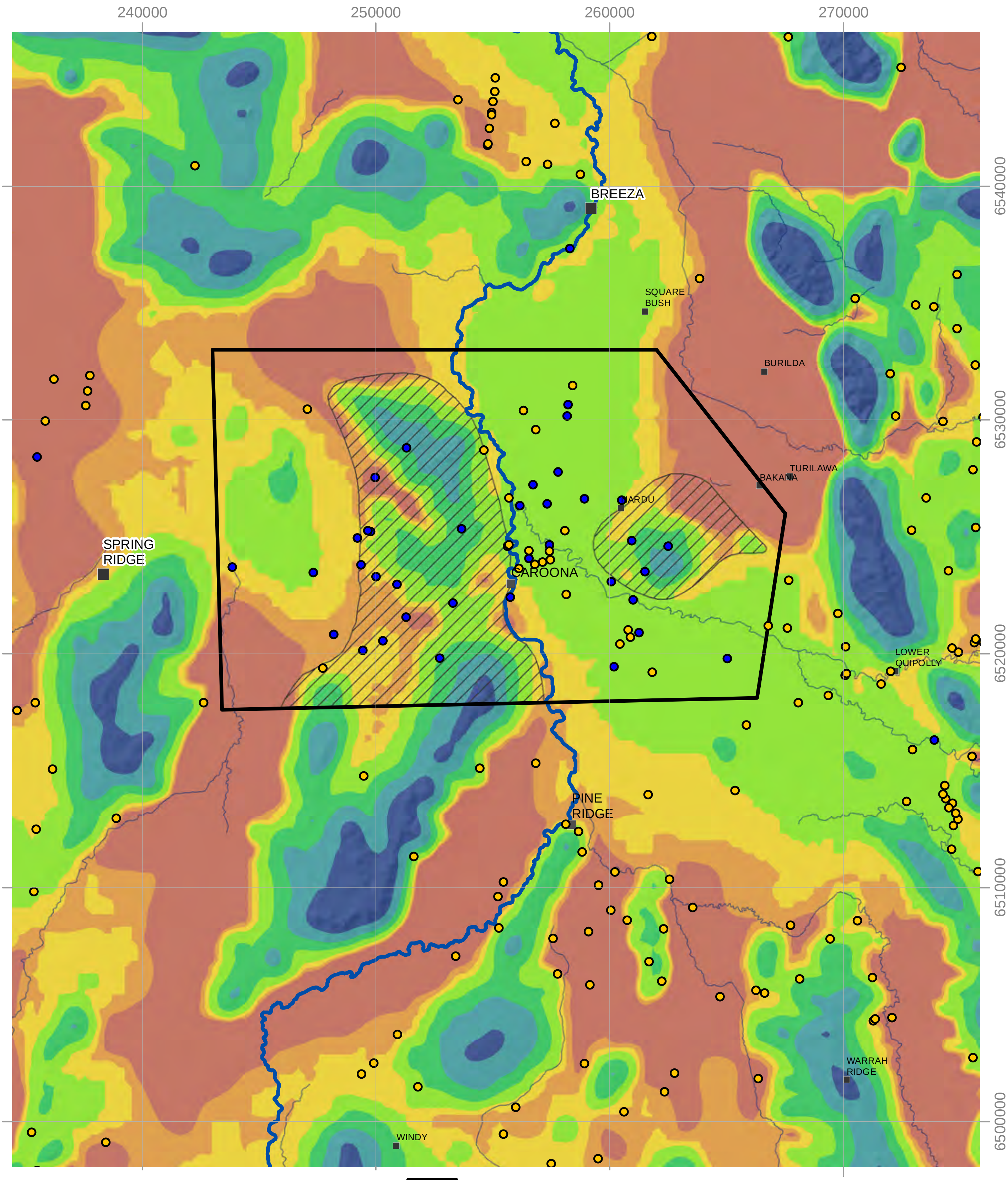

Watertable Bores

- Observation Bore
- Time of Drilling
- Town
- Village
- Locality
- River
- Creek

Watertable Depth (m)

- <=2
- 2.01 - 5
- 5.01 - 10
- 10.01 - 25
- 25.01 - 50
- 50.01 - 100
- >100

Exploration Licence

Targeted Exploration Area

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Caroona Coal Project

Figure 14

Interpolated Watertable Depth (February 2010)

DrawingNo: CAR001-016
Rev: B.
Created by: CNicol
Date: 16/01/2014.

