# Vickery Coal Project

# Environmental Impact Statement

## APPENDIX A

## GROUNDWATER ASSESSMENT

Resource Strategies

WHITEHAVEN COAL

**HERITAGE COMPUTING REPORT**

# VICKERY COAL PROJECT
# GROUNDWATER ASSESSMENT

FOR

WHITEHAVEN COAL LIMITED

**By**

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**Heritage Computing Pty Ltd**

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# A1 INTRODUCTION

Heritage Computing Pty Ltd (HCPL) has been engaged by Whitehaven Coal Limited (Whitehaven) to undertake a groundwater assessment as a component of the Environmental Impact Statement (EIS) for the proposed Vickery Coal Project (the Project). The EIS is to be lodged under Part 4.1 of the New South Wales (NSW) *Environmental Planning and Assessment Act, 1979.*

The Project area is located approximately 25 kilometres (km) north of Gunnedah in NSW. Whitehaven plans to develop the Project at the site of the former Vickery Coal Mine, which was operated during the 1990s. Whitehaven also owns and operates the Tarrawonga and Rocglen Coal Mines which are located approximately 10 km to the north and 5 km east of the Project respectively (**Figure A-1**). Whitehaven also continues to maintain the Canyon Coal Mine (where operations ceased in 2009), which is located to the immediate north of the Project (**Figure A-1**).

The Project would involve an open cut, waste rock emplacement areas, a Mine Infrastructure Area (MIA) and road diversions (**Figure A-2**). Mining would be conducted within:

- Mining Lease (ML) 1471;
- Coal Lease (CL) 316 (excluding the Vickery State Forest);
- Authorisation (AUTH) 406; and
- Mining Lease Application areas (MLA) 1, 2 and 3.

The Project would also involve construction of a 1 km long section of private haul road (including an overpass over the Kamilaroi Highway) between Blue Vale Road and the Whitehaven Coal Handling and Preparation Plant (CHPP), which is situated on the northern outskirts of Gunnedah (**Figure A-1**).

## A1.1 SCOPE OF WORK

The groundwater assessment of the Project comprised four stages:

1. Data Collation and Desktop Review;
2. Vickery Groundwater Investigation Program;
3. Numerical Modelling; and
4. Impact Assessment, Consultation and Reporting.

Stages 1, 3 and 4 were conducted by HCPL. Stage 2 was conducted by Groundwater Exploration Services Pty Ltd (GESPL).

The key tasks for this groundwater assessment are listed below:

- Characterisation of existing groundwater regime including identification of groundwater users (via a local area bore census) and potential groundwater dependent ecosystems in consultation with other relevant specialists.
- Collation, review and reporting of relevant background information including:
  - local and regional groundwater monitoring data;
  - mine dewatering records;
  - previous groundwater studies and impact assessments at the Vickery, Tarrawonga, Rocglen and Canyon Coal Mines and other mines in the wider region;
  - geological and hydrogeological mapping, drill logs and reports;
  - results of searches of NSW Office of Water (NOW) Pinneena Groundwater Works Database including registered bores and continuous monitoring data;
  - available records for groundwater users in the vicinity of the Project; and
  - other relevant reports and data.
- Review of the Project Groundwater Investigation Program findings.
- Development of a conceptual hydrogeological model.
- Development and calibration of a regional numerical groundwater model to predict potential impacts on local and regional groundwater resources associated with the Project.
- Simulation of the proposed Project during operations and post closure, taking into account the cumulative effects of nearby mining operations and other significant users of groundwater.
- Sensitivity analysis to demonstrate how the model responds to variations in key modelling parameters.
- Preparation of this groundwater assessment report for inclusion in the EIS that includes the following:
  - a detailed description of the hydrogeological characteristics of the Project area and surrounds;
  - a detailed analysis and assessment of the numerical model outputs, with particular attention to:
    - potential impacts on alluvial and hard rock groundwater sources;
    - potential impacts on other groundwater users;
    - the recovery of local and regional groundwater levels;
    - the post closure pit void water equilibrium level and chemistry; and
    - water management system implications of predicted mine inflow volumes;
  - a discussion of the sensitivity analysis and identification of the model constraints and limitations;
  - measures to avoid, mitigate and/or remediate potential impacts on groundwater resources; and

- a recommended groundwater monitoring program to measure potential impacts on groundwater resources.

In accordance with the NSW Department of Planning and Infrastructure (DP&I) Director-General's Requirements (DGRs) 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);
- NSW Aquifer Interference Policy (NOW);
- 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)*;
- *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* (NOW);
- 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);
- National Water Commission. Australian Groundwater Modelling Guidelines (Sinclair Knight Merz and National Centre for Groundwater Research and Training); and
- Draft Guidelines for the Assessment & Management of Groundwater Contamination (NSW Department of Environment and Climate Change [DECC]).

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

***Water Resources** – including:*

- *detailed assessment of potential impacts on the quality and quantity of existing surface and ground water resources, including:*
  - *detailed modelling of potential groundwater impacts;*
  - *impacts on affected licensed water users and basic landholder rights; and*
  - *impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including environmental flows;*
- *a detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures;*

- *an assessment of proposed water discharge quantity and quality against receiving water quality and flow objectives;*
- *assessment of impacts of salinity from mining operations, including disposal and management of coal rejects and modified hydrogeology, a salinity budget and the evaluation of salt migration to surface and groundwater resources;*
- *identification of any licensing requirements or other approvals under the* Water Act 1912 *and/or* Water Management Act 2000*;*
- *demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP) or water source embargo;*
- *a detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts; and*
- *a detailed flood impact assessment, which identifies impacts on local and regional flood regimes, including:*
  - *an assessment of the potential for flooding to occur in the open-cut pit; and*
  - *any measures proposed to mitigate potential flood impacts.*

The surface water components of the assessment are provided separately in the Project Surface Water Assessment (Evans & Peck, 2012) (Appendix B of the EIS).

This assessment has also been prepared in accordance with 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 Text of the EIS.

During the preparation of the EIS, an Environmental Risk Assessment was undertaken by SP Solutions in accordance with the DGRs (Appendix M of the EIS). This included a facilitated, risk-based workshop in July 2012 involving experts across a range of disciplines and experienced Whitehaven personnel. The objective of the risk assessment was to identify key potential environmental issues for further assessment in the EIS. The following key potential groundwater-related issues were identified and have been further assessed in this report:

- long-term changes to groundwater levels, flow direction and quality in the vicinity of the final void; and
- seepage from waste emplacements to alluvial materials adjacent to the Canyon Coal Mine final void leading to potential groundwater and surface water quality impacts.

### A1.2 PROPOSED MINE DEVELOPMENT

The main activities associated with the development of the Project are listed below:

- Development and operation of an open cut mine within CL 316, AUTH 406, ML 1471, MLA 1, MLA 2 and MLA 3 (**Figure A-2**).
- Use of conventional mining equipment, haul trucks and excavators to remove up to 4.5 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal and approximately 48 million bank cubic metres of waste rock per annum from the planned open cut.

- Placement of waste rock (i.e. overburden and interburden/partings) within external emplacements to the west and east of the planned open cut (i.e. Western Emplacement and Eastern Emplacement) and within mined-out voids (**Figure A-2**).
- Construction and use of a MIA, including on-site coal crushing, screening and handling facilities to produce sized ROM coal, workshops, offices and services (**Figure A-2**).
- Transport of sized ROM coal by haulage trucks to the Whitehaven CHPP on the outskirts of Gunnedah (approximately 20 km to the south of the Project open cut) for processing.
- Use of an 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 Project site.
- Use an on-site mobile crusher to produce up to approximately 90,000 cubic metres of gravel materials per annum for direct collection by customers at the Project site.
- Construction and use of water supply bores, and a surface water extraction point on the bank of the Namoi River and associated pump and pipeline systems.
- Construction and use of new dams, sediment basins, channels, dewatering bores and other water management infrastructure required to operate the mine.
- Construction and use of new soil stockpile areas, laydown areas and gravel/borrow areas.
- Construction of a 66 kilovolt (kV)/11 kV electricity substation and 11 kV electricity transmission line.
- Transport of coarse rejects generated within the Whitehaven CHPP via truck to the Project for emplacement within an in-pit emplacement area.
- Transport of tailings (i.e. fine rejects) generated within the Whitehaven CHPP via truck to the Project for emplacement within co-disposal storage areas in the open cut and/or disposal in existing off-site licensed facilities (e.g. the Brickworks Pit).
- Realignment of sections of Blue Vale Road, Shannon Harbour Road and Hoad Lane to the east and south of the open cut.
- Realignment of the southern extent of Braymont Road to the south of the open cut.
- Construction of an approximately 1 km long section of private haul road (including an overpass over the Kamilaroi Highway) between Blue Vale Road and the Whitehaven CHPP.
- Ongoing exploration, monitoring and rehabilitation activities.
- Construction and use of other associated infrastructure, equipment and mine service facilities.

The proposed life of the Project is 30 years. A detailed description of the Project is provided in Section 2 in the Main Report of the EIS.

## A2 HYDROGEOLOGICAL SETTING

### A2.1 OVERVIEW OF PREVIOUS GROUNDWATER ASSESSMENTS AND MONITORING PROGRAMS

A desktop review of the previous groundwater investigations, assessments and monitoring programs in the Project area and surrounds has been undertaken as part of this study. The relevant findings have been used to assist with the characterisation of the existing groundwater environment and in the regional numerical groundwater modelling and impact assessment.

The first assessments of the local hydrogeology and groundwater resources were undertaken in the early to mid 1980s as part of the original feasibility studies and environmental impact assessment of the Vickery Coal Mine. The studies included geotechnical, hydrogeological and hydrogeochemical studies undertaken by Coffey & Partners Pty Ltd (Coffey) (1982, 1984a, 1984b), as well as the EIS for the original Vickery Coal Mine (Vickery Joint Venture, 1986), which at the time was referred to as the ‘Namoi Valley Coal Project’.

The EIS for the original Vickery Coal Mine (Vickery Joint Venture, 1986) described two main groundwater systems as being present in the region:

- groundwaters associated with the unconsolidated alluvial sediments of the Namoi River floodplain which are characterised by high permeability and good water quality (i.e. less than 500 milligrams per litre [mg/L] Total Dissolved Solids [TDS]); and
- fractured hard rock groundwater systems with relatively low permeability with good to slightly brackish water quality (i.e. between 500 and 2,500 mg/L TDS).

The Coffey (1982) study broadly described the regional hydrogeology of the Namoi River floodplain upstream of Boggabri (i.e. the Upper Namoi Alluvium groundwater system). It described the groundwater system as being Cainozonic in age and consisting of two principal zones: an upper zone of sandy gravels which is widespread; and a lower zone of sands which is confined to a deeper ‘palaeochannel’. The lower zone was identified as having the highest groundwater potential. These two zones of the alluvial groundwater system are known as the Narrabri Formation (upper zone) and Gunnedah Formation (lower zone). The Namoi River was noted as being the major source of recharge to much of the alluvial groundwater.

The EIS for the original Vickery Coal Mine (Vickery Joint Venture, 1986) indicated that the Upper Namoi Alluvium groundwater system was sampled by a test bore located approximately 2 km to the south of the proposed mine. The main free yielding water bearing zone intersected by the test bore was described as occurring between 22 to 36 metres (m) from the surface and was comprised of cobbles, grading to gravels and sand. Pumping tests conducted at the time indicated that the groundwater in this zone could produce up to 5 megalitres per day (ML/day), with step testing indicating a long-term pumping rate of 2.4 ML/day.

The previous studies by Coffey (1982, 1984a, 1984b) and the Vickery Joint Venture (1986) also considered the local hydrogeology of the proposed Vickery Coal Mine site. The mine site was described as being situated within Permian-aged sedimentary rocks of the Maules Creek Formation, with the Namoi River floodplain and associated alluvium occurring to the north, south and west. A bore census conducted at the time indicated that 'unconfined' hard rock water bearing strata were present in the Maules Creek Formation at depths of 16 to 50 m, and usually occurred within weathered conglomerates and sandstones.

The quality of the hard rock groundwater was described in the EIS for the original Vickery Coal Mine as being of moderate to poor quality and unsuitable for domestic use, irrigation of salt sensitive crops and some industrial applications (Vickery Joint Venture, 1986). The water chemistry data indicated it was moderately saline, with high alkalinity and dissolved iron levels. TDS levels ranged between 900 and 5,700 mg/L (Vickery Joint Venture, 1986). A few bores equipped with windmills occur in the western portion of the Vickery area, but yields from these bores were noted as being low (i.e. in the order of 0.5 to 1 litres per second [L/s]).

Relevant pre-mine groundwater level and groundwater chemistry monitoring data obtained from the Coffey (1982, 1984a, 1984b) studies and the EIS for the original Vickery Coal Mine (Vickery Joint Venture, 1986) are discussed further in **Sections A2.13** and **A2.14** respectively.

Currently there is monitoring of water levels at the Canyon Coal Mine site (**Figure A-2**), which is located in the Permian-aged sedimentary rocks of the Maules Creek Formation to the immediate north of the Project area. Open cut mining operations at the Canyon Coal Mine commenced in 2000 and ceased in 2009. The site has been rehabilitated and is now in care and maintenance. Whitehaven monitors 11 groundwater bores in the vicinity of the Canyon Coal Mine site (i.e. GW1, GW2, GW4, GW5, GW7, GW8, GW9, GW10, GW11, VNW221, VNW223), and reports the results annually. The available monitoring results from the Canyon Coal Mine have been evaluated as part of this study and are discussed in **Section A2.13** (baseline groundwater level data) and **Section A2.14** (baseline groundwater chemistry data) where appropriate.

As described in **Section A1**, Whitehaven's Tarrawonga and Rocglen Coal Mines are located approximately 10 km to the north and 5 km to the east of the Project respectively. Groundwater impact assessments and numerical modelling have been conducted recently at both mines (Douglas and Partners, 2010; HCPL, 2011), and ongoing groundwater monitoring programs have been established by Whitehaven in accordance with the Project Approvals and licence conditions for each mine. Discussion of the numerical modelling and groundwater monitoring results at these existing mines is provided in **Section A4.2** (modelling), **Section A2.13** (baseline groundwater level data), and **Section A2.14** (baseline groundwater chemistry data) where appropriate.

Twenty baseline groundwater monitoring bores have been established in the past 24 months in the Vickery South area, which is located to the immediate south of the Project. These bores have been used to gather baseline groundwater information within the Upper Namoi Alluvium and Maules Creek Formation. The available monitoring results from the Vickery South area have been evaluated as part of this study.

The NOW Pinneena Groundwater Works Database contains information on groundwater works (e.g. their location, drillers logs, geologist logs, purpose of use, etc.), and water level and groundwater yield data for regional monitoring and production bores. In many cases, the regional monitoring bores provide continuous long-term groundwater level and quality data, particularly in the Upper Namoi Alluvium. The Pinneena database information for the Project area and the broader surrounds covered by the regional numerical groundwater model (i.e. 33 km by 29 km area) have been used in the numerical modelling and impact assessment where appropriate.

### A2.2 VICKERY GROUNDWATER INVESTIGATION PROGRAM

Based on the desktop review of the existing hydrogeological and monitoring information, a Groundwater Investigation Program was developed by HCPL and implemented by GESPL in order to gather additional information and to establish additional groundwater level and quality monitoring sites within and adjacent to the proposed Project area. The program included the following activities:

- installation of three vibrating wire piezometers (VWPs) (i.e. VKY3033, VKY3041 and VKY3053) and five standpipes (i.e. VKY34, VKY35, VKY36, VKY42 and VKY43) within the Maules Creek Formation within the proposed open cut extent;
- drilling and geological logging of 34 shallow investigation drillholes within the Upper Namoi Alluvium and weathered Maules Creek Formation strata within, and to the south of, the proposed open cut extent;
- conversion of four of the above shallow investigation holes to standpipe piezometers (i.e. TR7, TR18, TR26 and TR35);
- a pumping test at one of the drillholes to the south of the proposed open cut (i.e. VKY3092);
- drilling and logging of a shallow investigation drillhole within the Upper Namoi Alluvium to the west of the Western Emplacement (i.e. VNW385);
- monitoring of groundwater levels from installed bores;
- hydraulic testing and monitoring of some of the installed monitoring bores; and
- hydraulic testing of selected drillhole core from the Maules Creek Formation.

A copy of the Vickery Groundwater Investigation Program report (GESPL, 2012) is provided in **Attachment AA**, and the results are discussed where relevant in this document.

### A2.3 RAINFALL AND EVAPORATION

The Commonwealth Bureau of Meteorology (BoM) data has been obtained and used to evaluate the climatic conditions in the Project area and surrounds.

The Project area generally experiences a temperate climate. Boggabri Post Office, Boggabri (Retreat) and Turrawan (Wallah), the closest BoM rainfall gauges, have average rainfalls between 579 millimetres (mm) and 591 mm per year, with rainfall decreasing from north-east to south-west across the Project area (**Figure A-1**). The surface water assessment (Evans & Peck, 2012) has used the Boggabri (Retreat) station for runoff analysis.

Average potential (pan) evaporation at the Keepit Dam and Gunnedah Resource Centre stations (**Figure A-1**) is 1,825 mm and 1,752 mm per year, respectively. The average monthly rainfall and evaporation statistics from these stations are summarised in **Table A-1**.

**Table A-1. Average Rainfall and Evaporation Statistics**

| | **Average Monthly Rainfall (mm)** | | | **Average Monthly Evaporation (mm) *** | |
|---|---|---|---|---|---|
| **Station Name** | **Boggabri Post Office [55007]** | **Boggabri (Retreat) [55044]** | **Turrawan (Wallah) [55058]** | **Keepit Dam [55276]** | **Gunnedah Resource Centre [55024]** |
| January | 71.0 | 72.5 | 81.1 | 255.7 | 239.5 |
| February | 64.4 | 61.5 | 61.2 | 204.5 | 192.5 |
| March | 45.5 | 42.3 | 42.5 | 182.1 | 185.7 |
| April | 33.7 | 35.4 | 33.4 | 124.1 | 131.3 |
| May | 41.8 | 38.3 | 41.9 | 80.6 | 84.6 |
| June | 43.5 | 43.5 | 43.0 | 56.1 | 57.9 |
| July | 41.4 | 42.4 | 42.3 | 63.9 | 60.1 |
| August | 38.1 | 37.1 | 34.8 | 89.2 | 85.0 |
| September | 38.0 | 39.8 | 37.2 | 129.3 | 119.2 |
| October | 51.1 | 50.6 | 50.9 | 172.7 | 165.4 |
| November | 58.5 | 57.2 | 57.6 | 207.7 | 199.3 |
| December | 64.1 | 61.7 | 65.3 | 259.4 | 241.5 |
| **Annual Average (Total)** | **591** | **579** | **591** | **1,825** | **1,752** |

Sources: Gilbert & Associates (2011); Evans & Peck (2012)

* As measured by Class A Evaporation Pan.

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."*

Natural fluctuations in the watertable result from temporal changes in rainfall recharge to groundwater system. Typically, changes in the watertable elevation reflect the deviation between the long-term monthly (or yearly) average rainfall, and the actual rainfall, often illustrated by the Residual Mass Curve (RMC).

Groundwater levels recorded in shallower water bearing strata or sediments during periods of rising RMC are expected to rise while those recorded during periods of declining RMC are expected to decline. A RMC plot using rainfall data from the Boggabri Post Office since 1884 is shown on **Figure A-3**. This 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.

### A2.4 TOPOGRAPHY AND DRAINAGE

The Project is located in an area of mostly cleared, undulating land between the western boundary of the Vickery State Forest and the Namoi River (**Figure A-2**). The Vickery State Forest has a maximum elevation of approximately 479 m Australian Height Datum (AHD) (**Figures A-4, A-5** and **A-6**). A ridge runs diagonally from the Vickery State Forest in the north-east to the south-central part of CL 316 (**Figure A-6**). The minimum elevation in the vicinity of the Project area is about 245 m AHD on the floodplain near the Namoi River.

A number of ephemeral streams drain the Project area. In the surface water assessment report (Evans & Peck, 2012), they have been provisionally named as:

- North-West Drainage Line;
- West Drainage Line; and
- South Creek.

Off-site, the main local drainage systems in the vicinity of the Project are the Namoi River, Driggle Draggle Creek, and Bollol Creek that drains into Barbers Lagoon (**Figure A-4**). Stratford Creek, an ephemeral stream without a clearly defined channel, is aligned roughly with the southern boundary of the Project area (**Figure A-6**).

Other than the Namoi River, there are no flow gauges on any of the streams in the vicinity of the Project. The regional and local hydrological features are described in detail in Appendix B of the EIS.

### A2.5 LAND USE

The Project is located in a rural area characterised by cattle grazing and cereal/fodder cropping in the adjoining lower lying areas to the north, south and west. The Vickery State Forest lies to the immediate east of the Project (**Figure A-2**). With the exception of the forest, most of the land adjacent to the Project area has been cleared for agricultural purposes. Closer to the Namoi River, the availability of surface water and good quality groundwater has promoted irrigated agriculture.

A relatively large portion of the Project area that was previously disturbed by past mining activities is now rehabilitated (**Figure A-2**). Gently sloping, rehabilitated final voids remain where the former Canyon, Blue Vale and Greenwood open cut operations occurred. As described in **Section A1**, the two existing mining operations in the area are the Tarrawonga Coal Mine to the north and the Rocglen Coal Mine to the east (**Figure A-1**).

### A2.6 STRATIGRAPHY AND LITHOLOGY

The Project is located in the Gunnedah Basin, in the NSW Gunnedah Coalfield, which contains sedimentary rocks, including coal measures, of Permian and Triassic age. 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 dip towards the east and the south.

The targeted coal seams in the Project open cut extent are divided into upper and lower groups. The upper group of seams includes:

- Gundawarra Seam;
- Kurrumbede and Welkeree Seams;
- Shannon Harbour Upper Seam;
- Shannon Harbour Lower Seam; and
- Stratford Seam.

The lower group of seams includes:

- Bluevale Upper and Lower Seams;
- Cranleigh Upper Seam; and
- Cranleigh Middle and Lower Seams.

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 sedimentary rocks of the Permian-aged Maules Creek Formation. The broad valley and outflow plain areas on the lower slopes and surrounding the Project area comprise predominantly low lying undifferentiated colluvial and alluvial Quaternary sediments. Minor undifferentiated volcanic and igneous rocks of younger age form isolated outcrops in the surrounding area.

**Figure A-7a** is a plan of the regional geology and **Figure A-7b** is a regional cross-section through the Project area. **Figure A-7c** presents the legend for the regional geology maps.

The area included in the regional numerical groundwater model used for this study is also shown on **Figure A-7a**.

**Figures A-8a** and **A-8b** show the local geology of the Project area in plan view, and as cross-sections through the proposed open cut respectively.

### A2.7 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 structure which begins approximately 5 km west of the Project and continues to the south-east aligned with the Namoi River (**Figures A-7a** and **A-7b**).

The Mooki Thrust is a generally north-south trending structure which lies between the Rocky Creek Formation in the east and the Maules Creek Formation in the west (**Figures A-7a** and **A-7b**). 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 *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011*.

Named fault structures in the vicinity of the Project area from east to west are (**Figure A-8a**):

- Belmont Fault;
- Roseberry Fault;
- Woodlands Fault;
- Karu Fault;

- Whitehaven Fault System;
- Womboola Fault;
- Shannon Hill Fault; and
- Coalworks Fault.

### A2.8 ALLUVIAL GEOLOGY

The Project area is bordered by alluvial sediments which are associated with the Namoi River, Driggle Draggle Creek and Stratford Creek surface drainages (**Figure A-8a**). 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. **Figure A-9** shows the thickness of alluvium and regolith within and surrounding the Project area. As shown on the figure, the alluvial materials to the north of the Project area (i.e. between Driggle Draggle Creek and Bollol Creek) are typically 40 to 70 m thick, and to the south of the Project area, they are up to approximately 140 m thick.

As described in **Section A2.1**, alluvial sediments of the Upper Namoi Alluvium 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. The gravel and sand are the productive sediments from which groundwater is extracted for irrigation to the west and south of the Project area. The higher-elevation alluvial tongues along minor drainages are not as productive, have poorer water quality, and are suited for some stock and domestic use.

More broadly, the Upper Namoi Alluvium can reach maximum thicknesses of 170 m associated with the Namoi River (McNeilage, 2006). Separately, the Narrabri Formation has a maximum thickness of 70 m and the Gunnedah Formation peaks at 115 m (McNeilage, 2006). The combined thicknesses of the Narrabri Formation and the Gunnedah Formation are shown in **Figure A-9**. This shows thicknesses typically greater than 100 m along palaeochannels associated with ancient courses of the Namoi River and Coxs Creek.

To better define the geometry and properties of the alluvium to the immediate south of the Project area, Whitehaven installed five transects consisting of 33 shallow boreholes (TR1-TR35) as part of the Project Groundwater Investigation Program undertaken by GESPL (**Section A2.2**). The program also included downhole geophysical logging, a transient electromagnetic (TEM) survey (Groundwater Imaging, 2012) and a pumping test at a new bore (VKY3092). The bore locations and transects are shown in **Figure A-10**. The holes were drilled into the Maules Creek Formation bedrock where possible. Full details of the Vickery Groundwater Investigation Program are provided in **Attachment AA**.

One of the aims of the Vickery Groundwater Investigation Program was to delineate the extent of the Upper Namoi Alluvium along the full extent of the southern margin of the proposed Project open cut, and to determine the surface profile of the underlying Maules Creek Formation. Another aim was to determine the hydraulic conductivity of the alluvial/colluvial sediments and the spatial distribution of groundwater salinity/chemistry.

Stratigraphic sections along each transect are presented in **Attachment AA**. The boundary of the Upper Namoi Alluvium is difficult to distinguish because the alluvial deposits bordering the Project area merge with colluvium and regolith associated with the slopes of the rising Maules Creek Formation subcrop on the northern margins of the floodplain (e.g. at Transect 1 there is a gradual transition from alluvium to colluvium north of borehole TR05 [**Figure A-10**]). The bore transects revealed alluvial thickness to a maximum of 20 m, with groundwater levels measured in the range 245.5 to 246.3 m AHD (March 2012).

The TEM survey results are shown in **Figure A-11** in terms of the (inverted) true resistivity (ohm metres) for various depths from the surface. The results are consistent with the stratigraphic sections in **Attachment AA**, which suggests a gradual transition from alluvium to colluvium and weathered rock. The white-red tones on the plan view indicate the most conductive material, either colluvium or alluvium with a high clay content or high salinity. The resistivities across most of the surveyed plain are generally less than 10 ohm metres which is typical of clay or saline water-laden sediments.

As found with the bore transects, the Upper Namoi Alluvium boundary is difficult to distinguish using the TEM results. The green-blue tones show more resistive material, due to less weathered rock at depth coupled with dry conditions or lower salinity groundwater. In parts of the plan view, there is a clear contrast with the weathered Maules Creek Formation in the north-west and north-east corners of the TEM survey area.

Notwithstanding the limitations of the field investigations described above, the information obtained has been used by GESPL (2012) to map the approximate extent of the boundary between the Upper Namoi Alluvium and the Permian-aged Maules Creek Formation in the vicinity of the southern extent of the open cut (**Figure A-10**).

### A2.9 GROUNDWATER USERS

A search of the NOW Pinneena Groundwater Works Database identified 670 registered bores within the extent of the regional numerical groundwater model (**Figure A-12**). The majority of the registered bores are located within the Upper Namoi Alluvium.

In consultation with local landholders, Whitehaven also conducted a bore census in March 2012 of 53 privately-owned bores/wells on 21 properties in the vicinity of the Project. The locations of these bores are also shown on **Figure A-12**. The results of the Project bore census (e.g. confirmed bore/well locations and spot water levels/water quality measurements) have been used to confirm the number and type of groundwater users in the vicinity of the Project, as well as assisting in conceptualisation and the development of the regional numerical groundwater model (in the definition of initial water levels) and impact assessment (**Sections A5 and A6**).

**Figure A-13a** and **Figure A-13b** show the recent (2009-2010) distribution of groundwater abstraction from the Narrabri Formation and the Gunnedah Formation, respectively, for bores registered for irrigation purposes. As illustrated on the figures, activity is concentrated close to the Namoi River corridor in the Gunnedah Formation, to the north-west of the Project. The nearest active Gunnedah Formation production bore is located to the south-west and is about 2 km from the Project area.

The volume of water withdrawn annually from the 122 production bores in the model area varied from 11,300 ML in the 2009-2010 water year to about 28,800 ML in the 2006-2007 water year, with an average of about 21,200 ML over four recent water years. **Figure A-13c** shows the temporal variation in groundwater abstraction from year to year, from both formations, with the assumed monthly distribution peaking in January and February each year. The rainfall RMC (**Figure A-3**) shows drier conditions commencing in 2006, with a wetter sequence commencing in 2009. The much lower production in 2010 is consistent with rainfall trends.

**Figure A-14a** shows the registered groundwater bores that occur less than 4 km from the Project boundaries, based on the Pinneena Groundwater Works Database review. The existing bores identified during the Project census and land owned by Whitehaven are also illustrated on the figure.

**Figure A-14b** shows the Project census bores and monitoring bores less than 4 km from the Project boundaries, and **Figure A-14c** shows the monitoring bores only.

**Table A-2a** list the registered Pinneena groundwater bores, and **Table A-2b** lists the Project census bores that are situated within 4 km of the edge of the planned open cut, MIA and waste emplacements.

# Table A-2a
# Groundwater Production Bores in the Vicinity of the Project – Pinneena Records

| Work Number | Licence | Work Type | Date Completed | Completed Depth (m) | GWMA[1] | Bore Census I.D.[3] |
|---|---|---|---|---|---|---|
| GW031992 | 90BL024963 | Well | 1/01/1908 | 9.1 | UNA[2] | - |
| GW032001 | 90BL024954 | Bore open through rock | 1/12/1950 | 27.4 | - | - |
| GW005465 | - | Well & Bore | 1/01/1912 | 76.4 | - | - |
| GW032002 | 90BL024953 | Bore | 1/12/1950 | 15.2 | UNA[2] | - |
| GW031864 | 90BL024942 | Bore | 1/01/1950 | 61 | UNA[2] | BM5 |
| GW031865 | 90BL024941 | Well | 1/01/1949 | 15.2 | UNA[2] | - |
| GW032296 | 90BL024796 | Well | 1/01/1950 | 12.2 | UNA[2] | - |
| GW031855 | 90BL024857 | Bore | 1/01/1950 | 21.3 | UNA[2] | - |
| GW031866 | 90BL024943 | Bore | 1/01/1945 | 22.9 | UNA[2] | BM4 |
| GW031978 | 90BL024948 | Well | 1/01/1950 | 10.7 | UNA[2] | BM1 |
| GW031976 | 90BL024950 | Well | 1/01/1950 | 15.2 | UNA[2] | BM2 |
| GW031977 | 90BL024949 | Well | 1/01/1955 | 16.8 | UNA[2] | - |
| GW060183 | - | Bore | 1/05/1985 | 36 | - | - |
| GW030053 | - | Bore | 1/08/1970 | 0 | - | - |
| GW001602 | 90BL249901 | Bore | 1/05/1925 | 46.9 | - | BG3 |
| GW031896 | 90BL024999 | Bore | 1/01/1940 | 30.5 | UNA[2] | BG1 |
| GW031897 | 90BL025000 | Well | 1/01/1902 | 42.7 | UNA[2] | BG2 |
| GW000880 | - | Bore open through rock | 1/12/1921 | 76.2 | - | - |
| GW000891 | - | Bore | 1/02/1922 | 90.2 | - | - |
| GW065672 | - | Bore | 10/04/1989 | 65 | - | - |
| GW000848 | - | Bore open through rock | 1/02/1922 | 72.2 | - | BK2 |
| GW001762 | - | Bore open through rock | 1/02/1926 | 62.8 | - | - |
| GW003087 | - | Bore open through rock | 1/03/1932 | 95.4 | - | - |
| GW965430 | 90BL250230 | Bore | 28/07/2001 | 85 | - | SK1 |
| GW000815 | - | Bore open through rock | 1/09/1921 | 86.9 | - | WL1 |
| GW022319 | 90BL013922 | Bore | 1/06/1964 | 52.4 | - | - |
| GW020236 | 90BL013311 | Bore | 1/03/1963 | 47.2 | UNA[2] | CA3 |
| GW017198 | 90BL007680 | Bore | 1/01/1920 | 37.5 | UNA[2] | - |
| GW036484 | - | Bore | 1/12/1983 | 40 | - | - |
| GW013284 | 90BL007678 | Bore | 1/01/1920 | 18.3 | UNA[2] | - |
| GW013369 | 90BL007677 | Bore | 1/01/1946 | 22.3 | UNA[2] | - |
| GW017524 | 90BL012093 | Well & Bore | 1/01/1959 | 38.1 | UNA[3] | - |
| GW012307 | - | Bore | 1/02/1959 | 126.5 | - | - |
| GW036462 | - | Bore | 1/08/1983 | 29.5 | - | - |
| GW045941 | 90BL106114 | Bore | 1/07/1977 | 46 | - | - |
| GW032300 | 90BL024810 | Well | 1/01/1950 | 10.6 | UNA[2] | - |
| GW964945 | 90BL249486 | Bore | 23/12/1998 | 46.45 | - | - |
| GW060119 | 90BL131179 | Well | 1/01/1961 | 15.2 | UNA[2] | - |
| GW901431 | 90BL152502 | Bore | 24/05/1996 | 24 | UNA[2] | - |
| GW060118 | 90BL138031 | Well | 1/01/1960 | 4.9 | - | CL1 |
| GW062585 | 90BL134358 | Bore | 1/05/1986 | 21 | - | GB1 |
| GW057725 | 90BL122145 | Bore | 1/07/1983 | 47 | UNA[2] | - |
| GW032114 | 90BL024812 | Well | 1/01/1930 | 12.1 | UNA[2] | - |

# Table A-2a (Continued)
# Groundwater Production Bores in the Vicinity of the Project – Pinneena Records

| Work Number | Licence | Work Type | Date Completed | Completed Depth (m) | GWMA[1] | Bore Census I.D.[3] |
|---|---|---|---|---|---|---|
| GW027814 | 90BL021182 | Bore | 1/02/1968 | 28.7 | UNA[2] | MR1 |
| GW031960 | 90BL024813 | Well | 1/01/1930 | 12.1 | UNA[2] | - |
| GW017167 | 90BL011381 | Bore | 1/01/1960 | 15.2 | UNA[2] | - |
| GW069125 | 90BL141650 | Bore | 9/02/1968 | 28.7 | UNA[2] | - |
| GW035862 | 90BL030251 | Bore | 1/10/1970 | 32.9 | UNA[2] | MR2 |
| GW017166 | 90BL011382 | Bore | 1/01/1960 | 21.3 | UNA[2] | - |
| GW065550 | 90BL142023 | Bore | 20/01/1991 | 51.2 | UNA[2] | - |
| GW017168 | 90BL011280 | Well | 1/01/1960 | 8.2 | UNA[2] | - |
| GW901791 | 90BL150924 | Bore | 2/12/1992 | 37 | UNA[2] | - |
| GW900753 | 90BL248293 | Bore | 21/01/1997 | - | UNA[2] | - |
| GW053364 | 90BL112778 | Bore | 1/02/1981 | 36.6 | UNA[2] | - |
| GW020544 | 90BL011282 | Well | 1/11/1960 | 12.6 | UNA[2] | - |
| **WHC Owned** | | | | | | |
| GW032000 | 90BL024955 | Bore | 1/01/1909 | 61 | - | - |
| GW000921 | - | Bore | 1/04/1922 | 160 | - | - |
| GW001653 | - | Bore | 1/09/1925 | 59.7 | - | - |
| GW000965 | - | Bore | 1/05/1922 | 62.5 | - | - |
| GW005749 | 90BL000242 | Bore | 1/03/1933 | 59.7 | - | - |
| GW031999 | 90BL024956 | Bore | 1/01/1909 | 61 | - | - |
| GW965983 | 90BL249900 | Bore | 4/03/2000 | 42 | - | - |
| GW001613 | - | Bore open through rock | 1/06/1925 | 44.8 | - | - |
| GW009961 | - | Bore | 1/02/1952 | 102.7 | - | - |
| GW001622 | - | Bore open through rock | 1/09/1925 | 80.8 | - | - |
| GW000831 | - | Bore | 1/11/1921 | 100 | - | - |
| GW000858 | - | Bore open through rock | 1/12/1921 | 106.7 | - | - |
| GW064948 | - | Bore | 1/12/1985 | 49 | - | - |
| GW064949 | - | Bore | 1/12/1985 | 41 | - | - |
| GW017199 | 90BL007679 | Bore | 1/01/1939 | 37.5 | - | - |
| GW062364 | 90BL123440 | Bore | 1/10/1982 | 30.5 | - | - |
| GW062363 | 90BL124133 | Bore | 1/10/1982 | 43 | UNA[2] | - |
| GW017197 | 90BL007681 | Well | 1/01/1920 | 19.2 | UNA[2] | - |
| GW021536 | 90BL013756 | Bore | 1/02/1964 | 30 | UNA[2] | - |
| GW032127 | 90BL024929 | Bore | 1/01/1970 | 30.5 | UNA[2] | - |
| GW032126 | 90BL024930 | Bore | 1/01/1969 | 45.7 | - | - |
| GW001676 | - | Bore | 1/11/1925 | 80.8 | - | - |
| GW036459 | - | Bore | 1/10/1983 | 39 | - | - |
| GW001707 | - | Bore | 1/11/1925 | 19.2 | - | - |
| GW055937 | 90BL121712 | Bore | 1/11/1981 | 51.5 | - | - |
| GW055938 | 90BL135372 | Bore | 1/12/1981 | 35 | UNA[2] | - |
| GW037873 | 90BL030472 | Bore | 1/09/1972 | 52.7 | UNA[2] | - |
| GW032266 | 90BL024806 | Well | 1/01/1920 | 10.7 | UNA[2] | - |
| GW032267 | 90BL024807 | Well | 1/01/1920 | 10.7 | UNA[2] | - |
| GW033728 | 90BL026857 | Bore | 1/12/1971 | 15.8 | UNA[3] | - |
| GW031854 | 90BL024803 | Well | 1/01/1920 | 19.8 | UNA[2] | - |

## Table A-2a (Continued)
## Groundwater Production Bores in the Vicinity of the Project – Pinneena Records

| Work Number | License | Work Type | Date Completed | Completed Depth | GWMA[1] | Bore Census I.D.* |
|---|---|---|---|---|---|---|
| GW032268 | 90BL024808 | Bore | 1/01/1954 | 18.3 | UNA[2] | - |
| GW031925 | 90BL024816 | Bore | 1/01/1920 | 19.8 | UNA[2] | - |
| GW035316 | 90BL028445 | Bore | 1/01/1973 | 20.4 | UNA[2] | - |
| GW031924 | 90BL024815 | Bore | 1/01/1954 | 21.3 | UNA[2] | - |
| GW043990 | 90BL102512 | Bore | 1/09/1975 | 0 | - | - |
| GW032128 | 90BL108886 | Well | 1/01/1970 | 9.1 | - | BW1 |
| GW037468 | 90BL142388 | Well | 1/01/1954 | 9.7 | - | - |

[1] GWMA = Groundwater Management Area.
[2] UNA = Upper Namoi Alluvium.
[3] Refer to Table A-2b for further detail.

## Table A-2b
## Groundwater Production Bores in the Vicinity of the Project – Bore Census Records

| Bore Census ID | Ownership | Ownership Number | Bore Census ID | Ownership | Ownership Number |
|---|---|---|---|---|---|
| BM5 | Braymont | 88 | BR2 | Brolga | 101 |
| BM4 | Braymont | 88 | CL2 | Clinton | 133 |
| BM1 | Braymont | 88 | CL1 | Clinton | 133 |
| BM2 | Braymont | 88 | GB1 | Gunnabri | 128 |
| BG3 | Bungalow | 89 | MR3 | Mirabinda | 127 |
| BG1 | Bungalow | 89 | MR1 | Mirabinda | 127 |
| BG2 | Bungalow | 89 | MR2 | Mirabinda | 127 |
| BK2 | Brookvale | 65 | MR4* | Mirabinda | 127 |
| SK1 | Silkdale | 112 | **Whitehaven Owned** | | |
| RB1 | Roseberry | 98 | WL1 | Whitehaven | 1 |
| CA3 | Carlton | 99 | WG1 | Whitehaven | 1 |
| WS1 | Wundurra Stud | 102 | BW1 | Whitehaven | 1 |
| BR4 | Brolga | 101 | BW2 | Whitehaven | 1 |

### A2.10 WATER SHARING PLANS AND GROUNDWATER LICENSING

The Project coal resource is located within the Maules Creek sub-basin of the Early Permian Bellata Group (**Section A2.6**) which lies within the boundary defined in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* (**Figure A-15**)[1]. The Project coal resource is wholly located within the Management Zone of the Gunnedah-Oxley Basin – Namoi.

The Project is located outside, and approximately 7 km west, of the New England Fold Belt Murray Darling Basin – Namoi Management Zone boundary defined by the *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011* (**Figure A-16**).

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[1] 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-17**).

Consideration of the Project against the objects and regulatory requirements of the *Water Act, 1912*, the *Water Management Act, 2000*, the *NSW Aquifer Interference Policy*, and a discussion of the licences required for each water source associated with the Project are provided in the Main Report of the EIS. Where appropriate, the predicted inflows to the open cut and other groundwater effects have been attributed to the relevant water source under the relevant Water Sharing Plans.

### A2.11 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** – 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 (**Section A2.6**) which is within the sedimentary rock groundwater systems of the Gunnedah Basin. These sedimentary rock groundwater systems lie within the boundary defined in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* (as described in **Section A2.10**). There are no high priority groundwater dependent ecosystems as identified in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* in the vicinity of the Project.

Groundwater of variable quality to the north and south of the Project area is associated with the deep alluvial groundwater systems of the Upper Namoi Alluvium (i.e. Upper Namoi Zone 4 Groundwater Source – refer **Section A2.10**). There are no high priority groundwater dependent ecosystems identified in the Upper Namoi Alluvium (NOW, 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 vicinity of 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 EIS) and Ecological Assessment (Appendix E of the EIS).

### A2.12 GROUNDWATER MONITORING

As described in **Sections A2.1** and **A2.2**, there are numerous Whitehaven monitoring bores within and surrounding the Project area. These bores are shown on **Figure A-14b** and **Figure A-14c** and are listed in **Table A-3**.

Whitehaven also conducts groundwater monitoring at its Tarrawonga Coal Mine (10 km to the north of the Project) in accordance with the Project Approval and licence conditions for the mine.

There are 34 NOW observation bores located in the vicinity of the Project. These monitoring bores are listed in **Table A-4**, and approximately half of them are located within the area shown on **Figure A-14a**. The groundwater level response for each bore is also shown in the table, and is discussed further in **Section A2.13**.

# Table A-3
# Whitehaven Groundwater Monitoring Bores in the Vicinity of the Project

| Area | Bore Number/Name | Monitoring Period | Registered Bore/Licence Number |
|---|---|---|---|
| Vickery | VKY3034 | Mar 2012 – Present | 90BL256014 |
| | VKY3035 | Mar 2012 – Present | 90BL256013 |
| | VKY3036 | Mar 2012 – Present | 90BL256015 |
| | VKY3042 | Mar 2012 – Present | 90BL256016 |
| | VKY3043 | Mar 2012 – Present | 90BL256011 |
| | VKY3033* | Jan 2012 - Present | 90BL256012 |
| | VKY3041* | Jan 2012 - Present | 90BL256010 |
| | VKY3053* | Jan 2012 - Present | 90BL256009 |
| | TR7 | Mar 2012 – Present | 90BL256017 |
| | TR18 | Mar 2012 – Present | 90BL256018 |
| | TR26 | Mar 2012 – Present | 90BL256019 |
| | TR35 | Mar 2012 – Present | 90BL256020 |
| Canyon | GW-1 | Sep 2000 – Present | GW031896 |
| | GW-2 | Sep 2000 – Present | GW031897 |
| | GW-4 | Aug 2003 – Present | GW000880 |
| | GW-5 | Sep 2000 – Present | GW000891 |
| | GW-7 | Sep 2000 – Present | GW001653 |
| | GW-8 | Sep 2000 – Present | GW005749 |
| | GW-9 | Apr 2003 – Present | GW001613 |
| | GW-10 | Sep 2000 – Present | GW001602 |
| | GW-11 | Sep 2000 – Present | 90BL249739 |
| | VNW221 | Nov 2006 – Present | N/A |
| | VNW223 | Nov 2006 – Present | N/A |
| | VNW222 | Nov 2006 – Jul 2008 | N/A |
| | GW-12 | Nov 2003 – Feb 2006 | 90BL252067 |
| | GW-6 | Sep 2000 – May 2005 | GW031999 |
| | GW-3 | Sep 2000 – Feb 2005 | GW003087 |
| Vickery South | SB01 | Jan 2011 – Present | N/A |
| | SB02 | Jan 2011 – Present | N/A |
| | SB04 | Mar 2011 – Present | N/A |
| | SB05 | Jan 2011 – Present | N/A |
| | SB06 | Jan 2011 – Present | N/A |
| | SB07 | Mar 2011 – Present | N/A |
| | SB08 | Mar 2011 – Present | N/A |
| | SB09 | Jan 2011 – Present | N/A |
| | SB10 | Jan 2011 – Present | N/A |
| | SB11 | Jan 2011 – Present | N/A |
| | SB15 | Jan 2011 – Present | N/A |
| | GW01 | May 2011 – Present | N/A |
| | GW02 | Mar 2011 – Present | N/A |
| | GW03 | Mar 2011 – Present | N/A |
| | VS048* | Jun 2011 – Present | N/A |
| | VS054* | Jun 2011 – Present | N/A |
| | VS056* | Jun 2011 – Present | N/A |
| | VS058* | Jun 2011 – Present | N/A |
| | VS059* | Jun 2011 – Present | N/A |
| | VS062* | Jun 2011 – Present | N/A |

## Table A-3 (Continued)
## Whitehaven Groundwater Monitoring Bores in the Vicinity of the Project

| Area | Bore Number/Name | Monitoring Period | Registered Bore/Licence Number |
|---|---|---|---|
| Rocglen | MP-2 | Sep 2008 – Present | GW968534 |
| | MP-3 | Sep 2008 – Present | GW968535 |
| | MP-4 | Sep 2008 – Present | GW968536 |
| | MP-5 | Sep 2008 – Present | GW968537 |
| | WB-1 | Oct 2008 – Present | GW000743 |
| | WB-2 | Sep 2008 – Present | GW050395 |
| | WB-3 | Sep 2008 – Present | GW050166 |
| | WB-4 | Sep 2008 – Present | GW045621 |
| | WB-5 | Sep 2008 – Present | GW011066 |
| | WB-6 | Sep 2008 – Present | GW044068 |
| | WB-7 | Sep 2008 – Present | GW022319 |
| | WB-8 | Sep 2008 – Present | GW052958 |
| | WB-9 | Sep 2008 – Present | N/A |
| | WB-10 | Jul 2008 – Present | N/A |
| | WB-11 | Jul 2008 – Present | N/A |
| | WB-12 | Jul 2008 – Present | N/A |
| | Yarrari | Sep 2008 – Present | N/A |
| | MP-1 | Sep 2008 – May 2011 | GW968533 |

*VWP.

MCF: Maules Creek Formation. N/A: Not Available.

## Table A-4
## NOW Groundwater Monitoring Bores in the Vicinity of the Project

| No. | GW | Pipe | RL (m AHD) | Screen Height (m AHD) | Response |
|---|---|---|---|---|---|
| 1 | GW030048 | 1 | 242.363 | 217.463 | Rainfall Recharge |
| 2 | GW030049 | 1 | 243.567 | 223.767 | Rainfall Recharge |
| | GW030049 | 2 | 243.567 | 216.167 | Pumping |
| | GW030049 | 3 | 243.567 | 183.817 | Pumping |
| 3 | GW030050 | 1 | 243.205 | 211.005 | Rainfall Recharge & Pumping |
| | GW030050 | 2 | 243.205 | 193.055 | Rainfall Recharge & Pumping |
| | GW030050 | 3 | 243.205 | 140.98 | Rainfall Recharge & Pumping |
| 4 | GW030051 | 1 | 244.722 | 207.672 | Rainfall Recharge |
| 5 | GW030052 | 1 | 248.815 | 228.265 | Recovery |
| | GW030052 | 2 | 248.815 | 222.165 | Recovery |
| 6 | GW030468 | 1 | 240.392 | 217.542 | Rainfall Recharge |
| 7 | GW030469 | 1 | 240.696 | 214.846 | Rainfall Recharge |
| 8 | GW030470 | 1 | 241.155 | 228.006 | Rainfall Recharge |
| | GW030470 | 2 | 241.155 | 219.855 | Rainfall Recharge |
| 9 | GW030471 | 1 | 240.519 | 222.869 | Rainfall Recharge |
| | GW030471 | 2 | 240.519 | 213.069 | Rainfall Recharge |
| | GW030471 | 3 | 240.519 | 204.025 | Rainfall Recharge |
| 10 | GW030472 | 1 | 248.908 | 224.508 | Rainfall Recharge |
| | GW030472 | 2 | 248.908 | 190.408 | Rainfall Recharge & Pumping |
| 11 | GW030535 | 1 | 242.064 | 183.602 | Pumping |
| 12 | GW036092 | 1 | 238.694 | 217.394 | Rainfall Recharge |

# Table A-4 (Continued)
# NOW Groundwater Monitoring Bores in the Vicinity of the Project

| No. | GW | Pipe | RL (m AHD) | Screen Height (m AHD) | Response |
|---|---|---|---|---|---|
| 13 | GW036456 | 1 | 250.06 | 219.71 | Rainfall Recharge |
| | GW036456 | 2 | 250.06 | 199.56 | Rainfall Recharge |
| 14 | GW036457 | 1 | 252.808 | 217.308 | Rainfall Recharge |
| | GW036457 | 2 | 252.808 | 169.308 | Rainfall Recharge |
| | GW036457 | 3 | 252.808 | 151.808 | Rainfall Recharge |
| 15 | GW036458 | 1 | 254.835 | 216.835 | Rainfall Recharge |
| 16 | GW036459 | 1 | 256.11 | 226.11 | Rainfall Recharge |
| 17 | GW036460 | 1 | 255.67 | 226.67 | Rainfall Recharge |
| | GW036460 | 2 | 255.67 | 194.67 | Rainfall Recharge |
| 18 | GW036462 | 1 | 269.576 | 242.576 | Rainfall Recharge & Pumping |
| 19 | GW036463 | 1 | 268.489 | 243.489 | Pumping |
| | GW036463 | 2 | 268.489 | 219.989 | Pumping |
| | GW036463 | 3 | 268.489 | 196.989 | Pumping |
| 20 | GW036471 | 1 | 258.923 | 226.923 | Rainfall Recharge |
| | GW036471 | 2 | 258.923 | 199.923 | Rainfall Recharge |
| 21 | GW036473 | 1 | 250.912 | 197.912 | Rainfall Recharge |
| 22 | GW036476 | 1 | 267.875 | 220.525 | Pumping |
| | GW036476 | 2 | 267.875 | 201.875 | Pumping |
| | GW036476 | 3 | 267.875 | 181.875 | Pumping |
| 23 | GW036480 | 1 | 252.934 | 236.434 | Rainfall Recharge & Pumping |
| 24 | GW036481 | 1 | 251.387 | 213.387 | Rainfall Recharge |
| | GW036481 | 2 | 251.387 | 164.387 | Rainfall Recharge |
| 25 | GW036484 | 1 | 268.623 | 234.123 | Recovery |
| 26 | GW036485 | 1 | 269.53 | 217.53 | Rainfall Recharge & Pumping |
| | GW036485 | 2 | 269.53 | 206.53 | Rainfall Recharge & Pumping |
| 27 | GW036489 | 1 | 250.594 | 215.594 | Rainfall Recharge |
| | GW036489 | 2 | 250.594 | 153.594 | Rainfall Recharge |
| 28 | GW036510 | 1 | 246.84 | 211.84 | Rainfall Recharge |
| | GW036510 | 2 | 246.84 | 182.84 | Rainfall Recharge |
| 29 | GW036513 | 1 | 247.514 | 222.514 | Rainfall Recharge |
| 30 | GW036514 | 1 | 248.403 | 225.903 | Rainfall Recharge & Pumping |
| 31 | GW036548 | 1 | 246.74 | 212.46 | Rainfall Recharge |
| | GW036548 | 2 | 246.74 | 187.74 | Rainfall Recharge |
| | GW036548 | 3 | 246.74 | 156.24 | Rainfall Recharge |
| 32 | GW036565 | 1 | 243.801 | 228.051 | Rainfall Recharge & Pumping |
| 33 | GW036567 | 1 | 244.588 | 216.963 | Rainfall Recharge |
| 34 | GW036655 | 1 | 250.318 | 233.718 | Rainfall Recharge |
| | GW036655 | 2 | 250.318 | 213.718 | Rainfall Recharge & Pumping |

*RL: Reduced level.

