APPENDIX 4

Groundwater Assessment

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Yancoal Australia Ltd
Level 26, 363 George Street
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Attention: Mark Jacobs

Dear Mark,

Re: Austar Coal Mine – LWB4-LWB7 Modification – Groundwater Assessment

1. Background

The Austar Coal Mine is an underground mine located about 10 km southwest of Cessnock in the Newcastle Coalfields of NSW. The Austar Coal Mine incorporates the former Pelton, Ellalong, Cessnock No. 1 (Kalingo) and Bellbird South Collieries and is located in an area which has been an active mining area over many years. The locations of the Austar Coal Mine and previous underground workings in the area are shown on **Figure 1**.

The Austar Coal Mine is owned by Yancoal Australia Limited (Yancoal), and operated by its wholly owned subsidiary Austar Coal Mine Pty Ltd (Austar). Following its purchase in 2004, Austar recommenced underground mining in the Bellbird South Colliery area in 2005 under Development Consent DA29/95 (the Bellbird South Consent), later employing the Longwall Top Coal Caving (LTCC) mining method after modifications to the Bellbird South Consent were approved. Austar has completed coal extraction from the Greta Seam from the Bellbird South Colliery area (Longwalls A1 and A2 in Stage 1, Longwalls A3 to A5A in Stage 2), and from the Austar Coal Mine Stage 3 area (Longwalls A7 and A8) employing the LTCC mining method. Austar has approval to mine Longwalls A9 to A19 in Stage 3.

Austar gained approval on 29 January 2016 to modify Development Consent DA29/95 to allow the transfer and processing of coal from three additional Longwalls LWB1, LWB2 and LWB3, which are located to the south of the previously mined Longwalls A2 to A5A and east of Longwalls 1 to 9A at the (former) Ellalong Colliery (**Figure 2**). Austar is now seeking approval for a further Modification to DA29/95 to allow mining and processing of coal from four further longwalls LWB4, LWB5, LWB6 and LWB7 (LWB4-B7 – the proposed Modification), which are located immediately to the north of the approved LWB1 to LWB3 (see **Figure 2**).

Umwelt (Australia) Pty Ltd (Umwelt) has been engaged by Yancoal to prepare an Environmental Assessment (EA) for the proposed Modification. This letter report presents a qualitative groundwater impact assessment for the proposed four additional longwall panels, which has been carried out by Dundon Consulting Pty Ltd to support the EA. A review of existing available groundwater information was carried out by Umwelt to support the preparation of this groundwater impact assessment.

2. Nature of the Modification

In summary, the proposed Modification comprises the following:

- transfer and processing of coal from LWB4-B7 via the existing Bellbird mains; and
- extending the development consent area of the Bellbird South Consent to encompass LWB4-B7 (the proposed Modification Area – refer to **Figure 2**).

No other changes to the approved mining operations or existing surface facilities are proposed as part of the modification.

The proposed longwalls will have void lengths of approximately 1,125 m (LWB4), 1,105 m (LWB5), 1,065 m (LWB6) and 725 m (LWB7), and a void width including first workings of approximately 237 m (MSEC, 2017). The Greta Seam thickness in the proposed Modification area ranges from 3.7 to 4.8 m, and it is proposed that a constant seam thickness of 3.4 m will be mined by conventional longwall mining methods.

The locations of the proposed LWB4 to LWB7 are shown on **Figure 2**.

3. Groundwater Impact Assessment Requirements

Umwelt has been engaged by Yancoal to prepare an EA to support the proposed Modification, and their scope of work included aspects of groundwater assessment, viz:

- Review existing Austar Coal Mine subsidence and groundwater monitoring data;
- Review the October 2007 Connell Wagner groundwater assessment for the Austar Coal Mine;
- Review the 2013 Aurecon groundwater verification report following completion of LWA5;
- Review the draft subsidence impact assessment for the proposed Modification;
- Collate relevant groundwater monitoring results; and
- Undertake preliminary assessment relevant to the proposed Modification.

The above groundwater review and preliminary assessment work has been carried out by Umwelt and provided to Dundon Consulting Pty Ltd as briefing material to support the preparation of a qualitative groundwater impact assessment for the proposed Modification by Dundon Consulting Pty Ltd.

4. Description of Existing Hydrogeological Environment

The existing hydrogeological environment has been extensively described in previous groundwater reports, including the RPS Aquaterra (2014) groundwater monitoring and modelling plan for EL6598, and the Connell Wagner (2007) groundwater impact assessment report on future mine development at the Austar Coal Mine. The summarised description of the existing hydrogeological environment below draws heavily on these documents supplemented by the results of groundwater monitoring.

4.1 Climate

The lower Hunter Valley area where the Austar Coal Mine is located experiences a warm temperate climate, with seasonal variations from hot wet summers to mild dry winters. Rainfall in the region is generally summer dominant, and rainfall is less than potential evaporation for most months of the year.

4.2 Topography and Drainage

The following general descriptions of the site topography and drainage are derived mainly from the 2008 Flooding and Drainage Assessment for Stage 3 (Umwelt, 2008).

The proposed longwall panels are located beneath the Quorrobolong Valley, within which the Quorrobolong Creek / Cony Creek drainage system flows in a westerly direction across the mine area, eventually flowing into Wollombi Brook which in turn flows into the Hunter River. The main drainages of the Quorrobolong Valley are Quorrobolong Creek, Cony Creek and Sandy Creek. These creeks are largely ephemeral and are often present as a series of disconnected pools during the dry season. The catchment area of the Quorrobolong valley upstream of the Ellalong Bridge (about 2 km west of the proposed Modification Area) is approximately 80 km^2.

The surface elevations within the valley floor are around 130 mAHD, while the elevation rises to around 440 mAHD at the Myall Range to the south and to around 200 mAHD at the Broken Back Range to the north.

The two northernmost proposed longwall panels (LWB6 and LWB7) partly underlie the main Quorrobolong Creek drainage. LWB4 and LWB5 are located beneath the southern flank of the valley, and the eastern end of LWB4 extends beneath the small alluvial floodplain associated with a small, unnamed, north-flowing tributary of the main system. The area within the valley floor has been predominantly cleared for grazing. The creek lines on the valley floor mostly support riparian vegetation.

4.3 Stratigraphy and Structural Geology

The Austar Coal Mine extracts coal from the Greta Coal Seam of the Late Permian aged Greta Coal Measures.

The Greta Coal Measures (GCM) comprises the Neath Sandstone, Kurri Kurri Conglomerate, Kitchener Formation (including the Greta Seam) and the Paxton Formation, and all units are predominantly sandstone, conglomerate and coal. The top of the GCM is about 20 m or so above the top of the Greta Seam.

The GCM is overlain by a thick sequence of sedimentary rock including conglomerate, sandstone and siltstone of the Branxton Formation, and other higher units of the Maitland Group, which extend from the coal measures to outcrop. The project stratigraphy is summarised in **Table 1**. The geology of the proposed Modification Area and surrounds is presented on **Figure 3**.

Table 1: Austar Coal Mine Stratigraphic Summary (after Hawley and Brunton, 1995)

Age	Stratigraphy		Lithology
Late Permian	Maitland Group	Mulbring Siltstone	Siltstone with minor claystone and sandstone lenses.
		Muree Sandstone	Sandstone with minor conglomerate and siltstone
		Branxton Formation	Conglomerate and sandstone towards base, siltstone becoming more common towards top
	Greta Coal Measures	Paxton Formation	Conglomerate and micaceous sandstone with minor claystone and siltstone beds. Coal (Pelton Coal Member) and coaly shale.
		Kitchener Formation (including the Greta Seam)	Coal with minor claystone, siltstone and sandstone
		Kurri Kurri Conglomerate	Orthoconglomerate, minor sandstone, siltstone, claystone and coal near base.
		Neath Sandstone	Sandstone, minor conglomerate siltstone and claystone
Early Permian	Dalwood Group	Farley Formation	Fossiliferous silty sandstone
		Rutherford Formation	Siltstone and minor sandstone, with thin limestone and marl horizons (Pokolbin area)
		Allandale Formation	Lithic sandstone and conglomerate containing abundant invertebrate fossils
		Lochinvar Formation	Poorly fossiliferous siltstone, claystone and sandstone and interbedded basalt flows.

Structurally the Austar Coal Mine is situated on the south-eastern limb of the Lochinvar Anticline. The Greta Seam outcrops to the north near Cessnock, and dips variably to the south-east with a general dip of around 5 to 6 degrees. Within the current mining area, the seam occurs at depths ranging up to 740 m. In the proposed Modification Area, the expected depth of cover will be between 400 m and 505 m (MSEC, 2017).

Seam thickness generally increases eastward with thicknesses of up to 7 m in the Stage 3 mining area, and it is known to split along the eastern margin of the current mine area, with an interburden lens of siltstone, claystone and sandstone known as the Kearsley Lens.

Extensive faulting and deformation is associated with the Lochinvar Anticline, with a number of prominent fault zones controlling the longwall panel layouts, notably the Swamp Fault Zone, Quorrobolong Fault and the Abernethy Fault Zone. Dykes are also present in the Austar Coal Mine and have been intersected in the historical and current workings. The most prominent of these, the Central Dyke, runs parallel with the Quorrobolong Fault and forms the eastern boundary of the Stage 2 mining area.

A thin veneer of colluvium is believed to occur over the lower valley slopes, grading into alluvium associated with the main creeks and tributary streams.

4.4 Hydrogeological Units

Within the proposed Modification Area, two aquifer systems are identified, firstly the unconsolidated surficial material that includes alluvium, colluvium and weathered bedrock, and secondly the Permian hard rock aquifer system. A third potential source of water that needs to be considered in the assessment of groundwater impacts is the water stored in abandoned mine voids (RPS, 2014; Connell Wagner, 2008).

The main sources of water that make up the groundwater regime relevant to the Austar Coal Mine operations and proposed developments in the area are as follows:

- Alluvial aquifer system associated with the Quorrobolong Creek / Cony Creek drainages and their tributaries (minor localised aquifer).
- Non-alluvial hard rock aquifers (referred to as fractured rock aquifers in previous Austar Coal Mine groundwater assessment reports, and now formally termed ‘porous’ rock aquifers). The principal water bearing components of the hard rock aquifer system are the coal seams, which are relatively more permeable than the interburden and overburden sediments. Some fractured zones are present within the upper parts of the Branxton Formation.
- Water stored within abandoned underground mine voids.

Groundwater within the alluvial aquifer in the proposed Modification Area is part of the Congewai Creek Management Zone of the Upper Wollombi Water Source and is regulated under the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources (WSPHUAWS). The non-alluvial groundwater is regulated under the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources (WSPNCFPRGWS). Both the alluvial and non-alluvial groundwater are regulated by the *Water Management Act 2000*.

4.4.1 Alluvial Aquifer System

Distribution and Nature of Alluvium

The alluvial aquifer system comprises very poorly developed alluvial and/or colluvial/eluvial deposits within the floodplain of Quorrobolong Creek and its tributaries. For simplicity, these unconsolidated materials are loosely described collectively as “alluvium”. The estimated areal extent of alluvium associated with these creeks as shown on **Figure 4** has been derived initially from the 1995 published 1:100,000 scale map of the Newcastle Coalfield Regional Geology, and refined by Umwelt from topographic analysis.

Quorrobolong Creek and its tributaries comprise a series of ephemeral creeks which only flow after consistent or heavy rainfall. The alluvium associated with these surface drainage features in the vicinity of the proposed modification is generally shallow and low yielding (Connell Wagner, 2007). This is evidenced from the drilling logs of a number of bores in the alluvial floodplain, viz:

- A DPI Water[1] monitoring bore (GW080974) located close to the southeast corner of the proposed modification area, in the alluvium of the unnamed tributary overlying LWB1-B3 (**Figure 4**). The log of this bore indicates the alluvium is 6 m thick in this location with a standing water level of 1 m and a yield of 2 L/s. Monitoring records for this bore from 2010 to 2014 (NOW on-line groundwater database) indicate a water level ranging between 0.5 and 2.3 m below ground level, suggesting a saturated alluvium thickness at this bore site varying seasonally between 3.7 and 5.5 m.
- Between 2006 and 2011, Austar installed four shallow monitoring bores – AQD1073A (GW202493), WBH1 (GW202494), WBH2 (GW202495) and WBH3 (GW202496) in the vicinity of Quorrobolong Creek to the east/northeast of the proposed Modification Area. Locations are shown on **Figure 4**. AQD1073A was drilled in July 2006, and WBH1 to WBH3 in July 2011. Logs of these bores record only silts and clays grading downwards into weathered siltstone and

[1] NSW Department of Primary Industries, water division. Previously known as NSW Office of Water (NOW).

fine-grained sandstone rock. RPS (2014) interpreted a thickness of alluvial sediments ranging up to 6.2 m in AQD1073A, WBH2 and WBH3, but the driller's logs and photographs of cores from AQD1073A suggest that most of the unconsolidated material drilled in these four bores would be better described as colluvium or residual soils (extremely weathered rock). The log of WBH1 indicates less than 1 m of alluvial or colluvial material.

