VICKERY EXTENSION PROJECT
ENVIRONMENTAL IMPACT STATEMENT

APPENDIX A
GROUNDWATER ASSESSMENT

WHITEHAVEN COAL

Vickery Extension Project

Groundwater Assessment

FOR

Whitehaven Coal Pty Ltd

BY

NPM Technical Pty Ltd

trading as

HydroSimulations

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1 INTRODUCTION

The former Vickery Coal Mine and the former Canyon Coal Mine are owned by Whitehaven Coal Limited (Whitehaven) and are located approximately 25 kilometres (km) north of Gunnedah, in New South Wales (NSW) (**Figure 1**). Open cut and underground mining activities were conducted at the former Vickery Coal Mine between 1986 and 1998. Open cut mining activities at the former Canyon Coal Mine ceased in 2009. The former Vickery and Canyon Coal Mines have been rehabilitated following closure.

The approved Vickery Coal Project (herein referred to as the Approved Mine) is an approved, but yet to be constructed, project involving the development of an open cut coal mine and associated infrastructure, and would facilitate a run-of-mine (ROM) coal production rate of up to approximately 4.5 million tonnes per year (Mtpa) for a period of 30 years. Heritage Computing (2012) (now HydroSimulations) prepared the Groundwater Assessment for the Approved Mine.

Whitehaven is seeking a new Development Consent for extension of open cut mining operations at the Approved Mine (herein referred to as the Vickery Extension Project [the Project]). This would include a physical extension to the Approved Mine footprint to gain access to additional ROM coal reserves, an increase in the footprint of waste rock emplacement areas, an increase in the approved ROM coal mining rate and construction and operation of a Project Coal Handling and Preparation Plant (CHPP), train load-out facility and rail spur (**Figures 2** and **3**). This infrastructure would be used for the handling, processing and transport of coal from the Project, as well as other Whitehaven mines.

HydroSimulations has prepared this Groundwater Assessment which forms part of an Environmental Impact Statement (EIS) which has been prepared to accompany a Development Application made for the Project in accordance with Part 4 of the *NSW Environmental Planning and Assessment Act, 1979* (EP&A Act).

1.1 SCOPE OF WORK

The objective of this report is to provide an assessment of potential impacts to groundwater associated with the Project, in line with the NSW Department of Planning and Environment (DP&E) Secretary's Environmental Assessment Requirements (SEARs) for the Project.

This assessment involved the following:

- Review of groundwater and surface water monitoring data.
- Revision of the groundwater conceptual model developed for the Approved Mine to account for changes in the mine plan for the Project.
- Revision of the Approved Mine groundwater numerical model, and conversion from MODFLOW-SURFACT with an irregular cell mesh, to MODFLOW-USG with a regular cell mesh.
- Recalibration of the impact assessment groundwater model.
- Predictive modelling and sensitivity and uncertainty analysis.
- Impact assessment and reporting.

1.2 SECRETARY'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS

The SEARs for the Project were provided by the DP&E in February 2016 and updated in July 2018. The groundwater related requirements are as follows:

- an assessment of the likely impacts of the development on the quantity and quality of the region's surface and groundwater resources with regard to the requirements and recommendations of the NSW Environment Protection Authority (EPA) and the NSW Department of Primary Industries (DPI) (see below); and
- an assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users.

1.2.1 SPECIFIC DPI WATER REQUIREMENTS

It is recommended by DPI Water that the EIS be required to include:

- Annual volumes of surface water and groundwater proposed to be taken by the activity (including through inflow and seepage) from each surface and groundwater source as defined by the relevant water sharing plan (WSP).
- Assessment of any volumetric water licensing requirements (including those for ongoing water taken following completion of the Project).
- The identification of an adequate and secure water supply for the life of the Project. Confirmation that water can be sourced from an appropriately authorised and reliable supply. This is to include an assessment of the current market depth where water entitlement is required to be purchased. The EIS should outline current licences obtained for the mine, including volumes of water, and licences required for the expansion.
- An updated, detailed and consolidated site water balance for the expansion.
- A detailed assessment against the *NSW Aquifer Interference Policy* (AIP) (DPI Water, 2012) using DPI Water's assessment framework.
- Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, wetlands, and groundwater dependent ecosystems (GDEs), including measures proposed to reduce and mitigate these impacts.
- Full technical details and data of all surface and groundwater modelling and an independent peer review of the groundwater model.
- Proposed surface and groundwater monitoring activities and methodologies. The EIS should include a spreadsheet outlining all currently monitored bores for the site.
- Proposed management and disposal of produced or incidental water.
- Details of the final landform of the site, including final void management (where relevant) and rehabilitation measures.
- Assessment of any potential cumulative impacts on water resources and any proposed options to manage the cumulative impacts.
- Consideration of relevant policies and guidelines.

- Assessment of whether the activity may have a significant impact on water resources with reference to the Commonwealth Department of Environment's *Significant Impact Guidelines.*
- If the activity may have a significant impact on water resources, then a provision of information in accordance with the *Information Guidelines from the Independent Expert Scientific Committee's advice on coal seam gas and large coal mining development proposals* (Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development [IESC, 2015]).
- A statement in which each element of the SEARs is addressed in the EIS (i.e. in the form of a table).

It is recommended by the EPA that the EIS be required to assess impacts on groundwater and GDEs.

In accordance with the DP&E SEARs for the Project, this assessment has been prepared in consideration of the following groundwater-related policies, guidelines and plans:

- AIP (DPI Water, 2012);
- *Information Guidelines for Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals* (IESC, 2015);
- The *NSW State Groundwater Policy Framework Document* (NSW Department of Land and Water Conservation, [DLWC], 1997);
- The *NSW State Groundwater Quality Protection Policy* (DLWC, 1998);
- *National Environmental Protection Measure Guideline on the Investigation Levels for Soil and Groundwater* (Environment Protection and Heritage Council, 1999);
- *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012);
- *National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia* (ACDFMANZ/ANZECC, 1995);
- *Guidelines for the Assessment & Management of Groundwater Contamination* (NSW Department of Environment and Conservation [DEC], 2007);
- *Groundwater Sampling and Analysis: Field Guide* (Geoscience Australia, 2009);
- *Risk Assessment Guidelines for Groundwater Dependent Ecosystems* (DPI Water, 2012);
- *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*; and
- *Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources 2016*.

A reconciliation table of where each of the SEARs and the requirements of the EPA and DPI Water have been addressed is provided in **Appendix G**.

1.3 PROPOSED MINE DEVELOPMENT

The Project involves mining the coal reserves associated with the Approved Mine, as well as accessing additional coal reserves within the Project area. ROM coal would be mined by open cut methods at an average rate of 7.2 Mtpa over 25 years, with a peak production of up to approximately 10 Mtpa.

Figure 2 illustrates the general arrangement of the Project. A detailed description of the Project is provided in Section 2 in the Main Report of the EIS.

2 HYDROGEOLOGICAL SETTING

2.1 OVERVIEW OF PREVIOUS GROUNDWATER ASSESSMENTS AND MONITORING PROGRAMS

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

The first assessments of the local hydrogeology and groundwater resources were conducted 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 conducted 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:

- groundwater associated with the unconsolidated alluvial sediments of the Namoi River floodplain which are characterised by high hydraulic conductivity 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 hydraulic conductivity and 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 Cainozoic in age and consisting of two principal zones including an upper zone of sandy gravels which is widespread and a lower zone of sands which is confined to a deeper "paleochannel". 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), respectively. The Namoi River was noted as being the major source of recharge to the alluvium.

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 Vickery Coal 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 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 quality 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. 0.5 to 1 litre per second [L/s]).

Relevant pre-mine groundwater level and groundwater quality 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 2.10** and **2.11,** respectively**.**

There is monitoring of water levels at the former Canyon Coal Mine site, which is located in the Permian-aged sedimentary rocks of the Maules Creek Formation to the immediate north of the Project mining area. Open cut mining operations at Canyon Coal Mine commenced in 2000 and ceased in 2009. The site has been rehabilitated following closure. Whitehaven monitors 11 groundwater bores in the vicinity of the Canyon Coal Mine site (i.e. GW1, 2, 4, 5, 7, 8, 9, 10, 11; VNW221, 223; locations shown in **Figure 16**), and reports the results annually in the Canyon Coal Mine Annual Reviews. The available monitoring results from Canyon Coal Mine have been evaluated as part of this study and are discussed in **Section 2.10** (baseline groundwater level data) and **Section 2.11** (baseline groundwater quality data) where appropriate.

Whitehaven’s Rocglen and Tarrawonga Coal Mines are located approximately 5 km to the east and 10 km to the north of the Project, respectively. Groundwater impact assessments and numerical modelling have been conducted recently at both mines (Douglas Partners, 2010; Heritage Computing, 2011), and ongoing groundwater monitoring programs have been established by Whitehaven in accordance with the Development Approval and licence conditions for each mine. Discussion of the numerical modelling and groundwater monitoring results at these existing mines is provided in **Section 2.12** (modelling), **Section 2.10** (baseline groundwater level data), and **Section 2.11** (baseline groundwater quality data) where appropriate.

Twenty baseline groundwater-monitoring bores were established by Coalworks Limited in 2011 to 2012 in the Vickery South area, which is located to the immediate south of the Project mining area. 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, evaluated as part of the previous Heritage Computing (2012) assessment, are presented here as background information.

The DPI Water 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 mining area and the broader surrounds covered by the regional numerical groundwater model (33 km by 29 km area) have been used in the numerical modelling and impact assessment where relevant.

2.1.1 GROUNDWATER ASSESSMENT IN 2012

A groundwater assessment for the Approved Mine was conducted by Heritage Computing (2012). This assessment involved an investigation of groundwater at the proposed mine site, as well as numerical modelling to assess the impacts of the Approved Mine.

Supplementary to the groundwater assessment for the Approved Mine, Whitehaven installed five transects consisting of a total of 33 shallow boreholes in an effort to better define the geometry and properties of the alluvium to the immediate south of the Approved Mine area. This was part of the Groundwater Investigation Program conducted by Groundwater Exploration Services Pty Ltd (GESPL). The program included downhole geophysical logging, a transient electromagnetic (TEM) survey (Groundwater Imaging, 2012) and a pumping test at a new bore (VKY3092).

2.1.2 ASSESSMENT OF ALLUVIUM ADJACENT TO THE NAMOI RIVER

Following a desktop assessment, drilling was carried out by ENRS in 2015 to determine the nature and thickness of alluvium between the Project mining area and the Namoi River (**Appendix A**). The results of the investigation are summarised in **Section 2.5.3**.

2.2 RAINFALL AND EVAPORATION

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

The Project mining area generally experiences a temperate climate. Boggabri Post Office, Boggabri (Retreat) and Keepit Dam, the closest BoM rainfall gauges, have average rainfalls of 592 millimetres (mm), 581 mm and 613 mm per year, respectively (from commencement of data collection to 2015). A meteorological station also collects rainfall data at the Project mining area, but has only a limited history as the station was installed in 2013. The surface water assessment (Advisian, 2018) has used the Boggabri (Retreat) station for runoff analysis.

Average potential (pan) evaporation at the Gunnedah Resource Centre station is 1,752 mm per year (from commencement of data collection to 2015). The average monthly rainfall and evaporation statistics from these stations are summarised in **Table 1.**

The actual evapotranspiration (ET) in the district is about 600 mm per year, according to BoM (2016). 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 the 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 or Cumulative Deviation from the Mean (CDFM).

Table 1 Monthly Climate Statistics for Meteorological Stations near the Project

	Average Monthly Rainfall (mm)				Average Monthly Evaporation (mm)
	Boggabri Post Office (55007)	Boggabri (Retreat) (55044)	Keepit Dam (55276)	Site (99M1)	Gunnedah Resource Centre (55024)
Period of Record	**1884 to 2015**	**1899 to 2015**	**1955 to 2015**	**2013 to 2015**	**1948 to 2015**
January	71.1	71.4	84.3	68.7	238.7
February	64.1	62.3	65.4	31.0	190.4
March	45.8	43.0	42.8	75.5	182.9
April	33.9	35.3	36.0	49.7	129.0
May	41.4	37.9	42.8	37.6	83.7
June	43.7	44.1	36.0	71.6	57.0
July	41.2	42.2	39.0	24.3	58.9
August	37.7	37.2	34.3	41.9	86.8
September	37.8	39.7	38.3	16.4	120.0
October	49.9	49.2	52.5	19.1	167.4
November	59.6	58.5	67.2	51.4	201.0
December	63.7	61.5	75.0	55.9	238.7
Annual Average Total	**591.9**	**581.3**	**613.4**	**543.2**	**1752.0**

After: BoM (2016).

Groundwater levels recorded during periods of rising CDFM, in shallower water bearing strata or sediments, are expected to rise. However, groundwater levels recorded during periods of declining CDFM are expected to decline. A CDFM plot using rainfall data from the Boggabri Post Office, since 1885, is shown on **Figure 3**. This figure 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.

2.3 TOPOGRAPHY AND DRAINAGE

Mining as part of the Project would be located in an area of mostly cleared, undulating land between the western boundary of the Vickery State Forest and the Namoi River. The Vickery State Forest has a maximum elevation of approximately 479 metres (m) Australian Height Datum (AHD). Decreasing elevated terrain extends diagonally from the Vickery State Forest north-south ridge to the south-central part of the Project mining area (**Figure 4**). The minimum elevation near the Project mining area is about 245 m AHD on the floodplain near the Namoi River.

A number of ephemeral streams drain the Project mining area. In the Surface Water Assessment report (Advisian, 2018) (Appendix B of the EIS), they have been named as:

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

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

Other than the Namoi River, there are no flow gauges on any of the streams near the Project.

2.4 LAND USE

The Project mining area is located in a rural area characterised by cattle grazing and cereal/fodder cropping in the adjoining low-lying areas to the north, south and west. The Vickery State Forest lies to the immediate east of the Project mining area (**Figure 2**). With the exception of the Vickery State Forest, most of the land adjacent to the Project mining 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 mining area that was previously occupied by past mining activities is now rehabilitated. Rehabilitated final voids remain at the former Canyon, Blue Vale and Greenwood open cut areas. Rehabilitation works for the final voids have included partial backfilling, reshaping to reduce batter slopes and revegetation.

2.5 GEOLOGY

2.5.1 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, which are 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 for open cut mining 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. The Formations are basal units of the Gunnedah Basin sedimentary sequence and unconformably overlie the Boggabri Volcanics.

The upper and mid slopes of the Project mining area generally comprise of 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 of, and surrounding, the Project mining area comprise predominantly of low–lying, undifferentiated colluvial and alluvial Quaternary sediments. Minor undifferentiated volcanic and igneous rocks of a younger age form isolated outcrops in the surrounding area.

Figure 5 shows the regional surface geology and **Figure 6** is a regional cross-section through the Project mining area. **Figure 7** presents the legend for the regional geology maps. Local geology and geological structures can be seen in **Figure 8. Figure 9** shows an example of detailed stratigraphic cross-sections across the Project mining area.

2.5.2 STRUCTURAL GEOLOGY

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

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

The Boggabri Thrust is a north-west south-east trending structure, which is situated approximately 5 km west of the Project mining area. It continues to the south-east and aligns approximately with the Namoi River channel (**Figure 5** and **Figure 6**).

The Mooki Thrust is a generally north-south trending structure (Figure 5) which lies between the Maules Creek Formation in the west and the Currabubula Formation in the east at the Project mining area. 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* and *Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011*, respectively.

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

- Belmont Fault;
- Roseberry Fault;
- Woodlands Fault;
- Karu Fault;
- Whitehaven Fault System;
- Womboola Fault;
- Shannon Hill Fault; and
- Coalworks Fault.

2.5.3 ALLUVIAL GEOLOGY

The Project mining area is bordered by alluvial sediments of the Namoi River, Driggle Draggle Creek and Stratford Creek surface drainages **(Figure 5** and **Figure 8**). These sediments, also known as the Upper Namoi Zone 4 water source, are part of the Upper Namoi Alluvium that contain groundwater designated as the Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source.

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 mining area. The higher-elevation alluvial tongues along minor drainages have limited groundwater potential and caused poorer water quality, although the groundwater is still suitable for some stock and domestic use.

The combined thicknesses of the Narrabri Formation and the Gunnedah Formation are shown in **Figure 10**, which demonstrates thicknesses typically greater than 100 m along paleochannels associated with ancient courses of the Namoi River and Coxs Creek.
As shown on **Figure 10**, the alluvial materials to the north of the Project mining area (i.e. between Driggle Draggle Creek and Bollol Creek) are typically 40 to 70 m thick, and to the south of the Project mining area they are up to approximately 140 m thick. **Figure 10** also indicates that the Namoi River, adjacent to the Project mining area, is not aligned with the deepest sections of the paleochannel valley sediments with higher yielding groundwater potential. This is apparent particularly where the river swings in close to the south-west of the Project mining area.

Field investigations to better define the geometry and properties of the alluvium surrounding the Project mining area were conducted in conjunction with previous modelling work by Heritage Computing (2012). For that investigation Whitehaven installed five transects consisting of a total of 33 shallow boreholes (TR1-TR35) as part of the Vickery Groundwater Investigation Program conducted by Groundwater Exploration Services Pty Ltd (GESPL) (2012). The investigation delineated the extent of the Upper Namoi Alluvium along the full southern margin of the Project open cut extent, including the surface profile of the underlying Maules Creek Formation. In addition, the hydraulic conductivity values of the alluvial/colluvial sediments, the spatial distribution of groundwater salinity and water quality components were assessed.

Investigative drilling (**Appendix A**), installation of groundwater monitoring piezometers, and Geophysical (TEM) survey were carried out by Whitehaven in 2012 and 2015 to better identify the extent and nature of unconsolidated alluvial and colluvial deposits in the vicinity of the Project, adjacent to (west of) the Namoi River.

Apparent resistivity at a depth of 3 m, based on TEM surveys carried out in 2012 and 2015, is shown in **Figure 11**. Alluvial material to the south of the Project open cut and to the east of the Namoi River is of low resistivity, consistent with clay-rich material. Alluvial material adjacent to the Namoi River is inferred to be relatively thin with the northern boundary defined by a small, arcuate terrace feature (ENRS, 2016).

Drilling was carried out at seven locations, including a transect of four drill holes on the northern side of the Namoi River on Braymont Road (**Figure 11**) (ENRS, 2016). The drilling established that the alluvium adjacent to the Namoi River is relatively thin (< 6 m) and dominated by silt and clay of relatively low hydraulic conductivity (consistent with the Narrabri Formation). The alluvium grades into colluvium material (slope wash debris) at the lower break of slope. Importantly, the colluvium and alluvium adjacent to the Namoi River were found to be unsaturated (i.e. the regional water table is below the base of the alluvium). This is consistent with the observation that the base of the alluvium outcrops in the Namoi River bank at two locations (the upper and the lower rocks) at an elevation that is above the mean river level. The outcomes of the drilling investigation are important because they imply that (ENRS, 2016):

1. Mine-related drawdown would not affect the highly productive groundwater zones of the Upper Namoi Alluvium, because the proposed mine open cut would not intersect saturated alluvium.

2. There may be some seepage loss of groundwater from the alluvium to the coal measures as a result of mining-induced depressurisation of the coal measures. However, that loss is likely to be very minor compared to irrigation use and rainfall recharge due to the low hydraulic conductivity of the coal measures through which the seepage would occur.

3. Similarly, induced seepage loss from the Namoi River is likely to be very minor compared to the total river flow.

Piezometers were installed at five of the six locations to monitor groundwater levels in the coal measures. **Figure 12** shows a typical cross section through the alluvial deposits and coal measures to the west of the Project mining area from Bore A4 (VNW389) to Bore GW027814 (**Figure 11**).

2.6 GROUNDWATER USERS

A search of the DPI Water Pinneena Groundwater Works Database identified 635 registered bores within the regional numerical groundwater model area. 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 privately-owned bores/wells in the vicinity of the Project. The locations of these bores/wells are also shown on **Figure 15** as "Bore Identified during Bore Census". The results of the Project bore census (e.g. confirmed bore/well locations, standing water levels and water salinity measurements) have been used to confirm the number and type of groundwater users near the Project, as well as assist in the drawdown assessment (**Section 6**).

Figure 13 shows the distribution of groundwater abstraction from the Narrabri Formation and the Gunnedah Formation, respectively, for bores registered for irrigation purposes. The circles indicate the relative magnitudes of the average abstraction rates from 2006 to 2010. As illustrated on the figures, activity is concentrated close to the Namoi River corridor, in particular the paleochannel of the Gunnedah Formation to the west and north-west of the Project. The nearest active Gunnedah Formation production bore is located on the western side of the Namoi River, approximately 2 km south-west of the Project mining 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 from 2006 to 2010. **Figure 14** 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 residual mass curve (**Figure 3**) shows drier conditions commencing in 2006, with a wetter sequence commencing in 2009. The much lower production pumping in 2010 is consistent with rainfall trends. Overall total pumping rates have declined from late 2006 to 2010 (**Figure 14**)[1].

2.7 WATER SHARING PLANS AND GROUNDWATER LICENSING

The Project coal resource is located within the Maules Creek sub-basin of the Early Permian Bellata Group, which lies within the boundary defined in the *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* (**Figure 1**)[2]. The Project coal resource is wholly located within the Namoi Management area of the Gunnedah-Oxley Basin Groundwater Source.

The Project is located outside, and approximately 7 km west, of the New England Fold Belt Murray Darling Basin Groundwater Source boundary, defined by the *Water Sharing Plan for the NSW Murray-Darling Basin Fractured Rock Groundwater Sources 2011* (**Figure 1**).

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 1**).

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1 Groundwater abstraction records since 2010 are not readily available to the public.

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

Consideration of the Project against the objects and regulatory requirements of the *Water Act*, *1912*, the *Water Management Act, 2000*, the AIP, and a discussion of the licensing requirements for each water source associated with the Project are provided in **Section 8.3** and **Section** 9, and in Attachment 6 of the EIS. 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 (WSPs), where appropriate.

2.8 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, beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- Fractured Rock Groundwater Systems – outcropping and subcropping 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 2.5**) which is within the sedimentary rock groundwater systems of the Gunnedah Basin. These sedimentary rock groundwater systems are contained within the boundary defined in the *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011* (as described in **Section 2.7**). There are no high priority GDEs, as identified in the *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011*, within the Project mining area.

Groundwater of variable quality to the north and south of the Project mining area is associated with the deep alluvial groundwater systems of the Upper Namoi Alluvium (i.e. Upper Namoi Zone 4 Groundwater Source – refer **Section 2.7**). There are no high priority GDEs identified in the Upper Namoi Alluvium (DPI Water, 2010).

The *NSW State Groundwater Dependent Ecosystems Policy* (DLWC, 2002) also recognises the four Australian GDE 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 Namoi River is considered by Eco Logical Australia (2018) to be a GDE (i.e. the river and associated riparian vegetation) because groundwater interaction between the Namoi River and the underlying alluvium varies based on rainfall conditions (**Section 2.10**). However, in accordance with the GDE guidelines (Serov et al. 2012), the Namoi River is not considered to be a high value GDE given (Eco Logical Australia, 2018):

- it is not reserved as a National Estate, listed wetland or *State Environmental Planning Policy No 26 - Littoral Rainforests*;
- exotic species occur in large populations and multiple species; and
- it has undergone major changes in physical structure and species composition due to historical agriculture in the region.

In addition, the *National Atlas of Groundwater Dependent Ecosystems* (BoM, 2015) identifies some areas of vegetation within the vicinity of the Project as having a low or moderate potential for groundwater interaction (e.g. the Vickery State Forest). Furthermore, flora surveys undertaken for the Project have identified no woodland/forest vegetation communities in the Project locality which exhibit characteristics of groundwater dependency (FloraSearch, 2018). The Vickery State Forest consists of Dry Sclerophyll Forests that are not considered to be groundwater-dependent. This is consistent with the interpreted groundwater levels (**Section 2.10**), which indicate that the water table is typically deeper than 50 m below ground level in the Vickery State Forest.

2.9 GROUNDWATER MONITORING

The Whitehaven groundwater monitoring locations associated with Vickery, Canyon, Rocglen and Tarrawonga Coal Mines used in this assessment are listed in **Table 2** and shown in **Figure 16.** The DPI Water monitoring locations used in this assessment are listed in **Table 2** and shown in **Figure 16, Figure 17 and Figure 18.**

Table 2 Monitoring Locations Used in this Assessment

Area	Alluvial monitoring bores	Permian coal measures monitoring bores	Total
Vickery Extension Project (1)	VNW395WBB; VNW394WBB	VNW392WBA; VNW391WBB; VNW390WBA; VNW393WBB	**6**
Vickery Joint Venture (2)	Test Bore, WRC	WVK37, WVK62, WVK501, WVK505, WVK526, #9 (unknown)	**8**
Vickery Groundwater Investigation Program (2012)	**Monitoring bores:** GW01, GW01_29m, GW02, GW02_14m, GW03, SB01, SB02, SB04, SB05, SB06, SB07, SB08, SB09, SB10, SB11, SB15	**Monitoring bores:** MD01, MD02, TR0007, TR0018, TR0026, TR0035, VKY0034C, VKY0035C, VKY0036C, VKY0042C, VKY0043C **Vibrating Wire Piezometers:** VKY3053_35m, VKY3053_50m, VKY3053_68m, VKY3053_75m, VKY3053_89m, VKY33_115m, VKY33_140m, VKY33_170m, VKY33_200m, VKY33_38m, VKY33_51m, VKY33_70m, VKY33_90m, VKY41_115m, VKY41_140m, KY41_39m, VKY41_50m, VKY41_65m, VKY41_86m, VS048_27m,	**58**

Area	Alluvial monitoring bores	Permian coal measures monitoring bores	Total
		VS054_120m, VS054_167m, VS054_96m, VS056_25m, VS056_78m, VS058_158.8m, VS058_30m, VS058_87.5m, VS059_113m, VS059_30m, VS062_25m	
Canyon Coal Mine Monitoring Program	GW_1, GW_10, GW_11, GW_2, GW_4, GW_5, GW_9, VNW221, VNW223	GW_7, GW_8, VNW222	**12**
Rocglen Coal Mine Monitoring Program	MP-3, MP-4, WB-10, WB-11, WB-12, WB-2, WB-9	MP-1, MP-2, MP-5, WB-1, WB-3, WB-5, WB-7, WB-8	**15**
Tarrawonga Coal Mine Monitoring Program	GW031856, GW044997, GW052266, Templemore_A, Templemore_B, MW5	MW1, MW2, MW3, MW4, MW6, MW7, MW8	**13**
DPI Water Monitoring Locations	GW030048_1, GW030048_2, GW030049_1, GW030049_2, GW030050_1, GW030050_2, GW030051_1, GW030051_2, GW030052_1, GW030052_2, GW030468_1, GW030469_1, GW030470_1, GW030470_2, GW030471_1, GW030471_2, GW030472_1, GW030472_2, GW030535_1, GW036092_1, GW036456_1, GW036456_2, GW036457_1, GW036457_2, GW036458_1, GW036459_1, GW036460_1, GW036460_2, GW036462_1, GW036463_1, GW036463_2, GW036471_1, GW036471_2, GW036473_1, GW036476_1, GW036476_3, GW036480_1, GW036481_1, GW036481_2, GW036484_1, GW036485_1, GW036485_2, GW036489_1, GW036489_2, GW036510_1, GW036510_2, GW036513_1, GW036514_1, GW036548_1, GW036548_2, GW036565_1, GW036567_1, GW036655_1, GW036655_2		**54**
Total monitoring locations	**96**	**70**	**166**
Total Groundwater level monitoring locations	**90**	**62**	**152**

(1) New Vickery Extension Project monitoring bores installed in 2016.

(2) Only water quality monitoring data available from Vickery Joint Venture monitoring bores.

2.10 BASELINE GROUNDWATER LEVEL DATA

2.10.1 SPATIAL GROUNDWATER LEVEL DATA

Natural groundwater levels are sustained by rainfall recharge and are influenced by ground surface topography, geology and surface water elevations. Typically, local groundwater tends to mound beneath hills and discharges to low-lying areas, including creeks and rivers.

In short events of high surface flow streams lose surface water to the host groundwater system, but during recession groundwater slowly discharges back into the stream from bank or alluvial storage. In addition, groundwater discharges to streams in more distant zones in the form of rainfall recharge.

Water table contours calculated from groundwater levels that are not affected by historical mining or historical pumping from the Upper Namoi Alluvium are shown in **Figure 19.** All available groundwater level data from the 152 monitoring locations listed in **Table 2** were analysed and the effects of mining and pumping were removed. Long-term average water levels that are based on climatic variation were then calculated and contoured.

Mounding beneath the Vickery State Forest is evident on **Figure 19**. Groundwater flow direction is towards the west, south-west and north-west, following the topography and the Namoi River. The hydraulic gradient decreases appreciably to the north-west and the south west between the Project mining area and the Namoi River due to the higher hydraulic conductivity of alluvial sediments.

Water table contours calculated from groundwater levels at the end of 2017 are shown in **Figure 20.** Groundwater level drawdown due to mining at the Canyon and Rocglen Coal Mines is observed. Groundwater level drawdown due to pumping from the Upper Namoi Alluvium is observed compared to the water table contours in **Figure 19.**

2.10.2 TEMPORAL GROUNDWATER LEVEL DATA

The available groundwater level data within and surrounding the Project mining area have been investigated in detail to check for cause-and-effect responses in temporal water level changes. Cause-and-effect responses could result from rainfall recharge, irrigation pumping or a mining effect. Detailed groundwater hydrographs for all the Vickery, Canyon, Rocglen and Tarrawonga Coal mines monitoring bores and DPI Water monitoring bores are shown in **Appendix B**.

Representative hydrographs are shown in **Figure 21** to **Figure 26** for each monitoring network. They are compared with residual rainfall mass to indicate whether the local groundwater levels are responsive to rainfall recharge.

Several monitoring bores and vibrating wire piezometers (VWPs) were installed as part of the Vickery Groundwater Investigation Program (**Table 2**) after the previous groundwater assessment for the Approved Mine (Heritage Computing, 2012). Monitoring bore SB01 (screened in alluvium) shows decreasing water levels, since installation in 2013, in response to below average rainfall (**Figure 21a**). Monitoring bore VKY0043C shows no significant change in water levels since installation in 2014 (**Figure 21b**).

VWP VKY33 has not shown a response to rainfall recharge, since installation in 2012, and all other piezometers have only mild variations (**Figure 22a**). There is a downward vertical gradient at this site (for all piezometers). VWP VKY41 has shown declining water levels since installation in 2012 (**Figure 22b**). This may be a response to below average rainfall, although it is also likely that pressures at this VWP site have not yet equilibrated since installation. Further data should be collected before trends from this location can be considered reliable. Apart from an inconsistent piezometer at 170m, all other piezometers at VWP VKY41 indicate a downward vertical gradient.

New Project monitoring bores were installed in 2016 (**Table 2**). Surveyed water level information was not available for these locations at the time of calibration.

The DPI Water 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_1) 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.

Figure 23a shows good rainfall correlation at GW030051_1 (screened in alluvium) which is located to the north-west of the former Canyon Coal Mine. **Figure 23b** shows declining groundwater levels at GW036463 (screened in alluvium) to the south of the Project mining area due to regional agricultural pumping, but rainfall-related recovery is evident after 2010.

Some of the Canyon Coal Mine bores show a mining effect (e.g. VNW221, screened in alluvium) near the final void (**Figure 24b**), but most show mild fluctuations not well correlated with rainfall (e.g. GW_2, screened in alluvium) to the north of the mine in alluvium (**Figure 24a**).

Tarrawonga Coal Mine bores MW2 (Maules Creek Formation) (**Figure 25a**) and MW5 (alluvium) (**Figure 25b**) do not show a mining effect but are well correlated with rainfall.

Rocglen Coal Mine bore WB-1 (Maules Creek Formation), to the south of the mine, shows a delayed and subdued response to rainfall (**Figure 26a**). MP-5 (Maules Creek Formation), to the immediate west of the mine, shows a mining response (**Figure 26b**).

2.11 BASELINE GROUNDWATER QUALITY DATA

This section characterises the groundwater quality at and around the Project mining area using existing regional and local data in order to further assess the potential impacts of the Project.

Reporting requirements in relation to groundwater quality are listed in the SEARs and related documents (**Section 1.2**). Potential impacts to water quality are assessed in relation to the minimal impact considerations from the AIP as listed in **Table 3.**

Table 3 Water Quality Minimal Impact Considerations Relevant to the Project (AIP)

Groundwater Source	Minimal Impact Consideration
Highly productive alluvial groundwater	1. a) Any changes in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity; and b) 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. Redesign of a highly connected surface water source that is defined as a "reliable water supply" is not an appropriate mitigation measure to meet considerations 1 (a) and 1 (b) above c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source – whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". d) Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a "reliable water supply".
Less productive porous rock	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.

Baseline groundwater quality information for the Project mining area has been obtained from the following sources:

- Earlier groundwater investigations carried out during the 1980s by Coffey (1982; 1984a; 1984b) and Vickery Joint Venture (1986).
- The Vickery Groundwater Investigation Program (Heritage Computing, 2012).
- Groundwater investigations carried out for the Project by Whitehaven.
- Groundwater monitoring at the nearby Rocglen and Tarrawonga Coal Mine sites.

Groundwater monitoring bores for which water quality data are available are presented in **Table 4.**

Table 4 Groundwater Quality Monitoring Locations

Area	Alluvial monitoring bores	Permian coal measures monitoring bores	Total
Vickery Extension Project	VNW395WBB; VNW394WBB	VNW392WBA; VNW391WBB; VNW390WBA; VNW393WBB	**6**
Vickery Joint Venture	Test Bore, WRC	WVK37, WVK62, WVK501, WVK505, WVK526, #9 (unknown)	**8**
Vickery Groundwater Investigation Program		TR7, TR18, TR26, TR35, VKY3034, VKY3035, VKY3036, VKY3042, VKY3043	**9**
Canyon Coal Mine Monitoring Program	GW-1, GW-2, GW-4, GW-5, GW-9, GW-10, GW-11, VNW221, VNW223	GW-7, GW-8, VNW222	**12**
Rocglen Coal Mine Monitoring Program	MP-3, MP-3A, MP-4A, MP-4B, WB-2, WB-10, WB-11, WB-12, Yarrari Production	MP-1, MP-2, MP-2A, MP-5A, MP-6, MP-7, MP-8, WB-1, WB-13, WB-14, WB-3, WB-4, WB-5, WB-7, WB-8	**24**
Tarrawonga Coal Mine Monitoring Program	GW044997, GW031856, GW052266, Templemore A, Templemore B, MW5	MW1, MW2, MW3, MW4, MW6, MW7, MW8	**13**
Number of bores	**28**	**44**	**72**

Table 5 provides representative groundwater analyses for samples collected at groundwater monitoring bores installed in the Project mining area as part of the Vickery Groundwater Investigation Program.

Table 5 Vickery Groundwater Investigation Program Representative Major Ion Analyses

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
VNW392WBA	MCF	Feb 2016	7.4	3490	2210	269	98	348	20	652	737.61	311
VNW391WBB	MCF	Feb 2016	7.32	2550	1440	189	63	282	14	439	741.27	134
VNW390WBA	MCF	Feb 2016	7.3	2330	1400	178	43	268	14	386	716.88	104
VNW395WBB	UNA	Feb 2016	7.3	2380	2810	72	43	446	7	315	737.61	204
VNW393WBB	MCF	Feb 2016	8.07	2840	1660	75	29	463	12	688	179.22	197
VNW394WBB	UNA	Feb 2016	7.59	5720	3600	216	82	891	14	1190	437.69	593

Source: ERNS (2016). MCF: Maules Creek Formation. UNA: Upper Namoi Alluvium.

Note: Ca = Calcium. Mg = Magnesium. Na = Sodium. K = Potassium. Cl = Chlorine. HCO_3 = Bicarbonate. SO_4 = Sulfate.

2.11.1 GROUNDWATER ENVIRONMENTS

Groundwater investigations carried out at the site indicate three distinct groundwater environments for the purposes of water quality assessment:

1. Quaternary and Tertiary Alluvium: including the Upper Namoi Alluvium and minor alluvial deposits associated with tributaries to the Namoi River;

2. Coal Measures: weathered to fresh rock of the Maules Creek Formation;

3. Boggabri Volcanics: weathered to fresh volcanic rocks of Early Permian age which form immediate basement to the coal measures. No monitoring bores are known to be screened within the Boggabri Volcanics.

For the purposes of the AIP and the region's WSPs, the aquifers are divided into two primary water sources:

a) groundwater associated with the Upper Namoi Alluvium, and

b) groundwater associated with the porous rock groundwater system represented by the Permian Coal Measures and underlying volcanic rocks.

2.11.2 GROUNDWATER QUALITY AND BENEFICIAL USE

Figure 27 shows the ranges in groundwater electrical conductivity (EC) in microseimens per centimetre (µS/cm) for 850 field and laboratory measurements, arranged according to aquifer type and area. EC increases in proportion to the total dissolved ions in a water sample and is a commonly used proxy for water quality. Also shown are thresholds for groundwater use categories as recommended in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC, 2000).

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 WSP covers a very large area for which much of the groundwater is potable.

Groundwater quality within and surrounding the Project mining area is highly variable but generally poor, with most groundwater suitable only for livestock and irrigation of some salt tolerant crops. The highest groundwater salinity is associated with the Maules Creek Formation, but also with the alluvium and colluvium in the vicinity of the former Vickery and Canyon Coal Mines. Groundwater quality that is suitable for drinking and irrigation is associated with the thicker alluvial deposits of the Upper Namoi Alluvium (represented by monitoring at the Rocglen and Tarrawonga Coal Mines).

Groundwater pH is near neutral with 90% of all 850 measurements in the Vickery and Canyon Coal Mine area between pH 6.8 and pH 8.2. Anomalously high pH (i.e. pH 9.2 to 9.5) was noted in the first several measurements at the Canyon Coal Mine monitoring bore GW-11. It is assumed that those high pH values reflect residual grout-affected water in the monitoring bore following construction.

The spatial distribution of groundwater EC from data obtained during the 2012 bore census is shown in **Figure 28.** The monitored formation is differentiated by symbol, and the magnitude of the concentration is proportional to symbol colour. This plot also includes median values at the Vickery, Canyon, Tarrawonga and Rocglen Coal Mine monitoring networks. 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.

The spatial distribution of groundwater pH is shown in **Figure 29**. The plot illustrates the narrow range in groundwater pH across the area and at the site. The measured or median pH value at each location is illustrated by colour; however, in this case all locations are in the near-neutral range of pH 6.5 to 8.5, denoted by a green colour.

2.11.3 GROUNDWATER TYPES

Groundwater quality is characterised according to the abundances and types of dissolved ions in a water sample. The proportions of dissolved ions in the water often reflect the origin of the water and its interactions with aquifer materials (dissolution and precipitation of minerals). These attributes can be useful in classifying groundwater types and placing constraints on conceptual models for groundwater movement.

The major ion quality in representative analyses of groundwater is shown on Schoeller diagrams in **Figure 30**, and a Piper diagram in **Figure 31**. 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. A Piper diagram represents the major ion composition of a water sample in terms of its cations (Na^+K, Ca, Mg), and anions (Cl, HCO_3, SO_4) on triangular plots. The cation and anion compositions are also projected onto a diamond plot on the centre of the diagram which can be used to show overall groundwater types or facies.

Groundwater samples from the Project mining area have broadly similar major ion characteristics despite the wide range in salinity (as represented by EC). This is evident from the similar patterns on the Schoeller diagrams for groundwater samples obtained from different lithologies. The Piper plot on **Figure 31** shows that, in detail, groundwater typically is dominated by Na, Cl and HCO_3 ions, but ranges to Na-Cl and mixed ion Ca-Mg-Na-Cl-HCO_3 waters. In the Project mining area, there is no strong spatial or lithological relationship in water quality, reflecting the heterogeneous nature of the groundwater system.

Most of the variation in quality is as a result of reactions between relatively fresh (and Na-Cl dominated) rainfall recharge and carbon dioxide gas in the regolith, and ion exchange/dissolution reactions that occur with clay and other rock-forming minerals. As such, the observed ranges in water quality reflect the "evolution" from low-salinity, Na-Cl-HCO_3 dominated water to higher salinity, mixed cation water with increasing residence time and flow distance. Evaporation of water prior to recharge, or from shallow groundwater areas will result in increased salinity, while preserving the major ion ratios.

2.11.4 TRACE METALS

The concentrations of trace metals in over 400 groundwater samples are summarised according to groundwater environment in **Figure 32**. Individual analyses are shown as circles, coloured according to the monitored formation, and the median and inter-quartile ranges are shown as overlain box plots. The observed ranges in metal concentrations are considered typical for groundwater in the area and reflect baseline conditions. Despite the wide ranges in metal concentrations, the median metal concentrations in groundwater are similar between monitored formations. Metal concentrations tend to increase with salinity (or EC) as a result of evaporative concentration of ions. Calculated median, 5th and 95th percentile concentrations of dissolved metals for each of the monitored formations is shown in **Table 6**.

The ANZECC (2000) guidelines for fresh and marine water quality contain no specific trigger values for dissolved metals in groundwater. However, the guidelines indicate that it is appropriate to consider the environmental values of the receiving surface water systems or receptors (if and where groundwater emerges at the surface) in respect of groundwater quality. The ANZECC (2000) trigger levels for the protection of 95% of freshwater species (appropriate for moderately disturbed systems) are shown in **Table 6**. It is apparent that the median concentrations of Al, Cu, and Zn in groundwater samples taken prior to development are near or above the recommended trigger levels for surface water systems. This is common in natural groundwater systems of moderate to high salinity and does not indicate anthropogenic impact, or a risk to surface water systems in their natural state.

Table 6 Median and Percentile Trace Metal Concentrations in Groundwater

Formation	%ile	**Al**	**As**	**Cu**	**Co**	**Fe**	**Mn**	**Se**	**Zn**
ANZECC (2000) Freshwater 95% protection		0.055	0.024	0.0014	ND	ND	1.9	0.011	0.008
Alluvium (n = 227)	5%	<0.01	<0.001	<0.002	<0.001	<0.05	<0.001	<0.01	0.007
	50%	**0.04**	**0.001**	**0.009**	**0.001**	**0.24**	**0.03**	**<0.01**	**0.07**
	95%	1.7	0.01	0.1	0.004	26.7	1.7	<0.01	0.9
Maules Creek Formation (n = 137)	5%	<0.01	<0.001	<0.002	<0.001	<0.05	0.003	<0.01	0.006
	50%	**0.09**	**0.001**	**0.01**	**0.001**	**0.7**	**0.11**	**<0.01**	**0.09**
	95%	6.1	0.02	0.2	0.02	25.2	2.0	0.01	1.1

2.11.5 TEMPORAL CHANGES IN GROUNDWATER QUALITY

Time series plots of groundwater EC and pH for monitoring sites at the Canyon, Rocglen and Tarrawonga Coal Mines for which there are sufficient data, are shown in **Appendix C**. The most relevant baseline time series data for the Project are those for the former Canyon Coal Mine, immediately adjacent to the Project open cut. The time series plots for the Canyon Coal Mine monitoring bores show the following:

- Most locations show no significant long-term trends in salinity or pH. Natural variation in EC of 10% to 20% of the long term average value is typical.
- A gradual increase in salinity corresponding to a decrease in pH is evident at monitoring bore GW-11. However, the pH values as of 2015 do not appear to be anomalous with respect to other sites and do not indicate acid drainage conditions.
- Transient decreases in EC were recorded during 2012 in monitoring bores GW-7, GW-8 and GW-9. This apparent freshening of groundwater at these locations corresponds with unusually high rainfall during that year and reflects mixing of groundwater with relatively fresh recharge.

2.12 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 annual pit pumping volumes at the Rocglen Coal Mine (including rain water and surface runoff) are:

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

In 2010, Douglas Partners Pty Ltd (Douglas Partners) 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 inflow rate does not include evaporative loss from the pit.

The Heritage Computing (2012) groundwater model for the Approved Mine predicted peak mine inflows of 0.9 ML/day at the Rocglen Coal Mine.

The observations of pit pumping volumes at the Tarrawonga Coal Mine (including rain water and surface runoff) from May to April each year are:

- 2006-07: 28 ML (average 0.08 ML/day);
- 2007-08: 32 ML (average 0.09 ML/day);
- 2008-09: 45 ML (average 0.12 ML/day);
- 2009-10: 69 ML (average 0.19 ML/day);

- 2010-11: 79 ML (average 0.22 ML/day);
- 2011-12: 148 ML (average 0.41ML/day);

In 2011, Heritage Computing conducted regional numerical groundwater modelling as part of the assessment of the Tarrawonga Coal Project. The Heritage Computing (2011) groundwater model predicted mine inflows of 0.4 to 0.5 ML/day for a typical 6 km pit perimeter. This inflow rate does not account for evaporative loss in the pit.

The Heritage Computing (2012) groundwater model for the Approved Mine predicted peak mine inflows of 1.3 ML/day at the Tarrawonga Coal Mine. There are some differences between the modelled Tarrawonga Coal Mine inflows for the Tarrawonga Coal Project model (Heritage Computing, 2011) and the Approved Mine model (Heritage Computing, 2012). These differences are due to the Tarrawonga Coal Mine located some 10 km from the Project and close to the model boundary for the Approved Mine model; therefore, calibration of the Vickery model has not focused on the Tarrawonga Coal Mine. However, as the inflows for the Tarrawonga Coal Mine are higher for the Approved Mine model than the Tarrawonga model, this is considered to be conservative for the purposes of assessing potential impacts for this Project.

Modelled inflow volumes are typically conservative and higher than observed mine inflow volumes. This is often because observed inflow rates include evaporative losses from the pit.

3 CONCEPTUAL MODEL

A conceptual model of the groundwater regime has been developed based on the review of existing hydrogeological data as described in **Section 2**, including:

- Gunnedah Basin geology mapping.
- Whitehaven exploration (geological) data and logs.
- DPI Water Pinneena Groundwater Works Database records.
- Previous hydrogeological assessments/reviews conducted for earlier coal mining at Vickery Coal Mine and 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; Heritage Computing, 2011, 2012; and peer review KA, 2012).
- Groundwater level data from monitoring programs conducted 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 (2012).
- Drilling results (ENRS, 2016).

