

p r o p o s e d

Mt Arthur

UNDERGROUND PROJECT

Appendix 10



Groundwater Management Study

**MT ARTHUR UNDERGROUND PROJECT
ENVIRONMENTAL ASSESSMENT
GROUNDWATER MANAGEMENT STUDIES
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Executive summary

Mt Arthur Coal is seeking approval to undertake underground mining operations to the west of its existing open cut mine south-west of Muswellbrook in the Upper Hunter region. Proposed mining provides for the extraction of up to 8 Million tonnes per annum (Mtpa) of coal over a period of 21 years using the longwall retreat approach. Proposed longwall panels would be extracted over distances in the order of 2 to 5 kilometres.

Mining would exploit coal reserves from the Glen Munro, Woodlands Hill, Arrowfield, Bowfield and Piercefield seams. All panel extractions would be undertaken below the prevailing regional water table and will result in depressurisation of the exposed coal seams and strata above and below those seams. Depressurisation above seams would be accelerated through caving and subsidence. Such depressurisation will lead to changed groundwater flow directions within the coal measures and any connected aquifers including leakage from surface aquifers and drainages. Re-saturation of goaf and subsided zones after mining has been completed will alter the long term 'recovered' water table in mined areas and may affect the long term groundwater quality.

Studies have been conducted to assess the magnitude and extent of groundwater related impacts likely to arise from the proposed mining operations. These studies have included hydrogeological map preparation, pore pressure estimation for target coal seams, hydraulic properties measurements of different strata, groundwater quality assessments, identification of aquifers, identification of existing private bores and wells, and computer based modelling to assess impacts.

Water tables and groundwater pressures in the coal measures are sustained by rainfall infiltration to the regolith and to underlying coal measures strata with estimates of rainfall recharge to the deeper coal measures varying from zero to no more than 2% of annual rainfall based upon previous studies in the region. The regolith-weathered bedrock zone therefore basically acts as a water store with rainfall recharge percolating downwards at a reducing rate as reducing permeability with depth, impedes flow. Vertical flow is predominantly fracture flow where pathways depend upon fracture and joint connectivity.

A regional composite piezometric surface has been prepared from the available data. This surface has been based upon regional water level measurements and generally reflects a regime where elevated groundwater levels prevail in topographically high areas, and lower groundwater levels prevail beneath the major drainage systems. The Hunter River to the north of the project area and Saddlers Creek to the south, act as drainage sinks. Three broadly defined aquifer systems occur within this area – the coal measures where coal seams offer the highest permeability, the overlying regolith-weathered bedrock which acts as a water store during periods of extended rainfall, and the alluvial lands hosting the major drainages.

Formation hydraulic properties data has been gathered from testing within the project area, and testing and monitoring within and around the Mt Arthur Coal open cut areas to the north-east and east. Additional data has been sourced from the Saddlers Creek project area (EL5460) situated immediately to the south of the project area (Anglo Coal Pty. Ltd.). Core inspections and packer testing have been undertaken to assess the presence of fractures and joints, and the hydraulic conductivity of coal seams and interburden strata. Findings indicate target coal seam conductivities and interburden core conductivities are within the range typical of surrounding areas where mining has been undertaken for many years. Airlift and variable head testing have also been undertaken. Coal seams have been found to exhibit conductivities that are several orders of magnitude higher than adjacent interburden strata and as a result, they are expected to preferentially depressurise when seam extraction commences.

Groundwater qualities are consistent with regional qualities identified in other mining related studies. Current routine sampling indicates that shallower groundwaters in the coal measures are sometimes useful for stock watering while deeper groundwaters are often too brackish to have beneficial value for stock/irrigation supplies.

Salinity measured as electrical conductivity (EC) ranges from 3017 to 7773 uS/cm with an average of 4623 uS/cm for the alluvial lands (largely due to upwards leakage of coal measures groundwater), and 566 uS/cm to 9387 uS/cm with an average of 4295 uS/cm for the coal measures. pH values range from 7.06 to 7.41 with an average of 7.24 for the alluvial lands, and 6.53 to 11.30 with an average of 7.5 for the coal measures. There are likely to be some areas where improved quality prevails. These areas may be quite localised and subject to rapid rainfall recharge and flushing, especially where colluvial and alluvial deposits are well developed within drainages.

Evaluation of the likely impacts of mining on regional groundwater systems has been assessed using computer based modelling techniques. A regional groundwater model comprising 13 layers has been developed using a finite element based computer code known as Feflow. The model incorporates each target seam as a separate layer together with interburden strata which have been consolidated into single layer representations between seams. The Hunter River alluvium and Saddlers Creek alluvium have been included in order to assess leakage impacts from these aquifers although Saddlers Creek alluvium appears to be limited in thickness in some areas. Major structural features including the monocline and significant faults in the project area, have also been included. Mining has been represented by progressively extracting panels according to the proposed schedule.

Model predictions support the evolution of a complex depressurisation of strata as a result of multi seam extractions. Impact in the shallow regolith is mostly within the subsidence zone (within the longwall panel footprint) where loss of the water table is predicted via vertically downwards drainage induced by subsidence cracking. Beyond the subsidence zone, the shallow water table or zone of unsaturated flow is predicted to be maintained essentially through long term rainfall recharge to, and storage within the regolith-weathered bedrock. However beneath this zone the rock mass will be variably but significantly depressurised with pressure losses extending about 3 to 4 kilometres beyond parts of the panel footprint. This range of depressurisation is consistent with observations at other mine sites throughout the region.

Total mine water seepage to underground operations from groundwater storage within the coal measures is predicted to steadily increase over the period of mining from an initial rate below about 0.5ML/day during entry and development in the Woodlands Hill seam, to a maximum rate of about 6 ML/day on completion of mining in the deeper Piercefield seam. Model simulations suggest the greatest influx can be expected from the Glen Munro and Piercefield seams. This is attributed to the simplified representation of strata within the model where each of these seams has a much thicker subsided overburden (failure regime) contributing to vertical seepage when compared to the remaining seams. Infrequent contributions from localised areas of higher conductivity and storage associated with faults, dykes and/or sills, or from unmanaged surface runoff seepage through cracking, may also temporarily elevate seepage influx by 0.3 to 0.5 ML/day over periods of weeks to months.

Vertical leakage rates between the Hunter River alluvium and the underlying coal measures strata are predicted to remain unchanged during the course of mining as depressurisation that might induce significant leakage, is not predicted to extend beneath that alluvial system. Since groundwater piezometric levels are not expected to affect leakage to/from the Hunter River to a measurable extent, the Hunter River Water Sharing Plan would not be affected. However vertical leakage between the alluvial deposits associated with Saddlers Creek and the underlying coal measures may be affected. Analysis of localised groundwater flows generated by the aquifer model, indicates a pre-mining net upward seepage of the order of 0.34 ML/day which, when averaged over an area of some 3.5 sq.km. yields a rate of about 0.1 L /day/sq.m of surface area. Seepage fluxes determined at the cessation of mining indicate the net upward flux would continue at a reduced rate of 0.26 ML/day, over the same area – a reduction of 0.08 ML/day. No large scale reversal to downward leakage is indicated, hence the alluvial lands associated with Saddlers Creek are expected to continue to receive saline seepage from surrounding coal measures and to remain relatively unimpacted by the proposed mining operations. It is noted however that predictions do not discount the possibility of localised leakage reversals induced by underlying structure (faults, dykes, shear zones etc.).

Existing bores and wells throughout the area have been identified. Those nearest to the proposed underground operations are located in the south-western part of the project area. Vulnerable locations are considered to be those that may be potentially exposed to 2 m or more of strata depressurisation. Three are within the mine subsidence footprint and are predicted to dewater. The remaining bores and wells classed as vulnerable, are situated between 1 and 3 km beyond the panel footprint. Most of these bores draw groundwater from the coal measures for stock water supply at depths ranging from 18 m to more than 50 m. Some loss of groundwater head is predicted in the nearest bores but yield impact will depend upon the depth at which groundwater was intercepted - deeper interceptions are most likely to exhibit negligible impacts.

A number of bores and wells are also located in the alluvial lands associated with the Hunter River to the north of the project area. These bores are generally shallow with depths ranging from 8 to 11 m and water qualities ranging from fresh to brackish. However, the highest density of privately registered bores and wells is situated more than 3 km west of the panel footprint in alluvial lands associated with the Hunter River and its confluence with Sandy Creek. These bores are mostly constructed to depths of 8 to 20 m in water bearing alluvium. All the above noted bores are beyond the predicted depressurisation zone and would not be impacted by the proposed mine development.

There are no identified groundwater dependent eco-systems within the area likely to be impacted by loss of formation groundwater pressures.

Simulation of the recovery of groundwater levels indicates more than 50 years will pass before groundwater levels and pressures within the depressurised strata, substantially rebound. Groundwater quality within the coal measures both during and post mining, is expected to exhibit a speciated signature (cations and anions) consistent with the range of water qualities currently encountered in exploration holes and observation piezometers. That is, a sodium-magnesium bicarbonate-chloride water of brackish to saline quality.

An expanded groundwater piezometer network is proposed if the project is approved. This network would comprise an increased number of piezometers in areas surrounding the panel footprint with the inclusion of multi piezometer arrays to provide monitoring-mapping of depressurisation during mining and pressure recovery following mining.

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1. INTRODUCTION

Mt Arthur Coal is seeking approval to undertake underground mining operations in an area located 15 to 20km west of Muswellbrook in the Upper Hunter region. Proposed mining provides for the extraction of up to 8 Million tonnes per annum (Mtpa) of coal over a period of 21 years using the longwall retreat approach. Proposed longwall panels are expected to be extracted over distances in the order of 2 to 5 kilometres.

Mining will extract coal from the Glen Munro, Woodlands Hill, Arrowfield, Bowfield and Piercefield seams. All panel extractions will be undertaken below the prevailing regional water table and will result in depressurisation of mined coal seams and strata above and below those seams. Depressurisation above seams will be accelerated through caving and subsidence. Such depressurisation will lead to changed groundwater flow directions within the coal measures and any connected aquifers, including potential leakage from surface aquifers and drainages. Re-saturation of goaf and subsided zones after mining has been completed will alter the long term 'recovered' water table in mined areas and may affect the long term groundwater quality in these same areas.

The Environmental Planning & Assessment Act requires the impact of mining on regional groundwater systems to be addressed. Key areas of study have been broadly identified as follows:

- Description of the different aquifer systems including extent, inter-relationships and connectivity to surface water systems and any dependent eco-systems;
- Description of the potential interaction between hard rock aquifer systems and alluvial systems;
- Assessment of the regional groundwater elevations, flow directions, rates of flow and chemical signatures of the groundwaters;
- Details of proposed underground mining and any bore or other water supply works connected with the mining process that may intercept the aquifer systems;
- Details of the extent of predicted impacts of mining (water levels and water quality)
- Identification of the impacts on existing groundwater users likely to be affected by the proposed development;
- Details of any long term impacts on the groundwater regime.

Mackie Environmental Research Pty. Ltd. (MER) was commissioned by Mt Arthur Coal in 2005 to undertake groundwater management studies for the Mt Arthur Underground Project (MAU) and to provide advice in respect of future measurement and monitoring of aquifer conditions. The contained report provides results of those studies and includes groundwater hydrological data for the region, and computer simulations of aquifer systems in order to assess the likely impacts arising from proposed mining operations.

1.1 Previous and current studies of relevance

Numerous groundwater related studies have been conducted in the region over many years and include the following.

Williams (1958) provides the first regional study of the alluvial lands associated with the Hunter River upstream and downstream of the township of Muswellbrook. Bore and well locations, hydraulic properties estimates and regional piezometric surfaces within the alluvium, provide a valuable historical baseline reference.

Australian Groundwater Consultants (AGC 1979, 1980) undertook studies in the Mt Arthur North area on behalf of the Electricity Commission of NSW. Those studies included various tests to establish the hydraulic properties of strata as a pre cursor to mining, preparation of piezometric

surfaces, baseline hydrochemistry and general assessments of the prevailing hydrogeology. A number of piezometers and deep bores were constructed throughout the area and some have been retained as groundwater monitoring locations for current mining operations. AGC (1981) provides an assessment of groundwater resources in the Mt Arthur South area and estimates pit inflows and potential groundwater resources for water supply.

Laurie Montgomery & Pettit (LMP, 1982) conducted further studies of the Mt Arthur North area which included additional hydraulic testing and numerical modelling of a number of proposed pits.

Mackie Environmental Research (MER, 2000) provides a detailed environmental impact assessment of the hydrogeology of the Mt Arthur North open cut coal project and surrounding areas. Additional monitoring piezometers were constructed as part of those studies and a composite piezometric surface developed for the region. Historical and more recent hydraulic properties and hydrochemistry of groundwaters were summarised. Numerical modelling of the coal measures and open cut mine pit development was also undertaken.

Australian Groundwater & Environmental Consultants (AGE, 2003) undertook a preliminary study for the proposed underground mining operations within the underground project area. Findings from previous studies are summarised and preliminary estimates of mine water influx are presented for a multi seam progression extending from the shallow Blakefield seam to the deep Edinglassie seam. These estimates indicate a rate of 1.5 ML/day (17 L/s) might be expected with extraction of the Glen Munro seam and 3.3 ML/day (38 L/s) might be expected at the Piercefield seam depth, for steady state conditions. These rates are consistent with rates encountered in nearby open cut operations including Mt Arthur North, Bayswater Colliery, Drayton, Bengalla and Howick (West Pit) operations. The rates are also of similar magnitude to rates encountered in underground operations like Dartbrook mine to the north and Cumnock mine to the south-east.

AGE (2006) provides an environmental assessment of the South Pit Extension project area currently being assessed by the Dept. of Planning. This project is an open pit development located south of the existing MAC open cut operations and west of Drayton mine. Studies have drawn on hydrogeological data provided in MER (2000) and included development of a regional finite element model to assess the groundwater related impacts of mining seams below (and including) the Mt Arthur seam. Reported depressurisations extend 1 to 1.5 km beyond the pit crest while predicted maximum pit seepage is of the order of 0.3 ML/day after 21 years of mining.

2. REGIONAL SETTING

The project area is covered by Exploration Licence EL5965, Mining Leases ML1358, ML1487, ML1593 and ML1548 but areas of interest in respect of groundwater studies, extend up to five kilometres beyond the defined perimeter of this area.

The general area of interest is identified on Figure 1 together with the mine panel footprint. This area comprises undulating hills and grasslands in the eastern parts while in western parts, the countryside is interrupted by steeper hills with numerous more densely wooded areas on and around Mt. Ogilvie.

Topographic elevations range from about 120 to 130 metres - Australia Height Datum (mAHD) within the alluvial flats associated with the Hunter River situated to the north of the project area, to about 450 mAHD at the top of Mt. Ogilvie.

The nearest active mining areas are located north-east and east of the project area where Mt Arthur Coal operate the Mount Arthur North (MAN) open cut pit which mines seams within the same coal measures as the project but stratigraphically lower; and Bayswater Colliery Company No.3 (BCC3), which mines or has mined the Blakefield, Glen Munro and Woodlands Hill seams.

2.1 Rainfall and evaporation

The regional climate is temperate and influenced to some extent by coastal weather patterns. Rainfall averages about 620mm per annum; Denman and Muswellbrook are the nearest long term rain gauging stations. Rainfall statistics for Denman are provided in Appendix A from which it is noted that average rainfalls are highest in summer months.

A number of periods during the last decade or so have witnessed below average annual rainfalls; moderately dry years occurred from 1994 to 1997 while exceptionally dry conditions have prevailed throughout 2002-2006. The pattern of rainfall during these years has not been conducive to groundwater recharge and has resulted in water table declines in shallow bores and wells throughout the region.

The nearest long term gauging station for evaporation is located at Scone about 25km to the north-east where a mean annual average loss rate (Pan A) has been recorded at about 1600mm per annum. As a general guide, evaporation exceeds rainfall for all months of the year, the smallest difference occurring in June where average rainfall (40.3mm) and evaporation (48mm) are nearly balanced. Hence there is increased potential for rainfall recharge during winter months however this generally depends on the sequency of rainfall events.

2.2 Drainage and groundwater recharge

The project area can be broadly subdivided into two drainage catchments:

- drainages located over the northern part of the area that flow to the north or north-west eventually transgressing the Hunter River alluvial lands and discharging into the river;
- Saddlers Creek catchment located over much of the southern part of the area. Saddlers Creek itself enters the south-eastern corner of the project area and flows in a south-westerly direction eventually meeting the Hunter River some 6km downstream (see Figure 1).

During periods of high rainfall, creek runoff can be exceptionally high with local flooding occurring for short periods, especially around the lower parts of Saddlers Creek catchment and within the alluvial lands associated with the Hunter River. These flood prone areas particularly within the Hunter River flood plain, are important recharge areas for the underlying alluvial aquifers.

Rainfall recharge to other shallow groundwater systems situated in elevated areas including the weathered rock zone or regolith, is often variable. The coal measures in these areas tend to weather to a relatively thin regolith (5 to 10m thick) comprising mixed sandy, silty-clayey sediments. The silty-clayey zones have poor transmission characteristics but the sandy areas offer increased potential for groundwater recharge.

The regolith acts as a temporary water store during sustained wet periods and provides a source for recharge to the underlying coal measures. However, recharge to the underlying coal measures is inferred to be weak given the very low hydraulic conductivities of deeper strata and observed minimal change in water levels in deep monitoring bores throughout the region. This differentiation in properties between the regolith and underlying coal measures can sometimes result in the presence of shallow springs although few are noted within the project area.

2.3 Geology overview

Regional geology is summarised on the published 1:100,000 Geological Map (Dept. Mineral Resources) and described by Beckett (1988). Fundamentally the geology in the project area comprises strata within the Jerrys Plains Sub Group within the Permian Wittingham Coal Measures - see Figure 2 for stratigraphy.

These coal measures were deposited under conditions ranging from lower deltaic to upper deltaic (Beckett, 1988) which also included inter-distributary bay regimes, swamp environments and

emerging beach conditions. Upper deltaic conditions were more prevalent following deposition of the Vaux seam and were sustained until deposition of the Glen Munro seam when marine incursions were again more prevalent. These depositional environments have resulted in an interburden stratigraphy comprising well cemented sandstones, siltstones and shales with relatively low to negligible hydraulic conductivity (permeability) and quite variable mineral salts content.

Drainage channels have eroded the Permian strata over geologic time. These channels host Quaternary to Recent unconsolidated alluvial materials. The Hunter River alluvial lands represent the most significant of these drainage channels, extending over widths of 1.5km (orthogonal to the river valley) with unconsolidated deposits to depths of 15 to 20m. Deposited materials often comprise a silty clayey basal layer overlain by silty or sandy gravels exhibiting moderate hydraulic conductivities which in turn are commonly overlain by extensive and mixed silt-clay deposits offering low conductivities. Alluvial materials within other drainages (eg. Saddlers Creek) tend to be more silty and less transmissive than the Hunter River alluvial deposits, and generally thinner. Often the distinction between alluvial-colluvial materials and the underlying regolith in these tributary drainages proves difficult to identify.

Figure 3 provides a map showing the approximate extent of the alluvial lands associated with the major drainages and the approximate locations of the subcropping Glen Munro, Arrowfield and other seams. These seams also subcrop beneath the Hunter River alluvial lands. Generally the seams exhibit a south-westerly to south-easterly dip within the central part of the area and a westerly dip in the western part of the area although dip direction can vary locally as indicated on Figure 3 by the strike/dip symbols. A monocline or zone of increased dip prevails in a generally north-south direction along the eastern boundary of the proposed mine panel footprint. The westerly limit or toe of this zone is also shown on Figure 3.

Figure 4 provides three east-west sections illustrating the relatively weak dips of the strata within the project area, the location of a significant fault known as the Cottage Fault, and the monocline.

2.3.1 Target coal seams

Mt Arthur Coal propose to mine coal resources of the Glen Munro, Woodlands Hill, Arrowfield, Bowfield and Piercefield seams as indicated on the typical borehole stratigraphic succession – Figure 2. Seam descriptions are as follows:

The Glen Munro Seam has been mined via open cut methods by BCC3 (Belmont Pit). The seam shows considerable variation in character, especially with respect to splitting. In the north of the project area, the seam exists as a single coalesced unit approximately 3.5 to 4.5 m thick. In the southern and western parts the seam splits into four main plies each of which thins as they split. The plies (GM1, GM2, GM3 and GM4) are each separated by three distinct claystone bands which are recognisable even when the seam is coalesced. As a result it is relatively banded and has a moderate raw ash content.

The seam is generally clear of igneous intrusions although several irregular sills do occur throughout the project area.

Roof lithology is highly dependent on splitting but in the coalesced area the immediate roof consists of a weak, thinly laminated claystone that desiccates readily upon exposure to air. Once the GM1 ply has split away, the roof lithology of the GM2-4 working section (the target mining section) consists of moderately competent medium grained sandstone. Floor lithology also depends on splitting and adopted working section but the floor of the GM4 ply is commonly a siltstone.

The Woodlands Hill Seam occurs approximately 30 m below the lower most split of the Glen Munro Seam and the interburden lithologies are predominantly sandstones with interbedded siltstones near the top. The seam is relatively thick (>6 m) when coalesced but it develops a major split which separates the top ply (WH1) from the lower three plies (WH2, WH3 and WH4). The thickness of the split reaches a maximum of about 23 m and develops over a very short distance. The seam is coalesced in the eastern parts of the area where it has been mined by BCC3 (Saddlers Pit). As with the Glen Munro Seam, all four plies are recognisable when coalesced, and are

separated by claystone bands in the order of 0.1 to 0.6 m thick. One of these partings between the WH3 and WH4 plies is of particular interest, being the Milbrodale Claystone - a highly tuffaceous unit that forms a distinct and well known regional marker horizon that exhibits very low permeability regionally.

Extensive silling of both splits of the Woodlands Hill Seam occurs beneath the Belmont and McDonalds open cut pits (pits shown on Figure 1).

Lithology of the immediate roof of the coalesced seam (roof of WH1) generally consists of a moderately weak claystone and where split, the roof of the WH2 ply generally consists of a fine grained siltstone with occasional claystone. Floor lithology is generally siltstone with minor claystone.

The Arrowfield Seam is approximately 2.5 to 3.5 m thick and occurs about 40 m below the Woodlands Hill Seam. It is relatively consistent in thickness and extent over a large portion of the central part of the project area but develops a split in a north-westerly trending zone in the north east of the project area. The seam is intruded by a doleritic sill in the southern, central and western portions of the area.

The seam consists mostly of bright coal with a few stoney bands occurring towards the base. Three plies are noted - AF1A, AF1B and AF2, of which the AF2 is generally a lower quality ply at the base of the seam.

Lithology of the immediate roof and floor consists mostly of weak, thinly laminated claystone.

The Bowfield Seam is approximately 20 m below the Arrowfield seam. It is of similar thickness ranging from 1.5 to 3.5 m. It also has a notable lack of splitting and occurs as a singular entity over the majority of the area. Like the Arrowfield seam it is extensively sill intruded over a large part of the southern and western parts of the area. The seam consists of 3 plies identified as the BF1, BF2 and BF3.

The Piercefield Seam occurs as two distinct splits, the Piercefield Upper (PU) and Piercefield Lower (PL). The PU Seam is the main seam of interest being about 2 m in thickness. The PL Seam is about 0.5 m thick and is only included in the working section when it occurs close enough to the PU Seam.

The Piercefield Seam is comprised of generally bright coal with very few stone bands and has a relatively low raw ash content. The seam is also notably free of igneous intrusions over most of area although a few sills do occur in the far southern and western parts.

Immediate roof lithology consists of 2 to 8 m of weak, thinly laminated claystone which is overlain by a moderately strong medium grained sandstone. Floor lithology is also a weak laminated claystone.

2.3.2 Interburden

Interburden throughout the area varies from interbedded claystones to siltstones to coarse grained sometimes massive sandstones. Conglomeritic sandstone has also been noted but is relatively infrequent. These lithologies tend to be remarkably similar in mineral content throughout the entire succession.

Claystones have generally formed from the alteration of volcanic ash in a coal swamp or flood plain environment and often contain a high proportion of smectite (discrete or as mixed layer illite-smectite) with subordinate feldspars including albite and anorthite. Darker coloured claystones-shales tend to contain increased quartz, kaolinite and illite while feldspars are generally absent.

The sandstones and coarser grained siltstones are either lithic, composed of chert, claystone and siltstone fragments with minor quartz, feldspar and coal fragments, or tuffaceous with fragments and crystals of quartz, plagioclase, biotite and other volcanic minerals. The origin of these fragments is either the Carboniferous volcanics to the east, or intra-formational and derived through reworking.

The cementation matrix of these interburden strata often constitutes more than 30% of the rock mass. This matrix is largely comprised of clays (illite, mixed layer illite-smectite, smectite and kaolinite) and carbonates (dolomite, siderite and to a lesser extent dawsonite).

2.3.3 Structural features

A regional northerly trending monocline generally separates the proposed area for underground mining to the west of the monocline, from open cut operations to the north-east and east of the monocline as shown on Figures 3 and 4. The monocline is poorly developed in the north of the area (and presumably northward beneath the Hunter River alluvial lands) but develops in a southward direction. This is reflected in the bedding dips within the monocline that vary from 5° in the north to more than 40° in the south.

Major faulting within the area is infrequent. The history and causative stresses remain largely unresolved but regional east-west compression of the coal measures has probably influenced the development of a number of these faults. Several fault directions have been identified from exploration drilling, air photo and aeromagnetic analysis. These are shown on Figure 5 and include:

- northerly trending faults including the Mt. Ogilvie system in the west of the area. The Mt. Ogilvie Fault is the most significant and exhibits a regional displacement believed to be as much as 200 m which results in the exposure of the younger Wollombi (Newcastle) Coal Measures to the west of the fault(s);
- north-easterly and easterly trending faults. These include Trig, Cottage and F1 faults that have all affected longwall panel design. These are normal faults with displacements varying from 0 to 85 m (east to west) for the Trig fault, 0 to 120 m (east to west) for the Cottage fault, and 20 to 45 m (east to west) for the F1 fault.

Numerous dykes are noted throughout the area (Figure 5). The most significant is the north-westerly trending Lane dyke situated centrally within the proposed mine footprint and extending over a distance of 5 km. Other dykes adopt a north-easterly or northerly trend consistent with other areas throughout the Upper Hunter region. One of these dykes known as Shearers dyke which is also associated with a strike-slip fault, may have influenced the location of Saddlers Creek. Most are sub-vertical to vertical with thicknesses expected to vary from 1 to 5 m.

Sills occur throughout the strata and have in most instances, invaded seams to the extent that the potential for mining these areas has been significantly impacted.

3. GROUNDWATER HYDROLOGY

3.1 Aquifer systems

The Upper Hunter region hosts three recognised types of groundwater system which include:

- **coal measures aquifers** with groundwater storage in coal seams as cleat storage, or in interburden where weak intergranular storage is developed but hydraulic conductivity is generally low to negligible. Secondary storage may also be developed within fractures and faults in interburden. Water quality is generally brackish to saline;
- **the overlying weathered zone (regolith)** as intergranular storage. This zone is shallow and of limited extent with intergranular and fracture related storage governed by climatic conditions. Periods of high and sustained rainfall tend to saturate the regolith, often leading to the occurrence of springs. However most regolith storage is rapidly depleted during extended dry and drought periods. Water quality is variable from fresh to saline;

- ***alluvial lands of Quaternary to Recent age (Hunter River, Saddlers Creek and subsidiary drainages)*** as intergranular storage. These zones are shallow and often linked to the surface drainages. Areas conducive to water supply occur where porosity and hydraulic conductivity are developed sufficiently to enable exploitation of storage.