- Austar installed a new monitoring bore MB03 within the alluvium overlying panel LWB2 on 2 July 2016. This was installed to monitor for any impacts from extraction of panel LWB2 on the alluvium of the unnamed tributary which traversed LWB1 to LWB3. The log of this bore shows an alluvium depth of 8 m. Groundwater level has ranged between 1.5 and 1.7 m below ground level over the period July to December 2016. This suggests a saturated alluvium thickness in this location of 6-6.5 m. The bore was screened from 1 to 9 m below surface, and gravel-packed between a bentonite seal at 0-1 m depth and the bottom of the hole at 10 m, so that the bore is open to the full alluvial sequence as well as the uppermost 2 m of Permian basement.

Groundwater Levels

Groundwater level hydrographs are plotted for all five alluvium monitoring bores on **Figure 5**. This figure also shows the Rainfall Cumulative Deviation (RCD) curve, which is a plot based on the difference between observed monthly total rainfalls and the long-term average monthly total rainfall, accumulated as a continuing total deviation between the two. In this case, the monthly rainfall data from the nearest reliable BOM station, ie Pokolbin Jacksons Hill Station No 061329 (approximately 10 km to the north of the Austar Coal Mine) were used to generate the RCD curve.

The RCD curve is a useful tool to assess whether there are any mining-induced impacts on the groundwater. In times of above average rainfall, the RCD will show an upward trend, while periods of below-average rainfall will result in a downward trend. The role of rainfall infiltration as a primary mechanism for groundwater recharge is shown by a similar trend in the groundwater level hydrographs. If there is an ongoing divergence over time in the trends between the groundwater levels and the RCD curve, it may indicate a mining-induced drawdown effect, which can be difficult to see otherwise because of short term fluctuations in groundwater level.

The RCD curve is superimposed on the hydrographs on **Figure 5**. It can be seen that over the period of monitoring, there is no noticeable divergence between the RCD trend and the groundwater level hydrograph trends, suggesting no mining related impacts have occurred.

Groundwater Quality

Monitoring data from the Austar Coal Mine monitoring bores indicates that the shallow groundwater intersected by these bores is of variable quality over time, with reported EC values ranging from 33 µS/cm to 8,491 µS/cm. A plot of EC versus time for the five alluvium monitoring bores is shown in **Figure 5**. AQD1073A has been monitored since June 2010, WBH1 to WBH3 since July 2011, and MB03 since September 2016.

Figure 5 shows that the EC was generally above 2,500 µS/cm between July 2010 and April 2011, then less 1,000 µS/cm between July 2011 and July 2015 (although the EC started to trend higher in late 2013), and from September 2015 EC started rising sharply. During 2016, EC was in the range 2,500 to 8,500 µS/cm in all bores. Bore MB03 located above LWB2 reported EC values above 4,000 µS/cm on both the occasions it has been sampled in the second half of 2016.

It has been suggested (AGE, 2016a) that the EC measurements before June 2016 may be unreliable due to the sampling methodology employed by a previous monitoring contractor. It is not possible to confirm whether the notably higher ECs after January 2016 are due to a changed sampling methodology, or whether there are other factors involved.

However, there is no evidence that the increase in EC is due to mining effects. The higher ECs since June 2016 are observed in all five bores, four of which are located in the main Quorrobolong Valley floodplain and the fifth of which is located within an unnamed tributary, and thus is in a different sub-catchment.

It is also noted that at the time of the rise in EC, there was no mining activity in Stage 3 (which underlies bores AQD1073A and WBH1 to WBH3); and the longwall extraction from LWB2 which underlies MB03 did not reach that bore until November 2016

The RCD curve is superimposed on the EC plots on **Figure 5**. Up until January 2016, there appeared to be a close (albeit inverse) relationship between the RCD curve and the EC trend, indicating that the groundwater salinity variations over time are probably related to recharge. In times of above average rainfall, and therefore active recharge, the groundwater salinity was lower than in times of low rainfall, and hence no or only limited recharge. However, the observations after January 2016 are not consistent with such a relationship. EC values are all higher than previously recorded, at a time when the RCD curve was rising or steady.

It is considered therefore that the changes in EC may be due to improved sampling methodology since June 2016, and that the prior EC values may be unreliable. This would mean that the prevailing salinity of surficial groundwater within the alluvium and regolith is higher than previously thought, and generally above 2,500 µS/cm EC.

Beneficial Use Potential

The alluvial/colluvial aquifer associated with Quorrobolong Creek and its tributaries within the proposed Modification Area is limited in extent and depth, and is associated with ephemeral streamflow. The groundwater quality is variable, and is susceptible to elevated salinities, at least in periods of low or no rainfall recharge, if not at all times.

The alluvial aquifer system is therefore not characterised as a "highly productive" groundwater source or a highly connected surface water source, as defined by the NSW Aquifer Interference Policy. The lack of registered bores within the area also indicates that the alluvial aquifer in the vicinity of the proposed Modification Area has limited potential for use as a water supply for stock, domestic or other consumptive purpose.

4.4.2 Non-alluvial Hard Rock Aquifer System

Distribution and Nature of Hard Rock Aquifer System

'Porous rock' aquifers within the Permian hard rocks are limited to the Branxton Formation and the Greta Coal Seam itself.

Branxton Formation

The Branxton Formation is part of the non-coal bearing marine sequence of the Maitland Group which overlies the Greta Coal Measures. The sandstone is generally strong and massive with a silica and or clay matrix. Due to the massive nature and very low interstitial permeability ($<10^{-3}$ m/d) of the Branxton Formation it contains few if any major water bearing zones and is not likely to provide a viable source of groundwater (Connell Wagner, 2007). Nevertheless, zones of jointing or fracturing associated with major faults may form localised aquifers. The sequence has very low vertical permeability, and there is very little potential for leakage between any water-bearing zones or aquifers.

Two registered bores listed on the DPI Water groundwater database and located close to the eastern corner of the proposed Modification Area targeted the Branxton Formation strata. These were DPI Water monitoring bore GW080973 and private stock bore GW054676 shown on **Figure 4**.

Stock bore GW054676 was drilled to a depth of 39.6 m and intersected a shale water bearing zone between 10.1 m and 24.4 m below ground level. The bore reportedly (RPS, 2014) had a low yield (approximately 1 L/s) and poor water quality (10,000 to 16,000 µS/cm EC). The owner of bore GW054676 has advised Austar that the bore has been decommissioned and backfilled, as the water was too saline to use.

DPI Water monitoring bore GW080973 was drilled in September 1995 to a depth of 95 m and did not intersect any reported water bearing zones. DPI Water has advised that as the bore was dry, it was abandoned and backfilled.

DPI Water also has a monitoring bore GW080975 at a location approximately 35 m north of the LWB4 take-off line, which was drilled to a depth of 30 m, intersecting a low-yielding (1L/s) water-bearing zone in shale between 26 and 27 m below surface.

Drilling of coal investigation holes at the Austar Coal Mine indicates potential water-bearing zones in the Branxton Formation at a depth of around 100 to 130 m and at 170 m below ground level at bore locations across the mine area. Connell Wagner (2007) concluded that the importance of these water bearing zones as a water resource is likely to be minimal, since the water quality is poor (generally greater than 10,000 µS/cm EC) and the yield is low (generally less than 1 L/s).

Coal Measures

The Greta Coal Measures also have very low rock mass permeability (hydraulic conductivity less than 10^{-3} m/d), but they contain occasional layers which have slightly higher permeability (Connell Wagner, 2007), generally the coal seams and occasional fracture or bedding plane features.

The coal seams are normally relatively more permeable than the interburden lithologies due to the presence of cleats and fractures in the coal, and are therefore the main water-bearing zones in the coal measures. For this reason the coal seams represent the major 'aquifer' units purely by comparison with the much less permeable interburden strata, and their importance as an aquifer is generally minimal due to the poor quality groundwater as well as limited yield potential. Hitchcock (1995) concluded that the coal measures in the Newcastle Coalfield 'have a poor resource potential with low yielding aquifers of high salinity'.

Groundwater Levels / Pressures

In the vicinity of the proposed Modification, water levels are monitored at bore NER1010 (GW201408), which is located above and within the footprint of the proposed longwall panel LWB5, near its northern end. Bore NER1010 is a standpipe piezometer 102 m deep, and screened from 20 to 102 m in the Branxton Formation.

The water level hydrograph for NER1010 is shown on **Figure 6**. The water level in NER1010 is at around 15 to 25 m below ground surface, ie between 100 and 110 mAHD (**Figure 6**), deeper than the shallow alluvium/colluvium standpipe piezometers MB03, AQD1073A, WBH1, WBH2 and WBH3, where water level is within 10 m of the ground surface. The water level elevation at MB03 is around 126-127 mAHD, while at the other four bores it is around 120 to 124 mAHD (**Figure 5**).

Groundwater levels are clearly deeper in the Branxton Formation than in the surficial aquifer (alluvium/colluvium/regolith), showing that there is potential for downward percolation of water from the surficial groundwater into the underlying hard rocks, if hydraulic connection were to exist.

The RCD curve plotted on **Figure 6** shows a broad correlation with the overall trend on the NER1010 hydrograph. The hydrograph shows periodic rapid rises in water level in response to rainfall events and rapid recession, but these short-term features are superimposed on a more slowly trending rise in level during periods of rising RCD and decline during periods of falling RCD. A similar broad correlation between the hydrographs for the shallow surficial groundwater and the RCD can be seen, but the response in the hard rock groundwater is larger in magnitude. This is likely due to the much lower specific yield value for the hard rock relative to the alluvium/colluvium, and the actual volume of groundwater recharge occurring in the hard rock is likely to be very much less than in the surficial aquifer system.

Groundwater pressures at greater depth in the hard rocks have also been monitored at a number of multi-level vibrating piezometer bores, the closest to the proposed Modification Area being AQD1121, which is located about 1500 m east of the proposed LWB4 to B7 longwall panels, and two monitoring bores MB01 and MB02 located slightly further away (around 2500 m northeast), above the Stage 3 longwall panels (see locations on **Figure 4**).

MB01 and MB02 were installed in 2015, both screened in the Branxton Formation. MB01 is screened between 75 m and 174 m below ground level, which includes a groundwater inflow from a permeable zone intersected at a depth of 168 m. MB02 was installed in an existing deep exploration hole, which was grouted up to 140 m below surface and then casing and screen installed above that depth.

The water level in MB01 is more than 120 m below ground level (ie below around 40 mAHD), while in MB02 water level is around 14 to 16 m below ground level, at 117 to 119 mAHD.

MB01 and MB02 hydrographs are shown for the period 2015-2016 on **Figure 7** (together with the other bores in the monitoring network, both alluvium and Permian for comparison).

MB02 shows periodic responses to purging prior to sampling. Water level drops on 5 September, 29 September, 6 October and 3 November 2016 caused by purging prior to sample collection are clearly visible on the hydrograph (**Figure 7**). The slow water level recovery after each purging event is indicative of a low formation permeability. On each purging/sampling occasion, the water level has not yet fully recovered from the previous purging occasion to the pre-September 2016 water level.

A marked drawdown event occurred in MB01, starting on 19 August and still in progress four months later on 8 December 2016. **Figure 7** shows that the water level in MB01 started a sharp decline on 19 August 2016, coinciding with a vibration event that was recorded on the Austar Coal Mine vibration monitors. The bore is installed in close proximity to mapped faults, and it has been suggested by AGE (2017) that the water level decline may be due to draining of a fault of higher permeability which was intersected by the bore. Alternatively, it could be due to a partial formation collapse in the annulus, which may be blocking or restricting groundwater connection between the bore and the main zone of permeability at 168 m depth.

AQD1121 was installed in February 2015, and comprises 6 vibrating wire piezometers set at depths ranging from 280 to 617.8 m below surface (Douglas Partners, 2015). Depth of cover above the Greta Seam is 607 m.

Monitoring results are presented in **Figure 8**, which is a composite plot of hydrostatic head profiles for several dates between installation and the present time.

Figure 8 shows a number of relevant features:

- There is substantial depressurisation of the strata at depth, below at least 500 m, shown by the divergence of the hydrostatic head profile plots from the hydrostatic line which has a 45º slope as shown by the dotted lines on **Figure 8**.
- The hard rock strata are unlikely to be saturated above a depth of about 60-70 mAHD (ie about 80 m below surface), shown by projecting the hydrostatic head traces back to the zero piezometer pressure axis. There may be perched groundwater above this elevation, but the top of continuous saturation would be at around 60-70 mAHD.
- The greatest depressurisation is around the level of the Greta Seam, with the lowermost two piezometers showing about 300 m of depressurisation (ie 300 m displacement from the hydrostatic line.
- The two most recent dates plotted in **Figure 8** show substantial recovery in hydrostatic pressures in all but the two lowermost piezometers at and just below the Greta Seam. This recovery has occurred even at the piezometer located just 27 m above the Greta Seam roof, where the maximum hydrostatic pressure reduction of 300 m recorded in May 2015 has been reduced to a reduction of only 120 m by December 2016. No such recovery has been observed at the Greta Seam level.
- A temporary depressurisation of about 25 m had been seen at the 400 m level piezometer, which is 207 m above the Greta Seam roof. Subsequent monitoring showed that the pressures had fully recovered at this piezometer by August 2015, and by December 2016 were higher than pre-longwall extraction. The small depressurisation effect seen at the 400 m piezometer is interpreted to have been a temporary response to bed dilation rather than due to fracture effects extending to this height above the seam level. The bed dilation causes an increase in effective rock porosity, which is accompanied by a drop in water level as the water in storage redistributes into the increased available storage in the rock.

