Tarrawonga Coal Project

Environmental Assessment

APPENDIX A

GROUNDWATER ASSESSMENT

Resource Strategies

Tarrawonga Coal Pty Ltd

HERITAGE COMPUTING REPORT

APPENDIX A

GROUNDWATER ASSESSMENT

A HYDROGEOLOGICAL ASSESSMENT IN SUPPORT OF THE TARRAWONGA COAL PROJECT ENVIRONMENTAL ASSESSMENT

FOR

TARRAWONGA COAL PTY LTD

By

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Heritage Computing Pty Ltd

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A1 INTRODUCTION

This report has been prepared for Tarrawonga Coal Pty Ltd (TCPL) which is a joint venture between Whitehaven Coal Mining Pty Ltd (Whitehaven) (70% interest) and Boggabri Coal Pty Limited (BCPL) (a wholly owned subsidiary of Idemitsu Australia Resources Pty Ltd) (30% interest). TCPL owns and operates the existing mining operations at the Tarrawonga Coal Mine. The Tarrawonga Coal Mine is an open cut mining operation located within Mining Lease (ML) 1579, approximately 15 kilometres (km) north-east of Boggabri and 42 km north-northwest of Gunnedah in New South Wales (NSW) (**Figure A-1**). The Tarrawonga Coal Mine commenced operations in 2006 and currently produces up to approximately 2 million tonnes per annum (Mtpa) run-of-mine (ROM) coal.

This report provides a groundwater assessment of the proposed Tarrawonga Coal Project (the Project). The proposed life of the Project is 17 years, commencing 1 January 2013.

The approximate extent of the existing and approved surface development (including open cut, mine waste rock emplacement, soil stockpiles and infrastructure areas) at the Tarrawonga Coal Mine are shown on **Figure A-2**. The approximate extent of the Project surface development (incorporating the existing and approved development) lies within Mining Lease Applications (MLAs) 1, 2 and 3 as well as within existing ML 1579 and Coal Lease (CL) 368, and is also shown on **Figure A-2**. Exploration Licence (EL) 7435 is not part of the proposed development.

A description of the Project is provided in Section 2 in the Main Report of the Environmental Assessment (EA).

A1.1 SCOPE OF WORK

The key tasks for this assessment were:

- Characterisation of the existing groundwater regime including identification of groundwater users (including a bore census in consultation with local landholders) and potential groundwater dependent ecosystems in consultation with other relevant specialists.
- Collation and review of baseline groundwater data including:
  - existing TCPL exploration programme (i.e. geological) data;
  - results of searches of NSW Office of Water (NOW) Pinneena database including registered bores and continuous monitoring data;
  - existing water management records at the Tarrawonga Coal Mine and surrounding operations (past and present) including the neighbouring Boggabri Coal Mine;
  - groundwater monitoring data from monitoring programs and investigations undertaken by TCPL at the Tarrawonga Coal Mine, surrounding operations (past and present) including the neighbouring Boggabri Coal Mine and Canyon, Vickery and Rocglen Coal Mines, and proposed future projects (i.e. Maules Creek Coal Project);

- groundwater quality data from the above monitoring programs and investigations; and
- other additional geological and regional mapping data available.

- Development and refinement of a conceptual groundwater model as a basis for development and calibration of a numerical groundwater model to predict potential impacts of future mine development on the existing groundwater regime.

- Preparation of a Groundwater Assessment report for inclusion in the EA that includes the following:
  - assessment of potential mine groundwater impacts (e.g. pit inflows, depressurisation/drawdown, groundwater quality and recharge mechanisms), including assessment of mining scenarios and cumulative impacts with other existing and proposed/approved surrounding mines in the area;
  - assessment of post-mining groundwater impacts (e.g. recovery of groundwater levels and groundwater quality); and
  - assessment of any potential groundwater impacts associated with other Project-related infrastructure.

- Development of measures to avoid, minimise, mitigate and/or offset (if necessary) potential impacts on groundwater resources and provide recommendations for future groundwater monitoring for the purposes of model validation and to measure actual impacts on groundwater resources, as the mine develops.

In accordance with the NSW Department of Planning and Infrastructure (DP&I) Director-General's Environmental Assessment Requirements (EARs) for the Project, this assessment has been prepared in consideration of the following groundwater-related technical policies, guidelines and plans:

- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (Agriculture and Resource Management Council of Australia and Australian and New Zealand Environment and Conservation Council [ARMCANZ/ANZECC]);
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC]);
- NSW State Groundwater Quality Protection Policy (DLWC);
- NSW State Groundwater Quantity Management Policy (DLWC) Draft;
- NSW Groundwater Dependent Ecosystem Policy (DLWC);
- Upper and Lower Namoi Groundwater Water Sharing Plan (NSW Department of Water and Energy [DWE] [now NOW]) (herein referred as the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003)*;
- Murray-Darling Basin Groundwater Quality. Sampling Guidelines. Technical Report No 3 (Murray-Darling Basin Commission [MDBC]);
- MDBC. Groundwater Flow Modelling Guideline (Aquaterra Consulting Pty Ltd); and
- Draft Guidelines for the Assessment & Management of Groundwater Contamination (NSW Department of Environment and Climate Change [DECC]).

The specific EARs of relevance to water resources (including groundwater components) are:

> "***Water*** *– including:*
> - *detailed modelling of the potential surface and ground water impacts of the project, including any flooding impacts;*
> - *a detailed site water balance of the project, including description of the measures that would be implemented to minimise water use on site;*
> - *a detailed assessment of the potential impacts of the project on:*
>   - *the quality and quantity of surface and ground water resources;*
>   - *water users, including the availability of water for agricultural uses within the broader region;*
>   - *the riparian, ecological, geomorphological and hydrological values of watercourses both on the site and downstream of the project; and*
>   - *environmental flows;*"

The surface water components of the assessment are provided separately in the Surface Water Assessment (Gilbert & Associates, 2011) (Appendix B of the EA).

This assessment has also been prepared cognisant of the Namoi Catchment Management Authority's *Extractive Industries Policy* (2009) and the *Namoi Catchment Action Plan* (CAP) (2007). The relevant components are discussed further in Section 6 of the Main Report of the EA.

During the preparation of the EA, an Environmental Risk Assessment was also undertaken in accordance with the EARs by SP Solutions (Appendix O of the EA). This included a facilitated, risk-based workshop involving experts across a range of disciplines and experienced TCPL personnel. The objective of the risk assessment was to identify key potential environmental issues for further assessment in the EA. The following key potential groundwater-related issues were identified and have been further assessed in this report:

- Potential impacts on alluvial groundwater.
- Final void and associated surface and groundwater management.

A1.2 PROPOSED MINE DEVELOPMENT

The main activities associated with the development of the Project would include (**Figure A-2**):

- continued development of mining operations in the Maules Creek Formation to facilitate a Project ROM coal production rate of up to 3 Mtpa, including open cut extensions:
  - to the east within ML 1579 and MLA 2; and
  - to the north within CL 368 (MLA 3) which adjoins ML 1579;
- ongoing exploration activities;

- construction and use of a services corridor (including haul road link) directly from the Project open cut mining operation to the upgraded Boggabri Coal Mine Infrastructure Facilities[1];
- use of upgraded Boggabri Coal Mine Infrastructure Facilities for the handling and processing of Project coal and the loading of Project product coal to trains for transport on the Boggabri Coal Mine private rail spur to the Werris Creek Mungindi Railway[1];
- construction and use of a new mine facilities area including relocation of existing mine facilities infrastructure and service facilities;
- use of an existing on-site mobile crusher for coal crushing and screening of up to 150,000 tonnes (t) of domestic specification coal per annum for direct collection by customers at the mine site;
- use an existing on-site mobile crusher to produce up to approximately 90,000 cubic metres (m^3) of gravel materials per annum for direct collection by customers at the mine site;
- progressive backfilling of the mine void behind the advancing open cut mining operation with waste rock and minor quantities of coarse reject material;
- continued and expanded placement of waste rock in the Northern Emplacement (including integration with the Boggabri Coal Mine emplacement) and Southern Emplacement, as mining develops;
- progressive development of new haul roads and internal roads, as mining develops;
- realignment of sections of Goonbri Road and construction of new intersections;
- construction of an engineered low permeability barrier to the east and south-east of the open cut to reduce the potential for local drainage of alluvial groundwater into the open cut;
- removal of a section of Goonbri Creek within the Project open cut and the establishment of a permanent Goonbri Creek alignment and associated flood bund to the east and south-east of the open cut;
- progressive development of sediment basins and storage dams, pumps, pipelines and other water management equipment and structures;
- continued development of soil stockpiles, laydown areas and gravel/borrow areas;
- ongoing monitoring and rehabilitation; and
- other associated minor infrastructure, plant, equipment and activities.

The proposed life of the Project is 17 years, commencing 1 January 2013. A description of the Project is provided in Section 2 in the Main Report of the EA.

1 Subject to approvals and upgrades being in place for the transfer of Project ROM coal to the Boggabri Coal Mine Infrastructure Facilities.

A2 HYDROGEOLOGICAL SETTING

A2.1 RAINFALL AND EVAPORATION

The Project area generally experiences a temperate climate. Boggabri Post Office, Boggabri (Retreat) and Turrawan (Wallah), the closest Commonwealth Bureau of Meteorology (BoM) rainfall gauges, have average rainfalls between 581 millimetres (mm) and 591 mm per year, with rainfall decreasing from north-east to south-west across the Project area (**Figure A-1**). The average annual rainfall as predicted by the BoM Data Drill Application[2], located north of the Tarrawonga Coal Mine (**Figure A-1**), is 619 mm. Rainfall and local meteorological data are also available from the on-site meteorological station at the Tarrawonga Coal Mine (since November 2006).

Average potential (pan) evaporation at the Keepit Dam and Gunnedah Resource Centre stations is 1,825 mm and 1,853 mm per year, respectively. The average monthly rainfall and evaporation statistics from these stations is summarised in **Table A-1**.

Table A-1. Average Rainfall and Evaporation Statistics

	Average Monthly Rainfall (mm)				Average Monthly Evaporation (mm) *	
Station Name	**Data Drill Sequence****	**Boggabri Post Office**	**Boggabri (Retreat)**	**Turrawan (Wallah)**	**Keepit Dam**	**Gunnedah Resource Centre**
January	79.4	71.0	71.5	81.1	255.7	248.4
February	67.0	64.4	61.4	61.2	204.5	202.1
March	49.9	45.5	42.2	42.5	182.1	196.4
April	37.0	33.7	35.4	33.4	124.1	138.2
May	44.4	41.8	38.0	41.9	80.6	90.4
June	42.5	43.5	43.7	43.0	56.1	61.7
July	44.2	41.4	42.8	42.3	63.9	64.8
August	39.7	38.1	37.3	34.8	89.2	91.8
September	38.9	38.0	39.9	37.2	129.3	127.4
October	53.2	51.1	50.3	50.9	172.7	174.9
November	58.3	58.5	56.9	57.6	207.7	206.1
December	64.0	64.1	61.7	65.3	259.4	250.5
Annual Average (Total)	**619**	**591**	**581**	**591**	**1,825**	**1,853**

Note:
Source: Gilbert & Associates (2011)
* As measured by Class A Evaporation Pan.
** Data Drill located at 30.6°S, 150.15°E – north of Tarrawonga Coal Mine.

[2] The Data Drill Application is a system which provides continuous, synthetic daily data sets for a specified point by interpolation between surrounding point records held by the BoM.

The actual evapotranspiration (ET) in the district is about 600 mm per annum according to BoM (2009). 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."

Fluctuations in the watertable result from temporal changes in rainfall recharge to aquifers. Typically, changes in the watertable elevation reflect the deviation between the long-term monthly (or yearly) average rainfall, and the actual rainfall, usually described as the Residual Mass Curve (RMC).

The groundwater levels recorded during periods of rising RMC are expected to rise while those recorded during periods of declining RMC are expected to decline. An RMC plot using rainfall data from the Boggabri Post Office since 1884 is shown on **Figure A-3** and a plot using local data recorded at the Tarrawonga Coal Mine since 2006 is shown on **Figure A-4**.

The long-term plot at Boggabri (**Figure A-3**) shows a major dry period from 1909 to 1946 followed by a major wet period from 1949 to 1977. Since then, less emphatic wet and dry cycles of about 7 years duration have occurred. The short-term plot at Tarrawonga (**Figure A-4**) shows a similar pattern to Boggabri for the same time period, although the drier period from 2007 to 2010 is less pronounced near the mine. Conditions during 2010 are the wettest since records commenced at the Tarrawonga Coal Mine Meteorological Station.

A2.2 TOPOGRAPHY AND DRAINAGE

The Tarrawonga Coal Mine is located at the foothills of the Willowtree Range approximately 12 km east of the Namoi River (**Figure A-1**). Goonbri Mountain lies approximately 4 km north-east of ML 1579 and in conjunction with the Willowtree Range form the main topographic features in the north and east (**Figure A-1**).

The main local drainage systems associated with the Project area are Nagero Creek, Goonbri Creek and Bollol Creek (**Figures A-2** and **A-6**). As the creeks descend onto the expansive alluvial flats below the Project area, they transition into relatively poorly defined drainage paths which become expansive ponded overland flow areas during and following heavy rainfall. Where creeks cease to have permanent surface water, it is likely that sub-surface flow continues beneath the drainage lines. The overland flow moves slowly down-gradient (west and south-west) toward the Namoi River itself (Appendix B of the EA).

Surface elevations in the region vary from approximately 260 metres (m) Australian Height Datum (AHD) on the floodplains of Bollol Creek up to approximately 540 m AHD at the peak of Goonbri Mountain (**Figure A-1**).

The regional and local hydrological features are described in detail in Appendix B of the EA.

A2.3 LAND USE

The Tarrawonga Coal Mine is located on the fringe of a rural area characterised by cattle grazing and cereal/fodder cropping in the flatter areas to the south, east and west (Appendix I of the EA). State-owned forestry (Leard State Forest) which is primarily utilised for recreational purposes is located on the northern border of ML 1579, and is the other main land use in the area (**Figure A-2**). With the exception of Leard State Forest, a majority of the land adjacent to the Tarrawonga Coal Mine has been cleared for agricultural purposes.

The Tarrawonga Coal Mine and the Boggabri Coal Mine are the two existing mining operations in the area. Other operating mines in the region include the Narrabri Coal Mine (north-west) and the Rocglen Coal Mine (south-east) (**Figure A-1**).

Whitehaven owns most of the land to which the Project applies and a significant portion of the adjacent lands. The other land owners are Boggabri Coal Pty Ltd and NSW State Forestry.

A2.4 STRATIGRAPHY AND LITHOLOGY

The Tarrawonga Coal Mine is located in the Gunnedah Basin, in the NSW Gunnedah Coalfield, which contains sedimentary rocks, including coal measures, of Permian and Triassic age (**Figure A-5)**. Regionally, there are two coal-bearing sequences in the Gunnedah Basin, namely:

- Early Permian Bellata Group (comprising the Maules Creek sub-basin and Mullaley sub-basin, separated by the Boggabri Ridge); and
- Late Permian Black Jack Group.

The Project coal resource is located within the Maules Creek sub-basin of the Early Permian Bellata Group. The target coal seams within the Maules Creek sub-basin are contained within the Maules Creek Formation. They subcrop on low hills to the west of the Project area and dip towards the east.

Figure A-5 also presents the indicative stratigraphy of the Project area including the target coal seams within the open cut extent, as follows (Minarco-Mineconsult, 2011):

- Braymont;
- Bollol Creek;
- Jeralong;
- Jeralong Lower;
- Merriown;
- Merriown Lower;

- Velyama; and
- Nagero.

Individual coal seams range up to approximately 4.5 m thick, and average 1.5 m. They onlap the Boggabri Ridge to the west of the Project area and thicken towards the east. The coal reserve for the Project, based on the planned maximum production rate, is approximately 50.5 million tonnes (Mt) of ROM coal[3].

Below the Maules Creek Formation are the Goonbri and Leard Formations, which are basal units of the Gunnedah Basin sedimentary sequence and unconformably overlie the Boggabri Volcanics.

The upper and mid slopes of the Project area generally comprise moderate relief, rounded ridges and hills which are composed of Permian-aged Maules Creek Formation (**Figure A-6**). The broad valley and outflow plain areas in the lower slopes and downstream comprise predominantly low lying undifferentiated alluvial sediments (**Figure A-6**). Minor undifferentiated volcanic and igneous rocks of younger age are located in isolated outcrops in the area.

The Quaternary sediments comprise the (upper) Narrabri Formation and the (lower) Gunnedah Formation of the upper Namoi Valley.

A2.5 STRUCTURAL GEOLOGY

There are two major fault structures in the region, namely:

- Boggabri Thrust (to the west of the Project); and
- Mooki Thrust (to the east of the Project).

The Boggabri Thrust is a north-west south-east trending formation which begins approximately 12 km west of the Tarrawonga Coal Mine and continues to the south-east aligned with the Namoi River (**Figures A-7a** to **A-7c**).

The Mooki Thrust is a generally north-south trending formation which lies between the Rocky Creek Formation in the east and the Maules Creek Formation in the west (**Figures A-7a** to **A-7c**). The Mooki Thrust generally delineates the boundary between the 'Gunnedah-Oxley Basin – Namoi' and 'New England Fold Belt MDB – Namoi' Management Zones defined in the ***Draft*** *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* and ***Draft*** *Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011* respectively (Section A2.8).

[3] The total Project ROM coal reserve excludes the estimated coal reserve to be mined prior to 1 January 2013 associated with the continuation of existing/approved operations at the Tarrawonga Coal Mine in accordance with DA 88-4-2005 MOD 1.

There are many minor faults with east-west and north-south alignments, especially between the Tarrawonga and Vickery areas (**Figure A-7a**). As the target coal seams for this Project are truncated either by faulting or erosion, they do not persist to the south or to the east of the Project Area. Coal seam extents are illustrated in Coxhead (2009).

A2.6 ALLUVIAL GEOLOGY

The Project area is bordered by alluvial sediments which are associated with the Bollol Creek, Goonbri Creek and Nagero Creek surface drainages (**Figure A-6**). These sediments are part of the Upper Namoi Alluvium and their groundwaters lie within the Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source, also known as the Upper Namoi Zone 4 water source. The Bollol Creek, Goonbri Creek and Nagero Creek embayments have alluvial thicknesses in the order of 30 m maximum (McNeilage, 2006). On the floodplain between Bollol Creek and Driggle Draggle Creek farther south, the alluvium is generally 40 m to 70 m thick.

Alluvial sediments of the Upper Namoi are usually subdivided into two formations, although they are not always distinguishable. The uppermost Narrabri Formation consists predominantly of clays with minor sand and gravel beds. Underlying the Narrabri Formation is the Gunnedah Formation which consists predominantly of gravel and sand with minor clay beds. This is the productive aquifer used for irrigation to the west of the Tarrawonga Mine site. The higher-elevation alluvial tongues along Nagero Creek, Goonbri Creek and Bollol Creek are not as productive, have poorer water quality, and are suited for stock and domestic use.

More broadly, the Upper Namoi Alluvium can reach maximum thicknesses of 170 m associated with the Namoi River. Separately, the Narrabri Formation has a maximum thickness of 70 m and the Gunnedah Formation peaks at 115 m (McNeilage, 2006).

To better define the geometry and properties of the Goonbri Creek alluvium to the immediate east of the Project area, TCPL installed a transect of nine shallow boreholes (TAWB14-22) and commissioned a transient electromagnetic (TEM) survey (Groundwater Imaging, 2011). The bore transect revealed alluvial thickness from 3 m to 38 m with a median thickness of 26 m. Bore locations are shown in **Figure A-8**.

The TEM survey results are shown in **Figure A-9** in terms of (inverted) true resistivity (ohm.metres) for eight depths ranging from 1 m to 58 m. The white-red tones indicate the most conductive material, either dry weathered rock or alluvium with a high clay content or high salinity. The green-blue tones show more resistive material, due to less weathered rock at depth coupled with lower salinity groundwater.

For depths to 12 m, the survey has revealed clayey near-surface conditions vertically and horizontally, with resistivity generally less than 10 ohm.metres (typical of clay). The central-western part of the survey area is on weathered rock and this has a similar electrical character to alluvium to the east. There is no clear demarcation of the horizontal extent of the alluvium and only weak discrimination of the western rock-alluvium interface.

The Upper Namoi Zone 4 boundary in the vicinity of Goonbri Creek extends beyond the eastern limit of the TEM survey area, except for the north-eastern tip. Vertically, there is a clear change in resistivity character between 28 m and 45 m depth. Groundwater Imaging (2011) concluded that the TEM data at the site [subject to the TEM survey area] presents approximately 30 m of conductive alluvium (probably predominantly clay bound gravel) overlying more resistive rock.

Higher resistivities of about 100 ohm.metres to the west and at depth are likely to be indicative of less weathered conglomerate with few if any alluvial vestiges.

As the depth to the watertable is typically 5 m in the south to 10 m in the north of the TEM survey area, the resistivity patterns are more likely to indicate spatial variations in clay content rather than moisture content or salinity.

A2.7 GROUNDWATER BORE CENSUS

A broad search of the NOW Pinneena Groundwater Works Database identified over 1,000 registered bores within the extent of the regional groundwater model (**Figure A-10**). The majority of the registered bores are associated with the Namoi River and alluvial floodplain.

In consultation with local landholders, TCPL also conducted a bore census in May 2011 of a number of privately-owned bores/wells in the vicinity of the Project. The results of the bore census (e.g. confirmed bore/well locations and spot water levels/water quality measurements) have been considered in the development of the regional groundwater model and impact assessment (Sections A5 and A6).

A refined search of the NOW Pinneena Groundwater Works Database (and incorporating the results of the May 2011 bore census) identified that 121 bores are located within approximately 5 km of the Project, of which 37 are located on Whitehaven-owned land (**Figure A-11**).

A2.8 GROUNDWATER LICENSING

The Project coal resource is located within the Maules Creek sub-basin of the Early Permian Bellata Group (refer Section A2.4) which lies within the boundary defined in the ***Draft*** *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* (**Figure A-12**)[4]. The Project coal resource is wholly located within the Management Zone of the Gunnedah-Oxley Basin – Namoi.

The Project is located outside, and approximately 5 km west, of the New England Fold Belt Murray Darling Basin – Namoi Management Zone boundary defined by the ***Draft*** *Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011* (**Figure A-13**).

[4] The term "Porous Rock" here refers to strata that have both primary (matrix) and secondary (fracture) porosity.

The Project is also located on the boundary of the Upper Namoi Zone 4, Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source defined by the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003* (**Figure A-14**). Whitehaven currently holds 526 megalitres (ML) of volumetric licence allocation in the Upper Namoi Zone 4 – Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source. The allocation was approved on 14 October 2011 from WAL12622 (90AL806770) to WAL12714 (90AL807001).

A summary of the existing groundwater licensing regime at Tarrawonga Coal Mine is provided below. Future groundwater licensing for the Project is discussed in Section A8.3.

Licences Pursuant to Part 5 of the Water Act, 1912

TCPL holds an existing Bore Licence (90BL254692) issued by the DWE (now NOW), that allows for the extraction of up to 50 ML of groundwater in any 12 month period. Bore Licence 90BL254692 was issued under Section 115 of the *Water Act, 1912* on 12 May 2009. The licence excerpt relevant to this assessment states:

"*(16) The volume of groundwater extracted from the works authorised by this licence and by licence(s) shall not exceed 50 megalitres (ML) in any 12 month period commencing 1st July."*

Groundwater monitoring boreholes at the Tarrawonga Coal Mine are also licensed under the existing Bore Licences (e.g. 90BL253276, 90BL253278, 90BL253841, 90BL254214, 90BL254220, 90BL254255, 90BL254254, 90BL254253, 90BL102564, 90WA809087, 90BL116929, 90BL101861, 90WA809232), which set out conditions of use for the monitoring bores.

