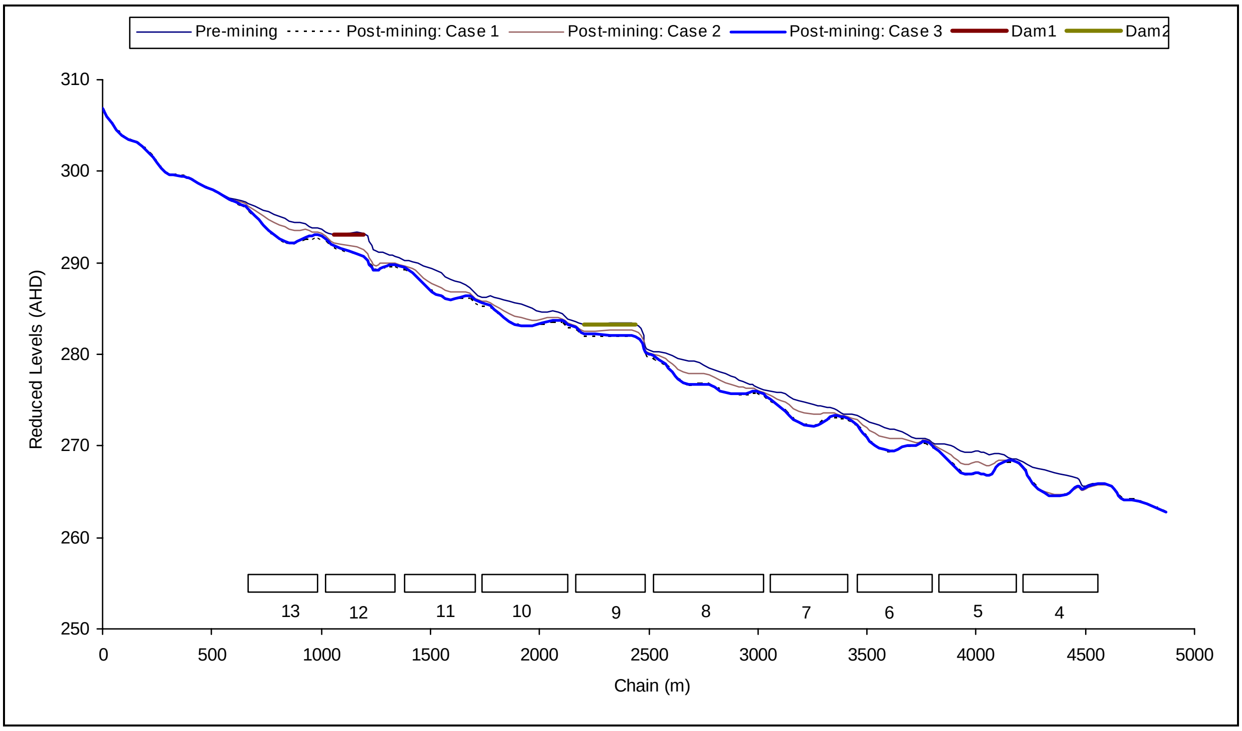
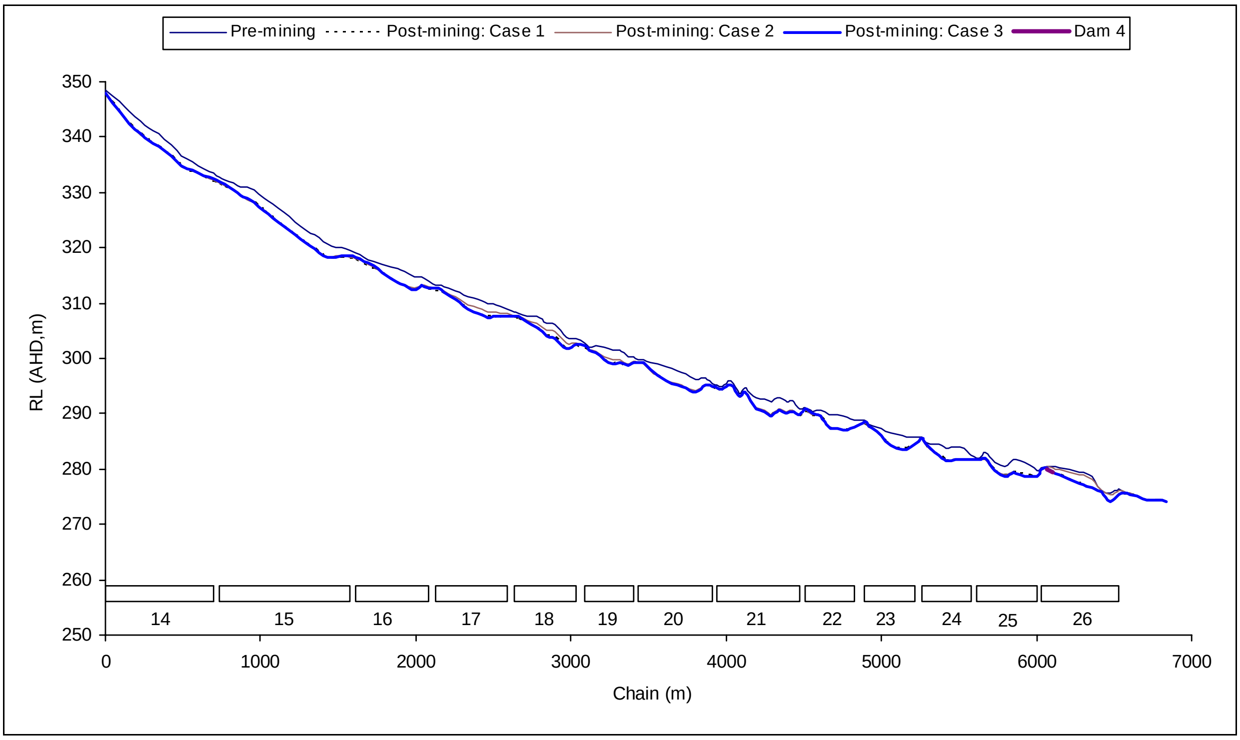


Pine Creek



Kurrajong Creek

Figure 4B.7
PRE-MINING AND PREDICTED POST-MINING SURFACE PROFILES ALONG PINE AND KURRAJONG CREEKS

Source: DGS (2009) – Figures 49 and 51

4B.1.6.4 Valley Closure and Uplift

Predicted Impacts

Valley closure and uplift movements are strongly dependent on the level of 'locked-in' horizontal stress immediately below the floor of the gullies and more importantly the bedding thickness of the floor strata, ie. thin to medium bedded sandstone is more likely to buckle than thicker beds. The influence of the aspect ratio, ie. valley width/depth, is also recognised as an important factor, with deep, narrow valleys having greater 'upsidence' than broad, rounded ones, due to higher stress concentrations.

As the valleys across the Mine Site are broad and there is a lack of thick, massive beds of conglomerate and/or sandstone units along the creeks / valleys, DGS (2009) concludes that the probability of 'upsidence' development and/or valley closure is likely to be negligible.

If 'upsidence' does occur, it may cause some minor, localised deviation of surface flows along ephemeral creek beds into sub-surface routes above the longwall panels. Failure and cracking of the near surface rocks due to tensile bending or compressive/shear strains would also contribute to the re-routing of surface flows. Re-routed surface flows would be expected to re-surface down stream of the damaged area.

Proposed Management

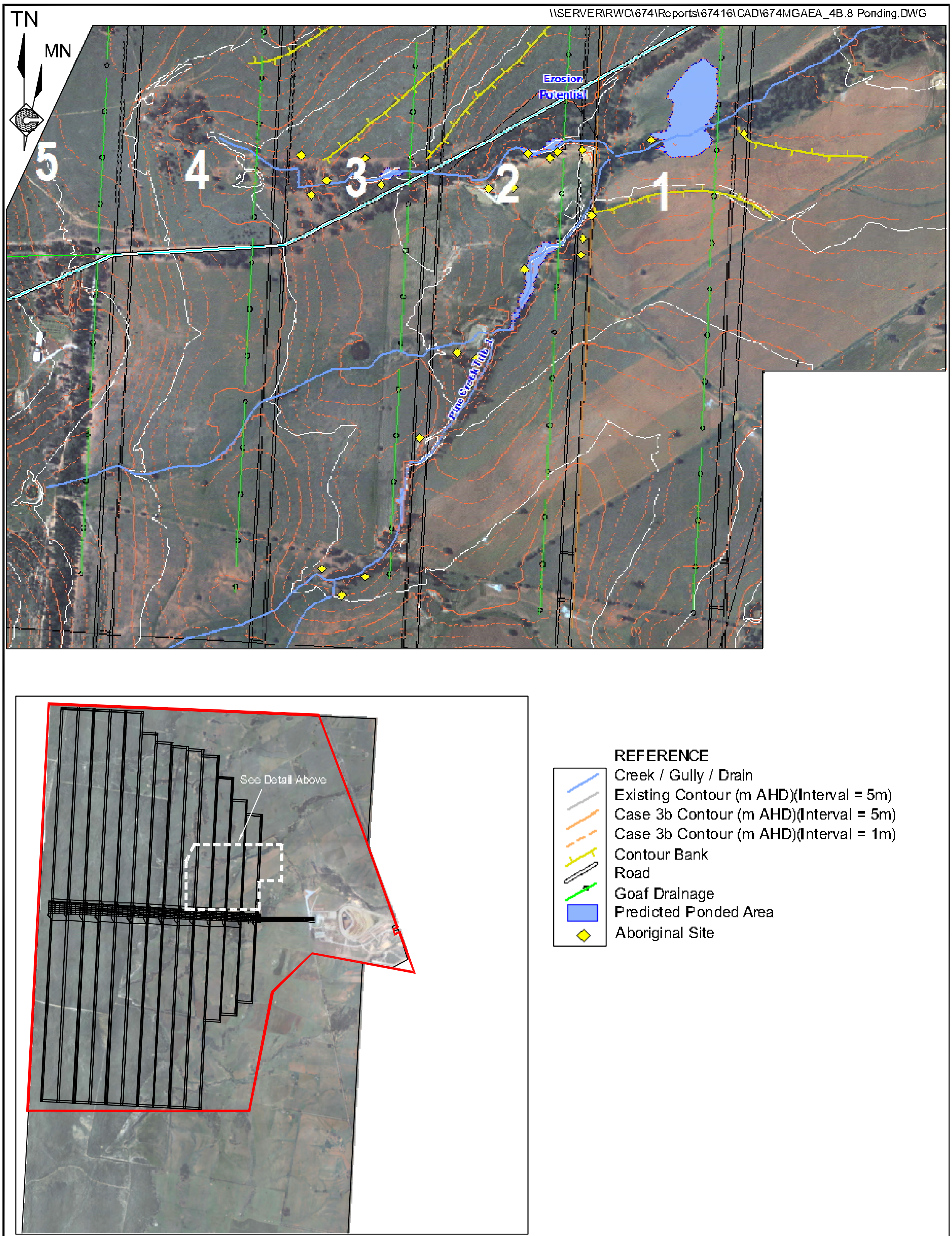
While the potential for 'upsidence' is considered negligible, the Proponent would undertake the following to manage the resultant impacts.