The AQD1121 water level data indicate that there is very limited or negligible hydraulic inter-connection between the groundwater in the hard rocks and surficial groundwater in the alluvium, colluvium and weathered bedrock zone. The AQD1121 pressure responses suggest that direct hydraulic connection from the goaf through the overlying strata following longwall extraction is likely to be minimal above 207 m above the seam.

Another vibrating wire piezometer monitoring AQD1077, where monitoring has now ceased as the piezometers failed following subsidence, was located approximately 3 km north from the northern end of the proposed LWB4-B7. Cover depth above the Greta Seam was approximately 440 m, and the piezometer showed similar results to AQD1121, with no noticeable depressurisation at the piezometer located 240 m above the Greta Seam.

The results from AQD1121 and AQD1077 indicate that there is unlikely to be direct hydraulic connection from the goaf to the ground surface following mining of the proposed LWB4-B7, where the depth of cover above the Greta Seam is expected to be between 400 m and 505 m.

Groundwater Quality

Water quality sampling from monitoring bore NER1010 has been undertaken quarterly since July 2010. MB01 and MB02 have only been monitored since June 2016.

The Permian groundwater salinities show a similar range to that in the surficial groundwater present in the alluvium, colluvium and weathered bedrock. EC in NER1010 ranged between 148 and 1658 µS/cm between July 2010 and September 2016 (**Figure 6**). However, the sample collected in December 2016 had a much higher EC at 5,203 µS/cm. Salinities in MB01 and MB02 in 2016 were in the range 6,000 to 7,500 µS/cm EC.

As with the alluvium bores, the higher salinity reported in NER1010 in December 2016 may be more representative of the Branxton Formation groundwater salinity, as suggested by AGE (2016a).

Former stock bore GW054676 was reported to have a salinity in the range 10,000 to 16,000 µS/cm EC (RPS, 2014), which is believed to be more typical of salinity in the Branxton Formation, away from sources of local recharge from rainfall infiltration.

Groundwater deeper in the Branxton Formation and in the Greta Coal Measures is saline to highly saline. Monitoring shows that water inflow to the Austar Coal Mine has high salinity and generally low pH, as well as elevated dissolved iron (Connell Wagner, 2007), as in **Table 2** below:

Table 2: Mine Water Quality Data (Connell Wagner, 2007)

Location	pH	EC (µS/cm)	Fe (mg/L)
Ellalong goaf (No 2 Shaft pump)	4.7	18,733	575
West Pelton goaf	6.8	8,350	52
East Pelton goaf	3.8	11,960	851
LW13 flank hole (adjacent to Kalingo workings)	3.8	15,382	507
LWA1 13 C/T flank hole (adjacent to Aberdare Central workings)	3.9	11,823	1,700

The sources listed in **Table 2** are all believed to comprise a mixture of in situ groundwater and stored water, and the water stored in former mine workings has probably undergone some increase in salinity over time, but the salinity is ultimately derived primarily from the in situ groundwater within the coal measures.

Beneficial Use Potential

Based on generally low formation permeability and poor water quality, the porous rock groundwater sources within the proposed Modification Area are not characterised as “highly productive” groundwater sources, as defined by the NSW Aquifer Interference Policy as they do not meet the water quality and yield requirements for highly productive groundwater sources.

4.4.3 Water Stored in Former Mine Voids

There is a long history of underground mining in the region around the Austar Coal Mine. **Figure 1** shows a number of former mine workings (voids) adjacent to the Austar Coal Mine which are partially filled with water. Austar uses some of these voids as part of its approved water management strategy described in the Austar Site Water Management Plan (Austar, 2013). Austar returns excess mine water to former mine workings located up dip of Austar’s current operations.

The quality of water in these old mine workings is extremely poor as evidenced by groundwater quality data obtained for water entering Austar workings through coal barriers from old workings. These data (**Table 2**) show salinity values of 8,350 to 18,733 µS/cm or greater with pH generally ranging between 3.8 and 6.8 (Connell Wagner, 2007).

Consequently, while the yield of these abandoned mine voids would theoretically satisfy the definition of a highly productive aquifer, the quality of the water within the old workings means it has limited beneficial use potential.

5. Potential Impacts of the Modification

5.1 Impact Assessment Methodology

A comprehensive groundwater assessment for the Austar Coal Mine was prepared by Ian Forster of Connell Wagner in October 2007. This assessment is supported by a verification review of groundwater impacts following the completion of LWA5 in the Stage 2 mining area undertaken by Aurecon in 2013, and by groundwater monitoring undertaken within the Stage 2 and Stage 3 mining areas.

Based on the findings of these previous groundwater investigations and ongoing groundwater monitoring at Austar Coal Mine, assessment of groundwater impacts for the proposed modification has been based on review of past and current monitoring above and surrounding current and prior underground mining areas. This review shows no adverse impacts on any high quality water resource or beneficial user. In addition, the proposed modification is encompassed within an area that has already been extensively mined. Recent approval applications at Austar Coal Mine have been based on similar empirical assessments of groundwater impacts, and this is an appropriate assessment approach for the proposed modification, as further discussed below.

Historical mining has occurred in a number of surrounding collieries resulting in previous depressurisation of the coal seam. The locations of former collieries are shown on **Figure 1**. After completion of mining at these nearby mines, groundwater has been allowed to inflow to the goaf areas, allowing partial recovery in groundwater levels within the coal measures, but the monitoring undertaken by Austar has shown that recovery is still incomplete.

The currently active mining areas at the Austar Coal Mine comprise several interconnected mining areas to the south (downdip) of the historical mining areas (Pelton, Kalingo, Bellbird, Aberdare Central, Aberdare South and others at greater distance). The historical mines are physically disconnected from the Austar Coal Mine workings, being separated from them by unmined barriers which range from 40m (Pelton) to 100m (Kalingo) to greater than 250m (Aberdare Central and Aberdare South, and others more distant). Limited hydraulic connection to the Austar Coal Mine workings occurs through the barriers, via the Greta coal seam and to a lesser extent the near roof and floor coal measures sediments.

Mining at the Austar Coal Mine (and its predecessor Southland Colliery and Ellalong Colliery) has been ongoing for many years, and includes the Ellalong longwall panels which were mined between 1983 and 1988, and the Bellbird South longwalls (Southland and Austar Coal Mine Stages 1 and 2) between 1999 and 2013. Austar Coal Mine Stage 3 was commenced in 2013, and longwall panels LWA7 and LWA8 were completed before mining proceeded to the LWB1 to LWB3 mining area, located between Austar Coal Mine Stage 2 and the Ellalong mine area, and immediately to the south of the four longwalls proposed in the current modification (LWB4 to LWB7) (**Figure 1**).

Thus the proposed LWB4-B7 panels are completely surrounded by interconnected longwall panel areas of the Austar Coal Mine itself.

Within the Austar Coal Mine workings, groundwater levels/pressures in the Greta Seam are at similar or lower elevations than the seam floor level in the proposed LWB4-B7 panels. Therefore, the groundwater levels/pressures in the Greta Seam and the coal measures generally would already be substantially lowered before mining starts in LWB4-B7, particularly as a result of the prior mining of LWB1-B3 immediately south of and downdip of LWB4-B7.

The Greta Seam floor elevations in LWB4-B7 range from -385 mAHD to -285 mAHD, whereas the seam floor levels range to as low as -405 mAHD and -420 mAHD in LWB2 and LWB3 respectively. As LWB2 and LWB3 will be mined out before LWB4-B7 are commenced, there will be minimal groundwater remaining in the Greta Seam in LWB4-B7.

Consequently, the additional impacts from the proposed Modification overall are anticipated to be quite small. No increase in groundwater inflows is anticipated, and all water takes would be able to be accounted through existing licensing held by Austar. No adverse impacts on the alluvial groundwater have been observed to date, including the main alluvial floodplain of Quorrobolong Valley which directly overlies extracted longwall panels LWA3 to LWA5a, where monitoring bores have shown no change to groundwater levels associated with the mining of these four panels.

Accordingly, as there have been no adverse impacts on groundwater from mining to date, and for the reasons outlined above, the incremental impacts that may occur with the proposed modification are expected to be negligible. Consequently, we consider that the use of a numerical groundwater model is not warranted. Further, the magnitude of incremental impacts which could potentially occur as a result of the proposed Modification, as discussed in the following sections, are expected to be of similar order to or less than the typical uncertainty range associated with numerical groundwater models.

Following an empirical approach as for previous impact assessments, the possible incremental impacts associated with the proposed modification are discussed in the following sections.

5.1 Predicted Subsidence Impacts

MSEC (2017) has assessed the likely subsidence impacts of the proposed Modification. MSEC's main findings which have a bearing on potential groundwater impacts are summarised as follows:

- The depth of cover to the Greta Seam above the proposed longwalls LWB4, LWB5, LWB6 and LWB7 varies between a minimum of 400 m to a maximum of 505 m.
- The Greta Seam thickness within the mining area ranges from 3.7 to 4.8 m, and it is proposed that a constant seam thickness of 3.4 m will be mined by conventional longwall mining methods in the Modification Area.
- Maximum predicted surface subsidence magnitudes for the proposed longwalls are 1250 mm above LWB4, 1250 mm above LWB5, 1050 mm above LWB6 and 750 mm above LWB7.
- Further subsidence is predicted to occur above LWB1-B3, above what was predicted for LWB1-B3 in the previous MOD, as a result of the additional longwall panels.
- The cumulative predicted surface subsidence magnitudes are 1200 mm after extraction of LWB4, 1250 mm after extraction of LWB5, and 1350 mm after extraction of LWB6 and LWB7. The maximum predicted value of 1350 mm represents about 39% of the extraction thickness of 3.4 m and occurs over LWB3 as a result of the extraction of LWB1 to LWB7 (i.e. total cumulative predicted vertical subsidence).
- Predicted far-field horizontal movements resulting from extraction of the proposed longwall panels are very small.
- In relation to rock fracturing above the extracted panels, four deformation zones have been suggested by MSEC, viz
  - Caved or collapsed zone – loose blocks of rock detached from the seam roof, likely to contain large void spaces
  - Disturbed or fractured zone – in situ material that has sagged and suffered significant bending, fracturing, joint opening and bed separation, leading to large increases in both horizontal and particularly vertical permeability
  - Constrained or aquiclude zone – confined rock above the disturbed zone which has experienced insufficient disturbance to suffer significant fracturing or alteration of the original physical rock properties. Some bed separation and discontinuous vertical fracturing can occur. Some increase in horizontal permeability can occur, but minimal change to vertical permeability.
  - Surface zone – unconfined strata at the ground surface that can experience surface cracking or heaving, but no deep connective cracking.
- At the Austar Coal Mine, the combination of large cover depths and the bridging properties of the thick sandstones of the Branxton Formation limit the upward extent of connective cracking (ie **the disturbed or fractured zone**) above extracted longwall panels. Extensometers installed above panels LWA1 and LWA2 showed vertical fractured heights of 85 m for extensometer AQD1074 above LWA1, and 150 m for extensometer AQD1085 above LWA2. Similar heights are expected above the proposed LWB4-B7.
- The height of discontinuous fracturing above LWB4-B7 (ie **the constrained or aquiclude zone**) could extend to between 235 m and 355 m above the seam. This is well short of the

ground surface (between 400 and 505 m above the seam) at the four proposed longwalls. Hence, the zone of discontinuous fracturing is not expected to reach the ground surface.

- Surface cracking (ie **the surface zone**) in the soils above the proposed longwalls is not expected to be observed, based on the depth of cover, and observations of prior panel extractions at the Austar Coal Mine. Any surface cracking that might occur in the creek beds above the panels is expected to be minor and to infill naturally with subsequent streamflow events.

5.2 Mine Water Inflows

Mine inflows at the Austar Coal Mine are complex, and include water released from the coal measures and water stored in voids in abandoned former mine workings adjacent to the Austar Coal Mine. The contribution from old mine voids has been identified by Austar, as inflows were more prominent along the barriers between the Austar Coal Mine and the nearest former workings. Water from the former mines enters the Austar Coal Mine workings primarily through the Greta Coal Seam, which makes it difficult to distinguish from the contribution coming from dewatering of the coal seam and the floor and roof sediments.

Attempts have been made to quantify the contributions from in situ groundwater and void storages respectively. The most recent assessment was that reported in the 2013 draft groundwater verification review by Aurecon after completion of longwall LWA5 (Aurecon, 2013).

Aurecon (2013) commented that "... total water make is a noisy dataset, with numerous peaks and troughs". They reported that fluctuations are due principally to the location of mining activity. They note that net inflow increases when headings are being driven into new areas initially, and that after initial increases after new ground has been entered by the drives, the incremental increase in inflow rate tails off fairly quickly. They also note that there is usually not a noticeable increase in inflow rate when major geological structures are encountered in the mine, but rather when new areas are entered by the development headings.

Aurecon (2013) also concluded that cumulative water make by the mine has climbed fairly steadily over time. This would undoubtedly be due to the fact that mining is progressively extending into new areas generally down-dip to the south and southeast, creating exposure to more groundwater in the newly opened up mine areas.

Aurecon (2013) concluded that after each new increase in water inflow associated with drivage into a new area, the inflow rate settled down to a base level that was essentially the rate of seepage through the barriers from the water stored in voids in the adjacent former mine workings. They noted that at the time of their report, the base level of inflow was on a slow increasing trend over time.