Scale: 230,000 @A4
GDA 1994 MGA Zone 56

0 1.25 2.5 5 7.5 10 km

HYDROSIMULATIONS

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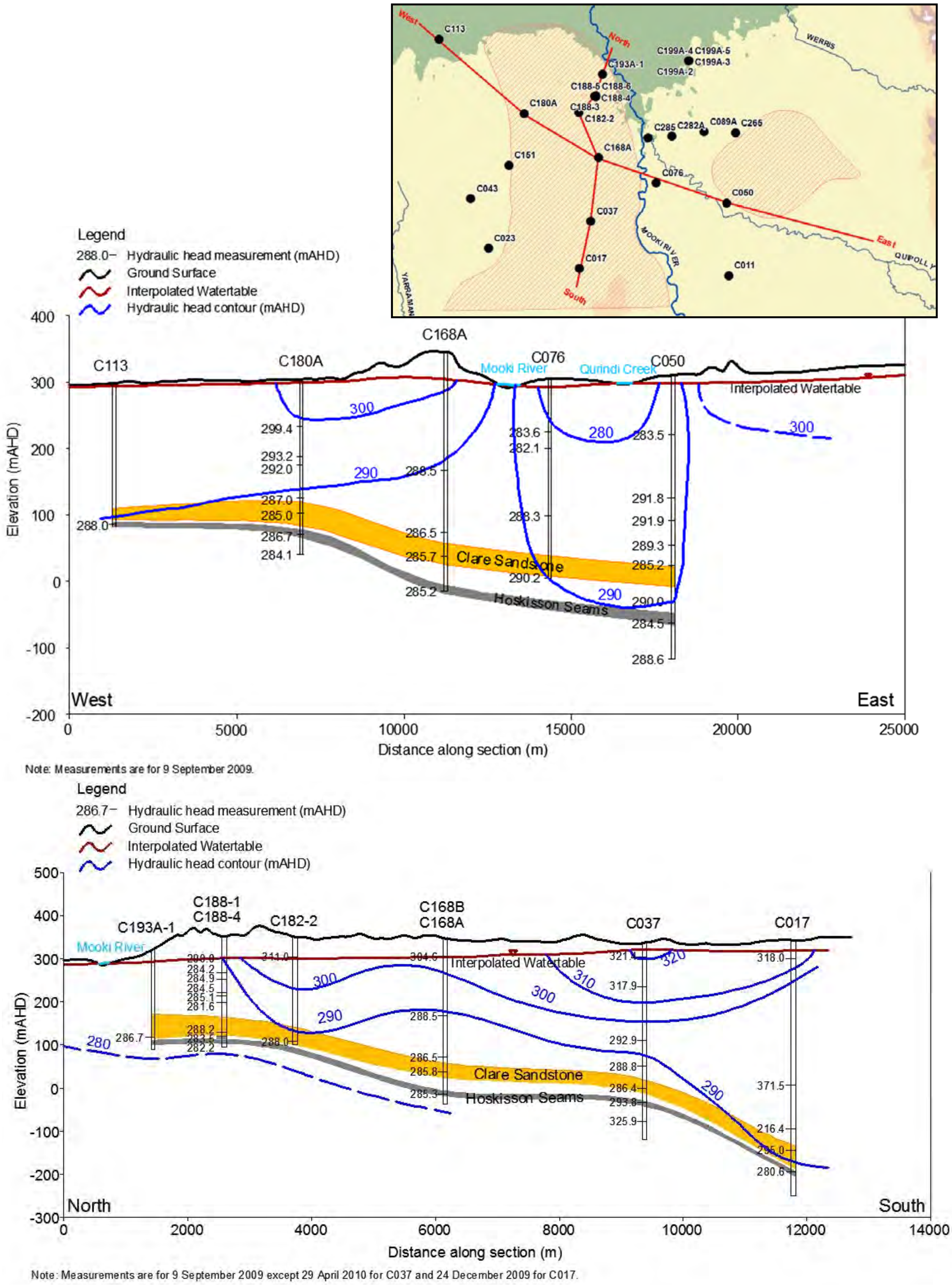
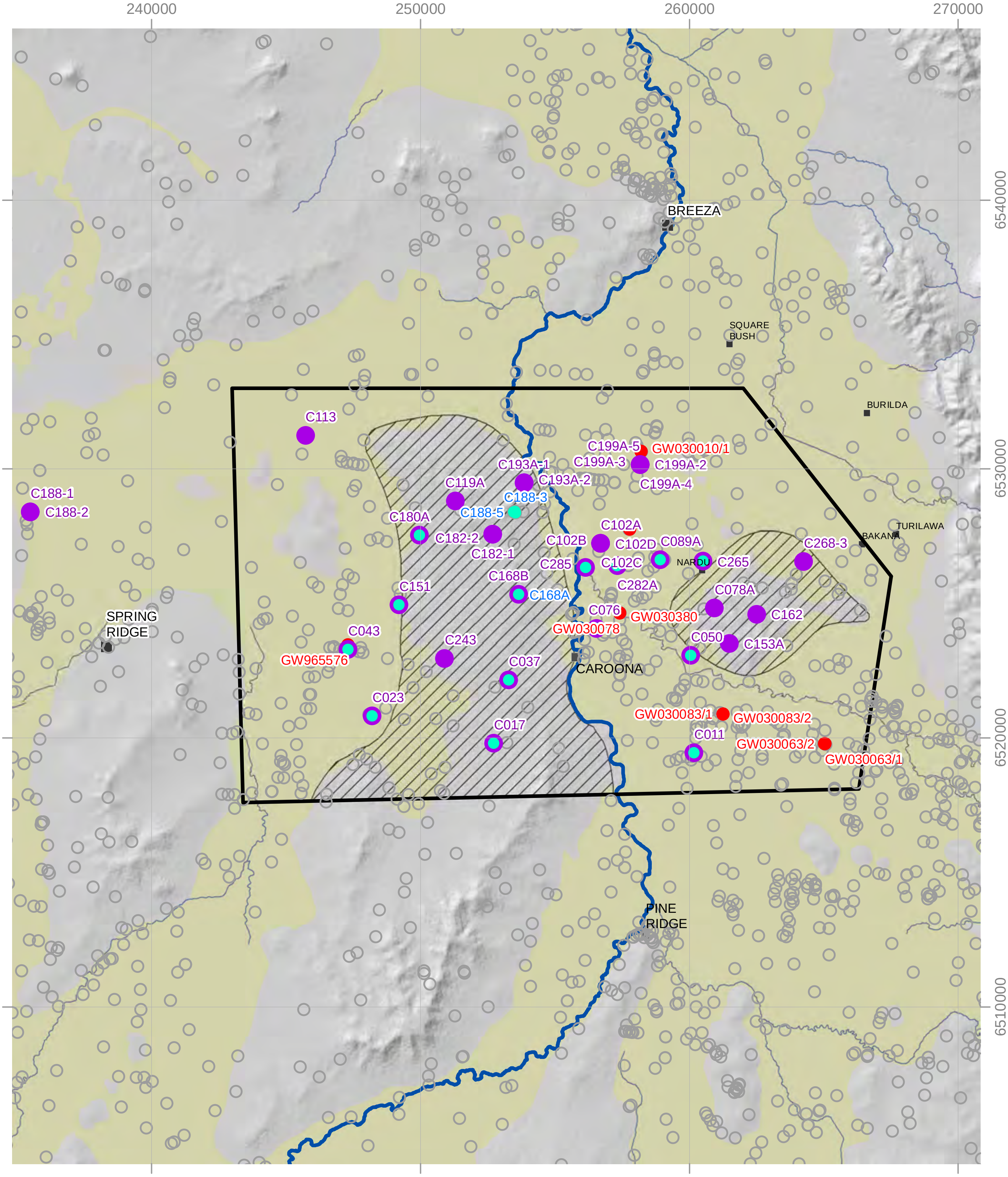


Figure 15 Potentiometric Head Cross-Sections for September 2009



Legend

■	Town	●	DWE Monitoring Bores	▭	Exploration Licence
■	Village	●	Vibrating Wire Piezometers	▨	Targeted Exploration Area
▪	Locality	●	Standpipe Piezometer Bores	▭	Alluvials
〰	River	○	NOW Registered Bores		
～	Creek				

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Caroona Coal Project

Figure 16

Existing Groundwater Monitoring Bores

DrawingNo: CAR001-014
Rev: C.
Created by: CNicol
Date: 13/02/2014.