TCPL submitted an application to the NSW Office of Water for a licence under Part 5 of the *Water Act, 1912* for the open cut mine pit in May 2008. Water reporting to the open cut mine pit is currently pumped via in-pit sumps to the Mine Water Dam (MWD). However, pursuant to Section 113A of the *Water Act, 1912* an embargo on any further applications for sub-surface water licences under Part 5 of the *Water Act, 1912* was declared on 22 December 2008 for all inland groundwater not within an alluvial aquifer or under a water sharing plan (NSW Inland Groundwater Shortage Zones Order No. 2 [22 December 2008]). The embargo area included the porous rock aquifers of the Project.

As the *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* is still in draft form, and has not been commenced, a groundwater licence for the open cut mine pit has not been issued by the NSW Office of Water.

It is anticipated that once the *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* is commenced, an appropriate licence for the open cut mine pit will be sought and obtained from the NSW Office of Water pursuant to the *Water Management Act, 2000* (refer below).

Licences Pursuant to Water Management Act, 2000

The existing operations at the Tarrawonga Coal Mine are located outside of the Upper Namoi Zone 4, Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source defined by the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003.* Therefore, no aquifer interference approvals or licences under the *Water Management Act, 2000* are currently required or held by TCPL.

As described above, an appropriate licence for the open cut mine pit at the Tarrawonga Coal Mine will be sought and obtained from the NSW Office of Water pursuant to the *Water Management Act, 2000* once the *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* is commenced.

A2.9 GROUNDWATER DEPENDENT ECOSYSTEMS

The *NSW State Groundwater Dependent Ecosystems Policy* (DLWC, 2002) describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems as follows:

- **Deep Alluvial Groundwater Systems –** occurring under floodplains of major rivers west of the Great Dividing Range (e.g. Namoi, Macquarie, Lachlan, Murrumbidgee and Murray alluvium).
- **Shallow Alluvial Groundwater Systems –** coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- **Fractured Rock Groundwater Systems –** outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and transmit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite).
- **Coastal Sand Bed Groundwater Systems –** significant sand beds along the coast of NSW (e.g. Botany and Tomago sand beds).
- **Sedimentary Rock Groundwater Systems –** sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).

The Project coal resource is located within the Maules Creek sub-basin of the Early Permian Bellata Group (refer Section A2.4) which is within the sedimentary rock groundwater systems of the Gunnedah Basin. These sedimentary rock groundwater systems lie within the boundary defined in the ***Draft*** *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* (as described in Section A2.8). There are no high priority groundwater dependent ecosystems as identified in the ***Draft*** *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* in the Project area (**Figure A-12**).

Groundwater resources in the south-east and to the south of the Project area are associated with the deep alluvial groundwater systems of the Namoi alluvium (i.e. Upper Namoi Zone 4 Groundwater Source – refer Section A2.8). There are no high priority groundwater dependent ecosystems identified in the Upper Namoi (NSW Office of Water, 2010).

The NSW State Groundwater Dependent Ecosystems Policy (DLWC, 2002) also recognises the four Australian groundwater dependent ecosystem types (Hatton and Evans, 1998) that can be found in NSW, namely:

- terrestrial vegetation;
- base flows in streams;
- aquifer and cave ecosystems; and
- wetlands.

The groundwater dependent ecosystems which are known or likely to occur within the Project area as well as the potential impacts of the Project on groundwater dependent ecosystems are described in the Surface Water Assessment (Appendix B of the EA), Flora Assessment (Appendix F of the EA) and Fauna (Terrestrial and Aquatic) Assessment (Appendix E of the EA).

A2.10 GROUNDWATER MONITORING

Groundwater level monitoring and groundwater quality sampling/analysis have been, and continue to be, undertaken at the Tarrawonga Coal Mine in accordance with the Water Management Plan (latest revision made in March 2011) (Whitehaven, 2011). The Tarrawonga Coal Mine groundwater monitoring program included as a sub-component of the Water Management Plan is summarised in **Table A-2**.

Additional groundwater level monitoring and groundwater quality sampling/analysis have also been undertaken as part of the groundwater investigation testwork commissioned by TCPL in 2011 and during the bore census (Section A2.7). The groundwater investigation included construction of an alluvial bore transect [TAWB16-TAWB22] across Goonbri Creek to ascertain the thickness of alluvium (**Figure A-15**).

The NOW and surrounding mining operations (and proposed future projects) also record groundwater data in the region as part of their respective programs.

The locations of groundwater monitoring locations (past and present) at the Tarrawonga Coal Mine and surrounds are shown on **Figure A-8**.

Table A-2. Groundwater Monitoring Program Summary

Parameters	Monitoring Site	Frequency
• Groundwater Levels.	MW1 and MW2.	Continuous (15 minute).
• Groundwater Levels	MW3 – MW8, GW044997, GW031856, GW052266, GW020432, GW002129* and GW002501*. Templemore A & Templemore B.	Quarterly.
• pH, Electrical Conductivity (EC), Lead (Pb)	MW1 – MW8, GW044997, GW031856, GW052266, GW020432, GW002129 and GW002501.	Bi-annually.
• Groundwater Levels	BCS1 – BCS7, Greentree A and Greentree B.	Quarterly monitoring undertaken in response to landholder complaint[1]
• Groundwater Levels • pH, EC, Total Suspended Solids (TSS), Alkalinity (as Calcium Carbonate [$CaCO_3$]), Bicarbonate (converted from alkalinity), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Pb, Zinc (Zn), Mercury (Hg), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Sulfate (SO_4), Chloride, Fluoride.	IEB-1^, IEB-2, IEB-5, IEB-6, IEB-40.	Sampled on 26 – 28 October 2004 as part of the RCA Australia Groundwater Assessment for the Proposed East Boggabri Coal Mine 2005

Source: Whitehaven (2011).
Note:
* Monitoring undertaken until bore was removed by the advancing open cut.
1 Monitoring of groundwater levels was undertaken in response to landholder complaints (in September 2007) of reduced groundwater levels. It was established that groundwater levels responded to seasonal fluctuations and monitoring was ceased in January 2009.
^ Not sampled for water quality

The bores that are monitored routinely are screened at a single depth, except for three screens in bore GW044997. The lithologies being monitored are summarised in **Table A-3**.

Table A-3. Groundwater Monitoring Lithologies

Lithology	Monitoring Site	Depth Range (m)
• Alluvium	MW2, MW4, MW5, MW6, GW044997, GW031856, GW052266	3.6 - 32
• Coal	GW002129	56.6
• Coal Measures (interburden)	MW1, MW7, MW8, GW002501	52.5 - 105
• Volcanics	MW3, GW020432	unknown

In May 2011, TCPL installed vibrating wire piezometers in two holes between the current Tarrawonga Coal Mine and Goonbri Creek (**Figure A-8**): TA-60C (4 piezometers) and TA-65C (8 piezometers). The monitored depths and lithologies are summarised in **Table A-4**.

Table A-4. Multi-Level Groundwater Monitoring Piezometers Details

Monitoring Site	Depth (m)	Lithology
• TA-60C	(1) 69 (2) 89 (3) 109 (4) 118	(1) Merriown - Velyama Interburden (2) Merriown - Velyama Interburden (3) Velyama Seam (4) Velyama - Nagero Interburden
• TA-65C	(1) 30 (2) 35 (3) 47 (4) 56 (5) 97 (6) 110 (7) 136 (8) 153	(1) Jeralong Overburden (2) Jeralong Seam (3) Jeralong - Merriown Interburden (4) Merriown Seam (5) Velyama - Nagero Interburden (6) Nagero Seam (7) Nagero - Upper Northam Interburden (8) Upper Northam Seam

As part of the groundwater investigation programme undertaken in 2011, TCPL also installed standpipe piezometers in TAWB14, TAWB15 and TAWB16 for the pumping test, and a nested standpipe piezometer (comprising two 50 mm Polyvinyl Chloride [PVC] standpipes) in a hole adjacent to TA-60C (**Figure A-8**). The installation details are summarised in **Table A-5**.

TAWB14 was screened across the shallowest coal seam, with the annulus gravel-packed through the screen interval, and sealed above with a bentonite/cement seal. TAWB15 was screened within conglomerate overburden and TAWB16 screened within clayey alluvium associated with Goonbri Creek. Static water levels in the bores indicate that the pressure levels in the conglomerate and coal strata lie within the alluvium, and that there is a downwards hydraulic gradient from the alluvium to the underlying formations.

The results of the pumping and slug tests are presented in **Section A3.1**.

Table A-5. Standpipe Piezometer Installation Details

Bore	Collar Height (m AHD)	Drilled Depth (m)	Screen (m)	Screened Strata	Water Level (m BGL)	Water Level (m AHD)
TAWB14	281.16	57	49.5 - 56.5	Coal	24.86	256.30
TAWB15	281.12	43	37.0 - 43.0	Conglomerate	10.72	270.40
TAWB16	281.17	28	8.0 - 28.0	Alluvium	5.03	276.14
TA-60C	310.00	119	86.5 – 89.5	Merriown - Nagero Interburden	65.52	244.48
			116.0 – 119.0		64.37	245.63

Note: BGL – Below Ground Level

A2.11 BASELINE GROUNDWATER LEVEL DATA

A2.11.1 Spatial Groundwater Level Data

Natural groundwater levels are sustained by rainfall infiltration and are controlled by ground surface topography, geology and surface water elevations. Typically, local groundwater would mound beneath hills and would discharge to incised creeks and rivers. During short events of high surface flow, streams would lose water to the host aquifer, but during recession, the aquifer would discharge water slowly back into the stream from bank storage and also discharge from more remote zones due to rainfall infiltration. Groundwater would flow from elevated to lower-lying terrain.

A contour map of measured watertable levels (**Figure A-16**) has been prepared from long-term average groundwater levels at 15 NOW alluvial bores and 159 mine monitoring sites measured at or near January 2010. Based on **Figure A-16**, groundwater flow direction is towards the west and south-west. The hydraulic gradient flattens appreciably to the south-west between the Tarrawonga Coal Mine and the Namoi River due to the higher permeability of alluvial sediments. Along Maules Creek there is a clear transition from gaining conditions (upstream) to losing conditions (downstream).

Representative depths to water (near January 2010) are displayed in **Figure A-17**. In the alluvium bordering the Tarrawonga Coal Mine site, the watertable typically is 5 m to 10 m below ground level.

A2.11.2 Temporal Groundwater Level Data

Groundwater levels have been monitored since June 2006 at and near the mine site (**Figure A-8**). In alluvial bores, groundwater levels have been fairly stable with only a mild response to rainfall (**Figure A-18**).

Of the bores screened in coal, interburden and volcanics, only two bores show any definite response to mining after commencement in September 2006 (**Figure A-19**). Bore GW002129 (**Figure A-8**) (in coal) was mined through in 2009, while bore MW7 (in Permian coal measures to the immediate east of the advancing open cut) has declined by 16 m so far. The other bores show no impact from mining and no apparent response to rainfall at the base and surface of the monitored lithological zone.

The vibrating wire piezometer responses at TA-60C and TA-65C are displayed in **Figure A-20** and **Figure A-21**, respectively. The plots are fairly stable, but there is a decline in head with time in the upper two piezometers (Merriown-Velyama interburden) at the site closest to current mining (TA-60C; **Figure A-20**). At TA-65C there is a slight reduction in head with time in the upper piezometers which might be far-field mining effects. Groundwater heads generally decrease with depth at each site but there are some reversals in gradient. As all data points lie reasonably close to the hydrostatic pressure line, no significant mining effects have yet been recorded.

A2.12 BASELINE GROUNDWATER CHEMISTRY DATA

The median values over the past five years of the major ions analysed at bores that are monitored routinely are displayed as Schoeller diagrams in **Figure A-22** for alluvium and in **Figure A-23** for coal, interburden and volcanics. A Schoeller Diagram is a semi-logarithmic plot of the concentrations of the major ionic constituents in groundwater, expressed in milliequivalents per litre (meq/L). These diagrams have the advantage of showing absolute concentrations at the same time as comparing ionic ratios. If the lines joining adjacent points are parallel from one bore to another, their ionic ratios are the same.

Figure A-22 shows a similar signature for alluvial bores with (sodium [Na] and potassium [K]) and (Chlorine [Cl] and Bicarbonate [HCO_3]) as the dominant type. The ionic ratios show only mild variability across the sites.

Figure A-23 suggests similar concentrations in hard rock bores as observed in alluvial bores, with the same (Na+K) and (Cl/HCO3) dominance. Ionic ratios are fairly uniform across the sites. The lowest normalised concentrations are observed in the coal sample, which has a strong NaCl type and lower sulphate [SO4] content.

Table A-6 summarises the EC statistics for laboratory samples analysed from the Tarrawonga Coal Mine and Boggabri Coal Mine monitoring networks. The median values are about 1000 micro siemens per centimetre (µS/cm) in coal, about 2000 µS/cm in alluvium and volcanics, and about 2500 µS/cm in coal measures interburden. The EC values for coal range from 530 µS/cm to 2760 µS/cm, increasing in the downdip direction. As the lower values tend to occur updip close to subcrop limits, this suggests that the inherent salinity in the coal seams is diluted by rainfall recharge. In the vicinity of the Project, the typical EC of groundwater in coal is in excess of 2000 µS/cm. The EC values for alluvium range from 440 µS/cm (e.g. in the headwaters of Bollol Creek) to 7,460 µS/cm (e.g. in near surface/shallower groundwater systems likely affected by ET effects).

Table A-6. Electrical Conductivity at Monitoring Sites

BORE	MEDIAN [µS/cm]	MEAN [µS/cm]	STANDARD DEVIATION [µS/cm]	LITHOLOGY
MW2	610	1171	1726	Alluvium
GW031856	1110	1117	40	Alluvium
GW052266	1360	1327	408	Alluvium
MW6	2030	2059	47	Alluvium
GW044997	3050	2741	811	Alluvium
MW5	3330	3811	2103	Alluvium
MW4	5000	4756	908	Alluvium
IBC2104	530	532	67	Coal
IBC2103	645	653	142	Coal
IBC2102	745	779	188	Coal
IBC2105	780	770	111	Coal
IBC2138	930	913	57	Coal
BC2181	980	917	110	Coal
GW002129	1210	1147	127	Coal
BC2193	1820	1837	29	Coal
IBC2114	2060	2044	133	Coal
TAWB14	2240	2263	96	Coal (Goonbri Ck.)
IBC2115	2280	2241	163	Coal
IBC2139	2760	2692	205	Coal
MW7	2275	2250	125	Coal Measures
MW1	3685	3791	1263	Coal Measures
GW002501	4500	3938	1709	Coal Measures
MW8	2260	2370	208	Conglomerate
MW3	1630	1610	214	Volcanics
IBC2110	1705	1642	184	Volcanics
GW020432	2115	2115	120	Volcanics
IBC2111	2120	2089	132	Volcanics
GW3115	3640	3543	195	Volcanics
Templemore A	1500	1500	100	Uncertain
Templemore B	1540	1553	140	Uncertain

Most groundwaters are at the limit of potable use but are suitable for livestock, irrigation and other general uses (**Table A-7**).

Table A-7. Groundwater Salinity Categories

Potable	Up to 781µS/cm (500 mg/L TDS)+	Suitable for all drinking water and uses.
Marginal Potable	781-2,344 µS/cm (500-1500 mg/L TDS) +	At the upper level this water is at the limit of potable water, but is suitable for watering of livestock, irrigation and other general uses.
Irrigation	2,344-7,813 µS/cm (1500-5000 mg/L TDS) +	At the upper level, this water requires shandying for use as irrigation water or to be suitable for selective irrigation and watering of livestock.
Saline	7,813-21,875 µS/cm (5000-14000 mg/L TDS) +	Generally unsuitable for most uses. It may be suitable for a diminishing range of salt-tolerant livestock up to about 6,500 mg/L [~10,150 µS/cm] and some industrial uses.
Highly Saline	> 21,875 µS/cm (14000 mg/L TDS) +	Suitable for coarse industrial processes up to about 20,000 mg/L [~31,000 µS/cm].

Note:
+Conversion Factor of 0.64 applied.
Source: MDBC (2005).
mg/L – Milligrams per Litre
TDS – Total Dissolved Solids

The spatial pattern of baseline groundwater salinity is illustrated in **Figure A-24**. This plot consists of median laboratory values at bores in the Tarrawonga Coal Mine and Boggabri Coal Mine monitoring networks, supplemented by spot field measurements at bores visited during the May 2011 bore census. The sample lithologies are differentiated by symbol, and the magnitude of the concentration is proportional to symbol size. The distribution of salinity is fairly uniform spatially, other than a few elevated concentrations close to the Tarrawonga Coal Mine site in lithologies other than coal.

The temporal variation in salinity has been examined for those bores with elevated EC: MW4, MW5 and GW44997 in alluvium; GW002501 and MW1 in interburden; and GW3115 in volcanics (**Figure A-8**). In alluvium, there is an increase in salinity associated with declining rainfall at two sites (MW4, GW44997) with no clear trend at the third site (MW5) (**Figure A-25**). In volcanics to the west of the mine, the EC is very stable in time (**Figure A-25**). In interburden, there is an increasing trend with time at MW1 and substantial increase at GW002501 followed by stabilisation at a lower value (**Figure A-26**). The latter two bores are screened below the level of the Nagero seam at distances of about 1200 m and 500 m from the nearest mining, respectively. Local groundwater flow directions will have been altered by mining, and this could introduce water of different salinity to the point of measurement.

The pH of groundwater at the Project site has a narrow range from 6.9 to 7.8.

The *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003* identifies agricultural use and raw water for drinking as the only beneficial water quality uses. Water quality decline is deemed unacceptable if groundwater extraction causes water quality to decline to a lower beneficial use class. The Water Sharing Plan covers a very large area for which much of the groundwater is potable. It is clear from **Table A-7**, however, that in the local area most groundwater has "marginal potable" status. Only one alluvial bore (MW2) has "potable" water, while four coal bores hold water of potable quality, but as discussed above tend to occur updip close to subcrop limits, suggesting that the inherent salinity in the coal seams is diluted by rainfall recharge. Away from the subcrop area, the coal and interburden strata contain poor quality groundwater.

Within the Project area, the coal seams have sufficient permeability[5] to be regarded as aquifers but the groundwater within the seams is not used for consumptive applications.

EC values for coal measures interburden in the Project area are also discussed in the Geochemistry Assessment (Appendix N of the EA).

[5] Permeability is used interchangeably with hydraulic conductivity in this report.

A3 CONCEPTUAL MODEL

A conceptual model of the groundwater regime has been developed based on the review of existing hydrogeological data as described in Section A2, including:

- Gunnedah Basin geology mapping;
- TCPL exploration (geological) data and logs;
- NOW Pinneena Groundwater Works Database records;
- *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003;*
- ***Draft** Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011;*
- Previous hydrogeological assessments/reviews undertaken for the Tarrawonga Coal Mine and surrounding mines (i.e. RCA Australia, 2005; GeoTerra Pty Ltd, 2009; GSS Environmental, 2011; Douglas Partners, 2010; Australasian Groundwater and Environmental Consultants Pty Ltd (AGE), 2010; R.W. Corkery & Co. Pty Limited, 2005; 2007; Vickery Joint Venture, 1986; Hansen Bailey, 2010a; 2010b; Schlumberger Water Services (Australia) Pty Ltd, 2011);
- Piezometric data from groundwater monitoring programs undertaken at the Tarrawonga Coal Mine and surrounding mines (i.e. TCPL, 2007; 2008; 2009; 2010; Whitehaven Coal Mining Pty Ltd, 2005; 2006a; 2007; 2008; 2009a; 2009b; 2010a; 2010b); and
- Other groundwater investigation testwork (e.g. slug tests) commissioned by TCPL in 2011.

Based on the above, and consistent with the relevant water sharing plans, the data supports two groundwater systems:

- **Porous Rock groundwater system** - including the coal measures of the Maules Creek Formation; and
- **Alluvial groundwater system** – associated with the low-lying floodplains of the Upper Namoi.

The conceptual groundwater models before mining and toward the end of mining are displayed in **Figure A-27**.

Recharge to the groundwater systems occurs from rainfall and runoff infiltration, lateral groundwater flow and some leakage from surface water sources (e.g. Namoi River). Although groundwater levels are sustained by rainfall infiltration, they are controlled by topography, geology and surface water levels in local drainages. Local groundwater tends to mound beneath hills, with ultimate discharge to local drainages and loss by evapotranspiration through geological outcrops and vegetation where the watertable is near the ground surface (generally 2 m to 3 m below ground level).

However, given the typical depth to water (5-10 m to the south-east of the Tarrawonga Coal Mine lease) contoured in **Figure A-17**, evapotranspiration is an unlikely occurrence in the vicinity of the mine and adjacent alluvium.

During mining, the potentiometric heads in the porous rock groundwater system will be reduced in the vicinity of the mine, but the watertable will tend to rise beneath emplacement mounds. **Figure A-27** shows also a low permeability barrier that will minimise leakage between the Goonbri Creek alluvium and the mine void. Groundwater sourced from the coal measures and the emplacement will report to the open cut pit.

A3.1 HYDRAULIC PROPERTIES

Indicative permeabilities for the various stratigraphic units, summarised in **Table A-8**, have been determined from slug/pumping tests, core measurements and model calibration conducted by previous studies including AGE (2010); RCA Australia (2005, 2007); and Douglas Partners (2010). Many field tests have found a high hydraulic conductivity for coal in the order of 0.5 metres per day (m/day). The hydraulic property data collected and reviewed as part of this assessment provide a firm basis for the development of the numerical groundwater model. The performance of the calibrated numerical model (including comparison to the ranges of indicative hydraulic properties) is discussed in Section A4.8.

The permeability values in **Table A-8** are also based on results of the groundwater investigation program undertaken by RPS Aquaterra at the Tarrawonga Coal Mine, including (**Figure A-8**):

- Core testwork (33 samples from three drill holes [TA-60C, TA-63C, TA-65C]);
- Pumping tests (TAWB14 and TAWB16); and
- Slug tests (TA60C at two depths targeting the Merriown-Nagero interburden).

A summary of the core testwork results is provided in **Table A-9**. These results can be regarded as lower limits for use in model calibration, as cores will not capture the bulk fractured characteristics of a formation.

At TAWB14, an 8 hour constant rate test (CRT) at 13 cubic metres (m^3/day), and recovery, was undertaken to establish hydraulic conductivity of the coal seam aquifer.

A pumping test was also attempted within the shallow bore screened within the alluvium (TAWB16). This was terminated very soon after the test started as the bore ran dry. A rising head test was then performed to assess hydraulic conductivity of the shallow alluvium associated with Goonbri Creek.

The graphical results of the pumping test (TAWB14) and subsequent rising head (TAWB16) test conducted by RPS Aquaterra are shown on **Figure A-28**.

Slug tests were conducted on each standpipe at TA60C to assess the hydraulic conductivity of the Merriown-Nagero interburden stratum. The graphical results of the slug tests are shown on **Figure A-29**.