In keeping with past experience at the Austar Coal Mine, it is expected that the proposed Modification will result in minimal increase in total water inflow to the mine, as the proposed panels are updip from the current LWB1 to LWB3 panels, into areas that are already substantially depressurised.

5.3 Impacts on Groundwater Levels / Pressures

5.3.1 Alluvium and Regolith

The proposed longwalls partly underlie the Quorrobolong Valley alluvial floodplain, and partly the alluvium associated with an unnamed tributary of Quorrobolong Creek. The very north-eastern end of LWB4 extends about 170 m beneath the tributary alluvium, while LWB6 and LWB7 both substantially underlie the main Quorrobolong Creek alluvium (**Figure 1**).

The impacts of previous mining on other parts of both of these alluvial areas provides confidence that the proposed extraction from LWB4 to LWB7 will have no noticeable impact on the alluvial groundwater resources.

Bore MB03 was installed in the alluvium of the unnamed tributary of Quorrobolong Creek at a location above LWB2. This bore was installed purely for the purpose of observing any impact from the extraction of the approved LWB1 to LWB3.

Longwall extraction from LWB2 started in July 2016 and was completed in February 2017. The panel face passed beneath the location of MB03 in November 2016. Water level monitoring in MB03 started in August 2016, 3 months before the longwall passed beneath the bore. The hydrograph

(**Figure 5**) shows the water level following a trend related solely to the rainfall pattern and has an identical trend with the other alluvial bores nearby, as well as the trend on the RCD curve. There is no interruption to this trend as the longwall passed beneath MB03. Monitoring confirmed that the mining of LWB2 produced subsidence of less than 150 mm at MB03. There is no visible subsidence trough in the alluvium above LWB2. No change in water level accompanying the onset of subsidence can be identified on the MB03 hydrograph.

Previously, mining of LWA4 and LWA5 had undermined the alluvium/colluvium monitoring bores AQD1073A, WBH1, WBH2 and WBH3 in March 2011 (LWA4) and August-October 2011 (LWA5), using the LTCC method. In that case also, the mining caused no observable drawdown of water levels in the surficial groundwater of the alluvium.

Based on these results, with a similar depth of cover above the proposed longwalls and a reduced extraction height (i.e. conventional longwall only) compared with the LTCC method, it is expected that the proposed Modification will have no adverse effect on groundwater levels in the surficial aquifer system.

A large part of LWB6 and LWB7 underlie the main Quorrobolong Valley alluvium, and a very small section of LWB4 underlies the alluvium associated with the unnamed tributary (**Figure 4**). Maximum cumulative surface subsidence predictions of 1250 mm above LWB4 and LWB5, 1050 mm above LWB6 and 750 mm above LWB7 (MSEC, 2017) mean that some of the alluvial floodplain will develop shallow subsidence troughs.

The parts of LWB1, LWB2 and LWB3 which underlie the unnamed tributary are also likely to develop slightly deeper subsidence troughs than previously predicted (Dundon, 2016), as a result of the proposal. To date, LWB2 has been completed, and Austar has advised (Mulhearn, pers comm) that up to 16 February 2017, maximum subsidence of 170 mm had been detected at the centreline of LWB2 within the alluvium associated with the tributary, but with no observable subsidence trough. This is slightly less than the 250 mm subsidence predicted after completion of LWB2 (MESC, 2016).

Within these troughs, there will likely be an initial drop in groundwater levels, as the base of the alluvium will subside by a similar magnitude to the ground surface. This decline in water levels will not represent a loss of groundwater from the alluvium, merely a drop in the aquifer as a whole. Experience elsewhere has shown that groundwater levels within the subsidence trough will quickly rise to re-establish equilibrium with the adjacent sections of the alluvium outside the subsidence zone, resulting in a greater thickness of saturated alluvium, and a shallower depth to the water table, with the water table re-establishing at about the same absolute elevation (in mAHD) as pre-extraction conditions.

No drop in groundwater level has been observed in monitoring bore MB03 coinciding with the subsidence above LWB2.

Apart from this small localised beneficial impact, no noticeable change in groundwater levels will be observed in the alluvium/colluvium/regolith aquifer after completion of the proposed Modification.

5.3.2 Branxton Formation

The bulk of the sediments overlying the Greta Seam are from the Branxton Formation.

The main water-bearing zones within the Branxton Formation are within the first 50 m or so below the base of weathering. Standpipe piezometer NER1010, which is located within the footprint of the proposed LWB5, monitors groundwater within the uppermost 100 m (approximately) of the Branxton Formation, and is screened from 20 to 102 m depth.

Groundwater is present at deeper levels of the Branxton Formation, in zones of fracturing. Bores MB01 and MB02 monitor deeper parts of the Branxton Formation above the Stage 3 mining area. They are located ahead of the completed longwall panels in Stage 3.

Water levels and salinity (EC) monitored in NER1010, MB01 and MB03 are plotted on **Figure 7**. This figure shows that the EC of groundwater in NER1010 is similar to the EC of groundwater in the shallow alluvium/colluvium/regolith bores, and like the alluvium showed generally low salinities until mid-2016. However the reliability of the sampling prior to June 2016 has been questioned (AGE, 2016a). If the salinity measurements after June 2016 are accepted as being more representative of the groundwater in the Branxton Formation at that site than earlier data, then the Branxton Formation groundwater intersected by this bore is saline, with EC greater than 1000 μS/cm, and possibly greater than 5,000 µS/cm (**Figure 7**). Salinity data for MB01 and MB02 are only available from June 2016 onwards. Both bores indicate saline water quality, with ECs between 6,000 and 7,500 µS/cm.

However, if the low salinity reported prior to June 2016 is reliable, it would suggest that the shallower Branxton Formation groundwater monitored in bore NER1010 may be subject to local recharge by infiltration of rainfall, like the alluvium/colluvium/eluvium monitored in the shallow bores in the Quorrobolong Valley floodplain.

The upper 100 m or so of the Branxton Formation has been targeted at times by local landowners in the Quorrobolong Valley as a potential water supply source. The only such bore near the proposed Modification Area (registered bore GW054676) produced a modest yield of saline groundwater, and the bore has been filled in because it was considered by the landowner to have no beneficial use value.

The uppermost 100 m of the Branxton Formation is at least 300 m above, and up to 405 m above the Greta Seam, above the proposed longwalls LWB4 to LWB7, and is therefore well above the predicted 150 m maximum height of connected fracturing from subsidence accompanying the proposed coal extraction from LWB4-B7, based on experience from extensometers above LWA1 and LWA2, and predictions by MSEC (2017).

The separation between the Greta Seam and the top 100 m of Branxton Formation is marginally less than the predicted 355 m maximum height of discontinuous fracturing (within the 'constrained zone') above the Greta Seam (MSEC, 2017). Discontinuous fracturing (ie the constrained zone as described by MSEC, 2017) could extend into the uppermost 100 m of the Branxton Formation above all of LWB7, the western third of LWB6 and the north-western corner of LWB5. Elsewhere within the Modification Area, some unaffected strata will remain between the predicted maximum height of discontinuous fracturing and the base of the uppermost 100 m of the Branxton Formation.

However, MSEC advise that any fracturing that does occur within the constrained zone will not result in an increase in vertical hydraulic conductivity, and will not result in direct hydraulic connection with the goaf. Any changes in the constrained zone will only affect horizontal hydraulic conductivity.

Across the Modification Area, there will always remain a significant thickness of either unaffected strata or constrained strata, as a buffer between near surface groundwater and the goaf. The thickness of the constrained zone remaining above the maximum height of continuous fracturing to the base of the uppermost 100 m of the Branxton Formation, will be at least 150 m above LWB7, 170 m above LWB6, 190 m above LWB5 and 215 m above LWB4.

Based on the experience above earlier longwalls LWA1 and LWA2, the maximum predicted continuous fracture heights reported by MESC (2017), and this significant buffer zone, groundwater levels in the uppermost 100 m or so of the Branxton Formation are predicted to be unaffected by the proposed Modification.

This prediction is also consistent with the hydrostatic head profiles from multi-level vibrating wire piezometer bores located close to extracted longwall panels (eg AQD1077) as discussed in Dundon (2015). AQD1077 showed that hydrostatic pressures are likely to be affected by subsidence induced fracturing up to at least 150 m above the seam, but not above about 200 m above the seam.

5.3.3 Coal Measures and Greta Seam

The Greta Coal Measures, including the Greta Seam, are predicted to be dewatered within the immediate proximity of LWB4-B7, and will also be substantially depressurised for some distance away from the longwalls, in a manner consistent with the already extracted longwall panels.

No beneficial users will be affected.

5.4 Impacts on Surface Streamflows

Impacts on surface streamflows are predicted to be negligible. Apart from the small localised beneficial impact within the subsidence trough across the Quorrobolong Valley floodplain when it is undermined by LWB6 and LWB7, and the small portion of the unnamed tributary above the north-eastern end of LWB4, the surficial groundwater will not be affected by the proposed Modification. Hence there will be no change to either baseflows or streambed leakage.

5.5 Impacts on Groundwater Recharge

As there are predicted to be no measureable impacts on the near surface groundwater in the alluvium/colluvium/regolith, groundwater recharge will be unaffected by the proposed Modification. Groundwater recharge occurs principally by direct infiltration of rainfall, and downward percolation into and through the alluvium/colluvium and weathered rock into the underlying Branxton Formation. Recharge to particular relatively more permeable zones within the Branxton Formation and the Greta Coal Measures likely occurs at some distance updip from the mine area, where those particular zones occur in subcrop beneath the surficial lithologies. This process will continue to occur and will be unaffected by the proposed Modification.

5.6 Groundwater Quality

As the region of connected fracturing due to subsidence is predicted to not extend to more than about 150 m above the Greta Seam, as a result of the proposed Modification (MSEC, 2017), there will be no possibility of any adverse impact on groundwater quality in either the alluvium/colluvium/regolith.

On worst case predictions of the possible heights of discontinuous fracturing (to a maximum of 355 m above the Great Seam), discontinuous fracturing may extend to between 45 m and 90 m below ground level above LWB7, between 65 m and 115 m above LWB6, between 90 m and 135 m above LWB5, and to between 110 m and 150 m. Therefore, above LWB7 and parts of LWB5 and LWB6, discontinuous fracturing may extend into the uppermost 100 m of the Branxton Formation, and could therefore cause temporary impacts on groundwater in that zone. However, this would not constitute connection to the mine, and any changes that might occur would be possible changes to the direction or rate of flow within the Branxton Zone. This is not expected to affect the water quality in the Branxton Formation or any other aquifer.

Salinity may increase over time in the mine inflow water from the deeper Greta Coal Measures, irrespective of whether the proposed Modification proceeds or not, partly from induced seepage from the less permeable parts of the coal measures, and partly through evaporation effects of recycling mine inflow water through the practice of storing excess water in the former mine workings of the Bellbird South Colliery updip from the current active mine area. It is considered that the proposed Modification will have negligible contribution to this process.

5.7 Impacts on Water Users

There are no registered groundwater bores targeting the alluvium or colluvium within the vicinity of the proposed Modification Area, which is a reflection of the very limited yield potential of this groundwater source in that area. In any case, it has been concluded that the potential for the proposed Modification to impact on the alluvium/colluvium is negligible.

There are a small number of bores which target groundwater in the upper parts of the Branxton Formation (uppermost 100 m or so). The nearest private stock bore registered in the DPI Water database, GW054676, is located just inside the proposed Modification Area (**Figure 4**). However, the owner has backfilled the bore due to its low yield potential and salinity. In any case, the aquifer contributing water to this bore is too shallow to be affected by the subsidence impacts of the proposed Modification.

Lowering of the piezometric surface and changes to quality are considered highly unlikely as discussed in the preceding sections of this report. However, it is possible for lateral dislocation or blockage to occur if horizontal far-field displacements are significant. MSEC (2017) indicate that far-field horizontal displacements may occur, and predict a 99 per cent confidence level that horizontal displacement beyond a distance of 2 km from a single active longwall would be less than 35 mm, and less than 60 mm beyond 1 km from an active longwall.

There is no registered bore within 2 km of the proposed Modification Area, so far-field displacements are not expected to have an adverse impact on any existing water supply bore.

5.8 Groundwater Dependent Ecosystems

Groundwater dependent ecosystems (GDEs) identified in the general region around the proposed Modification Area include Riparian Swamp Oak Open Forest, Riparian Cabbage Gum Forest, and a small soak area (Umwelt, 2015).

As indicated above, the predicted heights of either connected or discontinuous fracturing above the Greta Seam as a result of subsidence are significantly less than the depth of cover above the Greta Seam at the locations of the proposed longwalls. It has been concluded that any impacts on either the shallow surficial groundwater or on stream baseflows will be negligible.

Accordingly, no impacts on any GDEs dependent on the surficial groundwater or on groundwater baseflow are predicted to occur.

There are no known GDEs dependent on groundwater from the Branxton Formation or the Greta Coal Measures within or adjacent to the proposed Modification Area.

6. NSW Aquifer Interference Policy

The predicted groundwater impacts associated with the proposed Modification have been assessed against the NSW Aquifer Interference Policy which requires any mining activity to consider 'Minimal Impact Considerations' with respect to groundwater sources.

The NSW Aquifer Interference Policy considers two categories of groundwater sources, viz 'highly productive' and 'less productive'. Both the alluvial and porous rock groundwater sources within the proposed Modification Area are considered 'less productive' sources as they do not meet the water quality and yield requirements for 'highly productive' groundwater sources.