## A2.13 BASELINE GROUNDWATER LEVEL DATA

### A2.13.1 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 tends to mound beneath hills and discharges to incised creeks and rivers. During short events of high surface flow, streams lose surface water to the host groundwater system, but during recession, there is slow discharge of groundwater back into the stream from bank storage and also flow and discharge to streams from more distant zones originating as rainfall infiltration. Groundwater flows from elevated to lower-lying terrain.

An early attempt at defining local groundwater levels and flow directions was made by Coffey (1982) as part of the original feasibility studies and environmental impact assessment of the Vickery Coal Mine. Water levels were measured in open exploration holes at the time. The groundwater elevation contours are reproduced in **Figure A-18**. They show four pronounced groundwater mounds associated with elevated topography, with groundwater flow directions to the north-west and south-west of the investigated area.

Contour maps of recent measured and inferred shallow groundwater (potentiometric) levels at regional and local scales (**Figures A-19** and **A-20** respectively) have been prepared from long-term average groundwater levels at 111 NOW alluvial bores and 143 mine monitoring sites measured generally between 2010 and 2011. Average Vickery South water levels at 14 sites from January 2011 to June 2012 are included. The smaller, pre-mining groundwater mounds that were observed in 1982 (**Figure A-18**) are no longer discernible, but a pronounced mound beneath the Vickery State Forest is now evident. The Vickery South data suggest a small groundwater mound near the south-western edge of the Maules Creek Formation. Groundwater flow direction is towards the west, south-west and north-west from the Project area. The hydraulic gradient decreases appreciably to the north-west and the south-west between the Project area and the Namoi River due to the higher permeability of alluvial sediments.

A distribution of depths to groundwater that were measured in June 2011 (or as close as possible to this date) are displayed in **Figure A-21** at a regional scale, based on 223 measurements. In addition, the depths to groundwater measured in March 2012 during the bore census are posted (labelled) on the map for comparison, with generally consistent agreement. In the Upper Namoi Alluvium bordering the Project area, the bore water levels are typically 10 to 14 m below ground level. This suggests that local ephemeral streams are most likely naturally losing systems, with no baseflow components derived from groundwater discharge. Depths to groundwater are consistently about 10 m along the axis of the Namoi River. At the Vickery South standpipes the depth is typically 8 to 9 m.

### A2.13.2 Temporal Groundwater Level Data

The available groundwater level data within and surrounding the Project area have been investigated in detail to check for cause-and-effect responses in temporal water level changes which could result from rainfall recharge, irrigation pumping or a mining effect.

**Table A-4** summarises the groundwater level response for 34 NOW sites located in the Upper Namoi Alluvium groundwater system near the Project area. The NOW convention for ‘Pipes’ is that the lower numbers are always allocated to the shallower screened intervals. Most ‘Pipe 1’ bores have a strong response to rainfall recharge and some bores (e.g. GW030535) show a nearby pumping effect. Most bores show a pronounced decline from 2000 to 2010, contrary to cycles in residual mass, due to regional drawdown caused by agricultural pumping. However, GW030052 (Pipe 1 and 2) and GW036484 (Pipe 1) have recovery trends; as these responses are so different from neighbouring bores, the data are suspect.

Detailed hydrographs for NOW bores in Upper Namoi Alluvium groundwater system are displayed in **Attachment AB**. The storyboard figures for all monitoring bores located within and surrounding the Project area are illustrated in **Attachments AC** to **AG**.

Representative hydrographs are shown in **Figures A-22** to **A-25** for each monitoring network where they are compared with residual rainfall mass to indicate whether the local groundwater levels are responsive to rainfall recharge.

**Figure A-22a** shows good rainfall correlation at Bore 30051_1 which is located to the north-west of the Canyon Coal Mine. **Figure A-22b** shows declining groundwater levels at Bore 36459_1 to the south of the Project area due to regional agricultural pumping. The Tarrawonga Coal Mine bores in **Figure A-23** show only one bore (MW7) that has a clear mining effect. Some of the Canyon Coal Mine bores show a mining effect (e.g. Bore VNW221 near the final void, **Figure A-24b**), but most show mild fluctuations not well correlated with rainfall (e.g. Bore GW-2 to the north of the mine in alluvium, **Figure A-24a**). Most bores at the Rocglen Coal Mine show good correlation with rainfall (e.g. Bore MP-2 to the south of the mine, **Figure A-25a**) with rare evidence of any mining effect (e.g. Bore MP-5 to the immediate west of the mine, **Figure A-25b**).

## A2.14 BASELINE GROUNDWATER CHEMISTRY DATA

### *Summary of Available Data*

As per the baseline groundwater level data, there are several sources of groundwater quality information for the Project area and surrounds. These include the original studies in the 1980s by Coffey (1982; 1984a; 1984b) and Vickery Joint Venture (1986); the recent Vickery Groundwater Investigation Program (**Attachment AA**); the Canyon Coal Mine groundwater monitoring program; and the Rocglen groundwater monitoring program.

Tabulated summaries of the water quality data from these areas are provided below in **Tables A-5** to **A-8**, respectively. An analysis of the available data in terms of overall groundwater quality is provided after **Table A-8**.

As described in **Section A2.1**, the EIS for the original Vickery Coal Mine (Vickery Joint Venture, 1986) included analysis of eight groundwater bores within and surrounding the Project area. The locations of the bores (i.e. WVK37, WVK62, WVK501, WVK505, WVK526; WRC; 9; and the 'Vickery Test Bore') are shown on **Figure A-14b**.

**Table A-5** presents the available pre-mining water quality data for the Project area and surrounds.

### Table A-5
### Vickery Coal Mine (Pre-mining) Groundwater Quality Summary

| Bore Number/ Name | Lithology | Date | pH | EC | Ca | Mg | Na | K | Cl | $HCO_3$ | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | μS/cm | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| WVK37 | MCF | c1985 | 7.0 | 800 | 62 | 30 | 66 | 18 | 37 | 488 | 19 |
| WVK62 | MCF | c1985 | 6.8 | 2290 | 140 | 101 | 225 | 11 | 310 | 866 | 120 |
| WVK501 | MCF | c1985 | 7.4 | 1140 | 46 | 36 | 149 | 8 | 151 | 402 | 50 |
| WVK505 | MCF | c1985 | 6.9 | 2040 | 104 | 138 | 126 | 5 | 334 | 702 | 46 |
| WVK526 | MCF | c1985 | 6.8 | 1140 | 64 | 38 | 142 | 19 | 38 | 739 | 23 |
| #9 | Unknown | c1985 | 7.4 | 2490 | 120 | 76 | 32 | 24 | 435 | 740 | 106 |
| TEST_BOREeE | UNA | c1985 | 7.3 | 770 | 53 | 31 | 77 | 1 | 20 | 437 | 46 |
| WRC | UNA | c1985 | 8.0 | - | 46 | 19 | 81 | 2 | 47 | 316 | 34 |

Source: Vickery Joint Venture (1986).
μS/cm = microSiemens per centimetre.

As part of the Vickery Groundwater Investigation Program (**Attachment AA**), water quality sampling of the nine new standpipe bores has been initiated (i.e. VKY3034, VKY3035, VKY3036, VKY3042, VKY3043; TR7, TR18, TR26, TR35). The locations of the bores are shown on **Figure A-14c**. Sampling and analysis of a full suite of water quality parameters has been conducted at these bores in March and August 2012 to date.

**Table A-6** provides a summary of the water quality data for the new groundwater monitoring bores installed in the Project area as part of the Vickery Groundwater Investigation Program. Further details are contained in **Attachment AA**.

**Table A-7** provides a summary of the 15 groundwater monitoring bores installed in the Canyon Coal Mine area and surrounds (i.e. GW-1, GW-2, GW-3, GW-4, GW-5, GW-6, GW-7, GW-8, GW-9, GW-10, GW-11, GW-12, VNW221, VNW222 and VNW223). The locations of the bores currently monitored are shown on **Figure A-14c**. Sampling and analysis of groundwater quality has been conducted at these bores since the mine was operational in the 2000s.

**Table A-8** provides a summary of the 18 groundwater monitoring bores installed in the Rocglen Coal Mine area and surrounds (i.e. MP-1, MP-2, MP-3, MP-4, MP-5, WB-1, WB-2, WB-3, WB-4, WB-5, WB-6, WB-7, WB-8, WB-9, WB-10, WB-11, WB-12 and Yarrari). The locations of the bores currently monitored are shown on **Figure A-14c**. Sampling and analysis of groundwater quality has been conducted at these bores since 2008.

The Vickery South groundwater bores (**Figure A-14c**) are not currently monitored for water quality.

### Table A-6
### Vickery Groundwater Investigation Program Groundwater Quality Summary

| Bore (Registered Bore/Licence Number) | Lithology | Date | pH | EC | TDS | Ca | Mg | Na | K | Cl | $HCO_3$ | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | µS/cm | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| VKY3034 | MCF/Coal | Mar 2012 | 8.1 | 4040 | 2430 | 80 | 57 | 855 | 14 | 756 | 807 | 268 |
| (90BL256014) | | Aug 2012 | 7.9 | 3770 | 2703 | 79 | 58 | 800 | 12 | 668 | 826 | 260 |
| VKY3035 | MCF | Mar 2012 | 7.6 | 2980 | 1790 | 64 | 44 | 633 | 11 | 606 | 644 | 88 |
| (90BL256013) | | Aug 2012 | 7.8 | 3150 | 2203 | 55 | 43 | 645 | 10 | 596 | 742 | 112 |
| VKY3036 | MCF | Mar 2012 | 7.5 | 5080 | 2970 | 109 | 95 | 963 | 13 | 1180 | 706 | 235 |
| (90BL256015) | | Aug 2012 | 7.8 | 5350 | 3446 | 114 | 104 | 1020 | 13 | 1160 | 767 | 268 |
| VKY3042 | MCF/Coal | Mar 2012 | 7.8 | 4810 | 2810 | 126 | 125 | 829 | 17 | 1150 | 714 | 156 |
| (90BL256016) | | Aug 2012 | 7.7 | 5290 | 3536 | 171 | 210 | 803 | 22 | 1260 | 800 | 270 |
| VKY3043 | MCF | Mar 2012 | 8.1 | 2540 | 1550 | 12 | 4 | 663 | 7 | 331 | 909 | 8 |
| (90BL256011) | | Aug 2012 | 8.3 | 3030 | 2391 | 6 | 4 | 817 | 6 | 396 | 1160 | 2 |
| TR7 | MCF/Rego | Mar 2012 | 7.3 | 15900 | 12500 | 305 | 411 | 2870 | 20 | 5250 | 703 | 512 |
| (90BL256017) | | Aug 2012 | 7.2 | 14700 | 9231 | 261 | 356 | 2600 | 18 | 4770 | 739 | 487 |
| TR18 | MCF/Rego | Mar 2012 | 7.3 | 13500 | 8690 | 262 | 370 | 2490 | 16 | 4330 | 649 | 656 |
| (90BL256018) | | Aug 2012 | 7.3 | 13600 | 8293 | 232 | 359 | 2440 | 15 | 4380 | 722 | 145 |
| TR26 | MCF/Rego | Mar 2012 | 7.4 | 4640 | 2720 | 105 | 104 | 829 | 10 | 1040 | 844 | 117 |
| (90BL256019) | | Aug 2012 | 7.5 | 4950 | 3297 | 108 | 115 | 926 | 10 | 1070 | 923 | 145 |
| TR35 | MCF/Rego | Mar 2012 | 7.4 | 13200 | 9300 | 323 | 400 | 2190 | 21 | 4340 | 710 | 564 |
| (90BL256020) | | Aug 2012 | 7.3 | 15400 | 9940 | 322 | 468 | 2630 | 20 | 5020 | 742 | 738 |

Source: GESPL (2012).
Rego: Regolith.

# Table A-7
# Canyon Groundwater Quality Summary

| Bore (Registered Bore/Licence Number) | Most Recent Monitoring Date | pH[1] | EC[1] | TDS | Ca | Mg | Na | K | Cl | HCO3 | SO4 | Monitoring Period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | µS/cm | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | |
| GW-1 (GW031896) | Aug 2012 | 8.04 | 1070 | 644 | 85 | 31 | 158 | 2 | 79 | <1 | 24 | Sep 2000 – Present |
| GW-2 (GW031897) | Aug 2012 | 7.23 | 1080 | 778 | 82 | 30 | 156 | 2 | 75 | <1 | 23 | Sep 2000 – Present |
| GW-7 (GW001653) | Aug 2012 | 7.94 | 2390 | 1660 | 17 | 87 | 315 | 283 | 275 | <1 | 142 | Sep 2000 – Present |
| GW-8 (GW005749) | Aug 2012 | 7.27 | 2820 | 1670 | 56 | 53 | 454 | 31 | 732 | <1 | 2 | Sep 2000 – Present |
| GW-9 (GW001613) | Aug 2012 | 7.4 | 4750 | 2780 | 26 | 72 | 1020 | 15 | 1490 | <1 | 193 | Sep 2000 – Present |
| GW-11 (90BL249739) | Aug 2012 | 7.35 | 3850 | 2570 | 142 | 37 | 685 | 10 | 1320 | <1 | <1 | Sep 2000 – Present |
| VNW223 (N/A) | Aug 2012 | 7.15 | 7210 | 4790 | 157 | 241 | 1370 | 11 | 2090 | <1 | 399 | Nov 2006 – Present |
| GW-10 (GW001602) | Aug 2012 | N/A[2] | | | | | | | | | | Sep 2000 –Present |
| GW-5 (GW000891) | May 2012 | N/A[2] | | | | | | | | | | Sep 2000 –Present |
| VNW221 (N/A) | May 2012 | N/A[4] | | | | | | | | | | Sep 2007 – Present |
| GW-4 (GW000880) | May 2012 | N/A[3] | | | | | | | | | | Sep 2000 – May 2011 |
| VNW222 (N/A) | Jan 2009 | N/A[5] | | | | | | | | | | Sep 2006 – Jan 2009 |
| GW-6 (GW031999) | May 2006 | N/A[5] | | | | | | | | | | Sep 2000 – May 2006 |
| GW-12 (90BL252067) | May 2006 | N/A[5] | | | | | | | | | | Apr 2003 – May 2006 |
| GW-3 (GW003087) | May 2005 | N/A[6] | | | | | | | | | | Sep 2000 – May 2005 |

[1] Field reading.

[2] Pump installed within bore – unable to take water quality sample (water level reading taken).

[3] Windmill over bore – unable to take water quality sample (water level reading taken).

[4] Bore dry – unable to take water quality sample.

[5] Mined through – unable to take water quality sample.

[6] Monitoring ceased due to landholder request – unable to take water quality sample.

# Table A-8
# Rocglen Groundwater Quality Summary

| Bore (Registered Bore Number) | Lithology | Most Recent Monitoring Date | pH[1] | EC[1] | TDS | Ca | Mg | Na | K | Cl | $CaCO_3$ | $SO_4$ | Monitoring Period |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | µS/cm | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | |
| MP-2 (GW968534) | Gravel | Mar 2012 | 7.01 | 4330 | 3770 | 272 | 168 | 639 | 9 | 1530 | <1 | 25 | Sep 2008 – Present |
| WB-1 (GW000743) | Rock | Mar 2012 | 7.98 | 1640 | 932 | 12 | 13 | 420 | 7 | 286 | <1 | 10 | Oct 2008 – Present |
| WB-2 (GW050395) | Unknown | Mar 2012 | 8.46 | 2410 | 1540 | 57 | 110 | 335 | 4 | 804 | 32 | 17 | Sep 2008 – Present |
| WB-3 (GW050166) | Unknown | Mar 2012 | 6.95 | 3720 | 2750 | 256 | 184 | 393 | 2 | 1160 | <1 | 33 | Sep 2008 – Present |
| WB-4 (GW045621) | Unknown | Mar 2012 | 7.32 | 3680 | 2710 | 244 | 182 | 402 | 2 | 1170 | <1 | 33 | Sep 2008 – Present |
| WB-5 (GW011066) | Unknown | Mar 2012 | 7.82 | 6670 | 4810 | 176 | 301 | 1220 | 11 | 2680 | <1 | 95 | Sep 2008 – Present |
| WB-7 (GW022319) | Sandstone Grey | Mar 2012 | 7.41 | 3120 | 2420 | 203 | 71 | 475 | 5 | 845 | <1 | 49 | Sep 2008 – Present |
| WB-9 (N/A) | Unknown | Mar 2012 | 7.58 | 1126 | 780 | 102 | 49 | 141 | 2 | 67 | <1 | 80 | Sep 2008 – Present |
| WB-10 (N/A) | Unknown | Mar 2012 | 6.94 | 1880 | 1320 | 140 | 71 | 246 | 1 | 175 | <1 | 326 | Jul 2008 – Present |
| WB-11 (N/A) | Unknown | Mar 2012 | 7.93 | 910 | 522 | 31 | 24 | 140 | 4 | 258 | <1 | 1 | Jul 2008 – Present |
| WB-12 (N/A) | Unknown | Mar 2012 | 7.92 | 885 | 556 | 17 | 26 | 190 | 11 | 71 | <1 | 6 | Jul 2008 – Present |
| Yarrari (N/A) | Unknown | Mar 2012 | 6.92 | 3380 | 2320 | 213 | 42 | 591 | 4 | 1000 | <1 | 51 | Sep 2008 – Present |
| MP-3 (GW968535) | Gravel and Sandy | Mar 2012 | N/A[2] | | | | | | | | | | Sep 2008 – Present |
| MP-4 (GW968536) | Clay | Mar 2012 | N/A[2] | | | | | | | | | | Sep 2008 – Present |
| MP-5 (GW968537) | Conglomerate | Mar 2012 | N/A[2] | | | | | | | | | | Sep 2008 – Present |
| WB-6 (GW044068) | Rock Black | Mar 2012 | N/A[3] | | | | | | | | | | Sep 2008 – Present |
| WB-8 (GW052958) | Clay | Mar 2012 | N/A[4] | | | | | | | | | | Sep 2008 – Present |
| MP-1 (GW968533) | Conglomerate | May 2011 | N/A[5] | | | | | | | | | | Sep 2008 – May 2011 |

[1] Field reading.

[2] Bore dry – unable to take water quality sample.

[3] Windmill over bore – unable to take water quality sample (water level reading taken).

[4] Pump installed within bore – unable to take water quality sample (water level reading taken).

[5] Mined through – unable to take water quality sample.

### *Analysis of Available Water Quality Data*

The major ion values for samples taken in March 2012 from the nine new standpipe bores within the Project area (i.e. VKY3034, VKY3035, VKY3036, VKY3042, VKY3043; TR7, TR18, TR26, TR35) are displayed as Schoeller diagrams in **Figures A-26a** and **A-26b**. Three of the monitoring sites are located within a portion of the Upper Namoi Alluvium located in the vicinity of the proposed open cut southern boundary (i.e. TR7, TR18 and TR35), and six are located in the Maules Creek Formation within the proposed open cut (i.e. VKY3034, VKY3035, VKY3036, VKY3042, VKY3043 and TR26).

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. The particular shape of connected lines between each ionic concentration can show similarity or dissimilarity of the water's origin or mixing of waters of different origin.

**Figure A-26a** shows an almost identical signature for the three regolith bores screened in weathered conglomerate below the Upper Namoi Alluvium, with (sodium [Na] and potassium [K]) and (Chlorine [Cl]) as the dominant type. Ionic ratios are uniform across the sites. At all regolith sites, the absolute magnitudes are about a half-order of magnitude greater than the monitoring sites installed in the Maules Creek Formation.

For the monitoring sites situated within the Maules Creek Formation, **Figure A-26b** shows the same (Na+K) and (Cl) dominance, but bicarbonate [HCO3] levels are also high. The ionic ratios show only mild variability across the sites, the exception being site VKY3043 which has very low concentrations of calcium, magnesium and sulphate. This sample was taken at the greatest depth of all samples (i.e. at 237 to 246 m below ground level) in the interburden between the Bluevale and Cranleigh coal seams. The samples which were taken in coal seams (i.e. VKY3034 and VKY3042) show no substantial difference in signature from the samples taken in interburden (VK3035, VK3036) and overburden (TR26).

The major ion values for samples taken around 1985 during investigations for the original Vickery Coal Mine EIS are displayed as Schoeller diagrams in **Figures A-27a** and **A-27b**. The two alluvial monitoring sites are located about 2 km (Test_Bore) to the south and about 6 km (WRC) to the north-west of the Project open cut boundary. The other bores are located in the Maules Creek Formation. Five are within the proposed open cut (i.e. WVK37, WVK62, WVK501, WVK505, WVK526) and the other (#9) is about 500 m to the south-west of the open cut boundary.

**Figure 27a** shows an almost identical signature for the two Upper Namoi Alluvium bores, but the signature is very different from that observed at the recent regolith bores screened below the Upper Namoi Alluvium. The recent bores are located on the alluvium (or colluvium) that fringes the Maules Creek Formation outcrop, whereas the earlier bores are farther into the alluvial channel system. The overall ionic content is more than an order of magnitude lower at the distant bores. This is consistent with the availability of good quality water from the deeper sections of the Upper Namoi Alluvium.

For the monitoring sites situated within the Maules Creek Formation, **Figure A-27b** also shows a different signature from that observed at the recent bores. No particular ion is dominant, but the sulphate concentrations are consistently low.

The EC and salinity values recorded in the regolith and the Maules Creek Formation during the Vickery Groundwater Investigation Program have been analysed. The median EC value for the regolith is about 13,600 µS/cm, and the median value for the Maules Creek Formation is 3,900 µS/cm. The corresponding salinity medians are 9,000 mg/L and 2,600 mg/L. The four EC measurements in coal seams range from 3,800 to 5,300 µS/cm. This contrasts with observations at Tarrawonga to the north, where the typical EC of groundwater in coal is about 2,000 µS/cm. The highest salinity is recorded in the most southern sampling site at bore TR7 (16,600 µS/cm) that penetrates the edge of the mapped alluvium and most likely taps the underlying Permian weathered bedrock The groundwater quality suggests very low permeability strata, lack of groundwater flushing action and very old groundwater. Further to the south, the water quality in the Upper Namoi Alluvium improves significantly (i.e. the EC recorded at 'Test_Bore' in the mid 1980s was 770 µS/cm [**Table A-5**]).

Recent EC measurements in the groundwater of the Maules Creek Formation (median 3,900 µS/cm) are generally higher than was measured in the mid-1980s before mining commenced (median 1,600 µS/cm). However, the measurements were not made at the same locations. The early measurements were focused on the western portion of the Project area while the recent measurements were in the eastern portion. However, the measurements at WVK62 and VKY3043 were taken at a similar location, about 500 m apart. They differ only by about 20 percent (early 2,290 µS/cm vs. recent 2,790 µS/cm average). This suggests that there might be a general trend of decreasing salinity from east to west across the Project area.

The EC measurements in the Maules Creek Formation within the Project area are consistent with measurements at Rocglen and Canyon. The respective median values are 3,900 µS/cm, 3,700 µS/cm and 4,800 µS/cm. At Canyon and Rocglen the median values for alluvial groundwater are 1,700 µS/cm and 1,100 µS/cm, respectively. At the fringe of the Project site, the median is about 13,600 µS/cm. This suggests that the monitored bores near the Project site are not sampling alluvium but instead are sampling groundwater within weathered Permian material.

Canyon bores GW-8, VNW221 and VNW223 are located within the Western Emplacement area. As the bore at VNW221 on the southern side of the Canyon void is dry, no water quality information is available. Bore VNW223 on the northern edge of the Canyon void has a high salinity (7,200 µS/cm). Bore GW-8, more than 1 km south of the Canyon void, has a salinity (2,800 µS/cm) that is typical of values in the Maules Creek Formation. The nearest alluvial bore (GW-7) downgradient of the planned Project Western Emplacement area has an elevated salinity (2,400 µS/cm) that is higher than observed in deeper sections of the Upper Namoi Alluvium.

There are several monitoring bores and census bores located in the vicinity of the north-west corner of the Project mining area near to where the Western Emplacement is proposed to extend onto an embayment of the Upper Namoi Alluvium (i.e. Canyon Bores VNW223 and GW11, and census bores BG3, BM1, BM2, BM4, BM5, BG1 and BG2) (**Figure A-14b**). The water quality data indicate that in August 2012 the EC was highest at bore VNW223 (7,210 µS/cm) which is near the boundary between the Maules Creek Formation and the Upper Namoi Alluvium (and would be covered by the Western Emplacement). The bores located further down-gradient from the boundary had lower ECs, although they were still in the 3,000 to 5,000 µS/cm range (i.e. GW11, BG3, BM4) that is higher than observed in deeper sections of the Upper Namoi Alluvium. Bores further afield to the north and north-west had significantly lower ECs more typical of the higher yielding Upper Namoi Alluvium (i.e. BM1, BG1 and BG2, all less than 1,500 µS/cm). The above results suggest that there is poor rainfall recharge to the embayment of Upper Namoi Alluvium located near the north-west corner of the Western Emplacement.

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. The groundwater in the Maules Creek Formation within the Project area is not potable but would be suitable for livestock, irrigation of salt-tolerant crops and other general uses (**Table A-9**). The same conclusions were reached by the Vickery Joint Venture (1986) in the EIS for the original Vickery Coal Mine (**Section A2.1**). The groundwater in the portion of the Upper Namoi Alluvium near the southern extent of the proposed open cut is saline on most occasions and would not be suitable for any agricultural or farming purpose (**Table A-9**).

The spatial pattern of baseline groundwater salinity is illustrated in **Figure A-28a**. The sample lithologies are differentiated by symbol, and the magnitude of the concentration is proportional to symbol size. This plot consists of median values at the Vickery, Canyon, Tarrawonga and Boggabri Coal Mine monitoring networks, supplemented by spot field measurements at bores visited during the May 2011 bore census near Tarrawonga and the March 2012 bore census for this Project. Where alluvial cover is thick, the salinity is always low except for some elevated values along the downstream end of Driggle Draggle Creek. The highest salinities occur on the Project site, especially near the southern boundary of the open cut on the fringes of the Upper Namoi Alluvium.

## Table A-9
## Groundwater Salinity Categories

| | | |
|---|---|---|
| **Potable** | Up to 781µS/cm<br>(500 mg/L TDS)[+] | Suitable for all drinking water and uses. |
| **Marginal Potable** | 781-2,344 µS/cm<br>(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<br>(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<br>(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<br>(14000 mg/L TDS) [+] | Suitable for coarse industrial processes up to about 20,000 mg/L [~31,000 µS/cm]. |

Source: Murray Darling Basin Commission (2005).

[+] Conversion Factor of 0.64 applied.

The pH of groundwater at the Project site has a narrow range from 7.3 to 7.4 at the alluvium bores, and a wider range from 7.5 to 8.1 in the coal measures. The spatial pattern of baseline pH data is illustrated in **Figure A-28b**. The sample lithologies are differentiated by symbol, and the pH magnitude is proportional to symbol size. This plot consists of measurements at the Project monitoring network and spot field measurements at bores visited during the March 2012 bore census for this Project. The groundwaters generally fluctuate around neutrality (7.0) but waters close to the Namoi River are slightly acidic in general and on-site Project waters are slightly alkaline.

EC values for coal measures and interburden groundwater in the Project area are also discussed in the Geochemistry Assessment (Appendix L of the EIS).

### A2.15 REGIONAL MINE INFLOW INFORMATION

The Rocglen Coal Mine and the Tarrawonga Coal Mine are located within the Maules Creek Formation and have been operating since 2008 and 2006, respectively. As a result, they both provide useful information on actual mine inflows from the Maules Creek Formation for comparison with the predicted inflows at the Project site.

The observations of pit pumpage at the Rocglen Coal Mine (including rain water and surface runoff) are:

- 2009: nil;
- 2010: 23 ML, equivalent to 0.06 ML/day if steady; and
- 2011: 5 ML, equivalent to 0.01 ML/day if steady.

In 2010, Douglas Partners Pty Ltd conducted local area groundwater modelling as part of an assessment of the Rocglen Coal Extension Project. The Douglas Partners (2010) groundwater model predicted mine inflows of 0.5 to 1.0 ML/day for a typical 3 km pit perimeter. This amount was before evaporative loss in the pit.

The observations of pit pumpage at the Tarrawonga Coal Mine (including rain water and surface runoff) are:

- 2010: 25.4 ML, equivalent to 0.07 ML/day if steady; and
- other years: generally negligible.

In 2011, HCPL conducted regional numerical groundwater modelling as part of the assessment of the Tarrawonga Coal Project. The HCPL (2011) groundwater model predicted mine inflows of 0.4 to 0.5 ML/day steadily for a typical 6 km pit perimeter. This amount was before evaporative loss in the pit.

## 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.
- Whitehaven exploration (geological) data and logs.
- NOW Pinneena Groundwater Works Database records.
- Previous hydrogeological assessments/reviews undertaken for earlier coal mining at Vickery and the surrounding mines (i.e. Coffey, 1982, 1984a, 1984b; Vickery Joint Venture, 1986; 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; Hansen Bailey, 2010a, 2010b; Schlumberger Water Services (Australia) Pty Ltd, 2012; HCPL, 2011).
- Groundwater level data from monitoring programs undertaken at the Vickery Coal Mine and surrounding mines (i.e. Coffey, 1982, 1984a, 1984b; Tarrawonga Coal Pty Ltd, 2007, 2008, 2009, 2010; Whitehaven, 2005, 2006, 2007, 2008, 2009a, 2009b, 2010a, 2010b).
- The Vickery Groundwater Investigation Program conducted by GESPL (**Attachment AA**).

Based on the above, and consistent with the relevant Water Sharing Plans, two main groundwater systems occur within the Project area and surrounds:

- fractured hard rock groundwater system within the coal measures of the Maules Creek Formation; and
- groundwaters associated with the unconsolidated alluvial sediments of the Namoi River floodplain (i.e. the Upper Namoi Alluvium groundwater system).

The conceptual groundwater models for the Project area before mining and towards the end of the mine life are illustrated in **Figure A-29**.

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). Groundwater levels are sustained by rainfall infiltration; however, they are controlled by topography, geology and surface water levels in local drainages. Local groundwater tends to mound beneath hills, with ultimate discharge to distant drainages (via subsurface throughflow) and loss by evapotranspiration through geological outcrops and vegetation where the watertable is near the ground surface (generally 2 to 3 m below ground level). However, given the typical depth to water is 10 to 14 m to the south and west of the Project (as shown in **Figure A-21**), evapotranspiration is an unlikely occurrence in the vicinity of the Project area and adjacent Upper Namoi Alluvium.

During mining, the potentiometric heads in the Maules Creek Formation groundwater system would be reduced in the vicinity of the mine, but the watertable would tend to rise beneath the waste rock emplacements. Groundwater inflows from the Maules Creek Formation and the emplacements would report to the open cut.

### A3.1 HYDRAULIC PROPERTIES

Indicative permeabilities for the various stratigraphic units, summarised in **Table A-10**, have been determined from slug/pumping tests, core measurements and model calibration conducted by previous studies including AGE (2010); RCA Australia (2005, 2007); Douglas Partners (2010); and HCPL (2011). 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 regional numerical groundwater model. The performance of the calibrated model (including comparison to the ranges of indicative hydraulic properties) is discussed in **Section A4.9**.

**Table A-10**
**Indicative Hydraulic Properties of Stratigraphic Units**

| Unit | Horizontal Hydraulic conductivity Kx (m/day) | Vertical Hydraulic conductivity Kz (m/day) |
|---|---|---|
| Alluvium | 0.5[*]-20 | 0.5 |
| Regolith | 0.01-0.1 | 0.001-0.01 |
| Overburden (above Jeralong Seam) | 6.1 x $10^{-6}$ - 6.8 x $10^{-4}$ | 1.1 x $10^{-5}$ - 1.4 x $10^{-5}$ |
| Braymont/Jeralong Seams | 0.01-0.68 | - |
| Interburden (Jeralong to Merriown/Velyama Seams) | 7.2 x $10^{-7}$ - 8.1 x $10^{-4}$ | 2.4 x $10^{-7}$ - 1.9 x $10^{-4}$ |
| Merriown/Velyama Seams | 0.005-0.68 | - |
| Interburden (Velyama to Nagero Seam) | 6.3 x $10^{-7}$ - 1.0 x $10^{-4}$ | 3.6 x $10^{-7}$ - 4.4 x $10^{-5}$ |
| Nagero Seam | 0.025 | 0.0025 |
| Interburden (Nagero to Tralee Seam) | 8.2 x $10^{-7}$ - 3.2 x $10^{-4}$ | 1.8 x $10^{-7}$ - 2.2 x $10^{-4}$ |
| Tralee to Stratford Seams | 1.8 x $10^{-4}$- 0.5 | 0.0016 |
| Interburden (Stratford to Bluevale Seam) | 3.3 x $10^{-4}$- 7.3 x $10^{-4}$ | 4.2 x $10^{-7}$ - 7.2 x $10^{-6}$ |
| Bluevale to Cranleigh Seams | No estimate^ | No estimate^ |
| Underburden (below Cranleigh Seam) | 1.6 x $10^{-5}$- 0.0016 | 7.7 x $10^{-5}$ - 1.6 x $10^{-4}$ |
| Boggabri Volcanics | 2.4 x $10^{-6}$- 1 x $10^{-4}$ | 4.0 x $10^{-7}$- 1 x $10^{-5}$ |

After: RPS Aquaterra (2011); AGE (2010); RCA Australia (2005, 2007); Douglas Partners (2010); GESPL (2012).

[*] The NOW groundwater model for the Upper Namoi Groundwater Source assumed 0.5-1 m/day for alluvium to the north of the Project, 5 m/d to the south, and 20 m/d to the west along the Namoi River.

^ Seal failure in slug test (GESPL, 2012).

The hydraulic conductivity values in **Table A-10** are also based on results of the Vickery Groundwater Investigation Program undertaken by GESPL (2012), including:

- core testwork (29 samples from five drillholes [VKY002c, VKY006c, VKY010c, VKY017c and VKY020c]) (**Figure A-14b**);
- low flow constant rate pumping tests and slug tests at four standpipes screened within the weathered Maules Creek Formation (T7, T18, T35 and T26); and
- slug tests at five standpipes screened within the Maules Creek Formation (VKY3034, VKY3035, VKY3036, VKY3042and VKY3043).

A summary of the Vickery Groundwater Investigation Program core testwork results is provided in **Table A-11**, with further detail provided in **Attachment AA**. 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.

The slug test data were analysed using the Bouwer-Rice method for unconsolidated sediments and the Hvorslev Method for hard rock units (Kruseman and de Ridder, 1991; GESPL, 2012). The pumping tests were analysed using the Cooper-Jacob method (Kruseman and de Ridder, 1991; GESPL, 2012). Full details are disclosed in the report by GESPL contained in **Attachment AA**.

### Table A-11
### Core Hydraulic Conductivity Test Results from the Vickery Groundwater Investigation Program

| Horizontal Hydraulic Conductivity (m/d) | | | | |
|---|---|---|---|---|
| **Arithmetic Mean** | **Number of Samples** | **Maximum** | **Minimum** | **Formation** |
| $4.9 \times 10^{-6}$ | 11 | $2.22 \times 10^{-5}$ | $4.9 \times 10^{-7}$ | Tralee - Stratford Seam - Interburden |
| $1.8 \times 10^{-5}$ | 3 | $3.09 \times 10^{-5}$ | $3.16 \times 10^{-7}$ | Maules Creek Formation - Interburden |
| $4.0 \times 10^{-5}$ | 13 | $4.35 \times 10^{-4}$ | $6.36 \times 10^{-8}$ | Bluevale - Cranleigh Seam - Interburden |
| $2.4 \times 10^{-6}$ | 2 | $4.28 \times 10^{-5}$ | $5.4 \times 10^{-7}$ | Boggabri Volcanics |
| **Vertical Hydraulic Conductivity (m/d)** | | | | |
| **Harmonic Mean** | **Number of Samples** | **Maximum** | **Minimum** | **Formation** |
| $5.8 \times 10^{-7}$ | 11 | $1.19 \times 10^{-5}$ | $2.01 \times 10^{-7}$ | Tralee - Stratford Seam - Interburden |
| $7.2 \times 10^{-6}$ | 3 | $3.64 \times 10^{-5}$ | $3.12 \times 10^{-6}$ | Maules Creek Formation - Interburden |
| $4.2 \times 10^{-7}$ | 12 | $2.76 \times 10^{-5}$ | $1.03 \times 10^{-7}$ | Bluevale - Cranleigh Seam - Interburden |
| $4.0 \times 10^{-7}$ | 1 | $4.03 \times 10^{-6}$ | $4.03 \times 10^{-6}$ | Boggabri Volcanics |

Source: GESPL (2012).

# 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. New National Guidelines were announced in June 2012, sponsored by the National Water Commission (Barnett *et al.*, 2012). These guidelines build on the 2001 MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details. In the new guide, there are no specific guidelines on coal mine modelling.

The 2012 guide has replaced the model complexity classification by a "model confidence level". The Project model may be classified as Class 2 to Class 3 (effectively “medium to high confidence”), which is an appropriate level for this context. Under the 2001 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 6.22) software interface 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 layers 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/confidence level is adequate for simulation of 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

Douglas Partners (2010) developed a local area groundwater model for the Rocglen Coal Mine. The Rocglen model was evaluated for use in this assessment but was considered to be generally unsuitable as it is very local in scale and cannot accommodate the cumulative effects from neighbouring mines such as Tarrawonga.

The Tarrawonga regional numerical groundwater model (HCPL, 2011) was also evaluated and was considered to provide a suitable basis for this Project. However, the model area required extension to the south by about 6 km (to northing 6580000) and the Bluevale-Cranleigh coal seams (which do not occur at Tarrawonga) needed to be included as additional layers.

The Tarrawonga model was discretised into 1.23 million cells arranged into 12 layers comprising 374 rows and 274 columns. This is already over the notional limit of 1 million cells followed by the modelling fraternity. The extension to the south and inclusion of an extra two layers at the base to accommodate the Bluevale-Cranleigh coal seams would increase the number of model cells to 1.48 million.

The Tarrawonga model (HCPL, 2011) demonstrated that impacts from the Tarrawonga and Boggabri Coal Mines would not reach the Project, and it is therefore fair to assume that the Project mining effects would not propagate to the Tarrawonga Coal Mine. For this reason, a model of smaller areal extent has been developed as the main vehicle for assessing the Project.

There are several advantages in use of a smaller model:

(1) the model will be more stable numerically;

(2) there will not be a need to demonstrate calibration of alluvial groundwater hydrographs far to the north in the vicinity of Maules Creek;

(3) calibration can be focused in the vicinity of the Project; and

(4) model run times will be faster.

The same easting limits are retained for the smaller model, and the northern boundary of the model passes through the northern edge of the Tarrawonga Coal Mine so that it can be included in the cumulative impact assessment. The smaller model extends to MGA northing 6609000, compared with northing 6632000 for the Tarrawonga model (a reduction of 23 km).

In the Tarrawonga model the geometry of the coal seams was defined by the floor elevation of named seams in the Tarrawonga area (i.e. Jeralong, Velyama, Upper Nagero and Templemore). In the Project area, the Jeralong and Velyama coal seams are not present due to erosion. The Nagero seam is equivalent to the Tralee seam, and the Templemore seam is equivalent to the Stratford seam.

### A4.3 MODEL EXTENT

The extent of the regional numerical groundwater model has been selected to take into account cumulative mining effects from the Tarrawonga Coal Mine and the Rocglen Coal Mine and to include significant groundwater extraction from the Upper Namoi Alluvium for agricultural purposes. The model extent, indicated in **Figure A-7a**, extends between MGA eastings 209000 and 242000 and MGA northings 6580000 and 6609000. The area of coverage is 33 km east-west by 29 km north-south, a total of 957 square kilometres.

The model area includes portions of the Zone 4 and Zone 2 (Coxs Creek) groundwater sources in the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003*.

### A4.4 MODEL LAYERS

Fourteen 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 are assigned to be generally consistent with the NOW groundwater model for the Upper Namoi Alluvium.

The Maules Creek Formation has been split into multiple layers generally based on the targeted coal seams and in recognition of vertical hydraulic gradients. Layers 1 to 9 are the same as in the Tarrawonga model (HCPL, 2011). The targeted coal seams in the Project model are divided into two main groups: the upper and the lower (**Section A2.6**). The upper group of seams which includes Gundawarra, Kurrumbede, Shannon Harbour (upper and lower) and Stratford are represented in Layer 10 in the model. The lower group of seams is represented in Layer 12 and includes the Bluevale Seam (upper and lower) and the Cranleigh Seam (upper, middle and lower). Between these two groups of coal seams, an interburden layer is inserted as Layer 11 in the model.

Below the lower group of coal seams, two layers are inserted to represent the underlying coal measures and the basement Boggabri Volcanics (i.e. Layer 13 and Layer 14, respectively).

### A4.5 MODEL GEOMETRY

The model domain has been discretised into 1.26 million cells arranged into 14 layers comprising 267 rows and 338 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 five major groupings of coal seams (Layers 4, 6, 8, 10, 12) separated by overburden/interburden/underburden sandstone/siltstone sediments (Layers 3, 5, 7, 9, 11, 13). Layers 1 and 2 accommodate alluvium, regolith and overburden in rock outcrop areas. Layer 14 holds the Boggabri Volcanics.

The geometry of the coal seams is defined by the floor elevation of named seams (Jeralong, Velyama, Upper Nagero, Templemore/Upper Group, and Lower Group). The layer thickness is the aggregate of recorded coal thicknesses within the designated groupings. Structure contours have been extrapolated away from the Project area to define the stratigraphy throughout the model area, guided by median thicknesses from exploration drilling.

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 232500 (model column 191) and northing 6592100 (model row 220) through the proposed Project open cut in each direction.

The hydraulic properties initially were those found by calibration of the Tarrawonga model (HCPL, 2011), but were refined during model calibration of Vickery datasets.

### A4.6 MODEL STRESSES AND BOUNDARY CONDITIONS

The Mooki Thrust forms a natural boundary along the eastern edge of the model (**Figure A-7a**), and is therefore approximated as a no-flow boundary due to the exposure of low-permeability rocks of Carboniferous age on the eastern side of the boundary. No-flow boundaries have also been defined along the south-western and north-western edges of the model area due to the exposure of low-permeability rocks (**Figure A-33**). The northern model edge is approximated by streamlines, represented by no-flow boundaries, according to the regional watertable contours in **Figure A-19**. The southern and western boundaries are represented by general head boundary conditions in Layers 1 and 2 with heads set at the water levels in **Figure A-19**. Layer 3 has the same general head and no-flow boundary conditions as the overlying layers. 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, with occasional representation in Layer 2 (**Figure A-33**). The RIV package allows water exchange in either direction between the stream and the groundwater system, 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 if the watertable breaches the bed elevation of the stream, but they will never provide a source of water for the groundwater system. This feature has been implemented for the ephemeral streams across the Project area. The river conductances vary from 0.05 to 75 square metres per day ($m^2$/day), with median 0.1 $m^2$/day. The equivalent leakage coefficients are 0.003 to 0.03 $d^{-1}$ for the Namoi River; 0.0001 to 0.003 $d^{-1}$ for Driggle Draggle Creek; and 0.0001 $d^{-1}$ for the other creeks.

For the calibration period and during the prediction phase, constant average river levels are assumed.

“Drain” cells using the MODFLOW DRN package are used to represent mining in Layers 4, 6, 8, 10 and 12. 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 eliminate any resistance to flow.

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

1. Upper Namoi Alluvium;
2. Maules Creek Formation (Project area);
3. Maules Creek Formation (Tarrawonga area);
4. Boggabri Volcanics; and
5. Rock-alluvium contacts.

Local recharge rates were applied at the Canyon Coal Mine (Zone 6 on **Figure A-34**). The recharge rates determined during the Tarrawonga model calibration (HCPL, 2011) were used as initial estimates in the Project model. Additional recharge zones were defined during predictive simulations for the active Project mining area (zero recharge) and mine waste rock infiltration (assumed 5%).

For the calibration period, historical pumping from the Upper Namoi Alluvium groundwater system has been included in agreement with the stresses imposed in the NOW regional model for the Upper Namoi Groundwater Source. During the prediction phase, the pumping that occurred in 2010 (**Figures A-13a** and **A-13b**) has been assumed to continue at a constant rate. Sensitivity analyses were also conducted for continuous pumping during the prediction phase at the average rate that occurred at each production bore from 2006 to 2010 (1.9 times higher) (**Section A5.6**).

Evapotranspiration has been 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. The same parameters were applied in the Tarrawonga model (HCPL, 2011).

### A4.7 MODEL SIMULATIONS

Four model simulations were conducted as follows:

A. *Steady state calibration simulation*

   Initial calibration of hydraulic conductivities in order to replicate the regional hydraulic gradients, using data unaffected by mining.

*B. Transient calibration simulation*

Thorough calibration of groundwater system properties against hydrographic responses for dynamic monthly rainfall recharge and groundwater usage from registered alluvial bores, for Project and other mine monitoring bores and NOW observation bores in the Upper Namoi Alluvium.

*C. Transient prediction simulation (for single mine and cumulative effects)*

Simulation of the annual progression of open cut mining, allowing for time-varying properties for mine waste rock (hydraulic conductivity, specific yield and rainfall recharge), with prediction of potential impacts of Project development on the groundwater regime (particularly stream-groundwater system interaction, alluvium-coal interaction and groundwater dependent ecosystems) and prediction of mine inflow rates. The model was operated in this simulation in three different modes:

1) Project operating alone;
2) Project, Tarrawonga and Rocglen mines operating at the same time; and
3) use of Blue Vale Void as a water storage while all mines are operating.

*D. Transient recovery simulation*

Simulation of equilibrium groundwater levels for the final landform and pit voids.

The transient prediction simulation used the 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.[2]

**Table A-12** summarises the stress period setup in the model and the sequencing of open cut operations, backfilling, and duration of final voids.

### A4.8 STEADY STATE CALIBRATION

A long term steady state calibration was conducted with the aim of reproducing the watertable contours depicted in **Figure A-19**. Initial heads were provided by the representative field values contoured in **Figure A-19** and the initial hydraulic property values were guided by field measurements, the transient calibration of the Tarrawonga model (HCPL, 2011), and the steady state model calibration for Maules Creek and Boggabri models (to the north of the Tarrawonga Coal Mine) (AGE, 2011).

The objective was to produce long term average water levels to be used as initial conditions in the transient model calibration run

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[2] The alternative approach in common practice uses a set of sequential time-slices and numerous stop-start linked simulations. TMP is a routine in MODFLOW-SURFACT that allows changes in hydraulic properties as simulation progresses at particular time steps - in this case for simulating waste rock backfilling.

**Table A-12. Stress Period Definition and Sequencing of Mining Activities**

| Model Purpose | Stress Period | Start Date | End Date | Period Length | Timing of Operation | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Tarrawonga Pit Layers 1-8 | Rocglen Pit Layers 1-12 | Canyon Pit Layers 1-10 | Vickery Pit Layers 1-12 |
| CALIBRATION | 1 | 1/01/2006 | 31/01/2006 | Monthly | | | Backfilled | |
| | 2 | 1/02/2006 | 28/02/2006 | Monthly | | | | |
| | 3 | 1/03/2006 | 31/03/2006 | Monthly | | | | |
| | 4 | 1/04/2006 | 30/04/2006 | Monthly | | | | |
| | 5 | 1/05/2006 | 31/05/2006 | Monthly | | | | |
| | 6 | 1/06/2006 | 30/06/2006 | Monthly | | | | |
| | 7 | 1/07/2006 | 31/07/2006 | Monthly | | | | |
| | 8 | 1/08/2006 | 31/08/2006 | Monthly | | | | |
| | 9 | 1/09/2006 | 30/09/2006 | Monthly | Open Cut | | | |
| | 10 | 1/10/2006 | 31/10/2006 | Monthly | | | | |
| | 11 | 1/11/2006 | 30/11/2006 | Monthly | | | | |
| | 12 | 1/12/2006 | 31/12/2006 | Monthly | | | | |
| | 13 | 1/01/2007 | 31/01/2007 | Monthly | | | | |
| | 14 | 1/02/2007 | 28/02/2007 | Monthly | | | | |
| | 15 | 1/03/2007 | 31/03/2007 | Monthly | | | | |
| | 16 | 1/04/2007 | 30/04/2007 | Monthly | | | | |
| | 17 | 1/05/2007 | 31/05/2007 | Monthly | | | | |
| | 18 | 1/06/2007 | 30/06/2007 | Monthly | | | | |
| | 19 | 1/07/2007 | 31/07/2007 | Monthly | | | | |
| | 20 | 1/08/2007 | 31/08/2007 | Monthly | | | | |
| | 21 | 1/09/2007 | 30/09/2007 | Monthly | | | | |
| | 22 | 1/10/2007 | 31/10/2007 | Monthly | | | | |
| | 23 | 1/11/2007 | 30/11/2007 | Monthly | | | | |
| | 24 | 1/12/2007 | 31/12/2007 | Monthly | | | | |
| | 25 | 1/01/2008 | 31/01/2008 | Monthly | | | | |
| | 26 | 1/02/2008 | 29/02/2008 | Monthly | | | | |
| | 27 | 1/03/2008 | 31/03/2008 | Monthly | | | | |
| | 28 | 1/04/2008 | 30/04/2008 | Monthly | | | | |
| | 29 | 1/05/2008 | 31/05/2008 | Monthly | | | | |
| | 30 | 1/06/2008 | 30/06/2008 | Monthly | | | | |
| | 31 | 1/07/2008 | 31/07/2008 | Monthly | | | | |
| | 32 | 1/08/2008 | 31/08/2008 | Monthly | | | | |
| | 33 | 1/09/2008 | 30/09/2008 | Monthly | | | | |
| | 34 | 1/10/2008 | 31/10/2008 | Monthly | | | | |
| | 35 | 1/11/2008 | 30/11/2008 | Monthly | | | | |
| | 36 | 1/12/2008 | 31/12/2008 | Monthly | | | | |
| | 37 | 1/01/2009 | 31/01/2009 | Monthly | | Open Cut | | |
| | 38 | 1/02/2009 | 28/02/2009 | Monthly | | | | |
| | 39 | 1/03/2009 | 31/03/2009 | Monthly | | | | |
| | 40 | 1/04/2009 | 30/04/2009 | Monthly | | | | |
| | 41 | 1/05/2009 | 31/05/2009 | Monthly | | | | |
| | 42 | 1/06/2009 | 30/06/2009 | Monthly | | | | |
| | 43 | 1/07/2009 | 31/07/2009 | Monthly | | | | |
| | 44 | 1/08/2009 | 31/08/2009 | Monthly | | | Backfilled and Open Void | |
| | 45 | 1/09/2009 | 30/09/2009 | Monthly | | | | |
| | 46 | 1/10/2009 | 31/10/2009 | Monthly | | | | |
| | 47 | 1/11/2009 | 30/11/2009 | Monthly | | | | |
| | 48 | 1/12/2009 | 31/12/2009 | Monthly | | | | |
| | 49 | 1/01/2010 | 31/01/2010 | Monthly | | | | |
| | 50 | 1/02/2010 | 28/02/2010 | Monthly | | | | |
| | 51 | 1/03/2010 | 31/03/2010 | Monthly | | | | |
| | 52 | 1/04/2010 | 30/04/2010 | Monthly | | | | |
| | 53 | 1/05/2010 | 31/05/2010 | Monthly | | | | |
| | 54 | 1/06/2010 | 30/06/2010 | Monthly | | | | |
| | 55 | 1/07/2010 | 31/07/2010 | Monthly | | | | |
| | 56 | 1/08/2010 | 31/08/2010 | Monthly | | | | |
| | 57 | 1/09/2010 | 30/09/2010 | Monthly | | | | |
| | 58 | 1/10/2010 | 31/10/2010 | Monthly | | | | |
| | 59 | 1/11/2010 | 30/11/2010 | Monthly | | | | |
| | 60 | 1/12/2010 | 31/12/2010 | Monthly | | | | |
| | 61 | 1/01/2011 | 31/01/2011 | Monthly | | | | |
| | 62 | 1/02/2011 | 28/02/2011 | Monthly | | | | |
| | 63 | 1/03/2011 | 31/03/2011 | Monthly | | | | |
| | 64 | 1/04/2011 | 30/04/2011 | Monthly | | | | |
| | 65 | 1/05/2011 | 31/05/2011 | Monthly | | | | |
| | 66 | 1/06/2011 | 30/06/2011 | Monthly | | | | |
| | 67 | 1/07/2011 | 31/07/2011 | Monthly | | | | |
| | 68 | 1/08/2011 | 31/08/2011 | Monthly | | | | |
| | 69 | 1/09/2011 | 30/09/2011 | Monthly | | | | |
| | 70 | 1/10/2011 | 31/10/2011 | Monthly | | | | |
| | 71 | 1/11/2011 | 30/11/2011 | Monthly | | | | |
| | 72 | 1/12/2011 | 31/12/2011 | Monthly | | | | |

| Model Purpose | Stress Period | Start Date | End Date | Period Length | Timing of Operation | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Tarrawonga Pit Layers 1-8 | Rocglen Pit Layers 1-12 | Canyon Pit Layers 1-10 | Vickery Pit Layers 1-12 | |
| PREDICTION | 1 | 1/01/2012 | 31/12/2012 | Yearly | Open Cut and Backfilled | Open Cut and Backfilled | Backfilled and Open Void | | PROJECT |
| | 2 | 1/01/2013 | 31/12/2013 | Yearly | | | | | YEAR |
| | 3 | 1/01/2014 | 31/12/2014 | Yearly | | | | Open Cut and Backfilled | 1 |
| | 4 | 1/01/2015 | 31/12/2015 | Yearly | | | | | 2 |
| | 5 | 1/01/2016 | 31/12/2016 | Yearly | | | | | 3 |
| | 6 | 1/01/2017 | 31/12/2017 | Yearly | | | | | 4 |
| | 7 | 1/01/2018 | 31/12/2018 | Yearly | | Backfilled | | | 5 |
| | 8 | 1/01/2019 | 31/12/2019 | Yearly | | | | | 6 |
| | 9 | 1/01/2020 | 31/12/2020 | Yearly | | | | | 7 |
| | 10 | 1/01/2021 | 31/12/2021 | Yearly | | | | | 8 |
| | 11 | 1/01/2022 | 31/12/2022 | Yearly | | | | | 9 |
| | 12 | 1/01/2023 | 31/12/2023 | Yearly | | | | | 10 |
| | 13 | 1/01/2024 | 31/12/2024 | Yearly | | | | | 11 |
| | 14 | 1/01/2025 | 31/12/2025 | Yearly | | | | | 12 |
| | 15 | 1/01/2026 | 31/12/2026 | Yearly | | | | | 13 |
| | 16 | 1/01/2027 | 31/12/2027 | Yearly | | | | | 14 |
| | 17 | 1/01/2028 | 31/12/2028 | Yearly | | | | | 15 |
| | 18 | 1/01/2029 | 31/12/2029 | Yearly | | | | | 16 |
| | 19 | 1/01/2030 | 31/12/2030 | Yearly | | | | | 17 |
| | 20 | 1/01/2031 | 31/12/2031 | Yearly | | | | | 18 |
| | 21 | 1/01/2032 | 31/12/2032 | Yearly | Backfilled and Open Void | | | | 19 |
| | 22 | 1/01/2033 | 31/12/2033 | Yearly | | | | | 20 |
| | 23 | 1/01/2034 | 31/12/2034 | Yearly | | | | | 21 |
| | 24 | 1/01/2035 | 31/12/2035 | Yearly | | | | | 22 |
| | 25 | 1/01/2036 | 31/12/2036 | Yearly | | | | | 23 |
| | 26 | 1/01/2037 | 31/12/2037 | Yearly | | | | | 24 |
| | 27 | 1/01/2038 | 31/12/2038 | Yearly | | | | | 25 |
| | 28 | 1/01/2039 | 31/12/2039 | Yearly | | | | | 26 |
| | 29 | 1/01/2040 | 31/12/2040 | Yearly | | | | | 27 |
| | 30 | 1/01/2041 | 31/12/2041 | Yearly | | | | | 28 |
| | 31 | 1/01/2042 | 31/12/2042 | Yearly | | | | | 29 |
| RECOVERY | 1 | 1/01/2043 | 31/12/2243 | 200 Years | Backfilled and Open Void | Backfilled | Backfilled and Open Void | Backfilled and Open Void | |

The simulated watertable contours for steady state conditions are displayed in **Figure A-35** for comparison with the representative field contours in **Figure A-19**.