Based on the above, and consistent with the relevant WSPs, two main groundwater systems occur within the Project mining area and surrounds:

- porous rock groundwater 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 mining area before mining and towards the end of the mine life are illustrated in **Figure 33**.

Recharge to the groundwater systems occurs from rainfall and runoff infiltration, lateral groundwater flow, and some leakage from surface water sources. In particular, recharge to the alluvial sediments occurs primarily from the Namoi River. Groundwater levels are therefore sustained by rainfall recharge, but levels are influenced by topography, geology and surface water levels in local drainages. Groundwater tends to mound beneath hills, with ultimate discharge to adjacent drainages and loss by evapotranspiration at shallow depth. However, given the typical depth to groundwater is overall below the influence of evapotranspiration south and west of the Project mining area, evapotranspiration is unlikely to be a dominant outflow component within the Project mining area and adjacent Upper Namoi Alluvium.

During mining, drawdown created by the Project open cut will lower the potentiometric heads in the vicinity of the Project open cut with consequent inflow of groundwater from the Maules Creek Formation. Rainfall recharge to the waste rock emplacement would cause some mounding beneath these structures.

3.1 HYDRAULIC PROPERTIES

The hydraulic conductivity of various stratigraphic units has been assessed from slug/pumping tests, core measurements and model calibration conducted by previous studies including AGE (2010), RCA Australia (2005, 2007), Douglas Partners (2010), and Heritage Computing (2011). A summary of hydraulic conductivity estimates is shown in **Table 7**. The hydraulic property data collected and reviewed as part of this assessment provide a suitable basis for the development of a regional numerical groundwater model. The performance of the calibrated model (including comparison to the ranges of indicative hydraulic properties) is discussed in **Section 4.8.1.**

The hydraulic conductivity values in **Table 7** are also based on results of the Vickery Groundwater Investigation Program conducted by GESPL (2012), including:

- core test work (29 samples from five drill holes [VKY002c, VKY006c, VKY010c, VKY017c and VKY020c]);
- 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).

Table 7 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)	6.1×10^{-6} - 6.8×10^{-4}	1.1×10^{-5} - 1.4×10^{-5}
Braymont/Jeralong Seams	0.01-0.68	-
Interburden (Jeralong to Merriown/Velyama Seams)	7.2×10^{-7} - 8.1×10^{-4}	2.4×10^{-7} - 1.9×10^{-4}
Merriown/Velyama Seams	0.005-0.68	-
Interburden (Velyama to Nagero Seam)	6.3×10^{-7} - 1.0×10^{-4}	3.6×10^{-7} - 4.4×10^{-5}
Nagero Seam	0.025	0.0025
Interburden (Nagero to Tralee Seam)	8.2×10^{-7} - 3.2×10^{-4}	1.8×10^{-7} - 2.2×10^{-4}
Tralee to Stratford Seams	1.8×10^{-4} - 0.5	0.0016
Interburden (Stratford to Bluevale Seam)	3.3×10^{-4} - 7.3×10^{-4}	4.2×10^{-7} - 7.2×10^{-6}
Bluevale to Cranleigh Seams	No estimate^	No estimate^
Underburden (below Cranleigh Seam)	1.6×10^{-5} - 0.0016	7.7×10^{-5} - 1.6×10^{-4}
Boggabri Volcanics	2.4×10^{-6} - 1×10^{-4}	4.0×10^{-7}- 1×10^{-5}

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

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

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

A summary of the Vickery Groundwater Investigation Program core test work results is provided in **Table 8**. These results can be regarded as lower limits for use in model calibration, as cores do not capture the bulk hydraulic conductivity of the rockmass. In most cases secondary features, such as joints, fractures, faults and bedding plane partings, increase bulk hydraulic conductivity.

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).

Table 8 Core Hydraulic Conductivity Test Results from the Vickery Groundwater Investigation Program

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

Source: GESPL (2012)

4 GROUNDWATER MODELLING

4.1 MODEL SOFTWARE AND CONFIDENCE LEVEL

Groundwater modelling has been conducted in accordance with the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012). As this is mostly a generic guide, there are no specific guidelines on special applications, such as coal mine modelling.

The 2012 guide has replaced the “model complexity classification” of the previous guideline 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.

Numerical modelling was conducted using MODFLOW-USG Beta. Details of the model setup are listed in **Table 9**.

Table 9 Model Setup

Model aspect	Set-up	Details / key settings
Model code	MODFLOW-USG Beta	(Panday et al., 2013)
GUI	Groundwater Vistas, Version 6.84	Environmental Simulations Inc.
Model area & units	33 km x 29 km; 957 km^2	Length = metres, Time = days
Grid	Rectangular; regular	1.34 million cells; 100 m x 100 m
Grid rotation	None	
Layers and layer types	14 Layers	All layers unconfined (Type 3)
Unsaturated flow	Upstream weighting Richards equation[1]	Unsaturated zone properties: Alpha = 0.3 Beta = 2 Resid-Sat = 0.05 B-Corey = 2
Vertical conductance	Vertical K	LPF with NOVFC and CONSTANTCV
Solver	SMS	XMD HCLOSE = 0.001 m
Run modes	Initial calibration Transient calibration Verification Prediction	See Section 4.7
Calibration data	Heads (piezometers; VWP) Flow (mine inflow)	See Section 4.8
Boundary conditions (Additional detail provided below)	RCH	Aquifer recharge
	RIV	Rivers, ephemeral streams
	DRN	Mine drainage
	GHB	Boundary flow (some model edges)
	WEL	Pumping bores
	TVM	Temporal variation in aquifer conditions (mining, waste rock emplacement)

1 Attempts to run simulations without Rickards Equation were unsuccessful.

4.2 PREVIOUS MODELLING

Douglas Partners (2010) developed a local area groundwater model for the Rocglen Coal Mine. The Rocglen Coal Mine model was evaluated for use in the previous (Heritage Computing, 2012) 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 the Tarrawonga Coal Mine.

The Tarrawonga Coal Mine regional numerical groundwater model (Heritage Computing, 2011) was evaluated and considered as to whether it would provide a suitable basis for the original modelling of the Approved Mine (Heritage Computing, 2012). This model area would have required extension to the south by about 6 km (to northing 6580000) and inclusion of the Bluevale and Cranleigh coal seams, which do not occur at the Tarrawonga Coal Mine.

However, the Tarrawonga model (Heritage Computing, 2011) demonstrated that drawdown influence from the Tarrawonga, Maules Creek and Boggabri Coal Mines would not reach the Vickery Coal Mine. It is, therefore, reasonable to assume that the Project mining effects would not propagate to the Tarrawonga Coal Mine. Hence, a model focusing on the Vickery Coal Mine was developed as the model for assessing the Approved Mine.

The current HydroSimulations model for this Project uses the same total area as the previous (Heritage Computing, 2012) model for the Approved Mine. The current model has been converted from the previous MODFLOW-SURFACT model with an irregular cell mesh, to MODFLOW-USG Beta with a regular cell mesh.

4.3 MODEL EXTENT

The area of the regional numerical groundwater model for this Project includes the Rocglen Coal Mine to the east, the Tarrawonga Coal Mine to the north, as well as significant agricultural groundwater extraction from bores accessing the Upper Namoi Alluvium. The model area, shown on **Figure 35,** lies within MGA eastings 209000 and 242000 and MGA northings 6580000 and 6609000 (i.e. 33 km east-west by 29 km north-south for a total area of 957 km^2).

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*.

4.4 MODEL LAYERS

The regional hydrogeological units have been approximated using 14 model layers (**Figure 34**). The layering is also summarised later in **Table 13**.

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 DPI Water 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 (Heritage Computing, 2011). The targeted coal seams in the Project model are divided into two main groups: the upper seams and the lower seams (**Section 2.5**). The upper group of seams, which includes Gundawarra, Kurrumbede, Welkeree, 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).

4.5 MODEL GEOMETRY

The groundwater model domain has been discretised using uniform 100 m x 100 m cells, resulting in 1.34 million cells over 14 layers, comprising 290 rows and 330 columns[3] (**Figure 35**).

The modelled stratigraphic section has five major groupings of coal seams (Layers 4, 6, 8, 10 and 12) separated by overburden/interburden/underburden and sandstone/siltstone sediments (Layers 3, 5, 7, 9, 11 and 13). Layers 1 and 2 accommodate alluvium, regolith and overburden in rock outcrop areas. Layer 14 represents the Boggabri Volcanics.

The overburden/interburden/coal seam outcrops on the western and eastern sides of the model. Therefore, the model contains several thin (dummy) layers in the centre of the model area from Layers 2 to 13.

The geometry of the coal seams is defined by the floor elevation of named seams (i.e. 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 mining area to define the stratigraphy throughout the model area, guided by median thicknesses from exploration drilling.

The hydraulic properties were initially based on those used in the Heritage Computing (2012) model for the Approved Mine.

4.6 MODEL STRESSES AND BOUNDARY CONDITIONS

The Mooki Thrust forms a natural boundary along the eastern edge of the model. It is, therefore, approximated as a no-flow boundary due to the exposure of low hydraulic conductivity rocks of Carboniferous age on the eastern side of the boundary. A no-flow boundary has also been defined along the northern edge of the model area due to the exposure of low hydraulic conductivity rocks (**Figure 35**). The southern and western boundaries are represented by general head boundary conditions with heads set at the regional water table, as shown in **Figure 19.** All layers have the same no-flow and general head boundaries.

3 The previous model had variable cell sizes from 50 m to 500 m (263 rows, 338 columns).

Major and minor streams are established as river cells in model Layer 1 using the MODFLOW river package, with occasional representation in Layers 2 and 3. The river 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 water table breaches the bed elevation of the stream, but will not provide a source of water for the groundwater system. This feature has been implemented for the ephemeral streams across the Project mining area. The river bed conductance varies from 0.05 to 75 square metres per day (m^2/day), with a median value of 0.1 m^2/day. The equivalent leakage coefficients are 0.003 to 0.03 per day 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 drain 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 either a percentage of actual rainfall (for transient calibration), or long-term average rainfall (for prediction simulations) across the following zones (**Figure 36**):

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

The recharge rates were initially based on those used in the Heritage Computing (2012) model for the Approved Mine.

Historical pumping from the Upper Namoi Alluvium groundwater system has been included in the transient calibration period (not the initial calibration simulation) in agreement with the stresses imposed in the DPI Water regional model for the Upper Namoi Alluvium groundwater system. During the prediction phase the pumping that occurred in 2010 has been assumed to continue at a constant rate[4].

Evapotranspiration has been applied uniformly using MODFLOW's linear function with a maximum rate of 140 mm/yr and an extinction depth of 3 m. The choice of values would not be sensitive, as Section 3 has noted that evapotranspiration would not be an important natural process on the mine site or on the adjacent alluvium due to depths to the water table being in excess of 3 m.

4 Actual pumping records are not readily available to the public.

Waste rock would be placed within the footprint of the open cut void as the extraction proceeds. Emplaced waste rock has been given uniform hydraulic conductivity of 1 m/day, specific yield of 10% and rainfall recharge set to 5% of average rainfall. The final void was given a higher hydraulic conductivity of 1,000 m/day, specific yield of 1.0 and rainfall recharge equal to 100% of average rainfall. The hydraulic properties were varied with time using the TVM package of MODFLOW-USG Beta.

4.7 MODEL SIMULATIONS

Five model simulations were conducted as follows:

1. Initial calibration simulation (pre-mining and pre-pumping)

Initial calibration of hydraulic properties was conducted to replicate regional groundwater levels, using data unaffected by mining and groundwater pumping from the Upper Namoi Alluvium groundwater system. The groundwater levels from this calibration simulation were then used to provide the initial heads for the transient calibration simulation.

2. Transient calibration simulation (2006 – 2011)

Transient calibration included calibration of hydraulic properties versus time, groundwater hydrographs at Project and other mine monitoring bores, and DPI Water observation bores in the Upper Namoi Alluvium. The transient calibration also included rainfall recharge, historical pumping from the Upper Namoi Alluvium groundwater system, and historical mining (e.g. Rocglen Coal Mine) based on monthly stress periods from 2006 to 2011.

3. Verification (2012 – 2017)

Verification included verification of hydraulic properties (hydraulic conductivity and specific yield) versus groundwater hygrographs at Project and other mine-monitoring bores, and DPI Water observation bores in the Upper Namoi Alluvium. The verification also included rainfall recharge, historical pumping from the Upper Namoi Alluvium groundwater system, and historical mining based on six monthly stress periods from 2012 to 2017.

4. Transient prediction simulation (incremental and cumulative effects)

Transient predictions included simulation of the annual progression of open cut mining, allowing for time-varying properties for mine waste rock (hydraulic conductivity and specific yield) and rainfall recharge. Other potential impacts of Project development t on the groundwater regime, including stream-groundwater system interaction, alluvium-coal interaction and mining influence on GDEs and mine inflow rates were simulated. Long-term average rainfall recharge was included and pumping that occurred from the Upper Namoi Alluvium groundwater system in 2010 has been assumed to continue at a constant rate. The prediction simulations used an annual stress period from 2018 to 2044. Three prediction scenarios were simulated:

1. Baseline scenario – Rocglen and Tarrawonga Coal Mines operating without the Project.
2. Cumulative scenario – the Project, Rocglen and Tarrawonga Coal Mines operating at the same time.
3. Blue Vale Void Water Storage – the Cumulative Scenario operating, with the use of the Blue Vale Void as a water storage.

5. Transient recovery simulation

In this phase, groundwater level recovery close to equilibrium for the final landform and open cut void was simulated.

Figure 37 summarises the stress period setup in the model, as well as the sequencing of open cut operations, waste rock emplacement and timing of establishing the final void.

4.8 INITIAL CALIBRATION (PRE-MINING)

A long-term initial calibration was conducted with the aim of reproducing pre-mine and pre-pumping groundwater levels, as shown contoured in **Figure 19**. Initial heads were provided by the observed water table contours shown in **Figure 19**, and the initial hydraulic properties were based on those used in the Heritage Computing (2012) model for the Approved Mine.

The groundwater levels in **Figure 19** are based on contouring of a limited set of measured values that were outside the influence of mining and also included adjustments made for the effects of pumping. This same dataset was used as the calibration targets for the initial calibration simulation. Thus, only some of the monitoring bore records associated with the Vickery, Canyon, Tarrawonga and Rocglen Coal Mines, and all DPI Water observation bores within the model area, were included in the model calibration. **Table 10** shows the number of monitoring targets at each mine site.

Table 10 Initial Calibration Monitoring Targets

Site	No. of Monitoring Targets
Tarrawonga	13
Canyon	12
Rocglen	15
Vickery	58
DPI Water	54
Total	**152**

To achieve the initial calibrated groundwater levels before Upper Namoi Alluvial pumping and mining in the region a 10,000-year transient run was used to allow groundwater levels in the Project mining area to reach equilibrium. This was done instead of using steady state simulation, because strong hydraulic conductivity contrasts in the region would have led to numerical instability. The extended run time period was necessary because of the very low hydraulic conductivities of the Maules Creek Formation and Boggabri Volcanics.

4.8.1 INITIAL CALIBRATION PERFORMANCE

The modelled groundwater level contours for the initial calibration are shown in **Figure 38** for comparison with the observed groundwater level contours pre-mining and pre-pumping in **Figure 19.** Differences in the contours are due to resolution between the plotted contours and those generated by the model that also include the effects of outcrops.

The scattergram of modelled versus observed heads in **Figure 41** demonstrates good agreement across the whole range of measurements. There is no bias towards overestimation or underestimation.

The overall performance of the initial (before mining and pumping) calibration is quantified by a number of statistics in **Table 11**. The key statistic is 6.3% Scaled Root Mean Square (SRMS), which is within the groundwater modelling guideline value of 5-10% (MDBC, 2001; Barnett et al., 2012) for acceptable model calibration.

Table 11 Initial Calibration Performance

Calibration Statistics	Value
Root Mean Square (RMS) (m)	4.1
Scaled Root Mean Square (SRMS) (%)	6.3
Average residual (m)	2.8

4.8.2 INITIAL CALIBRATION WATER BALANCE

The water balance at the end of the initial (before mining and pumping) calibration period across the entire model area is summarised in **Table 12**. The average inflow (recharge) to the groundwater system was approximately 35 ML/d, comprising mainly rainfall recharge (43%) and natural leakage from streams into the groundwater system (35%).

Aquifer outflow from the model domain accounts for the majority of groundwater discharge (60%), followed by stream baseflow (31%). Evapotranspiration is a relatively small proportion of the total model water loss (9%).

Table 12 Simulated Initial Calibration Water Balance

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	15.1	-
Evapotranspiration	-	3.0
Rivers/Creeks	12.4	11.0
Production Bores	-	-
Mines	-	-
Boundary Flow	7.8	21.3
TOTAL	**35.3**	**35.3**
Storage	**-**	
Discrepancy (%)	**0.00**	

4.9 TRANSIENT CALIBRATION (2006 – 2011)

The transient calibration was conducted for the time period January 2006 to December 2011, based on 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. The initial hydraulic properties were based on those used in the Heritage Computing (2012) model for the Approved Mine, which were then updated based on the initial calibration.

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 initial calibration as shown in **Figure 38** and discussed previously.

All time data in monitoring bores associated with the Vickery, Canyon, Rocglen and Tarrawonga Coal Mines, and all DPI Water observation bores within the model area, were included in this model calibration. A reduced weighting was applied to VWP monitoring data (generally 0.5) as some of the sensors are still equilibrating and are, therefore, considered inaccurate, as discussed in **Section 2.10**.[5]

The use of target weighting ensured that the transient calibration is focused on reliable data from the Project mining area.

Data over the period January 2006 to December 2011 was used for 152 monitoring locations shown in **Table 10**, resulting in 2,867 transient calibration head targets. Calibration was conducted manually.

4.9.1 PIT INFLOWS

Predicted average annual pit inflows to the Rocglen and Tarrawonga Coal Mines and former Canyon Coal Mine over the transient calibration and verification periods are shown in **Figure 40**.

For calibration purposes groundwater inflow records at neighbouring mines have not been used, as the inflow volumes are so low that they are largely consumed by evaporation off wall seeps and floor pools (**Section 2.12**). However, modelled pit inflows from the Project groundwater model compare well with previous modelling:

- The Douglas Partners (2010) groundwater modelling of the Rocglen Coal Mine predicted mine inflows of 0.5 to 1.0 ML/d. The Project groundwater model predicted average pit inflows of 0.8 ML/d at the Rocglen Coal Mine.

- The Heritage Computing (2011) groundwater modelling of the Tarrawonga Coal Mine predicted mine inflows of 0.4 to 0.5 ML/d, while observations of pit pumping volumes (including rain water and surface runoff) averaged 0.2 ML/d for the first six years. The Project groundwater model predicted average pit inflows of 0.09 ML/d at the Tarrawonga Coal Mine.

- The Project groundwater model predicted pit inflows of 0.2 ML/d at the Canyon Coal Mine, before it ceased operation in 2009.

4.9.2 CALIBRATED MODEL PROPERTIES

Table 13 summarises the hydraulic properties for all hydrogeological units at the end of transient calibration. The values for horizontal hydraulic conductivity (Kx) are consistent with field estimates listed in **Table 7** and with estimates from other models. Vertical hydraulic conductivity (Kz) is one order of magnitude lower than horizontal hydraulic conductivity.

[5] VWP data is also considered to have a low inherent accuracy level (of the order of about +/- 10m).

Table 13 **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
		Regolith/Weathered Permian	0.01	0.001	$1x10^{-4}$	0.01
2		Alluvium	0.35-40	0.05	0.005	0.2
		Overburden/Weathered Permian	0.01	0.001	$1x10^{-4}$	0.01
3		Overburden	$3x10^{-4}$	$3x10^{-5}$	$5x10^{-5}$	0.005
4		Braymont Seam to Jeralong Seam	$4x10^{-3}$	$4x10^{-5}$	$1x10^{-4}$	0.01
5		Interburden	$4x10^{-4}$	$4x10^{-5}$	$5x10^{-5}$	0.005
6		Merriown Seam to Velyama Seam	$4x10^{-3}$	$4x10^{-4}$	$1x10^{-4}$	0.01
7		Interburden	$4x10^{-4}$	$4x10^{-5}$	$5x10^{-5}$	0.005
8		Nagero Upper Seam	$3x10^{-3}$	$3x10^{-4}$	$1x10^{-4}$	0.01
9		Interburden	$3x10^{-4}$	$3x10^{-5}$	$5x10^{-5}$	0.005
10		Tralee Seam to Stratford Seam	$5x10^{-3}$	$5x10^{-4}$	$1x10^{-4}$	0.01
11		Interburden	$3x10^{-4}$	$3x10^{-5}$	$5x10^{-5}$	0.005
12		Bluevale to Cranleigh Seam (Whitehaven Seam)	$5x10^{-3}$	$5x10^{-4}$	$1x10^{-4}$	0.01
13		Underburden	$3x10^{-4}$	$3x10^{-5}$	$5x10^{-5}$	0.005
14		Volcanics	$2.5x10^{-3}$	$2.5x10^{-4}$	$1x10^{-4}$	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): 1.0%
- Maules Creek Formation Vickery Area (Zone 2): 0.01%
- Maules Creek Formation Tarrawonga Area (Zone 3): 0.01%
- Boggabri Volcanics (Zone 4): 0.01%
- Rock-alluvium contacts (Zone 5): 12%

4.9.3 TRANSIENT CALIBRATION PERFORMANCE

A scattergram of modelled versus observed heads in **Figure 42** 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 14**. The key statistic is 5.0% SRMS, which is within the groundwater modelling guideline value of 5-10% (MDBC, 2001; Barnett et al., 2012) for acceptable model calibration. This performance is consistent with the Heritage Computing (2012) model for the Approved Mine.

Table 14 Transient Calibration Performance

Calibration Statistics	Value
Root Mean Square (RMS) (m)	3.7
Scaled Root Mean Square (SRMS) (%)	5.0
Average residual (m)	2.2

Transient calibration hydrographs showing modelled and observed heads over time for all monitoring locations are shown in **Appendix D**. **Figure 43** to **Figure 47** show comparisons of simulated and observed groundwater levels at representative sites associated with the DPI Water observation bores, Tarrawonga, Canyon, Rocglen and Vickery Coal Mines (for calibration and verification periods). Model water level trends and absolute elevations, in the majority of cases, are consistent with the observed water levels.

None of the DPI Water alluvial bores are affected by mining, but the deeper alluvial bores show characteristic responses to agricultural pumping. The responses to stresses are simulated well 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[6] (**Figure 43**). Only one Tarrawonga Coal Mine bore (MW7, see **Appendix D**) shows a mining response. Transient calibration has not focused on bores affected by drawdown from the Tarrawonga Coal Mine (which is more than 10 km away). The local stresses due to the final stages of the mining at the Canyon Coal Mine, and the residual void, are replicated well by the model (**Figure 45**). The model underestimates water levels at the Rocglen Coal Mine at MP-2, although the water level fluctuations are well represented (**Figure 46**). Groundwater levels at the Project in the alluvium and Maules Creek Formation are generally well represented (**Figure 47**).

4.9.4 TRANSIENT WATER BALANCE

The water balance at the end of the transient calibration period across the entire model area is summarised in **Table 15**. The average inflow (recharge) to the groundwater system was approximately 70 ML/d, comprising mainly rainfall recharge (25%) and leakage from streams into the groundwater system (46%). The leakage from all streams is simulated to be about 32 ML/d. Boundary inflow was also significant (29%).

Production bore abstraction accounts for the majority of the groundwater discharge (68%) followed by aquifer outflow from the model domain (16%) and stream baseflow (11%). Evapotranspiration is a relatively small proportion of the total model water loss (4%). The computed inflow to all mines (0.6 ML/day) is about 1% of the total groundwater discharge over the model area. Transient losses to irrigation pumping in excess of rainfall and river recharge are represented by the loss of storage from the aquifer (~5ML/d).

6 And lack of publicly available abstraction data after 2010.

Table 15 Simulated Average Water Balance During the Transient Calibration Period

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	17.4	-
Evapotranspiration	-	2.8
Rivers/Creeks	32.6	8.0
Production Bores	-	52.0
Mines	-	0.6
Boundary Flow	20.2	12.1
TOTAL	**70.2**	**75.6**
Storage	**5.4 LOSS**	
Discrepancy (%)	**0.00**	

4.10 VERIFICATION (2012 – 2017)

The verification simulation was conducted for the period from January 2012 to December 2017, based on six monthly stress periods till the end of 2015, then yearly stress periods to the end of 2017. The hydraulic properties that were used in the transient calibration, as shown in **Table 13**, were also used for the verification period. Longer stress periods (yearly) were used in the verification period compared to the transient calibration period (monthly). The aim of the verification simulation was to replicate average long-term groundwater levels, not to represent monthly responses to rainfall recharge or historical pumping from the Upper Namoi Alluvium groundwater system.

Monitoring bores associated with the Vickery, Canyon, Rocglen and Tarrawonga Coal Mines, and all DPI Water observation bores within the model area, have been included in the verification simulation. A reduced weighting was applied to VWP monitoring data (generally 0.5) as many of the sensors are still equilibrating and are therefore considered inaccurate, as discussed in **Section 2.10**.[7]

Data over the period January 2012 to December 2017 was used for 152 monitoring locations shown in **Table 10**, resulting in 3,195 verification head targets.

4.10.1 VERIFICATION PERFORMANCE

The modelled water table contours at the end of the verification period (December 2017) are shown in **Figure 39** for comparison with the observed water table contours at the end of 2017 shown in **Figure 20.**

The overall performance of the verification is quantified by statistics shown in **Table 16**. The key statistic is 7.1% SRMS, which is within the groundwater modelling guideline value of 5-10% (MDBC, 2001; Barnett et al., 2012) for acceptable model calibration.

[7] VWP data is also considered to have a low inherent accuracy level (of the order of about +/- 10m).

Table 16 Verification Performance

Calibration Statistics	Value
Root Mean Square (RMS) (m)	5.0
Scaled Root Mean Square (SRMS) (%)	7.1
Average residual (m)	3.3

The SRMS for the verification period (7.1%) is slightly increased compared to the transient calibration period (5.0%). The longer stress periods (yearly) used in the verification period compared to the calibration period (monthly) mean that simulation of short-term fluctuations in response to rainfall recharge and pumping in the verification period is not possible. However, the average long-term groundwater levels are well represented in the verification period, as shown in the representative calibration hydrographs in **Figure 43** to **Figure 47**. Transient calibration hydrographs showing modelled and observed heads over time for all monitoring locations are shown in **Appendix D**, including the model verification period.

4.10.2 VERIFICATION WATER BALANCE

The water balance at the end of the verification period across the entire model area is summarised in **Table 17**. The average inflow (recharge) to the groundwater system was approximately 55 ML/d, comprising of rainfall recharge (27%), leakage from streams into the groundwater system (45%) and boundary inflow (28%).

Production bore abstraction accounts for the majority of the groundwater discharge (55%), followed by aquifer outflow from the model domain (21%) and stream baseflow (18%). Evapotranspiration is a relatively small proportion of the total model water loss (5%). The computed inflow to all mines (0.9 ML/day) is about 1% of the total groundwater discharge over the model area.

The water balance during the verification period (**Table 17**) is comparable to the water balance during the calibration period (**Table 15**).

Table 17 Simulated Average Water Balance During the Verification Period

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	14.9	-
Evapotranspiration	-	2.6
Rivers/Creeks	24.8	10.0
Production Bores	-	31.0
Mines	-	0.9
Boundary Flow	15.3	11.6
TOTAL	**55.0**	**56.1**
Storage	**1.1 LOSS**	
Discrepancy (%)	**0.00**	

4.11 SENSITIVITY ANALYSIS

Parameter sensitivity is a measure of how much the model output changes (for example, as measured by the calibration statistics), when the parameter is changed by a given amount. A parameter that is insensitive can be varied by a large amount without having a significant effect on the model calibration or prediction. On the other hand, very small changes to a highly sensitive parameter may have a large influence on the calibration performance or model prediction. It is important to identify the most sensitive parameters with respect to model calibration performance and prediction, because uncertainty in a sensitive parameter can translate to uncertainty in the prediction. Prediction uncertainty is considered further in **Section 7.2**.

As described in **Sections 4.8 and 4.9**, the groundwater model was calibrated by varying a large number of parameters related to rock mass permeability and storage to match groundwater level and mine inflow time-series data. The model run time (10+ hours) precluded a full PEST-based sensitivity analysis. However, information on parameter sensitivities was obtained through observations during the calibration process. The most sensitive parameters with respect to calibration of measured groundwater levels and mine inflows were found to be:

- Vertical hydraulic conductivity of the coal measures (Kv).
- Horizontal hydraulic conductivity of the coal measures (Kh).
- Specific yield in the alluvium (for transient calibration of hydrographs).

5 MODEL RESULTS

As described in **Section 4.7**, the transient prediction simulation was operated in two different modes:

1. Baseline scenario – Rocglen and Tarrawonga Coal Mines operating without the Project.

2. Cumulative scenario – the Project, Rocglen and Tarrawonga Coal Mines operating at the same time.

5.1 MINING SCHEDULE

Using the hydraulic properties from the transient calibration the model was run from January 2018 (after the end of the verification period) to December 2044 in annual steps. The Project commenced in the model in January 2020 and finished in December 2044. The Tarrawonga Coal Mine was active from January 2006 to the end of 2030, and the Rocglen Coal Mine was active from January 2009 to the end of 2020 (**Figure 37** and **Figure 48**).

Mining was modelled using drain cells with the sequencing of the mine progression as shown in **Figure 48**.

Waste rock is deposited both inside and outside the pit. Placement of waste rock within the footprint of the open cut void was simulated as the extraction proceeded. Waste rock has been given uniform hydraulic conductivity of 1 m/day, specific yield of 10% and rainfall recharge set to 5% of average rainfall. Waste rock hydraulic properties and increased recharge were applied one year after mining commenced (i.e. one year after the mine progression shown in **Figure 48** began). The hydraulic properties were varied with time using the TVM package of MODFLOW-USG Beta.

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 from July 2009 to June 2010 were assumed to continue at a constant rate.

The progression of mining in the model was consistent with the respective EAs for the Tarrawonga Coal Mine and Rocglen Coal Mine.

5.2 CHANGES TO THE WATER BALANCE

The modelled water balance for the entire model has been averaged over the 25 years of the Project mine life for the baseline scenario and the cumulative scenario (**Table 18**).

For the baseline scenario recharge is dominated by river/creek leakage (44%), rainfall infiltration (28%) and boundary flow (28%). Groundwater pumping by irrigation bores accounts for 56% of groundwater discharge from the model area. The other significant discharge mechanisms are boundary flow (21%) and river/creek baseflow (18%). Average inflow to the Rocglen and Tarrawonga Coal Mines over the Project mine life is predicted to be 0.4 ML/day, which equates to 1% of all groundwater discharge.

For the cumulative scenario the Project is predicted add about 0.8 ML/day on average, to the inflow at the Rocglen and Tarrawonga Coal Mines. This increase is supplied primarily from groundwater storage. There is expected to be negligible reduction in groundwater discharge to rivers and creeks (<0.01 ML/day). There is expected to be a slight increase in rainfall recharge (0.6 ML/d) due to infiltration through the waste rock emplacement.

Table 18 Simulated Average Water Balance for the Prediction Model During the Project Period

Component	Groundwater Inflow (Recharge) (ML/day)		Groundwater Outflow (Discharge) (ML/day)	
	Baseline Scenario	Cumulative Scenario	Baseline Scenario	Cumulative Scenario
Rainfall Recharge	15.8	16.4	-	-
Evapotranspiration	-	-	2.5	2.5
Rivers/Creeks	24.8	24.8	9.9	9.9
Production Bores	-	-	31.0	31.0
Mines	-	-	0.4	1.2
Boundary Flow	15.4	15.4	11.6	11.6
TOTAL	**56.0**	**56.6**	**55.5**	**56.3**
Storage	**0.5 LOSS**	**1.0 LOSS**	**-**	**-**

5.3 PREDICTED GROUNDWATER INFLOW TO MINING PIT

The time-varying pit inflows predicted by the model are shown in **Figure 49** and **Table 21** for the cumulative scenario.

The Project inflow is expected to vary between 0.01 and 1.42 ML/day during the mine life.

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

5.4 PREDICTED DRAWDOWN OF GROUNDWATER LEVELS

Modelled water table drawdowns at the end of Project mining are shown in **Figure 50** and **Figure 51**. Water table drawdown is shown for the cumulative scenario (**Figure 50**) and for the Project only (calculated from the difference between the baseline and cumulative scenarios in (**Figure 51**).

The water table drawdown for the cumulative scenario at the end of Project mining (**Figure 50**) shows that the outer 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 at the end of Project mining (**Figure 50**).

Similarly, for the Project only, the 1 m water table drawdown contour remains within the Maules Creek Formation and does not extend into the Upper Namoi Alluvium boundary at the end of Project mining (**Figure 51**).

Modelled groundwater level contour plots at the end of Project mining for the cumulative scenarios for different model layers are shown in **Appendix E**.

5.5 PREDICTED GROUNDWATER FLOW

5.5.1 POROUS ROCK

The Maules Creek Formation at the Project is part of the NSW Murray-Darling Basin Porous Rock Groundwater Source (**Section 2.7**). Groundwater inflow to the pit is provided by a loss in storage from the Maules Creek Formation.

Figure 49 and **Table 21** show that the predicted pit inflow, and therefore loss from the Maules Creek Formation, during the Project is expected to vary between 0.01 ML/day and 1.42 ML/day.

5.5.2 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 Alluvium Groundwater Source.

Groundwater would not be lost directly from the alluvium to the pit, 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 has been examined for the Upper Namoi Zone 4 Alluvium.

The increase in flux from the alluvium to the hard rock during the Project and post-mining is presented in **Figure 52** and **Table 21**. During the Project mining period, the average increase in flux from the alluvium to the porous rock is 0.007 ML/d, with a maximum value (Project year 25) of 0.045 ML/d (see **Table 21)**. A maximum increase in total flux of about 0.1 ML/d is predicted from 2073 to 2094 post-mining (see **Figure 52)**. The drawdown from the Project will continue to extend post-mining due to the low permeability of the Maules Creek Formation. This will result in an increasing flux from the alluvium to the hard rock, post-mining.

5.5.3 WESTERN EMPLACEMENT SEEPAGE

The Western Emplacement (**Figure 2**) overlaps a thin alluvium embayment to the north-west of the open cut. There is potential for seepage to occur from the emplacement to the alluvium in this area. The potential for seepage was assessed by assigning different zones to the alluvium and the emplacement to determine the groundwater flow between these units. During the Project period the average groundwater flow from the Western Emplacement to alluvium is 0.013 ML/d for the cumulative scenario. The average flow increased to 0.032 ML/d during the initial 20 years of recovery, before reaching a long-term equilibrium flow of 0.022 ML/d from the emplacement to the alluvium (**Table 19**).

Table 19 Average Flow from Western Emplacement to Alluvium (ML/d)

Model scenario	Project mining	Initial recovery (20 years post-mining)	Long-term recovery (20-100 years post-mining)
Baseline	0.012	0.029	0.022
Cumulative	0.013	0.032	0.022

The long-term flow of water from the Western Emplacement to the alluvium is restricted by the residual final void, which operates as a strong sink (**Section 5.8**).

5.6 PREDICTED BASEFLOW CHANGES

Surface water/groundwater exchanges have been examined between the Upper Namoi Alluvium, and the Namoi River and Driggle Draggle Creek, respectively (**Figure 53**). The other streams located near the Project are ephemeral streams that are dry most of the time.

Figure 54 and **Figure 55** show the simulated exchange of water between a stream and the groundwater system for a 4 km reach of the Namoi River to the immediate west of the Project mining area and a 28 km section of Driggle Draggle Creek (Reaches 20 and 9 respectively, locations shown in **Figure 53**), for the baseline (Rocglen and Tarrawonga Coal Mines operating without the Project) and cumulative (Project, Rocglen and Tarrawonga Coal Mines operating) prediction scenarios. A positive river flux indicates river leakage (flow from surface water to groundwater) and a negative river flux indicates baseflow (flow from groundwater to surface water).

The Namoi River 4 km reach has no significant water exchange for the baseline scenario, with a possible increased leakage of about $2x10^{-4}$ ML/day for the cumulative scenario, which is insignificant compared to normal river flow. Driggle Draggle Creek has a constant baseflow discharge of about 0.026 ML/day (average $9x10^{-4}$ ML/day/km). There are insignificant reductions in the baseflow of about $5x10^{-4}$ and 0.001 ML/day for the baseline and cumulative scenarios respectively.

There is a small predicted increase in river leakage from the 4 km reach of the Namoi River to the immediate west of the Project mining area. As shown in **Figure 56a** and **Table 21**, average river leakage is expected to increase to about $1x10^{-4}$ ML/day at the end of the Project in 2044, and then to increase over about 50 years and stabilise at approximately $2x10^{-4}$ ML/day. There is a small predicted increase in river leakage across the whole of the Namoi River within the model domain (56 km). As shown in **Figure 56b** and **Table 21**, average river leakage is expected to increase by about 0.03 ML/day (i.e. less than $6x10^{-4}$ ML/day/km) at the end of the Project in 2044 (**Table 21**) and to peak at less than 0.075 ML/day in the 2080s, and then stabilise at a slightly lower level.

5.7 BLUE VALE VOID WATER STORAGE

The third transient prediction simulation 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 mAHD 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 (**Figure 53**).

5.7.1 PREDICTED CHANGES IN NAMOI RIVER BASEFLOW

Figure 57 shows the simulated stream baseflow for the 4 km reach of the Namoi River with and without the Blue Vale void. During the period of mining, water storage in the void would mitigate the effects of mining, which otherwise would cause the insignificant river leakage described in Section 5.6 (i.e. with water storage in the Blue Vale void, the 4 km Namoi River reach is predicted to have no significant water exchange).

Driggle Draggle Creek is also predicted to experience a minor reduction in baseflow due to the water storage, of about 3×10^{-04} ML/day, which is about 1% of the constant baseflow discharge of about 0.026 ML/day (**Figure 58**).

5.7.2 PREDICTED CHANGES IN SURFACE WATER QUALITY

There is limited potential for solute migration into the 4 km reach of the Namoi River to the immediate west of the Project from the planned use of the Blue Vale void as an intermittent water storage, given the predicted changes to baseflow from mining described above in **Section 5.7.1** (i.e. insignificant change in groundwater discharge to the Namoi River).

Notwithstanding, to conservatively assess potential changes to surface water quality, solute migration has been estimated assuming that any hydraulic gradient from the water stored in the Blue Vale void toward the Namoi River (to the west) is not affected by depressurisation associated with open cut mining for the Project (to the east).

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 2.11). The outflow from the Blue Vale water storage towards the Namoi River is predicted to be about 0.015 ML/day. Consequently, the mass of dissolved solids that could migrate from the water storage would be about 38 kg/day (about 14 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. Beneath the river, there is a 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 alluvium-regolith 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:

$$VD = K\left({}^{\Delta h}/_{\Delta L}\right) \qquad (1)$$

$$VS = {}^{VD}/_{n} \qquad (2)$$

$$t = {}^{L}/_{VS} \qquad (3)$$

where: VD is Darcy velocity (m/d)

K is hydraulic conductivity (m/d)

${}^{\Delta h}/_{\Delta L}$ is the hydraulic gradient

VS is seepage velocity (m/d)

n is effective porosity

t is travel time (days)

L is 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.

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 (0.04 t/day), the increase in salt load, and hence salinity, would be approximately 0.03% (i.e. 0.04/140). 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 0.007%.

5.8 POST MINING RECOVERY

A final void water balance was prepared by Advisian (2018) for the Project Surface Water Assessment (Appendix B of the EIS) using a rainfall-runoff model. Estimates of groundwater inflow at varying void water levels were calculated as inputs to the model by HydroSimulations through treating the void in the Project groundwater model as highly permeable water bearing material (K = 1000 m/d; Sy = 1.0). No rainfall recharge or ET was applied to the void, while 5% rainfall recharge was applied to the waste rock emplacement areas.

The results of the post-mining estimates of groundwater inflows from the final void model are presented as an Inflow-Stage curve in **Figure 59**. This curve serves as a lookup table for the final void modelling by Advisian (2018) (Appendix B of the EIS). Priority is given to the modelling results in Appendix B of the EIS rather than the groundwater model estimates; as the groundwater model does not include surface water runoff into the void. The equilibrium long-term groundwater inflow to the final void is expected to be between 0.3 and 0.5 ML/day.

Appendix B of the EIS estimates that the final void would reach a water level of about 125 m AHD approximately 300 years after mining ceases. The equilibrium water levels would be about 125 m lower than current groundwater levels at the final void (Advisian, 2018). Consequently, the void would act as a permanent groundwater sink.

The shallow groundwater level pattern predicted by the groundwater model (without the benefit of extra surface water runoff) is displayed in **Figure 60** at 100 years after the end of the Project. The contours confirm that the final void would act as a strong sink for groundwater entering from all directions.

Representative recovery hydrographs at monitoring bores VKY0036C, VK41C and VKY0043C are displayed in Figure 61. The graphs are ordered north to south with depth increasing from 112 to 242 m below natural surface. As the bores are close to the final void, the groundwater levels are consistent with the areal water level in **Figure 60**. Monitoring bores reach 75% of their equilibrium water levels 10 years, 1 year and 2 years after maximum drawdown, respectively.

6 IMPACTS ON THE GROUNDWATER RESOURCE

6.1 POTENTIAL IMPACTS ON GROUNDWATER

6.1.1 CHANGES IN HYDRAULIC PROPERTIES

Hydraulic properties in the mine footprint would change where waste rock is emplaced in the excavated area (down to the floor of the open cut) at the end of mining. 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 waste rock emplacement areas in **Figure 60**. As the final void is to be located at the south-eastern corner of the excavation, the groundwater flow direction would be reversed from the pre-mining, westerly direction to an easterly direction, post-mining. This would be a permanent change.

6.1.2 CHANGES IN GROUNDWATER FLOW AND QUALITY

As mining progresses the void would act as a groundwater sink. This sink would cause a change in groundwater flow direction towards the void.

The post-mining groundwater level pattern in **Figure 60** shows that the final void would act as a permanent groundwater sink. The final equilibrium groundwater levels are expected to be about 100 m lower than current groundwater levels near the void.

The quality of the inflow water would be a mixture of different source lithologies, primarily coal and coal measures of the Maules Creek Formation and leachate from rainfall infiltration through the waste rock emplacement. The coal and coal measure waters have similar ionic signatures with median EC values of about 4,200 µS/cm and salinities of about 2,600 mg/L.

6.1.3 GEOCHEMISTRY

The Geochemical Assessment undertaken for the Project in Appendix M of the EIS (GEM, 2018) 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). Management measures for PAF materials have been developed for the Project. A minor proportion of sampled material was found to be moderately or highly sodic. Management procedures to counteract erosion potential would be implemented for the Project to avoid downgrading water quality.

Although some coal reject samples had enhanced concentrations of sulphur, selenium and arsenic with the planned co-disposal of this material, GEM (2018) concluded that "*Based on the quantity and low acid capacity of this material, the co-disposed material is expected to be overall NAF*".

GEM (2018) also found that the mine waste rock is typically expected to contain enriched concentrations of Arsenic (As), Boron (B), Antimony (Sb) and Selenium (Se) compared to the average crustal abundance of these elements. As and Se concentrations in mine waste rock are likely to be slightly soluble under the prevailing quasi-neutral pH conditions.

In consideration of the above, and with the adoption of appropriate management measures, there would be negligible impacts to groundwater quality (either directly or via the final open cut void) because of PAF material.

6.1.4 WESTERN EMPLACEMENT SEEPAGE

The proposed Western Emplacement will overlap with an embayment of thin, clay-dominated alluvium near the former Canyon Coal Mine. As discussed in **Section 5.5.3**, there is potential for some seepage to occur between the emplacement material and the alluvium within the embayment (once the groundwater level within the Western Emplacement recovers to an elevation above the alluvium surface).

In **Section 5.5.3**, the maximum long-term seepage rate from the Western Emplacement to the alluvium embayment was determined from the numerical model to be very minor, ranging from 0.03 ML/day during initial recovery to 0.02 ML/day over the long-term. The existing groundwater flow at the Project is generally from east to west. The pre-mining seepage from the weathered coal measures to the alluvium in the embayment is calculated to be in the same order of magnitude as the predicted seepage from the Western Emplacement. The potential groundwater quality impact will, therefore, be related to the change in water quality of the seepage water.

The existing groundwater quality within the alluvium embayment and coal measures near the Project open cut and Western Emplacement, based on groundwater monitoring data, is summarised in **Table** 20. Also shown in **Table 20** is an estimate of the groundwater quality within the emplacement material. While there is some uncertainty regarding the quality of groundwater that accumulates, and from rainfall infiltration in the Western Emplacement, broad constraints can be drawn from Mackie (2009) who carried out extensive leach testing and modelling of fragmented spoil materials from the Hunter Valley of NSW. Mackie's (2009) work indicates that the groundwater quality within spoil heaps depends on the initial quality of the infiltration water (assumed here to mostly comprise of rainwater), the mineralogy and grainsize of the spoils, and the kinetics of mineral dissolution. With the appropriate management of PAF materials, and given overburden/interburden materials are expected to have low potential for soluble salt generation (**Section 6.1.3**), groundwater within the spoils is likely to develop salinities in the range 1,000 mg/L to 5,000 mg/L, depending on the presence of exchangeable sodium (Na) in clay minerals (Mackie, 2009). For this assessment a median value is assumed (~3,000 mg/L).

Table 20 Estimate of Groundwater Quality of Seepage from the Western Emplacement

Unit / lithology	Monitoring bores	Samples (n)	Groundwater salinity (TDS, mg/L)*		
			Median	25th Percentile	75th Percentile
Alluvium (within the embayment)	VNW221, VNW223	28	5,245	4,685	6,010
Maules Creek Formation coal measures near the pit	GW7, GW8, VNW222, VKY34, VKY35, VKY36, VKY42, VKY43, TR7, TR18, TR26, TR35, WVK37, WVK62, WVK501, WVK505, WVK526	70	2,666	1,868	3,443
Spoil (estimate)	Mackie (2009)	N/A	3,000	1,000	5,000

* TDS was calculated from field EC measurements assuming a TDS/EC conversion factor of 0.62 (the average factor for all analyses in the database for which both EC and TDS were determined is 0.62 +/- 0.16 1σ).