Key criteria to demonstrate minimal impact for less productive groundwater sources include:

- less than 10% variation in the water table, 40 m from any high priority groundwater dependent ecosystem or high priority culturally significant site listed in the schedule of the WSPHUAWS;
- a maximum 2 m decline at any water supply work;
- no mining activity to be within 200 m laterally from the top of high bank or 100 m vertically beneath of a highly connected surface water source that is defined as a 'reliable water supply'; and
- any change in groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.

The closest high priority groundwater dependent ecosystem or high priority culturally significant site listed in Schedule 4 of the WSPHUAWS is located more than 30 km away from the proposed Modification Area. The proposed Modification will not impact the water table at that distance.

The closest registered privately owned bore is GW054676 located just inside the proposed Modification Area, which targeted a shallow water bearing zone in the Branxton Formation. However, the landowner has advised that this bore has been decommissioned and backfilled. There are no other registered privately owned bores within the zone of potential impact on groundwater levels or quality from the proposed Modification.

There are no highly connected surface water sources as defined by the NSW Aquifer Interference Policy and Water Management Regulations within 200 m laterally or 100 m vertically of the proposed longwalls. Nor are there any water sources that represent a 'reliable water supply' as defined by the NSW Aquifer Interference Policy and Strategic Regional Land Use Plan – Upper Hunter.

The assessment in the preceding sections of this report has concluded that any impacts on either the surficial groundwater of the alluvium/colluvium/regolith, or the hard rock groundwater in the uppermost 100 m or so of the Branxton Formation, from the proposed Modification, will be negligible, due to a combination of the large cover depth over the Greta Seam and the limited height of either connected or discontinuous fracturing above the goaf (MSEC, 2017). This conclusion is consistent with observations of responses to prior mining of Stages 2 and 3 (Connell Wagner, 2007).

There are no known users of this groundwater resource within or near the proposed Modification Area and, as the impact on the aquifer is predicted to be negligible, any potential future groundwater users are unlikely to be adversely affected.

The quality of water within the alluvium/colluvium aquifer is variable and there is no known current use of the surficial groundwater. This is consistent with our conclusion the surficial aquifer has limited beneficial use potential. The proposed Modification is therefore not expected to further limit potential beneficial uses of this water supply.

Likewise, the generally poor quality of groundwater within the upper parts of the underlying Branxton Formation means that it has limited beneficial use potential. Nevertheless, the predicted negligible impact from the proposed Modification will not inhibit any potential future use of that aquifer system. Groundwater in the deeper parts of the Branxton Formation and the Greta Coal Measures is believed to be saline, and therefore has very low potential for future beneficial use other than for coal mining operations. Accordingly, the proposed Modification is not predicted to unduly restrict future use.

In summary, the alluvial/colluvial aquifer associated with Quorrobolong Creek and its tributaries within the proposed Modification Area is not characterised as a 'highly productive' groundwater source or a highly connected surface water source, as defined by the NSW Aquifer Interference Policy. The lack of registered bores within the area also indicates that the alluvial aquifer in the vicinity of the proposed Modification has limited use as a water supply for stock, domestic or other consumptive purpose.

On this basis, it is considered that the proposed Modification adequately satisfies the minimal impact considerations for less productive groundwater sources defined by the NSW Aquifer Interference Policy.

7. Groundwater Licensing Requirements

Groundwater impacts associated with the Austar Coal Mine involve a water take from the 'Porous Rock' groundwater source which is regulated by the *Water Management Act 2000*.

The water takes from the 'porous rock' water source for the currently approved mine plan are estimated by mine site Technical Services personnel to be less than 2 ML/d during the period from June 2016 to present, which equates to approximately 730 ML/y. This is based on a maximum rate of water removal from the mine of around 5 ML/d, of which approximately 3 ML/d is imported water. The proposed Modification is predicted to result in a minimal change to the total water take from this source.

The current water takes are authorised under access licences 20BL171481, 20BL173349, and 20BL173350, which have a combined capacity of 770 ML/y.

It is concluded therefore that current water take from the hard rock water source is below the current licence capacity, and an increase in the licence allocation will not be required for the proposed Modification.

8. Groundwater Management and Monitoring

The current groundwater monitoring program includes:

- Water production volumes from underground and through the water management system;
- Water levels in shafts or bores into the former workings, including Bellbird boreholes BB1 and BB2, Ellalong No 2 Shaft, and old mine shafts into Kalingo, Aberdare Central, Hepburn No 2 and Elrington (for locations see **Figure 1**), to monitor the accumulation of water in the former mine workings;
- Monitoring of groundwater levels and quality in 5 shallow bores in alluvium/colluvium or weathered bedrock, and 1 shallow Branxton Formation bore, in the Stage 2 mining area, to the north of the proposed Modification (for locations see **Figure 4**);
- Monitoring of groundwater levels and quality in 2 deeper bores in the Branxton Formation above the Stage 3 mining area (for locations see **Figure 4**); and
- Monitoring of hydrostatic pressures at multi-level vibrating wire piezometer bore AQD 1121 located between the Stage 2 and Stage 3 mining areas (for location see **Figure 4**).

This monitoring program has shown no impacts from mining on the surficial groundwater in the alluvium/colluvium aquifer or the upper parts of the Branxton Formation within the Stage 2 mining area to date.

It is recommended that water levels and water quality will continue to be monitored in the 6 shallow piezometers in this area on a regular basis, in accordance with the existing Site Water Management Plan (Austar, 2013), and EL6598 Groundwater Monitoring and Modelling Plan (RPS, 2014). These measures will be reflected in the Extraction Plan for LWB4-B7 following approval of the proposed Modification.

The following additional monitoring and management measures are recommended for incorporation into the Extraction Plan for LWB4-B7 and are consistent with the requirements of the existing approved Austar Site Water Management Plan (Austar, 2013):

- Establish one shallow groundwater monitoring bore in the alluvial area of the Quorrobolong Creek floodplain at a location above LWB6 or LWB7 (preferably LWB6 if possible), and monitor the groundwater levels on a regular basis to give an indication of the impact of longwall mining on the groundwater in the alluvium. EC readings should be measured on samples taken in this bore and the 6 existing monitoring bores in the Stage 2 area every three months. The installation and final location of the groundwater monitoring bore would be subject to landholder agreement, but should be located centrally within the predicted subsidence zone across the alluvium if possible.
- Review local daily rainfall record when undertaking groundwater monitoring reviews so that the timing of any groundwater level fluctuations can be compared with the occurrence of rainfall events, consistent with the requirements of the current approved Austar Site Water Management Plan (Austar, 2013).
- Review the results of the above monitoring at three monthly intervals and report results annually in accordance with Annual Review Report requirements, consistent with the requirements of the current approved Austar Site Water Management Plan (Austar, 2013).

9. Conclusions

This letter report details the expected incremental impacts of the proposed Modification which was described in **Section 2**.

The key findings of this assessment are:

- There are essentially two aquifer systems in the vicinity of the proposed Modification, namely a surficial aquifer system comprising unconsolidated material including alluvium (‘alluvial’ aquifer), colluvium/eluvium and/or highly weathered bedrock, and a ‘hard rock’ aquifer system that includes fractured zones in the Permian Branxton Formation and the Greta Coal Measures.
- Both aquifer systems are assessed to be ‘less productive’ groundwater sources in terms of the requirements of the NSW Aquifer Interference Policy, on the basis of low yield potential, as well as marginal and variable salinity.
- A third potential source of water inflow to the Austar Coal Mine is water stored in nearby abandoned mine workings. This water source is saline to highly saline, and is not subject to any beneficial use.
- The depth of cover above the Greta Seam in the proposed longwalls is much greater than the predicted maximum extent of either connected or discontinuous fracturing above the goaf. Consequently, surficial groundwater in the unconsolidated material comprising alluvium, colluvium and weathered rock within the floodplain of Quorrobolong Valley overlying the longwall panels will not be impacted by the proposal.
- Based on worst case predictions of subsidence fracturing impacts, groundwater in fracture zones in the uppermost 100 m or so of the Branxton Formation could theoretically experience temporary impacts within part of the Modification Area, as discontinuous fracturing within the ‘constrained zone’ could extend to within 100 m of the ground surface within all of LWB7 and parts of LWB6 and LWB5. Nevertheless, based on prior experience above nearby longwalls LWA1 and LWA2, groundwater within the Branxton Formation is expected to be at most only minimally impacted by the proposed Modification.
- The Greta Seam and the roof and floor sediments of the Greta Coal Measures are already

substantially depressurised as a result of prior mining. They are expected to undergo only marginal additional depressurisation as a result of the proposed Modification.

- No changes to groundwater quality are predicted to occur as a result of the proposed Modification.
- No adverse impacts on either baseflow of stream leakage are predicted to occur as a result of the proposed Modification.
- No increase in groundwater inflow to the mine is predicted to occur as a result of the proposed Modification, consistent with the historical observation that increases in inflow rates are associated with the mine progressing further downdip over time. The proposed longwall panels are located up-dip from the current mining of the approved LWB1-B3 panels to the south in Stage 2, and the coal measures have already experienced significant depressurisation or dewatering in the vicinity of the proposed longwalls, and the proposed Modification therefore does not involve any real downdip extension of mining.
- Any increased groundwater inflow that might occur to the proposed longwalls will not result in the current licensed entitlement being exceeded, and no new licence will be required.
- There are no high priority GDEs listed in the WSPHUAWS within the region potentially impacted by the Austar Coal Mine. Accordingly, the proposed Modification will have no impact on any high priority GDEs. In any case, the surficial groundwater of the alluvium/colluvium/regolith is predicted to be un-impacted by the proposed Modification, by virtue of the very large depth of cover relative to the maximum predicted extent of both connected and discontinuous subsidence-induced fracturing above the goaf.
- Likewise, no existing groundwater user is expected to be impacted by the proposed Modification. No drawdown impacts are predicted to occur in the alluvial aquifer system, which in any case is not utilised by other users in the vicinity of the proposed Modification. The limited potential use of the upper 50 to 100 m of the Branxton Formation as a stock water supply is also predicted to be not adversely impacted by the proposed Modification, due to the large depth of cover relative to the predicted maximum heights of subsidence-induced fracturing.
- The current monitoring program should be continued, with the addition of a further shallow standpipe piezometer in the Quorrobolong Valley alluvium above LWB6 or LWB7, which should be monitored for both water level and water quality, in conjunction with the current monitoring regime. The installation and final location of the groundwater monitoring bore would be subject to landholder agreement.

In summary, the proposed Modification is predicted to not have a significant additional impact above the impacts associated with the approved mining at the Austar Coal Mine.

10. References

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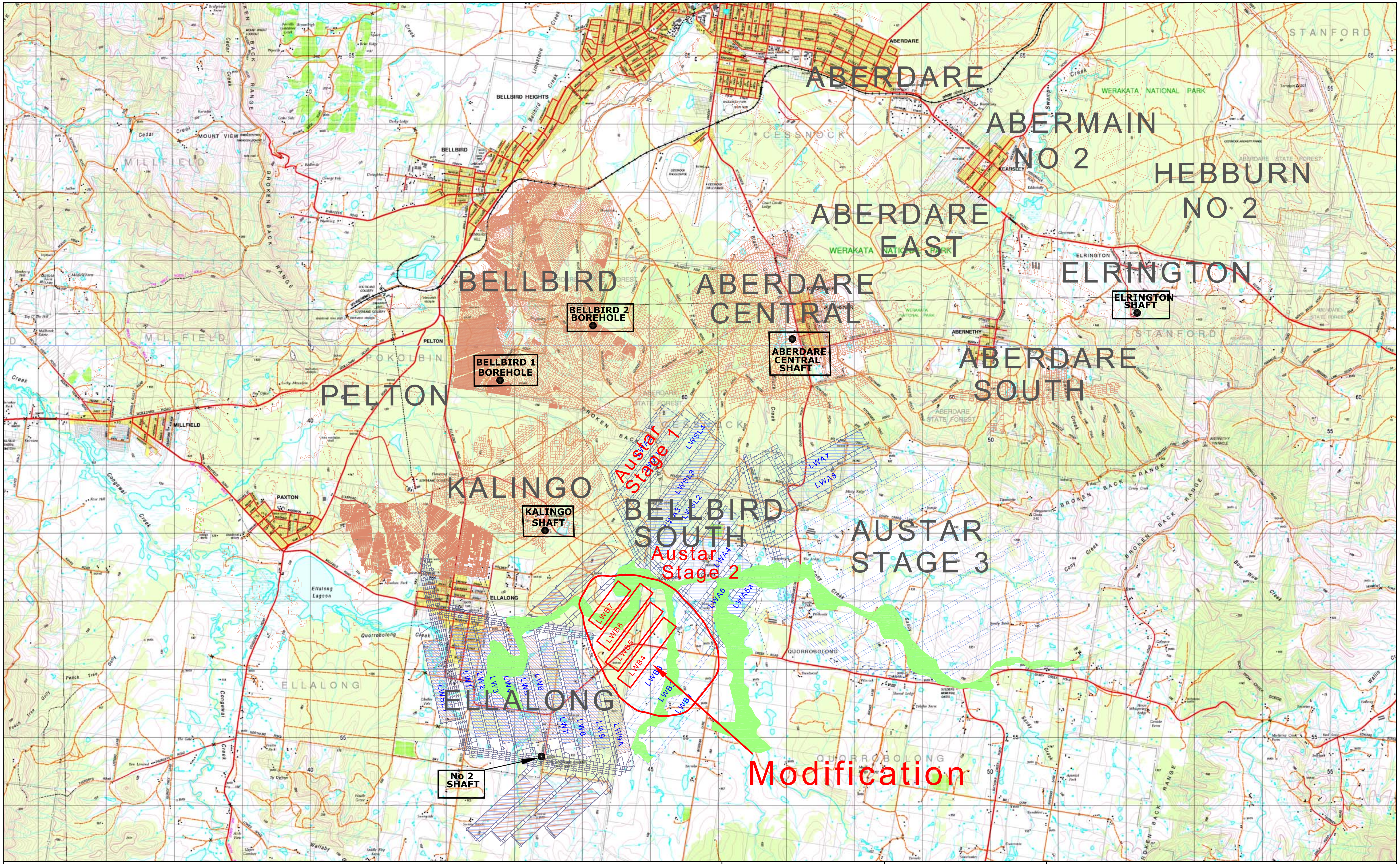
Tables