- Survey lines along ephemeral drainage gullies and along gully crests would be installed and monitored during and after longwall mining. This monitoring would be combined with visual inspections to identify any signs of cracking or 'upsidence'.
- The predictions of 'upsidence' and valley crest movements would be reviewed after each longwall is completed.
- In the event that 'upsidence' results in the appearance of large cracks, remedial works such as those identified for surface cracking (see Section 4B.1.6.1) and erosion (see Section 4B.1.6.3) would be implemented.

4B.1.6.5 Ponding on Tributaries of Kurrajong and Pine Creeks

Predicted Impacts

DGS (2009) suggests that some of the watercourses present within the Mine Site could be susceptible to potential ponding depths of between 0.5m and 1.5m, based on the predicted final surface level profiles of Pine and Kurrajong Creeks (see **Figures 4B.7**). Surface gradients may subsequently increase or decrease by up to 6% (3^{o}) along creeks. The actual ponding depths would depend upon several other factors, such as rain duration, surface cracking and effective percolation rates of the surface soils and fractured rock bars/outcrops along the creeks. An assessment of the possible ponding that may occur on and adjacent to Pine Creek Tributary 1 during the initial years of mining has been completed by WRM Water and Environment Pty Ltd (WRM, 2009) (see **Figure 4B.8**). Additional predictions of ponding within the creeks and their tributaries on the Mine Site is provided by WRM (2009 – *Figures 7.1 to 7.4*). Notably, the predicted ponding would generally be restricted to within the existing channel banks (in-stream), with only one additional area of possible overbank ponding identified on a tributary to Kurrajong Creek near the southeastern corner of the Mining Area (over LW22).



SCALE 1:12 500

200 0 200 400 600 m

Source: Modified after WRM (2009) - Figure 7.1

Figure 4B.8

PREDICTED PONDING ON PINE CREEK TRIBUTARY 1 OVER LONGWALL PANELS LW1 to LW3

The impacts within this area are likely to include the following.

- In-stream and over bank ponding over LW1 and in-stream ponding (limited to within the channel of Pine Creek Tributary 1) over LW2 and LW3. Ponding is most likely to occur when the tributary channel is perpendicular to the longwall panels (as the change in channel slope is more significant).
- Over bank ponding and possible flow re-direction along the contour banks north of Pine Creek Tributary 1 over LW2 and LW3. This would occur as the variable subsidence across the retained chain pillars would result in the contour banks no longer run along contour.
- The bed slope of the channels would increase on the downstream (eastern) side of the chain pillars, which may increase channel erosion along these areas.
- Increased in-stream sedimentation would occur on the downstream (eastern) side of the longwall panels in the areas of in-stream ponding. The source of the increased sediment would be due to the channel erosion on the upstream (western) side of the same long wall panel draining from the chain pillars.

Additional impacts associated with the ponding illustrated on **Figure 4B.8** may be as follows.

- The short term loss of riparian vegetation.
- Inundation of identified (and unidentified) Aboriginal sites.
- Increased salinity of downstream flows as a result of ponding over saline soils. Notably, some sub-soils derived from the Purlawaugh Formation have been identified as slightly to moderately saline (GCNRC, 2009) and if exposed as a result of subsidence could increase the salinity of the water discharged from the Mine Site.

Following inspection of the post mine subsidence contours predicted along the tributaries of Kurrajong and Pine Creeks, WRM (2009) determines that the impacts illustrated on **Figure 4B.8** are likely to be typical and repeated across all watercourses within the subsidence zone of the Mine Site. WRM (2009) concludes that major changes in channel geomorphology due to changes in channel location (avulsions) are unlikely.

In considering the impacts of ponding, it is worthy of note that the ponded water would also be likely to provide an additional source of drinking water for local fauna.

Proposed Management

WRM (2009) suggests that the continual action of erosion and sedimentation without mitigation measures is likely to ‘self correct’ the geomorphic characteristics of the waterways over time. Water would be regularly sampled (in accordance with a Surface Water Monitoring Procedure – see Section 4B.3.8) to confirm no increase in the salinity of water which may be attributable to ponding over saline soils.

The above notwithstanding, the Proponent would regularly inspect the watercourses over the subsidence zone of the Mine Site and implement the following mitigation strategy.

- If little vegetation of significance is impacted and water quality analysis confirms no increase in salinity, the ponding would be left to self correct over time.

- If significant areas of vegetation (or vegetation of conservation significance) occur within the ponded area, the channel across the chain pillars would be excavated to reduce the gradient change which causes the pond to form. If this occurs, appropriate management measures (in accordance with an Aboriginal Cultural Heritage Management Plan – see Section 4B.5.5 and vegetation clearing procedures – see Section 4B.4.5.1) would be followed to ensure that Aboriginal sites or significant vegetation is not impacted by the excavation.
- In the event that an increase in salinity is observed, the channel across the chain pillars would be excavated to reduce the gradient change which causes the pond to form (thereby reducing the time over which the salts can leach from the soil and enter the water).

4B.1.6.6 Far-field Horizontal Displacements

Predicted Impacts

DGS (2009) reports that Far-field Displacements (FFDs) generally only have the potential to damage long, linear features such as pipelines, bridges, railway and dam walls. Therefore, any surface features such as bridges or culverts within three or four times the cover depth, ie. approximately 600m from the proposed LW1 and LW26 on the eastern side would be monitored for FFD movements during mining. The deeper western side of the proposed Stage 2 Longwall Project mining area may affect a larger area of up to 1.5km away.

Notably, FFDs outside a distance equal to one cover depth from the longwall extraction limits are unlikely to generate significant strains or movement to cause cracking or damage to the surface (DGS, 2009).

DGS (2009) concludes that the closest linear structures to the mining area (the Main Western Branch Railway Line and the Kamilaroi Highway) would be beyond the area likely to be affected by far-field movements. Hence, no management strategies would need to be adopted.

4B.1.6.7 Aboriginal Artefacts

Section 4B.5.6.2 presents the results of the assessment of potential impact(s) upon the predicted subsidence on Aboriginal sites and artefacts.

4B.1.6.8 Other Surface Features and Infrastructure

4B.1.6.8.1 Unsealed Gravel Access Roads and Tracks

Predicted Impacts

The unsealed gravel access public and private roads and tracks above the proposed longwall panels are likely to be damaged by cracking and ‘shoving’ at tensile and compressive strain zones.

Proposed Management

Given the maximum crack width is unlikely to exceed 380mm in the eastern side of the mining area (see Section 4B.1.6.1), this could be effectively managed through regular inspection and maintenance of the roads and access tracks undertaken after each longwall block is mined or as required when the impacts occur. Particular attention would be paid to public roads maintained by Narrabri Shire Council.

4B.1.6.8.2 Water Storage Dams

Predicted Impacts

Non-engineered farm dams and water storages would be susceptible to surface cracking and tilting due to mine subsidence. The tolerable tilt and strain values for the dams would depend upon the materials used, construction techniques, foundation type and likely repair costs to re-establish the dam’s function and pre-mining storage capacity.

The expected phases of tensile and compressive strain development may result in breaching of contour banks or dam walls or water losses through the floor of the dam storage area. Loss or increase of storage areas may also occur due to the predicted tilting. Damage to windmills and fences around the dams may also occur and require repair.

Proposed Management

Notably, the damage to water management structures on the Mine Site would be largely on properties owned by the Proponent. It is also highly likely that any damage caused to these structures could be remediated, or the structure replaced with a comparable one in an appropriate location. For impacts on dams, contour banks, or windmills on the limited number of properties not owned by the Proponent, the Proponent would re-instate or replace the damaged structure in a timely manner and in the case of dams or windmills provide an alternative supply of water during the interim period. DGS (2009) notes that dams similar to those across the Mine Site have been undermined by longwall mining elsewhere in Australia with any damage effectively managed in the manner proposed.