Table A-8. Indicative Hydraulic Properties of Stratigraphic Units

Unit	Horizontal Permeability Kx (m/day)	Vertical Permeability Kz (m/day)
Alluvium	0.5*-10	0.5
Regolith	0.01-0.1	0.001-0.01
Overburden (above Jeralong Seam)	6.1×10^{-6} - 6.8×10^{-4}	1.1×10^{-5} - 1.4×10^{-5}
Braymont/Jeralong Seams	0.01-0.68	-
Interburden (Jeralong to Merriown/Velyama Seams)	7.2×10^{-7} - 8.1×10^{-4}	2.4×10^{-7} - 1.9×10^{-4}
Merriown/Velyama Seams	0.005-0.68	-
Interburden (Velyama to Nagero Seam)	6.3×10^{-7} - 1.0×10^{-4}	3.6×10^{-7} - 4.4×10^{-5}
Nagero Seam	0.025	0.0025
Interburden (Nagero to Lower Northam Seams)	8.2×10^{-7} - 3.2×10^{-4}	1.8×10^{-7} - 2.2×10^{-4}
Northam to Templemore Seams	0.016 - 0.51	0.0016
Underburden (below Lower Northam Seam)	1.6×10^{-5}- 0.0016	7.7×10^{-5} - 1.6×10^{-4}
Boggabri Volcanics	1×10^{-4}	1×10^{-5}

Source: After: RPS Aquaterra (2011); AGE (2010); RCA Australia (2005, 2007); Douglas Partners (2010).

* The NOW groundwater model for the Upper Namoi Groundwater Source assumed 0.5-1m/day for alluvium adjacent to Tarrawonga Coal Mine.

A suite of published analytical methods (Kruseman and de Ridder, 1991) was used by RPS Aquaterra to analyse the test data from the piezometers. The following methods were used in the analysis:

- Jacob's straight-line method for unsteady flow in a confined aquifer.
- Theis's Recovery method, which is derived for confined aquifers.
- Hvorslev solution was used to analyse the recovery data ('rising head') measured in TAWB16 after the terminated constant-rate test. This analysis was deemed suitable due to the rapid dewatering of this piezometer during pumping and the very slow subsequent recovery of groundwater levels.
- Bouwer-Rice and Hvorslev solutions were used to analyse the falling head slug test data in TA60C.

The analysis of the test results is presented in **Table A-10**.

Table A-9. Summary of Groundwater Investigation Program Core Testwork Results

Unit		Overburden (above Jeralong Seam)	Interburden (Jeralong to Merriown Seam)	Interburden (Merriown to Velyama Seam)	Interburden (Velyama to Nagero Seam)	Interburden (Nagero to Upper Northam Seam)	Interburden (Upper Northam to Lower Northam Seam)	Underburden (below Lower Northam Seam)
Model Layer		3	5	5-6	7	9	9-10	11
Horizontal	Arithmetic Mean	3.42×10^{-4}	2.46×10^{-4}	1.02×10^{-4}	3.99×10^{-5}	3.05×10^{-5}	1.21×10^{-4}	1.61×10^{-5}
	Maximum	6.80×10^{-4}	8.07×10^{-4}	3.00×10^{-4}	1.01×10^{-4}	1.12×10^{-4}	3.17×10^{-4}	-
	Minimum	6.05×10^{-6}	2.31×10^{-5}	7.18×10^{-7}	6.26×10^{-7}	8.24×10^{-7}	1.13×10^{-5}	-
	Sample Count	2	6	5	4	9	3	1
Vertical	Harmonic Mean	1.23×10^{-5}	1.33×10^{-6}	3.72×10^{-6}	1.09×10^{-6}	8.27×10^{-7}	1.04×10^{-5}	7.67×10^{-5}
	Maximum	1.39×10^{-5}	1.90×10^{-4}	5.48×10^{-5}	4.35×10^{-5}	5.80×10^{-5}	2.16×10^{-4}	-
	Minimum	1.10×10^{-5}	2.36×10^{-7}	1.44×10^{-6}	3.61×10^{-7}	1.81×10^{-7}	3.60×10^{-6}	-
	Sample Count	2	6	4	4	9	3	1

Source: RPS Aquaterra (2011)

Table A-10. Summary of Pumping and Slug Tests Results

Bore	Depth (m)	Screen (m)	Screened Strata	Calculated Hydraulic Conductivity (m/day)
TAWB14	57	49.5 - 56.5	Coal	0.130
TAWB16	28	8.0 - 28.0	Alluvium	0.002
TA60C	119	86.5 – 89.5	Merriown - Nagero Interburden	0.005
		116 - 119		0.003

Source: RPS Aquaterra (2011)

A4 GROUNDWATER SIMULATION MODEL

A4.1 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the MDBC Groundwater Flow Modelling Guideline (MDBC, 2001). As this is mostly a generic guide, there are no specific guidelines on special applications such as coal mine modelling.

Under the modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. The guide (MDBC, 2001) describes this model type as follows:
"Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies."

Numerical modelling has been undertaken using the Groundwater Vistas (Version 6.07) software interface (Environmental Simulations Inc [ESI], 2011) in conjunction with MODFLOW-SURFACT (Version 4) distributed commercially by Hydrogeologic, Inc. (Virginia, USA). MODFLOW-SURFACT is an advanced version of the popular MODFLOW code developed by the United States Geological Survey (McDonald and Harbaugh, 1988). MODFLOW is the most widely used code for groundwater modelling and is considered an industry standard.

MODFLOW-SURFACT is a three-dimensional modelling code that is able to simulate variably saturated flow and can handle desaturation and resaturation of multiple aquifers without the "dry cell" problems of Standard-MODFLOW. This is pertinent to the dewatering of layers adjacent to open pit coal mines. Standard-MODFLOW can handle this to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by "dry cells".

The model complexity is considered adequate to simulate contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the Project.

A4.2 PRIOR MODELLING

In 2005, localised groundwater modelling of the impacts of the Tarrawonga Coal Mine (then East Boggabri) was conducted by RCA Australia (2005). Due to limited spatial extent this model was considered unsuitable for the current Project as it does not accommodate the cumulative effects from recent neighbouring mines. In 2010, AGE included Tarrawonga Coal Mine in separate cumulative impact assessments for the Boggabri Mine (AGE, 2010) and the Maules Creek Mine (AGE, pers. comm.).

Douglas Partners (2010) developed a local area model for the Rocglen Mine. This also was considered unsuitable for the current Project as it does not accommodate the cumulative effects from recent neighbouring mines.

The AGE models are regional in extent and are suitable as a basis for the current Project model. However, the Tarrawonga model requires a greater southern extent and has coal seams aggregated differently (see Section A4.5). The AGE Boggabri model extends to Northing 6624000 and the AGE Maules Creek model extends to Northing 6632000. The Tarrawonga Project model also extends to Northing 6632000, but it extends farther to the south. The Mooki Thrust eastern boundary is the same for the Maules Creek model and the Project model, but the latter extends farther to the west to include more of the Upper Namoi Valley.

A4.3 MODEL EXTENT

A regional model extent has been selected to take into account cumulative mining effects from Maules Creek Mine, Boggabri Mine and Rocglen Mine, and to include significant groundwater production from the Upper Namoi Alluvium for agricultural purposes. The model extent, indicated in **Figure A-7a** and **Figure A-10**, extends between MGA Eastings 209000 and 242000 and MGA Northings 6586000 and 6632000. The area of coverage is 33 km east-west by 46 km north-south, a total of 1,518 square kilometers (km^2).

The model area includes portions of the Upper Namoi Zone 2, Zone 4, Zone 5 and Zone 11 water sources in the alluvial groundwater system.

A4.4 MODEL LAYERS

Twelve (12) layers are conceptualised in **Figure A-30** for the purpose of numerical modelling.

The top two layers comprise alluvium, regolith or overburden in different parts of the model. Where the layers represent alluvium, they have been assigned to be generally consistent with the NOW groundwater model for the Upper Namoi Groundwater Source.

The Maules Creek Formation has been split into multiple layers generally based on the targeted coal seams and in recognition of vertical hydraulic gradients. The Nagero Upper Seam is the lowest seam to be mined in this Project.

Below the targeted coal seams, three layers have been inserted to represent the interburden and underlying coal measures. The basement layer represents the Boggabri Volcanics.

A4.5 MODEL GEOMETRY

The model domain is discretised into 1.23 million cells arranged into 12 layers comprising 374 rows and 274 columns. The dimensions of the model cells vary from 50 m at mine sites to 500 m towards the model edges (**Figure A-31**). A maximum aspect ratio of 1.5 has been maintained.

The modelled stratigraphic section (**Figure A-30**) has four major groupings of coal seams (Layers 4, 6, 8, 10) separated by overburden/interburden/underburden sandstone/siltstone sediments (Layers 3, 5, 7, 9, 11). Layers 1 and 2 accommodate alluvium, regolith and overburden in rock outcrop areas. Layer 12 holds the Boggabri Volcanics.

The geometry of the coal seams is defined by the floor elevation of named seams (Jeralong, Velyama, Upper Nagero, Templemore). The layer thickness is the aggregate of recorded coal thicknesses within the designated groupings. The same approach has been followed by the AGE regional models for Boggabri and Maules Creek, but the grouping of coal seams is different[6]. Structure contours have been extrapolated away from the exploration leases to define the stratigraphy throughout the model area, guided by median thicknesses from exploration drilling. The assistance of Aston Resources is acknowledged for providing access to the geological model structural information for the Maules Creek Coal Project.

Where layers pinch out or are eroded, the layers must continue laterally in a MODFLOW model and therefore have a notional thickness but are given properties associated with the underlying lithology.

Representative model cross-sections are displayed in **Figure A-32** for Easting 228425 (model column 110) and Northing 6606725 (model row 165), through the centre of the Tarrawonga Coal Mine in each direction. As designated coal seams are not continuous everywhere due to faulting and erosion, in the model these layers are given interburden properties where appropriate.

A4.6 MODEL STRESSES AND BOUNDARY CONDITIONS

The Mooki Thrust forms a natural boundary along the eastern edge of the model, approximated as a no-flow boundary due to the exposure of low-permeability rocks of Carboniferous Age on the eastern side of the boundary. The northern and southern model edges are approximated by streamlines in alluvium, represented by no-flow boundaries, according to the regional watertable contours in **Figure A-16**. The western boundary is represented by general head boundary conditions in Layers 1 and 2 with heads set at the water levels in **Figure A-16**. All deeper layers have no-flow boundaries by default, given that their lower permeabilities would be associated with only minor lateral flow.

Major and minor streams are established as "river" cells in model Layer 1 using the MODFLOW RIV package (**Figure A-33**). The RIV package allows water exchange in either direction between the stream and the aquifer, unless the river stage is set equal to the bottom of the streambed layer in the model river. This has been done for minor streams so that these cells will accept baseflow when the watertable breaches the bed elevation of the stream, but they will never provide a source of water for the aquifer. The river conductances vary from 15 to 75 square metres per day (m^2/day).

For the calibration period, historical river levels are in agreement with those used in the NOW regional model for the Upper Namoi. During the prediction phase, constant average river levels have been assumed.

"Drain" cells using the MODFLOW DRN package are used to represent mining in Layers 4, 6, 8, 10 and 11. Invert levels are generally 0.1 m above the floor of the lowest mined coal seam, and 0.1 m below base levels for layers overlying the mined seam. The drain conductance value is set at 1,000 m^2/day to virtually eliminate any resistance to flow.

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[6] The Maules Creek model has layer floors coincident with the bases of the Braymont, Velyama, Flixton and Templemore Seams.

Rainfall infiltration has been imposed as a percentage of actual rainfall (for transient calibration) or long-term average rainfall (for prediction simulations) across five zones (**Figure A-34**):

1. Alluvium;
2. Maules Creek Formation;
3. Upper Permian and Triassic outcrop;
4. Boggabri Volcanics; and
5. Rock-alluvium contacts.

The recharge rates were determined during model calibration. Additional recharge zones (21 to 37 in **Figure A-34**) are defined during predictive simulations for the active mining area (zero recharge) and mine waste rock infiltration (initially zero, then 5% after five years).

For the calibration period, historical pumping from the alluvial aquifer has been included in agreement with the stresses imposed in the NOW regional model for the Upper Namoi. During the prediction phase, the pumping that occurred in 2010 has been assumed to continue at a constant rate.

Evapotranspiration is applied uniformly using MODFLOW's linear function, with a maximum rate of about 150 millimetres per annum (mm/a) and an extinction depth of 2 m.

A4.7 MODEL VARIANTS

The modelling approach has necessitated the development of three model variants:

A. *Transient calibration model*.
Thorough calibration of aquifer system properties against hydrographic responses for dynamic rainfall recharge, dynamic Namoi River levels and groundwater usage from registered alluvial bores, for Project and other mine monitoring bores and NSW Office of Water alluvial observation bores.

B. *Transient prediction model*.
Simulation of the annual progression of open-cut mining, allowing for time-varying properties for mine waste rock (hydraulic conductivity, specific yield and infiltration), with prediction of potential impacts of mine development on the groundwater regime (particularly stream-aquifer interaction, alluvium-coal interaction and groundwater dependent ecosystems) and prediction of mine inflow rates. Three versions of the model were developed:

1) Without a low permeability barrier and before the permanent Goonbri Creek alignment is commissioned;
2) With a low permeability barrier for Tarrawonga Coal Mine excavation only to assess the incremental effect of the Project alone; and
3) With a low permeability barrier and with all mines operating to assess the cumulative impacts of the Project in association with the effects of other mines.

C. *Transient recovery model*.
Simulation of equilibrium groundwater levels for the final landform and pit void.

Model variant B has made use of the new time-varying materials (TMP) facility in MODFLOW-SURFACT (released July 2010). This allows hydraulic and storage subsurface properties to be updated each stress period, whenever and wherever necessary, in transient groundwater flow simulations.[7]

A4.8 TRANSIENT CALIBRATION

Calibration was conducted on model variant A for the time period January 2006 to December 2010 for 60 monthly stress periods. The start date precedes the commencement of mining at Tarrawonga in September 2006, mining at Boggabri in October 2006, and coincides with the commencement of water level and water quality monitoring. Initial hydraulic property values in the Project model were guided by field measurements and by steady-state model calibration for the Maules Creek and Boggabri models. This approach obviated the need to conduct steady-state calibration for this Project. The transient calibration conducted here has enabled better estimation of storage properties required for transient simulation. Initial heads were provided by the representative field values contoured in **Figure A-16**.

The monitoring bores associated with the Vickery, Canyon and Rocglen Mines have allowed calibration of the model in that area and have enhanced the reliability of cumulative impact assessment. The model also has included transient calibration against all NOW observation bores within the model area. In all, 1681 target heads were established for 89 sites. Calibration was conducted manually. A separate verification process was not conducted as the full length of mine monitoring records was required for calibration of hydrographs exhibiting mining effects.

An upper limit on pit inflow has been inferred from dewatering volumes reported in Annual Environmental Management Reports (AEMRs) (TCPL, 2007; 2008; 2009; 2010). These volumes include direct rainfall, surface runoff and groundwater inflow but exclude evaporative losses. **Table A-11** shows that pit inflows varied from an average of 0.07 megalitres per day (ML/day) to 0.19 ML/day during the 2006-2010 model calibration period.

Table A-11. Reported Pit Inflow Rates (Surface Water and Groundwater)

AEMR YEAR	2006-2007	2007-2008	2008-2009	2009-2010
ML/day	0.07	0.09	0.12	0.19

Source: TCPL (2007, 2008, 2009, 2010)

[7] The alternative approach in common practice uses a set of sequential time-slices and numerous stop-start linked models.

A4.8.1 Calibrated Model Properties

Table A-12 summarises the hydraulic and storage properties for the stratigraphic section at the end of transient calibration. The adopted property distributions are displayed in **Attachment AA**. The values for horizontal hydraulic conductivity (K_X) are consistent with field estimates listed in **Table A-8** and with estimates from other models. In particular, the two alluvial layers have the following Kx values in various models:

Layer 1: 5 m/day [Tarrawonga model]; 7.0 m/day [Maules Creek model]; 6.3 m/day [NOW model average];

Layer 2: 8 m/day [Tarrawonga model]; 8.3 m/day [Maules Creek model]; 7.1 m/day [NOW model average].

Table A-12. Calibrated Horizontal and Vertical Hydraulic Conductivities, Storage Coefficient and Specific Yield

LAYER		LITHOLOGY	Kx (m/day)	Kz (m/day)	S	Sy
1		**Alluvium**	5	0.01	0.001	0.2
		Regolith/Weathered Permian	0.1	0.009	0.0005	0.01
2		**Alluvium**	8	0.05	0.001	0.2
		Overburden/Weathered Permian	0.1	0.009	0.0005	0.01
3		**Overburden**	3.4E-04	1.2E-05	1.0E-05	0.0001
4		**Braymont Seam to Jeralong Seam**	0.4	0.01	0.0001	0.005
5		**Interburden**	2.5E-04	1.3E-06	1.0E-05	0.0001
6		**Merriown Seam to Velyama Seam**	0.4	0.01	0.0001	0.005
7		**Interburden**	4.0E-05	1.1E-06	1.0E-05	0.0001
8		**Nagero Upper Seam**	0.3	0.01	0.0001	0.005
9		**Interburden**	3.1E-05	8.3E-07	1.0E-05	0.0001
10		**Northam Seam to Templemore Seam**	0.3	0.01	0.0001	0.005
11		**Underburden**	1.6E-05	3.6E-06	1.0E-05	0.0001
12		**Volcanics**	0.005	0.0005	0.0001	0.001

Note: Kx – horizontal hydraulic conductivity, Kz – vertical hydraulic conductivity, S – Storage Coefficient, Sy – specific yield

The adopted values for rainfall recharge expressed as percentages of rainfall are:

- Alluvium [Zone 1]: 1.2%
- Maules Creek Formation [Zone 2]: 0.1%
- Upper Permian and Triassic outcrop [Zone 3]: 0.1%
- Boggabri Volcanics [Zone 4]: 0.5%
- Rock-alluvium contacts [Zone 5]: 10%

A4.8.2 Transient Calibration Performance

The simulated pit inflow illustrated in **Figure A-35** is of the right order of magnitude at Tarrawonga Coal Mine, but the actual pit inflow at Boggabri Coal Mine is unknown. The median simulated values are 0.19 ML/day and 0.40 ML/day at Tarrawonga and Boggabri Coal Mines, respectively. The AGE model for Boggabri Coal Mine reported inflows ranging from 0.4 to 0.6 ML/day, and the Maules Creek model reported a range of 0.5 to 1.2 ML/day at the Boggabri Coal Mine during 2006-2010 (AGE, 2010; pers. comm.)

A scattergram of simulated versus measured heads in **Figure A-36** demonstrates good agreement across the whole range of measurements. There is no bias towards overestimation or underestimation.

The overall performance of the transient calibration is quantified by a number of statistics in **Table A-13**. The key statistic is 3.5% Scaled Root Mean Square (SRMS), which is well below the target 10% SRMS suggested in the MDBC flow model guidelines (MDBC, 2001).

Table A-13. Transient Calibration Performance

Calibration Statistics	Value
Number of Data (n)	1681
Root Mean Square (RMS) (m)	4.7
Scaled Root Mean Square (SRMS) (%)	3.5
Average residual (m)	0.8
Absolute average residual (m)	2.3

The ability of the model to replicate observed groundwater hydrographs is reported in full in **Attachment AB**. For illustration, **Figure A-37** to **Figure A-39** show comparisons at representative sites within the Tarrawonga Coal Mine monitoring network, the Boggabri Coal Mine monitoring network and NOW alluvial bore network, respectively. Model water level trends and absolute elevations, in the majority of cases, are consistent with the observed water levels.

Only one Tarrawonga Coal Mine bore shows a mining response, while many of the Boggabri Coal Mine bores are affected by mining. None of the NOW alluvial bores are affected by mining, but the deeper bores show characteristic responses to agricultural pumping. The responses to stresses are simulated faithfully by the Project model, although the agricultural pumping effects are difficult to match due to uncertainty in the timing of monthly pumping by groundwater users.

A4.8.3 Transient Water Balance

The instantaneous transient water balance across the entire model area is summarised in **Table A-14** at the end of the calibration period (December 2010). The total inflow (recharge) to the aquifer system was approximately 95 ML/day at that time, comprising mainly rainfall recharge (59%), and leakage from the rivers into the aquifer (22%). The leakage from all streams is simulated to be about 21 ML/day. Boundary inflow was also significant (19%).

Production bore abstraction accounts for the majority of the groundwater discharge, at 49%. Next in order of importance is stream baseflow (34%). Evapotranspiration and boundary flows are similar in magnitude (6% and 9%, respectively). The computed inflow to all mines (1.0 ML/day) is less than 1% of the total groundwater discharge over the model area.

At the end of the calibration period (December 2010), discharge exceeded recharge by over 9 ML/day.

Table A-14. Simulated Water Balance for the Transient Calibration Model at the End of the Calibration Period

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	56.1	-
Evapotranspiration	-	6.3
Rivers/Creeks	20.8	36.1
Production Bores	-	51.8
Mines	-	1.0
Boundary Flow	18.5	9.8
TOTAL	**95.4**	**105.0**
Storage	**9.6 LOSS**	
Discrepancy (%)	**0.30**	

A4.8.4 Transient Sensitivity Analysis

During the calibration process, the most important parameters were found to be the horizontal hydraulic conductivities of the coal layers, and the vertical hydraulic conductivities of the intervening aquitards. An informal sensitivity analysis established the need for a relatively high coal permeability (about 0.4 m/day).

A sensitivity analysis has been done for the vertical hydraulic conductivity of Layer 2 alluvium, as this parameter controls the degree of water exchange between alluvial sediments and the underlying bedrock. The base value is 0.05 m/d. By increasing this value to 2.4 m/d, there was no change in the calibration performance statistic or any significant change in local stream-aquifer interaction at Goonbri Creek. The model reported a reduction in leakage from Goonbri Creek to the underlying alluvium of about 1% (from 0.57 ML/day to 0.56 ML/day). The change in mine inflow was much less than 0.1%.

A5 SCENARIO ANALYSIS

Three model versions were considered for predictive scenario analysis:

1) Without a low permeability barrier and before the permanent Goonbri Creek alignment is commissioned;
2) With a low permeability barrier for Tarrawonga Coal Mine excavation only to assess the incremental effect of the Project alone; and
3) With a low permeability barrier and with all mines operating to assess the cumulative impacts of the Project in association with the effects of other mines.

A5.1 MINE SCHEDULE

Using the hydraulic and storage properties found during transient calibration and a pit activation period of one year, the model was run in transient mode from January 2011 to December 2032 in annual steps. The Project is taken to commence in January 2013 (stress period 3) and finish in December 2029 (stress period 19)[8]. An additional three years (to stress period 22) was required to take Maules Creek Mine and Boggabri Mine to completion. The Rocglen Mine was activated from stress period 1 to stress period 6 (end 2016).

Rainfall recharge was deactivated in cells where mining was currently active, for a period of five years, as mine waste rock would require roughly this length of time to wet up through the unsaturated zone. After five years, 5% recharge is applied to mine waste rock. The sequencing of time-varying recharge is illustrated by the colour mosaics in **Figure A-34**. The same colour pattern denotes the application of time-varying mine waste rock permeability (set at 1 m/day), which was done using the new TMP facility in SURFACT.

The only time-varying stress in the prediction model is mining. Rainfall was applied at constant long-term average rates; constant average river levels were assumed; and the pumping that occurred in 2010 was assumed to continue at a constant rate.