Scale: 200,000 @A4
GDA 1994 MGA Zone 56

0 1 2 4 6 8 km

HydroSimulations

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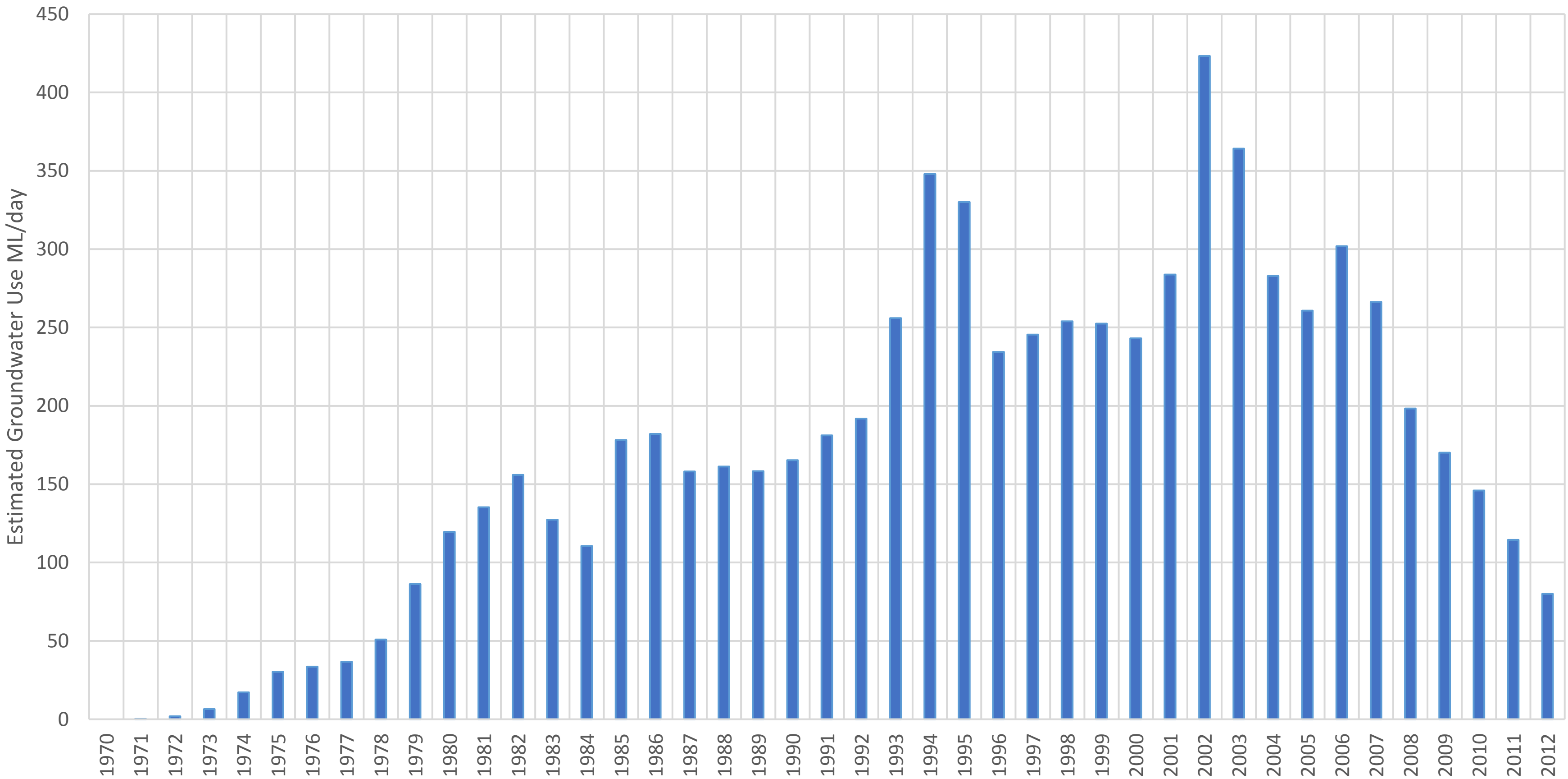


Source: NOW Upper Namoi groundwater flow model (C. McNeilage, pers. comm. 2013).