4B.1.6.8.3 Property Fences and Livestock

The impact of subsidence on the grazing of livestock would primarily require the management and repair of surface cracking and fences. Ponding is not expected to affect grazing or pasture areas.

4B.1.6.8.4 Residential Dwellings and Machinery Sheds

Predicted Impacts

It is estimated that there are seven buildings, two orchards and two water tanks present above longwall panels LW5, LW7, LW21 and LW22. These structures and features may be subject to subsidence of up to 2.44m. DGS (2009) considers that the predicted level of subsidence, and the associated tilts and strains, is likely to significantly damage these features. The ultimate impact cannot be predicted, however, it may result in the structures becoming structurally unstable and therefore uninhabitable. The only residential dwellings above the underground Mining Area are on land owned by the Proponent and only two are occupied. The Proponent has already made provision for these dwellings to be vacated well ahead of the predicted subsidence occurring.

Mine subsidence impacts on surface structures are expected to develop soon after a longwall retreats beneath each structure and would be expected to continue until the longwall face is one to two times the cover depth past the structure. Subsidence movements would also be expected to commence again as the subsequent longwall panel(s) pass, albeit at decreasing rates and magnitudes. It is considered likely that subsidence movements would affect undermined properties for periods of at least 2 years after mining.

Structures located outside the Mining Area, but within the angle of draw, may be subject to subsidence movements <200 mm, tilts <4mm/m and strains <1mm/m. Within this zone, and regardless of the type of structure, DGS (2009) predicts damage to these structures to be minor.

Structures that are further than distances of 0.5 to 0.7 times the cover depth (ie. at angles of draw of 26.5^{o} and 35^{o}) from the limits of longwall extraction are likely to be subsided < 20mm with negligible tilts (<1mm/m) and strains (<0.5mm/m). It is very unlikely that mining would cause any damage to these buildings. There are several structures (ie. residences, machinery sheds and tanks) on the "Kurrajong" property which are 80 to 350m south of LW26 and 135m to 155m southeast of the starting position of LW25. The cover depth of 170m gives an effective angle of draw of 25.5 to 64^{o} for these structures.

A detailed assessment of all structures would be undertaken during the development of the Subsidence Management Plan for the Longwall Project.

Proposed Management

A dilapidation survey and inspection of all structures not owned by NCOPL would be made by a qualified building consultant within the proposed angle of draw (+200m) before and after mine subsidence. The report could then be referred to in individual property subsidence management plans (IPSMP) to provide fair and reasonable outcomes between the land owner and the Proponent. The IPSMPs should address the following issues in consultation between the stakeholders (ie. land owners, mine, Council and Utilities).

- When mining impacts would occur and the predicted damage to property structures.
- The monitoring plan for the property during mining and safety/hazard management plan.
- The timing of disconnection of power supply etc.
- The post-mining inspection and reporting of property damage and repair works options.

Any repair works to internal/externals cracking or re-levelling of damaged structures on non-project related properties would be implemented to ensure the properties are safe and serviceable before allowing re-entry to the property.

4B.1.6.8.5 Narrabri Coal Mine Site and Other Infrastructure

No damage or impacts are expected to the proposed Mine Site infrastructure given it is located east of the subsidence zone or along the West Mains, which would cause negligible subsidence.

DGS (2009) reports that the Kamilaroi Highway and North Western Branch Railway Line are well outside the limits of subsidence impact, including impacts from far-field displacements. Notwithstanding this, DGS (2009) recommends, as a precaution, that risk management zones are defined around the mine site infrastructure, highway and railway line.

4B.1.7 Monitoring Program

DGS (2009) notes that measurable subsidence at a given location above the longwall panel centreline is likely to commence at a distance of approximately 50m to 100m ahead of the retreating longwall face and may develop at rates of 50mm/day to 300mm/day. The Proponent would undertake a subsidence and strain-monitoring program in order to provide adequate information to enable the design and implementation of appropriate subsidence impact management plans, as well as to provide pillar stability data for the gate road and main headings. A Subsidence Monitoring Program would be prepared as part of a Subsidence Management Plan for the Longwall Project, which would allow a comparison between predicted and measured subsidence parameters for a given feature. The Subsidence Monitoring Program would include the following elements.

- A transverse subsidence line across the northern and southern panels. The lines would be installed to at least the middle of the next adjacent longwall before undermining occurs.
- A longitudinal line extending in-bye and out-bye from the starting and finishing point of each panel, for a minimum distance equal to the cover depth.
- A survey line along the riparian management zone of Kurrajong and Pine Creeks and their tributaries over the Mine Site.
- A minimum of three monitoring pegs spaced 10m apart in a line or triangle at any feature of interest, eg. dam walls, archaeological sites, to measure subsidence, tilt and strain.
- Visual inspections and mapping of damage before, during and after mining.

In each case, monitoring survey pegs would be spaced between 10m and 20m apart with a minimum of two baseline surveys of subsidence and strain completed before mine subsidence effects occur. Survey frequency would be determined by mine management and be dependent upon requirements for subsidence development data in order to implement subsidence and mine operation management plans.

An alternative method of subsidence monitoring that may be undertaken is Aerial Laser Scanning (ALS). This technique allows a reduction in ground monitoring to key baseline monuments and provide subsidence data to within +/- 0.15m. ALS scans also provide a more thorough picture of the subsidence development along creeks and surface terrain generally and without the need for intrusive surveys or monitoring pegs (which can be a hazard to livestock and be lost by farming activities). The Proponent has already acquired ALS data across the entire mining area to enable comparisons to be made with post-mining data.

4B.2 GROUNDWATER

The groundwater assessment was undertaken by Aquaterra Consulting Pty Ltd (Aquaterra, 2009). The full assessment is presented as Part 2 of the Specialist Consultant Studies Compendium, with the relevant information from the assessment summarised in the following subsections. A peer review of the groundwater modelling was undertaken by Professor Noel Merrick. A copy of Professor Merrick's review is behind the groundwater assessment in the compendium.

4B.2.1 Introduction

Based on the risk analysis undertaken for the Longwall Project (see Section 3.3 and **Table 3.5**), the potential groundwater impacts requiring assessment and their unmitigated risk rating are as follows.

- Groundwater pollution as a result of leakage or spillage (low to moderate risk).
- Drawdown of groundwater resulting in:
  - reduced water levels within the aquifers of the Intake Beds to the Great Artesian Basin Groundwater Source (high risk);
  - reduced water levels within the aquifers of the Lower and Upper Namoi Alluvial Groundwater Source (moderate risk); and
  - reduced water levels within the aquifers of the Gunnedah Basin Groundwater Source (high risk).
- Reduction in the yield / saturated thickness of groundwater bores:
  - on the Mine Site or Proponent-owned land (high risk);
  - by <15% on non-project related properties (moderate risk); and
  - by >15% on non-project related properties (high risk).
- Impacts on groundwater-dependent ecosystems (high risk).

In addition, the Director-General's Requirements identify "soil and water" as a key issue for assessment and require the *Environmental Assessment* to pay particular attention to:

- any potential impacts on the Great Artesian Basin intake beds;
- the requirements of the *NSW Great Artesian Basin Groundwater Sources Water Sharing Plan* and the *Upper and Lower Namoi Groundwater Water Sharing Plan*;
- demonstrating how the Proponent would manage mine water, especially any mine water brought to the surface; and
- any potential subsidence-induced soil and stream erosion.

This section commences with a review of the existing regional and local hydrogeology, local availability and use of groundwater resources and current statutory framework for the management of groundwater. Potential sources of groundwater contamination are then identified and the operational safeguards, controls and mitigation measures described. The section concludes with an assessment of the residual impacts following the implementation of these safeguards, controls and mitigation measures.

4B.2.2 The Existing Environment

4B.2.2.1 Regional and Local Hydrogeology

4B.2.2.1.1 Regional Hydrogeology

Section 2.2.1 records the Mine Site is located within the Mullaley Sub-basin, which is part of the Gunnedah Basin. In the western part of the Mine Site, the Gunnedah Basin sequence is unconformably overlain by the Jurassic age Surat Basin sequence. The Jurassic and Triassic sequences are overlain in northern and western parts of the Mine Site by Quaternary sand and talus material. These alluvial channel and overbank deposits of gravels, sand, silt and clay are associated with the Namoi River and can reach a thickness of up to 120m.

Regional Aquifers and Groundwater Management Areas (GWMAs)

The Triassic, Jurassic and Quaternary sequences contain differentiated aquifers which have been defined by the former Department of Water and Energy (DWE) as groundwater management areas (GWMAs). These are described as follows, with reference to the relevant geological units within the Mine Site.

- The Intake Beds of the Great Artesian Basin (GAB) GWMA (601) which are defined by the easterly extent of the Surat Basin sequence. The Surat Basin is a large intra-cratonic basin covering approximately 270 000km^2 with the southern third of the basin occupying a large part of northern New South Wales. The Surat Basin sequence of the Mine Site includes the following formations.
  - The Pilliga Sandstone: which is a Jurassic age braided stream deposit consisting of very well sorted medium to very coarse grained, quartzose sandstone with very minor interbeds of mudstone and siltstone. This formation constitutes the major intake beds and aquifers for the Great Artesian Basin groundwater system and sub-crops across the western part of the Mining Area (see **Figure 4B.9**). Aquaterra (2009) concurs with GHD (2007) which reported that the Pilliga Sandstone is not saturated within the Mine Site. Aquaterra (2009) notes, however, that the Pilliga Formation becomes partly saturated to the west of (down-dip from) the Mine Site, as the formation dips below the regional water table level.
  - The Purlawaugh Formation: which consists of thinly bedded, lithic, fine to medium grained sandstone interbedded with siltstone and mudstone. Soils derived from the readily weatherable argillaceous sediments of this formation occur over the eastern half of the Mining Area (see **Figure 4B.9**). The sandstone of this formation is noted as having low porosity and permeability and are rarely considered as aquifers with bore yields generally less than 0.5 L/s.