The progression of mining in the model was applied consistent with the general arrangement snapshots for the Project presented in Section 2 of the Main Report of the EA and the respective EAs and Preliminary Environmental Assessment for the Boggabri Coal Mine, Rocglen Coal Mine and Maules Creek Coal Project.

A5.2 WATER BALANCE

Simulated water balances for the entire model extent have been averaged over the 17 years of proposed Project life (stress periods 3 to 19) and are examined in **Table A-15** and **Table A-16**.

Table A-15 compares the Project averages with simulated values at the commencement of the Project (end of stress period 2), considering mining only at the Tarrawonga Coal Mine. An increase in mine inflow of about 0.5 ML/day is expected, on average. This increase in inflow will be supplied primarily from aquifer storage. As variations in the fluxes of other components of the water balance exceed 0.5 ML/day, it is apparent that the model has experienced some instability when it is stressed by mining over the prediction period.

[8] A stress period is the timeframe in the model when all hydrological stresses (e.g. rain recharge, river stage, etc.) remain constant.

This is reflected in spurious simulated drawdowns (in the order of 1 m) at large distances from the mine that cannot be the result of mining (see **Attachment AC**). However, close to the mine, the numerical noise is not significant when compared with predictions of mining effects in the vicinity of the mine.

Table A-15. Simulated Water Balance Changes due to the Project

Component	PROJECT START Groundwater Inflow (Recharge) (ML/day)	PROJECT AVERAGE Groundwater Inflow (Recharge) (ML/day)	PROJECT START Groundwater Outflow (Discharge) (ML/day)	PROJECT AVERAGE Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	30.3	30.6	-	-
Evapotranspiration	-	-	5.9	4.4
Rivers/Creeks	20.4	19.3	32.8	25.3
Production Bores	-	-	50.9	50.9
Tarrawonga Mine	-	-	0.24	0.71
Boundary Flow	19.1	21.3	8.3	6.3
TOTAL	**69.8**	**71.2**	**98.3**	**87.9**
Storage	28.5 LOSS	16.7 LOSS		
Discrepancy (%)	**0.1**	**0.4**		

Table A-16 gives the simulated average components over the entire model extent for the Tarrawonga Coal Mine operating alone, as well as illustrating the incremental effect of neighbouring mining at Boggabri Coal Mine, Maules Creek Coal Project and Rocglen Coal Mine.

With only the Tarrawonga Coal Mine operating, recharge is dominated by rainfall infiltration (43%), lateral boundary flow (30%) and river/creek leakage (27%). Groundwater pumping by production bores accounts for 58% of groundwater discharge from the model area. The other significant discharge mechanism is river/creek baseflow (28%). Average mine inflow during the Project period is predicted to be about 1% of all groundwater discharge.

The aquifer system, on the whole (over the model area), is being managed with a significant reliance on groundwater held in storage (about 17 ML/day), if production bores continue to operate at 2010 rates as assumed for the prediction simulations.

The cumulative effect of other mines is discussed in Section A5.5.

Table A-16. Average Simulated Water Balance for the Prediction Model during the Project Period

Component	TARRAWONGA MINE Groundwater Inflow (Recharge) (ML/day)	FOUR MINES Groundwater Inflow (Recharge) (ML/day)	TARRAWONGA MINE Groundwater Outflow (Discharge) (ML/day)	FOUR MINES Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	30.6	30.8	-	-
Evapotranspiration	-	-	4.4	4.3
Rivers/Creeks	19.3	19.3	25.3	25.2
Production Bores	-	-	50.9	50.9
Mines	-	-	0.7	3.8
Boundary Flow	21.3	22.5	6.3	6.1
TOTAL	**71.2**	**72.6**	**87.9**	**90.3**
Storage	**16.7 LOSS**	**17.7 LOSS**		
Discrepancy (%)	**0.4**	**0.3**		

A5.3 PREDICTED PIT INFLOW

The time-varying pit inflows predicted by the model are illustrated in **Figure A-40** with all four mines operating. The Tarrawonga Coal Mine inflow is expected to vary between 0.3 ML/day and 1.0 ML/day during the Project. The Boggabri and Rocglen Mines are expected to peak around 1.2 ML/day, while the Maules Creek Mine could peak around 3-4 ML/day. The large amplitudes in the predicted pit inflows are in part a modelling artifice, in that model pits are “opened” suddenly; in reality, actual pit inflows can be expected to be more subdued with time.

The Tarrawonga Coal Mine pit first encroaches on alluvium associated with Goonbri Creek in approximately Project Year 12 (2024). At this time there is a noticeable increase in pit inflow (of about 0.5 ML/day) due to excavation of the alluvium (**Figure A-41**). As demonstrated in **Figure A-41**, the presence of the low permeability barrier causes a reduction in peak mine inflow of about 2 ML/day.

An independent assessment of alluvial seepage with and without a low permeability barrier has been conducted by Allan Watson Associates (2011), in Appendix R of the EA, by applying the SEEP/W finite element code to an indicative cross section. Without the barrier, the predicted seepage is about 1.7 megalitres per day per kilometer (ML/day/km); for an open-cut face of about 2 km, the anticipated seepage is about 3.3 ML/day. This is a similar magnitude, but larger, than the value obtained by 3D MODFLOW-SURFACT modelling (about 2 ML/day). When the barrier is introduced, the seepage is reduced to about 0.05 ML/day/km which is about 0.1 ML/day for an open-cut face of 2 km. This is similar in magnitude to the value obtained by 3D MODFLOW-SURFACT modelling, which reports about 0.3 ML/day initially when mining first enters the alluvium, reducing to a negligible rate at the end of the Project.

It is not surprising that the models differ a little in the magnitude of predicted inflows. The SEEP/W model is 2-dimensional, with linear extrapolation to accommodate the third dimension, whereas the MODFLOW-SURFACT model is fully 3-dimensional. The models also differ in lateral model extent, so that one has imposed head boundary conditions while the other has dynamic heads computed in response to multiple recharge/discharge mechanisms. The MODFLOW-SURFACT model also accounts for upflow from deep layers.

A5.4 PREDICTED BASEFLOW CHANGES

Stream-aquifer water exchanges with alluvium have been examined for Goonbri Creek, Bollol Creek and Nagero Creek during the 22 years of model prediction. Only in the upgradient reaches of each creek does baseflow occur through groundwater discharge to each stream. For most of the length of each stream, water leaks through the stream bed to the underlying aquifer.

Figure A-42 shows the simulated stream leakage for Goonbri Creek and Bollol Creek. Goonbri Creek has an average leakage of about 260 kilolitres per day (kL/day) and is predicted to vary from about 230 kL/day to 330 kL/day due to the effects of mining and permanent Goonbri Creek alignment. Bollol Creek has an average leakage of 1760 kL/day and is predicted to vary by no more than 15 kL/day from the mean. Nagero Creek has a very low constant leakage of about 0.02 kL/day.

The changes in leakage from commencement of the Project (in model year 3) are shown in **Figure A-43**. The changes in Bollol Creek leakage are less than 1% in all years. Goonbri Creek shows an initial reduction in leakage (by 5% maximum) until mining enters the alluvium, at which time leakage from the creek increases by about 5%. The reason for the initial reduction in leakage is that the MODFLOW HFB package requires simulated slurry walls to be active for the entire simulation. The wall has the effect of raising some groundwater levels on its western side, thereby reducing the potential leakage rate from the creek. When the new alignment of Goonbri Creek is established, the new creek will have a different creek-aquifer interaction behaviour by virtue of passing over different ground and being situated in a different part of the groundwater flow field. It is not possible to make the usual comparisons of creek leakage/baseflow before and after mining, as the creek segments are necessarily different. All the model can say is that there is about 30% difference in the creek leakage characteristics for the two creeks, with higher leakage likely along the new alignment. However, this difference is not caused by the mining. From the perspective of an integrated water source, there is expected to be no net change. Along the new alignment the leakage is expected to be higher than along the original alignment, but this water will appear as extra storage in the aquifer system. One cannot expect any two creeks of similar length, passing over different ground, to give the same leakage rates. The difference here is due to the slightly higher natural ground levels along the new alignment (further east) and slightly higher stream stages in the model relative to the watertable. A head differential of 5 cm along the creek alignment is sufficient to account for the 30% difference. Volumetrically, this accounts to approximately 25 ML/annum, which when compared to the total alluvial aquifer storage within Bollol/Goonbri and Driggle Draggle Creeks Embayment is 0.002% to 0.003%.

A5.5 CUMULATIVE IMPACTS

Table A-16 illustrates the incremental effect on water balance components of neighbouring mining at Boggabri Coal Mine, Maules Creek Coal Mine and Rocglen Coal Mine. The coal exploration activities currently being undertaken by Goonbri Coal Company Pty Limited in the Goonbri Exploration License (EL 7435) area are not expected to have any additional cumulative groundwater impacts to those effects shown.

With all four mines operating, recharge will continue to be dominated by rainfall infiltration (42%), lateral boundary flow (31%) and river/creek leakage (27%) at almost the same rates. Groundwater pumping by production bores accounts for 56% of groundwater discharge from the model area. The other significant discharge mechanism is river/creek baseflow (28%). Average inflow to the four mines during the Project period is predicted to be about 4% of all groundwater discharge.

The neighbouring mines are predicted to make about 3 ML/day in addition to the mine inflow at Tarrawonga Coal Mine, on average. This increase in inflow is supplied primarily from storage and lateral boundary flow (extra 2.3 ML/day). There is expected to be a minor reduction in groundwater discharge to the rivers and creeks (0.1 ML/day) and also a slight increase in rainfall recharge (0.2 ML/day) due to infiltration through spoil.

Although **Figure A-41** is included primarily to demonstrate the sensitivity of Tarrawonga mine inflow to the low permeability barrier, the green and red data points/lines show the cumulative effect of neighbouring mines on mine inflow. It can be seen that, without the neighbouring mines in operation, the mine inflow at Tarrawonga Coal Mine could be expected to be about 0.1 ML/day higher in the last five years of mine life. This suggests that the neighbouring mines would have some drawdown effect at the location of the Tarrawonga Coal Mine, so that groundwater levels and hydraulic gradients would be reduced a little.

The predicted drawdown effects for the Project alone are contoured in **Attachment AC** for model layers 1, 2, 4, 6 and 8 for model years 5, 10, 15 and 19. Similarly, the predicted cumulative drawdown effects for all four mines are also contoured in **Attachment AC** for model layers 1, 2, 4, 6 and 8 for model years 5, 10, 15 and 19. The contour maps suggest that the model cannot resolve drawdowns of 1 m and less, as off-site drawdowns of 1 m appear as numerical "noise".

Close to the Tarrawonga Mine site, for the Project alone, the 1 m drawdown extent for the alluvium/regolith watertable extends about 4 km to the north and east, and about 5 km to the west, with no extension to the south (due to truncation of target coal seams) (**Figure A-44**). **Figure A-45** shows the cumulative drawdown in the watertable with all mines operating, at the end of the Tarrawonga Project. There is a marginal increase in drawdown at Nagero Creek but no substantial differences close to the Tarrawonga Mine.

Figure A-46 shows the 1 m drawdown predictions for separate and combined mines as reported in three independent studies. The cumulative impact determined by the Maules Creek model and the current Tarrawonga model agree very well, with the current model giving a slightly smaller areal extent.

A5.6 SENSITIVITY ANALYSIS

Early model test runs without a low permeability barrier, and before the permanent Goonbri Creek alignment was implemented, demonstrated the necessity for the installation of a barrier to isolate Goonbri Creek alluvium from the progressing open pit and from the final void. **Figure A-41** (blue line) indicates that potential inflow to the pit, supplied largely from alluvium, is likely to exceed 2 ML/day unless mitigation is planned. For this reason, all subsequent modelling included a low permeability barrier in the base case.

The adopted hydraulic conductivity for the barrier is 0.001 m/day, approximately equal to 10^{-8} m/s. The barrier in the model fully penetrates alluvial Layers 1 and 2. **Figure A-41** demonstrates a significant reduction in mine inflow to less than 1 ML/day with a barrier in place. At the end of the Project, the inflow to the void is sourced from rock and spoil, with a negligible alluvial source component. This is in general agreement with the SEEP/W prediction of about 0.1 ML/day steady-state seepage (Section A5.3).

A sensitivity analysis was conducted for the circumstance of the low permeability barrier being more permeable by a factor of 10 (that is, 0.01 m/day or 10^{-7} m/s hydraulic conductivity). **Figure A-41** shows that with effectiveness of the barrier reduced, the pit inflow is still substantially lower than would occur without a barrier in place. In this circumstance, the marginal increase in pit inflow is about 0.5 ML/day.

A5.7 POST-MINING EQUILIBRIUM

A final void water balance was prepared by Gilbert & Associates (2011) (Appendix B of the EA) using a rainfall-runoff model. Estimates of groundwater inflow over time required as inputs to the model were provided by conducting a transient groundwater recovery simulation with the void treated as highly permeable water bearing material (K = 1000 m/day; Sy = 0.99). The ET package in MODFLOW was used to represent open water evaporation[9].

The results of the post-mining estimates of groundwater inflows are presented in **Table A-17**.

TCPL propose to manage the final void and its catchment configuration by changes to the final mine plan (e.g. partial backfill) and closure works to achieve a final void water level between 240 to 260 m AHD. Appendix B of the EA estimates that, with partial backfill, an equilibrium final void water level of 240 to 250 m AHD would be reached approximately 130 years after mining ceases. The final water level would be about 25 m lower than current watertable levels to ensure the void acts as a groundwater sink. The equilibrium long-term groundwater inflow to the void is expected to be about 0.3 ML/day.

The predicted watertable pattern is displayed in **Figure A-47** at 50 years and 200 years after the end of the Project. The contours confirm that final void will act as a sink for groundwater entering from the north and west, with the effects of the low permeability barrier evident in maintaining groundwater levels in the alluvial plains to the south and east.

[9] The ET surface was set at original ground level and the extinction depth was set at 300 m. This ensured maximum evaporative flux for all void water levels.

Table A-17. Post-mining Transient Simulation Results – Input to Rainfall-Runoff Model

RECOVERED WATER LEVEL (m AHD)	TARRAWONGA FINAL VOID Post-Mining Groundwater Inflow (ML/day)
178.9	1.08
203.1	0.28
225.0	0.10
234.9	0.12
245.1	0.22
253.4	0.29

A6 IMPACTS ON THE GROUNDWATER RESOURCE

A6.1 POTENTIAL IMPACTS ON GROUNDWATER

A6.1.1 Changes in Hydraulic Properties

There would be a change in hydraulic properties over the mine footprint where mine waste rock infills the excavation down to the floor of the mined coal seam. As mine waste rock would have a higher permeability than any natural material in this area, with the possible exception of alluvium, there would be associated reductions in hydraulic gradients in accordance with Darcy's Law. As one increases, the other must decrease to maintain the same flow.

The flattening of the hydraulic gradient in the mine waste rock material is evident in the spacing of the contours across the Boggabri Coal Mine and Tarrawonga Coal Mine infilled areas at the end of the Project (**Figure A-48)**.

Rainfall recharge is expected to be higher in the mine waste rock than in any natural local material.

A6.1.2 Changes in Groundwater Flow and Quality

As mining progresses, the void would act as a groundwater sink. This would cause a temporary change in groundwater flow direction, in places reversal of direction, until mining is completed and the aquifer system recovers to a new equilibrium (**Figure A-47**). As a possible response to mining from 2006 to date, the salinity at two interburden monitoring bores close to the mine has changed due to water being drawn in from adjacent lithologies (as discussed in Section A2.12).

The post-mining groundwater level pattern in **Figure A-47** shows that the final void would act as a permanent groundwater sink. The final water level in the void is expected to be about 250 m AHD, which is about 25 m lower than current levels in the alluvium.

The quality of the inflow water will be a mixture of the qualities of the waters in source lithologies, primarily coal and coal measures. These waters have similar ionic signatures with median EC ("salinity") values of about 1000 µS/cm in coal and about 2500 µS/cm in coal measures interburden (**Table A-6**). Given higher rainfall infiltration rates through mine waste rock, it is possible that the inflow waters could be freshened by lateral flow from mine waste rock to the void. Over time, the salinity in the final void will increase through evaporative concentration. As long as the void remains a groundwater sink, there will be no deleterious effect on the beneficial uses of any groundwater sources. Most waters are currently at the limit of potable use but are suitable for livestock, irrigation and other general uses. The median electrical conductivity in alluvium is about 2000 µS/cm.

As the final void would remain a groundwater sink, no long-term impacts to groundwater quality are expected as a result of the final void water quality.

Salinity in the partially backfilled final void is generally predicted to increase slowly with time, reaching about 5,000 mg/L after 350 years (Appendix B of the EA). Given the long time frame, it is expected that groundwater quality would not be impacted by final void water quality after mining.

A6.1.3 Geochemistry

Geochemical investigation undertaken in Appendix N of the EA (GEM, 2011) found that the overburden and interburden materials in the proposed pit extension areas are expected to be non-acid forming (NAF) with low potential for soluble salt generation. Some materials sampled close to seam levels had slightly increased sulphur concentrations, and these materials present a risk of being potentially acid forming (PAF) [low capacity]. As a high proportion of sampled material was found to be moderately or highly sodic, special procedures are recommended to counteract erosion potential on dump faces and pit walls to avoid consequent impacts on downgradient water quality.

Due to enhanced concentrations of sulphur, selenium and arsenic in coarse reject (chitter) samples, GEM (2011) recommended continuation of the practice of disposal in dedicated emplacements within the mined-out pits.

Based on these results, it is expected that use of the existing mine waste segregation and handling practices would be sufficient to maintain adequate control over Acid Rock Drainage risk on-site.

In consideration of the above, there would be negligible impacts to groundwater quality (either directly or via final pit voids) as a result of PAF [low capacity] material.

A6.1.4 Pit Inflows

Up to the end of mining, there would be a continuous loss of water from the aquifer system to the mining void. The porous rock system would be the groundwater source until Project year 12 (2024), from which point onwards the alluvium will be the primary source until the end of the Project. After the end of mining, long-term groundwater inflow will come from porous rock and waste rock sources, with negligible contribution from alluvium due to the effectiveness of the low permeability barrier.

The predictive simulation in Section A5.3 and the sensitivity analysis in Section A5.6 demonstrated that pit inflow is expected to vary between approximately 0.4 and 1.1 ML/day during the Project.

The year-by-year expected pit inflows (without mitigating effects from other mines) are listed in **Table A-18**.

Table A-18. Predicted Pit Inflows for Tarrawonga Coal Mine Acting Alone

Project Year	Calendar Year	Pit Inflow [ML/d]
1	2013	0.40
2	2014	0.55
3	2015	0.60
4	2016	0.63
5	2017	0.60
6	2018	0.50
7	2019	0.46
8	2020	0.60
9	2021	0.69
10	2022	0.69
11	2023	0.57
12	2024	1.11
13	2025	0.91
14	2026	0.85
15	2027	0.97
16	2028	0.89
17	2029	1.03

A6.1.5 Upper Namoi (Zone 4) Alluvium

The proposed extension of operations at the Tarrawonga Coal Mine will impinge on the Upper Namoi Zone 4, Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source in the vicinity of Goonbri Creek. This will occur from Project year 12 (2024) to Project year 17 (2029).

Water can be lost from the alluvial groundwater source by two mechanisms:

- Direct excavation as part of the mine pit; and
- Enhanced leakage from the alluvium to the underlying porous rock.

Based on a porosity ranging from 10 to 20%, approximately 1.4 GL to 2.8 GL of stored alluvial groundwater would be excavated during the life of the Project[10]. This volume would appear partly as mine inflows (Section A6.1.4) or as water contained in excavated material (i.e. remaining within vestiges of alluvium). For comparison purposes, the change in total alluvial aquifer storage volume for the maximum predicted inflows to the open cut (i.e. 198 ML/annum) is provided in Table A-19.

The direct loss of water from storage due to excavation of alluvium will occur from Project year 12 (2024) to Project year 17 (2029). After the alluvial material is removed, there will be minimal loss of water from any vestiges of alluvium that remain between the mine void and the low permeability barrier, and negligible losses from alluvium on the far side of the barrier.

[10] Basis: Area of Alluvium = 8.2 x 10^5 m^2; sediment thickness = 25 m; depth to water = 8m; saturated thickness = 17 m; porosity = 0.1-0.2.

Table A-19. Predicted Change in Total Alluvial Aquifer Storage Volumes

Upper Namoi Alluvium	Estimated Total Alluvial Aquifer Volume (GL)*	Change in Total Alluvial Aquifer Storage (%)
Within Model Extent	2,400 – 4,800	0.004 – 0.008
Within Bollol/Goonbri and Driggle Draggle Creeks Embayment	750 – 1,500	0.013 – 0.026

* Based on a specific yield ranging from 0.1 to 0.2.

The removal of alluvium will reduce rainfall recharge permanently by about 6 megalitres per annum (ML/a), assuming 1.2% infiltration over an area of about 8.2×10^5 square metres (m^2).

As mining progresses, an increase in natural leakage of groundwater from the alluvium to the underlying consolidated sediments would be expected. This has been examined for the Goonbri Creek alluvium to the east of the low permeability barrier. At the start of the Project, the model reports an upflow of about 1 kL/day from model layer 3 (conglomerate) to model layer 2 (alluvium).

At the end of the Project, the model reports net downwards leakage of about 12 kL/day, giving a net impact of about 13 kL/day (about 0.01 ML/day).

Watertable contour maps have been prepared for the alluvium in the vicinity of Tarrawonga Mine at the start of the Project, and at years 3, 8, 13 and 17 of the Project life. There is no significant change in the contour patterns. A comparison of contours at the start and end of the Project suggests no significant drawdown.

A6.1.6 Porous Rock

The current and proposed operations at the Tarrawonga Coal Mine lie within the NSW Murray-Darling Basin Porous Rock Groundwater Source.

Table A-18 shows that the average predicted pit inflow prior to Project year 12, when the pit will enter alluvium for the first time, is 0.5 ML/day with variation from 0.4 to 0.7 ML/day. The predicted flows from this source are low and steady, and will reduce during post-mining recovery.

A6.1.7 Potential Impacts on Registered Production Bores

The maximum regional drawdowns are expected within model Layer 8 (Upper Nagero seam). **Figure A-49** shows the drawdown magnitude and pattern for model Layer 8 at the end of Project year 17 (simulation year 19) with only the Tarrawonga Mine active, whereas **Figure A-50** shows the cumulative effect with all mines in operation. Drawdowns are naturally limited to the west by outcropping volcanics and to the east by the Mooki Thrust. However, they propagate readily to the north towards Maules Creek and are less than 1 m at the northern model boundary. Drawdown to the south of the Tarrawonga Coal Mine reduces sharply to less than 1 m beneath the alluvium associated with Bollol Creek, due to the faulting and erosion of the Upper Nagero seam.

There are 121 registered bores located within approximately 5 km of the Project, of which 37 are located on Whitehaven-owned land and 30 are on BCPL-owned land (**Figure A-11**). The predicted drawdown impacts of the Project are tabulated in **Attachment AD**. The single bore within the Leard State Forest (GW967859) must draw water from the porous rock source, if it is in use. At this location, the combined drawdown from all mines is expected to be about 20 m and the impact of the Tarrawonga Project alone is expected to be about 8 m. All other privately owned bores are sited in alluvium and it can be expected that they will draw water preferentially from alluvium. In all cases, the maximum drawdown at these sites is predicted to be no more than 1 m, which is well within the natural fluctuation in water levels.

The impact on the water level in each privately owned bore is expected to be negligible.