Figure 17 Estimated Historical Alluvial Groundwater Use

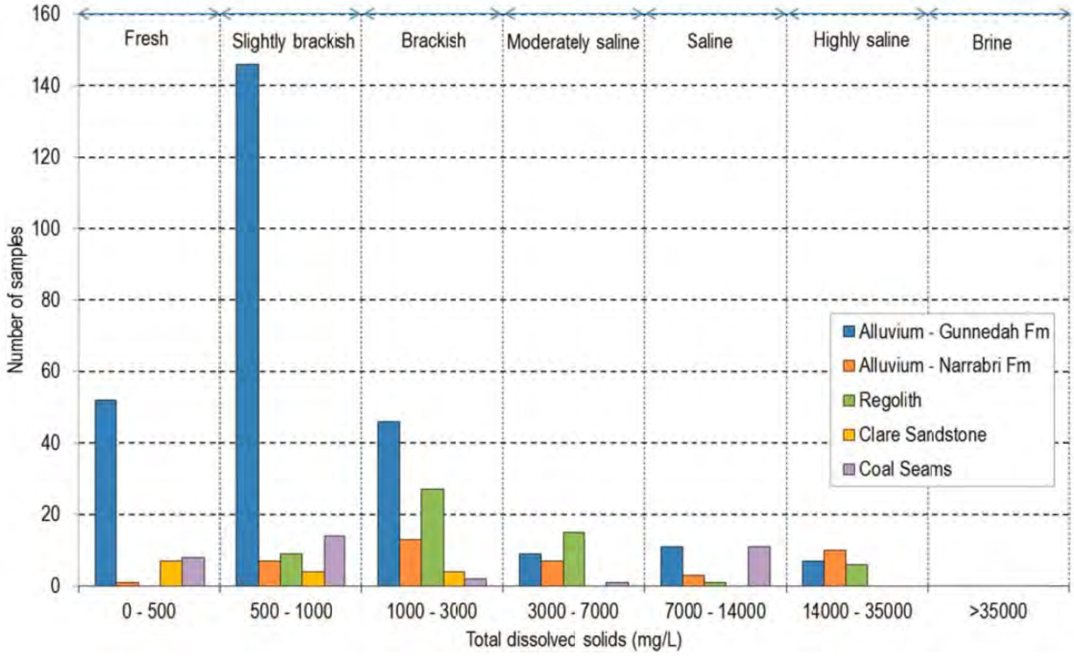
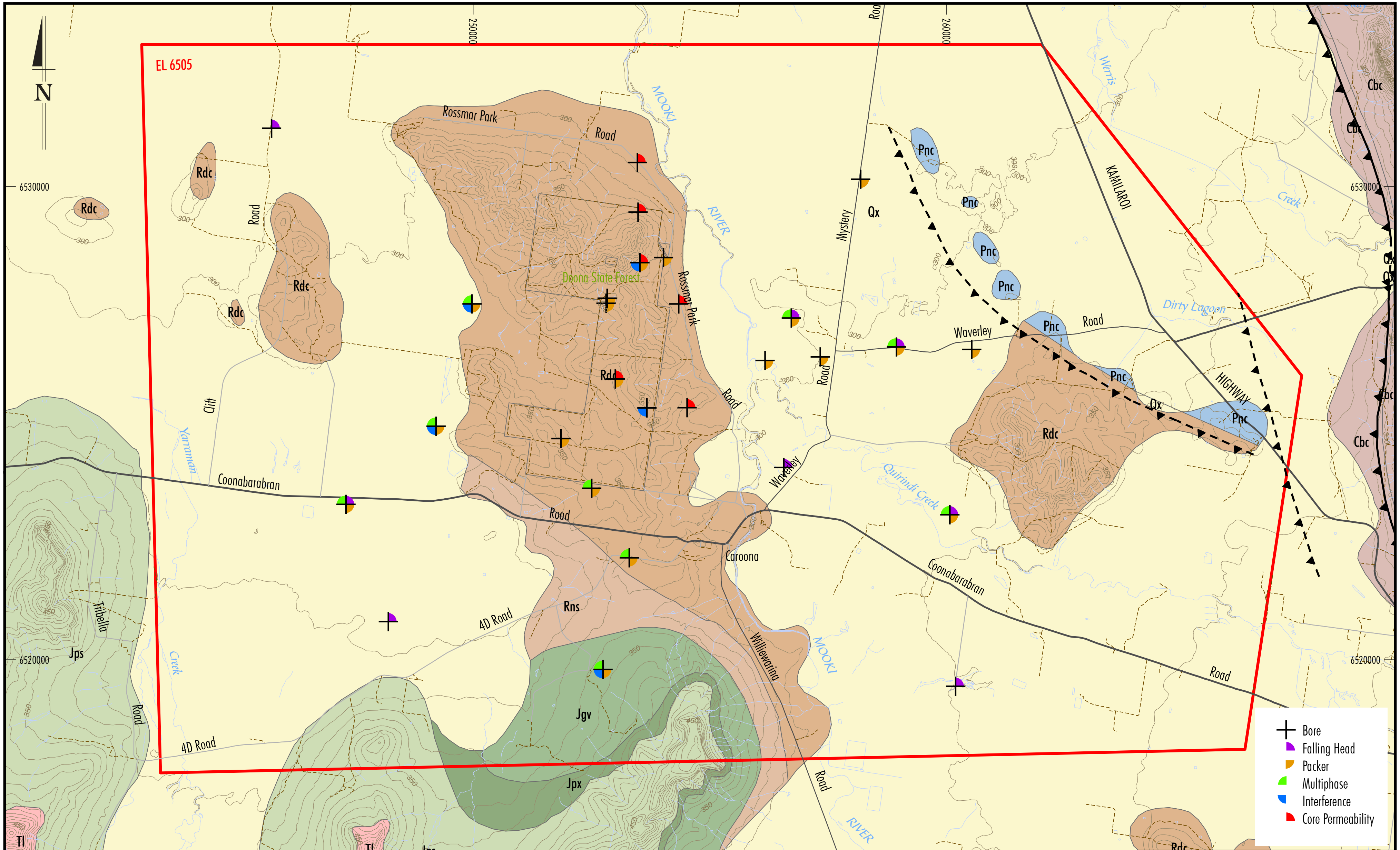


Figure 18 Regional Groundwater TDS Data Summary (from AGE, 2013)



0 1 2 3 4

Kilometers

GDA 94 MGA Zone 56

Source: Land and Property Management Authority (2010); NSW Department of Primary Industries - Gunnedah Coalfield South (2013); and AGE (2013)

LEGEND

- Exploration Licence (EL 6505)
- Thrust
- Fault

Qx	Undifferentiated sediments
Tl	Liverpool Range beds
Jps	Pilliga Sandstone
Jpx	Purlawaugh Formation
Jpv	Garrawilla Volcanics
Rns	Napperby Formation
Rdc	Digby Formation
Cbc	Currabubula Formation
Pnc	Nea/Coogal Subgroup Trinkey Formation, Wallala Formation, Clare Sandstone, Benalabri Formation, Hoskissons Coal

