# Appendix D

# Preliminary Groundwater Assessment

# Narrabri Underground Mine Stage 3 Extension Project:

# Gateway Application Preliminary Groundwater Assessment

FOR

Narrabri Coal Operations Pty Ltd

BY

NPM Technical Pty Ltd
trading as
HydroSimulations

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# 1 INTRODUCTION

The Narrabri Mine (NM) is an existing underground mining operation situated approximately 25 kilometres (km) south-east of Narrabri, New South Wales (NSW). The mine is located within Mining Lease (ML) 1609 and Exploration Licence (EL) 6243 (**Figure 1**) in the Gunnedah Coalfield within the Gunnedah-Oxley Basin.

The NM is operated by Narrabri Coal Operations Pty Ltd (NCOPL) on behalf of the Narrabri Joint Venture, which consists of Whitehaven Coal Limited's (Whitehaven) subsidiary Narrabri Coal Pty Limited (NCPL) (70%), Upper Horn Investments (Australia) Pty Limited (7.5%), J Power Australia Pty Limited (7.5%), EDF Trading Australia Pty Limited (7.5%), and Daewoo International Narrabri Investment Pty Limited and Kores Narrabri Pty Limited (7.5%).

NCOPL plans to seek a new approval under the State Significant Development provisions of the *NSW Environmental Planning & Assessment Act 1979*. The Narrabri Underground Mine Stage Extension 3 Project (herein referred as the Project) involves extension of the approved NM longwall panels outside the existing NM ML (Figure 2). NCOPL expects that the Project will be a State Significant Development, and, as such, will require a full Environmental Impact Assessment.

This report documents a preliminary groundwater assessment of the Project for the purposes of the Gateway Application process. This process applies to State Significant Developments located on Biophysical Strategic Agricultural Land (BSAL) (**Figure 3**), as defined in Strategic Regional Land Use Plans (SRLUPs).

## 1.1 MINING AT NARRABRI MINE

The NM was developed after substantial investigations were undertaken under EL 6243, granted in May 2004. In March 2007, NCOPL lodged an Environmental Assessment (EA) Report for the proposed development of surface infrastructure and initial underground mine development, with coal production by first workings of up to 2.5 million tonnes per annum (Mtpa). This was referred to as Stage 1.

A groundwater assessment was prepared and submitted (GHD, 2007) as part of the Stage 1 EA, which supported the application for Project Approval. Stage 1 was granted approval on 13$^{th}$ November 2007 (Project Approval 05_0102). Following approval, ML 1609 was granted on 18$^{th}$ January 2008. After completion of a box cut and drift tunnels, coal production from development headings commenced in June 2010.

A further groundwater assessment was prepared and submitted (Aquaterra, 2009) as part of the EA undertaken for Stage 2 comprising the development of longwall mining operations on ML 1609 for the extraction of coal up to 8 Mtpa. The Stage 2 groundwater assessment further developed the Stage 1 groundwater model to include longwall progression and was granted Part 3A approval (Project Approval 08_0144) on 26$^{th}$ July 2010. At this time, the mine plan consisted of 26 longwall (LW) panels (LW101-LW126).

Modification 08_0144 MOD 5 in 2015 allowed widening of future longwall panels and reduction to 20 panels in all (LW101-LW120) (**Figure 2**). The groundwater assessment was prepared by HydroSimulations (2015).

NCOPL is seeking a new Development Consent for the Project to extend the underground mining areas at the NM to gain access to additional areas of run-of-mine (ROM) coal reserves within EL 6243. This report covers the preliminary groundwater assessment for extension of longwall panels to the south into EL 6243, as indicated on the general arrangement shown in **Figure 2**. The longwall nomenclature is LW101 to LW111 to the north of the mains in ML 1609, and LW201 to LW210 to the south of the mains.

Longwall mining is currently being undertaken in LW108, with extraction of LW101 to LW107 complete.

## 1.2 OTHER PROJECTS IN THE REGION

As shown on **Figure 1** several other operating open cut mines exist in the region, the nearest being approximately 25 km to the east of the NM, and on the opposite side of the Namoi River, including:

- Maules Creek Coal Mine;
- Boggabri Coal Mine; and
- Tarrawonga Coal Mine.

Given the significant distance to the other operating open cut mines, and their respective predicted maximum drawdown extents, cumulative assessment considerations are not pursued in this preliminary assessment.

It is also recognised that the Santos NSW (Eastern) Pty Ltd proposed Narrabri Gas Project (currently the subject of assessment by the NSW and Commonwealth Governments) proposes to develop a gas field with production and appraisal wells, gas and water gathering systems from the coal seams to the west of ML 1609 and EL 6243 (**Figure 1**).

The Commonwealth Independent Expert Scientific Committee (IESC) provided assessment advice (IESC 2017-086) for the Narrabri Gas Project (EPBC 2014/7376; SSD 6456) on 8 August 2017. Key potential risks identified by the IESC for the Narrabri Gas Project include: salt and chemical management and disposal; groundwater depressurisation and drawdown in aquifers within the area and surrounds that may impact groundwater dependent ecosystems (GDEs) and other groundwater users; and changes to surface water flow and quality as a result of discharges to Bohena Creek. Potential areas at risk from these impacts include: landowner bores in the northern portion of the project area, outside the Pilliga State Forest; Bohena Creek downstream of the discharge location; and areas where co-produced brine, salt and waste are stored. The NM and Project areas are located within the potential areas at risk from some of these impacts.

As this report documents a preliminary groundwater assessment for a Gateway Application, based on an appropriate "simple modelling platform" as specified in the Aquifer Interference (AI) Policy, more complex modelling of the Narrabri Gas Project as a cumulative effect is deferred until Environmental Impact Statement (EIS) submission.

An assessment of cumulative impacts of all proposed and existing coal mining and coal seam gas projects in the Namoi catchment was undertaken by Schlumberger Water Services (SWS) (2012) in the Namoi Catchment Water Study (NCWS). The study involved the development of numerical models, which were used to review risks on key water resources in the Namoi Catchment associated with coal mining and coal seam gas extraction.

## 1.3 WATER REGULATION

With respect to water management, the NM is located within the Namoi Water Management Area and is subject directly to the water sharing rules of the following Water Sharing Plan (WSP) under the *Water Management Act 2000*.

- **WSP for the NSW Murray-Darling Basin Porous Rock Groundwater Sources 2011**

  Of specific relevance to the NM area is the Gunnedah-Oxley Basin Murray-Darling Basin (MDB) Groundwater Source, consisting of the Permian and Triassic rocks associated with the Gunnedah Basin and the overlying younger Jurassic and Cretaceous rocks associated with the Oxley Basin.

  This Groundwater Source is noted under the WSP as having a high risk to its aquifer assets based on the likelihood of permanent habitat loss in listed high priority GDEs in the event of significant groundwater level fluctuations.

  There are no high priority GDEs listed in the WSP in the vicinity of the Project.

  However, it is recognised that the closest GDEs identified within the Gunnedah-Oxley Basin MDB Groundwater Source on the water-dependent asset register and asset list for the Namoi subregion in the Australian Government Bioregional Assessments (O'Grady *et al,* 2015) are:

  - Euglah Spring, about 33 km north-east of the mine site;
  - Jokers Spring, about 33 km north-east of the mine site; and
  - Yarrie Lake, about 27 km north-west of the mine site.

- **WSP for the NSW Great Artesian Basin Groundwater Sources 2008;**

  This WSP applies to management of the upper hard rock (sandstone) aquifers of the Great Artesian Basin (GAB). Of specific relevance to the NM area is the Southern Recharge Groundwater Source. This occupies most of the non-artesian portion of the GAB in NSW and is limited to the sandstone aquifers of Jurassic age. At the time of commencement of the WSP (in 2008), there were 68 aquifer access licences with a total of 15,533 unit shares in the Southern Recharge Groundwater Source and a further 274 works approvals for domestic and stock basic water rights.

  It is also recognised that the closest GDEs identified within the GAB Southern Recharge Groundwater Source on the water-dependent asset register and asset list for the Namoi subregion in the Australian Government Bioregional Assessments (O'Grady *et al,* 2015) are:

  - Hardys Spring, about 5.5 km south-west of the mine site; and
  - Eather Spring, about 7.5 km south-west of the mine site.

Other GDEs not listed in the WSP or water-dependent asset register and asset list that have been identified in other studies (i.e. Mayfield in CDM Smith, 2016) have also been considered for the purposes of this assessment.

NCOPL holds water licences and approvals for several bores located in the general vicinity of the mine. Details of the water licences and approvals are provided in **Table 1**. The table provides specific reference to the WSP and Water Source relevant to each licence and cites some that lie beyond the NM area, specifically:

- **WSP for the Upper and Lower Namoi Groundwater Sources 2003** (e.g. Upper Namoi Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source);

  No high-priority GDEs associated with the Upper and Lower Namoi Groundwater Sources have been identified in the vicinity of the Project.

- **WSP for the Upper Namoi and Lower Namoi Regulated River Water Sources 2016** (e.g. Lower Namoi Regulated River Water Source).

**Figure 4** provides a map of the NM site in relation to the areas covered by the relevant WSPs and Water Sources.

In summary, the licensed volumes in each water source each year are[1]:

1. Gunnedah - Oxley Basin MDB Groundwater Source: 818 ML;
2. Southern Recharge Groundwater Source: 248 ML;
3. Upper Namoi Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source: 217 ML; and
4. Lower Namoi Regulated River Water Source: 678 ML[2].

[1] Based on an available water determination (AWD) of 100%.

[2] As of 1 July 2018, the AWD for general security licences in the Lower Namoi Regulated River Source was 0%. Therefore, the current licensed volume held is 20 ML (high security) and zero (general security).

**Table 1 NCOPL Water Licences/Approvals**

| Issuing Authority | WSP | Water Source | Licence/ Approval | Comments |
|---|---|---|---|---|
| DPI Water/ Water NSW | NSW MDB Porous Rock Groundwater Sources 2011 | Gunnedah - Oxley Basin MDB Groundwater Source | WAL29549 (90BL254679) | Aquifer (818 units) |
| | | | 90WA822539 (Nominated WAL29549) | Water Supply – Extraction Works (Bore & Excavation – Groundwater) |
| | NSW Great Artesian Basin Groundwater Sources 2008 | Southern Recharge Groundwater Source | WAL15922 (90AL811346) | Aquifer (248 units) |
| | | | 90WA822539 (WAL15922 Nominated) | Water Supply – Extraction Works (Bore & Excavation – Groundwater) |
| | | | 90CA811347 (90WA822539 Nominated) | Industrial (Mineral Water Extraction) and Irrigation |
| | Upper and Lower Namoi Groundwater Sources 2003 | Upper Namoi Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source | **WAL12833** (90AL807276) | Aquifer (67 units) |
| | | | **WAL20131** (90AL812858) | Aquifer (150 units) |
| | | | 90WA812891 (WAL12833 & WAL20131 Nominated) | Water Supply – Extraction Works |
| | Upper Namoi and Lower Namoi Regulated River Water Sources 2016 | Lower Namoi Regulated River Water Source | **WAL6762** (90AL802129) | River – High Security (20 units) |
| | | | **WAL2671** (90AL801995) | River – General Security (48 units) |
| | | | **WAL2728** (90AL802212) | River – General Security (10 units) |
| | | | **WAL20152** (90AL812863) | River – General Security (600 units) |
| | | | 90CA802130 (WAL6762, WAL2671, WAL2728 & WAL20152 Nominated) | Diversion Works – Pumps |

## 1.4 APPROACH TO THE GATEWAY PROCESS

The Gateway process includes an assessment of potential impacts on water resources by the NSW Minister for Primary Industries and the Commonwealth IESC. The State assessment is to focus on the "minimal impact considerations" prescribed in NSW's *Aquifer Interference Policy* (AI Policy) (2012). Supporting documentation is required for, amongst other matters, "any impacts on highly productive groundwater (within the meaning of the AI Policy)" (*Mining State Environmental Planning Policy* Clause 17H [4] [iv]).

The minimal impact considerations of the AI Policy are expressed as a number of prescriptive criteria that apply to highly productive groundwater sources, less-productive groundwater sources, groundwater dependent ecosystems, culturally significant sites, connected water sources (for a stream that is a reliable water supply), and other production bores. Less-productive groundwater sources are exempt from consideration under the Gateway Application Guidelines (i.e. consistent with the BSAL criteria).

The AI Policy requires estimation of "all quantities of water that are likely to be taken from any water source during and following cessation of the activity and all predicted impacts associated with that activity...". The estimation is to be based on a "simple modelling platform" that the Minister determines to be "fit-for-purpose", where the model makes use of the "available baseline data that has been collected at an appropriate frequency and scale".

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

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

- The assessment would not have the benefit of information usually provided by associated disciplines (especially surface water hydrology, geochemistry and ecology studies); although in this case previous assessments are available for Stages 1 and 2 at the NM, and for the Narrabri Gas Project.
- Often the available data for hydrogeological conceptualisation and model calibration would be limited; although in this case there is an extensive dataset available at the NM.
- There is a limited 90-day period for assessment by the Gateway Panel, who must obtain the advice of the NSW Minister for Primary Industries and the IESC within that period of time.
- There is to be no public consultation or exhibition of submitted documents.

In combination, the above constraints lead to the conclusion that it would be inappropriate to offer the same level of detail and effort that is normally expended in an EIS.

Rather than "simple modelling", this assessment relies on numerical modelling based on previous transient calibration to assess potential risks of mine development in terms of the AI Policy and Gateway process requirements. An existing numerical model (HydroSimulations, 2015; 2016) has been adapted for this purpose, retaining full spatial and temporal detail.

Focus is placed on assessment of the baseflow/leakage interactions with the Namoi River, associated highly productive alluvium (i.e. Upper Namoi Zone 5 Namoi Valley [Gins Leap to Narrabri] Groundwater Source) and other highly productive groundwater sources, with quantification of likely mine inflow, groundwater heads generally and drawdowns at registered bores in accordance with the AI Policy. The groundwater takes from each designated water source are quantified and interpreted in terms of licensing requirements. Gateway process requirements are listed and cross-referenced in **Table 2**.

Groundwater modelling has been conducted to the standards documented in:

- Murray-Darling Basin Commission (MDBC) *Groundwater Flow Modelling Guideline* (MDBC, 2001); and
- Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012).

**Table 2 Gateway Process Requirements**

| Requirement | Section Reference |
|---|---|
| Estimates of all quantities of water that are likely to be taken from any water source on an annual basis during and following cessation of the activity; | **Section 6** |
| A strategy for obtaining appropriate water licence/s for maximum predicted annual take; | **Section 6.6** |
| Establishment of baseline groundwater conditions including groundwater depth, quality and flow based on sampling of all existing bores in the area, any existing monitoring bores and any new monitoring bores that may be required under an authorisation under the *Mining Act 1992* or the *Petroleum (Onshore) Act 1991*; | **Section 2** |
| A strategy for complying with any water access rules applying to relevant categories of water access licences, as specified in relevant water sharing plans; | **Section 6** |
| Estimates of potential water level, quality and pressure drawdown impacts on nearby water users who are exercising their right to take water under a basic landholder right; | **Section 6.7** |
| Estimates of potential water level, quality and pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources; | **Sections 6.2, 6.4** and **6.7** |
| Estimates of potential water level, quality and pressure drawdown impacts on groundwater dependent ecosystems; | **Table 29** |
| Estimates of potential for increased saline and contaminated water inflows to aquifers and highly connected river systems; | **Table 29** |
| Estimates of the potential to cause or enhance hydraulic connection between aquifers; | **Sections 3.6** and **3.8** |
| Estimates of the potential for river bank instability, or high wall instability or failure to occur; | Not Applicable |
| Outline of the method for disposing of water inflows to a mine or extracted water (in the case of coal seam gas activities); | Not Applicable |
| Assess the project against the criteria specified in 'Table 1 – Minimal Impact Considerations for Aquifer Interference Activities' in the Aquifer Interference Policy. | **Table 29** and **Table 30** |

*Source: NSW Government (2013)*

# 2 HYDROGEOLOGICAL SETTING

## 2.1 CLIMATE

The nearest Bureau of Meteorology (BoM) climate stations are located at Narrabri West Post Office (station 053030) and Narrabri Rosewood Farm (station 053103). Rainfall records, collected since 1891 from Narrabri West Post Office and since 1980 from Narrabri Rosewood Farm, show a long-term average rainfall of 657.9 millimetres per annum (mm/a) and 651.7 mm/a, respectively (**Table 3**).

Average monthly rain records (**Table 3**) show the highest mean rainfall occurring during the summer months and lower rainfall in winter months.

**Table 3 Average Monthly Rainfall (mm) at BoM Stations in the Region**

| Station Name | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Narrabri West PO | 83.3 | 63.2 | 58.5 | 38.2 | 47.3 | 48.3 | 46.5 | 40.3 | 42.1 | 51.9 | 61.2 | 77.1 | **657.9** |
| Narrabri Rosewood Farm | 83.0 | 66.8 | 40.2 | 26.1 | 48.1 | 48.0 | 49.8 | 27.9 | 41.5 | 47.2 | 77.6 | 95.5 | **651.7** |

Information on long-term rainfall trends is provided by the Residual Mass Curve (RMC, also known as a cumulative departure from the mean (CDM) curve, **Figure 5**). This curve is generated by aggregating the residuals between actual monthly rainfall and long-term average rainfall for each month. The procedure is essentially a low-pass filter operation that suppresses the natural spikes in rainfall and enhances the long-term trends. The RMC displays trends in rainfall, with positive slope indicating periods of rainfall greater than the mean, and negative slope indicating below-mean conditions. Given the usually slow response of groundwater levels to rainfall inputs, the RMC can be expected to correlate well with groundwater hydrographs over the long term.

The RMC plot using rainfall data from the Narrabri West Post Office and Narrabri Rosewood Farm since 1980 is shown in **Figure 5b**. This plot suggests that current mining operations have experienced fluctuating weather conditions, with dry conditions from late-2006 to late-2009 and from September 2012 to present. Earlier dry periods occurred from 1980 to late-1982, late-1993 to mid-1995, and from April 2002 to January 2003. Conditions have been wetter than average from late-1982 to late-1984, early-1998 to mid-1999, late-2004 to mid-2006 and from mid-2011 to mid-2012. The break in data (e.g. Rosewood Farm, **Figure 5b**) is probably responsible for the discrepancy between the RMC values, while the subsequent curve patterns are comparable.

The actual evapotranspiration (ET) in the district is about 680 mm/a according to the BoM (2014). 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 ET which would occur over a large area of land under existing (mean) rainfall conditions*."

## 2.2 GEOLOGY

The NM is situated within the Permo-Triassic Gunnedah Basin, which forms the central part of the north-south elongate Sydney-Gunnedah-Bowen Basin (Geological Survey of NSW, 2002; Welsh *et al*., 2014; CDM Smith, 2016). The mine is located near the northern and western boundaries of the Gunnedah Basin and the eastern margin of the Surat Basin, a sub-basin of the Great Artesian Basin. The outcropping geology within the model domain is shown in **Figure 6** (legend **Figure 6a)**.

The geology has previously been described in GHD (2007), Aquaterra (2009), Welsh *et al.* (2014) and CDM Smith (2016). The simplified stratigraphic column presented in **Figure 7** shows that the stratigraphy in the Narrabri area is characterised by deposits in two main basins:

- Surat Basin Units of Jurassic age which includes Pilliga Sandstone, Purlawaugh Formation and Garrawilla Volcanics; and
- Gunnedah Basin Units:
  - Napperby and Digby Formations of Triassic age; and
  - Permian coal measures within the Black Jack Group which includes the Hoskissons Coal Seam, and Arkarula and Pamboola Formations.

Adjacent to the NM are alluvial sediments of Quaternary age (Narrabri Formation and Gunnedah Formation) within the upper Namoi Valley.

The Digby Formation Conglomerate is about 15 to 20 metres (m) thick. A dolerite sill intrudes the Napperby Formation about 40 m above the roof of the Digby Formation Conglomerate.

The coal resource of the NM is contained within the Hoskissons Coal Seam, which strikes generally north-south and dips gently to the west. The seam is 8 to 10 m thick over the western half of ML 1609.

## 2.3 GROUNDWATER USAGE

As listed in **Table 4**, there are 87 registered bores belonging to other groundwater users within 10 km of NM. Boreholes registered on the 'PINNEENA' (v4.1) database are shown in **Figure 8**.

For the bores shown in **Table 4**, the mean and median depths are 42 m and 40 m, respectively. Except for two bores in the deepest part (Pamboola Formation) of the geological section, the bores are distributed in the shallower formations as shown below:

- Alluvium and regolith — 44 bores
- Pilliga Sandstone — 28 bores
- Purlawaugh Formation — 11 bores
- Garrawilla Volcanics — 1 bore
- Napperby Formation — 1 bore (above basalt sill)
- Digby Formation — Nil
- Hoskissons Coal Seam — Nil
- Arkarula, Pamboola Formations — 2 bores.