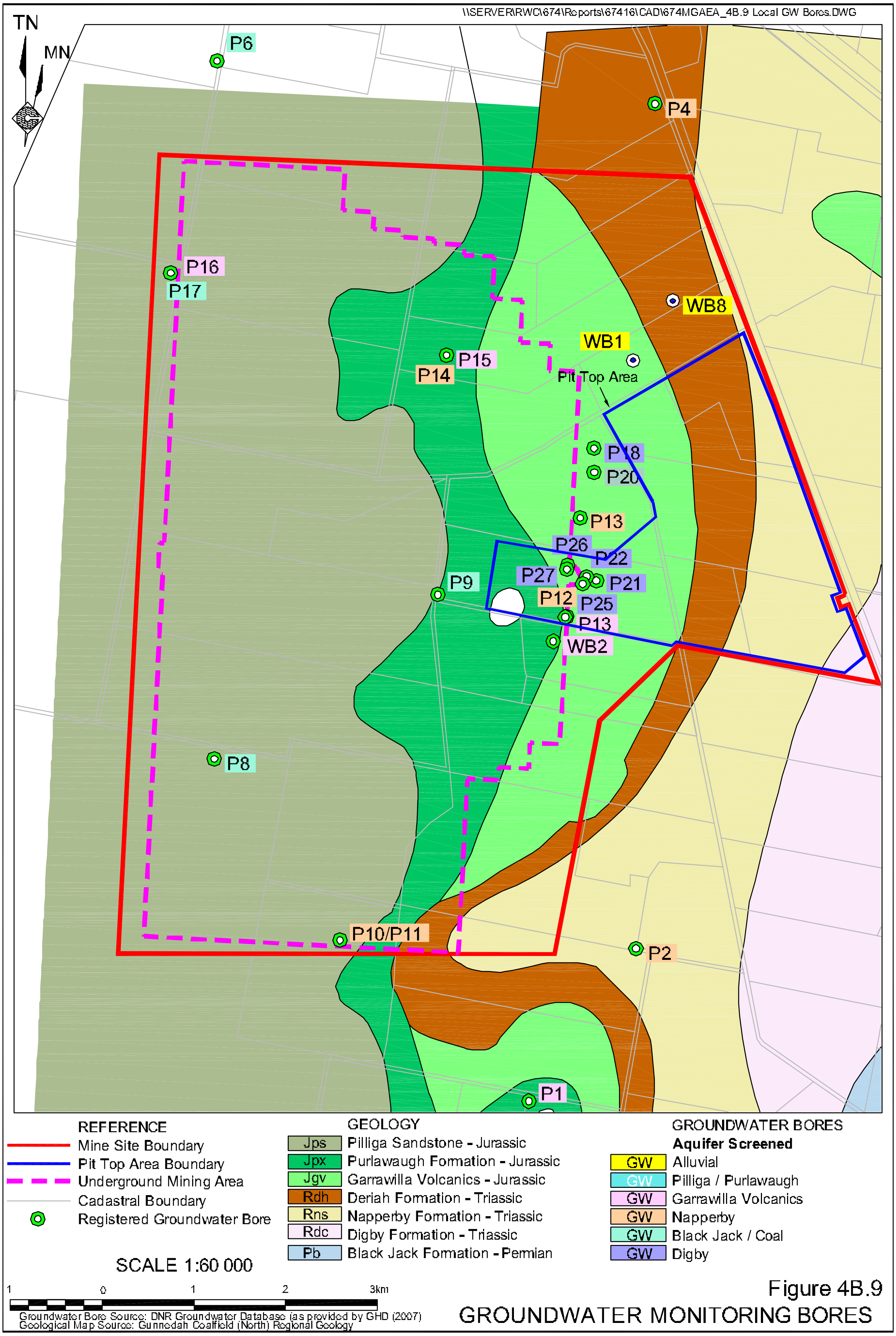


Figure 4B.9
GROUNDWATER MONITORING BORES

- The Garrawilla Volcanics: which consists of flows of basalt and trachyte and interbedded pyroclastics. Individual flows range in thickness from 1m to 8m and range from extremely vesicular to non-vesicular. The volcanics are found sub-cropping under alluvium generally to the east of the Mining Area (see **Figure 4B.9**) and represent the north-south trending boundary between the Surat Basin and Gunnedah Basin Sequence.

Aquaterra (2009) reports that no groundwater flows have previously been recorded from these units within the Mine Site, however, during construction of the box cut for the Stage 1 Narrabri Coal Mine, groundwater inflows were observed emanating from the base of the weathered profile. The groundwater observed was restricted to small amounts of perched water accumulating between the more permeable weathered profile and relatively impermeable fresh rock below and while in this instance was restricted to the box cut area, could occur elsewhere across the Mine Site. Aquaterra (2009) notes that as the Mine Site is located above younger geological units that are topographically higher than the Namoi River floodplain, the groundwater of the intake beds of the GAB is not hydraulically connected with alluvial groundwater associated with the Namoi River.

- Gunnedah GWMA (604) which comprises the Permo-Triassic Gunnedah Basin sequence and is found in the eastern part of the Mine Site. The Gunnedah Basin sequence of the Mine Site includes the following formations.
  - The Mid Triassic Napperby Formation which is a thick sequence of siltstone/sandstone laminite overlain by sandstone. This formation sub-crops under alluvium/talus material in the eastern part of the Mine Site (see **Figure 4B.9**).
  - The Early Triassic Digby Formation which is a poorly sorted lithic conglomerate alluvial fan deposit and has not been mapped as sub-cropping on the Mine Site.
  - The Late Permian Black Jack Group which includes the Hoskissons Coal Seam with subordinate layers of fine grained sandstone, carbonaceous siltstone and claystone. These layers have been classified as follows.
    - Arkarula Formation – Quartzose sandstone and siltstone, typically the upper 10m of the Black Jack Formation throughout the Mine Site.
    - Brigalow Formation – Coarse sandstone and conglomerate interbedded within the coal seam and grades laterally into the Arkarula Formation, thickening to the west across the Mine Site from 2m to 10m.
    - Pamboola Formation – Lithic sandstone, siltstone, claystone and coals. Continuous over the Mine Site below the Arkarula Formation and Brigalow Formation with a thickness of between 55m to 75m.
  - The Late Permian Millie Group, Early Permian Bellata Group and Gunnedah Basin sequence basement lie beneath the Black Jack Group but would not be intersected by the proposed underground workings.
- Aquaterra notes that the Gunnedah Basin sequence contains local groundwater flow systems in fractured rock. Bore yields within the Gunnedah GWMA on and surrounding the Mine Site are generally low and similar to the Purlawaugh Formation.

- The Upper Namoi GWMA (004) which is contained in the unconsolidated sediments of the Namoi River and its tributaries. The Upper Namoi GWMA is divided into 11 zones of which Zone 5 is found to the east of the Mine Site. The alluvium associated with the Namoi River valley can exist to depths in excess of 100m, as is seen in the palaeochannels to the north of Narrabri. The aquifer is considered to be stressed due to large over-allocations of groundwater extraction.

Elsewhere, alluvial / colluvial sediments form surface cover over the sub-cropping geological units (see **Figure 4B.9**), with thicknesses that can extend up to 30m.

4B.2.2.1.2 Local Hydrogeology

Local hydrogeological conditions have been identified based on the following investigations.

Groundwater Modelling of the Saturated Aquifer System of the Upper and Lower Namoi Valley Alluvium

Identified as a narrow palaeochannel 3km to 10km in width, the Namoi Valley contains a sequence of non-marine alluvial deposits (up to 120m thick) of Tertiary and Quaternary age. A numerical groundwater flow model (using MODFLOW), periodically revised since 1982, has been developed to simulate the behaviour of this aquifer system and has been incorporated into the model developed for the Mine Site and surrounds.

Groundwater Investigations Undertaken by GHD (2007) for the Stage 1 Narrabri Coal Mine

Through a review of the available literature and mapping of the hydrogeological properties of the various formations below the Mine Site, and site investigations which involved the construction and permeability testing of eight groundwater bores, GHD (2007) reported that the groundwater at the Mine Site is typically associated with fractures encountered in the consolidated sedimentary rocks and volcanics. In consolidated sandstones and shales, groundwater can occur both in the pore space in the rock matrix and within fractures and joints, whereas in the volcanics groundwater is generally only associated with fractures and joints. In the absence of fracturing, the inter-bedded and laminated nature of the Napperby and Purlawaugh Formations is likely to restrict vertical groundwater flow in these formations.

Shallow groundwater intersections at depths of 15m to 30m below surface are associated with the weathered and fractured strata of the Garrawilla Volcanics. Between 35m and 75m below surface, groundwater intersections within a confined to semi-confined fractured rock aquifer occur within the Purlawaugh, Napperby and Garrawilla Volcanics formations. Deeper groundwater intersections, typically associated with the fractures in the Basalt Sill and Napperby Formation, are encountered from 74m to 144m below surface. The pump testing of piezometers within the Hoskissons Coal Seam, Arkarula Formation and Pamboola Formation encountered groundwater, however, low permeability values and slow recharge rates suggest the three formations are unlikely to provide significant groundwater intersections.