These three identified systems act in an integrated way in some areas while in other areas they may act in isolation.

The coal seams themselves are mostly confined aquifers. That is, groundwater encountered during drilling, commonly rises above the seams. Such confinement is supported by continuous water level monitoring at a number of piezometers located immediately to the south of the project area where oscillations in the piezometric level of up to 150 mm can be attributed to barometric change - elastic storage is inferred from such movements. Confinement has also been exhibited at a number of exploration boreholes drilled in lower lying parts of the area where artesian flowing conditions have been noted prior to grouting.

The alluvial lands associated with the Hunter River are identified as a regional unconfined aquifer system. Useful groundwater supplies from wells or boreholes are generally restricted to areas where intermediate and deeper materials comprise sands or gravels that offer favourable storage and transmission characteristics. In this regard, it is noted that the alluvial lands adjacent to the river north of the project are poorly exploited with very few boreholes or wells installed. This may in part be due to the silty and low permeability nature of the sediments and/or the generally elevated salinities attributed to upwards leakage of groundwater from the underlying coal measures.

The alluvial system generally maintains some hydraulic connectivity with the river itself with groundwater levels rising following river level rises. Perching of the water table can also occur during periods of heavy rainfall with local flooding accompanying these periods. However the perched water table usually dissipates downwards over a period of days to weeks after rain events, resulting in an increase in the water table associated with the deeper alluvial system. This mechanism tends to flush saline waters from the system.

3.2 Groundwater flow

Water tables and groundwater pressures in the deeper coal measures are sustained by rainfall percolation from the shallow regolith to sub cropping coal measures strata. Estimates of rainfall recharge vary from zero to no more than 1 or 2% of annual rainfall based upon previous studies in the region. The regolith therefore basically acts as a water store. Rainfall recharge percolates downwards from the regolith at a reducing rate as increasing confinement and reducing permeability (with depth) impedes flow. This vertical flow regime is influenced by fracture flow, where pathways depend upon fracture and joint connectivity.

Flow directions and rates can also be affected by changes in hydraulic properties within strata (facies changes), by the presence of faulting, or by the presence of igneous intrusives – dykes and sills. Faults may act as transmission conduits that establish preferential flow or groundwater mixing zones. Dykes throughout the Upper Hunter region are generally recognised as impermeable structures. Dykes therefore tend to act more often as localised barriers to flow forcing some compartmentalisation of the flow regime. Major dykes occurring within the project area might act in this way while minor dykes may have little effect on flows. In some cases they provide localised potential for groundwater storage mostly within adjacent heat affected zones. Extensive sills are noted within most seams targeted for mining. These structures have been observed to generate indurated zones and increased fracturing within the invaded seam. Such zones are capable of hosting increased groundwater storage but generally this storage is inferred to be finite and drainable under mining conditions from observations at other mine sites. Interburden storage within the same (indurated) zones is expected to be lower on a unit volume basis, than seam storage.

3.2.1 Flow rates

Groundwater flow rates within the interburden and coal seams are governed by the prevailing piezometric surface and the hydraulic properties of respective strata. The velocities of flow are currently estimated to be very low and are calculated to range from 10^{-3} to 10^{-6} m/day based on the hydraulic conductivities described in Appendix D and mapped hydraulic gradients.

In contrast to the coal measures, the alluvial lands adjacent to the Hunter River (and other significant drainages) act as a much more dynamic flow system with rainfall recharge penetrating the sandy and silty aquifer materials. This infiltration mechanism sustains a groundwater flow regime towards the river where bank and river bed seepage eventually discharges groundwater to the river. Velocities of flow are calculated to be 10^{-1} to 10^{-4} m/day depending on the hydraulic conductivity of materials.

3.2.2 Regional piezometric surface

More than 60 borehole-piezometer sites are distributed throughout the region. These are or have been routinely monitored for water level and basic water quality parameters (pH and EC) at intervals varying from monthly to quarterly. Within this network 12 are located in specific coal seams, at least 39 are open to numerous seams, and 9 are located within the Hunter River alluvial lands. Automated water level logging apparatus is also installed at 16 piezometer locations in order to more accurately record short term events associated with rainfall recharge. Appendix B provides a summary of site locations and details.

A regional composite pre-mining (Mt Arthur Coal open cut) piezometric surface has been mapped using water level monitoring data together with numerous spot measurements from exploration holes. It is noted that for the small number of seam specific piezometers installed within the project area (locations identified on Figure B1, Appendix B), piezometric levels measured after installation of piezometer standpipes, are generally within ± 10 m of the composite surface observed in open holes. Exceptions are two piezometers OR2051 and OD1073 which are isolated within the Arrowfield seam. These piezometers exhibit lower piezometric levels than the composite surface. The reason for this may be shallow leakage from the seam in subcrop areas at lower (down slope) elevations to the north-east of the piezometers.

Figure 6 gives a regionally averaged interpolation of equipotentials generated using measured water levels, approximate river and creek bed elevations, and steady state groundwater model predictions as a general guide to the likely geometry. Strata depressurisation relating to open cut operations at McDonalds, Belmont and Saddlers open cut pits has not been included due to relatively localised impacts and limited submergence below the water table. Reference to Figure 6 shows a surface that reflects a subdued image of topography with elevated piezometric levels extending from Mt. Ogilvie eastwards. Elevated levels are also observed in the area around Mt. Arthur. This broad correlation with topography for pre-mining conditions is commonly recognised over most of the Upper Hunter region.

Lowest levels occur near the major drainages like Saddlers Creek and the Hunter River. The marked difference in piezometric levels between elevated areas and the major drainages infers a regional groundwater flow system from topographic highs towards the major drainages. Approximate groundwater flow directions are indicated by the arrows on Figure 6.

Upwards leakage of groundwater to the alluvium may be occurring preferentially from any subcropping coal seams beneath the alluvium. This leakage probably contributes to the relatively saline groundwaters observed in deeper parts of the alluvial aquifers.

The hydraulic gradient across the area varies from about 1 in 8 in steep terrain, to about 1 in 800 in subdued terrain near the Hunter River.

3.2.3 Pre mining seam hydrostatic pressures

The approximate virgin or pre mining hydrostatic pore pressures have been calculated for each target coal seam by subtracting the respective seam floor elevations from the composite regional piezometric surface. Appendix C provides plots for the target seams.

As expected, lowest hydrostatic pressures tend to occur in the eastern part of the area east of the monocline toe, or beneath the alluvial lands to the north where lower ground elevations prevail. Relatively steep pressure gradients are observed across the Cottage Fault in the central part of the area with lower pressures exhibited to the south of the fault. These lower pressures result from lower topographic elevations (and a lower piezometric surface) towards and beneath Saddlers Creek.

3.3 Strata hydraulic properties

Hydraulic conductivities for coal seams, interburden and alluvium have been measured using various techniques over numerous drilling campaigns including the Mt Arthur North and South areas and Bayswater No 2 and 3, in addition to specific drilling undertaken for the underground project. Coal seam conductivities are governed by the presence and frequency of cleating, and the depth of individual seams. Interburden conductivities are governed by a combination of intergranular conductivity and fracturing, while alluvium conductivities are intergranular in nature.

The most commonly applied test methods have involved variable head, air lift yield and pumping tests to determine hydraulic conductivity. These various tests have been undertaken at more than 45 locations including installed piezometers and exploration holes within the project area, the open cut areas to the north-east and east and EL5460 to the south. Many of the tests were conducted in open holes and as such, they only provide an indicative estimate of the 'saturated column' conductivity. A low value determined from these 'bulk' tests is assumed to imply low conductivity within coal seams intercepted by the test hole.

Numerous coal seam conductivities have also been measured through carefully controlled packer testing. This type of testing is focussed on the influence of coal cleats on seam conductivity but since testing is conducted in a small diameter HQ size borehole, the number of cleat intersections can be highly variable. Hence the conductivities determined in this way, while accurate for a given seam test section, can vary from hole to hole.

Selected core from 14 exploration bore sites has also been subjected to laboratory determination of hydraulic conductivity. These tests have specifically targeted interburden lithologies and are considered to provide accurate estimates of the intergranular conductivity at a small scale. All tests have returned low conductance values consistent with similar tests conducted at other locations throughout the Upper Hunter region.

Test methodologies, analytical procedures and results are provided in Appendix D while broadly indicative ranges of hydraulic conductivities for different lithologies, are provided in the following Table 1.

Table 1: Hydraulic conductivities for different lithologies

Description	Hyd. conductivity (Kxy) (m/day)
silty alluvium (in deep alluvium)	1.0E-01 to 5.0E+01
coal, dull to bright	1.0E-03 to 1.0E+00
conglomerate	1.0E-04 to 1.0E-02
sandstone	1.0E-05 to 5.0E-04
siltstone	1.0E-06 to 1.0E-04
laminite	5.0E-06 to 1.0E-04
shale	1.0E-07 to 1.0E-05
dolerite	1.0E-07 to 1.0E-05

3.4 Groundwater quality

Data relating to regional groundwater qualities has been generated from routine monitoring of water quality parameters pH, salinity (EC) and speciation of water samples obtained from piezometers within the project area, piezometers within and around the open cut areas to the north-east and east, and monitoring conducted within EL5460 to the south over a number of years. Summary data is provided in Appendix B while Appendix E provides more detailed hydrochemistry assessments.

In general, data reflects brackish to saline waters both within the coal measures and within the alluvial lands the latter being attributed to upwards leakage of saline coal measures groundwaters without significant rainfall or river water flushing. There are occasional exceptions where the shallow regolith hosts relatively fresh water zones but these are infrequent.

Salinity measured as electrical conductivity (EC) ranges from 3017 uS/cm to 7773 uS/cm with an average of 4623 uS/cm for the alluvial lands, and 566 uS/cm to 9387 uS/cm with an average of 4295 uS/cm for the coal measures. pH values range from 7.06 to 7.41 with an average of 7.24 for the alluvial lands, and 6.53 to 11.30 with an average of 7.5 for the coal measures. Elevated pH (above 10.0) at some locations may reflect the influence of in-hole cement grouting back to the level of the piezometer installation. Ionic speciation is characterised by $\text{Na} > \text{Mg} > \text{Ca}$ and $\text{Cl} > \text{HCO}_3 > \text{SO}_4$ as indicated on Figure E2 in Appendix E.

Established water quality guideline data are summarised in the following Table 2 together with typical groundwaters sampled in observation piezometers in the coal measures within the project area and the alluvial lands north of the area. In general, most groundwaters have limited environmental value, being restricted to stock watering. More favourable conditions can be found in certain parts of the Hunter River alluvial lands, the south-western corner of EL5965 and a few isolated locations where alluvium-colluvium is exploited within minor drainages.

Table 2: Generalised water quality criteria and comparison with regional waters

Beneficial use	TDS (mg/L)	Equivalent EC (uS/cm)
acceptable taste limit for humans	1000 ¹	1540
general upper limit based on taste	1500	2300
approx. limit for lucerne on alluvial lands	1300 ²	2000
limit for poultry and pasture/fodder	3000 ²	4600
limit for dairy cattle	4000 ²	6100
sea water	32500	50000
average coal seam salinity across all monitoring bores	2792	4295
measured average in HR deep alluvium monitoring	3005	4623

Source: 1=ADWG - 1996, 2=ANZECC, 2000, Equivalent TDS is approximate and depends on specific ions.

3.5 Existing bores and wells in the region

Department of Water and Energy (DWE) retain a database of registered bores and wells in NSW. This database includes both exploration/test wells which may have been completed as permanent structures, together with observation/monitoring bores and privately owned bores and wells currently in use, and facilities that have been either temporarily or permanently abandoned.

Figure 7 identifies bore/well locations situated in proximity to proposed underground mining operations. Identifying numbers are either GW type or BCGW. GW type numbers refer to DWE registered locations while BCGW numbers refer to locations visited as part of a regional bore census. These BCGW locations include unregistered, and registered bores or wells, and abandoned sites.

Bores located near to and generally on the western side of Edderton Rd are owned by Mt Arthur Coal. Most of these locations are in a state of disrepair. Nearest privately owned bores or wells are located in the south-western, western or north-western parts of the project area. Three are located within the proposed mine panel footprint and are identified as BCGW10, BCGW11 and BCGW12.

The highest density of privately owned bores and wells is situated more than 3 km west of the panel footprint in alluvial lands associated with the Hunter River and its confluence with Sandy Creek (see Figure 7). These bores are mostly constructed to depths of 8 to 18 m in water bearing alluvium. A number of bores and wells are also located in the alluvial lands north of the project area. These bores are generally shallow with depths ranging from 8 to 11 m and water qualities ranging from fresh to brackish.

Bores located in hardrock areas beyond the alluvial lands draw groundwater from the regolith and underlying coal measures for stock water supply at depths typically ranging from 18 to +50 m.

4. COMPUTER SIMULATION OF COAL MEASURES

Proposed mining will extract coal from longwall panels within the Glen Munro, Woodlands Hill, Arrowfield, Bowfield and Piercefield seams at increasing depths. Panel extractions will be undertaken below the prevailing regional water table and will result in depressurisation of the exposed coal seam and depressurisation of strata above and below mined seams. Depressurisation above mined seams will be accelerated through caving and subsidence, leading to changed groundwater flow directions within the coal measures. A pressure (loss) wave will propagate beyond the extracted panels at a rate governed by the prevailing hydraulic properties of the strata. Some dewatering of shallow strata above the extracted panels may also occur.

Evaluation of the pressure loss regime for multi seam extraction is extremely difficult and complex, requiring analyses in both space and time. The most appropriate analytical technique to undertake such an evaluation is numerical simulation using computer based modelling techniques.

A relatively sophisticated computer based mathematical model of the region has been developed in order to understand the likely regional extent of depressurisation and to predict mine water influx. The modelling method (WASY, 2002) employs a numerical finite element scheme for solving a set of differential equations known to govern groundwater flow. Importantly, the code is generally robust in handling steep hydraulic gradients that are likely to evolve around the subsided panels. The code also includes a capacity for temporal changes in hydraulic properties that occur with subsidence, and for inclusion of discrete elements for representation of narrow transmissive (fault) zones.

The modelling method requires dividing the overall area of interest into a large number of separate triangular prisms or elements. The number of finite elements defined in the model mesh has been determined by the proposed seam extraction sequence, the spatial variations occurring in strata properties, the prevailing drainage system, mine panel geometry (at depth) and the expected hydraulic gradients developed in the course of modelling.

The constructed model is a variably saturated scheme comprising 13 transversely anisotropic layers representing a total modelled area of about 400 sq. km. Elements and nodes have been carefully designed to represent the Hunter River, Saddlers Creek, other regional drainages, the alluvial aquifers, the coal measures, MAN open cut operations and panel extractions in all seams. BCC3 open cut operations, including completed pits (Blakefield and Glen Munro seams) and active pits (Woodlands Hill seam) have not been included since they impact in a relatively minor way on the prevailing water table. Model details are provided in Appendix F.

Properties assigned to the model which govern groundwater flow, include hydraulic conductivity, compressive storage and specific yield. Hydraulic conductivity distributions have been assigned using six exploration boreholes as type sections. In addition, enhanced vertical conductivities

representing the subsidence zones above target seams have been assigned. These zones enhance vertical drainage downwards to the underlying extracted panels.

Hydraulic conductivity of the alluvium adjacent to the Hunter River and within Saddlers Creek catchment has been included within the uppermost layer of the model. The alluvium is assumed to exhibit homogeneity and isotropy even though data suggests stratification of unconsolidated sands, silts and clays. In the absence of field test data for specific stratified zones within the alluvium, adoption of a uniform conductivity is considered to represent a conservative approach in determining potential leakage from the alluvium.

Rainfall recharge to the coal measures has been applied at an average rate of a less than 2 mm/year. A conservative 90 mm/year has been applied to alluvial areas (sandy soil) in line with previous modelling in the region. These recharge rates have been used to generate an initial steady state water table prior to any mining activity.

4.1 Strata depressurisation, seepage and leakage

The aquifer model starts simulations in 2002-3 prior to commencement of significant open cut operations at MAN. The model then progresses to 2007 simulating open cut operations in a simplified manner in order to establish an approximate groundwater level/pressure distribution prior to the commencement of proposed underground mining. Underground development relating to trunk and gate road development in the Woodlands Hill seam has been programmed to commence at this time. Thus 5 years of open cut mining are simulated before any underground mining simulations commence.

Modelling has then progressed by assigning underground development and incremental panel extractions to the Woodlands Hill seam according to the planned extraction schedule. Mining in the Woodlands Hill seam has then been followed by the proposed panel extractions in the shallower Glen Munro seam followed by the deeper Arrowfield, Bowfield and Piercefield seams respectively.

Appendix F, Figure F9 illustrates the initial groundwater piezometric surfaces generated by the model prior to commencement of open cut or underground operations. These surfaces vary from layer to layer as a result of the complex flow and pressure distributions established by recharge from the regolith zone (layer 1) downwards to underlying strata. The shallowest layer (1) is a subdued reflection of topography with piezometric highs to the west of the proposed area of mining and in an area to the east beneath Mt. Arthur. Piezometric lows in all layers are situated beneath the Hunter River and beneath Saddlers Creek as expected. Deeper surfaces associated with the target coal seams are progressively more subdued reflections of topography.

Appendix F, Figures F10 through F14 illustrate the drawdown surfaces generated by the model for each seam following completion of mining in progressively deeper seams. These surfaces have been calculated by subtracting the piezometric surface resulting from staged panel extraction, from the pre mining surfaces shown on Figure F9. Reference to these plots shows the depressurisation surface associated with the underground operations varies with depth as expected. Figure 8 provides a larger plot of predicted head losses in the regolith. Impacts in this shallow zone are generally restricted to the mine panel footprint due to vertically enhanced conductivity (connective cracking) within the failure regimes above extracted panels. This is especially apparent above the Glen Munro seam panels in the northern part, and less so above the deeper Woodlands Hill extracted panels in the southern part. Impacts relating to the MAN open cut are also shown to the north-east (Figure 8). Contours associated with open cut impacts are coloured grey for clarity.

Figure 9 illustrates the predicted drawdown in the interburden just above the Glen Munro seam at the end of mining. This representation is at variable depth below the regolith (between 10 and 200m), hence pressure-head losses at intervening depths between this surface and the base of the regolith will occur as a gradient between the two zones. Losses related to both the Glen Munro seam and Woodlands Hill seam extractions, are clearly evident.

Figure 10 illustrates losses at the Piercefield seam depth at the end of mining. The head losses at this depth are almost entirely attributed to Piercefield seam extraction although some southward extension of depressurisation is evident as a result of earlier Woodlands Hill seam extraction.

The overall impact zone predicted by computer simulations extends about 3 to 4 kilometres beyond the footprint when defined by the 2m drawdown contour. This range of depressurisation is consistent with observations at other mine sites throughout the region. The 2m contour is considered to represent the pressure loss level where noticeable impacts might be observed in windmill-pump intake submergence, with potential for loss of yield albeit minor.

Total mine water seepage to active underground operations is predicted to steadily increase over the period of mining from an initial rate below 0.5 to 0.8 ML/day during entry and development in the Woodlands Hill seam, to a maximum rate of about 6 ML/day on completion of mining in the Piercefield seam. This assumes all goafed areas are maintained in a fully dewatered state.

Model simulations suggest the greatest influx can be expected from the Woodlands Hill, Glen Munro and Piercefield seams. Each of these seams has a much thicker subsided overburden contributing to vertical seepage than the remaining intermediate seams where preceding drainage has been partly initiated by overlying seam extractions. The monocline zone also contributes to the predicted influx as a consequence of an assumed increased fracture frequency and connectivity within the zone of bedding flexure. If this fracture connectivity is not widespread, then predicted mine water seepage could be significantly lower.

Infrequent contributions from localised areas of higher conductivity and storage related to minor fault zones may temporarily elevate seepage influx, by 0.3 to 0.5 ML/day over a period of weeks to months. Rainfall may also contribute depending upon connectivity of fractures and connectivity of near surface regolith cracking to surface drainages.

Vertical leakage rates between the Hunter River alluvium and the underlying coal measures strata are predicted to remain generally unchanged since significant depressurisation is not predicted to extend beneath that alluvial system in a significant way. However vertical leakage flows between the alluvial deposits associated with Saddlers Creek and the underlying coal measures could be affected since model simulations indicate head losses (drawdown) of between zero and about 20 m in the vicinity of this alluvium based on pressure gradients between surfaces represented on Figures 8 and 9. These losses are governed by the adopted vertical conductivities within the model rather than by any surface cracking which will generally be confined to the subsidence zone inside the panel footprint. Accurate estimates of losses are difficult to calculate since the loss rate will vary from place to place depending upon the head difference between Saddlers Creek alluvium and the underlying strata. An estimate has been made by assuming the impact area to be defined by the intersection of the 2 m contour with Saddlers Creek alluvium on Figure 9. An analysis of model fluxes within this area (greater than 2 m) indicates a pre-mining net upward seepage of the order of 0.34 ML/day averaged over an area of some 3.5 sq.km. This equates to about 0.1 L/day/sq.m. Seepage fluxes determined at the cessation of mining after 21 years, indicate the net upward flux would decline to 0.26 ML/day, a relatively small loss of 0.08 ML/day in upward seepage over the 3.5 sq.km. There is no apparent reversal to downward leakage from Saddlers Creek alluvium to the coal measures. Leakage losses are also predicted to occur from localised colluvial-alluvial deposits situated within the minor un-named drainages but the magnitude of these losses are generally expected to be consistent with those calculated for Saddlers Creek alluvium.

There is a potential for increased surface water runoff losses where surface drainages are situated within the subsidence zone and where bare rock or very thin regolith prevails. In these areas, direct connection to underlying workings may evolve. Any connection of this type would facilitate preferential crack type vertical flows during rainfall events. Mitigation measures proposed as part of the project include surface inspections following subsidence, and repair and infilling of open cracks with suitable soil materials to impede losses. The rate of seepage through such cracks can be estimated using Darcy's law and assuming parallel crack sides through the soil zone. Allowing for a cumulative tensile strain displacement of say 1.0 m and a total crack length of 100 m transverse to drainages in any one panel (10 creek bed crossings of 10 m length - from air photography), the

potential seepage per panel is estimated at 0.1 ML/day assuming crack infill material exhibits an initial hydraulic conductivity of 1 m/day for sandy silty transported sediments (prior to mitigative maintenance). Seepage at this rate would occur during a rainfall-runoff event and would subside after the event. In the course of time the hydraulic conductivity of crack infill material could be expected to decline to below 0.1 m/day with settlement and consolidation. This could reduce seepage to less than 0.01 ML/day per panel.

4.2 Recovery of aquifer pressures post mining

Following completion of mining in the Piercefield seam, pumping from underground would cease unless a subsequent approval is granted to continue mining operations. Regional aquifer pressures may be permitted to recover following closure. The rate of recovery would be dependent upon the remaining water held in storage within the coal measures, the hydraulic properties of goaf and the contribution from rainfall recharge via the regolith zone.

An estimate of the rate of recovery of pressures has been made using the aquifer simulation model with the pressure distributions defined in Figure F14 (Appendix F) at the completion of mining, used as the initial conditions for recovery. Findings indicate more than 50 years would be required to achieve significant rebound in formation pressures.

5. POTENTIAL ENVIRONMENTAL IMPACTS

Proposed underground mining will induce change to the local groundwater environment. Potential impacts arising from the development include:

- change in regional aquifer pressures
- loss of groundwater yield at existing bore locations
- leakage of groundwater from alluvial lands
- change in groundwater quality
- rising aquifer pressures post mining
- potential impacts on groundwater dependent ecosystems

5.1 Change in regional aquifer pressures

Multi seam longwall mining will cause a cumulative pressure loss regime that will include losses induced by the existing MAN open cut operations. Panel extraction will depressurise the Glen Munro, Woodlands Hill, Arrowfield, Bowfield and Piercefield seams. The loss of aquifer pressures predicted by computer modelling will initially migrate preferentially in seam(s) away from the mine panels then upward through interburden lithologies via subsidence induced cracking and interstitial porosity.

Depressurisation surrounding the failure regime above extracted panels is predicted to have a steep sided surface around the perimeter of the panels although structural features may also conduit the pressure waves outward from the subsidence zone(s). The expanding depressurisation wave would be a complex three dimensional surface that is predicted to extend up to 3 kilometres beyond the mine panel footprint in most directions but extending up to 4 kilometres in a south-easterly direction in deeper strata. The predicted magnitude and extent of depressurisation is reasonably well illustrated on Figure 10 where drawdown (in the piezometric surface) is shown for the Piercefield seam. Reference to this figure shows drawdown contours almost reaching the mapped extent of the Hunter River alluvium. This is approximately the most northward extent of the 2m depressurisation contour – the contour line considered to have minimal impact on water resources. To the south, the

depressurisation would extend beneath Saddlers Creek (within the seam) at depths of more than 300 m and is unlikely to impact upon pressure and flow distributions within shallow strata.

In contrast, Figure 8 represents the maximum predicted drawdown in the water table within the shallow unconfined regolith and alluvial aquifer zone. Since this zone is maintained by rainfall recharge, the regional extent of water table losses is generally minimal except within the mine panel footprint. Within the footprint the underlying subsidence failure regimes associated with extracted panels will facilitate downwards seepage at a rate greater than rainfall recharge is able to sustain a saturated zone. This results in water table losses of the order of 5 to 20 m over the southern part of the footprint (partial connection to the deep Woodlands Hill seam) while water table losses greater than 40 or 50 m are predicted over the northern part where reasonably direct connection to the Glen Munro seam workings is assumed. Depressurisation within this zone has the potential to impact upon shallow existing boreholes and surface drainage systems (potential leakage losses).

Other strata are depressurised to a greater or lesser extent as indicated by the plots provided in Appendix F – Figures F10 to F14.

5.2 Loss of groundwater yield at existing bore locations

Existing bores and wells throughout the area have been identified and are shown on Figure 7. Those situated within the Hunter River alluvial lands are considered to be much less vulnerable than bores located within the coal measures since the former are generally situated in aquifer materials that offer high storage and recharge characteristics. Indeed model outcomes indicate bores within the alluvial lands will be unaffected since significant depressurisation is not predicted to extend a sufficient distance that would affect those locations.

Figure 8 shows depressurisation contours for the shallow regolith while Figure 9 shows contours in the coal measures below the regolith and at a horizon a short distance above the Glen Munro seam. These plots represent the maximum predicted depressurisation that bores drawing a supply from these zones might encounter.

Vulnerable bore/well locations are considered to be those that may be potentially exposed to 2 m or more of drawdown. However vulnerability may also depend upon the localised geometry of the regolith and other factors including vertical connectivity of strata joints, and as yet unidentified structural features like faults and dykes. Boreholes and vertical pressure distributions to the west of the panel footprint should therefore be closely monitored.

Vulnerable locations are mostly situated to the west of Edderton Road (on property owned by Mt Arthur Coal) and south-west of the mine panel footprint. Locations are listed in Table 3 from which only 3 privately registered bores (on land not owned by Mt Arthur Coal), have been identified as vulnerable. Only one of these is intermittently used - BCGW11, which is operated by a private landholder to fill a nearby dam. A bore known as Jones coal bore (BCGW10) is situated a few metres from BCGW11 and could also be equipped and utilised if required. BCGW12 is a bore known as Jones windmill situated about 100 m south of the previously noted bores and is currently not in use as a result of poor yield.