A6.2 POTENTIAL IMPACTS ON SURFACE WATERBODIES

The main local drainage systems associated with the Project area are Goonbri Creek, Bollol Creek and Nagero Creek. As the creeks descend onto the expansive alluvial flats below the Project area, they transition into relatively poorly defined drainage paths which become expansive ponded overland flow areas during and following heavy rainfall.

The Project includes realignment of Goonbri Creek and installation of a protective low permeability barrier between the final void and the permanent Goonbri Creek alignment. Once constructed, this clay/bentonite trench would impede flow of any groundwater from the alluvium to the void, thereby maintaining the stream-aquifer interaction status of the permanent Goonbri Creek alignment.

The stream-aquifer interaction status of several creeks has been examined in Section A5.4 and in **Figure A-42** and **Figure A-43**.

Bollol Creek is predicted to maintain its status as a losing stream with leakage rates varying by no more than 1%. Goonbri Creek, however, is predicted to have about 5% more leakage when mining first enters the alluvium, and about 30% more leakage when it follows the new alignment.

A6.2.1 Changes in Surface Water Quality

There are not expected to be any significant changes in the quality of groundwater as a consequence of the Project (Section A6.1.2), other than possible freshening over the mine footprint due to higher rainfall infiltration rates through mine waste rock.

As described in Section A6.1.2, no significant groundwater quality impact is expected from groundwater interactions with the final void water. Therefore, it is unlikely the water quality of any surface water body would be impacted via final void water migration through groundwater. Maintenance of the void as a groundwater sink will ensure that ambient groundwater flows towards the void rather than from the void towards surface water receptors.

As described in Section A6.2, the clay/low permeability barrier between the final void and the Goonbri Creek alignment would limit flow of any groundwater from the alluvium (and associated water quality effects) to the void.

Given the localised disturbance of open pit mining, and the demonstration of inconsequential changes in stream leakage, baseflow and groundwater quality, no effects on water quality of the adjacent creeks are anticipated as a consequence of excavation.

A6.2.2 Changes in Water Balance

The predictive simulation in Section A5.4 demonstrates that leakage from Goonbri Creek to the alluvial aquifer will increase by less than 0.02 ML/day (in Model Years 14-16) due to mining, and by less than 0.1 ML/day (in Model Years 17-22) due to a change in creek alignment (**Figure A-42**). No measurable change is expected for Bollol Creek or Nagero Creek, or for the more distant Namoi River.

With only the Tarrawonga Coal Mine operating, recharge is dominated by rainfall infiltration (43%), lateral boundary flow (30%) and river/creek leakage (27%). Groundwater pumping by production bores accounts for 58% of groundwater discharge from the model area. The other significant discharge mechanism is river/creek baseflow (28%).

Average mine inflow during the Project period is predicted to be about 1% of all groundwater discharge. There is expected to be a mild increase in mine inflow from about 0.4 ML/day at the start of the Project to a maximum of about 1 ML/day. Most of this water will be supplied initially from porous rock and alluvial storage.

The aquifer system, on the whole (over the model area), is being managed with a significant reliance on groundwater held in storage, if production bores continue to operate at 2010 rates as assumed for the prediction simulations.

These figures suggest that the Project would have a minimal effect on the water balance component relativities.

A6.2.3 Effects on Surface Ecosystems

Given the localised disturbance of open pit mining, and the demonstration of inconsequential changes in river leakage or baseflow, no effects on surface ecosystems are anticipated in relation to mining-induced changes to the water system.

A6.3 PROPOSED GROUNDWATER MONITORING PROGRAMME

The proposed groundwater monitoring programme for the Project is summarised in **Table A-20** and described below. The groundwater monitoring programme should augment the existing TCPL groundwater monitoring programme and utilise the results of other mine groundwater monitoring programmes in the vicinity of the Project (i.e. Boggabri Coal Mine and Maules Creek Coal Project). The groundwater monitoring programme should comply with the Murray-Darling Basin Groundwater Quality Sampling Guidelines (MDBC, 1997).

The groundwater monitoring programme should monitor groundwater conditions for changes as a result of mining and should include consideration of aquifer definition and interactions, strata hydraulic properties, expected drawdown extent and groundwater quality.

The results of the groundwater monitoring programme should be used to validate modelling predictions.

Table A-20. Proposed Groundwater Monitoring Programme

Parameter	Location	Timing
Piezometers (Groundwater Levels – m AHD)	• Existing monitoring network (TCPL and surrounding mines/projects).	• Quarterly - Project life.
	• Additional Alluvial groundwater system monitoring network (pit side and floodplain side of low permeability barrier).	• Years 10-17 and 2 years post-mining.
	• Additional Porous Rock groundwater system monitoring bores (floodplain side of low permeability barrier).	• Years 10-17 and 2 years post-mining.
	• Additional bore installations in the mine waste rock emplacement behind the advancing open cut.	• Progressive over the Project life.
Groundwater Quality (pH, DO, EC, TDS, Fe, Al, As, Mg, Mo, Se, Ca, Na, Cl, SO_4)	• At piezometers above.	• Quarterly for field pH and EC; six-monthly for laboratory analysis of full suite.
Mine Water Balance	• Measurement of volumes extracted from the open cut/sump to MWDs, pumped water, coal moisture, etc.	• Project life.

A6.3.1 Monitoring Piezometers

The existing TCPL network of piezometer installations should be augmented as mining progresses to the east, particularly prior to and during Years 12 to 17 of the Project (i.e. coincidental with the anticipated interaction with the Alluvial groundwater system) (**Table A-20**).

A network of piezometers should be installed at least two years prior to excavation of the saturated Alluvial groundwater system. The network of piezometers should be focussed on (**Figure A-51)**:

- monitoring the construction of the low permeability barrier (to quantify and validate the predicted short term/localised dewatering impacts);
- monitoring of groundwater levels and water quality in the Alluvial groundwater system on the pit side of the low permeability barrier as mining advances to the east (to validate the predicted mine inflow and dewatering rates);
- monitoring of groundwater pressures in the Porous Rock groundwater system/coal measures (to validate the predicted depressurisation effects at depth to the east or trigger appropriate responses);

- monitoring of groundwater levels and water quality in the Alluvial groundwater system on the floodplain side of the low permeability barrier as mining advances to the east (to validate the predicted negligible impacts or trigger appropriate responses).

The final location of piezometers should include consideration of site characteristics, their location relevant to the mine plan, access and site inspection.

Additional piezometers should also be installed into mine waste rock emplacement behind the advancing open cut to provide information on the recharge rates and mine waste rock permeabilities and to validate modelling assumptions and predictions.

Water level measurements should be automated with daily or more frequent recordings and should continue for at least two years following mining.

A6.3.2 Groundwater Quality

The groundwater monitoring network should be sampled for water quality on a regular basis during mining (e.g. quarterly), and for at least two years following mining. Groundwater quality samples should also be taken during drilling of any new/future piezometer or hydrogeological investigation bores.

Groundwater quality monitoring should include, but not necessarily be limited to, analysis of the following parameters: pH, dissolved oxygen, EC, TDS, iron, aluminium, arsenic, magnesium, molybdenum, selenium, calcium, sodium, chloride and sulphate. Analysis should be undertaken at a National Association of Testing Authorities (NATA) accredited laboratory. Water quality data should be evaluated as part of the AEMR process and should aim to identify any potential mining related impacts.

A6.3.3 Mine Water Balance

Water balances should be conducted continuously, accounting for all monitored volumes (including pit groundwater inflows/pumping records) and should be reported in the AEMR.

The water balance should be reviewed annually to confirm groundwater transmission characteristics and modelling predictions. Monitoring results which indicate anomalous/high groundwater inflows should be investigated. If anomalous/high groundwater inflows are detected, TCPL should notify and consult with the relevant regulator regarding further courses of action.

The Project water management system is discussed further in the Surface Water Assessment (Appendix B of the EA).

A7 CLIMATE CHANGE AND GROUNDWATER

The effects of climate change on groundwater are projected to be negative in some places on earth, but positive in other places. In the Netherlands, for example, beneficial effects are anticipated (Kamps et al., 2008). There it is expected that coastal water tables will rise but evapotranspiration will reduce in response to the adaptation of vegetation to higher levels of carbon dioxide. Modelling shows more pronounced seasonal watertable fluctuations by accounting for vegetation feedback mechanisms (Kamps et al., 2008). Plants are expected to have a lower water demand under higher carbon dioxide levels due to production of more biomass, increased leaf area index, and a shorter time to reach the saturation point for carbon demand (Kamps et al., 2008).

In New Hampshire USA, on the other hand, negative effects on the watertable are expected due to the onset of spring recharge 2 to 4 weeks earlier (Mack, 2008). This shift will allow a longer period for evapotranspiration prior to summer months, at which time groundwater availability is likely to decrease.

The modelling of climate change effects needs to take into account complex vegetation and hydrologic feedback mechanisms, coupled surface water and groundwater interactions, and inter-annual temporal variations. Very few modelling studies have been conducted so far. Hunt et al. (2008) reported on the difficulties to be overcome in doing comprehensive modelling using newly released integrated GSFLOW software (MODFLOW plus PRMS).

Order of magnitude estimates can be found by ignoring feedback mechanisms and changing the currently calibrated rain infiltration percentages. However, more intense rainfall events would be expected to increase fast runoff and lead to a reduction in infiltration. This should be taken into account to allow for short-term temporal variations.

Annual rainfall is expected to change by -10 to +5% by 2030 (Pittock, 2003) in parts of south-eastern Australia. In addition, annual average temperatures are projected to increase by 0.4 to 2.0 degrees Celsius (°C) (relative to 1990) at that time.

The approach taken for this assessment has been to conduct a transient simulation for the full prediction period for rainfall infiltration reduced by 20%.

The results of the climate change scenario analysis are summarised in **Table A-21** in terms of the percentage changes in pit inflow and percentage changes in leakage from the three creeks near the Tarrawonga Mine that drain into the Upper Namoi (Zone 4) Alluvium.

There is expected to be a maximum reduction in pit inflow of about 2% for 20% less recharge from rainfall. The simulated reduction in pit inflow is due to reduced groundwater levels adjacent to the final void.

Table A-21. Predicted Changes in Pit Inflow and Creek Leakage due to Climate Change

	Change in Mean Value	Change in Maximum Value
Pit Inflow	- 0.8 %	- 1.8 %
Goonbri Creek	7.6 %	1.8 %
Bollol Creek	0.8 %	0.7 %
Nagero Creek	0.0 %	0.0 %

Due to an anticipated reduction in watertable levels in the event of climate change, there is expected to be a maximum of about 2% increase in Goonbri Creek leakage and less than 1% increase in Bollol Creek leakage to the Upper Namoi (Zone 4) Alluvium. No change is anticipated for Nagero Creek leakage.

A8 MANAGEMENT AND MITIGATION MEASURES

TCPL should implement the proposed groundwater monitoring programme outlined in Section A6.3.

The numerical groundwater model developed as part of this groundwater assessment should be used as a management tool for validating the predicted groundwater impacts throughout the Project life. The results of the groundwater monitoring programme (Section A6.3) should be used to inform progressive development, verification and refinement of the numerical model. Revised outputs from the numerical model should be reported in subsequent relevant groundwater assessments over the life of the Project.

A8.1 SURFACE WATER FEATURES

As described in Section 2 of the Main Report of the EA, TCPL has committed to the development and construction of a low permeability barrier and permanent Goonbri Creek alignment to the east of the open cut extent. The key performance objectives of these works are described by Allan Watson Associates (2011) as being:

- to reduce the potential for local drainage of groundwater from the Alluvial groundwater system into the open cut mine pit during operational and post-closure periods;
- to reduce the potential for local instability of pit batters as a result of groundwater infiltration;
- to avoid and significantly reduce the risk of Goonbri Creek inflows reporting to the open cut mine pit, whilst ensuring that the hydrological character of the Goonbri Creek system is maintained in a permanent Goonbri Creek alignment and that the potential for loss of baseflow from Goonbri Creek to the mine workings (both operationally and post-closure) is reduced; and
- to reduce the potential for impacts on groundwater quality of the regional groundwater resource resulting from flow (if any) from the final void water level to the Alluvial groundwater system under post-closure conditions.

The numerical groundwater modelling conducted for this assessment, and the concept design study undertaken by Allan Watson Associates (2011), indicate that the low permeability barrier will significantly reduce local drainage from the Alluvial groundwater system into the open cut during operations and post closure. It is therefore recommended that:

- the low permeability barrier be conducted in accordance with the design criteria described in the concept design study prepared by Allan Watson Associates (2011);
- the low permeability barrier be constructed prior to mining in the saturated Alluvial groundwater system; and

- a comprehensive groundwater monitoring programme (Section A6.3) be established to measure the actual groundwater effects of the Project and to enable contingency measures to be implemented if the actual impacts exceed agreed trigger levels.

Other potential management measures (e.g. management of PAF [low capacity] material) are discussed in Appendix N of the EA and the proposed surface water monitoring programme is described in Appendix B of the EA.

A8.2 GROUNDWATER USERS

The numerical modelling indicates that the drawdown effects on groundwater users in the vicinity of the mine are not likely to be significant (that is, less than 1 m) and would not materially affect the existing or potential future beneficial use of groundwater (refer to Section A6.1.7). Notwithstanding the above, it is recommended that a comprehensive groundwater monitoring programme (Section A6.3) be established to monitor the groundwater effects of the Project (including triggers for investigation) and to enable contingency measures to be implemented in the event that agreed trigger levels are breached.

In the event that a complaint is received in relation to depressurisation of a privately-owned bore, well or spring by local groundwater users, the relevant data set should be reviewed by TCPL as part of a preliminary evaluation to determine if further investigation, notification and mitigation is required.

A8.3 GROUNDWATER LICENSING

As described in Section A2.8, an appropriate groundwater licence for the open cut mine pit at the Tarrawonga Coal Mine will be sought and obtained from the NOW pursuant to the *Water Management Act, 2000* once the *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* is commenced.

The predicted average annual groundwater volumes required to be licensed over the life of the Project and post-mining are summarised in **Table A-22**.

Table A-22. Project Groundwater Licensing Summary

Water Sharing Plan	Management Zone/ Groundwater Source	Predicted Average Annual Inflow Volumes requiring Licensing [ML/annum]*			
		Years 1 to 11	Year 12	Years 13-17	Post-Mining
NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011 [Draft]	Gunnedah-Oxley Basin - Namoi	Av. 209 Max. 252	209	209	Max. 167+
Upper and Lower Namoi Groundwater Sources 2003	Upper Namoi Zone 4 - Namoi Valley (Keepit Dam to Gin's Leap)	Negligible	198	Av. 142 Max. 169	Negligible

* Refer to Figure A.40 and Table A.17 for predicted groundwater inflows [total] over the life of the Project.

+ Groundwater inflows would reduce as the final void water level reaches equilibrium.

Whitehaven currently holds 526 megalitres (ML) of volumetric licence allocation in the Upper Namoi Zone 4 – Namoi Valley (Keepit Dam to Gin’s Leap) Groundwater Source. The allocation was approved on 14 October 2011 from WAL12622 (90AL806770) to WAL12714 (90AL807001).

A9 MODEL LIMITATIONS

Although MODFLOW-SURFACT is capable of simulating unsaturated conditions, the focus in this study has been on the saturated part of the groundwater system. Nevertheless, MODFLOW-SURFACT will report groundwater heads (equivalent to negative pore pressures) in dry portions of model layers.

At this stage the model has adopted laterally uniform properties in distinct lithologies within model layers and uniform rainfall recharge across five zones. As more data are gathered, the spatial distributions of aquifer properties can be refined.

Lower pit inflows can be expected as coal seam permeability reduces with depth, which has been applied in model Layers 8 and 10. At this stage, there is no hydrographic evidence for hydraulic conductivity reduction with depth, but this can be expected as mining proceeds to greater depths.

As there is limited knowledge of formation interface elevations and geometry in the Porous Rock groundwater system (i.e. beneath the Alluvial groundwater system) in the south of the model area near the Canyon and Rocglen Coal Mines, predictions in these areas should be regarded as indicative only.

With the exception of the Mooki Thrust, the model does not include structural features such as faults or dykes, except to the extent that they determine formation thicknesses observed in exploration holes. There is uncertainty as to their size, scale, vertical persistence, locations of smaller structures and whether they are resistive barriers or transmissive conduits. Geological structures are more likely to compartmentalise aquifers and thereby localise drawdown effects and limit pit inflows. However, where target coal seams are known to be truncated by faulting, the corresponding model layer is given interburden properties. By ignoring such structures in the model, predictions of pit inflow would tend to over-estimation, and predicted environmental effects are expected to be conservative. Geological features can be added to subsequent model revisions to refine prediction of effects on the groundwater system.

The model has experienced some numerical instability due most likely to the abutment of lithologies with properties that differ by orders of magnitude. This is reflected in spurious simulated drawdowns (in the order of 1 m) at large distances from the mine that cannot be the result of mining. As the numerical noise is not significant when compared with predictions of mining effects in the vicinity of the mine, local impact assessments are considered robust.

A10 CONCLUSIONS

Consistent with the relevant water sharing plans, the data supports two groundwater systems:

- **Porous Rock groundwater system** - including the coal measures of the Maules Creek Formation; and
- **Alluvial groundwater system** – associated with the low-lying floodplains of the Upper Namoi.

Mining since 2006 at Tarrawonga Coal Mine and previous mining at the Boggabri Coal Mine, provide strong hydrographic evidence of mining effects on the Porous Rock groundwater system, with no discernible effect on the Alluvial groundwater system.

The Project involves the advancing open cut mine pit to excavate and intercept a small portion of the Alluvial groundwater system. To avoid, and significantly reduce the risk of, higher groundwater inflows to the open cut mine pit from the Alluvial groundwater system during the life of the Project, and in the long term, a low permeability barrier is proposed. Based on the evidence from hydrographic data, field investigations and analytical review and experience at other similar projects in NSW and overseas, there is expected to be:

- negligible loss of groundwater yield to/from surface stream systems (i.e. Bollol Creek, Goonbri Creek[11], Nagero Creek and the Namoi River); and
- limited potential for reduction in groundwater levels or groundwater yield for groundwater users with privately owned bores in the Alluvial groundwater system.

These conclusions are consistent with and supported by the results of the numerical groundwater model, described below.

As would be expected, a lateral hydraulic gradient towards the open cut mine pit has developed and groundwater flow from the Porous Rock groundwater system would continue to move toward the open cut as mining progresses.

Based on the numerical groundwater modelling, there is expected to be:

- negligible drawdown in the aquifers of the Alluvial groundwater system;
- negligible impact on groundwater levels or groundwater yield for groundwater users with privately owned bores in the Alluvial groundwater system;
- a reduction in potentiometric head in the aquifers of the Porous Rock groundwater system to the east and north of the Project;
- negligible loss of groundwater yield to/from surface stream systems (i.e. Bollol Creek, Goonbri Creek[11], Nagero Creek and the Namoi River);

[11] Incorporating the permanent Goonbri Creek alignment.

- total pit inflows ranging between approximately 0.4 ML/day and 1.1 ML/day during the Project open cut operations;
- a final pit inflow in the order of 1.0 ML/day at the completion of mining (Year 17) reducing to about 0.3 ML/day once the final void water level reaches equilibrium over many decades;
- an average pit inflow of 0.7 ML/day during the 17 years of the Project; and
- negligible change in groundwater quality as a result of mining in the short term and in the long term.

A groundwater licence for the open cut mine pit inflows at the Tarrawonga Coal Mine should be sought and obtained from the NOW pursuant to the *Water Management Act, 2000* once the *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* is commenced.

Prior to mining in the saturated alluvial groundwater system associated with the Upper Namoi Zone 4 - Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source (i.e. approximately Year 12), TCPL should also obtain and hold appropriate volumetric licences in accordance with the legislative requirements of the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003*. Whitehaven currently holds 526 megalitres (ML) of volumetric licence allocation in the Upper Namoi Zone 4 – Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source. The allocation was approved on 14 October 2011 from WAL12622 (90AL806770) to WAL12714 (90AL807001).

The potential impacts of mining on surface water resources, other than those assessed within this report, are assessed in Appendix B of the EA.

A11 BIBLIOGRAPHY

Allan Watson Associates (2011) *Concept Design for Low Permeability Barrier and Permanent Goonbri Creek Alignment.* Report prepared for Tarrawonga Coal Pty Limited.

Australasian Groundwater and Environmental Consultants Pty Ltd (2010) *Continuation of Boggabri Coal Mine Groundwater Assessment.* Report prepared for Boggabri Coal Pty Limited.

Australasian Groundwater and Environmental Consultants Pty Ltd (2011) *Maules Creek Coal Project Groundwater Impact Assessment*. Report prepared for Aston Resources Limited

BoM (2009). "Climate Data Online", accessed September 2009, <http://www.bom.gov.au/climate/averages/>.

Coxhead, C. (2009) *Coal Resource Report for the Tarrawonga Open Cut Coal Mine and Adjacent Exploration Area, Gunnedah Coalfield, NSW, Australia*. Report prepared for Whitehaven Coal Limited.

Department of Land and Water Conservation (2002) *NSW State Groundwater Dependent Ecosystems Policy*.

Douglas Partners (2010) *Report on Hydrogeological Assessment for Rocglen Coal Mine Extension Project.* Report prepared for Whitehaven Coal Limited.

Geo-Environmental Management (2011) *Tarrawonga Coal Project – Geochemistry Assessment of Overburden, Interburden and Coarse Rejects.* Report Prepared for Tarrawonga Coal Pty Ltd.

GeoTerra Pty Ltd (2009) *Tarrawonga Coal Pty Ltd Surface Water and Groundwater 2006/2009 Monitoring Tri-annual Review, Boggabri, NSW.*

Gilbert & Associates (2011) *Tarrawonga Coal Project Surface Water Assessment*. Report Prepared for Whitehaven Coal Pty Ltd.

Groundwater Imaging (2011) *Goonbri Creek - Tarrawonga Coal Mine Transient electromagnetic groundwater investigation*. Report by Groundwater Imaging Pty Ltd for Whitehaven Coal Limited.

GSS Environmental (2011) *Rocglen Coal Mine Extension Project Environmental Assessment.* Report prepared for Whitehaven Coal Limited.

Hansen Bailey (2010a) *Continuation of Boggabri Coal Mine Environmental Assessment.* Report prepared for Boggabri Coal Pty Limited.

Hansen Bailey (2010b) *Maules Creek Coal Project Preliminary Environmental Assessment.* Report prepared for Aston Resources.

Hatton, T. and Evans, R. (1998) *Dependence of Ecosystems on Groundwater and Its Significance to Australia.* LWRDC Occasional Paper No 12/98.

Hunt, R. J., Walker, J. F. and Doherty, J. (2008) *Using GSFLOW to simulate climate change in a northern temperate climate*. In: Poeter, Hill, & Zheng, MODFLOW and More 2008: Ground Water and Public Policy - Conference Proceedings, Golden Colorado, 109-113.

Kamps, P., Nienhuis, P. and Witte, F. (2008) *Effects of climate change on the water table in the coastal dunes of the Amsterdam Water Supply*. In: Poeter, Hill, & Zheng, MODFLOW and More 2008: Ground Water and Public Policy - Conference Proceedings, Golden Colorado, 125-129.