Calibration of groundwater conditions at the Project site has focused on replication of the natural vertical head profiles measured by the three vibrating wire peizometers in the Project area (i.e. VKY3033, VKY3041 and VKY3053). The simulated and observed head profiles, shown in **Figure A-36**, are in good agreement.

Calibration has also been done on seven of the single standpipe bores installed in the Project area. The results in **Table A-13** show that the residual varies from -3.4 m to +4.5 m, with median -0.6 m.

**Table A-13**
**Calibration Performance at Project Bores**

| Bore | Layer | Measured Water Level (m AHD) | Simulated Water Level (m AHD) | Residual |
|---|---|---|---|---|
| TR7 | 2 | 245.5 | 246.1 | -0.6 |
| TR18 | 5 | 246.0 | 249.4 | -3.4 |
| VKY3034 | 10 | 244.8 | 246.5 | -1.7 |
| VKY3035 | 11 | 243.7 | 246.3 | -2.6 |
| VKY3036 | 11 | 250.8 | 246.2 | 4.5 |
| VKY3042 | 10 | 249.5 | 246.7 | 2.8 |
| VKY3043 | 13 | 247.7 | 245.7 | 2.0 |

### A4.9 TRANSIENT CALIBRATION

The transient calibration was conducted for the time period January 2006 to December 2011 for 72 monthly stress periods. The starting date precedes the commencement of mining at the Tarrawonga Coal Mine in September 2006, and coincides with the commencement of water level and water quality monitoring at the Tarrawonga Coal Mine. Initial hydraulic property values in the Project model were guided by field measurements and by transient model calibration for the Tarrawonga model and steady state model calibration for Maules Creek and Boggabri models.

The transient calibration conducted here has enabled better estimation of storage properties required for transient prediction. Initial heads were based on the heads generated by the long term steady state calibration as shown in **Figure A-35**.

The monitoring bores associated with the Vickery, Tarrawonga, Canyon and Rocglen Coal Mines have allowed calibration of the Project model in each area and thereby enhance the reliability of cumulative impact assessment. The Project model has included transient calibration against all NOW observation bores within the model area (i.e. Zone 4 and Zone 2 water sources of the Upper Namoi Alluvium groundwater system).

**Table A-14** lists the number of monitoring sites and the number of head targets which were used to calibrate the model between the period of January 2006 to December 2011. In all, 3329 target heads were established for 146 sites. Calibration was conducted manually and automatically using PEST software. A separate verification process was not conducted as the full length of mine monitoring records was required for calibration of hydrographs exhibiting mining effects.

**Table A-14**
**Transient Calibration Head Targets**

| Site | No. of Monitoring Bores | No. of Transient Points |
|---|---|---|
| Tarrawonga | 21 | 408 |
| Rocglen | 15 | 185 |
| Canyon | 12 | 203 |
| Vickery | 27 | 27 |
| NOW Zone 2 | 12 | 315 |
| NOW Zone 4 | 59 | 2191 |
| **Total** | **146** | **3329** |

For calibration purposes, there are no usable groundwater inflow records at neighbouring mines as the inflow volumes are so low that they are likely to be consumed by evaporation off wall seeps and floor pools (**Section A2.15**). However, an initial estimation of pit inflow variability with time was made by calculating the approximate annual perimeter and floor area exposed within the Project open cut. The analysis of annual mine stage polygons gave an average area of 171 hectare and a 9.3 km average pit perimeter. The temporal variation in **Figure A-37** shows very similar patterns for the two attributes, with pit perimeter being the smoother of the two.

The variability of pit perimeter with time has been used to weight annual inflows according to an assumed long-term average pit inflow. While observations (after evaporation) are extremely low (i.e. less than 0.1 ML/day), previous models consistently predict about 0.5 ML/day before evaporation.

Pit inflow variability is indicated in **Figure A-38** for a range of long-term averages from 0.3 ML/day to 1.0 ML/day. The peak inflow is expected to be about 35% higher than the long-term average. This inflow would be distributed around a typical perimeter of the open cut of about 10 km. Physically, an inflow rate of 1.0 ML/day would appear as a seep of about 0.1 L/s for each 100 m length of pit wall.

### A4.9.1 Calibrated Model Properties

**Table A-15** summarises the hydraulic and storage properties for the stratigraphic section at the end of transient calibration. The adopted property distributions are displayed in **Attachment AH**. The values for horizontal hydraulic conductivity (Kx) are consistent with field estimates listed in **Table A-10** and with estimates from other models.

## Table A-15
## Calibrated Horizontal and Vertical Hydraulic Conductivities, Storage Coefficient and Specific Yield

| Layer | | Lithology | Kx (m/d) | Kz (m/d) | S | Sy |
|---|---|---|---|---|---|---|
| **1** | 🟨 | Alluvium | 0.35-40 | 0.1-0.01 | 0.001 | 0.05-0.2 |
| | 🟦 | Regolith/Weathered Permian | 0.01 | 0.001 | 0.0001 | 0.01 |
| **2** | 🟨 | Alluvium | 0.35-40 | 0.05 | 0.005 | 0.2 |
| | 🟦 | Overburden/Weathered Permian | 0.01 | 0.001 | 0.0001 | 0.01 |
| **3** | 🟦 | Overburden | 3.4E-04 | 1.2E-05 | 5.0E-05 | 0.005 |
| **4** | ▨ | Braymont Seam to Jeralong Seam | 0.4 | 0.01 | 0.0001 | 0.01 |
| **5** | 🟦 | Interburden | 2.5E-04 | 1.3E-06 | 5.0E-05 | 0.005 |
| **6** | ▨ | Merriown Seam to Velyama Seam | 0.4 | 0.01 | 0.0001 | 0.01 |
| **7** | 🟦 | Interburden | 4.0E-05 | 1.1E-06 | 5.0E-05 | 0.005 |
| **8** | ▨ | Nagero Upper Seam | 0.3 | 0.01 | 0.0001 | 0.01 |
| **9** | 🟦 | Interburden | 3.1E-05 | 8.3E-07 | 5.0E-05 | 0.005 |
| **10** | ▨ | Tralee Seam to Stratford Seam | 0.05 | 0.01 | 0.0001 | 0.01 |
| **11** | 🟦 | Interburden | 3.0E-05 | 3.6E-06 | 5.0E-05 | 0.005 |
| **12** | ▨ | Bluevale to Cranleigh Seam (Whitehaven Seam) | 0.05 | 0.01 | 0.0001 | 0.01 |
| **13** | 🟦 | Underburden | 3.0E-05 | 2.0E-06 | 5.0E-05 | 0.005 |
| **14** | 🟧 | Volcanics | 2.5E-03 | 5.0E-04 | 0.0001 | 0.01 |

*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 Vickery Area [Zone 2]: 0.15%
- Maules Creek Formation Tarrawonga Area [Zone 3]: 0.2%
- Boggabri Volcanics [Zone 4]: 0.25%
- Rock-alluvium contacts [Zone 5]: 10%

### A4.9.2 Transient Calibration Performance

A scattergram of simulated versus measured heads in **Figure A-39** 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-16**. The key statistic is 2.6% Root Mean Square, which is well below the groundwater modelling guideline value of 5-10% (MDBC, 2001; Barnett *et al*., 2012) for acceptable model calibration.

**Table A-16**
**Transient Calibration Performance**

| Calibration Statistics | Value |
|---|---|
| Number of Data (n) | 3329 |
| Root Mean Square (m) | 2.8 |
| Scaled Root Mean Square (%) | 2.6 |
| Average residual (m) | -0.6 |
| Absolute average residual (m) | 1.8 |

The ability of the model to replicate observed groundwater hydrographs is reported in full in **Attachment AI**. For illustration, **Figure A-40** to **Figure A-43** show comparisons of simulated and observed hydrographs at representative sites within the NOW alluvial bore network, the Tarrawonga Coal Mine monitoring network, the Canyon Coal Mine monitoring network and the Rocglen Coal Mine monitoring network. Model water level trends and absolute elevations, in the majority of cases, are consistent with the observed water levels.

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 (**Figure A-40**). Only one Tarrawonga Coal Mine bore (MW7) shows a mining response, and this is simulated faithfully (**Figure A-41**). The local stresses due to the final stages of the mining at the Canyon Coal Mine, and the residual void, are replicated very well by the model (**Figure A-42).** In general, the model overestimates water levels at the Rocglen Coal Mine (**Figure A-43**).

### A4.9.3 Transient Water Balance

The transient water balance across the entire model area is summarised in **Table A-17** for the full calibration period (January 2006 to December 2011). The average inflow (recharge) to the groundwater system was approximately 51 ML/day, comprising mainly rainfall recharge (39%) and leakage from streams into the groundwater system (24%). The leakage from all streams is simulated to be about 12 ML/day. Boundary inflow was also significant (37%).

## Table A-17
## Simulated Average Water Balance during the Transient Calibration Period

| Component | Groundwater Inflow (Recharge) (ML/day) | Groundwater Outflow (Discharge) (ML/day) |
|---|---|---|
| Rainfall Recharge | 19.8 | - |
| Evapotranspiration | - | 1.9 |
| Rivers/Creeks | 12.4 | 6.1 |
| Production Bores | - | 49.5 |
| Mines | - | 1.3 |
| Boundary Flow | 18.9 | 3.0 |
| **TOTAL** | **51.1** | **61.8** |
| **Storage** | **10.5 LOSS** | |
| **Discrepancy (%)** | **-0.3** | |

Production bore abstraction accounts for the majority of the groundwater discharge, at 80%. Next in order of importance is stream baseflow (10%). Evapotranspiration and boundary flows are similar in magnitude (3% and 5%, respectively). The computed inflow to all mines (1.3 ML/day) is about 2% of the total groundwater discharge over the model area.

Over the calibration period (January 2006 to December 2011), discharge exceeded recharge by about 10 ML/day.

### A4.9.4 Transient Sensitivity Analysis

During the calibration process, the most important parameters were found to be the horizontal hydraulic conductivities of the coal layers. An informal sensitivity analysis established the need for a relatively high coal hydraulic conductivity (about 0.4 m/d in the upper coal seams and 0.05 m/d in the lower coal seams at the Project site).

For the previous Tarrawonga model (HCPL, 2011), sensitivity analysis was 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. When the base value of 0.05 m/d was increased to 2.4 m/d, there was no change in the calibration performance statistic or any significant change in local stream-groundwater interaction.

## A5 SCENARIO ANALYSIS

As described in **Section A4.7**, model transient predictive simulations were conducted in three operational modes:

1) with the Project alone (referred to herein as the Project-only scenario);
2) with the Project, plus the Rocglen and Tarrawonga Coal Mines operating, including a low permeability barrier at Tarrawonga, to assess the cumulative impacts of the Project in association with the effects of other mines (referred to herein as the cumulative scenario); and
3) with all three mines operating, including a water storage in the Blue Vale void at a level of 265 m AHD, to assess the impacts of the water storage on groundwater flows and water quality (referred to herein as the cumulative Blue Vale scenario).

### A5.1 MINING 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 2012 (after the end of the calibration Period) to December 2042 in annual steps. The Project is taken to commence in the model in January 2014 (stress period 3) and finish in December 2042 (stress period 31)[3]. The Tarrawonga Coal Mine was activated from stress period 1 to stress period 20 (end 2031) and the Rocglen Coal Mine was activated from stress period 1 to stress period 6 (end 2017) (**Table A-12**).

To allow time for mine waste rock to wet up through the unsaturated zone, the rainfall recharge rate was increased from natural calibrated rates to 5% of average rainfall after five years. The sequencing of time-varying recharge is illustrated by the colour mosaics in **Figure A-44**. The same colour pattern denotes the application of time-varying mine waste rock hydraulic conductivity (set at 1 m/d), which was done using the 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 average irrigation pumping rates that occurred between July 2009 to June 2010 were assumed to continue at a constant rate. As stated in **Section A4.6**, a sensitivity analysis was conducted also for higher continuous irrigation pumping rates (reported in **Section A5.6**).

The progression of mining in the model was applied consistent with the general arrangement snapshots for the Project presented in the Main Report of the EIS and the respective Environmental Assessments for the Tarrawonga Coal Mine and Rocglen Coal Mine.

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[3] The model timing is deliberately lagged six months behind the actual proposed mining in order to counteract the sudden opening of a model pit at the start of a stress period.

### A5.2 WATER BALANCE

Simulated water balances for the entire model extent have been averaged over the proposed Project mine life (stress periods 3 to 31) and are examined in **Table A-18** and **Table A-19**.

**Table A-18**
**Simulated Water Balance Changes for the Project-only Scenario**

| Component | Groundwater Inflow (Recharge) (ML/day) | | Groundwater Outflow (Discharge) (ML/day) | |
|---|---|---|---|---|
| | Project Start | Project Average | Project Start | Project Average |
| Rainfall Recharge | 20.1 | 20.3 | - | - |
| Evapotranspiration | - | - | 2.2 | 2.2 |
| Rivers/Creeks | 10.6 | 10.5 | 8.3 | 8.4 |
| Production Bores | - | - | 31.0 | 31.0 |
| Vickery Open Cut | - | - | 0.0 | 1.2 |
| Boundary Flow | 14.3 | 14.6 | 3.0 | 3.0 |
| **TOTAL** | **45.0** | **45.4** | **44.5** | **45.8** |
| **Storage** | **0.5 GAIN** | **0.4 LOSS** | - | - |

**Table A-19**
**Average Simulated Water Balance for the Prediction Model during the Project Period**

| Component | Groundwater Inflow (Recharge) (ML/day) | | Groundwater Outflow (Discharge) (ML/day) | |
|---|---|---|---|---|
| | Project-only Scenario | Cumulative Scenario | Project-only Scenario | Cumulative Scenario |
| Rainfall Recharge | 20.3 | 20.7 | - | - |
| Evapotranspiration | - | - | 2.2 | 2.3 |
| Rivers/Creeks | 10.5 | 10.5 | 8.4 | 8.4 |
| Production Bores | - | - | 31.0 | 31.0 |
| Mines | - | - | 1.2 | 2.4 |
| Boundary Flow | 14.6 | 14.7 | 3.0 | 3.0 |
| **TOTAL** | **45.4** | **45.9** | **45.8** | **47.1** |
| **Storage** | **0.5 LOSS** | **1.2 LOSS** | | |

**Table A-18** presents the simulated water balance changes for the Project-only scenario. Mine inflow of about 1.2 ML/d is expected, on average. This inflow would be supplied primarily from groundwater storage. Variations in the average flows of other components of the water balance, compared to pre-Project flows, do not exceed 0.3 ML/day which is less than 1 percent of the total water budget.

For the Project-only scenario, recharge is dominated by rainfall infiltration (45%), lateral boundary flow (32%) and river/creek leakage (23%). Groundwater pumping by production bores accounts for 68% of groundwater discharge from the model area. The other significant discharge mechanism is river/creek baseflow (19%). Average inflow to the Project open cut during the mine life is predicted to be about 3% of all groundwater discharge.

**Table A-19** gives the simulated average components over the entire model extent for the Project-only scenario and the cumulative scenario. The three mines are expected to have a combined average inflow of about 2.4 ML/day.

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

### A5.3 PREDICTED PIT INFLOW

The time-varying pit inflows predicted by the model are illustrated in **Figure A-45** for the cumulative scenario. These inflows are calculated as the average rates over the stress period. The Project inflow is expected to vary between 0.3 and 1.7 ML/day during the mine life. Inflows to the Tarrawonga and Rocglen Coal Mines are expected to peak around 1.3 and 0.9 ML/day respectively. With the other mines deactivated in the model (i.e. the Project-only scenario), the Project pit inflows increase a little to a range of 0.4 to 1.9 ML/day.

The variability of predicted inflows to the Project open cut with time closely resembles the empirical chart of **Figure A-38** which was based on the growth in pit perimeter.

### A5.4 PREDICTED BASEFLOW CHANGES

Stream-groundwater water exchanges with the Upper Namoi Alluvium have been examined for the 4 km reach of the Namoi River to the immediate west of the Project area (marked in red on **Figure A-33a** and **Figure A-46a**), Driggle Draggle Creek, North-West Drainage Line, West Drainage Line, South Creek and Stratford Creek during the 31 years of model prediction. Only in the examined reach of the Namoi River, Barbers Lagoon and the upgradient reach of Driggle Draggle Creek does baseflow occur through groundwater discharge to each stream. The other streams located near the Project are ephemeral streams and are dry most of the time.

**Figure A-46b** and **Figure A-46c** show the simulated stream baseflow for the 4 km Namoi River reach and a 28 km section of Driggle Draggle Creek (marked in pink on **Figure A-46a**), respectively. The Namoi River reach has an average baseflow of about 0.09 ML/day (i.e. 0.023 megalitres per day per kilometre [ML/day/km]) and is predicted to vary from about 0.08 to 0.10 ML/day due to the effects of mining. Driggle Draggle Creek has a very constant baseflow of 0.2 ML/day (average 0.007 ML/day/km), with no perceptible change due to mining. Barbers Lagoon receives about 0.01 ML/day steadily from groundwater discharge, and there is no change in the amount of baseflow during mining.

There is a small predicted reduction in baseflow to the 4 km reach of the Namoi River to the immediate west of the Project area. As illustrated in **Figure A-47**, baseflow is expected to decrease by about 0.015 ML/day (i.e. less than 0.004 ML/day/km) from commencement of the Project (in model year 3).

### A5.5 CUMULATIVE IMPACTS

**Table A-19** illustrates the cumulative effect on water balance components of the Project operating in conjunction with the neighbouring Tarrawonga and Rocglen Coal Mines.

For the cumulative scenario, recharge would continue to be dominated by rainfall infiltration (45%), lateral boundary flow (32%) and river/creek leakage (23%) at almost the same rates. Groundwater pumping by production bores accounts for 65% of groundwater discharge from the model area. The other significant discharge mechanism is river/creek baseflow (18%). Average inflow to the three mines during the life of the Project is predicted to be about 6% of all groundwater discharge.

The neighbouring mines are predicted to make about 1.2 ML/day in addition to the mine inflow at the Project, on average. This increase in inflow is supplied primarily from groundwater storage. 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 (0.4 ML/day) due to infiltration through the overburden emplacements.

The predicted drawdown effects for the Project-only scenario are provided in **Attachment AJ** for model layers 1, 2, 4, 6, 8, 10 and 12 for model years 5, 10, 15, 20, 25, and 31. Similarly, the predicted drawdown effects for the cumulative scenario are also provided in **Attachment AJ** for model layers 1 and 2 for model year 19 at the time of the maximum cumulative impact (at the end of the Tarrawonga Coal Mine life). Although the Tarrawonga mining was simulated, the close model boundary caused slightly higher drawdown than was reported in the Tarrawonga assessment due to the unavailability of groundwater replenishment from the northern side of the model boundary. Accordingly, on the basis of the Principle of Superposition[4], the drawdown contours from the Tarrawonga assessment report have been adopted (HCPL, 2011).

For the Project-only scenario, the 1 m drawdown contour in the near surface model layers (i.e. regolith/alluvium) at the end of the mine life extends just east of the Woodlands Fault and west of the Womboola Fault but does not extend past the Upper Namoi Alluvium boundary (**Figure A-48**). **Figure A-49** shows the drawdown in the watertable at Project Year 17 for the cumulative scenario (when the Tarrawonga Project ceases). The 1 m drawdown contours for the Project and the Rocglen Coal Mine coalesce, but there is no interaction with effects from the Tarrawonga Coal Mine. The 1 m drawdown contour for the Project and Rocglen Coal Mine remains within the Maules Creek Formation and does not impinge on the Upper Namoi Alluvium. The western extent is constrained by the Womboola Fault.

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[4] "The principle of superposition means that for linear systems, the solution to a problem involving multiple inputs (or stresses) is equal to the sum of the solutions to a set of simpler individual problems that form the composite problem." (Reilly et al., 1984)

### A5.6 SENSITIVITY ANALYSIS

In order to check whether the assumed irrigation pumping rates from the Upper Namoi Alluvium groundwater had any effect on predicted mining-induced drawdowns, simulations for the prediction phase were also conducted for continuous pumping at the average rate that occurred at each production bore from 2006 to 2010 (1.9 times higher).

**Figure A-50** shows the predicted drawdown patterns for two scenarios: the low pumping base case, and the high pumping case. Drawdowns have been calculated from the end of prediction stress period 2 (31 December 2013) to the end of prediction stress period 31 (31 December 2042).

The 1 m drawdown contour is almost identical in each case, and remains confined to the Maules Creek Formation. It is clear that the predicted drawdown extent due to mining is insensitive to the assumptions made for the magnitude of irrigation pumping in the Upper Namoi Alluvium.

### A5.7 BLUE VALE VOID WATER STORAGE

The third model operational mode considered the use of the existing Blue Vale void as a water storage plus the cumulative effect of the Project operating in conjunction with the Tarrawonga and Rocglen Coal Mines. The Blue Vale void has a minimum floor elevation of 255 m AHD.

The use of the Blue Vale void as a water storage would be intermittent during the life of the Project. For this reason, it has been simulated at a constant half-full level (265 m AHD) to discern likely average effects. The water storage would revert to a quiescent void at the end of the Project.

The water storage was defined in the model as having a constant head of 265 m AHD from the alluvium-regolith (Layer 1) to the Upper Group seams (Layer 10). The impact of using the Blue Vale void as a water storage was examined for a 4 km reach of the Namoi River located to the immediate west of the Project area (marked in red on **Figure A-46a**).

**Figure A-51** shows the simulated stream baseflow for the 4 km reach of the Namoi River with and without the Blue Vale void. The average baseflow into the Namoi River reach is predicted to increase from about 0.09 to 0.16 ML/day due to the effects of the water storage in the void. This would more than offset the anticipated reduction of about 0.015 ML/day in natural baseflow due to mining (**Section A5.4**) if there were no managed water storage in the void.

The outflow from the water storage predicted by the model is illustrated in **Figure A-51.** The average outflow from the water storage is expected to be constant at about 0.08 ML/day. This would be partitioned as about 0.025 ML/day to the north-east and about 0.055 ML/day to the south-west.

The seepage flow directions from the Blue Vale void are represented as a plan view in **Figure A-52a** and as a west-east cross-section in **Figure A-52b** passing through the Blue Vale void and the 4 km reach of the Namoi River at Northing 6591930 (Model Row 221). The baseflow to the river occurs in the upper few layers and is not sourced from the deeper more saline coal measures. Beneath the river, there is a definite downwards hydraulic gradient to the deeper layers. The water quality risks of mine-sourced water in the water storage migrating to the river are assessed in **Section A6.2.1**.

### A5.8 POST-MINING EQUILIBRIUM

A final void water balance was prepared by Evans & Peck (Appendix B of the EIS) 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 voids treated as highly permeable water bearing material (K = 1000 m/d; Sy = 1.0). The ET package in MODFLOW was used to represent open water evaporation[5] assumed to be 70 percent of pan evaporation

The results of the post-mining estimates of groundwater inflows are presented as Inflow-Stage curves in **Figure A-53**. These curves serve as lookup tables for the final void modelling by Evans & Peck (Appendix B of the EIS). Priority is given to the modelling results in Appendix B rather than the groundwater model estimates as the groundwater model does not include surface water runoff into the voids. The equilibrium long-term groundwater inflow to the voids is expected to be about 0.8 ML/day for the northern void and 0.6 ML/day for the southern void.

Whitehaven propose to manage the final voids and their catchment configurations by changes to the final mine plan (e.g. final void catchment areas) and closure works to achieve groundwater levels in the final voids that are lower than the pre-mining conditions. Appendix B of the EIS estimates that the northern void would reach an average water level of 168.8 m AHD approximately 100 years after mining ceases and the level would oscillate between about 164 and 173 m AHD thereafter (under current climate situations).

The southern void would reach an average water level of 146.7 m AHD approximately 100 years after mining ceases and the level would oscillate between about 145 and 151 m AHD thereafter (under current climate situations).

The equilibrium water levels would be about 90-100 m lower than current groundwater levels at the northern void, and about 105 to 115 m lower at the southern void. Both voids would act as permanent groundwater sinks.

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[5] 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.

The shallow groundwater level pattern predicted by the groundwater model (without the benefit of extra surface water runoff) is displayed in **Figure A-54** at 200 years after the end of the Project. The contours confirm that the two final voids in the north-eastern and south-eastern corners of the excavation would act as strong sinks for groundwater entering from all directions.

Representative recovery hydrographs at monitoring bores VKY3036, VKY3041 and VKY3043 are displayed in **Figure A-55**. The graphs are ordered north to south with depth increasing from 112 m to 242 m below natural surface. As the bores are close to the final voids, the groundwater levels are consistent with the areal water level in **Figure A-54**. From north to south, the bores reach 75% of their equilibrium water levels after 70 years, 50 years and 15 years, respectively.

# 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 open cut. 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.

A decrease in the hydraulic gradient in the mine waste rock material is evident in the spacing of the contours across the infilled areas in **Figure A-54**. As the final voids are to be located at the north-eastern and south-eastern corners of the excavation, the groundwater flow direction would be reversed from a westerly direction pre-mining to an easterly direction post-mining. This would be a permanent change.

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, generally reversal of direction due to the direction of excavation, until mining is completed and the groundwater system recovers to a new equilibrium (**Figure A-54**).

The post-mining groundwater level pattern in **Figure A-54** shows that the two final voids would act as permanent groundwater sinks. The final equilibrium groundwater levels are expected to be about 95 m lower than current groundwater levels near the northern void and about 110 m lower near the southern void.

The quality of the inflow water would be a mixture of the qualities of the waters in source lithologies, primarily coal and coal measures of the Maules Creek Formation, and leachate from rainfall infiltration through the waste emplacements. The coal and coal measures waters have similar ionic signatures with median EC values of about 4,000 µS/cm and salinities of about 2,400 mg/L (**Section A2.14**).

Over time, the salinity in the final voids would increase through evaporative concentration. As long as the void remains a groundwater sink, there would be no deleterious effect on the beneficial uses of any groundwater sources. As the final voids would remain as groundwater sinks, no long-term impacts to groundwater quality are expected to occur in the Upper Namoi Alluvium groundwater system or the porous/fractured rock groundwater systems surrounding the Project area.

Final void salinity is predicted to increase slowly with time, reaching about 5,000 mg/L and 7,000 mg/L after 100 years in the northern and southern voids, respectively (Appendix B of the EIS). Given the long time period, and the direction of groundwater flow in the infilled excavation area, it is expected that groundwater quality would not be impacted by final void water quality after mining. Evidence for the slow rate of change of salinity in void waters is offered by the September 2012 measurement of 3,700 µS/cm in the Greenwood void, which has been in place for about 11 years. This value is similar to the median EC measurement in the Maules Creek Formation within the Project area (3,900 µS/cm).

### A6.1.3 Geochemistry

Geochemical investigation undertaken in Appendix L of the EIS (GEM, 2012) found that the overburden and interburden materials in the proposed open cut are expected to be non-acid forming (NAF) with low potential for soluble salt generation. Some materials sampled close to the coal seams had slightly increased sulphur concentrations, and these materials present a risk of being potentially acid forming (PAF). 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 down gradient water quality.

Due to enhanced concentrations of sulphur, selenium and arsenic in coarse reject (chitter) samples, and planned co-disposal of this material, GEM (2012) recommended that "the closure plan for the in-pit disposal of this material will require a cover system designed to sufficiently reduce oxygen diffusion and/or water infiltration into the coal rejects material and provide a suitable growth medium to support successful long-term revegetation".

In consideration of the above and assuming standard PAF identification and management practices are adopted, there would be negligible impacts to groundwater quality (either directly or via final pit voids) as a result of PAF material.

### A6.1.4 Pit Inflows

Up to the end of mining, there would be a continuous loss of water from the groundwater system to the mining void. The hard rock groundwater within the coal measures of the Maules Creek Formation are the only groundwater source for pit inflows. After the end of mining, there would be long-term groundwater inflow from these coal bearing rock including the Project waste emplacements, with no contribution of groundwater from the Upper Namoi alluvium.

The predictive simulation in **Section A5.3** demonstrates that pit inflow is expected to vary between approximately 0.4 and 1.9 ML/day during the life of the Project.

The year-by-year expected pit inflows (without mitigating effects from other mines) are listed in **Table A-20**.

## Table A-20
## Predicted Pit Inflows for the Project

| Project Year | Pit Inflow (ML/day) | Project Year | Pit Inflow (ML/day) |
|---|---|---|---|
| 1 | 0.00 | 16 | 1.32 |
| 2 | 0.40 | 17 | 1.26 |
| 3 | 0.37 | 18 | 1.57 |
| 4 | 0.54 | 19 | 1.53 |
| 5 | 0.63 | 20 | 1.41 |
| 6 | 0.67 | 21 | 1.53 |
| 7 | 0.68 | 22 | 1.73 |
| 8 | 0.65 | 23 | 1.79 |
| 9 | 0.66 | 24 | 1.77 |
| 10 | 0.66 | 25 | 1.81 |
| 11 | 0.75 | 26 | 1.77 |
| 12 | 0.79 | 27 | 1.78 |
| 13 | 0.80 | 28 | 1.91 |
| 14 | 0.87 | 29 | 1.82 |
| 15 | 1.25 | 30 | 1.00 |

### A6.1.5 Upper Namoi (Zone 4) Alluvium

The Project is located within a hard rock "island" of the Maules Creek Formation encircled by alluvium that has been designated as the Upper Namoi Zone 4, Namoi Valley (Keepit Dam to Gin’s Leap) Groundwater Source.

Groundwater would not be lost directly from the alluvium, but there could be incidental loss through enhanced leakage from the bordering alluvium to the underlying Maules Creek Formation.

The potential increase in leakage of groundwater from the alluvium to the underlying consolidated sediments as mining progresses has been examined for the two ‘regions’ where the Project is closest to the Upper Namoi Alluvium. These ‘regions’ are marked in **Figure A-56**. There is also an offsetting potential for enhanced lateral flow from the Western and Eastern Emplacements across the alluvial contact.

At the start of the Project, the model reports a net upflow of about 0.15 ML/day from model layer 3 (conglomerate) to model layer 2 (alluvium) in the northern region, and a net upflow of about 0.023 ML/day in the southern region (**Figure A-57**). At the end of the Project, for the northern region, the model reports a reduction of about 0.085 ML/day (31 megalitres per year [ML/year]) in the net upflow to a rate of about 0.06 ML/day. In the southern region, the polarity reverses to a net downwards leakage of about 0.11 ML/day, giving a net impact of about 0.13 ML/day (about 47 ML/year) (**Figure A-57**).

During the recovery period, the changes in alluvial-rock groundwater flows in both regions are predicted to continue increasing for 10 to 20 years, after which time they return to rates similar to those at the end of mining (**Figure A-58**). The permanent losses average about 0.15 ML/day (55 ML/year) in the southern region and about 0.11 ML/day (41 ML/year) in the northern region.

The vertical losses are offset a little by increased lateral groundwater flows to bordering alluvium from the mine site during mining and from the Eastern and Western Emplacements during recovery. However, the rates are less than about 0.01 ML/day (4 ML/year) in each region (**Figure A-59**).

The reduced upflow (from rock to alluvium) in the northern area and the increased downflow (from alluvium/colluvium to rock) in the southern area would have beneficial effects in both areas. In the northern area, the salinity is about 2,400 mg/L in rock and less than 1,000 mg/L in alluvium. Due to the reduced upwards flux of 0.11 ML/day, there would be a reduction in mass of about 100 t/year transferred to the alluvium. In the southern area, the salinity is about 2,400 mg/L in rock and about 9,000 mg/L in alluvium/colluvium bordering the Project site. Due to the increased downwards flux of 0.15 ML/day, there will be transfer of about 500 t/year from the alluvium to the underlying conglomerate. As the saline alluvium/colluvium is a natural source of salt that would eventually migrate to the Namoi River, this amount of mass would be removed from the source and held in a material with much slower groundwater velocity.

The waste rock emplacements would be a new source of salt to the adjacent alluvium. The salinity of the waste rock is expected initially to be similar to that of the coal measures (about 2,400 mg/L) but should freshen with time as the spoil is flushed by enhanced rainfall recharge. Assuming 2,000 mg/L as a representative salinity and a lateral seepage of 0.01 ML/day, the expected increase in salt transferred to the alluvium would be about 7 t/year in each area. This is much lower than the beneficial reductions of about 100 t/year in the northern area and about 500 t/year in the southern area due to vertical mass transfers.

#### A6.1.6 Porous Rock

As described in **Section A6.1.5**, the Project is located within an hard rock island of the Maules Creek Formation encircled by the Upper Namoi Alluvium. The Maules Creek Formation at the Project is part of the NSW Murray Darling Basin Porous Rock Groundwater Source (**Section A2.10**) that also includes fractured strata.

**Table A-20** shows that the average predicted pit inflow during the Project is expected to be 1.2 ML/day (430 ML/year) with a maximum in latter years of 1.9 ML/day (700 ML/year).

The equilibrium long-term groundwater inflow to the voids is expected to be about 0.7 ML/day for the northern void and 0.5 ML/day for the southern void. The combined steady inflow of 1.2 ML/day would be sustained primarily by rainfall infiltration through the Western Emplacement (assuming 5% recharge).

### A6.1.7 Potential Impacts on Registered Production Bores

As described in **Section A2.9**, there are 670 registered bores within the 33 km x 29 km extent of the Project regional numerical groundwater model (**Figure A-12**), but the majority of the registered bores are associated with the Namoi River and alluvial floodplain.

The bore census conducted by Whitehaven in March 2012 identified 53 privately-owned bores/wells on 21 properties in the vicinity of the Project. During the census the owners of the properties indicated that the bores that were inspected were the only accessable existing bores on each property. Most of the census bores coincided with officially registered bores, however it is evident from **Figure A-14a** that there are many more registered bore sites in the area, which do not appear to actually exist on the ground.

Within the extent of the Maules Creek Formation ‘island’, there is one census bores (i.e. SK1) on privately-owned land that coincides with (and presumably is the same as) a registered bore (i.e. GW965430). Bore WL1 on the Whitehaven-owned property “Woodland” coincides with another registered bore (i.e. GW 000815) (**Figure A-14a**). There is also a windmill (i.e. census bore WG1) located on the Whitehaven-owned ‘Wilgai’ property, which is currently not in use. WG1 does not coincide with a Pinneena registered bore, and would therefore appear to be unregistered. The other ‘registered’ bores within the Maules Creek Formation “island” that do not coincide with a census bore appear to have been destroyed and/or are not known by the current landholders.

The privately-owned registered (and census) bore within the extent of the Maules Creek Formation ‘island’ has been drilled to a depth of between 85 and 87 m. This depth coincides with Model Layer 7, and as a result the predicted groundwater impact at this location is conservatively based on the drawdown contour for Model Layer 8 of the regional numerical groundwater model (**Figure A-60**).

**Table A-21** indicates the predicted drawdown for the privately-owned bore within the Maules Creek Formation “island”, plus the other Project census bores within the adjoining Upper Namoi Alluvium. Bore GW965430 (i.e. census bore SK1) is predicted to experience a drawdown of 1 to 5 m.

Drawdown effects of up 5 m and 10 m are also predicted to occur at WG1 and WL1 respectively, however these bores are located on Whitehaven-owned land. WG1 is unregistered, and consists of a currently disused windmill. The effect on WG1 is therefore not considered to be material and is not discussed further. Bore WL1 is a registered bore equipped with a pump and storage tank.

As illustrated in **Figure A-60**, the modelled 1 m drawdown effect in Model Layer 1 and Model Layer 8 is predicted to not extend beyond the boundary of the Maules Creek Formation "island" in which the Project is located. As a result, no privately-owned census bores within the Upper Namoi Alluvium surrounding the Project are predicted to be measurably impacted during mining operations or post closure (i.e. any drawdown effect would be less than 1 m and is therefore considered to be negligible) (**Table A-21**). The Project would therefore not impact the agricultural use of the Upper Namoi Alluvium groundwater system for irrigation purposes.

## Table A-21
## Bores within the Predicted Drawdown Impact Zone of the Project

| Bore Census ID | Ownership | Ownership Number | Predicted Groundwater Drawdown (m) | Approximate Distance from Open Cut (m) |
|---|---|---|---|---|
| BM5 | Braymont | 88 | <1 | 3,900 |
| BM4 | Braymont | 88 | <1 | 4,600 |
| BM1 | Braymont | 88 | <1 | 6,000 |
| BM2 | Braymont | 88 | <1 | 5,000 |
| BG3 | Bungalow | 89 | <1 | 2,800 |
| BG1 | Bungalow | 89 | <1 | 4,500 |
| BG2 | Bungalow | 89 | <1 | 4,200 |
| BK2 | Brookvale | 65 | <1 | 4,200 |
| SK1 | Silkdale | 112 | 1-5 | 3,200 |
| RB1 | Roseberry | 98 | <1 | 5,800 |
| CA3 | Carlton | 99 | <1 | 5,900 |
| WS1 | Wundurra Stud | 102 | <1 | 5,800 |
| BR4 | Brolga | 101 | <1 | 4,800 |
| BR2 | Brolga | 101 | <1 | 5,200 |
| CL2 | Clinton | 133 | <1 | 5,300 |
| CL1 | Clinton | 133 | <1 | 4,500 |
| GB1 | Gunnabri | 128 | <1 | 5,000 |
| MR3 | Mirabinda | 127 | <1 | 5,100 |
| MR1 | Mirabinda | 127 | <1 | 3,300 |
| MR2 | Mirabinda | 127 | <1 | 4,800 |
| MR4* | Mirabinda | 127 | <1 | 5,000 |
| **Whitehaven Owned** | | | | |
| WL1 | Whitehaven | 1 | 10 | 1,800 |
| WG1 | Whitehaven | 1 | 5 | 2,500 |
| BW1 | Whitehaven | 1 | <1 | 4,800 |
| BW2 | Whitehaven | 1 | <1 | 4,200 |

### A6.2 POTENTIAL IMPACTS ON SURFACE WATERBODIES

As described in **Section A2.4**, the main local drainage systems associated with the Project are Namoi River, Driggle Draggle Creek, North-West Drainage Line, West Drainage Line, South Creek and Stratford Creek (**Figure A-6**). The North-West Drainage Line and the West Drainage Line would be diverted around the mining area (Appendix B of the EIS).

The stream-groundwater interaction status of several creeks has been examined in **Section A5.4**.

Baseflow only occurs to the Namoi River, Barbers Lagoon and the headwaters of Driggle Draggle Creek due to discharge of groundwater to the stream. The other streams located near the Project are ephemeral streams and are dry most of the time. No ephemeral stream impact will occur due to the proposed mining.

The examined 4 km reach of the Namoi River is predicted to maintain its status as a gaining stream with a reduction of about 0.015 ML/day baseflow (**Figure A-47**). However, use of the Blue Vale void as a water storage during the life of the Project (**Section A5.7**) would increase the natural baseflow by about 0.07 ML/day (**Figure A-51**). As this water storage is part of the proposed water management plan, there is no case for licensing of any baseflow impacts on the Namoi River.

Driggle Draggle Creek has a very constant baseflow of about 0.2 ML/day, concentrated in the headwaters, with no perceptible change predicted due to mining (**Figure A-46c**).

### A6.2.1 Changes in Surface Water Quality

There are not expected to be any significant changes in the quality of the groundwater in the Maules Creek Formation ‘island’ or Upper Namoi Alluvium groundwater system surrounding the Project (**Section A6.1.2**). During operations it is possible that there will be a lowering of groundwater salinity over the mine footprint due to higher rainfall infiltration rates into mine waste rock.

As described in **Section A6.1.2**, no significant groundwater quality impacts are expected from groundwater interactions with the final void waters because the voids would remain as groundwater sinks for the long-term. Therefore, it is unlikely the water quality of any surface waterbody would be impacted. Maintenance of the void as a groundwater sink would ensure that ambient groundwater flows towards the void rather than from the void towards surface water receptors.

As identified in **Section A5.7**, there is potential for some solute migration into the 4 km reach of the Namoi River to the immediate west of the Project, due to the planned operation of the Blue Vale void as an intermittent water storage. As water would be pumped to the water storage from operational parts of the mine, the void water is likely to have a salinity similar to coal measure strata groundwater, in the range 2,000 to 3,000 mg/L (**Section A2.14**). The outflow from the Blue Vale water storage towards the Namoi River is predicted to be about 0.055 ML/day (**Figure A-51**). Consequently, the mass of dissolved solids that could migrate from the water storage would be about 140 kg/day (about 50 t/year), distributed across the 10 layers in the model down to the Upper Group Seams in the vicinity of the Blue Vale void.

The baseflow to the Namoi River reach occurs in the upper few layers and is not sourced from the deeper more saline coal measures of the Maules Creek Formation (**Figure A-52**). Beneath the river, there is a definite downwards hydraulic gradient to the deeper layers.

Hence, the risk of impact on the Namoi River is isolated to migration through the upper layers, primarily the two alluvial layers in the model.

In order to assess the potential salinity impact of water moving from the Blue Vale void to the 4 km reach of the Namoi River, Darcy's Law, in terms of pore velocity, was used to calculate the travel time of solute from the water storage to the river for each layer. The travel time is calculated as:

$$V_D = K (\Delta h / \Delta L) \quad (1)$$

$$V_S = V_D / n \quad (2)$$

$$t = L / V_S \quad (3)$$

where:

$V_D$: Darcy Velocity (m/d)

$K$: Hydraulic Conductivity (m/d)

$\Delta h/\Delta L$: Hydraulic Gradient

$V_S$: Seepage Velocity (m/d)

$n$: Effective Porosity

$t$: Travel Time (days)

$L$: Distance (m)

Based on the above equations, the hydraulic gradient was calculated for each layer from the simulated water levels and hence the Darcy velocity, seepage velocity and travel time were calculated for each formation. The results indicate that groundwater containing solute would migrate from the water storage to the 4 km reach of the Namoi River through the alluvium-regolith formations (Layers 1 and 2) over a period of about 43 years. When the groundwater reaches the Upper Namoi Alluvium, its salinity would undergo dilution from rainfall infiltration before the groundwater reaches the river. The source of the water in the water storage would cease at the end of the Project (31 years).

The *NSW Aquifer Interference Policy* requires "*No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity*". The long-term average salinity in the Namoi River near the Project site is about 350 mg/L, based on monitoring data from NOW monitoring stations in the vicinity of the Project, and measurements reported in the original Namoi Valley Coal Mine EIS (data presented in Appendix B of the EIS).

The median flow in the Namoi River (at the Boggabri gauging station) is 402 ML/day (Appendix B of the EIS). The long-term average salt load in the Namoi River is calculated to be approximately 140 t/day (based on median flow). Assuming a worst case of the total salt load released from the void being captured by the river (0.14 t/day), the increase in salt load, and hence salinity, would be approximately 0.1% (i.e. 0.14/140). If average flow (1,694 ML/day [Appendix B of the EIS]) is used in place of median flow, the increase in salinity would be approximately 0.02%.

### A6.2.2 Changes in Water Balance

With only the Project operating, recharge is dominated by rainfall infiltration (45%), lateral boundary flow (32%) and river/creek leakage (23%). Groundwater pumping by production bores accounts for 68% of groundwater discharge from the model area. The other significant discharge mechanism is river/creek baseflow (19%).

Average mine inflow during the Project mine life is predicted to be about 3% of all groundwater discharge. Three-quarters of the mine inflow is sourced from formation storage during the life of the Project. The balance comes mostly from extra boundary inflows (**Table A-18**).

With the Blue Vale void acting as a water storage, there is expected to an increase in baseflow to the Namoi River of about 0.07 ML/day. No other Project-related effects are expected on other streams.

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

### A6.2.3 Effects on Surface and Groundwater Dependent Ecosystems

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

## A6.3 PROPOSED GROUNDWATER MONITORING PROGRAM

The proposed groundwater monitoring program for the Project is summarised in **Table A-22** and described below. The groundwater monitoring program should augment the existing Vickery groundwater monitoring program and use the results of other mine groundwater monitoring programs in the vicinity of the Project (i.e. Canyon Coal Mine and Rocglen Coal Mine).

## Table A-22
## Proposed Groundwater Monitoring Program

| Parameter | Location | Timing |
|---|---|---|
| Groundwater Levels (m AHD) | - Existing monitoring network (Vickery and surrounding mines). | - Quarterly - Project life. |
| | - Additional Upper Namoi Alluvium groundwater system monitoring bores (adjacent to Western and Eastern Emplacements). | - Progressive over the Project life and two years post-mining. |
| | - Additional Maules Creek Formation groundwater system monitoring bores. | - Progressive over the Project life and two years post-mining. |
| | - Additional bore installations in the waste rock emplacement behind the advancing open cut. | - Progressive over the Project life and two years post-mining. |
| Groundwater Quality<br>(pH, DO, EC, TDS, Fe, Al, As, Mg, Mo, Se, Ca, Na, Cl, $SO_4$) | - At standpipe bores above that are installed in alluvium and waste rock material. | - 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 mine water dams, pumped water, coal moisture, etc. | - Project life. |

The groundwater monitoring program should monitor groundwater conditions for changes in expected drawdown extent and groundwater quality. The groundwater quality sampling should comply with the Murray Darling Basin Groundwater Quality Sampling Guidelines (MDBC, 1997).

The results of the groundwater monitoring program for drawdown should be used to validate modelling predictions. Trigger levels are discussed later in this report.

### A6.3.1 Groundwater Levels

The existing Project monitoring bores should be augmented as mining progresses. As most Project monitoring sites are positioned along the eastern edge of the mine footprint, most would remain serviceable until late in the life of the Project. At least two years before any of the bores are destroyed, replacement bores should be positioned to the east of VKY3035 and to the north of VKY3033 (**Figure A-60).**

Monitoring bores should be added to the Project network at five sites marked on **Figure A-60**. Also shown on this figure are the predicted drawdown extents in model Layers 1 and 8. The rationale for these selections is given in **Table A-23**, as well as a recommendation for either a standpipe bore or installation of a string of VWPs down to the level of the deepest mined coal seam. The network of observation bores and piezometers should be focussed on:

- sites P1 and P5: monitoring of groundwater levels and water quality in the Upper Namoi Alluvium groundwater system adjacent to the two waste emplacements (to validate the predicted seepages and to check for any deterioration in groundwater quality);
- sites P2 and P3: monitoring of groundwater pressures in the Maules Creek Formation (to validate the predicted depressurisation effects at depth); and
- site P4: monitoring of groundwater levels and water quality in the waste rock (to validate the predicted level of groundwater mounding and to check on the water quality of leachate).

**Table A-23**
**Proposed Additional Groundwater Monitoring Sites**

| Bore ID | Easting | Northing | Type | Purpose |
|---|---|---|---|---|
| P1 | 228460 | 6595680 | Standpipe | Monitor seepage from Western Emplacement |
| P2 | 232020 | 6595650 | VWP | Monitor vertical head profile adjacent to open cut |
| P3 | 233930 | 6593400 | VWP | Monitor vertical head profile adjacent to open cut |
| P4 | 230220 | 6591870 | Standpipe | Monitor water level mounding in Western Emplacement |
| P5 | 235370 | 6589800 | Standpipe | Monitor seepage from Eastern Emplacement |

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

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 during mining at the frequency specified in **Table A-22**, and for at least two years following mining. Groundwater quality samples should also be taken during drilling of any new/future monitoring 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 accredited laboratory. Water quality data should be evaluated annually and should aim to identify any potential mining related impacts.

Given the risk of water quality impacts on the 4 km reach of the Namoi River, a shallow standpipe bore should be installed midway between the river and the rock outcrop nearest the Blue Vale void for the purpose of electrical conductivity monitoring. However, there is no urgency for this, as possible effects are not likely to be seen for about 40 years.

## 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°C (relative to 1990) at that time.

The approach taken for this assessment has been to conduct transient simulations for the full prediction period for rainfall infiltration reduced by 20 percent or increased by 20 percent.

The results of the climate change scenario analysis are summarised in **Table A-24** in terms of the percentage changes in pit inflow and percentage changes in baseflow to the 4 km reach of the Namoi River to the west of the Project, and to Driggle Draggle Creek.