Table 3: Bores considered to be vulnerable to loss of groundwater yield

Identifier	Owner	Status	Depth (m)	Pot. head loss (m)	Comment
BCGW09	Private landholder 1	dry	36	4	Back paddock windmill
BCGW13	Private landholder 1	dry	-	5	paddock spring
BCGW10	Private landholder 1	not equipped	-	>30	Jones coal bore
BCGW11	Private landholder 1	used for dam	41	>30	Jones jet pump

Identifier	Owner	Status	Depth (m)	Pot. head loss (m)	Comment
BCGW12	Private landholder 1	poor supply	43	>30	Jones windmill – not used
BCGW22	Mt Arthur Coal	abandoned	-	>60	collapsed windmill
BCGW29	Mt Arthur Coal		61	>45	
BCGW21	Mt Arthur Coal	used for dam ?	40	>40	windmill
BCGW20	Mt Arthur Coal	abandoned	53	>80	windmill not in use
BCGW28	Mt Arthur Coal		47	>50	
BCGW32	Mt Arthur Coal	abandoned	38	>60	collapsed windmill
BCGW31	Mt Arthur Coal	abandoned	33	>20	collapsed well
BCGW18	Mt Arthur Coal	abandoned	12	2	collapsed windmill
BCGW19	Mt Arthur Coal	in use	9	4	well

5.3 Leakage of groundwater from alluvial lands and surface drainages

The current hydrogeological regime favours elevated groundwater levels and pressures within the coal measures which dissipate regionally through upward leakage into the low lying alluvial aquifer systems along the Hunter River and Saddlers Creek. This flow regime leads to a generally brackish or saline environment in basal sections of the alluvium. Shallower sections (in the alluvium) generally exhibit improved quality groundwater through the downward migration of rainfall recharge and river/creek recharge.

Longwall panel extractions are situated 1.2 km south of the Hunter River alluvial lands at the nearest point (Bowfield seam panel LW102) and typically more than 2 km south elsewhere. Numerical modelling of the proposed mining operations predicts migration of the depressurisation surface, northwards almost to, but not measurably beneath these alluvial lands. Consequently no leakage impacts are predicted on alluvial lands associated with the Hunter River as a result of proposed underground mining.

However vertical leakage flows between the alluvial deposits associated with Saddlers Creek and the underlying coal measures may be affected. Analysis of fluxes indicates a pre-mining net upward seepage of the order of 0.34 ML/day averaged over an area of some 3.5 sq.km. or about 0.1 L/day/sq.m of surface area. Seepage fluxes determined at the cessation of mining indicate the net upward flux would continue at a reduced rate of 0.26 ML/day, over the same area – a reduction of 0.08 ML/day. No large scale reversal to downward leakage from the alluvium, is indicated. Hence the alluvial lands associated with Saddlers Creek are expected to continue to receive saline seepage and to remain relatively unimpacted by the proposed mining operations. It is noted that predictions do not discount the possibility of localised leakage reversals induced by underlying structure (faults, dykes, shear zones etc.).

In some areas within the subsidence zone, there is a potential for direct connection to underlying workings. Any connection of this type would facilitate preferential crack type vertical flows during rainfall events. Mitigation measures normally include surface inspections and infilling of open cracks with suitable soil materials to impede flows. The rate of seepage through such cracks has been estimated at 0.1 ML/day assuming crack infill material is sandy silty transported sediments

(prior to mitigative maintenance) and allowing for creek transgression over 10 fractures of 10 m length before any crack maintenance is implemented. Seepage at this rate would occur during a rainfall-runoff event and would subside after the event. If crack management measures were invoked prior to rainfall runoff events, seepage losses would be significantly reduced.

5.4 Change in groundwater quality

Groundwater quality within the underground workings will be governed by the mixing of waters from different horizons and the interaction of these waters with goaf materials. Since goaf materials are not highly fragmented (like open cut spoils), leachate generation is expected to be relatively minor. The resulting water quality in goaf is therefore expected to be similar to mixed groundwater qualities observed in open holes and in piezometers that are exposed to numerous interburden and seam zones. An expected range in TDS is from 3500 to 5500 mg/l with ionic speciation being characterised by $\text{Na} > \text{Mg} > \text{Ca}$ and $\text{Cl} > \text{HCO}_3 > \text{SO}_4$. It is unlikely that there will be a change in regional groundwater qualities as a result of mining.

5.5 Recovery of aquifer pressures post mining

Numerical modelling predicts more than 50 years will be required for equilibration of rebounding water levels post mining. However, full recovery may not occur since large voids associated with the MAN open cut operations to the north-east, are likely to act as evaporative sinks in the very long term. These sinks will retain a depressed water level relative to pre mining conditions and are likely to influence strata pressures within the underground project area.

5.6 Groundwater dependent ecosystems

Umwelt (Australia) Pty. Limited has undertaken eco-systems mapping throughout the project area and has not identified any groundwater dependent eco-systems likely to be affected within the groundwater depressurisation impact zone.

6. DWE LICENSING REQUIREMENTS

Licensing relating to groundwater seepage to longwall and goafed areas will be required under Part 5 of the Water Act 1912. For assessment purposes, an estimate of seepage over the mine life has been made. Seepage is predicted to rise from zero to a maximum rate of about 6.0 ML/day on completion of mining in the Piercefield seam as indicated in Figure F15 (Appendix F). It is noted however this may be an over estimate due to simplifications of strata and subsidence zone hydraulic properties within the groundwater numerical model. The rate also assumes that all goafed areas are maintained in a dewatered state – some areas may be permitted to recover prior to cessation of mining.

In order to improve estimations and to verify depressurisation during mining, an expanded groundwater monitoring network is proposed. This network should include existing bores indicated on Figure B1 in Appendix B, and installation of a number of multi level piezometers in areas surrounding the panel footprint (see below).

7. IMPACTS VERIFICATION CRITERIA

Groundwaters are currently monitored by Mt Arthur Coal for the purpose of assessing local and regional impacts relating to open cut operations. Such impacts are broadly defined as:

- physical depressurisation of the shallow coal measures rock strata and potential indirect impacts on alluvial aquifer systems associated with the Hunter River;

- and changes to groundwater hydrochemistry induced by regional depressurisation.

Falling water levels have been observed in piezometers situated close to open cut mining operations while stable water levels have been observed in more distant piezometers. Stable water levels have also been observed in the underground project area. Depressurisation near the open cut has been calculated by regular measurement of the prevailing groundwater levels in the rock strata and comparing these levels with those measured prior to mining impacts.

A decline in pressure in shallow strata near the Hunter River alluvium or near Saddlers Creek alluvium (subject to prevailing climatic conditions) could signal a change in seepage rates. Future impacts assessment criteria should therefore address the pressure regime within the coal measures and more especially, the pressure regime within shallow strata near and beneath the Hunter alluvium and other surface drainages. Leakage can be estimated by interpolation of the pressure/water table hydraulic gradients and calculation of the leakage flux from measured rock permeabilities. This estimate can also be reconciled with the volume of mine water pumped from the underground operations. In order to establish both the strata hydraulic gradients and the rock mass permeabilities it will be necessary to expand the groundwater monitoring network. The following recommendations are provided.

Depressurisation monitoring should include:

- Construction of 7 piezometers to facilitate measurement of pressures/water levels in shallow coal measures to a depth of 50 to 70 m within the hardrock (buffer) corridor between the predicted subsidence zone(s) and the alluvial aquifers associated with the Hunter River and Saddlers Creek. Proposed locations are indicated on Figure 11 (HR1, HR2, HR3, HR4, SC1, SC2, SC3) subject to consultation with the DWE. As a minimum, the design should allow for isolation of bottom hole strata from mid hole strata utilising dual piezometer completions and allowing for simultaneous measurement of piezometric levels;
- Strata hydraulic conductivity measurement on rock core obtained at the above noted piezometer locations. Such measurement should comprise testing for intergranular permeability and insitu testing for conductivity over the piezometric intervals;
- Construction of piezometers in explorations holes associated with the proposed exploration adit in the Woodlands Hill seam to verify model predictions in respect of strata depressurisation (Figure 11 piezometers within the panel footprint);
- Installation of 3 and possibly 4 multi level piezometer strings equipped with vibrating wire piezometers set within target seams and in various interburden (ranked on Figure 11 – VBW1, VBW2, VBW3, VBW4);
- Quarterly monitoring of water levels in all existing piezometers and in new piezometers;
- Daily monitoring of water levels by installed auto recorders in selected existing piezometers and in new piezometers in order to discriminate between oscillatory groundwater movements attributed to rainfall recharge, and longer term pressure losses related to mining.

Mine water seepage monitoring should include:

- Measurement of all water pumped underground and all mine water pumped to surface on a daily basis. Measurement should be undertaken using flow meters or other suitable gauging apparatus;
- Monthly monitoring of coal moisture content delivered from the working face in order to more accurately determine the underground water balance.

Water quality monitoring should include:

- Quarterly monitoring of basic water quality parameters pH and EC in selected piezometers and pumped mine water. Such monitoring may provide early indication of mixing of shallow groundwaters with groundwaters in deeper strata. While this process is expected within the subsidence zone, it may not be evident within the wider piezometer network at the leakage levels predicted by groundwater monitoring;
- Six monthly measurement of total dissolved solids (TDS) and speciation of water samples in selected piezometers to support identification of mixing of groundwater types. Speciation should include major ions Ca, Mg, Na, K, CO₃, HCO₃, Cl, SO₄ and elements including Al, As, B, Ba, F, Fe (soluble), Li, Mn, P, Se, Si, Sr, Zn which are occasionally identified in regional groundwaters and which may assist in understanding mixing processes, should they occur;
- Graphical plotting of basic water quality parameters and identification of trend lines and statistics including mean and standard deviation calculated quarterly. Comparison of trends with rainfall and any other identifiable processes that may influence such trends.

The monitoring network and monitoring programme should be reviewed on an annual basis to determine ongoing suitability and any proposed changes should be discussed in the Annual Environmental Management Report (AEMR).

Impact verification analyses could include:

- Quarterly assessment of departures from identified monitoring or predicted data trends. The key data sets in this regard should be the mine water seepage rate calculated from the underground water balance, and the pressure monitoring data for buffer zone piezometers. If the average daily seepage rate exhibits an increase beyond the rate predicted (allowing for 0.5ML/day additional transient storage depletion), or if consecutive pressure monitoring data over a period of 6 months exhibit an increasing divergence in an adverse impact sense from the previous data or from the established or predicted trend, then such departures should initiate further actions. These may include a need to conduct more intensive monitoring (including installation of additional piezometers) or to invoke impacts re-assessment and/or mitigative measures;
- Formal review of depressurisation of coal measures and comparison of responses with aquifer model predictions biennially. Expert review should be undertaken by a suitably qualified hydrogeologist;
- Annual reporting (including all water level and water quality data) as part of the AEMR.

7.1 Impact mitigation measures

Mitigative measures for any identified negative impacts beyond those predicted, may include replacement in water supply or relinquishment of groundwater or surface water allocations as an offset to monitored leakage from the alluvial aquifers in excess of predictions.

Mackie Environmental Research

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IMPORTANT INFORMATION ABOUT YOUR HYDROLOGICAL REPORT

Mackie Environmental Research (MER) has applied skills and standards appropriate for a Chartered Professional (AusIMM) in the preparation of this report, the content of which is governed by the scope of the study and the database utilised in generating outcomes.

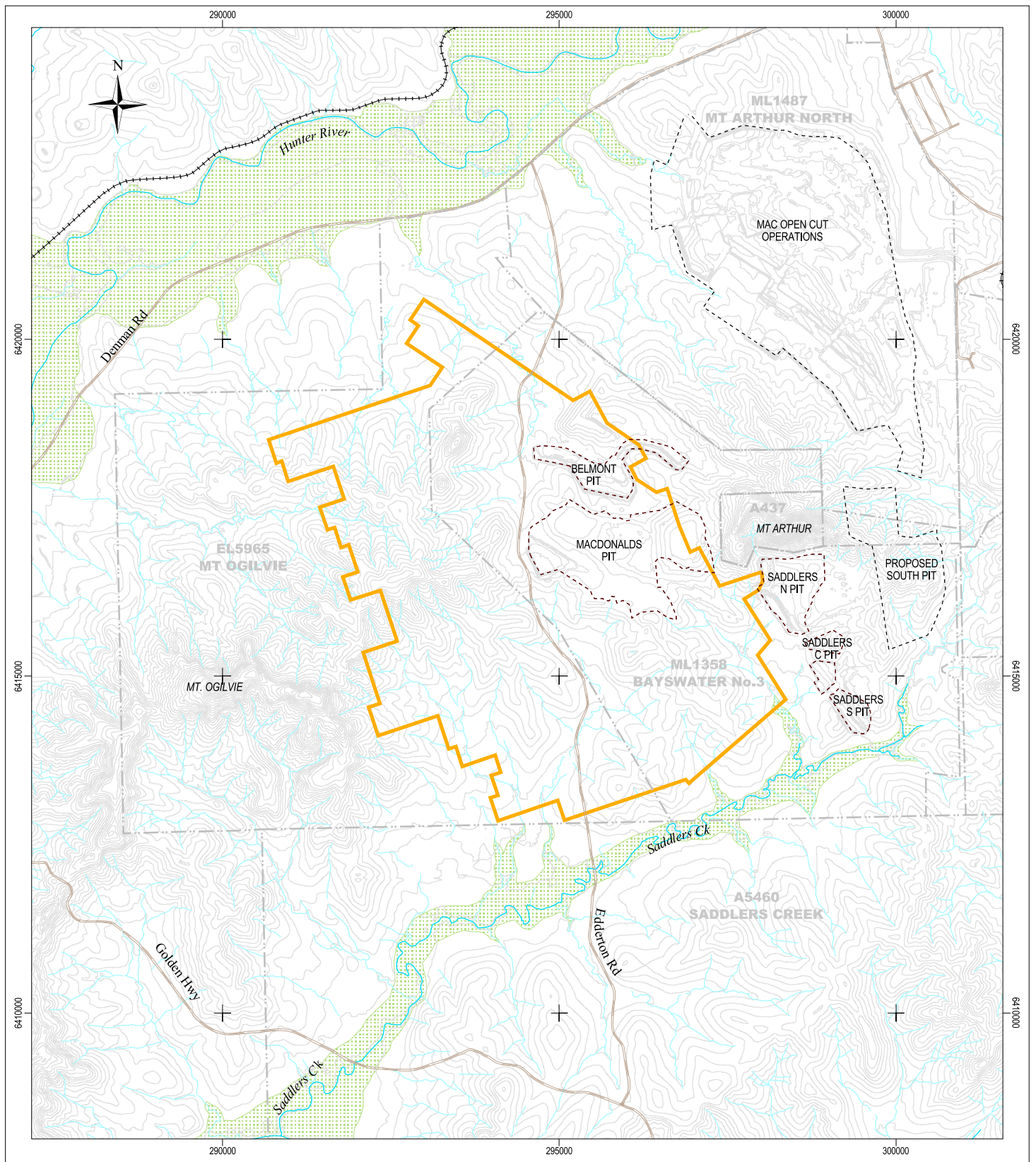
In respect of the database, historical data is often obtained from different sources including clients of MER, Government data repositories, public domain reports and various scientific and engineering journals. While these sources are generally acknowledged within the report, the overall accuracy of such data can vary. MER conducts certain checks and balances and employs advanced data processing techniques to establish broad data integrity where uncertainty is suspected. However the application of these techniques does not negate the possibility that errors may be carried through the analytical process. MER does not accept responsibility for such errors.

It is also important to note that in the earth sciences more so than most other sciences, conclusions are drawn from analyses that are based upon limited sampling and testing which can include drilling of exploration and test boreholes, flow monitoring, water quality sampling or many other types of data gathering. While conditions may be established at discrete locations, there is no guarantee that these conditions prevail over a wider area. Indeed it is not uncommon for some measured geo-hydrological properties to vary by orders of magnitude over relatively short distances. In order to utilize discrete data and render an opinion about the overall surface or subsurface conditions, it is necessary to apply certain statistical measures and other analytical tools that support scientific inference. Since these methods often require some simplification of the systems being studied, results should be viewed accordingly. Importantly, predictions made may exhibit increasing uncertainty with longer prediction intervals. Verification therefore becomes an important post analytical procedure and is strongly recommended by MER.

This report, including the data, graphs and drawings generated by MER, and the findings and conclusions contained herein remain the intellectual property of MER. A license to use the report is granted to Mt Arthur Coal and Umwelt (Australia) Pty. Limited. The report should not be used for any other purpose than that which it was intended and should not be reproduced, except in full.

C. Mackie
CP. No. 113049





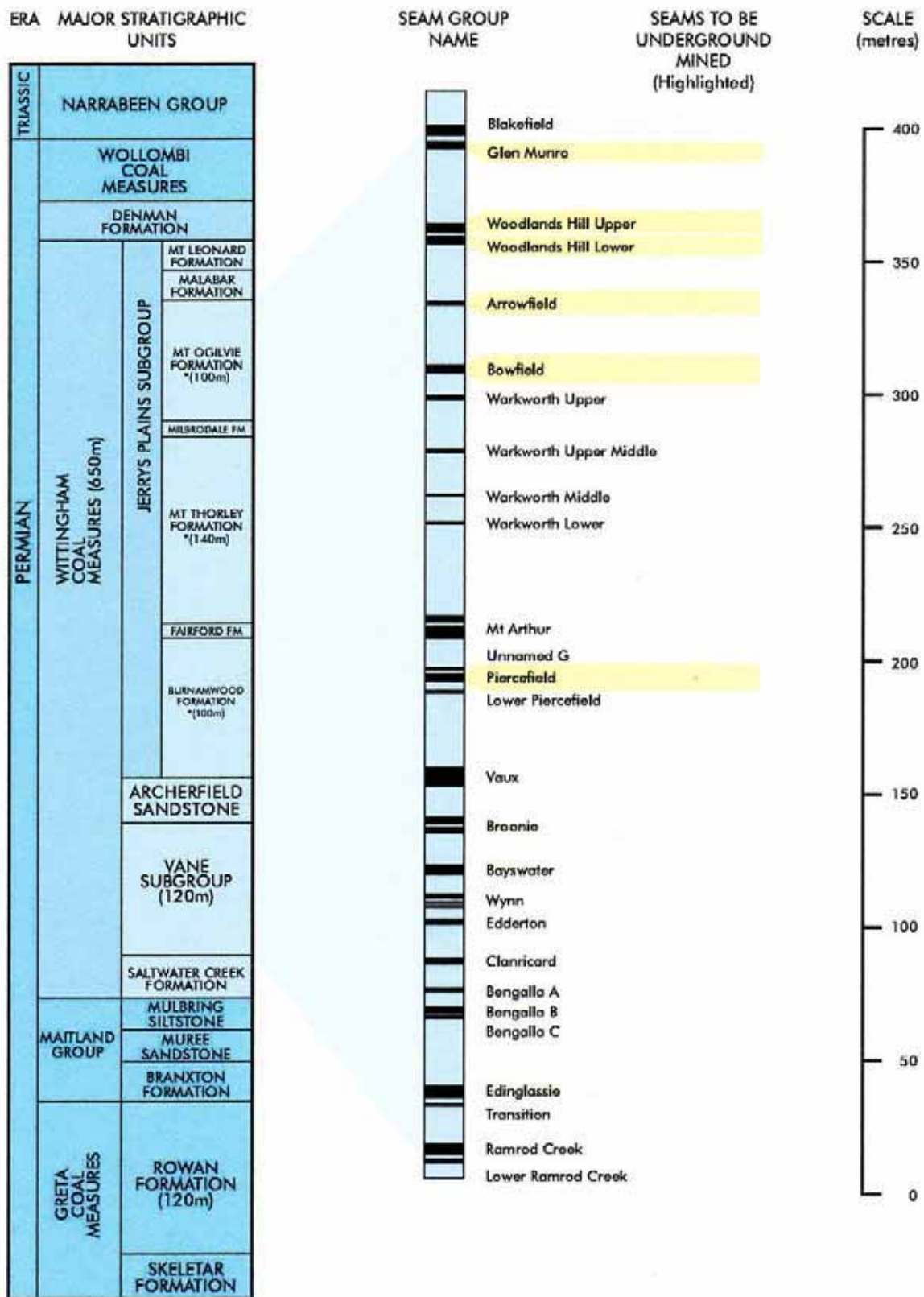
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colluvium in minor drainages not shown

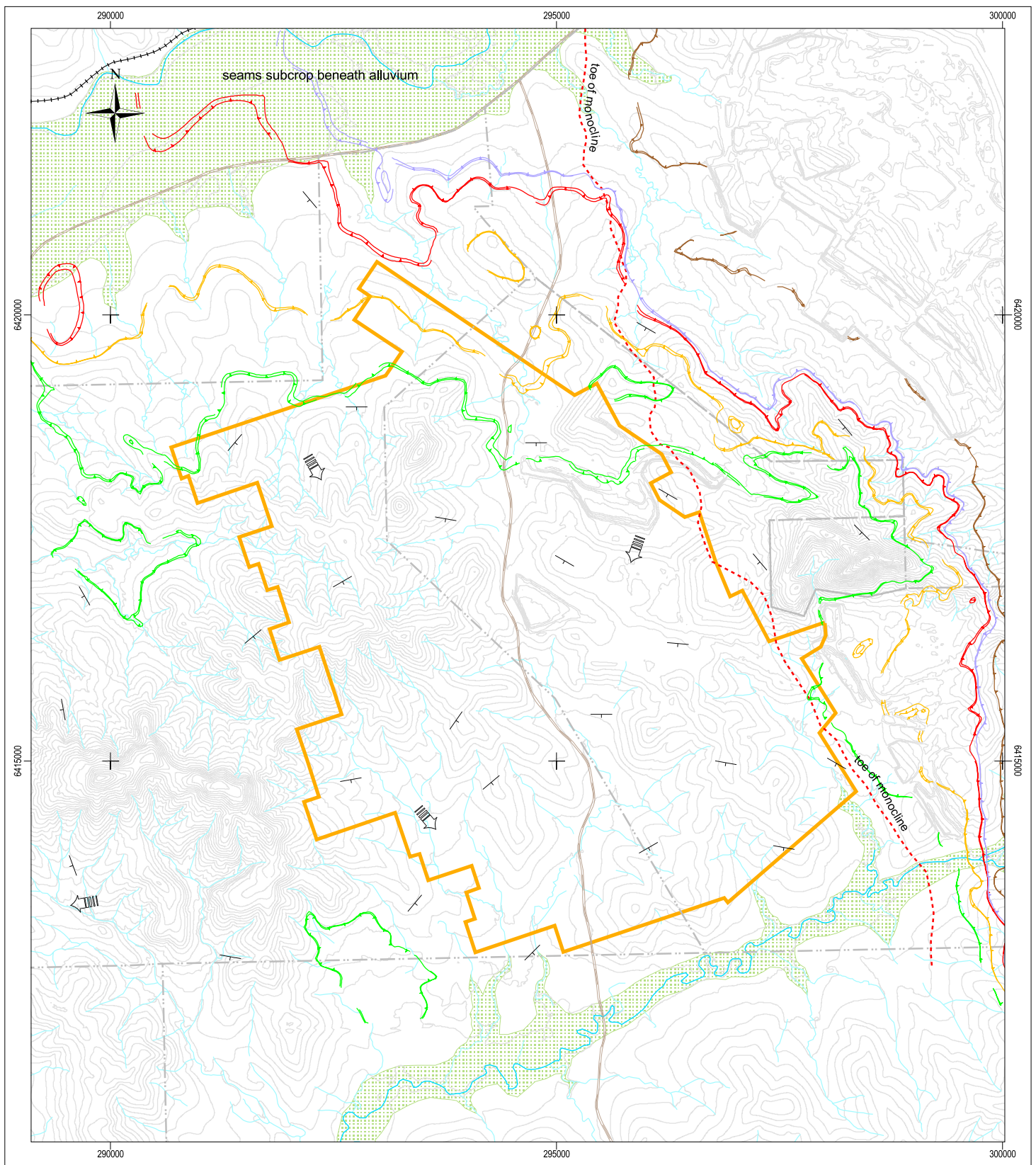
- -- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHd - 10m interval)
- open cut shell outlines (partly or fully filled)
- alluvial aquifer

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Locality - key features and proposed mine panel footprint



Stratigraphic column plot supplied by Mt. Arthur Coal



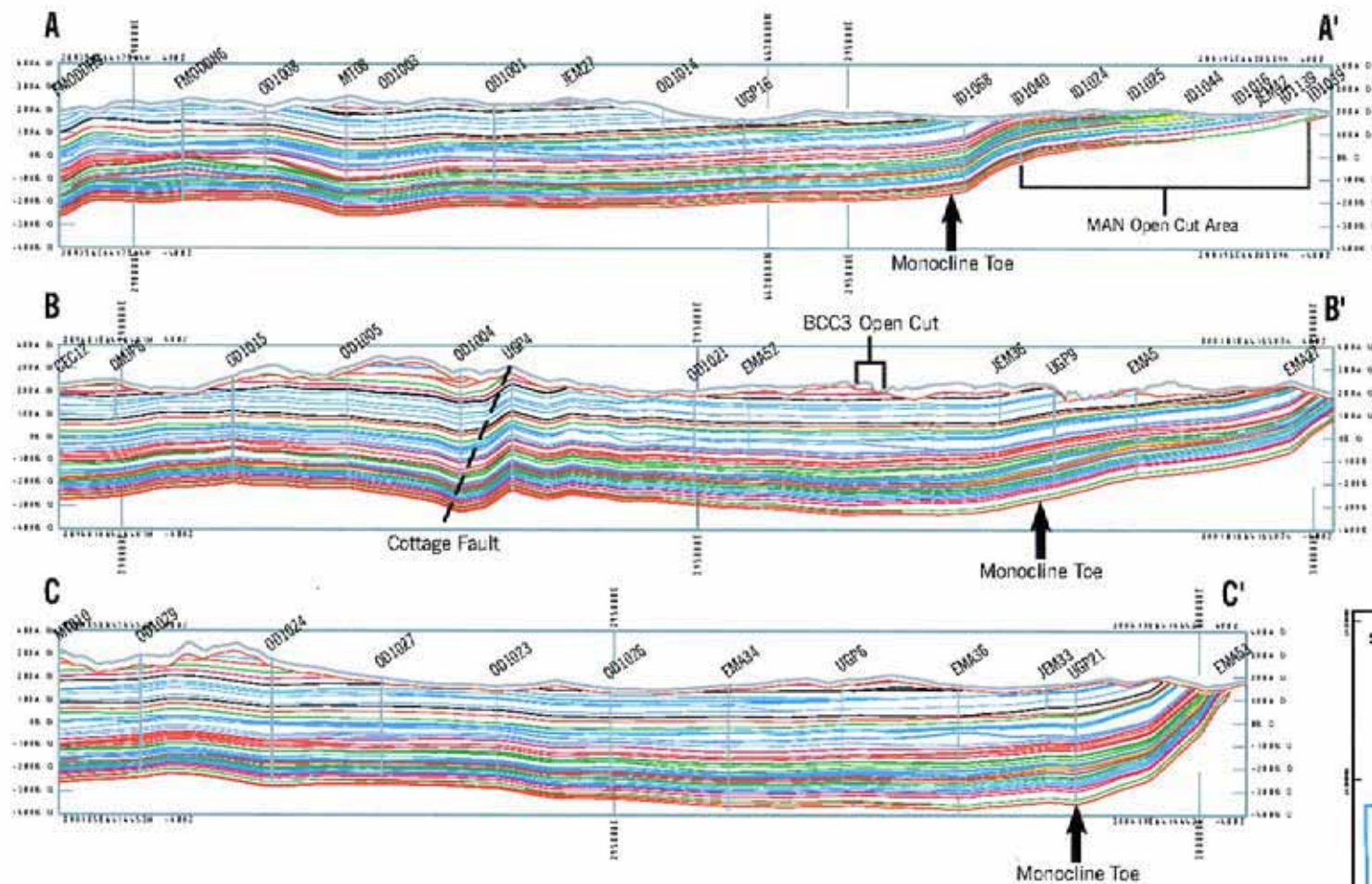
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indicative strike/dip symbols shown for Glen Munro seam