Groundwater Investigations Undertaken by Aquaterra (2009) for the Stage 2 Longwall Project

Additional monitoring bores have been installed within and surrounding the Mine Site since the completion of the Stage 1 groundwater assessment. These additional installations bring the total dedicated groundwater monitoring bores within the monitoring network to 26. **Figure 4B.9** presents the location of the groundwater monitoring bores, targeting the principal

hydrogeological units of the Mining Area, on the Mine Site[2]. Monitoring of groundwater levels in 20 of the 26 piezometers (P1 to P20) and 12 existing registered bores (WB1 to WB12) indicates that groundwater levels in most bores have generally been very stable and are not influenced greatly by direct rainfall recharge.

Permeability testing undertaken by Aquaterra (2009) (by falling head slug tests) were conducted on the new monitoring bores (constructed since the Stage 1 testing) and a selection of Stage 1 monitoring bores. The test results for both the Stage 1 and Stage 2 Longwall Project tests are summarised in **Table 4B.7**.

Table 4B.7
Permeability Testing Results for Selected Monitoring Bores

Monitoring Bore ID[1]	Screen Interval (m bgl)	Hydraulic Conductivity(K) (m/day)			Target Formation
		Stage 1 Test Results[2]	Stage 2 Test Result[3]		
			Method		
P1	44 – 50	NT	Slug	0.11	Garrawilla Volcanics
P2	44 – 50	NT	Slug	0.057	Napperby Formation
P3	34 – 40	NT	Slug	0.03	Pamboola Formation
P4	24 – 30	NT	Slug	0.004	Napperby Formation
P5	24 – 30	NT	Slug	0.002	Pamboola Formation
P6	78 – 90	NT	Slug	0.029	Pilliga Sandstone
P7	78 – 90	NT	Slug	0.19	Pilliga Sandstone
P8	57 – 63	NT	Slug	0.017	Purlawaugh Formation
P9	24 – 30	0.41	NT	0.032	Purlawaugh Formation
P10	118 – 130	NT	Slug	0.049	Napperby Formation (no sill)
P11	44 – 50/ 24 – 40	0.0007	Slug	0.00055	Napperby Formation
P12	84 - 90	0.0016	Slug	0.09	Napperby Formation above sill
P13	24 - 30	0.068	Constant Rate -DD	0.44	Garrawilla Volcanics / Napperby Formation
			Constant Rate - Recovery	0.016	
			Slug	0.13	
P15	24 – 30	0.047	NT		Garrawilla Volcanics
P16	137 - 146	NT	Slug	0.003	Garrawilla Volcanics
P17	47 - 56	NT	Slug	0.0028	Purlawaugh Formation
P18	143 - 146	0.0086	Slug	0.013	Hoskissons Coal Seam
P19	184 - 187	0.0028	Slug	0.023	Pamboola Formation
P20	159 - 162	0.012	Slug	0.013	Arkarula Formation
GWB4S	57 – 63	0.0011	NT		Purlawaugh Formation
Claremont Bore	?	NT	Constant Rate - Recovery	2.0[4]	Garrawilla Volcanics

NT = No Test
Note 1: See **Figure 4B.9** Note 2: Recorded by GHD (2006) or RCA (2007) Note 3: Recorded by Aquaterra (2009)
Note 4: The calculated hydraulic conductivity was assessed to be approximately 2m/day based on a measure transmissivity of $75 m^2$/d and an aquifer thickness of 37m. This result indicates a higher permeability for the volcanic unit than normally encountered and is probably related to localised fracturing.

Source: Modified after Aquaterra (2009) – Table 3.2

2 It is noted that several monitoring bores located to the west (P7), north (P5) and east (P3) of the Mine Site are beyond the coverage of **Figure 4B.9**.

On the basis of the hydraulic conductivity results presented in **Table 4B.7** the hydraulic conductivity within the geological units of the Mine Site has been summarised as follows.

- Several zones of elevated hydraulic conductivity occur within various formations (up to 0.44m/d in the Garrawilla Volcanics and the Pilliga Formation). Moderately high conductivity (0.09m/day) was also found in the Napperby Formation (above the basalt sill).
- Other units show a wide range of conductivities (0.0005m/d to 0.03m/d), with the higher conductivities generally in sub-crop areas. The mean conductivity of the Purlawaugh Formation and Basalt Sill is an order of magnitude lower (0.01m/d to 0.02m/d). All formations are assumed to be fractured and range from unconfined to semi-confined.
- The geological units underlying the Basalt Sill are characterised as being of low inherent permeability. The mean permeability of the Napperby Formation (below the sill) and the Digby Formation range from 1 x 10-4 m/d to 8 x 10-5 m/d.
- The mean permeabilities of the Black Jack Group, comprising the Hoskissons Coal Seam, Arkarula Formation/Brigalow Formation and the Pamboola Formation, ranged from 2 x 10^{-3} m/d to 3 x 10^{-2} m/d.

4B.2.2.1.3 Groundwater Systems and Flow Patterns

By reviewing the information gathered on local hydrogeology (see Section 4B.2.2.1.2), Aquaterra (2009) identifies two groundwater flow systems occur below the Mine Site, namely a shallow aquifer system and a deep aquifer system.

The shallow groundwater system occurs in the upper part of the Permo-Triassic sequence where it is weathered and locally fractured. This shallow aquifer effectively occurs within a range of geological units, due to the westerly dip on the strata. Groundwater in this aquifer is localised and influenced primarily by topography and local surface drainage, ie. flow is north to northeast towards the Namoi River. Recharge to the shallow aquifer system is believed to occur by infiltration of rainfall through the surficial alluvium and regolith (weathered material of the Surat Basin), with discharge occurring at the lower regional drainage lines.

The deeper aquifer system is influenced by regional features such as basin structure and regional recharge and discharge processes, and groundwater flow occurs primarily in fractures. Visual inspection of drill core suggests that the stratigraphic units are heterogeneous with aquifer properties varying depending on the nature and continuity of fractures and joints. The limited number of formation-specific monitoring points over the Mine Site makes it difficult to accurately map groundwater flow patterns. An analysis of temperature variations within the monitored bores indicates an increase in temperature at depths which correspond to the Hoskissons Coal Seam. This has been interpreted to correspond to increased groundwater flow within the coal seam.

4B.2.2.2 Surface Water – Groundwater Interaction

Groundwater Recharge

The main recharge mechanism for the groundwater within the Mine Site is local infiltration of rainfall with recharge rates a function of rainfall intensity, evaporation, vegetation coverage and density, topography and soil properties of the surficial aquifer material. Recharge occurs by direct infiltration of rainfall and local runoff into the unconsolidated surficial material, comprising alluvium/colluvium in low-lying areas, and the weathered zone of the bedrock (regolith layer) in more elevated areas. Water percolates downwards until reaching a zone of reduced permeability (top of fresh bedrock beneath the alluvium/colluvium, or the base of weathering), and then flows laterally above the less permeable aquitard layer.

The Permian and Triassic aquifers of the Mine Site are also recharged at the outcrop or sub-crop of the Surat Basin units (beneath the Quaternary alluvium or weathered ‘regolith’ layer). Where permeable areas of the Jurassic, Triassic and/or Permian formations sub-crop beneath alluvium, colluvium or highly weathered bedrock, recharge can also occur to these hard rock formations by downward percolation through the unconsolidated materials.