Table 4 Registered Bores within 10 km of Narrabri Mine

| Work no. | Licence | Easting | Northing | Depth (m)[1] | Layer[2] |
|---|---|---|---|---|---|
| GW051128 | 90BL112469 | 773121 | 6634127 | 33 | 3 |
| GW051980 | 90BL115713 | 770899 | 6633936 | 58 | 3 |
| GW053774 | 90BL248187 | 773649 | 6633898 | 23 | 3 |
| GW053849 | 90CA807210 | 784688 | 6620465 | 47.2 | 1 |
| GW054227 | - | 775401 | 6630279 | 38.1 | 3 |
| GW054228 | 90WA809762 | 775967 | 6630480 | 15.8 | 1 |
| GW055085 | 90BL119116 | 763296 | 6615694 | 65 | 2 |
| GW056030 | 90BL121913 | 785488 | 6622805 | 18.6 | 1 |
| GW056964 | 90BL150047 | 778955 | 6629294 | 18.3 | 1 |
| GW057478 | 90WA811393 | 768263 | 6631074 | 61.3 | 2 |
| GW057740 | 90CA807232 | 780227 | 6628922 | 20.4 | 1 |
| GW058777 | 90BL124298 | 768351 | 6632458 | 41.3 | 2 |
| GW059278 | 90CA807144 | 785415 | 6614978 | 43.5 | 1 |
| GW059354 | 90CA807240 | 780075 | 6629234 | 23.2 | 1 |
| GW059365 | 90CA811343 | 768358 | 6631657 | 60 | 2 |
| GW059552 | 90BL131305 | 773208 | 6632276 | 38.5 | 2 |
| GW059838 | 90BL131534 | 784324 | 6621171 | 20 | 1 |
| GW059958 | 90BL131661 | 763118 | 6613880 | 66 | 2 |
| GW060055 | - | 784793 | 6615672 | 30.5 | 1 |
| GW060267 | 90CA807243 | 784466 | 6617438 | 61 | 1 |
| GW060422 | 90CA807243 | 784615 | 6617033 | 52 | 1 |
| GW060423 | - | 784315 | 6616795 | 95 | 11 |
| GW060609 | 90BL131325 | 774196 | 6632251 | 32.2 | 3 |
| GW060688 | 90BL131813 | 770245 | 6634507 | 33.5 | 2 |
| GW060976 | 90BL132595 | 776941 | 6617387 | 26.5 | 5 |
| GW060977* | - | 774351 | 6617299 | 0 | 1 |
| GW060978* | - | 777651 | 6616999 | 0 | 1 |
| GW062391 | 90CA807235 | 786287 | 6621736 | 60 | 1 |
| GW062433 | 90CA811347 | 769948 | 6632689 | 45.7 | 2 |
| GW062614 | 90BL134412 | 766960 | 6629103 | 60 | 2 |
| GW062695 | 90BL134535 | 774013 | 6631362 | 39.5 | 2 |
| GW062918 | 90BL135023 | 769215 | 6630680 | 57.5 | 2 |
| GW063058 | 90CA807185 | 785991 | 6623686 | 103 | 1 |
| GW063061 | 90CA807280 | 785285 | 6624229 | 78.2 | 1 |
| GW063065 | 90CA807243 | 782859 | 6619237 | 16.1 | 1 |
| GW064089 | 90BL136121 | 767855 | 6632933 | 39 | 2 |
| GW064094 | 90BL136088 | 784840 | 6624549 | 40 | 1 |
| GW064478 | - | 767061 | 6631072 | 40 | 2 |
| GW065032 | 90BL248152 | 784485 | 6626315 | 21.3 | 1 |
| GW065982 | 90CA807199 | 781816 | 6630938 | 76.5 | 1 |

Table 4 Registered Bores within 10 km of Narrabri Mine (continued)

| Work no. | Licence | Easting | Northing | Depth (m)[1] | Layer[2] |
|---|---|---|---|---|---|
| GW067626 | 90BL139277 | 770930 | 6625737 | 88 | 3 |
| GW067919 | 90BL138918 | 775023 | 6631477 | 39.6 | 3 |
| GW068060 | 90BL139750 | 770452 | 6634386 | 35.6 | 2 |
| GW068591 | 90BL141830 | 771621 | 6629594 | 54.9 | 2 |
| GW068714 | 90BL141410 | 769188 | 6633107 | 34.4 | 2 |
| GW068815 | - | 783343 | 6624003 | 33.5 | 1 |
| GW070027 | 90BL150077 | 765835 | 6627897 | 48.7 | 2 |
| GW070534 | 90CA807271 | 779651 | 6630386 | 41.5 | 1 |
| GW070841 | 90BL151717 | 772227 | 6629373 | 51.82 | 2 |
| GW071281 | 90CA807255 | 776977 | 6631317 | N/A | 1 |
| GW071313 | 90BL153424 | 774294 | 6630920 | 30.5 | 2 |
| GW071993 | - | 774993 | 6630229 | 49 | 3 |
| GW072008 | 90BL152544 | 770340 | 6632964 | 36.5 | 2 |
| GW098012 | - | 774011 | 6630801 | N/A | 2 |
| GW900085 | 90CA811363 | 768174 | 6631558 | 64 | 2 |
| GW900417 | 90CA807265 | 779771 | 6630907 | 45 | 1 |
| GW901089 | 90CA807214 | 783462 | 6619869 | 40 | 1 |
| GW901138 | 90CA807273 | 775404 | 6632707 | 22 | 1 |
| GW901289 | 90BL246356 | 774721 | 6630671 | 35.94 | 3 |
| GW901422 | 90CA807243 | 785076 | 6617483 | 49 | 1 |
| GW901842 | 90CA807192 | 784256 | 6621269 | 45.5 | 1 |
| GW901887 | 90BL248373 | 781201 | 6629335 | 18.7 | 1 |
| GW902183 | 90BL252352 | 770015 | 6632121 | 14 | 2 |
| GW902246 | 90CA807194 | 784507 | 6626129 | 60.96 | 1 |
| GW902299 | 90CA811335 | 771611 | 6633561 | 42 | 2 |
| GW902348 | 90BL246871 | 768481 | 6632332 | 41.3 | 2 |
| GW902511 | - | 784759 | 6624551 | 60 | 1 |
| GW902579 | 90CA807290 | 779823 | 6628830 | 15.55 | 1 |
| GW902674 | 90BL249581 | 774468 | 6632460 | 17.5 | 3 |
| GW965300 | 90WA810692 | 769790 | 6632931 | 60.3 | 2 |
| GW965354 | 90CA807210 | 784248 | 6620385 | 44.5 | 1 |
| GW965579 | 90BL250565 | 785306 | 6621445 | 67 | 1 |
| GW965964 | 90CA807243 | 784128 | 6618532 | 53 | 1 |
| GW965969 | 90BL251439 | 785788 | 6617002 | 23.75 | 1 |
| GW966352 | 90BL247940 | 781436 | 6628235 | 18 | 1 |
| GW966836 | 90BL246067 | 776382 | 6619701 | 30 | 4 |
| GW966837 | 90BL155449 | 774580 | 6630789 | 35.34 | 3 |
| GW967194 | 90CA807280 | 784527 | 6624478 | 61 | 1 |
| GW967625 | 90BL252649 | 787255 | 6616647 | 24 | 1 |
| GW967680 | 90BL252745 | 784931 | 6616287 | 31 | 1 |

Table 4 Registered Bores within 10 km of Narrabri Mine (continued)

| Work no. | Licence | Easting | Northing | Depth (m)[1] | Layer[2] |
|---|---|---|---|---|---|
| GW968251 | 90WA810748 | 767351 | 6629098 | 66 | 2 |
| GW968260 | 90BL254652 | 784400.9 | 6622365 | 15 | 1 |
| GW968261 | 90BL254159 | 784213.5 | 6622477 | 67.5 | 11 |
| GW968262 | 90BL254159 | 784208.8 | 6622486 | 37 | 1 |
| GW968264 | 90BL254159 | 784503.1 | 6622719 | 33 | 1 |
| GW968265 | 90BL254159 | 784491.2 | 6622717 | 28 | 1 |
| GW968801 | 90BL254718 | 769504 | 6633570 | 60 | 2 |

Notes:
* Indicates bore has collapsed according to works summaries on PINNEENA database.
[1] Depth as listed in PINNEENA database
[2] Layer:
1 Alluvium and regolith
2 Pilliga Sandstone
3 Purlawaugh Fm
4 Garrawilla Volcanics
5 Napperby Fm above Sill
6 Basalt Sill
7 Napperby Fm below Sill
8 Digby Fm
9 Hoskissons Coal Seam
10 Arkarula Fm
11 Pamboola Fm
N/A Indicates not reported

## 2.4 GROUNDWATER MONITORING

Groundwater monitoring for the NM is undertaken in accordance with the Groundwater Monitoring Program (GWMP) within the NM Water Management Plan (URS Australia, 2013). The objectives of the GWMP are to establish baseline groundwater quality and water level data and to implement a program of data collection that provides a basis for assessing potential impacts of mining activities on the groundwater resources of the area.

The groundwater monitoring network currently consists of more than 50 monitoring sites. The details of monitoring bores in the network are summarised in **Table 5, Table 6** and **Table 7**. The locations of the bores in the groundwater monitoring network are shown in **Figure 9**.

**Table 5 Summary of Groundwater Monitoring Site Measurements**

| Monitoring Site | Parameter | Frequency |
|---|---|---|
| All Standpipes<br>P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P28, P29, P30, P31, P32, P33, P34, P47, WB1, WB2, WB3a, WB3b, WB4, WB5a, WB5b, WB6a, WB6b, WB7 and WB8 | Water level<br>EC<br>pH<br>TDS<br>Metals<br>Anions and Cations | Quarterly (water level, pH and EC)<br><br>Bi-annually (full water quality) |
| Vibrating Wire Piezometers<br>P21, P22, P25, P26, P27 and P48 | Water Level | Daily (Data Logger) |
| Multi-Level Vibrating Wire Piezometers<br>P23, P24, P35, P36, P37, P38, P40, P44, P45 and P46 | Water Level | Daily (Data Logger) |

Note: EC = electrical conductivity
TDS = total dissolved solids

**Table 6 Summary of Groundwater Monitoring Site Types**

| Monitoring Site | Lithology | Start Date | TYPE |
|---|---|---|---|
| WB3A, WB3B, WB4, WB5A, WB5B, WB6A, WB6B and WB7 | Alluvium | All from September 2008 except WB7 from November 2008 | Standpipe |
| P6 and P7 | Pilliga Sandstone | From November 2007 | Standpipe |
| P8, P9, P11 and P17 | Purlawaugh Formation | All from March 2008<br>P17 stopped on February 2009 | Standpipe |
| P1, P13, P15, P16, P47, WB1 and WB2 | Garrawilla Volcanics | P1 from November 2007<br>P15 from January 2009<br>P13, P16 from March 2008<br>P32 from June 2012<br>WB1 from August 2008 – December 2008<br>WB2 from August 2008 – October 2011<br>P47, from June 2012 | Standpipe |
| P2, P4, P10, P12, P14, P28, P29, P30, P31, P32, P33 and P34 | Napperby Formation | P2, P4 from November 2007<br>P10, P12 from March 2008<br>P14 from January 2009 – April 2012<br>P28, P29, P30, P31, P32, P33, P34 from June 2012 | Standpipe |
| P18, P21, P22, P25, P26 and P27 | Hoskissons Seam | P18 from March 2008<br>P21, P22, P25, P26, P27 from June 2009 | Standpipe<br>Vibrating Wire |
| P23, P24, P35, P36, P37, P38, P40, P44, P45 and P46 | Multi-Level | Variable time | Multi-Level Vibrating Wire |
| P20 | Arkarula Formation | From March 2008 to June 2010 | Standpipe |
| P3, P5 and P19 | Pamboola Formation | P3, P5 from November 2007<br>P19 from March 2008 | Standpipe |

Table 7 Monitoring Bore Construction Details

| Name | Type | Unit | RL (mAHD) | Bore Depth (mBGL) | Screen Interval / Sensor Depths (mBGL) |
|---|---|---|---|---|---|
| P01 | Standpipe | Garrawilla Volcanics | 316.059 | 50 | 44-50 |
| P02 | Standpipe | Napperby Formation | 275.917 | 50 | 44-50 |
| P03 | Standpipe | Pamboola Formation | 236.312 | 45 | 34-40 |
| P04 | Standpipe | Napperby Formation | 248.957 | 30 | 24-30 |
| P05 | Standpipe | Pamboola Formation | 233.408 | 30 | 24-30 |
| P06 | Standpipe | Pilliga Sandstone | 326.189 | 90 | 78-90 |
| P07 | Standpipe | Pilliga Sandstone | 289.694 | 90 | 78-90 |
| P08 | Standpipe | Purlawaugh Formation | 322.11 | 65 | 57-63 |
| P09 | Standpipe | Purlawaugh Formation | 287.6 | 30 | 24-30 |
| P10 | Standpipe | Napperby Formation | 302.53 | 130 | 118-130 |
| P11 | Standpipe | Purlawaugh Formation | 302.4 | 50 | 44-50 |
| P12 | Standpipe | Napperby Formation | 276.48 | 90 | 84-90 |
| P13 | Standpipe | Garrawilla Volcanics | 276.48 | 30 | 24-30 |
| P14 | Standpipe | Napperby Formation | 277.41 | 78 | 72-78 |
| P15 | Standpipe | Garrawilla Volcanics | 277.41 | 30 | 24-30 |
| P16 | Standpipe | Garrawilla Volcanics | 303.51 | 146 | 137-146 |
| P17 | Standpipe | Purlawaugh Formation | 303.24 | 56 | 47-56 |
| P18 | Standpipe | Hoskissons Coal Seam | 270.9 | 146 | 143-146 |
| P19 | Standpipe | Pamboola Formation | 275.09 | 187 | 184-187 |
| P20 | Standpipe | Arkarula Formation | 272.94 | 162 | 159-162 |
| P21 | Vibrating Wire | Hoskissons Coal Seam | 275 | 200 | 160 |
| P22 | Vibrating Wire | Hoskissons Coal Seam | 274.12 | 180 | 165 |
| P23 | Vibrating Wire | Multiple | 286.035 | 199 | 45, 120, 169, 188 |
| P24 | Vibrating Wire | Multiple | 277.594 | 181 | 112, 148, 166, 180 |
| P25 | Vibrating Wire | Hoskissons Coal Seam | 270 | 200 | 165 |
| P26 | Vibrating Wire | Hoskissons Coal Seam | 275.413 | 200 | 176 |
| P27 | Vibrating Wire | Hoskissons Coal Seam | 275.355 | 180 | 176 |
| P28 | Standpipe | Napperby Formation | 262.46 | 25 | 19-25 |
| P29 | Standpipe | Napperby Formation | 256.84 | 25 | 19-25 |
| P30 | Standpipe | Napperby Formation | 254.95 | 15 | 9-15 |
| P31 | Standpipe | Napperby Formation | 264.39 | 15 | 9-15 |
| P32 | Standpipe | Napperby Formation | 252.49 | 15 | 9-14 |
| P35 | Vibrating Wire | Hoskissons Coal Seam | 278.71 | 183.1 | 173 |
| P36 | Vibrating Wire | Hoskissons Coal Seam | 281.5 | 190.1 | 176 |
| P37 | Vibrating Wire | Hoskissons Coal Seam | 277.384 | 186.3 | 177 |
| P38 | Vibrating Wire | Hoskissons Coal Seam | 274.16 | 169 | 153.5, 155.5 |

Table 7 Monitoring Bore Construction Details (continued)

| Name | Type | Unit | RL (mAHD) | Bore Depth (mBGL) | Screen Interval / Sensor Depths (mBGL) |
|---|---|---|---|---|---|
| P40 | Vibrating Wire | Multiple | 321.22 | 360 | 95, 135, 307, 322, 346, 357 |
| P44 | Vibrating Wire | Multiple | 268.15 | 471 | 95.5, 134, 245, 330, 375, 445 |
| P45 | Vibrating Wire | Multiple | 247.265 | 291 | 42.5, 80, 150, 200, 240, 276 |
| P46 | Vibrating Wire | Multiple | 262.325 | 396 | 70, 87, 151, 250, 308, 343 |
| P47 | Standpipe | Garrawilla Volcanics | 288.78 | 30.5 | 8-30.5 |
| WB1 | Production Bore | Garrawilla Volcanics | 265.839 | Unknown | Unknown |
| WB2 | Production Bore | Garrawilla Volcanics | 281 | Unknown, assume 26 | 22-26 |
| WB3a | Production Bore | Alluvium | 226 | Unknown, assume 8.5 | 8.2-8.5 |
| WB3b | Production Bore | Alluvium | 226 | Unknown, assume 36.3 | 35.1-36.3 |
| WB4 | Production Bore | Alluvium | 224 | Unknown, assume 15.9 | 11.3-15.9 |
| WB5a | Production Bore | Alluvium | 233 | Unknown, assume 14.5 | 11-14.5 |
| WB5b | Production Bore | Alluvium | 233 | Unknown, assume 28 | 26.5-28 |
| WB6a | Production Bore | Alluvium | 234 | Unknown, assume 13 | 11.5-13 |
| WB6b | Production Bore | Alluvium | 234 | Unknown, assume 78 | 76.7-78 |
| WB7 | Production Bore | Alluvium | 230 | Unknown | Unknown |

Note: mAHD = elevation in metres with respect to the Australian Height Datum
mBGL = metres below ground level

## 2.5 BASELINE GROUNDWATER LEVEL DATA

The network of monitoring bores (piezometers) has been established in different formations associated with the principal drainage pathways. Multi-level vibrating wire piezometers (VWPs) have been installed within the Jurassic, Triassic and Permian formations (**Table 6**). Hydrographs for monitoring sites listed in **Table 6** are presented in **ATTACHMENT A** to **ATTACHMENT H**. For ease of reference the hydrographs are grouped according to type as summarised in **Table 8**.

**Table 8 Monitoring Bore Groups**

| Bore Type | No. of Monitoring Bores | Group |
|---|---|---|
| Standpipe (SP) | 26 | 1 |
| Production Bore (PB) | 10 | 2 |
| Vibrating Wire Piezometers (VWP) | 5 | 3 |
| Multi-level Vibrating Wire Piezometers | 10 | 4 |
| Total | 51 | |

### 2.5.1 SPATIAL GROUNDWATER LEVELS

Natural groundwater levels are sustained by rainfall infiltration and are controlled by ground surface topography, geology and surface water elevations. Typically, local groundwater would mound beneath hills and would discharge to incised creeks and rivers (**Figure 10**). During short events of high surface flow, streams would lose water to the host aquifer but, during recession, the aquifer would discharge water slowly back into the stream from bank storage. Groundwater would flow from elevated to lower-lying terrain.

Groundwater levels within the alluvium generally follow topography, draining from the east towards the Namoi River.

### 2.5.2 TEMPORAL GROUNDWATER LEVELS IN ALLUVIUM

The key monitoring bores for this study are located within the alluvium associated with the Namoi River (at locations shown on **Figure 9**):

- WB3a and WB3b — located approximately 7 km north-east of the NM lease;
- WB4 — located approximately 5 km north-east of the NM lease;
- WB5a and WB5b — located approximately 9.5 km east of the NM lease;
- WB6a and WB6b — located approximately 11 km south-east of the NM lease; and
- WB7 — located approximately 6.5 km east of the NM lease.

**ATTACHMENT A** displays the groundwater level hydrographs for the above alluvial bores, compared with the rainfall RMC since March 2007, and with the commencement dates for LW101, LW102 and LW103. During a wetter than normal period, the curve climbs. Conversely, the curve falls during a drier than normal period. If rainfall is the primary driver for groundwater level dynamics, the groundwater hydrographs can be expected to follow a similar trend. The data in **Figure A2 to A6** show that the water table at alluvium bores responds rapidly to rainfall events with amplitude of between 1 and 4 m.

### 2.5.3 GROUNDWATER LEVELS IN PILLIGA SANDSTONE

Two monitoring bores are located in the Pilliga Sandstone: P6 located 1 km north of LW110 and P7 located 3.5 km west of LW111[3] (**Figure B1**).

P6 water level ranges between 235.8 and 237.2 mAHD and shows a good response to the rainfall event in late-2008 (**Figure B2**). P6 has been fluctuating around dry level (approximately 236 mAHD) since late 2009.

The P7 hydrograph (**Figure B3**) shows a sharp decline in water level from 226.8 mAHD in November 2007 to 199.3 mAHD in January 2008, roughly coincident with a dry period. The water level remained around this level until mid-2009 with one exception. Since then the water level has been quite stable around 226.0 mAHD irrespective of rainfall conditions. The occasional drawdowns of about 25 m are likely due to the influence of a nearby pumping bore[4]. A mining effect is not possible as the low water levels in 2008 precede the commencement of mining, and the bore is located 3.5 km west of LW111.

### 2.5.4 GROUNDWATER LEVELS IN PURLAWAUGH FORMATION

Four standpipe monitoring sites are located in the Purlawaugh Formation: P8, P9, P11 and P17 (**ATTACHMENT C**).

P8 is located in the middle of LW208. The P8 hydrograph (**Figure C2**) shows the water level fluctuates between 271.3 and 272.0 mAHD with only weak correlation to rainfall trends.

P9 is located near the main central heading on LW203. The P9 hydrograph shows a weak correlation with the rainfall mass curve (**Figure C3**); water level ranges between 266.6 and 268.9 mAHD over the period from March 2008 to June 2015. Some effect from the mining of LW104 can be observed from November 2014; however, a sharper decline in water levels occurred co-incident to the start of mining LW105 in September 2015. At June 2016 water levels were at 262.7 mAHD, approximately 5 m lower than average pre-mining levels.

P11 is located in the middle of LW205. The P11 water level ranges between 271.6 and 285.1 mAHD from March 2008 to June 2016. The P11 hydrograph (**Figure C4**) shows that the water level appears to respond to the rainfall trend but with a considerable time lag.

P17 is located at the western edge of LW111. The water level was measured only between March 2008 and February 2009 and had dramatic fluctuations between 243.8 and 259.8 mAHD

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4 The nearest registered bore is 2 km away

(**Figure C5**). P17 is located approximately 3 km from P7 which had a sharp decline in water level at the same time as P17. The sudden decline in water level in these two bores could be from pumping effects from the same nearby production bore. P17 has been dry since June 2009.

### 2.5.5 GROUNDWATER LEVELS IN GARRAWILLA VOLCANICS

**ATTACHMENT D** shows the hydrographs for seven standpipe monitoring sites located in Garrawilla Volcanics; these are P1, P13, P15, P16, P47, WB1 and WB2.

P1 is located approximately 0.4 km north of LW210. The P1 hydrograph (**Figure D2**) shows that the water level increased gradually from 264 mAHD in November 2007 to 295 mAHD in June 2016. The P1 hydrograph reveals that the water level is possibly recovering from a pumping effect as there is no apparent correlation with rainfall, although the closest registered pumping bore is approximately 1.5 km away.

P13 is located on LW201 just south of LW101 and the main central headings. The P13 hydrograph (**Figure D3**) shows that the water level correlates relatively well with the rainfall RMC. Water levels range between 263.6 and 271.6 mAHD with an average 267.7 mAHD over the period from March 2008 to June 2016. The water level decreased gradually from 271.2 mAHD in July 2013 to 269.1 mAHD in September 2013 to 267.5 mAHD in December 2013, and then to approximately 204.0 mAHD in March 2015. This decline in water level is unlikely to be due to extraction of LW101 at that time (as the bore is about 600 m away from LW101 but would be due to the dry period from September 2013 to March 2015 as shown in the rainfall residual mass curve. Water levels increased to 265.3 mAHD in December 2015 before declining again to approximately 263.5 m AHD in the first half of 2016.

P15 is located on LW105. The P15 hydrograph (**Figure D4**) shows that the water level ranges between 261.0 and 261.5 mAHD from January 2009 to March 2014 and declines rapidly thereafter to 249.1 mAHD at December 2015. The declining water level appears to be related to the start of mining of LW103 to the east, with continuing declines due to being undermined by LW104 and LW105; however, the decline also follows the rainfall trend. A short-term sharp rebound of over 8 m occurs in June and September 2015 and may be related to increased rainfall over the winter period; however, this is not observed in other nearby piezometers. These outlier data points may represent an error in data collection or short-term ingress of rainwater into the piezometer. Laboratory data records lower than average EC and dissolved ions for this period suggest it is likely the latter.

P16 is located at the western edge of LW111. The water level ranges between 247.3 and 257.5 mAHD over the period from March 2008 to March 2015. The P16 hydrograph (**Figure D5**) shows that the water level was low from March 2008 to December 2008, increased gradually, plateauing at about 257.3 mAHD during 2012 to 2014, then declined slowly thereafter. P16 is located in the same area as bores P7 and P17 that showed the same water level trend unrelated to rainfall, and is likely relating to groundwater abstraction at the nearby bore.

The P47 Hydrograph (**Figure D6**) shows a small range in water levels from 264.6 to 265 mAHD over the period from June 2012 to June 2016. The measured water level for this bore does not show any mining effect although this bore is located at the northern edge of LW102.

WB1 is located 600 m north-east of LW101. The water level was measured over a short period of time between August 2008 and December 2008 and had a steady water level of around 257.4 mAHD (**Figure D7**).

WB2 is located around the middle of LW201. The water level ranges between 272 and 278 mAHD over the period August 2008 to October 2011 (**Figure D8**), independent of rainfall. No water level measurements have been taken in this bore since October 2011.

### 2.5.6 GROUNDWATER LEVELS IN NAPPERBY FORMATION

P2, P4, P10, P12, P14, P29, P31 and P32 are standpipe monitoring sites located in the Napperby Formation (**ATTACHMENT E),** Bores P2 and P4 are labelled P02 and P04, respectively, in **Figure E1**.

P2 is located south-east of the NM lease approximately 2 km east of LW203. The P2 water level (**Figure E2**) ranges from 245.3 mAHD to 247.7 mAHD over the period from November 2007 to June 2016. The hydrograph shows a very gradual rise and fall in water levels following the RMC, with occasional short-term variations of up to 1 m, presumably related to nearby pumping.