CAROONA COAL PROJECT

FIGURE 19

Monitoring sites with permeability test method

bhpbilliton resourcing the future

HVE-13-02_Gateway_GWA_201B

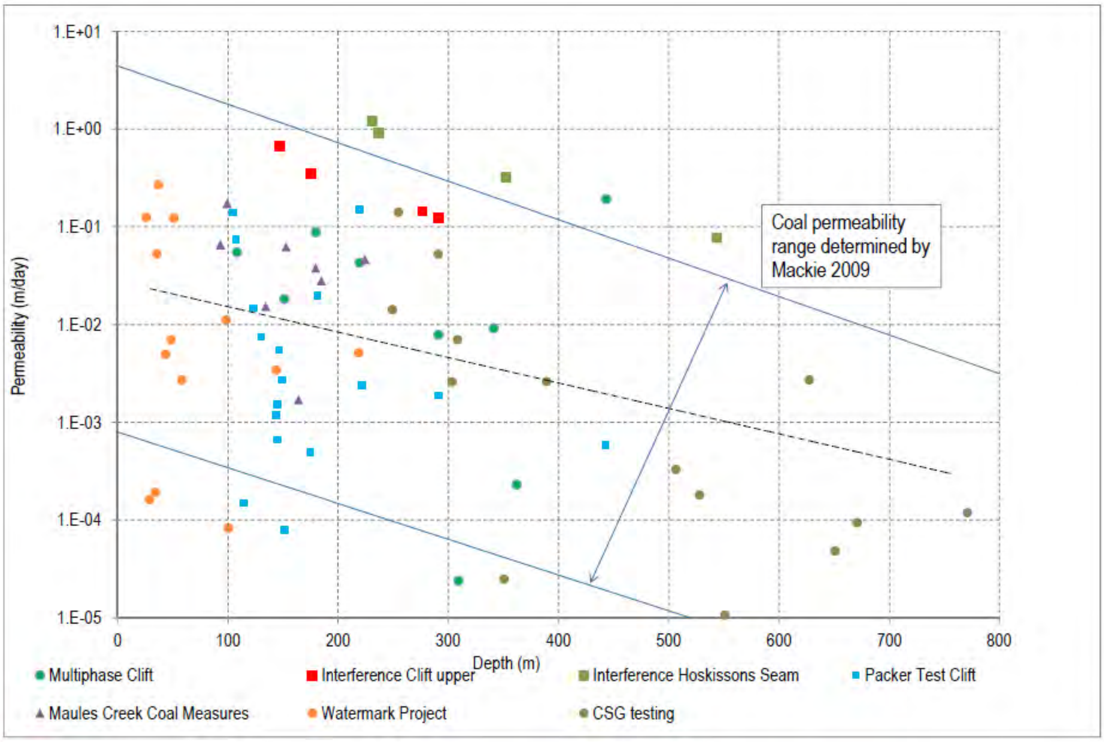
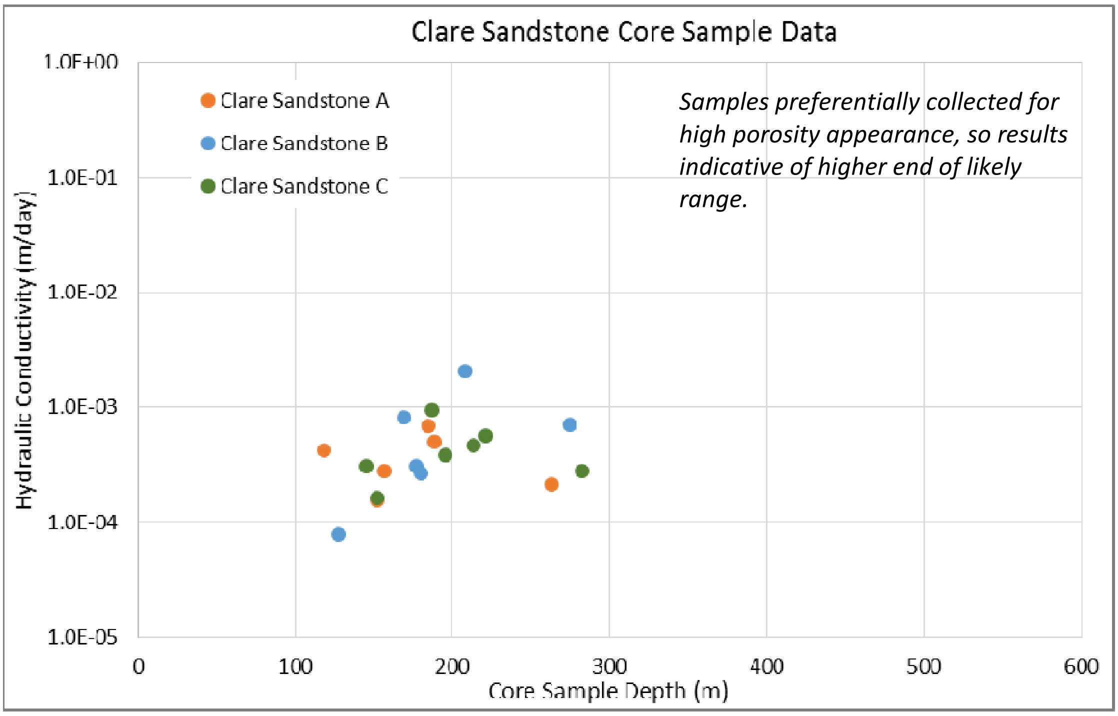


Figure 20 Coal seam hydraulic conductivity (from AGE, 2013)