Kruseman and de Riddler (1991) *Analysis and Evaluation of Pumping Test Data.* International Institute for Land Reclamation and Improvement. http://www2.alterra.wur.nl/Internet/webdocs/ilri-publicaties/publicaties/Pub47/Pub47.pdf

Mack, T. J. (2008) *Simulation of water use increases and potential climate change on the ground-water availability of southeastern New Hampshire*. In: Poeter, Hill, & Zheng, MODFLOW and More 2008: Ground Water and Public Policy - Conference Proceedings, Golden Colorado, 114. [Abstract]

McDonald, M.C. and Harbaugh, A.W. (1988) *MODFLOW, A Modular Three-Dimensional Finite Difference Groundwater Flow Model.* U.S. Geological Survey, Open File Report 91-536, Denver.

Minarco-Mineconsult (2011) *Tarrawonga Open Cut Coal Mine 2011 Life of Mine Plan*.

McNeilage, C. (2006) *Upper Namoi Groundwater Flow Model: Model Development and Calibration*. NSW Department of Natural Resources, draft report.

Murray-Darling Basin Commission (1997) *Murray-Darling Basin Groundwater Quality Sampling Guidelines*. Technical Report No. 3.

Murray-Darling Basin Commission (2001) *Groundwater Flow Modelling Guideline.* Canberra, August 2001, 125p. ISBN: 1876830166.

Murray-Darling Basin Commission (2005) *Murray Darling Basin e-Resources*. Website: http://www2.mdbc.gov.au/subs/eResource_book. Date Accessed: September 2011

Namoi Catchment Management Authority (2007) *Namoi Catchment Action Plan.* Namoi Catchment Management Authority. January, 2007.

Namoi Catchment Management Authority (2009) *Extractive Industries Policy.* November, 2009.

NSW Office of Water (2010) *Upper Namoi Groundwater Sources: Resource Condition Assessment Report – 2010.*

Pittock, B. (2003) (ed.) *Climate Change – An Australian Guide to the Science and Potential Impacts*. Australian Greenhouse Office.

RCA Australia (2005) *Groundwater Assessment of the Proposed East Boggabri Coal Mine.*

RCA Australia (2007) *Groundwater Monitoring Report, Tarrawonga Coal Mine.*

Resource Strategies (2010) *Tarrawonga Coal Mine Modification Environmental Assessment.* Report prepared for Whitehaven Coal Mining Pty Ltd.

R.W. Corkery & Co. Pty Limited (2005) *East Boggabri Joint Venture Environmental Impact Statement for the Proposed East Boggabri Coal Mine.* Report prepared for East Boggabri Joint Venture.

R.W. Corkery & Co. Pty. Limited (2007) *Environmental Assessment of the Belmont Coal Project via Gunnedah.* Report prepared for Whitehaven Coal Mining Pty Ltd.

Schlumberger Water Services (Australia) Pty Ltd (2011) *Namoi Catchment Water Study Independent Expert Phase 2 Report*. Report IINSW09/19 50371/P2-R1 prepared for Department of Trade and Investment, Regional Infrastructure and Services. August 2011.

Tarrawonga Coal Pty Ltd (2007) *Annual Environmental Management Report for the Tarrawonga Coal Mine (ML 1579).*

Tarrawonga Coal Pty Ltd (2008) *Annual Environmental Management Report for the Tarrawonga Coal Mine (ML 1579).*

Tarrawonga Coal Pty Ltd (2009) *Annual Environmental Management Report for the Tarrawonga Coal Mine (ML 1579).*

Tarrawonga Coal Pty Ltd (2010) *Annual Environmental Management Report for the Tarrawonga Coal Mine (ML 1579).*

Vickery Joint Venture (1986) *Environmental Impact Statement Namoi Valley Coal Project.*

Whitehaven Coal Mining Pty Ltd (2005) *Annual Environmental Management Report for the Canyon Coal Mine (MLs 1464 and 1471).*

Whitehaven Coal Mining Pty Ltd (2006a) *Annual Environmental Management Report for the Canyon Coal Mine (MLs 1464 and 1471).*

Whitehaven Coal Mining Pty Ltd (2006b) *Mining Operations Plan for the "Whitehaven" Open Cut Coal Mine.*

Whitehaven Coal Mining Pty Ltd (2007) *Annual Environmental Management Report for the Canyon Coal Mine (MLs 1464 and 1471).*

Whitehaven Coal Mining Pty Ltd (2008) *Annual Environmental Management Report for the Canyon Coal Mine (MLs 1464 and 1471).*

Whitehaven Coal Mining Pty Ltd (2009a) *Annual Environmental Management Report for the Canyon Coal Mine (MLs 1464 and 1471).*

Whitehaven Coal Mining Pty Ltd (2009b) *Annual Environmental Management Report for the Rocglen Coal Mine (ML 1620).*

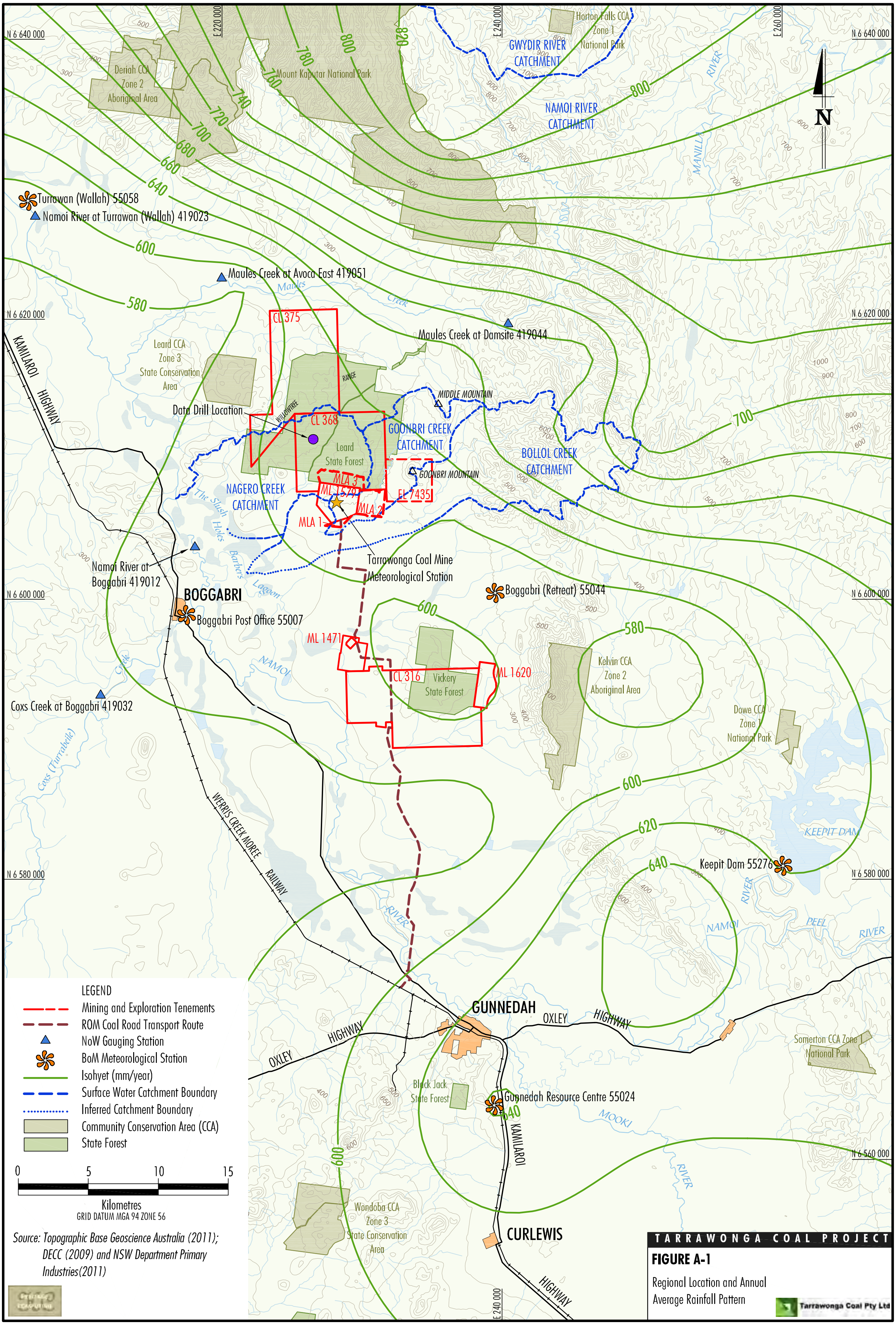
Whitehaven Coal Mining Pty Ltd (2009c) *Canyon Open Cut Coal Mine Closure Plan.*

Whitehaven Coal Mining Pty Ltd (2010a) *Annual Environmental Management Report for the Canyon Coal Mine (MLs 1464 and 1471).*

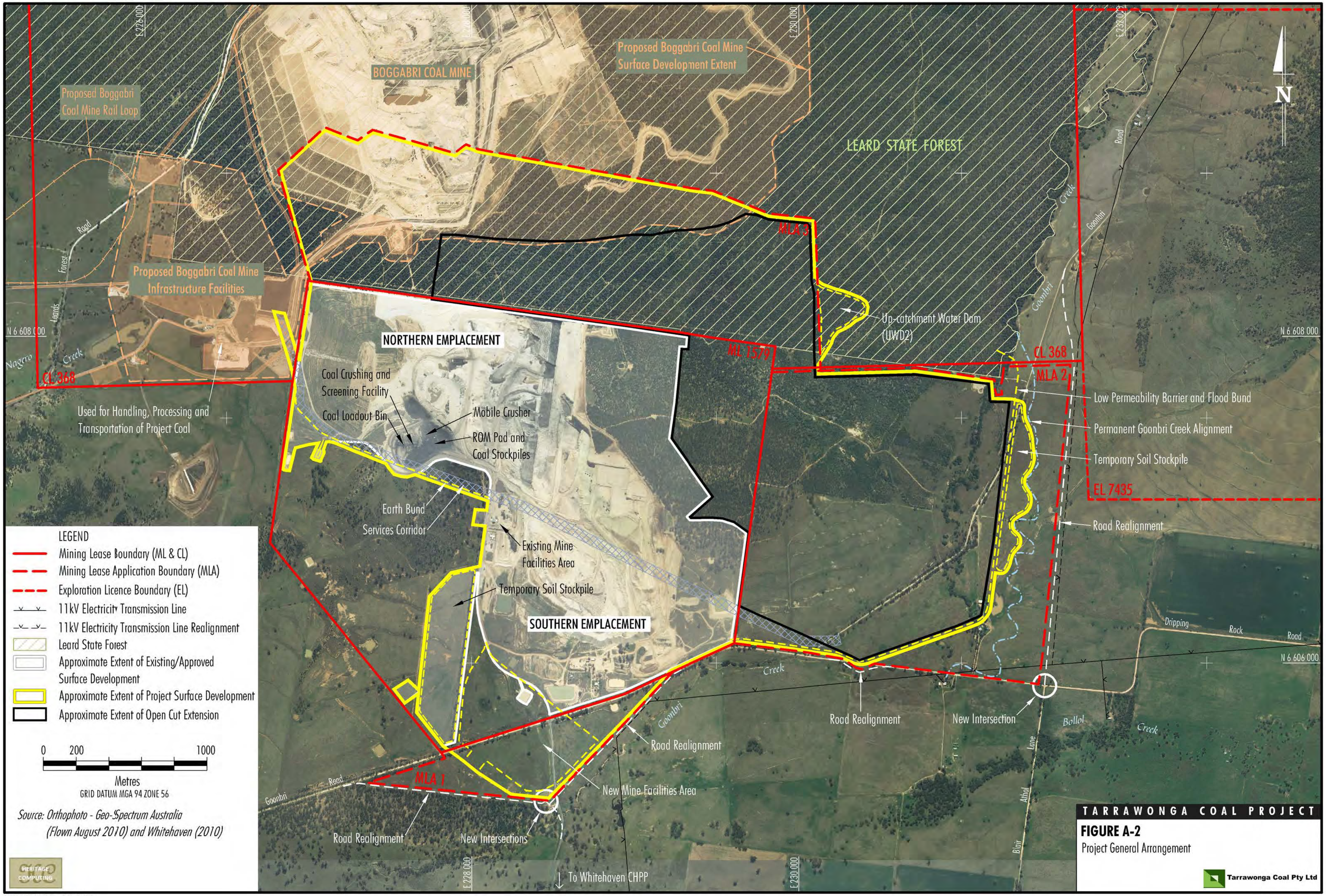
Whitehaven Coal Mining Pty Ltd (2010b) *Annual Environmental Management Report for the Rocglen Coal Mine (ML 1620).*

Whitehaven Coal Mining Pty Ltd (2011) *Water Management Plan.*

FIGURES



GWYDIR RIVER CATCHMENT
NAMOI RIVER CATCHMENT
Horton Falls CCA Zone 1 National Park
Deriah CCA Zone 2 Aboriginal Area
Mount Kaputar National Park
Turrawan (Wallah) 55058
Namoi River at Turrawan (Wallah) 419023
Maules Creek at Avoca East 419051
Maules Creek at Damsite 419044
Leard CCA Zone 3 State Conservation Area
Data Drill Location
CL 375
CL 368
Leard State Forest
GOONBRI CREEK CATCHMENT
MIDDLE MOUNTAIN
GOONBRI MOUNTAIN
BOLLOL CREEK CATCHMENT
NAGERO CREEK CATCHMENT
MLA 3
ML 1579
MLA 2
MLA 1
EL 7435
Tarrawonga Coal Mine Meteorological Station
Namoi River at Boggabri 419012
BOGGABRI
Boggabri Post Office 55007
Boggabri (Retreat) 55044
ML 1471
CL 316
Vickery State Forest
ML 1620
Kelvin CCA Zone 2 Aboriginal Area
Dawe CCA Zone 1 National Park
Coxs Creek at Boggabri 419032
KAMILAROI HIGHWAY
WERRIS CREEK MOREE RAILWAY
KEEPIT DAM
Keepit Dam 55276
NAMOI RIVER
PEEL RIVER
GUNNEDAH
OXLEY HIGHWAY
Somerton CCA Zone 1 National Park
Black Jack State Forest
Gunnedah Resource Centre 55024
MOOKI RIVER
Wondoba CCA Zone 3 State Conservation Area
CURLEWIS
LEGEND
Mining and Exploration Tenements
ROM Coal Road Transport Route
NoW Gauging Station
BoM Meteorological Station
Isohyet (mm/year)
Surface Water Catchment Boundary
Inferred Catchment Boundary
Community Conservation Area (CCA)
State Forest
0 5 10 15
Kilometres
GRID DATUM MGA 94 ZONE 56
Source: Topographic Base Geoscience Australia (2011); DECC (2009) and NSW Department Primary Industries(2011)
TARRAWONGA COAL PROJECT
FIGURE A-1
Regional Location and Annual Average Rainfall Pattern
Tarrawonga Coal Pty Ltd
WHC-10-04 EA AppGW_101E



TARRAWONGA COAL PROJECT

FIGURE A-2
Project General Arrangement

WHC-10-04 EA AppGW_102D

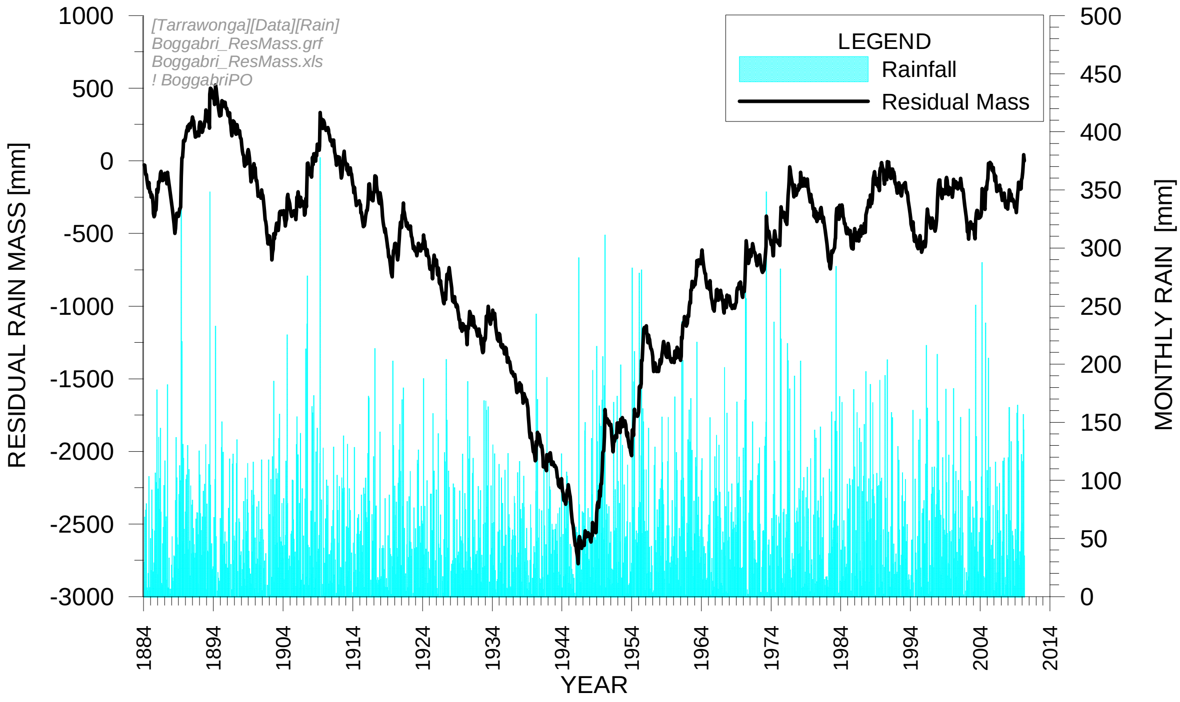


Figure A-3. Rainfall – Residual Mass Curve for Boggabri Post Office (since 1884)

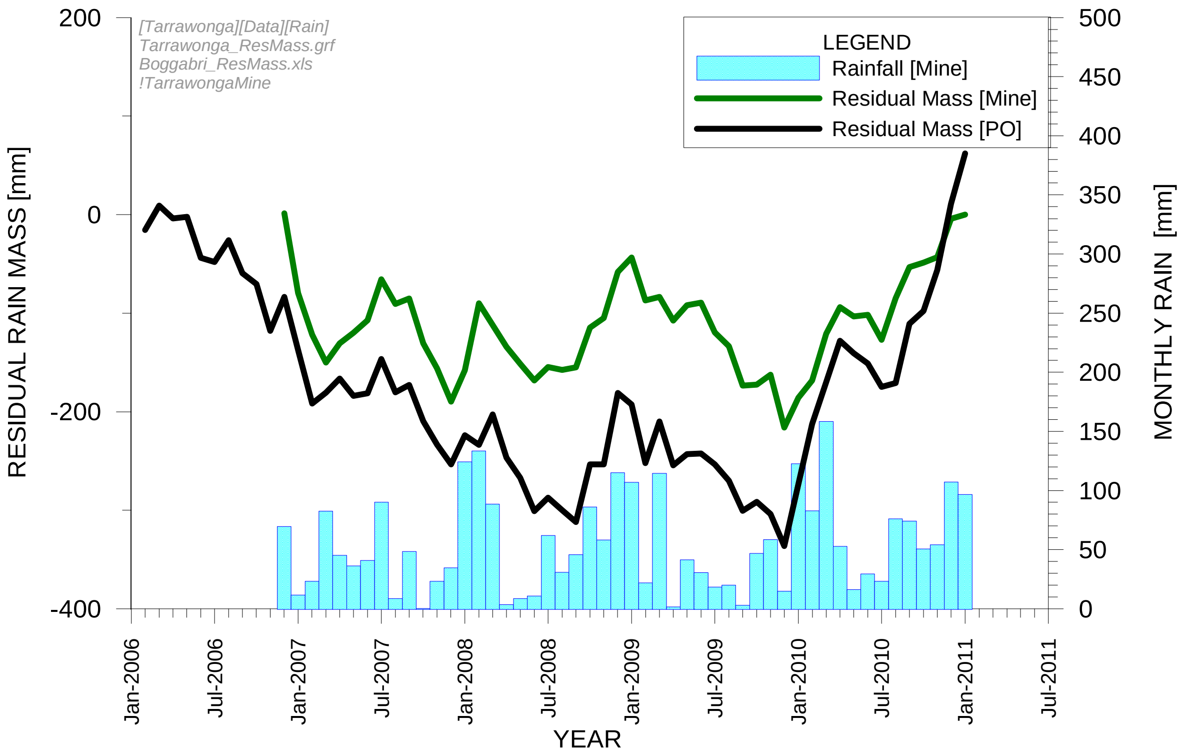
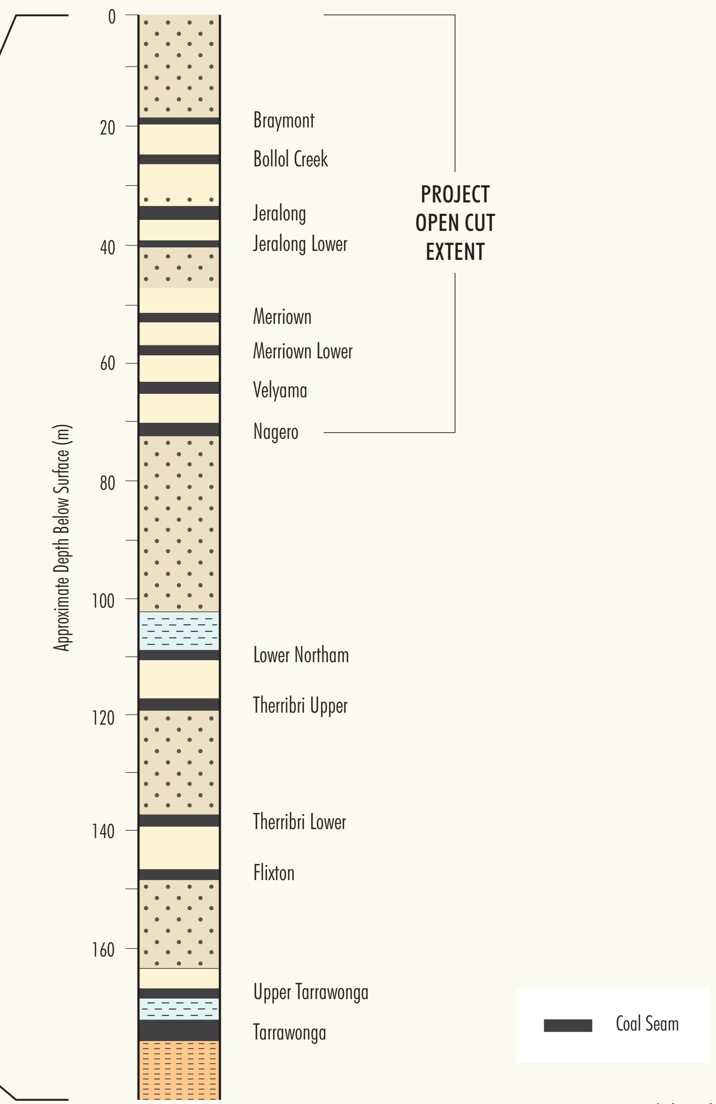


Figure A-4. Rainfall – Residual Mass Curves for Tarrawonga Coal Mine Meteorological Station and Boggabri Post Office (since 2006)

BASIN	PERIOD		GROUP/FORMATION	
GUNNEDAH	TRIASSIC	MIDDLE	Napperby Formation	
		EARLY	Digby Formation	
	PERMIAN	LATE	Black Jack Group	
		EARLY	Millie Group	
			Bellata Group	Maules Creek Formation
				Goonbri Formation
				Leard Formation
			Boggabri Volcanics	