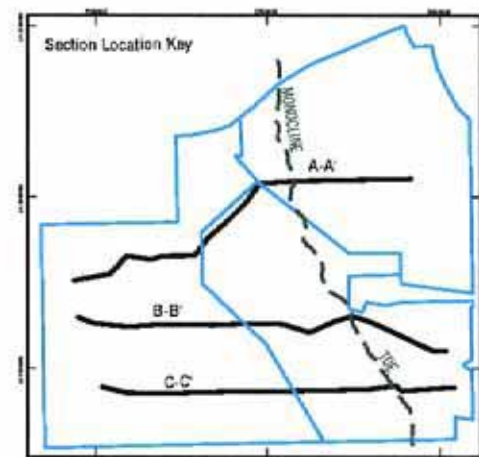
- | | |
|--|--------------------------|
| -- -- lease boundary | Arrowfield subcrop |
| ++++ railway | Bowfield subcrop |
| — main road | Glen Munro subcrop |
| — drainage | Piercefield subcrop |
| — mine panel footprint | Woodlands Hill subcrop |
| — topographic contours (mAHD - 10m interval) | strike and dip of strata |
| — alluvial aquifer | general direction of dip |

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

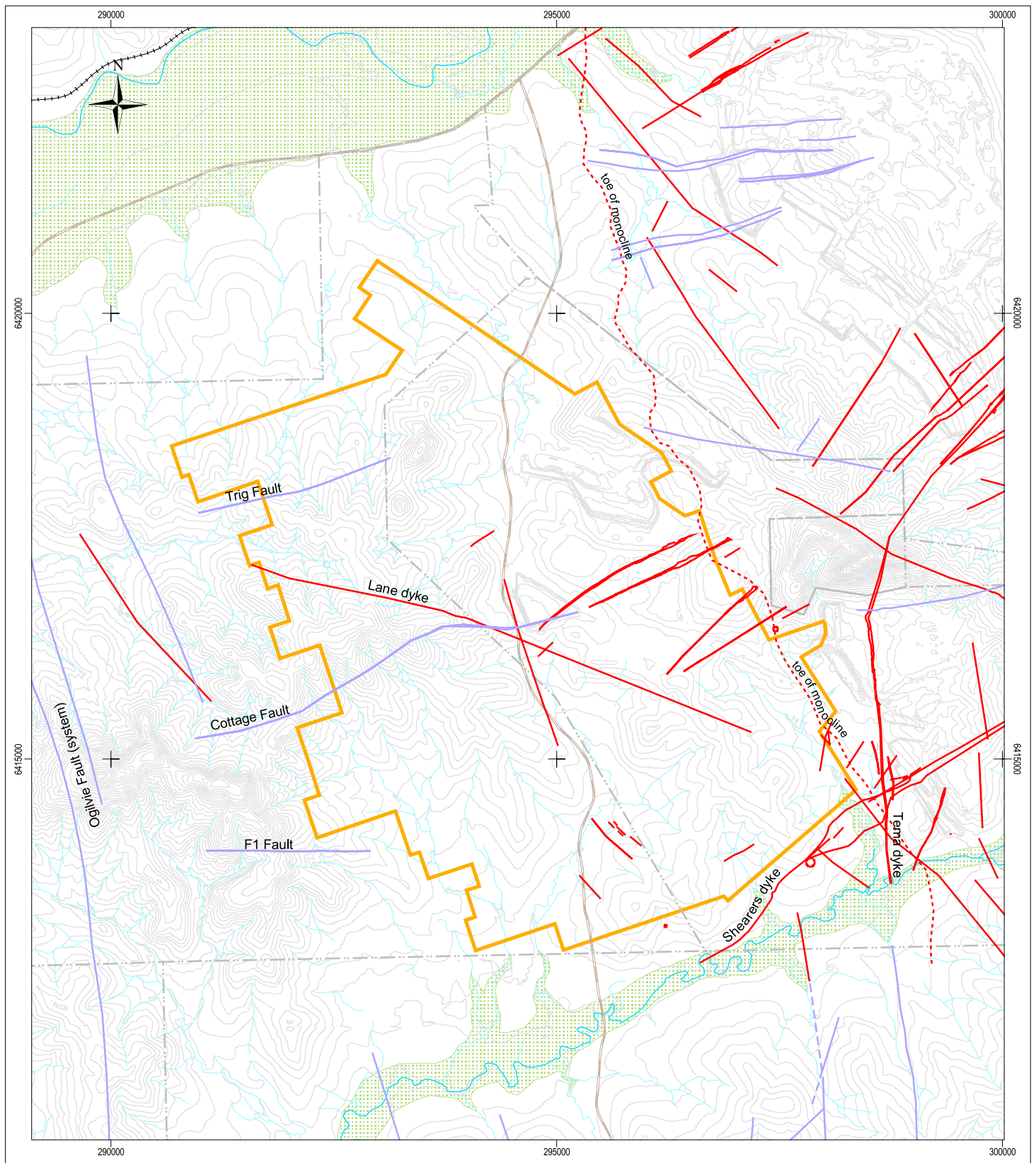
Regional seam subcrops



Cross sections supplied by Mt. Arthur Coal



East - west cross sections

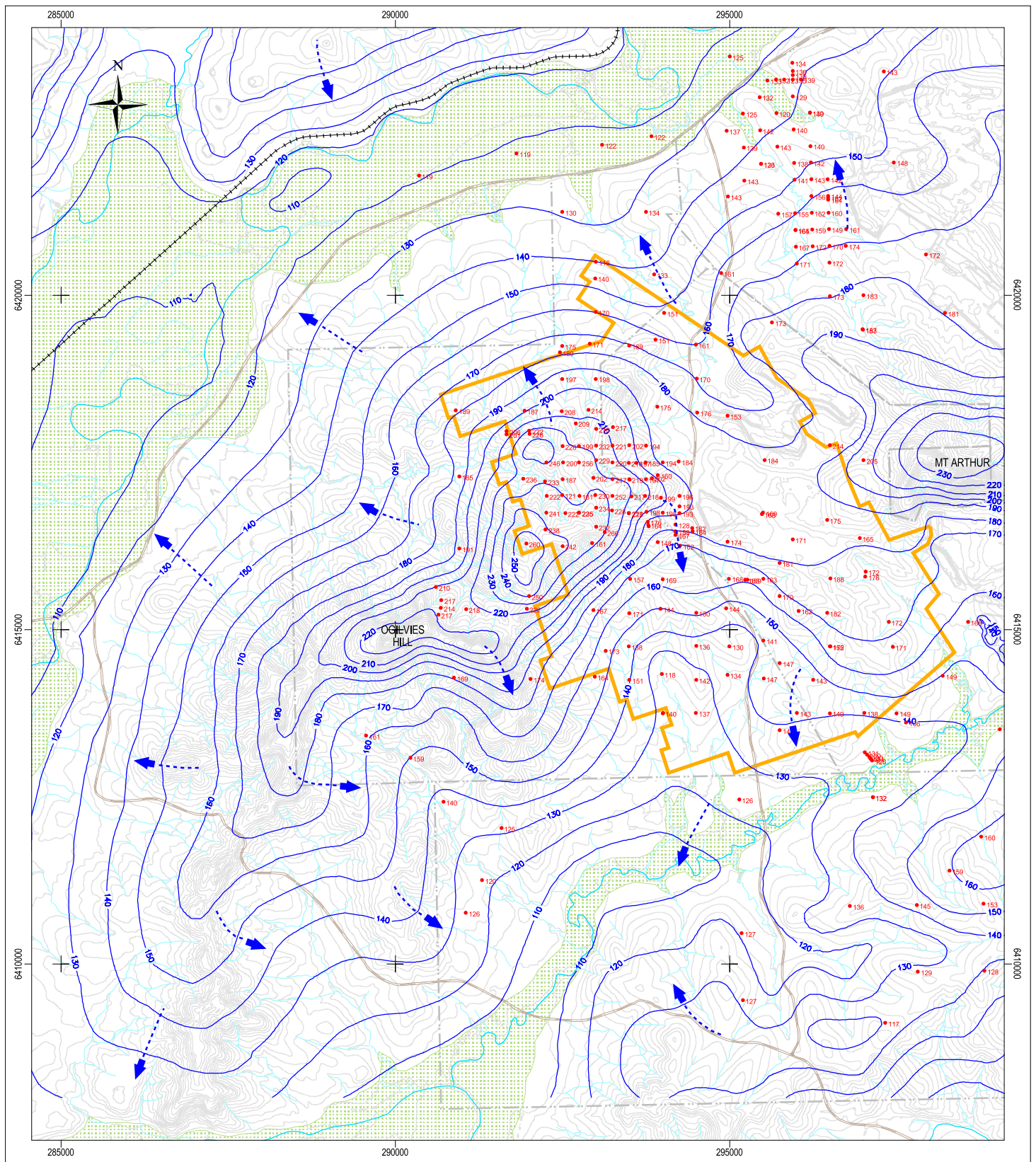


0 1000 2000 3000 Metres
Scale 1:60000

- | | |
|--|------------------------|
| -- -- lease boundary | — faults |
| ++++ railway | — dykes |
| — main road | - - - toe of monocline |
| — drainage | |
| — mine panel footprint | |
| — topographic contours (mAHD - 10m interval) | |
| — alluvial aquifer | |

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Regional faults and dykes



0 1000 2000 3000 4000 Metres

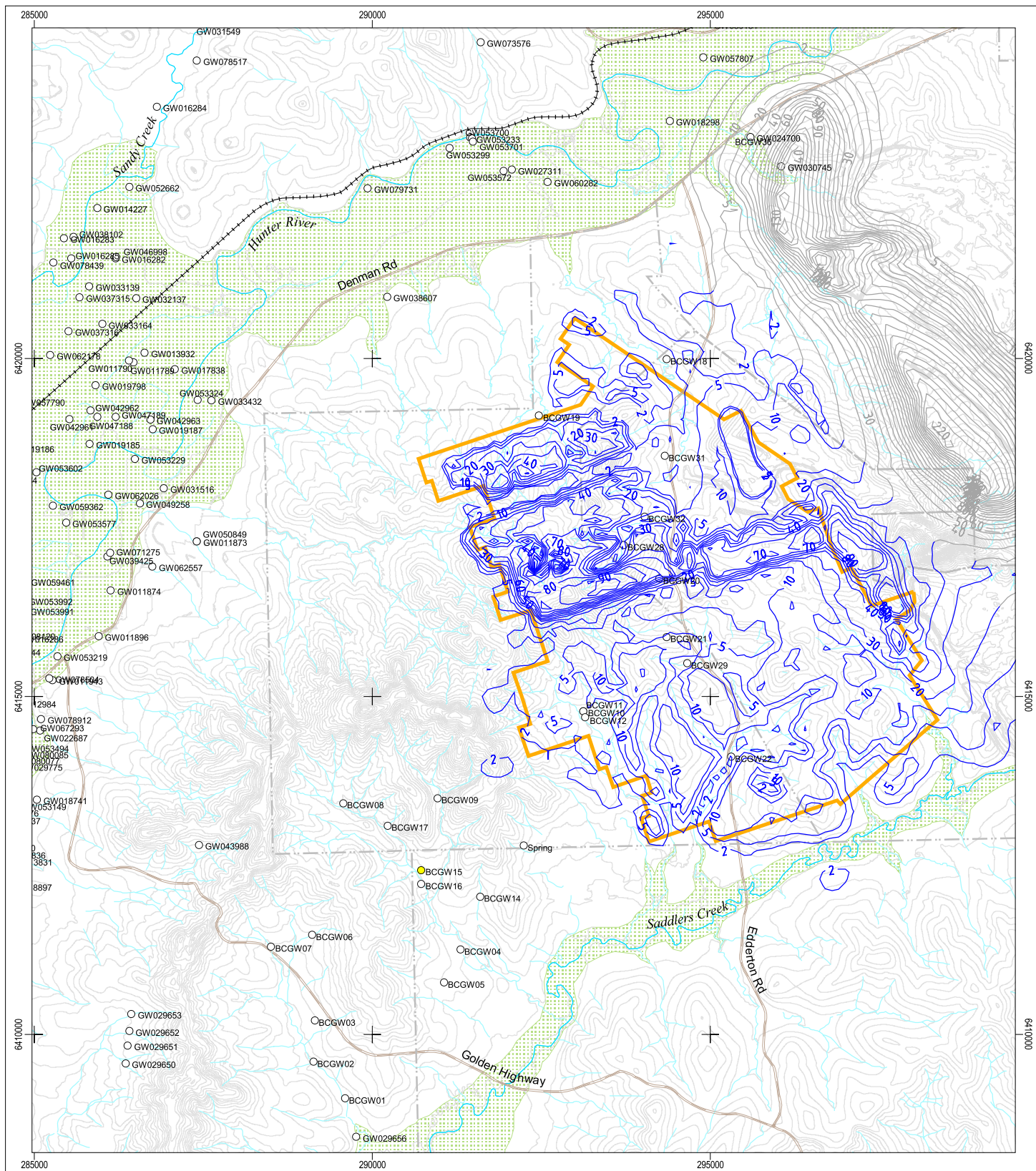
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Arrows indicate approximate flow direction

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHd - 10m interval)
- piezometric elevation (mAHd)
- piezo. level (mAHd)
- alluvial aquifer

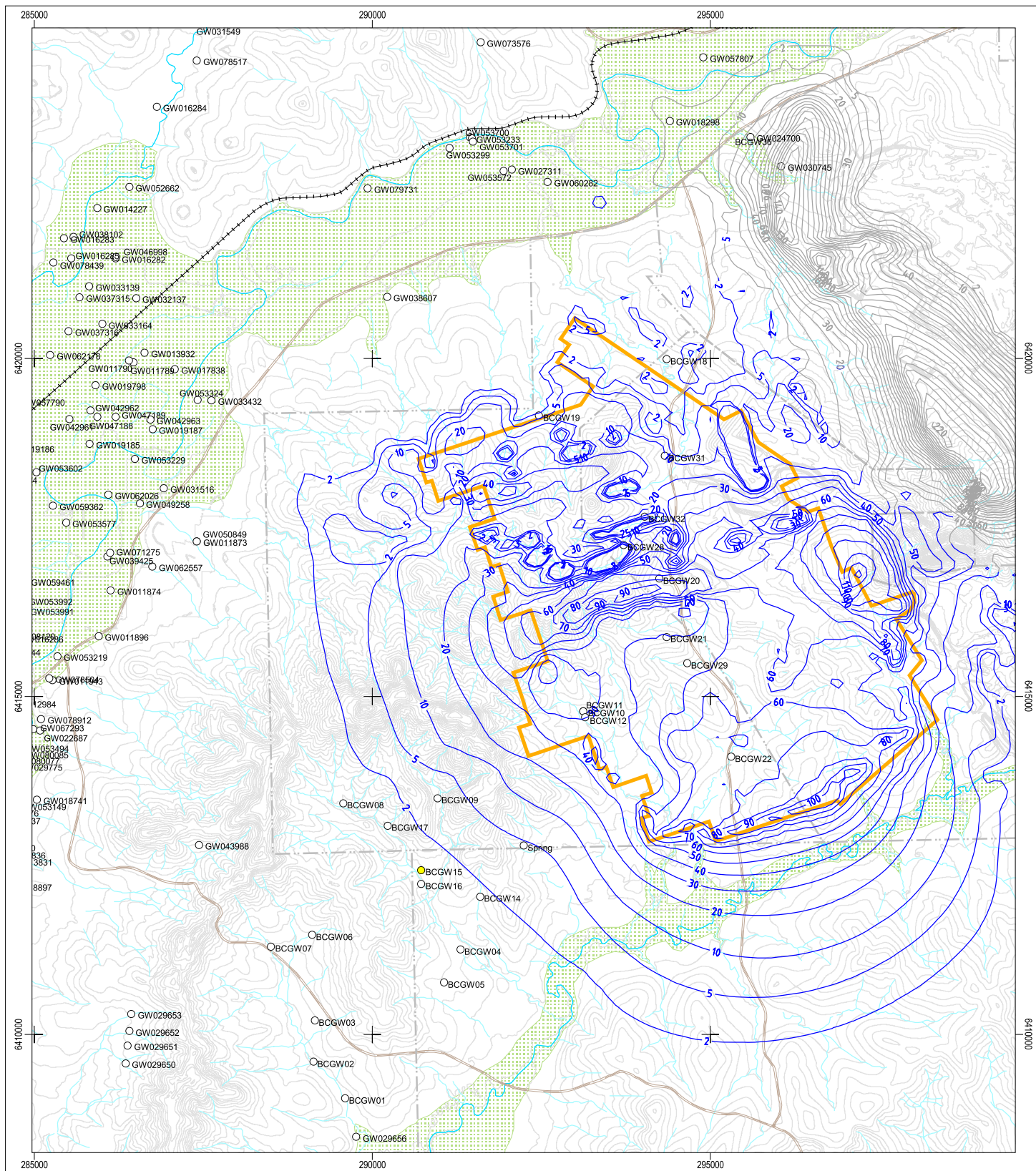
MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Pre mining composite piezometric surface



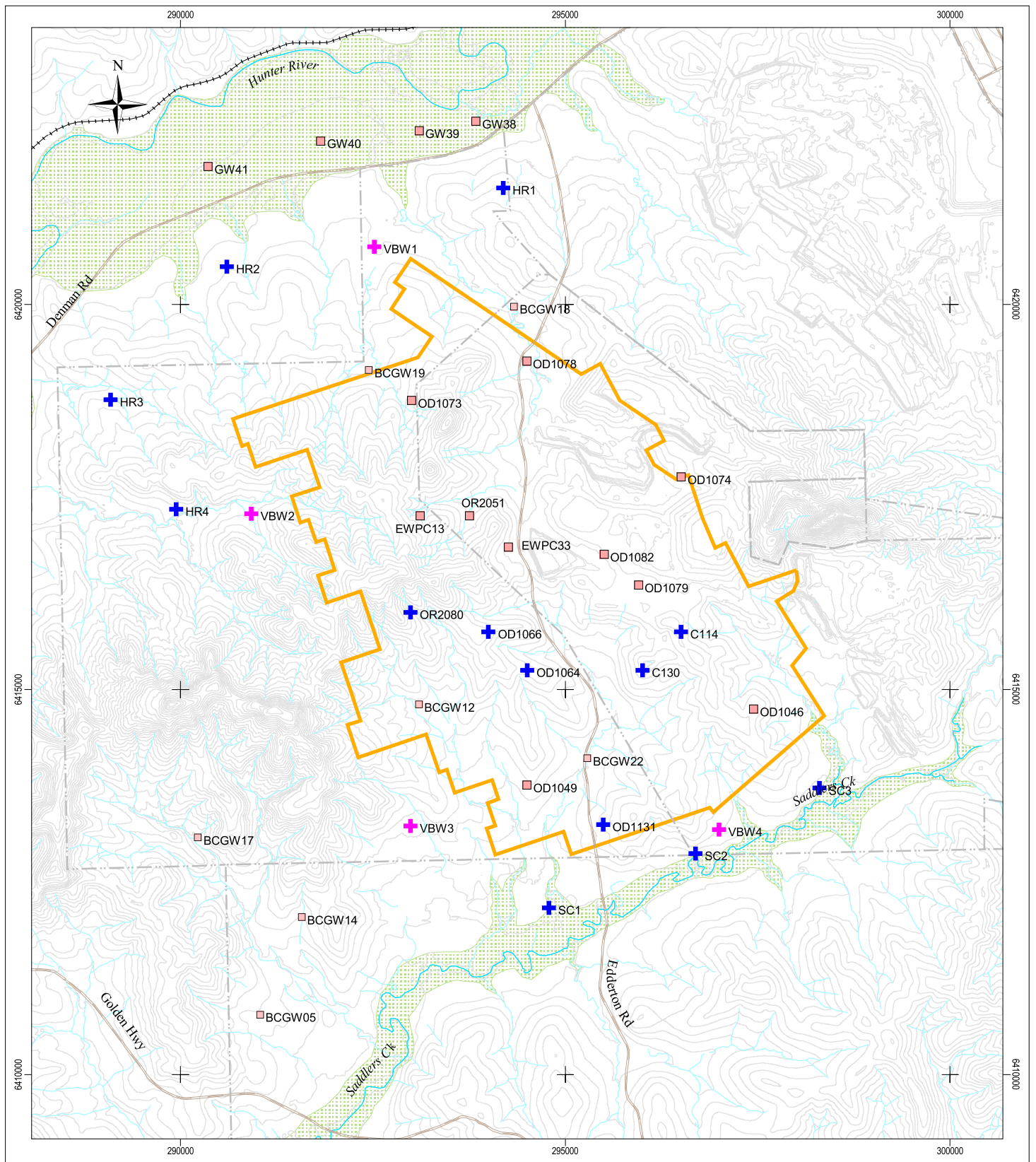
MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Regional drawdown impacts in the shallow regolith zone at the end of mining



MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Regional drawdown impacts in the coal measures above the Glen Munro seam at the end of mining



0 2000 4000 6000 Metres
Scale 1:70000

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHD - 10m interval)
- + proposed dual standpipe piezometer
- + proposed multi level vibrating wire piezometers
- existing MAC-UG monitoring locations
- alluvial aquifer

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Proposed future groundwater monitoring network

APPENDIX A: CLIMATE DATA

Climate data has been sourced from the Bureau of Meteorology for use in groundwater system modelling.

Long term data for Denman has been reviewed and compared to available local mine data. Both stations exhibit reasonably close correlation in respect of key statistics like average monthly and annual rainfalls. Denman rainfall has been used in void water management simulations where testing has been conducted against the historical record. In addition, data has been processed to generate recurrence intervals and average exceedance probabilities for specified rainfall durations up to 20 days. The following Table A1 provides a summary.

Evaporation data has been sourced from the Scone Research Centre and is summarised in table A2.

Table A1: Longer term intensity, frequency, duration statistics for 115 years of data.

ARI	AEP %	1 day	2 day	3 day	4 day	5 day	6 day	8 day	10 day	15 day	20 day
once in 1 years	63.2	46	59	65	70	74	77	83	90	103	114
once in 2 years	39.3	60	76	84	90	95	99	106	114	131	146
once in 5 years	18.1	80	100	111	119	124	128	137	146	170	190
once in 10 years	9.5	95	118	132	141	146	151	161	171	199	225
once in 20 years	4.9	110	137	153	164	168	174	185	195	229	259
once in 50 years	2.0	131	162	181	195	198	205	217	227	269	306
once in 100 years	1.0	147	182	203	219	222	229	242	253	300	342

Durations are based on screening of daily Denman data within each year of available records from 1890 to 2005 - a log normal distribution is assumed.

ARI (Average Recurrence Interval) is the average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. For example, a continuous rainfall event total of 90 mm over 10 days has an average recurrence interval of 1 year.

AEP (Average Exceedance Probability) is the probability that a given rainfall total accumulated over a given duration will be exceeded in any one year. For example, a continuous rainfall event total of 90 mm over 10 days has a 63.2% probability of being equalled or exceeded in any one year.

Table A2: Average potential evaporation (Pan A) and rainfall in mm - Scone.

	Jan	Feb	Mar	Apl	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec
Daily evaporation	7.1	6.2	5.0	3.5	2.2	1.6	1.8	2.8	3.9	5.1	6.1	7.3
Monthly evaporation	220.1	173.6	155.0	105.0	68.2	48.0	55.8	86.8	117.0	158.1	183.0	226.3
Monthly rainfall	74.4	67.0	54.2	39.0	35.7	40.3	38.4	33.9	38.6	49.9	51.8	64.6

APPENDIX B: GROUNDWATER MONITORING DATA

A network of monitoring bores has been established within the project area and surrounding areas. This network includes composite piezometers (screened over coal and interburden) constructed within the project area, piezometers located in the Mt Arthur Coal open cut areas to the north-east and east and EL5460 to the south. Discrete zone piezometers have also been constructed in the project area, in the Bayswater No.3 area, and in the Hunter River alluvial lands. A number of these are dual/multi piezometer completions to examine vertical pressure distributions. The following Table B1 and Figure B1 provide a summary of monitoring locations.

Piezometers are attended routinely by Mt Arthur Coal or their appointed contractors and water level, pH and EC parameters are measured. Water level monitoring data is summarised in the plots provided as Figure B2 for selected piezometers. Reference to these plots supports the following:

- Piezometric levels in the Hunter River alluvial lands have been generally stable over the respective monitoring periods. Rises (1999 to 2001) equate to periods of high rainfall and elevated river levels while declining and stable levels equate to the more recent dry and drought period.
- Piezometric levels in the coal measures have been stable in regional piezometers located generally more than 2 or 3 km from existing open cut operations. Further south in EL5460, levels have been stable over a relatively long period of monitoring which is more than 7 years at some locations. These stable levels through both wet and dry periods reflect the confinement of the coal seams and lack of hydraulic connection between deep strata and shallow water tables.
- Piezometric levels have fallen in areas close to the Mt Arthur Coal open cut operations. Notably, piezometers GW9 and GW11 exhibit significant falls prior to being mined through. GW8 and GW13 also exhibit significant declines even though they are located more than 1 km west of the current pit highwall. These declines are most likely related to faulted zones acting as transmission conduits. Certainly GW13 is located close to an identified significant east-west fault zone.
- Piezometric levels in the coal measures buffer zone between mining operations and the Hunter River alluvial lands to the north, exhibit modest declines of the order of several metres (eg. GW15, GW19, GW22, GW23). These piezometers reflect composite levels but depressurisation within certain seams is likely to be more extensive. Piezometric levels should continue to fall as mining operations continue to depressurise strata.

Table B2 provides a summary of basic water quality parameters pH and electrical conductivity (EC – $\mu\text{S}/\text{cm}$).

B1.1 Semi continuous water level measurements

In addition to routine monitoring, a number of piezometers are equipped with automated water level loggers capturing levels at 8 hour intervals (below Nyquist frequency for daily oscillation). These locations are either to the north-east in the open cut area or south within EL5460. They are specifically installed to generate information in respect of rainfall recharge, barometric efficiencies and other processes.

Results to-date support the following:

- Effective rainfall recharge is not evident over the period of monitoring;

- Barometric oscillations of up to 150mm are evident in deep piezometers confirming semi confined to confined storage conditions at these locations.