P4 is located northeast of the NM lease approximately 3 km north-east of LW101. The water level (**Figure E5**) ranges from 230.4 mAHD to 231.3 mAHD over the period from November 2007 to June 2016. The hydrograph shows an overall rising trend that has a poor correlation with the RMC.

P10 is located near the midpoint of LW205. The P10 water level ranges between 249.2 and 287.4 mAHD from March 2008 to March 2015. The P10 hydrograph (**Figure E4**) shows that the water level sharply declined from 282.5 mAHD in September 2008 to the minimum 249.2 mAHD in November 2008, then the water level started to recover gradually from January 2009 to reach a steady water level at 279.6 mAHD in February 2011. The 33 m drawdown (from September 2008 to November 2008) is probably caused by pumping from an unregistered bore[5]. There appears to be no correlation with rainfall.

P12 is located on LW201 just south of the main central heading, approximately 650 m south of LW101. The water level (**Figure E5**) ranges between 233.9 mAHD and 240.2 mAHD over the period from March 2008 to June 2016. The hydrograph shows natural water level fluctuation from March 2008 until February 2011. It can be noticed that the water level started to gradually decline from early 2011 at the same time as the central development heading passed below bore P12. The water level continued to decline to reach 238.7 mAHD in June 2013 (at the end of extraction LW101), with a sharp decline from the commencement of LW102 to 233.9 mAHD in June 2016. Although the water level decline coincided with a dry period, a longwall mining effect is likely at bore P12 (given no similar response to climate at bore P10).

P14 is located on LW105. The water level measured between January 2009 and April 2012 ranged from 216.4 mAHD to 220.1 mAHD. The P14 hydrograph appears to respond to weather variations (**Figure E6**). P14 has been mostly dry since June 2012 which corresponds with the start of mining LW101, but also to a long period of below-average rainfall. Two water level

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5 The nearest registered bore is 3 km away

records were able to be taken from the standpipe in June and September 2015 before it went dry again.

P29, P31 and P32 are located to the east of the main central development headings by approximately 500 m for P31 to 1.2 km for P32.

These bores were installed in 2009 and monitored since the beginning of mining LW101 (June 2012) to monitor potential seepage from the water storage ponds in the rail loop. The boreholes were installed “dry” (i.e. above the shallow water table) to determine whether local water mounding was occurring adjacent to the ponds (GES, 2013). Water levels have been recorded in P29, P31 and P32 since June 2012, which may indicate some seepage from the ponds, although the natural groundwater level is also likely to have risen from the 2009 level due to increased recharge from above average rainfall as shown by the RMC. The ongoing trend in water levels monitored in these boreholes does not, however, correspond with the RMC curve, suggesting that the water level recorded is in fact related to seepage. For P29 (**Figure E7**), the water level rose significantly from mid-2013 (soon after commencement of LW102), then at an increasing rate as LW103 was activated. At P31 (**Figure E8**) and P32 (**Figure E9**), water levels have fluctuated almost cyclically, with increasing water levels from the commencement of each longwall and gradually declining as the end of the longwall is reached, rising again as the next longwall is started. This is likely to reflect the pond storage levels which are directly related to the dewatered (drainage) volumes during mining.

### 2.5.7 GROUNDWATER LEVELS IN HOSKISSONS SEAM

The Hoskissons Seam is monitored by standpipe piezometer P18, and vibrating wire piezometers P21, P22, P25, P26, P27, P35, P36, P37 and P38. **ATTACHMENT F** displays the hydrographs for these monitoring sites.

The P18 standpipe is located at just east of LW101. The P18 hydrograph (**Figure F2**) shows the water level was stable around 257.6 mAHD from March 2008 to June 2009; then the water level declined rapidly to 229.5 mAHD in September 2010, at which time measurements ceased. The sudden drop in water level would have been caused by the drift tunnel construction as it preceded the start of LW101 headings (January 2011).

The VWPs P21, P22, P25, P26, P27, P35, P36 and P37 are located on the main central heading just south and south-east of LW101. All hydrographs (**Figures F3** to **F10**) show a sharp decline in water level at the time of drift tunnel construction or development of main headings.

P38 is a multi-level vibrating wire within upper and lower Hoskissons Seam plies, located in the middle of LW101.. The hydrographs (**Figure F11**) show the water level declined from 180 mAHD from November 2010 to 120 mAHD at December 2012. The sharp decline in water level for P38 is evident due to the passage of LW101 headings, with a smaller effect from LW101 extraction (LW101 started in June 2012 and ended in June 2013).

### 2.5.8 GROUNDWATER LEVELS IN ARKARULA FORMATION

P20, a standpipe located on LW101, measured the water level in the Arkarula Formation between March 2008 and June 2010. The hydrograph (**ATTACHMENT G, Figure G2**) shows the water level fluctuated around 259 mAHD from March 2008 to June 2009 and then declined sharply to reach 223.5 mAHD in June 2010. As at P18, the drawdown would have been caused by the drift tunnel construction as it preceded the start of LW101 headings (January 2011).

### 2.5.9 GROUNDWATER LEVELS IN PAMBOOLA FORMATION

Three standpipe monitoring sites are located in the Pamboola Formation: P3, P5 and P19.

P3 is located approximately 4 km east of LW201. The P3 water level ranges between 226.2 and 227.5 mAHD over the period from November 2007 to June 2016. The P3 hydrograph shows no response to rainfall trend (apart from two anomalous readings that could be related to a rainfall event) (**Figure G3**).

P5 is located approximately 5.7 km north-east of LW101. The P5 hydrograph shows the water level increased gradually from 204.4 to 210.8 mAHD over the period from November 2007 to June 2016 (**Figure G4**) with no clear correlation with rainfall.

P19 is located just east of LW101. As P19 is located close to standpipe bores P18 and P20 but in a different formation, the P19 hydrograph (**Figure G5**) has a trend similar to these bores but with much less drawdown magnitude, and the decline starts earlier. The water level fluctuated around 259 mAHD from March 2008 until June 2009, and then declined to 250.3 mAHD in August 2009. The water level started gradually to recover to reach 254.4 mAHD in June 2016. The initial decline would have been due to drift tunnel construction.

### 2.5.10 GROUNDWATER LEVELS IN MULTI-LEVEL VIBRATING WIRE PIEZOMETERS

**ATTACHMENT H** shows VWP groundwater hydrographs from the monitoring network at locations shown in **Figure H1**. They include hydrographs in the Purlawaugh Formation, Garrawilla Volcanics, Napperby Formation, Digby Formation, Hoskissons Seam, Arkarula and Pamboola Formations.

The vibrating wire P23 is located on the LW101 heading about 150 m away from the central mains. **Figure H2** shows the hydrographs for four different depths; at 45 m depth (Garrawilla Volcanics), at 120 m (Napperby Formation), at 169 m (Digby Formation) and at 188 m depth (Hoskissons Seam). The hydrographs show that only the two deeper VWPs respond to the underground mining due to the drift tunnel construction and the start of the main development headings (June 2010). The water levels in these two vibrating wires declined sharply initially from 240 mAHD in May 2009 then more gradually to about 200 mAHD in June 2010 before a further rapid decline of about 40 m to about 155 mAHD in late 2010. A gradual decline to below 140 mAHD occurred to December 2012. The water levels in the two upper vibrating wires were steady at about 260 mAHD and 240 mAHD at 45 m depth and 120 m depth, respectively.

The vibrating wire P24 is located just east of LW101 and about 600 m away from the central mains. The vibrating wires are installed at four different depths: at 112 m depth (Napperby Formation), at 148 m (Digby Formation), at 166 m (Hoskissons Seam) and at 180 m depth (Arkarula Formation). **Figure H3** shows the hydrographs for these depths from May 2009 to April 2016. The water level in the Hoskissons Seam (166 m depth) shows a strong response to the Narrabri underground mining since the drift tunnel construction and the start of the main development headings (June 2010). The water level declined sharply from 240 mAHD in May 2009 to about 121 mAHD in January 2015. The water levels in the Digby and Arkarula Formations declined slightly when drift construction commenced, and declined markedly when the mains and LW101 headings started. The water level in the upper 120 m piezometer (Napperby Formation) was stable around 220 mAHD until the LW101 mining passed by P24 when the water level declined sharply to 195 mAHD in April 2013.

P40 is located on LW110 just north of the central mains. The vibrating wires were installed in November 2012 at six different depths: at 95 m depth (Purlawaugh Formation), at 135 m (Garrawilla Volcanics), at 307 m (Napperby Formation), at 322 m (Digby Formation), at 346 m (Hoskissons Seam) and at 357 m (Arkarula Formation). **Figure H4** shows the hydrographs for these depths from November 2012 to April 2016. The lower depths 322 m, 346 m and 357 m show some impacts from the mining of LW101 to LW103. In the Arkarula Formation, the water level decreased from about 240 mAHD in November 2012 to about 220 mAHD in April 2014. The upper 135 m and 307 m piezometers show a stable water level about 260 and 262 mAHD, respectively. The shallowest vibrating wire at 95 m depth in the Purlawaugh Formation showed a drawdown of about 20 m, unrelated to mining but probably due to nearby pumping from an existing bore on the property.

P44 is located approximately 800 m northeast of LW101. It was installed in August 2012 to monitor the groundwater level at six different depths: at 95.5 m (Napperby Formation), 134 m (Digby Formation), 245 m (Pamboola Formation) and at 330 m, 375 m and 445 m (depths greater than the bottom layer of the groundwater model). The hydrographs for these vibrating wires are shown in **Figure H5**. The vibrating wire hydrograph at 134 m located in the Digby Formation shows a gradual decline in water level from 225 mAHD in August 2012 to 216 mAHD in April 2015, which is likely due to the mining activities in LW101, LW102 and LW103. The water level in the 95.5 m and the 245 m vibrating wires are stable at about 208 mAHD and 242 mAHD, respectively, unaffected by mining. All of the represented depths demonstrate an upward hydraulic gradient at this location except for 375 m.

P45 is located approximately 3 km east of LW101. The P45 vibrating wires were installed in November 2012 at depths of 42.5 m (Digby Formation), 80 m (Arkarula Formation) and 150 m, 200 m, 240 m and 276 m, all deeper than the lower-most layer (Pamboola Formation) of the groundwater model. The hydrographs for these vibrating wires (**Figure H6**) show that the water level is steady over the period from December 2012 to April 2016, about 205 mAHD and 226 mAHD at depths 42.5 m and 80 m, respectively. All of the represented depths, except 200 m, demonstrate an upward hydraulic gradient at this location. The record at 240 m is anomalous.

The vibrating wire P46 is located approximately 3 km south-east of LW101. The vibrating wires were installed in May 2013 at depths of 70 m (Napperby Formation), 87 m (Digby Formation), 151 m (Pamboola Formation) and 250 m, 308 m and 343 m, all deeper than the lower-most layer (Pamboola Formation) of the groundwater model. Over the period of data record, the hydrograph for the 151 m vibrating wire shows a gradual decline in water level from 242 mAHD to 222 mAHD, and the shallowest VWP also shows a mild decline (**Figure H7**). As the Digby Formation VWP shows a rise in water level, it is likely the responses are equilibration responses rather than mining effects. Anomalous responses are recorded at 250 m and 308 m.

## 2.6 GROUNDWATER CHEMISTRY

Assessments of groundwater quality can be useful in understanding conceptual hydrogeology. For example, groundwater salinity tends to be low in areas of high recharge or connectivity with surface waters. The findings from the MOD 5 Groundwater Assessment (HydroSimulations, 2015) are summarised in this section. Relevant graphs are provided in **Attachment I**.

Sites monitoring groundwater salinity in the alluvium are all some distance (north and east) from the NM, located close to the Namoi River. Only spot readings are available at most of the sites and, with one exception, values are below 1,500 microSiemens per centimetre (µS/cm).

None of the monitoring sites is located sufficiently close to the NM to suggest any impact of mining on alluvial groundwater.

Only two sites monitor salinity in the Pilliga Sandstone. Site P7 is located approximately 6 km west of NM and displays a low median salinity of 239 µS/cm, with values over time consistently lower than 500 µS/cm since 2009. In 2011 a single higher value (2,320 µS/cm) was measured at P6, located about 1 km north of the NM; however, this may not be representative.

For the Purlawaugh Formation, four sites monitor salinity in the immediate vicinity of the NM. Mid-range median values (2,440, 4,410 µS/cm) are apparent 3-4 km west and south of the existing mine and at the limits of proposed operation. Approximately 1 km south-west of the existing mine, site P9 has almost consistently demonstrated high values (above 15,000 µS/cm) since 2009.

Seven sites monitor salinity in the Garrawilla Volcanics. All are located within close proximity of existing or proposed mining, except for site P1, which is about 6 km south of current extraction. For most sites, salinities since 2009 have been in the range 1,000-4,000 µS/cm. Greater variability is apparent for site P15; prior to 2012 values were consistently greater than 10,000 µS/cm (gradually declining), but a significant and rapid decline (to less than 2,000 µS/cm) occurred early in 2012 with a subsequent rapid rise from mid-2013. Since that time values have returned to around 10,000 µS/cm.

Salinities within the Napperby Formation are represented by monitoring at eight sites that are distributed north, east and south of the existing mining area. The highest values occur some distance away. Site P12, located about 600 m south of the present mine, exhibits the lowest median value (2,790 µS/cm) with values consistently below 3,500 µS/cm since 2009.

Only one site has monitored salinity within the Hoskissons Seam: site P18, immediately east of the present mine. From 2009 to 2010 values were above 4,000 µS/cm.

Within the Arkarula and Pamboola Formations, sites P19 and P20 are in the immediate vicinity of present operations. Monitoring at P20 ceased in 2010 at which time a value of about 6,000 µS/cm represented a decline from above 10,000 µS/cm in earlier years. At P19 salinity values have been consistently below 5,000 µS/cm from 2009 to the present.

**Table 9** summarises the probability of exceedance levels of groundwater salinity. This clearly demonstrates the presence of the highest salinities in the Purlawaugh, Napperby and Arkarula and Pamboola Formations, with lower salinities in the Pilliga Sandstone and the alluvium. There is a general (but not entirely consistent) increase with depth.

**Table 9 Cumulative Probability Distributions of Groundwater Salinity (µS/cm)**

| Probability of Exceedance (%) | Alluvium | Pilliga Sandstone | Purlawaugh Formation | Garrawilla Volcanics | Napperby Formation | Hoskissons Seam | Arkarula & Pamboola Formation |
|---|---|---|---|---|---|---|---|
| **90** | 625 | 150 | 330 | 1,158 | 2,540 | * | 2,456 |
| **80** | 688 | 165 | 362 | 1,315 | 3,060 | 1,410 | 3,652 |
| **50** | 796 | 239 | 4,173 | 2,490 | 7,850 | 5,125 | 15,810 |
| **20** | 1,120 | 390 | 17,180 | 3,944 | 18,910 | 7,490 | 22,656 |
| **10** | 1,175 | 475 | 19,835 | 5,935 | 24,290 | * | 25,884 |

*Note: * Insufficient data.*

## 2.7 CONCEPTUAL MODEL

The hydrogeological regime of the NM and surrounds comprises two main systems (CDM Smith, 2016):

- a porous hard rock groundwater system that occurs throughout the stratigraphic sequence of Jurassic and Triassic formations and Permian coal measures; and
- aquifers associated with the unconsolidated alluvial sediments of the Namoi River floodplain (i.e. the Upper Namoi Alluvial aquifer).

The conceptual model is illustrated in **Figure 10**. The dominant recharge process would be the infiltration from rainfall and runoff. The dominant natural discharge processes would be ET, seepage face flow and baseflow to the local streams. Under mining conditions, localised groundwater flow paths would be altered to flow towards the goaf which would act as a groundwater sink.

### 2.7.1 ALLUVIAL GROUNDWATER SYSTEM

Groundwater flow patterns within the shallow alluvial aquifer reflect topographic levels and the containment of alluvium within the principal drainage pathways. Evidence from temporal groundwater monitoring hydrographs (**ATTACHMENT A**) within the alluvium indicates that the shallow aquifer is responsive to rainfall recharge and it is likely that the alluvium plays an important role in supplying recharge to the underlying Permian strata as well as, in places, contributing to baseflow of the perennial surface water features. In some areas upward or lateral flow may occur from the Permian and Triassic rock, but downward leakage seems to be the more common behaviour.

CDM Smith (2016) notes a smaller alluvial deposit named the Bohena Creek Alluvium to the west of the Project, with an average thickness of 6 m of "gravel and sand with clay lenses". This is not mapped as a "highly productive" groundwater source. No stygofauna were found in sampled bore waters.

### 2.7.2 PERMIAN GROUNDWATER SYSTEM

Prior to the commencement of mining operations in the region, the piezometric surface within the NM area most probably reflected the topography, with elevated water levels/pressures in areas distant from the major drainages and reduced levels in areas adjacent to the alluvial lands.

The Permian groundwater system within the NM area is continuous through the major geological formations. The various sedimentary rocks at NM have low permeability due to their fine-grained nature, the predominance of cemented lithic sandstones and the common occurrence of a clayey matrix in the sandstones and conglomerates. The permeability of the groundwater system is related to the joint spacing and aperture width. Permeability of the rock units generally decreases with depth of burial as the joints tighten and become less frequent.

The laminated fabric of the interbedded sandstone/siltstone/mudstone strata suggests that vertical hydraulic conductivities are significantly lower than horizontal hydraulic conductivities. Due to the laminar nature of the coal measures, groundwater flow generally occurs within, or along the boundaries between, stratigraphic layers.

The permeability of the coal measures is generally low, with levels of rock mass permeability more than two orders of magnitude lower than the unconsolidated alluvial aquifers. Within the coal measures, the most permeable horizons are the coal seams, which commonly have hydraulic conductivity one to three orders of magnitude higher than the siltstones, shales and sandstone units.

The coal seams are generally more brittle and, therefore, more densely fractured than the overburden and interburden strata, which causes the higher permeability. Within the coal seams, groundwater flows predominantly through cleat fractures, although structure-related fracturing may play a role in local groundwater flow paths.

### 2.7.3 RECHARGE AND DISCHARGE MECHANISMS

The main recharge mechanism is infiltration of rainfall through the alluvium layer, and through weathered rock exposed in subcrop areas.

As there is an annual rainfall deficit and the permeability of underlying rock is low, recharge rates to the coal measures are low. Significant groundwater recharge will tend to occur only following major, prolonged rainfall events.

The high clay content, and hence long storage/residence times, in the weathered soils that occur above the Permian subcrop areas cause recharge to be particularly low in those areas. Actual vertical percolation of recharge through rock layers is very limited and most recharge is likely to occur at subcrops after which the recharge water will move along relatively more permeable strata, parallel to bedding. The higher permeability of the alluvial areas and runoff concentration within drainage channels means that recharge will also tend to be higher in those areas.

Surface water associated with the principal drainage features will tend to be connected with the associated alluvium, and groundwater within the alluvium will discharge to the stream channels in some areas. However, connectivity with the wider geological environment is thought to be limited due to the low vertical permeability of the underlying strata. Creeks may ‘lose’ or ‘gain’ groundwater from alluvium depending on the relative level of groundwater in the alluvium compared with that of the creeks. Connectivity with the regional hard rock aquifers is very low.

# 3 GROUNDWATER SIMULATION MODEL

## 3.1 EXISTING GROUNDWATER MODELS

### 3.1.1 REGIONAL MODELS

There are two extensive hard-rock regional models in the vicinity of the Project, developed by SWS (2012) for the Namoi Catchment Water Study and by CDM Smith (2016) for the Narrabri Gas Project. There are alluvium-only models developed by the State Government for the Lower Namoi Valley (Merrick, 2001) and the Upper Namoi Valley (McNeilage, 2006), and many mine-specific groundwater models for neighbouring mines, none of which would pose cumulative effects on the Project.

The most recent Narrabri Gas Project groundwater model is classified as Class 1 (Barnett *et al*., 2012) due to limited data to constrain parameterisation.

### 3.1.2 NM-SPECIFIC MODELS

Four groundwater models have been constructed specifically to simulate and evaluate the impact of the stresses on the groundwater environment from the development and operation of the NM in detail.

The first model was an 11-layer numerical groundwater model developed using MODFLOW 2000 by GHD (2007) to simulate the groundwater flow regime for the Stage 1 Project. This model supported the EA for the proposed development of surface infrastructure and initial underground mine development, with coal production by first workings of up to 2.5 Mtpa.

The second model was constructed by Aquaterra (2009) as part of the EA undertaken for Stage 2 comprising the development of longwall mining operations on ML 1609 for the extraction of coal up to 8 Mtpa. The Stage 2 groundwater assessment further developed the Stage 1 groundwater model to include longwall progression. The Aquaterra model also defined 11 layers but its development was achieved with the use of MODFLOW-SURFACT version 3 software operating under the Groundwater Vistas Version 5 graphic user interface.

The third model was developed by HydroSimulations (2015). This model maintained the same layering as the earlier models but incorporated changes to the layer geometry and fracture zone simulation. A recalibration of its predecessor was conducted and, consequently, it assigned updated values to some of the model parameters. The recalibration was based on observation data extending to April 2015 and was achieved with the use of more recent software tools (MODFLOW-SURFACT version 4).

The fourth model was developed by HydroSimulations (2016). This model is the same as that developed by HydroSimulations (2015) but model performance was verified against observation data to June 2016.

## 3.2 SOFTWARE

The software packages used to run the model for the current project are:

- MODFLOW-SURFACT v4 (by HydroGeoLogic Inc.), which allows for both saturated and unsaturated flow conditions. The TMP (Time-Varying Material Properties) package in MODFLOW-SURFACT has been used to change the model properties through time, allowing mine scheduling to be run within a single model.
- Groundwater Vistas (Version 6) software package (ESI, 2011).

## 3.3 MODEL LAYERS AND GEOMETRY

The model domain is discretised into 798,930 cells comprising 269 rows, 270 columns and 11 layers. The dimensions of the model cells vary from 50 m at the NM to 500 m towards the model edges. The model extent is 75 km from west to east (Eastings 747000-822000) and 52.9 km from south to north (Northings 6591000-6643900), covering an area of approximately 3,970 square kilometres ($km^2$). The extent of the model domain and the regional topography are shown in **Figure 11**.

Representative model cross-sections are displayed in **Figure 12** for Easting 772650 (model column 80) and Northing 6622000 (model row 100) through the Project site in each direction.

Based on the conceptual hydrogeology described in **Section 2.7**, 11 layers are used in the model to represent the stratigraphic section:

- Layer 1: Alluvium and Regolith.
- Layer 2: Pilliga Sandstone.
- Layer 3: Purlawaugh Formation.
- Layer 4: Garrawilla Volcanics.
- Layer 5: Napperby Formation (above Sill).
- Layer 6: Basalt Sill.
- Layer 7: Napperby Formation (below Sill).
- Layer 8: Digby Formation.
- Layer 9: Hoskissons Coal Seam.
- Layer 10: Arkarula Formation.
- Layer 11: Pamboola Formation.

The model domain was designed to be large enough to prevent boundary effects on model outcomes associated with mining-related stress on the groundwater environment as a result of mining.

The model domain and boundaries have been selected to incorporate any potential receptors (i.e. surface water bodies and alluvial water sources) that could be adversely affected by mining.

## 3.4 HYDRAULIC PROPERTIES

The geological formations are split into multiple model layers in recognition of the vertical hydraulic gradient through the stratigraphic column and the different ages of geological formations.