There is expected to be a maximum reduction in pit inflow of about 1% for 20% less recharge from rainfall. The simulated reduction in pit inflow is due to reduced groundwater levels adjacent to the void. In the event of higher rainfall, the maximum increase in pit inflow would be slightly more than 1% for 20% higher recharge from rainfall. Neither case poses concerns for water management.

## Table A-24
## Predicted Changes in Pit Inflow and Baseflow due to Climate Change

| | 20% decrease in Rainfall Infiltration | | 20% increase in Rainfall Infiltration | |
|---|---|---|---|---|
| | **Change in Mean Value** | **Change in Maximum Value** | **Change in Mean Value** | **Change in Maximum Value** |
| Pit Inflow | -0.8 % | -1.1 % | +0.9% | +1.4% |
| Namoi River (4 km Reach) | -45 % | -53 % | +45% | +53% |
| Driggle Draggle Creek | -15 % | -18 % | +16% | +7% |

Due to an anticipated reduction in watertable levels in the event of climate change, there is expected to be a maximum decrease in baseflow of about 50% for the examined 4 km reach of the Namoi River and a little less than 20% decrease in Driggle Draggle Creek baseflow. In the event of higher rainfall, the Namoi River baseflow would increase by about 50%, while Driggle Draggle Creek would gain about 16% on average.

## A8 MANAGEMENT AND MITIGATION MEASURES

Whitehaven should implement the proposed groundwater monitoring program outlined in **Section A6.3**.

The regional 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 program (**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.

A high level assessment of how actual data compares to what was modelled and predicted should be undertaken during routine environmental audits.

### A8.1 SURFACE WATER FEATURES

The regional numerical groundwater modelling indicates that the potential for a change in water quality over the short reach (4 km) of the Namoi River due to inflow of solute from the Blue Vale void is negligible. If necessary this influence could be mitigated by using the water storage sparingly, by giving priority to other water storages in the water management plan (Appendix B of the EIS). However, at least some use should be made of the void as a water storage, as it confers a benefit on the Namoi River in maintaining and enhancing the natural baseflow to the river, which otherwise would be reduced during mining.

Other potential management measures (e.g. management of PAF material) are discussed in Appendix L of the EIS and the proposed surface water monitoring program is described in Appendix B of the EIS.

### A8.2 GROUNDWATER USERS

The regional numerical groundwater modelling indicates that the drawdown effects on groundwater users in the vicinity of the Project are likely to be significant (that is, greater than 2 m) at one privately owned bore, namely SK1.

It is recommended also that a comprehensive groundwater monitoring program (**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. If necessary an alternative supply should be explored or the existing supply improved.

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

### A8.3 GROUNDWATER LICENSING

An appropriate groundwater licence for the Project open cut would be sought and obtained from the NOW pursuant to the *Water Management Act, 2000* under the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011*.

The predicted average annual groundwater volumes required to be licensed over the life of the Project and post-mining are summarised in **Table A-25**.

## Table A-25
## Project Groundwater Licensing Summary

| **Water Sharing Plan** | **Management Zone/ Groundwater Source** | **Predicted Average Annual Inflow Volumes requiring Licensing [ML/annum]*** | |
|---|---|---|---|
| | | **During Project** | **Post-Mining** |
| *NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* | Gunnedah-Oxley Basin - Namoi | Average 430<br>Maximum 700 | Max. 430 |
| *Upper and Lower Namoi Groundwater Sources 2003* | Upper Namoi Zone 4 - Namoi Valley (Keepit Dam to Gin's Leap) | Average 44<br>Maximum 78 | Average 88<br>Maximum 98 |

* Refer to **Figure A-45** and **Table A.20** for predicted groundwater inflows over the life of the Project.

## A9 MODEL LIMITATIONS

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

Lower pit inflows can be expected as coal seam permeability reduces with depth. As this is essentially a greenfield (pre-mine) site, 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 Maules Creek Formation groundwater system (i.e. beneath the Upper Namoi Alluvium groundwater system) outside the mining leases, 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 the groundwater systems 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.

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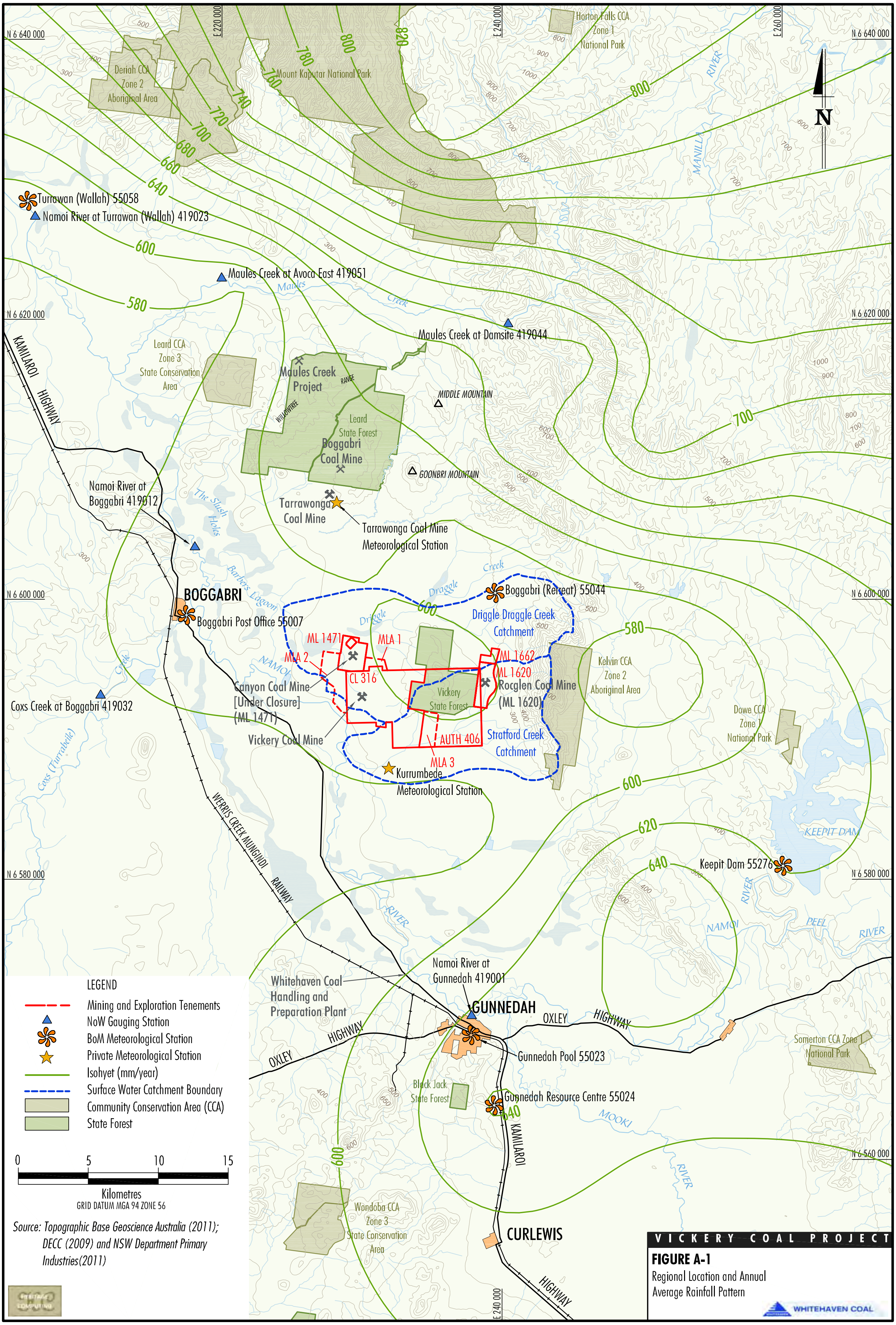
# ILLUSTRATIONS

## Figures A-1 to A-60

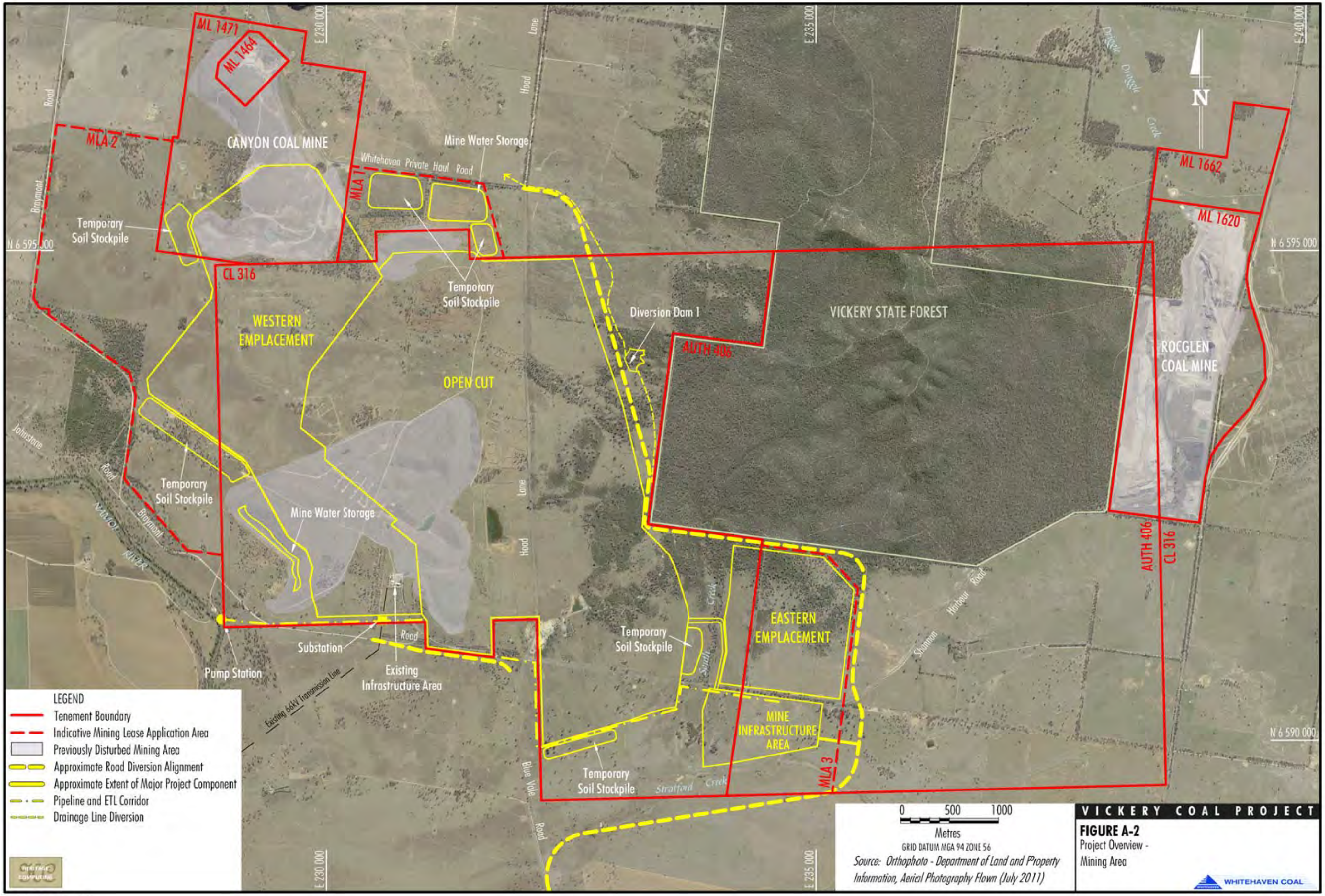


*Source: Topographic Base Geoscience Australia (2011); DECC (2009) and NSW Department Primary Industries(2011)*

VICKERY COAL PROJECT

**FIGURE A-1**

Regional Location and Annual Average Rainfall Pattern



GRID DATUM MGA 94 ZONE 56

*Source: Orthophoto - Department of Land and Property Information, Aerial Photography Flown (July 2011)*

**VICKERY COAL PROJECT**

**FIGURE A-2**
Project Overview -
Mining Area

WHITEHAVEN COAL

WHC-10-03 EA AppGW_107C

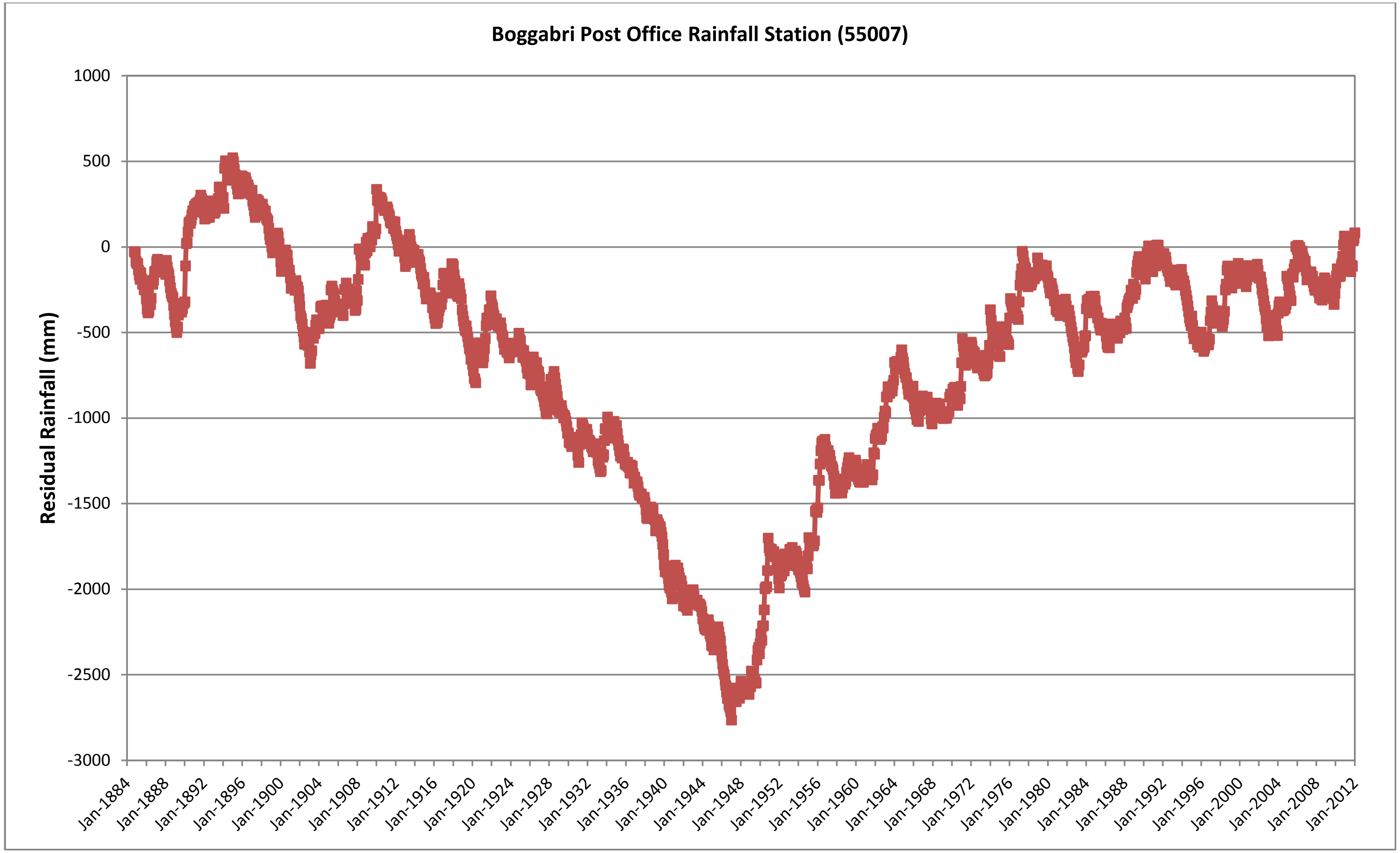


Figure A-3. Rainfall Residual Mass Curve for Boggabri Post Office (since 1884)

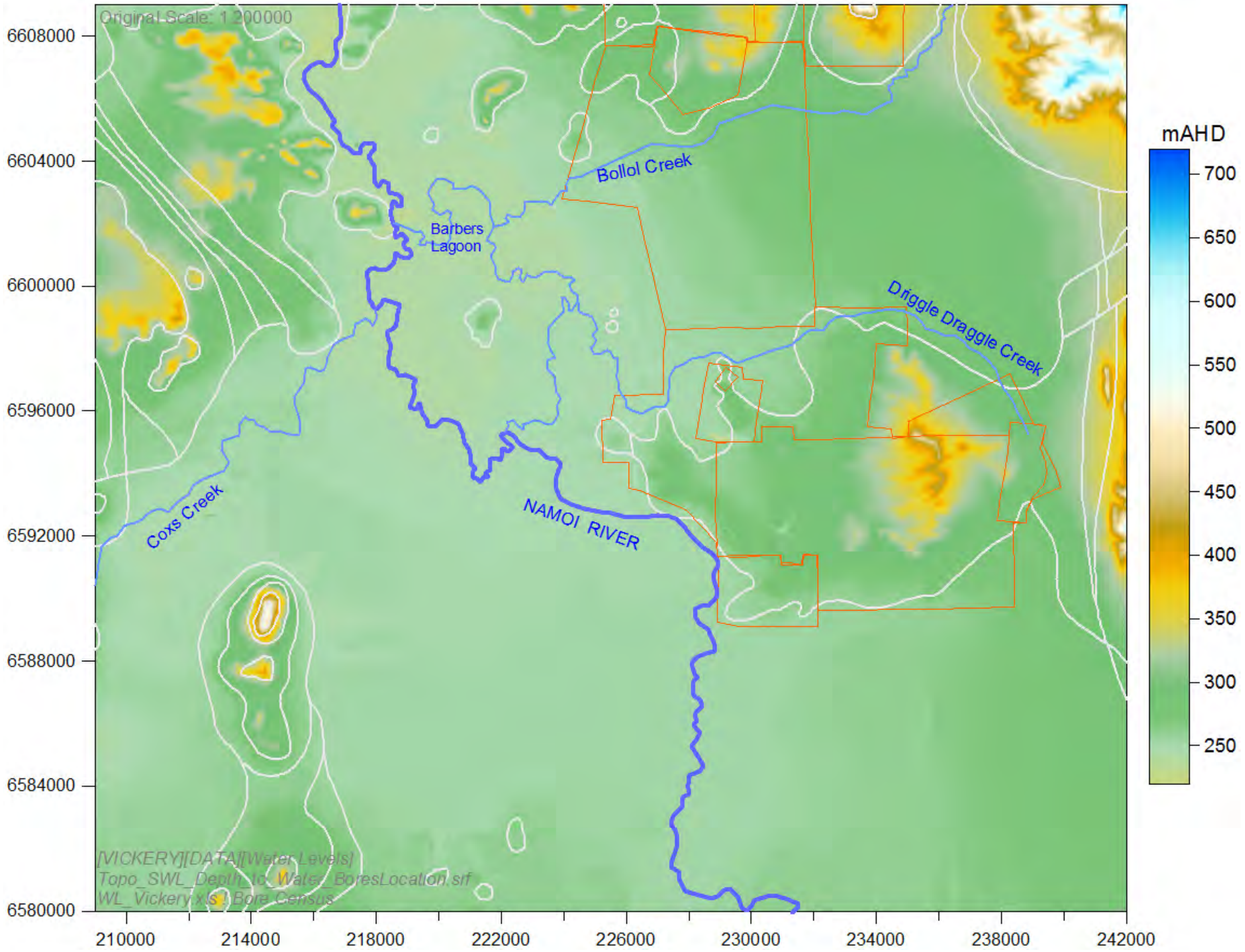


Figure A-4. Topographical Image Map for the Project Area Showing Geological Contacts and Major Drainages

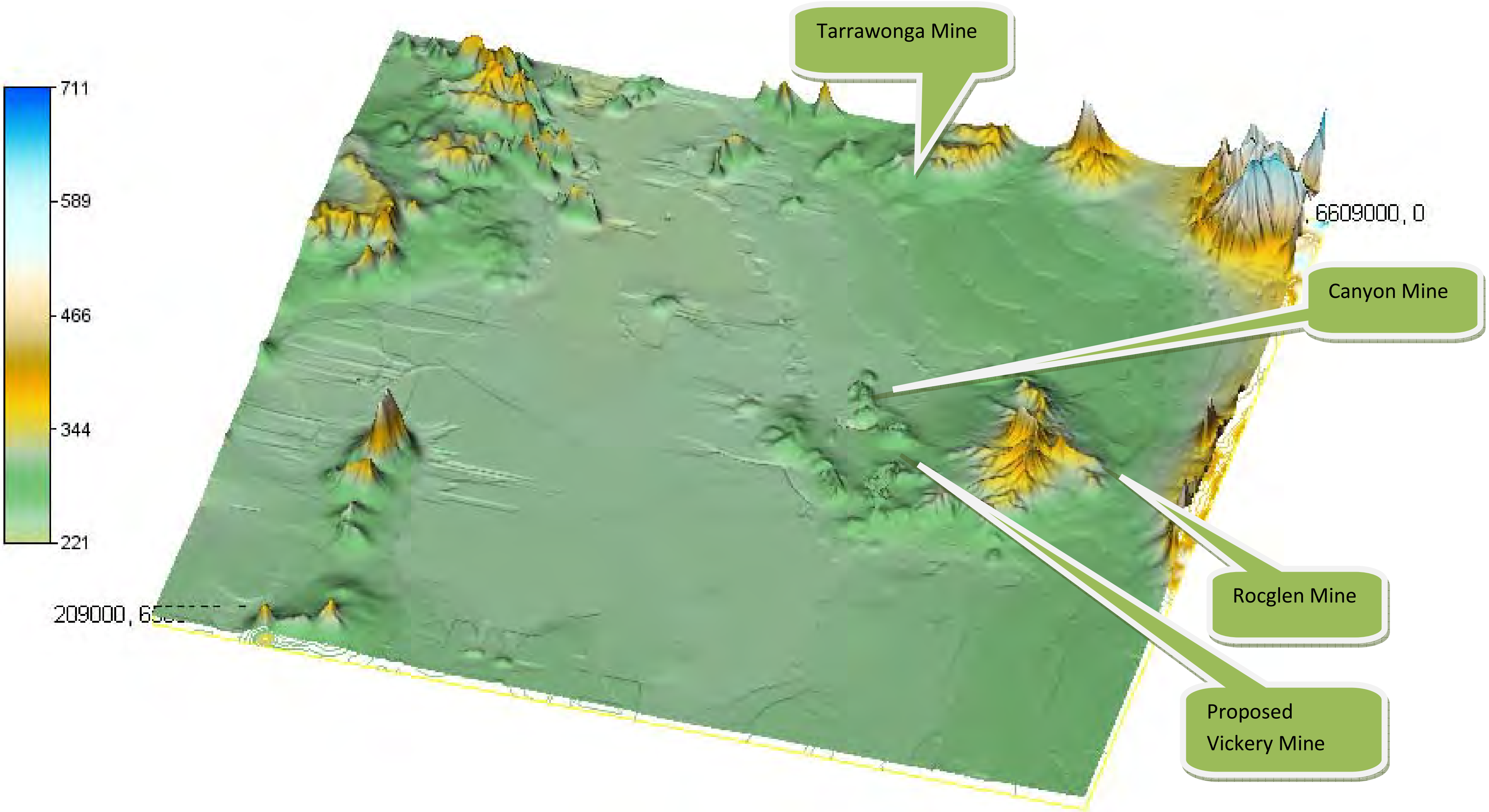
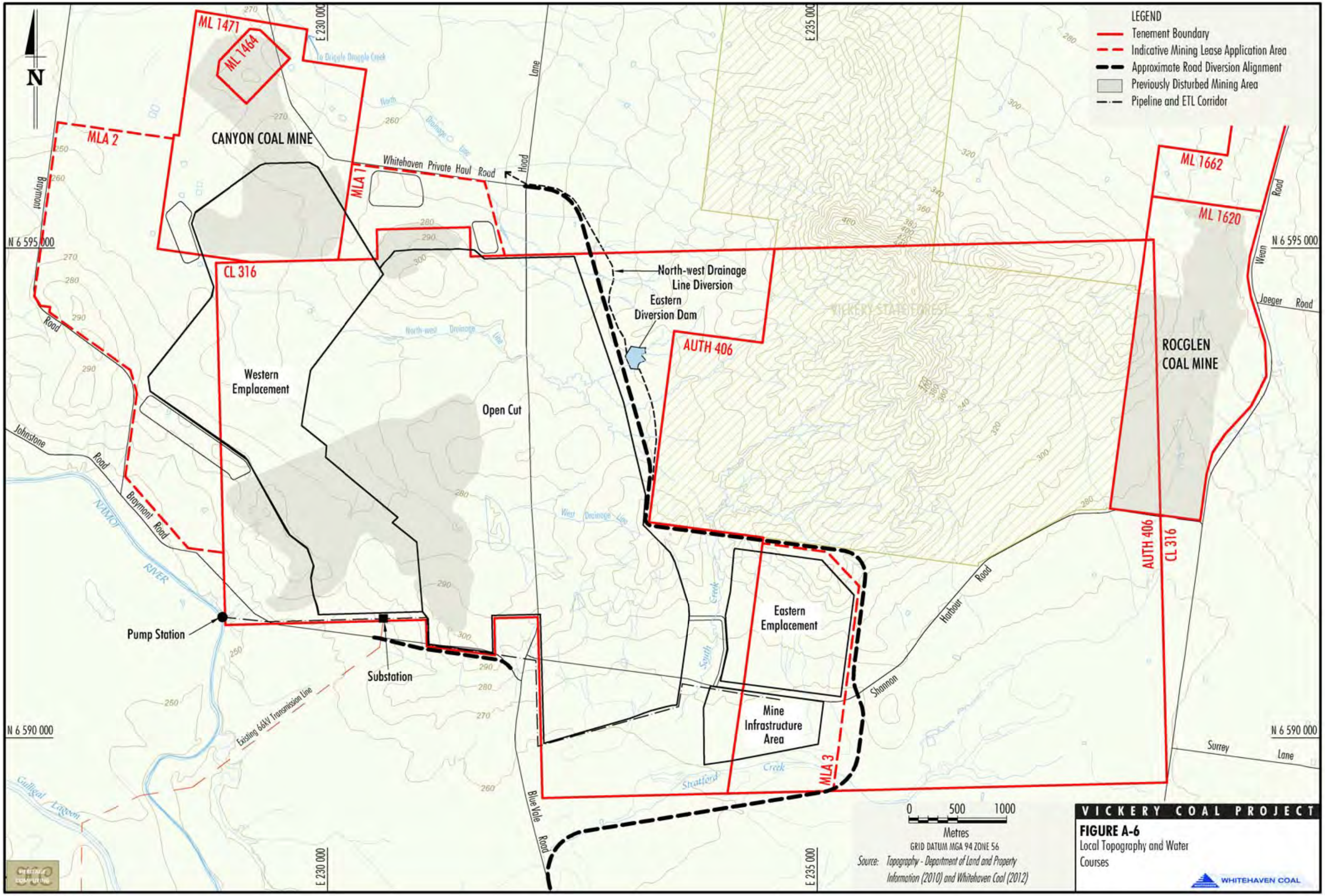


Figure A-5. Three-dimensional Topographical Map [mAHD]

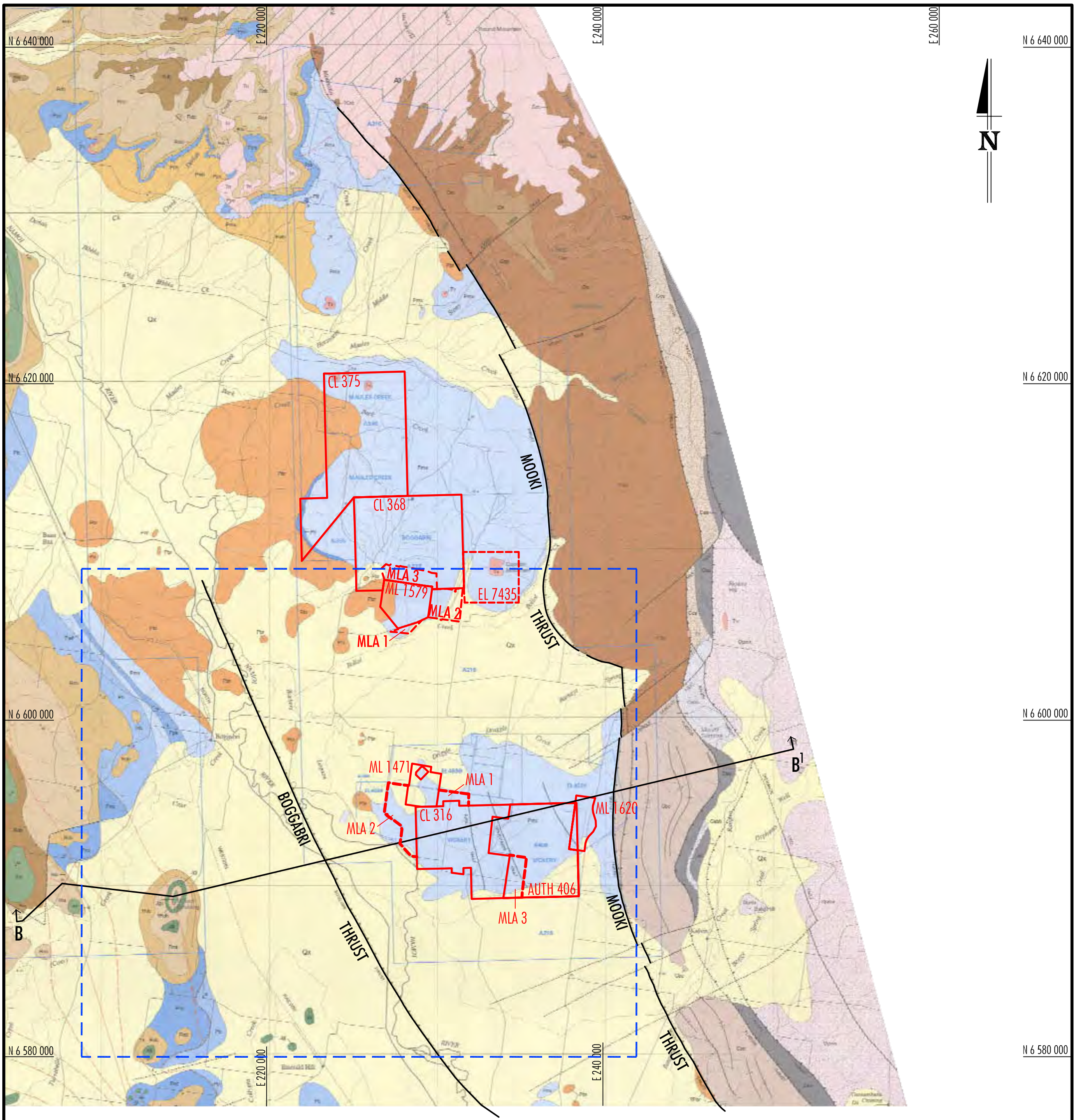


Source: Topography - Department of Land and Property Information (2010) and Whitehaven Coal (2012)

VICKERY COAL PROJECT

**FIGURE A-6**
Local Topography and Water Courses

WHITEHAVEN COAL



LEGEND

Mining and Exploration Tenements

Approximate Extent of the Vickery Regional Numerical Groundwater Model

*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)*

VICKERY COAL PROJECT

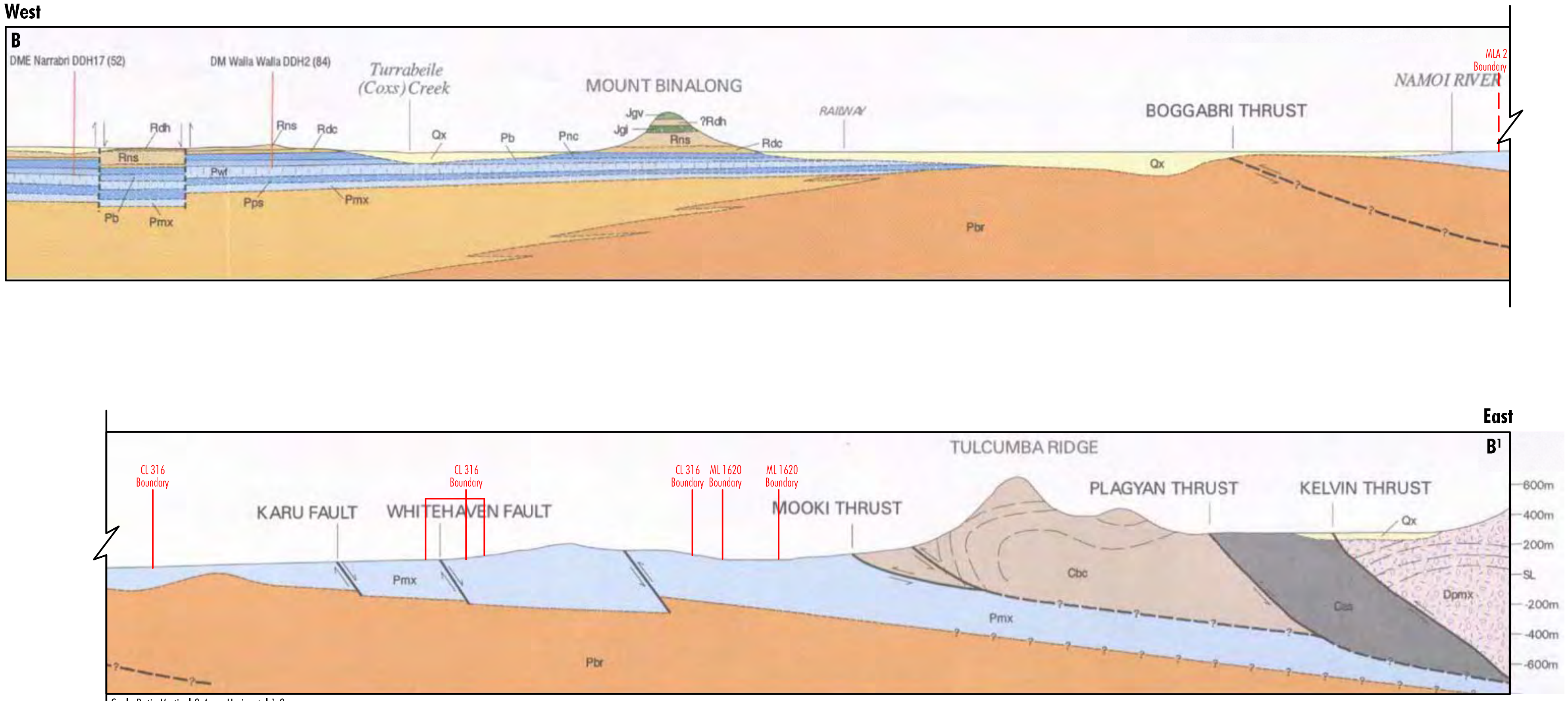
**FIGURE A-7a**

Regional Geology

WHITEHAVEN COAL

HERITAGE COMPUTING

WHC-10-03 EA AppGW_102B



Scale Ratio Vertical 0.4 = Horizontal 1.0

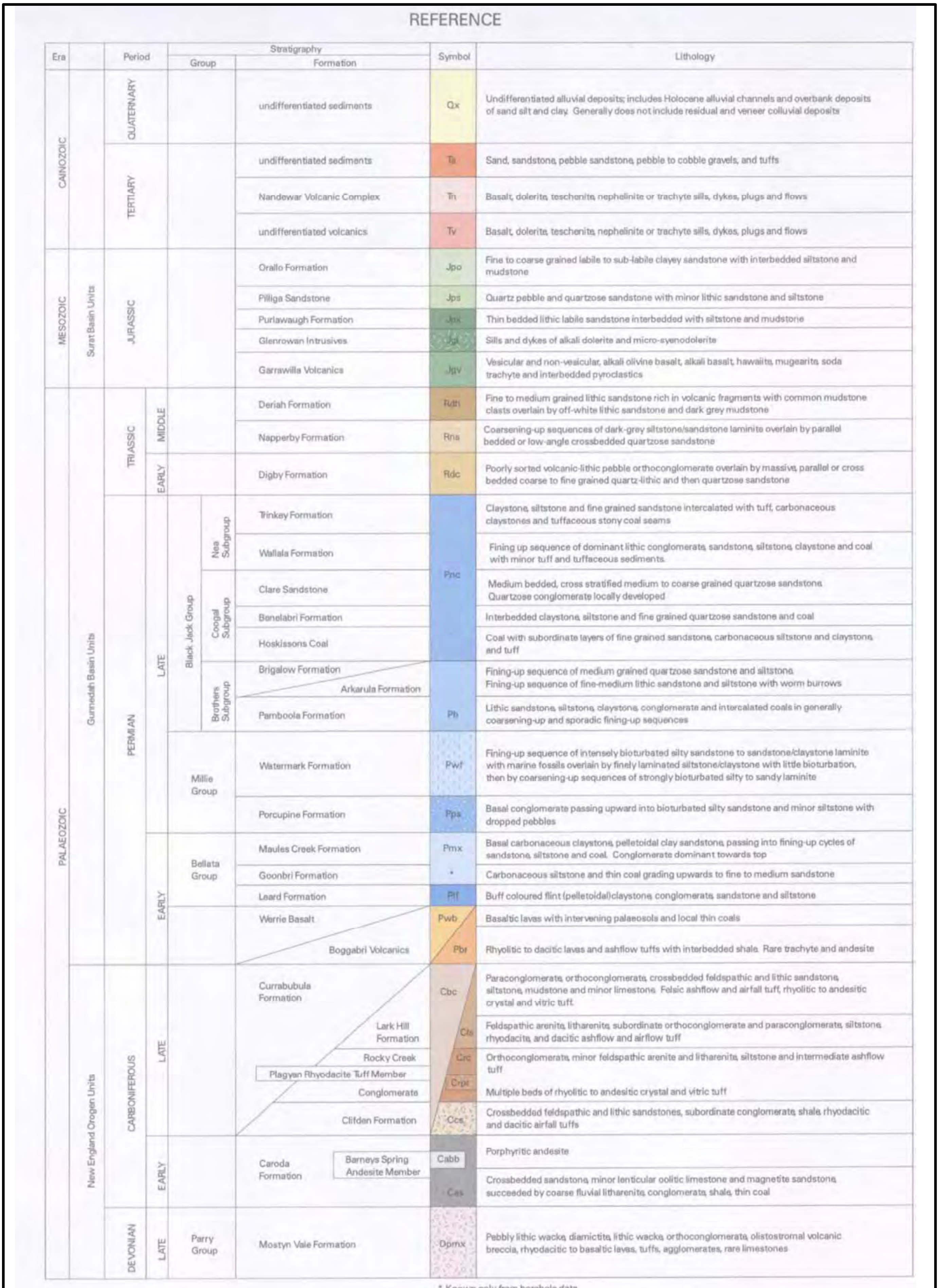
*Note: Refer Figure A-7a for Cross-section Location and Figure A-7c for Geology Legend.*

VICKERY COAL PROJECT

**FIGURE A-7b**

Regional Geology -
Section B-B¹

WHITEHAVEN COAL



# REFERENCE

| Era | | Period | | Stratigraphy | | | Symbol | Lithology |
|---|---|---|---|---|---|---|---|---|
| | | | | Group | | Formation | | |
| 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 |
| | | TERTIARY | | | | undifferentiated sediments | Ta | Sand, sandstone, pebble sandstone, pebble to cobble gravels, and tuffs |
| | | | | | | Nandewar Volcanic Complex | Tn | Basalt, dolerite, teschenite, nephelinite or trachyte sills, dykes, plugs and flows |
| | | | | | | 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 |
| | | | | | | Pilliga Sandstone | Jps | Quartz pebble and quartzose sandstone with minor lithic sandstone and siltstone |
| | | | | | | Purlawaugh Formation | Jpx | Thin bedded lithic labile sandstone interbedded with siltstone and mudstone |
| | | | | | | Glenrowan Intrusives | Jgi | Sills and dykes of alkali dolerite and micro-syenodolerite |
| | | | | | | 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 |
| | | | | | | Napperby Formation | Rns | Coarsening-up sequences of dark-grey siltstone/sandstone laminite overlain by parallel bedded or low-angle crossbedded quartzose sandstone |
| | | | 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 |
| | | 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 |
| | | | | | | Wallala Formation | | Fining up sequence of dominant lithic conglomerate, sandstone, siltstone, claystone and coal with minor tuff and tuffaceous sediments |
| | | | | | Coogal Subgroup | Clare Sandstone | | Medium bedded, cross stratified medium to coarse grained quartzose sandstone. Quartzose conglomerate locally developed |
| | | | | | | Benelabri Formation | | Interbedded claystone, siltstone and fine grained quartzose sandstone and coal |
| | | | | | | Hoskissons Coal | | Coal with subordinate layers of fine grained sandstone, carbonaceous siltstone and claystone, and tuff |
| | | | | | Brothers Subgroup | Brigalow Formation<br>Arkarula Formation | Pb | Fining-up sequence of medium grained quartzose sandstone and siltstone<br>Fining-up sequence of fine-medium lithic sandstone and siltstone with worm burrows |
| | | | | | | Pamboola Formation | | Lithic sandstone, siltstone, claystone, conglomerate and intercalated coals in generally coarsening-up and sporadic fining-up sequences |
| | | | | 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 |
| | | | | | | Porcupine Formation | Pps | Basal conglomerate passing upward into bioturbated silty sandstone and minor siltstone with dropped pebbles |
| | | | 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 |
| | | | | | | Goonbri Formation | * | Carbonaceous siltstone and thin coal grading upwards to fine to medium sandstone |
| | | | | | | Leard Formation | Plf | Buff coloured flint (pelletoidal) claystone, conglomerate, sandstone and siltstone |
| | | | | | | Werrie Basalt | Pwb | Basaltic lavas with intervening palaeosols and local thin coals |
| | | | | | | Boggabri Volcanics | Pbr | Rhyolitic to dacitic lavas and ashflow tuffs with interbedded shale. Rare trachyte and andesite |
| | 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 |
| | | | | | | Lark Hill Formation | Cls | Feldspathic arenite, litharenite, subordinate orthoconglomerate and paraconglomerate, siltstone, rhyodacite, and dacitic ashflow and airflow tuff |
| | | | | | | Rocky Creek Conglomerate | Crc | Orthoconglomerate, minor feldspathic arenite and litharenite, siltstone and intermediate ashflow tuff |
| | | | | | | Plagyan Rhyodacite Tuff Member | Crpt | Multiple beds of rhyolitic to andesitic crystal and vitric tuff |
| | | | | | | Clifden Formation | Ccs | Crossbedded feldspathic and lithic sandstones, subordinate conglomerate, shale, rhyodacitic and dacitic airfall tuffs |
| | | | EARLY | | | Caroda Formation<br>Barneys Spring Andesite Member | Cabb | Porphyritic andesite |
| | | | | | | | Cas | Crossbedded sandstone, minor lenticular oolitic limestone and magnetite sandstone, succeeded by coarse fluvial litharenite, conglomerate, shale, thin coal |
| | | 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 |

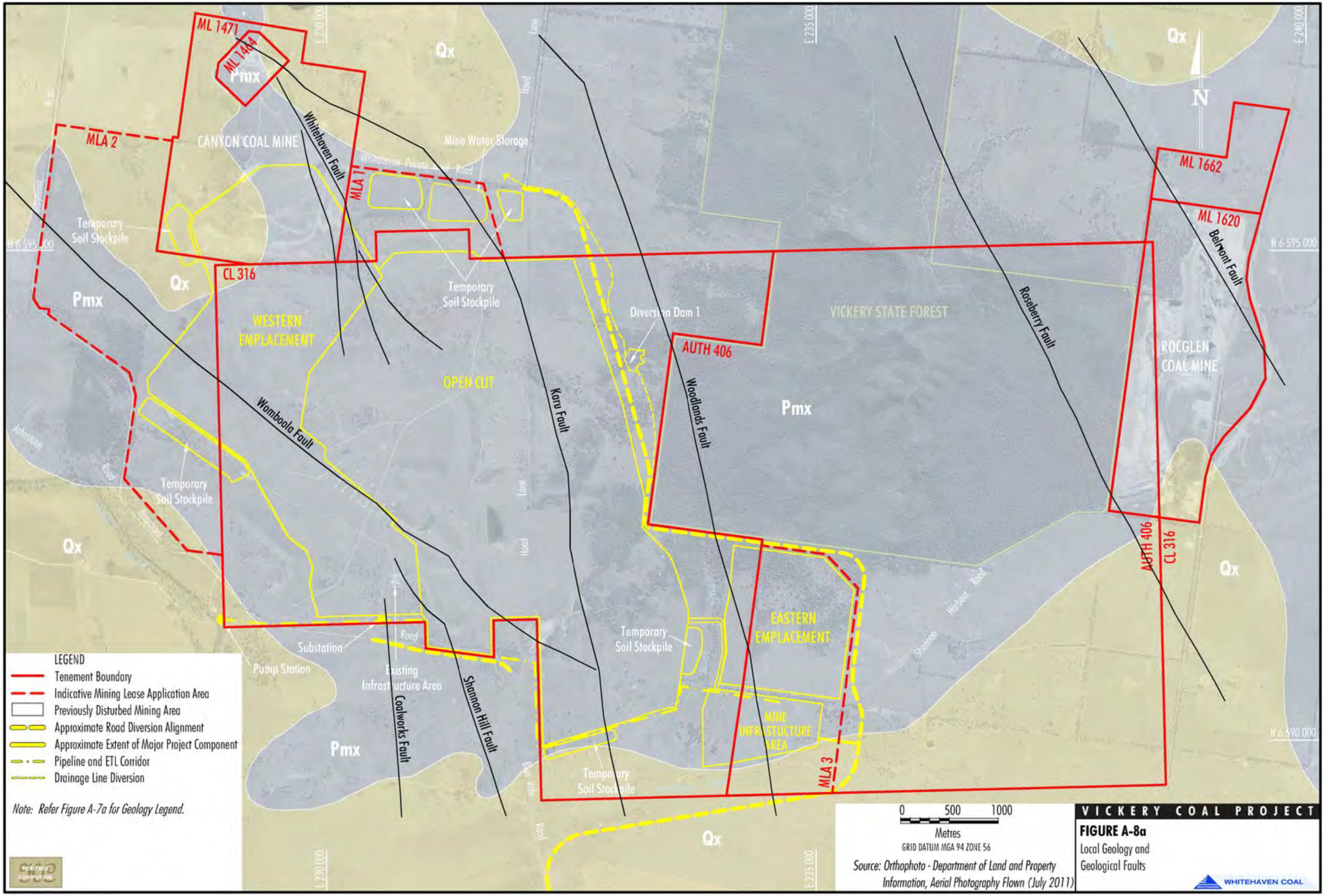
* Known only from borehole data

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

**VICKERY COAL PROJECT**

**FIGURE A-7c**

Regional Geology -
Legend



*Note: Refer Figure A-7a for Geology Legend.*

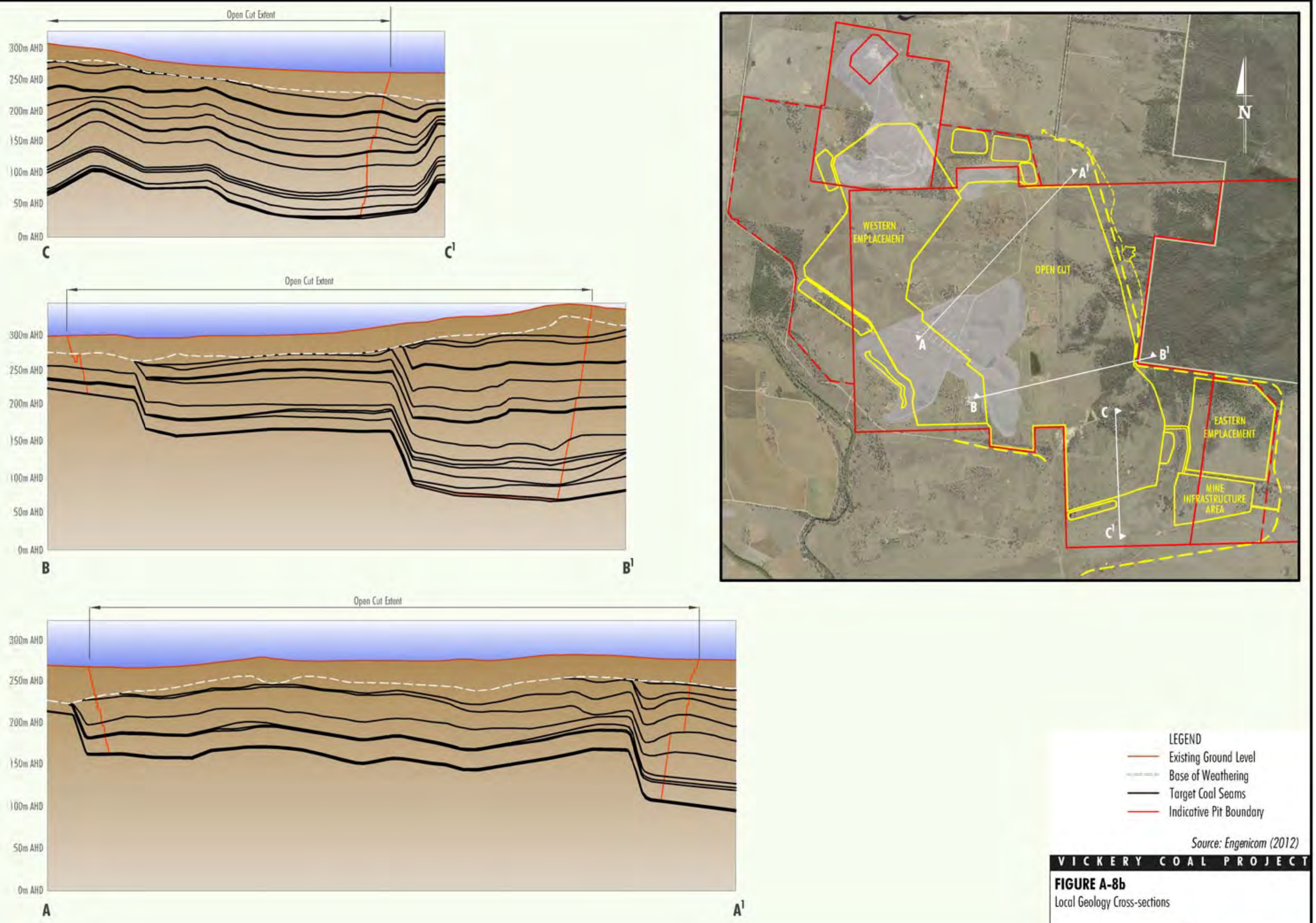
*Source: Orthophoto - Department of Land and Property Information, Aerial Photography Flown (July 2011)*

VICKERY COAL PROJECT

**FIGURE A-8a**

Local Geology and Geological Faults

WHC-10-03 EA AppGW_101C



LEGEND

- Existing Ground Level
- Base of Weathering
- Target Coal Seams
- Indicative Pit Boundary