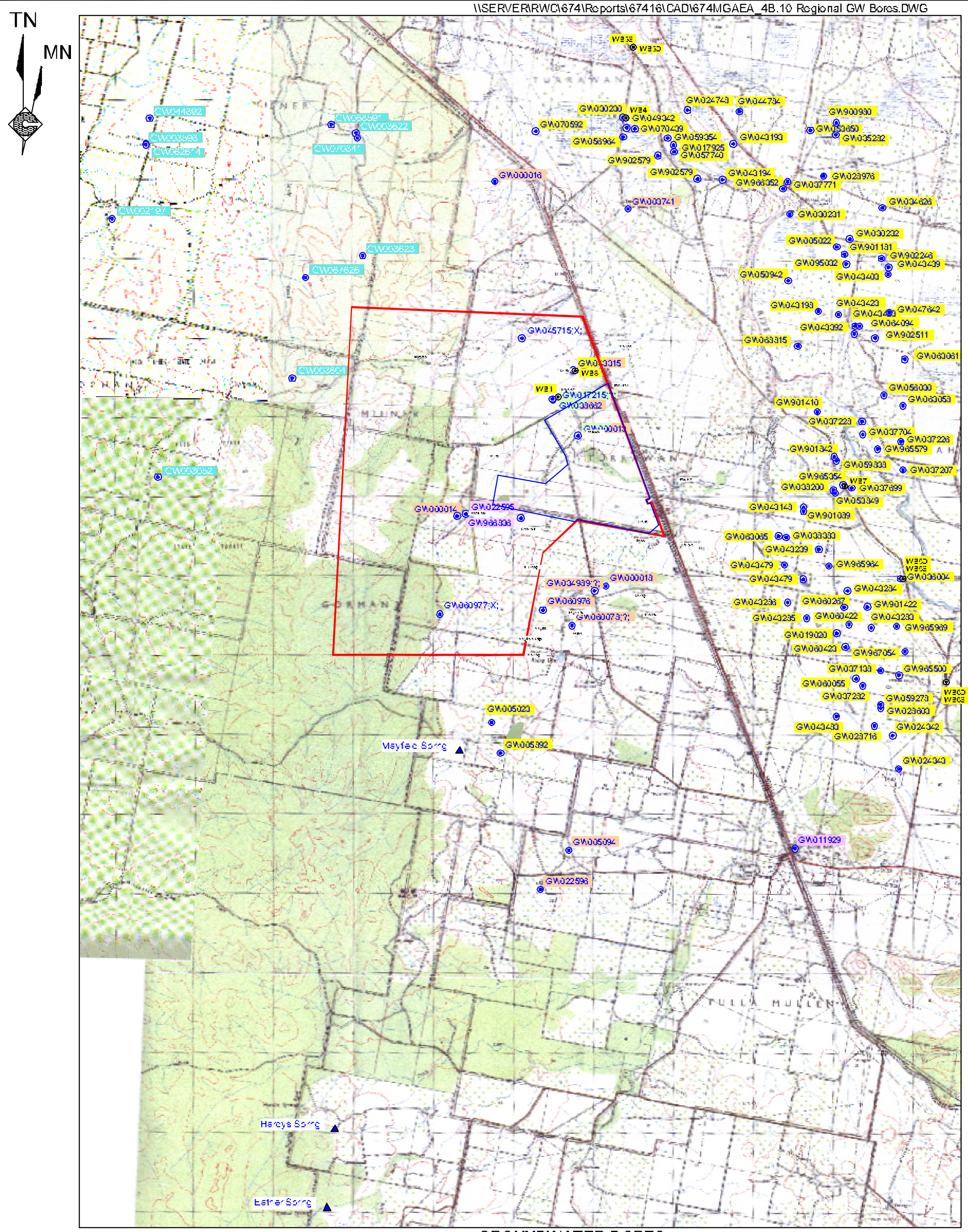
Natural groundwater discharge occurs through evapotranspiration, seepage and spring flow where the watertable intersects the ground surface, and through base flow contributions to creeks and rivers, including possible discharge to the alluvium in some locations. Local spring or seepage discharges may also occur wherever a permeable fractured zone within a hard rock unit crops out, such as on hillsides or the flanks of creeks and gullies, if the water level in that unit is higher than the ground surface.

Groundwater Discharge

With the possible exception of the area of the Mine Site around P13, where a perched groundwater aquifer was measured at 5m below surface (formed by the sub-crop zone of the Garrawilla Volcanics in a low lying area adjacent to a local drainage channel), Aquaterra (2009) reports that as groundwater generally occurs >15m below surface across the Mine Site, there is a very low likelihood for groundwater discharge to surface water systems.

To the south of the Mine Site, a spring discharging to surface (referred to as the “Mayfield Spring”) has been identified and is utilised for stock watering (**Figure 4B.10**). It is believed to be derived from the Purlawaugh Formation with a flow rate not exceeding 0.1L/s. The Department of Environment, Climate Change and Water – NSW Office of Water (NOW) has also recorded the occurrence of an additional two groundwater derived springs further south of the Mine Site. **Figure 4B.10** identifies the locations of these groundwater dependent ecosystems to the south of the Mine Site referred to locally as Hardys Spring and Eather Spring.

More regionally, Aquaterra (2009) report that there is probably some discharge from the Jurassic-Permian formations to the Namoi Valley alluvium to the east of the Mine Site.



REFERENCE
- Mine Site Boundary
- Pit Top Area Boundary
- Registered Groundwater Bore
- Spring

GROUNDWATER BORES
Aquifer / Formation

- Alluvium
- Pilliga / Purlawaugh
- Garrawilla Volcanics
- Napperby
- Basalt Sill
- Digby
- Hoskisson's Coal Seam
- Other Strata (below coal seam)

SCALE 1:150 000

2.5 0 2.5 5.0 7.5 km

Groundwater Bore Source: DNR Groundwater Database (as provided by GHD (2007)

Figure 4B.10
REGIONAL REGISTERED GROUNDWATER BORES AND IDENTIFIED SPRINGS

4B.2.2.3 Groundwater Quality

Groundwater monitoring undertaken since the approval of the Stage 1 Narrabri Coal Mine has been analysed and compared to the groundwater quality analysis of GHD (2007) by Aquaterra (2009) to gain an understanding of the groundwater contained within the various geological units above the Hoskissons Coal Seam. Aquaterra (2009) reports that groundwater quality is variable, both in terms of key field parameters such as salinity and pH, and also in terms of major and minor hydrochemical constituents. The analytical testing of groundwater data collected from the geological units that would potentially be affected by the Longwall Project indicates the following.

- Groundwater pH is in the neutral to slightly alkaline range of 6.7 to 8.2.
- **Figure 4B.11** presents the distribution of salinity (as mg/L TDS) measured at various boreholes over the Mine Site. Groundwater salinity varies considerably, with recorded values of total dissolved solids (TDS) ranging from less than 100mg/L in the Garrawilla Volcanics and less than 500 mg/L within the Pilliga and Purlawaugh formations, to more than 16,000 mg/L in the Napperby Formation and the Basalt Sill.
- Limited sampling from the Hoskissons Coal Seam suggests that salinity within the coal seam would be around 2000mg/L (TDS), which is lower than overlying Triassic and Permian strata where salinities ranging from 6000mg/L to 8000mg/L TDS are typical. Aquaterra (2009) notes, however, that recent groundwater sampling and analysis from the SIS drilling program suggests that the TDS concentration within the Hoskissons Coal Seam may be up to 8000mg/L. Aquaterra (2009) suggests that the lower salinity determined from earlier monitoring may be limited to areas close to outcrop/subcrop.
- Laboratory analyses of groundwater samples indicate moderately elevated dissolved metals concentrations in groundwater. Notably, most sampled groundwater exceeded the ANZECC (2000) dissolved metal concentration guideline values for Cu, Pb, Ni and Zn. A number of groundwater samples (from bores P1, P2, P4, P5, P10 and P11) exceed the ANZECC (2000) guidelines for Mn as well.
- An analysis of major ions contained within the sampled groundwater identified that all groundwater was low in sulphate, but there is a broad distribution from bicarbonate to chloride dominance among the other anions. Chloride dominance occurs in the higher salinity waters from deeper intersections, particularly in the Pamboola Formation and the Napperby Formation. Bicarbonate dominance is normally associated with low salinity, and is typically an indicator of recent recharge or proximity to recharge in the flow system. An exception to this is found in the groundwater of the Hoskissons Coal Seam and Arkarula Formation where bicarbonate dominates despite relatively high salinity. In this case, the high bicarbonate is believed to be derived from some mineralisation source in the Permian sequence.

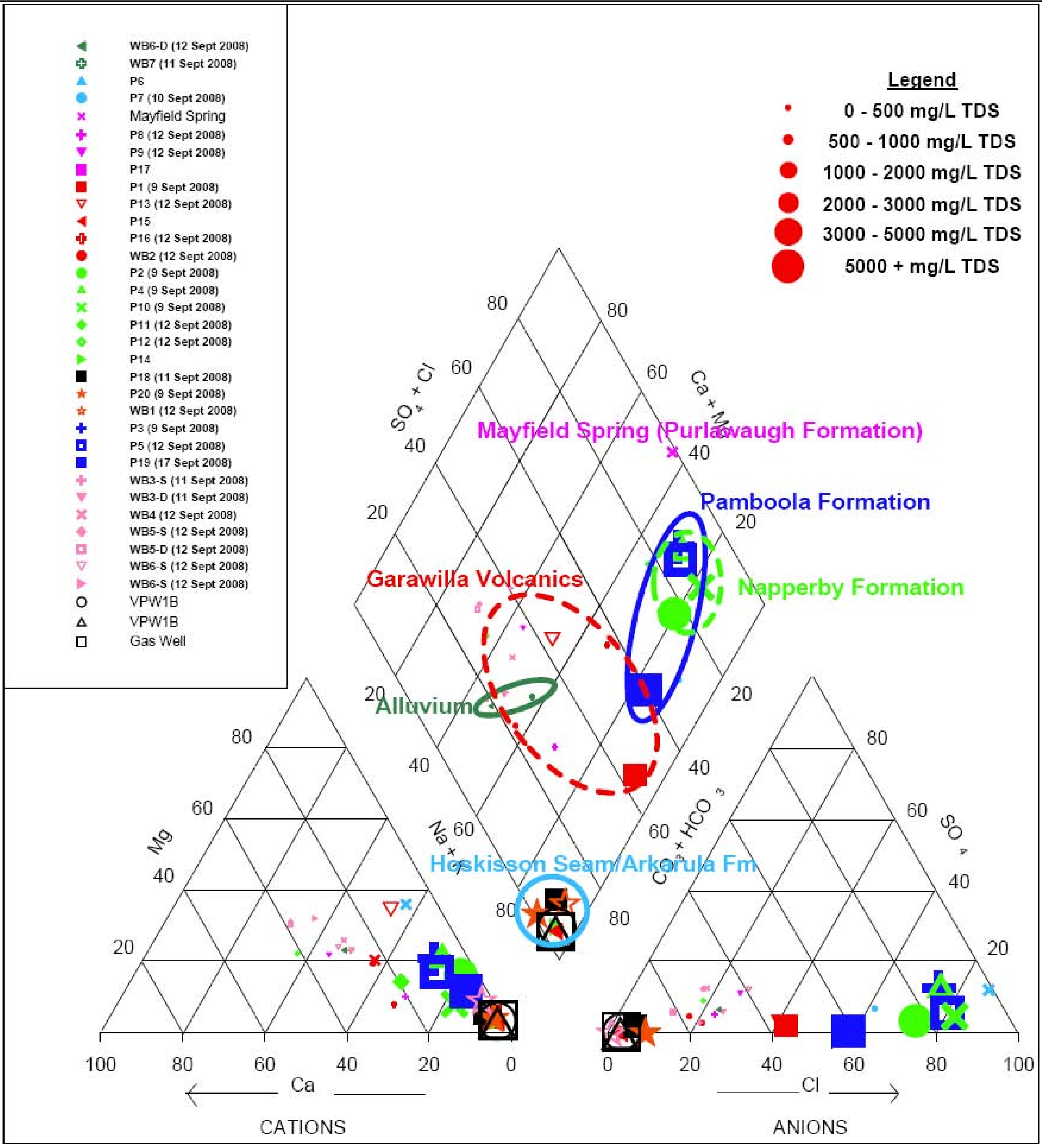


FIGURE 4B.11
GROUNDWATER QUALITY

Source: Aquaterra (2009) – Figure 4.9

4B.2.2.4 Water Use and Availability

Groundwater use within the boundaries of the Mine Site is restricted to a number of low yielding groundwater bores used for stock and domestic purposes. Surrounding the Mine Site, ie. within 5km of the Mine Site, groundwater is also used predominantly for domestic or agricultural purposes, with the extent of use invariably dependent on the quality of water and/or