Figures

Yours faithfully,

Peter Dundon



Legend

BELLBIRD 1 BOREHOLE	Shafts/Boreholes into Old Workings
	Former Mine Workings
	Ellalong / Bellbird South / Austar Stage 3
	Stage 3 / Bellbird South Modification First Workings
	Modification Longwall Panels
	Predicted 20mm subsidence line
	Alluvial floodplain

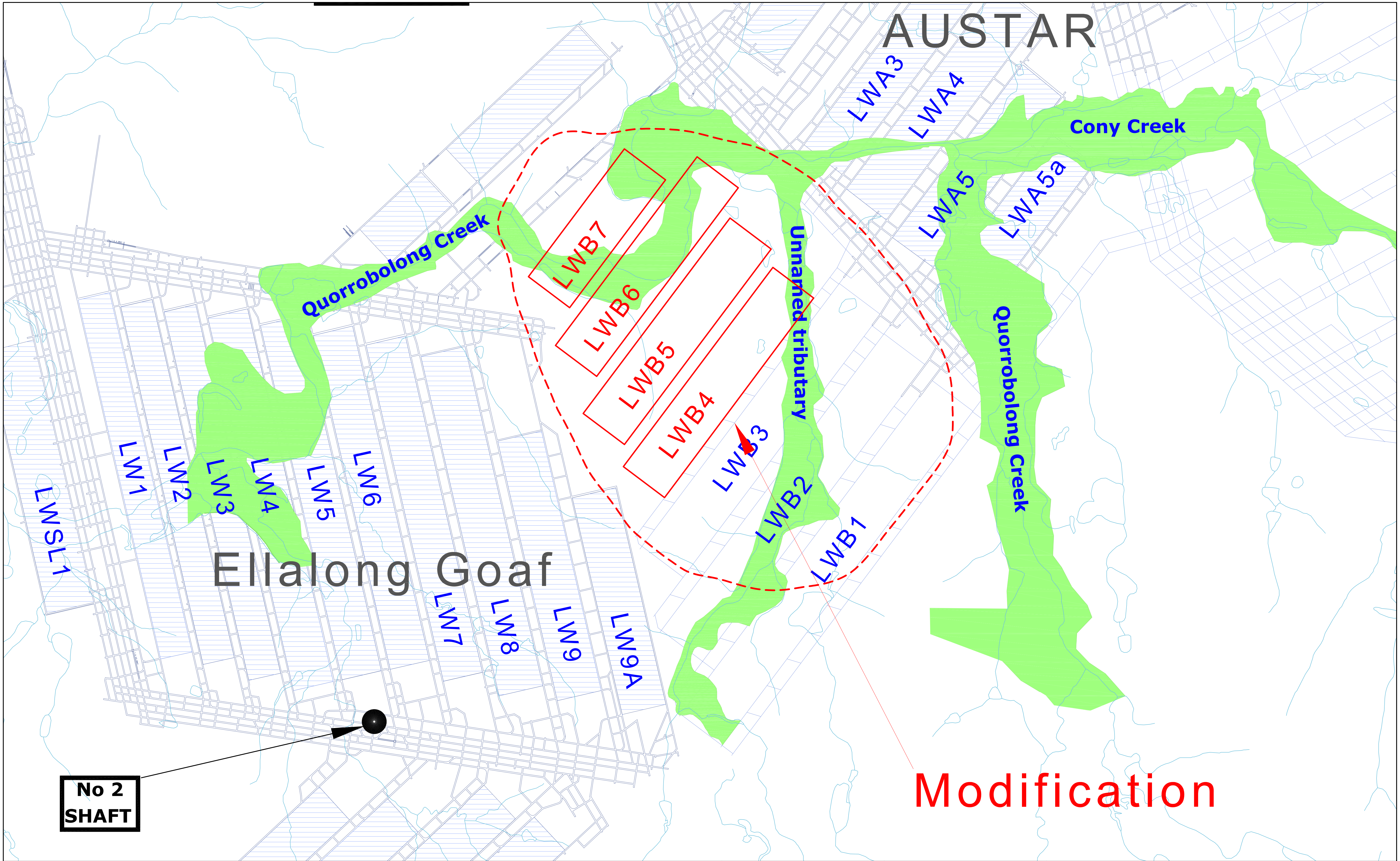
Date: 19 March 2017	Scale: As shown		
Initials: PJD	Job No: 16-0319		
Drawing No: 0319-001	Rev:		

Dundon Consulting Pty Limited

Austar Coal Mine Pty Ltd

BELLBIRD SOUTH MODIFICATION LWB4-B7
REGIONAL LOCATION

Figure 1



Legend
- Ellalong / Bellbird South / Austar Stage 3
- Stage 3 / Bellbird South Modification First Workings
- Alluvial floodplain
- MOD LWB4-LWB7 Longwall Panels
- Predicted 20mm subsidence line

Date: 9 March 2017	Scale: As shown	Austar Coal Mine Pty Ltd
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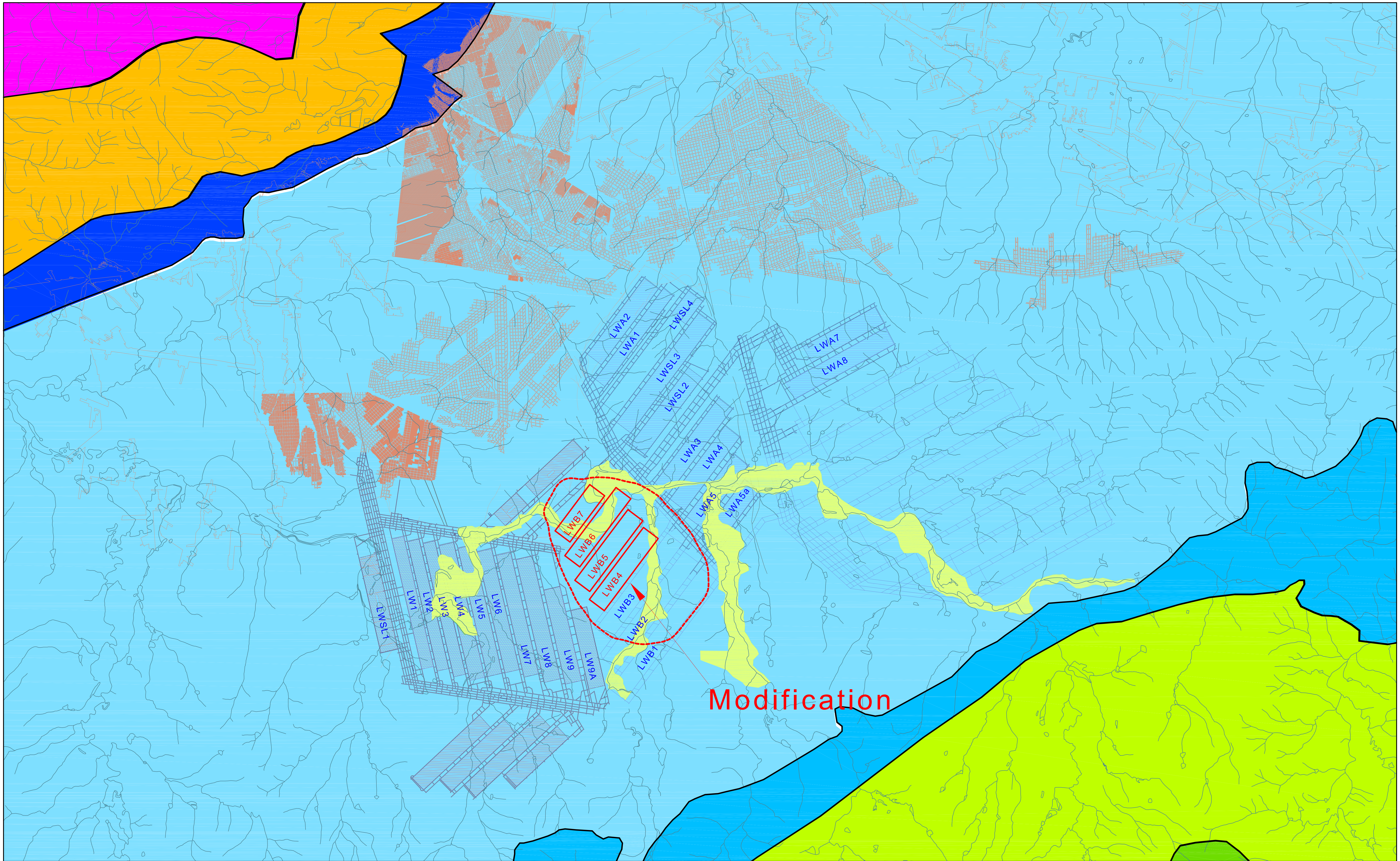
Drawing No: 0319-002	Rev:	
Dundon Consulting Pty Limited		Figure 2



Legend

Alluvium	Branxton Formation
Narrabeen Group	Greta Coal Measures
Mulbring Siltstone	Farley Formation
Muree Sandstone	Rutherford Formation

Predicted 20mm subsidence line

MOD LWB4-B7 Longwall Panels

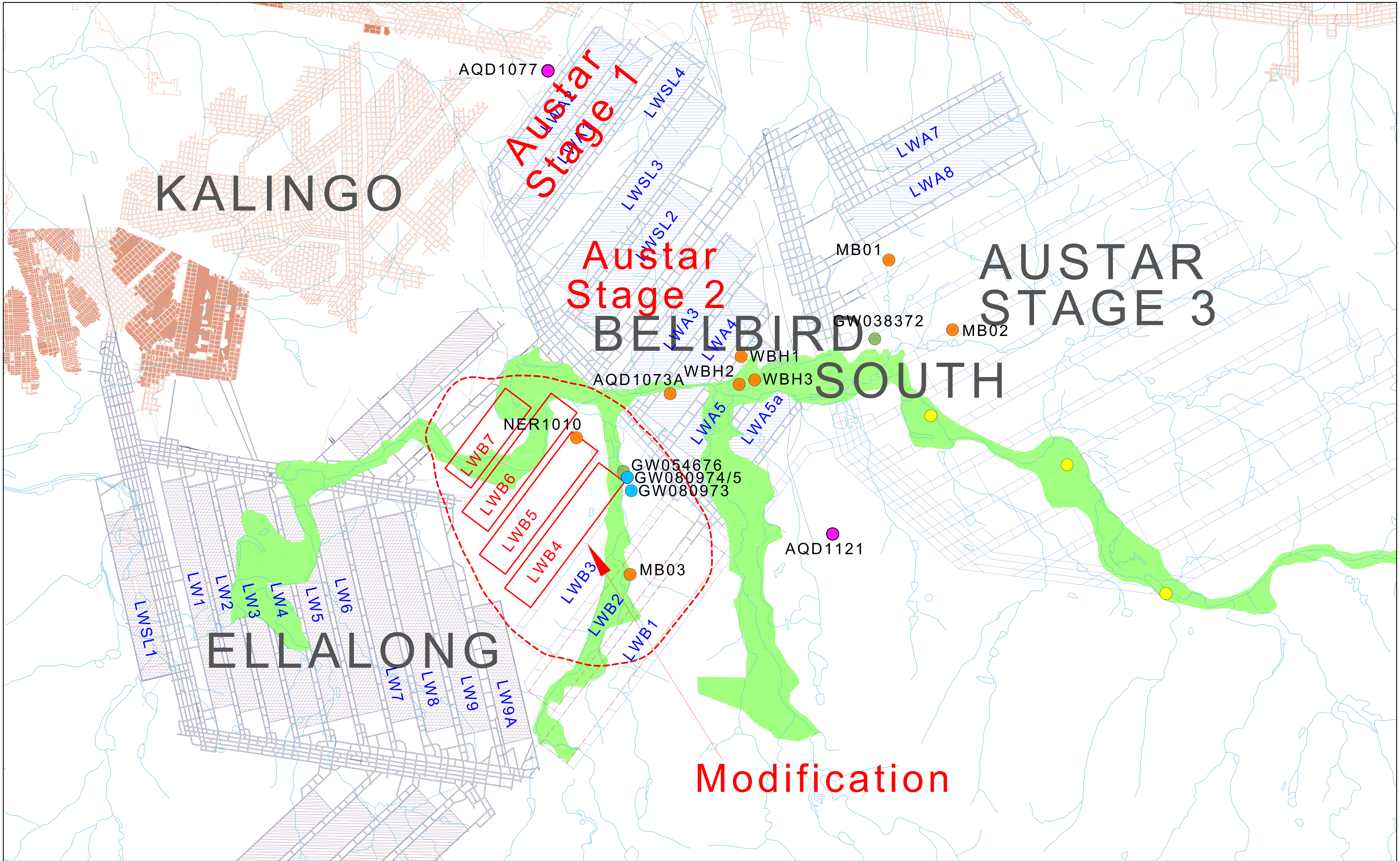
Date:	19 March 2017	Scale:	As shown
Initials:	PJD	Job No:	16-0319
Drawing No:	0319-003	Rev:	0