Based on the estimates of groundwater and seepage quality in **Table 20**, it is apparent that the seepage from the Western Emplacement into the alluvium embayment is likely to be of significantly lower salinity than the groundwater currently within the shallow alluvium in that location. It can also be concluded that this seepage will have approximately similar salinity to the groundwater in the coal measures adjacent to the alluvium. In addition, while waste rock may contain enriched concentrations of slightly soluble metals (**Section 6.1.3**) the Project would not increase concentration of these metals in comparison to the in-situ material. Therefore, concentrations of these materials in seepage from the Western Emplacement are expected to be similar to existing seepage from the coal measures. In conclusion, the small amount of seepage from the Western Emplacement will cause no adverse water quality impacts to the alluvium.

6.1.5 INDUCED LOSSES FROM CONNECTED WATER SOURCES

Table 21 shows the induced losses from connected water sources based on financial years: from Namoi River to alluvium, from Zone 4 alluvium to porous rock, and from porous rock to the pit. **Table 21** shows that predicted losses from the alluvium and Namoi River are very small. Losses from the porous rock, Upper Namoi Zone 4 Alluvium and the Namoi River are described in detail in **Sections 5.5.1, 5.5.2 and 5.6** respectively.

Partitioning of project pit inflows into takes from the various water sources is summarised in **Section 8.3** in terms of groundwater and surface water licensing requirements.

Table 21 Induced Losses from Connected Water Sources

Project Mining Year	Project Pit Inflows (ML/d)	Upper Namoi (Zone 4) Alluvium Losses to Porous Rock (ML/d)	Namoi River Losses to Alluvium (ML/d)
1	0.762	0.000	0.000
2	0.655	0.000	0.000
3	0.761	0.000	0.000
4	0.850	0.000	0.000
5	0.833	0.000	0.000
6	0.850	0.000	0.001
7	0.799	0.000	0.001
8	0.743	0.000	0.001
9	0.954	0.000	0.001
10	1.351	0.001	0.002
11	1.417	0.001	0.002
12	1.169	0.001	0.002
13	1.050	0.001	0.003
14	1.069	0.002	0.003
15	1.088	0.002	0.004
16	0.834	0.003	0.004
17	0.966	0.004	0.005
18	1.045	0.006	0.006
19	1.010	0.008	0.008
20	0.841	0.012	0.010
21	0.706	0.016	0.012
22	0.745	0.021	0.015

Project Mining Year	Project Pit Inflows (ML/d)	Upper Namoi (Zone 4) Alluvium Losses to Porous Rock (ML/d)	Namoi River Losses to Alluvium (ML/d)
23	0.488	0.028	0.020
24	0.259	0.036	0.025
25	0.006	0.045	0.030

6.1.6 POTENTIAL IMPACTS ON PRIVATELY-OWNED BORES

Table 22 indicates the maximum predicted drawdowns, during mining and recovery, for the privately-owned bores identified during the census.

As illustrated in **Figure 51,** the modelled 1 m water table drawdown at the end of mining is not predicted to extend beyond the boundary of the Maules Creek Formation "island", in which the Project is located. As a result, no privately-owned bores identified during the bore census (see **Section 2.6**) (or any other privately-owned bores that may have been constructed since the bore census) surrounding the Project are predicted to experience greater than "minimal impact", as defined in the AIP, during mining operations (i.e. any drawdown effect would generally be less than 0.2 m and at most 0.61 m and therefore considered to be negligible).

Appendix F provides the maximum predicted drawdowns for bores on Whitehaven owned properties.

Table 22 Predicted Groundwater Drawdown at Privately-owned Bores

Bore Census ID	Cumulative Scenario		Borefield Scenario	
	Predicted Maximum Groundwater Drawdown (m)	Year of Maximum Predicted Drawdown	Predicted Maximum Groundwater Drawdown (m)	Year of Maximum Predicted Drawdown
MR1	<0.2	2100	<0.2	2100
MR2	<0.2	2097	<0.2	2046
MR3	<0.2	2091	<0.2	2053
MR4	<0.2	2097	<0.2	2046
CA1	outside of model active area	n/a	outside of model active area	n/a
CA2	<0.2	2107	<0.2	2107
CA3	<0.2	2107	<0.2	2107
SR1	<0.2	2127	<0.2	2127
SR2	outside of model active area	n/a	outside of model active area	n/a
DM1	<0.2	2104	<0.2	2104
DM2	<0.2	2104	<0.2	2104
WS1	<0.2	2104	<0.2	2104
GB1	<0.2	2094	<0.2	2057
CL1	<0.2	2091	<0.2	2077
CL2	<0.2	2086	<0.2	2075
BR1	<0.2	2097	<0.2	2097
BR2	<0.2	2100	<0.2	2100
BR4	<0.2	2100	<0.2	2100

RB1	0.61	2145	0.61	2145
KH1	outside of model active area	n/a	outside of model active area	n/a
KH2	outside of model active area	n/a	outside of model active area	n/a
KH3	outside of model active area	n/a	outside of model active area	n/a
CR1	<0.2	2111	<0.2	2044
CR2	<0.2	2111	<0.2	2044
CR3	<0.2	2115	<0.2	2044
CR4	<0.2	2119	<0.2	2044
YA1	<0.2	2123	<0.2	2044
NW1	<0.2	2119	<0.2	2044
NW2	<0.2	2142	<0.2	2044
NW3	<0.2	2142	<0.2	2044
NW4	<0.2	2145	<0.2	2044

6.2 POTENTIAL IMPACTS ON SURFACE WATER BODIES

6.2.1 CHANGES IN SURFACE WATER QUALITY

The regional numerical groundwater modelling indicates that the potential for a change in water quality in the Namoi River is negligible, given that the closest reach (of 4 km length) is a losing system under current, pre-mining conditions; the reach would become slightly more so during mining. It is not physically possible for Project mining to cause an increase in the average river salinity, a minimal harm consideration in the AIP.

6.2.2 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 adverse effects on surface ecosystems are anticipated in relation to mining-induced changes to the water system.

6.2.3 FINAL VOID WATER QUALITY

Modelling of the water balance in the final void was carried out both as part of the groundwater modelling and by Advisian (2018) (Appendix B of the EIS). Both approaches indicate that a lake will form within the final void and that the water level will slowly rise to an equilibrium level that is approximately 100 m below the pre-mining groundwater level (and below the rim of the final void). The final open cut void would, therefore, act as an ongoing groundwater sink. Ongoing evaporation of the lake water will lead to progressive increase in salinity. Modelling by Advisian (2018) indicates that in the long-term the lake will become increasingly saline. Because the hydraulic gradient remains towards the void, poorer quality water within the final void would not migrate outside the void; therefore, it would not adversely affect surrounding groundwater resources.

6.3 POTENTIAL IMPACTS ON MATTERS OF NATIONAL ENVIRONMENTAL SIGNIFICANCE

The Project was referred to the Commonwealth Minister for the Environment in February 2016. The Referral Decision made on 14 April 2016 (EPBC Ref: 2016/7649) (and subsequently revised on 12 March 2018) was that the Project is a “controlled action” and, therefore, the Project requires approval under the Commonwealth *Environment Protection and Biodiversity Conservation Act, 1999* (EPBC Act). One of the controlling provisions for the Project is “water resources.”

The elements of the Project which require EPBC Act approval ("the Action") exclude the Approved Mine, which was referred to the Commonwealth in January 2012 and determined not to be a "controlled action", if undertaken in a particular manner. Notwithstanding, the assessment that follows considers the potential impacts of the Action on water resources cumulatively with the Approved Mine, as well as other relevant operations (e.g. Rocglen and Tarrawonga Coal Mines).

6.3.1 POTENTIAL IMPACTS ON HYDROLOGICAL CHARACTERISTICS

The *Significant impact guidelines 1.3: Coal seam gas and large coal mining developments— impacts on water resources* (DotE, 2013) (Significant Impact Guidelines for Water Resources) provide the following guidance on potential impacts of an action on hydrological characteristics:

> *"A significant impact on the hydrological characteristics of a water resource may occur where there are, as a result of the action:*
>
> *a) changes in the water quantity, including the timing of variations in water quantity*
>
> *b) changes in the integrity of hydrological or hydrogeological connections, including substantial structural damage (e.g. large-scale subsidence)*
>
> *c) changes in the area or extent of a water resource where these changes are of sufficient scale or intensity as to significantly reduce the current or future utility of the water resource for third party users, including environmental and other public benefit outcomes."*

Based on the results of the groundwater modelling, the Project would result in negligible changes in water quantity, including the timing of variations in water quantity, given there is predicted to be:

- negligible drawdown (less than 1 m) in the Upper Namoi Alluvium;
- negligible impacts to the utility of water resources for third party users (i.e. no privately-owned bores are predicted to experience greater than 0.61 m drawdown due to the Project);
- no adverse effects on GDEs; and
- negligible induced loss from the Namoi River (maximum of less than 0.1 ML/day).

The Project would result in a localised change in hydrological or hydrogeological connections over the mine footprint and a permanent reversal in groundwater flow direction in the immediate vicinity of the Project (from a westerly direction, pre-mining, to an easterly direction, post-mining). However, these changes are not considered to be of sufficient scale or intensity in order to significantly reduce the current or future utility of the water resource for third party users (including environmental and other public benefit outcomes, particularly given the Maules Creek Formation is considered "less productive" under the AIP and does not currently support any private groundwater users or GDEs). These changes would have a negligible effect on the Upper Namoi Alluvium.

The Project would not result in any changes in the area or the extent of a water resource.

Therefore, it is unlikely that the action would result, directly or indirectly, in a substantial change in the hydrology of groundwater resources.

6.3.2 POTENTIAL IMPACTS ON WATER QUALITY

The *Significant Impact Guidelines for Water Resources* provide the following guidance on potential impacts of an action on water quality:

"A significant impact on a water resource may occur where, as a result of the action:

a) there is a risk that the ability to achieve relevant local or regional water quality objectives would be materially compromised, and as a result the action:

i. creates risks to human or animal health or to the condition of the natural environment as a result of the change in water quality

ii. substantially reduces the amount of water available for human consumptive uses or for other uses, including environmental uses, which are dependent on water of the appropriate quality

iii. causes persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment

iv. seriously affects the habitat or lifecycle of a native species dependent on a water resource, or

v. causes the establishment of an invasive species (or the spread of an existing invasive species) that is harmful to the ecosystem function of the water resource, or

b) there is a significant worsening of local water quality (where current local water quality is superior to local or regional water quality objectives), or

c) high quality water is released into an ecosystem which is adapted to a lower quality of water."

As described in the assessment above:

- the small amount of seepage from the Western Emplacement will cause no adverse water quality impacts to the alluvium;
- there would be negligible impacts to groundwater quality (either directly or via the final open cut void) because of PAF material; and
- it is not physically possible for Project mining to cause an increase in the average river salinity.

Accordingly, the Project would not:

- compromise the ability to achieve relevant local or regional water quality objectives;
- significantly worsen local water quality; or
- release high quality water into an ecosystem adapted to lower quality water.

Therefore, the Project could not be considered to have a significant impact on groundwater quality.

6.3.3 POTENTIAL CUMULATIVE IMPACTS

The Significant Impact Guidelines for Water Resources require the action to be:

> *"considered with other developments, whether past, present or reasonably foreseeable developments."*

The assessment that the Project would not result in a substantial change in the hydrology or significantly impact the quality of groundwater resources (presented in **Sections 6.1** and **6.2**) considers the cumulative impacts of the Action with the Approved Mine as well as the Rocglen and Tarrawonga Coal Mines.

6.3.4 CONSIDERATION OF POTENTIAL FOR SIGNIFICANT IMPACT

Based on the assessment presented above, the action would not result in significant changes to the quantity or quality of water available to third party users or the environment.

Accordingly, the Action would not have a significant impact on water resources.

6.4 WATER SUPPLY BOREFIELD

The site water balance prepared for the Project (Advisian, 2018) identifies that water supplied from the Namoi River and/or groundwater bores (both in accordance with licences held by Whitehaven) would be required to meet on-site water demands for the Project.

Section 8.3 identifies a maximum water licensing requirement of 5 ML/year during the life of the Project, associated with inflows to the open cut under the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003*. By comparison, Whitehaven currently holds 396 unit shares under the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003* (refer to Attachment 6 of the Main Text of the EIS).

Residual Whitehaven entitlements (i.e. beyond what is required for groundwater inflows to the open cut) would be used for consumptive purposes to meet on-site water demands. Water would be extracted using a series of groundwater bores located north of the Project mining area. To minimise potential impacts to other water users, the bores would be positioned in accordance with the requirements of Clause 36 of the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003*. Therefore, unless further assessment is conducted, the groundwater bores would not be located within:

- 100 m of any bore for the supply of basic landholder rights;
- 400 m of a water supply work (bore) not owned by Whitehaven;
- 200 m of a property boundary with an adjoining property not owned by Whitehaven;
- 500 m of a bore nominated by a local water utility access licence;
- 400 m of a Departmental monitoring bore;
- 400 m of a bore extracting from the Great Artesian Basin;
- 200m from a river (including Driggle Draggle Creek); or
- 500 m of a wetland.

6.4.1 APPROACH

The site water balance prepared by Advisian (2018) predicts that the maximum annual water requirement from the groundwater bores ranges between approximately 200 ML/year and 390 ML/year (for the 10%ile and 90%ile probabilities of all climate sequences modelled). The maximum annual water requirement would occur early in the Project life.

The regional numerical model developed for the Project was used to assess the potential groundwater impacts associated with the proposed borefield. To conservatively predict groundwater impacts, a total of 600 ML/year (i.e. ten bores pumping at a combined rate of 1.64 ML/d at the locations shown in **Figure 62**) was modelled over the life of mine. It is assumed that the bores would be installed in the Gunnedah Formation of the Upper Namoi Alluvium (Layer 2 in the numerical model).

The results of two prediction scenarios are presented for comparison:

1. Cumulative scenario - Vickery (incorporating the Project), Rocglen and Tarrawonga mines operating at the same time.

2. Borefield scenario - Vickery (incorporating the Project), Rocglen and Tarrawonga mines operating at the same time. Pumping from the ten proposed water supply bores included.

The prediction scenarios included simulation of the annual progression of open cut mining, allowing for time-varying properties for mine waste rock (hydraulic conductivity and specific yield) and rainfall recharge. Long-term average rainfall recharge was included. Pumping by district landholders that occurred from the Upper Namoi Alluvium groundwater system in 2010 has been assumed to continue at a constant rate.

It should be noted that the regional numerical model was developed with the aim of assessing the potential groundwater impacts of the Project. The focus of the conceptual and numerical model development was on the Maules Creek Formation groundwater system within the mining leases. Calibration to DPI Water monitoring bores in the Upper Namoi Alluvium showed good agreement between modelled and observed water level trends and elevations in the majority of locations. However, most DPI Water monitoring bores are located to the west and south of the proposed borefield and associated with the main Namoi River channel. There is less data available about the Upper Namoi Alluvium at the location of the proposed borefield and surrounding Driggle Draggle Creek. It is therefore recommended that field investigations are carried out to assess the thickness and hydraulic conductivity of the alluvium and determine whether the proposed borefield location would be suitable with respect to yields required for water supply.

6.4.2 MODEL RESULTS

6.4.2.1 PREDICTED DRAWDOWN OF GROUNDWATER LEVELS

Modelled water table drawdown at the end of Project mining for the cumulative mining and borefield scenarios is shown in **Figure 63**. The 1 m drawdown contour for the borefield scenario coalesces with the drawdown from the Project and Tarrawonga Coal Mine. The 1 m drawdown contour extends a maximum of approximately 2 km to the west and the east of the borefield in the Upper Namoi Alluvium. Proposed bores BH8, BH9 and BH10 are in a zone of lower hydraulic conductivity in the numerical model, and therefore a maximum drawdown of about 10 m is predicted to be associated with these bores. A maximum drawdown of less than 5 m is predicted at BH1 to BH7.

6.4.2.2 PREDICTED BASEFLOW CHANGES

Figure 64 and **Figure 65** show the simulated river flux for the Namoi River and Driggle Draggle Creek respectively. A positive flow indicates river leakage (flow from surface water to groundwater), and a negative river flux indicates baseflow (flow from groundwater to surface water).

The Namoi River has an average river leakage of 18.7 ML/d during the Project mining period (2018-2044) for the borefield scenario. There is a small predicted increase in river leakage due to the proposed borefield (compared to the cumulative scenario) of 0.17 ML/d (0.003 ML/d/km) at the end of the Project in 2044 (**Figure 64)**. Whitehaven holds sufficient licences for the Namoi River to account for this predicted leakage.

Driggle Draggle Creek has an average baseflow of 0.026 ML/d (9×10^{-4} ML/day/km) over the Project period, with no perceptible reduction in baseflow due to the proposed borefield (**Figure 65**).

6.4.2.3 POTENTIAL IMPACTS ON PRIVATELY-OWNED BORES

Table 22 (section 6.1.6) indicates the maximum predicted drawdown during mining and recovery, for the cumulative and borefield scenarios, for the privately-owned bores identified during the 2012 bore census (bores not located on Whitehaven-owned properties or properties under option agreement with Whitehaven).

As shown in **Figure 65,** the modelled 1 m water table drawdown at the end of Project mining and borefield pumping is not predicted to extend as far as any of the privately-owned bores. Maximum predicted drawdown at any privately-owned bore (cumulative with mining operations) is 0.61 m or less (**Table 22**).

6.4.3 CONCLUSIONS

Numerical modelling has been carried out to assess the potential groundwater impacts associated with the proposed borefield.

It is predicted that the 1 m drawdown contour will extend a maximum of approximately 2 km to the west and east of the borefield in the Upper Namoi Alluvium. To the north and south, drawdown due to the borefield will coalesce with drawdown associated with the Project and Tarrawonga Coal Mine.

There is predicted to be a small increase in river leakage from the Namoi River due to the proposed borefield. The increase in leakage is predicted to be 0.17 ML/d, which is <1 % increase from baseline conditions. There is no predicted perceptible reduction in baseflow at Driggle Draggle Creek due to the proposed borefield.

No privately-owned bores surrounding the Project identified during the bore census are predicted to experience “minimal impact” as defined in the AIP during mining operations (i.e. any drawdown would be generally less than 0.2 m, and at most 0.61 m, and is therefore considered negligible).

7 CLIMATE CHANGE AND MODEL UNCERTAINTY

7.1 CLIMATE CHANGE AND GROUNDWATER

The effects of climate change on rainfall patterns in the Project mining area have been taken from the following two sources:

- New England North West Region for the NSW/ACT Regional Climate Modelling (NarClim)[8]; and
- Eastern Australia Region for the Climate Change in Australia Model (CCiA)[9].

Table 23 presents the median projection for change in rainfall from these sources during Project mining and a long-term projection for post-mining. These projections are similar for 2030, but more variable for the post-mining forecast. NarClim projections suggest that the climate will become wetter, while the CCiA projections suggest that the climate will become drier.

Table 23 Climate Change Projections – Percentage Change in Rainfall

Period	Project mining		Post mining		
	NarClim 2029-2039	CCiA RCP 4.5 2030	NarClim 2060-2079	CCia RCP 4.5 2090	CCiA RCP 8.5 2090
Summer	-3.3%	-2.0%	+9.8%	-2.0%	4.0%
Autumn	+14.9%	-4.0%	+16.8%	-7.0%	-8.0%
Winter	-7.6%	-3.0%	-0.7%	-10.0%	-16.0%
Spring	+2.6%	-2.0%	-0.7%	-10.0%	-16.0%
Annual	**+1.6%**	**-1.0%**	**+7.7%**	**-7.0%**	**-10.0%**

The changes in rainfall are predicted to result in changes in rainfall recharge similar to:

- NarClim recharge scenario: 4.8% during Project mining, increasing to 23.1% post mining.
- CCiA recharge scenario: -3% during Project mining, decreasing to -25.5% post mining.

These recharge projections are based on experience and literature, with a general rule being that changes in rainfall are typically magnified 2-4 times when converted to rainfall recharge (rainfall elasticity in recharge), as described in Barron et al. (2012). Note that the CCiA recharge scenario uses the mean from the RCP4.5 and RCP8.5 projected change in rainfall for 2090 (**Table 23**).

A single transient predictive simulation for rainfall recharge, altered according to the drier of the projections, was conducted; i.e. the CCiA recharge scenario. The effect of climate change on predicted Project pit inflows has been assessed compared to the cumulative scenario (**Table** 24). There was found to be <1% reduction in pit inflows for the climate change scenario in response to the small (3%) reduction in rainfall during the Project period.

[8] http://www.climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM
[9] http://www.climatechangeinaustralia.gov.au/en/

Table 24 Predicted Project Open Cut Inflows over the Project Period for Climate Change and Uncertainty Analysis Scenarios

Model scenario	Average Project Pit Inflows (ML/d)	Maximum Project Pit Inflows (ML/d)
Cumulative scenario (see **Section 5**)	0.85	1.42
Climate change scenario	0.89	1.56
Vertical hydraulic conductivity decreased^	0.82	1.44
Vertical hydraulic conductivity increased^	1.04	1.83

^ Transient prediction runs to assess model uncertainty detailed in **Section 7.2**.

7.2 MODEL UNCERTAINTY

The *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012) state that *"because models simplify reality, their outputs are uncertain. Model outputs presented to decision-makers should include estimates of the goodness or uncertainty of the results"*.

It has been identified in the sensitivity analysis (**Section 4.11**) that the Project groundwater model is sensitive to the vertical hydraulic conductivity assigned to the model layers. A high-level assessment of model uncertainty was conducted by analysing the effect of vertical hydraulic conductivity on predicted pit inflows. Two additional transient prediction simulations were run:

1. Vertical hydraulic conductivity decreased by an order of magnitude (divided by 10) for all model layers.

2. Vertical hydraulic conductivity increased by an order of magnitude (multiplied by 10) for all model layers.

Changing the vertical hydraulic conductivity of all model layers by one order of magnitude results in an estimate of pit inflows of -8% to +16% (**Table 24**). The model results presented in **Sections** 5 and 6 are, therefore, considered to have negligible uncertainty.

8 MANAGEMENT AND MITIGATION MEASURES

8.1 SURFACE WATER FEATURES

As noted in **Section 6.2.1**, the regional numerical groundwater modelling indicates that the potential for a change in water quality in the Namoi River is negligible, given that the closest reach (of 4 km length) is a losing system under current, pre-mining conditions and would become slightly more so during mining. No mitigation measures are warranted.

Other potential management measures (e.g. management of PAF material) are discussed in the Geochemistry Assessment (Appendix M of the EIS), and the proposed surface water monitoring program is described in the Surface Water Assessment (Appendix B of the EIS).

8.2 GROUNDWATER USERS

The regional numerical groundwater modelling indicates that the drawdown effects on privately-owned groundwater bores would be less than 2 m.

It is recommended that a comprehensive groundwater monitoring program (**Section 8.4**) be established to monitor the groundwater effects of the Project (including triggers for investigation) and to prepare contingency measures in the event that agreed trigger levels are breached.

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

If the investigation concludes drawdown greater than 2 m has occurred and is attributable to the Project, Whitehaven would implement make-good provisions (e.g. deepening or replacement of the bore) in consultation with the landowner.

8.3 GROUNDWATER AND SURFACE WATER LICENSING

Appropriate groundwater licences for the Project will be sought from DoI Water under the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003* and the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011*.

Appropriate surface water licences for the Project will be sought from DoI Water under the *Water Sharing Plan for the Upper and Lower Namoi Regulated River Water Sources 2016*.

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

Attachment 6 of the EIS provides a reconciliation of groundwater and surface water licences held by Whitehaven against the licensing requirements. It concludes that Whitehaven already holds sufficient licences to account for all licensing requirements associated with groundwater inflows during operations (these requirements are summarised in **Table 25**).

Table 25 Project Licensing Summary

Water Sharing Plan		NSW Murray Darling Basin Porous Rock Groundwater Sources 2011 (ML/year)	Upper and Lower Namoi Groundwater Sources 2003 (ML/year)	Upper and Lower Namoi Regulated River Water Sources 2016 (ML/year)
During Project	Average	308	<1	2
	Maximum	517	5	11
Post-Mining	Maximum	< 500	9	27

* Refer to **Figure 49** and **Table 21** for predicted groundwater inflows over the life of the Project.

8.4 PROPOSED GROUNDWATER MONITORING PROGRAM

The proposed groundwater monitoring program for the Project is summarised in **Table 26** and described below.

The groundwater monitoring program should monitor groundwater conditions for changes in expected drawdown extent and groundwater quality. The results of the groundwater monitoring program for drawdown should be used to validate modelling predictions every 5 years following Project commencement.

Table 26 Proposed Groundwater Monitoring Program

Parameter	Location	Timing
Groundwater Levels (m AHD)	Vickery and surrounds.	Quarterly - Project life.
	Additional bore installations in the mine waste rock emplacement behind the advancing open cut.	Progressive over the Project life and two years post-mining.
Groundwater Quality (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 material.	Six monthly for field pH and EC; annually 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.

8.4.1 GROUNDWATER LEVELS

The existing network is considered adequate for providing information on groundwater flow and a basis for groundwater model calibration and verification and could be continued for the Project. Two additional groundwater level and quality monitoring bores should be installed in the waste rock to validate the predicted level of groundwater mounding and to check on the water quality of the leachate. Water level measurements should be continued as outlined in **Table 26.**

8.4.2 GROUNDWATER QUALITY

The groundwater monitoring network should be sampled for water quality during mining at the frequency specified in **Table 26,** and for at least two years following mining. Two additional bores to monitor water quality should be installed in the waste rock emplacement behind the open cut. Groundwater quality monitoring should include, but not necessarily be limited to, analysis of the following parameters: pH, dissolved oxygen, EC, TDS, iron, aluminium, arsenic, magnesium, molybdenum, selenium, calcium, sodium, chloride and sulphate. Analysis should be undertaken at a National Association of Testing Authorities (NATA) accredited laboratory. Water quality data should be evaluated as part of the Annual Review process and should aim to identify any potential mining related impacts.

9 CONCLUSIONS

This report provides an assessment of potential impacts to groundwater associated with the Project. The groundwater assessment for the Approved Mine was conducted by Heritage Computing in 2012 and the conceptual and numerical groundwater models have been updated to account for additional data and changes in the mine plan for the Project. The Approved Mine groundwater model was converted from MODFLOW-SURFACT with an irregular cell mesh to MODFLOW-USG with a regular cell mesh.

Groundwater and surface water monitoring data has been reviewed and the numerical groundwater model has been recalibrated based on data from 2006 to 2011. Model verification was carried out based on data from 2012 to 2017.

Predictive modelling to assess potential impacts to groundwater has been conducted with the following key results:

- The Project pit inflows are expected to vary between 0.01 and 1.42 ML/day during the mine life with an average inflow of approximately 0.8 ML/day.

- The modelled 1 m water table drawdown at the end of mining is not predicted to extend beyond the boundary of the Maules Creek Formation “island” in which the Project is located. As a result, no privately-owned bores identified during the bore census within the Upper Namoi Alluvium surrounding the Project are predicted to be measurably impacted during mining operations (i.e. any drawdown effect would be less than 1 m and is therefore considered to be negligible).

- 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. During the Project period, the average increase in flux from the alluvium to the porous rock is predicted to be about 0.007 ML/day. A maximum increase in flux of about 0.1 ML/day is predicted about 30 years after mining has finished.

- The Western Emplacement overlaps a thin alluvium embayment to the north-west of the Project open cut. There is, therefore, potential for seepage to occur from the emplacement to the alluvium in this area. Maximum long-term seepage rate from the Western Emplacement to the alluvium embayment was predicted to be very minor, ranging from 0.03 ML/day, during initial recovery, to 0.02 ML/day over the long-term.

- Seepage from the Western Emplacement into the alluvium embayment is likely to be of lower salinity than the groundwater currently within the shallow alluvium in that location. The seepage will also have approximately similar salinity to the groundwater in the coal measures adjacent to the alluvium. It is, therefore, concluded that the small amount of seepage from the Western Emplacement would cause no adverse water quality impacts to the alluvium.

- There is a small effect on flows in a 4km stretch of the Namoi River to the immediate west of the Project. The reach shows baseflow of about 0.00008 ML/day initially, reducing to zero baseflow at year 16, after which leakage increases to about 0.00005 ML/day at year 23 and stabilising at about 0.0003 ML/day by year 100 (2118).

- The regional numerical groundwater modelling indicates that the potential for a change in water quality in the Namoi River is negligible, given that the closest reach (of 4 km length) is a losing system under current, pre-mining conditions and would become slightly more so during mining.

- There are no high priority GDEs listed in the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003* or in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* in the study area.

- There are no culturally significant sites listed in the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003* or in the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011* in the study area.

- Equilibrium water levels will be about 125 m lower than current groundwater levels at the final void. The final void will therefore act as a sink for groundwater entering from all directions. The equilibrium long-term groundwater inflow to the void is expected to be between 0.3 and 0.5 ML/day. This inflow would be sustained primarily by rainfall infiltration through the Western Emplacement (assuming 1% recharge). Because the hydraulic gradient remains towards the void, it is unlikely that groundwater quality would be adversely impacted by the final void lake.

- In regard to MNES, the 'Action' would not result in significant changes to the quantity or quality of water available to third party users or the environment. Accordingly, the 'Action' would not have a significant impact on water resources when assessed against the *Significant Impact Guidelines for Water Resources*.

- An assessment against the AIP Minimal Harm Considerations is presented in **Table 27** and **Table** 28. This is based on data analysis, conceptualisation and numerical modelling.

- It is concluded the Project would have "minimal impact" when assessed against the AIP Minimal Harm Considerations.

Table 27 Summary of AIP Assessment – Upper Namoi (Zone 4) Alluvium

Aquifer	Upper Namoi (Zone 4) Alluvium *(Water Sharing Plan - Upper and Lower Namoi Groundwater Sources 2003)*
Category	Highly Productive
Level 1 Minimal Impact Consideration	**Assessment**
Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: • high priority GDE; or • high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	There are no High Priority GDEs listed in this WSP in the study area. There are no Culturally Significant Study Sites in the study area listed in the WSP. There are therefore no known risks of mine development to such sites. Groundwater modelling for the Project predicts that drawdowns at all privately-owned bores would be less than 2 m. **Level 1 minimal impact consideration classification.**
Water pressure A cumulative pressure head decline of not more than 40% of the post-water sharing plan pressure head above the base of the water source to a maximum of a 2m decline, at any water supply work.	Groundwater modelling for the Project predicts that drawdowns at all privately-owned bores would be less than 2 m. **Level 1 minimal impact consideration classification.**
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity. 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. No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three-dimensional extent of the alluvial water source – whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply." Not more than 10% cumulatively of the three-dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a "reliable water supply."	The Project is not predicted to result in a change to the beneficial use of groundwater in the alluvium. There is no mechanism in which the Project would result in an increase in the average salinity of a highly connected water source of more than 1%. **Level 1 minimal impact consideration classification.**

Table 28 Summary of AIP Assessment - Porous Rock

Aquifer	Porous Rock *(Water Sharing Plan - NSW Murray Darling Basin Porous Rock Groundwater Sources 2011)*
Category	Less Productive
Level 1 Minimal Impact Consideration	**Assessment**
Water table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: • high priority GDE; or • high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR A maximum of a 2 m water table decline cumulatively at any water supply work.	There are no High Priority GDEs listed in this WSP in the study area. There are no Culturally Significant Study Sites in the study area listed in the WSP. There are, therefore, no known risks of mine development to such sites. Groundwater modelling for the Project predicts that drawdowns at all privately-owned bores would be less than 2 m. **Level 1 minimal impact consideration classification.**
Water pressure A cumulative pressure head decline of not more than a 2 m decline at any water supply work.	Groundwater modelling for the Project predicts that drawdowns at all privately-owned bores would be less than 2 m. **Level 1 minimal impact consideration classification.**
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.	The Project is not predicted to result in a change in the beneficial use of groundwater in the Maules Creek Formation. **Level 1 minimal impact consideration classification.**

10 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. These assumptions are considered reasonable based on the current status of knowledge about subsurface conditions. 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. There is no hydrographic evidence for hydraulic conductivity reduction with depth at this site as mining at depth has not commenced. However, based on other mining examples 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 for the Maules Creek Formation in these areas should be regarded as indicative only. Calibration to DoI-Water monitoring bores in the Upper Namoi Alluvium showed good agreement between modelled and observed water level trends and absolute elevations in most cases. Therefore, higher confidence can be held in the predictions for the Upper Namoi Alluvium (including predictions at all privately-owned bores).

With the exception of the Mooki Thrust, there is no indication that other structural features, such as faults or dykes, have any measurable effect on the groundwater system. In that case, the Principle of Parsimony should apply - that is, apply the simplest system consistent with observed data. The effect of a structural feature on formation thicknesses, as observed in exploration holes, is incorporated in the model with an assumption of coal seam continuity across the structure. 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 far-field environmental effects are expected to be conservative.

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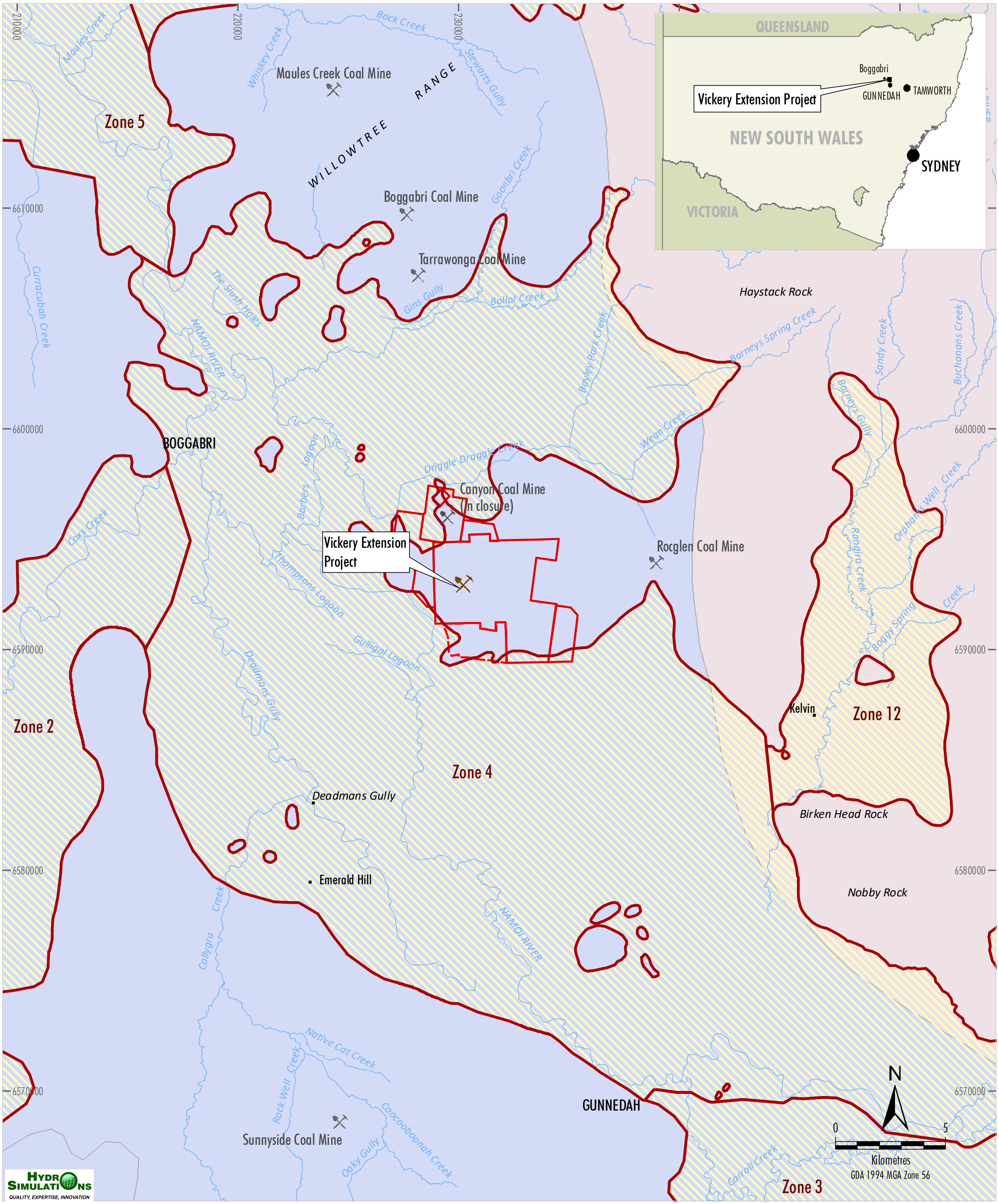
FIGURES



LEGEND

Mining Tenement Boundary (ML and CL)

Mining Lease Application (MLA)

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

Alluvial Groundwater Source

Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011

Gunnedah-Oxley Basin MDB Groundwater Source

Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011

New England Fold Belt MDB Groundwater Source

Source: Geoscience AustraliaTopographic Base (2006); NSW Department of Industry (2015); NOW (2011)

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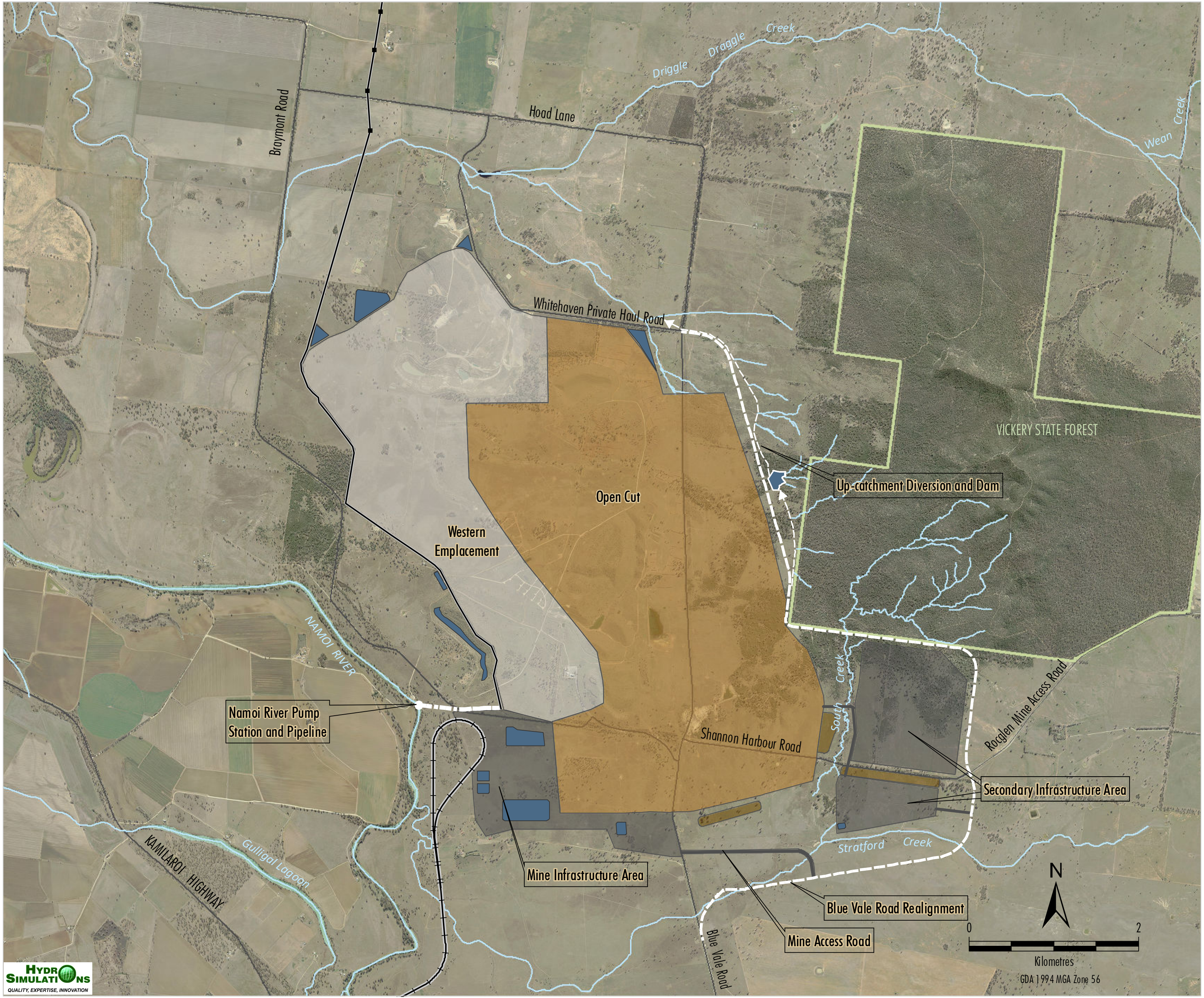
VICKERY EXTENSION PROJECT

Relevant Groundwater Sources

Figure 1



LEGEND

- State Forest

Project Components

- Indicative Extent of Open Cut
- Indicative Extent of Out of Pit Waste Rock Emplacement
- Indicative Extent of Infrastructure Area
- Indicative Extent of Soil Stockpile
- Indicative Extent of Water Storage
- Indicative Mine Access Road Alignment
- Indicative Namoi River Pump Station and Pipeline
- Indicative Road Realignment
- Indicative Up-catchment Diversion and Dam Location
- Indicative Rail Spur Alignment
- Indicative Location of Groundwater Bores and Pipeline

Source: Orthophoto - Department of Land and Property Information, Aerial Photography (July 2011); Department of Industry (2015); Essential Energy (2015)

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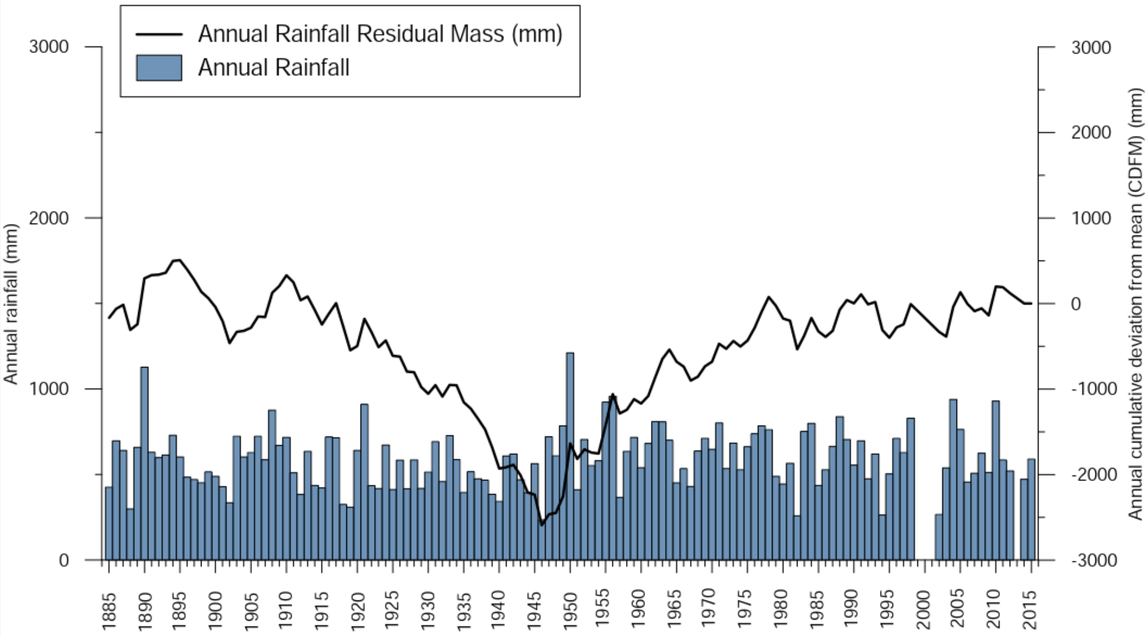
VICKERY EXTENSION PROJECT