*Source: Engenicom (2012)*

VICKERY COAL PROJECT

**FIGURE A-8b**

Local Geology Cross-sections

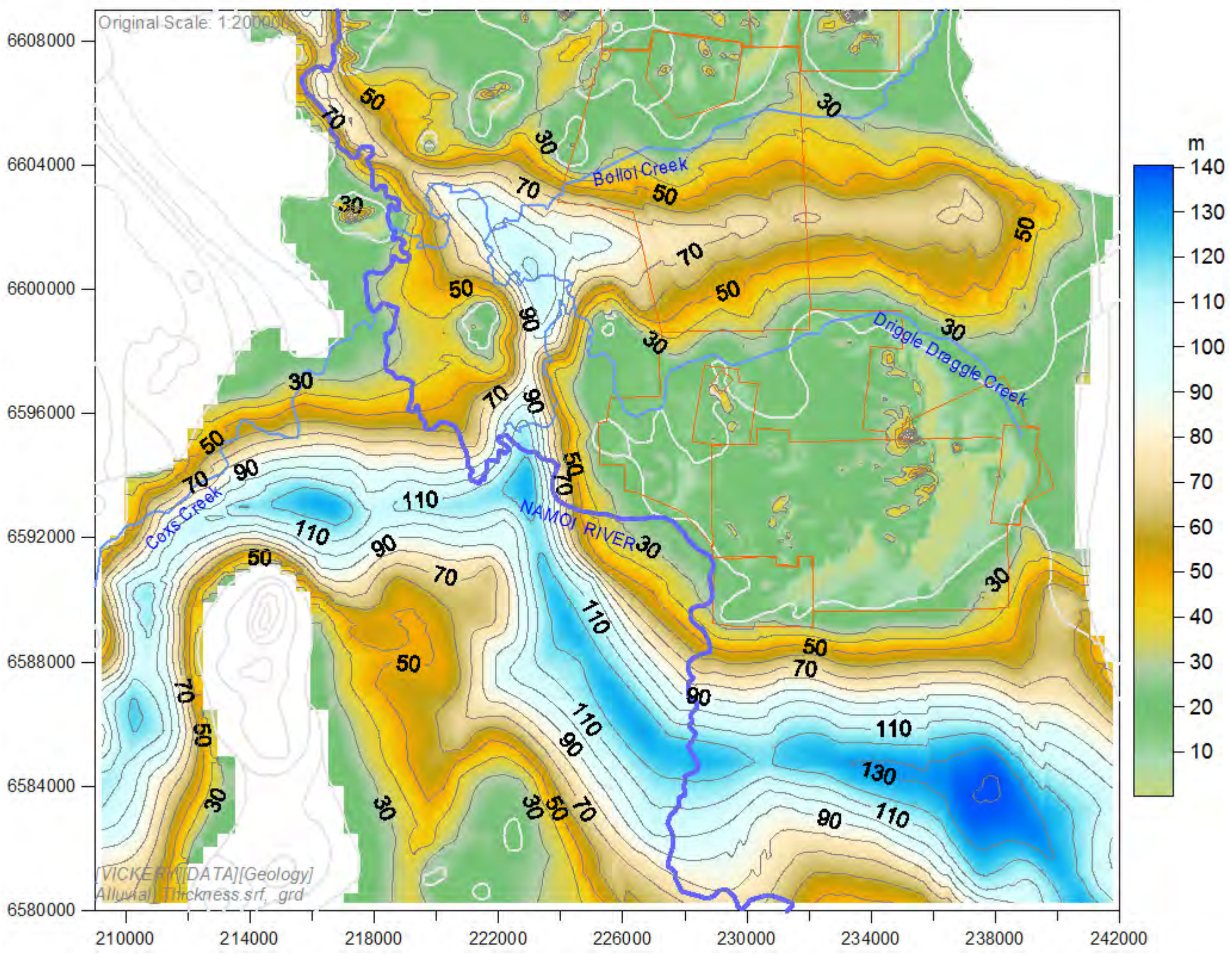
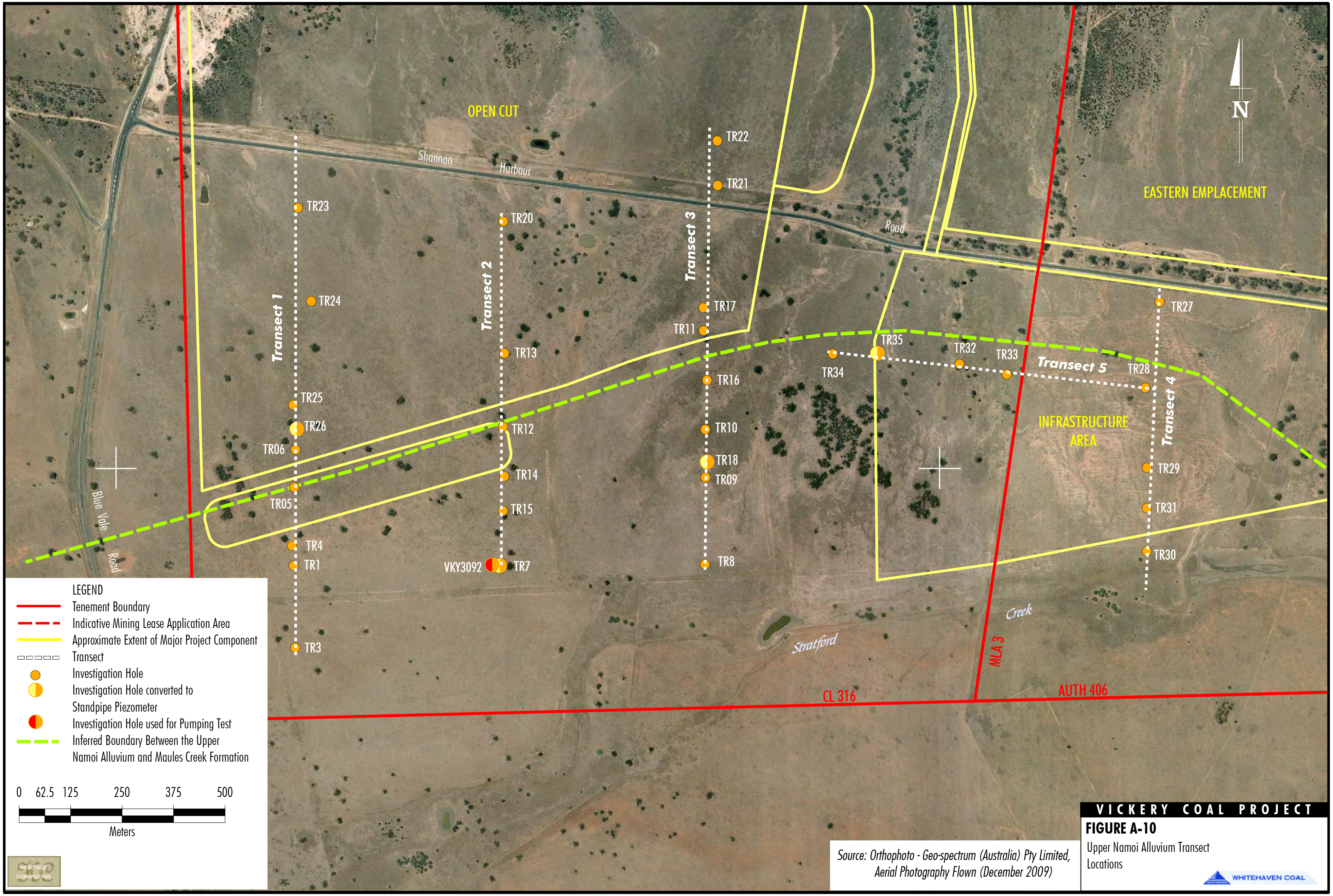


Figure A-9. Thickness of Alluvium and Regolith [m]

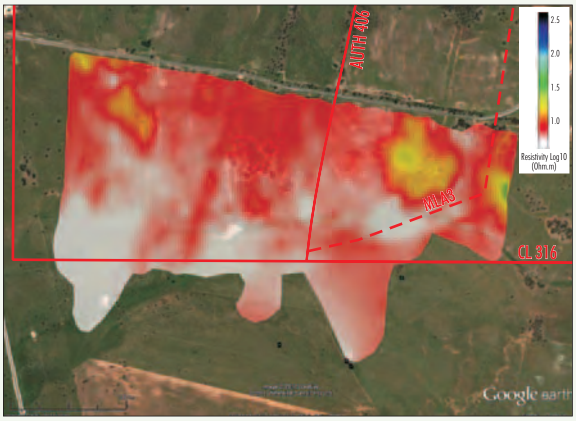


*Source: Orthophoto - Geo-spectrum (Australia) Pty Limited, Aerial Photography Flown (December 2009)*

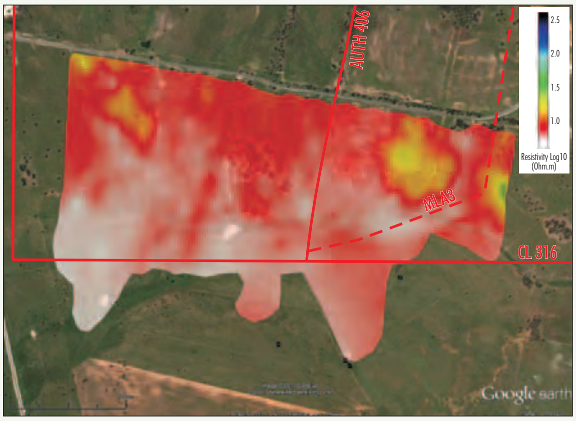
VICKERY COAL PROJECT

**FIGURE A-10**

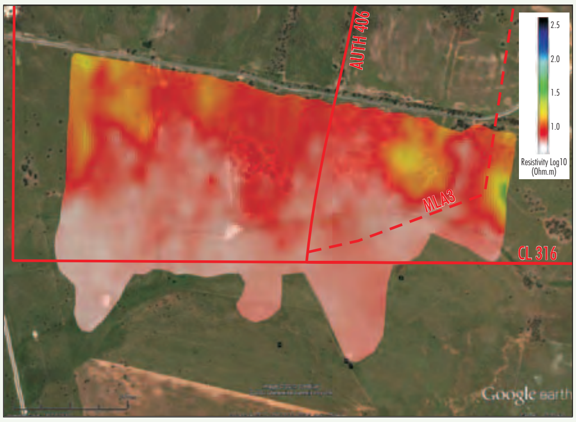
Upper Namoi Alluvium Transect Locations



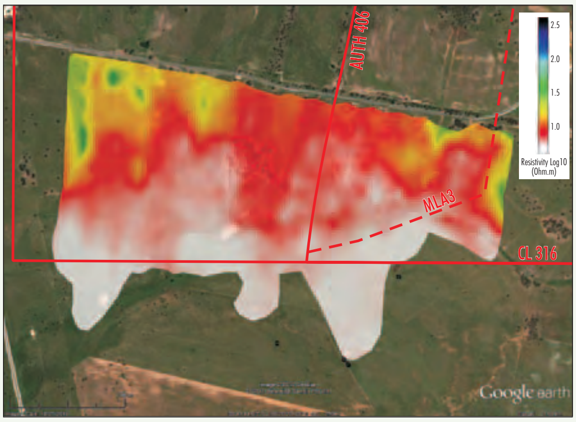
@1m Depth



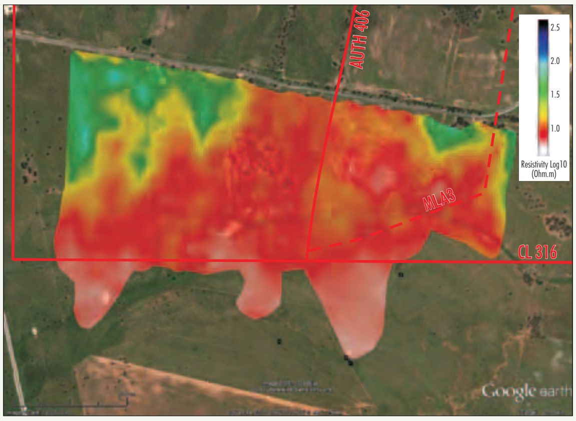
@3m Depth



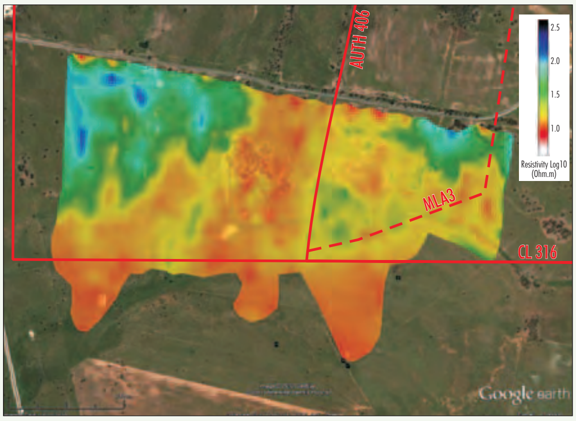
@7m Depth



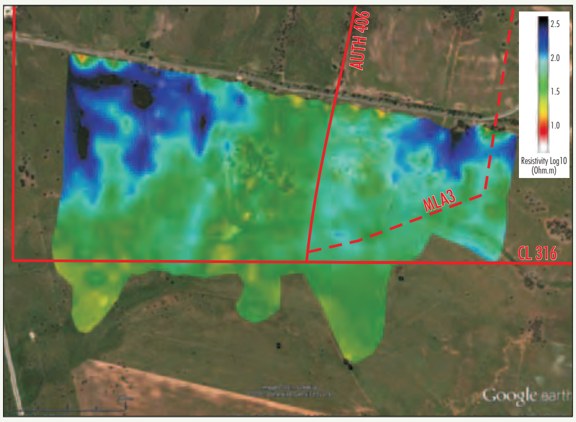
@12m Depth



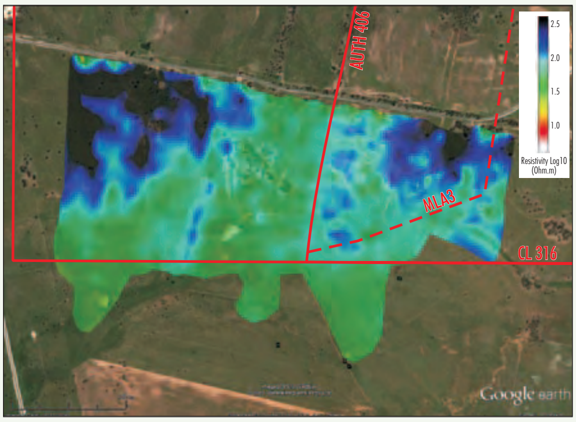
@20m Depth



@28m Depth



@45m Depth



@58m Depth

—— Tenement Boundary
- - - Indicative Mining Lease Application Area

0 200 1000
Metres

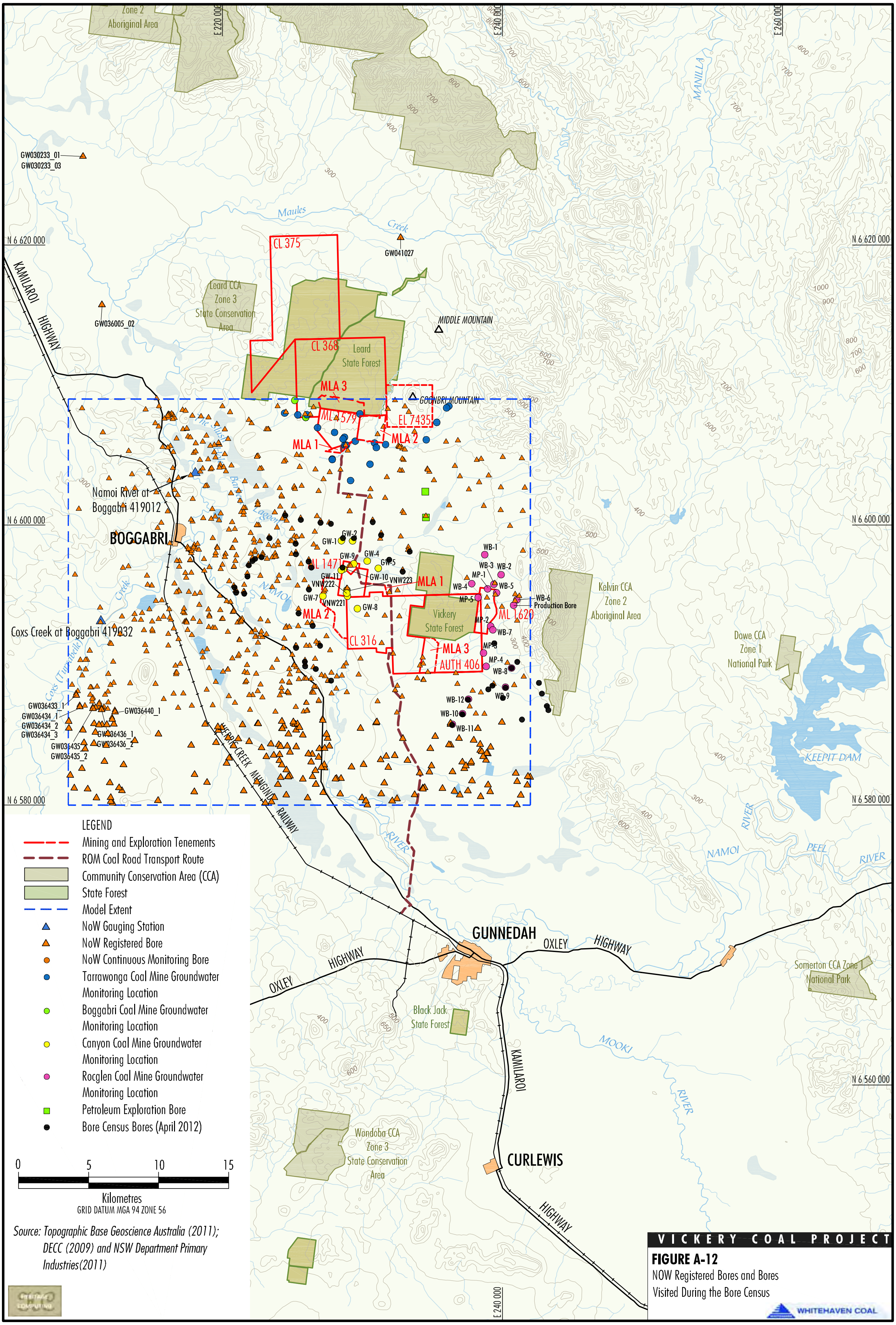
*Source: Groundwater Imaging (2012)*

VICKERY COAL PROJECT

**FIGURE A-11**

TEM Survey Results

WHITEHAVEN COAL



*Source: Topographic Base Geoscience Australia (2011); DECC (2009) and NSW Department Primary Industries(2011)*

VICKERY COAL PROJECT

**FIGURE A-12**

NOW Registered Bores and Bores Visited During the Bore Census

WHITEHAVEN COAL

WHC-10-03 EA AppGW_103C

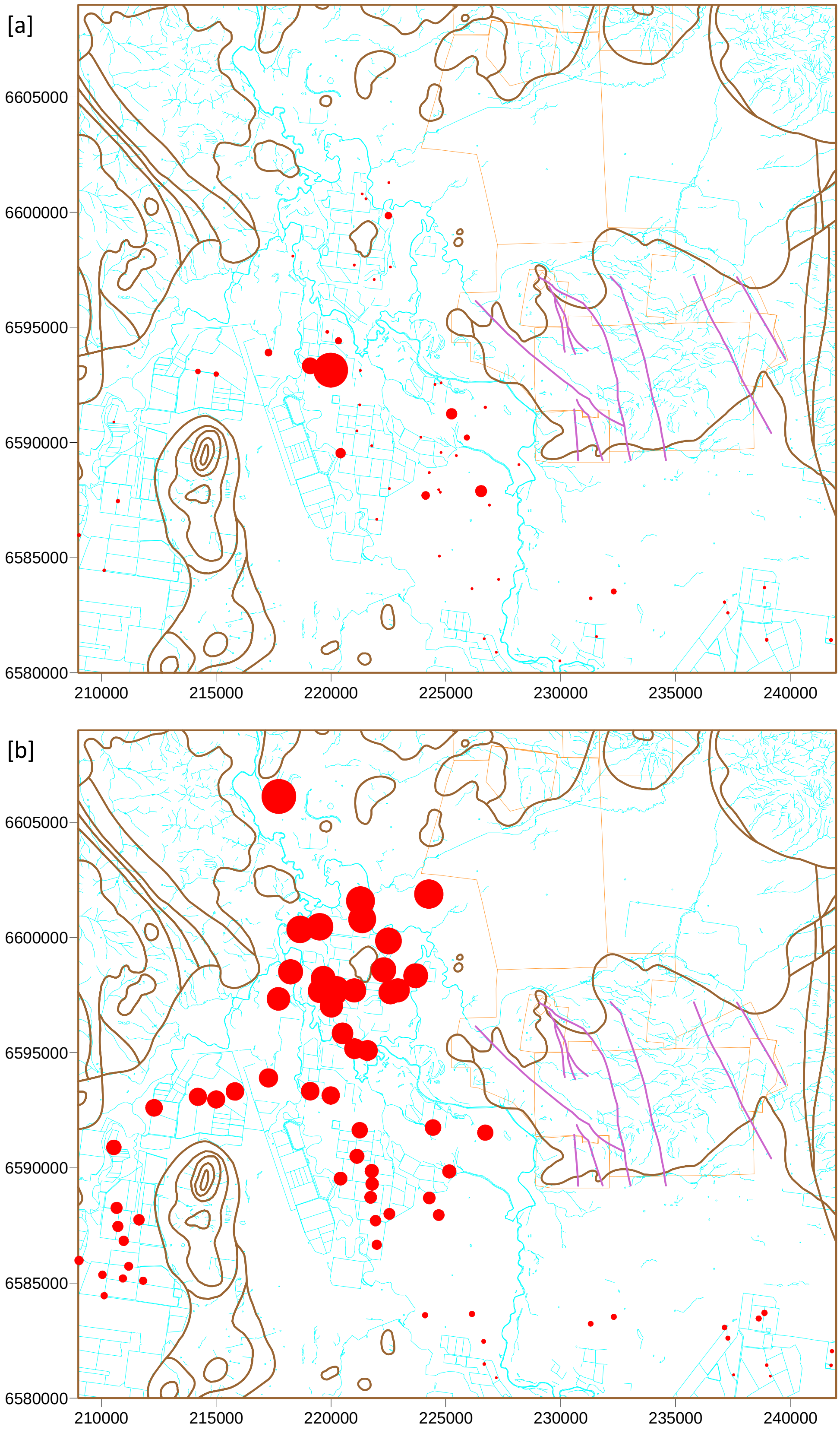


Figure A-13. Spatial Distribution of Groundwater Pumping in 2009-2010:
[a] Narrabri Formation
[b] Gunnedah Formation

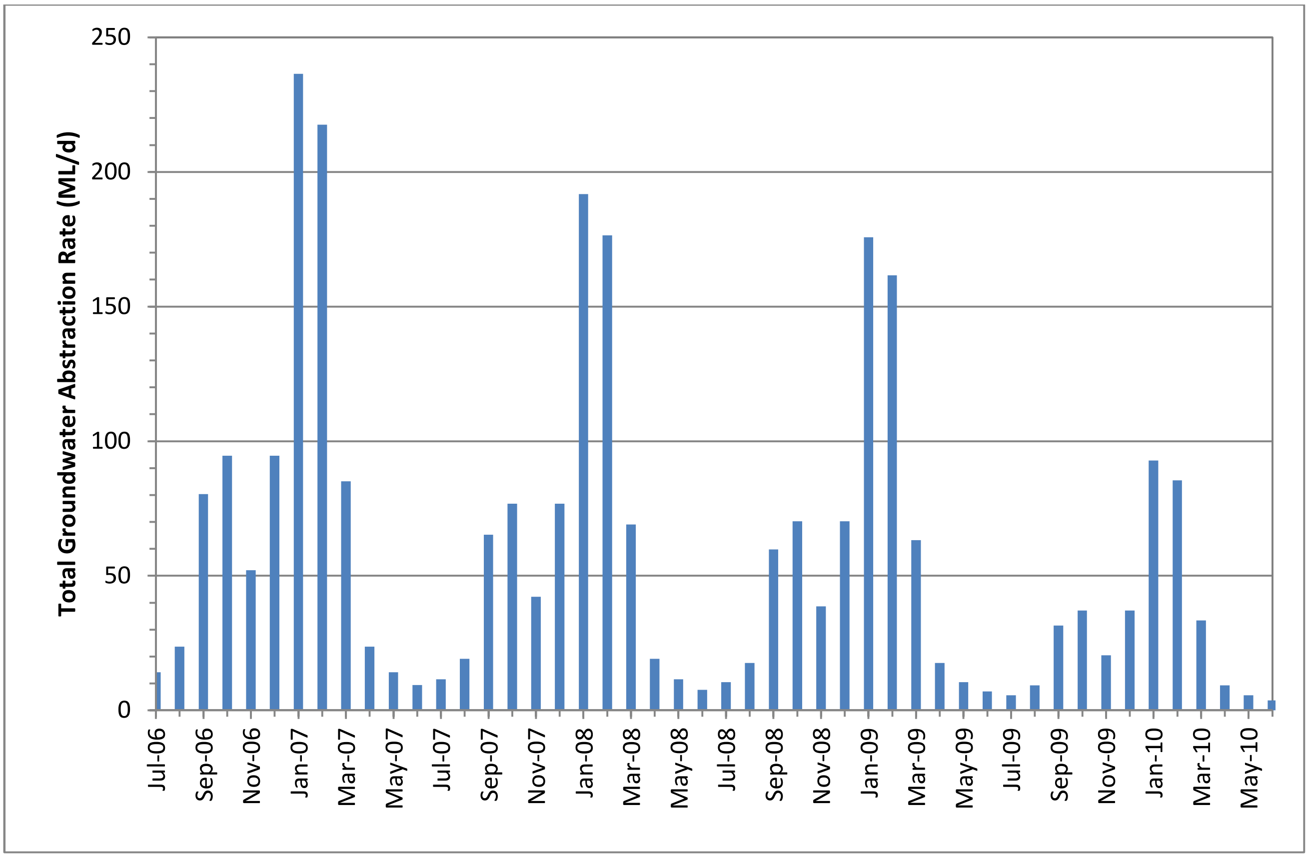
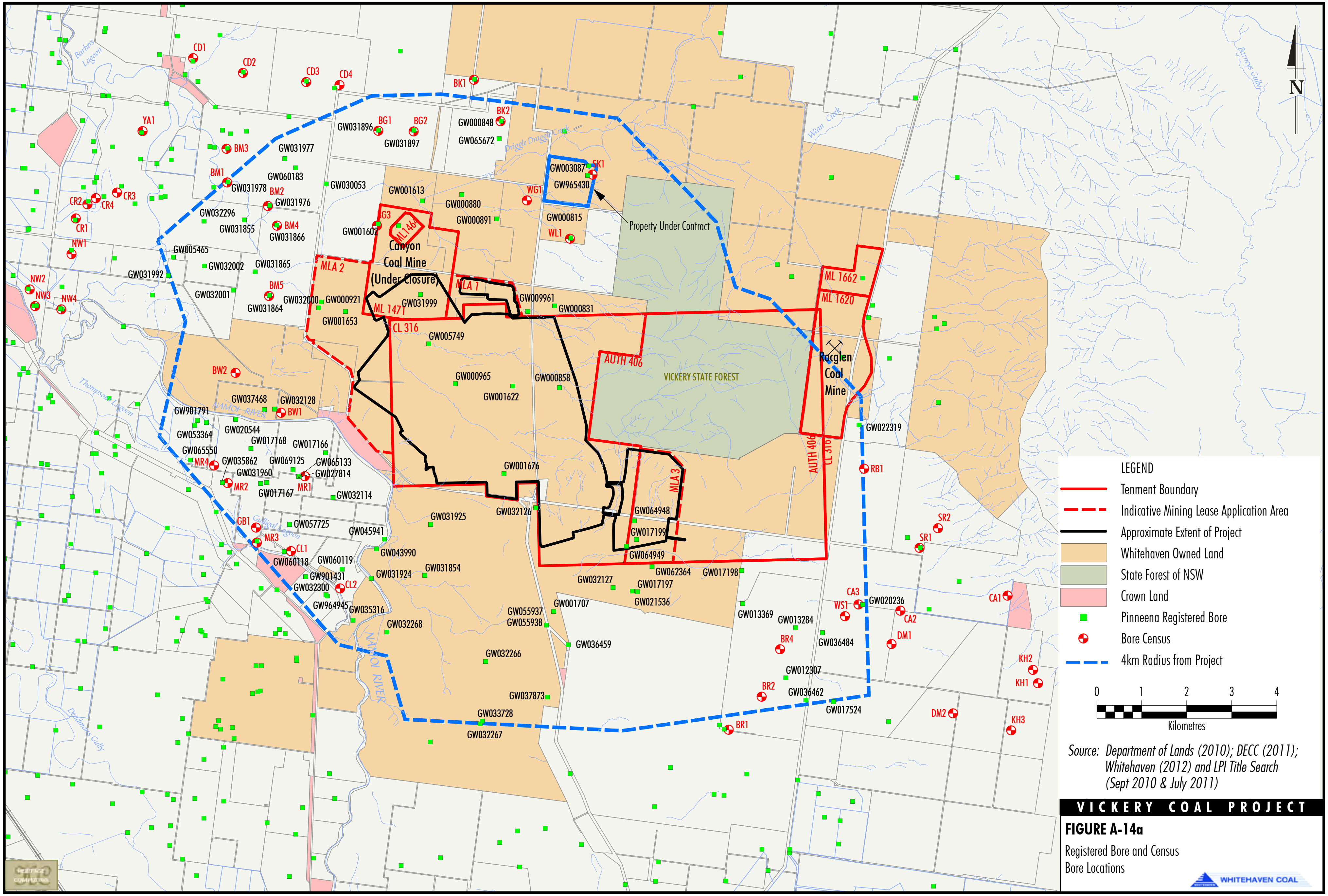


Figure A-13c. Temporal Distribution of Groundwater Pumping from 2006 to 2010



LEGEND

| | |
|---|---|
| 🟥 | Tenment Boundary |
| - - | Indicative Mining Lease Application Area |
| ▬ | Approximate Extent of Project |
| 🟧 | Whitehaven Owned Land |
| 🟩 | State Forest of NSW |
| 🟥 | Crown Land |
| ■ | Pinneena Registered Bore |
| ● | Bore Census |
| - - | 4km Radius from Project |

0 1 2 3 4
Kilometres

*Source: Department of Lands (2010); DECC (2011); Whitehaven (2012) and LPI Title Search (Sept 2010 & July 2011)*

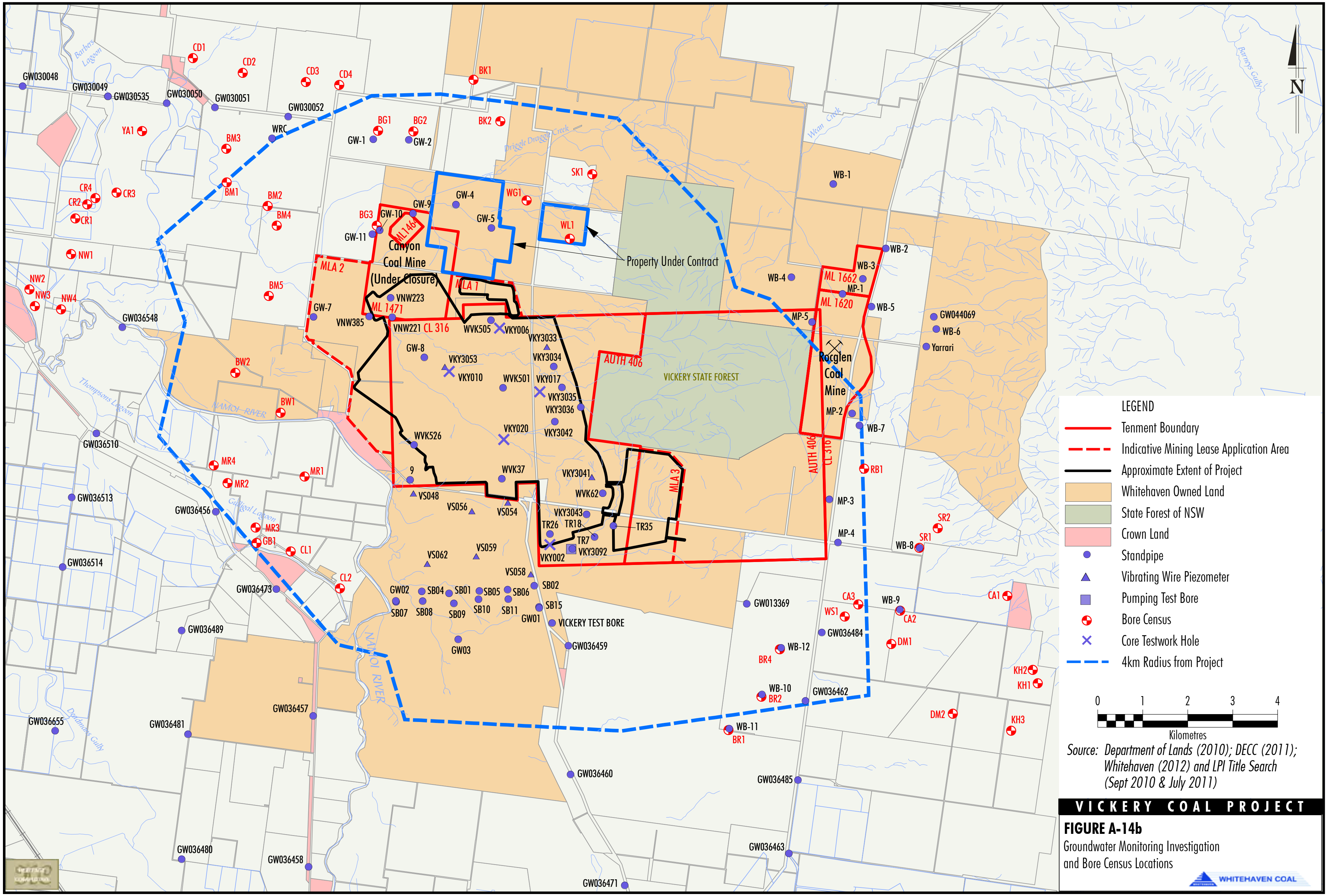
VICKERY COAL PROJECT

**FIGURE A-14a**

Registered Bore and Census Bore Locations

WHITEHAVEN COAL

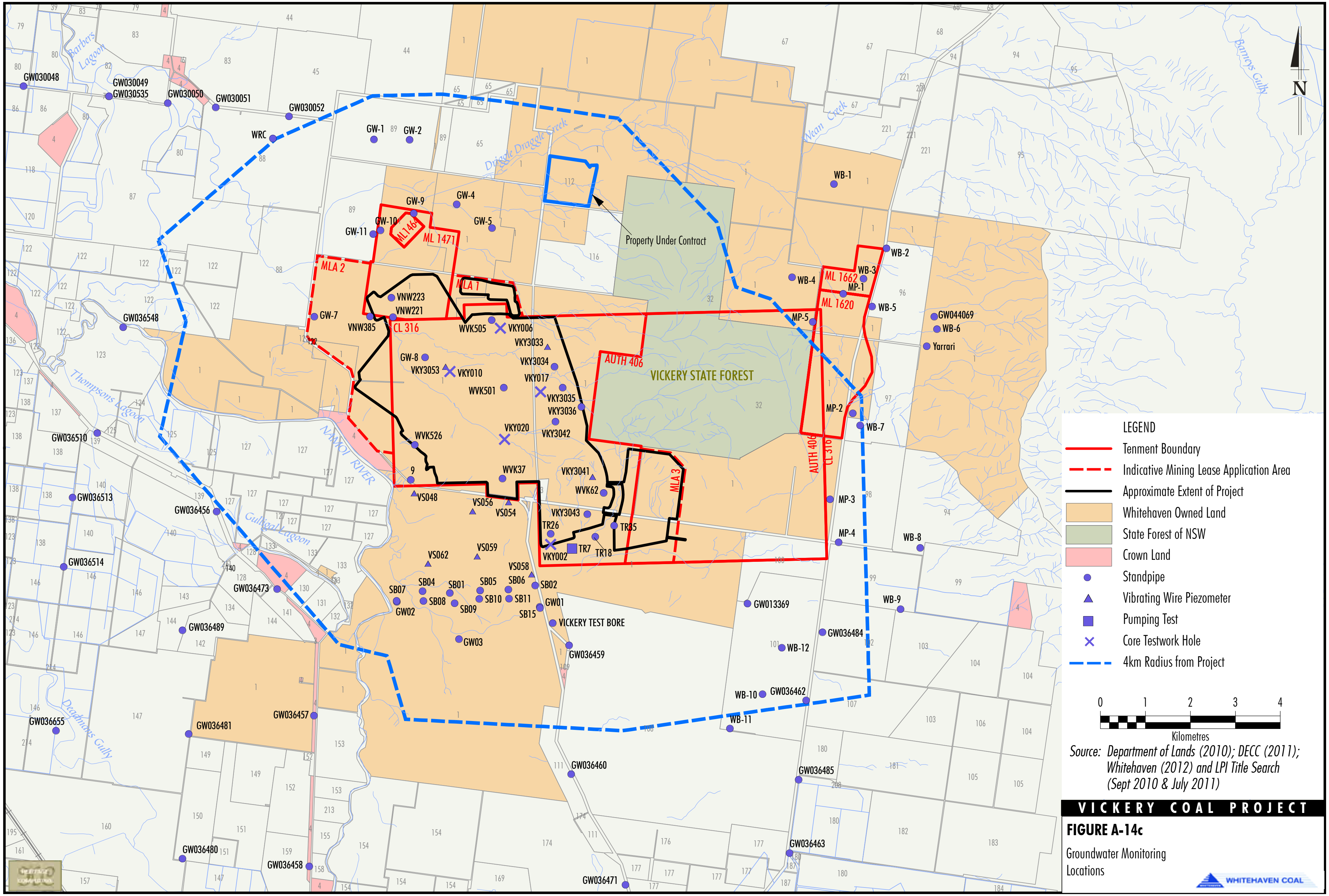
WHC-10-03_EIS_AppGW_205C



Source: *Department of Lands (2010); DECC (2011); Whitehaven (2012) and LPI Title Search (Sept 2010 & July 2011)*

VICKERY COAL PROJECT

**FIGURE A-14b**
Groundwater Monitoring Investigation and Bore Census Locations



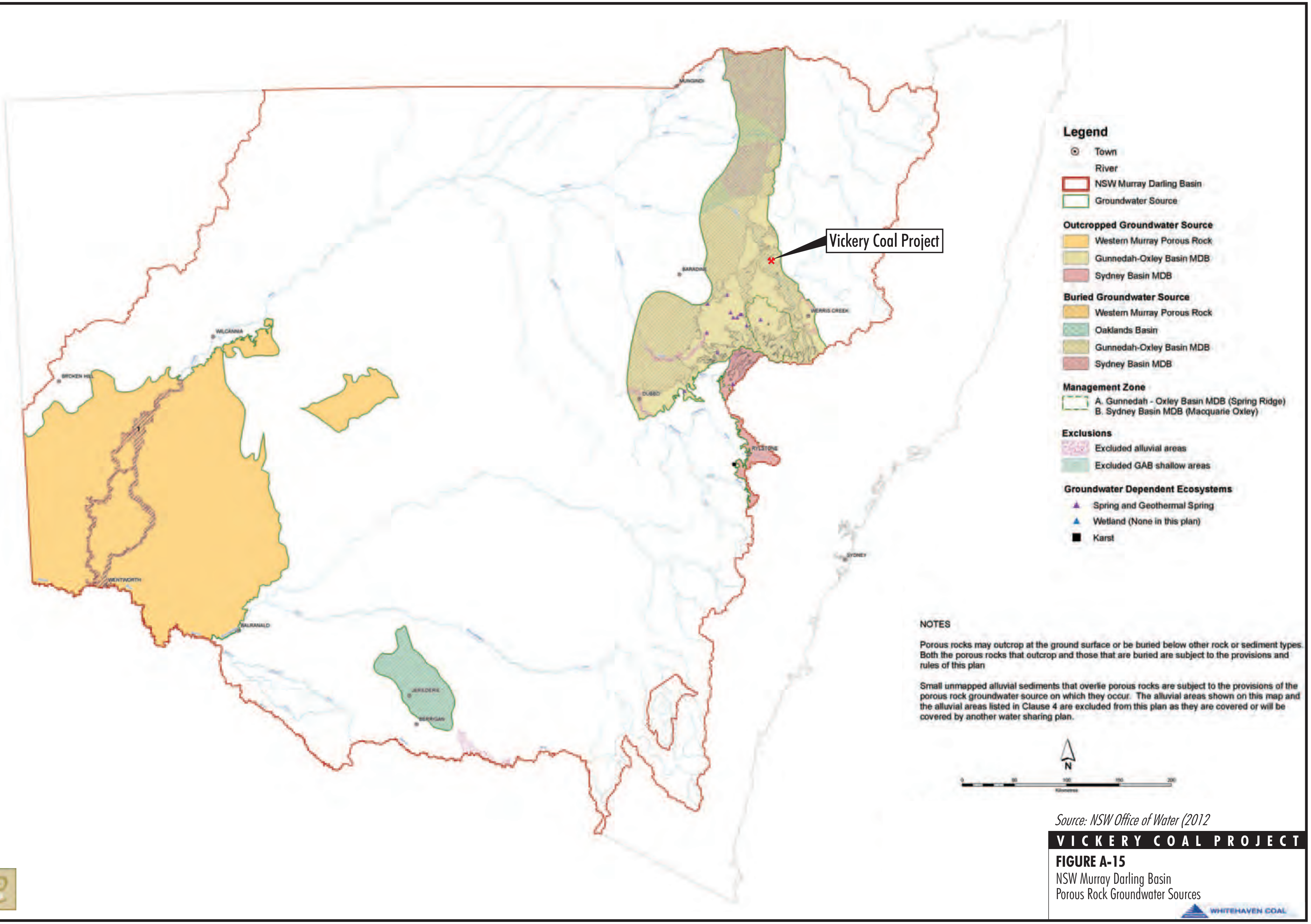
Source: *Department of Lands (2010); DECC (2011); Whitehaven (2012) and LPI Title Search (Sept 2010 & July 2011)*

**VICKERY COAL PROJECT**

**FIGURE A-14c**

Groundwater Monitoring Locations

WHC-10-03_EIS_AppGW_201E



NOTES

Porous rocks may outcrop at the ground surface or be buried below other rock or sediment types. Both the porous rocks that outcrop and those that are buried are subject to the provisions and rules of this plan

Small unmapped alluvial sediments that overlie porous rocks are subject to the provisions of the porous rock groundwater source on which they occur. The alluvial areas shown on this map and the alluvial areas listed in Clause 4 are excluded from this plan as they are covered or will be covered by another water sharing plan.

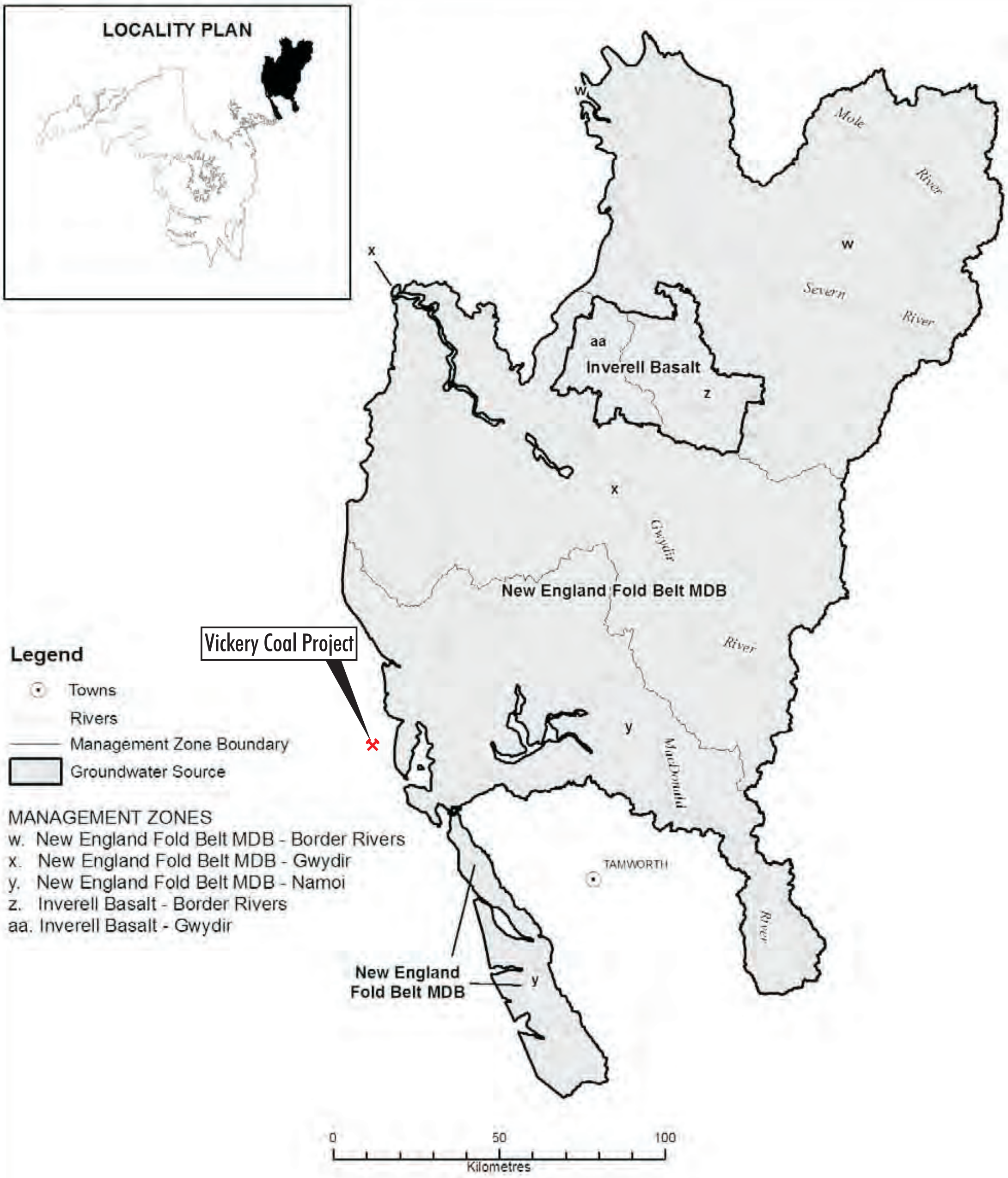
*Source: NSW Office of Water (2012*

VICKERY COAL PROJECT

**FIGURE A-15**
NSW Murray Darling Basin
Porous Rock Groundwater Sources

WHITEHAVEN COAL

WHC-10-03 EA AppGW_001A



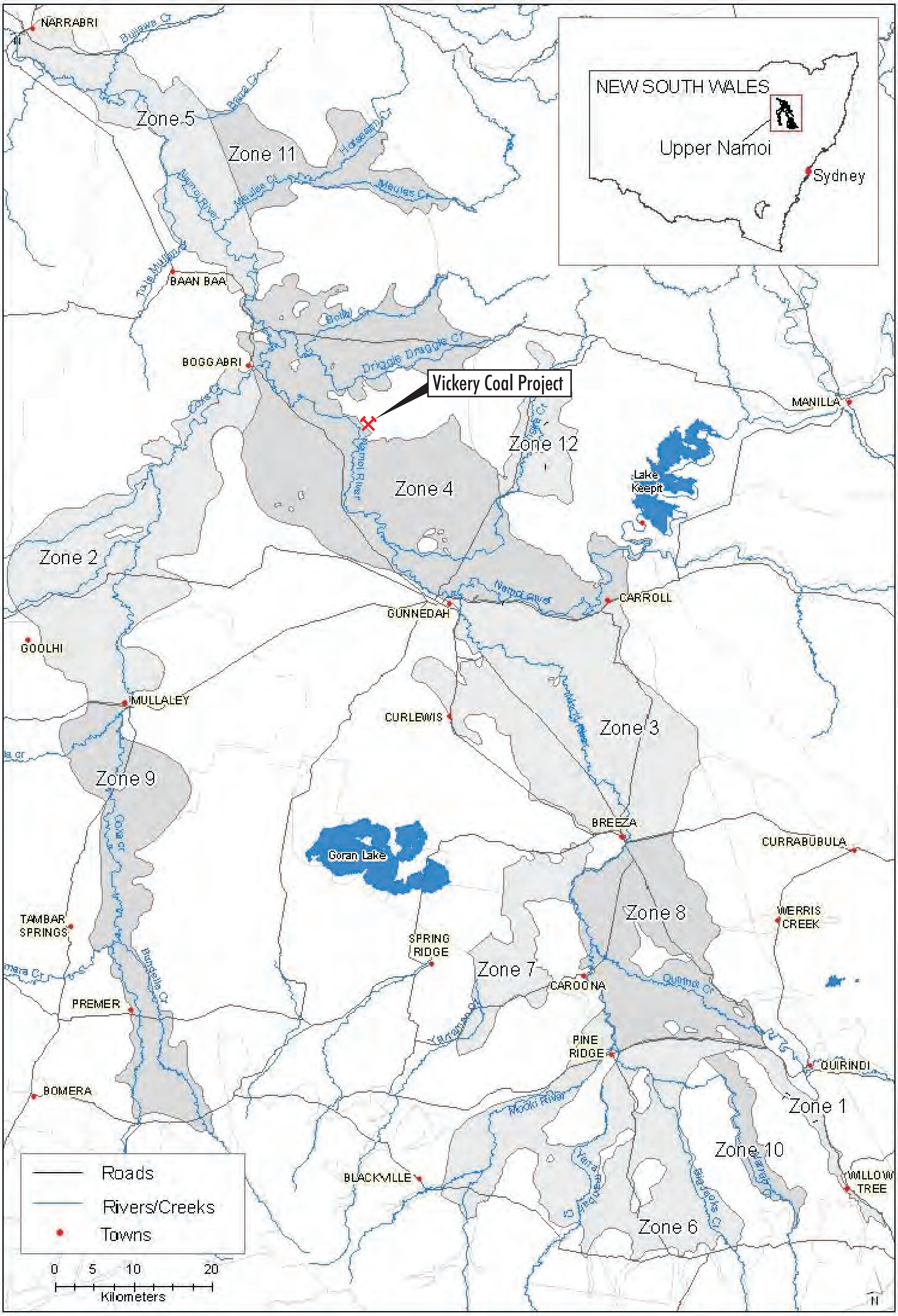
## DRAFT WATER SHARING PLAN FOR THE NSW MURRAY DARLING BASIN FRACTURED ROCK GROUNDWATER SOURCES 2011

### MANAGEMENT ZONES FOR THE NEW ENGLAND FOLD BELT MDB AND INVERELL BASALT GROUNDWATER SOURCES

Source: NSW Office of Water (2011)

**VICKERY COAL PROJECT**

**FIGURE A-16**
NSW Murray Darling Basin
Fractured Rock Groundwater Sources

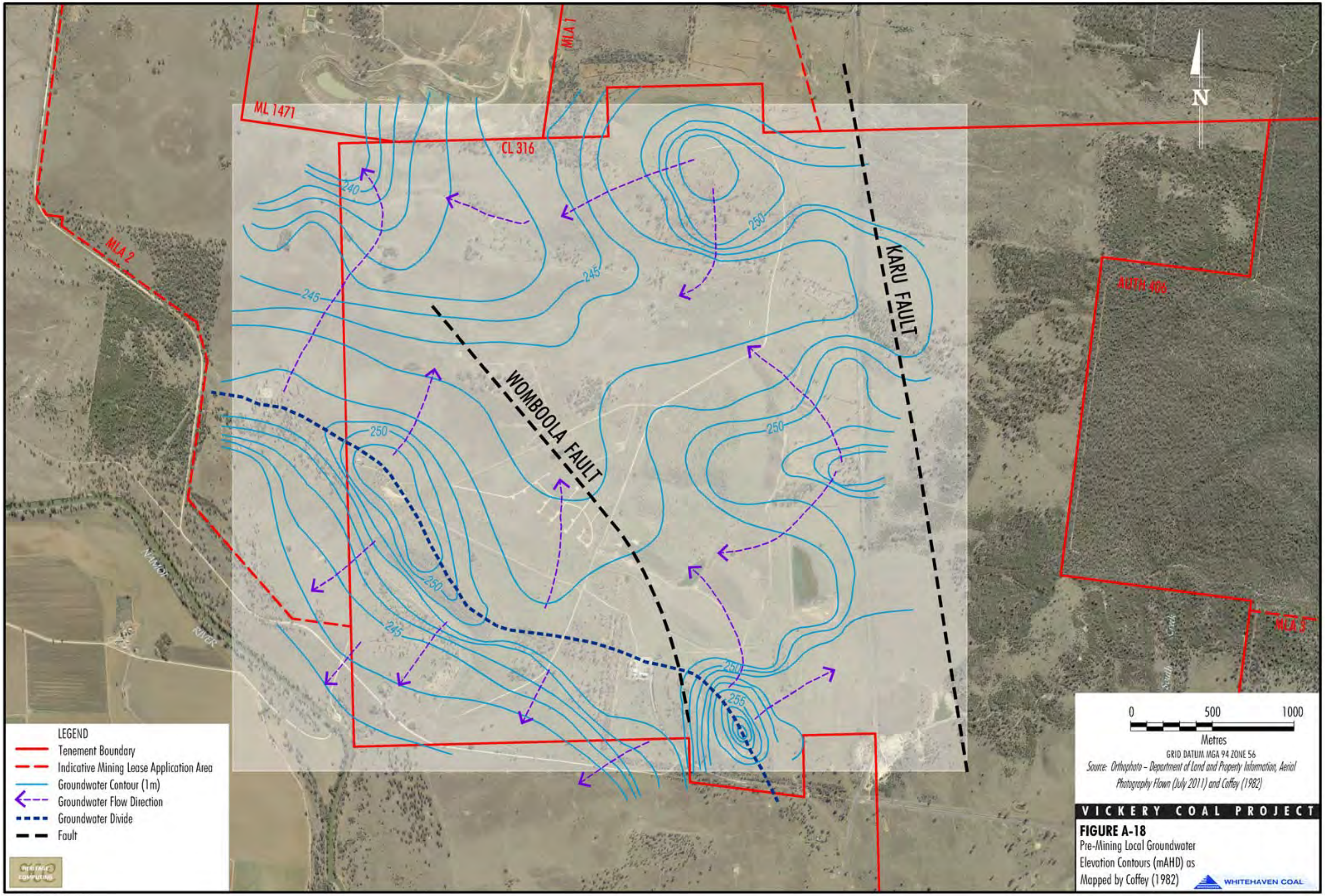


*Source: NSW Office of Water (2010)*

**VICKERY COAL PROJECT**

**FIGURE A-17**

Upper Namoi
Groundwater Sources



GRID DATUM MGA 94 ZONE 56

*Source: Orthophoto – Department of Land and Property Information, Aerial Photography Flown (July 2011) and Coffey (1982)*