Previous studies and investigations within the region provided the basis for initial model hydraulic property parameter values used for the coal seam and interburden. The testing of the aquifer hydraulic parameters was reported for earlier investigations by GHD (2007) and Aquaterra (2009), respectively. Hydraulic properties from that work are summarised in **Table 10**.

Aquaterra (2009) collected a range of hydraulic conductivity data for the interburden units from falling head slug tests and two constant rate pumping tests of the Jurassic age Garrawilla Volcanics and Triassic age Napperby Formation. Of interest are the results of the two pumping tests for the Garrawilla Volcanics / Napperby Formation. The first test (Bore P13) yielded hydraulic conductivities of 0.44 metres per day (m/d) (constant rate drawdown test), 0.016 m/d (constant rate recovery test) and 0.13 m/d (slug test). The second test (Claremont Property Bore) indicated an average hydraulic conductivity of about 2 m/d based on a measured transmissivity of 75 square metres per day ($m^2$/d) and an assumed aquifer thickness of 37 m. The latter pumping test result, which returned a comparatively higher hydraulic conductivity, is considered less representative for the unit and is attributed to localised fracturing.

In addition, drill stem tests were undertaken in earlier stages of the Project by Sigra in 2006. Eight locations were targeted. While the interburden units were the primary intervals tested, a number of drill stem tests overlapped with the Hoskissons Seam. The falling head test results are not directly comparable to the drill stem test results for the area due to the nature of the tests and differences in the locations and intervals targeted.

Geotechnical properties (Young's Modulus and Poisson's Ratio) for 41 core samples have been analysed to infer specific storage values ranging from 3.9E-07 $m^{-1}$ ($10^{th}$ percentile) to 2.4E-06 $m^{-1}$ ($90^{th}$ percentile), with a median of about 1E-06 $m^{-1}$.

**Table 11** summarises the calibrated model hydraulic conductivities for the current model, compared with median field values. In addition to host layer hydraulic conductivities, **Table 11** also lists values for the mining-induced fracture zone (**Section 3.6**). Hydraulic properties for the present model differ somewhat from those of the earlier models, reflecting the availability of a larger and more recent observation data set used for the most recent calibration.

The adopted model hydraulic conductivity and storage areal distributions are displayed in **ATTACHMENT J**.

Table 10 Summary of Hydraulic Properties from Field Testing (Aquaterra, 2009)

| Model Layer | Target Formation | New Bore ID | Former Bore ID | Screen Int. (mBGL) | Hydraulic Conductivity (m/d) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | GHD 2007 | RCA 2007 | Aquaterra, 2009 | |
| | | | | | | | Method | |
| 2 | Pilliga Sandstone | P6 | NG6 | 78 - 90 | - | - | Slug | 0.029 |
| 2 | | P7 | NG7 | 78 - 90 | - | - | Slug | 0.19 |
| 3 | Purlawaugh Formation | P9 | GWB5S | 24 - 30 | 0.41 | - | Slug | 0.032 |
| 3 | | P17 | NC119S | 47 - 56 | - | - | Slug | 0.0028 |
| 3 | | P8 | NC110S | 57 - 63 | - | - | Slug | 0.017 |
| 3 | | - | GWB4S | 57 - 63 | 0.0011 | - | - | - |
| 4 | Garrawilla Volcanics | P15 | NC100S | 24 - 30 | 0.047 | - | - | - |
| 4 | | P1 | NG1 | 44 - 50 | - | - | Slug | 0.11 |
| 4 | | P16 | NC119D | 137 - 146 | - | | Slug | 0.003 |
| 4 | ? Garrawilla Volcanics | - | Claremont Bore | ? | - | - | Constant Rate - Drawdown | T = 150 m²/d |
| | | | | | | | Constant Rate - Recovery | T = 75 m²/d |
| | | | | | | | Constant Rate - Drawdown | 0.44 |
| 4, 5 | Garrawilla Volcanics/ Napperby Formation | P13 | NC98S | 24 - 30 | 0.068 | - | Constant Rate - Recovery | 0.016 |
| | | | | | | | Slug | 0.13 |
| 5 | Napperby Formation above sill | P14 | NC100D | 72 - 78 | ? | ? | - | - |
| 5 | | P12 | NC98D | 84 - 90 | 0.0016 | - | Slug | 0.09 |
| 5, 7 | Napperby Formation | P4 | NG4 | 24 - 30 | - | - | Slug | 0.004 |
| 5, 7 | | P2 | NG2 | 44 - 50 | - | - | Slug | 0.057 |
| 5, 7 | Napperby Formation (no sill at bore site) | P11 | NC30S | 44 - 50/ 24 - 40 | 0.0007 | - | Slug | 0.0005 5 |
| 5, 7 | Napperby Formation (no sill) | P10 | NC30D | 118 - 130 | - | - | Slug | 0.049 |
| 9 | Hoskissons Coal Seam | P18 | NC122 | 143 -146 | 0.0086 | 0.0086 | Slug | 0.013 |
| 10 | Arkarula Formation | P20 | NC127 | 159 - 162 | 0.012 | 0.012 | Slug | 0.013 |
| 11 | Pamboola Formation | P5 | NG5 | 24 - 30 | - | - | Slug | 0.002 |
| 11 deep | | P3 | NG3 | 34 - 40 | - | - | Slug | 0.03 |
| 11 deep | | P19 | NC123R | 184 - 187 | 0.0021 | 0.0028 | Slug | 0.023 |

Note: ? as interpreted from Aquaterra (2009); no data currently available to HS.

**Table 11 Calibrated Model Hydraulic Conductivities (m/day) Compared with Field Measurements**

| Layer | Lithology | Zone | Host Kx | Host Kz | Narrabri Underground Fracture Zone Kz | GHD / RCA / Aquaterra Kx (Median) |
|---|---|---|---|---|---|---|
| 1 | Alluvium | 1 | 5.0E+00 | 5.0E-03 | NA | - |
| 2 | Pilliga Sandstone | 2 | 3.0E-01 | 5.0E-05 | NA | 1.1E-01 |
| 3 | Purlawaugh Formation | 3 | 5.0E-02 | 2.0E-05 | NA | 1.7E-02 |
| 4 | Garrawilla Volcanics | 4 | 2.4E-02 | 3.0E-05 | 5.3E-05 | 6.8E-02 |
| 5 | Napperby Formation (above Sill) | 5 | 4.0E-03 | 1.0E-06 | 6.9E-05 | 3.3E-02 |
| 6 | Basalt Sill | 6 | 1.2E-01 | 5.0E-05 | 8.6E-05 | - |
| 7 | Napperby Formation (below Sill) | 7 | 2.1E-02 | 2.4E-06 | 9.3E-05 | 4.0E-03 |
| 8 | Digby Formation | 8 | 4.0E-03 | 1.5E-06 | 1.1E-04 | - |
| 9 | Hoskissons Coal Seam | 9 | 5.0E-03 | 6.0E-06 | 10 | 8.6E-03 |
| 10 | Arkarula Formation | 10 | 1.0E-03 | 1.0E-05 | 3 x Kz host | 1.2E-02 |
| 11 | Pamboola Formation | 11 | 4.0E-02 | 1.0E-05 | NA | 1.3E-02 |

Note: For each fractured layer Kx = 10 x Kx host

For Layer 4, median value in final column is calculated using four values representing Layer 4 and one value representing Layers 4 and 5

For Layer 5, median value in final column is calculated using two values representing Layer 5, one value representing Layers 4 and 5 and four values representing Layers 5 and 7

For Layer 7, median value in final column is calculated using four values representing Layers 5 and 7

## 3.5 MODEL STRESSES AND BOUNDARY CONDITIONS

The model domain covers all of the potentially sensitive receptors. All creeks, rivers and GDEs that could be affected by mining activities are fully contained within the model domain and have been represented in the model, as shown in **Figure 13**.

### 3.5.1 WATERCOURSES

All major waterbodies are represented using the MODFLOW River (RIV) package, as shown in **Figure 13**. Of the water bodies within the model domain, the Namoi River, Coxs Creek and Maules Creek are considered to be the most important watercourses. The alluvia associated with the Namoi River, Coxs Creek and Maules Creek occupy a large portion of the eastern model domain (**Figure 14**). Bohena Creek occupies the western sector of the model domain. The river stage is not varied with time in the model. These watercourses are represented by river cells allocated distinct *reach* numbers (**Figure 13**) to permit separate accounting of baseflows during model simulations.

The northerly flowing Namoi River is divided into three reaches: upstream of Boggabri, upstream of Maules Creek between Baan Baa and Boggabri, and downstream of Maules Creek between Baan Baa and Narrabri (**Figure 13**). The RIV package for the Namoi River is defined in the model with the streambed 2 m below the stream stage to allow water to move in either direction from the groundwater system into the stream as baseflow (if the water table rises above the water elevation of the stream) or from the stream into the aquifer as river leakage (when the water table drops below the stream water level). The conductance varies from 2 to 2,300 $m^2$/day for stream lengths from 1 to 1,160 m within the model cell, for hydraulic conductivity of the stream bed of about 0.1 m/day.

Other creeks and minor drainage lines are also represented as RIV boundary cells in the model with stage equal to bed level. This allows groundwater to discharge to the drainage lines as baseflow, but does not allow these watercourses to leak to the underlying groundwater system. This has been done for the minor streams that cross the NM and the tributaries of Bohena Creek so that these cells will accept baseflow if the water table rises above the bed elevation of the stream, but they will never provide a source of water for the modelled groundwater system.

### 3.5.2 NARRABRI MINE

The underground mining and dewatering activity is defined in the model as MODFLOW Drain (DRN) cells with the head set to 1 m above the floor of the Hoskissons coal seam. DRN cells are active in a panel while a panel is being mined, and are deactivated as soon as mining of that panel is completed. This best simulates underground pumpout procedures when mining downdip. At that time, the physical properties of the goaf and the overlying fracture zone are updated. As mining progresses, the physical properties are gradually changed with time in the goaf and the overlying fracture zone. Horizontal and vertical permeabilities are raised to 10 m/day to simulate the highly disturbed nature of materials within the caved zone. The hydraulic properties are varied with time using the TMP package of SURFACT v4. DRN cells along the development headings remain active for the entire period of mining and do not require temporal changes in physical properties.

### 3.5.3 RECHARGE AND EVAPOTRANSPIRATION

An overview of the recharge zones used within the model is provided in **Figure 14**. Rainfall recharge has been specified as a percentage of historical rainfall at the NM Weather Station for transient calibration across four geologically-based zones:

- Zone 1: Alluvium 1.5%
- Zone 2: Jurassic strata 0.2%
- Zone 3: Triassic and Permian strata 0.1%

The adopted values for rainfall recharge expressed as percentages of long-term average rainfall are similar to those found by CDM Smith (2016) and in steady-state calibration by HydroSimulations (2015).

The ET package was used in the NM model with an extinction depth of 2.0 m and a maximum ET rate of 146 mm/a. This was done to ensure that the model simulates the relatively high ET that can occur in low-lying areas where the water table is close to the surface (along river/creek margins).

## 3.6 FRACTURE ZONE IMPLEMENTATION

### 3.6.1 BACKGROUND

The hydraulic properties of overburden material above a mined coal seam will change in time as a result of caving and subsidence above longwall panels. It is generally accepted that there will be a sequence of deformational zones consisting of the caved zone, the fracture zone (a lower zone of connective-cracking and an upper zone of disconnected-cracking), the constrained zone and the surface zone.

It is noted that the NM undertakes preconditioning of the strata, in particular the Digby Conglomerate, to assist this caving process for mine safety reasons.

High permeability is expected in the caved zone where there is direct connectivity with the mined goaf. In the lower part of the fracture zone, the collapsed rocks will have a substantially higher vertical permeability than the undisturbed host rocks. In the disconnected-cracking fractured zone, the vertical permeability should not be significantly greater than under natural conditions. Depending on the width of the longwall panels and the depth of mining, and the presence of low permeability lithologies, some increase in horizontal permeability can be expected in the constrained zone. Near-surface fracturing can occur due to horizontal tension at the edges of a subsidence trough in the surface zone.

### 3.6.2 MODEL SIMULATION

The fracture zone within the model is simulated with horizontal hydraulic conductivity enhanced by a factor of ten (10), and with vertical hydraulic conductivity enhanced according to a log-linear monotonic (ramp) function. The function varies the vertical hydraulic conductivity field within the deformation zone overlying coal extraction areas and weights the permeability changes on layer thickness. For the current model, the lower and upper limits used for the ramp function are 5.0E-05 and 1.0E-04 m/day, respectively.

Deformation of floor strata, directly beneath longwall panels, occurs due to unloading as the coal seam is removed. To simulate this, the host permeability values have been increased by a factor of three (3) in the model layer immediately beneath the mined seam within a longwall.

Storage properties (specific yield [Sy]) were also increased in the mined coal seam layer to 15%. For the layer above the coal seam Sy was increased to 5% in areas overlying the longwall panels. The hydrostratigraphic unit (HSU) zonation facility in the Groundwater Vistas 6 software has been used to delineate the fractured zones and to attribute these in time consistent with mine progression. Groundwater Vistas then writes the TMP package for use with MODFLOW-SURFACT v4 (HydroGeoLogic Inc.).

The height of fracturing in the model is based on the Ditton and Merrick (2014) subsurface fracture height prediction model for longwall mines in NSW Coalfields. This model includes the key fracture height driving parameters of panel width (W), cover depth (H), mining height (T) and local geology factors to estimate the A and B zone horizons above a given longwall panel. The A-Zone corresponds with the connective-cracking part of the fracture zone, while the B Zone corresponds with the disconnected-cracking part of the fracture zone which is equivalent to the lower dilated part of the constrained zone. Formulas are offered for two models:

- Geometry Model, which depends on W, H and T; and
- Geology Model, which depends on W, H, T and t' (where t' is the effective thickness[6] of the strata where the A-Zone height occurs).

The formulas for fracture zone height (A) for single-seam mining are:

- Geometry Model: $A = 2.215\ W'^{0.357}\ H^{0.271}\ T^{0.372} \pm (0.10 - 0.16)\ W'$; and
- Geology Model: $A = 1.52\ W'^{0.4}\ H^{0.535}\ T^{0.464}\ t'^{-0.4} \pm (0.10 - 0.15)\ W'$.

where W' is the minimum of the panel width (W) and the critical panel width (1.4H).

The 95th percentile (maximum) A-heights are estimated by adding *aW'* to *A*, where *a* varies from 0.1 for supercritical panels to 0.16 (geometry model) or 0.15 (geology model) for subcritical panels. The models have been validated to measured Australian case-studies (including West Wallsend, Mandalong, Springvale, Abel, Ashton, Austar, Berrima, Metropolitan and Wollemi/North Wambo Underground Mines) with a broad range of mining geometries and geological conditions included. The database also includes three cases in which connective fracturing reached land surface (South Bulga, Homestead and Invincible Collieries).

There is a large range in cover depth (H) from 143 m to 376 m and differences in panel widths (W) between the earliest and future longwalls. To facilitate computation of spatially varying fracture zone heights, all longwall panels have been classified into 40 segments with about 20 m difference in H. **Figure 15a** shows the assigned segment numbers corresponding to the depths of cover in **Figure 15b**.

The A-Zone heights according to the Ditton Geology Model are listed in **Table 12** for all segments with panel widths of 300 m to 407 m. Segments 1 to 6 have been completed with a mining height of 4.2 m for Segment 1 and 4.3 m for Segments 2 to 6; for all others the mining height is 4.3 m. Calculated fracture zone heights range from 106 m to 238 m.

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6 Typically 15-20 m in the Gunnedah Coalfield.

Table 12 Ditton Geology Model A-Zone Heights (m)

| Segment Number | Panel Width Min (m) | Panel Width Max (m) | Cover Depth Min (H [m]) | Cover Depth Max (H [m]) | Mining Height (T [m]) | A-Zone Height Min (A [m]) | A-Zone Height Max (A [m]) |
|---|---|---|---|---|---|---|---|
| 1 | 300 | 300 | 143 | 165 | 4.20 | 106 | 121 |
| 2 | 300 | 300 | 165 | 185 | 4.30 | 122 | 136 |
| 3 | 300 | 300 | 185 | 205 | 4.30 | 136 | 150 |
| 4 | 300 | 300 | 205 | 225 | 4.30 | 150 | 160 |
| 5 | 300 | 300 | 225 | 245 | 4.30 | 160 | 168 |
| 6 | 300 | 300 | 245 | 261 | 4.30 | 168 | 173 |
| 7 | 360 | 360 | 173 | 185 | 4.30 | 128 | 136 |
| 8 | 360 | 360 | 185 | 204 | 4.30 | 136 | 149 |
| 9 | 372 | 372 | 301 | 305 | 4.30 | 204 | 205 |
| 10 | 372 | 372 | 305 | 325 | 4.30 | 206 | 213 |
| 11 | 372 | 372 | 325 | 345 | 4.30 | 213 | 219 |
| 12 | 372 | 372 | 345 | 361 | 4.30 | 220 | 225 |
| 13 | 372 | 372 | 367 | 368 | 4.30 | 227 | 227 |
| 14 | 392 | 392 | 162 | 165 | 4.30 | 120 | 122 |
| 15 | 387 | 392 | 184 | 185 | 4.30 | 135 | 136 |
| 16 | 387 | 392 | 186 | 205 | 4.30 | 137 | 150 |
| 17 | 387 | 392 | 206 | 225 | 4.30 | 150 | 163 |
| 18 | 387 | 392 | 225 | 245 | 4.30 | 163 | 177 |
| 19 | 387 | 389 | 245 | 265 | 4.30 | 177 | 190 |
| 20 | 389 | 389 | 265 | 285 | 4.30 | 190 | 202 |
| 21 | 389 | 389 | 285 | 305 | 4.30 | 202 | 209 |
| 22 | 389 | 389 | 305 | 324 | 4.30 | 209 | 216 |
| 23 | 398 | 398 | 220 | 225 | 4.30 | 160 | 163 |
| 24 | 398 | 398 | 225 | 245 | 4.30 | 164 | 177 |
| 25 | 398 | 400 | 245 | 265 | 4.30 | 177 | 190 |
| 26 | 398 | 400 | 265 | 285 | 4.30 | 190 | 204 |
| 27 | 398 | 400 | 285 | 305 | 4.30 | 204 | 211 |
| 28 | 398 | 400 | 305 | 325 | 4.30 | 211 | 219 |
| 29 | 400 | 400 | 325 | 345 | 4.30 | 219 | 226 |
| 30 | 400 | 400 | 345 | 365 | 4.30 | 226 | 233 |
| 31 | 400 | 400 | 365 | 373 | 4.30 | 233 | 235 |
| 32 | 407 | 407 | 161 | 164 | 4.30 | 119 | 122 |
| 33 | 406 | 407 | 166 | 185 | 4.30 | 123 | 136 |
| 34 | 406 | 407 | 185 | 197 | 4.30 | 136 | 144 |
| 35 | 407 | 407 | 278 | 285 | 4.30 | 199 | 204 |
| 36 | 407 | 407 | 285 | 305 | 4.30 | 204 | 213 |
| 37 | 407 | 407 | 305 | 325 | 4.30 | 213 | 220 |
| 38 | 407 | 407 | 325 | 345 | 4.30 | 220 | 227 |
| 39 | 407 | 407 | 345 | 365 | 4.30 | 227 | 234 |
| 40 | 407 | 407 | 365 | 376 | 4.30 | 234 | 238 |

The risk of adverse groundwater effects would be higher where the fracture zone heights are closer to the 95th percentile A-Zone height. In this case they could reach ground surface or the base of the surficial cracking zone (expected to be about 10 m deep at most). **Table 13** lists 95th percentile A-Zone heights for all segments. Values range from 126 m to 288 m.

The depth from land surface to the top of the 95th percentile estimate of the top of the fracture zone ("vertical buffer") is also listed in **Table 13**. The vertical buffer ranges from 17 m to 111 m. This suggests that fracturing to land surface is unlikely, as fracturing from below does not link anywhere with cracking from above. The areas with higher susceptibility to potential fracturing to surface are segments 1, 2, 14, 32 and 33, all with 20 m or less distance from land surface to the estimated 95$^{th}$ percentile top of the fracture zone.

No segment is predicted to fracture to the surface. The highest fracturing is predicted to occur into layer 4, with a minimum buffer depth to the surface of 17 m, when considering the conservative 95$^{th}$ percentile fracture heights.

## 3.7 MODEL VARIANTS

No change has been made to the steady-state model reported by HydroSimulations (2016).

The calibration performance of both steady-state and transient models is summarised below:

- steady-state model of pre-mining conditions: Calibration against the inferred pre-mining groundwater levels; and
- transient model of the transition from pre-mining to early mining: Calibration against groundwater hydrographs.

The steady-state simulation was used to generate transient model starting heads.

Table 13 Ditton Geology Model 95th Percentile A-Zone Heights (m) and Vertical Buffer Depths (m)

| Segment Number | Panel Width Min (m) | Panel Width Max (m) | Mining Height (T [m]) | 95% A-Zone Height Min (A+ [m]) | 95% A-Zone Height Max (A+ [m]) | Vertical Buffer Min (m) | Vertical Buffer Max (m) |
|---|---|---|---|---|---|---|---|
| 1 | 300 | 300 | 4.20 | 126 | 144 | 17 | 21 |
| 2 | 300 | 300 | 4.30 | 145 | 162 | 20 | 23 |
| 3 | 300 | 300 | 4.30 | 162 | 178 | 23 | 27 |
| 4 | 300 | 300 | 4.30 | 178 | 192 | 27 | 33 |
| 5 | 300 | 300 | 4.30 | 177 | 202 | 48 | 43 |
| 6 | 300 | 300 | 4.30 | 187 | 209 | 58 | 52 |
| 7 | 360 | 360 | 4.30 | 152 | 162 | 21 | 23 |
| 8 | 360 | 360 | 4.30 | 162 | 178 | 23 | 26 |
| 9 | 372 | 372 | 4.30 | 227 | 248 | 74 | 57 |
| 10 | 372 | 372 | 4.30 | 229 | 257 | 76 | 68 |
| 11 | 372 | 372 | 4.30 | 238 | 265 | 87 | 79 |
| 12 | 372 | 372 | 4.30 | 247 | 272 | 98 | 89 |
| 13 | 372 | 372 | 4.30 | 256 | 275 | 111 | 93 |
| 14 | 392 | 392 | 4.30 | 143 | 145 | 19 | 20 |
| 15 | 387 | 392 | 4.30 | 161 | 162 | 23 | 23 |
| 16 | 387 | 392 | 4.30 | 163 | 178 | 23 | 27 |
| 17 | 387 | 392 | 4.30 | 179 | 195 | 27 | 30 |
| 18 | 387 | 392 | 4.30 | 195 | 211 | 30 | 34 |
| 19 | 387 | 389 | 4.30 | 211 | 227 | 34 | 38 |
| 20 | 389 | 389 | 4.30 | 228 | 242 | 38 | 43 |
| 21 | 389 | 389 | 4.30 | 222 | 252 | 63 | 53 |
| 22 | 389 | 389 | 4.30 | 232 | 261 | 73 | 63 |
| 23 | 398 | 398 | 4.30 | 191 | 195 | 29 | 30 |
| 24 | 398 | 398 | 4.30 | 195 | 211 | 30 | 34 |
| 25 | 398 | 400 | 4.30 | 211 | 227 | 34 | 38 |
| 26 | 398 | 400 | 4.30 | 227 | 244 | 38 | 41 |
| 27 | 398 | 400 | 4.30 | 224 | 254 | 61 | 51 |
| 28 | 398 | 400 | 4.30 | 234 | 264 | 71 | 61 |
| 29 | 400 | 400 | 4.30 | 244 | 273 | 81 | 72 |
| 30 | 400 | 400 | 4.30 | 253 | 282 | 92 | 83 |
| 31 | 400 | 400 | 4.30 | 262 | 285 | 104 | 88 |
| 32 | 407 | 407 | 4.30 | 142 | 145 | 19 | 20 |
| 33 | 406 | 407 | 4.30 | 146 | 162 | 20 | 23 |
| 34 | 406 | 407 | 4.30 | 162 | 171 | 23 | 25 |
| 35 | 407 | 407 | 4.30 | 238 | 244 | 40 | 41 |
| 36 | 407 | 407 | 4.30 | 244 | 256 | 41 | 49 |
| 37 | 407 | 407 | 4.30 | 236 | 266 | 69 | 59 |
| 38 | 407 | 407 | 4.30 | 245 | 275 | 80 | 70 |
| 39 | 407 | 407 | 4.30 | 254 | 284 | 91 | 81 |
| 40 | 407 | 407 | 4.30 | 263 | 288 | 102 | 88 |

## 3.8 MODEL CALIBRATION

### 3.8.1 STEADY-STATE CALIBRATION

The steady-state calibration model has been run to simulate the distribution of groundwater heads in early 2008, as these are likely to be close to long-term average groundwater levels.