Project General Arrangement - Project Mining Area

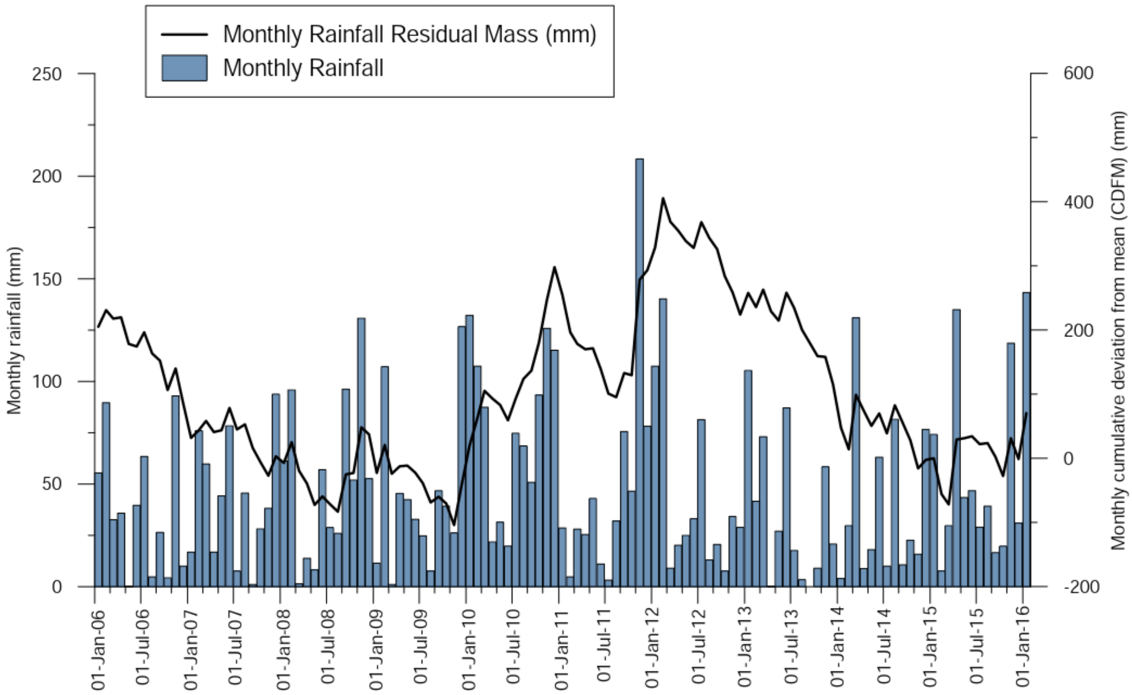
Figure 2

HYDRO SIMULATIONS QUALITY, EXPERTISE, INNOVATION

WHC-15-33_EIS GW_212D



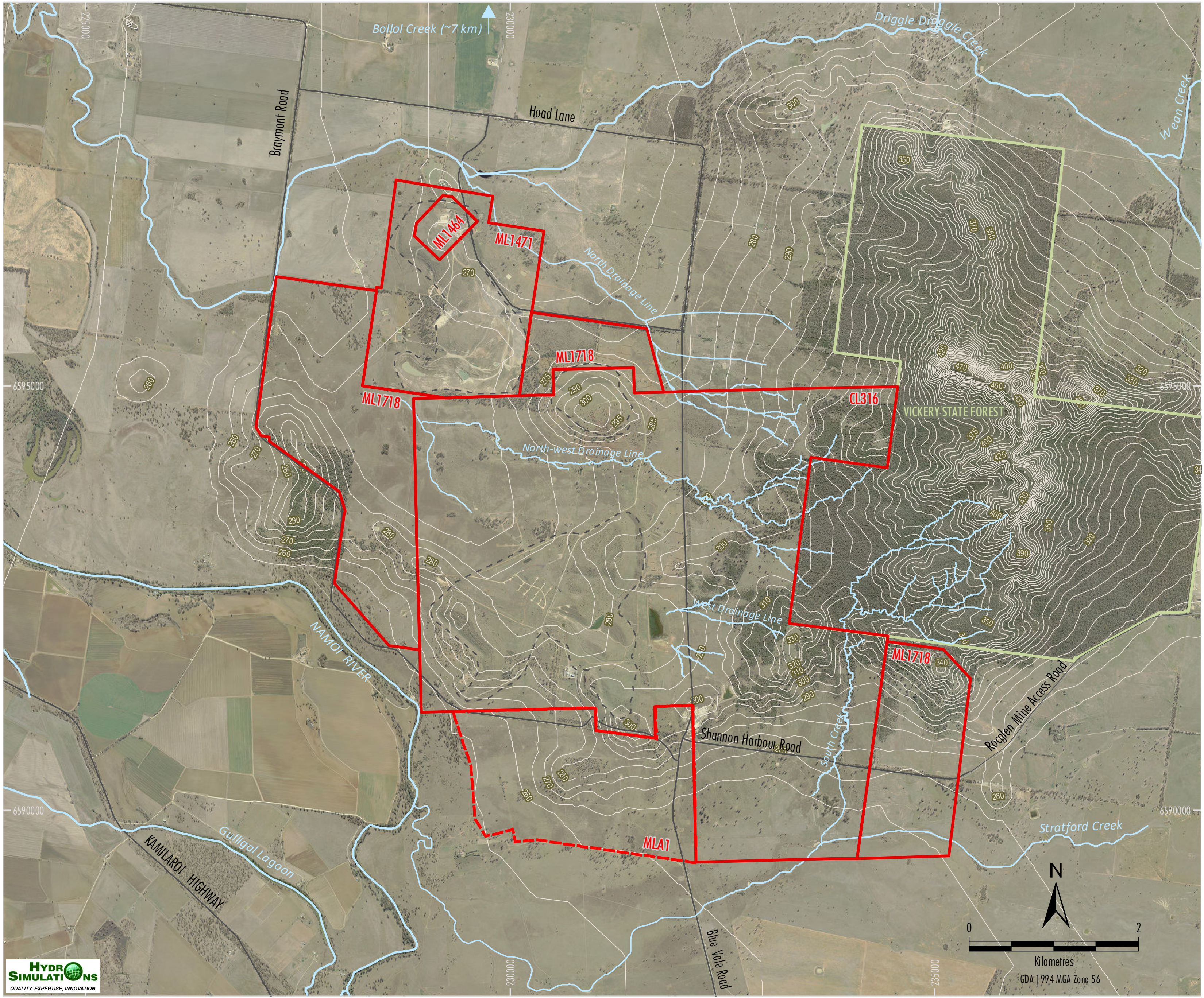
a. Long term annual rainfall, and cumulative deviation from the annual mean rainfall (CDFM) at Boggabri Post Office BoM station 055007



b. Monthly rainfall and cumulative deviation from the monthly mean rainfall (CDFM) at Boggabri Post Office station since 2006

HYDRO SIMULATIONS | Vickery Extension Project
Boggabri rainfall data | Figure 3

Figure 3 Boggabri Post Office Rainfall Data



LEGEND

- Mining Tenement Boundary (ML and CL)
- Mining Lease Application (MLA)
- State Forest
- Historic Mining Area

Source: Orthophoto - Department of Land and Property Information, Aerial Photography (July 2011); Department of Industry (2015); Essential Energy (2015)

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VICKERY EXTENSION PROJECT

Topography and Watercourses in the Project Mining Area

Figure 4

HYDRO SIMULATIONS QUALITY, EXPERTISE, INNOVATION

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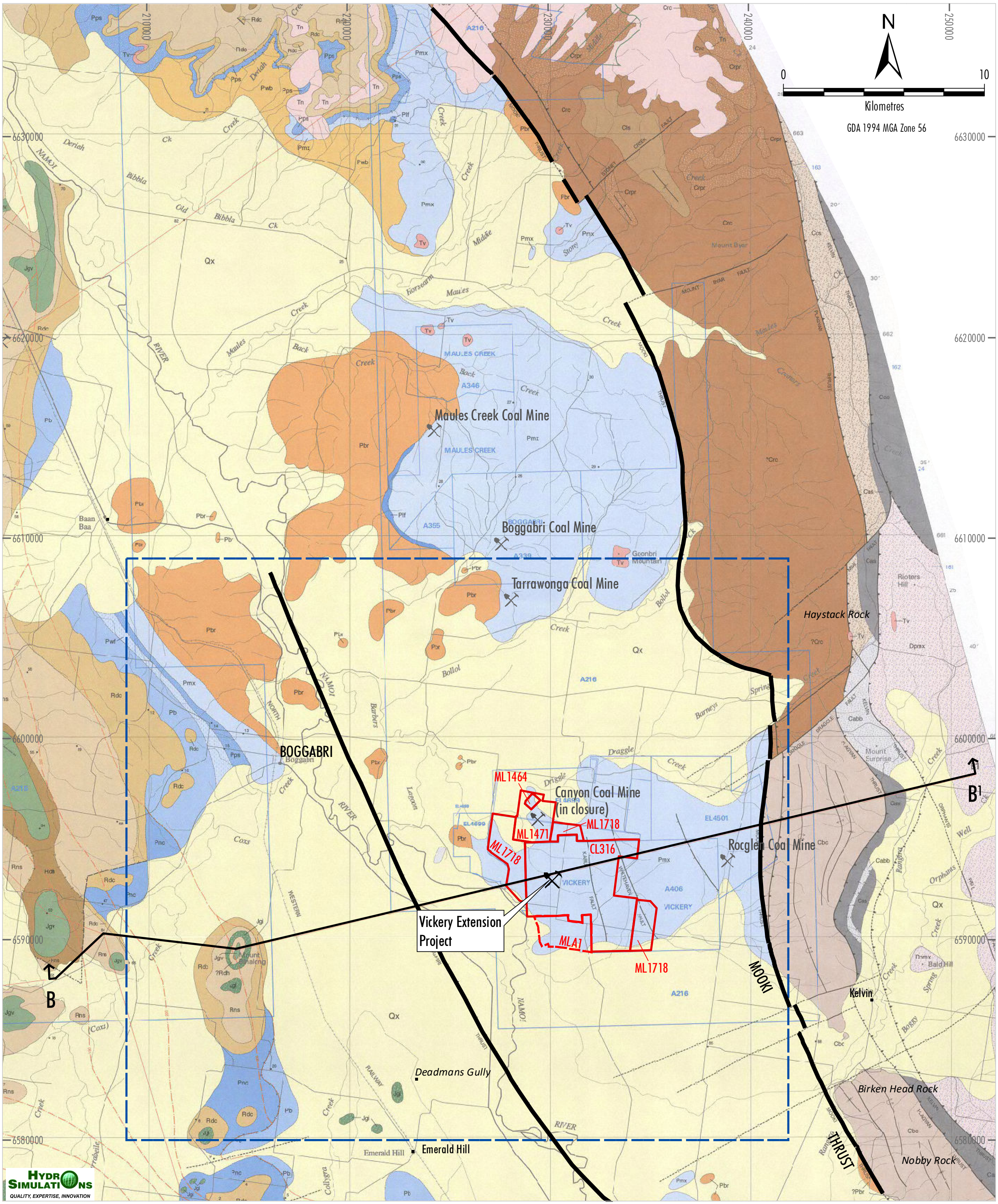

WHC-15-33_EIS GW_202D

HYDROSIMULATIONS
QUALITY, EXPERTISE, INNOVATION

LEGEND

- Mining Tenement Boundary (ML and CL)
- Mining Lease Application (MLA)
- Groundwater Model Extent
- Cross-Section Location*

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

Note: Refer Figure 6* for Cross Section B-B[1] and
Figure 7 for Regional Geology Legend

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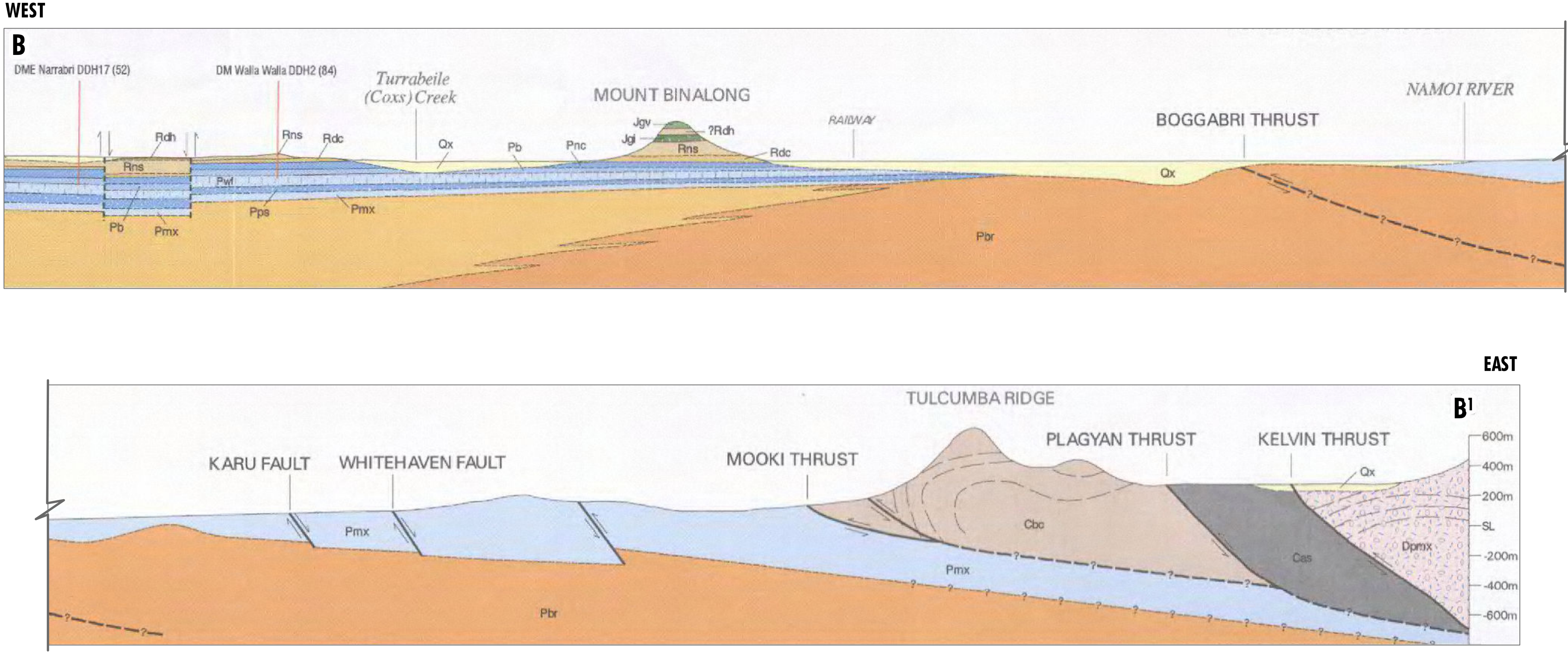
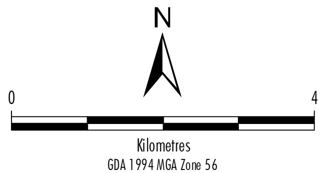
VICKERY EXTENSION PROJECT

Regional Geology

Figure 5



Scale Ration Vertical 0.4 = Horizontal 1.0



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HYDROSIMULATIONS QUALITY, EXPERTISE, INNOVATION

Note: Refer Figure 7 for Regional Geology Legend

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

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VICKERY EXTENSION PROJECT

Regional Geology - Cross Section B -B1

Figure 6

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

* Known only from borehole data

WHC-15-33_EIS GW_001C

HYDROSIMULATIONS
QUALITY, EXPERTISE, INNOVATION

Source: Dept of Mineral Resources NSW (2006)

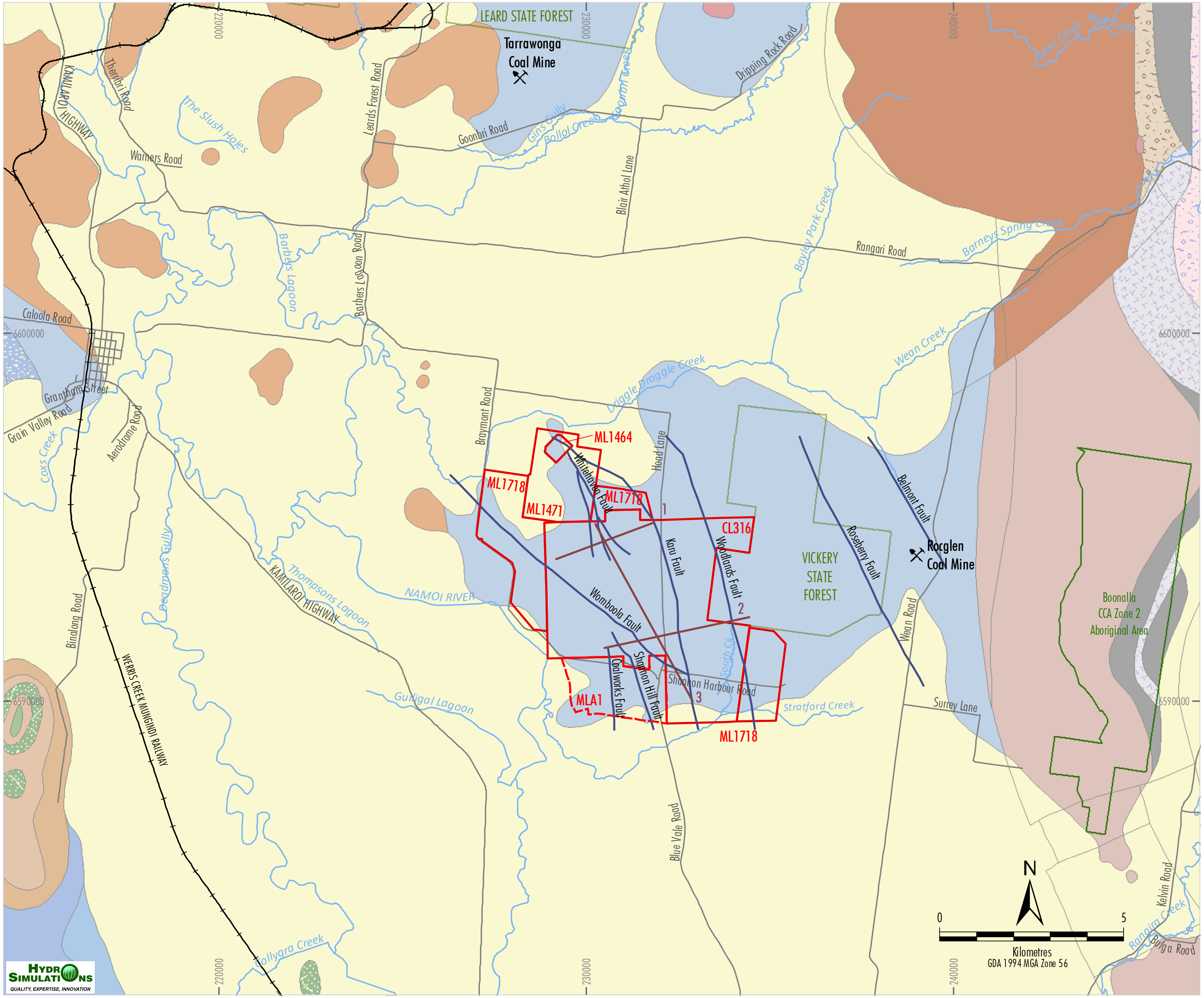
Note: Refer Figure 5 for Regional Geology Mapping.

WHITEHAVEN COAL

VICKERY EXTENSION PROJECT

Regional Geology Legend

Figure 7



LEGEND

- Mining Tenement Boundary (ML and CL)
- Mining Lease Application (MLA)
- State Forest
- State Conservation Area, Aboriginal Area
- Faults
- Open Cut Cross Section (Refer Figure 9)

Regional Geology Legend
Refer Figure 7

Source: *Department of Industry (2015); DPI - Gunnedah Coalfield South (2013)*

WHITEHAVEN COAL

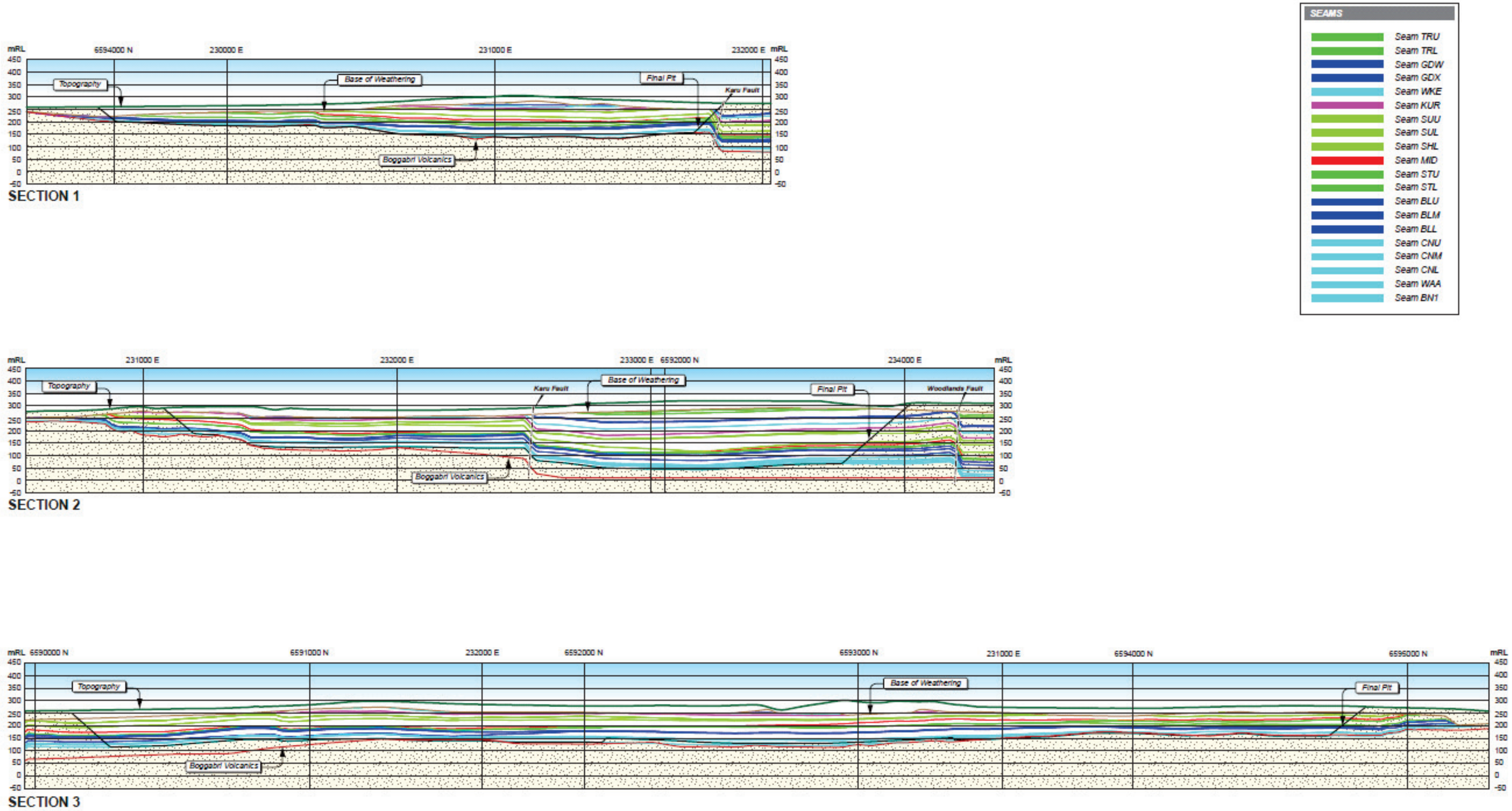
VICKERY EXTENSION PROJECT

Local Geology and Geological Structures

Figure 8

HYDRO SIMULATIONS
QUALITY, EXPERTISE, INNOVATION

WHC-15-33_EIS GW_204D



WHC-15-33_EIS App GW_002B

HYDRO SIMULATIONS
QUALITY, EXPERTISE, INNOVATION

Source: Whitehaven (2016)

WHITEHAVEN COAL

VICKERY EXTENSION PROJECT

Open Cut Coal Seam Geology -
Cross Sections

Figure 9

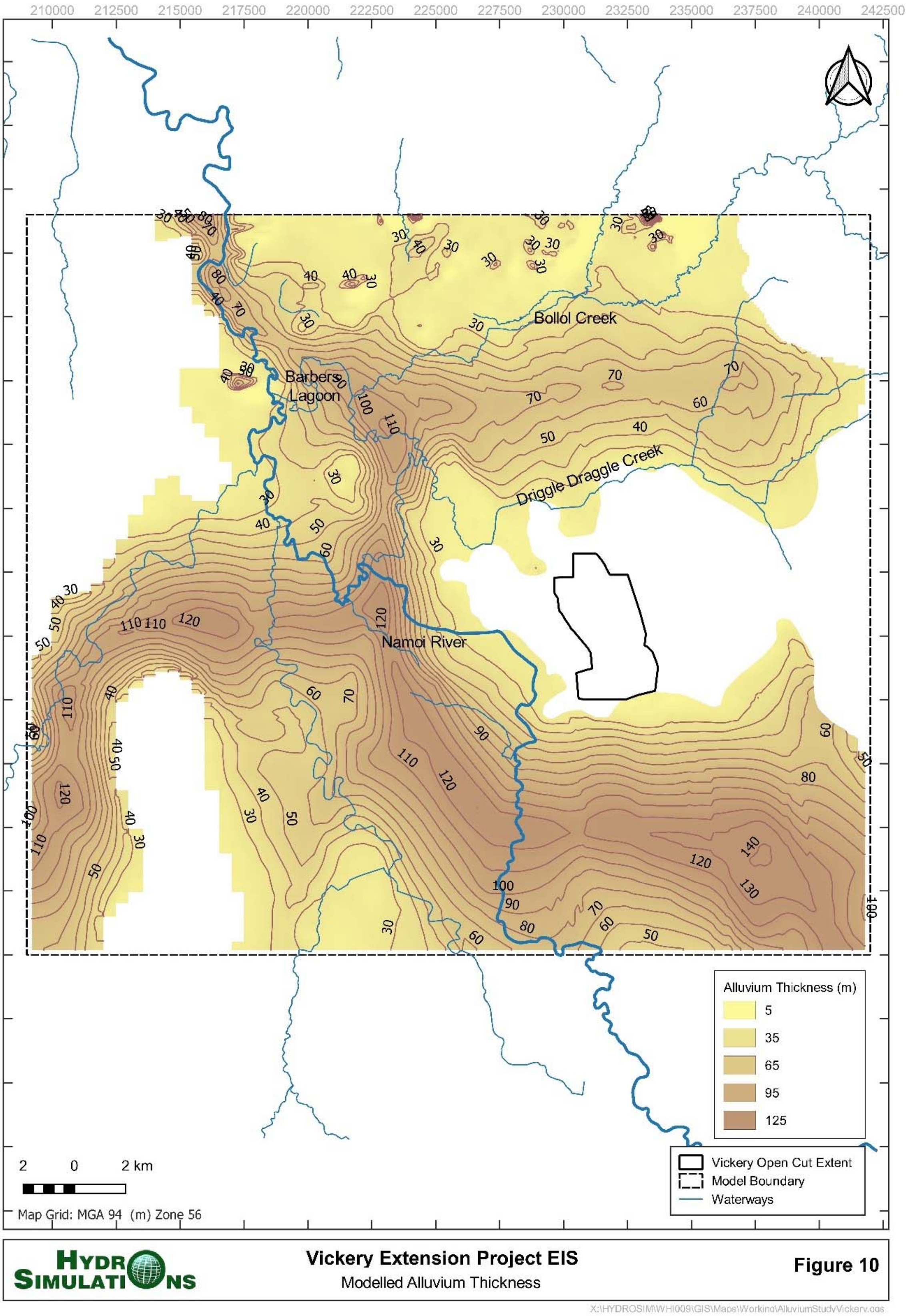


Figure 10 Modelled Alluvium Thickness (m)

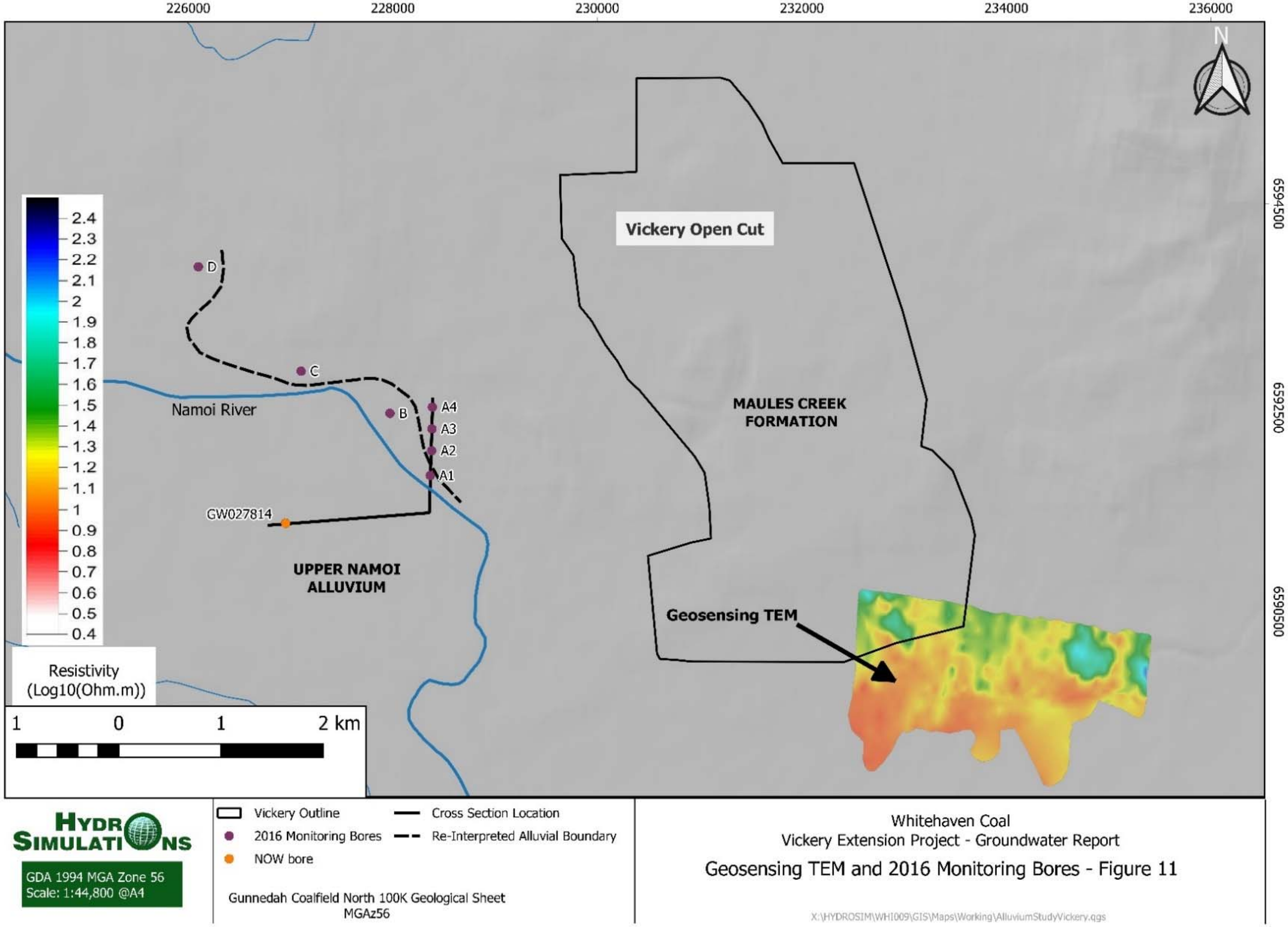
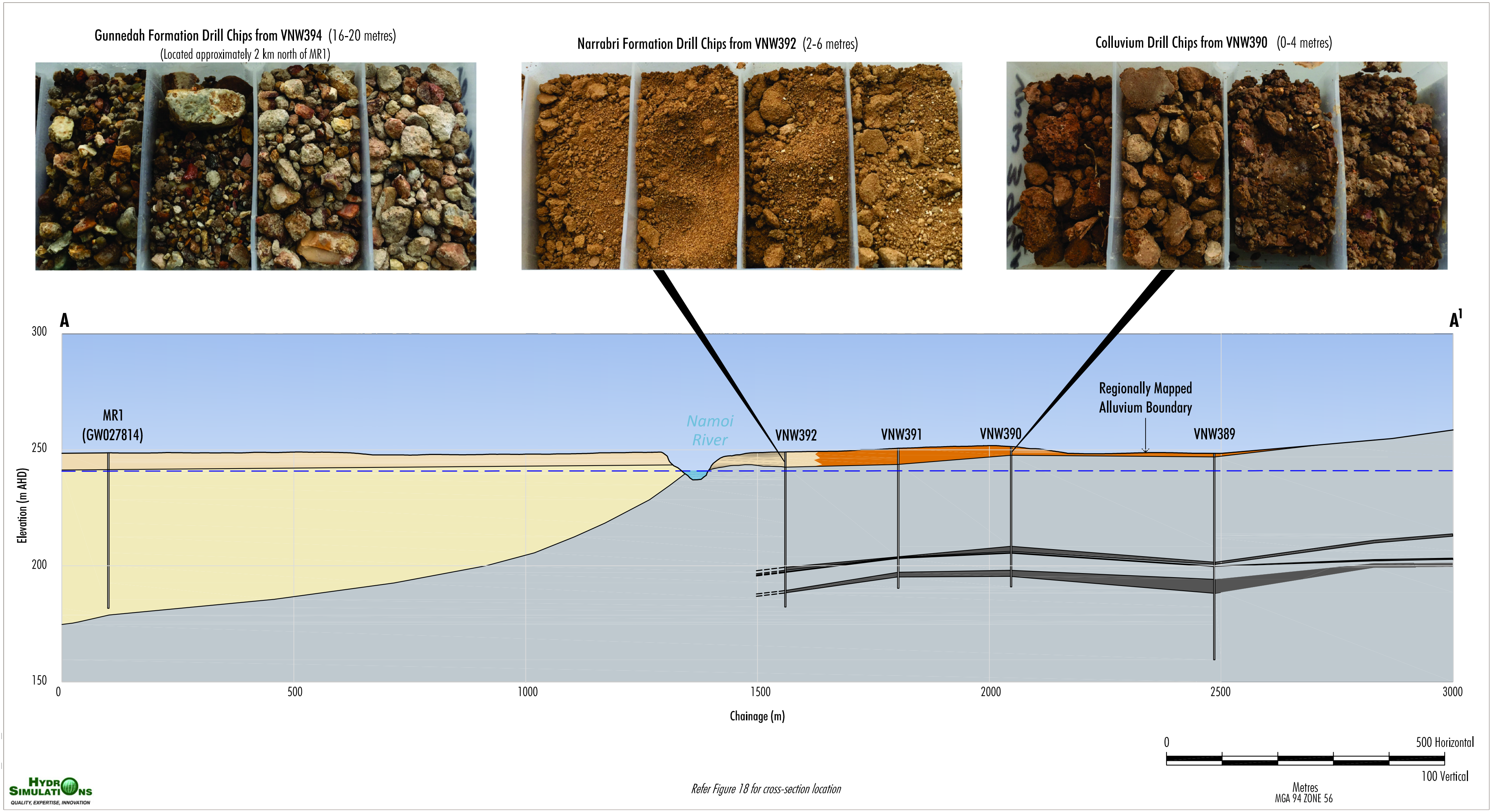


Figure 11 TEM Survey Results and 2016 Monitoring Bores



WHC-15-33_EIS GW_101K

LEGEND

- Narrabri Formation
- Gunnedah Formation
- Colluvium
- Maules Creek Formation
- Coal Seam
- Water Table

Source: DPI - Gunnedah Coalfield South (2013); ENRS (2016)

WHITEHAVEN COAL

VICKERY EXTENSION PROJECT

Upper Namoi Alluvium Cross-Section

Figure 12

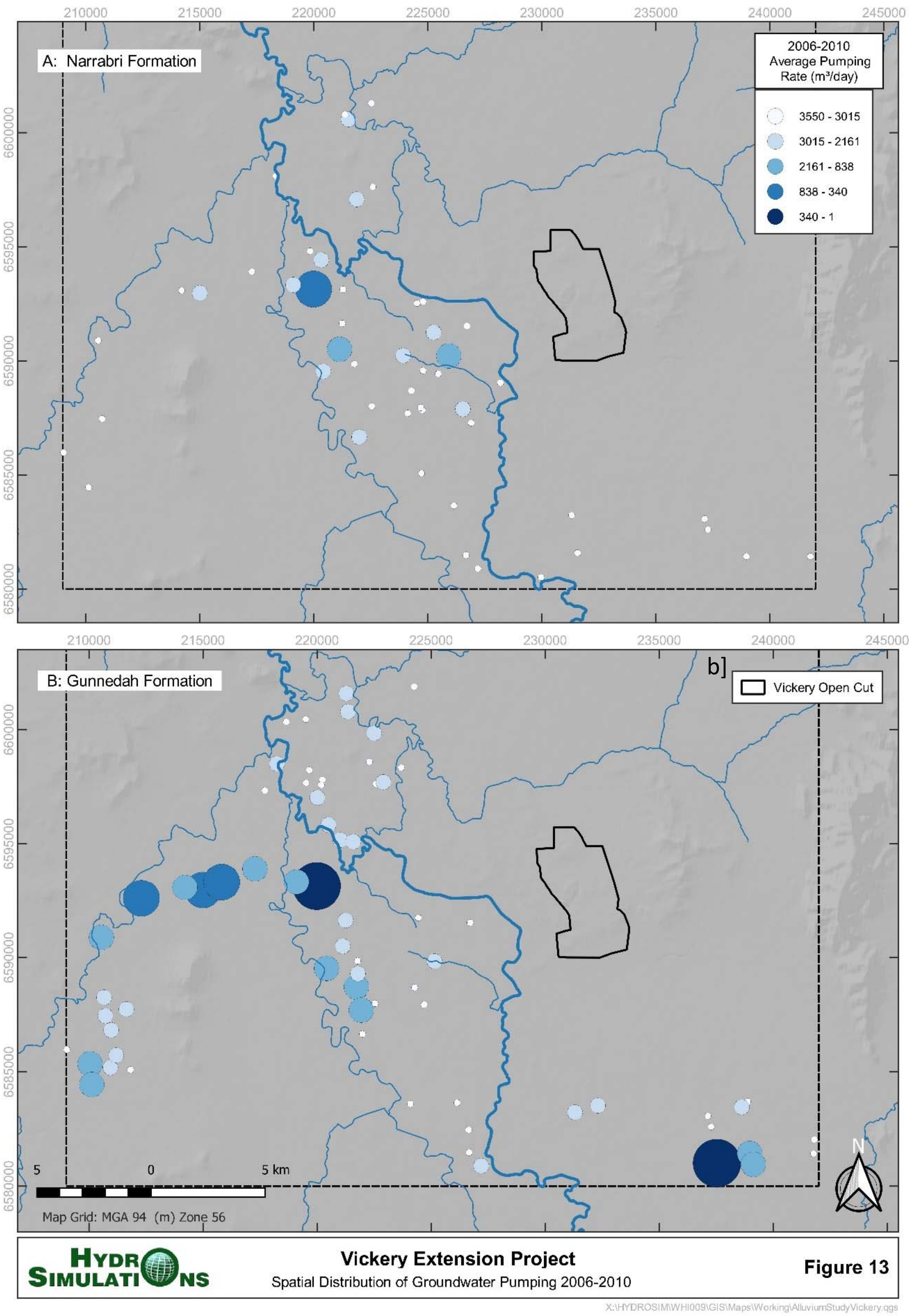


Figure 13 Spatial Distribution of Average Groundwater Pumping Rates from 2006 to 2010 [a] Narrabri Formation [b] Gunnedah Formation

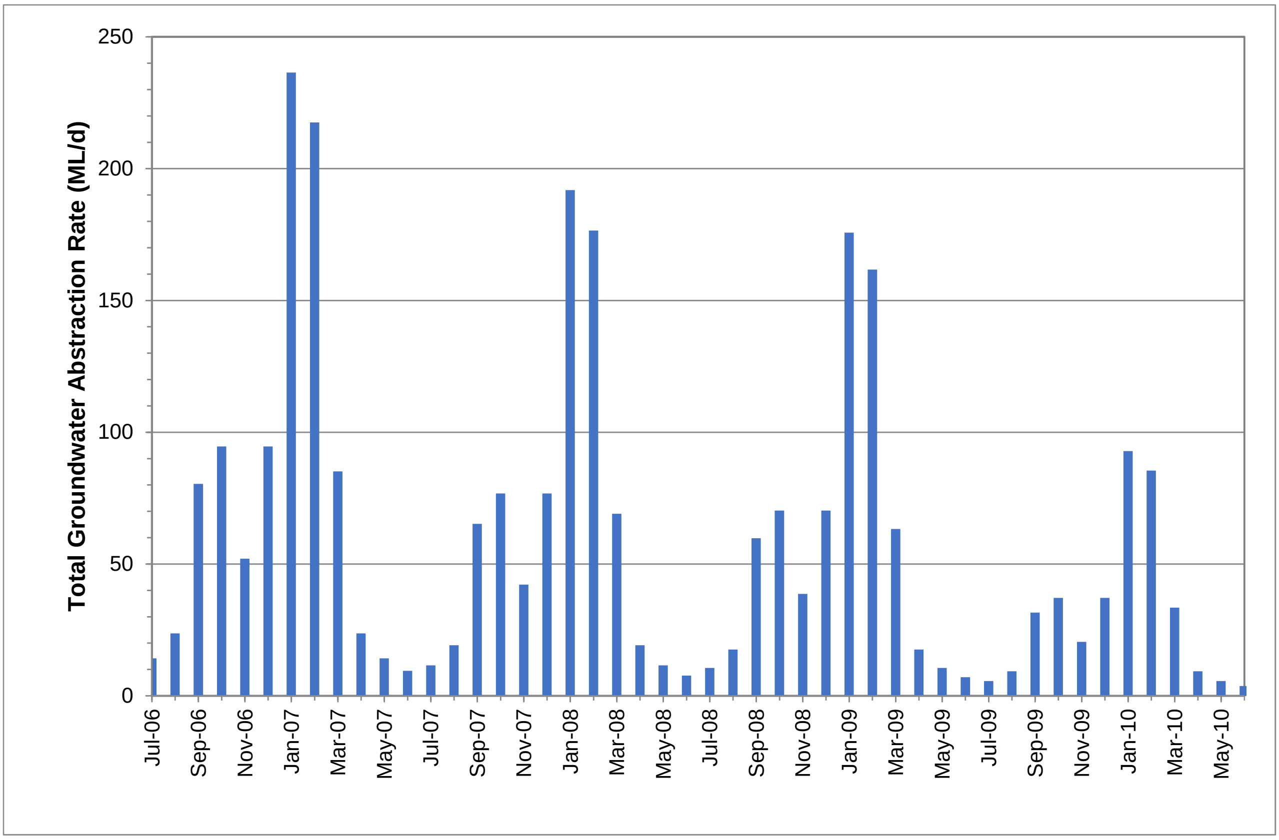
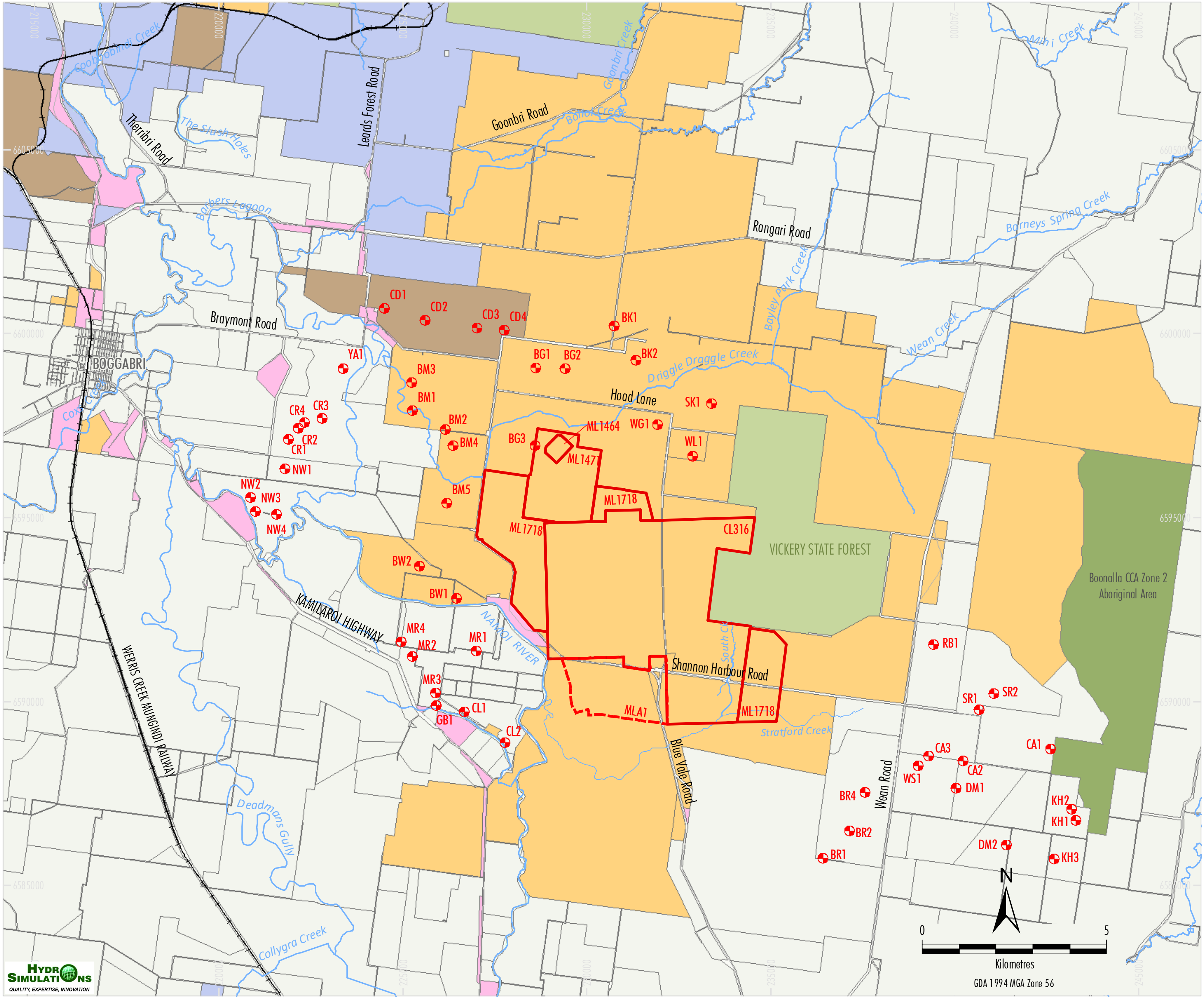


Figure 14 Temporal Distribution of Groundwater Pumping 2006 to 2010



LEGEND

- Mining Tenement Boundary (ML and CL)
- Mining Lease Application (MLA)
- Railway
- State Conservation Area, Aboriginal Area
- State Forest
- Crown Land
- Whitehaven Owned Land
- Whitehaven/Idemitsu Boggabri Coal Joint Owned Land
- Idemitsu Boggabri Coal Owned Land
- Privately Owned Land and Other Land
- Bore Identified during Bore Census (labels reflect property names)

Source: Department of Land and Property Information - Land Tenure (2016); Department of Industry (2016); Whitehaven (2016)