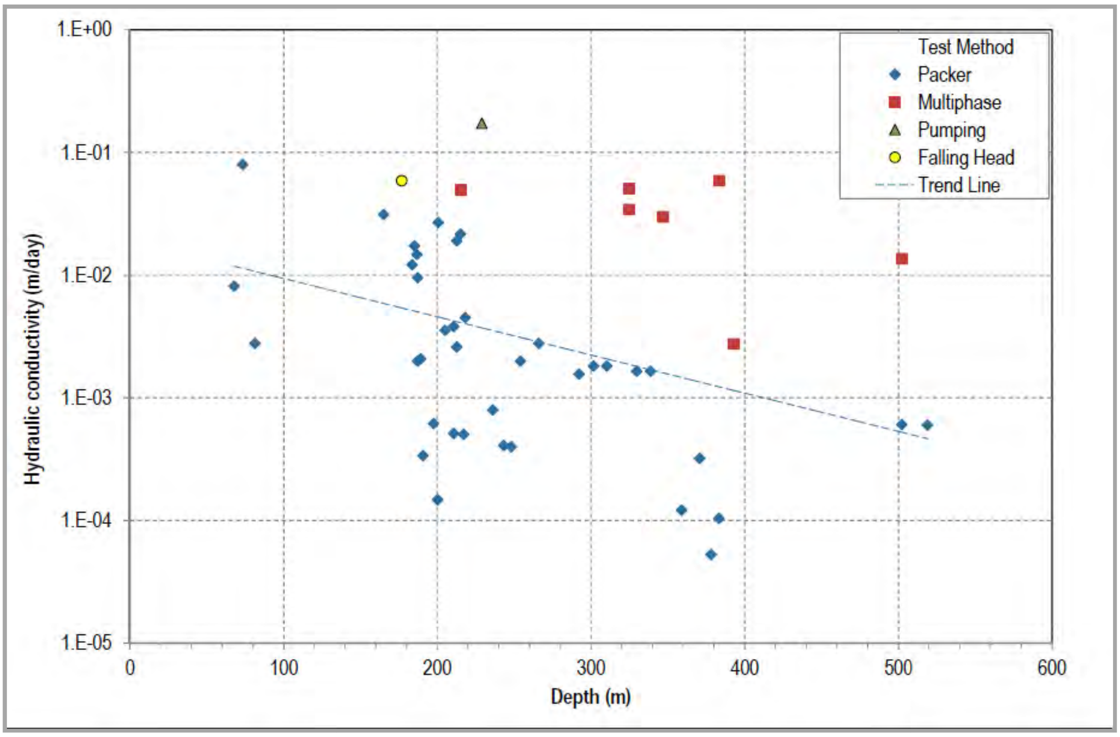
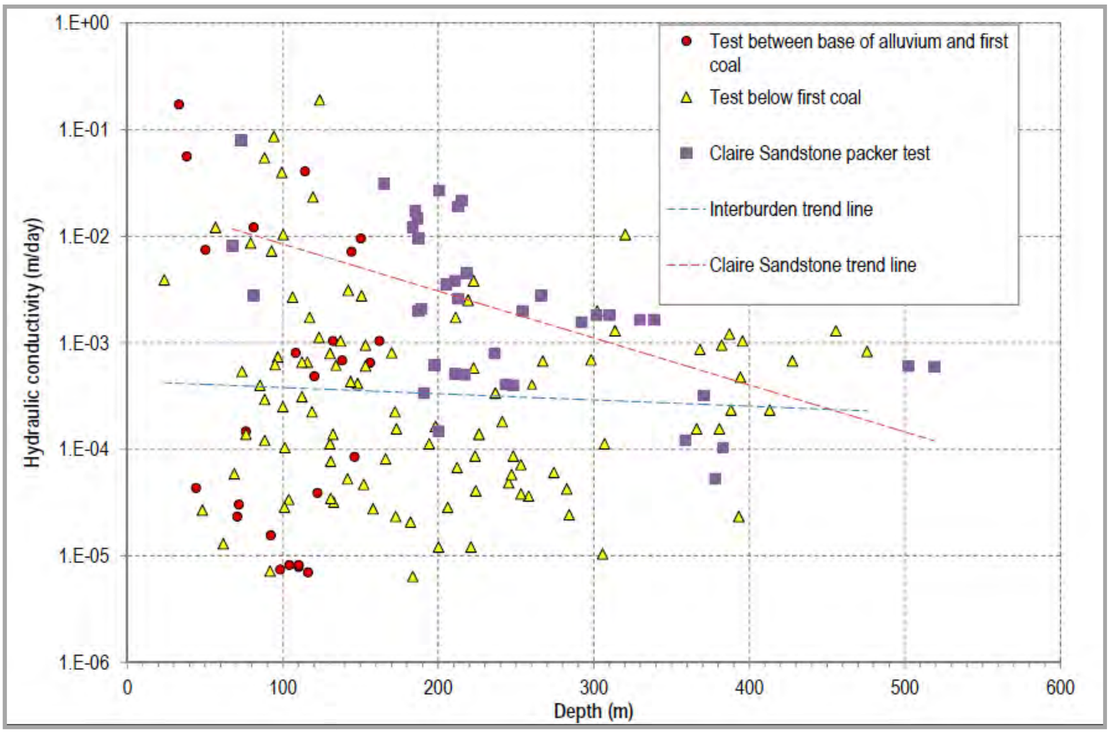


Figure 21 Summary of Clare Sandstone hydraulic conductivity (from AGE, 2013 and SCT, 2012)