Calibration was carried out against 59 target water levels, using a combination of auto-sensitivity analysis and manual modification of zones and model parameters. These targets were distributed throughout the model layers. A scattergram of simulated versus measured heads in **Figure 16** demonstrates good agreement across the whole range of measurements. The overall performance of the steady-state calibration is quantified by several statistics in **Table 14**. The key statistic, Scaled Root Mean Square (SRMS), is 6.7% which is below the target 10% SRMS suggested in the MDBC flow model guideline (MDBC, 2001). The mass balance error was less than 0.01%, which is acceptable under the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012).

**Table 14 Steady-State Calibration Performance**

| Calibration Statistics | Value |
|---|---|
| Number of Data (n) | 59 |
| Root Mean Square (RMS) (m) | 10.5 |
| Scaled Root Mean Square (SRMS) (%) | 6.7 |
| Average residual (m) | -0.4 |
| Absolute average residual (m) | 7.4 |

### 3.8.2 TRANSIENT CALIBRATION

The aim of the transient calibration was to achieve good agreement with reported mine inflows, and a history match to observed groundwater levels during the period January 2008 to April 2015 for 88 monthly stress periods, which included the effects of the NM LW101, LW102, LW103 and LW104 dewatering, as well as varying recharge conditions in response to actual rainfall. Verification of the model has been undertaken by extending the calibration dataset to June 2016.

**Table 15** summarises the stress period (SP) distribution over the model duration. In total, the combined calibration and verification model consists of 93 stress periods (January 2008 to May 2016), covering the mining periods through to the end of LW104 (completed August 2015).

The water level calibration is based on all NM monitoring bores (standpipe and vibrating wires) located inside the model domain (**Figure 9**).

**Table 15 Stress Period Definition and Sequencing of Mining Activities for the Calibration / Verification Model**

| Stress Period | Period Length (days) | Start | End | Mining |
|---|---|---|---|---|
| SP1 | 31 | 1/01/2008 | 31/01/2008 | |
| SP2 | 29 | 1/02/2008 | 29/02/2008 | |
| SP3 | 31 | 1/03/2008 | 31/03/2008 | |
| SP4 | 30 | 1/04/2008 | 30/04/2008 | |
| SP5 | 31 | 1/05/2008 | 31/05/2008 | |
| SP6 | 30 | 1/06/2008 | 30/06/2008 | |
| SP7 | 31 | 1/07/2008 | 31/07/2008 | |
| SP8 | 31 | 1/08/2008 | 31/08/2008 | |
| SP9 | 30 | 1/09/2008 | 30/09/2008 | |
| SP10 | 31 | 1/10/2008 | 31/10/2008 | |
| SP11 | 30 | 1/11/2008 | 30/11/2008 | |
| SP12 | 31 | 1/12/2008 | 31/12/2008 | |
| SP13 | 31 | 1/01/2009 | 31/01/2009 | |
| SP14 | 28 | 1/02/2009 | 28/02/2009 | Drift Tunnels |
| SP15 | 31 | 1/03/2009 | 31/03/2009 | |
| SP16 | 30 | 1/04/2009 | 30/04/2009 | |
| SP17 | 31 | 1/05/2009 | 31/05/2009 | |
| SP18 | 30 | 1/06/2009 | 30/06/2009 | |
| SP19 | 31 | 1/07/2009 | 31/07/2009 | |
| SP20 | 31 | 1/08/2009 | 31/08/2009 | |
| SP21 | 30 | 1/09/2009 | 30/09/2009 | |
| SP22 | 31 | 1/10/2009 | 31/10/2009 | |
| SP23 | 30 | 1/11/2009 | 30/11/2009 | |
| SP24 | 31 | 1/12/2009 | 31/12/2009 | |

| Stress Period | Period Length (days) | Start | End | Mining | |
|---|---|---|---|---|---|
| SP50 | 29 | 1/02/2012 | 29/02/2012 | LW103 Heading | Calibration |
| SP51 | 31 | 1/03/2012 | 31/03/2012 | | |
| SP52 | 30 | 1/04/2012 | 30/04/2012 | | |
| SP53 | 31 | 1/05/2012 | 31/05/2012 | | |
| SP54 | 30 | 1/06/2012 | 30/06/2012 | | |
| SP55 | 31 | 1/07/2012 | 31/07/2012 | LW101 start | |
| SP56 | 31 | 1/08/2012 | 31/08/2012 | | |
| SP57 | 30 | 1/09/2012 | 30/09/2012 | | |
| SP58 | 31 | 1/10/2012 | 31/10/2012 | | |
| SP59 | 30 | 1/11/2012 | 30/11/2012 | | |
| SP60 | 31 | 1/12/2012 | 31/12/2012 | | |
| SP61 | 31 | 1/01/2013 | 31/01/2013 | | |
| SP62 | 28 | 1/02/2013 | 28/02/2013 | | |
| SP63 | 31 | 1/03/2013 | 31/03/2013 | | |
| SP64 | 30 | 1/04/2013 | 30/04/2013 | | |
| SP65 | 31 | 1/05/2013 | 31/05/2013 | LW104 Heading | |
| SP66 | 30 | 1/06/2013 | 30/06/2013 | LW101 complete | |
| SP67 | 31 | 1/07/2013 | 31/07/2013 | LW102 Start | |
| SP68 | 31 | 1/08/2013 | 31/08/2013 | | |
| SP69 | 30 | 1/09/2013 | 30/09/2013 | | |
| SP70 | 31 | 1/10/2013 | 31/10/2013 | | |
| SP71 | 30 | 1/11/2013 | 30/11/2013 | | |
| SP72 | 31 | 1/12/2013 | 31/12/2013 | | |
| SP73 | 31 | 1/01/2014 | 31/01/2014 | LW102 complete | |

Table 15 Stress Period Definition and Sequencing of Mining Activities for the Calibration / Verification Model (continued)

| Stress Period | Period Length (days) | Start | End | Mining | |
|---|---|---|---|---|---|
| SP25 | 31 | 1/01/2010 | 31/01/2010 | | |
| SP26 | 28 | 1/02/2010 | 28/02/2010 | | |
| SP27 | 31 | 1/03/2010 | 31/03/2010 | | |
| SP28 | 30 | 1/04/2010 | 30/04/2010 | | |
| SP29 | 31 | 1/05/2010 | 31/05/2010 | | |
| SP30 | 30 | 1/06/2010 | 30/06/2010 | Main Heading | |
| SP31 | 31 | 1/07/2010 | 31/07/2010 | | |
| SP32 | 31 | 1/08/2010 | 31/08/2010 | | |
| SP33 | 30 | 1/09/2010 | 30/09/2010 | | |
| SP34 | 31 | 1/10/2010 | 31/10/2010 | | |
| SP35 | 30 | 1/11/2010 | 30/11/2010 | | |
| SP36 | 31 | 1/12/2010 | 31/12/2010 | LW101 Heading | |
| SP37 | 31 | 1/01/2011 | 31/01/2011 | | |
| SP38 | 28 | 1/02/2011 | 28/02/2011 | | |
| SP39 | 31 | 1/03/2011 | 31/03/2011 | | |
| SP40 | 30 | 1/04/2011 | 30/04/2011 | | |
| SP41 | 31 | 1/05/2011 | 31/05/2011 | | |
| SP42 | 30 | 1/06/2011 | 30/06/2011 | LW102 Heading | |
| SP43 | 31 | 1/07/2011 | 31/07/2011 | | |
| SP44 | 31 | 1/08/2011 | 31/08/2011 | | |
| SP45 | 30 | 1/09/2011 | 30/09/2011 | | |
| SP46 | 31 | 1/10/2011 | 31/10/2011 | | |
| SP47 | 30 | 1/11/2011 | 30/11/2011 | | |
| SP48 | 31 | 1/12/2011 | 31/12/2011 | | |
| SP49 | 31 | 1/01/2012 | 31/01/2012 | | |
| SP74 | 28 | 1/02/2014 | 28/02/2014 | | |
| SP75 | 31 | 1/03/2014 | 31/03/2014 | LW103 start | |
| SP76 | 30 | 1/04/2014 | 30/04/2014 | | |
| SP77 | 31 | 1/05/2014 | 31/05/2014 | LW105 Heading | |
| SP78 | 30 | 1/06/2014 | 30/06/2014 | | |
| SP79 | 31 | 1/07/2014 | 31/07/2014 | | |
| SP80 | 31 | 1/08/2014 | 31/08/2014 | | |
| SP81 | 30 | 1/09/2014 | 30/09/2014 | | |
| SP82 | 31 | 1/10/2014 | 31/10/2014 | LW103 complete | |
| SP83 | 30 | 1/11/2014 | 30/11/2014 | LW104 start | |
| SP84 | 31 | 1/12/2014 | 31/12/2014 | | |
| SP85 | 31 | 1/01/2015 | 31/01/2015 | | |
| SP86 | 28 | 1/02/2015 | 28/02/2015 | | |
| SP87 | 31 | 1/03/2015 | 31/03/2015 | | |
| SP88 | 30 | 1/04/2015 | 30/04/2015 | LW106 Heading | |
| SP89 | 31 | 1/05/2015 | 31/05/2015 | | |
| SP90 | 30 | 1/06/2015 | 30/06/2015 | | Verification |
| SP91 | 31 | 1/07/2015 | 31/07/2015 | | |
| SP92 | 31 | 1/08/2015 | 31/08/2015 | LW104 complete/ LW107 Heading | |
| SP93 | 274 | 1/09/2015 | 31/05/2016 | LW105 start | |
| Total | 3,074 days | | | | |

### 3.8.3 STATISTICAL MEASURES OF MODEL PERFORMANCE

The overall performance of a groundwater model can be quantified by various measures of agreement between observed water levels and corresponding model simulated values. **Table 16** summarises several statistics commonly used for this purpose. Values for both the calibration period only (January 2008 to April 2015) and the verification period (data to June 2016) are included. A scattergram of calibration results is presented in **Figure 17**.

**Table 16 Model Performance Statistics**

| Statistics | Calibration Period Only | Including Verification Data |
|---|---|---|
| Number of Data (n) | 2,191 | 2,622 |
| Root Mean Square (RMS) (m) | 18.3 | 19.6 |
| Scaled Root Mean Square (SRMS) (%) | 9.3 | 10.0 |
| Average residual (m) | -2.0 | -0.1 |
| Absolute average residual (m) | 12.0 | 12.6 |

The values calculated for calibration and verification do not differ significantly. The one change to the model for reduced specific storage has improved calibration performance from 11.0 to 9.3% RMS for the calibration period and from 11.3 to 10.0% RMS for the verification period. The average residual for the verification period has improved from 3.25 to -0.1 m.

The SRMS measure of 9.3% is around the level normally sought for mining models. The MDBC flow model guideline (MDBC, 2001) suggests targets of 5-10% RMS for models of all types. However, the 2012 Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012) warn against prescriptive performance targets but note that "*Targets such as SRMS < 5% or SRMS < 10% ... may provide useful guides*". There is always difficulty for mining models in matching absolute values and trends for VWP readings, as not all VWP sensors are reliable and a slight lag between actual and assumed mining progression can contribute to elevated RMS statistics. As the RMS definition involves data only at coincident times, a hydrograph could agree perfectly in pattern and amplitude, but a slight timing shift would cause a large RMS error to be reported. The common inability to match VWP readings is well illustrated by the green and yellow points in **Figure 17**.

Model performance statistics for the individual bore groups of **Table 8** are summarised in **Figure 17**, highlighting that the greatest model error comes from matching the VWP dataset. Discrepancies between modelled and observed data for the standpipe bores also occur at early times within the model simulation, and are likely due to the variable water level presumably caused by nearby extraction bores that are not included in the model (see **Section 2.4**). There are also short-term spikes in the standpipe dataset due to recharge events of short time scale which cannot be replicated in a long-period regional model.

When compared with the corresponding table in HydroSimulations (2016), all but one of the statistics (Group 1 SRMS) has improved by reducing the specific storage values in the model. As an example, the SRMS for Group 2 production bores has improved from 9.7 to 5.0%.

Table 17 Model Performance Statistics by Group

| Statistics | GROUP 1 Standpipes | GROUP 2 Production Bores | GROUP 3 Multi-Level VWPs | GROUP 4 Single VWPs |
|---|---|---|---|---|
| Number of Data (n) | 712 | 247 | 1,131 | 525 |
| Root Mean Square (RMS) (m) | 13.6 | 3.2 | 25.0 | 16.9 |
| Scaled Root Mean Square (SRMS) (%) | 13.8 | 5.0 | 9.0 | 10.6 |
| Average residual (m) | 0.94 | 0.36 | 2.16 | 4.72 |
| Absolute average residual (m) | 8.8 | 2.2 | 17.4 | 11.7 |

### 3.8.4 CALIBRATED MODEL PROPERTIES

The final calibrated hydraulic conductivities for the stratigraphic section and for the constrained and fracture zones are summarised in **Table 18**. The adopted property distributions are displayed in **ATTACHMENT J**.

Table 18 Calibrated Hydraulic Conductivities (m/day)

| Layer | Lithology | Zone | Host Kx | Host Kz | Narrabri Underground Fracture Zone Kz |
|---|---|---|---|---|---|
| 1 | Alluvium | 1 | 5.0E+00 | 5.0E-03 | N/A |
| 2 | Pilliga Sandstone | 2 | 3.0E-01 | 5.0E-05 | N/A |
| 3 | Purlawaugh Formation | 3 | 5.0E-02 | 2.0E-05 | N/A |
| 4 | Garrawilla Volcanics | 4 | 2.4E-02 | 3.0E-05 | 5.3E-05 |
| 5 | Napperby Formation (above Sill) | 5 | 4.0E-03 | 1.0E-06 | 6.9E-05 |
| 6 | Basalt Sill | 6 | 1.2E-01 | 5.0E-05 | 8.6E-05 |
| 7 | Napperby Formation (below Sill) | 7 | 2.1E-02 | 2.4E-06 | 9.3E-05 |
| 8 | Digby Formation | 8 | 4.0E-03 | 1.5E-06 | 1.1E-04 |
| 9 | Hoskissons Coal Seam | 9 | 5.0E-03 | 6.0E-06 | 10 |
| 10 | Arkarula Formation | 10 | 1.0E-03 | 1.0E-05 | 3 x Kz host |
| 11 | Pamboola Formation | 11 | 4.0E-02 | 1.0E-05 | N/A |

Note: For each fractured layer Kx = 10 x Kx host

### 3.8.5 TRANSIENT WATER BALANCE

The average water balance for the calibration period from January 2008 to the end of April 2015 across the entire model area is summarised in **Table 19**[7]. The water balance reports the average inflows, outflows and change in storage over the entire model domain. The values are not materially different from those reported in HydroSimulations (2016); mine inflow, for example, is about 3% lower.

The total inflow (recharge) to the groundwater system is approximately 54 megalitres per day (ML/d), comprising rainfall recharge (75%), and leakage from streams into the groundwater system (25%).

Groundwater discharge is dominated by stream baseflow (72%), and outflow from the general head boundary on the western margins (17%) and ET (9%), with lesser roles played by mine inflow (2%). The computed inflow to the NM LW101, LW102, LW103 and LW104 (1.1 ML/day) is insignificant in comparison with the total groundwater discharge over the model area and the aggregate rainfall recharge.

Over the calibration period (January 2008 to April 2015), discharge exceeded recharge by about 15 ML/day. This means that a net loss of about 15 ML/day from storage is expected to have occurred from January 2008 to April 2015, primarily due to drier weather conditions.

For comparison, the transient mass balance over the same period is also presented for a “Null” scenario (**Table 19**), which is a scenario that does not include any mining stresses but is otherwise identical to the calibration model. It can be observed that the storage declines significantly under natural conditions without any mining. **Figure 18** shows the relationship of storage changes with time for both the rainfall and RMC, showing strong correlation between storage changes and climatic trends. **Figure 18** also indicates that the majority of storage change happens in the alluvium and, to a lesser extent, the Pilliga Sandstone, due primarily to weather. This is supported by the alluvium monitoring hydrographs following the RMC in many cases. The difference between the mining and null model simulations is small, with the difference in storage being entirely due to mine depressurisation (**Figure 18c**), as would be expected.

**Table 19 Average Simulated Water Balance for the Calibration Period (1 Jan 2008 to 30 April 2015)**

| | Mining | | Null (no mining) | |
|---|---|---|---|---|
| **Component** | **Inflow (ML/d)** | **Outflow (ML/d)** | **Inflow (ML/d)** | **Outflow (ML/d)** |
| Drains (Mine inflow) | - | 1.14 | - | - |
| Recharge (Direct Rainfall) | 40.19 | 0.23 | 40.19 | 0.23 |
| Evapotranspiration (ET) | - | 6.29 | - | 6.29 |
| River (Leakage / Baseflow) | 13.42 | 49.33 | 13.42 | 49.35 |
| Regional GW flow (GHB) | 0.02 | 11.44 | 0.02 | 11.44 |
| Total | 53.63 | 68.43 | 53.63 | 67.31 |
| Storage | 14.80 loss | | 13.68 loss | |

[7] Minor differences in the reported numbers in **Table 19** are due to a slight difference in output times of the mass balance due to the use of the adaptive time-stepping package.

### 3.8.6 GROUNDWATER LEVELS

**Figure 19** and **Figure 20** show comparisons of simulated and observed hydrographs at representative sites within the four groups of monitoring bores. The entire suite of observed and simulated hydrographs covering the extended model period is presented in **ATTACHMENT J**.

Simulated heads agree well with the magnitude of measured heads across the whole range of measurements except for the VWPs in Groups 3 and 4 where some large differences occur. However, the drawdown patterns at VWP sites agree very well, illustrating the weakness of the RMS statistic as a measure of performance when there is a mismatch between actual and simulated timing of excavation, especially for development headings.

Additionally, some of the Group 1 and Group 2 bores (for example P1, P7, P10 and WB6b) show clear pumping effects in the observation records. As the model does not include private pumping due to lack of publicly available data and the resulting difficulty in estimating timing and pumping rates, this has caused some deterioration in the achievable RMS value.

### 3.8.7 SIMULATED MINE INFLOW

The simulated groundwater inflow rates to the NM for the calibration model are summarised in **Figure 21** for the respective model years. **Table 20** compares measured and simulated mine inflows pertaining to mining already completed (LW101 to LW104). Modelled inflows have been calculated as time-weighted averages for the exact stress periods that cover the respective reporting periods.

**Table 20 Measured and Simulated Mine Inflows**

| Mining Period | Longwall | Average Measured mine Dewatering* (ML/d) | Model Periods | Average Modelled mine Inflow (ML/d) |
|---|---|---|---|---|
| 1/4/2012 – 31/3/2013 | LW101 | 0.59 | SP52-63 | 0.43 |
| 1/4/2013 – 31/3/2014 | LW101, LW102 and start of LW103 | 0.81 | SP64-75 | 0.70 |
| 1/4/2014 – 31/3/2015 | LW103 and LW104 | 0.86 | SP76-87 | 0.76 |
| 1/4/2015 – 31/7/2015 | LW104 | 0.93 | SP73-91 | 0.98 |

Note: * Based on measured inputs, measured outputs and moisture calculations by NCOPL not currently available to HS

Modelled dewatering rates are lower than measured by about 12 to 27% for the first three years from 2012 to 2014. For 2015, the modelled inflow is about 5% higher than the actual dewatering rate, giving confidence in the reliability of model predictions of mine inflow.

The agreement with measured mine inflows is much improved over that reported in HydroSimulations (2016) due primarily to the shorter activation period of DRN cells as mining progresses down-dip.

## 3.9 SENSITIVITY ANALYSIS

Sensitivity analysis is the process of identifying the model parameters that have the most effect on model calibration or on model prediction. In this study, a sensitivity analysis has been conducted on fracture zone height using other approaches. These include:

- Ditton method [base case]
- Tammetta method
- Multiplier (0.6) on panel width [W]
- Multiplier (32) on mining height [T]

The reason for this investigation is that the Tammetta and Ditton algorithms for calculation of the height of "complete drainage" (Tammetta's terminology) or "connective fracturing" (Ditton's terminology) have been criticised by three peer reviewers engaged by the Department of Planning and Environment: Pells Sullivan Meynink (PSM) (March 2017); Mackie (February 2017); Galvin (February 2017); and Galvin (June 2017). Both methods predict the height of fracturing as a function of longwall panel width (W), cover depth (H) and mining height (T). The other commonly applied empirical methods depend on a single geometrical element (W or T).

The base case using the Ditton method has been discussed in previous **Section 3.6**. The corresponding Tammetta (2012) formula is shown below to calculate fracturing height C:

Geometry Model: $C = 1438 \ln[(4.315 \times 10^{-5})\, H^{0.2}\, T^{1.4}\, W + 0.9818] + 26$ (metres)

The two algorithms differ in their sensitivity to extraction height, but only the Ditton method conforms to laboratory evidence (Whittaker and Reddish, 1989) - a square root dependence on T, that is an exponent of about 0.5; Tammetta has 1.4 while Ditton has 0.464 for the geology model.

Apart from alternative methods for calculation of a fracture height, there are different ways in which fracture zones are represented in numerical models. These approaches are reviewed by Merrick (2017) in the following words:

"There are several approaches in use for representing the properties of the connective fracture zone: (1) an equivalent porous medium, using either multipliers on the host properties, or a monotonic ramp function; (2) a connected linear network (CLN), using a few macro-fractures per model cell; (3) stacked drains along the edges of the fracture space, with flow controlled by drain conductance (either calibrated to mine inflow or estimated from CLN theory)."

Accordingly, several sensitivity scenarios have been designed to assess the consequences of the various approaches:

- TR5 [base case] - Equivalent porous medium time-varying ramp function using the Ditton height.
- TR8 - Equivalent porous medium time-varying ramp function using the Tammetta height.
- TR10 - Stacked drains to the Ditton height (assuming zero pressure) with drain conductance of 1 $m^2$/day.
- TR12 - Stacked drains to the Ditton height (assuming zero pressure) with drain conductance of 10 $m^2$/day.
- TR13 - Stacked drains to the Tammetta height with drain conductance of 1 $m^2$/day.
- TR14 - Stacked drains to the Tammetta height with drain conductance of 10 $m^2$/day.