Table B1: Monitoring locations – survey details

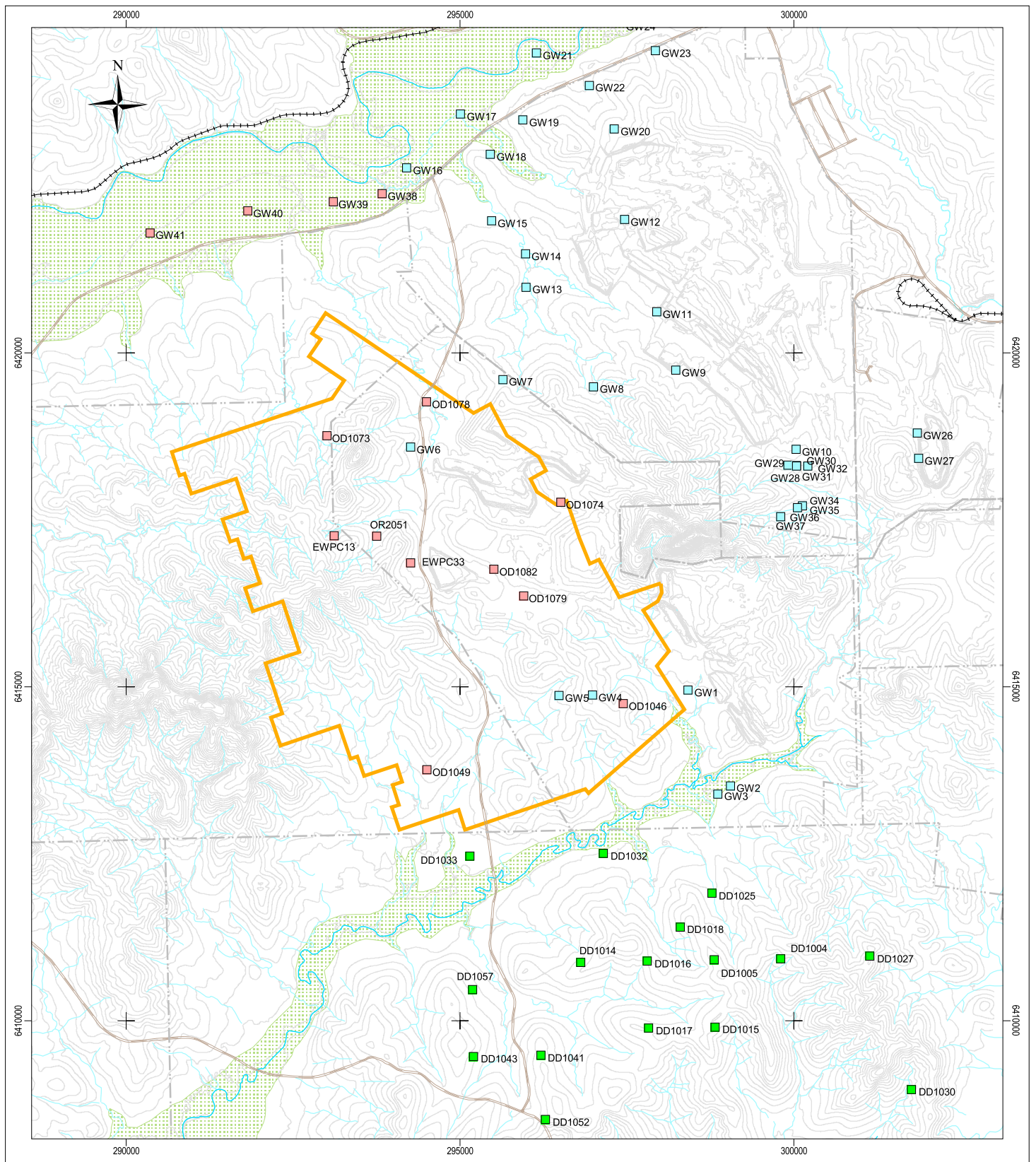
Bore ID	Old ID	Area	MGA East	MGA North	Collar RL	Depth	Strata
			(m)	(m)	(mAHD)	(m)	coal measures composite
GW1	LOX3013	Open Cut	298410	6414945	167.63	30.0	coal measures composite
GW2	SDP35	Open Cut	299045	6413511	153.74		coal measures composite
GW3	SDP47	Open Cut	298856	6413389	151.57		coal measures composite
GW4	L90	Open Cut	296976	6414871	220.51	150.0	coal measures composite
GW5	L100	Open Cut	296476	6414860	191.64		coal measures composite
GW6	LOX3112	Open Cut	294254	6418579	196.00	27.0	coal measures composite
GW7	GM57	Open Cut	295635	6419594	214.40		Glen Munro seam (composite)
GW8	ID1014A	Open Cut	296993	6419486	207.11	221.1	coal measures composite
GW9	P3R	Open Cut	298224	6419734	212.96		Ram Rod Ck. seam
GW10	ID1059	Open Cut	300025	6418547	251.81		coal measures composite
GW11	P1R	Open Cut	297940	6420608	193.50		Ram Rod Ck. seam
GW12	ID1049	Open Cut	297458	6421988	153.06	33.2	coal measures composite
GW13	ID1061	Open Cut	295985	6420977	165.29	282.5	coal measures composite
GW14	ID1069	Open Cut	295976	6421475	156.55		coal measures composite
GW15	ID1035	Open Cut	295466	6421968	148.38	285.0	coal measures composite
GW16	MGW3	Open Cut	294197	6422759	131.77		Hunter River alluvium
GW17	MGW4	Open Cut	295003	6423570	134.63		Hunter River alluvium
GW18	ID1047	Open Cut	295450	6422964	141.86	246.6	coal measures composite
GW19	ID1030	Open Cut	295938	6423477	163.03	210.4	coal measures composite
GW20	WT2	Open Cut	297305	6423344	194.54		coal measures composite
GW21	MGW5	Open Cut	296141	6424483	136.06		Hunter River alluvium
GW22	ID1062	Open Cut	296930	6423998	154.05	96.3	coal measures composite
GW23	ID1029	Open Cut	297919	6424515	181.40	54.6	coal measures composite
GW24	MGW2	Open Cut	297386	6424914	137.10		Hunter River alluvium
GW25	MGW1	Open Cut	298376	6425231	140.05		Hunter River alluvium
GW26	West cut	Open Cut	301841	6418792	234.20		West Cut Tailings emplacement
GW27	West cut	Open Cut	301863	6418412	235.46		West Cut Tailings emplacement
GW28	IR2088	Open Cut	299911	6418305	265.01	144.0	Ram Rod Ck. seam
GW29		Open Cut	299907	6418309	265.50	91.0	composite below Edinglassie seam
GW30	IR2085	Open Cut	300036	6418302	258.28	98.8	Ram Rod Ck. seam
GW31		Open Cut	300036	6418299	258.10	55.0	composite below Edinglassie seam
GW32	IX7899	Open Cut	300203	6418300	262.76	54.6	coal measures composite
GW34	IX7981	Open Cut	300124	6417704	227.51	96.0	coal measures composite
GW35	IR2096	Open Cut	300049	6417675	230.42	93.0	coal measures composite
GW36		Open Cut	300046	6417673	230.60	48.0	composite below Edinglassie seam
GW37	ID1148	Open Cut	299796	6417537	245.35	183.2	Ram Rod Ck. seam
GW38-P/A	HR3	MAU	293831.5	6422377	131.24	34.4	alluvium (A) + coal measures (P)
GW39-P/A	HR1	MAU	293094.5	6422251	130.35	42.8	alluvium (A) + coal measures (P)
GW40-P/A	HR4	MAU	291815.4	6422119	128.89	32.3	alluvium (A) + coal measures (P)
GW41-P/A	HR2	MAU	290354.3	6421789	125.96	34.7	alluvium (A) + coal measures (P)
EWPC13		MAU	293110	6417252		47.0	Blakefield 3 seam
EWPC33		MAU	294253	6416846		58.0	Blakefield 3 seam
OD1079		MAU	295946	6416350	226.00	546.0	Glen Munro

Bore ID	Old ID	Area	MGA East	MGA North	Collar RL	Depth	Strata
OR2051		MAU	293750	6417250	230.00	185.0	Glen Munro + Arrowfield seams
OD1073		MAU	293000	6418750	215.11	157.0	Glen Munro + Arrowfield seams
OD1082		MAU	295500	6416750	224.00	496.0	Woodlands Hill seam
OD1046		MAU	297442	6414741	210.69	560.0	Woodlands Hill seam
OD1049		MAU	294498	6413753	156.38	460.0	Woodlands Hill seam
OD1074		MAU	296501	6417756	233.56	475.0	Bowfield seam
OD1078		MAU	294495	6419259	171.00	85.0	Bowfield seam
SDD1004		Saddlers	299798	6410922	217.38	105.7	coal measures composite
SDD1005		Saddlers	298799	6410908	225.00	135.9	coal measures composite
SDD1014		Saddlers	296800	6410864	183.40	90.5	coal measures composite
SDD1015		Saddlers	298815	6409900	212.65	162.5	coal measures composite
SDD1016		Saddlers	297801	6410883	201.15	126.2	coal measures composite
SDD1017		Saddlers	297819	6409882	198.60	102.4	coal measures composite
SDD1025		Saddlers	298765	6411902	169.81	44.6	coal measures composite
SDD1027		Saddlers	301134	6410959	235.82	252.8	coal measures composite
SDD1030		Saddlers	301754	6408962	160.08	282.5	coal measures composite
SDD1032		Saddlers	297144	6412496	140.25	276.5	coal measures composite
SDD1033		Saddlers	295145	6412458	125.47	228.4	coal measures composite
SDD1041		Saddlers	296203	6409476	187.32	387.3	coal measures composite
SDD1043		Saddlers	295200	6409458	173.78	342.3	coal measures composite
SDD1052		Saddlers	296274	6408513	183.12	432.0	coal measures composite
SDD1057		Saddlers	295181	6410458	146.93	303.3	coal measures composite

Table B2: Basic water quality parameters (routine averaged)

Borehole	Lithology	pH	EC
GW16	alluvium	7.15	4546
GW17	alluvium	7.06	5396
GW21	alluvium	7.24	3017
GW24	alluvium	7.22	3412
GW25	alluvium	7.06	7773
GW38A	alluvium	7.41	3550
GW39A	alluvium	7.33	5460
GW40A	alluvium	7.37	4400
GW41A	alluvium	7.34	4050
GW1	coal measures	7.32	6357
GW10	coal measures	6.84	4256
GW11	coal measures	6.53	9387
GW12	coal measures	7.17	8240
GW13	coal measures	7.6	4605
GW15	coal measures	7.65	3763
GW18	coal measures	7.7	6239
GW19	coal measures	7.31	2803
GW2	coal measures	7.74	3705
GW22	coal measures	7.12	5568
GW23	coal measures	6.78	5033
GW3	coal measures	7.94	4510
GW38P	coal measures	7.71	2383

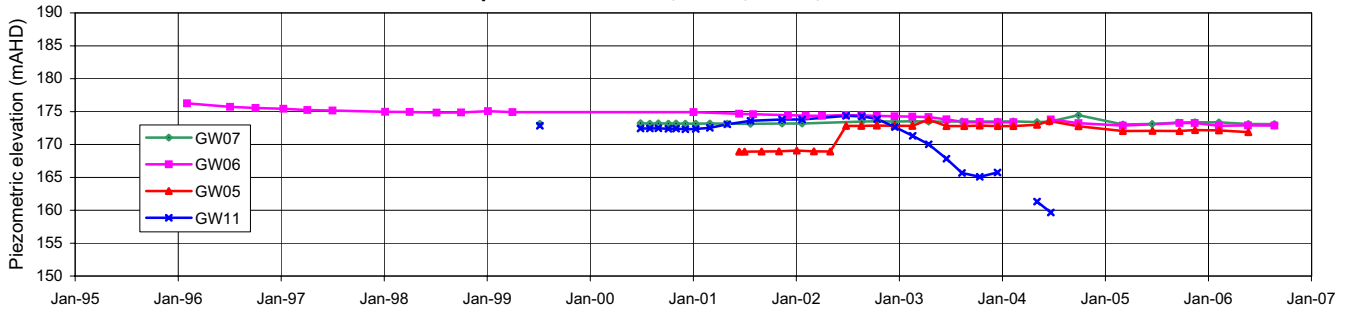
Borehole	Lithology	pH	EC
GW39P	coal measures	7.49	5240
GW4	coal measures	6.97	4733
GW40P	coal measures	7.98	3700
GW41P	coal measures	7.11	4480
GW5	coal measures	6.97	4145
GW6	coal measures	6.82	4308
GW7	coal measures	6.97	4996
GW8	coal measures	7.21	566
GW9	coal measures	6.93	4905
SDD1004	coal measures	7.06	5566
Sdd1005	coal measures	7.01	7513
SDD1014	coal measures	6.93	2329
SDD1015	coal measures	6.86	5643
SDD1016	coal measures	6.67	4524
SDD1017	coal measures	6.96	5278
SDD1025	coal measures	7.20	698
SDD1030	coal measures	6.94	1208
SDD1032	coal measures	7.24	1999
SDD1043	coal measures	10.46	1874
SDD1052	coal measures	11.30	2182
SDD1057	coal measures	10.51	3248
BCGW01	shallow coal measures	7.62	4640
BCGW05	shallow coal measures	7.48	9780
BCGW06	shallow coal measures	7.98	3970
BCGW10	shallow coal measures	7.05	4500
BCGW11	shallow coal measures	7.11	3810
BCGW15	shallow coal measures	6.97	7960
BCGW16	shallow coal measures	7.26	6010



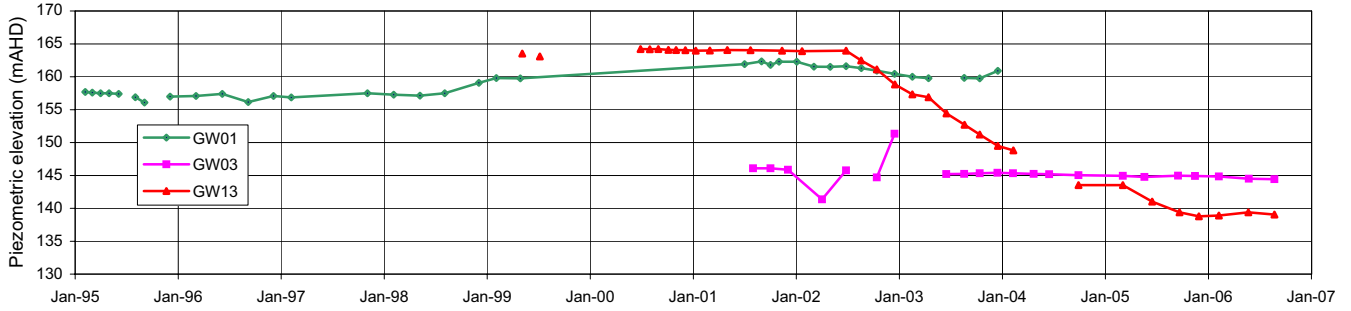
MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Routine groundwater level and water quality monitoring locations

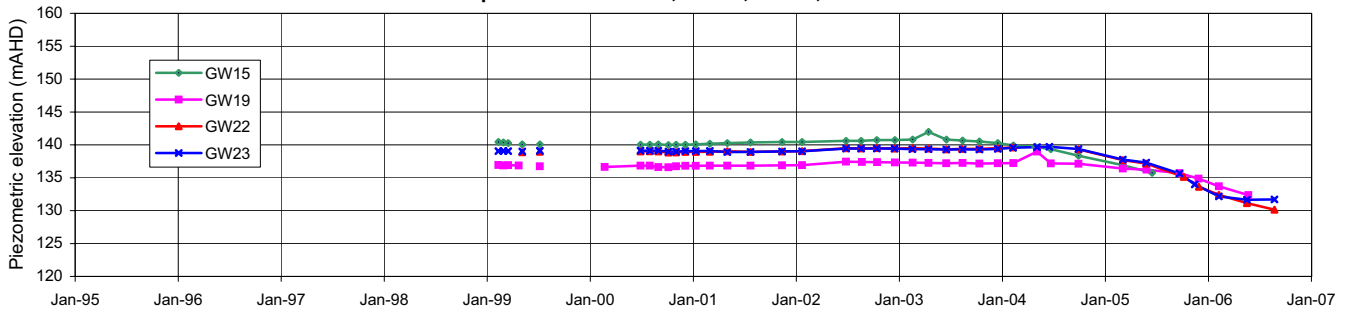
MAC piezometers GW05, GW06, GW07, GW11



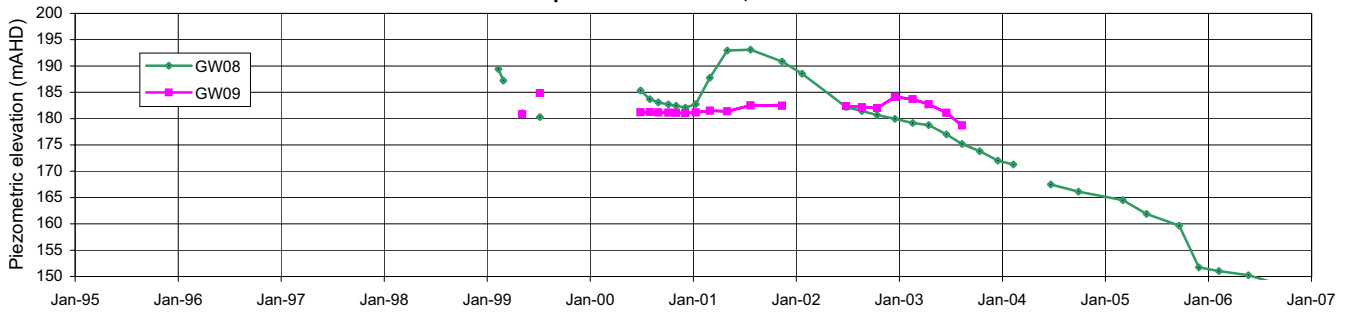
MAC piezometers GW01, GW03, GW13



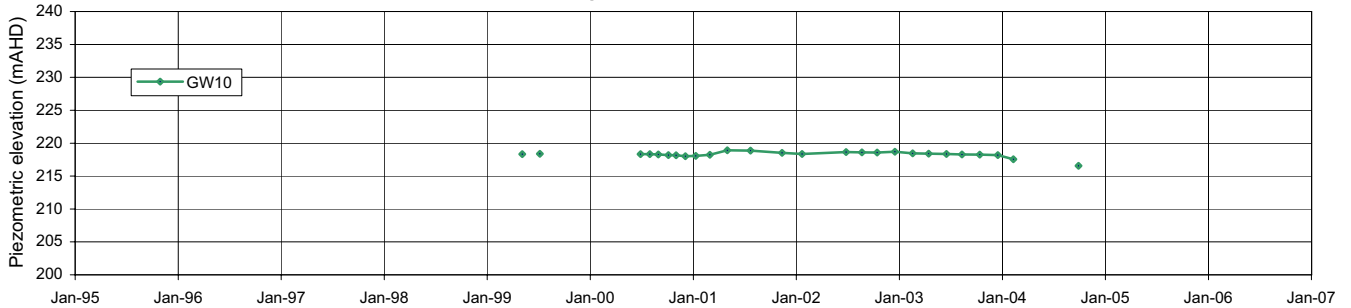
MAC piezometers GW15, GW19, GW22, GW23

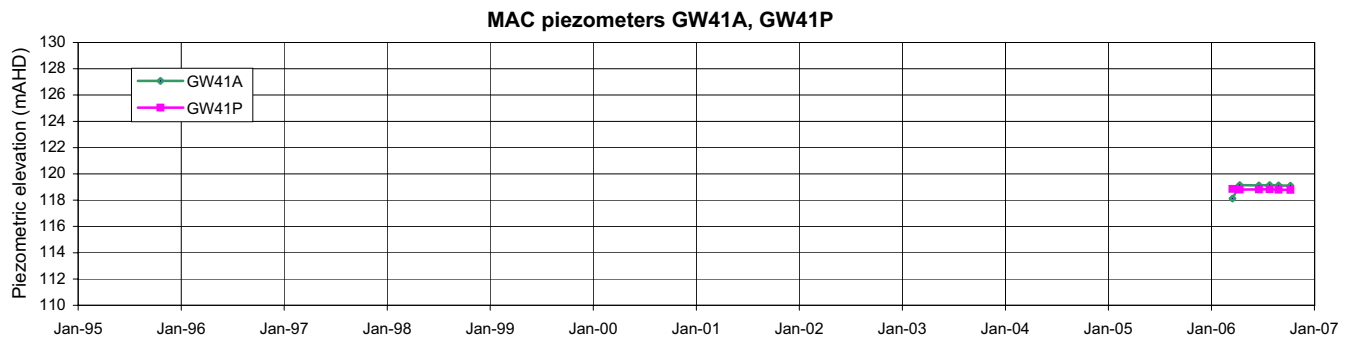
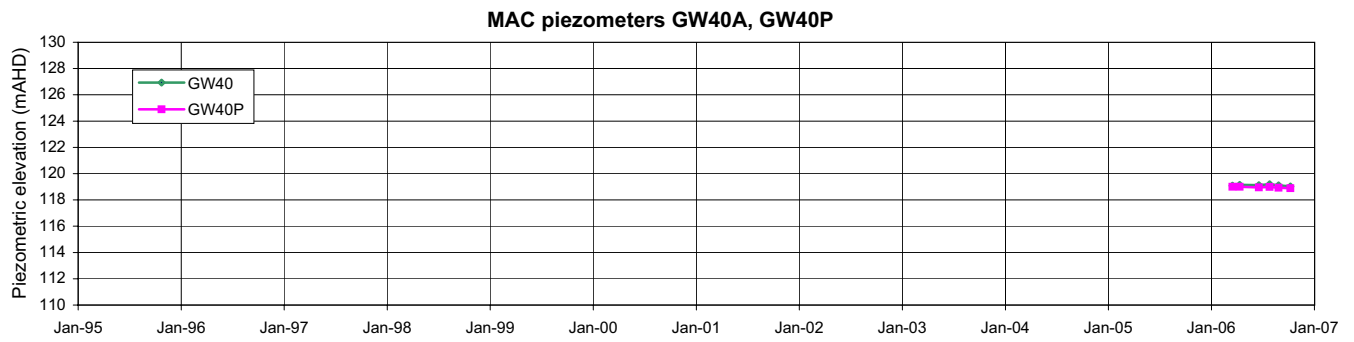
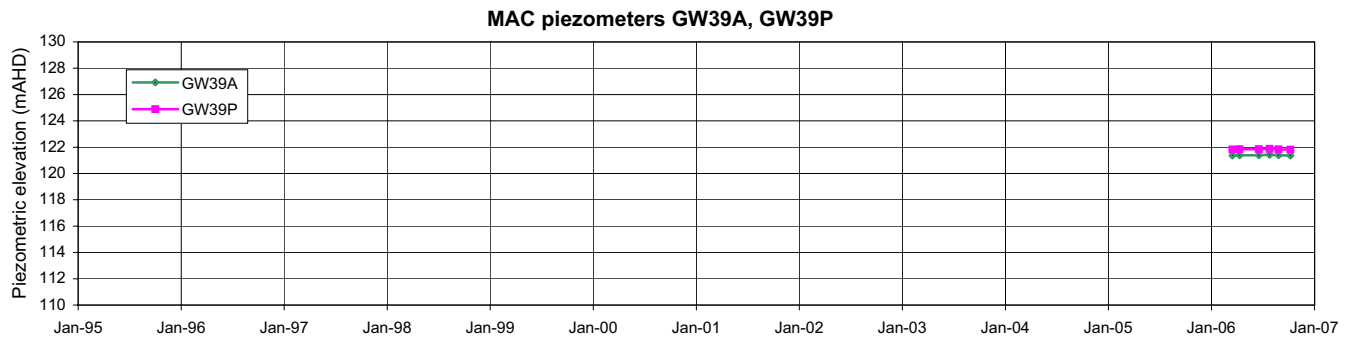
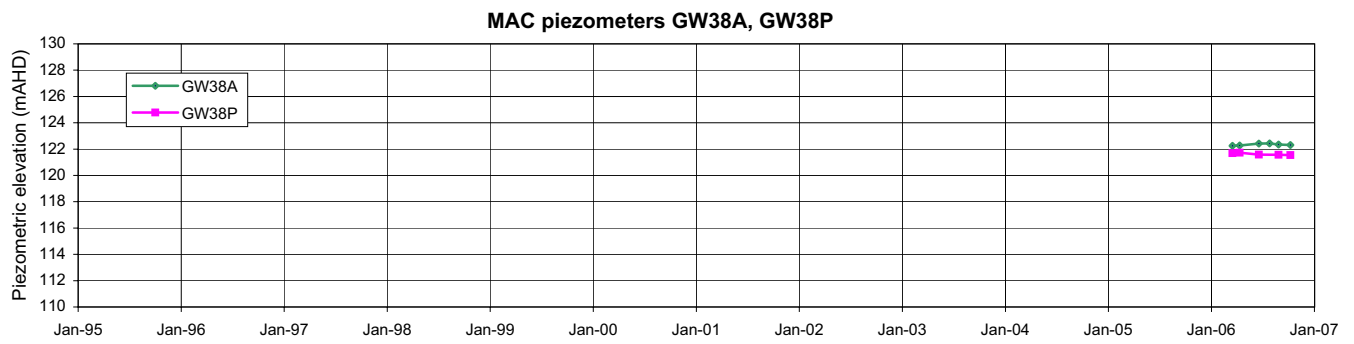


MAC piezometers GW08, GW09

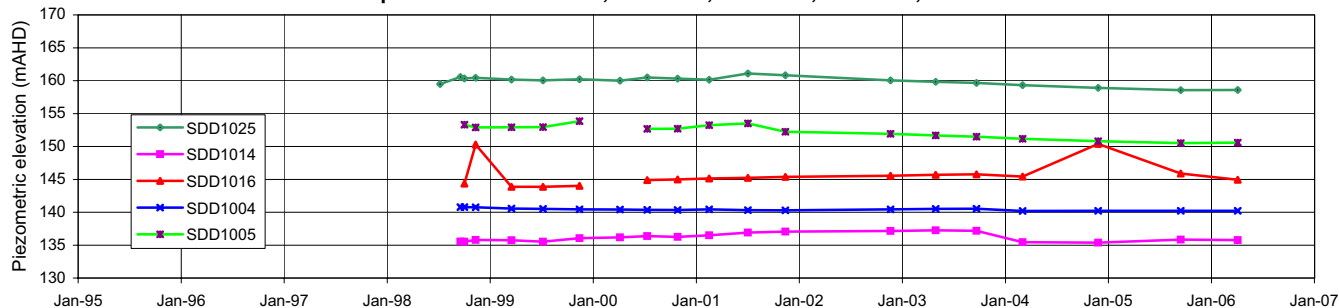


MAC piezometers GW10

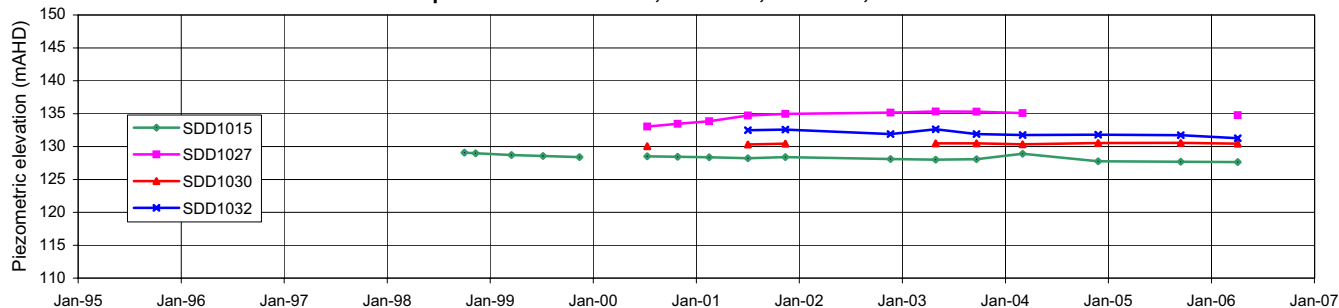




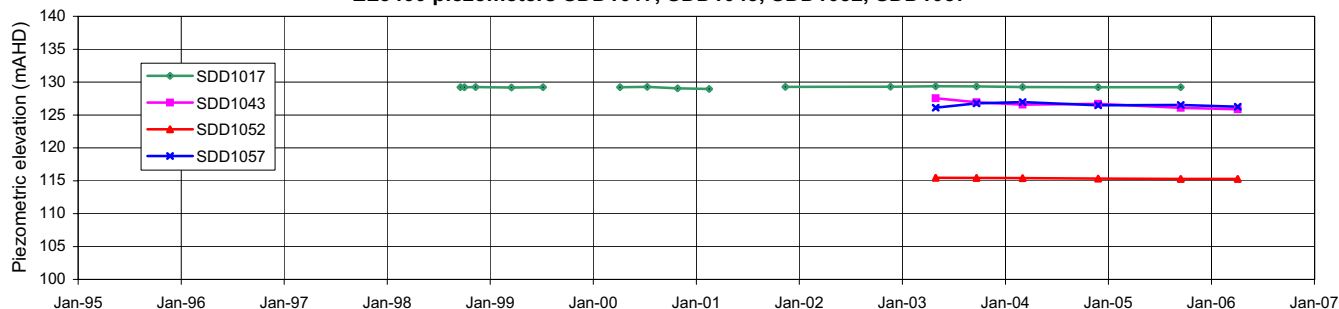
EL5460 piezometers SDD1004, SDD1005, SDD1014, SDD1016, SDD1025