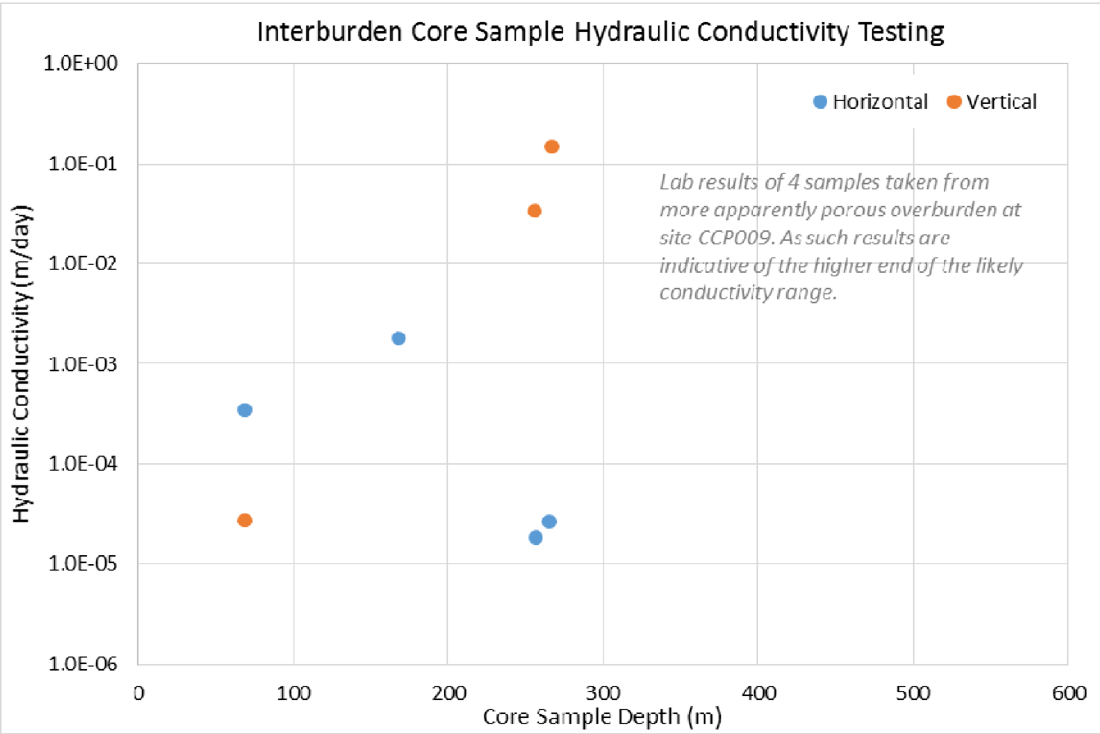
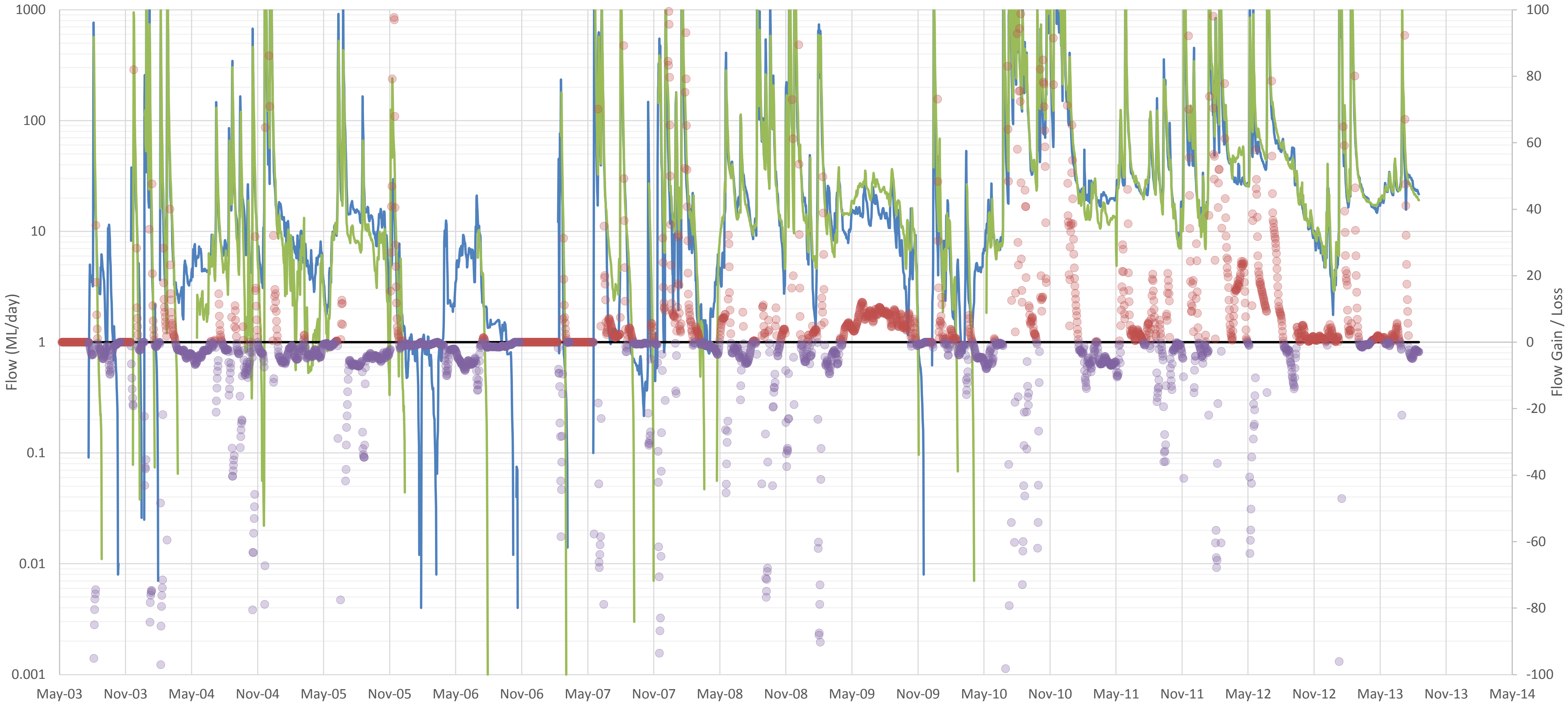
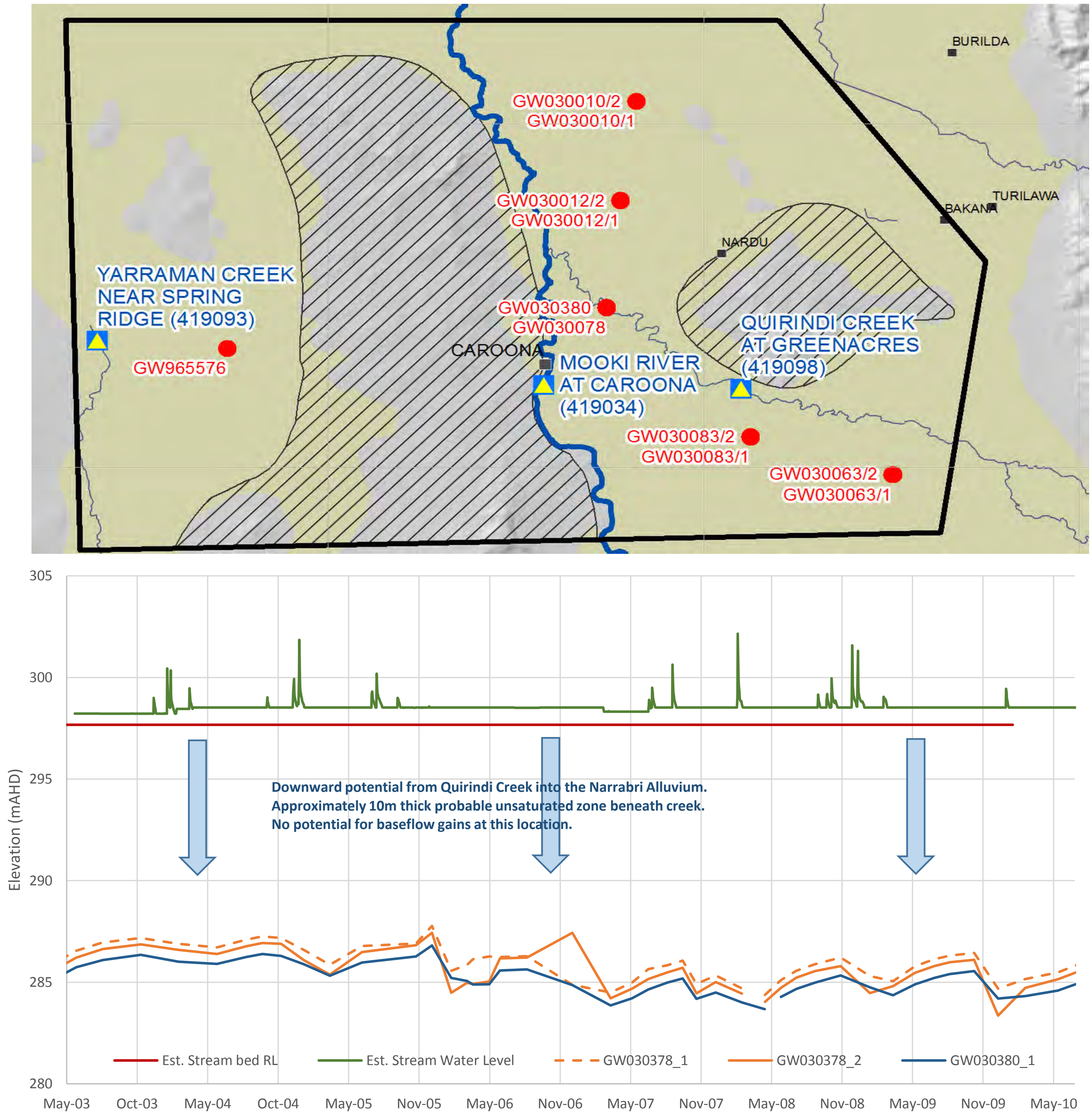