Source: Minarco-Mineconsult (2011) and NSW Industry and Investment (2011)

TARRAWONGA COAL PROJECT

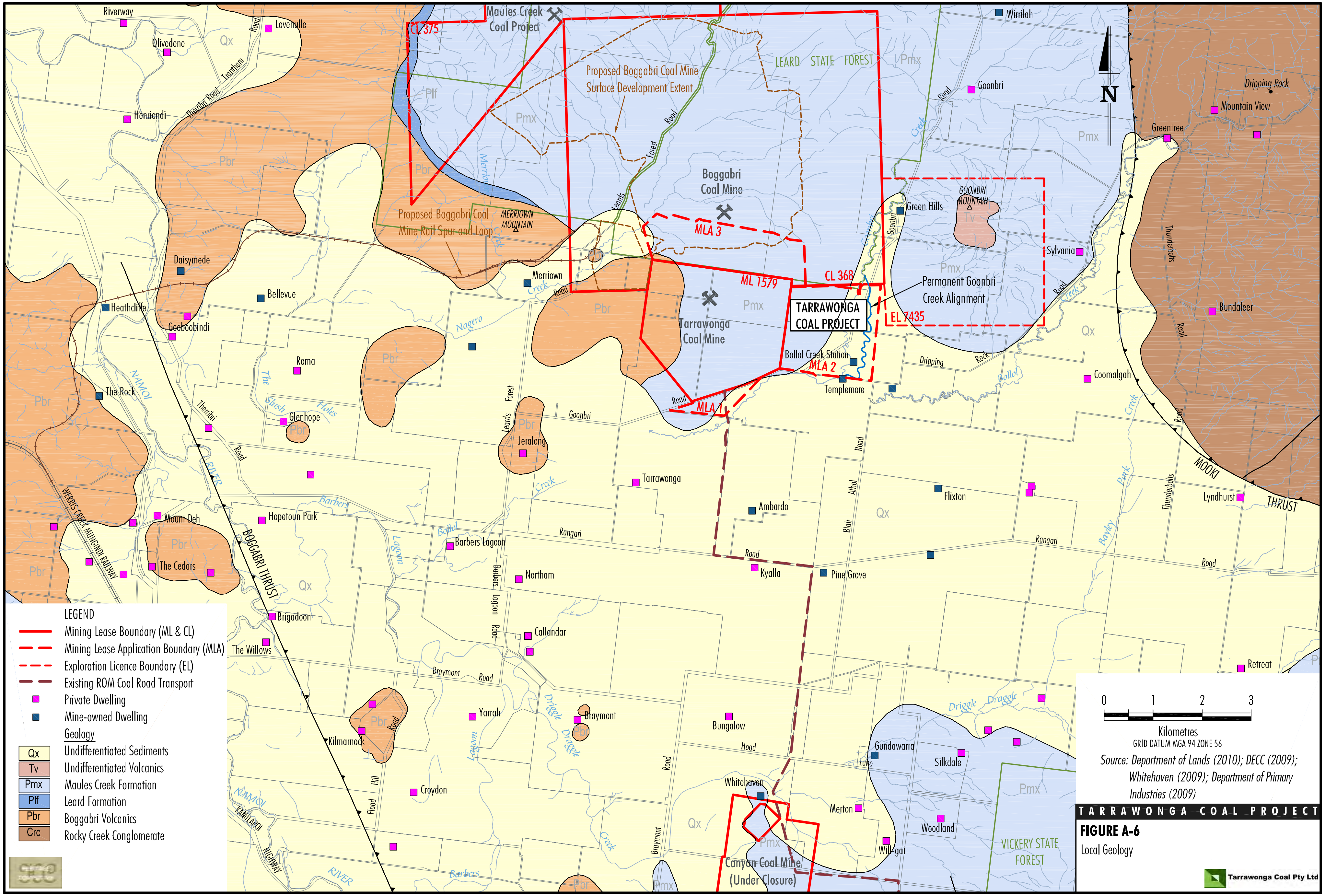
FIGURE A-5

Stratigraphy of the Project Area

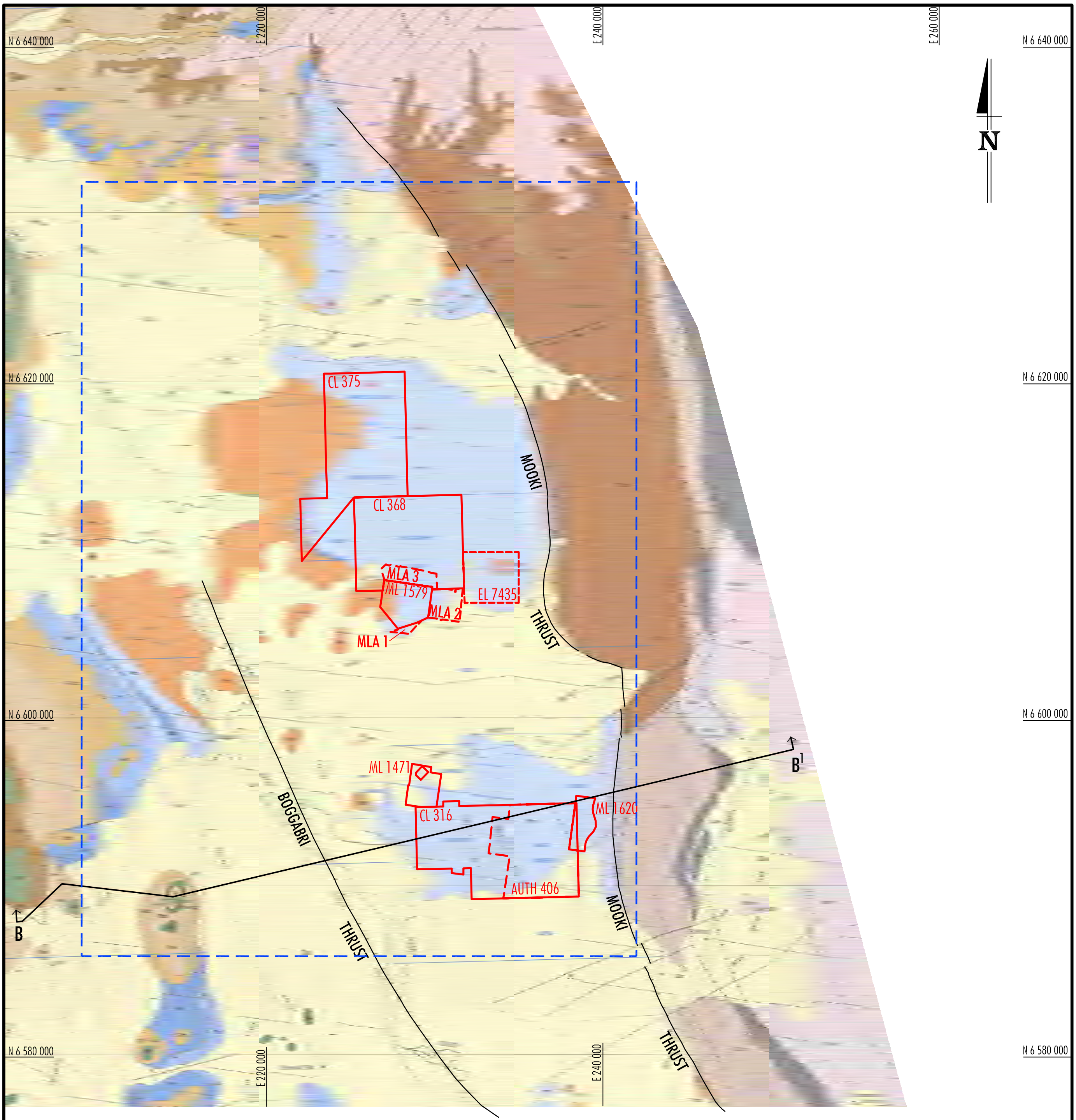
Tarrawonga Coal Pty Ltd

HERITAGE COMPUTING

WHC-10-04 EA AppGW_001D



WHC-10-04 EA AppGW_103F



LEGEND

Mining and Exploration Tenements

Approx Model Extent

Note: Refer Figure A-7b for Cross Section and Figure A-7c for Geology Legend

0 5 10 15

Kilometres

GRID DATUM MGA 94 ZONE 56

Source: NSW Department Primary Industries - Gunnedah Coalfield North 100k (2011)

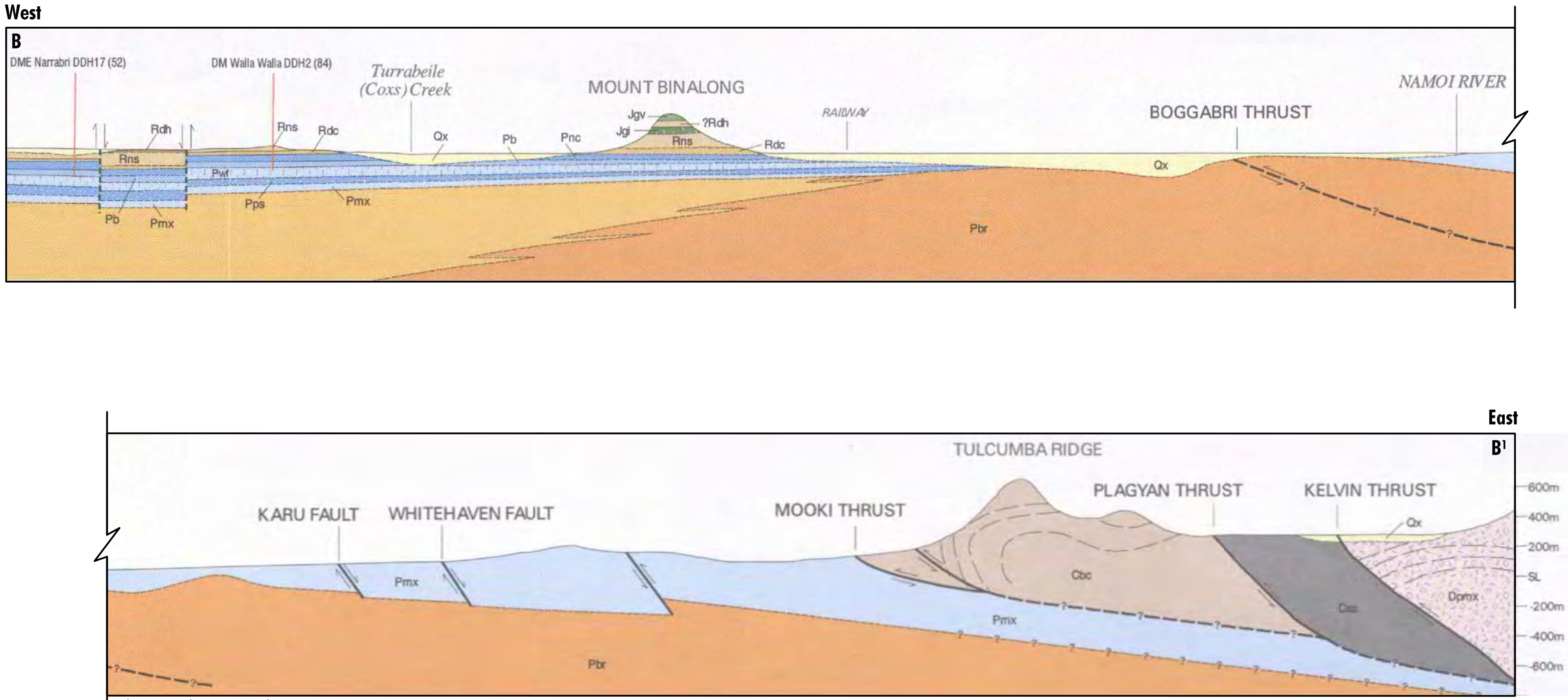
TARRAWONGA COAL PROJECT

FIGURE A-7a

Regional Geology - Fault Structures

Tarrawonga Coal Pty Ltd

WHC-10-04 EA AppGW_104E



Scale Ratio Vertical 0.4 = Horizontal 1.0

Note: Refer Figure A-7a for Cross Section location and Figure A-7c for Geology Legend.

TARRAWONGA COAL PROJECT

FIGURE A-7b

Regional Geology - Section B-B1

Tarrawonga Coal Pty Ltd

HERITAGE COMPUTING

WHC-10-04 EA AppGW_111C

REFERENCE

Era		Period		Group		Formation	Symbol	Lithology
CAINOZOIC		QUATERNARY				undifferentiated sediments	Qx	Undifferentiated alluvial deposits; includes Holocene alluvial channels and overbank deposits of sand silt and clay. Generally does not include residual and veneer colluvial deposits
CAINOZOIC		TERTIARY				undifferentiated sediments	Ts	Sand, sandstone, pebble sandstone, pebble to cobble gravels, and tuffs
CAINOZOIC		TERTIARY				Nandewar Volcanic Complex	Tn	Basalt, dolerite, teschenite, nephelinite or trachyte sills, dykes, plugs and flows
CAINOZOIC		TERTIARY				undifferentiated volcanics	Tv	Basalt, dolerite, teschenite, nephelinite or trachyte sills, dykes, plugs and flows
MESOZOIC	Surat Basin Units	JURASSIC				Orallo Formation	Jpo	Fine to coarse grained labile to sub-labile clayey sandstone with interbedded siltstone and mudstone
MESOZOIC	Surat Basin Units	JURASSIC				Pilliga Sandstone	Jps	Quartz pebble and quartzose sandstone with minor lithic sandstone and siltstone
MESOZOIC	Surat Basin Units	JURASSIC				Purlawaugh Formation	Jpx	Thin bedded lithic labile sandstone interbedded with siltstone and mudstone
MESOZOIC	Surat Basin Units	JURASSIC				Glenrowan Intrusives	Jgi	Sills and dykes of alkali dolerite and micro-syenodolerite
MESOZOIC	Surat Basin Units	JURASSIC				Garrawilla Volcanics	Jgv	Vesicular and non-vesicular, alkali olivine basalt, alkali basalt, hawaiite, mugearite, soda trachyte and interbedded pyroclastics
PALAEOZOIC	Gunnedah Basin Units	TRIASSIC	MIDDLE			Deriah Formation	Rdh	Fine to medium grained lithic sandstone rich in volcanic fragments with common mudstone clasts overlain by off-white lithic sandstone and dark grey mudstone
PALAEOZOIC	Gunnedah Basin Units	TRIASSIC	MIDDLE			Napperby Formation	Rns	Coarsening-up sequences of dark-grey siltstone/sandstone laminite overlain by parallel bedded or low-angle crossbedded quartzose sandstone
PALAEOZOIC	Gunnedah Basin Units	TRIASSIC	EARLY			Digby Formation	Rdc	Poorly sorted volcanic-lithic pebble orthoconglomerate overlain by massive, parallel or cross bedded coarse to fine grained quartz-lithic and then quartzose sandstone
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Nea Subgroup	Trinkey Formation	Pnc	Claystone, siltstone and fine grained sandstone intercalated with tuff, carbonaceous claystones and tuffaceous stony coal seams
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Nea Subgroup	Wallala Formation	Pnc	Fining up sequence of dominant lithic conglomerate, sandstone, siltstone, claystone and coal with minor tuff and tuffaceous sediments
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Coogal Subgroup	Clare Sandstone	Pnc	Medium bedded, cross stratified medium to coarse grained quartzose sandstone. Quartzose conglomerate locally developed
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Coogal Subgroup	Benelabri Formation	Pnc	Interbedded claystone, siltstone and fine grained quartzose sandstone and coal
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Coogal Subgroup	Hoskissons Coal	Pnc	Coal with subordinate layers of fine grained sandstone, carbonaceous siltstone and claystone, and tuff
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Brothers Subgroup	Brigalow Formation / Arkarula Formation	Pb	Fining-up sequence of medium grained quartzose sandstone and siltstone. Fining-up sequence of fine-medium lithic sandstone and siltstone with worm burrows
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Black Jack Group	Brothers Subgroup	Pamboola Formation	Pb	Lithic sandstone, siltstone, claystone, conglomerate and intercalated coals in generally coarsening-up and sporadic fining-up sequences
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Millie Group		Watermark Formation	Pwf	Fining-up sequence of intensely bioturbated silty sandstone to sandstone/claystone laminite with marine fossils overlain by finely laminated siltstone/claystone with little bioturbation, then by coarsening-up sequences of strongly bioturbated silty to sandy laminite
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	LATE	Millie Group		Porcupine Formation	Pps	Basal conglomerate passing upward into bioturbated silty sandstone and minor siltstone with dropped pebbles
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY	Bellata Group		Maules Creek Formation	Pmx	Basal carbonaceous claystone, pelletoidal clay sandstone, passing into fining-up cycles of sandstone, siltstone and coal. Conglomerate dominant towards top
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY	Bellata Group		Goonbri Formation	*	Carbonaceous siltstone and thin coal grading upwards to fine to medium sandstone
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY	Bellata Group		Leard Formation	Plf	Buff coloured flint (pelletoidal)claystone, conglomerate, sandstone and siltstone
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY			Werrie Basalt	Pwb	Basaltic lavas with intervening palaeosols and local thin coals
PALAEOZOIC	Gunnedah Basin Units	PERMIAN	EARLY			Boggabri Volcanics	Pbr	Rhyolitic to dacitic lavas and ashflow tuffs with interbedded shale. Rare trachyte and andesite
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Currabubula Formation	Cbc	Paraconglomerate, orthoconglomerate, crossbedded feldspathic and lithic sandstone, siltstone, mudstone and minor limestone. Felsic ashflow and airfall tuff, rhyolitic to andesitic crystal and vitric tuff
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Lark Hill Formation	Cls	Feldspathic arenite, litharenite, subordinate orthoconglomerate and paraconglomerate, siltstone, rhyodacite, and dacitic ashflow and airflow tuff
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Rocky Creek Conglomerate	Crc	Orthoconglomerate, minor feldspathic arenite and litharenite, siltstone and intermediate ashflow tuff
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Plagyan Rhyodacite Tuff Member	Crpr	Multiple beds of rhyolitic to andesitic crystal and vitric tuff
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	LATE			Clifden Formation	Cce	Crossbedded feldspathic and lithic sandstones, subordinate conglomerate, shale, rhyodacitic and dacitic airfall tuffs
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	EARLY			Caroda Formation: Barneys Spring Andesite Member	Cabb	Porphyritic andesite
PALAEOZOIC	New England Orogen Units	CARBONIFEROUS	EARLY			Caroda Formation	Cas	Crossbedded sandstone, minor lenticular oolitic limestone and magnetite sandstone, succeeded by coarse fluvial litharenite, conglomerate, shale, thin coal
PALAEOZOIC	New England Orogen Units	DEVONIAN	LATE	Parry Group		Mostyn Vale Formation	Dpmx	Pebbly lithic wacke, diamictite, lithic wacke, orthoconglomerate, olistostromal volcanic breccia, rhyodacitic to basaltic lavas, tuffs, agglomerates, rare limestones

* Known only from borehole data

Source: *NSW Department Primary Industries - Gunnedah Coalfield North 100k (2011)*

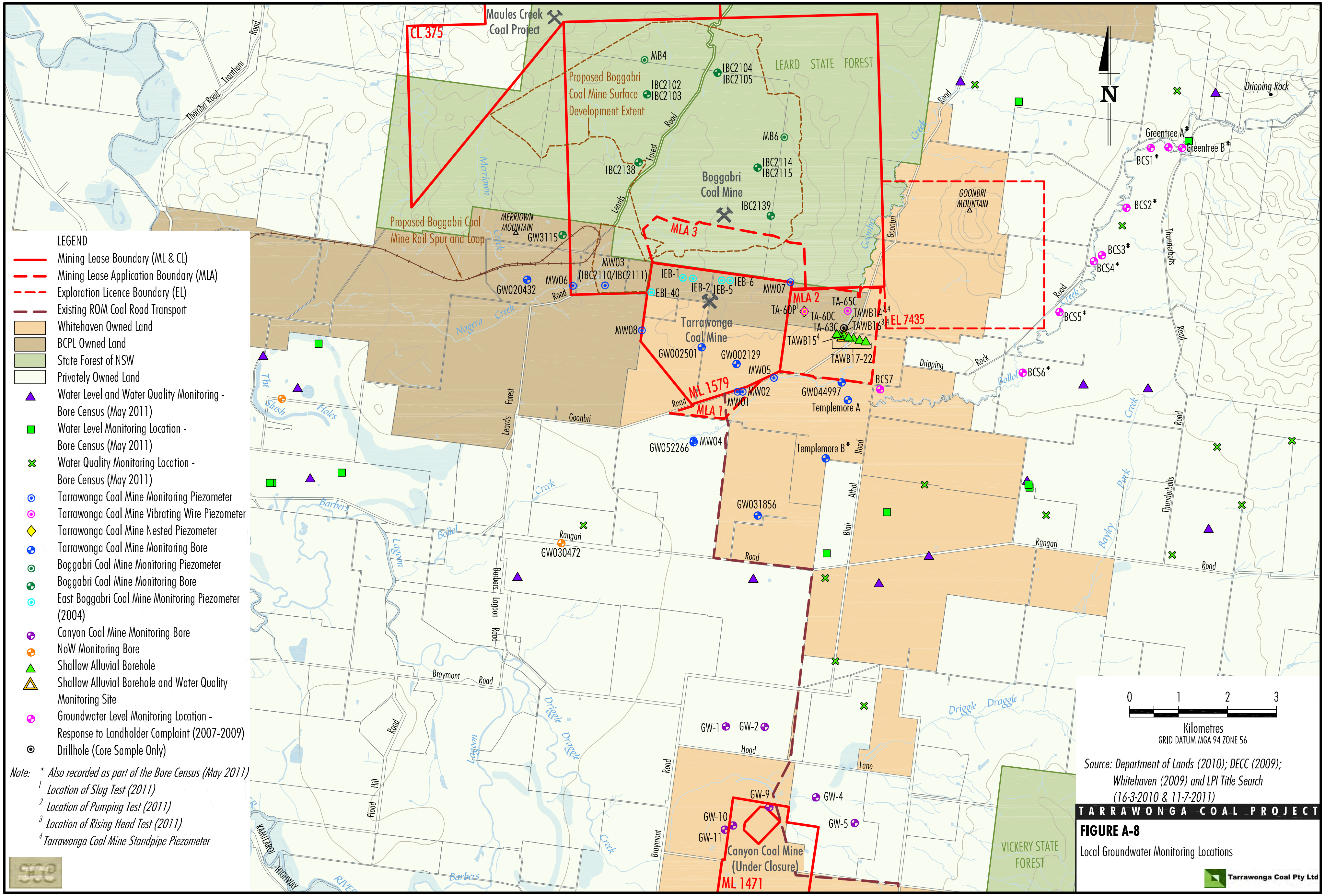
TARRAWONGA COAL PROJECT

FIGURE A-7c

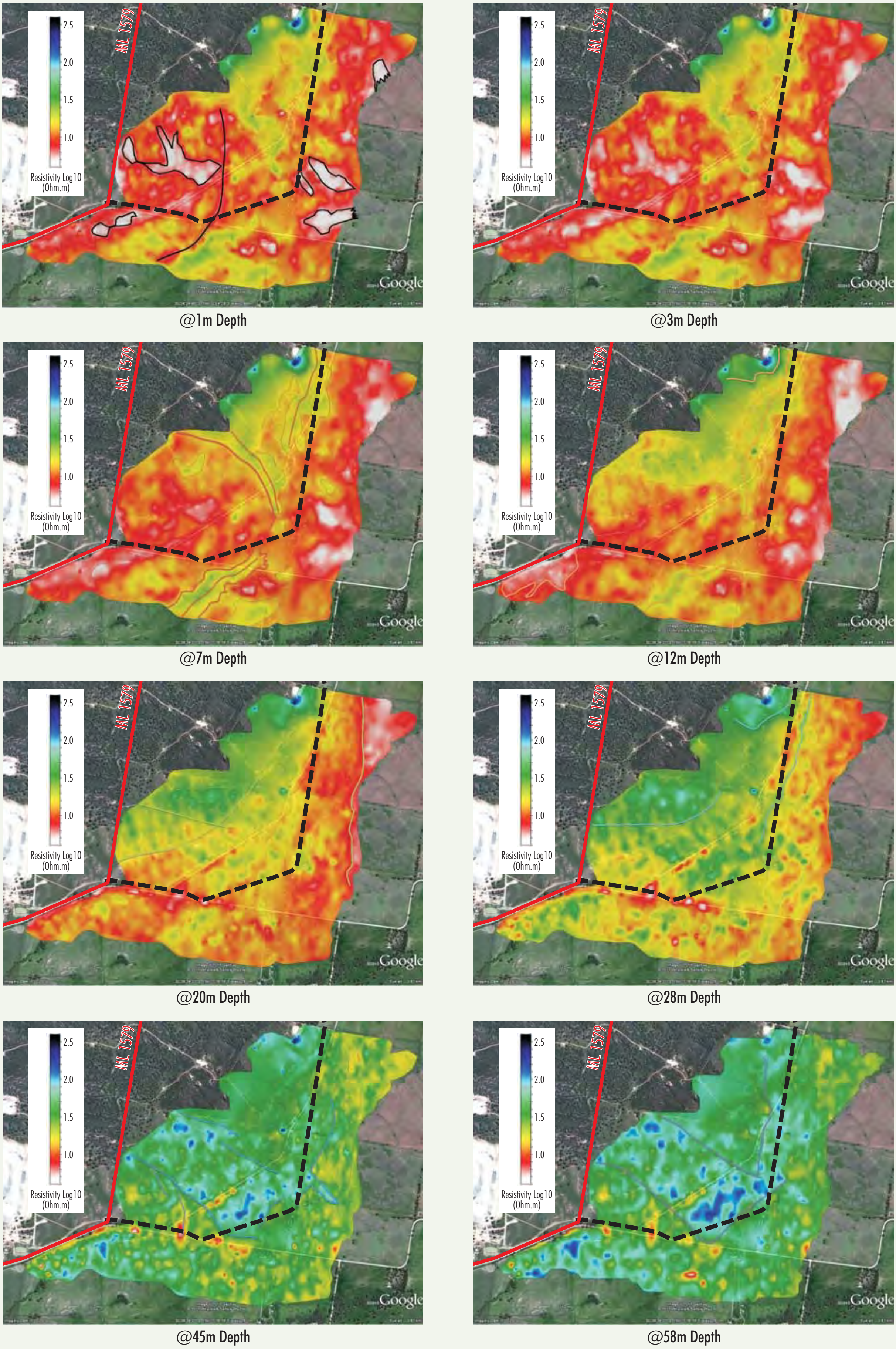
Regional Geology - Legend

Tarrawonga Coal Pty Ltd

WHC-10-04 EA AppGW_106C



WHC-10-04 EA AppGW_108L



Mining Lease (ML 1579)