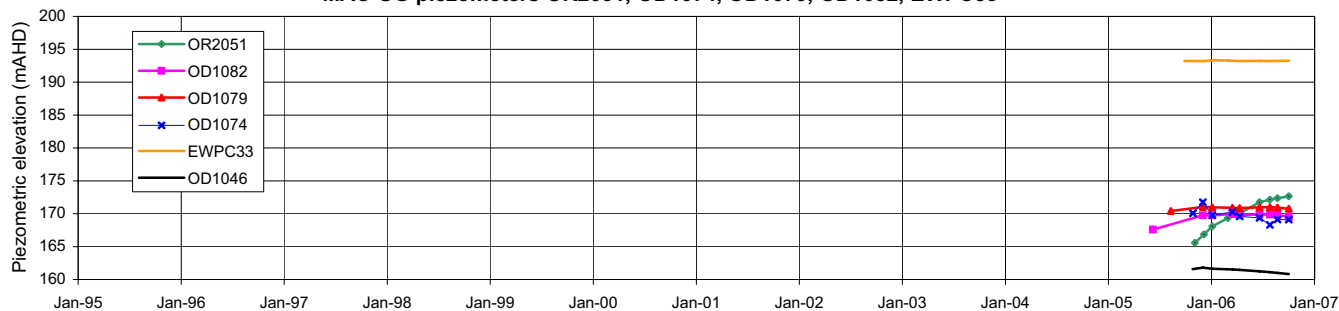
EL5460 piezometers SDD1015, SDD1027, SDD1030, SDD1032



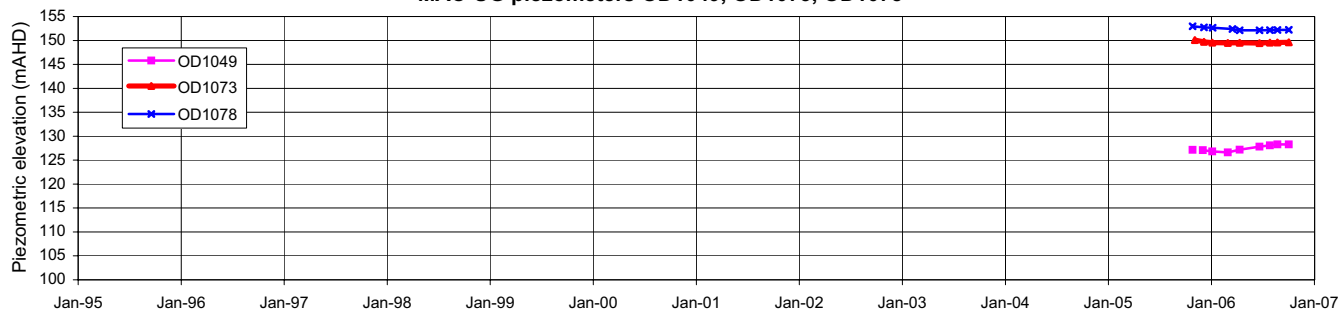
EL5460 piezometers SDD1017, SDD1043, SDD1052, SDD1057



MAC-UG piezometers OR2051, OD1074, OD1079, OD1082, EWPC33



MAC-UG piezometers OD1049, OD1073, OD1078

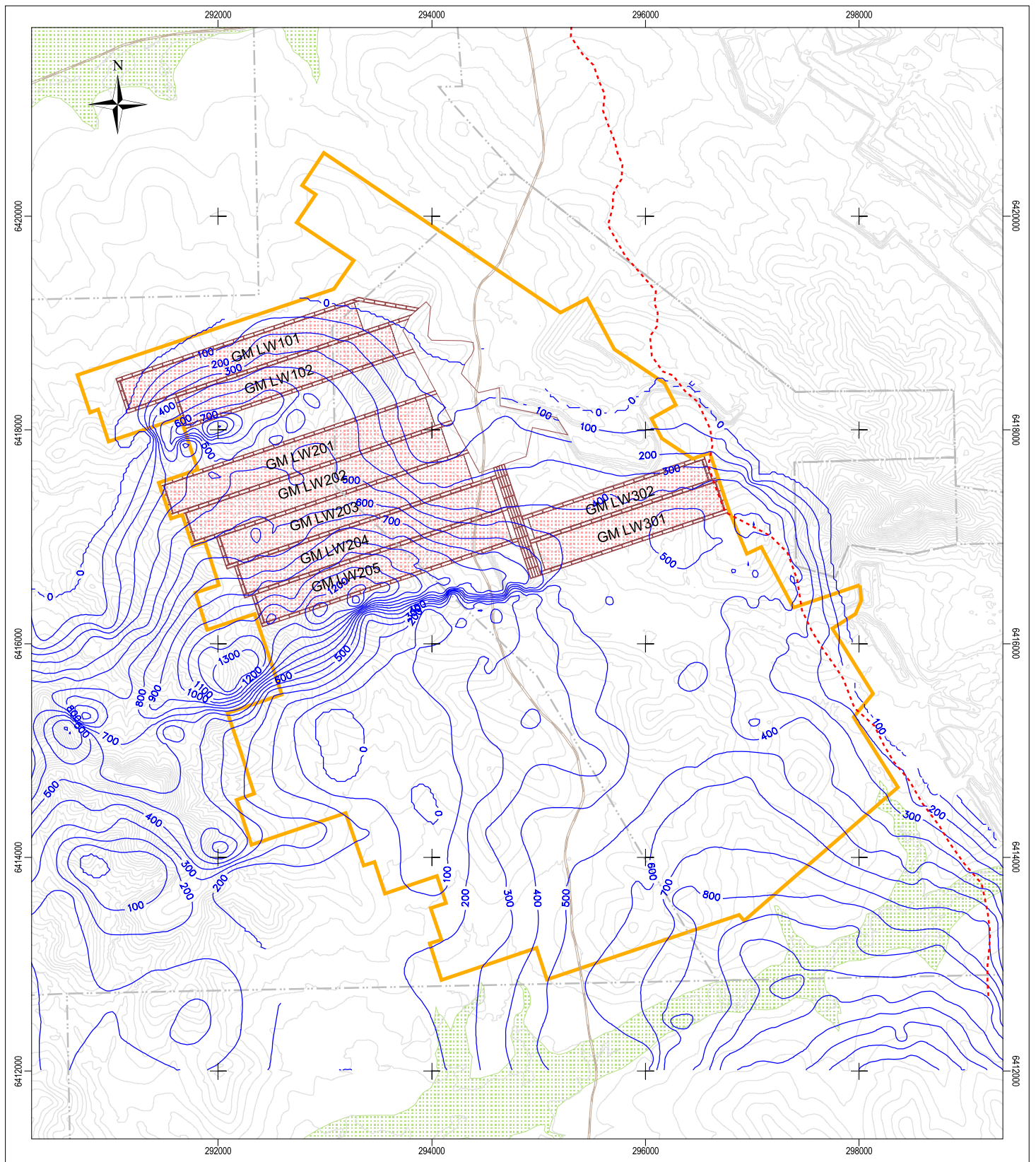


APPENDIX C: PRE MINING SEAM PRESSURES

Pre-mining seam hydrostatic pore pressures have been calculated by subtracting working seam floor levels from the pre-mining piezometric surface (Figure 6 in main text). Note that the pre-mining surface has been generated from composite piezometric levels in many instances. These levels have been measured at different times over a number of years with certain measurements probably reflecting hydrostatic conditions prior to any influences from open cut operations at Mt Arthur Coal.

Installation of seam specific piezometers during 2005 indicates lower pressures within the Arrowfield and shallower seams probably induced by natural seepage losses through the seam at lower (subcrop) elevations. Some contribution to losses may also have resulted from open cut operations in Belmont and Macdonald pits located in the Bayswater No. 3 mining area which commenced in 1995-1996.

Figures C1 to C5 provide results for the Glen Munro, Woodlands Hill, Arrowfield, Bowfield and Piercefield seams respectively. Proposed longwall panels are also shown for reference.



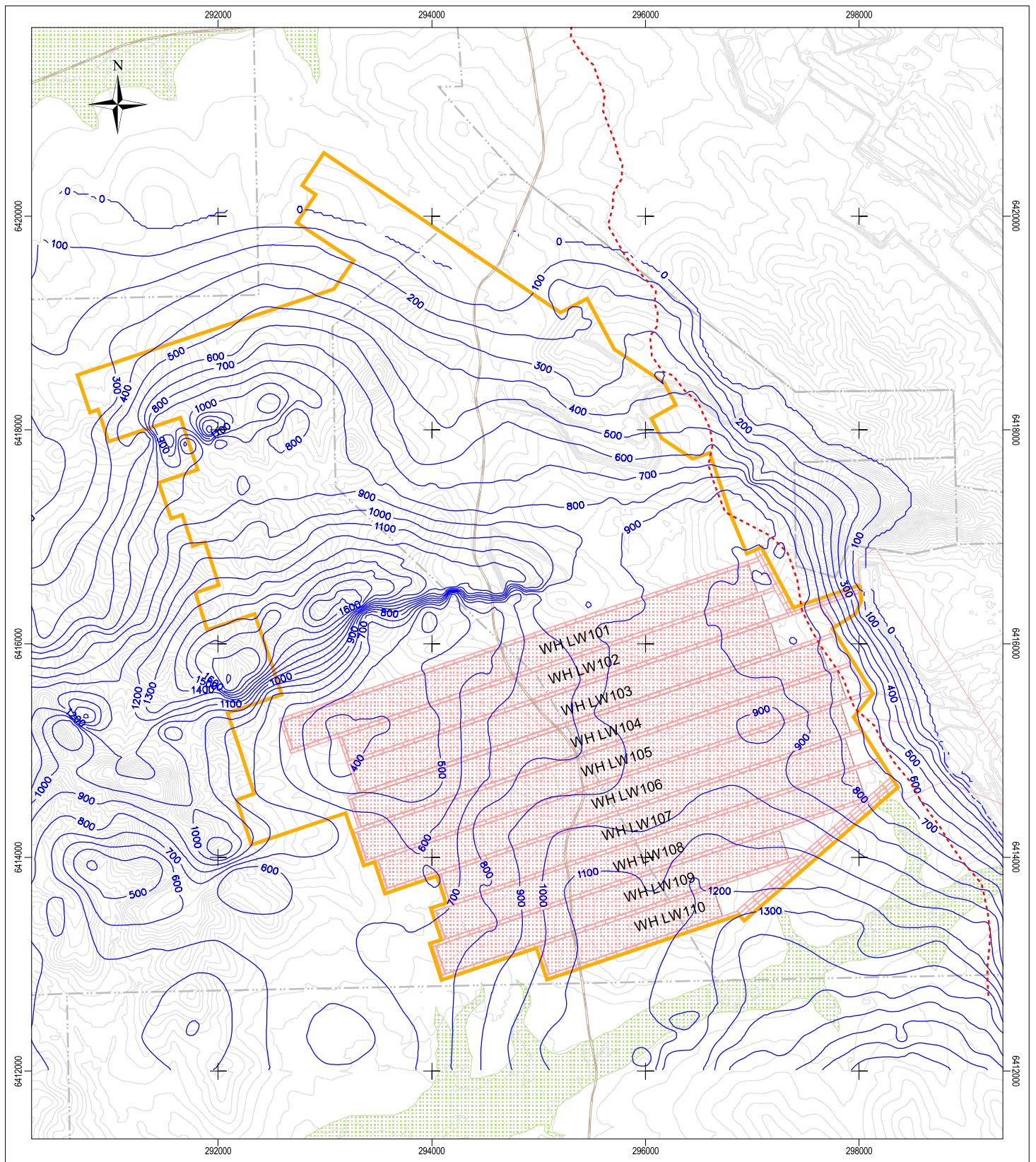
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Scale 1:50000

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHD - 10m interval)
- alluvial aquifer
- hydrostatic pressure (kPa)
- toe of monocline

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Pre mining hydrostatic pressure distribution Glen Munro seam



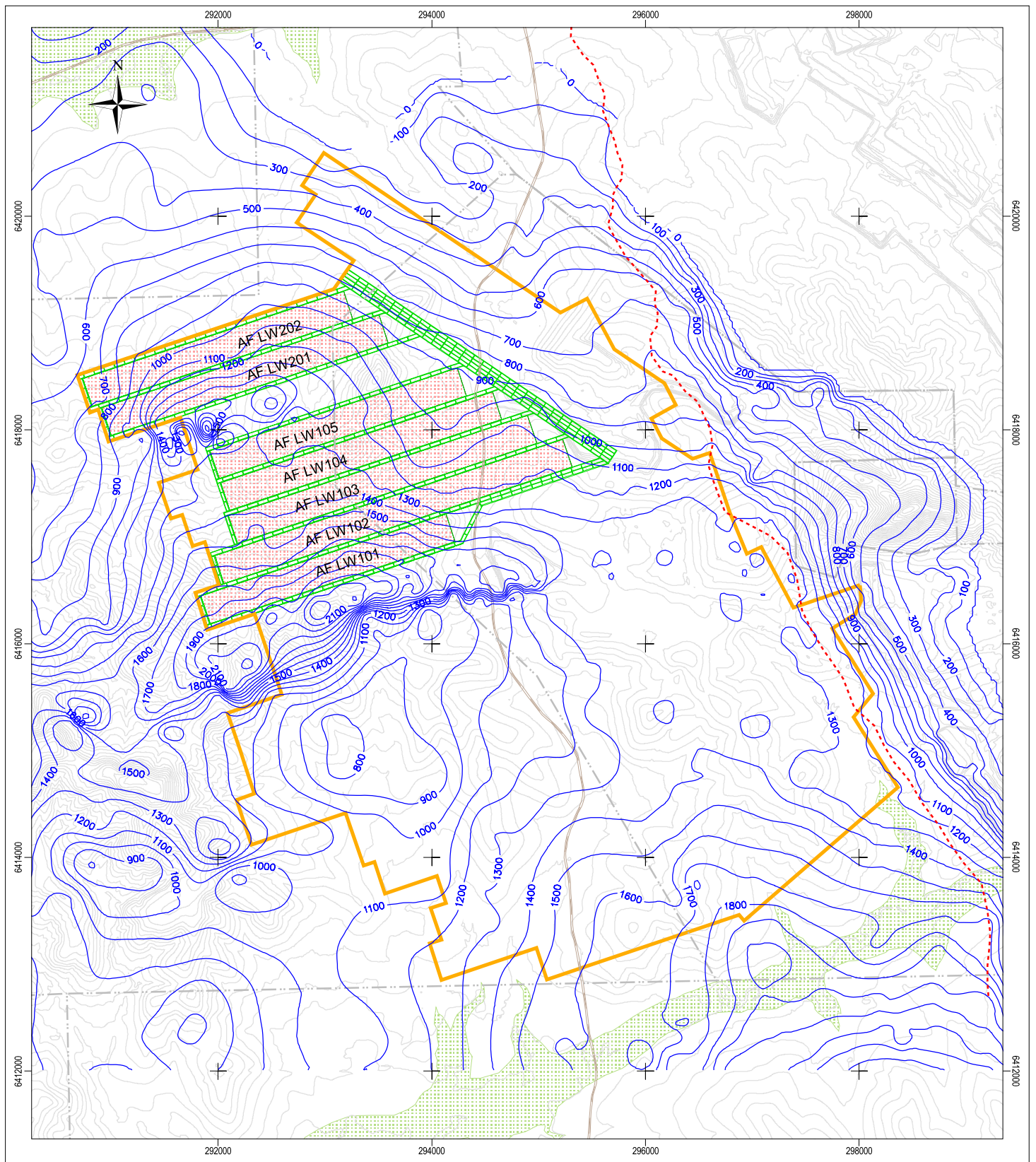
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Scale 1:50000

- | | |
|--|-------------------------------------|
| --- lease boundary | [Green dotted box] alluvial aquifer |
| ++++ railway | — hydrostatic pressure (kPa) |
| — main road | - - - toe of monocline |
| — drainage | |
| — mine panel footprint | |
| — topographic contours (mAHd - 10m interval) | |

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Pre mining hydrostatic pressure distribution Woodlands Hill seam



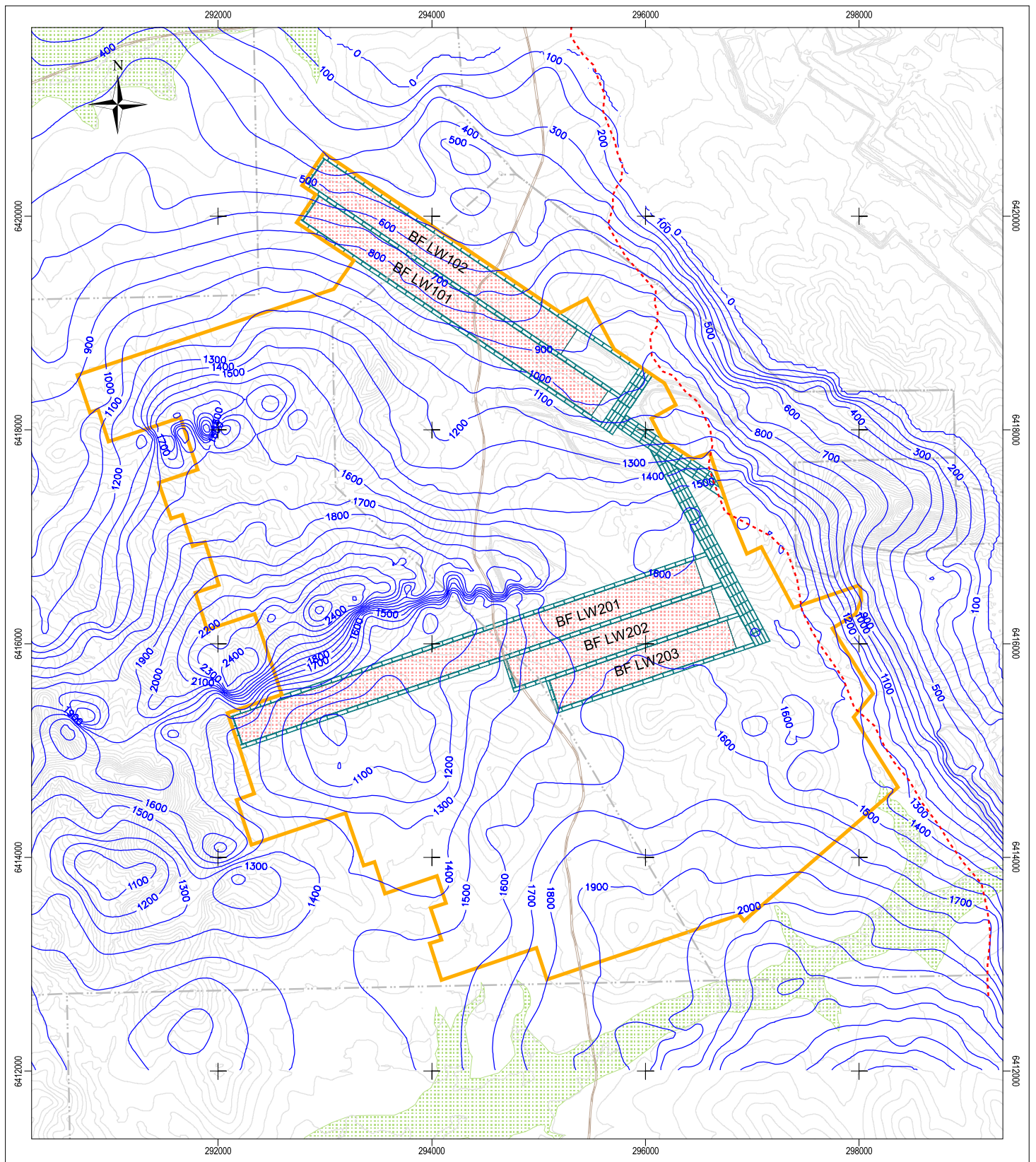
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Scale 1:50000

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHd - 10m interval)
- alluvial aquifer
- hydrostatic pressure (kPa)
- toe of monocline

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

**Pre mining hydrostatic pressure distribution
Arrowfield seam**



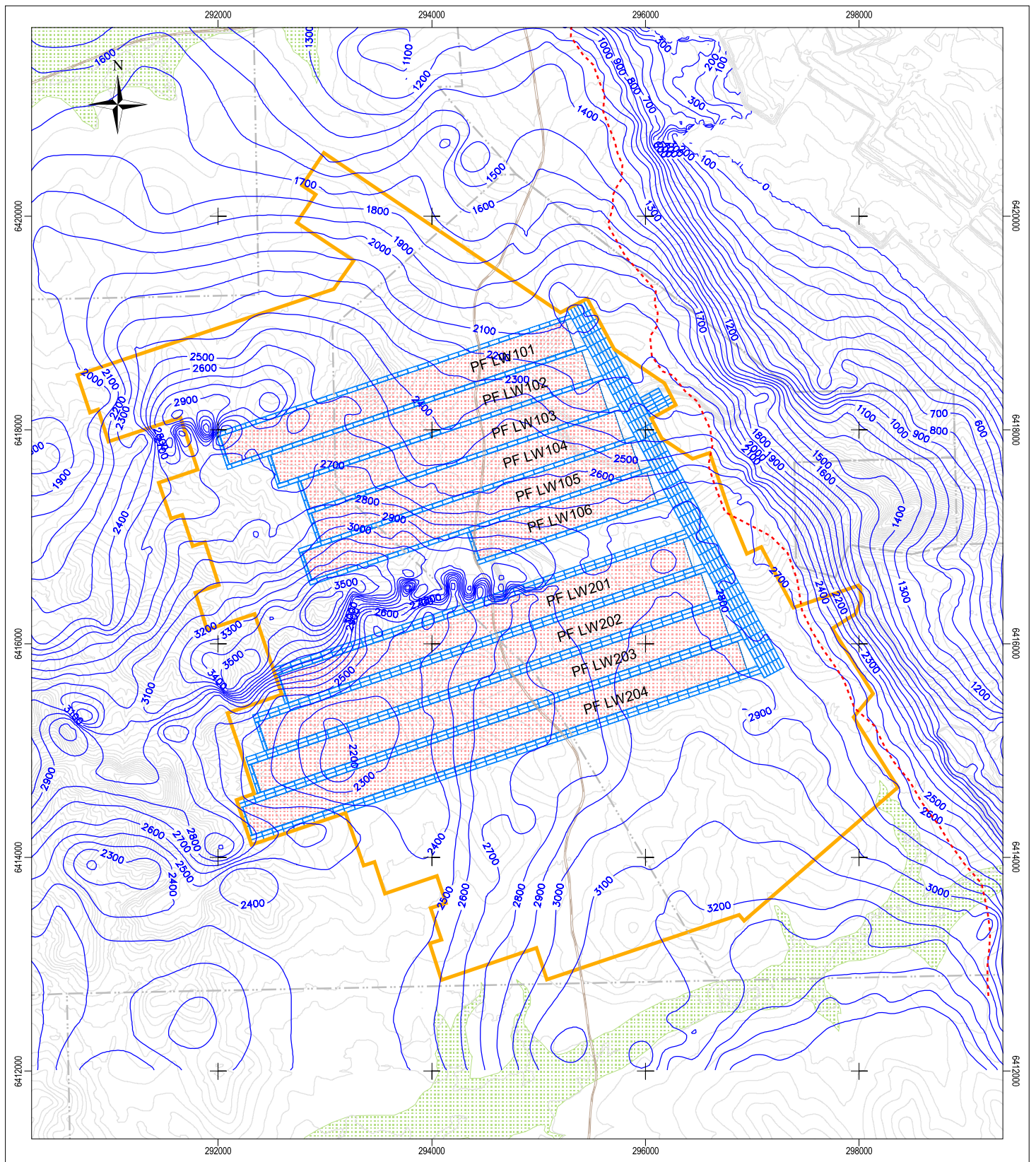
0 1000 2000 3000 Metres

Scale 1:50000

- | | |
|--|----------------------------|
| --- lease boundary | alluvial aquifer |
| ++++ railway | hydrostatic pressure (kPa) |
| main road | toe of monocline |
| drainage | |
| mine panel footprint | |
| topographic contours (mAHd - 10m interval) | |

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Pre mining hydrostatic pressure distribution Bowfield seam



0 1000 2000 3000 Metres

Scale 1:50000

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHD - 10m interval)
- alluvial aquifer
- hydrostatic pressure (kPa)
- toe of monocline

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Pre mining hydrostatic pressure distribution Piercefield seam

APPENDIX D: AQUIFER HYDRAULIC PROPERTIES

Hydraulic properties of the various strata have been determined as part of numerous exploration and testing campaigns conducted over the last 20 years. Some have targeted specific coal seams while others have been of a more general nature eg. open hole air lift tests. MER (2000) provides a useful summary of data for the Mt Arthur Coal open cut area which is represented below together with other relevant and more recent data.

D1.1 Historical hydraulic properties data (pre Mt Arthur Coal)

Estimates of coal seam and interburden hydraulic conductivities are available in numerous research based reports and groundwater studies conducted for the Electricity Commission of NSW. These include pumping tests, packer tests, and back analyses using analytical methods or aquifer computer simulation modelling techniques to establish bulk properties for the coal measures.

Australian Groundwater Consultants (AGC, 1979) conducted a series of tests in the northern part of the open cut area. These comprised falling head and packer tests at bore location WT1 to depths of around 160m. Pumping tests were also conducted at relatively shallow depths in the Ramrod Creek and Edinglassie seams at boreholes WT3, WT4 and WT5 near east-west faulting in the central part of the area, and WT6. Table D1 provides a summary of packer testing at bore site WT1 within the various coal seams while Table D2 gives results of pumping tests.

Table D1: Summary estimates of historical packer tests

Bore	Seam	Kxy (m/day)
WT1	Vaux	2.30E-01
WT1	Bayswater	2.30E-01
WT1	Wynn	6.00E-02
WT1	Clanricard	8.00E-02
WT1	Bengalla	8.00E-02
WT1	Edinglassie	1.50E-01
WT1	U. Ramrod Creek	3.50E-01
WT1	L. Ramrod Creek	8.00E-01
WT1	Interburden	< 1.00E-03
T13 (BH403)	Mt. Arthur	4.30E-01
T13 (BH403)	Piercefield	6.90E-01
T13 (BH403)	Vaux	5.10E-01
T13 (BH403)	Broonie-Bayswater	3.40E-01
T13 (BH403)	Wynn-Edderton	3.40E-01
T13 (BH403)	Clanricard	2.60E-01
T13 (BH403)	Bengalla	1.20E-01
T13 (BH403)	Edinglassie	1.50E-01
T13 (BH403)	Ramrod Creek	6.00E-02
T16 (BH401)	Piercefield	6.00E-01
T16 (BH401)	Vaux	5.20E-01
T16 (BH401)	Broonie-Bayswater	4.30E-01
T16 (BH401)	Wynn-Edderton	1.70E-01
T16 (BH401)	Clanricard	3.40E-01
T16 (BH401)	Bengalla	6.00E-01
T16 (BH401)	Edinglassie	2.60E-01
T16 (BH401)	Ramrod Creek	8.60E-02

Kxy = horizontal hydraulic conductivity

A series of packer and pumping tests were also conducted at bore locations P1R and P3R (Figure D1) in 1982 as part of mine feasibility assessments. These were restricted to the Ramrod Creek and Edinglassie seams and comprised staged discharge and constant yield methods with observations on both the pumping well and numerous observation wells (LMP,1982).