WHITEHAVEN COAL

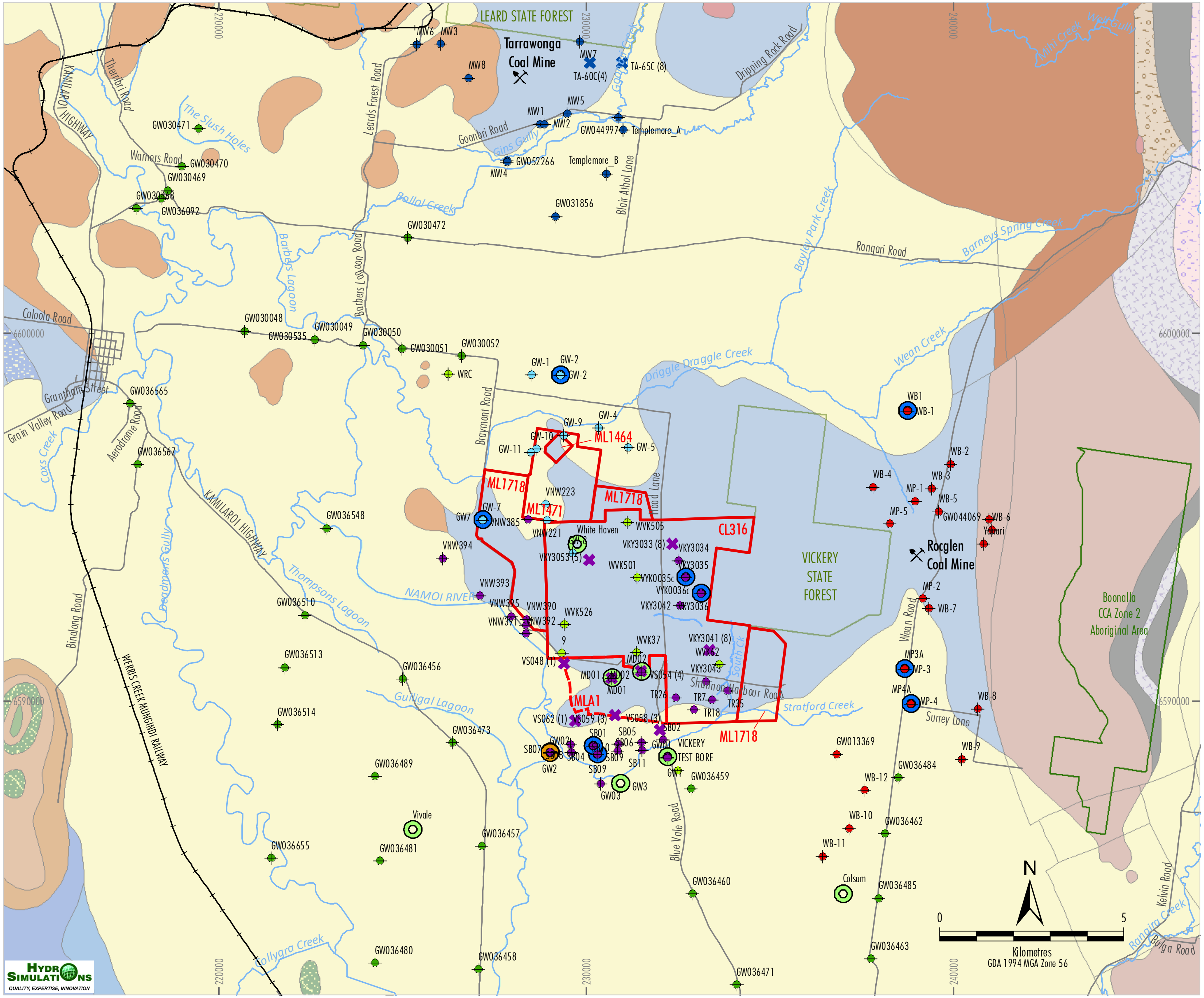
VICKERY EXTENSION PROJECT

Bore Census

Figure 15

HYDRO SIMULATIONS QUALITY, EXPERTISE, INNOVATION

WHC-15-33_EIS GW_206H



LEGEND

- Mining Tenement Boundary (ML and CL)
- Mining Lease Application
- State Forest
- State Conservation Area, Aboriginal Area
- Vickery Standpipe
- Vickery
- Stygofauna Sampling Location
- Stygofauna Sampling Location (2012 and 2016)
- Stygofauna Sampling Location
- Canyon Standpipe
- Rocglen Standpipe
- Tarrawonga Standpipe
- Tarrawonga Vibrating Wire Piezometer
- Namoi Valley Project Standpipe
- DPI Water Standpipe

Regional Geology Legend
Refer Figure 7

Source: Department of Industry (2015); DPI - Gunnedah Coalfield South (2013)

WHITEHAVEN COAL

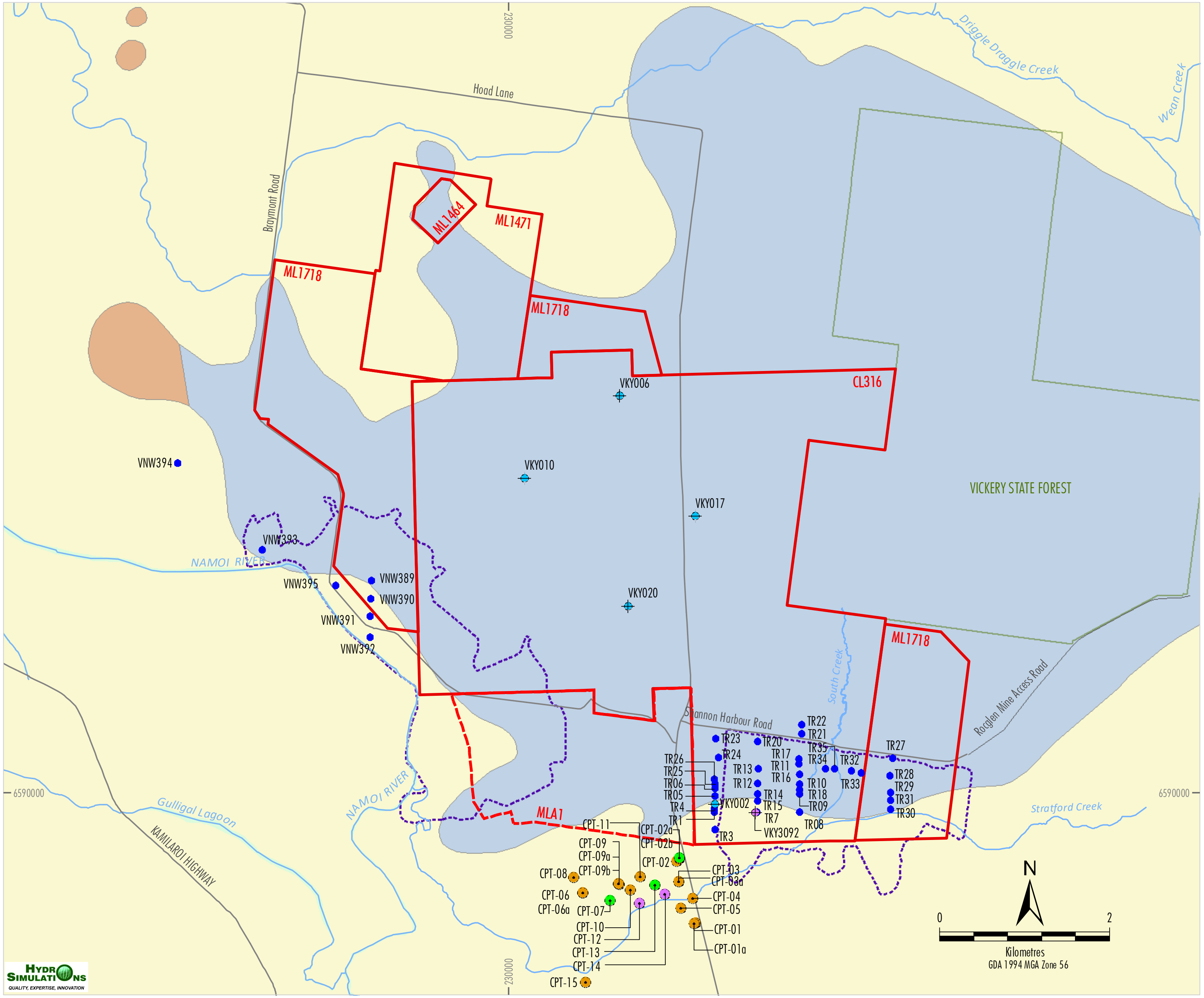
VICKERY EXTENSION PROJECT

Groundwater Monitoring Locations

Figure 16

HYDROSIMULATIONS QUALITY, EXPERTISE, INNOVATION

WHC-15-33_EIS GW_207E



LEGEND

Mining Tenement Boundary (ML and CL)
Mining Lease Application (MLA)
State Forest
Alluvium Investigation Hole
Cone Penetration Test
Cone Penetration Test - Dissipation
Cone Penetration Test - Permeability
Core Testwork
Pumping Test
TEM Survey Extent

Regional Geology Legend
Refer Figure 7

Source: Department of Industry (2015); DPI - Gunnedah Coalfield South (2013); HydroSimulations (2016)

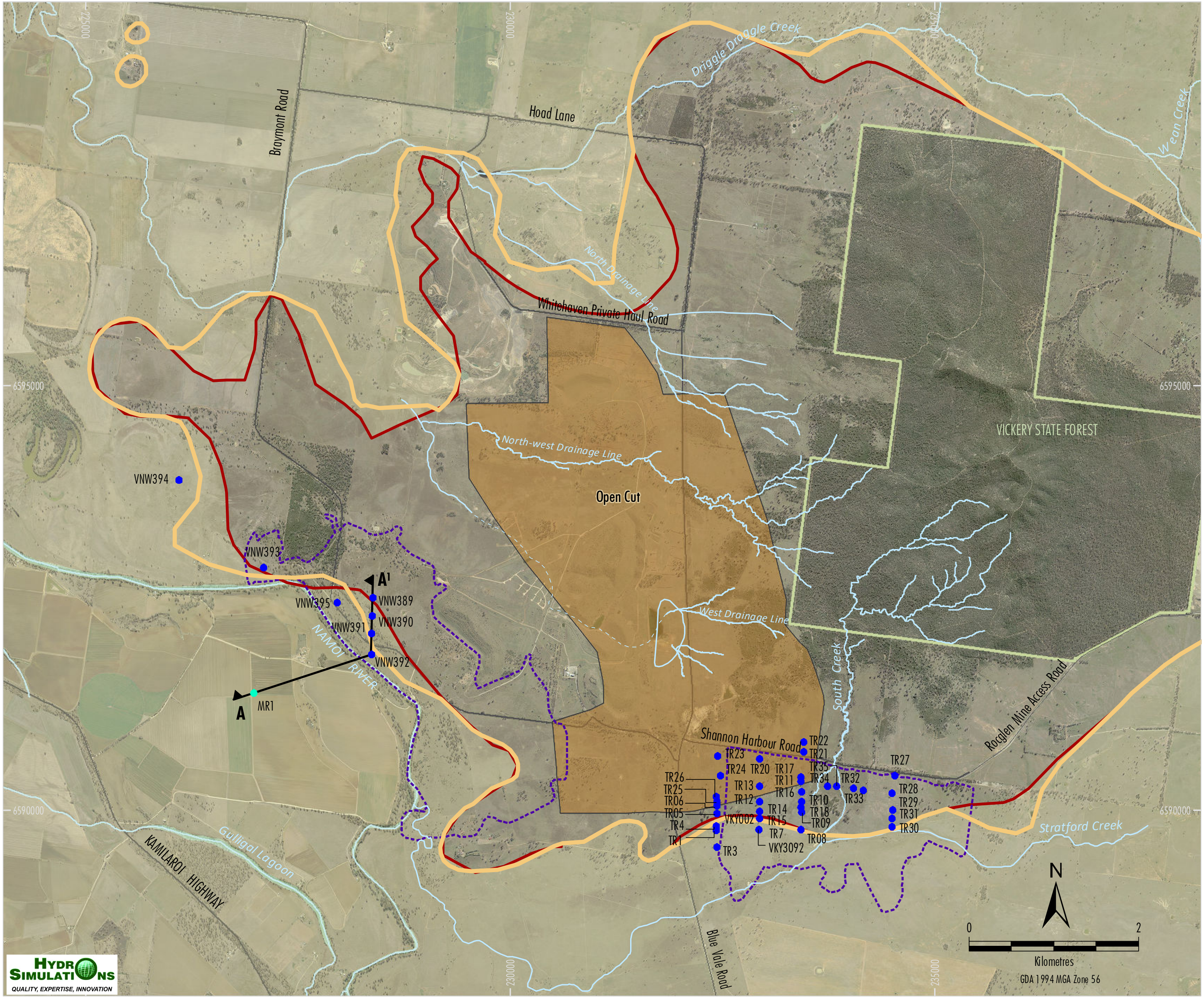
WHITEHAVEN COAL

VICKERY EXTENSION PROJECT

Groundwater Investigation Programme

Figure 17

WHC-15-33_EIS GW_209F



LEGEND

- State Forest
- Indicative Extent of Open Cut
- Alluvium Investigation Hole
- Private Bore
- TEM Survey Extent
- Cross-Section Location *
- Regionally Mapped Alluvial Boundary
- Interpreted Alluvial Boundary
- Drainage Path
- Modified Drainage Path

* Refer Figure 13 for Cross-Section A-A¹

Source: Orthophoto - Department of Land and Property Information, Aerial Photography (July 2011); Department of Industry (2015); Essential Energy (2015)

WHITEHAVEN COAL

VICKERY EXTENSION PROJECT

Upper Namoi Alluvium Extent

Figure 18

HYDROSIMULATIONS
QUALITY, EXPERTISE, INNOVATION

WHC-15-33_EIS GW_211D

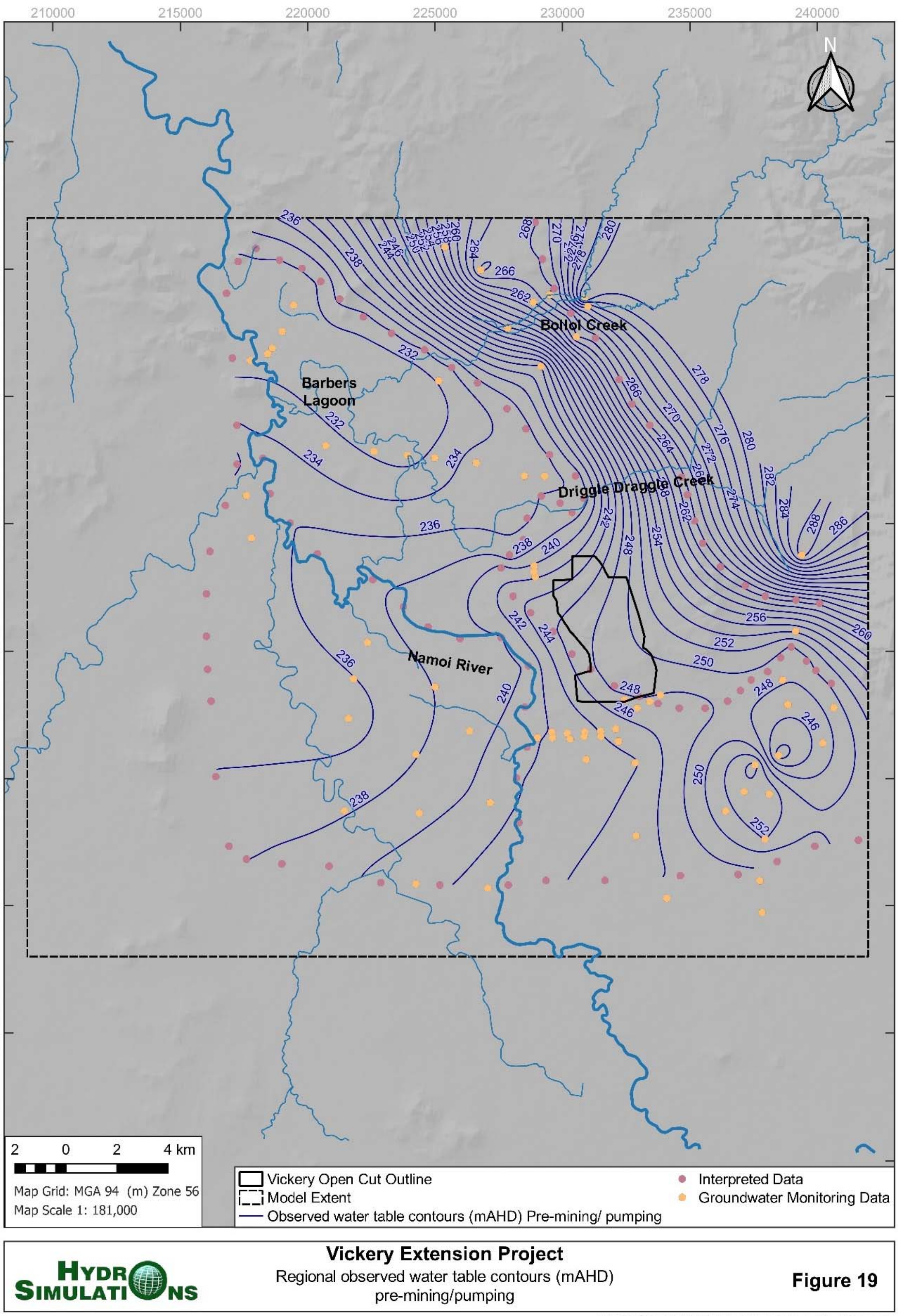


Figure 19 Regional Observed Water Table Contours (mAHD) Pre-Mining/Pumping

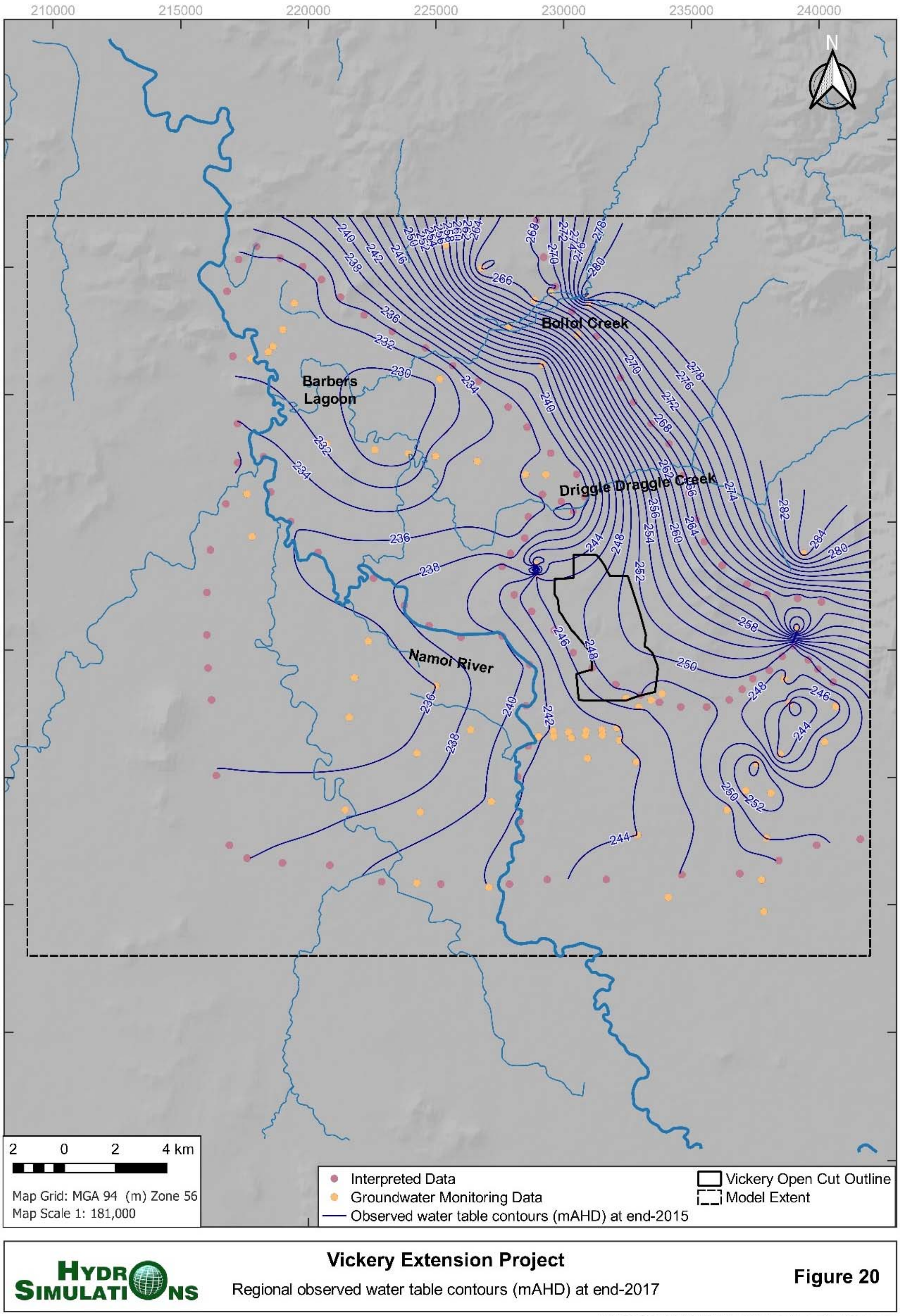
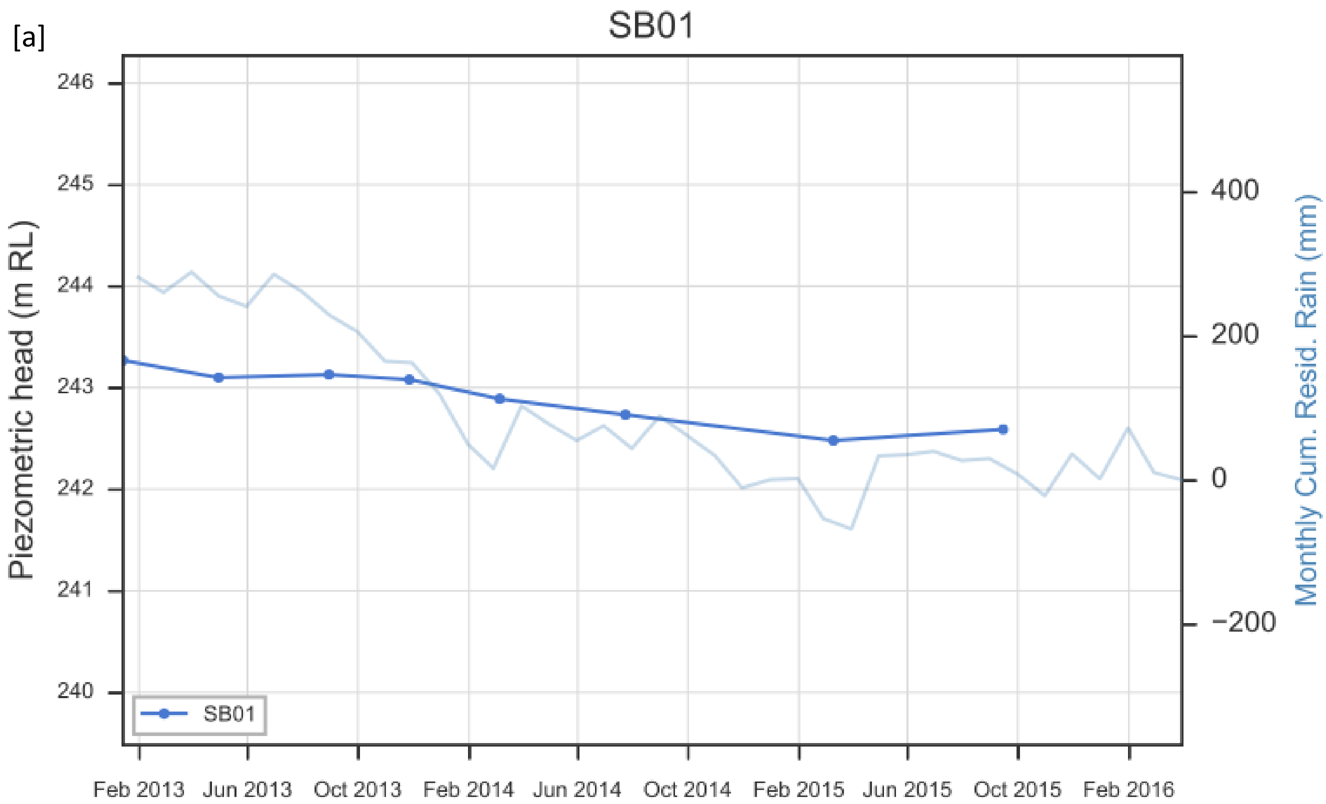


Figure 20 Regional Observed Water Table Contours (mAHD) at End-2017

[a]



[b]

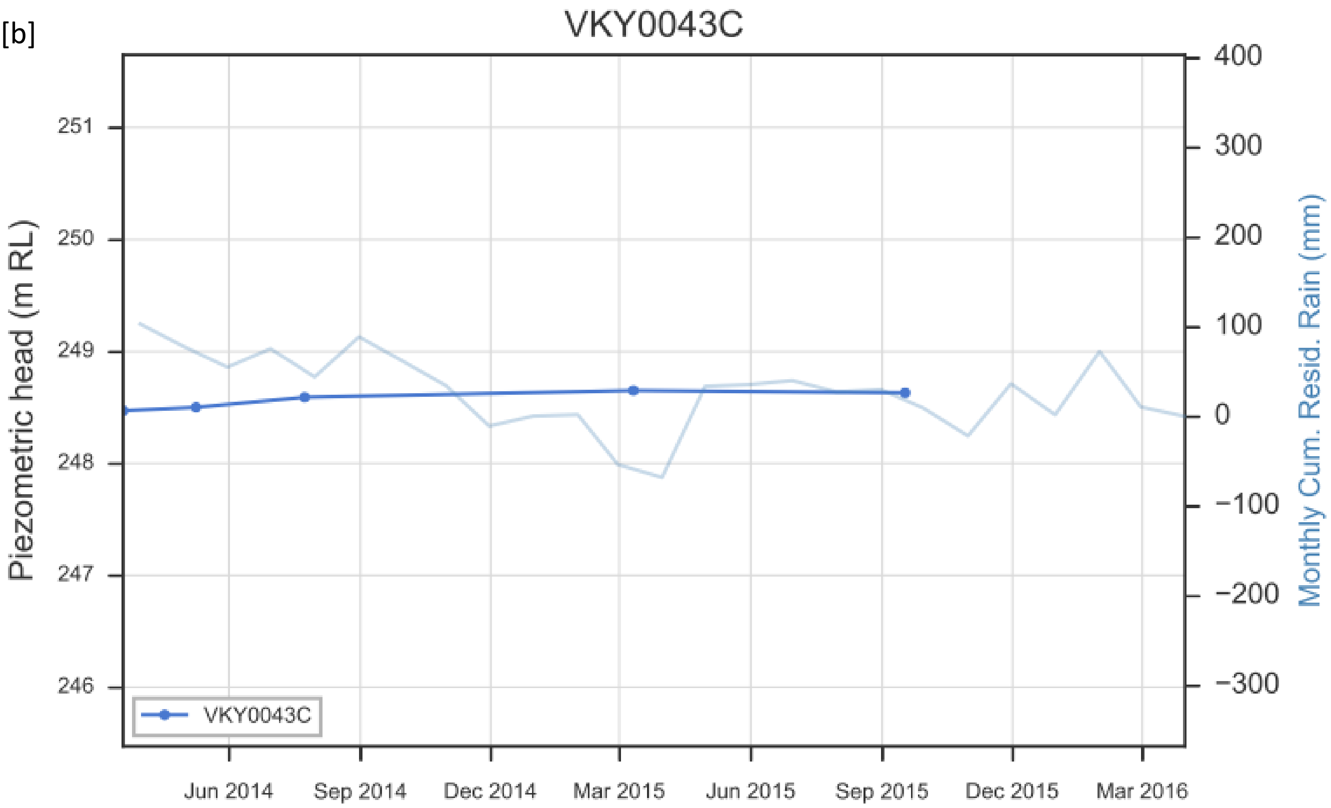
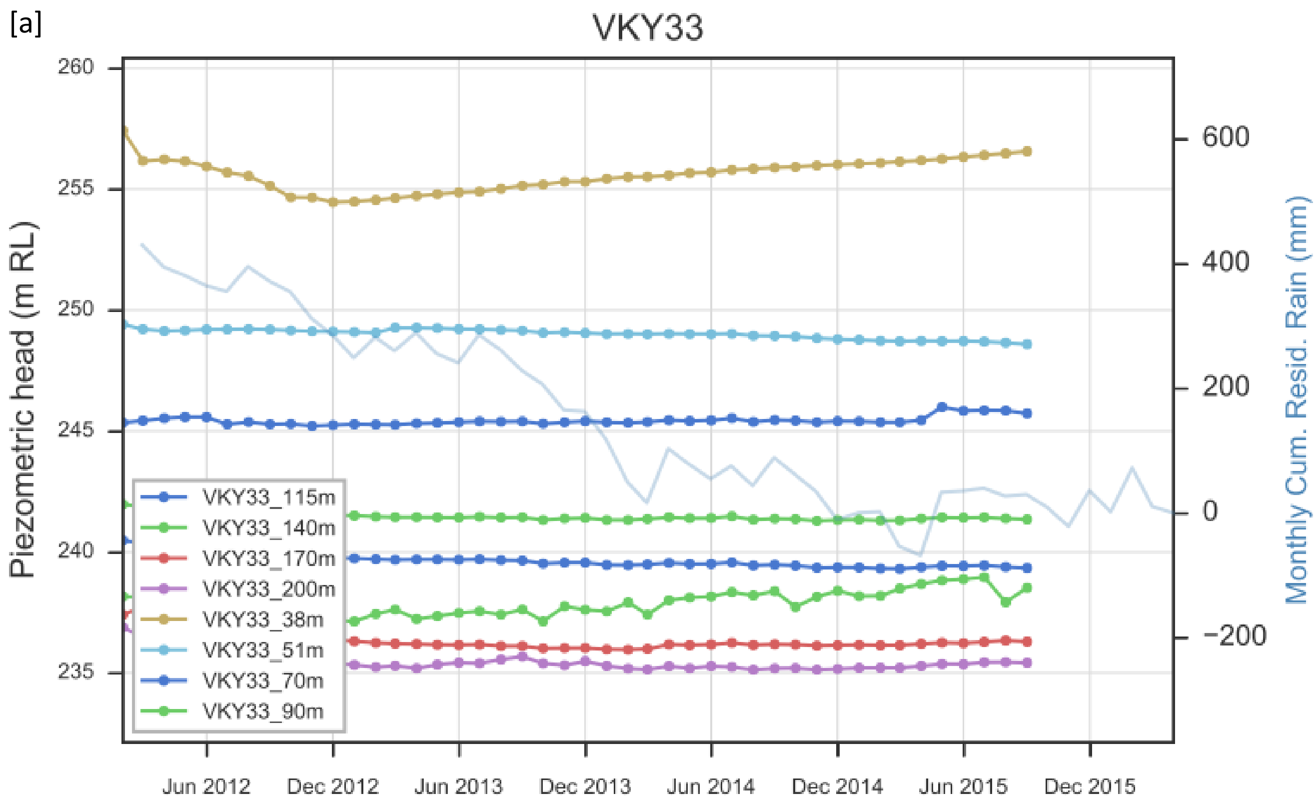


Figure 21 Representative Vickery Hydrographs a) SB01 (Alluvium) b) VKY0043C (Maules Creek Formation) (locations shown in Figure 17)



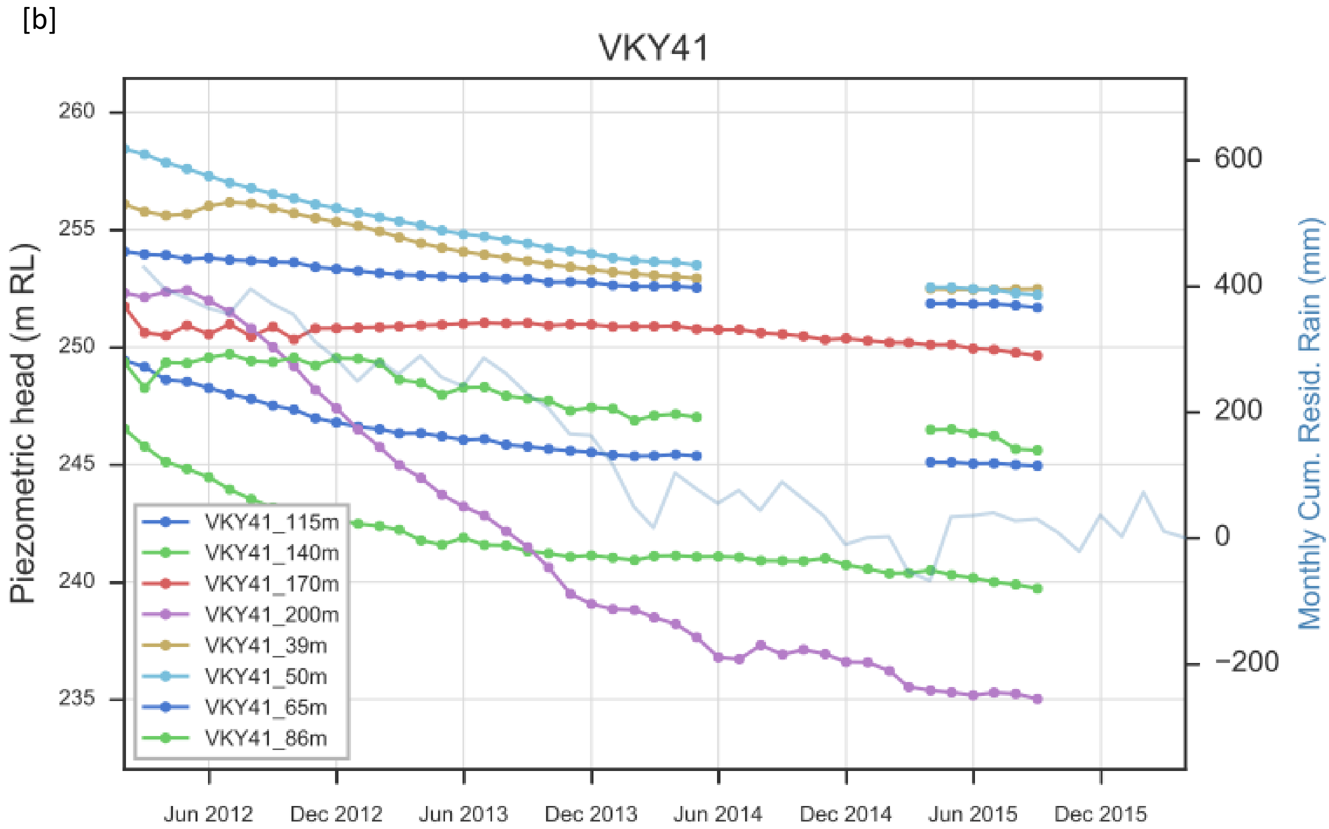


Figure 22 Representative Vickery Vibrating Wire Piezometer Hydrographs a) VKY33 (Maules Creek Formation) b) VKY41 (Maules Creek Formation) (locations shown in Figure 17)

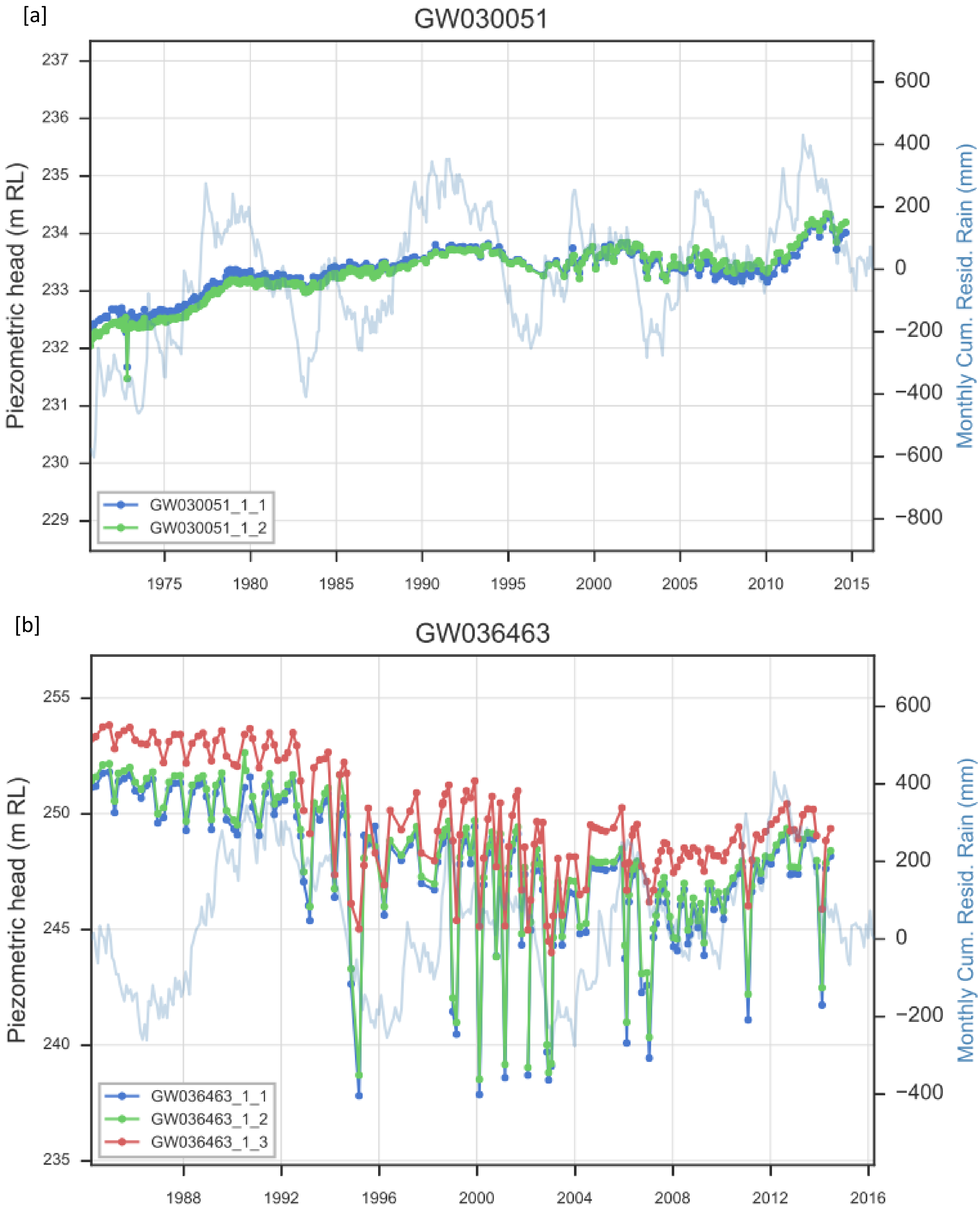
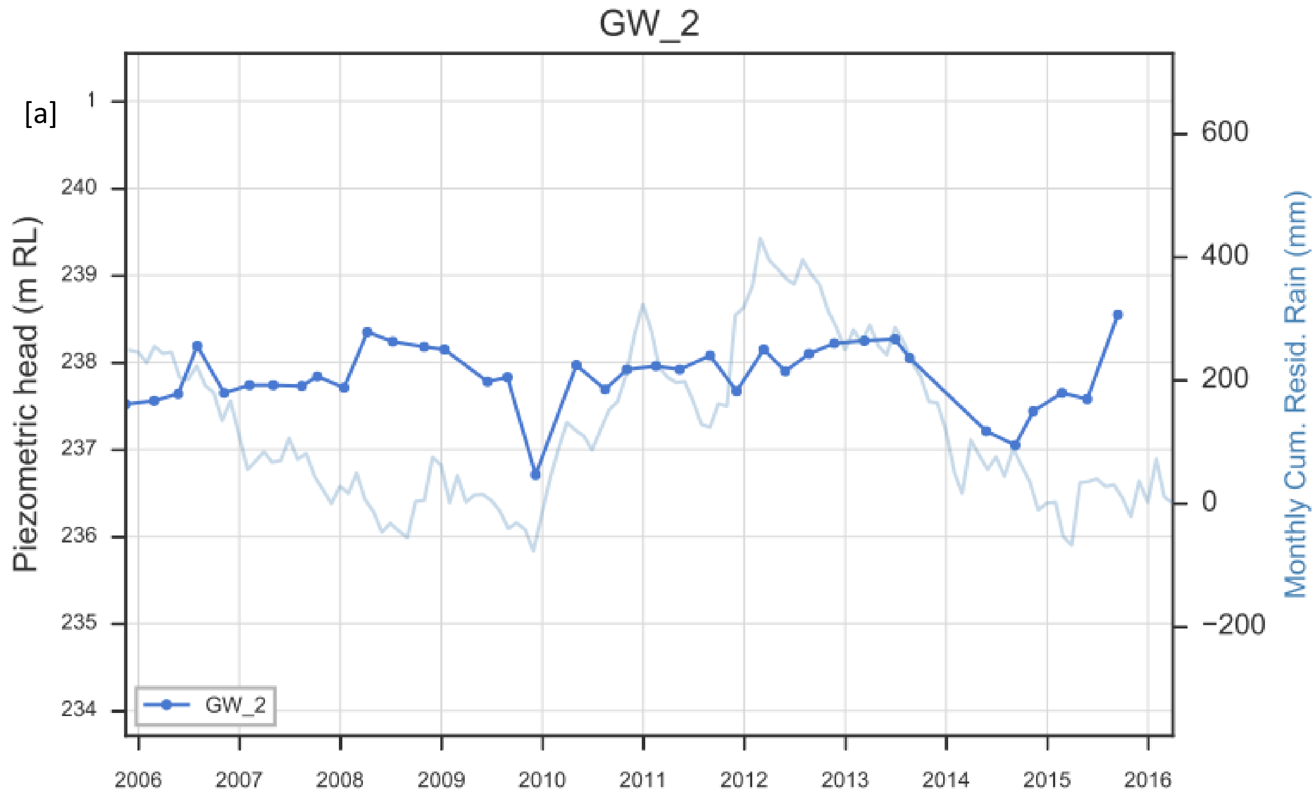


Figure 23 Representative DoI Water Hydrographs: a] GW30051 (Alluvium) north-west of former Canyon Coal Mine b] GW036463 (Alluvium) south of Vickery lease (locations shown in Figure 17)



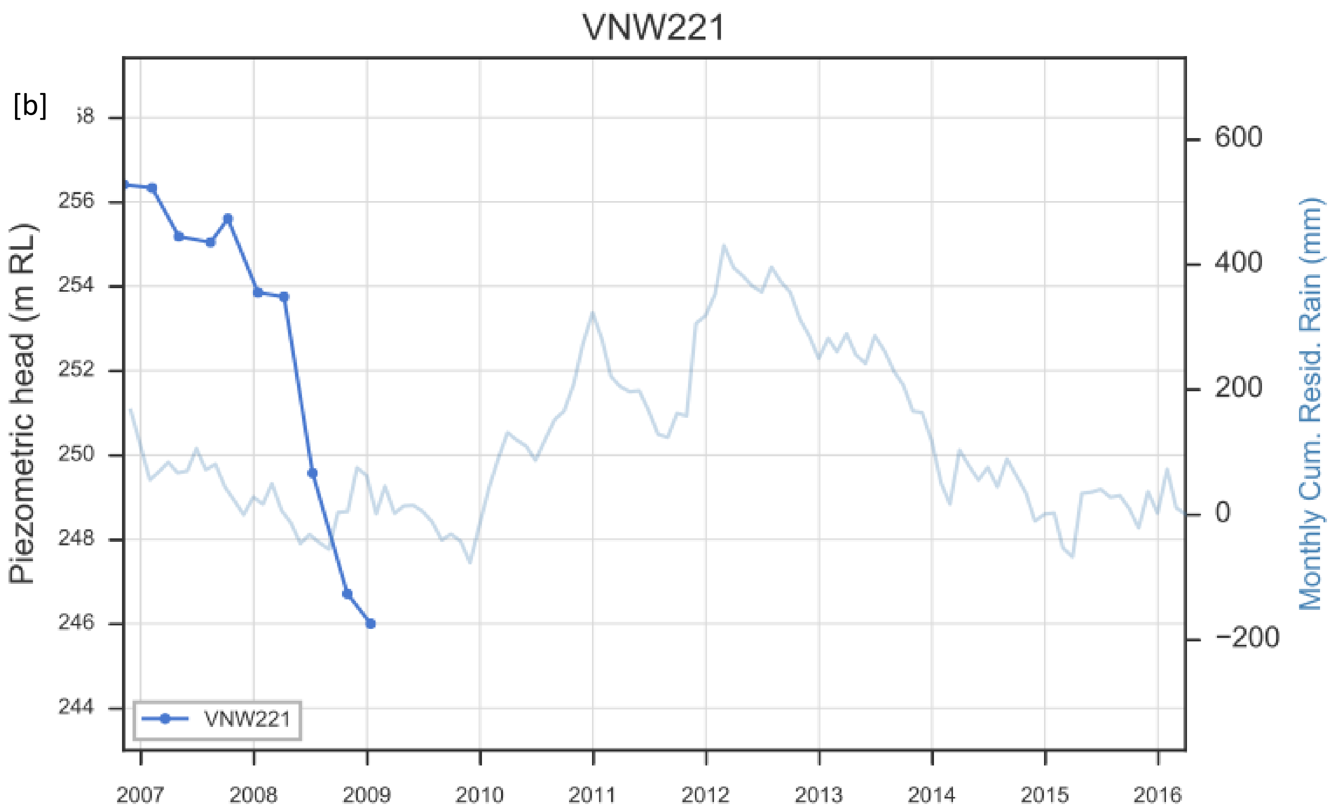
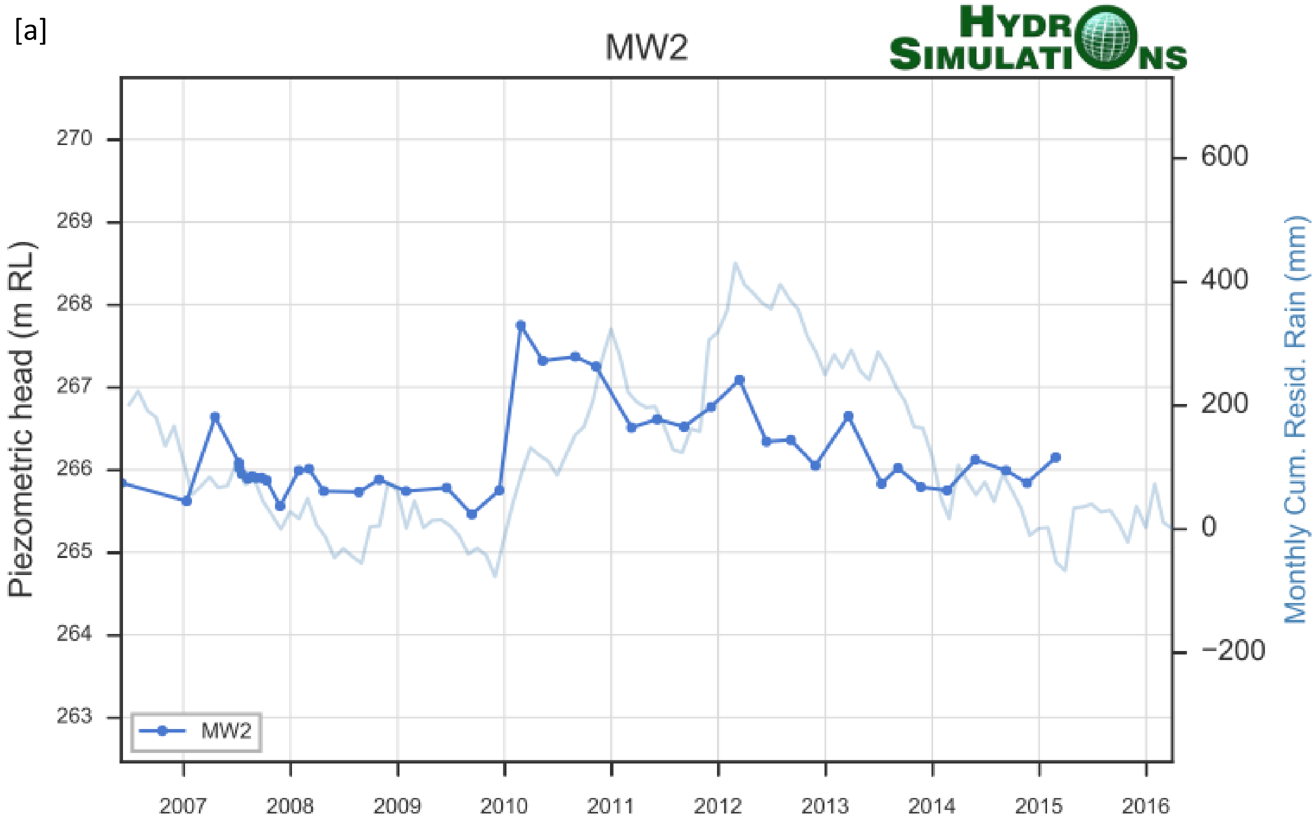