Dundon Consulting Pty Limited

Austar Coal Mine Pty Ltd

BELLBIRD SOUTH MODIFICATION LWB4-B7 SURFACE GEOLOGY

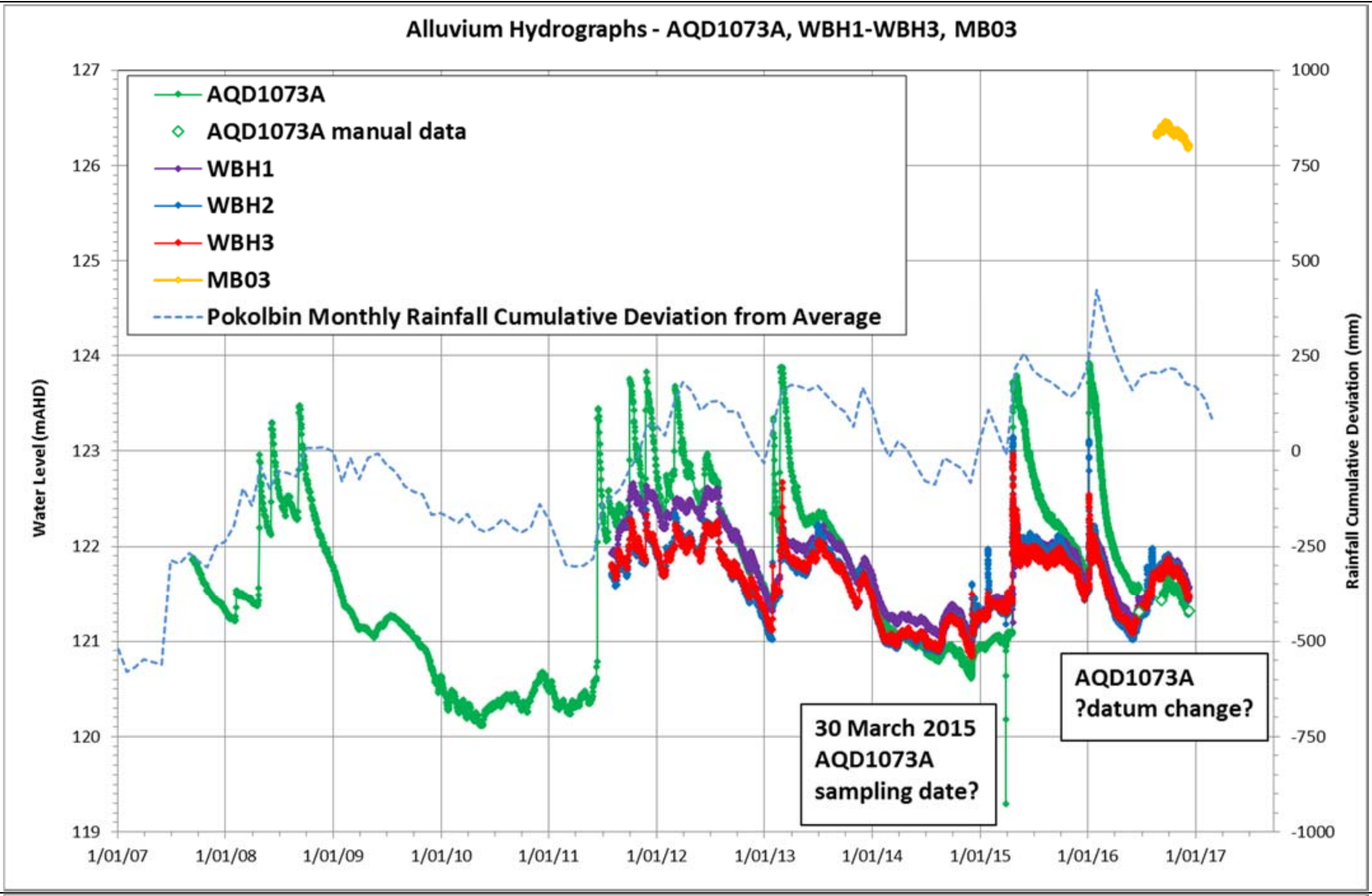
Figure 3

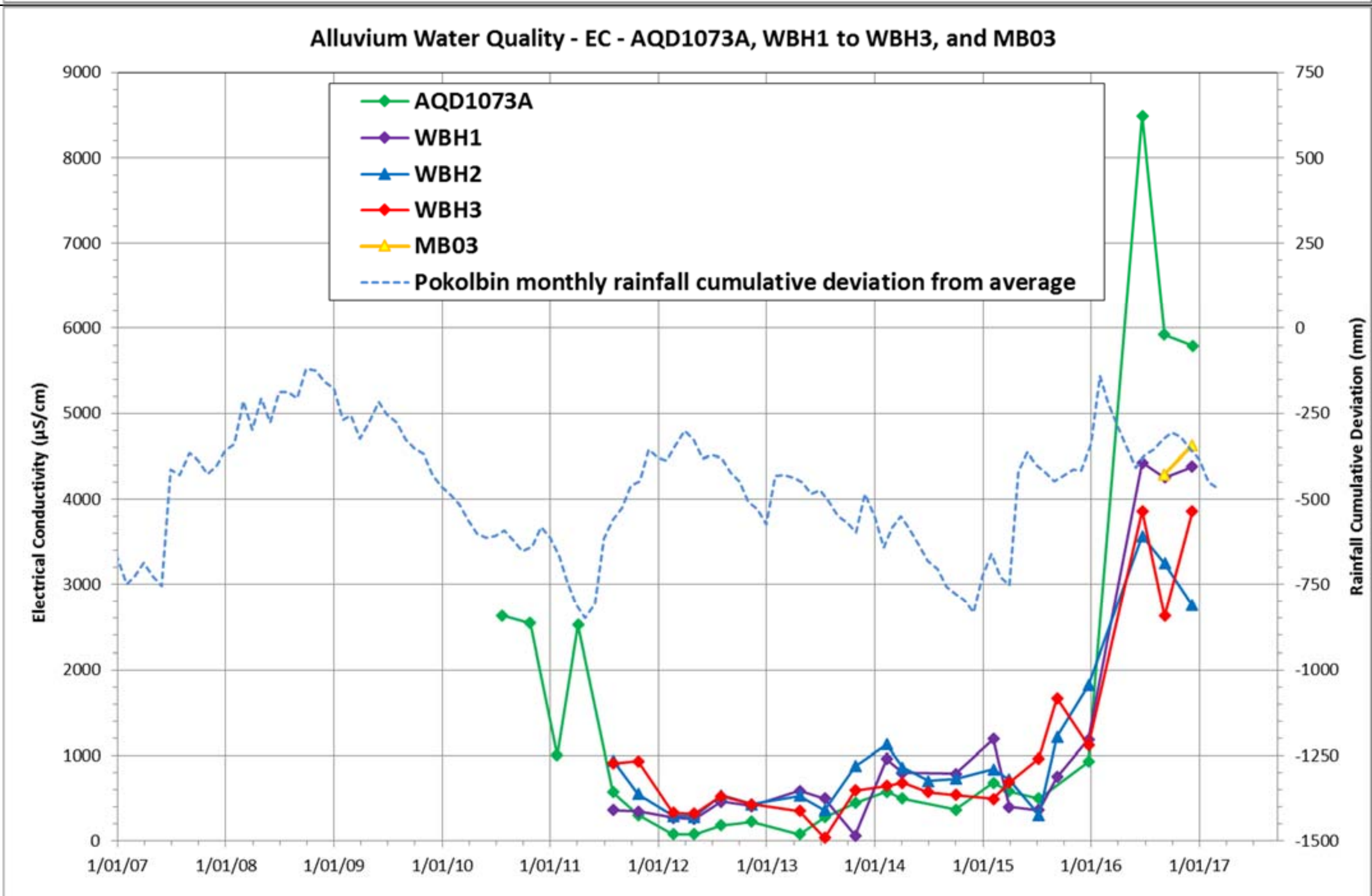


Legend

- Ellalong / Bellbird South / Austar Stage 3
- MOD LWB4-LWB7 Longwall Panels
- Predicted 20mm subsidence line
- Alluvial floodplain
- Austar Monitoring Bore
- Austar Proposed Shallow Monitoring Bore
- Austar Vibrating Wire Piezometer Bore
- DPI Water Monitoring Bore
- Registered Private Bore

Date: 9 March 2017	Scale: As shown	**Austar Coal Mine Pty Ltd**	
Initials: PJD	Job No: 16-0319	**BELLBIRD SOUTH MODIFICATION LWB4-B7 ALLUVIAL FLOODPLAIN and BORE LOCATIONS**	
Drawing No: 0319-004	Rev: B		
Dundon Consulting Pty Limited			**Figure 4**





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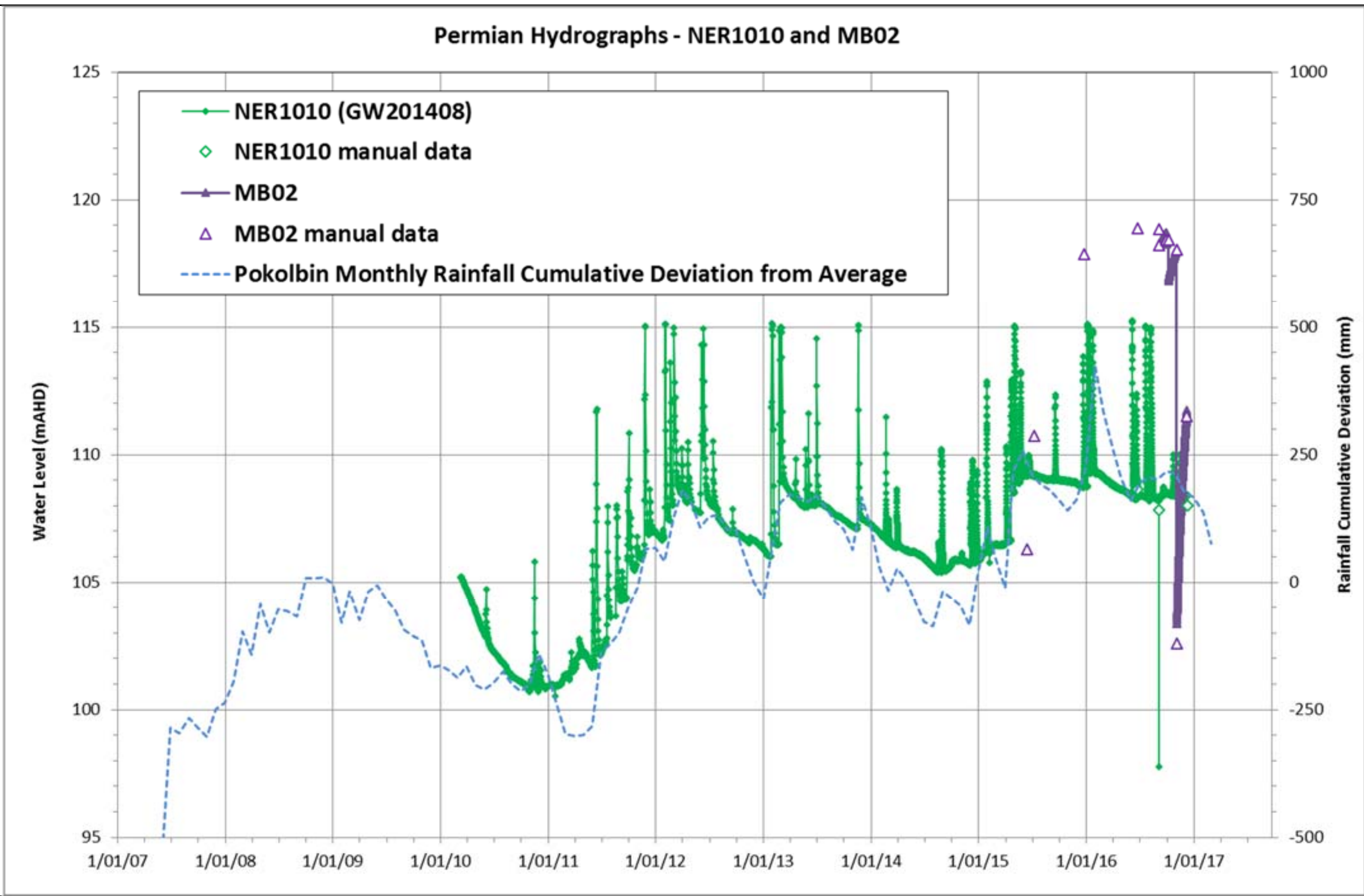
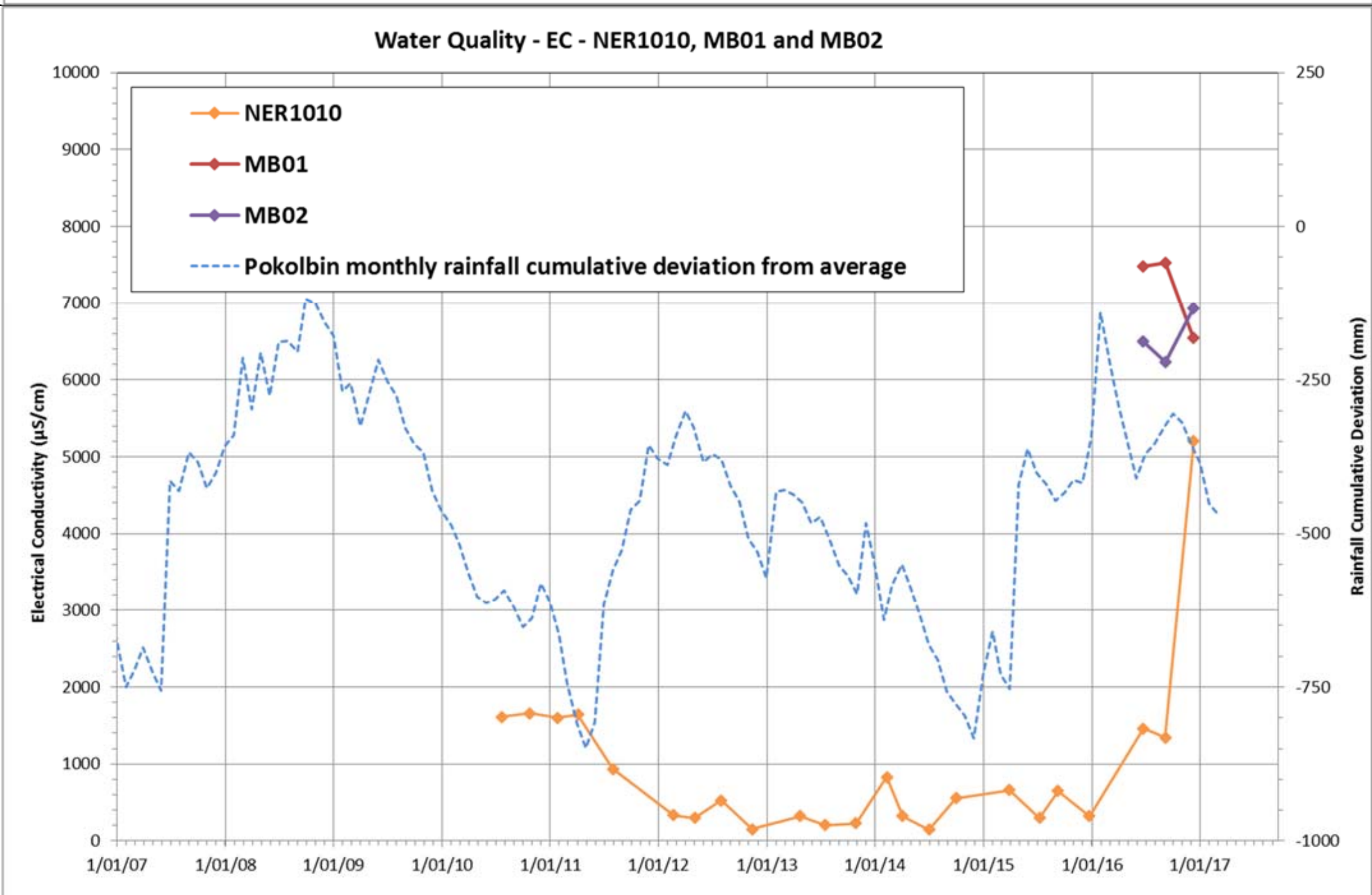
Dwg No: 0319-005		Revision:	**WATER LEVEL AND EC**
Dundon Consulting Pty Ltd			**SURFICIAL GROUNDWATER** — **Figure 5**