Table D2: Summary estimates of historical coal seam pumping tests

Bore	Seam	Interval depth (m)	Seam Kxy (m/day)	Storativity
WT5	Edinglassie	25	4	5.00E-04
WT6	Edinglassie	40	8.57	1.20E-03
WT3	Ramrod Creek	25	32.8	3.00E-04
WT4	Ramrod Creek	55	26.8	7.00E-04
WT6	Ramrod Creek	70	32.8	4.00E-04
P3R	Edinglassie	147	0.95	6.00E-05
P1R	Ramrod Creek	177	3.45	2.00E-04

Kxy = horizontal hydraulic conductivity

In addition to the above, AGC (1984) provides a summary of coal measures hydraulic properties based on consolidation of testing at numerous locations throughout the Upper Hunter. The permeability of seams is noted to be in the range 0.005 m/day to more than 1 m/day. A generalised relationship of declining permeability with increasing depth was noted.

MER (2000) conducted constant pump in tests on 5 piezometers located within the Hunter River alluvial lands and 9 piezometers distributed across the open cut area. Testing within the coal measures was undertaken in piezometers screened over the saturated thickness. Tests are therefore composite; derived hydraulic conductivities reflect the entire test interval but flows are most likely restricted to the coal seams. Results are represented as Table D3 – bore locations have been re-named since MER (2000).

Table D3: MER (2000) pump in tests for open cut assessments

Bore ID	Old Bore ID	Lithology	Composite Kxy (m/day)
GW25	MGW1	alluvium	4.25E+01
GW24	MGW2	alluvium	3.44E+01
GW16	MGW3	alluvium	4.70E+00
GW17	MGW4	alluvium	4.40E+00
GW21	MGW5	alluvium	5.27E+01
GW8	ID1014	coal measures	1.29E-02
GW23	ID1029	coal measures	2.41E-01
GW19	ID1030	coal measures	7.33E-03
GW15	ID1035	coal measures	6.52E-04
GW18	ID1047	coal measures	2.70E-03
GW12	ID1049	coal measures	2.01E-02
GW10	ID1059	coal measures	7.95E-04
GW13	ID1061	coal measures	8.00E-04
GW22	ID1062	coal measures	5.47E-04

Kxy = horizontal hydraulic conductivity

D1.2 Injection-packer tests

Injection packer testing has been conducted on a number of seams within the project area and at several locations within the Saddlers Creek project area to the south (EL5460). Targeted seams include the Glen Munro, Woodlands Hill, Arrowfield, Bowfield and Warkworth (Multiphase Technologies-2003 and 2005, Sibra-2004). Results are summarised in the following Table D4. Note that these results are generally based on the mean of values determined using different analytical techniques.

Table D4: Coal seam packer tests (EL5965) including Saddlers Creek area (EL5460)

Bore	Area	Seam	Depth Int. (m)	Seam Kxy (m/day)
OD1053	MAU	Arrowfield	137.0 to 144.9	4.45E-03
OD1053	MAU	Bowfield	155.5 to 163.4	1.93E-02
OD1053	MAU	Piercefield	272.0 to 279.9	5.14E-03
OD1060	MAU	Woodlands Hill	76.6 to 84.5	4.98E-03
OD1070	MAU	Glen Munro	102.5 to 110.4	8.09E-02
OD1083	MAU	Glen Munro	96.5 to 104.4	1.63E-02
OD1083	MAU	Woodlands Hill	144.3 to 152.2	2.38E-02
OD1083	MAU	Bowfield	206.0 to 213.9	1.40E-02
DDH1045	Saddlers Ck	Woodlands Hill	113.0 to 120.7	3.01E-03
DDH1045	Saddlers Ck	Arrowfield	158.0 to 165.7	8.74E-02
DDH1045	Saddlers Ck	Bowfield	187.0 to 194.7	4.01E-03
DDH1046	Saddlers Ck	Woodlands Hill	208.5 to 216.2	3.48E-02
DDH1046	Saddlers Ck	Arrowfield	254.5 to 262.2	2.67E-02
DDH1046	Saddlers Ck	Bowfield	294.0 to 301.7	1.03E-02
DDH1046	Saddlers Ck	Warkworth	327.0 to 335.0	2.80E-04
DDH1047	Saddlers Ck	Woodlands Hill	278.3 to 286.0	3.68E-02
DDH1047	Saddlers Ck	Arrowfield	316.7 to 324.4	1.42E-01
DDH1047	Saddlers Ck	Bowfield	361.7 to 369.4	1.78E-02
DDH1047	Saddlers Ck	Warkworth	399.0 to 408.0	2.52E-04
DD1076A	Saddlers Ck	Woodlands Hill	222.8 to 229.6	4.27E-02
DD1076A	Saddlers Ck	Arrowfield	265.6 to 270.3	5.15E-02
DD1076A	Saddlers Ck	Bowfield	301.9 to 309.3	7.90E-02
DD1076A	Saddlers Ck	Warkworth	335.9 to 343.3	3.37E-02

Kxy = horizontal hydraulic conductivity

D1.3 Variable head tests

As part of more recent testing, variable head or slug type tests have been conducted in open holes or piezometers located within the project area and in areas to the south (EL5460). This procedure involves the introduction or removal of a volume of water within the test borehole, and monitoring of the subsequent change in water level.

These tests are considered to be composite; derived hydraulic conductivities reflect the entire test interval but flows are most likely restricted to the coal seams. Results are represented as Table D5

Table D5: Variable head tests

Bore	Area	Lithology	Composite Kxy (m/day)
GW38P	MAU	coal measures	<< 1.0E-03
GW38A	MAU	alluvium	1.6E+01
GW39P	MAU	coal measures	1.2E-03
GW39A	MAU	alluvium	6.2E+01
GW40P	MAU	coal measures	3.9E-04
GW40A	MAU	alluvium	1.7E+00
GW41P	MAU	coal measures	1.7E-02
GW41A	MAU	alluvium	4.9E+01
OD1044a	MAU	coal measures	3.0E-05
OD1046	MAU	coal measures	7.5E-05
OD1049	MAU	coal measures	2.9E-05
OD1053	MAU	coal measures	8.7E-04
OD1079	MAU	coal measures	4.1E-05
DD1081	EL5460	coal measures	2.5E-03
DD1082	EL5460	coal measures	<1.6E-04
DD1084	EL5460	coal measures	2.5E-02
DD1085	EL5460	coal measures	4.7E-03
RD1095	EL5460	fault	3.4E+00
RD1096	EL5460	coal measures near fault	1.9E-03
RD1097	EL5460	coal measures near fault	1.2E-02
RD1098	EL5460	coal measures near fault	3.9E-03
RD1099	EL5460	coal measures near fault	1.5E-03
RD1100	EL5460	fault	1.2E+00
RD1101	EL5460	fault	1.9E+00
RD1102	EL5460	coal measures near fault	1.2E-01
RD1104	EL5460	fault	1.1E+00
RD1105	EL5460	coal measures near fault	3.9E-02
RD1125	EL5460	coal measures near fault	1.6E-01
DD1086	EL5460	coal measures	1.6E-03
DD1087	EL5460	coal measures	1.1E-03
DD1088	EL5460	coal measures	1.0E-02
DD1091	EL5460	coal measures	3.2E-03
DD1091A	EL5460	coal measures	5.1E-02
DD1092	EL5460	coal measures	3.42E-03
DD1094	EL5460	coal measures	1.2E-03
DD1099	EL5460	coal measures	1.4E-03
DD1100	EL5460	coal measures	6.9E-03
DD1104	EL5460	coal measures	1.9E-03
DD1106	EL5460	coal measures	3.4E-05
DD1108	EL5460	coal measures	2.2E-04
DD1109	EL5460	coal measures	1.4E-03
DD1110	EL5460	coal measures	2.4E-04
RD1147	EL5460	coal measures near fault	2.9E-02

Kxy = horizontal hydraulic conductivity (preliminary estimate using Hvorslev or KGS method)

D1.4 Interburden core tests

Laboratory core testing provides a means of determining the hydraulic conductivity of materials at an intergranular scale consistent with porous media (Darcian) flow. This estimate is typically the lowest conductivity for a specific rock type and is most representative of strata where fracturing and jointing is absent or relatively disconnected thereby inhibiting conduit type flow.

Numerous cores from exploration bores located within the project area, the Mt Arthur Coal open cut area and within EL5460 to the south, have been inspected by MER over a number of years. Representative samples have been taken from interburden sections displaying relatively uniform properties in respect of rock type, grain size, etc. These samples have comprised sandstones, siltstones, claystones, shales and tuffs that together provide a comprehensive overview of interburden conductivities throughout the region.

All core samples were tested by Core Laboratories Australia at a confining pressure of 5.5 MPa. The test method employed helium gas as the test 'fluid' and generated an estimate of Klinkenberg permeability (K_{inf}). Conversion has provided a measure of the saturated hydraulic conductivity at 20°C. Porosity was also determined for a number of samples. Results are summarised in the following Table D6.

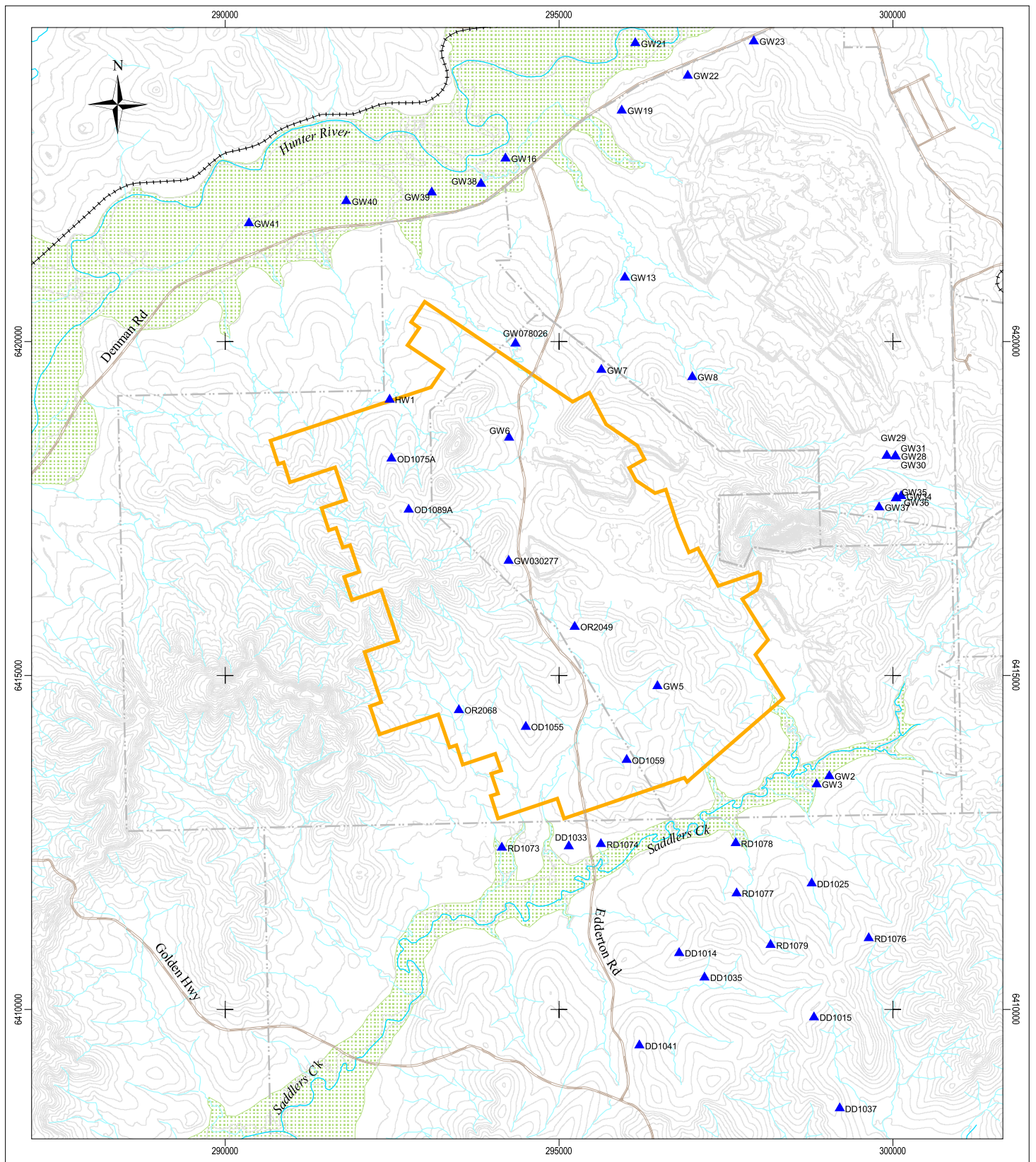
Table D6: Hydraulic conductivity estimates from interburden core (laboratory) tests

Bore	Area	Depth (m)	Lithology	Stratigraphic Location	Orientation	K (m/day)
OD1033	MAU	67.9	sandstone - medium to fine grained, sorted, well cemented	between Whynot and Blakefield seams	Vertical	3.23E-05
OD1033	MAU	133.1	sandstone - conglomeritic, poorly sorted (0.3 to >4mm dia), well cemented	between Glen Munro GM1 and GM2 seams	Vertical	3.35E-05
OD1046	MAU	117.8	sandstone - medium grained, well sorted, well cemented	between Glen Munro and Woodlands Hill seams	Vertical	6.75E-04
OD1046	MAU	311.0	sandstone - very fine grained, well cemented, coaly wiaps	between Mt. Arthur and Piercefield seams	Vertical	6.41E-07
OD1046	MAU	323.9	sandstone - coarse to medium grained, well cemented	between Mt. Arthur and Piercefield seams	Vertical	2.84E-06
OD1047	MAU	55.1	sandstone - fine grained, well sorted, well cemented	between Glen Munro GM3 and GM4 seams	Horizontal	6.07E-05
OD1047	MAU	55.1	sandstone - fine grained, well sorted, well cemented	between Glen Munro GM3 and GM4 seams	Vertical	1.65E-05
OD1047	MAU	69.0	sandstone - fine grained, well sorted, well cemented	between Glen Munro and Woodlands Hill seams	Vertical	1.55E-06
OD1047	MAU	88.1	sandstone/siltstone - ss is fine grained, well cemented	between Glen Munro and Woodlands Hill seams	Vertical	1.28E-06
OD1047	MAU	155.0	sandstone - fine grained, well cemented	between Arrowfield (absent) and Bowfield seams	Horizontal	1.67E-05
OD1047	MAU	155.0	sandstone - fine grained, well cemented	between Arrowfield (absent) and Bowfield seams	Vertical	3.22E-05
OD1047	MAU	280.8	sandstone/siltstone - ss is fine grained, well cemented	between Mt. Arthur and Piercefield seams	Vertical	6.11E-07
OD1047	MAU	300.3	sandstone/siltstone - ss is fine grained, well cemented	between Piercefield and Vaux seams	Vertical	7.25E-07
OD1049	MAU	71.1	sandstone - fine grained, well cemented, minor coaly wisps	between Glen Munro and Woodlands Hill seams	Horizontal	4.36E-07
OD1049	MAU	71.1	sandstone - fine grained, well cemented, minor coaly wisps	between Glen Munro and Woodlands Hill seams	Vertical	5.60E-07
OD1049	MAU	85.1	siltstone/laminite - grey to dark grey	between Woodlands Hill WH1C and WH2 seams	Vertical	1.58E-06
OD1049	MAU	98.0	sandstone - fine grained, well cemented, minor coaly wisps	between Woodlands Hill WH1C and WH2 seams	Vertical	1.56E-06
OD1049	MAU	114.0	sandstone - medium fine grained, moderately sorted	between Woodlands Hill and Arrowfield (absent) seams	Vertical	3.01E-06
OD1052	MAU	83.2	laminite - finely intercalated sandstone, siltstone, claystone	between Woodlands Hill WH1C and WH2 seams	Vertical	5.50E-07
OD1052	MAU	92.9	laminite - finely intercalated sandstone, siltstone, claystone	between Woodlands Hill WH1C and WH2 seams	Vertical	4.67E-07
OD1052	MAU	105.5	sandstone - fine grained, well cemented	between Woodlands Hill and Arrowfield (absent) seams	Vertical	8.14E-07
OD1052	MAU	130.8	sandstone - fine grained, well cemented	between Woodlands Hill and Arrowfield (absent) seams	Vertical	4.59E-07
OD1052	MAU	155.1	sandstone - medium grained, well cemented, minor coaly wisps	between Arrowfield and Bowfield seams	Vertical	9.30E-07
OD1052	MAU	166.7	sandstone - medium fine grained, well cemented, minor coaly wisps	between Bowfield and Warkworth seams	Horizontal	3.87E-06
OD1052	MAU	166.7	sandstone - medium fine grained, well cemented, minor coaly wisps	between Bowfield and Warkworth seams	Vertical	2.10E-06
OD1052	MAU	267.5	sandstone - fine grained, well sorted, well cemented	between Mt. Arthur and Piercefield seams	Horizontal	3.92E-07
OD1052	MAU	267.5	sandstone - fine grained, well sorted, well cemented	between Mt. Arthur and Piercefield seams	Vertical	3.49E-07
OD1052	MAU	291.3	sandstone - fine grained, well sorted, well cemented	between Piercefield and Vaux seams	Vertical	2.04E-07
OD1052	MAU	305.1	sandstone/siltstone - finely laminated, ss is fine grained	between Piercefield and Vaux seams	Vertical	2.90E-07
OD1053	MAU	34.7	sandstone/siltstone - finely laminated, ss is very fine grained	between Blakefield and Glen Munro seams	Vertical	2.03E-06
OD1053	MAU	56.0	sandstone - medium fine grained, well cemented	between Glen Munro and Woodlands Hill seams	Vertical	4.34E-05



Bore	Area	Depth (m)	Lithology	Stratigraphic Location	Orientation	K (m/day)
OD1053	MAU	64.3	sandstone/siltstone - finely laminated, ss is very fine grained	between Glen Munro and Woodlands Hill seams	Vertical	7.09E-06
OD1053	MAU	123.2	sandstone - medium fine grained, well sorted, well cemented	between Woodlands Hill and Arrowfield seams	Horizontal	1.18E-06
OD1053	MAU	123.2	sandstone - medium fine grained, well sorted, well cemented	between Woodlands Hill and Arrowfield seams	Vertical	7.76E-06
OD1053	MAU	136.5	siltstone/laminite - fine grained ss	between Woodlands Hill and Arrowfield seams	Vertical	4.06E-06
OD1053	MAU	150.4	sandstone - white to cream, fine grained, well sorted, well cemented	between Arrowfield and Bowfield seams	Vertical	3.10E-07
OD1053	MAU	165.3	sandstone - white to cream, coarse grained, poorly sorted, well cemented	between Bowfield and Warkworth seams	Vertical	4.43E-06
OD1053	MAU	257.5	sandstone - grey to white, medium grained, well sorted, well cemented	between Mt. Arthur and Piercefield seams	Vertical	2.80E-07
OD1053	MAU	285.3	sandstone - grey to white, fine grained, well sorted, well cemented	between Piercefield and Vaux seams	Vertical	3.01E-07
OD1074	MAU	46.5	sandstone - grey to cream, fine grained, well sorted, very well cemented	between Blakefield and Glen Munro seams	Vertical	1.44E-07
OD1074	MAU	61.1	siltstone/shale, grey to dark grey carbonaceous	between Blakefield and Glen Munro seams	Vertical	3.01E-07
OD1074	MAU	80.6	sandstone/siltstone - finely laminated, ss is fine grained, cream, well cemented	between Glen Munro and Woodlands Hill seams	Vertical	3.64E-07
OD1074	MAU	98.4	sandstone - white, coarse to medium grained, well cemented	between Glen Munro and Woodlands Hill seams	Vertical	2.26E-05
OD1074	MAU	118.5	sandstone/siltstone - finely laminated, ss is fine grained, cream, well cemented	between Woodlands Hill and Arrowfield seams	Vertical	5.95E-07
OD1074	MAU	144.3	siltstone/sandstone - finely laminated, ss is fine grained, cream, well cemented	between Woodlands Hill and Arrowfield seams	Vertical	4.29E-07
OD1074	MAU	164.0	sandstone - grey, fine grained, well sorted, well cemented	between Arrowfield and Bowfield seams	Vertical	4.57E-06
OD1074	MAU	180.1	sandstone - grey to cream, fine grained, well sorted, well cemented	between Bowfield and Warkworth seams	Horizontal	6.51E-07
OD1074	MAU	180.1	sandstone - grey to cream, fine grained, well sorted, well cemented	between Bowfield and Warkworth seams	Vertical	4.61E-07
OD1074	MAU	275.0	sandstone - grey to cream, fine grained, well sorted, well cemented, vert. fracture	between Mt. Arthur and Piercefield seams	Vertical	5.13E-02
OD1074	MAU	292.1	sandstone/siltstone - finely laminated, ss is fine grained, cream, well cemented	between Mt. Arthur and Piercefield seams	Vertical	3.39E-07
OD1080	MAU	120.0	sandstone - white to grey, very coarse to coarse grained (conglomeritic)	between Warkworth and Mt. Arthur seams	Vertical	1.52E-02
ID1001	Open Cut	77.1	sandstone, coarse to medium grained	below Broonie seam	Vertical	1.08E-04
ID1001	Open Cut	131.7	sandstone, medium grained	above Bengalla seam	Vertical	5.89E-05
ID1033	Open Cut	122.3	sandstone, medium fine grained	below Bengalla seam	Vertical	1.03E-05
ID1033	Open Cut	158.0	sandstone, fine grained, carb. fleks	between Edinglassie and Ramrod Ck seams	Vertical	8.30E-07
ID1033	Open Cut	177.1	sandstone, fine grained	below Ramrod Ck seam	Vertical	8.30E-07
ID1037	Open Cut	108.6	sandstone, fine grained	between Edinglassie and Ramrod Ck seams	Vertical	1.53E-05
ID1044	Open Cut	75.4	sandstone, medium finr grained	above Edinglassie seam	Vertical	6.14E-05
ID1044	Open Cut	101.4	sandstone/siltstone, interbedded	between Edinglassie and Ramrod Ck seams	Vertical	8.30E-07
ID1052	Open Cut	115.1	sandstone, medium fine grained, carb fleks	below Broonie seam	Vertical	7.80E-06
ID1052	Open Cut	136.6	sandstone, medium grained	above Edderton seam	Vertical	1.60E-06
ID1052	Open Cut	216.8	sandstone, fine grained, carb fleks	between Edinglassie and Ramrod Ck seams	Vertical	8.30E-07
ID1052	Open Cut	243.5	sandstone, medium grained, carb fleks	between Ramrod Ck seams	Vertical	1.24E-06
DDH1046	Saddlers Ck	186.7	sandstone - medium fine grained, well cemented	between Glen Munro and Woodlands Hill seams	Horizontal	1.87E-07

Bore	Area	Depth (m)	Lithology	Stratigraphic Location	Orientation	K (m/day)
DDH1046	Saddlers Ck	186.7	sandstone - medium fine grained, well cemented	between Glen Munro and Woodlands Hill seams	Vertical	1.78E-07
DDH1046	Saddlers Ck	201.5	sandstone - medium grained, well cemented	between Glen Munro and Woodlands Hill seams	Horizontal	1.20E-05
DDH1046	Saddlers Ck	216.0	sandstone - very fine grained, silt bands	between Woodlans Hill WH2 and WH3 seams	Vertical	6.30E-07
DDH1046	Saddlers Ck	226.9	sandstone - coarse grained	between Woodlans Hill WH2 and WH3 seams	Horizontal	4.04E-05
DDH1046	Saddlers Ck	226.9	sandstone - coarse grained	between Woodlans Hill WH2 and WH3 seams	Vertical	3.44E-05
DDH1046	Saddlers Ck	239.0	sandstone/siltstone interbedded	between Woodlands Hill and Arrowfield seams	Vertical	4.59E-07
DDH1046	Saddlers Ck	251.1	sandstone - coarse grained	between Woodlands Hill and Arrowfield seams	Horizontal	5.24E-07
DDH1046	Saddlers Ck	268.0	siltstone - shaley laminations	between Arrowfield and Bowfield seams	Vertical	4.14E-07
DDH1046	Saddlers Ck	279.3	sandstone - coarse to medium grained	between Arrowfield and Bowfield seams	Horizontal	6.11E-06
DDH1046	Saddlers Ck	290.5	sandstone - coarse to medium grained	between Arrowfield and Bowfield seams	Horizontal	7.24E-06
DDH1046	Saddlers Ck	290.5	sandstone - coarse to medium grained	between Arrowfield and Bowfield seams	Vertical	2.70E-06
DDH1046	Saddlers Ck	305.8	siltstone - fine grained with carb. fleks	between Bowfield and Warkworth seams	Vertical	5.83E-07
DDH1046	Saddlers Ck	321.7	siltstone - fine grained with carb. fleks	between Bowfield and Warkworth seams	Vertical	4.24E-07
DDH1046	Saddlers Ck	343.6	sandstone - coarse grained	between Warkworth and Mt. Arthur seams	Horizontal	1.43E-06



0 2000 4000 Metres
Scale 1:80000

excludes routine airlift yield test sites

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHD - 10m interval)
- ▲ bore location (hydraulic conductivity)
- alluvial aquifer

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES
Bore locations for hydraulic conductivity tests

APPENDIX E: HYDROCHEMICAL DATA

Characterisation of groundwaters within the project area has been conducted by obtaining groundwater samples, routinely determining pH and EC, and submitting a number of samples for laboratory analyses of major ions, selected metals and rare elements. pH and EC results are provided in Appendix B for the project area including Mt Arthur Coal open cut and EL5460 located to the south. Borehole locations where major ion speciations have been conducted, are shown on Figure E1.

E1.1 Regional groundwater speciation

Data for major ions has been reviewed and summarized on the trilinear speciation plot also known as a Piper diagram – Figure E2. This plot comprises two triangular fields representing cations and anions, and a central diamond field. Samples are represented as percentage milli equivalents within the lower triangular fields where each apex represents 100% of the nominated ion. Plotted positions within the triangular fields are then projected into the central diamond field, thereby facilitating a generalised classing of groundwaters and examination of possible mixing trends.