Figure 24 Representative Canyon hydrographs: a] GW_2 (Alluvium) north of Driggle Draggle Creek and former Canyon Coal Mine b] VNW221 (Alluvium) <50 m south of former Canyon Coal Mine (locations shown in Figure 17)

[a]



[b]

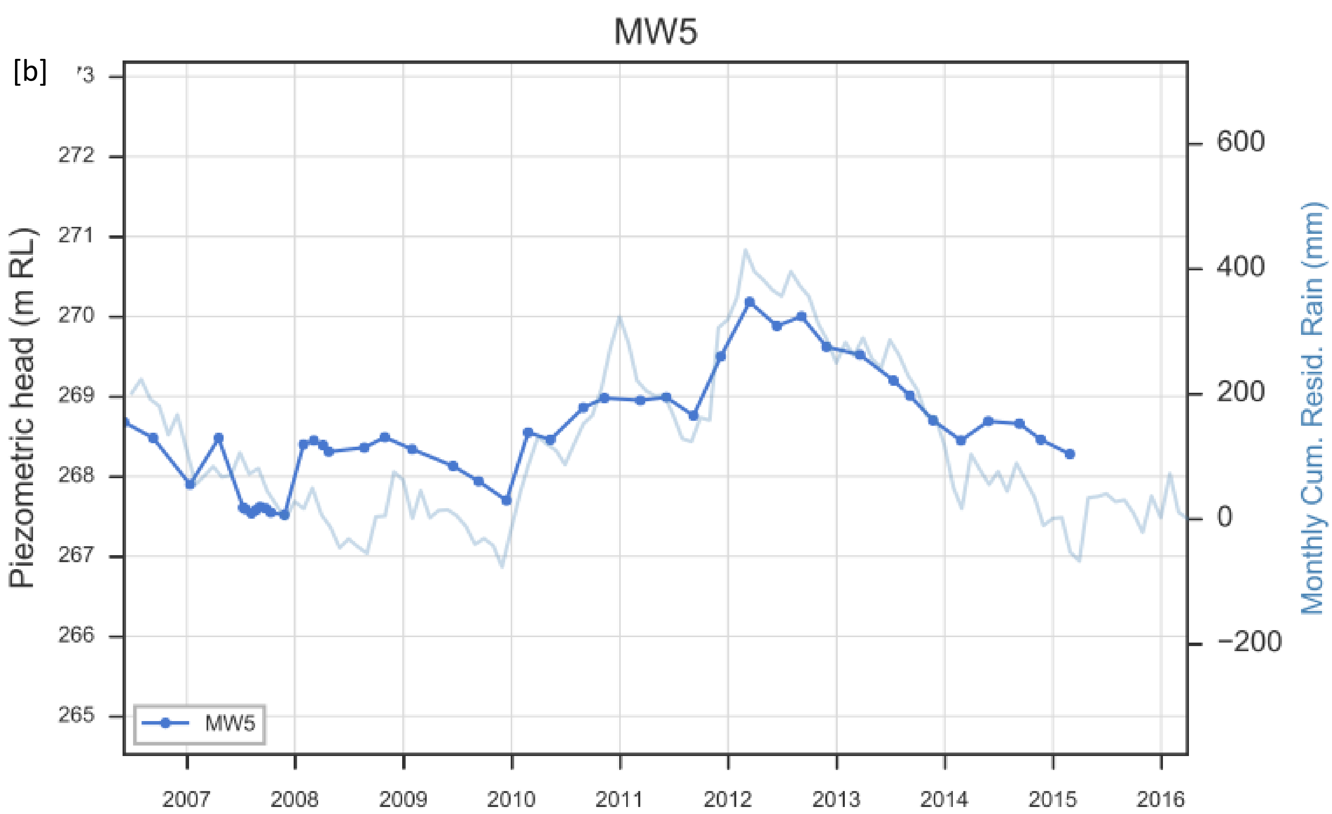


Figure 25 Representative Tarrawonga hydrographs: a] MW2 (Maules Creek Formation) bore 500m south of Tarrawonga Open Cut b] MW5 (Alluvium) bore 500 m south of Tarrawonga Open Cut (locations shown in Figure 17)

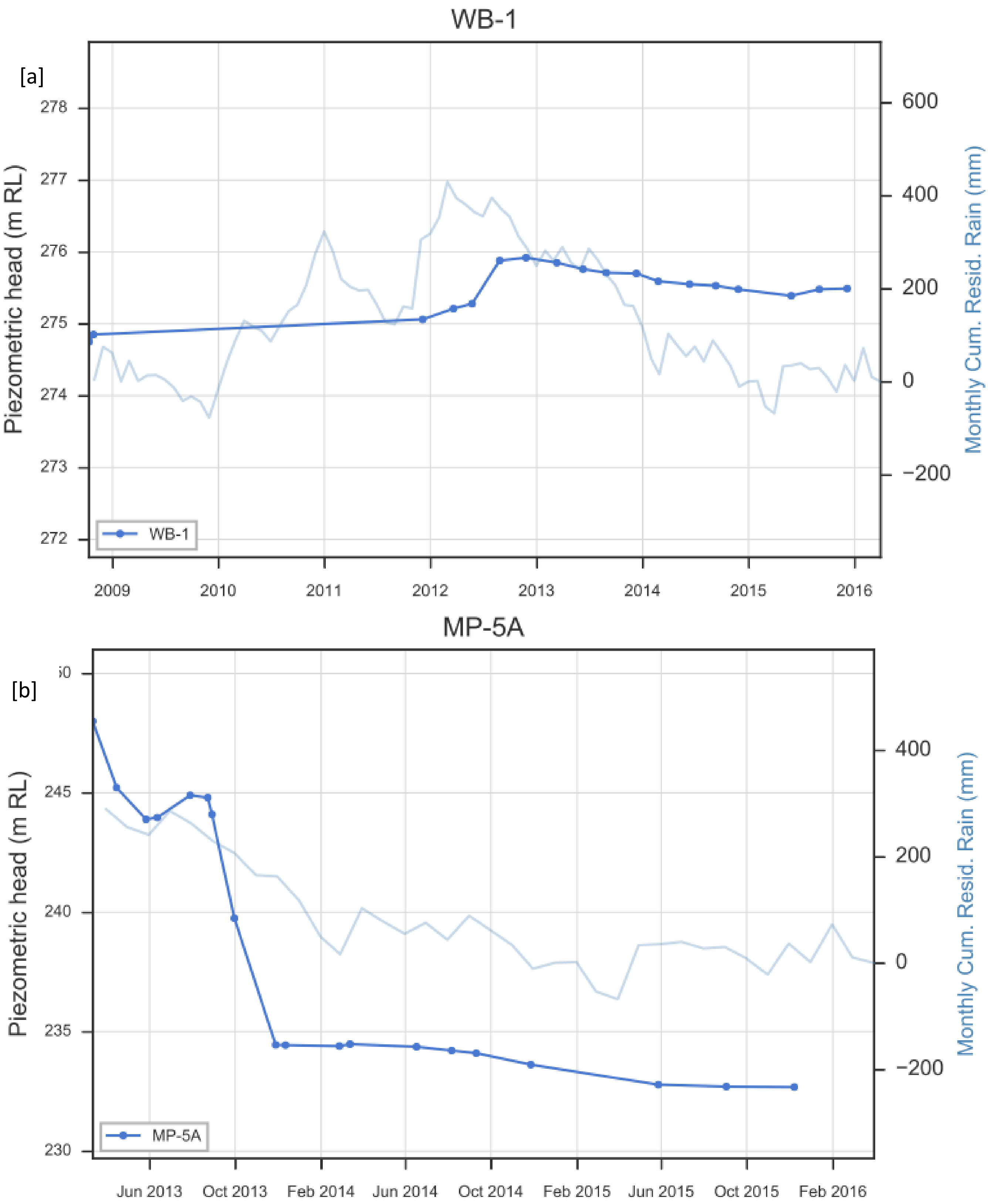


Figure 26 Representative Rocglen Hydrographs: a] WB-1 (Maules Creek Formation) 3 km north of Rocglen Open Cut and b] MP-5A (Maules Creek Formation) 200 m north of Rocglen Open Cut (locations shown in Figure 17)

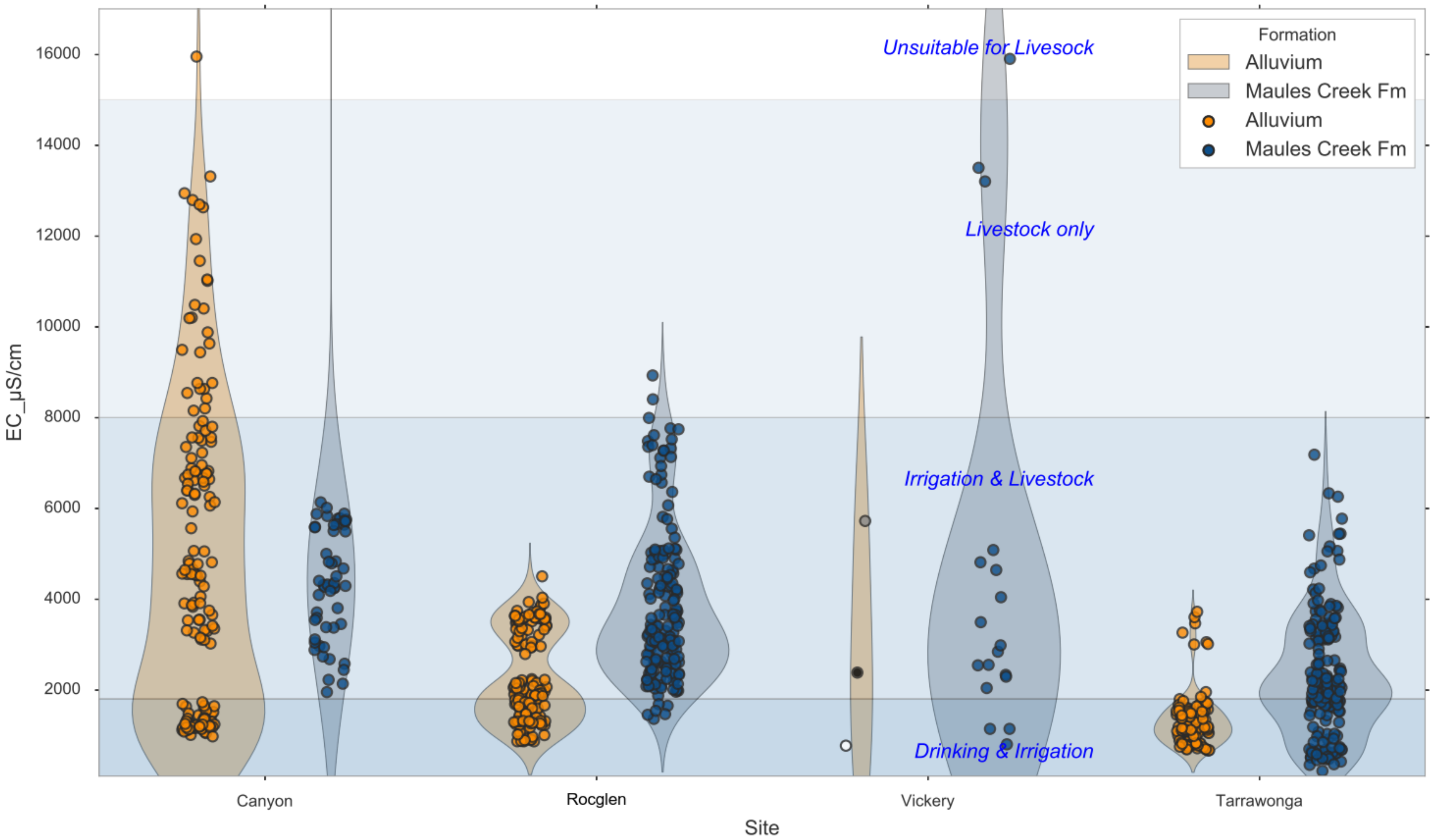


Figure 27 Violin Plots Showing Ranges in EC for Groundwater (curves represent kernel density estimation of the data)

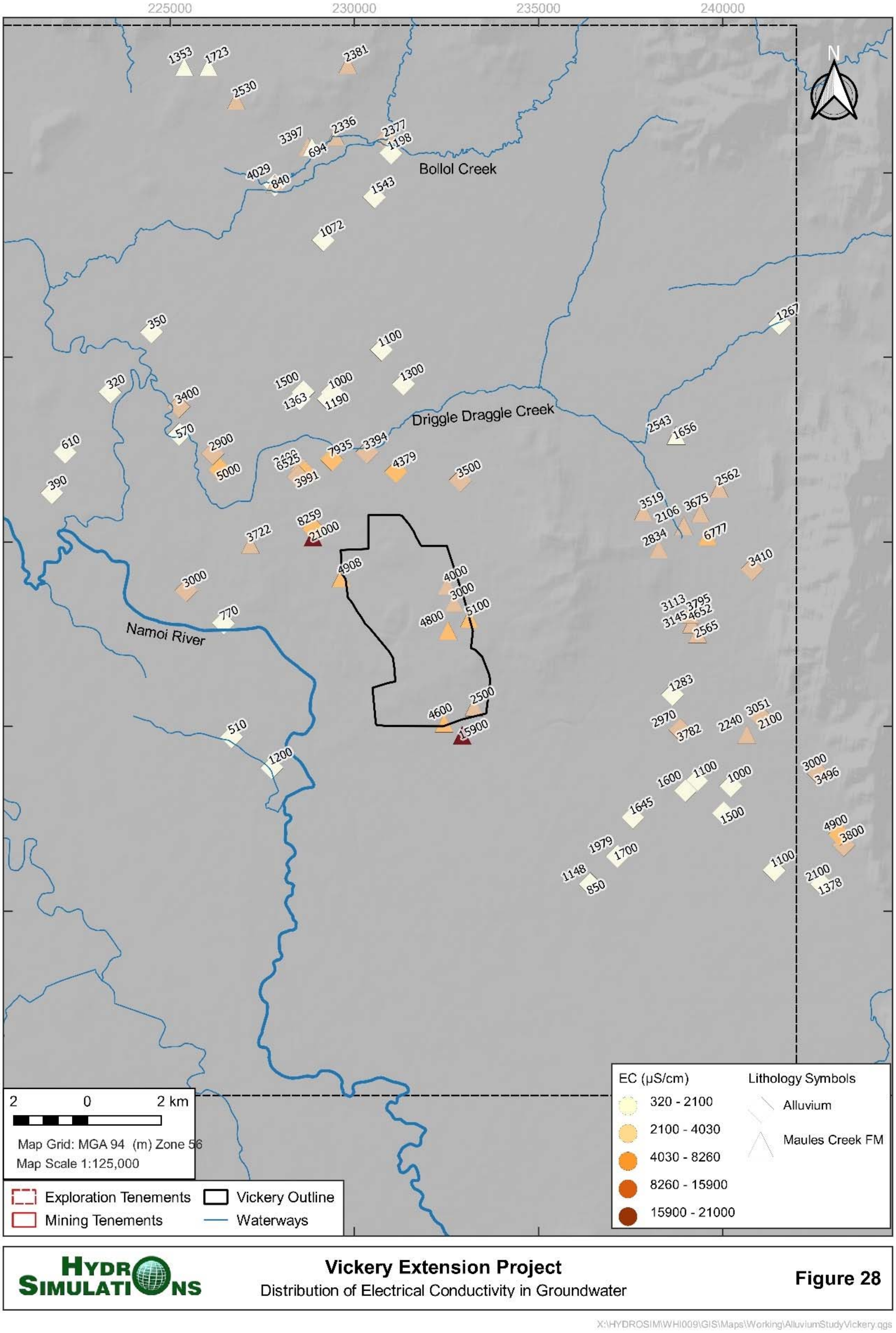


Figure 28 Distribution of Electrical Conductivity in Groundwater

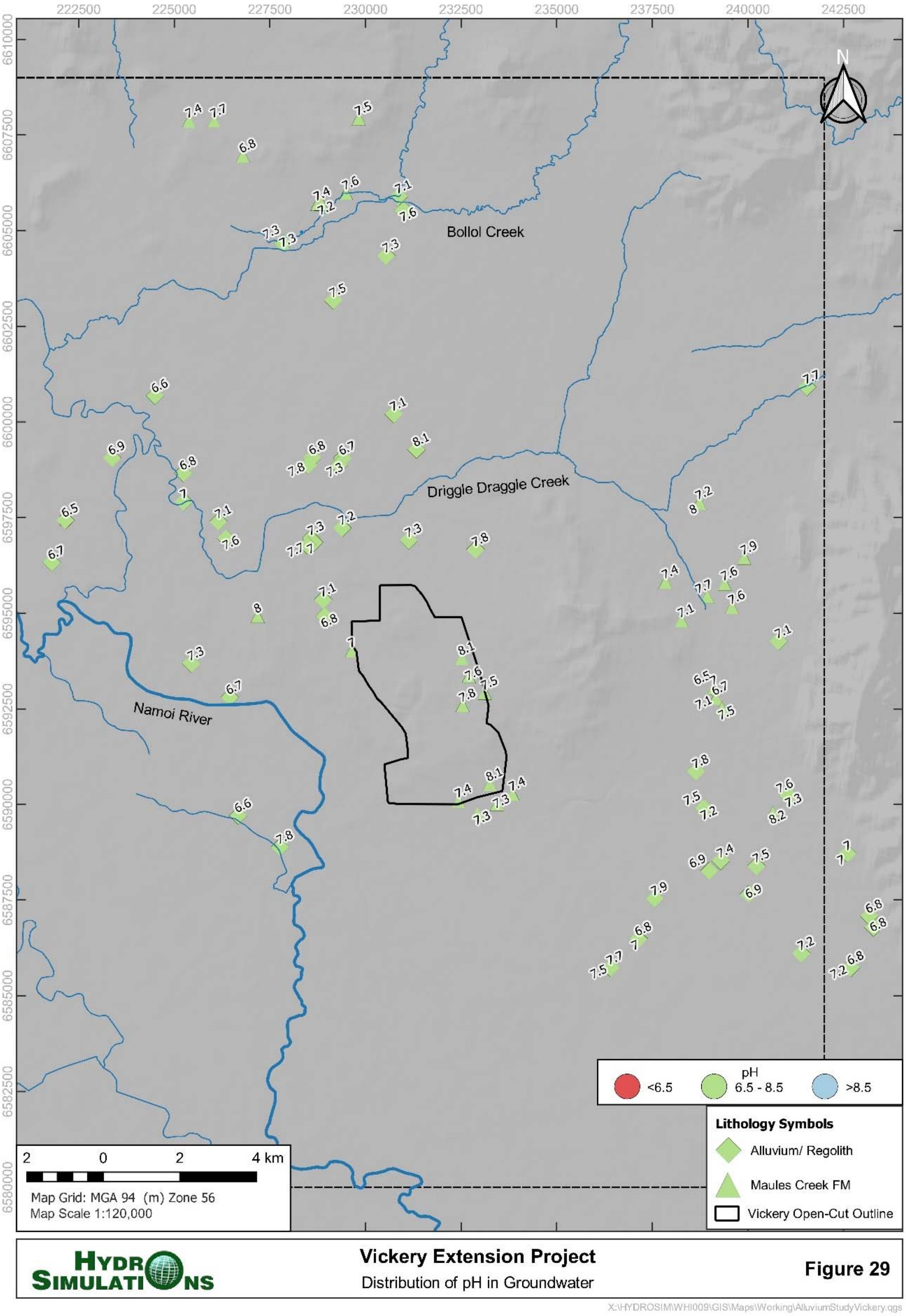
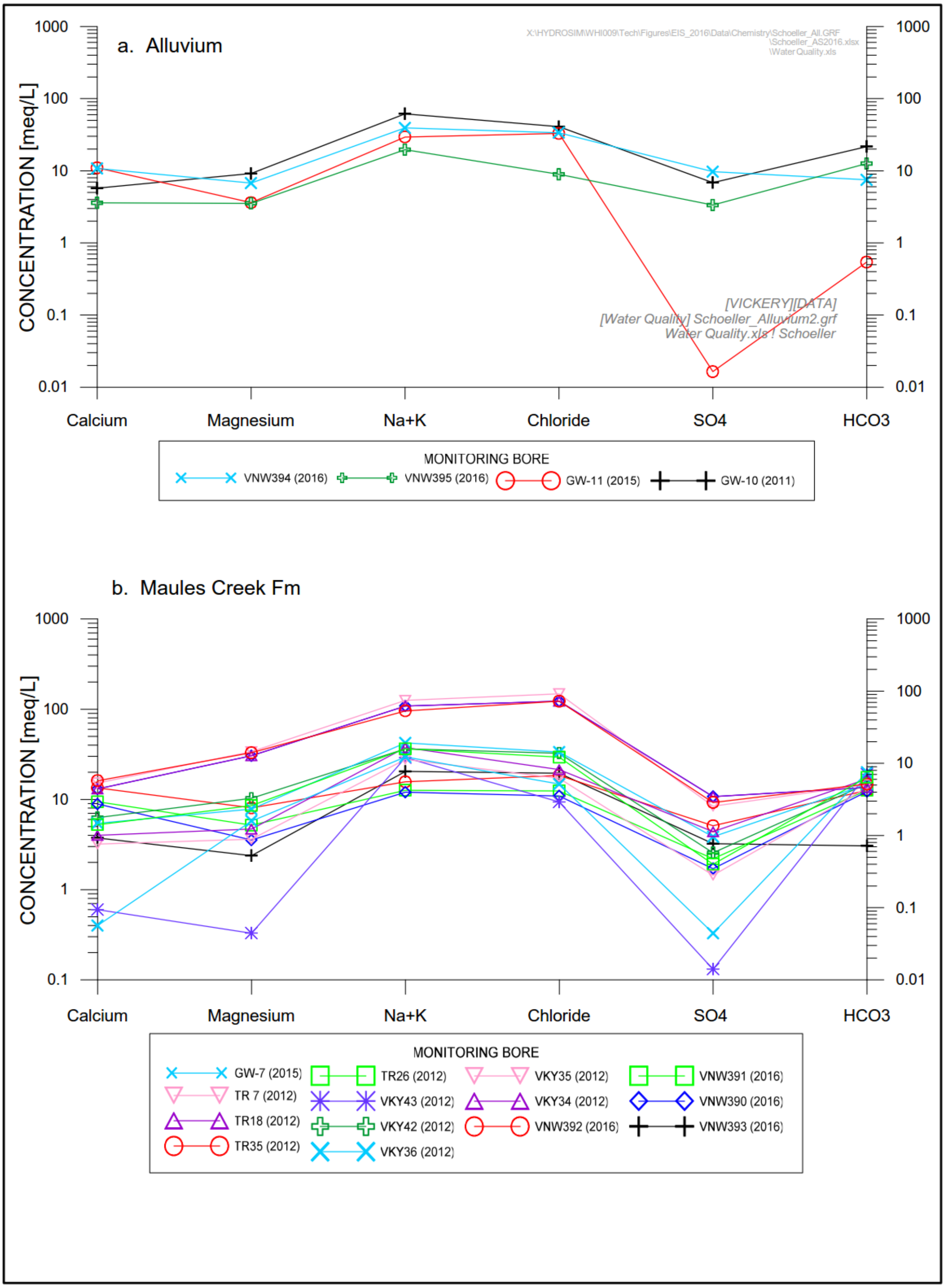


Figure 29 Distribution of pH in Groundwater



HYDROSIMULATIONS	**Vickery Extension Project** Vickery Area Schoeller Plots for Major Ions in Groundwater	Figure 31

Figure 30 Schoeller Plots for Major Ions in Groundwater

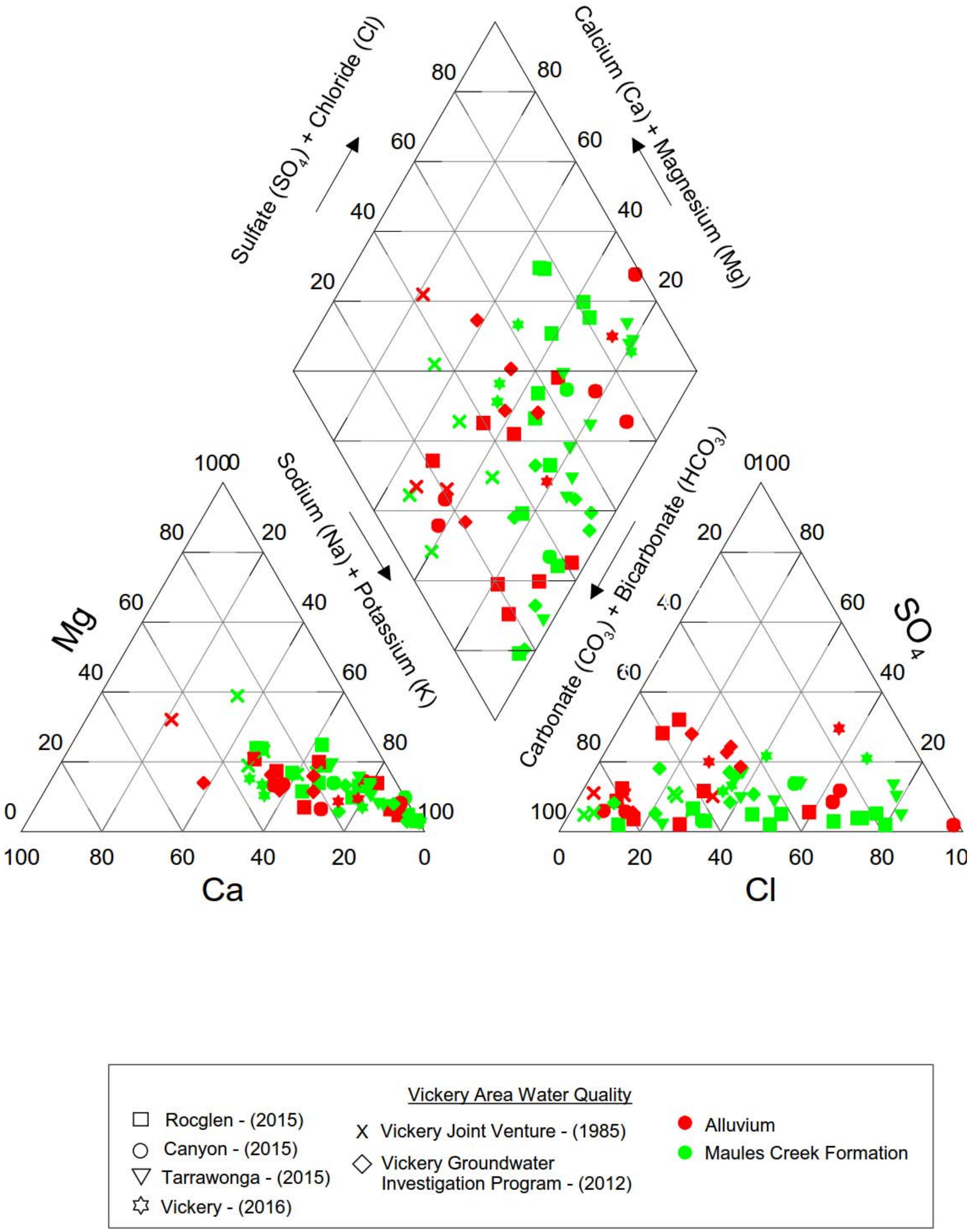


Figure 31 **Piper Plot Showing Major Ion Composition of Groundwater**

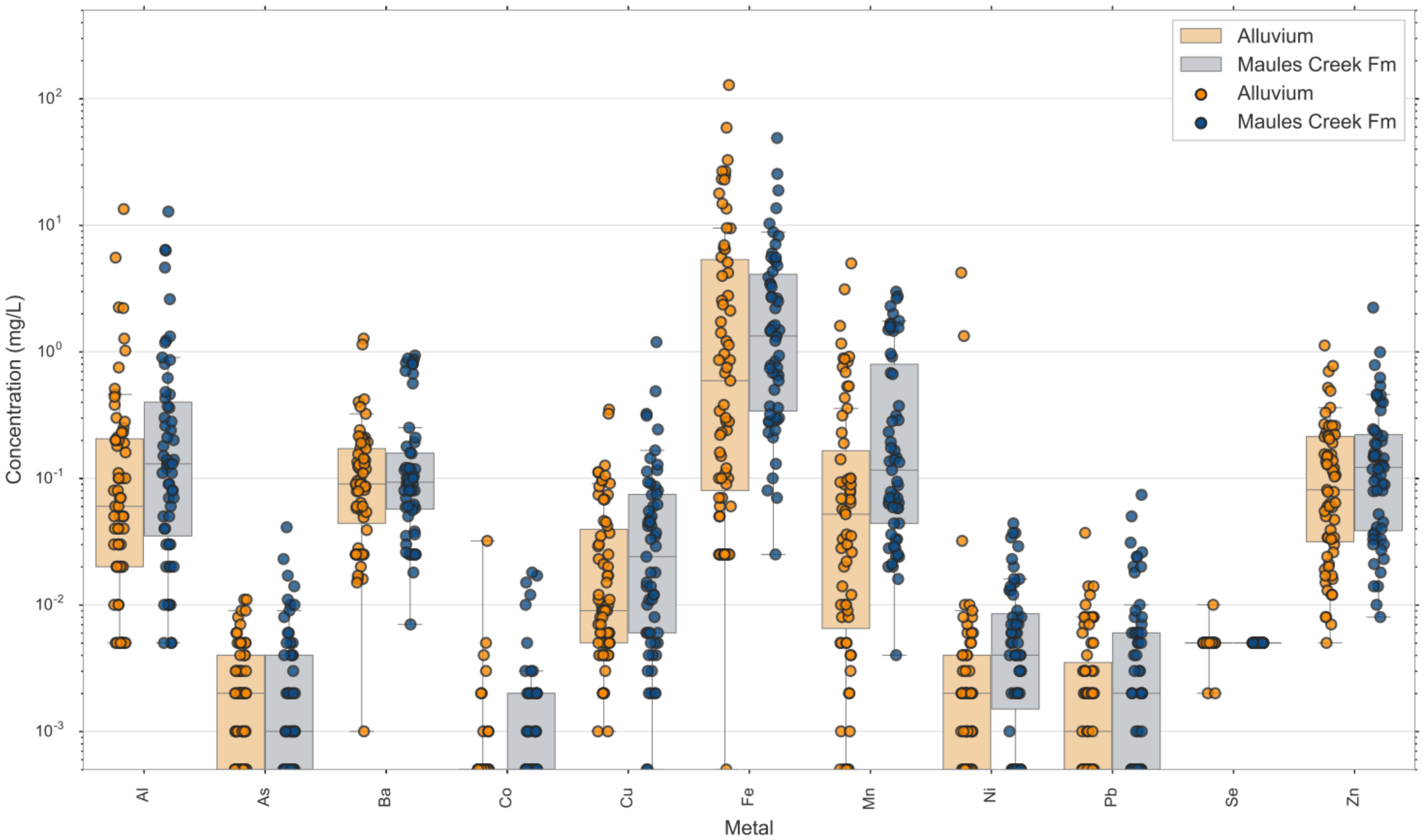


Figure 32 Ranges in Dissolved Metal Concentrations in Groundwater

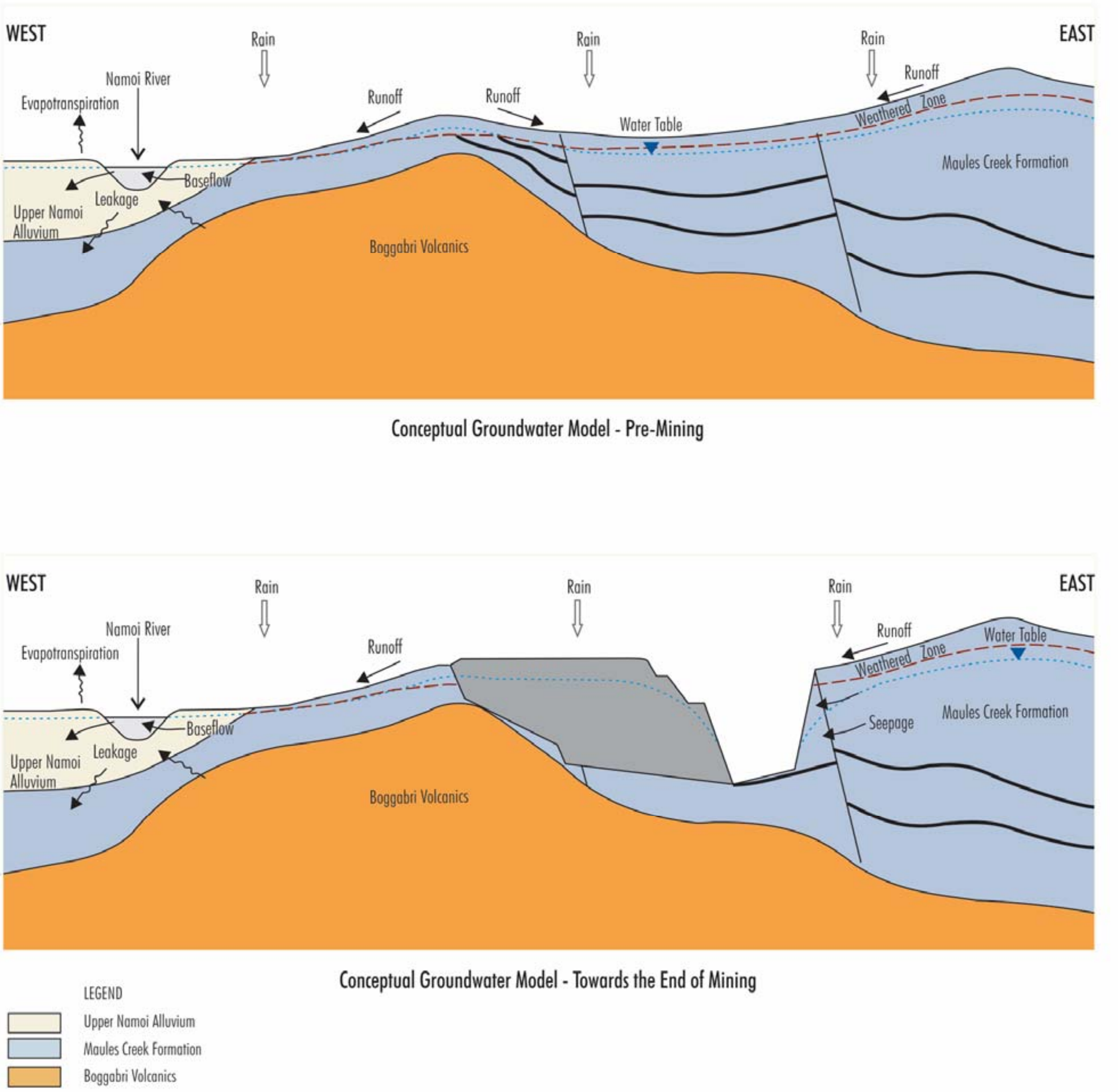


Figure 33 Conceptual Groundwater Models – Pre-Mining and During Mining

INDICATIVE THICKNESS (m)	LAYER	LITHOLOGY	
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)	Bluevale (3 Splits), Cranleigh Seams
40	13	Underburden	Laird and Goonbri Formations
50	14	Volcanics	Boggabri Volcanics

	Mine	Mined seams
NORTH	Maules Creek Coal Mine	Herndale Seam to Templemore Seam
	Boggabri Coal Mine	Braymont Seam to Merriown Seam
	Tarrawonga Coal Mine	Braymont Seam to Nagero Upper Seam
SOUTH	Approved Mine and Project	Tralee, Gundawarra, Kurrumbede, Shannon Harbour, Stratford, Bluevale and Cranleigh
	Canyon Coal Mine	Whitehaven Seam (Cranleigh and Bluevale)
	Rocglen Coal Mine	Tarrawonga (Glenroc) Seam to Templemore (Belmont) Seam

NB. Orange shading represents mined seams at each mine.

Figure 34 Numerical Model Layers

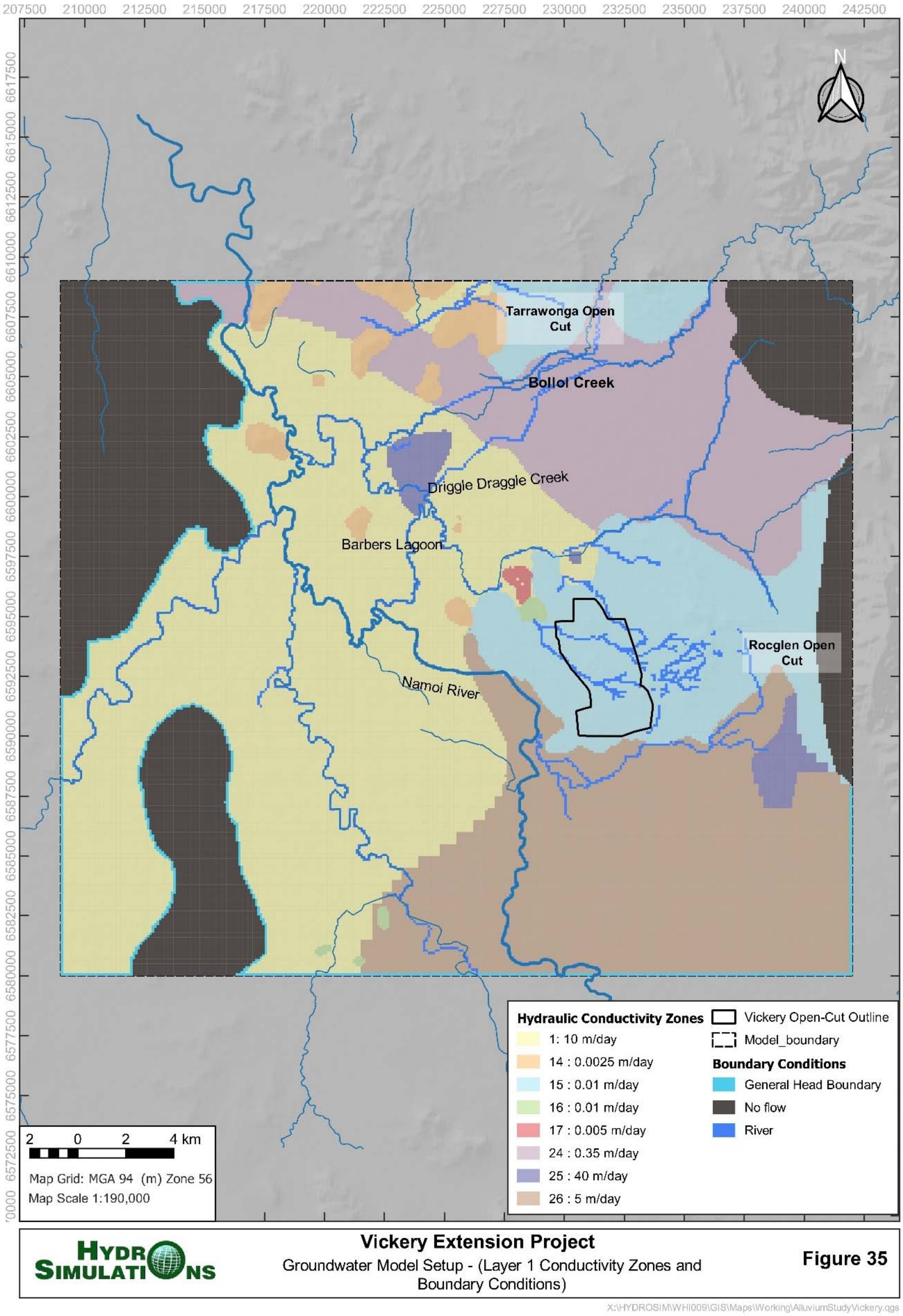


Figure 35 Groundwater Model Setup (Layer 1 Conductivity Zones and Boundary Conditions)

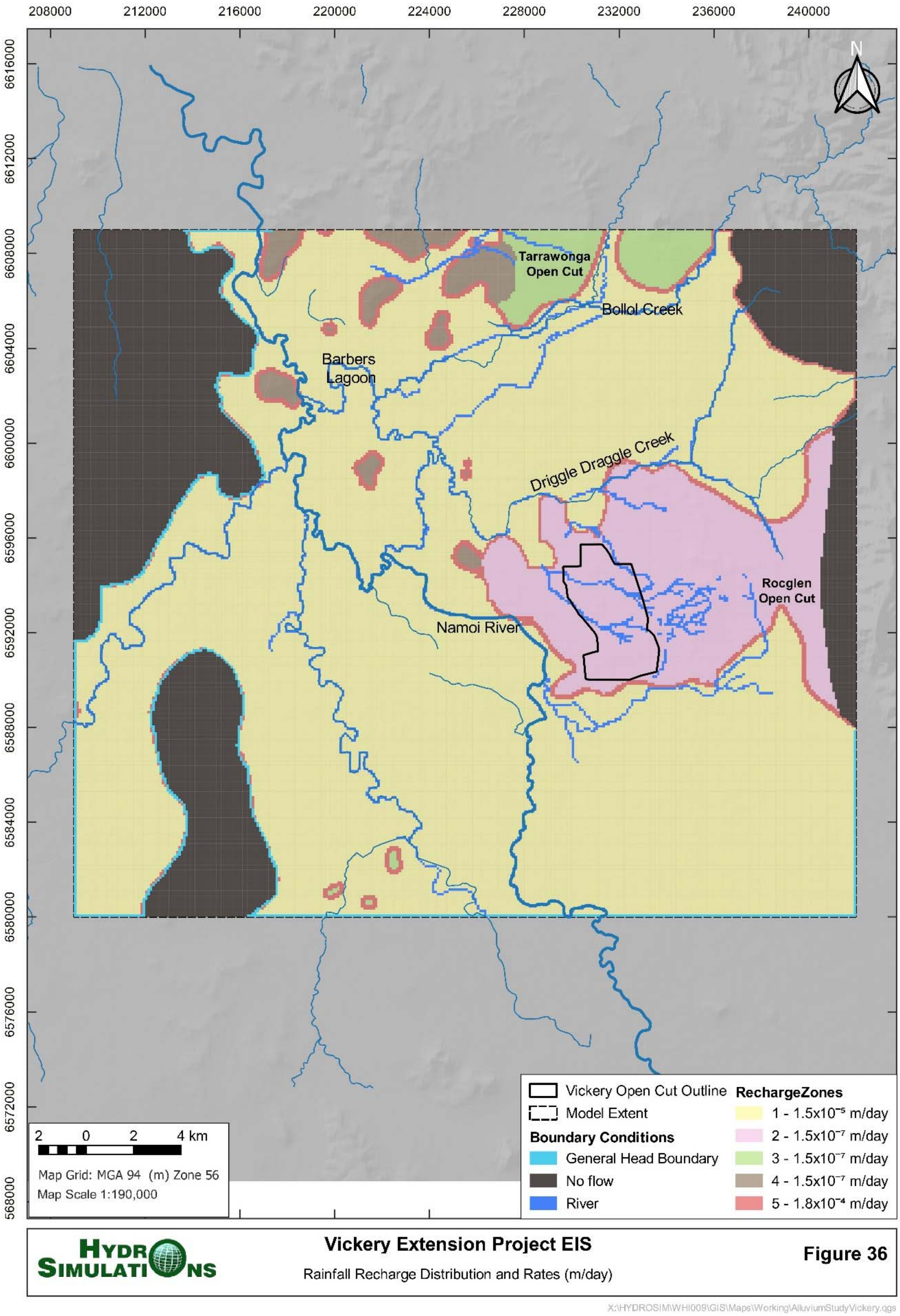
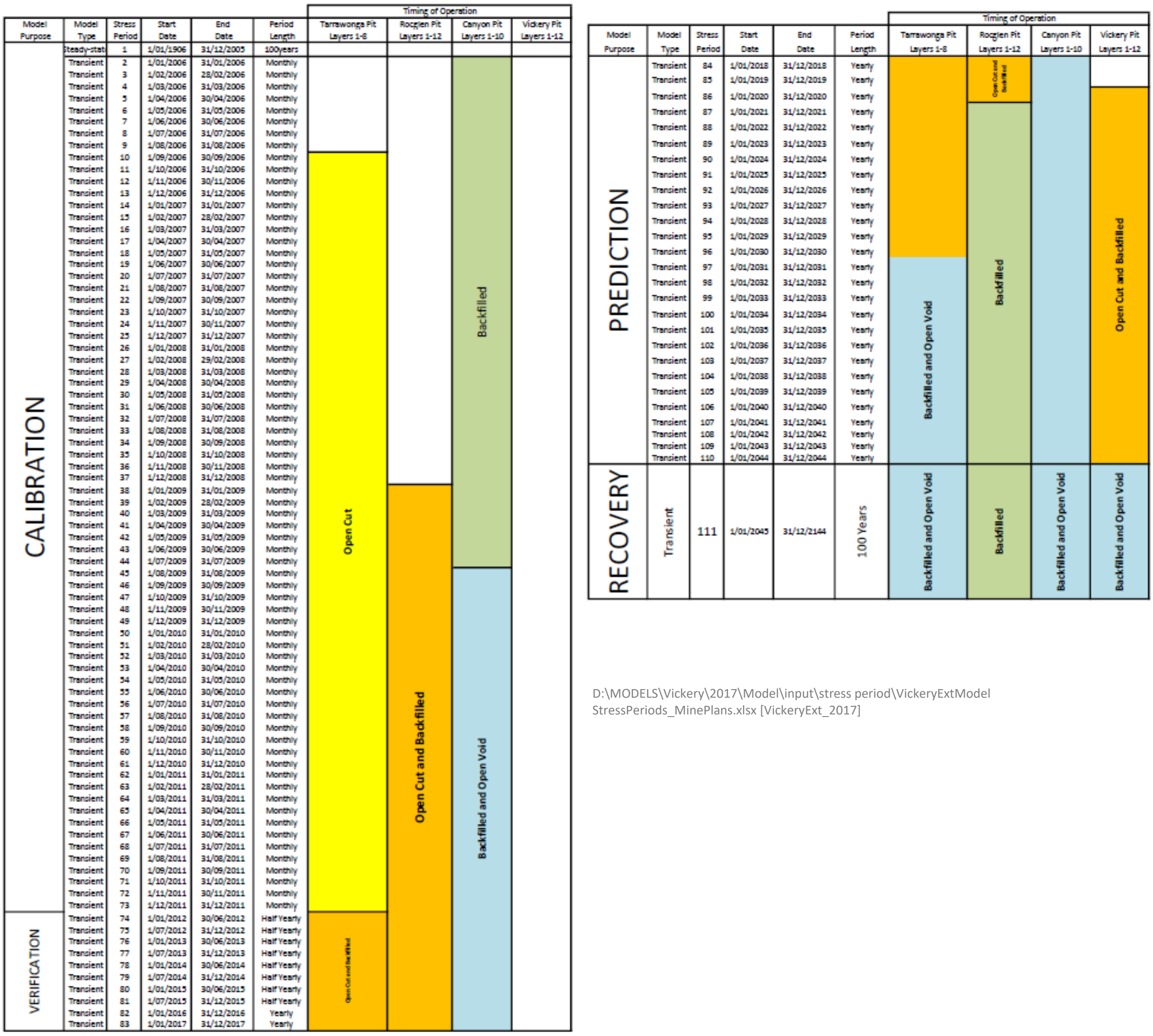