The 95th percentile fracturing heights of the Tammetta geometry model are much higher than for the Ditton geology model with the range from 379 to 571 m as shown in **Table 21** (after **Table 13**, which shows maximum and minimum values). This means that fracturing to land surface would occur everywhere. The theoretical heights would extend hundreds of metres above the land surface. This is a consequence of the high exponent on the mining height term (T). The *0.6 W* method gives average fracture heights in the range of 180 to 244 m for the variable panel widths, closer to Ditton than Tammetta values. The *32 T* method gives average fracture heights of 134 to 138 m, matching only the lowest of the Ditton values.

**Table 21 Ditton and Tammetta Algorithms 95th Percentile A-Zone Average Heights (m), Vertical Buffer Depths (m) and Fractured Layers**

| Segment Number | Panel Width Min (m) | Panel Width Max (m) | Mining Height (T [m]) | Ditton 95% | | | Tammetta 95% | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Average Height (A+ [m]) | Vertical Buffer (m) | Fractured up to Model Layers | Average Height (A+ [m]) | Vertical Buffer (m) | Fractured up to Model Layers |
| 1 | 300 | 300 | 4.20 | 135 | 19 | 5 | 379 | -225 | 1 |
| 2 | 300 | 300 | 4.30 | 154 | 21 | 5 | 398 | -223 | 1 |
| 3 | 300 | 300 | 4.30 | 170 | 25 | 5 | 405 | -210 | 1 |
| 4 | 300 | 300 | 4.30 | 185 | 30 | 4 | 411 | -196 | 1 |
| 5 | 300 | 300 | 4.30 | 189 | 46 | 4 | 417 | -182 | 1 |
| 6 | 300 | 300 | 4.30 | 198 | 55 | 4 | 422 | -169 | 1 |
| 7 | 360 | 360 | 4.30 | 157 | 22 | 5 | 462 | -283 | 1 |
| 8 | 360 | 360 | 4.30 | 170 | 25 | 5 | 468 | -274 | 1 |
| 9 | 372 | 372 | 4.30 | 237 | 65 | 4 | 516 | -213 | 1 |
| 10 | 372 | 372 | 4.30 | 243 | 72 | 4 | 519 | -204 | 1 |
| 11 | 372 | 372 | 4.30 | 252 | 83 | 4 | 524 | -189 | 1 |
| 12 | 372 | 372 | 4.30 | 260 | 94 | 4 | 528 | -175 | 1 |
| 13 | 372 | 372 | 4.30 | 265 | 102 | 4 | 532 | -164 | 1 |
| 14 | 392 | 392 | 4.30 | 144 | 19 | 6 | 487 | -324 | 1 |
| 15 | 387 | 392 | 4.30 | 161 | 23 | 6 | 494 | -310 | 1 |
| 16 | 387 | 392 | 4.30 | 171 | 25 | 4 | 498 | -303 | 1 |
| 17 | 387 | 392 | 4.30 | 187 | 28 | 4 | 506 | -291 | 1 |
| 18 | 387 | 392 | 4.30 | 203 | 32 | 4 | 513 | -278 | 1 |
| 19 | 387 | 389 | 4.30 | 219 | 36 | 4 | 518 | -263 | 1 |
| 20 | 389 | 389 | 4.30 | 235 | 40 | 4 | 525 | -250 | 1 |
| 21 | 389 | 389 | 4.30 | 237 | 58 | 4 | 531 | -236 | 1 |
| 22 | 389 | 389 | 4.30 | 246 | 68 | 4 | 536 | -222 | 1 |
| 23 | 398 | 398 | 4.30 | 193 | 30 | 4 | 518 | -295 | 1 |
| 24 | 398 | 398 | 4.30 | 203 | 32 | 4 | 522 | -287 | 1 |
| 25 | 398 | 400 | 4.30 | 219 | 36 | 4 | 530 | -275 | 1 |
| 26 | 398 | 400 | 4.30 | 236 | 39 | 4 | 536 | -261 | 1 |
| 27 | 398 | 400 | 4.30 | 239 | 56 | 4 | 542 | -247 | 1 |
| 28 | 398 | 400 | 4.30 | 249 | 66 | 4 | 548 | -233 | 1 |

**Table 21 Ditton and Tammetta Algorithms 95th Percentile A-Zone Average Heights (m), Vertical Buffer Depths (m) and Fractured Layers (continued)**

| Segment Number | Panel Width Min (m) | Panel Width Max (m) | Mining Height (T [m]) | Ditton 95% | | | Tammetta 95% | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Average Height (A+ [m]) | Vertical Buffer (m) | Fractured up to Model Layers | Average Height (A+ [m]) | Vertical Buffer (m) | Fractured up to Model Layers |
| 29 | 400 | 400 | 4.30 | 258 | 77 | 4 | 554 | -219 | 1 |
| 30 | 400 | 400 | 4.30 | 267 | 88 | 4 | 559 | -204 | 1 |
| 31 | 400 | 400 | 4.30 | 273 | 96 | 4 | 562 | -193 | 1 |
| 32 | 407 | 407 | 4.30 | 143 | 19 | 6 | 501 | -339 | 1 |
| 33 | 406 | 407 | 4.30 | 154 | 21 | 5 | 507 | -332 | 1 |
| 34 | 406 | 407 | 4.30 | 167 | 24 | 5 | 514 | -323 | 1 |
| 35 | 407 | 407 | 4.30 | 241 | 41 | 4 | 547 | -265 | 1 |
| 36 | 407 | 407 | 4.30 | 250 | 45 | 4 | 551 | -256 | 1 |
| 37 | 407 | 407 | 4.30 | 251 | 64 | 4 | 556 | -241 | 1 |
| 38 | 407 | 407 | 4.30 | 260 | 75 | 4 | 562 | -227 | 1 |
| 39 | 407 | 407 | 4.30 | 269 | 86 | 4 | 567 | -212 | 1 |
| 40 | 407 | 407 | 4.30 | 276 | 95 | 4 | 571 | -200 | 1 |

For the equivalent porous medium representation of the fracture zone, the calculated ramp function fracture zone hydraulic conductivities for both Ditton and Tammetta models are listed in **Table 22** for scenarios TR5 and TR8. In each case the performance statistics are identical with the same 9.3% RMS as shown in **Table 23**. This indicates that the normal practice of calibration to historical groundwater levels is insufficiently sensitive to discern which fracturing extent is more likely. In addition, **Figure 22** shows that both TR5 and TR8 scenarios give essentially the same mine inflow, both of which match measured inflow reasonably well.

For the stacked drains representation of the fracture zone, the conductance of the drains has to be calibrated to measured mine inflow (where available). **Figure 23** shows little difference between different stacked drain heights, or conductances of 1 or 10 $m^2$/day; however, convergence could not be achieved with conductance of 1,000 $m^2$/day. **Figure 23** indicates that the stacked drain approach underestimates mine inflow in early years and overestimates in the latest year of record. The best agreement was found with a conductance of about 10 $m^2$/day. A stacked drain model with conductance equal to 1 $m^2$/day would have over-predicted mine inflow by about 26% compared to what had been measured. This compares with overestimations of about 18% for stacked drains at 10 $m^2$/day and about 7% for the porous medium approach. The stacked drain approach caused only minor deterioration of groundwater level calibration statistics, as shown in **Table 23**.

**Table 22 Narrabri Underground Fracture Zone Hydraulic Conductivities (m/day)**

| Layer | Lithology | Host Kx | Host Kz | Ditton 95% Fracture Zone Kz | Tammetta 95% Fracture Zone Kz |
|---|---|---|---|---|---|
| 1 | Alluvium | 5.0E+00 | 5.0E-03 | N/A | 2.5E-04 |
| 2 | Pilliga Sandstone | 3.0E-01 | 5.0E-05 | N/A | 5.1E-05 |
| 3 | Purlawaugh Formation | 5.0E-02 | 2.0E-05 | N/A | 5.8E-05 |
| 4 | Garrawilla Volcanics | 2.4E-02 | 3.0E-05 | 5.3E-05 | 6.7E-05 |
| 5 | Napperby Formation (above Sill) | 4.0E-03 | 1.0E-06 | 6.9E-05 | 7.9E-05 |
| 6 | Basalt Sill | 1.2E-01 | 5.0E-05 | 8.6E-05 | 9.1E-05 |
| 7 | Napperby Formation (below Sill) | 2.1E-02 | 2.4E-06 | 9.3E-05 | 9.5E-05 |
| 8 | Digby Formation | 4.0E-03 | 1.5E-06 | 1.1E-04 | 1.0E-04 |
| 9 | Hoskissons Coal Seam | 5.0E-03 | 6.0E-06 | 10 | 10 |
| 10 | Arkarula Formation | 1.0E-03 | 1.0E-05 | 3 x Kz host | 3 x Kz host |
| 11 | Pamboola Formation | 4.0E-02 | 1.0E-05 | N/A | N/A |

Note: For each fractured layer Kx = 10 x Kx host

**Table 23 Sensitivity Analysis Models Performance Statistics**

| Statistics | TR5 | TR8 | TR10 | TR12 | TR13 | TR14 |
|---|---|---|---|---|---|---|
| Number of Data (n) | 2,191 | 2,191 | 2,191 | 2,191 | 2,191 | 2,191 |
| Root Mean Square (RMS) (m) | 18.3 | 18.3 | 19.0 | 19.0 | 19.0 | 19.0 |
| Scaled Root Mean Square (SRMS) (%) | 9.3 | 9.3 | 9.7 | 9.7 | 9.7 | 9.7 |
| Average residual (m) | -2.0 | -2.0 | -1.6 | -1.3 | -1.6 | -1.3 |
| Absolute average residual (m) | 12.0 | 12.1 | 12.6 | 12.5 | 12.5 | 12.5 |

# 4 PREDICTIVE MODELLING

Predictive modelling has been undertaken to the end of mining in September 2045. A Null model with no mining stresses was also run to allow for impact prediction specific to mining at NM. Predictive model simulations have been run to aid assessment of the future impacts of mining.

## 4.1 MINING LAYOUT AND SCHEDULE

The scheduling for the predictive model run is summarised in **Table 24** and is illustrated in **Figure 24** for the complete mining sequence from commencement in 2009. Mining is to progress from east to west. The scheduling during the calibration and verification periods was introduced in **Table 15**.

**Table 24** summarises the stress period setup from September 2015 (the last verification stress period) to September 2045. The shorter longwall panels are mined in one stress period while the longer panels are allocated two or three stress periods. Development headings are mined in advance of corresponding panels.

Table 24 Stress Period Definition and Sequencing of Mining Activities for the Prediction Model

| Stress Period | Period Length (days) | Start | End | Mining | |
|---|---|---|---|---|---|
| SP93 | 274 | 1/09/2015 | 31/05/2016 | LW105 start | Prediction |
| SP94 | 304 | 1/06/2016 | 31/03/2017 | LW106 start | |
| SP95 | 548 | 1/04/2017 | 30/09/2018 | LW107 start | |
| SP96 | 396 | 1/10/2018 | 31/10/2019 | LW108A start | |
| SP97 | 121 | 1/11/2019 | 29/02/2020 | LW108B start | |
| SP98 | 275 | 1/03/2020 | 30/11/2020 | LW109 start | |
| SP99 | 274 | 1/12/2020 | 31/08/2021 | | |
| SP100 | 487 | 1/09/2021 | 31/12/2022 | LW110 start | |
| SP101 | 456 | 1/01/2023 | 31/03/2024 | LW111 start | |
| SP102 | 183 | 1/04/2024 | 30/09/2024 | LW201 start | |
| SP103 | 488 | 1/10/2024 | 31/01/2026 | LW203 start | |
| SP104 | 515 | 1/02/2026 | 30/06/2027 | | |
| SP105 | 489 | 1/07/2027 | 31/10/2028 | LW204 start | |
| SP106 | 516 | 1/11/2028 | 31/03/2030 | | |
| SP107 | 487 | 1/04/2030 | 31/07/2031 | LW205 start | Prediction |
| SP108 | 488 | 1/08/2031 | 30/11/2032 | | |
| SP109 | 516 | 1/12/2032 | 30/04/2034 | LW206 start | |
| SP110 | 518 | 1/05/2034 | 30/09/2035 | | |
| SP111 | 489 | 1/10/2035 | 31/01/2037 | LW207 start | |
| SP112 | 515 | 1/02/2037 | 30/06/2038 | | |
| SP113 | 518 | 1/07/2038 | 30/11/2039 | LW208 start | |
| SP114 | 517 | 1/12/2039 | 30/04/2041 | | |
| SP115 | 518 | 1/05/2041 | 30/09/2042 | LW209 start | |
| SP116 | 517 | 1/10/2042 | 29/02/2044 | | |
| SP117 | 396 | 1/03/2044 | 31/03/2045 | LW210 start | |
| SP118 | 183 | 1/04/2045 | 30/09/2045 | LW202 start | |

## 4.2 PREDICTED GROUNDWATER LEVELS

### 4.2.1 WATER TABLE

Water table contours at the start of longwall panel mining (June 2012) and water table drawdown contours at the end of mining (September 2045) are shown in **Figure 25a** and **Figure 25b**, respectively. The water table is extracted from the model outputs as the highest groundwater level in any model cell, regardless of model layer.

The impact of mining is up to 200 m drawdown above the eastern longwalls where the cover depth is about 250 to 300 m (**Figure 15**). The 2 m drawdown contour extends about 6 km to the east and north-east to the edge of the Namoi alluvium.

For the Narrabri Gas Project, CDM Smith (2016) predicted a maximum water table drawdown of less than 0.5 m.

### 4.2.2 REGOLITH/ALLUVIUM – LAYER 1

**Figure 26a** shows regolith and alluvium (layer 1) groundwater levels at the start of longwall panel mining (June 2012), and **Figure 26b** shows the expected drawdown at the end of mining (September 2045).

As the regolith in the vicinity of the mining area was dry before mining, there cannot be any drawdown at the same locations at the end of mining. **Figure 26b** indicates slight drawdowns of less than 2 m in the alluvium associated with river reaches 20 (Bohena Creek), 12 (Maules Creek) and 22 (Tulla Mullen/Sandy/Little Sandy Creeks) between 2012 and 2045; this is at least partially due to dynamic rain recharge application in 2012 (and the subsequent calibration period) contrasting with steady rain recharge during prediction.

### 4.2.3 PILLIGA SANDSTONE – LAYER 2

**Figure 27a** shows layer 2 groundwater levels at the start of longwall panel mining (June 2012), and **Figure 27b** shows the expected drawdown at the end of mining (September 2045). The Pilliga Sandstone outcrops over most of the mine site and to the west towards Bohena Creek (**Figure 6**).

Similar to the prediction of the regolith and alluvium, **Figure 27b** shows that water levels are not impacted significantly by mining, with a maximum drawdown of 5 m over the western mine footprint and small patches of off-site drawdown exceeding 1 m. At the three springs (Mayfield, Hardys and Eather) sourced in the Pilliga Sandstone, the predicted drawdown is much less than 1 m.

For the Narrabri Gas Project, CDM Smith (2016) predicted a maximum Great Artesian Basin drawdown of less than 0.5 m.

### 4.2.4 NAPPERBY FORMATION – LAYER 5

**Figure 28a** shows layer 5 groundwater levels at the start of longwall panel mining (June 2012) and predicted levels at the end of mining (September 2045). The Napperby Formation outcrops between the mine site and the Namoi River (**Figure 6**). **Figure 28b** suggests that the Napperby Formation would experience significant decline (drawdowns of up to 130 m above the southern longwalls and 140 m above the northern longwalls), with drawdowns of greater than 10 m extending well beyond the mine site in all directions[8]. The flow pattern is particularly affected west of the mine site.

### 4.2.5 HOSKISSONS COAL SEAM – LAYER 9

**Figure 29a** and **Figure 29b** show layer 9 groundwater levels at the start of longwall panel mining (June 2012) and predicted levels at the end of mining (September 2045), respectively.

For the Hoskissons Coal Seam there is a significant predicted decline in levels over the mining period (**Figure 29b**). As is to be expected, the area of greatest impact closely coincides with the mined area (about 260 m drawdown above the southern longwalls and 250 m drawdown above the northern longwalls). Greater than 30 m drawdown is predicted away from the mine in all directions, more significantly to the west. The apparent anomaly at June 2012, east of the mine site, relates to drift and development headings at that time.

### 4.2.6 COMPARISON TO PREVIOUS REPORTING

The depth and extent of drawdown predicted in all layers is generally greater than predicted by Aquaterra (2009) who simulated fracturing due to mining to Layer 5 (Napperby Formation), while the updated Ditton formula used in the current model predicts the maximum A-Zone fracturing to extend to the Garrawilla Volcanics (Layer 4) (**Section 3.6**). There have also been changes made to the model geometry and hydraulic conductivity during re-calibration which would also be a source of the differences.

The minimal harm considerations of the AI Policy were addressed in the MOD 5 Groundwater Assessment (HydroSimulations, 2015). The findings at that time remain consistent with the results of current modelling:

- No alluvial bores have a drawdown in excess of 2 m (the threshold for the AI Policy minimal harm consideration).
- No Great Artesian Basin bores have a drawdown in excess of 2 m.
- One bore (GW067626) in the Purlawaugh Formation is expected to have a drawdown in excess of 2 m.
- One bore (GW966836) in the Garrawilla Volcanics is expected to have a drawdown in excess of 2 m.

[8] Note that the western model boundary extends far beyond the limit of the displayed map.

## 4.3 PREDICTED BASEFLOW CAPTURE

**Table 25** summarises the predicted baseflows to the river system to the end of mining. The seven reaches represented in the groundwater model are referenced in the table by RIV11 (downstream Namoi River), RIV12 (Maules Creek), RIV13 (mid Namoi River), RIV14 (upstream Namoi River), RIV15 (Coxs Creek), RIV20 (Bohena Creek) and RIV22 (Tulla Mullen/Sandy/Little Sandy Creeks). (River reaches are defined in **Figure 13**).

**Figure 30** to **Figure 36** show predicted changes in baseflow (relative to the corresponding null scenario) from 2008 to the end of mining; this includes the Project and all NM longwalls. For river reaches other than the Namoi River and the Tulla Mullen/Sandy/Little Sandy Creeks nearest the mining, there is no effective difference in predicted baseflow between the mining and null scenarios. The values are not materially different from those reported in HydroSimulations (2016).

The maximum modelled impact by the end of mining is less than 0.3 ML/day at River Reach 11 (**Figure 30**), in the Namoi River downstream of Maules Creek between Baan Baa and Narrabri. This value is slightly higher than the maximum baseflow reduction of 0.22 ML/day predicted by Aquaterra (2009), which is attributable to the increased drawdown predicted by the current model. The maximum modelled impact at the Tulla Mullen/Sandy/Little Sandy Creeks is less than 0.2 ML/day (**Figure 36**).

**Table 25 Predicted Baseflows to the End of Mining (ML/day)**

| [ML/day] | RIV11 | RIV12 | RIV13 | RIV14 | RIV15 | RIV20 | RIV22 |
|---|---|---|---|---|---|---|---|
| MAX | 11.5 | 1.0 | 9.4 | 5.7 | 1.6 | 4.4 | 1.7 |
| MEDIAN | 7.8 | -0.34 | 7.9 | 4.6 | 0.8 | 3.0 | 1.3 |
| MIN | 6.7 | -0.84 | 7.4 | 4.2 | 0.4 | 2.6 | 1.1 |

Note: +ve numbers represent baseflow; -ve numbers represent river leakage

River Reach 12 (Maules Creek, **Figure 31**) is the only instance in which the predicted baseflow becomes negative (i.e. the minimum value in the table is negative), indicating variability with time between being a gaining and losing stream. All other reaches are predicted to be gaining over the respective mining periods. This is consistent with modelling by Aquaterra (2009); however, analysis undertaken by Ivkovic (2006) suggests that the Namoi River reaches in the vicinity of NM are predominantly losing systems. As the Namoi River alluvium is heavily pumped for irrigation purposes, which is not represented in the model, inclusion of this pumping would likely alter the flow characteristics of the Namoi River.

## 4.4 PREDICTED MINE INFLOW

**Figure 37** shows simulated annual mine inflow rates using a weighted-average method for each water year from 2011. Rates of mine inflow increase progressively, to peak values of about 5.1 ML/day in water year 2037 (about 1,847 ML for the year). This is more than the maximum inflow of about 3.8 ML/day (1,395 ML/a) predicted by Aquaterra (2009).

As noted in **Section 3.8.3**, based on actual mine dewatering to date, the model is likely to be overestimating mine inflows (by about 5-10%).

# 5 UNCERTAINTY ANALYSIS

Two prediction models are compared for the uncertainty analysis with respect to mine inflow:

1. The base case model with Ditton fracturing height and ramp function properties; and
2. The ramp model for the Tammetta fracturing height.

**Figure 38** shows that the two prediction models give almost identical mine inflows. For the base case model based on Ditton A95 fracturing height, inflow to the Hoskissons Coal Seam NM workings is expected to peak at about 5.1 ML/day (about 1,847 ML) during 2037. For the uncertainty analysis model based on the Tammetta C95 fracturing height, the predicted peak inflow occurs in the same year with the same value as the base case model, but differentiates slightly after one year, and is about 0.6 ML/day (about 221 ML) higher during 2039.

Difference values are defined as Ditton mine inflows minus Tammetta mine inflows. The range is from -0.6 ML/day to 0.01 ML/day as shown in **Figure 38**. The Tammetta inflows are generally higher than the Ditton inflows, but only marginally.

**Figure 39a** and **Figure 39b** show the groundwater level differences at the end of Mining (September 2045) between Ditton and Tammetta models in layer 5 (Napperby Formation) and layer 9 (Hoskissons Coal Seam), respectively. In the Napperby Formation, the Ditton scenario groundwater levels are about 5 m lower than the Tammetta scenario levels above the north-western longwalls and about 5 m higher in the south-eastern area. In the Hoskissons Coal Seam the levels are very similar. The Ditton scenario groundwater levels are about 0.6 m lower than the Tammetta scenario levels above the north-western area of the mine plan with the differences in other areas less than 0.5 m.

# 6 POTENTIAL IMPACTS

## 6.1 POTENTIAL IMPACTS ON GROUNDWATER

The main effect of underground mining upon the groundwater regime comes from changes in bulk rock mass permeability caused by the fracturing associated with longwall subsidence, and the pumping out of groundwater that enters the mine as a consequence. This caving, and associated extraction of groundwater, potentially impact on several components of the hydrogeological system, both during and following mining operations, for example:

- groundwater levels both within the exposed and deeper hard rock strata in the mine vicinity and the alluvium of the Namoi River and its tributaries;
- inflow of water to the underground mine and the management of that mine water; and
- baseflow to the Namoi River and its tributaries.

## 6.2 POTENTIAL IMPACTS ON GROUNDWATER LEVELS

### 6.2.1 PERIOD OF MINING

Predicted impacts on groundwater levels over the period of mining have already been discussed in **Section 4.2**, in which changes in groundwater levels were addressed individually for layers 1 (regolith/alluvium), 2 (Pilliga Sandstone), 5 (Napperby Formation) and 9 (Hoskissons Coal Seam) for the entire NM from commencement of underground mining. The significant outcomes of that discussion are summarised below.