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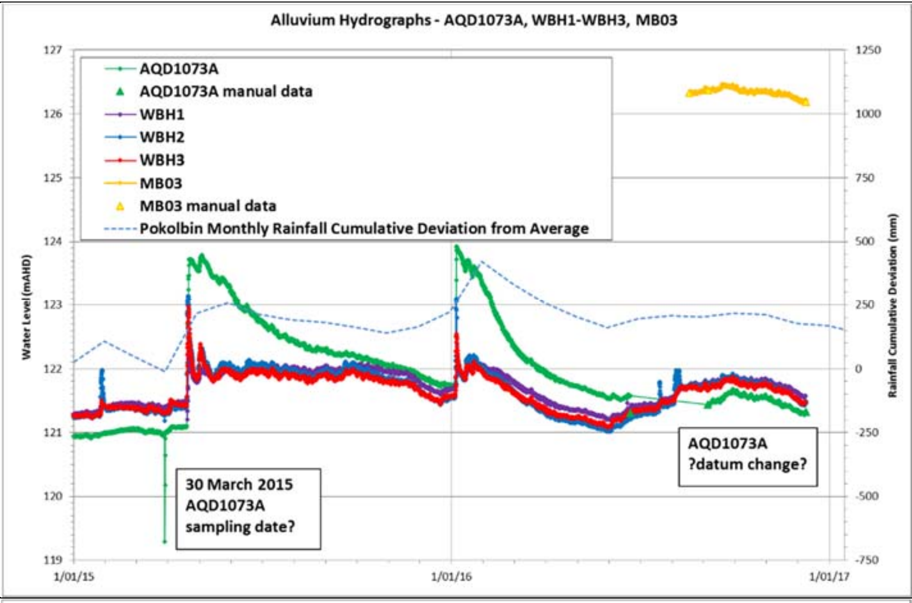
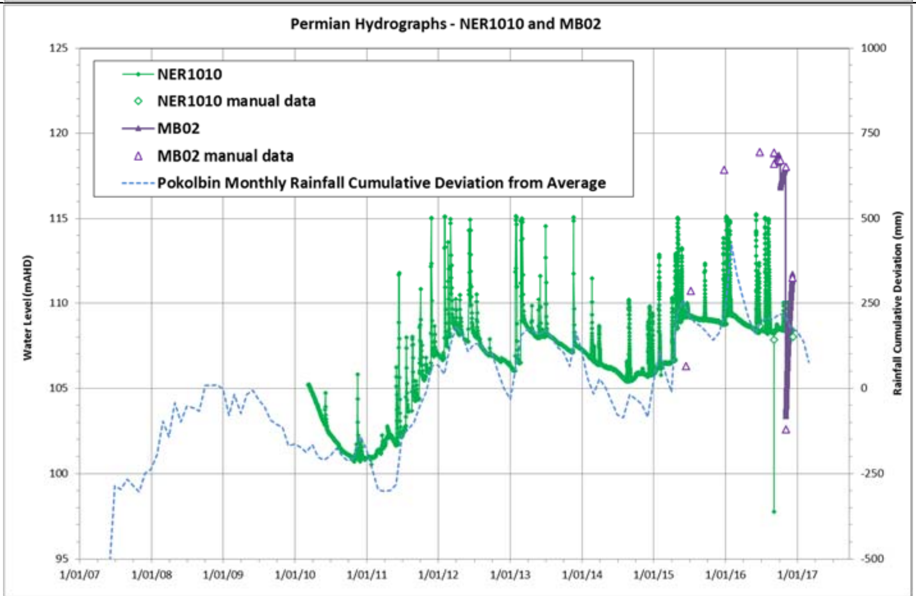
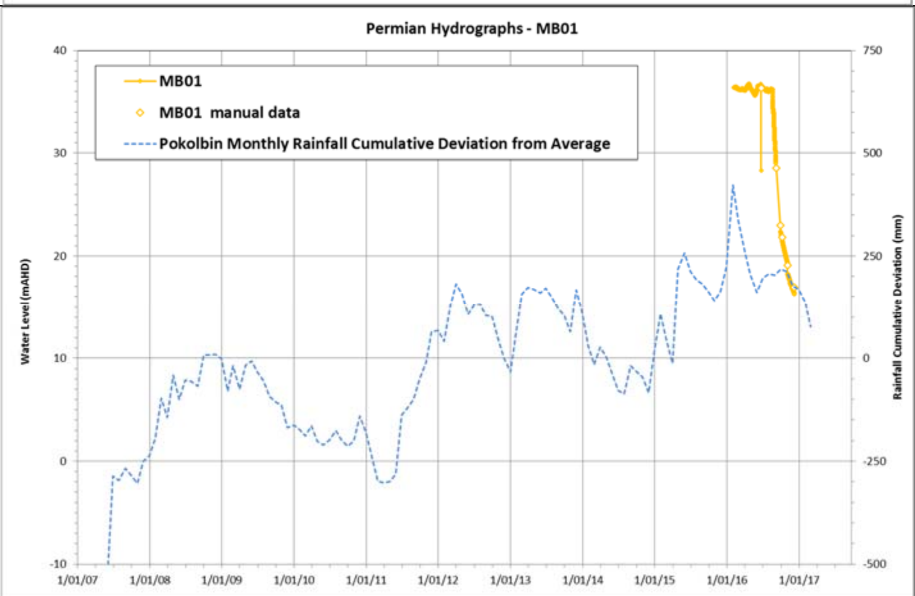
Dwg No: 0319-006		Revision:	
Dundon Consulting Pty Ltd			**PERMIAN GROUNDWATER** / **Figure 6**







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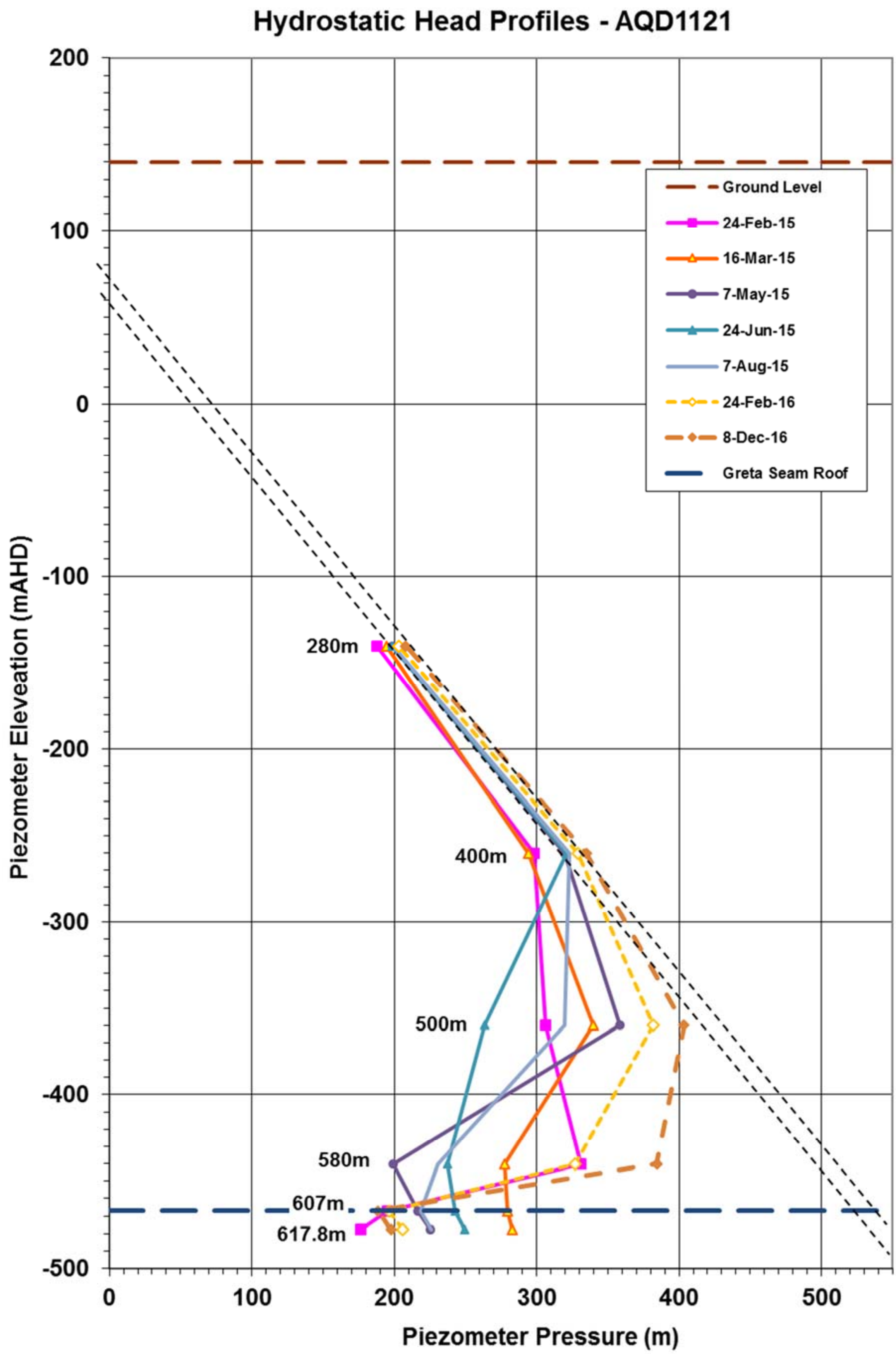
Dwg No: 0319-007		Revision:	
Dundon Consulting Pty Ltd			**Figure 7**



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Dwg No: 0319-008		Revision:	
Dundon Consulting Pty Ltd			**AQD1121** — **Figure 8**