Figure 22 Summary of Interburden hydraulic conductivity (from AGE, 2013 and SCT, 2012)



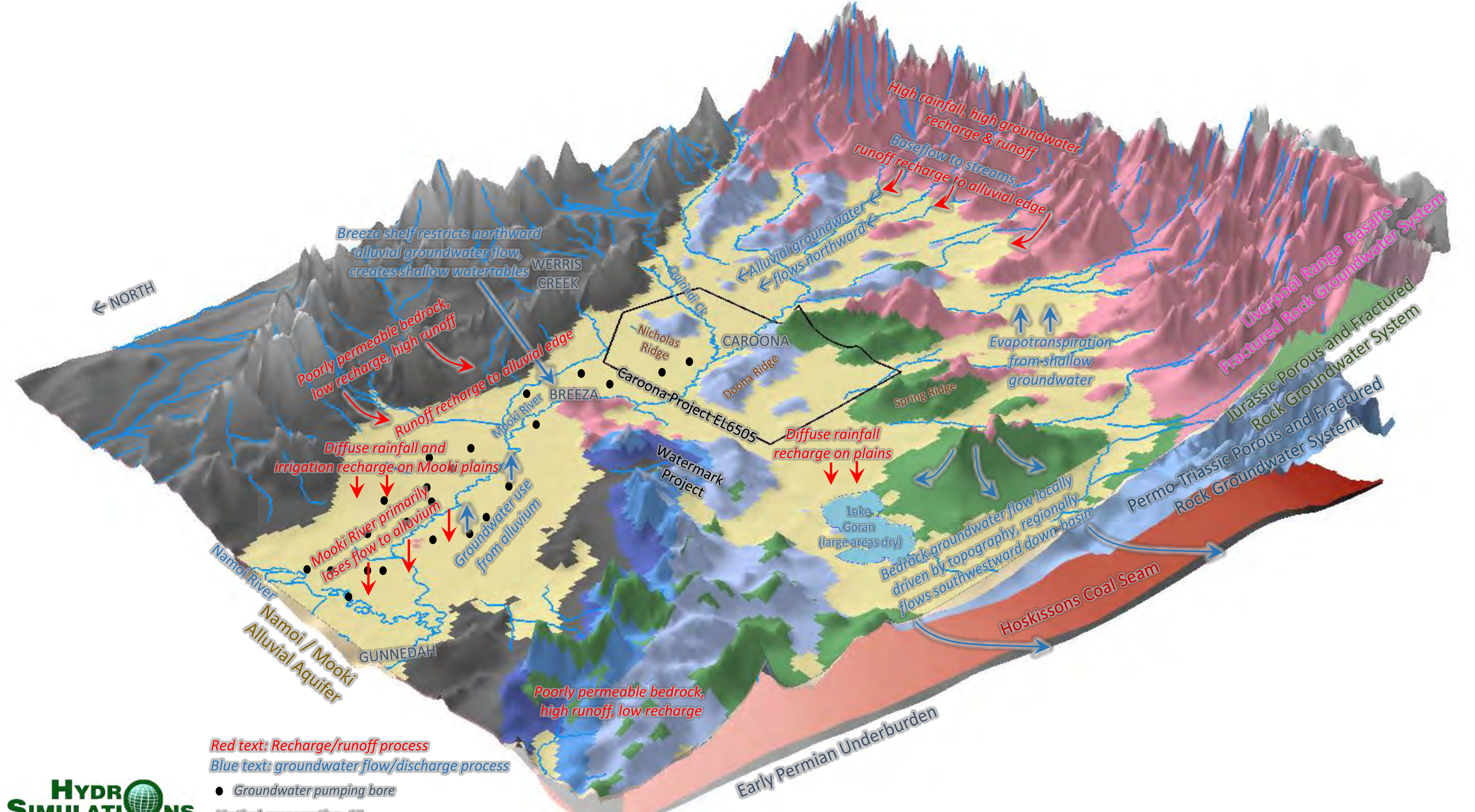
	Average	Median
Flow gain:	*37.7*	*4.4*
Flow loss:	*-43.8*	*-3.6*
Gain/loss:	*-7.3*	*-0.5*

Figure 23 Mooki River Flow Gains and Losses between Caroona and Breeza



HYDRO SIMULATIONS

Figure 24 Groundwater Surface Water Interaction at Lower Quirindi Creek



Source: D:\HydroSim\CAR001\WP\Figures_Rev3\Figure 22 Conceptual model.pptx

Figure 25 Conceptual Hydrogeological Model