yield available from the bore. A summary of groundwater use, based on consideration of the former DWE groundwater bore database and general liaison between the Proponent and local landholders, is as follows.

- Numerous bores are registered in the Quaternary alluvium of the Namoi River Valley (Lower and Upper Namoi Alluvial Groundwater Source) (see **Figure 4B.10**). These bores are typically shallow bores screened within the Quaternary alluvium and the pumped water used for domestic, stock and irrigation purposes. Some of the deeper irrigation bores are up to 80m deep and have yields of up to 90L/s.
- To the south, north and west of the Mine Site, some groundwater bores screen the Pilliga Sandstone and possibly other deeper Jurassic sediments. The groundwater of these bores is generally non-saline with bore yields of between 0.1L/s and 0.8L/s. The standing water levels vary between 50m to 80m below surface level close to the Mine Site to typically between 30m to 40m depth further to the northeast. Other groundwater bores on or surrounding the Mine Site with better quality water screen the Garrawilla Volcanics.
- A limited number of groundwater bores within 5km of the Mine Site are identified as screening the deeper formations of the Gunnedah Basin Groundwater Source. This water is generally more saline than water drawn from the geological units of the intake beds of the GAB, with yields less than 2L/s.

As noted in Section 4B.2.2.2, GDEs to the south of the Mine Site, occurring as groundwater derived springs, draw water from the Purlawaugh Formation.

It is noted that Narrabri Shire Council sources the town water supplies for both Narrabri and Boggabri from groundwater bores within the Upper Namoi Alluvial Groundwater Source. Discussions held with Narrabri Shire Council personnel indicate that while in recent times recovery times within these bores has increased slightly, groundwater draw from these bores remains well below their licenced and operational capacity.

4B.2.2.5 Regulatory Framework

Water sharing plans (WSPs), ie. statutory instruments under the *Water Management Act 2000*, have been prepared for the Great Artesian Basin Groundwater Sources (with the Mine Site located within the Southern Recharge (non-artesian) zone of the GAB) and the Upper and Lower Namoi Groundwater Sources (the Mine Site is located within the Upper Namoi Groundwater Source). These WSPs are designed to provide long term environmental protection and achieve a level of sustainability of the groundwater resources as well as directing how water would be allocated and shared among the different water users and apply the goals and principles of the State Groundwater Policy at the regional and local level.

The NSW EPA 2003 State of the Environment Report identified groundwater use in the Great Artesian Basin (GAB) Groundwater Sources exceeded 100% of the sustainable yield. In the Upper Namoi GWMA, groundwater use is 70% to 100% of sustainable yield (DEC, 2003). As a consequence, the Upper Namoi and GAB Groundwater Sources have been identified by the former Department of Water and Energy as high risk aquifers (DLWC, 1998).

4B.2.3 Potential Impacts on Groundwater Quality and Availability

4B.2.3.1 Potential Sources of Groundwater Contamination

The potential sources of groundwater contamination include:

- fuel, oil or other hydrocarbon spills or leaks;
- recharge of saline water and/or concentrated brine to fresh water aquifers; and
- explosives residues.

Based on experience elsewhere, explosives residues would be unlikely to have any measurable effect on the chemistry of the groundwater. In any event, negligible quantities of explosives would be used throughout the life of the mine. Potential contamination by fuel, oil or other hydrocarbons, and/or localised increases in the salinity of currently non-saline aquifers, are therefore the main issue that needs to be managed across the Mine Site.

4B.2.3.2 Potential Impacts on Groundwater Availability

Longwall mining would create a pressure gradient between the aquifers surrounding the underground mine (high pressure) and void (low pressure) resulting in the movement of groundwater flow into the underground void. This groundwater would be pumped from the underground mine resulting in the continuance of these mine in-flows. As water is drawn from the aquifers of the underground mine (Hoskissons Coal Seam) and immediately above, the vertical movement of groundwater from aquifers higher in the geological sequence downwards (from higher to lower pressure) may be accelerated. Ultimately, this movement of groundwater into the underground mine or accelerated vertical movement of groundwater would lead to a lowering of the water levels within the intercepted aquifers, which may subsequently impact on the yield of the groundwater bores on landholdings surrounding the Mine Site (see **Figure 4B.10**).

Continuous sub-surface fracturing resultant from mine subsidence may increase vertical movement of groundwater from the strata higher in the geological sequence by creating higher permeability flow paths along the cracks. This may increase the lowering of groundwater levels within affected geological units, thereby increasing the impact on groundwater availability and yield. Flow between geological units higher in the sequence, not directly connected to the underground mine, may also occur as a result of discontinuous sub-surface fracturing. The impact of this discontinuous fracturing would be less influential on groundwater levels and yields as the pressure gradient between the units linked by cracking would not be as great as that created by continuous cracking into the underground mine. The results of subsidence modelling provided in Section 4B.1.6 have been used to assess the impact of mine subsidence on mine in-flows and movement of groundwater between geological units, and subsequently groundwater levels and availability.

The potential lowering of shallow and non-saline aquifers which recharge the GAB and Upper Namoi Groundwater Sources also has the potential to affect groundwater dependent ecosystems (GDEs) which may be dependent to varying degrees on this water supply.

4B.2.4 Management Measures and Mitigation Measures

4B.2.4.1 Groundwater Contamination

Although it is not anticipated that the Longwall Project would have a significant or long-term impact on the level or quality of groundwater beneath landholdings surrounding the Mine Site, specific controls and mitigation measures have been proposed by the Proponent for surface hydrocarbon and saline water management. These measures are described in relation to the overall surface water management system in Section 4B.3.4.2.5.

It is currently proposed to re-inject concentrated brine solution into the completed underground workings following the cessation of mining. Transfer of the brine from the Brine Storage Area to the injection points (goaf gas drainage holes likely to be located over the western-most longwall panels) would be managed to minimise the risk of pipeline leakage or break. A HDPE pipe would be placed within an excavated channel such that should a leak occur, the discharged brine would remain within the channel. The length of the pipe would be regularly inspected to ensure no breaks or leaks. At the time of installation, additional monitoring controls would be considered, eg. flow meters linked by telemetry. In the event of a large spill or leak, the spill control measures outlined in Section 4B.3.4.2.5 would be implemented.

Based on modelling of the injection process, the brine would be re-injected over a 2 year period. This would ensure that groundwater levels do not rise to elevations which would have allowed saline water to enter the Garrawilla Volcanics via the subsidence zone. With a 2 year re-injection period, Aquaterra (2009) established that water levels in the goaf area would not rise above the top of the Napperby Formation during the re-injection period.

Finally, the Proponent is committed to continuing its ongoing investigations into alternative uses for the brine (see Section 2.14.4). Feasible and cost effective alternatives to brine re-injection will continue to be considered throughout the life of the mine.

4B.2.4.2 Groundwater Availability

Given the bulk of the groundwater in-flows would originate from the Gunnedah Basin Groundwater Source geological units which are saline and, with the possible exception of fractured zones, low in permeability, the likely impact on groundwater levels, bore yields and groundwater availability generally is predicted not to be significant. As such, emphasis in the management of groundwater availability (and groundwater quality) would be placed on the implementation of a groundwater monitoring program, as recommended by Aquaterra (2009). Section 4B.2.6.1 presents further detail on the preparation of the groundwater monitoring program while Parts 6 and 16 of **Table 5.1** present the details of commitments made in relation to this groundwater monitoring program.

4B.2.5 Assessment of Impacts

4B.2.5.1 Impact Assessment Criteria

Water Quality

Table 4B.8 presents the National Environment Protection Measure (NEPM) groundwater quality criteria (NEPC, 1999). Groundwater quality would be assessed predominantly against the NEPM livestock guideline levels, given this is the predominant use of groundwater in the vicinity of the Mine Site.

Impacts on the water quality parameters of pH, TDS, other anions and heavy metals (not considered by the NEPM criteria) would be based on comparisons to baseline monitoring of groundwater quality taken from all groundwater bores within the Mine Site.

Groundwater Levels and Water Availability

Groundwater levels and the saturated thickness within bores on neighbouring landholdings would be monitored with any variations over 15% considered a significant impact given these levels would be expected to naturally vary by this much. The criteria for groundwater level and saturated thickness has therefore been determined to be a >15% decrease in water level or saturated thickness.