- The water table will occur at progressively deeper layers moving from the Namoi River to the mine; the area of significant effect will be confined to hard rock outcrops.
- For layer 1 regolith/alluvium, layer 1 is dry pre-mining near the NM but minor far-field drawdown (<2 m) is simulated (due to differing climate).
- For layer 2 in the Pilliga Sandstone drawdowns of 1 to 2 m are expected along the western edge of the mine layout, extending about 4 km north and about 10 km south.
- For layers 5 and 9, groundwater levels will exhibit a significant decline over a wide area beyond the mine site.

### 6.2.2 RECOVERY

Longer-term impacts are addressed here by reference to the 200-year scenario model outputs.

Predicted groundwater levels at the end of 200 years (September 2245) are shown in **Figure 40** for layer 1 (regolith/alluvium) and layer 2 (Pilliga Sandstone). For layer 1, the 200-year water levels are very similar to those depicted in **Figure 26a**, which shows water levels at the start of the mining period. For layer 2, the 200-year water levels are very similar to those depicted in **Figure 27a**, which shows water levels at the start of the mining period. For both layers, minor differences are apparent in the vicinity of the mine but the high degree of similarity between the two sets of water levels implies that long-term water levels would recover, to a large extent, to pre-mining levels.

Predicted groundwater levels at the end of 200 years are shown in **Figure 41a** for layer 5 (Napperby Formation). For this layer, the 200-year water levels are very similar to those depicted in **Figure 28a**, which shows water levels at the start of the mining period. Small differences are apparent well beyond the mine area but the high degree of similarity between the two sets of water levels implies that long-term water levels are likely to recover, to a large extent, to pre-mining levels.

Predicted groundwater levels at the end of 200 years are shown in **Figure 41b** for layer 9 (Hoskissons Coal Seam). The 200-year water levels are, overall, similar to those depicted in **Figure 29a**, which shows water levels at the start of the mining period. Minor differences are apparent well beyond the mine area and large differences are apparent in the vicinity of the mine. These differences relate to the initial drift tunnel and development headings (**Figure 29a**). The high degree of similarity suggests that long-term water levels will recover, to a large extent, to pre-mining levels.

The likelihood of long-term recovery of water levels is emphasised by the prediction/recovery hydrographs shown in **Figure 42** to **Figure 45**, for four representative monitoring sites distributed about the mine site vicinity. Site P6 is a single standpipe in the Pilliga Sandstone located 1 km from the mine site, whereas P17 is a single standpipe in the Purlawaugh Formation over the westernmost longwall panel. Site P24 is a VWP site at the eastern updip edge of the mine site, while P40 is located over the mains at the western downdip end (where early recovery is promoted).

**Figure 42** shows a drawdown of about 24 m in the Pilliga Sandstone at site P6, reaching a maximum about 25 years after completion of mining. The water level would recover to a final level about 4 m lower than the natural pre-mining level (228 mAHD minimum; previously 238), taking about 60 years to achieve 50% recovery.

At site P17 in the Purlawaugh Formation, a drawdown of about 32 m is expected (**Figure 43**). As this site is over a downdip panel and the maximum drawdown occurs 15 years post-mining, the early recovery promoted at the downdip panels had not reached the Purlawaugh Formation at that time. The water level recovers to a final level that is about 5 m lower than the natural pre-mining level due to the permanently enhanced vertical hydraulic conductivity in the fractured zone above the mine area (224 mAHD minimum; previously 235). The water level would achieve 50% recovery in about 60 years.

**Figure 44** represents recovery hydrographs at site P24, for sampling depths 112 m, 148 m, 166 m and 180 m. The maximum drawdown ranges from 90 to 120 m for the four monitoring depths. Drawdown is very sudden, and recovery is initially slow, reaching 50% after about 60 years. The final water levels are expected to be 6 to 8 m higher than pre-mining levels (120 to 145 mAHD minima; previously 120 to 150 mAHD).

**Figure 45** represents recovery hydrographs at site P40 at the western boundary of the mine site over the mains. The maximum drawdown ranges from 30 to 265 m for the six monitoring depths. Drawdown occurs later than at P24, as expected, and drawdown is similarly sudden. Recovery is more rapid in deeper formations, taking about 25 years to 50% recovery, but is slow in upper layers, taking up to 65 years for 50% recovery. The final water levels are expected to be very similar to pre-mining levels, but the shallowest levels could be about 10 m lower (25 to 220 mAHD minima; previously 25 to 240 mAHD).

## 6.3 POTENTIAL IMPACTS ON GROUNDWATER FLOW DIRECTION

For layer 1 (regolith/alluvium), groundwater levels at the start of mining and predicted levels 200 years after the end of mining are represented in **Figure 26a** and **Figure 40a**, respectively.

For layer 2 (Pilliga Sandstone), groundwater levels at the start of mining and predicted levels 200 years after the end of mining are represented in **Figure 27a** and **Figure 40b**, respectively.

For both layers, the two relevant pairs of diagrams show contour patterns that are very similar, with exceptions limited to the immediate vicinity of the mine area. Groundwater lateral flow directions (inferred as being perpendicular to the contours) can, therefore, be assumed to be unaffected in the long term except for the limited area around the mine site. Within this area, the change of direction is spatially variable.

For layer 5 (Napperby Formation), groundwater levels at the start of mining and predicted levels 200 years after the end of mining are represented in **Figure 28a** and **Figure 41a**, respectively. The diagrams show contour patterns with few discernible differences, suggesting that lateral flow directions in this layer would be unaffected by mining in the long term.

For layer 9 (Hoskissons Coal Seam), groundwater levels at the start of mining and predicted levels 200 years after the end of mining are represented in **Figure 29a** and **Figure 41b**, respectively.

Beyond the mine site, the diagrams exhibit very similar contour patterns and imply that lateral flow directions at this depth and at distance would be largely unaffected by mining. Closer to the mine there are discernible differences, near the eastern and southern boundaries of the mine site, from which it can be concluded that spatially variable disruption to lateral flow directions would occur. However, the water level contours in **Figure 29a** depict conditions in this area that were subject to early mining activity (drift and headings) and which, therefore, are not indicative of pre-mining conditions. It is likely that there would be little effective long-term disruption to lateral flow directions for this layer.

The 200-year recovery hydrographs for sites P6, P7, P24 and P40 (**Section 6.2.2**, **Figure 42** to **Figure 45**) provide some insight into likely long-term changes in vertical flow direction. For example, at the shallower depths at site P40 (95 m and 135 m), a long-term decline in water level is predicted. At greater depths, the strong downward flow during mining would be replaced by mild downflow or possibly upflow during the recovery period. Strong downward flow would continue from the shallower levels for many decades until a new equilibrium is reached.

## 6.4 POTENTIAL IMPACTS ON GROUNDWATER QUALITY

Given that groundwater flow direction is little affected for all layers, except for the area limited to the vicinity of the mine, there is likely to be negligible impact on water quality for nearby water users, ecosystems or on the salinity of water in the Namoi River.

## 6.5 PREDICTED GROUNDWATER INFLOW

The predicted groundwater inflows to the NM are shown in **Figure 37**. Inflow to the Hoskissons Coal Seam NM workings is expected to peak at about 5.1 ML/day (about 1,847 ML) during 2037.

As noted in **Section 3.8.7,** based on actual mine dewatering to date, the modelled estimate of mine inflow is probably accurate to about 5-10%.

## 6.6 GROUNDWATER LICENSING

Quantification of water take is required for four relevant water sources (**Section 1.3**):

1. Gunnedah - Oxley Basin MDB Groundwater Source.
2. Southern Recharge Groundwater Source.
3. Upper Namoi Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source.
4. Lower Namoi Regulated River Water Source.

The Gunnedah – Oxley Basin MDB Groundwater Source is quantified by the simulated mine inflow less the takes from the other three water sources. For the Southern Recharge Groundwater Source, the net vertical flow at the base of the Jurassic Pilliga Sandstone has been examined for the mining and null mining simulations. Similarly, the net downward flow from alluvium to rock has been examined for the extent of Upper Namoi Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source. For the Lower Namoi Regulated River Water Source, the river features in the models have been interrogated for any reduced baseflow or increased leakage.

From 2010 to 2012 (stress period 31 to stress period 53), prior to the commencement of LW101, the loss of alluvial groundwater to the underlying rock is estimated to have been about 42 kilolitres per day (kL/day) for both scenarios. The difference between the two scenarios is negligible, being in the order of 0.01 kL/day at most.

The temporal variations for the groundwater takes are summarised in **Table 26**, showing minimum, median and maximum rates for natural and mining conditions.

The take from the Gunnedah - Oxley Basin MDB Groundwater Source was investigated in **Section 4.4** and **Figure 37**. The peak rate of mine inflow is predicted to be about 5.1 ML/day in year 2037 or 1,847 ML for the year.

**Figure 46** shows the predicted impact on Great Artesian Basin aquifers in the Southern Recharge Groundwater Source to the end of mining. The key feature is a maximum additional loss of 0.85 ML/d (**Table 26**) from the Pilliga Sandstone to underlying rock, consisting of increased downflow, about 0.52 ML/d) and reduced upflow (about 0.36 ML/d).

**Figure 46** also shows the predicted impact on the Upper Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source to the end of mining. The key feature is a maximum 0.38 ML/d additional loss from alluvium to underlying rock, consisting of increased downflow (about 0.25 ML/d) and reduced upflow (about 0.13 ML/d).

The take from the Lower Namoi Regulated River Water Source was investigated in **Section 4.3** and **Figure 30** to **Figure 36**. Each figure shows predicted changes in baseflow (relative to corresponding null scenarios) from 2008 to the end of mining. The maximum impact on the Namoi River by the end of mining is 0.50 ML/d.

The predicted annual groundwater volumes required to be licensed over the life of the mine are summarised in **Table 27**.

**Table 26 Predicted Water Source Groundwater Takes to the End of Mining (ML/day)**

<table>
<tr><th>Water Source</th><th>ML/day</th><th>Natural</th><th>Mining</th></tr>
<tr><td rowspan="3">Southern Recharge Groundwater Source</td><td>MIN</td><td>-0.32</td><td>-0.32</td></tr>
<tr><td>MEDIAN</td><td>0.10</td><td>0.37</td></tr>
<tr><td>MAX</td><td>0.85</td><td>0.98</td></tr>
<tr><td rowspan="3">Upper Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source</td><td>MIN</td><td>-0.15</td><td>-0.14</td></tr>
<tr><td>MEDIAN</td><td>-0.09</td><td>0.16</td></tr>
<tr><td>MAX</td><td>-0.03</td><td>0.29</td></tr>
<tr><td rowspan="3">Gunnedah – Oxley Basin MDB Groundwater Source</td><td>MIN</td><td>0.00</td><td>-0.42</td></tr>
<tr><td>MEDIAN</td><td>0.00</td><td>-2.98</td></tr>
<tr><td>MAX</td><td>0.00</td><td>-5.18</td></tr>
</table>

Note: +ve numbers represent losses; -ve numbers represent gains to a water source

**Table 27 Groundwater Licensing Summary for Narrabri Mine**

<table>
<tr><th rowspan="2">Water Sharing Plan</th><th rowspan="2">Management Zone/ Groundwater Source</th><th colspan="2">Predicted Annual Groundwater Takes Requiring Licensing (ML/a)</th><th rowspan="2">Licence Shares/Units Currently Held by NCOPL at NM</th></tr>
<tr><th>Median</th><th>Maximum</th></tr>
<tr><td>NSW MDB Porous Rock Groundwater Sources 2011</td><td>Gunnedah - Oxley Basin MDB Groundwater Source</td><td>834</td><td>1,247</td><td>818*</td></tr>
<tr><td>NSW Great Artesian Basin Groundwater Sources 2008</td><td>Southern Recharge Groundwater Source</td><td>86</td><td>321</td><td>248</td></tr>
<tr><td>Upper and Lower Namoi Groundwater Sources 2003</td><td>Upper Namoi Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source</td><td>92</td><td>139</td><td>217</td></tr>
<tr><td>Upper Namoi and Lower Namoi Regulated River Water Sources 2016</td><td>Lower Namoi Regulated River Water Source</td><td>77</td><td>185</td><td>678</td></tr>
</table>

* Following a successful bid under the Controlled Allocation Order 403 ML/year of additional share component is to be issued by DI Water

NCOPL should monitor underground mine inflows versus model predictions and obtain additional licensed volumes from the relevant water sources to account for actual inflows, as necessary. The trading markets for each of the water sources have been established for several years and NCOPL should be able to purchase the additional licensed volumes as required, particularly as the volumes are comparatively low relative to the total number of available/tradeable shares in each water source. Considerations should, however, be made by NCOPL based on available water determinations as necessary.

## 6.7 POTENTIAL IMPACTS ON REGISTERED PRODUCTION BORES

**Figure 47** shows the locations of registered production bores in the vicinity of NM, in relation to the predicted drawdown in the alluvium and regolith (model layer 1) between the start and end of longwall mining. No alluvial bores have a drawdown in excess of 2 m (the threshold for the AI Policy minimal harm consideration).

**Figure 48** shows the locations of registered bores interpreted as drawing groundwater from the Pilliga Sandstone, a Great Artesian Basin aquifer. There are no privately-owned bores with predicted drawdown greater than 2 m.

**Figure 49** shows the locations of registered production bores in relation to the predicted drawdown (m) in the Purlawaugh Formation. One privately-owned bore (GW067626) in the Purlawaugh Formation is expected to have a drawdown in excess of 2 m. The details of the bore are listed in **Table 28**.

There are no registered privately-owned bores in the Garrawilla Volcanics that are predicted to have drawdown greater than 2 m. One NCOPL owned bore (GW966836) in the Garrawilla Volcanics is expected to have a drawdown in excess of 2 m. The details of the bore are also listed in **Table 28**.

**Table 28 Predicted Drawdown Effects at Registered Bores**

| Work No. (bore) | Licence | Owner Type | Bore Depth (m) | Aquifer | Predicted drawdown [m] | Comment |
|---|---|---|---|---|---|---|
| GW067626 | 90BL139277 | Private | 88 | Purlawaugh | 15 | Layer 3 |
| GW966836 | 90BL246067 | NCOPL | 30 | Garrawilla Volcanics | >15 | Layer 4 |

## 6.8 ASSESSMENT AGAINST THE MINIMAL IMPACT CONSIDERATIONS

The NSW *Aquifer Interference Policy* (NSW Government, 2012) establishes minimal impact considerations for highly productive and less-productive groundwater. Only the Namoi Alluvium (Upper Namoi Zone 5 Namoi Valley [Gins Leap to Narrabri] Groundwater Source) and Southern Recharge Groundwater Source highly productive groundwater sources are relevant to a Gateway assessment.

**Tables 29** and **30** provide an assessment of the Project against the minimal impact considerations in the AI Policy.

Table 29 Highly Productive Alluvial Aquifer – Minimal Impact Considerations

| | |
|---|---|
| **Aquifer** | **Upper and Lower Namoi Groundwater Sources – Upper Namoi Zone 5 Namoi Valley (Gins Leap to Narrabri) Groundwater Source** |
| **Type** | **Alluvial Aquifer** |
| **Category** | **Highly Productive** |

| Level 1 Minimal Impact Consideration | Assessment |
|---|---|
| **Water Table**<br>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:<br>high priority groundwater dependent ecosystem; or<br>high priority culturally significant site;<br>listed in the schedule of the relevant water sharing plan.<br>OR<br>A maximum of a 2 m water table decline cumulatively at any water supply work. | **Within Level 1**<br>There are no high priority groundwater dependent ecosystems listed in the Upper and Lower Namoi Groundwater Sources Water Sharing Plan.<br>There are no High Priority Culturally Significant Sites listed in the Upper and Lower Namoi Groundwater Sources Water Sharing Plan.<br>NCOPL mining would not result in drawdown of more than 2 m at any privately-owned water supply work in the declared alluvial aquifer. |
| **Water pressure**<br>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 2 m decline, at any water supply work. | **Within Level 1**<br>NCOPL mining would not result in cumulative drawdown of more than 40% of the pressure head at any privately-owned water supply work in an alluvial aquifer. |
| **Water quality**<br>Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.<br>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.<br>No mining activity to be below the natural ground surface within 200 m laterally from the top of the high bank or 100 m 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".<br>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 200 m laterally from the top of the high bank and 100 m vertically beneath a highly connected surface water source that is defined as a "reliable water supply". | **Within Level 1**<br>There are no simulated risks of reduced beneficial uses of the highly productive alluvium as a result of proposed mining (Section 6.4).<br>NCOPL mining would have no significant impact on stream baseflow or natural river leakage for the Namoi River. Consequently, NCOPL mining would have negligible impact on the long-term salinity of the Namoi River.<br>The Namoi River is a "reliable water supply" associated with Highly Productive groundwater.<br>The proposed longwall panels are located well away from the Namoi River.<br>NCOPL mining will not extract alluvial material associated with the Highly Productive alluvial groundwater system. |

Table 30 Highly Productive Great Artesian Basin Aquifer – Minimal Impact Considerations

| | |
|---|---|
| **Aquifer** | **NSW Great Artesian Basin Groundwater Sources Southern Recharge Groundwater Source** |
| **Type** | **Porous Rock Water Sources (Great Artesian Basin) Aquifer** |
| **Category** | **Highly Productive** |

| **Level 1 Minimal Impact Consideration** | **Assessment** |
|---|---|
| **Water Table**<br>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:<br>high priority groundwater dependent ecosystem; or<br>high priority culturally significant site;<br>listed in the schedule of the relevant water sharing plan.<br>OR<br>A maximum of a 2 m water table decline cumulatively at any water supply work. | **Level 1 – Highly Productive**<br>There are no high priority groundwater dependent ecosystems listed in the NSW Great Artesian Basin Groundwater Sources WSP. However, three identified springs are predicted to have much less than 1 m drawdown.<br>There are no High Priority Culturally Significant Sites listed in the NSW Great Artesian Basin Groundwater Sources WSP in the proximity to the NM.<br>NCOPL mining would not result in drawdown of more than 2 m at any privately-owned water supply work in the highly productive Pilliga Sandstone. |
| **Water pressure**<br>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 2 m decline, at any water supply work. | **Level 2 – Highly Productive**<br>NCOPL mining would not result in cumulative drawdown of more than 40% of the pressure head at any privately-owned water supply work in the Pilliga Sandstone aquifer.<br>There are two bores (GW067626 [privately owned] and GW966836 [NCOPL-owned]) within the Purlawaugh formation and the Garrawilla Volcanics that are predicted to experience a drawdown effect of >2 m and, although being less productive groundwater sources, are conservatively assigned to the NSW Great Artesian Basin Groundwater Sources WSP. NCOPL would implement "make good" provisions to privately owned bores. |
| **Water quality**<br>Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. | **Within Level 1**<br>There are no simulated risks of reduced beneficial uses of the highly productive Great Artesian Basin Groundwater as a result of proposed mining (Section 6.4). |

# 7 CONCLUSIONS

The NM is an existing underground mining operation that is extracting coal from the Hoskissons Coal Seam at a depth of about 143 m minimum to a maximum future depth of about 376 m, with longwall panel widths of 309 and 407 m and extraction heights of 4.2 to 4.3 m. Seven longwall panels have been completed to date, since 2008. The Project involves extension to the south of the approved longwall panels outside the existing ML. This report documents a preliminary groundwater assessment of the Project for the purposes of the Gateway process.

Rather than the “simple modelling” required for a Gateway Certificate, this assessment has relied on the numerical model used for previous groundwater assessments that have focused on assessing potential risks of mine development in terms of the AI Policy. The model is immediately applicable to Gateway process requirements, while retaining full spatial and temporal detail.

The focus of this study is on assessment of the baseflow/leakage interactions with the Namoi River, associated highly productive alluvium and the Great Artesian Basin highly productive groundwater source, with quantification of likely mine inflow, groundwater heads generally and drawdowns at registered bores. The groundwater takes from each designated water source are quantified and interpreted in terms of licensing requirements.

Groundwater modelling has been conducted to the standards promoted in national guidelines. The groundwater model has essentially Class 2 “confidence”, with many elements of Class 3, as indicated by the checklist in **Table 31**. The model has undergone transient calibration for about 7 years (88 months), followed by verification for a further 14 months, then prediction for about 29 years with recovery investigated for 200 years post-mining.

The AI Policy framework identifies two levels of minimal impact considerations:

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

The key findings of this assessment are:

- A Level 1 impact has been assessed for:
  - high priority groundwater dependent ecosystems;
  - high priority culturally significant sites;
  - water table decline at any water supply work in the alluvium of the Upper Namoi Zone 5 Namoi Valley Groundwater Source;
  - pressure decline at any water supply work in the Pilliga Sandstone of the NSW Great Artesian Basin Groundwater Sources Southern Recharge Groundwater Source;
  - lowering of beneficial use categories;
  - increase in Namoi River salinity; and
  - excavation of alluvium.

- A Level 2 impact has been assessed for:
  - pressure decline at one privately-owned water supply work in the Purlawaugh Formation of the NSW Great Artesian Basin Groundwater Sources Southern Recharge Groundwater Source; this formation is not a *highly productive* groundwater source; and
  - pressure decline at one NCOPL-owned water supply work in the Garrawilla Volcanics of the NSW Great Artesian Basin Groundwater Sources Southern Recharge Groundwater Source; this formation is not a *highly productive* groundwater source.
- Assessment of likely fractured zone heights confirms that connective fracturing is not likely to reach land surface or the surficial zone of tensile cracking where the Hoskissons Coal Seam is to be mined.
- Sensitivity analysis for the conservative assumption of connective fracturing to land surface has resulted in negligible additional predicted increase to mine inflow or off-site environmental impacts.
- During the period of mining, the peak inflow is estimated to be up to 1,847 ML/a (in year 2037); the predicted takes are distributed between the contributory sources as follows:
  - Porous rock (Gunnedah - Oxley Basin MDB Groundwater Source): 66.1%.
  - Great Artesian Basin (Southern Recharge Groundwater Source): 16.5%.
  - Namoi River (Lower Namoi Regulated River Water Source): 9.9%.
  - Namoi River alluvium (Upper Namoi Zone 5 Namoi Valley [Gins Leap to Narrabri] Groundwater Source): 7.5%.
- Over the period of mining, significant groundwater level declines would occur for all layers down to the target Hoskissons Coal Seam, within a few km of the mine site.
- Groundwater level decline would occur, as a result of mining, at greater distances from the mine site for deeper layers (represented, for this study, by the Napperby Formation and the Hoskissons Coal Seam).
- Changes in direction of lateral groundwater flow would be layer-dependent. For the shallow layers (regolith/alluvium and Pilliga Sandstone), changes would be restricted to the close environs of the mine site and would be spatially variable. Lateral flow direction would be unaffected for the Napperby Formation. At the level of the Hoskissons Coal Seam, lateral flow direction in areas distant from the mine site would be largely unaffected. Areas close to the mine site would exhibit changes to flow direction for this layer.
- Based on calibration to actual mine dewatering to date, the model's estimate for mine inflow is likely to be accurate to 5 to 10%.

Following grant of a Gateway Certificate, the groundwater assessment and supporting numerical model would be refined and developed further to meet the requirements of the Secretary's Environmental Assessment Requirement (SEARs) and the IESC *Information Guidelines for Proponents Preparing Coal Seam Gas and Large Coal Mining Development Proposals* (IESC, 2013). This assessment would be presented in the EIS.

More complex modelling, including cumulative impact assessment with the Narrabri Gas Project, would be conducted for the EIS. The EIS assessment would also consider additional groundwater data obtained by NCOPL, core permeability test work and data collected from a calibration borehole installed by NCOPL.