VICKERY COAL PROJECT

**FIGURE A-18**
Pre-Mining Local Groundwater Elevation Contours (mAHD) as Mapped by Coffey (1982)

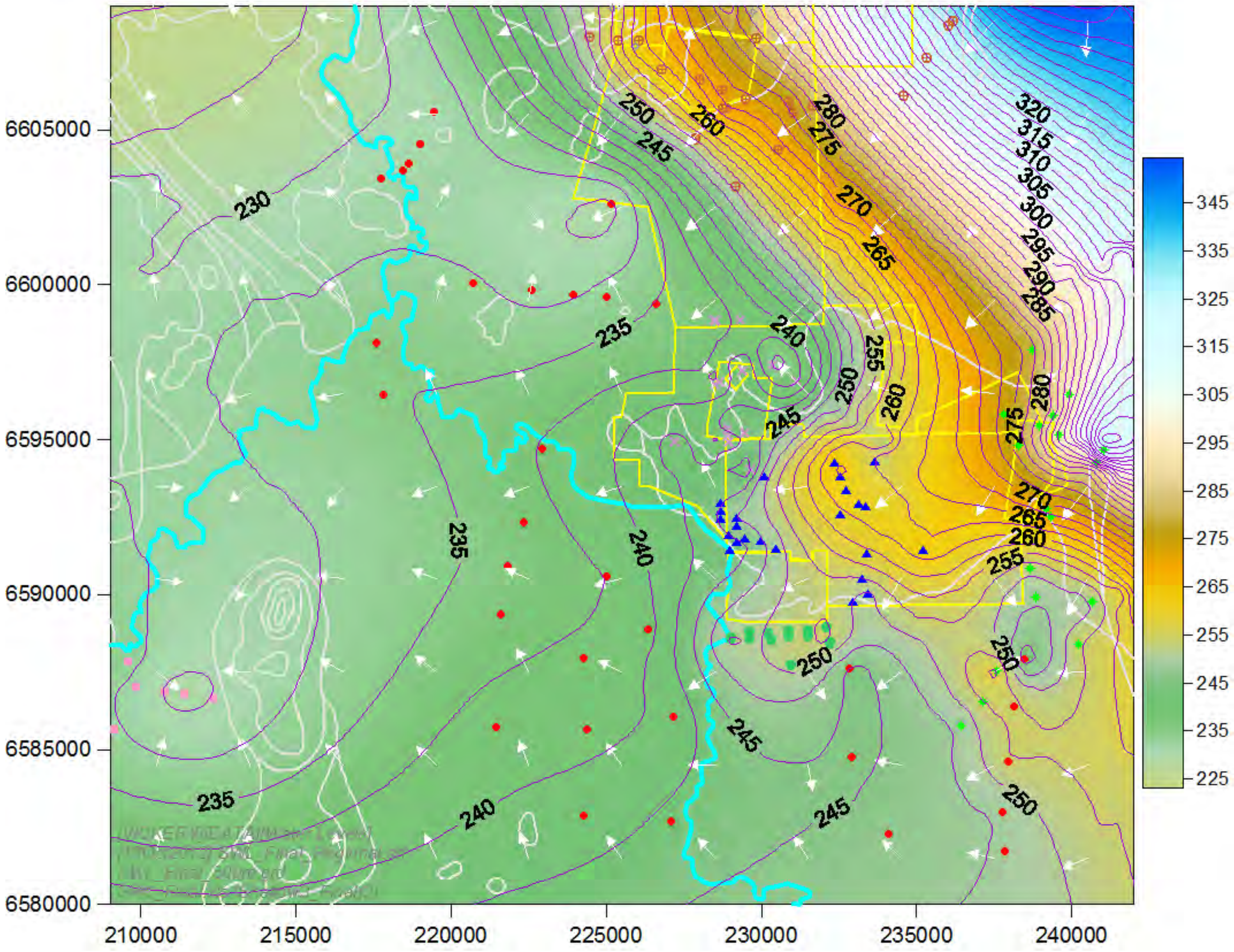


Figure A-19. Regional Groundwater Level (Potentiometric) Contours [mAHD] and Flow Directions in Regolith/Alluvium (contour interval 2.5m)

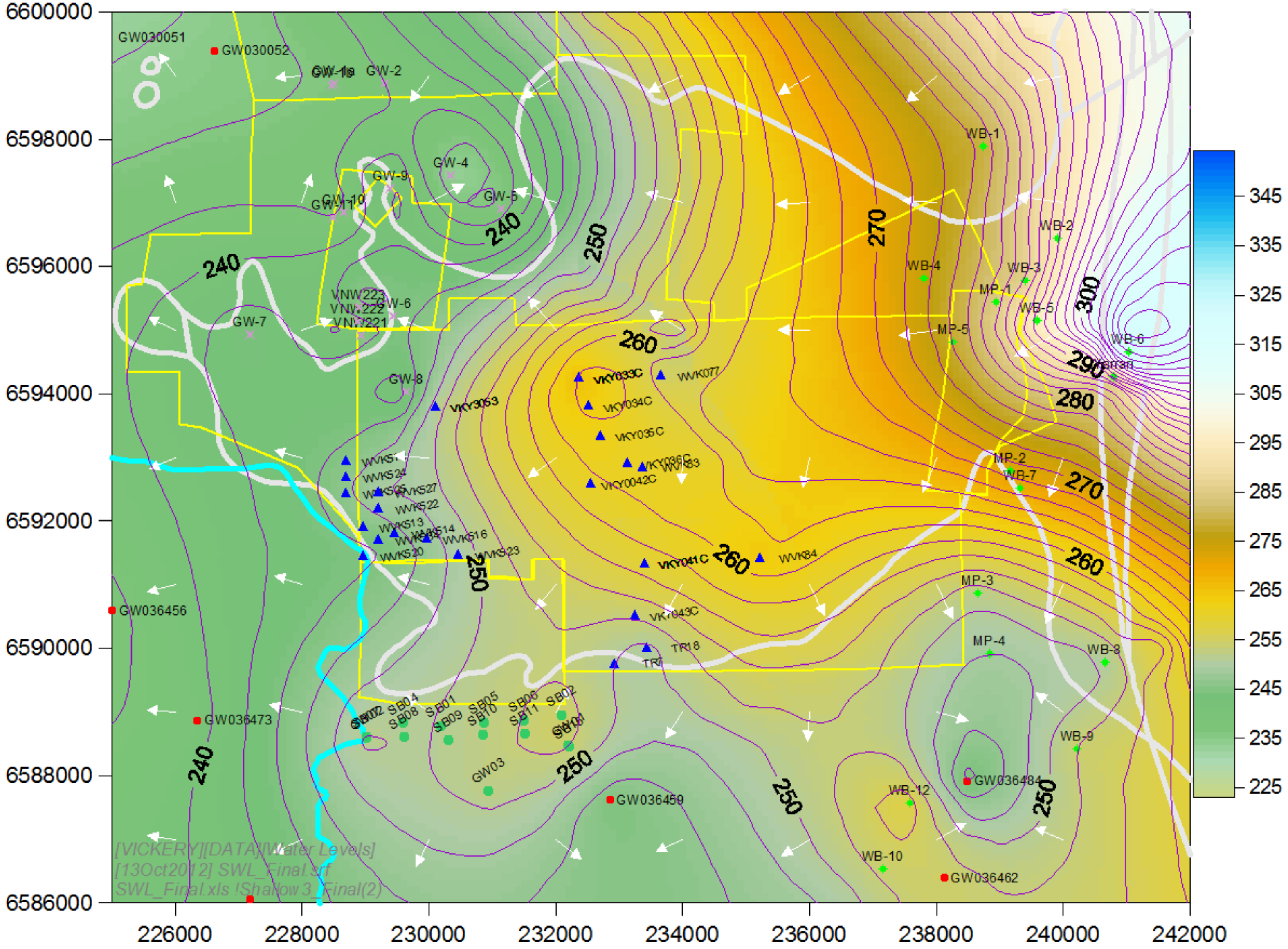


Figure A-20. Local Groundwater Level (Potentiometric) Contours [mAHD] and Flow Directions in Regolith/Alluvium (contour interval 2m)

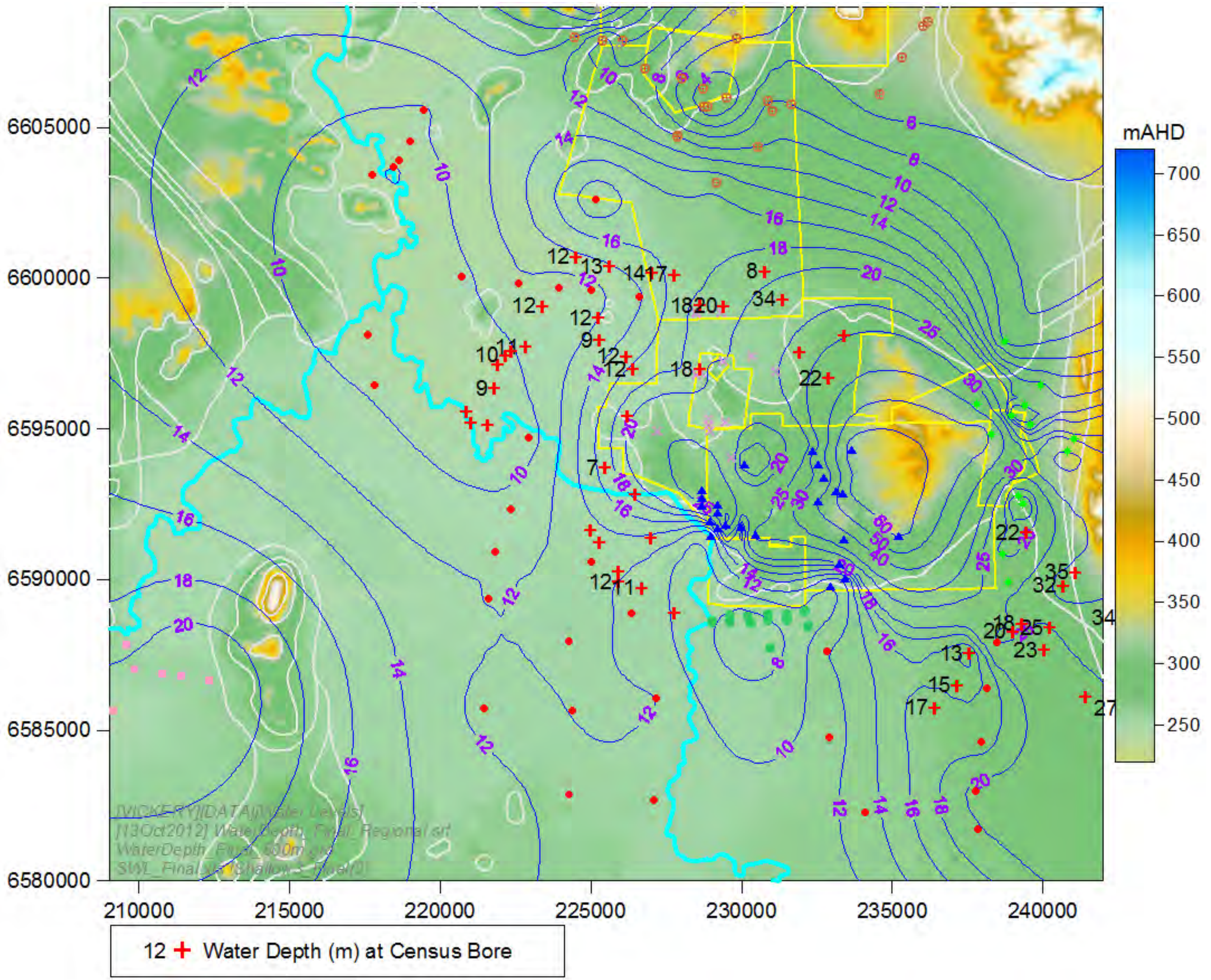


Figure A-21. Regional Depth to Groundwater Contours [m] Showing Ground Surface Topography [mAHD]

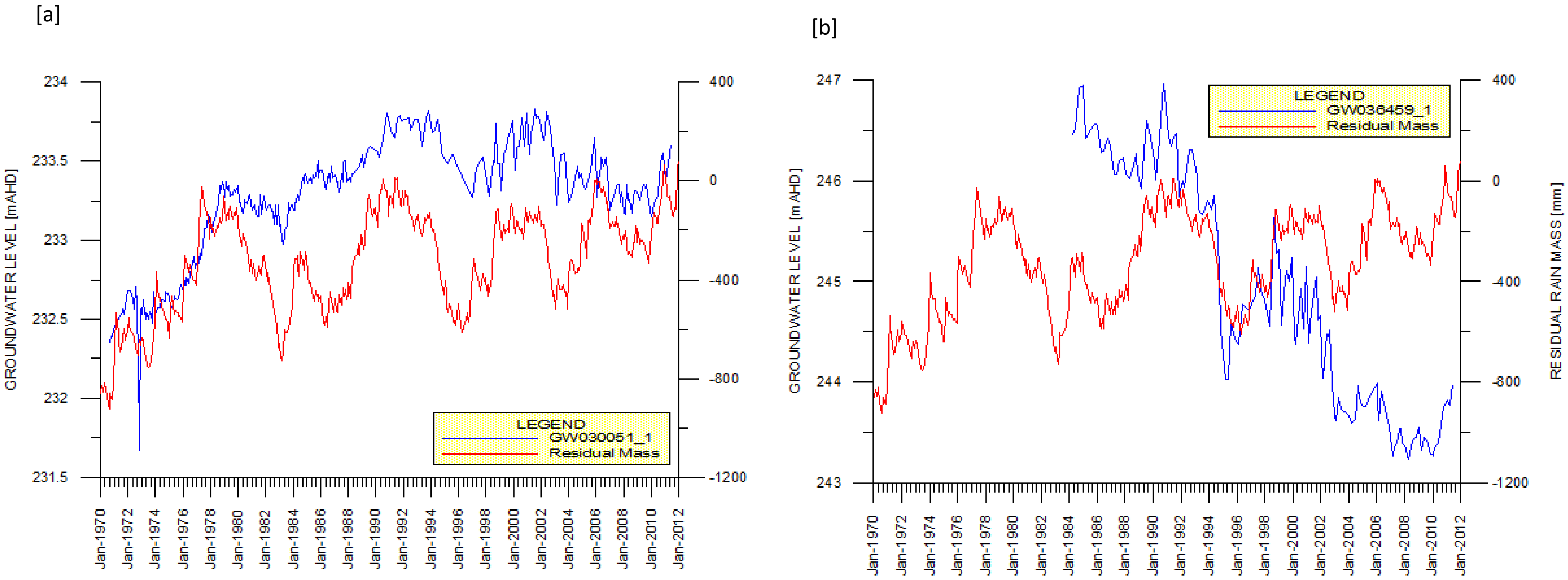


Figure A-22. Representative NOW Hydrographs:

[a] Bore 30051_1 (north-west of Canyon Mine)

[b] Bore 36459_1 (south of Project)

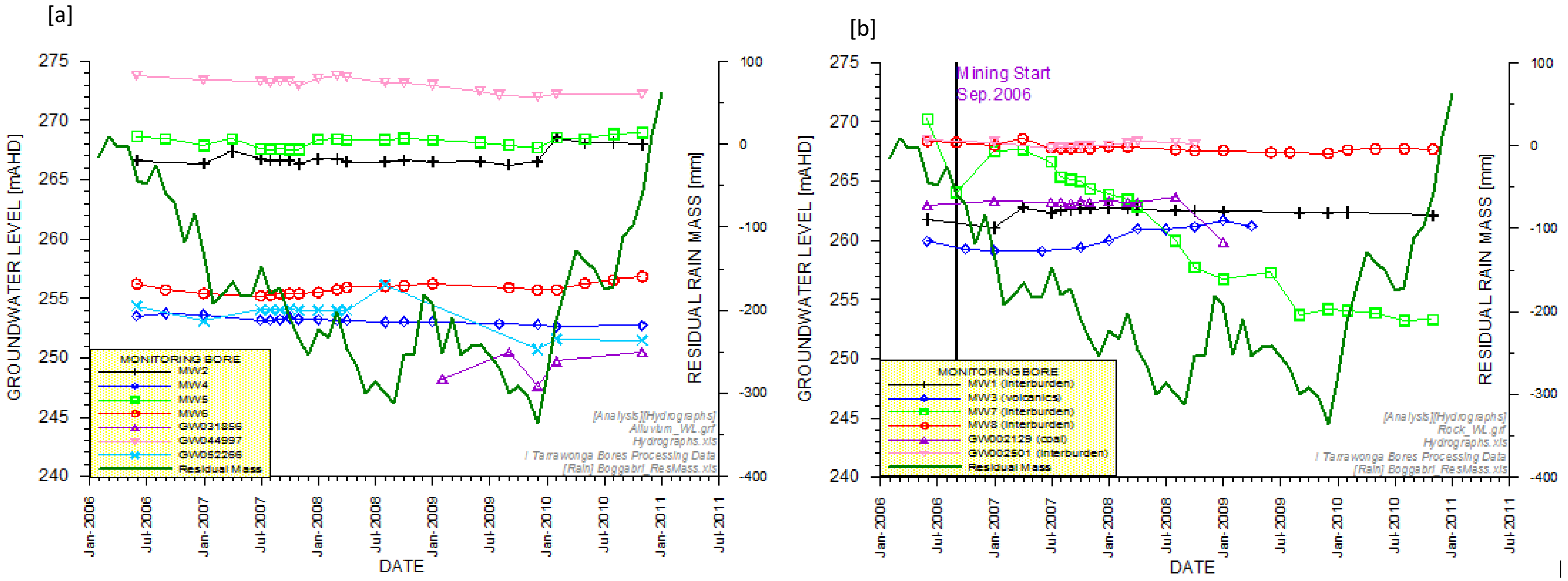


Figure A-23. Representative Tarrawonga Hydrographs:

[a] Screened in Alluvium

[b] Screened in Coal, Interburden and Volcanics

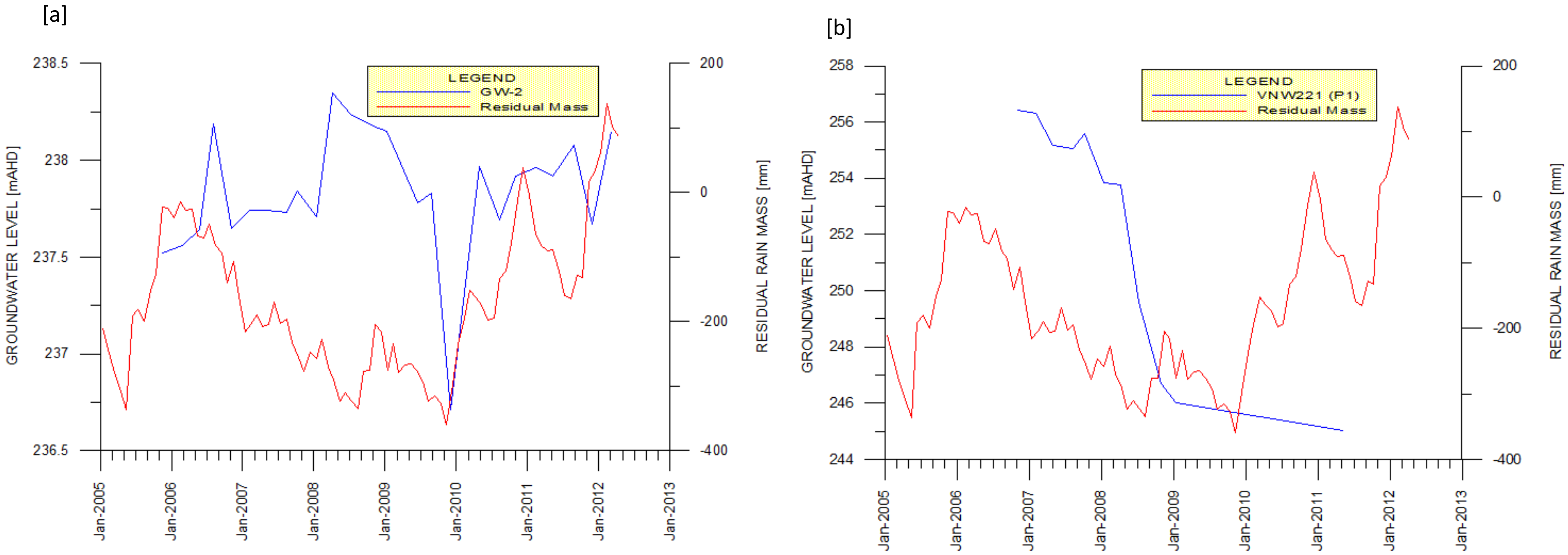


Figure A-24. Representative Canyon Hydrographs:

[a] Bore GW-2 (north of Canyon Mine)

[b] Bore VNW221 (south of Canyon void)

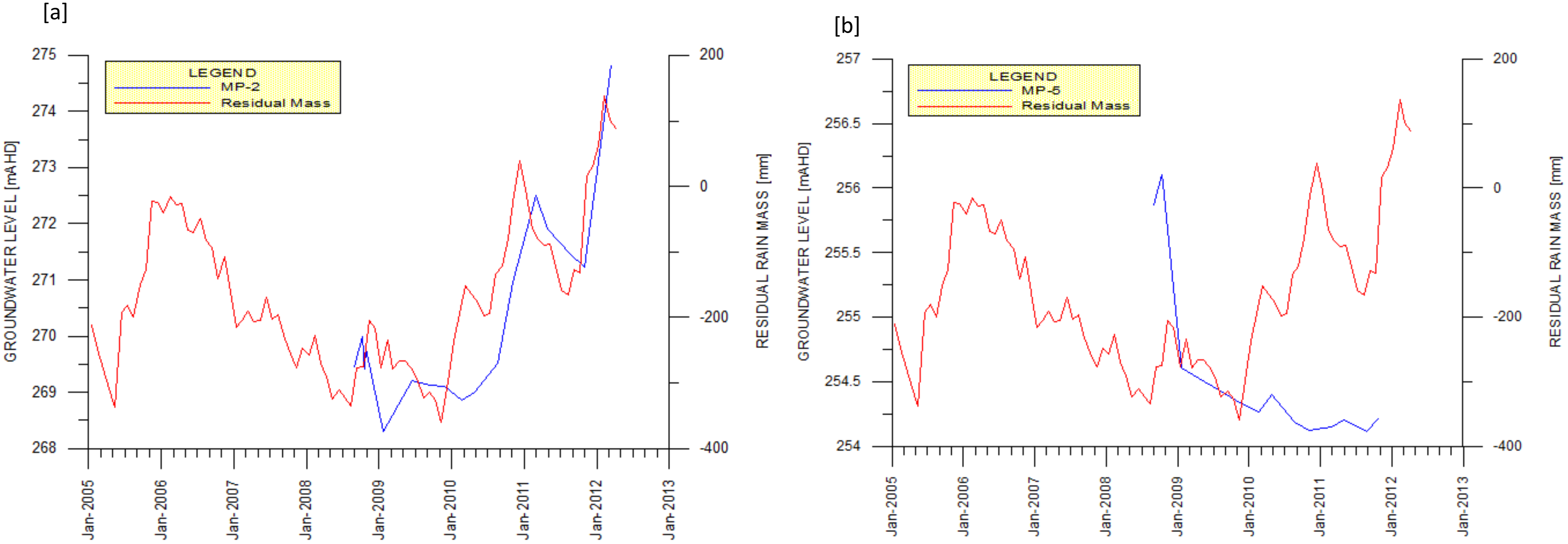


Figure A-25. Representative Rocglen Hydrographs:

[a] Bore MP-2 (south of Rocglen Mine)

[b] Bore MP-5 (west of Rocglen Mine)

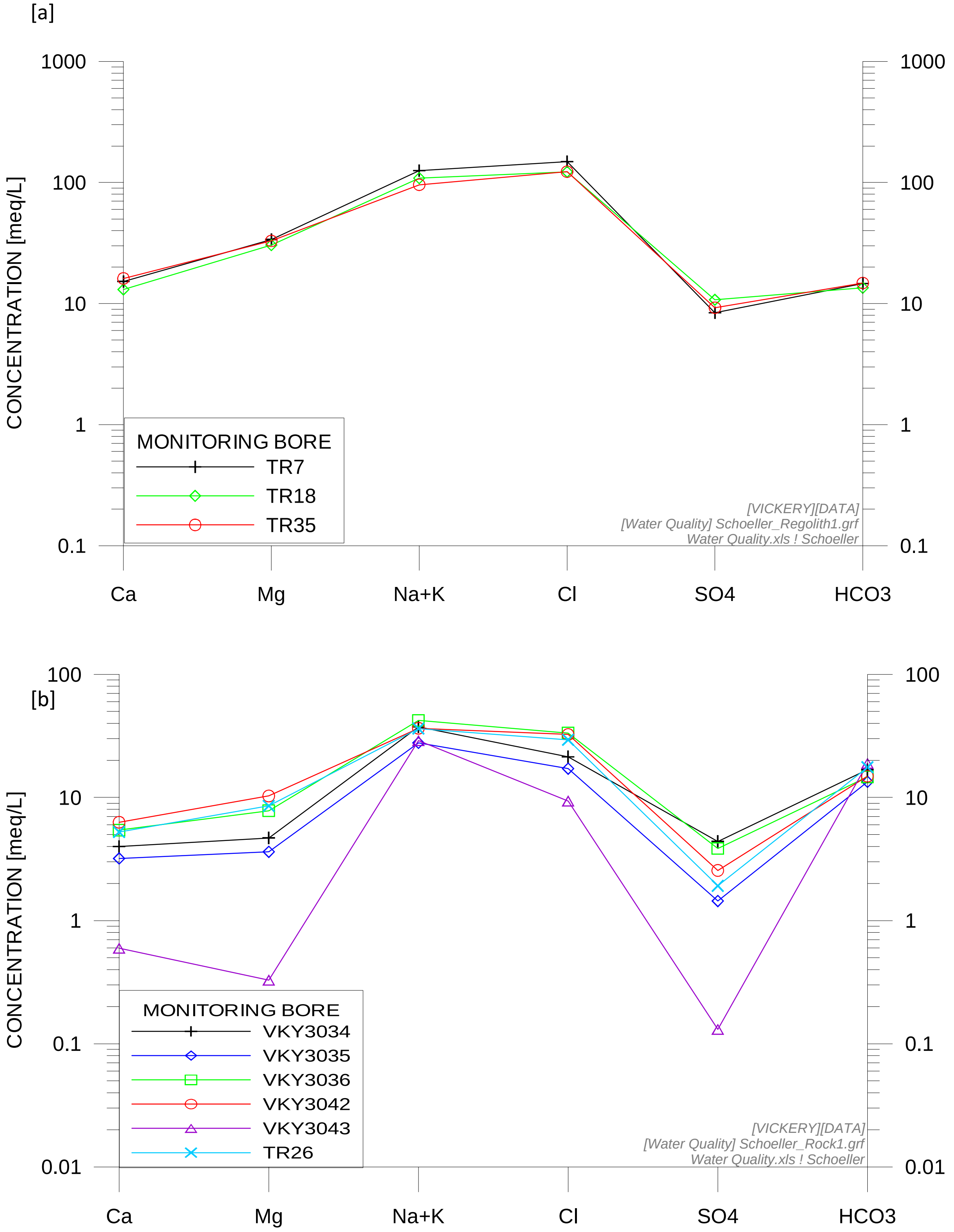
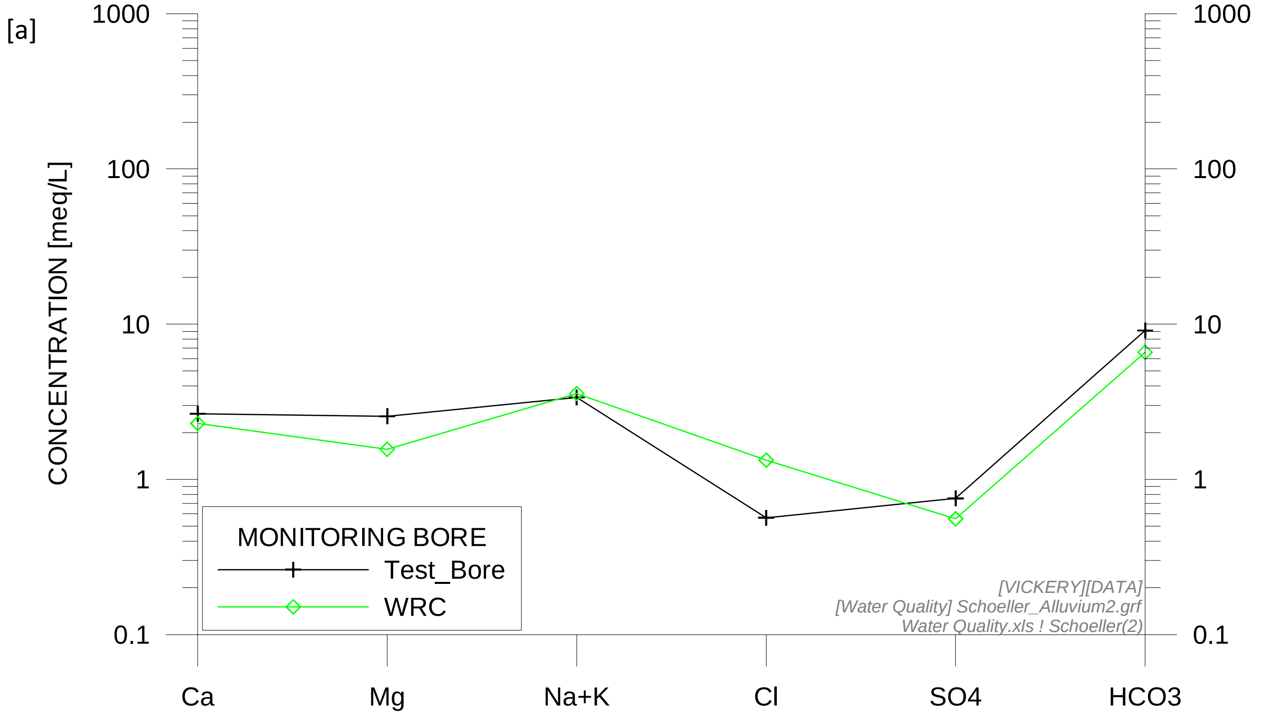


Figure A-26. Schoeller Plots for Major Ions in Groundwater (March 2012):

[a] Regolith

[b] Coal Measures



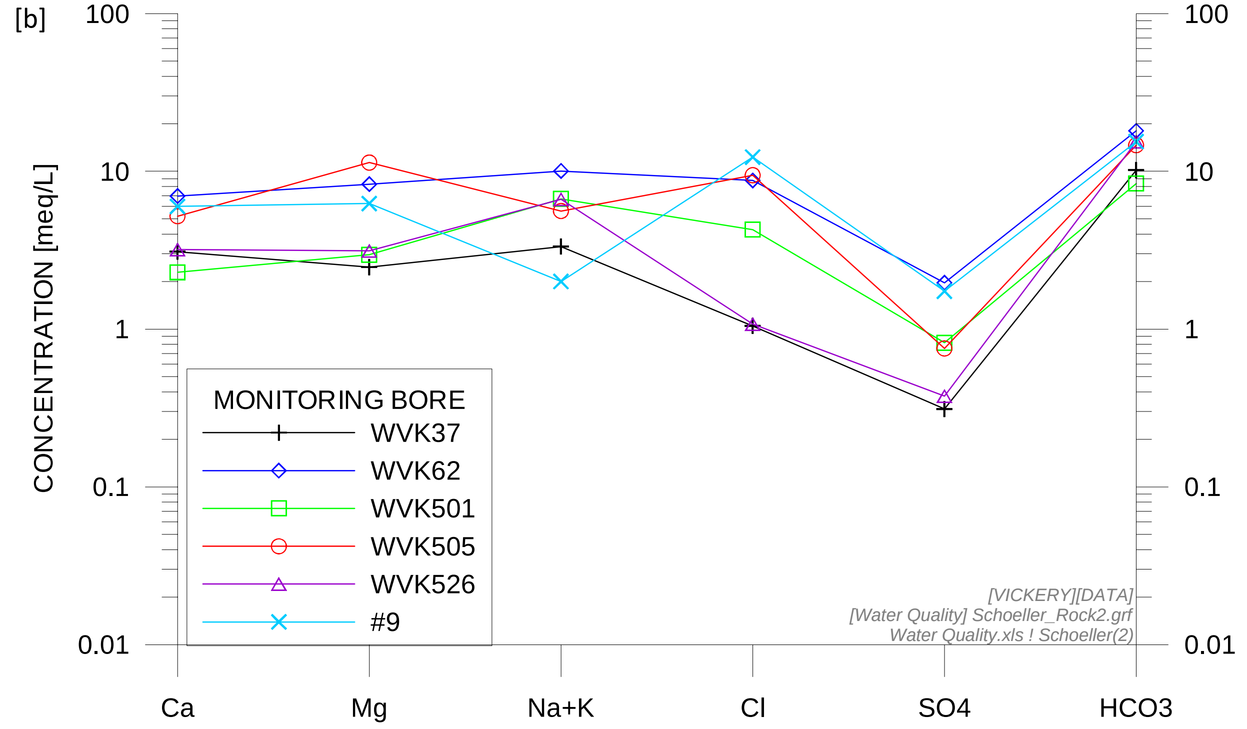


Figure A-27. Schoeller Plots for Major Ions in Groundwater (1985):
[a] Alluvium
[b] Coal Measures

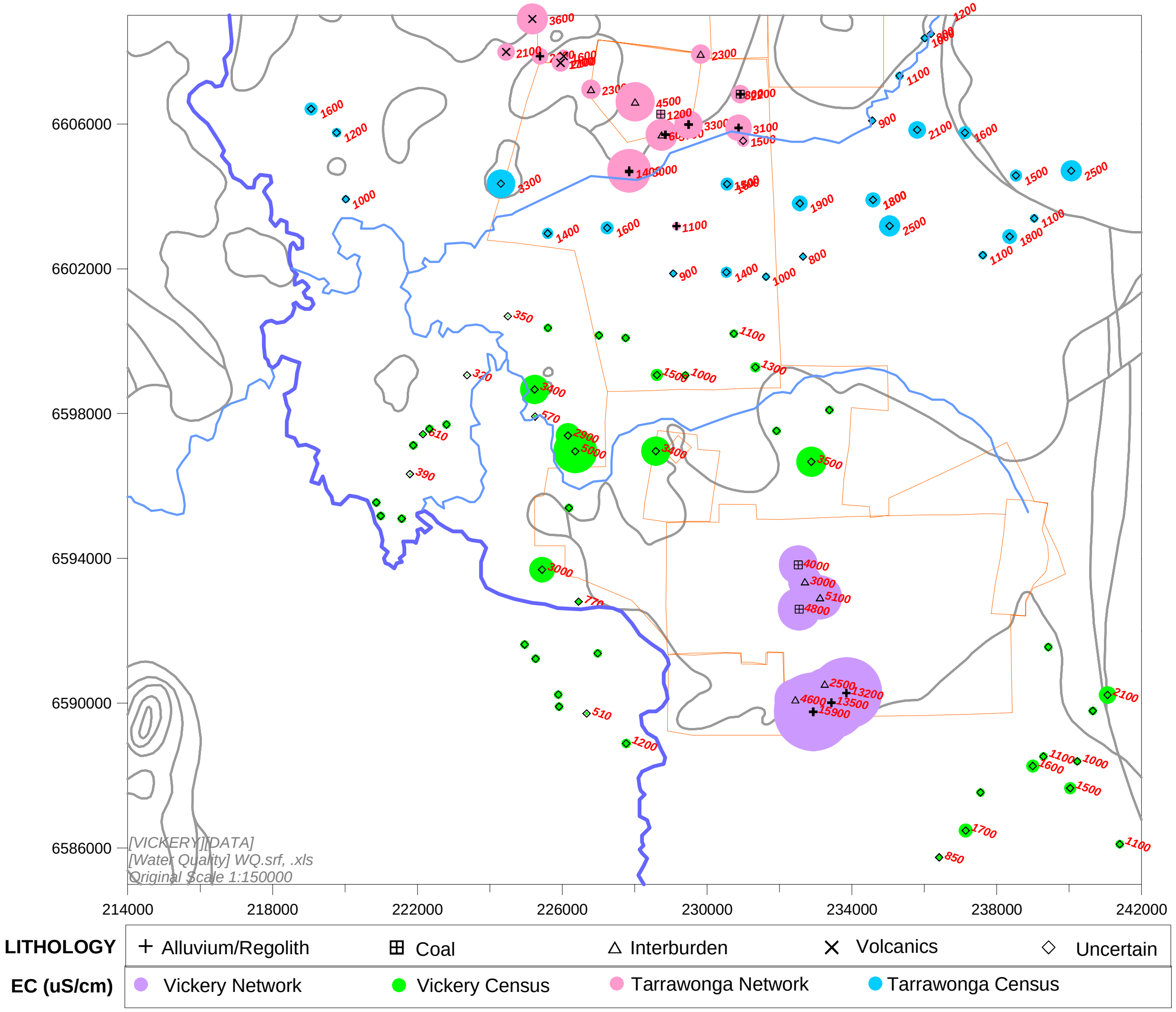


Figure A-28a. Distribution of Electrical Conductivity in Groundwater

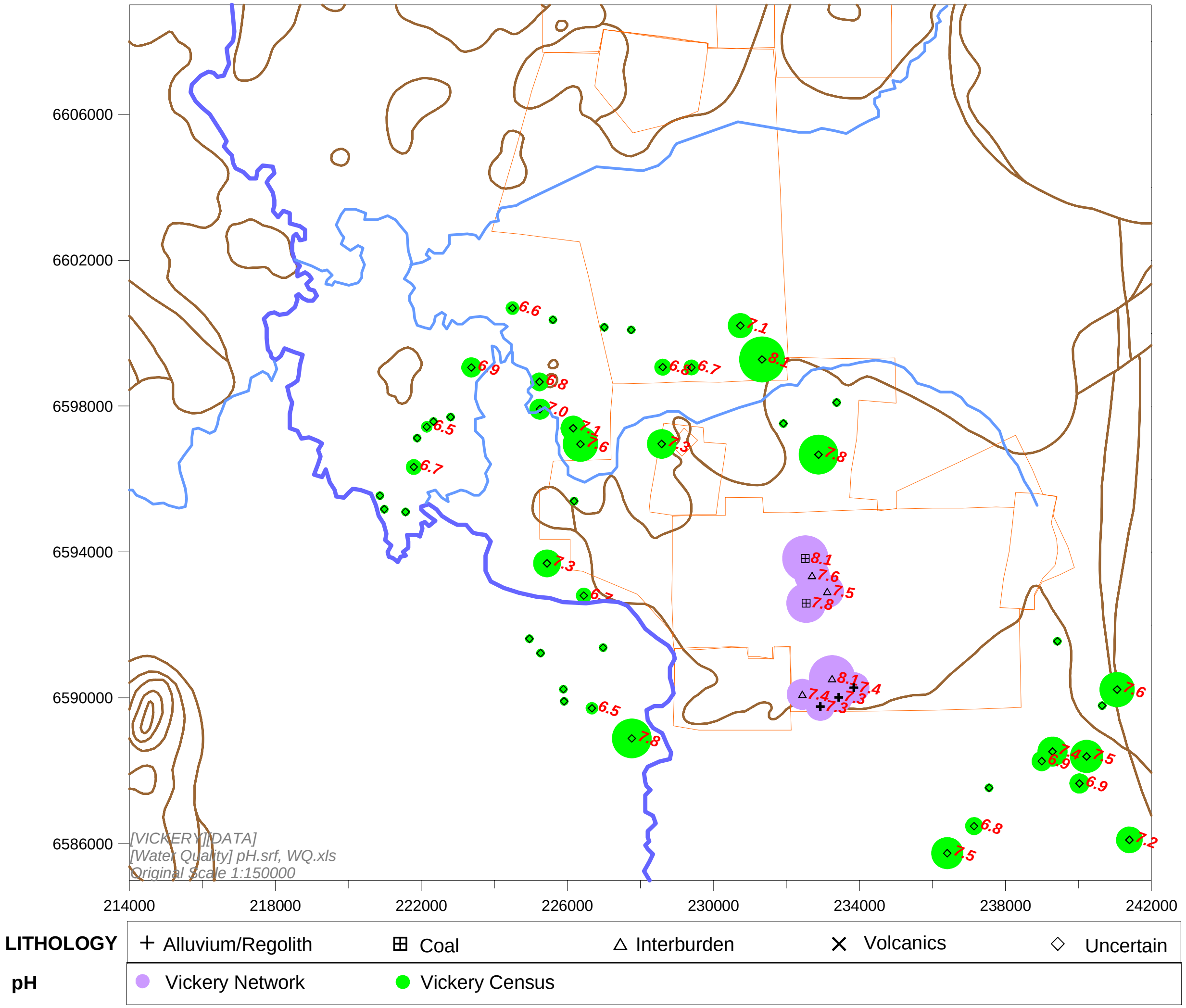
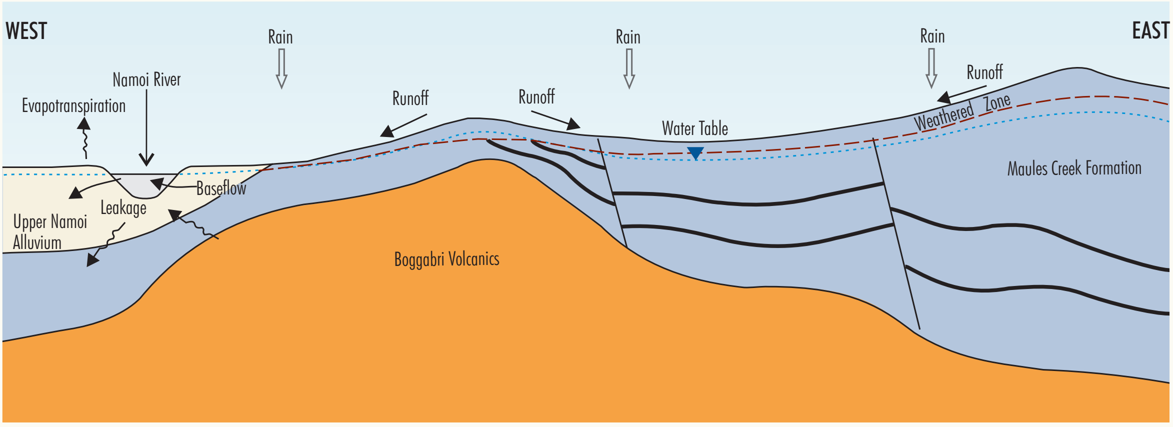
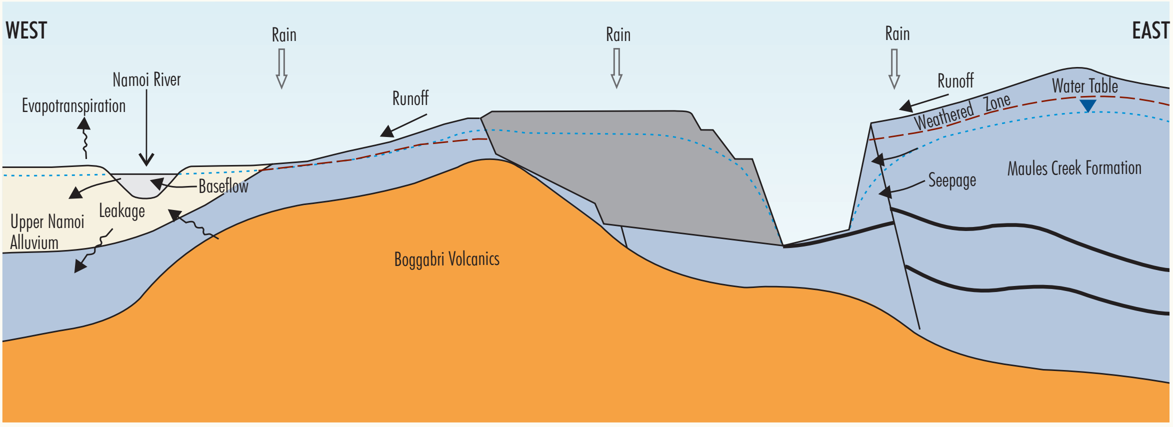


Figure A-28b. Distribution of pH in Groundwater



Conceptual Groundwater Model - Pre-Mining



Conceptual Groundwater Model - Towards the End of Mining

LEGEND

- ☐ Upper Namoi Alluvium
- ▨ Maules Creek Formation
- 🟧 Boggabri Volcanics

*Not to Scale*

**VICKERY COAL PROJECT**

**FIGURE A-29**

Conceptual Groundwater Models -
Pre-mining and During Mining

| INDICATIVE THICKNESS (m) | LAYER | | LITHOLOGY | NORTH | | | SOUTH | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Maules Creek Mine | Boggabri Mine | Tarrawonga Mine | Vickery and Vickery South Mines | Canyon Mine | Rocglen Mine | |
| 30 | 1 | 🟨 | **Alluvium or Regolith** | | | | | | | Narrabri Formation, Maules Ck Fm, Boggabri Volcanics |
| 70 | 2 | 🟧 | **Alluvium or Overburden** | | | | | | | Gunnedah Formation, Maules Ck Fm, Boggabri Volcanics |
| 15 | 3 | 🟨 | **Overburden** | 🟧 | | | | | | Maules Ck Fm |
| 20 | 4 | ◼ | **Braymont Seam to Jeralong Seam** | 🟧 | 🟧 | 🟧 | | | | Braymont, Bollol Creek, Jeralong Upper & Lower Seams |
| 10 | 5 | 🟨 | **Interburden** | 🟧 | 🟧 | 🟧 | | | | Maules Ck Fm |
| 15 | 6 | ◼ | **Merriown Seam to Velyama Seam** | 🟧 | 🟧 | 🟧 | | | | Merriown Upper and Lower, Velyama Seams |
| 5 | 7 | 🟨 | **Interburden** | 🟧 | | 🟧 | | | | Maules Ck Fm |
| 2 | 8 | ◼ | **Nagero Upper Seam** | 🟧 | | 🟧 | | | | Nagero Upper Seam |
| 35 | 9 | 🟨 | **Interburden** | 🟧 | | | | | | Maules Ck Fm & Nagero Lower Seam |
| 90 | 10 | ◼ | **Northam Seam to Templemore Seam. Tralee Seam to Stratford Seam.** | 🟧 | | | 🟧 | | 🟧 | Northam, Therribri, Flixton, Tarrawonga, Templemore Seams in north. Tralee, Gundawarra, Kurrumbede, Shannon Harbour, Stratford seams in south. Roseberry, Glenroc and Belmont Seams in southeast |
| 20 | 11 | 🟨 | **Interburden** | | | | 🟧 | | | Maules Ck Fm |
| 70 | 12 | ◼ | **Bluevale Seam to Cranleigh Seam (Whitehaven Seam)** | | | | 🟧 | 🟧 | | TAK, KAZ, JN, JR seams in north. Bluevale (3 Splits), Cranleigh Seams in south. |
| 40 | 13 | 🟨 | **Underburden** | | | | | | | Laird and Goonbri Formations |
| 50 | 14 | 🟦 | **Volcanics** | | | | | | | Boggabri Volcanics |
| | | | | Herndale Seam to Templemore Seam | Braymont Seam to Merriown Seam | Braymont Seam to Nagero Upper Seam | Tralee, Gundawarra, Kurrumbede, Shannon Harbour, Stratford, Bluevale and Cranleigh | Whitehaven Seam (Cranleigh and Bluevale) | Tarrawonga (Glenroc) Seam to Templemore (Belmont) Seam | |

Figure A-30. Numerical Model Layers

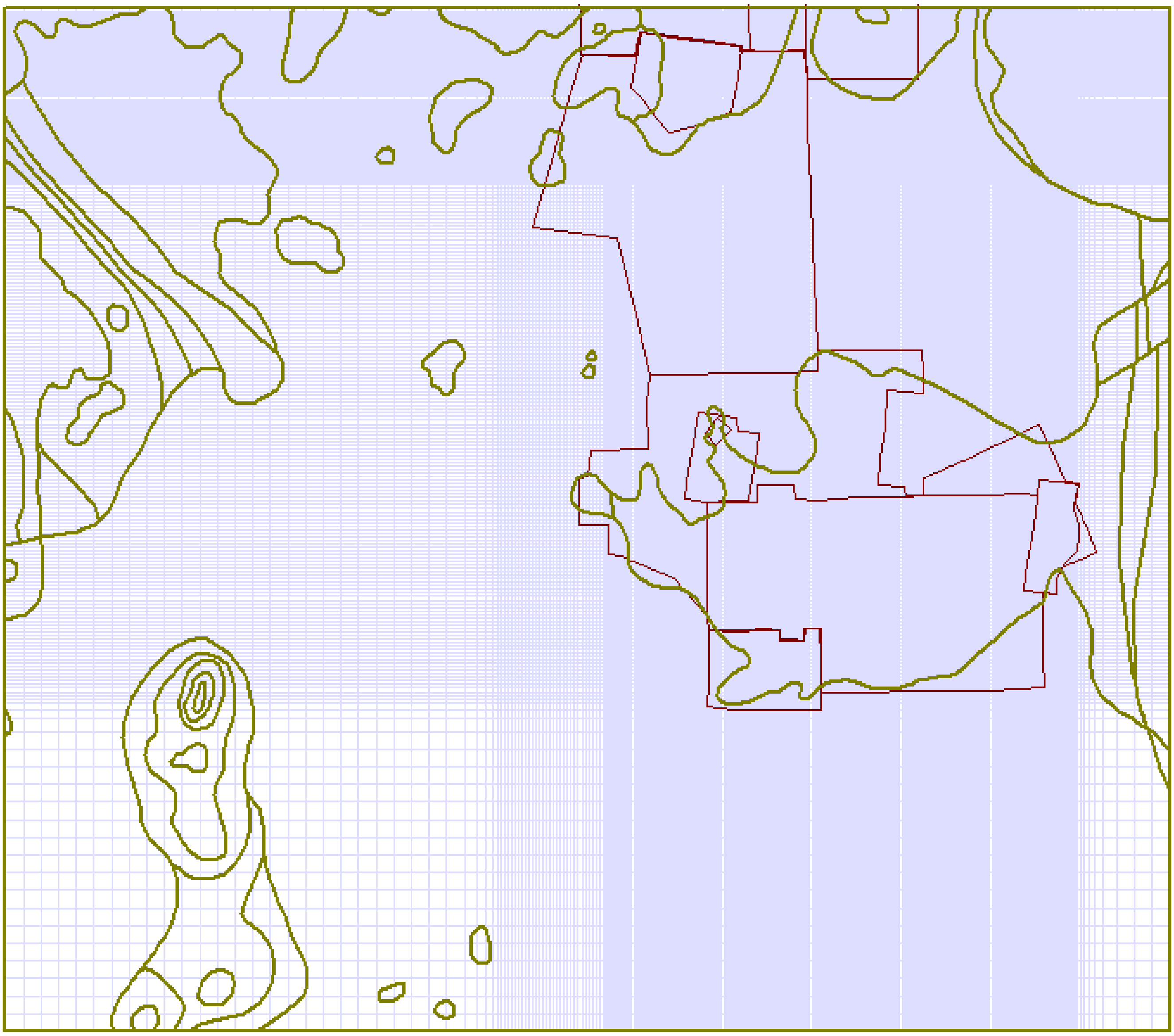


Figure A-31. Model Grid with Geological Boundaries and Mine Leases [cell dimension 50-500m]