Table 4B.8
Groundwater Quality Criteria

Analyte	Agricultural Irrigation (mg/L)	Livestock (mg/L)
Arsenic (total)	0.1	0.5
Cadmium	0.01	0.01
Chromium (Total)	1.0	-
Chromium (VI)	0.1	1.0
Copper	0.2	0.5
Lead	0.2	0.1
Manganese	2.0	-
Mercury (total)	0.002	0.002
Nickel	0.02	1.0
Zinc	2.0	20.0
Calcium	-	1 000
- No published values		
Source: Modified after NEPC (1999)		

4B.2.5.2 Assessment Methodology

4B.2.5.2.1 Groundwater Model Construction

The extent of mine in-flows into the underground workings and the effect the Longwall Project would have on groundwater levels, borehole yields, groundwater level re-establishment and availability of groundwater from existing surrounding bores has been predicted using the United States Geological Survey (USGS) finite-difference groundwater flow modelling code MODFLOW 2000 (Harbaugh et al., 2000) in conjunction with the SURFACT module (SURFACT Version 3, HydroGeoLogic, 2006 – cited in Aquaterra, 2009).

The MODFLOW package is the industry-leading groundwater modelling software, and has advanced modules for simulating surface water and groundwater interaction which allows for the assessment of impacts on creeks and rivers. Aquaterra (2009) has identified that MODFLOW has two notable limitations when simulating longwall mining.

- MODFLOW does not allow aquifer properties to change with time as mining progresses. In order to overcome this potential limitation, the model simulation has been run in a series of consecutive time slice models, with model hydraulic parameters changed from one time slice to the next to reflect the mining advance and associated subsidence.

- Standard MODFLOW cannot routinely simulate free draining conditions in rock layers above a longwall panel. By using the SURFACT module, saturated and unsaturated flow conditions can be simulated allowing for more stable drying and re-wetting of cells in thin model layers (such as coal seams and thin aquitards).

Aquaterra (2009) reports that the modelling and hydrogeological assessment generally was undertaken in accordance within the '*Guidelines for Management of Stream/Aquifer Systems in Coal Mining Developments – Hunter Region*' (DNR, 2005), and the modelling was undertaken in accordance with the best practice guideline on groundwater flow modelling (MDBC, 2001).

The extent of the model used for the Longwall Project extends that constructed by GHD (2007) to cover an area which includes the Boggabri Ridge extending west of the Mullaley Sub-basin and parts of the Gunnedah Basin, Upper Namoi and intake beds for the GAB Groundwater Sources. The model domain was also extended to capture the Namoi River alluvial aquifer system.

Similar to the GHD (2007) model, the Longwall Project groundwater model contains 11 active layers representing the major hydrogeological units of the Mine Site (see **Table 4B.9**) and differentiates between the Gunnedah Basin sequence (Gunnedah Basin GWMA), the Jurassic formations which comprise the Great Artesian Basin GWMA and Upper Namoi Alluvium GWMA.

A significant change made to the model of GHD (2007) was the direct physical disconnection of basal units, ie. Digby Formation and Blackjack Formation, from any direct connection with shallow alluvial sediments associated with the Namoi River. Aquaterra (2009) notes that this is in keeping with the geological model for the local stratigraphy, and in recognition that the Digby Formation and the Black Jack Formation have been partly truncated by the overlying Napperby Formation.

Table 4B.9
Conceptual Model Structure

Model Layer	Formation	Groundwater Source
1	Alluvium	Upper Namoi Alluvium
2	Pilliga Sandstone	Great Artesian Basin
3	Purlawaugh Formation	
4	Garrawilla Volcanics	
5	Napperby (above Sill)	Gunnedah Basin
6	Basalt Sill	
7	Napperby (below Sill)	
8	Digby Formation	
9	Hoskissons Coal Seam	
10	Arkarula Formation	
	Brigalow Formation	
11	Pamboola Formation	

Source: Modified after Aquaterra (2009) – Table 4.3

Values for the initial input parameters of the model were generated through a review of GHD (2007), historic literature and mapping available for the region and local area, as well as additional on-site testing conducted since the approval of the Stage 1 Narrabri Coal Mine. Aquaterra (2009) provides a detailed description of the on-site testing completed and historic literature reviewed.

The Aquaterra (2009) model was then calibrated, firstly in steady state mode to simulate long term average aquifer conditions and then in transient mode to improve the model calibration by means of a historic match to the observed groundwater levels during the period November 2007 to August 2008. The calibrated aquifer hydraulic parameters resulting from the steady and transient model calibration are summarised in **Table 4B.10**.

Table 4B.10
Calibrated Aquaterra (2009) Model Aquifer Parameters

Model Layer	Formation	Hydraulic Conductivity (m/day)		Storativity	
		Horizontal (Kh)	Vertical (Kv)	Unconfined Sy (-)	Confined S (-)
1	Alluvium	0.5-5.0	0.0005-0.005	0.1	$5x10^{-6}$
2	Pilliga Sandstone	0.001-0.5	0.000005-0.0005	0.1	
3	Purlawaugh Formation	0.001-0.3	0.000005-0.0003	0.1-0.2	$5x10^{-6}$
4	Garrawilla Volcanics	0.001-0.3	0.000002-0.0003	0.1	
5	Napperby Formation (above Sill)	0.001-0.05	0.000002-0.0001	0.1	$5x10^{-6}$
6	Basalt Sill	0.001-0.01	0.000002-0.00005	0.1	
7	Napperby Formation (below Sill)	0.001-0.01	0.000002-0.000008	0.1	$5x10^{-6}$
8	Digby Formation	0.001-0.01	0.000002-0.000005	0.1-0.15	
9	Hoskissons Coal	0.005-0.01	0.000002	0.1-0.15	$5x10^{-6}$
10	Arkarula Formation	0.001-0.01	0.000001	0.1	$5x10^{-6}$
11	Pamboola Formation	0.01	0.001	0.1	$5x10^{-6}$
Source: Modified after Aquaterra (2009) – Table 6.7					

In general, overall simulated transient hydrograph results coincided very well with the actual hydrographs, confirming the model as a good predictive tool to simulate the complex multi-layer Narrabri aquifer system.

Further detail on the design and calibration and running of the model is provided in Aquaterra (2009) (*Sections 6.2 to 6.5*).

4B.2.5.2.2 Predictive Modelling (Base Case)

Using the calibrated set of boundary and hydraulic properties identified in Section 4B.2.5.2.1 (and **Table 4B.10**), the impact of the Longwall Project on the hydrogeological conditions of the Mine Site was simulated. Specific impacts of the longwall mining on the following parameters were then measured.

- Mine in-flow rates.
- Regional changes in groundwater levels, both during mining and after mine closure.
- Changes in base flow contributions to surface watercourses, particularly the Namoi River system.

- Impacts of re-injecting concentrated brine into the underground void at the completion of longwall mining. Potential impacts on groundwater quality and local groundwater table recovery were considered.

The "Base Case" simulation of potential mining impacts involved a simulation comprising 14 time slices, with the first time slice representing 3 years (from commencement of the Longwall Project) and then at 2 yearly intervals for the remaining life of the mine. The Base Case model also provides for hydrogeological conditions 100 years post-completion of the Longwall Project.

The hydraulic properties of the model cells within the region above the progressively collapsed goaf of the completed longwall panels was changed progressively to reflect progressive effects of subsidence fracturing. As the longwall mine progresses, it is expected that mine in-flows would increase (as the total void space created increases). However, to simulate the fact that once longwall mining commences in the southern longwall panels (LW14 to LW26), in-flowing groundwater could be retained in the down-dip (western) section of the underground mine (and would not need to be dewatered), the drain cells of the model associated with the down-dip section of the mine were turned off.

Post-mining recovery was simulated for a period of 100 years from the completion of mining. The recovery modelling simulated the re-injection of brine stored within the Brine Storage Area over a two year period into 20 large diameter goaf gas drainage bores screened within the goaf zone of the Hoskissons Coal Seam. Based on a water balance for the Mine Site prepared by WRM (2009) (see Section 4B.3.5), approximately 2 000ML of brine would be re-injected. In order to ensure that groundwater levels would not rise to elevations which could allow saline water to enter the Garrawilla Volcanics (via the subsidence zone), a 2 year re-injection period was used modelled. The results from the end of re-injection were used as the initial conditions for modelling the remaining 98 year recovery period.

Further detail on the simulation of the changing model conditions associated with the progressive gate road headings, longwall mining and goaf collapse is provided in Aquaterra (2009) (*Section 6.5*).

4B.2.5.2.3 Predictive Modelling (Sensitivity and Uncertainty Analysis)

Sensitivity Analysis

In order to assess the sensitivity of the model calibration to the assumed input parameters and boundary conditions, Aquaterra (2009) has undertaken a sensitivity analysis by sequentially changing key input parameters or boundary conditions, and evaluating the impacts of the changes on the calibration statistics. Any parameter change that resulted in a significant change to the scaled root mean square (SRMS) value of the model was identified as a sensitive parameter in the model.

Sensitivity analyses were undertaken on the horizontal conductivity, vertical conductivity and recharge parameters of the model to determine the impact on the SRMS value of the model. Aquaterra (2009) found the model was not highly sensitive to either horizontal or vertical hydraulic conductivity of the in-situ rock strata. However, it was assessed that the model would likely be sensitive to the hydraulic properties that were assumed for the subsidence fracture zone extending from the goaf.