Figure 36 Rainfall Recharge Distribution and Rates



D:\MODELS\Vickery\2017\Model\input\stress period\VickeryExtModel
StressPeriods_MinePlans.xlsx [VickeryExt_2017]

Figure 37 Stress Period Setup and Sequencing of Mine Activities

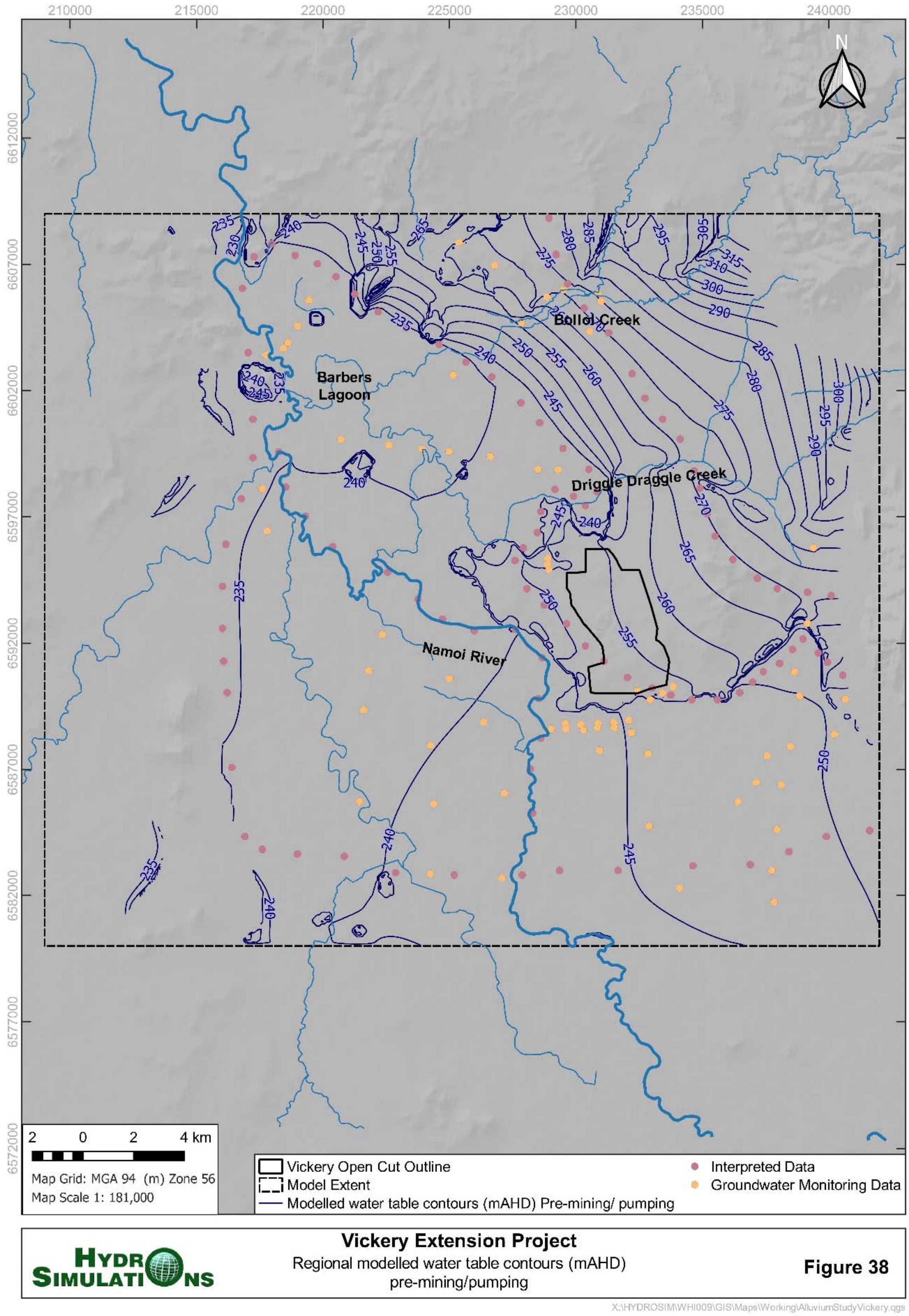


Figure 38 Regional Modelled Water Table Contours (mAHD) Pre-Mining/Pumping

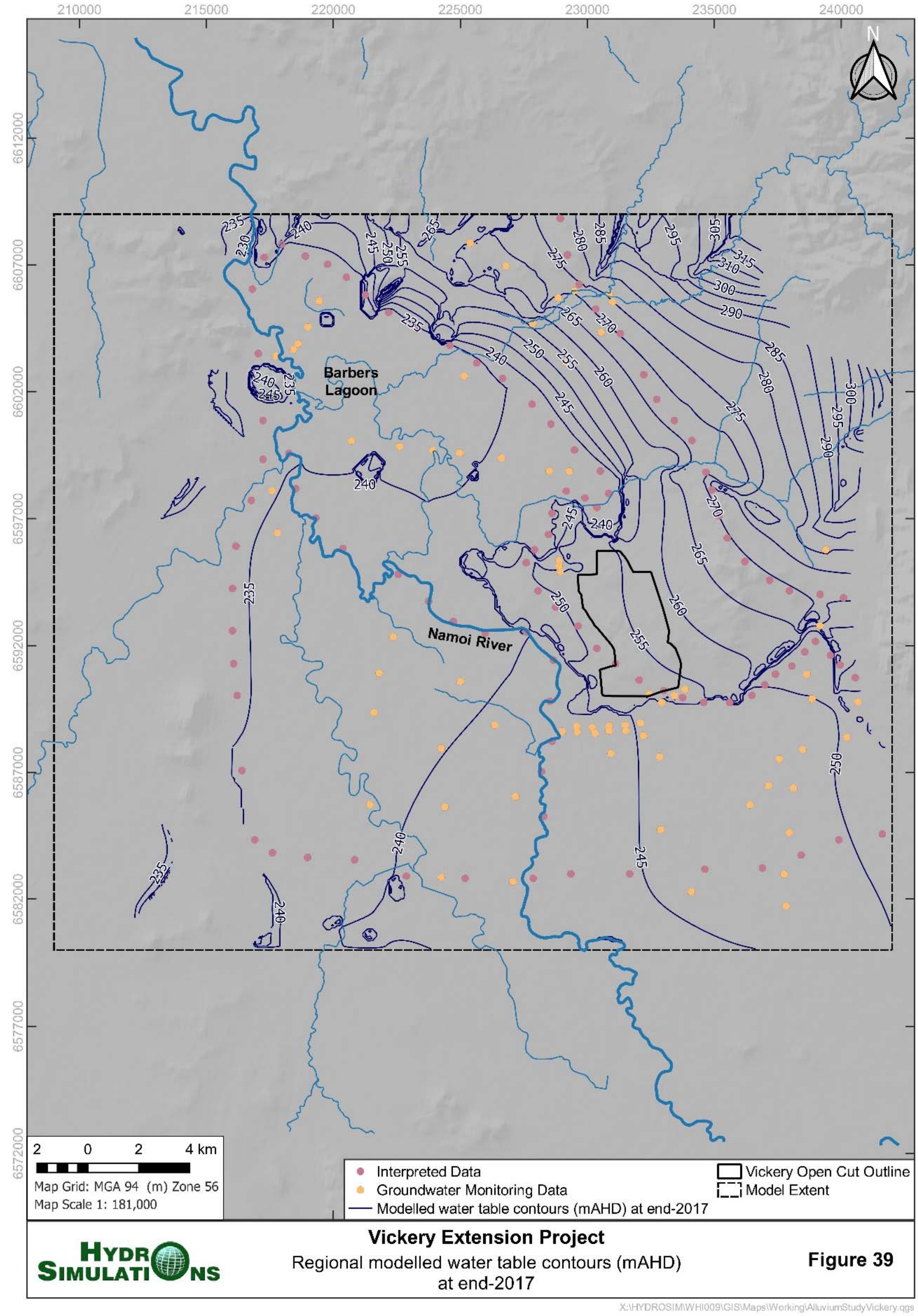
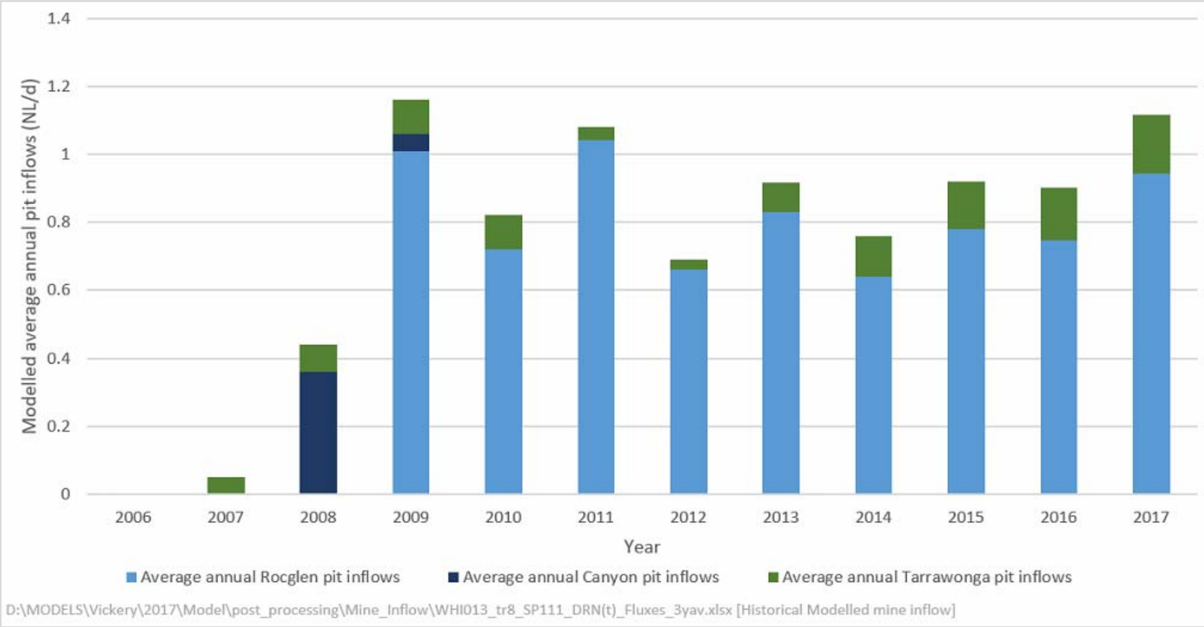


Figure 39 Regional Modelled Water Table Contours (mAHD) at End-2017



Note – Annual pit inflows based on calendar years

Figure 40 Historical Modelled Average Annual Pit Inflows from Canyon, Tarrawonga and Rocglen Coal Mines over the Transient Calibration Period

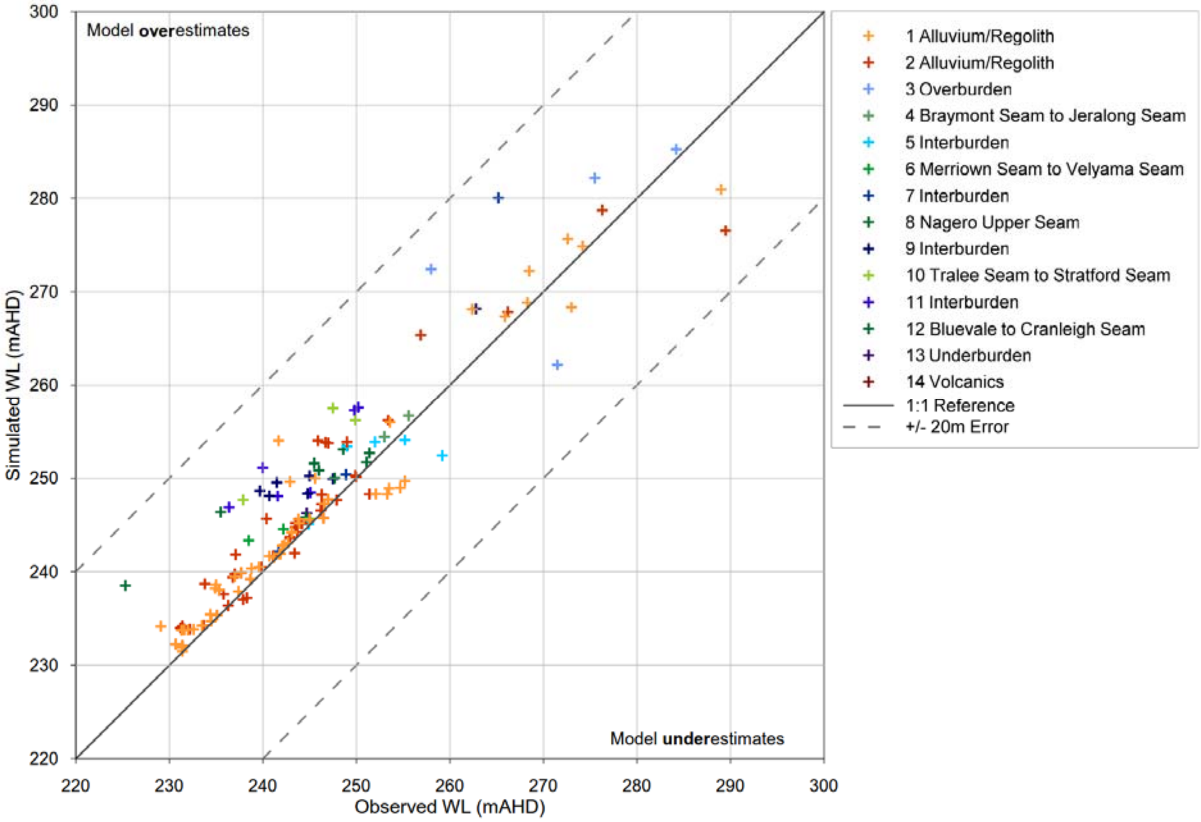


Figure 41 Scattergram of Observed and Simulated Heads for Initial Calibration

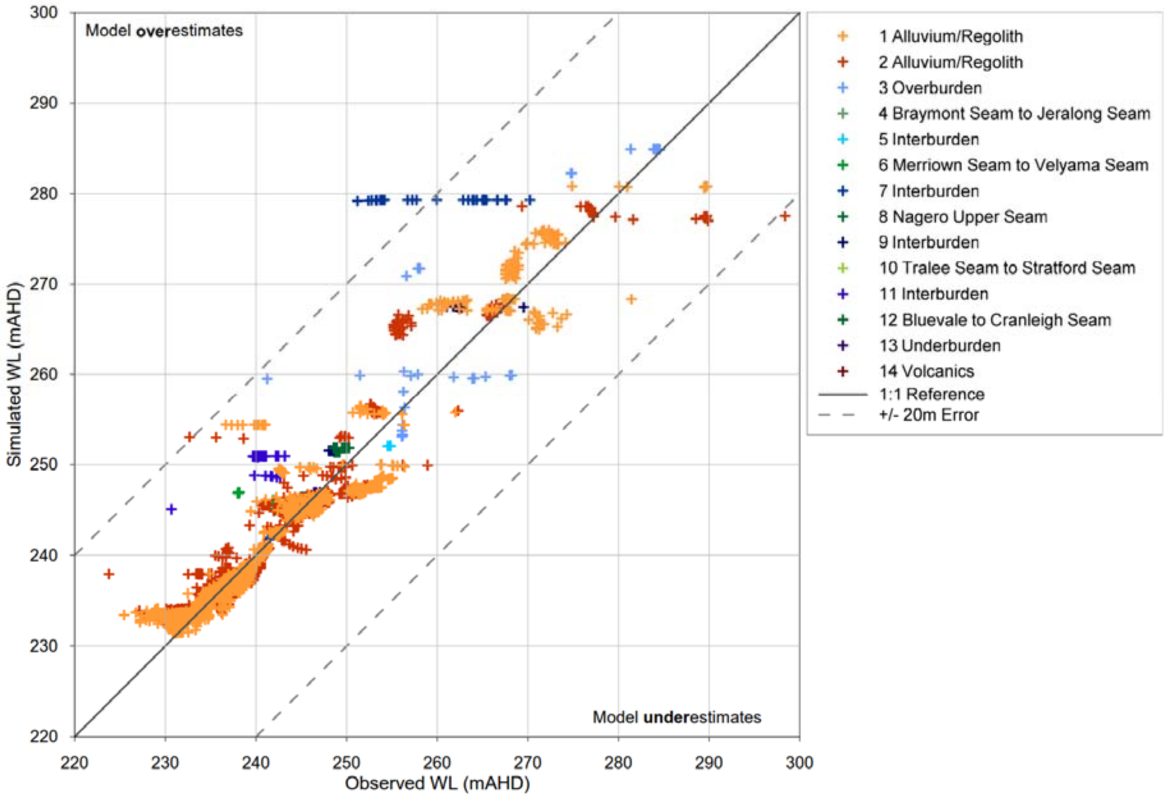


Figure 42 Scattergram of Observed and Simulated Heads for Transient Calibration (2006-2011)

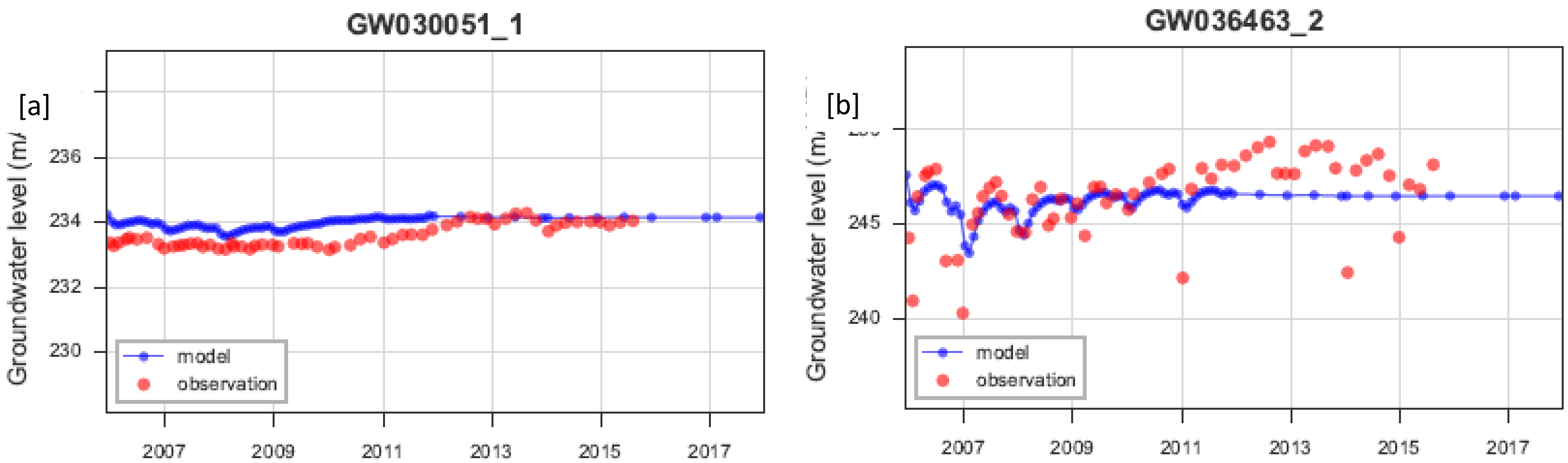


Figure 43 **Representative Simulated and Observed DoI Water Hydrographs a) GW030051_1 (Alluvium) b) GW036463_2 (Alluvium)**

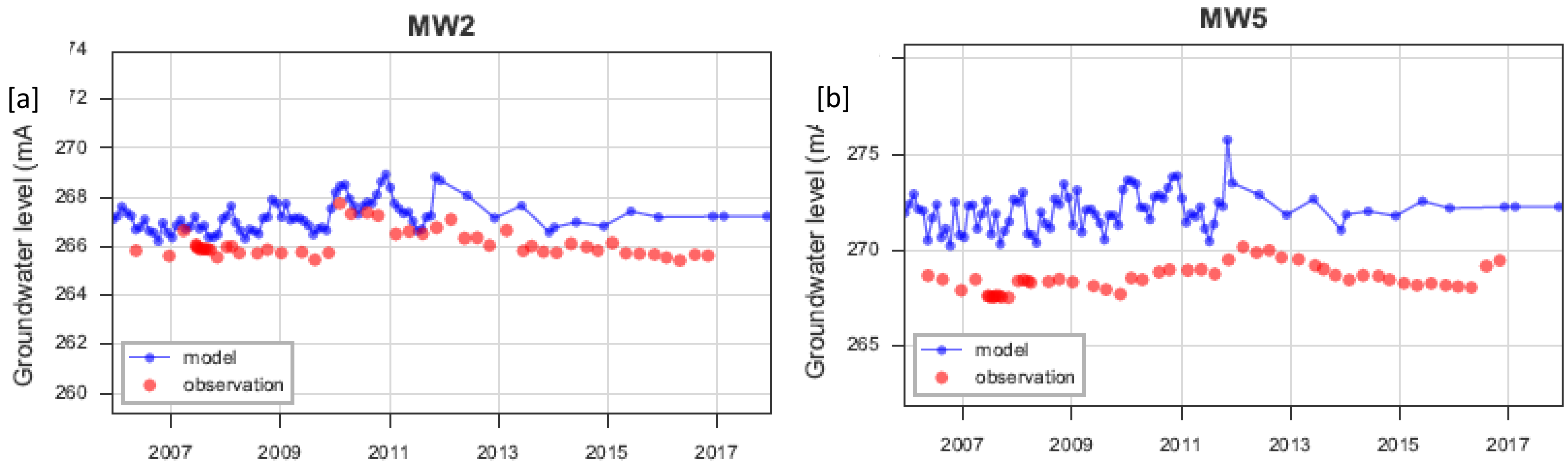


Figure 44 **Representative Simulated and Observed Tarrawonga Hydrographs a) MW2 (Maules Creek Formation) b) MW5 (Alluvium)**

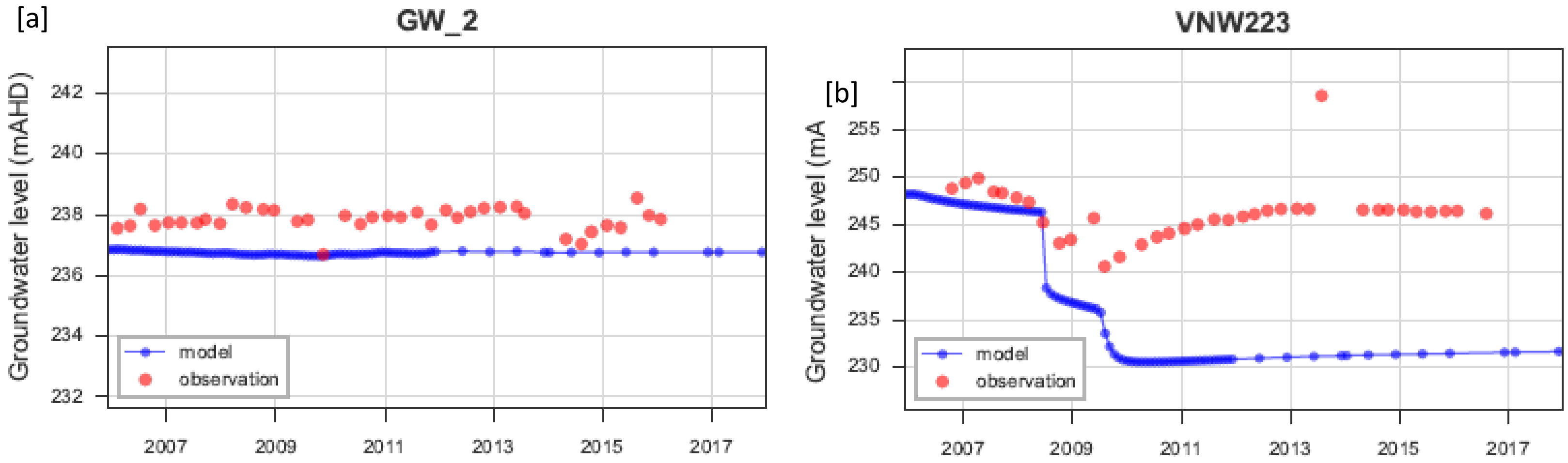


Figure 45 Representative Simulated and Observed Canyon Hydrographs a) GW2 (Alluvium) b) VNW223 (Alluvium)

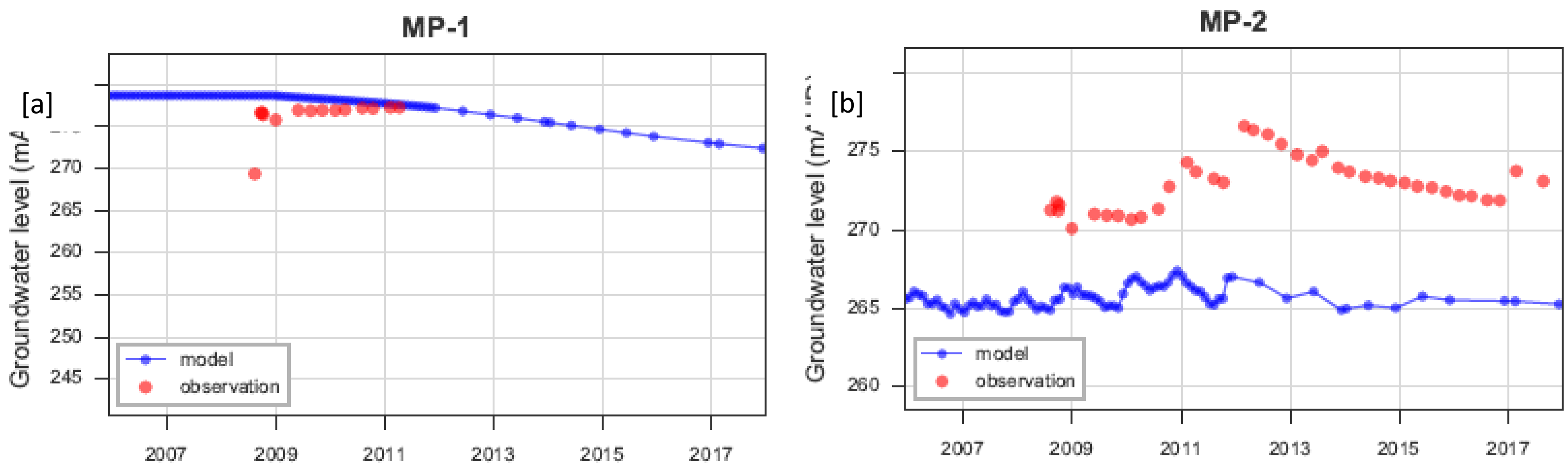


Figure 46 Representative Simulated and Observed Rocglen Hydrographs a) MP-1 (Maules Creek Formation) b) MP-2 (Maules Creek Formation)

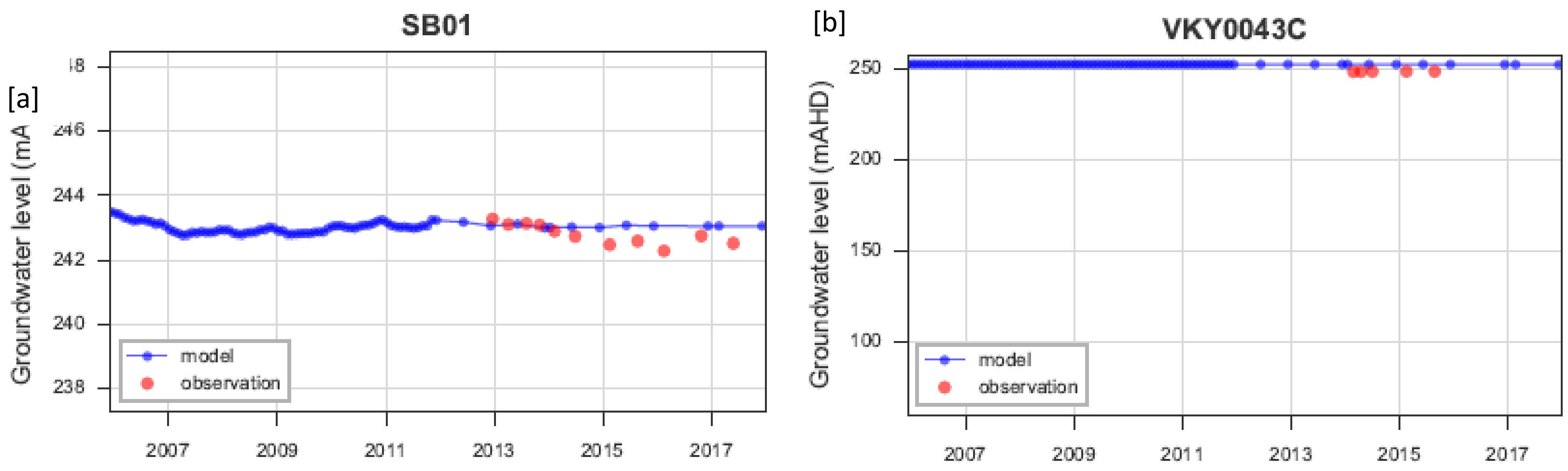


Figure 47 Representative Simulated and Observed Vickery Hydrographs a) SB01 (Alluvium) b) VKY0043C (Maules Creek Formation)

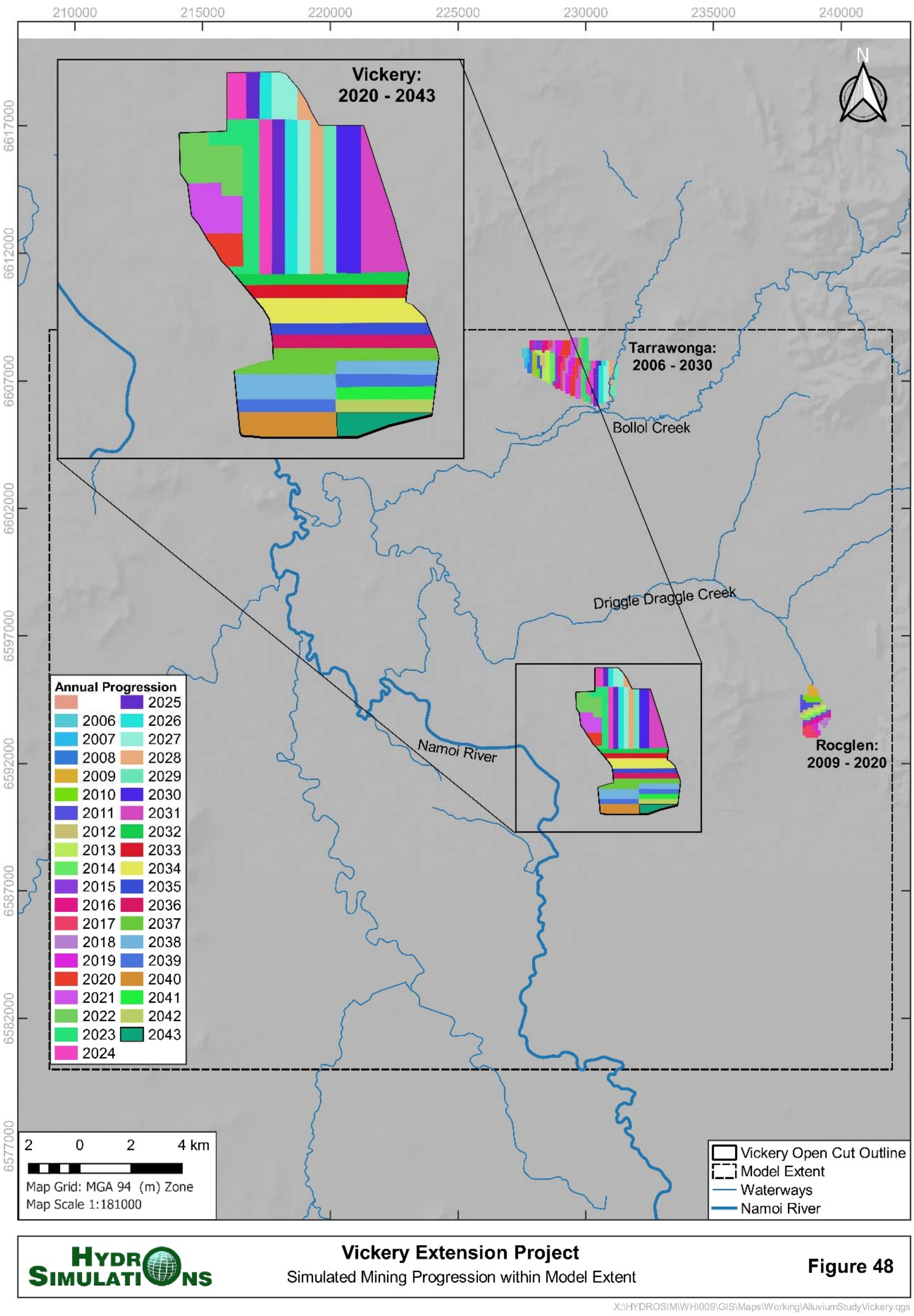
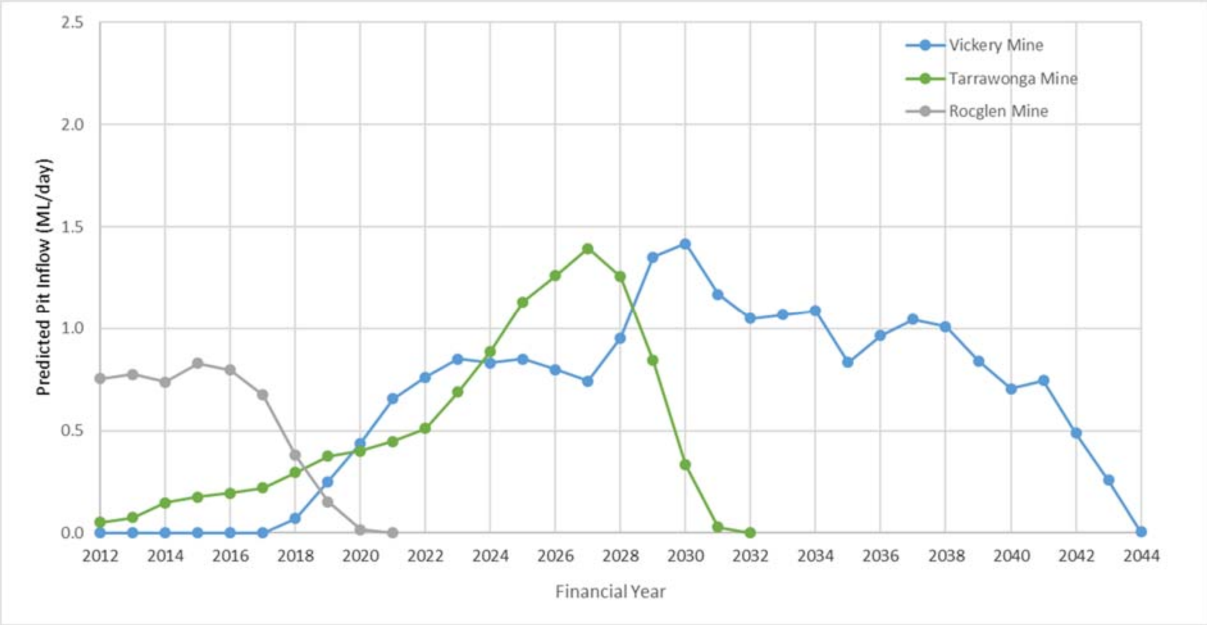


Figure 48 Simulated Mining Progression



NB. Inflows are average annual rates and the year ticks refer to June of each year

Figure 49 Simulated Pit Inflows at All Mines from 2012 to 2044

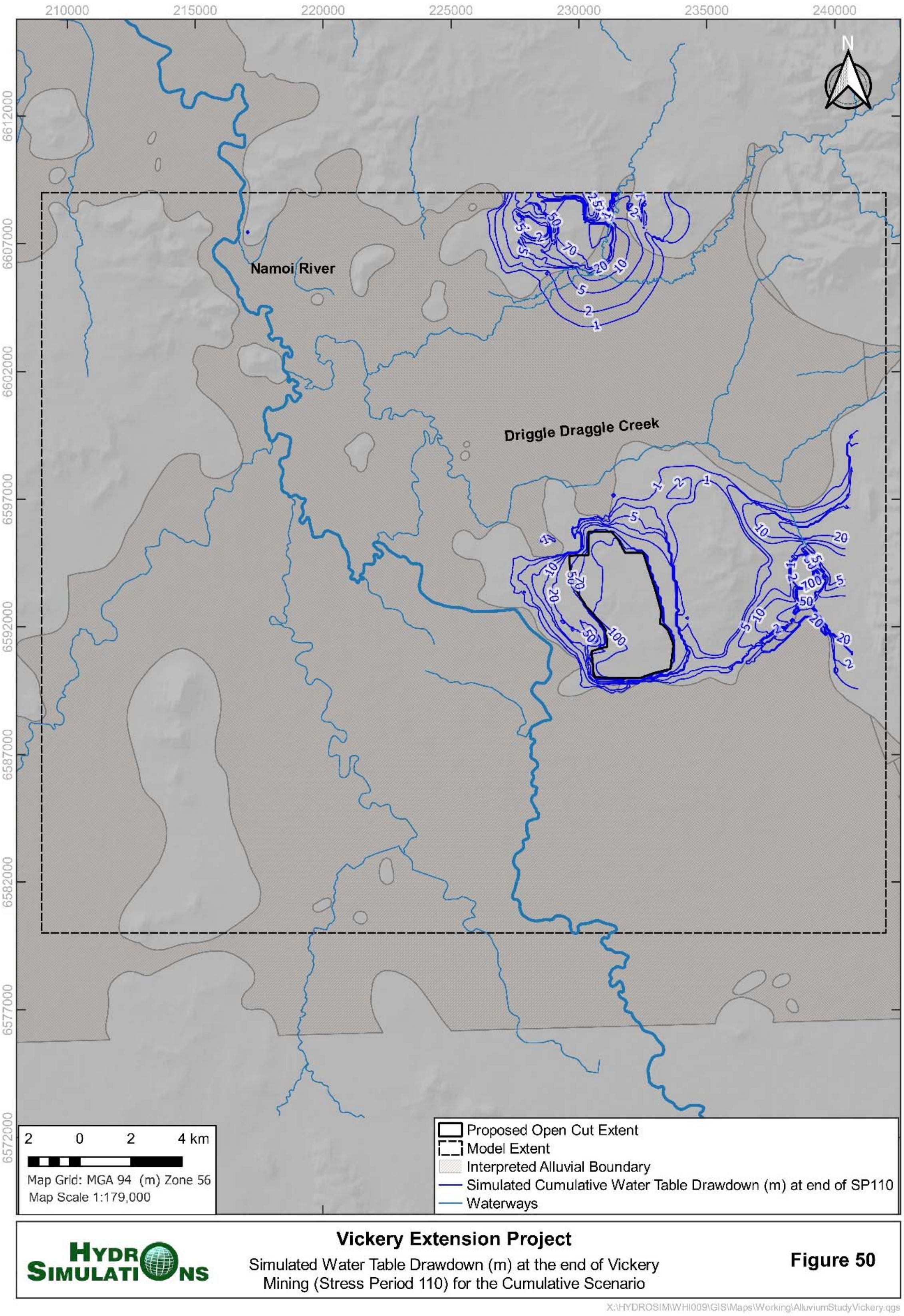


Figure 50 Simulated Water Table Drawdown (m) at the end of Vickery Mining (Stress Period 110) for the Cumulative Scenario

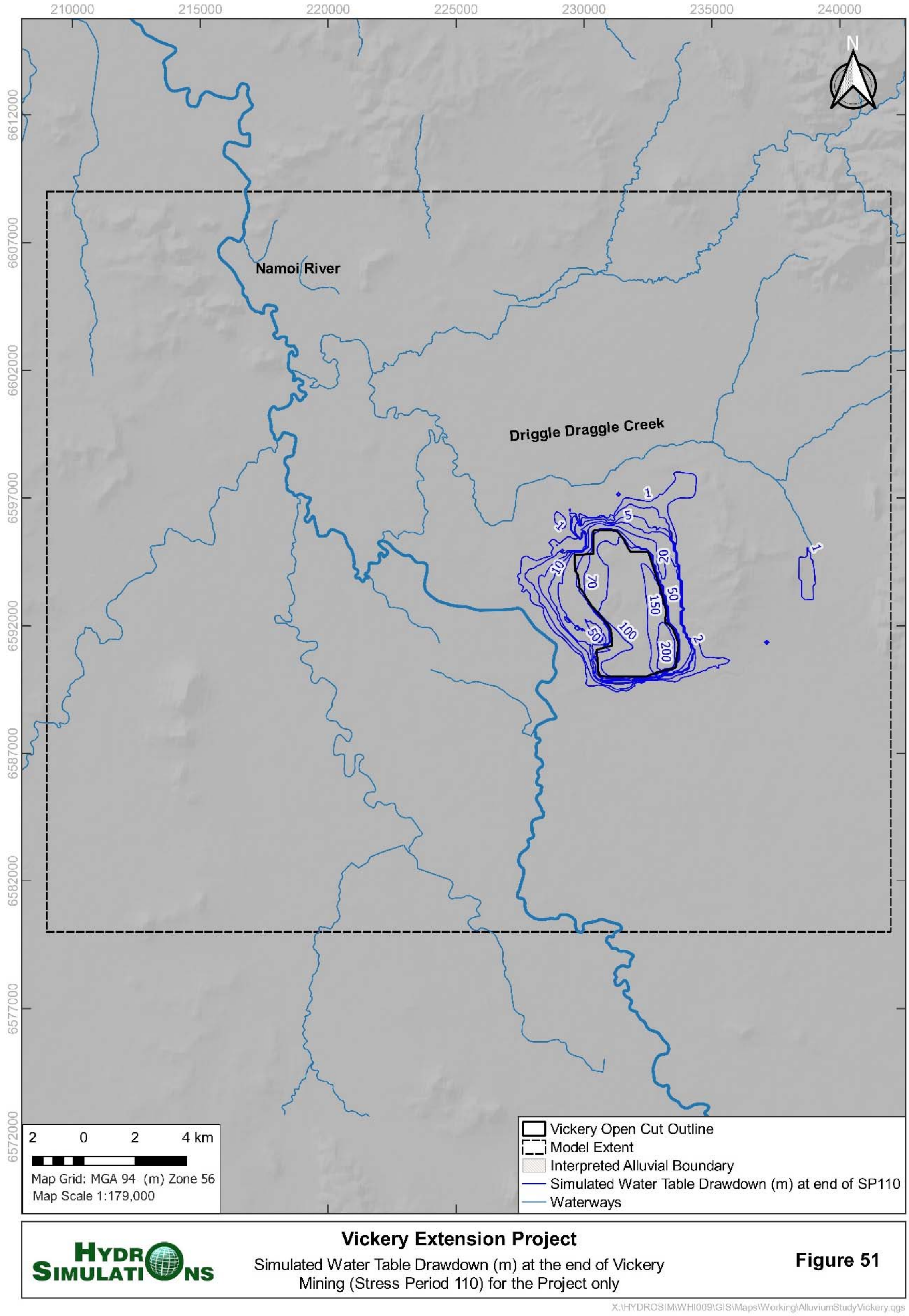


Figure 51 Simulated Water Table Drawdown (m) at the End of Project Mining (Stress Period 110) for the Project only