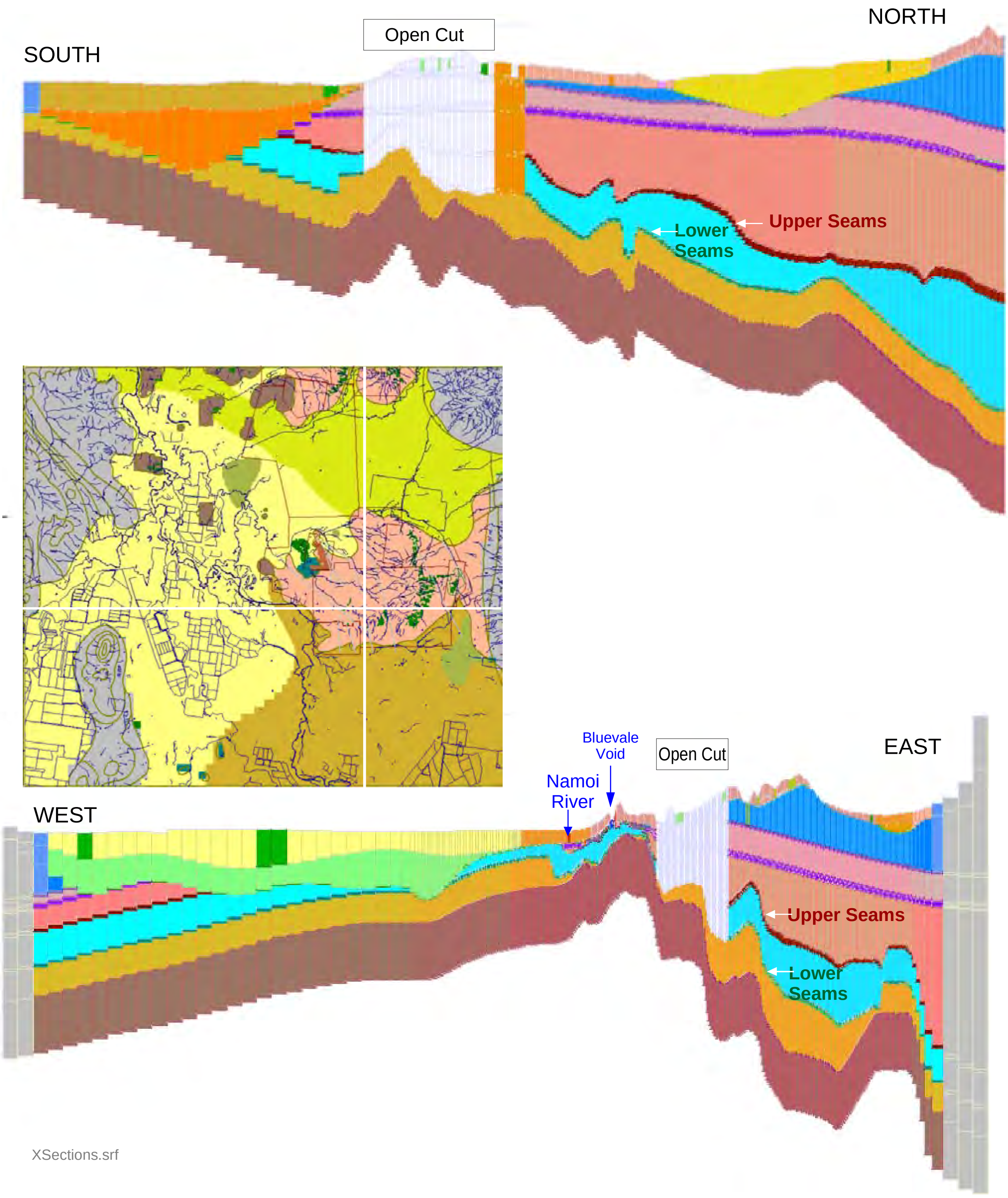


Figure A-32. Representative Model Cross-sections through Vickery Coal Mine at Easting 232500 and Northing 6592100

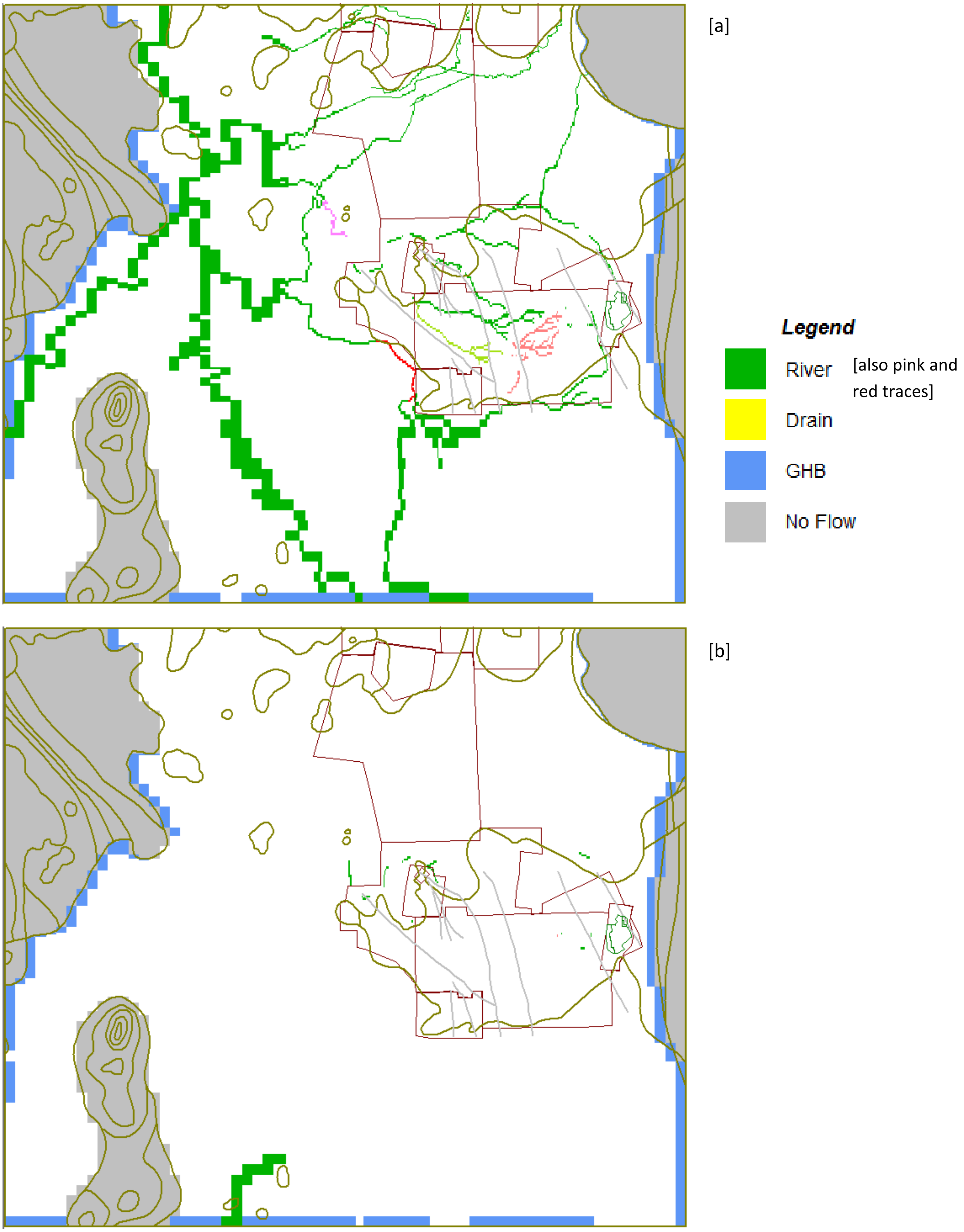


Figure A-33. Model Boundary Conditions:
[a] Layer 1
[b] Layer 2

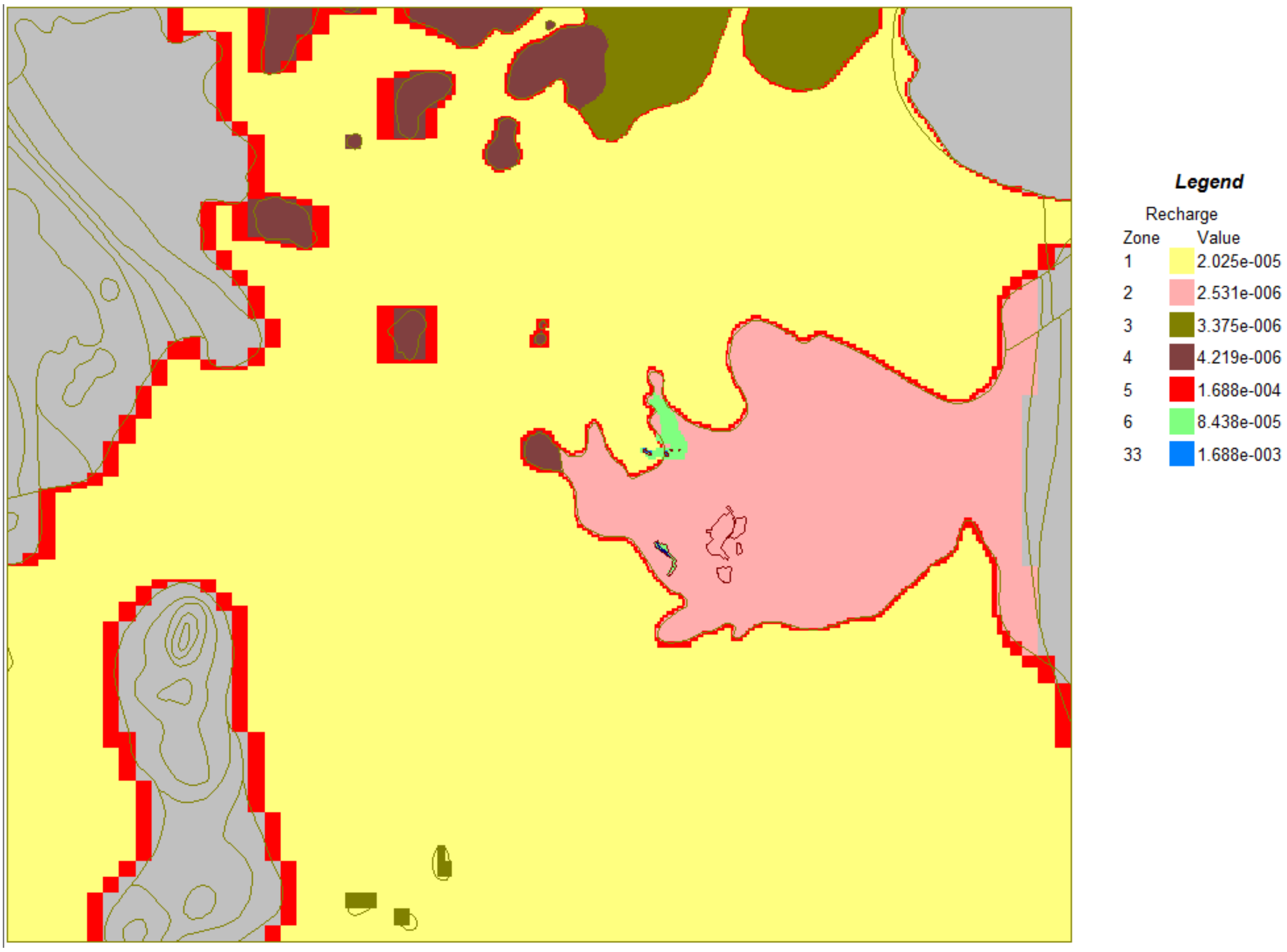


Figure A-34. Rainfall Recharge Distribution and Rates [m/day]

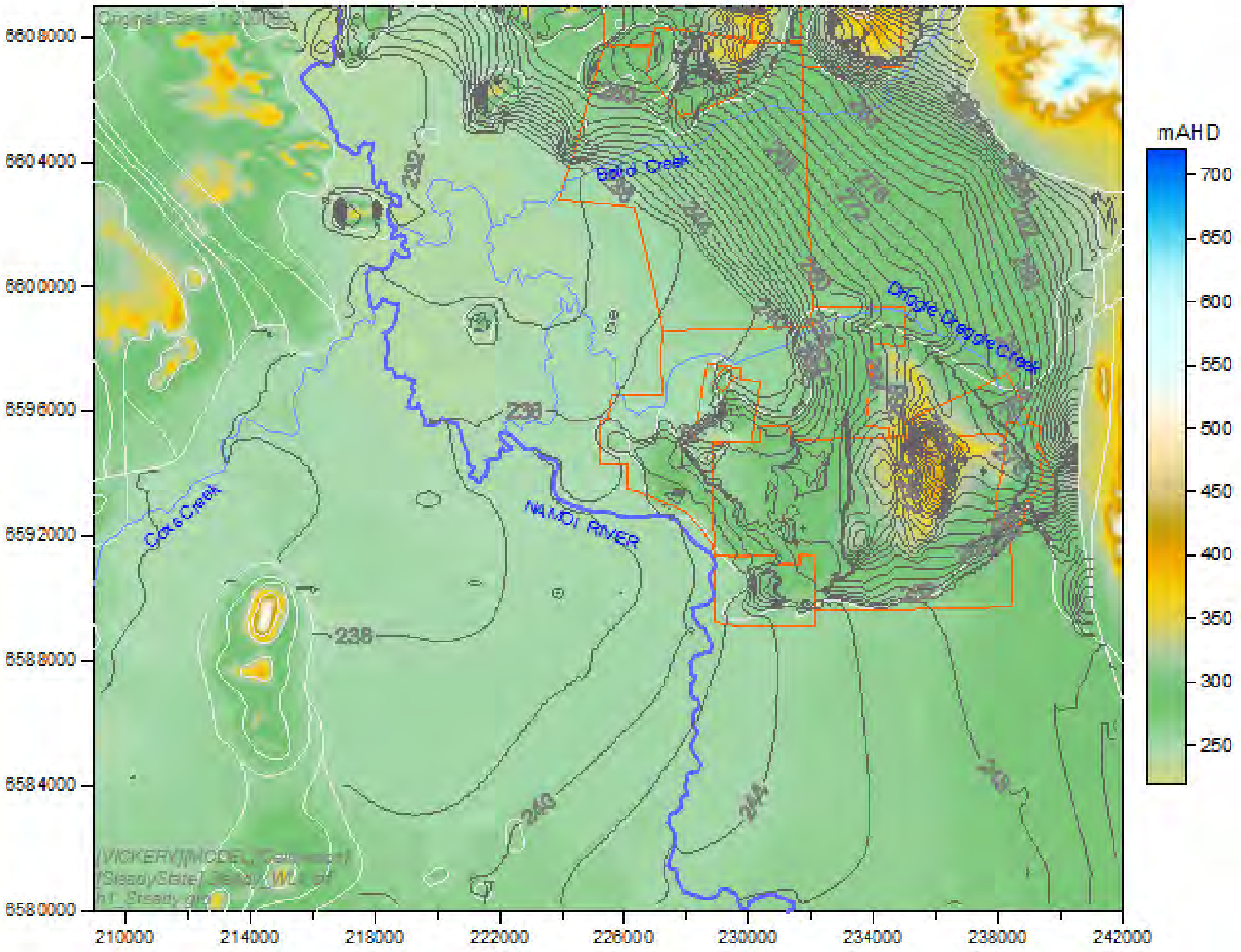


Figure A-35. Simulated Steady State Watertable Contours [mAHD] with Topography Underlay

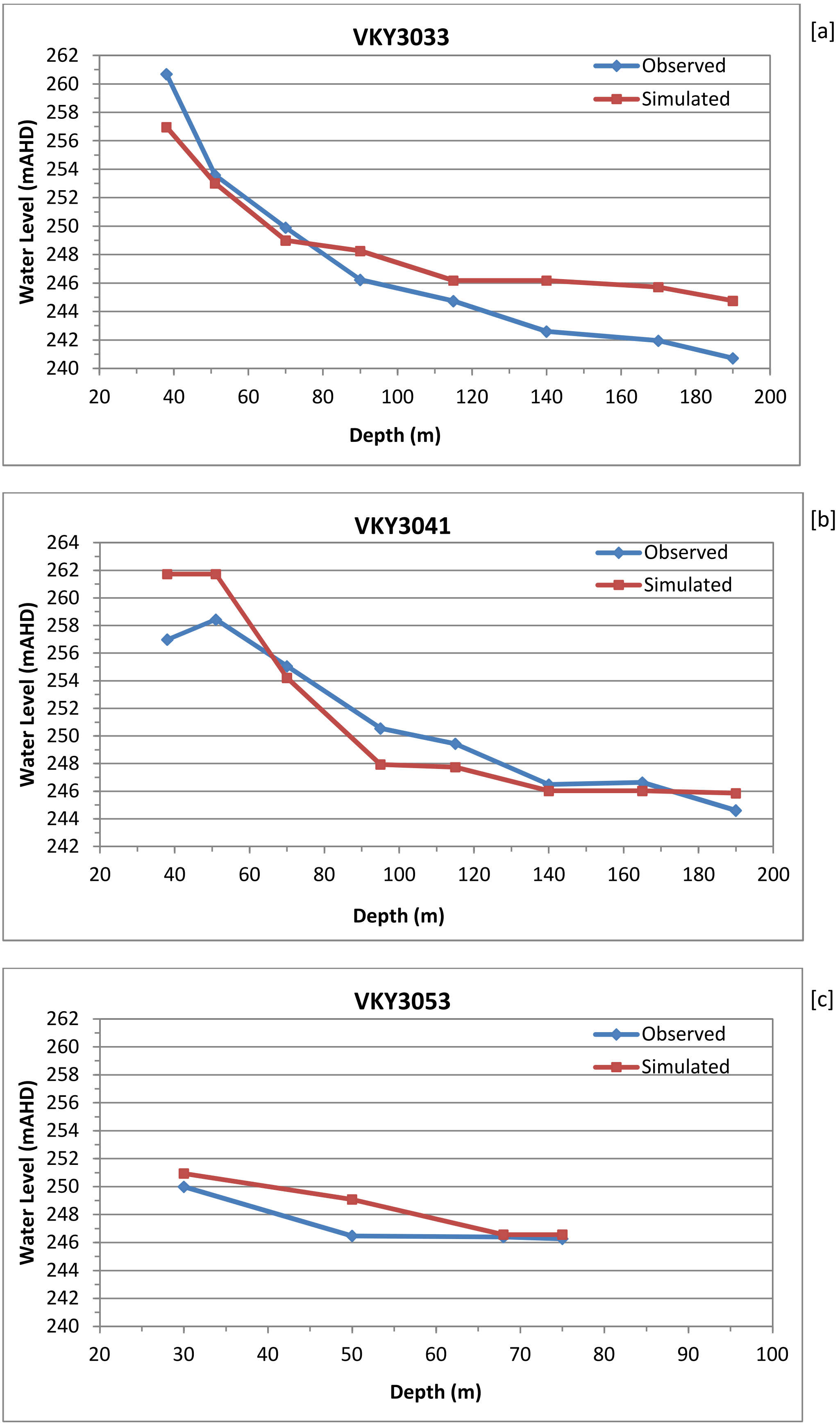


Figure A-36. Simulated and Observed Vickery Vertical Head Profiles:

[a] Bore VKY3033

[b] Bore VKY3041

[c] Bore VKY3053

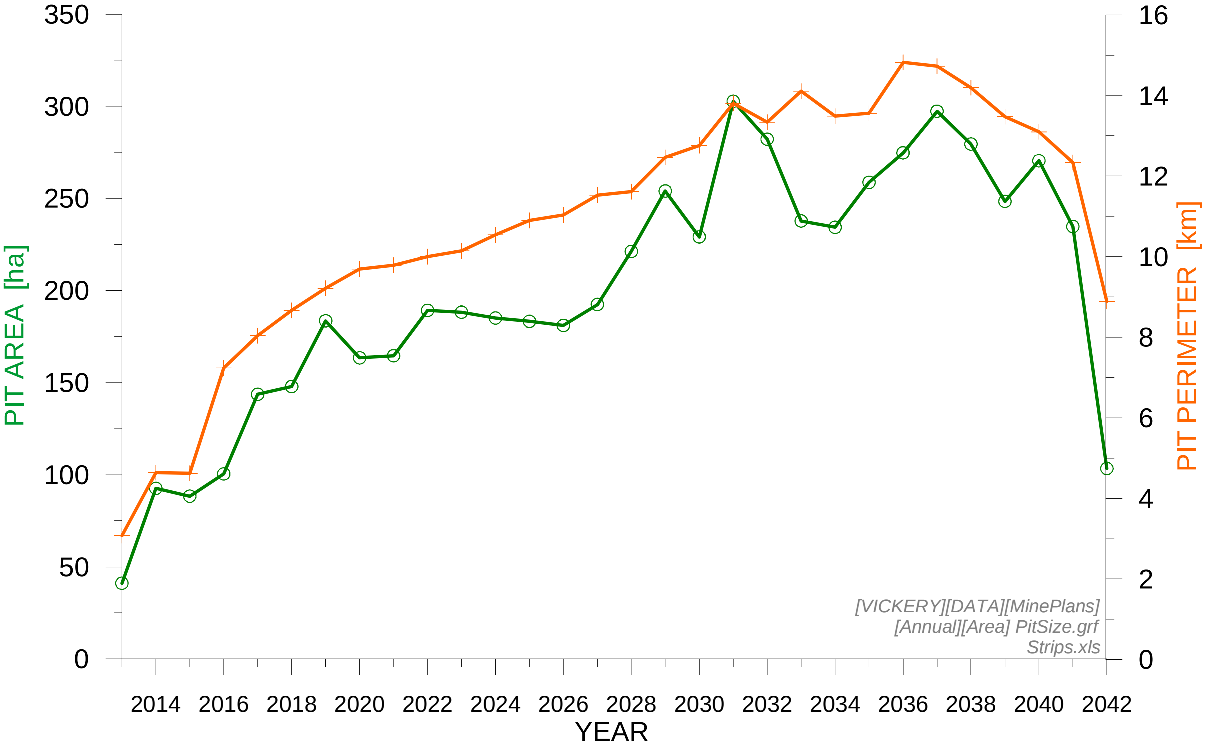


Figure A-37. Estimated Area and Perimeter of Annual Pit Stages

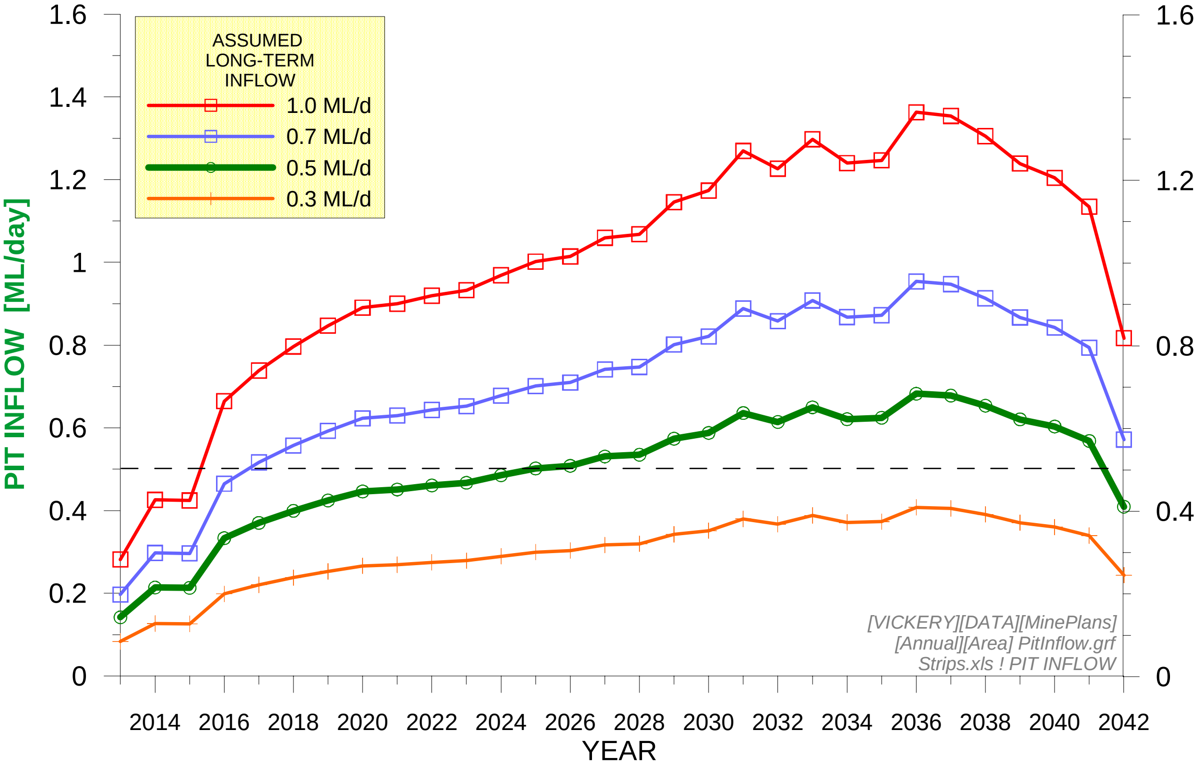


Figure A-38. Estimated Pit Inflow Variability

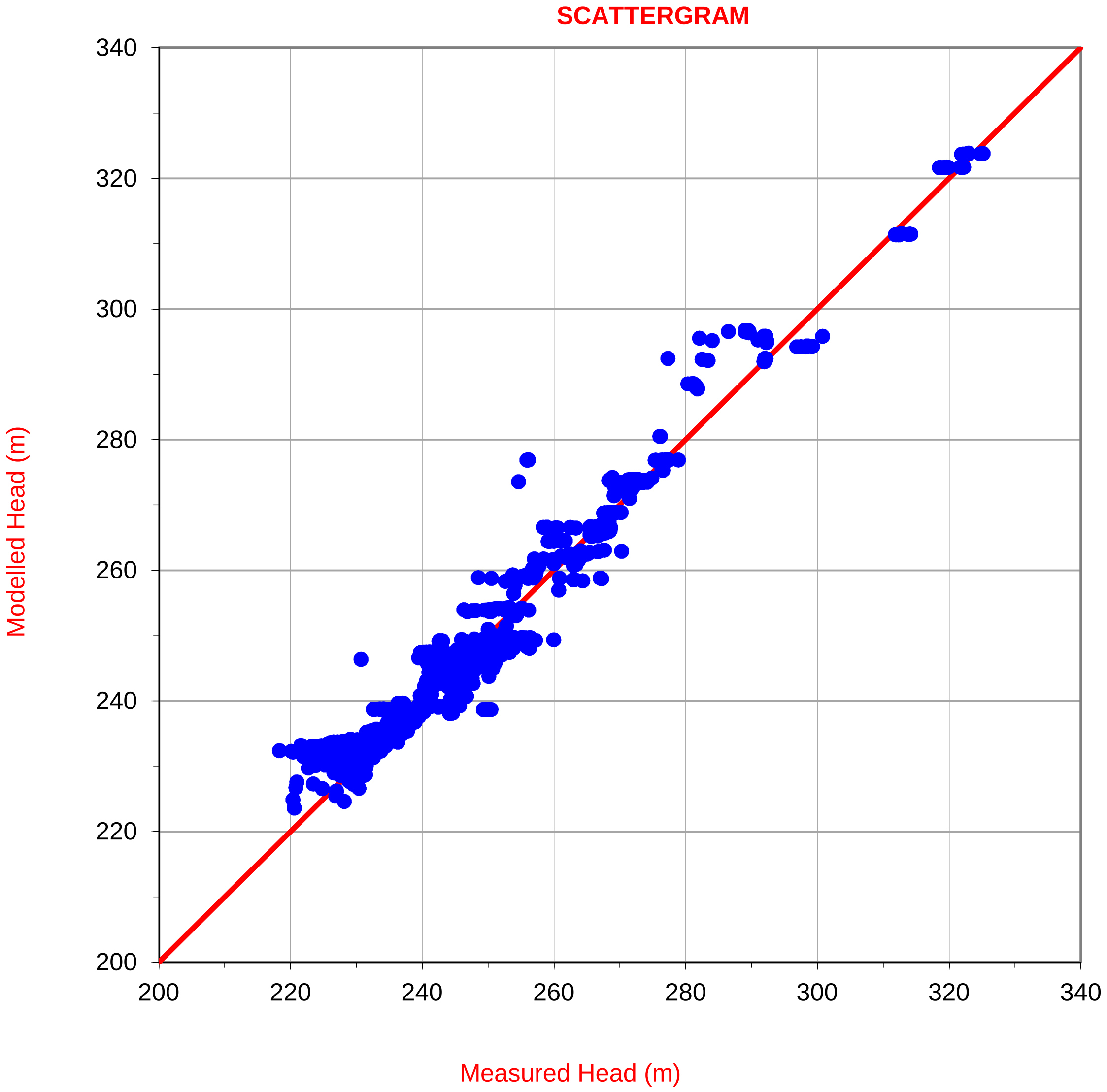


Figure A-39. Scattergram of Simulated and Measured Heads for Transient Calibration

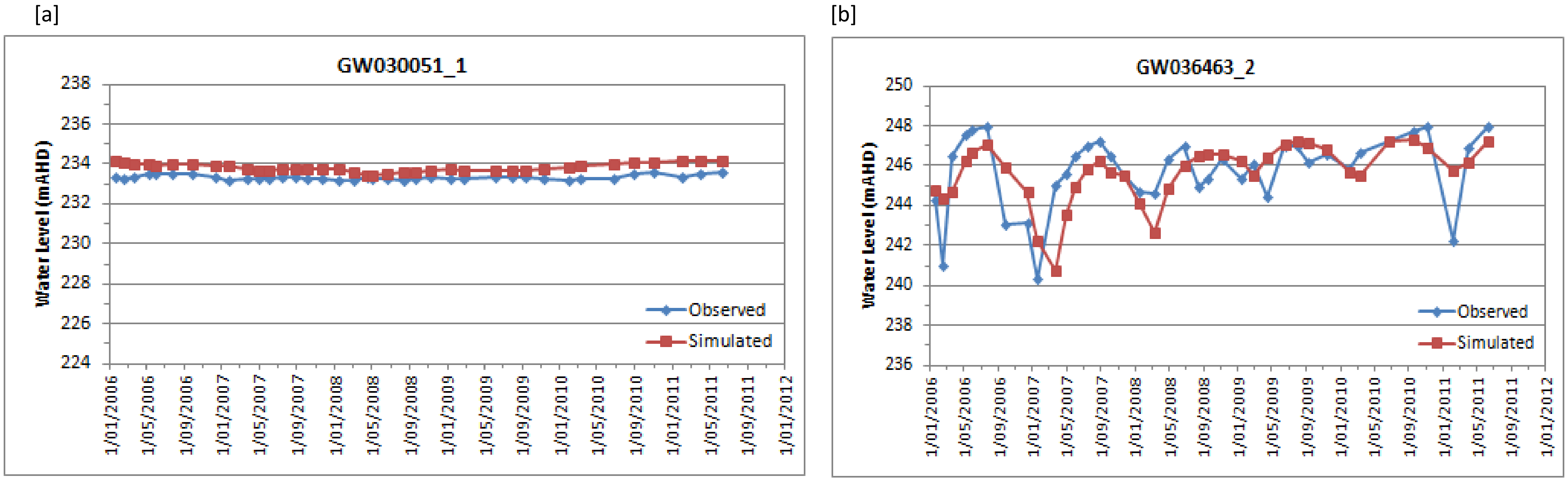


Figure A-40. Representative Simulated and Observed NOW Zone 4 Hydrographs:
[a] Bore 30051_1 (3 km north-west of Canyon Mine)
[b] Bore 36436_2 (8 km south of Project)

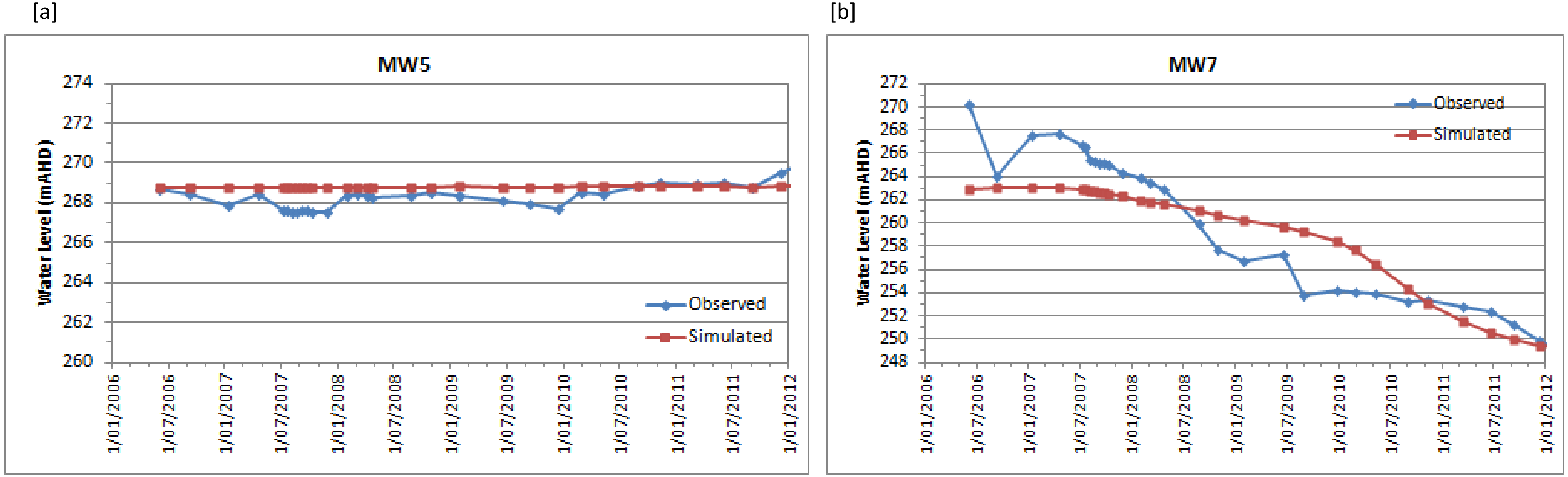


Figure A-41. Representative Simulated and Observed Tarrawonga Hydrographs:

[a] Screened in Alluvium

[b] Screened in Interburden

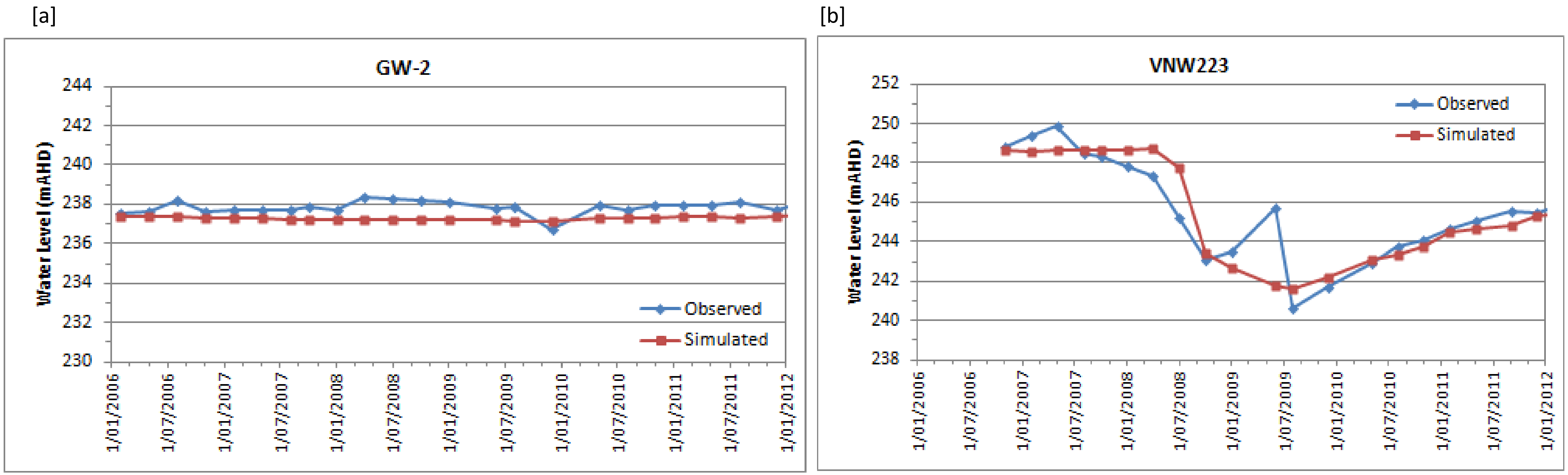


Figure A-42. Representative Simulated and Observed Canyon Hydrographs:

[a] Bore GW-2 (north of Canyon Mine)

[b] Bore VNW223 (northern edge of Canyon void)

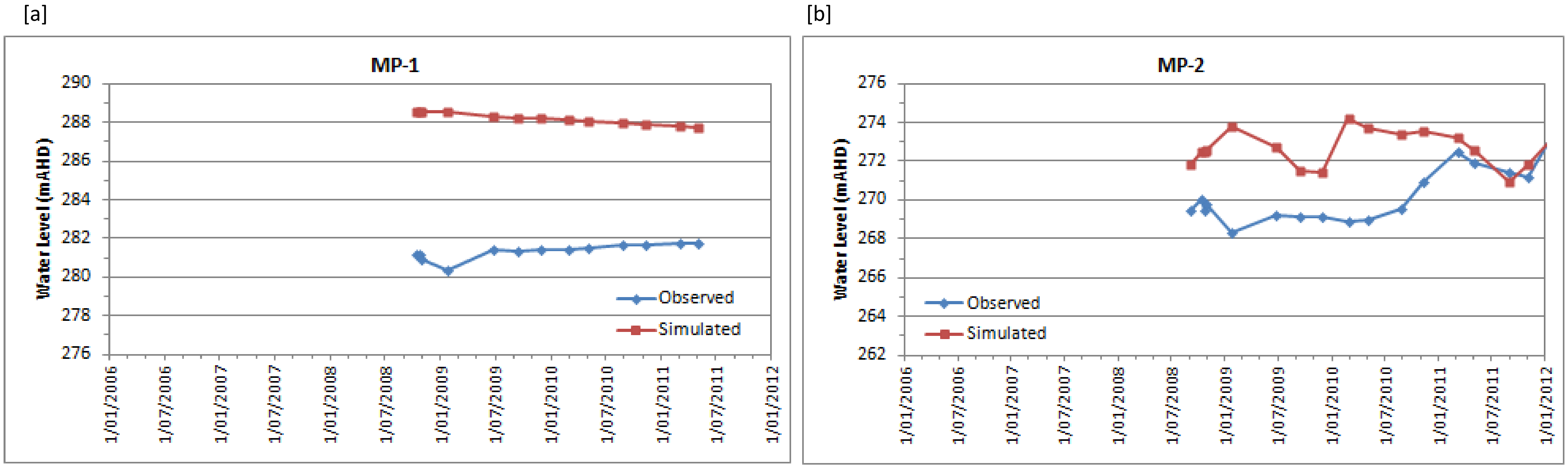


Figure A-43. Representative Simulated and Observed Rocglen Hydrographs:

[a] Bore MP-1 (north of Rocglen Mine)

[b] Bore MP-2 (south of Rocglen Mine)

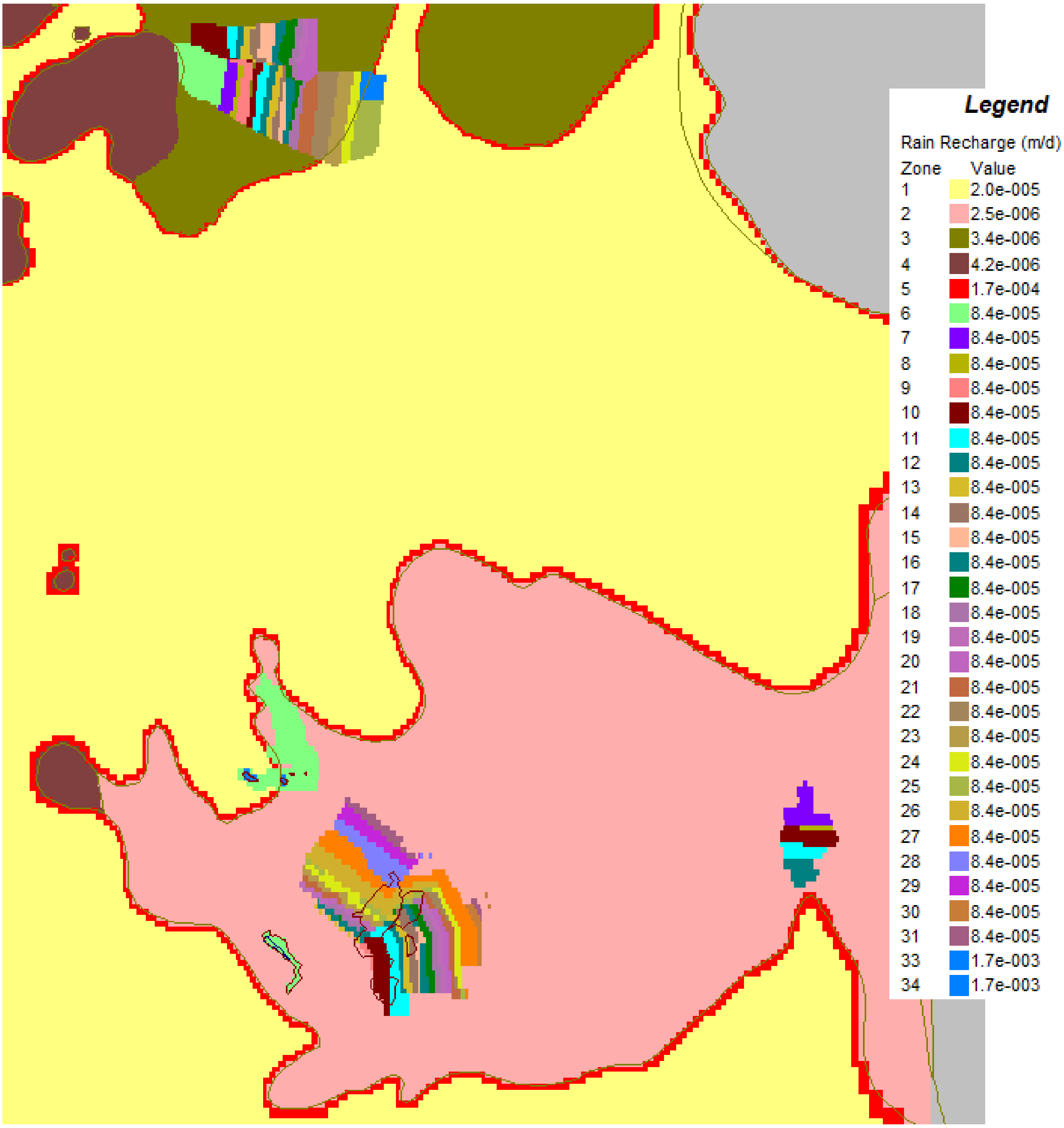


Figure A-44. Pit Sequencing and Applied Rainfall Recharge Rates at the End of the Predictive Simulation

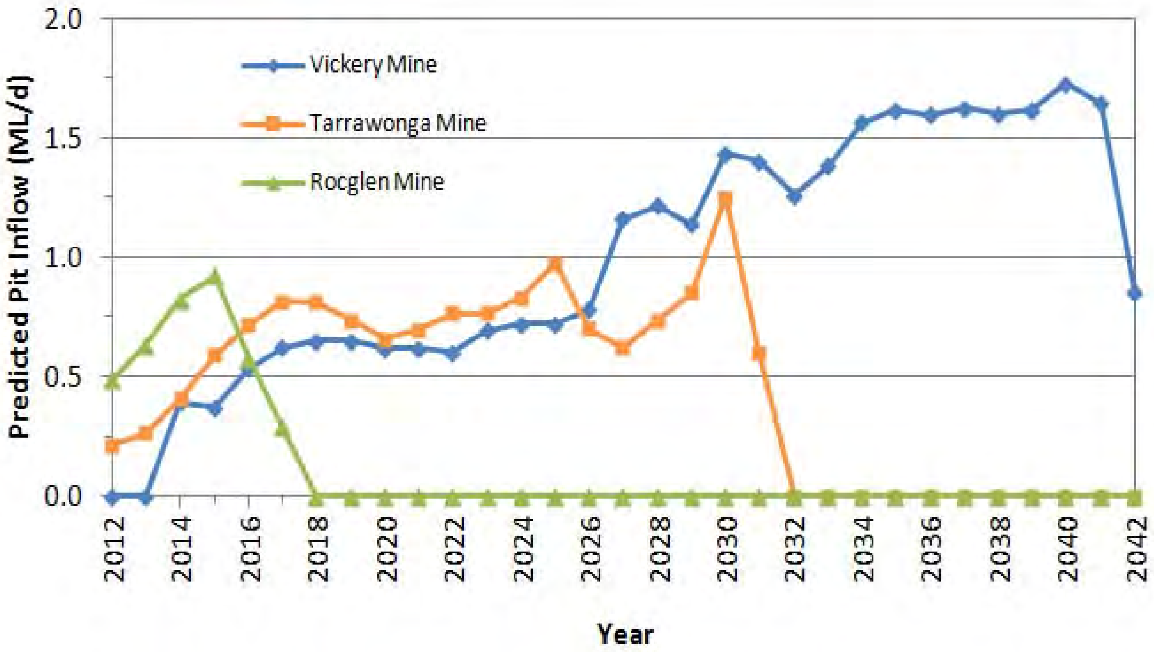


Figure A-45. Simulated Pit Inflow at All Mines from 2012 to 2042.