Furthermore, consideration of the potential impacts against the *Significant Impact Guidelines 1.3: Coal Seam Gas and Large Coal Mining Developments – Impacts on Water Resources* (IESC, 2013) concludes that the Project is unlikely to have a significant impact on groundwater resources.

**Table 31 Groundwater Model Confidence Classification**

| CLASS | DATA | CALIBRATION [8.5 yrs] | PREDICTION [28 yrs] | INDICATORS |
|---|---|---|---|---|
| 1<br>[count = 3] | Not much.<br>Sparse.<br>✱ No metered usage.<br>✱ Remote climate data. | Not possible.<br>Large error statistic.<br>Inadequate data spread.<br>Targets incompatible with model purpose. | Timeframe >> calibration<br>Long stress periods.<br>Transient prediction but steady-state calibration.<br>Bad verification. | Timeframe > 10x<br>Stresses > 5x<br>Mass balance > 1% (or single 5%)<br>Properties <> field.<br>Bad discretisation.<br>✱ No review. |
| 2<br>[count = 8] | Some.<br>Poor coverage.<br>✱ Some usage info. [mine]<br>Baseflow estimates. | ✱ Partial performance.<br>Long-term trends wrong.<br>Short time record.<br>✱ Weak seasonal replication.<br>No use of targets compatible with model purpose. | ✱ Timeframe > calibration.<br>✱ Long stress periods.<br>New stresses not in calibration.<br>Poor verification. | ✱ Timeframe = 3-10x<br>✱ Stresses = 2-5x<br>✱ Mass balance < 1%<br>Some properties <> field measurements.<br>Some key coarse discretisation.<br>Review by hydrogeo. |
| 3<br>[count = 9] | ✱ Lots.<br>Good aquifer geometry.<br>Good usage info.<br>Local climate info.<br>✱ K measurements.<br>Hi-res DEM. | ✱ Good performance stats.<br>✱ Long-term trends replicated.<br>Seasonal fluctuations OK.<br>✱ Present day data targets.<br>✱ Head and flux targets. | Timeframe ~ calibration.<br>Similar stress periods.<br>✱ Similar stresses to those in calibration.<br>Steady-state prediction consistent with steady-state calibration.<br>✱ Good verification. | Timeframe < 3x<br>Stresses < 2x<br>Mass balance < 0.5%<br>✱ Properties ~ field measurements.<br>Some key coarse discretisation.<br>Review by modeller. |

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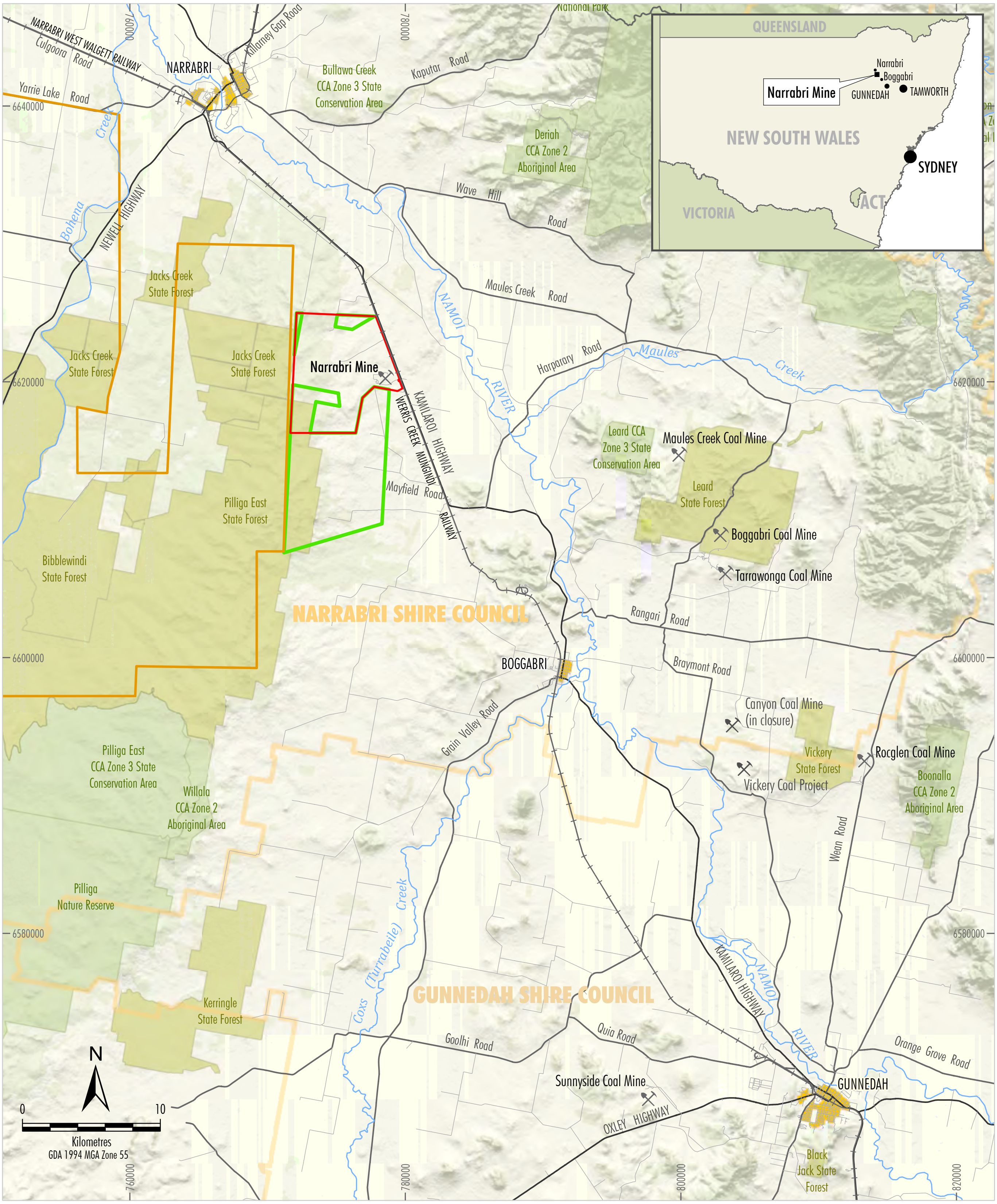
# 9 FIGURES




LEGEND

- Mine Site
- Mining Lease (ML 1609)
- Exploration Licence (EL 6243)
- Local Government Boundary
- State Forest
- State Conservation Area, Aboriginal Area
- Proposed Narrabri Gas Project (Santos NSW [Eastern] Pty Ltd)

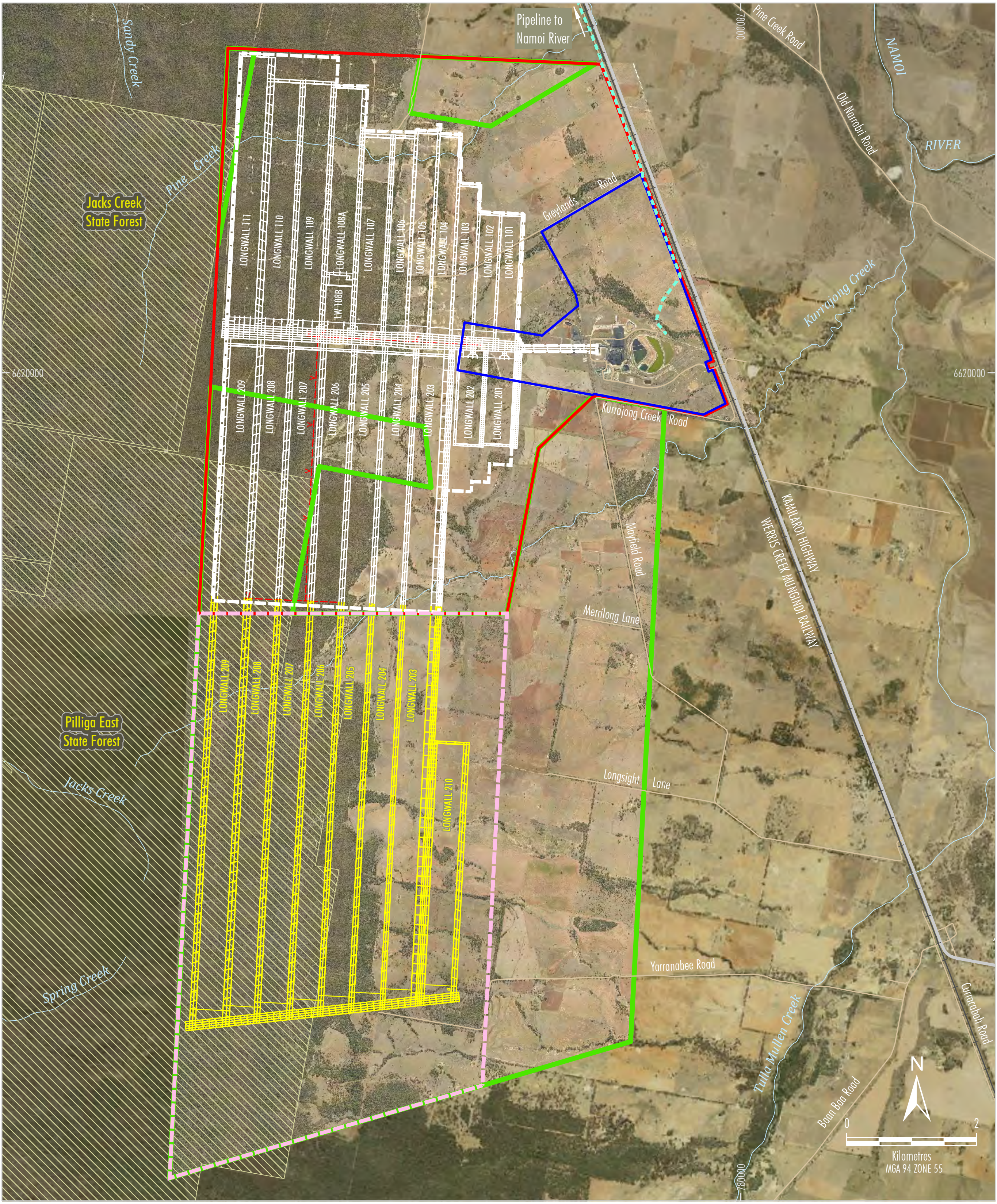
*Source: Department of Land and Property Information (2017); NSW Department of Industry (2017); Geoscience Australia (2011)*

WHITEHAVEN COAL

NARRABRI STAGE 3 PROJECT

**Regional Location**

**Figure 1**




LEGEND

State Forest
Mining Lease Boundary (ML 1609)
Exploration Licence (EL 6243)
Project Underground Mine Development
Approved Narrabri Mine
Pit Top Area
Underground Mine Footprint
Underground Mine Development
Namoi River Water Pipeline
Gateway Certificate Application Area

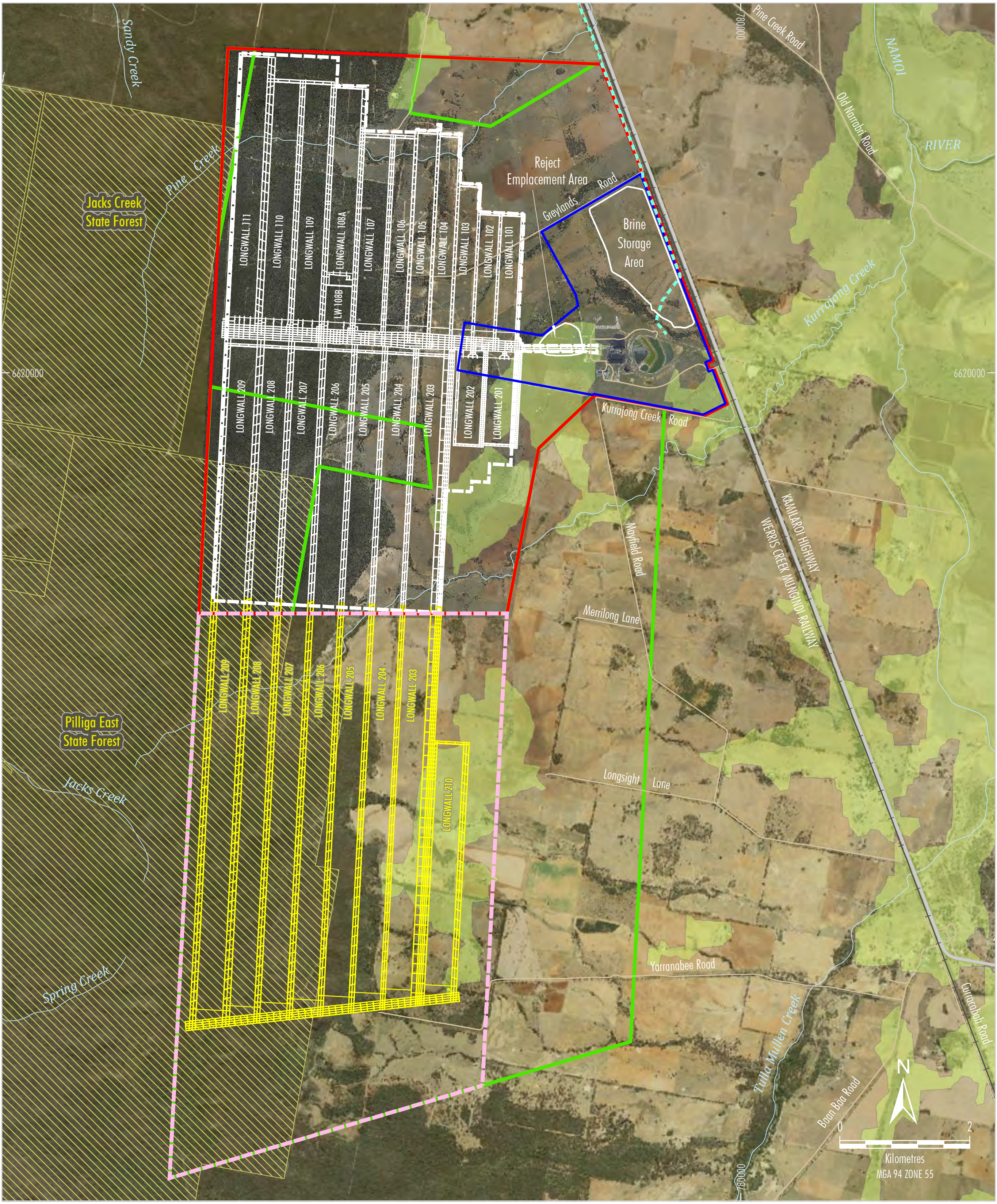
*Source: Orthophotos - Whitehaven Coal (2017); R.W. Corkery & Co Pty Ltd (2009); NSW Trade & Investment (2017); NCOPL (2018)*

WHITEHAVEN COAL

NARRABRI STAGE 3 PROJECT

**General Arrangement for Approved and Proposed Mine Plans**

**Figure 2**




LEGEND

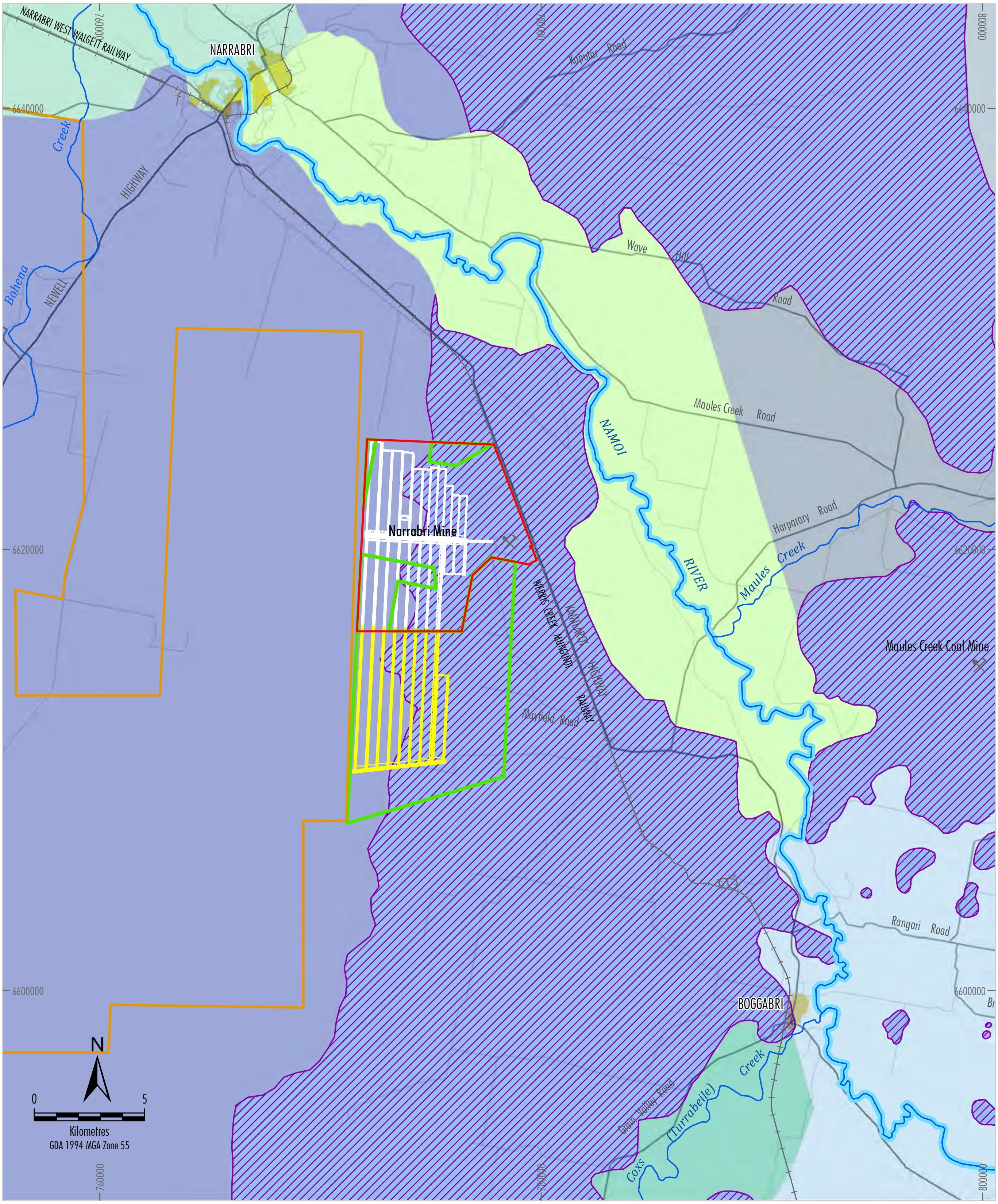
- State Forest
- Mining Lease Boundary (ML 1609)
- Exploration Licence (EL 6243)
- Project Underground Mine Development
- Approved Narrabri Mine
- Pit Top Area
- Underground Mine Footprint
- Underground Mine Development
- Namoi River Water Pipeline
- Gateway Certificate Application Area
- Mining SEPP Potential BSAL

*Source: Orthophotos - Whitehaven Coal (March 2015); R.W. Corkery & Co Pty Ltd (2009), NSW Trade & Investment (2015) and NCOPL (2015)*

NARRABRI STAGE 3 PROJECT

**Biophysical Strategic Agricultural Land Mapping**

**Figure 3**




LEGEND

- Mine Site
- Mining Lease (ML 1609)
- Exploration Licence (EL 6243)
- Proposed Narrabri Gas Project (Santos NSW [Eastern] Pty Ltd)
- Project Underground Mine Development
- Approved Underground Mine Development

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

- Gunnedah-Oxley Basin MDB (Other) Management Zone
- Gunnedah-Oxley Basin MDB Groundwater Source

Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008

- Southern Recharge Groundwater Source

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

- Upper Namoi Zone 2, Cox's Creek (Mullaley to Boggabri) Groundwater Source
- Upper Namoi Zone 4, Namoi Valley (Keepit Dam to Gin's Leap) Groundwater Source
- Upper Namoi Zone 5, Namoi Valley (Gin's Leap to Narrabri) Groundwater Source
- Upper Namoi Zone 11, Maules Creek Groundwater Source
- Lower Namoi Groundwater Source

Water Sharing Plan for the Upper and Lower Namoi Regulated River Water Sources

- Lower Namoi Regulated River Water Source

*Source: Department of Land and Property Information (2017); NSW Department of Industry (2017); Geoscience Australia (2011); NCOPL (2018)*

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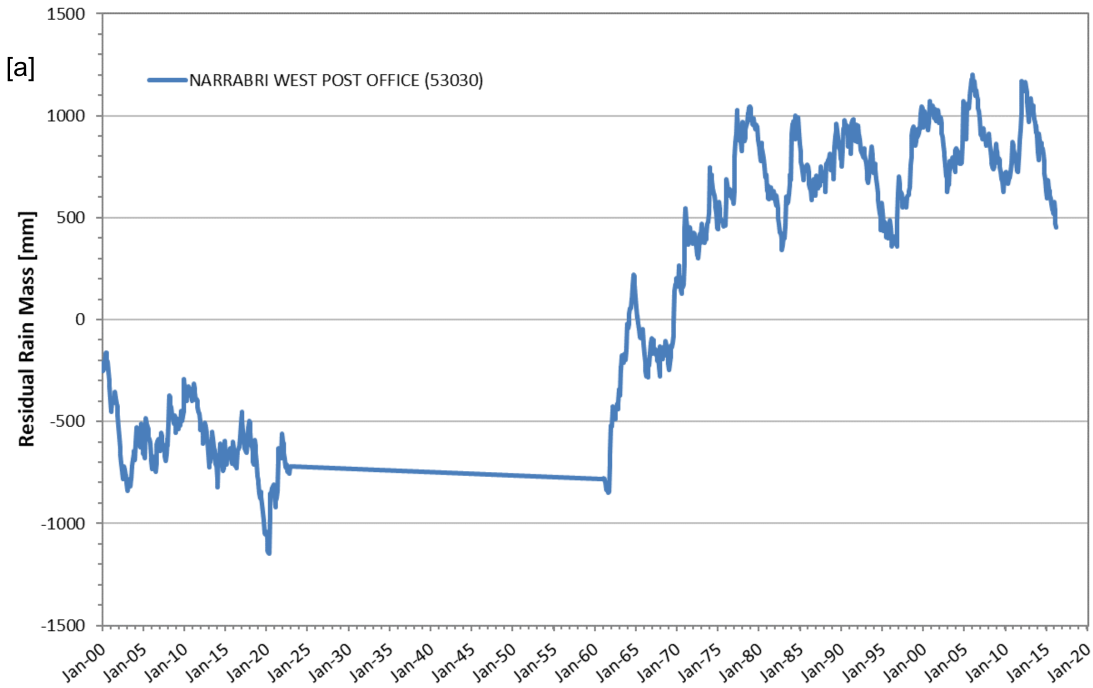
NARRABRI STAGE 3 PROJECT

**Water Sharing Plan Areas and Narrabri Mine**

**Figure 4**




\\Linmodel1\models2\Narrabri\Reports\Nov2018\Figures\Narrabri_Hyd_2018\Narrabri GW Hydrographs_Rainfall Mass Curve_2018_updated.xlsx(NarrabriWestPostOffice)]


**Figure 5 Rainfall Residual Mass Curves for: [a] Narrabri West Post Office (1900-2017), [b] Narrabri West Post Office and Narrabri Rosewood Farm (1980-2017), (straight lines represent periods with no data).**