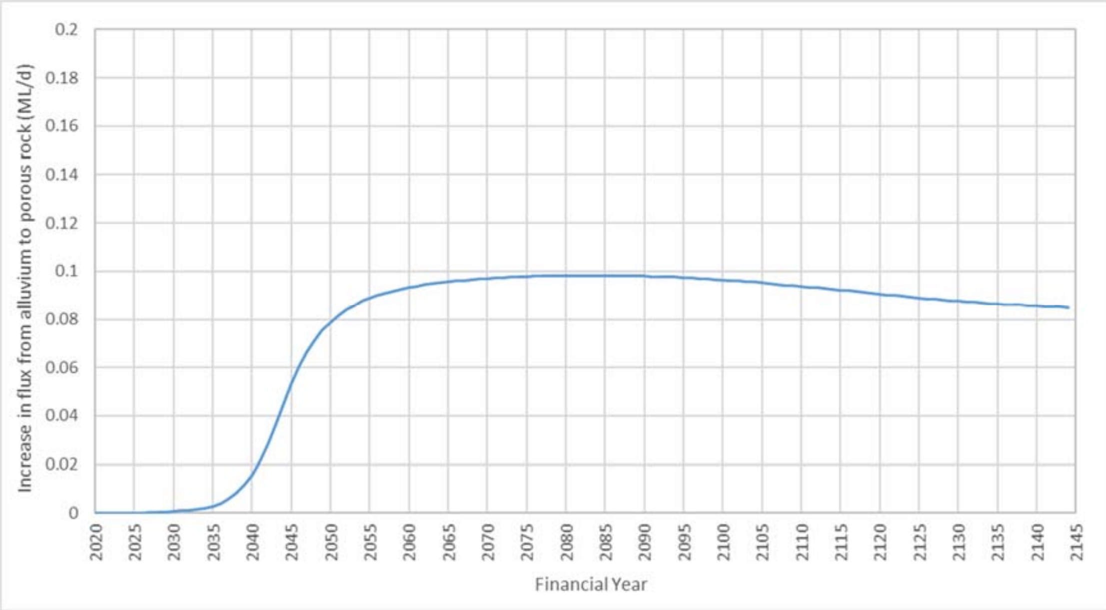


Figure 52 Predicted Change in Alluvial Flux During Project Mining and Recovery (ML/d)

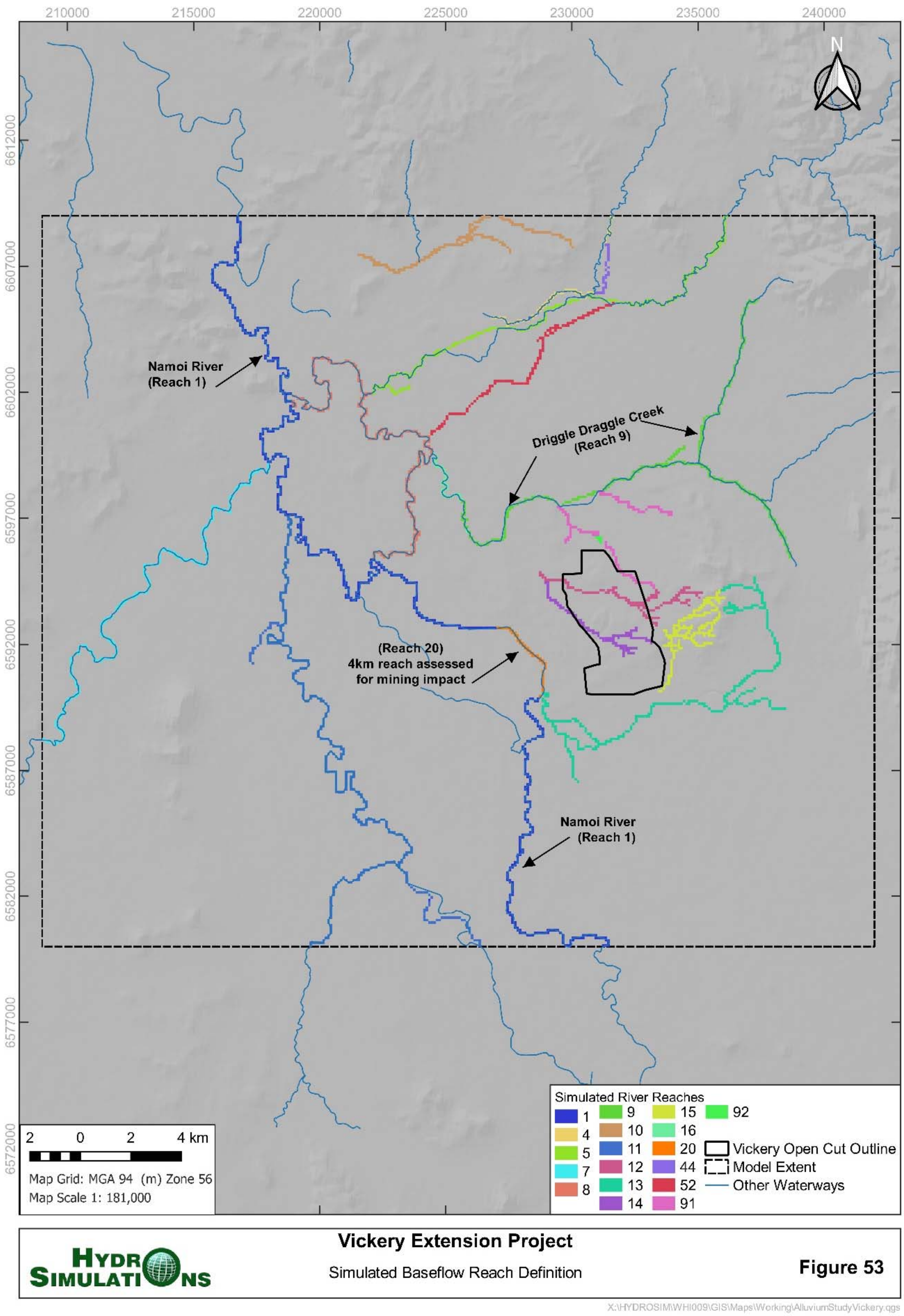


Figure 53 Simulated Stream Baseflow Reach Definition

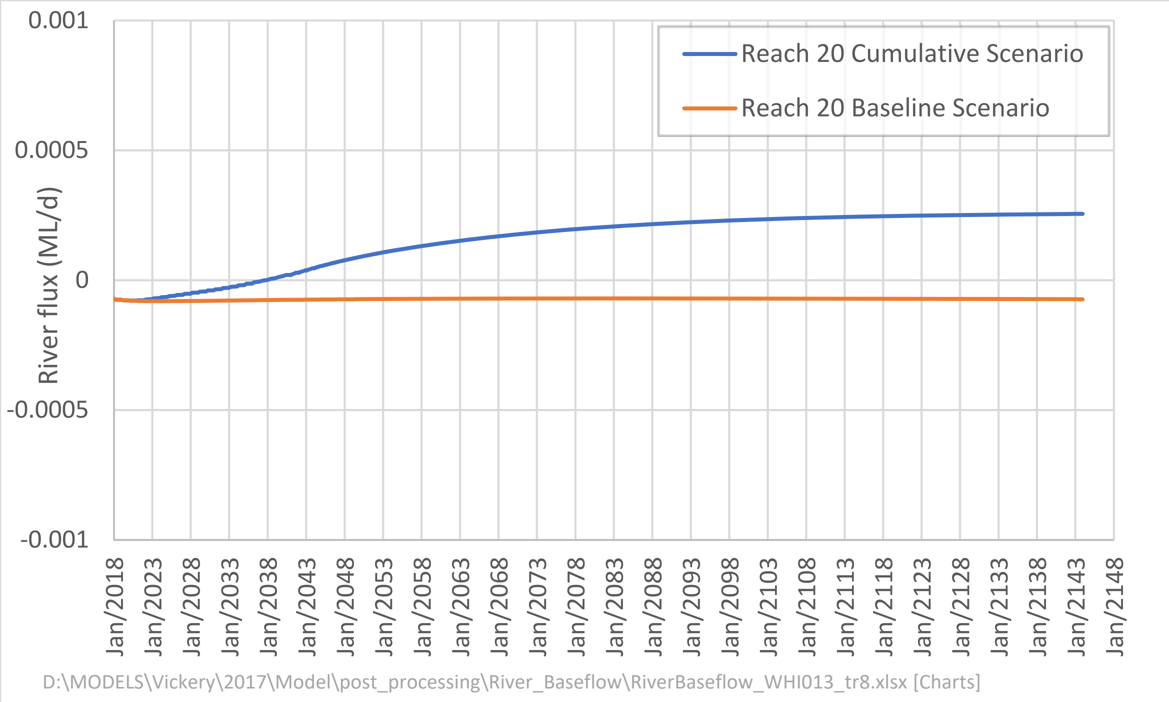


Figure 54 **Simulated River Flux for a 4km Reach of the Namoi River (Baseline and Cumulative Scenarios)**

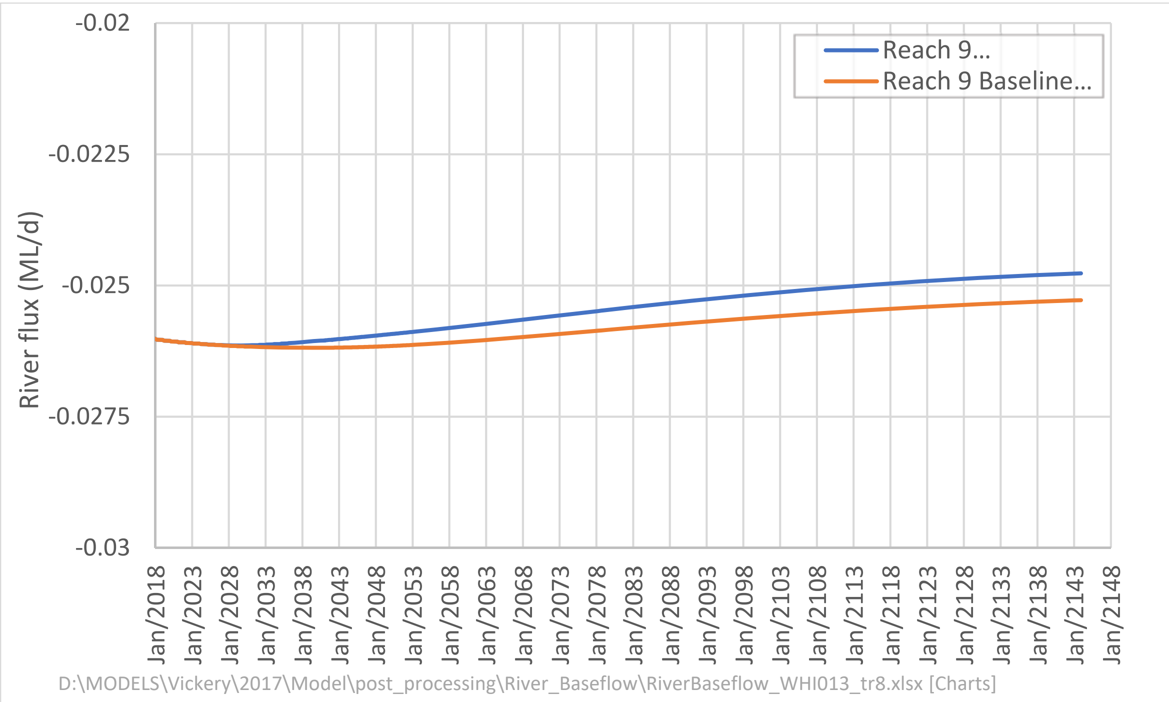
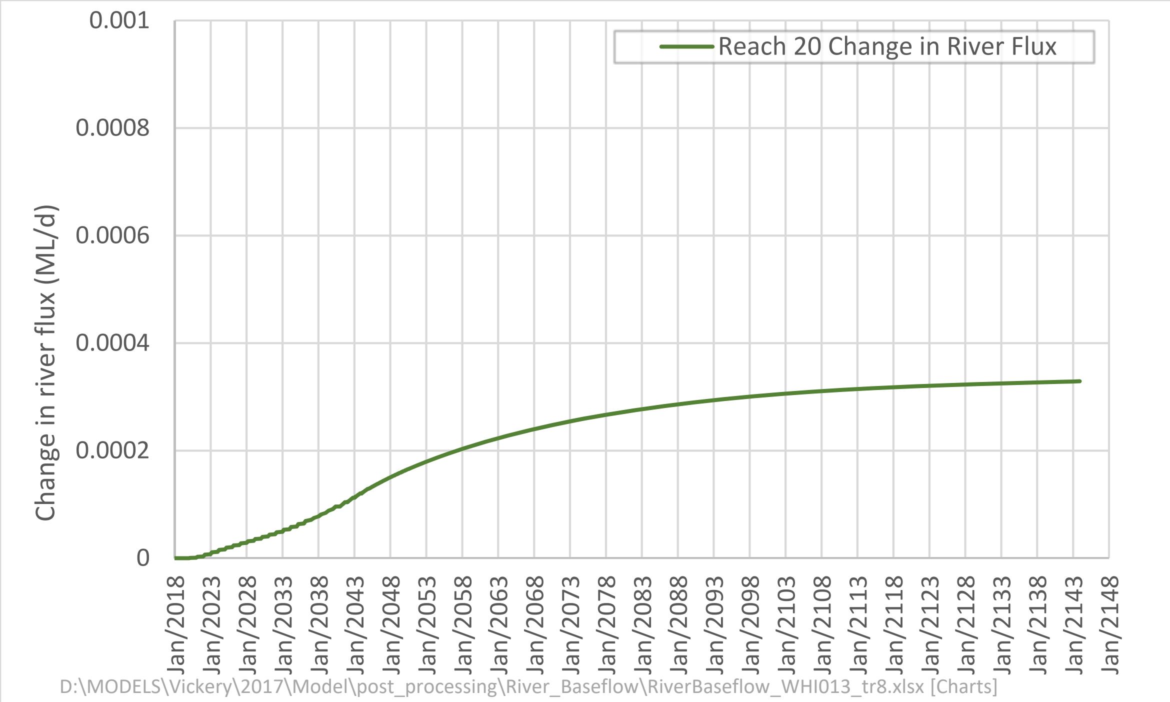


Figure 55 **Simulated River Flux for Driggle Draggle Creek (Baseline and Cumulative Scenarios)**



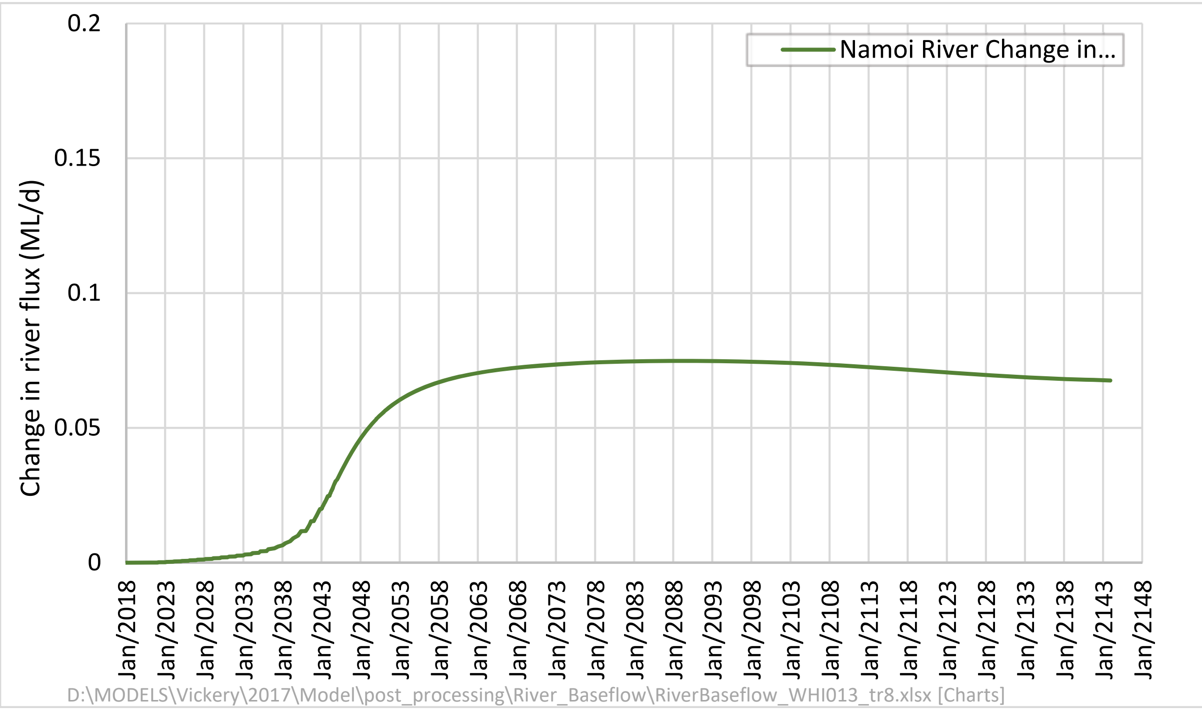


Figure 56 Predicted Change in River Flux Due to the Project only along a) 4 km Reach of the Namoi River b) Namoi River water source

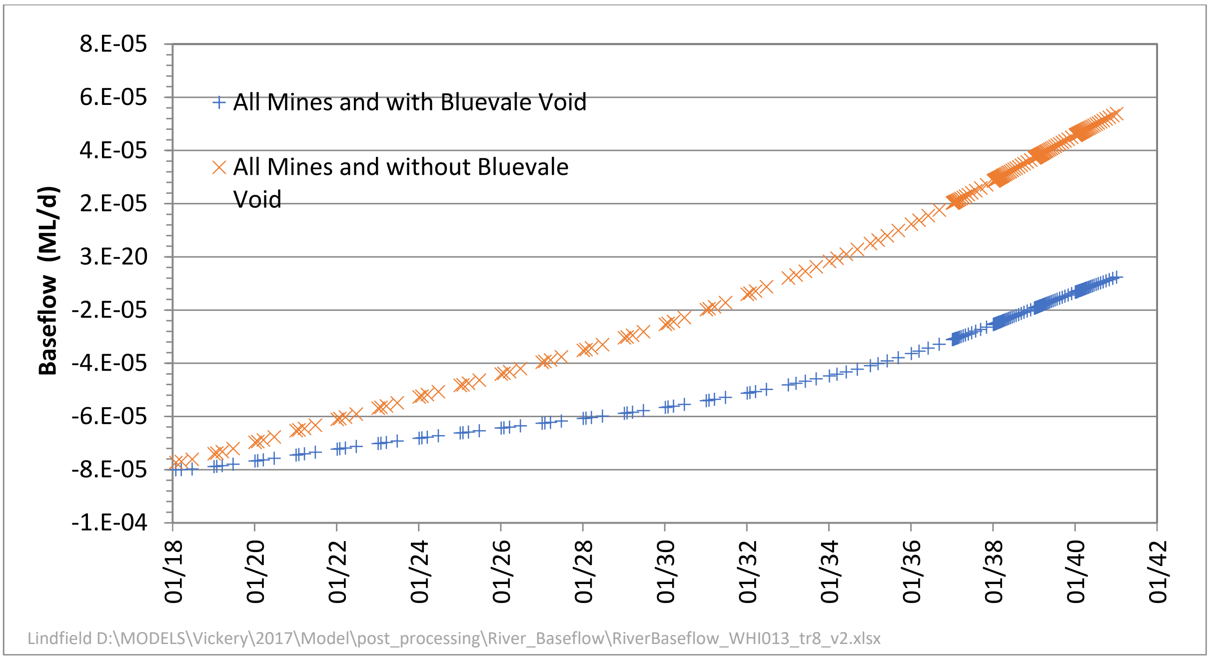


Figure 57 Simulated stream baseflow for the 4 km reach of the Namoi River, with and without Blue Vale void as storage

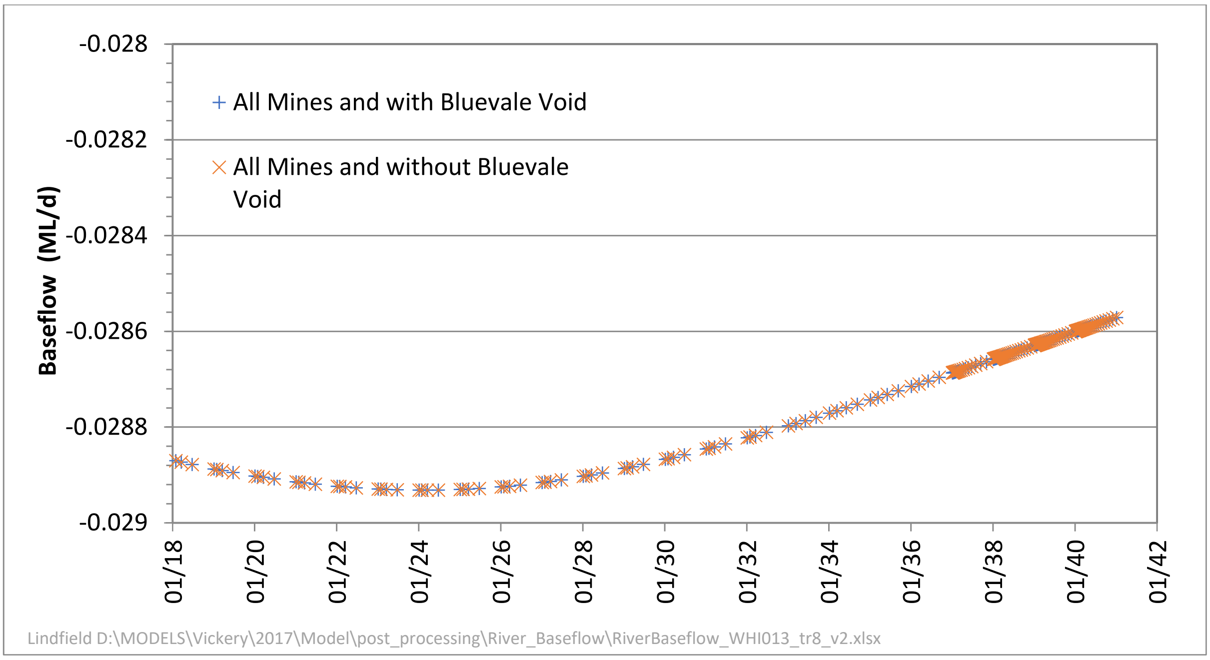


Figure 58 Simulated stream baseflow for Driggle Draggle Creek with Blue Vale Void as storage

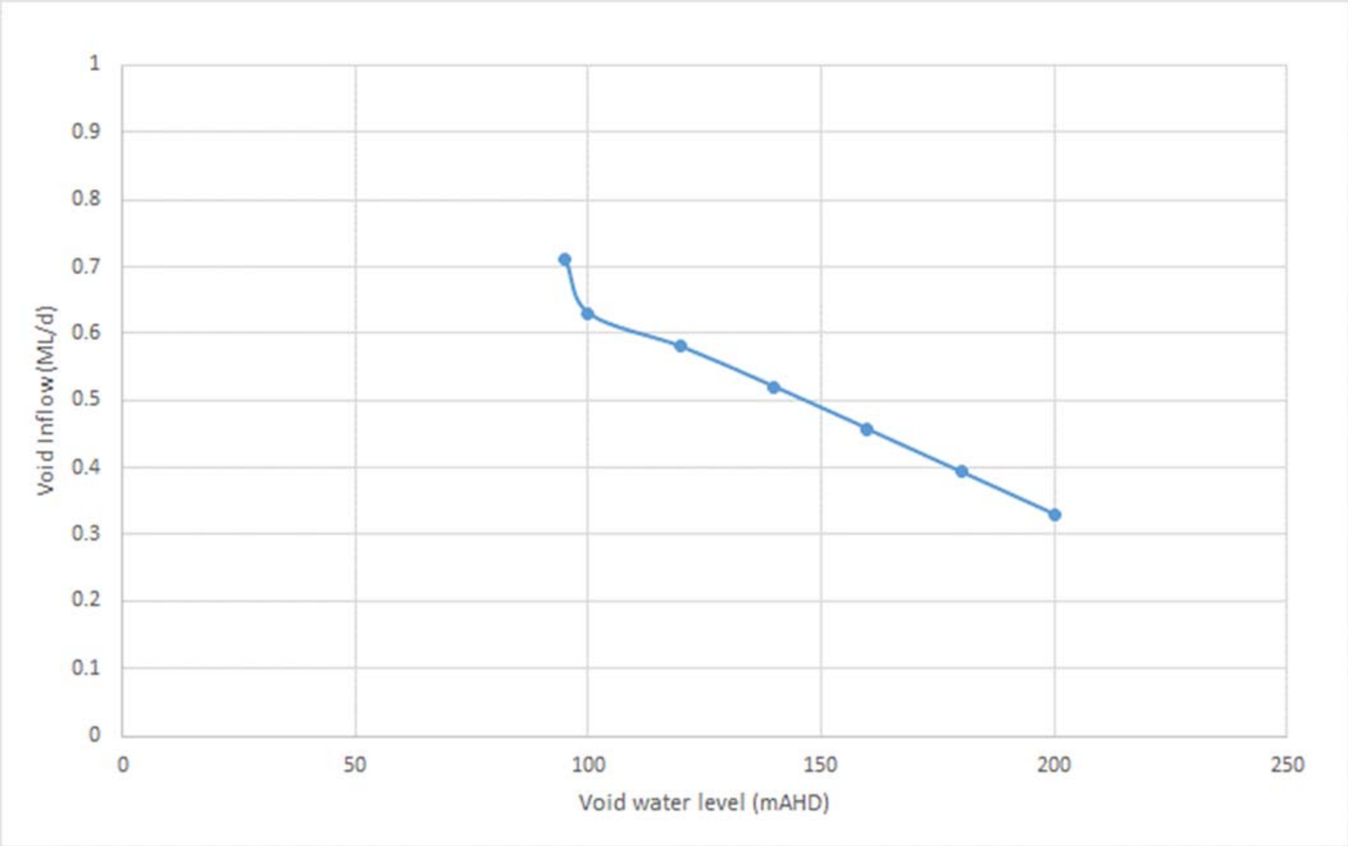


Figure 59 Final Void Inflow-Stage Relationship

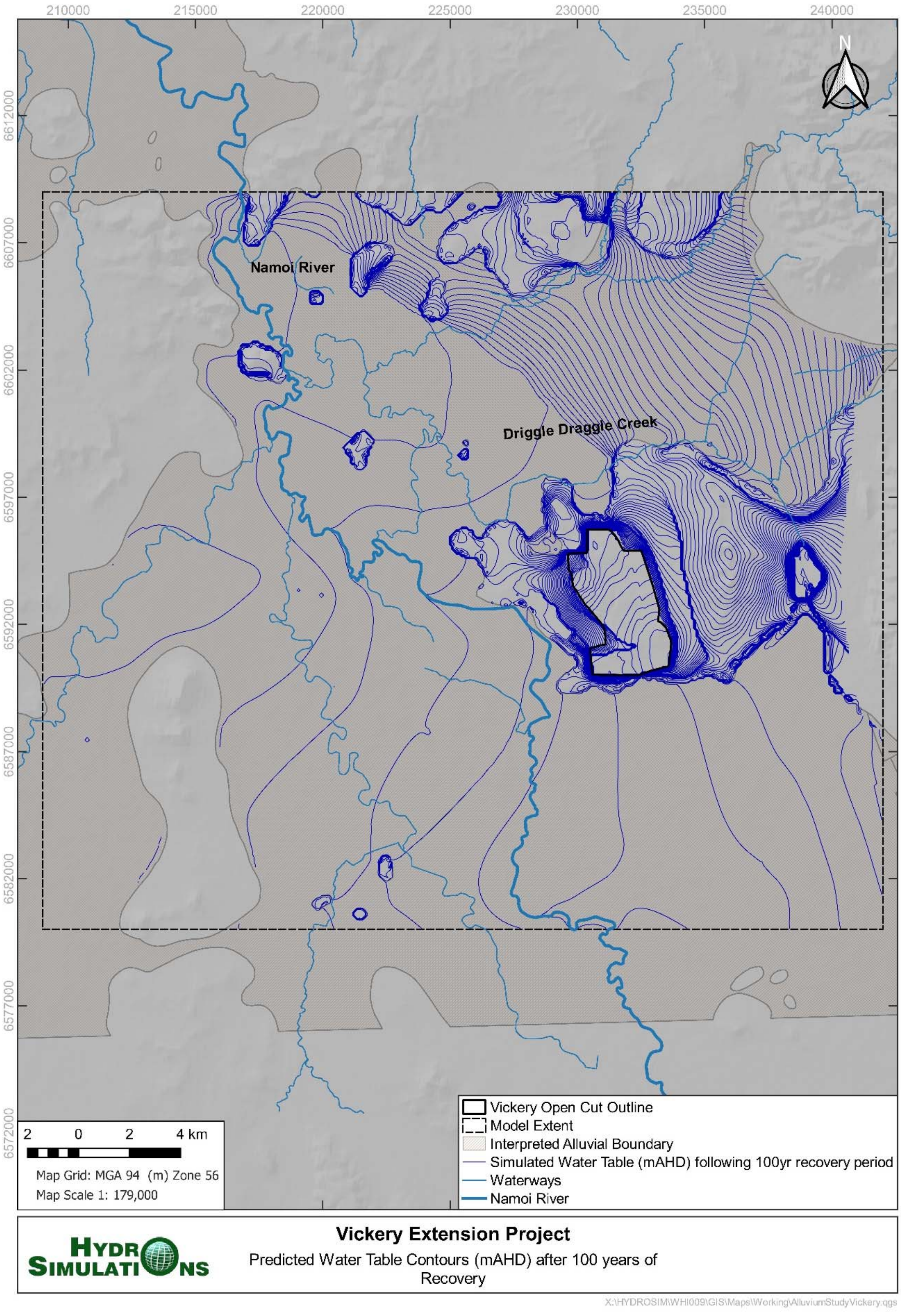


Figure 60 Predicted Water Table Contours (mAHD) after 100 Years of Recovery

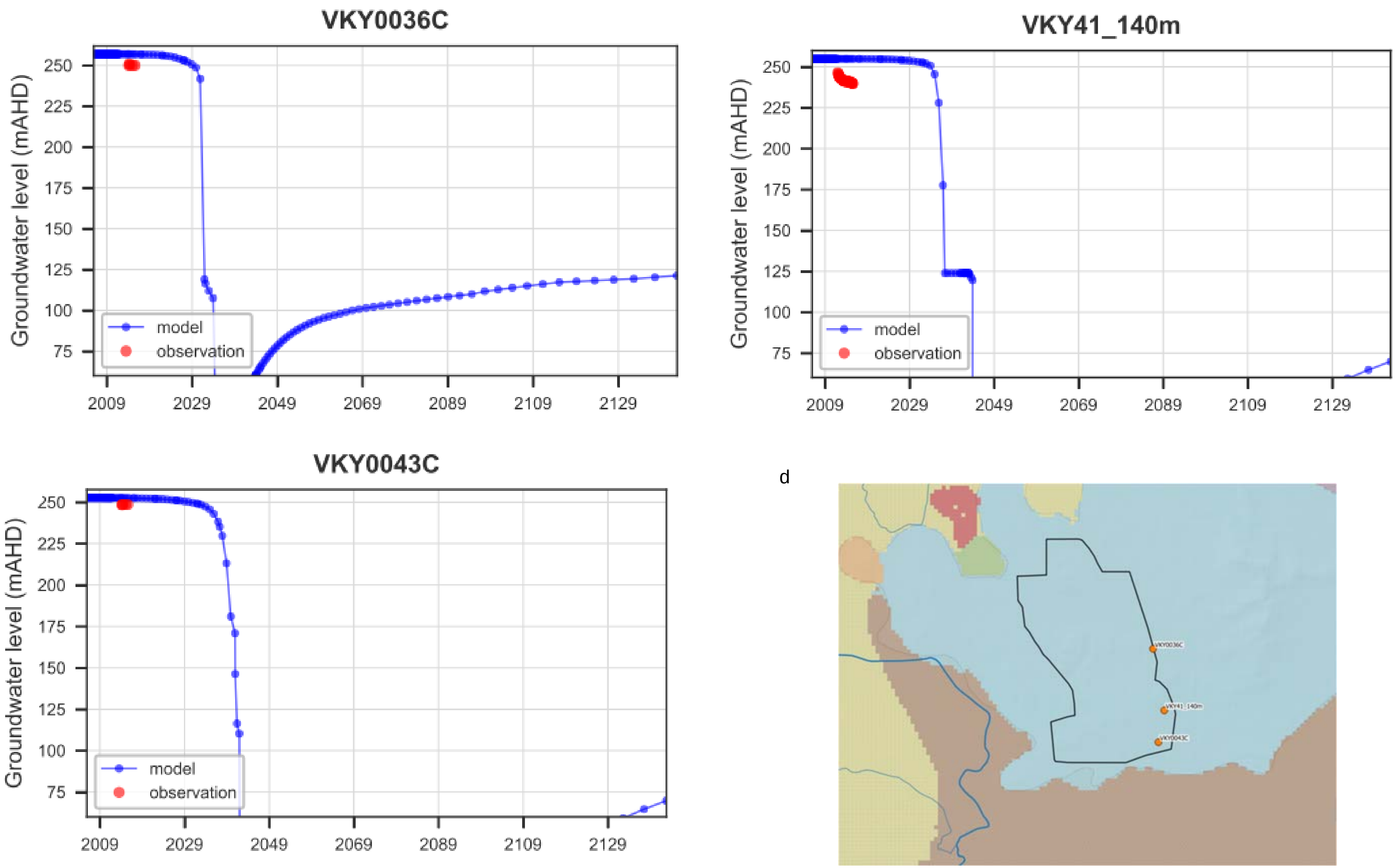


Figure 61 Prediction and Recovery Hydrographs at Representative Vickery Monitoring Bores a) VKY0036C at 112m depth; b) VKY41C at 140 m depth; c) VKY0043C at 242 m depth. Bore locations indicated in d)

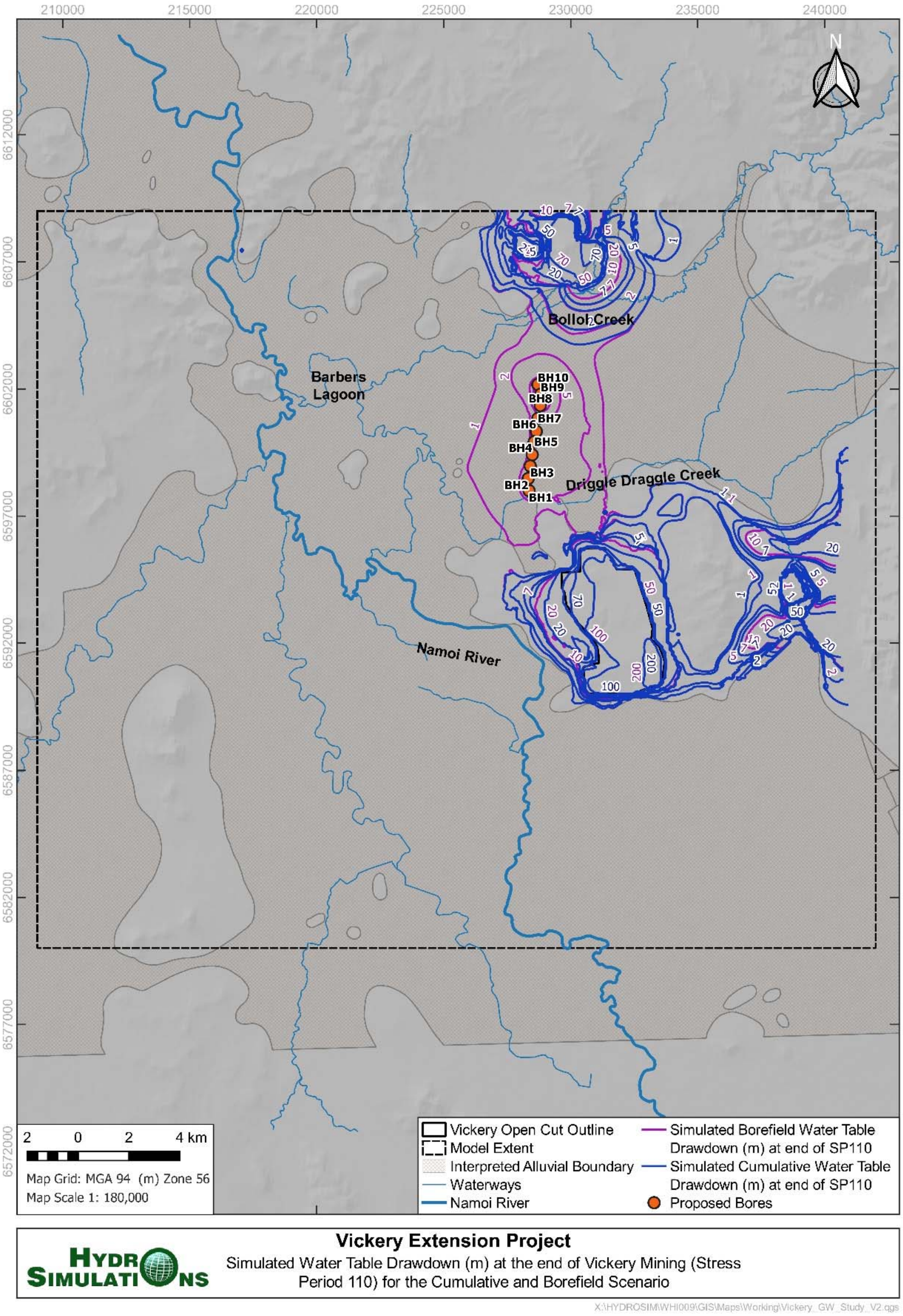


Figure 62 Proposed Borefield Location

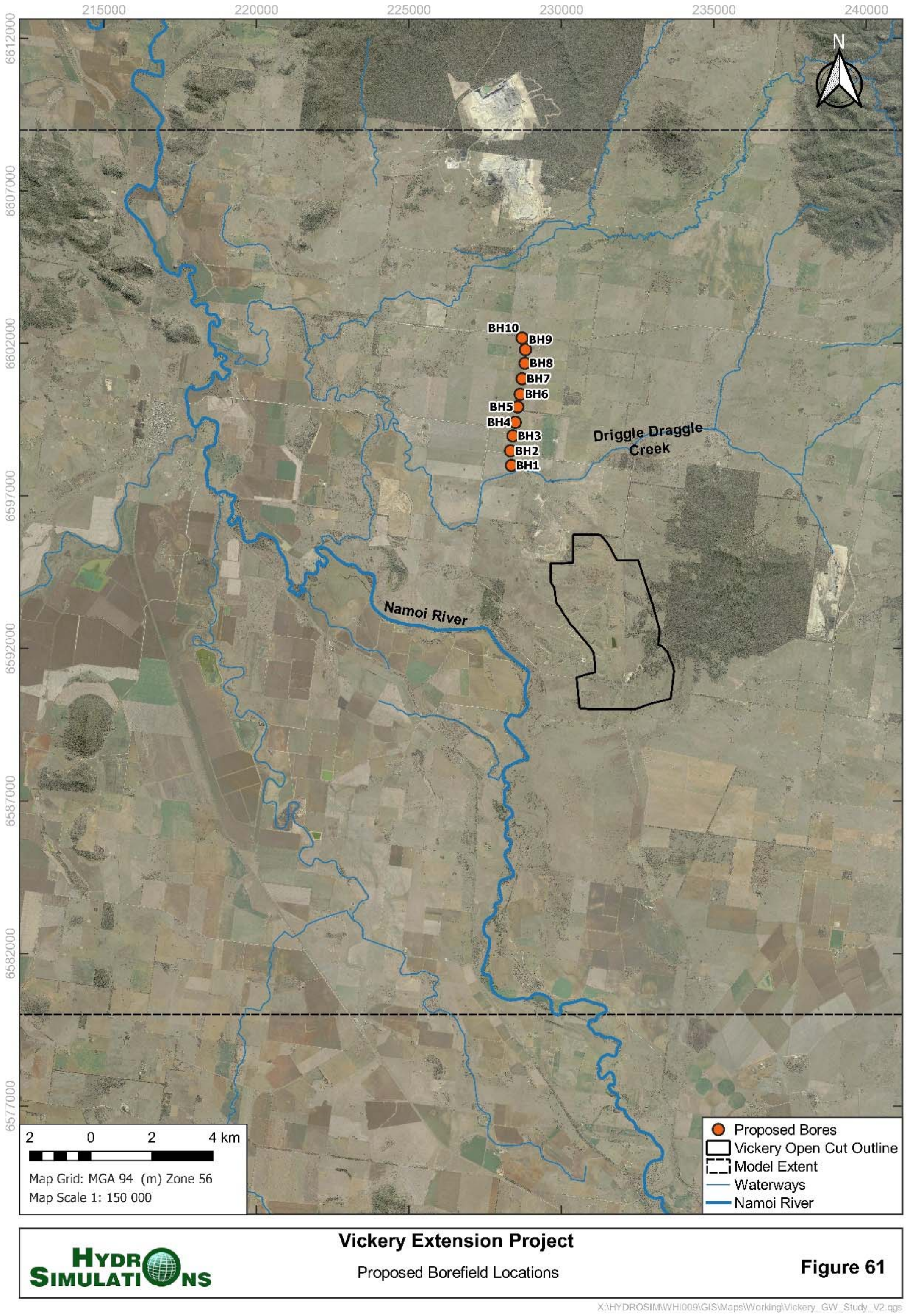


Figure 63 Simulated Water Table Drawdown at the End of Vickery Mining for the Cumulative and Borefield Scenarios

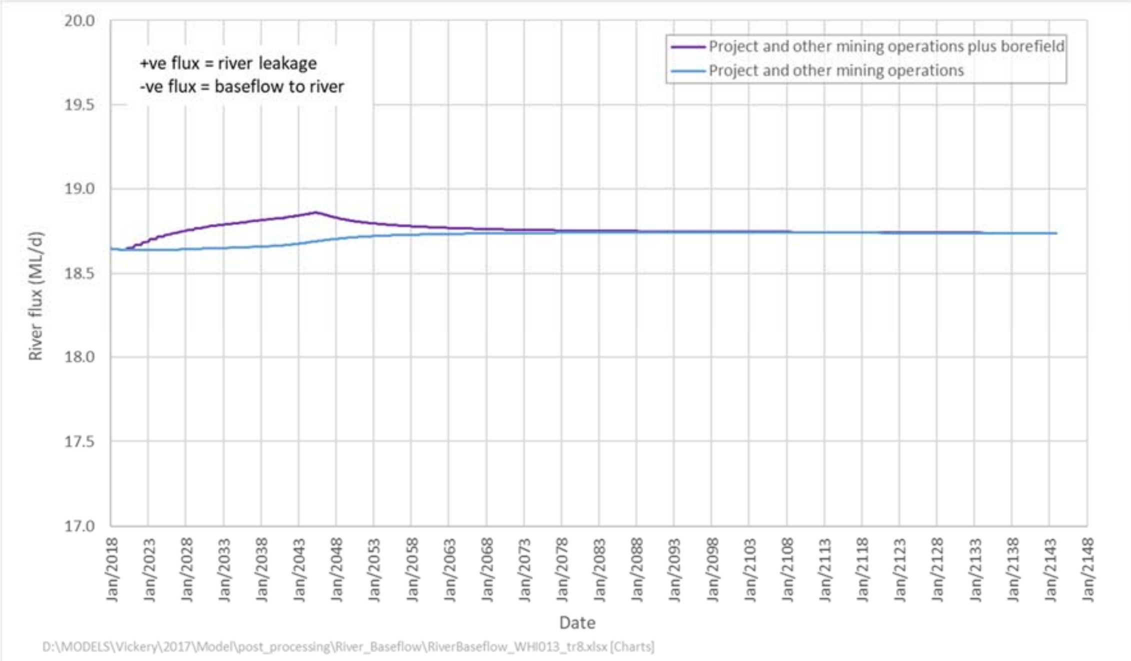


Figure 64 Simulated River Flux for the Namoi River

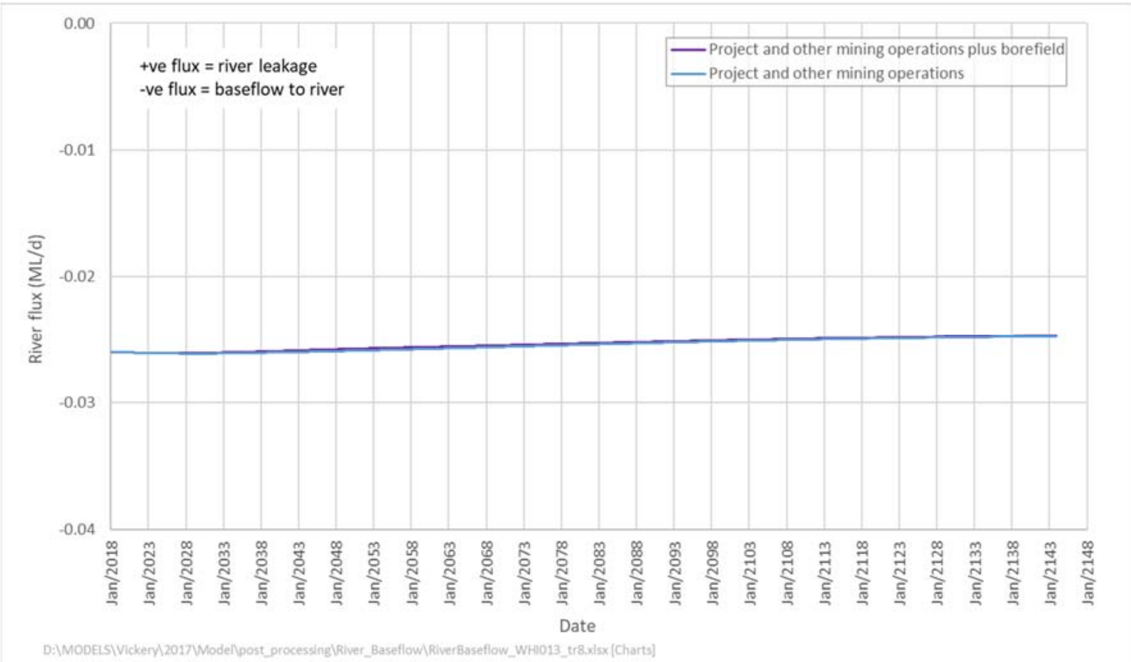


Figure 65 Simulated River Flux for Driggle Draggle Creek