Approximate Location of Low Permeability Barrier

0 200 1000

Metres

Source: Groundwater Imaging (2011)

TARRAWONGA COAL PROJECT

FIGURE A-9

TEM Survey Results

Tarrawonga Coal Pty Ltd

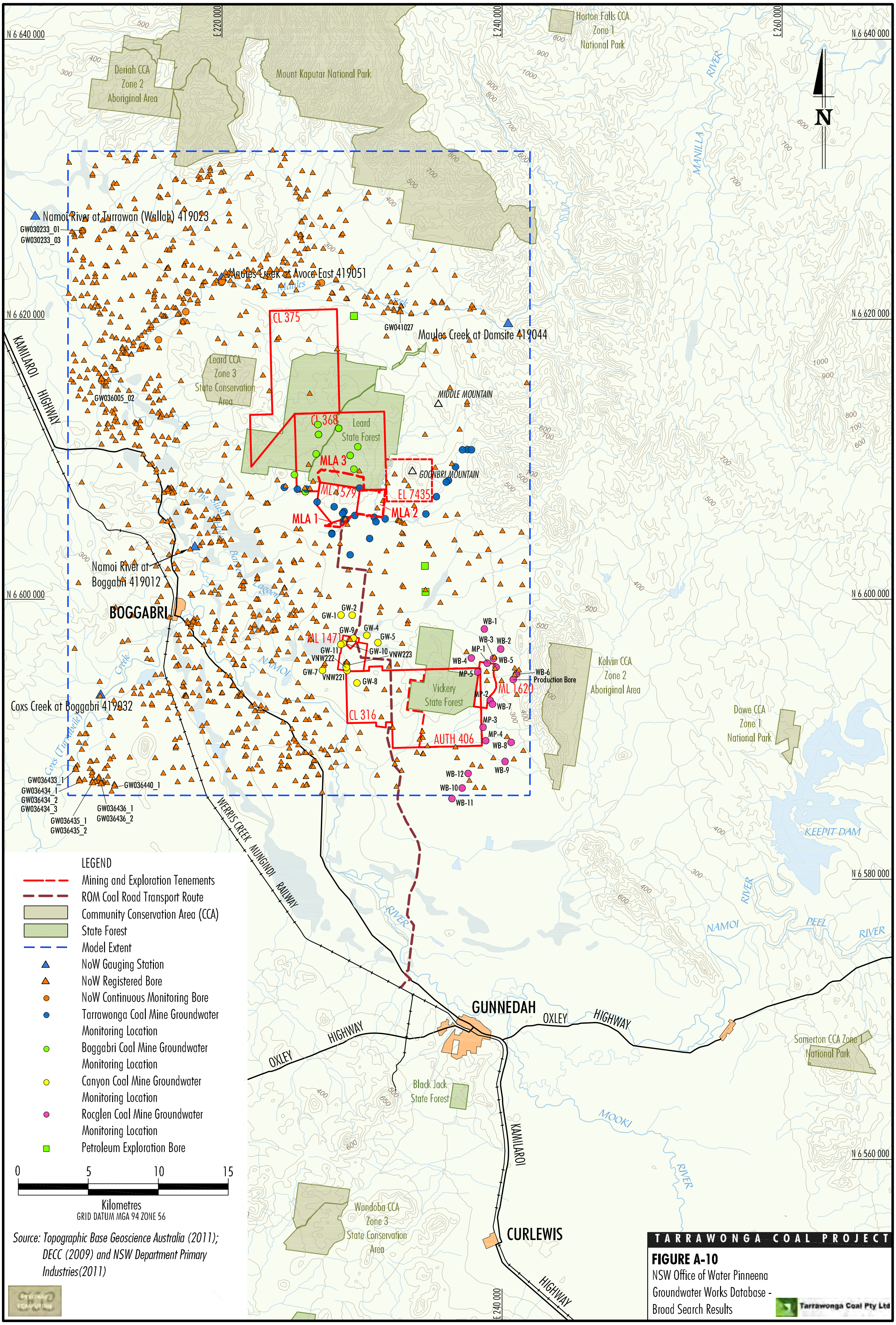


FIGURE A-10
NSW Office of Water Pinneena Groundwater Works Database - Broad Search Results

WHC-10-04 EA AppGW_105G

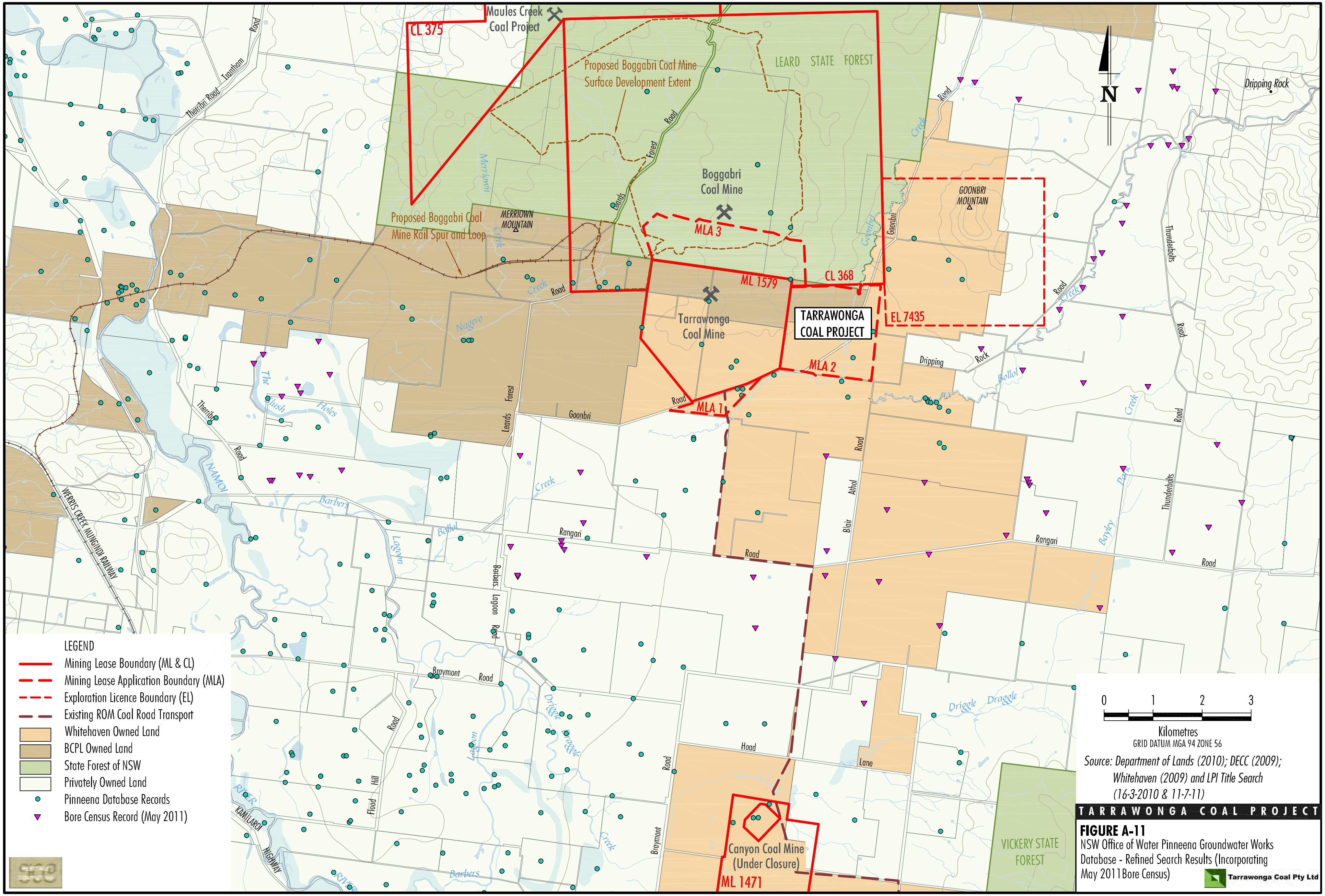
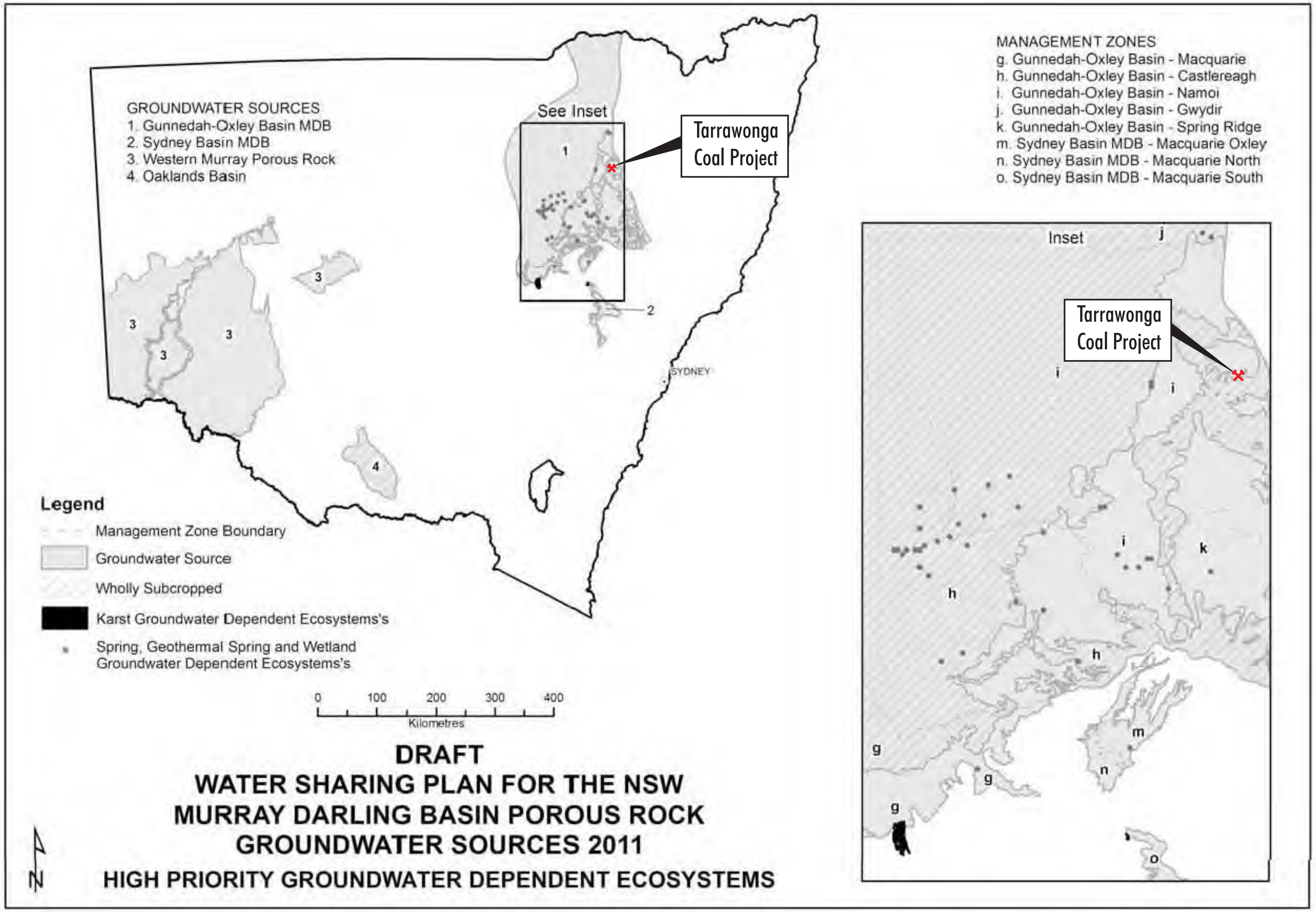


FIGURE A-11
NSW Office of Water Pinneena Groundwater Works Database - Refined Search Results (Incorporating May 2011 Bore Census)

WHC-10-04 EA AppGW_107G



Source: NSW Office of Water (2010)

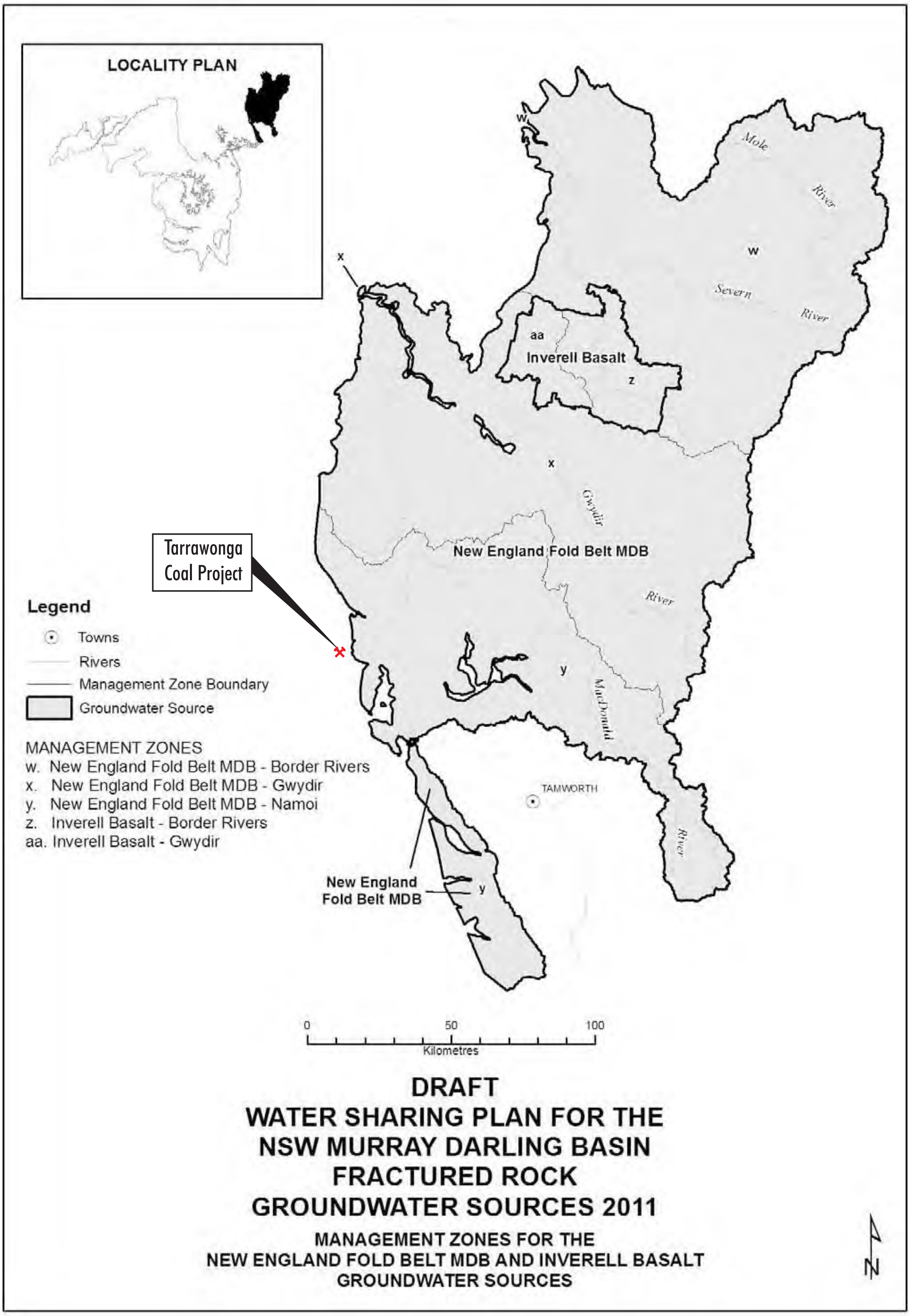
TARRAWONGA COAL PROJECT

FIGURE A-12
NSW Murray Darling Basin
Porous Rock Groundwater Sources

Tarrawonga Coal Pty Ltd

HERITAGE COMPUTING

WHC-10-04 EA AppGW_002B



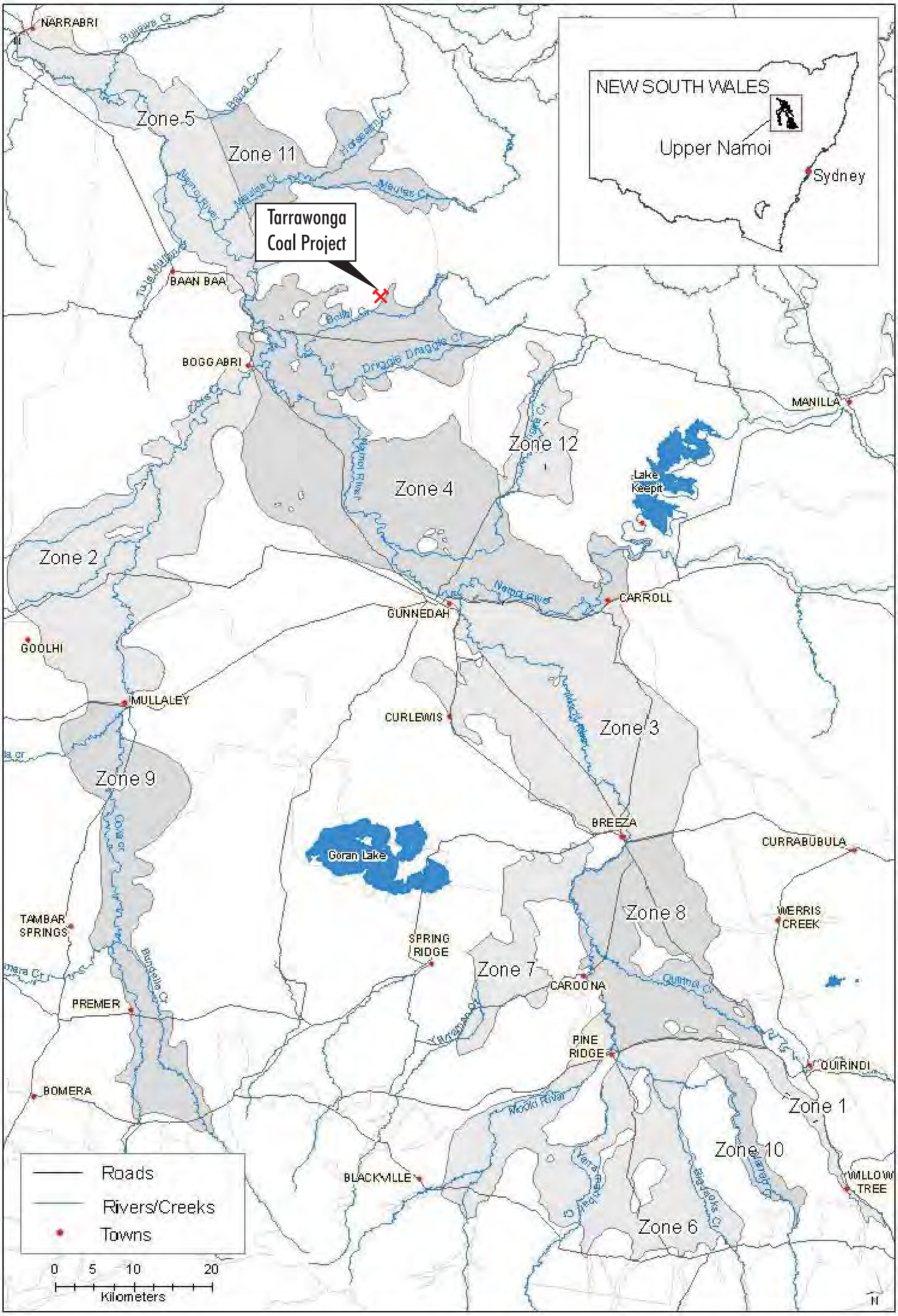
Source: NSW Office of Water (2010)

TARRAWONGA COAL PROJECT

FIGURE A-13
NSW Murray Darling Basin
Fractured Rock Groundwater Sources

Tarrawonga Coal Pty Ltd

HERITAGE COMPUTING



Source: NSW Office of Water (2010)

TARRAWONGA COAL PROJECT

FIGURE A-14

Upper Namoi
Groundwater Sources

Tarrawonga Coal Pty Ltd

HERITAGE COMPUTING