[The inflows are annual average rates and the year ticks refer to June of each year]

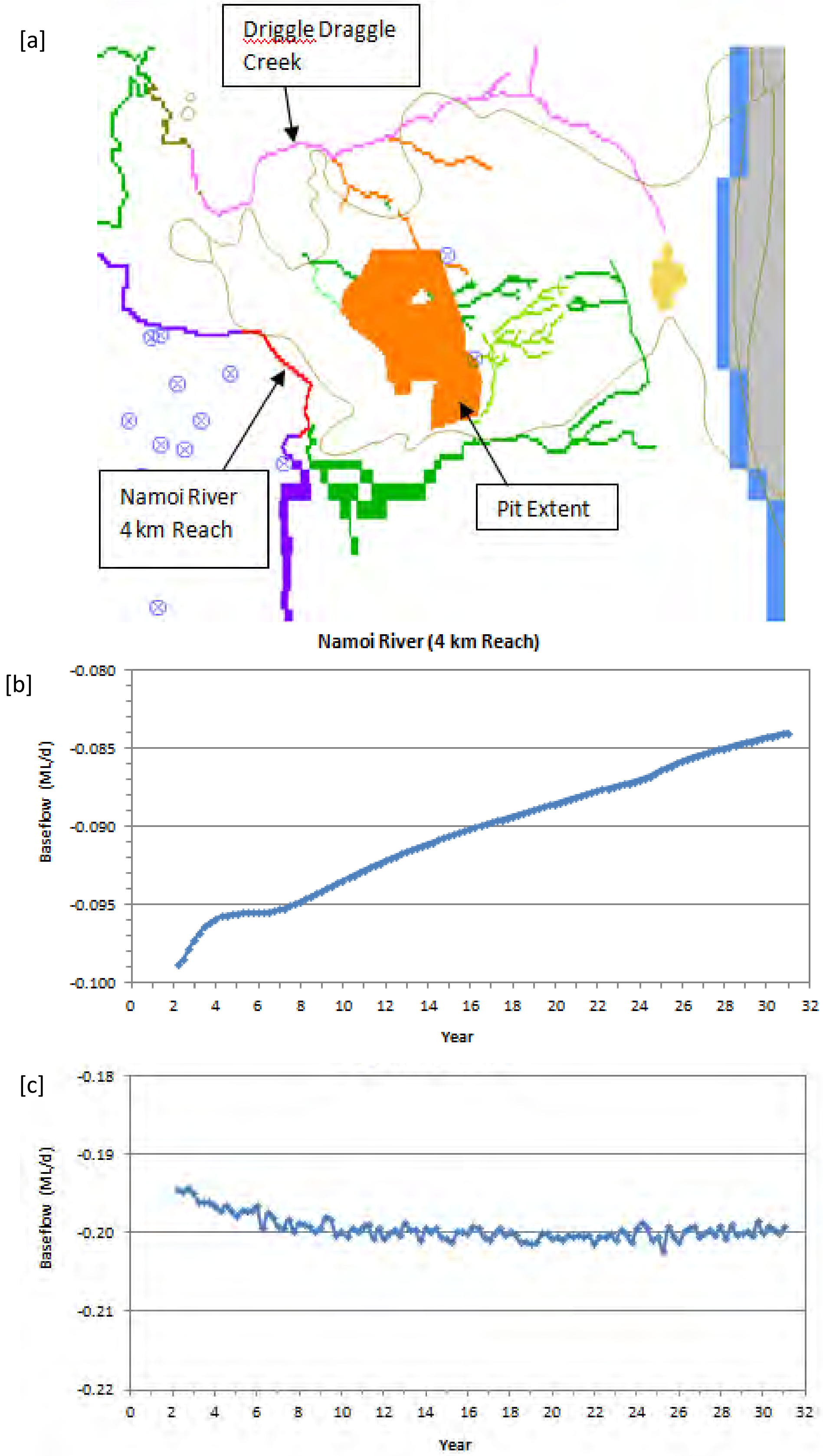


Figure A-46. Simulated Stream Baseflow:
[a] Reach Definition
[b] Namoi River
[c] Driggle Draggle Creek

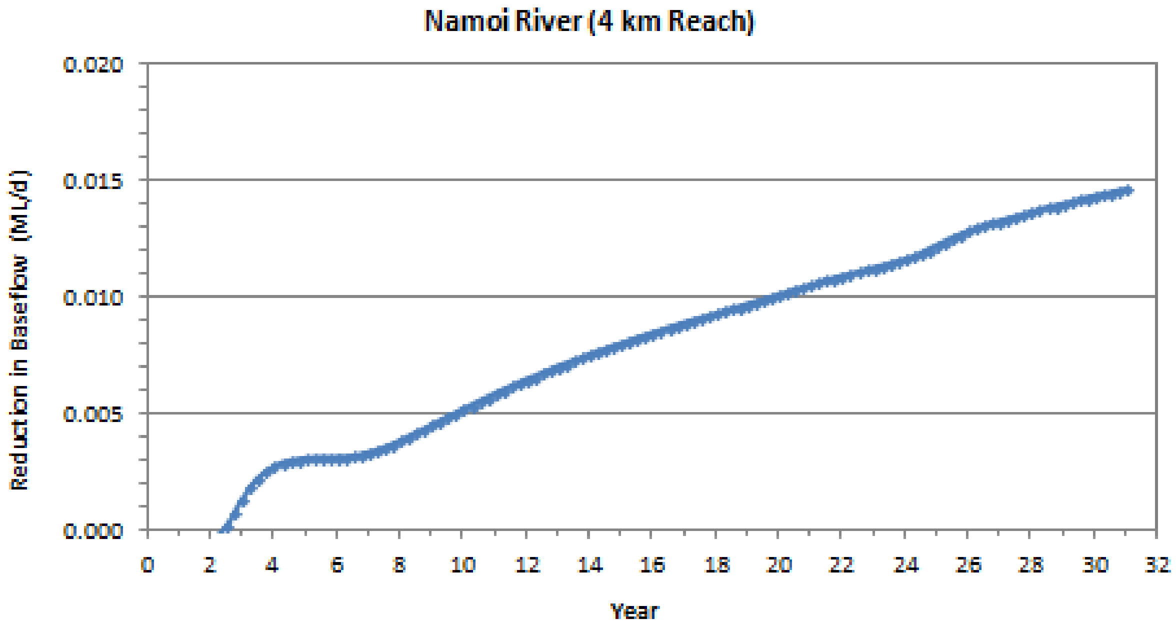


Figure A-47. Predicted Reduction in Baseflow along a 4km Reach of the Namoi River

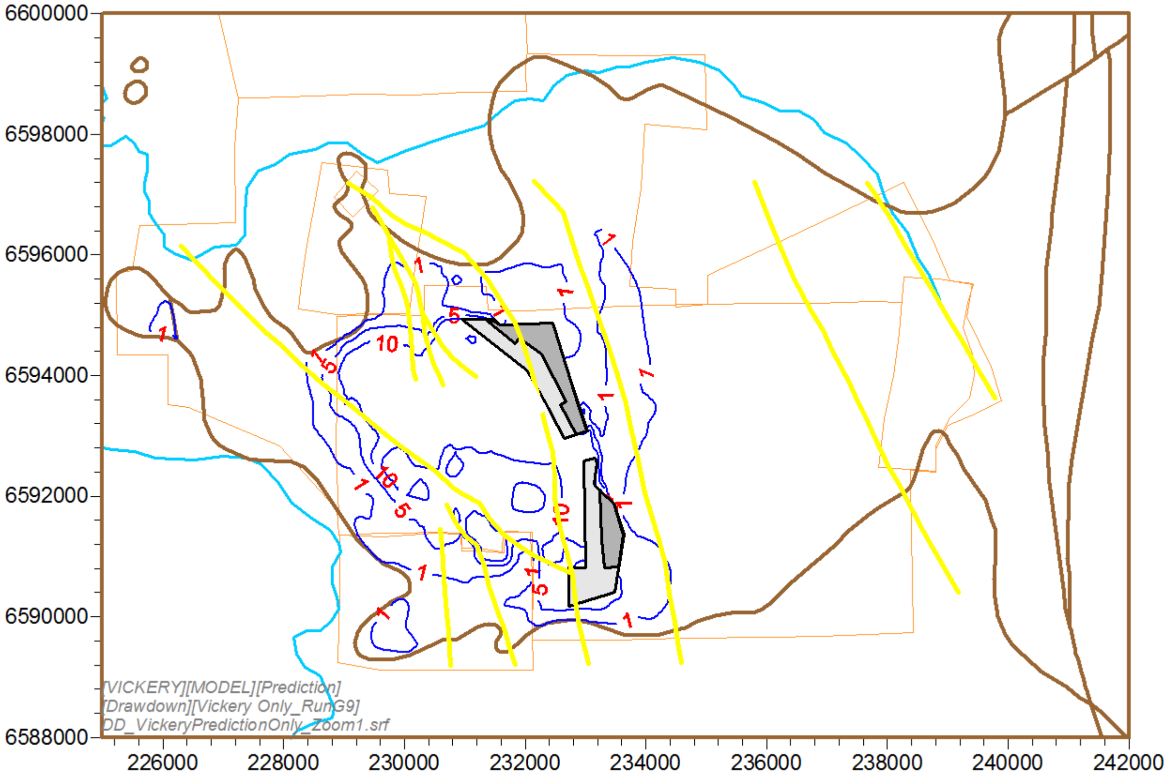


Figure A-48. Simulated Drawdown in Regolith/Alluvium at the end of the mine life for the Project-only scenario [m]

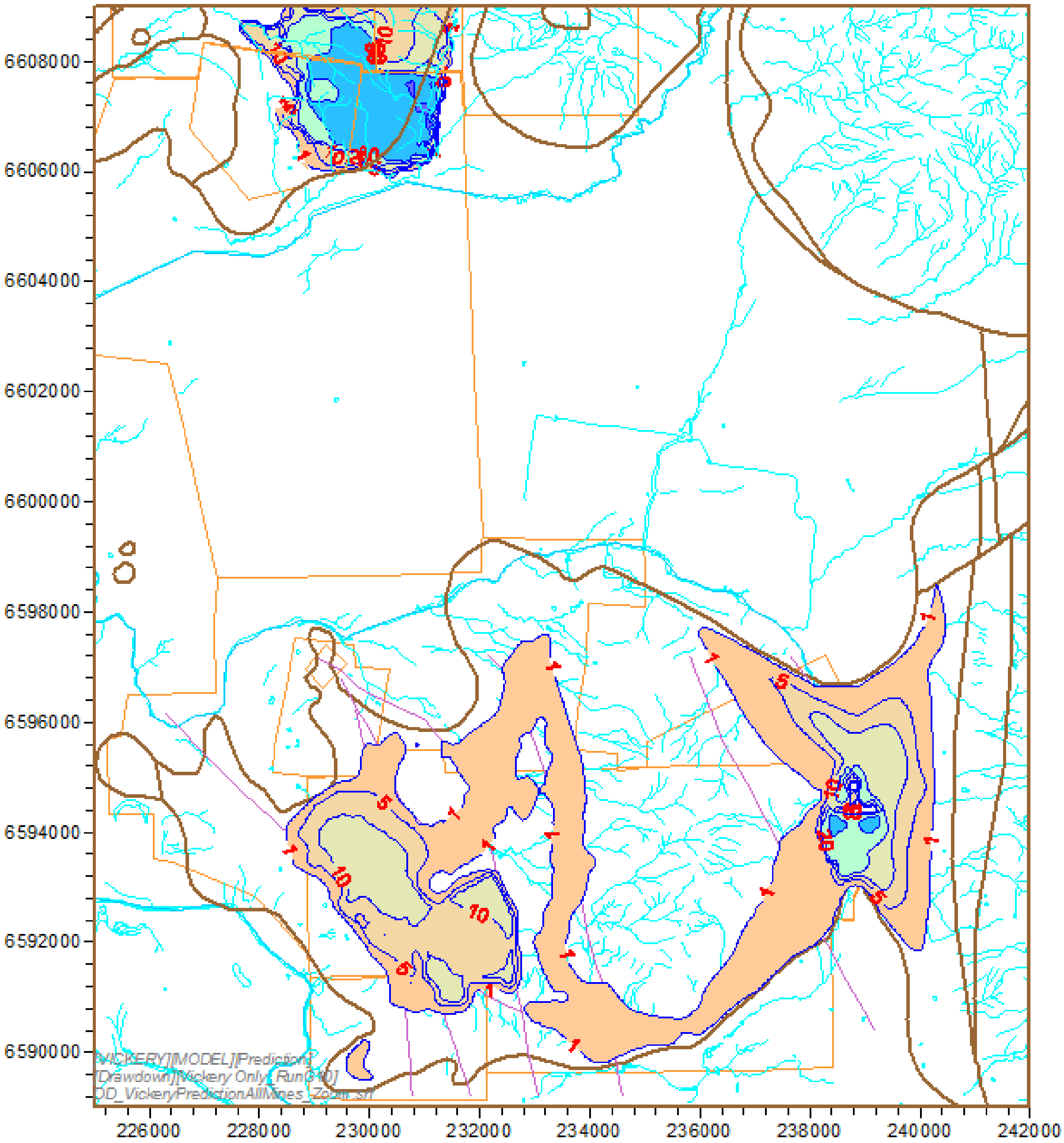


Figure A-49. Simulated Drawdown in Regolith/Alluvium at Project Year 17 for the cumulative scenario [m]

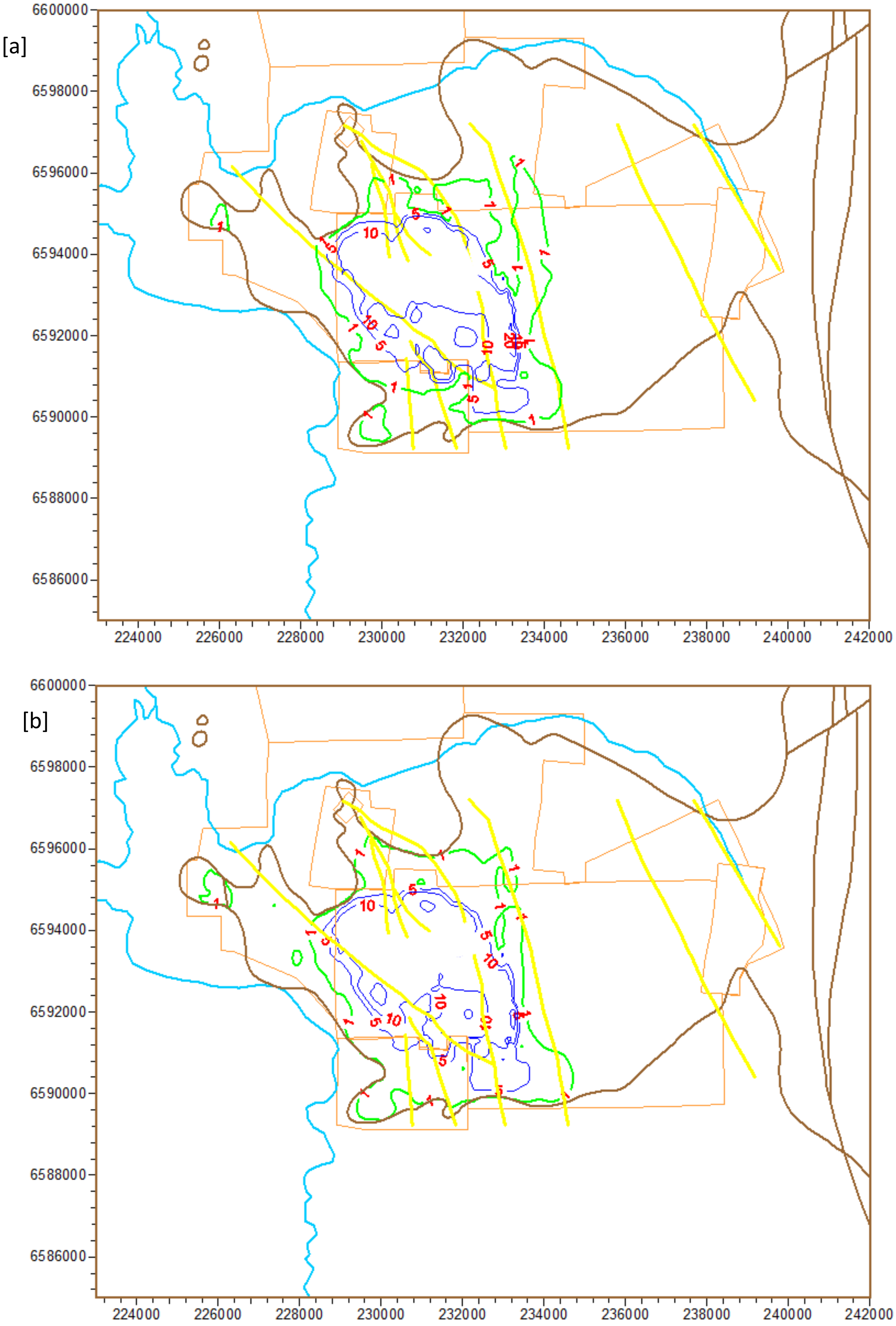


Figure A-50. Simulated Drawdown [m] in Regolith/Alluvium at the End of the Mine Life for the Project-only Scenario:

[a] Low Irrigation Pumping (Base Case)

[b] High Irrigation Pumping

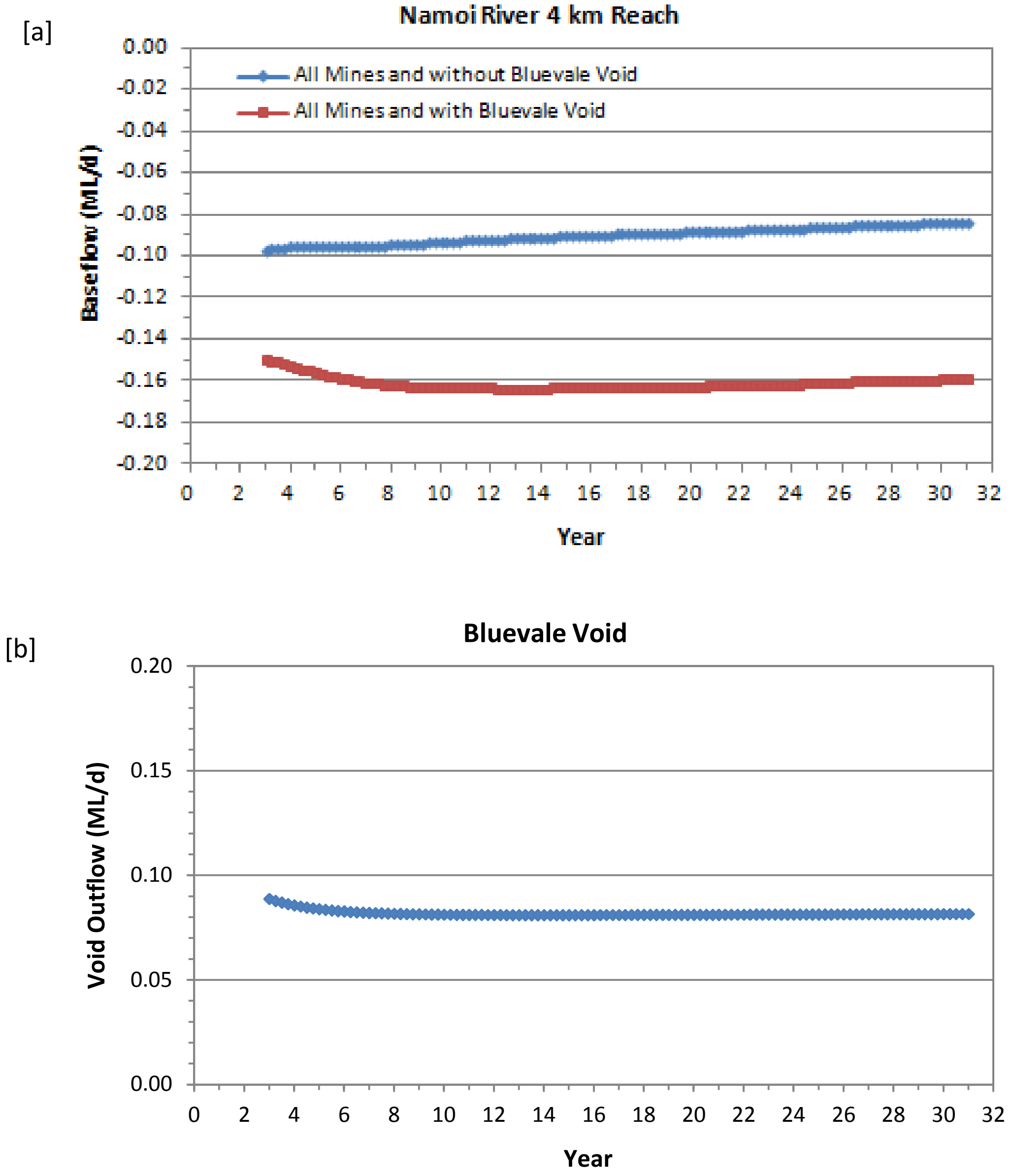


Figure A-51.

[a] Simulated Stream Baseflow Comparison with and without the Blue Vale Void Water Storage

[b] Blue Vale Void Outflow

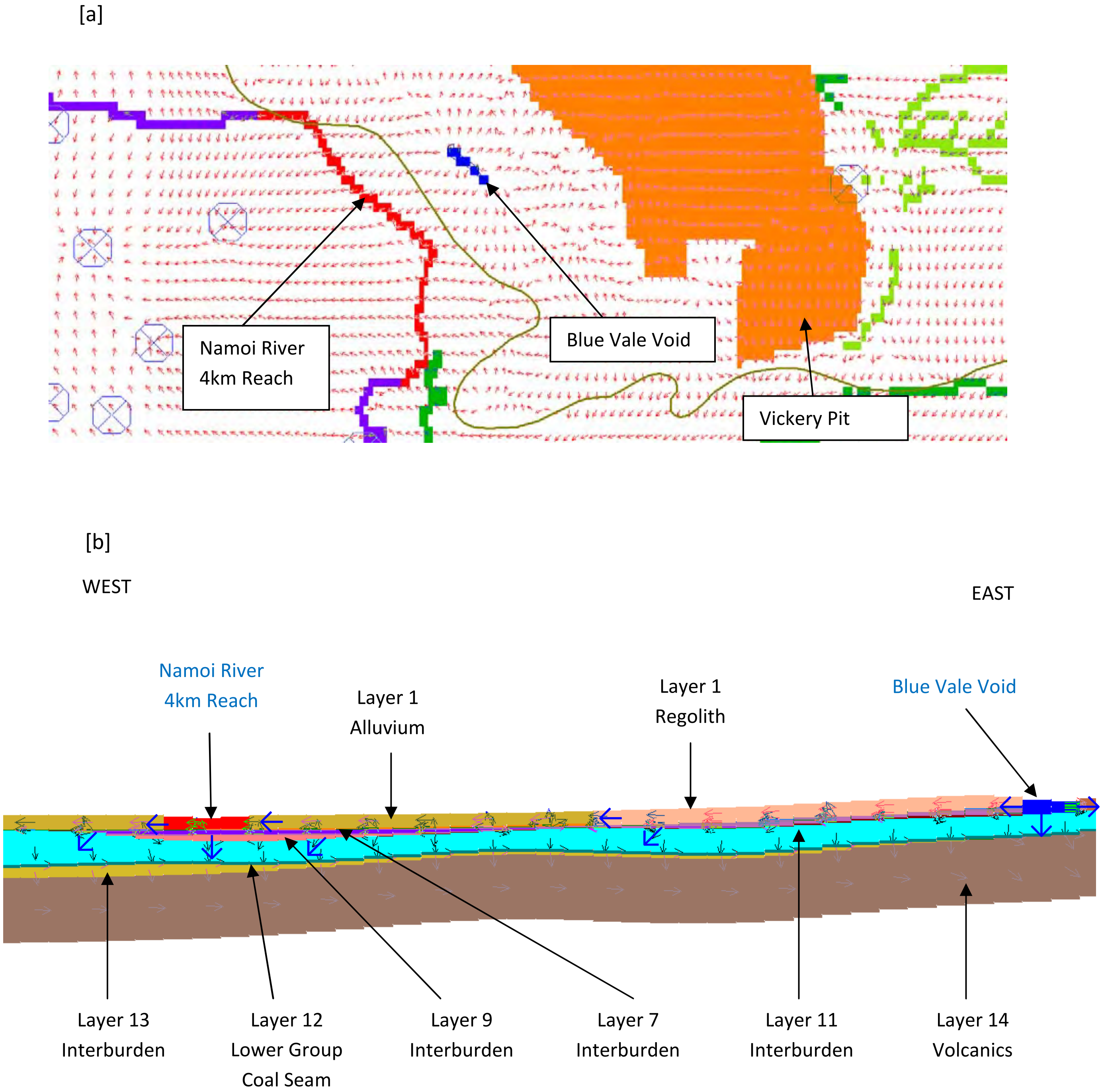
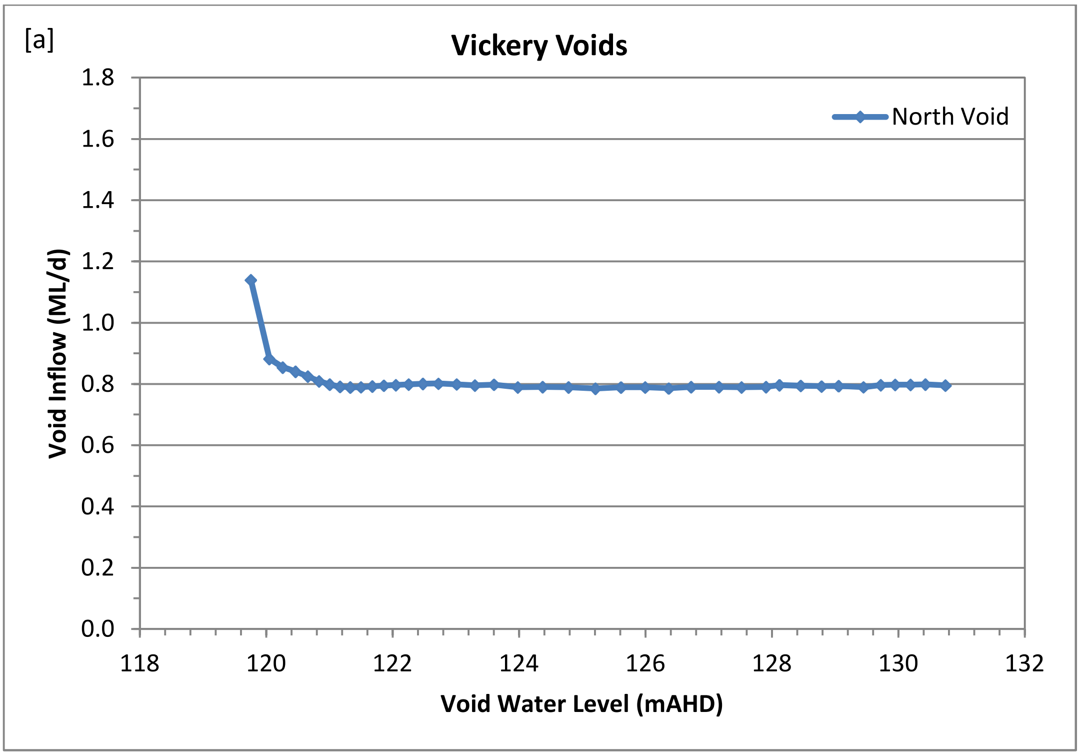


Figure A-52.
[a] Plan View of Seepage Flow Directions from Blue Vale Void to Namoi River 4 km Reach
[b] Cross-section through Namoi River and Blue Vale Void at Northing 6591930



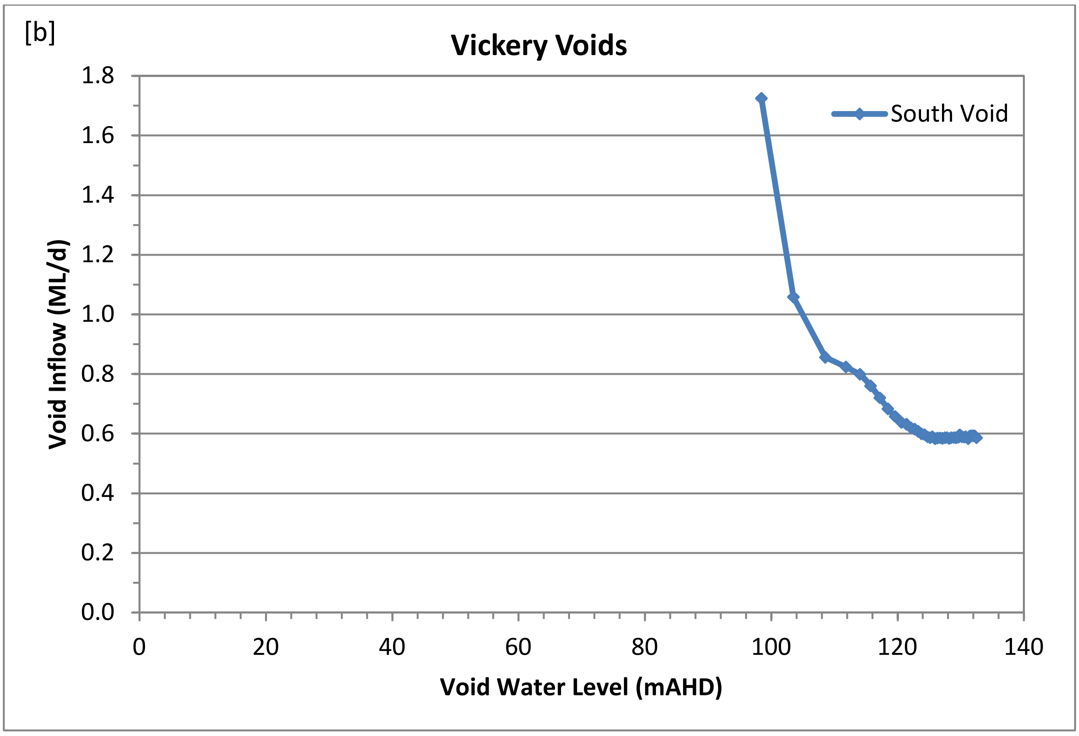


Figure A-53. Final Void Inflow-Stage Curves:
[a] Northern Void
[b] Southern Void

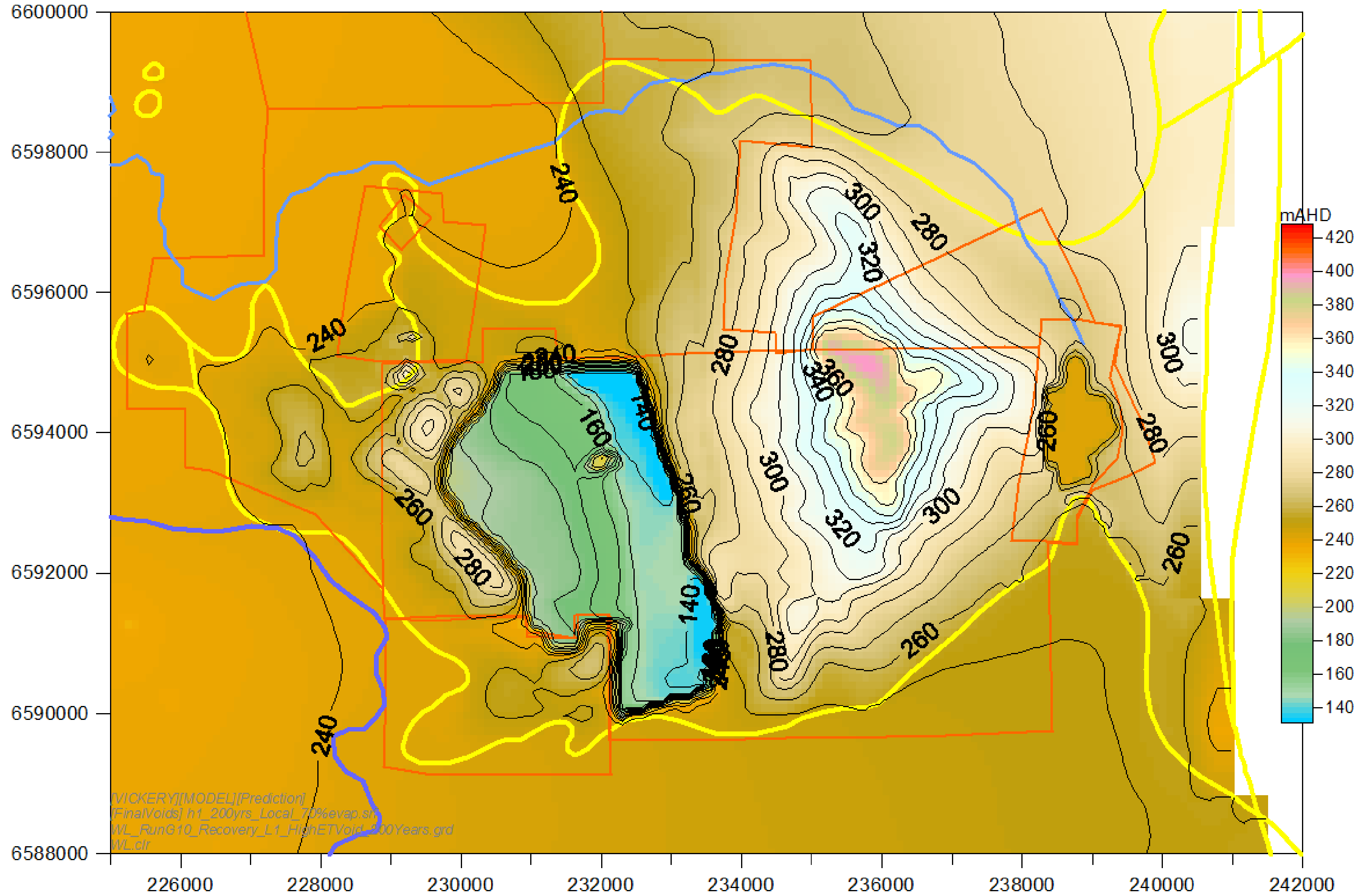


Figure A-54. Predicted Groundwater Level (Potentiometric) Contours in Regolith/Alluvium after 200 Years [mAHD]

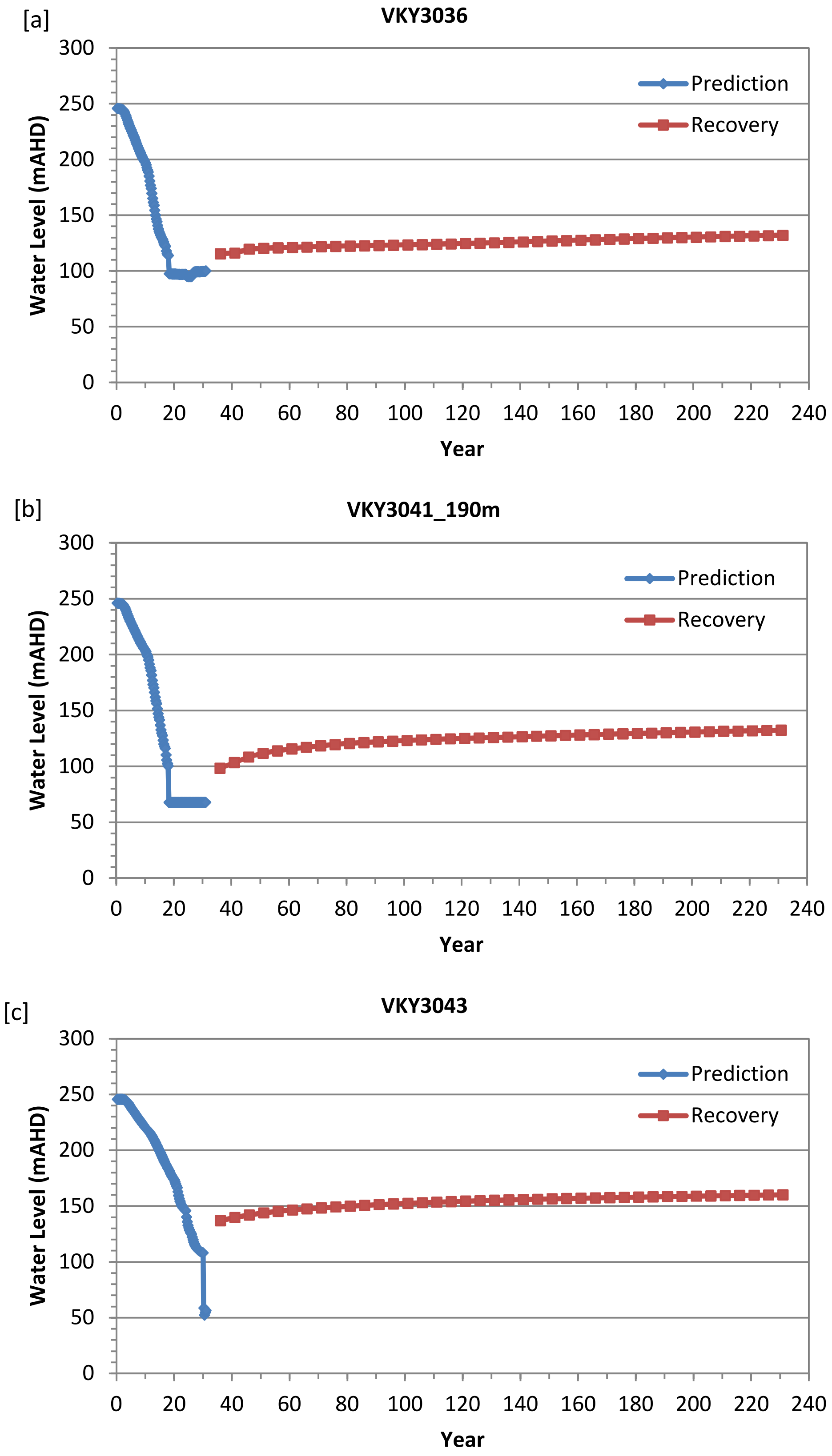


Figure A-55. Prediction and Recovery Hydrographs at Representative Vickery Monitoring Bores:
[a] VKY3036 at ~112 m Depth
[b] VKY3041 at 190 m Depth
[c] VKY3043 at ~242 m Depth

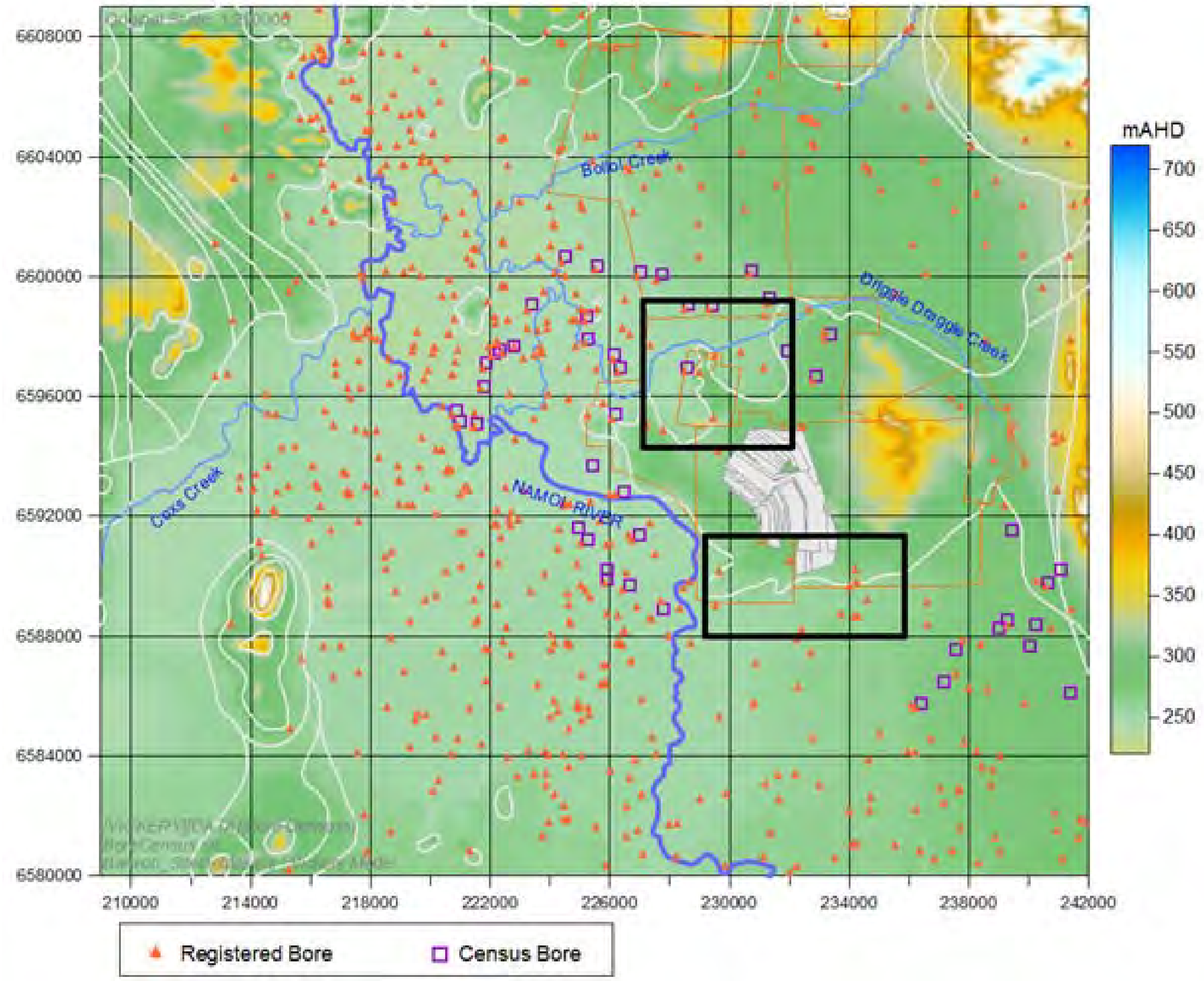


Figure A-56. Alluvial Areas Examined for Possible Enhanced Leakage to Underlying Porous Rock

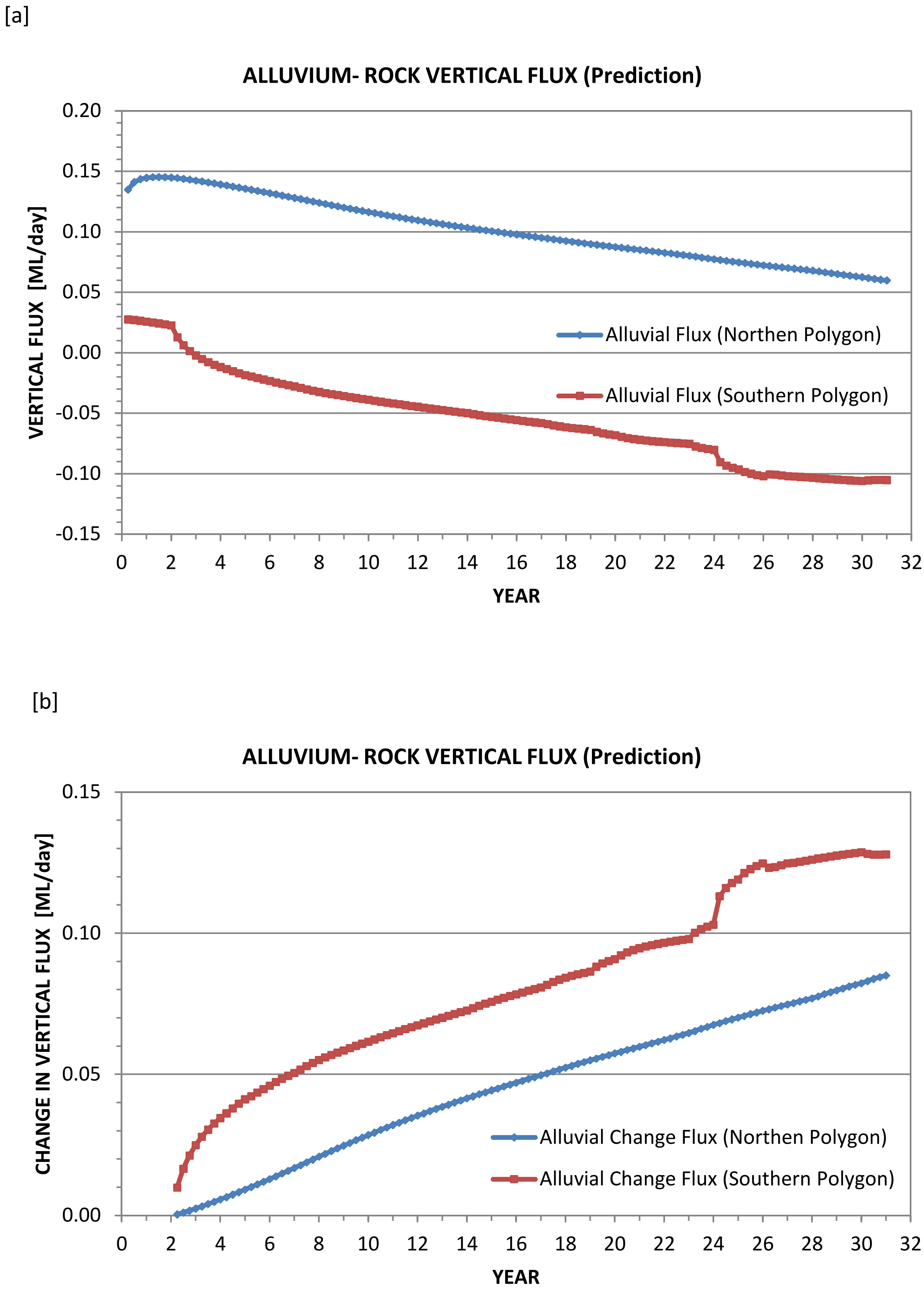
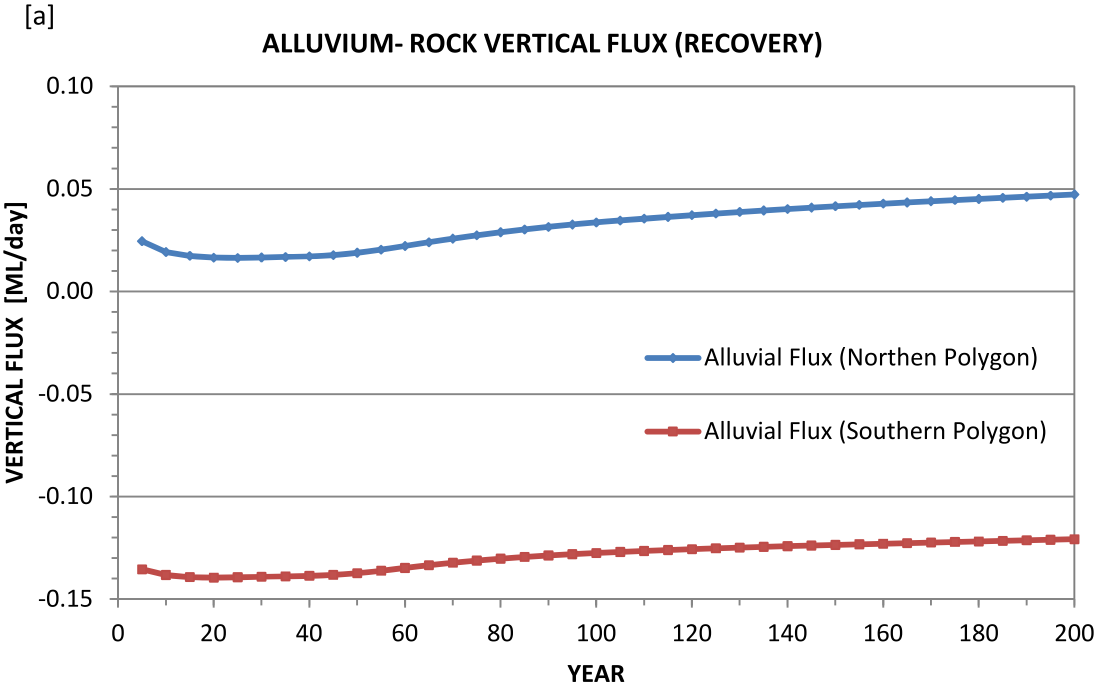


Figure A-57. Predicted Enhanced Leakage from Alluvial Areas to Underlying Porous Rock:
[a] Flux Magnitude (ML/day)
[b] Change in Flux during Project Mining (ML/day)



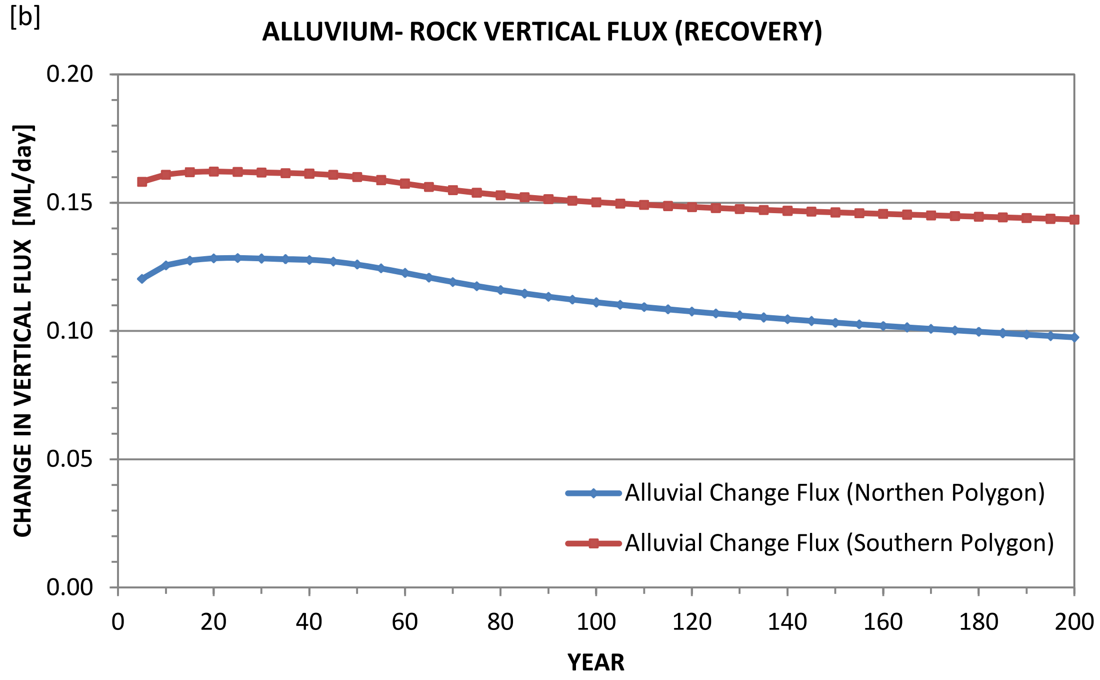
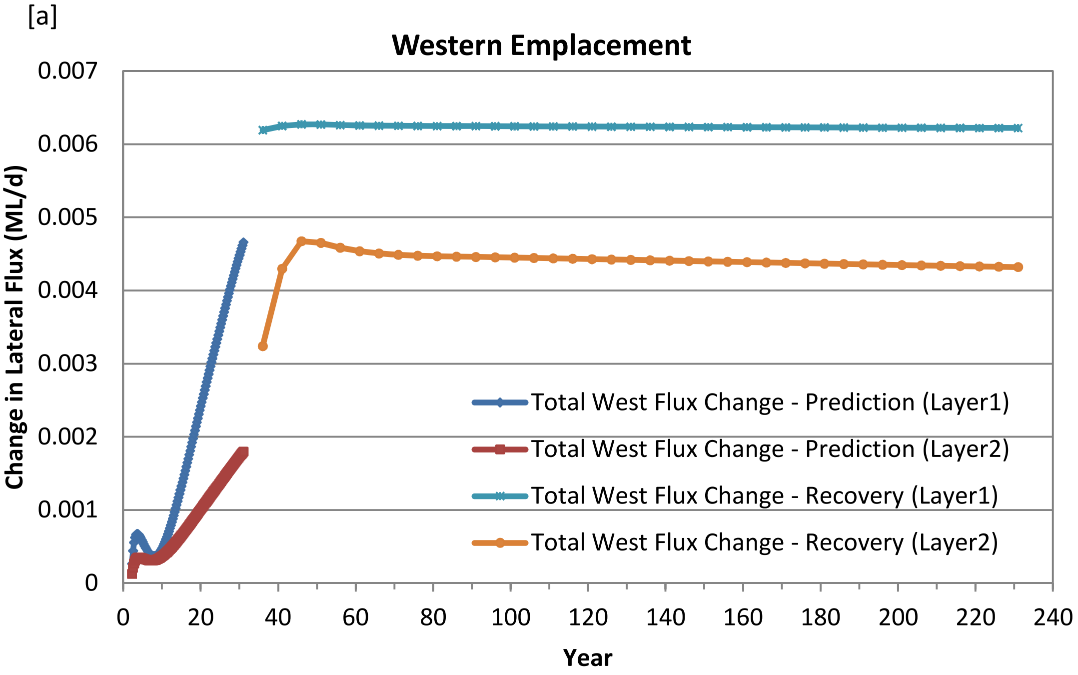


Figure A-58. Predicted Enhanced Leakage from Alluvial Areas to Underlying Porous Rock:
[a] Flux Magnitude (ML/day)
[b] Change in Flux during the Recovery Period Following Project mining (ML/day)

[a]



[b]

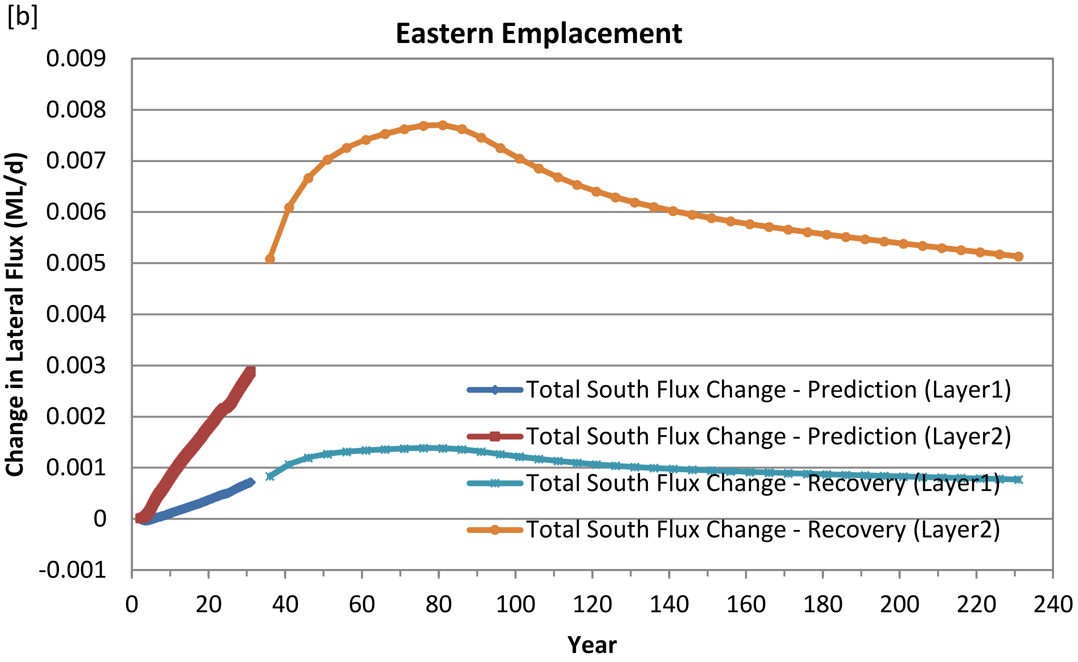


Figure A-59. Predicted Lateral Groundwater Flow from Waste Emplacements to Bordering Alluvium:
[a] Western Emplacement
[b] Eastern Emplacement

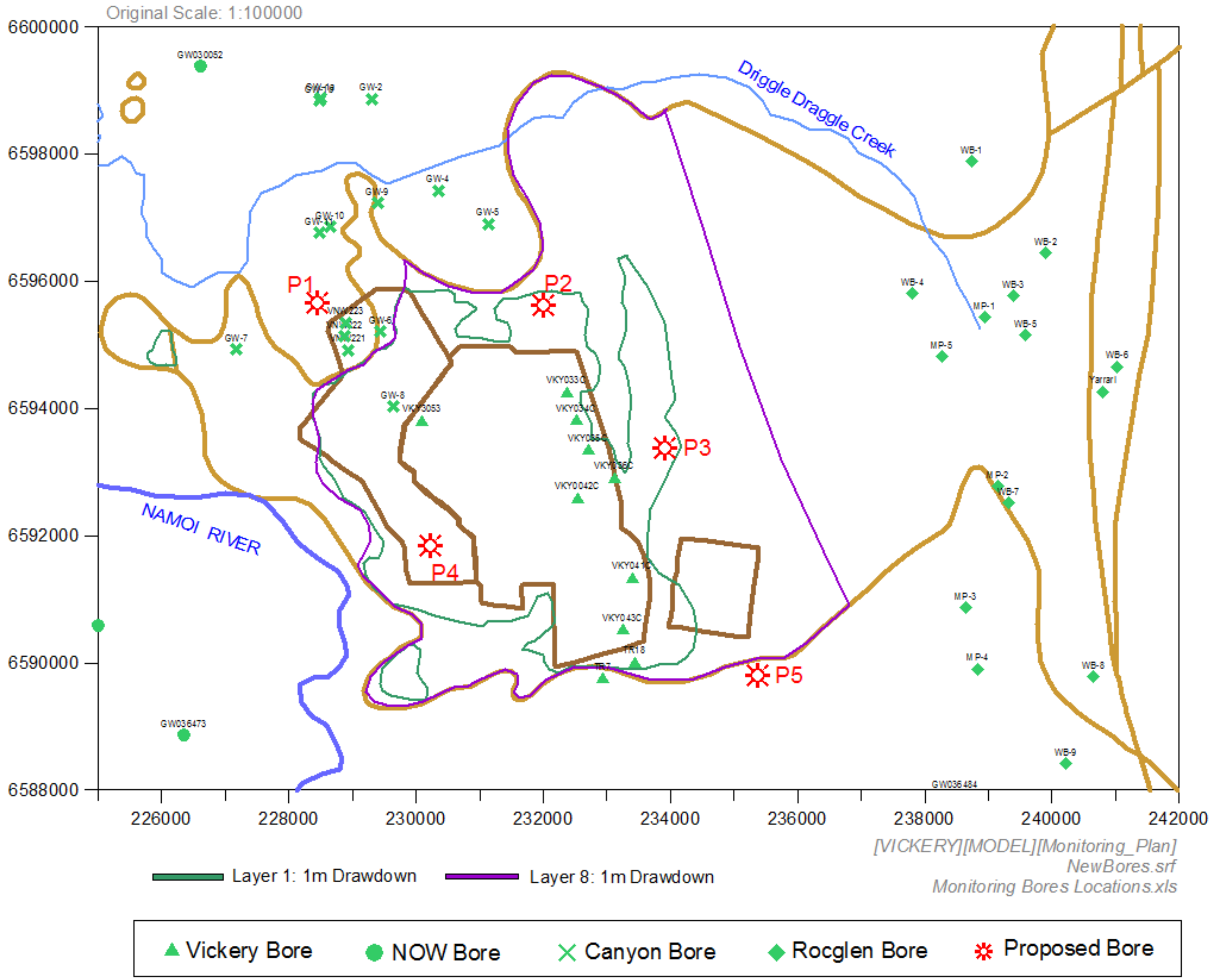


Figure A-60. Proposed Groundwater Monitoring Network