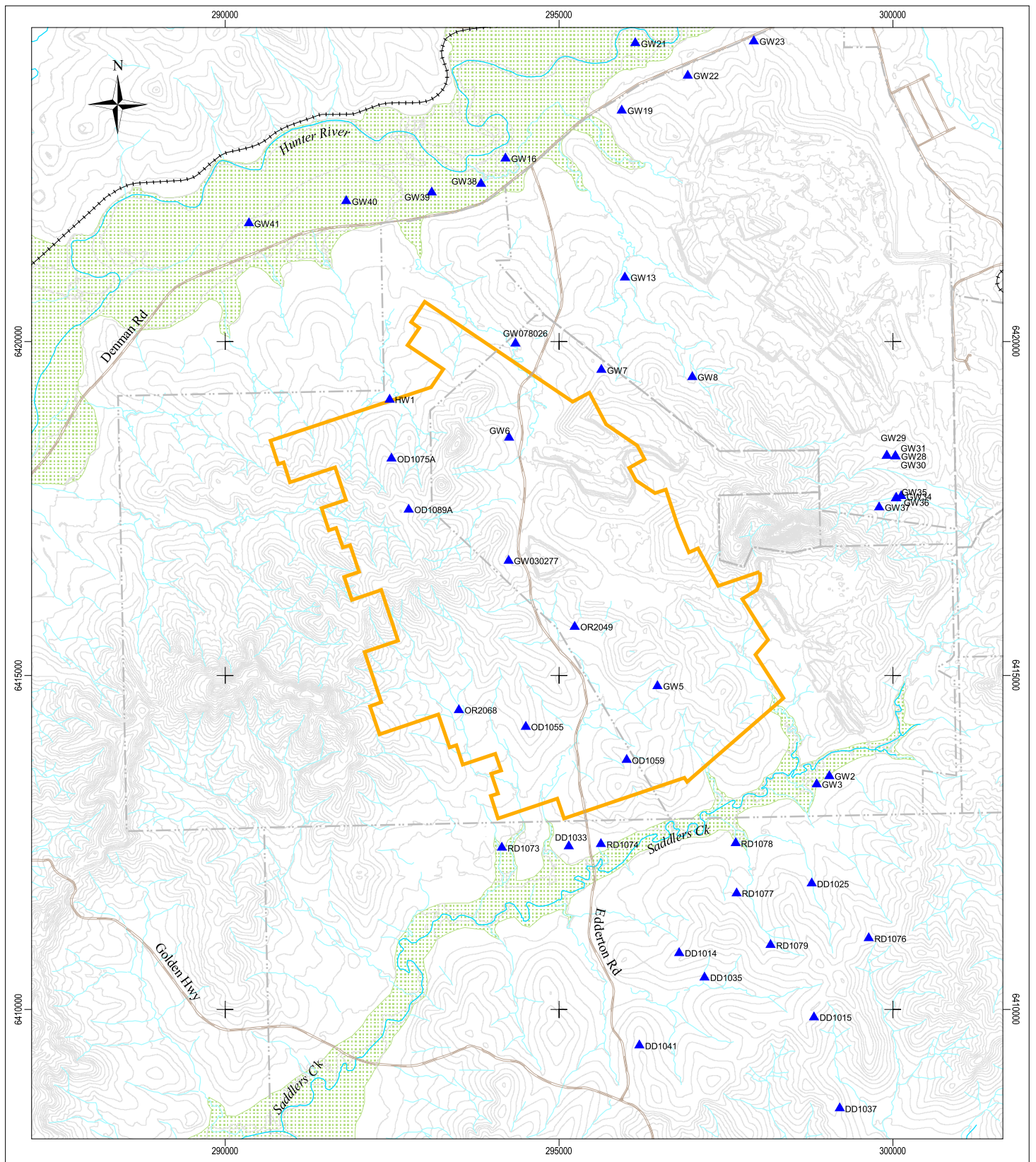
Reference to Figure E2 indicates a classing of waters where sodium chloride (primary salinity) dominates but a trend line prevails between sodium (Na) and magnesium (Mg) in the cationic lower left field. Sodium presence is attributed to halite dissolution and exchange processes relating to the ubiquitous presence of Na-smectite (tuffaceous sandstones). Magnesium contributions may be derived from the presence of dolomitic cements, and/or the frequent occurrence of igneous sills and dykes. Anions are mostly distributed between bicarbonate (HCO_3) and chloride (Cl). This distribution is quite typical of coal measures groundwaters throughout the Upper Hunter region.

Groundwaters from the Saddlers Creek investigation area tend to be more dominant in sodium than groundwaters from the Mt Arthur Coal area. This may be attributed to the predominance of samples from the Saddlers Creek area being mostly within the upper parts of the Wittingham Coal Measures (as are strata within the underground project area), while Mt Arthur Coal samples comprise upper middle and lower parts.

Figure E3 provides additional characterisation of the groundwaters using bivariate plotting to explore relationships. Figure E3a suggests many of the samples derive Na and Cl through dissolution of halite. These samples plot near the 45° line. However ion exchange plays a role as indicated on Figure E3b where numerous samples plot above the line defined by $\text{Na}/\text{Cl} = 1$. Figures E3c, E3d and E3e further support ion exchange as a mechanism. Figure E3f identifies samples that are not strongly influenced by ion exchange (plotting close to the centre of the plot - intersection of zero axes). Waters undergoing ion exchange plot along the line with a slope of -1 in the lower right quadrant.

Table E1: Speciation of major ions at monitoring bores and wells

Bore	pH	TDS mg/L	EC uS/cm	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L
GW2	7.4	2500	4350	6	14	950	5	1342	130	681
GW3	7.8	2400	4190	5	4	970	4	1464	130	588
GW5	6.8	2600	4710	73	140	720	15	1220	40	922
GW6	6.8	3500	6000	52	250	730	22	1586	1300	362
GW7	6.7	2900	5030	44	240	690	18	1220	150	975
GW8	6.6	650	1210	30	37	151	9	281	51	206
GW13	7.1	2700	4800	48	78	880	20	1061	270	922
GW16	6.9	3100	5200	214	210	600	28	537	450	1120
GW19	6.8	3800	6710	36	64	1280	18	1464	78	1436
GW21	6.8	690	1210	80	52	100	1	403	70	128
GW22	6.5	3400	6300	99	230	890	22	1342	180	1312
GW23	6.5	3200	5220	102	230	720	15	952	510	1010
GW25	6.8	4300	7100	172	218	1050	2	683	690	1560
GW27	6.7	5600	8500	412	328	900	37	793	2100	1010
GW28	6.9	2600	6000	115	228	680	20	1000	210	922
GW29	7.0	3500	5700	85	138	800	21	1171	350	1170
GW30	8.0	1900	3350	30	48	670	20	305	250	762
GW31	7.0	2500	4600	79	167	640	21	1086	170	886
GW34	6.6	1800	3200	93	126	385	10	830	150	546
GW35	6.5	1900	3400	123	162	335	11	769	230	574
GW36	6.8	3900	6400	147	260	800	23	1342	390	1205
GW37	6.7	2500	4400	90	155	600	22	1049	330	674
GW38A	8.2	2527	3660	105	118	579	3	1050	171	735
GW38P	8.6	1577	2600	17	22	543	8	645	29	513
GW39A	8.1	3453	5270	133	242	734	7	865	210	1539
GW39P	8.5	2568	4180	34	39	896	10	1218	11	855
GW40A	8.3	2714	4260	137	199	550	8	738	317	1197
GW41A	8.4	2455	3850	104	137	561	10	605	144	924
DD1014	7.3	2760	4720	24	17	944	6	720	19	1270
DD1015	6.8	3400	5590	90	181	1006	17	1330	139	1320
DD1025	7.3	500	826	17	12	151	5	293	4	150
DD1033	7.5	3860	6300	7	6	1532	6	1824	0	1360
DD1035-84m	8.2	3160	5880	28	92	1126	12	1232	97	1240
DD1037-172m	8.4	1840	3390	17	36	740	14	1074	67	520
DD1041-83m	8.0	3740	6050	30	103	1345	27	1617	269	1230
OD1055	7.2	2707	2980	33	58	505	10	697	67	633
OD1059	8.5	1846	2980	103	178	341	9	963	31	582
OD1075A	8.5	2300	3490	54	333	299	17	1060	117	667
OD1089	8.0	4131	5790	54	164	1200	33	2597	64	1060
OR2049	8.5	3061	4930	21	61	1062	13	1552	1	1026
OR2068	8.3	3182	5190	20	334	743	24	1736	134	1197
RD1073-207m	8.6	4200	7260	5	14	1740	10	2471	23	930
RD1074-242m	8.5	3760	7120	12	67	1350	18	799	162	1680
RD1076-399m	8.3	2280	3170	14	68	833	11	964	89	740
RD1077-339m	8.5	3000	5670	5	13	1213	12	1055	97	1060
RD1078-285m	8.4	3120	5730	12	32	1182	12	1147	100	1050
RD1079-393m	8.2	3600	6910	10	50	1339	19	1263	160	1300
HW1	8.4	2803	4380	43	234	662	22	1227	115	992
GW78026	8.5	2827	5080	1	61	997	63	1607	4	992
WMill2	8.4	2470	3730	22	158	649	19	1410	40	650

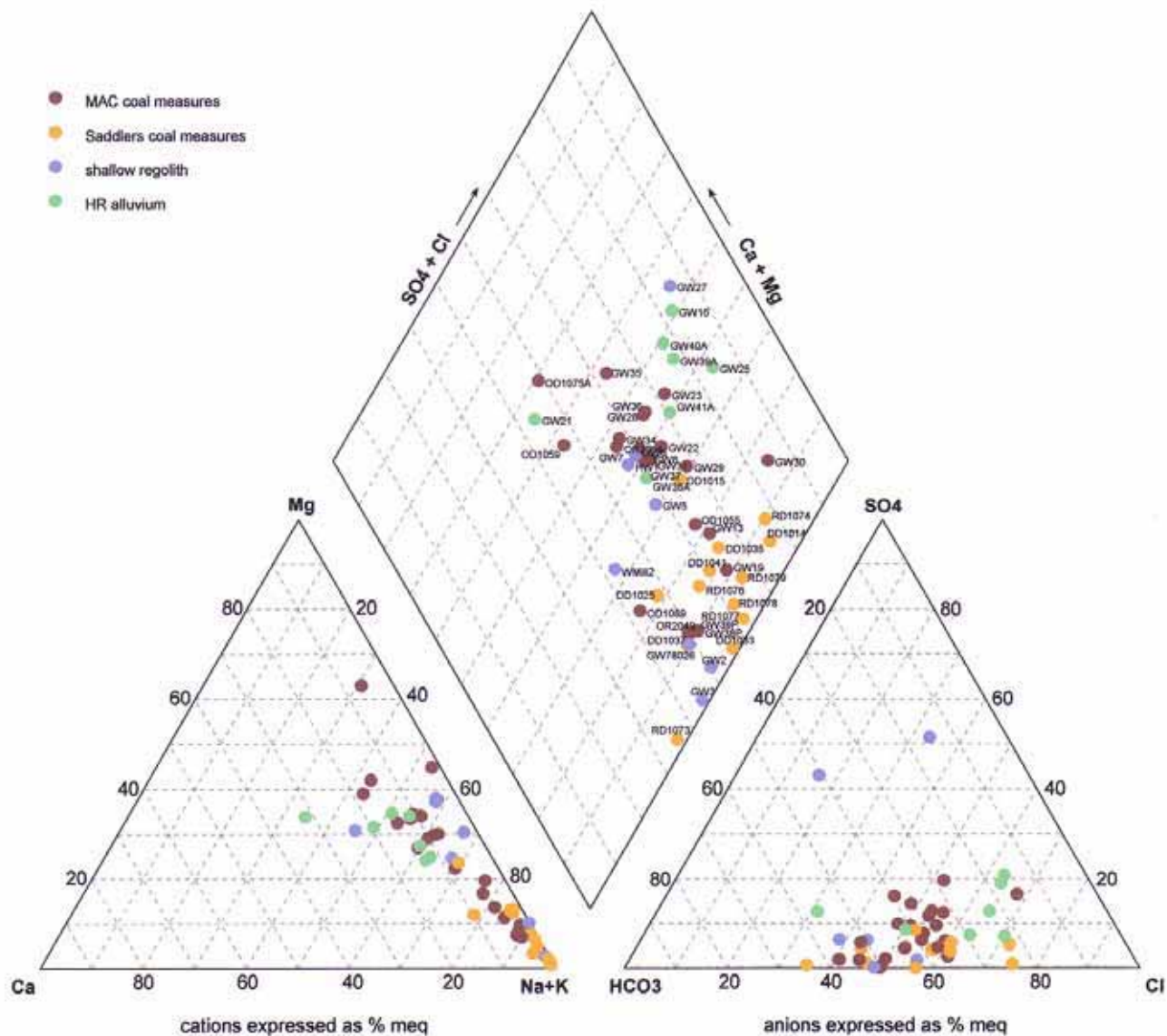


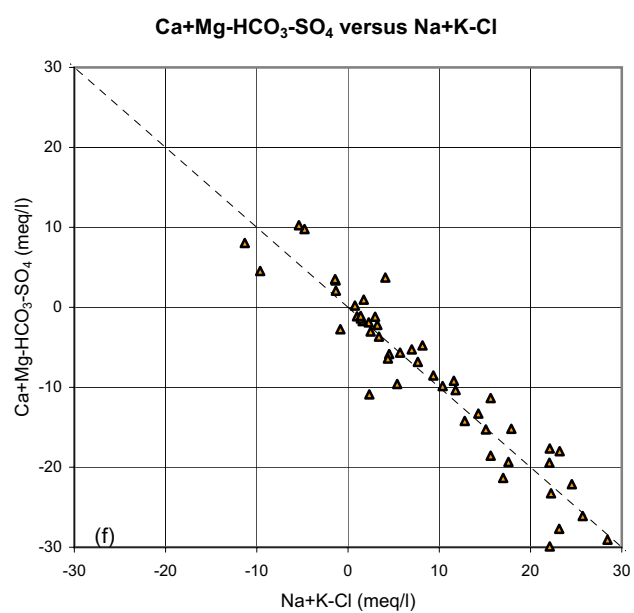
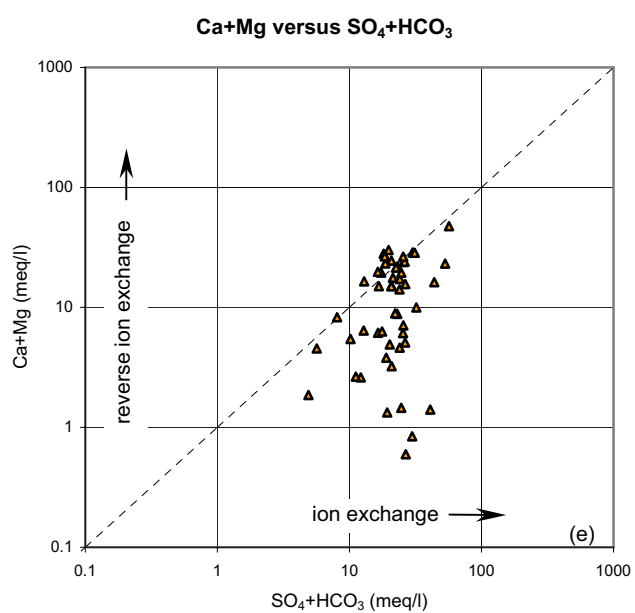
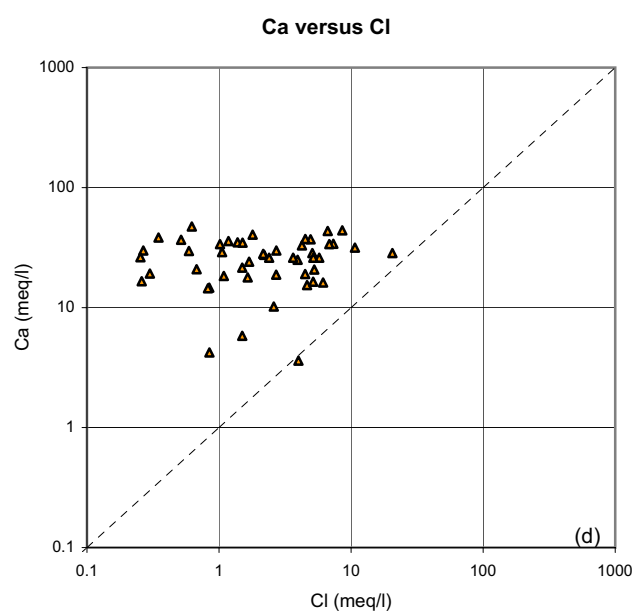
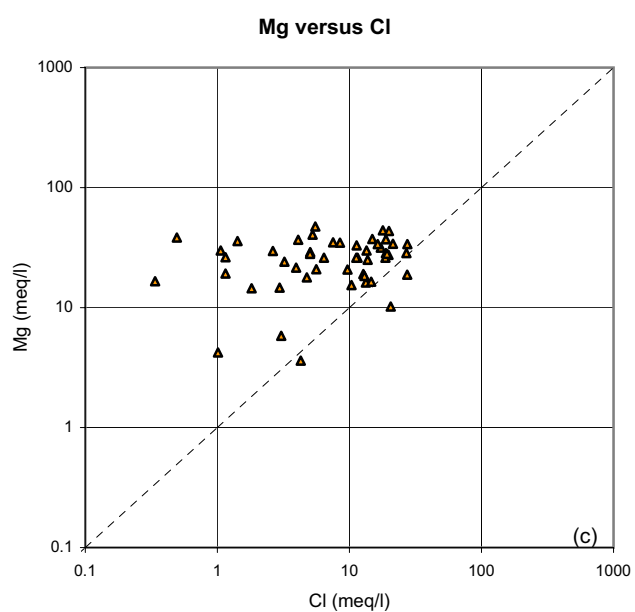
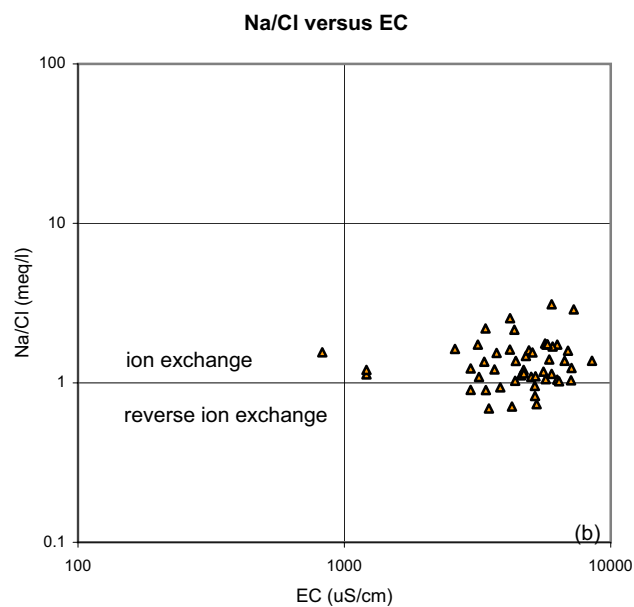
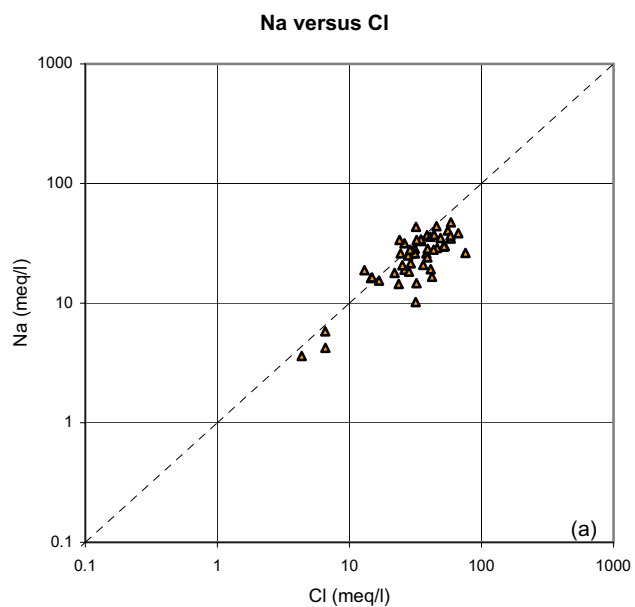
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Scale 1:80000

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHD - 10m interval)
- ▲ bore location (speciated water sample)
- alluvial aquifer

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Bore locations for groundwater speciation (major ions)





APPENDIX F: **AQUIFER NUMERICAL MODEL DESIGN**

The application of computer based numerical models to problem solving in groundwater engineering provides a powerful tool for the rationalization of spatially and temporally varying field conditions. The modelling process utilizes a system of mathematical equations for water flow through porous media subject to prescribed boundary conditions. The process requires simplification and definition of the aquifer system in respect of geometry, hydraulic properties and applied hydraulic stresses including rainfall, pumpage, river/creek leakage and underground seepage. However it is important to note that the simulation of deep open cut or underground mining operations is especially challenging for numerical models due to the prevalence of very steep hydraulic gradients above mine workings, and the potential for multiple horizons where zero pore pressures can prevail.

In the present study, a finite element approach (Feflow - WASY, 2002) has been utilized due to the large area of study, the variable topography and extensive drainage systems, the extent of the depressurisation halo that will evolve at depth during the course of multi seam extraction, and the highly non-linear nature of the problem.

The method requires division of the overall area of interest (the domain) into a large number of separate triangular prisms or elements. The number of elements defined in the model mesh has been determined by the mine panel geometry at depth, the spatial variations occurring in aquifer properties, the prevailing drainage system, and the expected hydraulic gradients developed in the course of model simulations. Competition between accuracy and computing efficiency affects the overall number of elements chosen and consequently the fineness of the element mesh has been varied from small elements within and around the longwall panels, to relatively large elements at distance from the mine panels.

The basic model is a variably saturated scheme and comprises 13 transversely anisotropic layers with 12863 triangular prism elements per layer. The overall model extents are indicated on Figure F1 which shows element geometry, alluvial areas and the regional drainage network. Total model area is about 400 sq. km. with elemental areas ranging from $5.0\text{e}+03 \text{ m}^2$ to more than $7.0\text{E}+05 \text{ m}^2$.

F1.1 Model geometry

Model layers adopt a simplified geometry consistent with the known stratigraphy. Layer 1 represents the topographically elevated regolith and weathered bedrock across the entire model domain. Layer 1 also includes the approximate distribution of alluvium adjacent to the Hunter River and Saddlers Creek. An average regolith zone thickness of 8 m is assumed throughout the region. Hence the base of the regolith (base of layer 1) has been calculated directly from the topographic digital terrain model (DTM). Hunter River alluvium retains an average maximum thickness of about 18 m while 12 m thickness has been adopted for Saddlers Creek alluvium. Both of these alluvial features have been pinched down to weathered zone thickness along their boundaries in a natural way. The base of these lithologies has then been calculated by subtraction from the regional DTM.

Remaining layers have been carefully defined from structure contour information interpolated regionally for the five seams of interest. Seam floor structure contours for the project area have been merged with available data from EL5460 (Saddlers Creek project) located to the south. Each of the resultant surfaces has then been extrapolated to the model perimeter.

The base of the model has been defined as 100 m lower than the Ramrod Creek seam floor and incorporating part of the relatively impermeable Maitland Group. Figure F2 provides perspectives showing layer geometry looking to the north-east and south-west from above.

F1.2 Model hydraulic properties

Hydraulic conductivities assigned to each model layer have been calculated by a rigorous process of assignment by lithology type followed by consolidation to hydraulically equivalent layers.

The methodology comprised calculation of the conductivity distribution at 6 exploration boreholes deemed as ‘type boreholes’ – OD1002, OD1005, OD1021, OD1030, OD1048 and OD1051. The locations of these boreholes are shown on Figure F3. Representative hydraulic conductivities based on laboratory core analyses (upscaled by a factor of 10 for joint related conductivity) together with injection packer testing of the target seams (Appendix D) were used in generating representative hydraulic conductivities for different lithologies given in the following Table F1. These conductivities were then used to develop full vertical profile sections for each borehole based on detailed logging of all core by MAU geologists with strata ranging in thickness from 10 mm to more than 2 m. Figure F4 shows typical transmissivity profiles (K_{xy} multiplied by the logged section thickness) for two boreholes OD1048 and OD1051. Each borehole profile was then reduced to hydraulically equivalent conductivities in both horizontal and vertical directions for the overburden above the Glen Munro seam, and for interburdens between target seams and interburden below the Piercefield seam. Mean layer conductivity values were then calculated using the six type holes assuming a log normal distribution. These values were assigned to individual layers within the model. Where present, silling within seams was also included.

Table F1: Adopted hydraulic conductivities for different lithologies

Description	K_{xyz} (m/day)
alluvium/colluvium	5.0E+00
basalt	1.0E-04
carbonaceous claystone	5.0E-06
clay	1.0E-04
clayey gravel	1.0E+00
claystone	5.0E-06
coal, bright	1.0E-01
coal, bright with minor dull bands	8.0E-02
coal, cindered	2.0E-02
coal, coked	1.0E-02
coal, dull	5.0E-03
coal, dull and bright	3.0E-02
coal, dull with minor bright bands	8.0E-03
coal, dull with numerous bright bands	1.0E-02
coal, fusainous	5.0E-03
coal, heat affected	4.0E-02
coal, stoney	1.0E-02
coal, weathered	1.0E-03
conglomerate	2.0E-04
dolerite	1.0E-04
gravel	4.0E+01
gravelly sand	1.0E+01
laminite	8.0E-06
mudstone	5.0E-06
pebble conglomerate	2.0E-04
sand	5.0E+00
sandstone	1.0E-04
sandstone, coarse grained	5.0E-04

Description	Kxyz (m/day)
sandstone, fine grained	5.0E-05
sandstone, medium grained	1.0E-04
sandy clay	1.0E-04
sedimentary rock	1.0E-06
shale	5.0E-06
silt	1.0E-02
siltstone	1.0E-05

It is noted that upscaling of measured core conductivities effectively assumes a linear relationship between intergranular conductivity and joint related conductivity. Such a relationship may be tenuous – lithologies may exhibit a higher upscaling in relatively thin strata via frequent jointing, while the same lithologies may exhibit a lower upscaling in a thick section due to infrequent jointing. There is no universal way of accounting for this ‘fracture randomness’ if present.

It is further noted that the process of consolidation to hydraulically equivalent layers does not account for the effect of increasing confining stress (with depth) which logically would tend to reduce conductivity. In the absence of specific and reliable criteria, uniform conditions are assumed throughout the depth section(s) – that is, conductivity has not been reduced with increasing depth. This may favour over estimation of the extent of pressure losses and groundwater seepage to mine workings.

Major faults have been included as discrete vertical planar elements connecting through relevant layers. Properties assigned to these fault features have been calculated from assumed average fracture spacings of 50 mm and apertures of 100 microns extending over a zone 50 m wide.

Table F2: Hydraulic properties assigned to the aquifer model

Layer	Lithology	Thickness (m)	Kx m/day	Ky m/day	Kz m/day	Ss 1/m	Sy
1	regolith	8	9.0E-02	9.0E-02	9.0E-02	1.0E-04	5.0E-02
1	alluvium	variable	5.0E+00	5.0E+00	5.0E+00	1.0E-04	2.0E-01
2	coal + interburden	variable	2.6E-04	2.6E-04	1.1E-05	5.0E-06	1.0E-04
3	Glen Munro seam	3	3.6E-02	3.6E-02	3.6E-03	1.0E-05	1.0E-03
4	interburden	variable	6.6E-04	6.6E-04	1.6E-05	5.0E-06	1.0E-04
5	Woodlands Hill seam	3	1.6E-02	1.6E-02	1.6E-03	1.0E-05	1.0E-03
6	interburden	variable	8.3E-04	8.3E-04	1.3E-05	5.0E-06	1.0E-04
7	Arrowfield seam	3	3.7E-02	3.7E-02	3.7E-03	1.0E-05	1.0E-03
8	interburden	variable	3.8E-04	3.8E-04	1.7E-05	5.0E-06	1.0E-04
9	Bowfield seam	3	1.6E-02	1.6E-02	1.6E-03	1.0E-05	1.0E-03
10	coal + interburden	variable	1.5E-03	1.5E-03	1.5E-05	5.0E-06	1.0E-04
11	Piercefield seam	3	1.6E-02	1.6E-02	1.6E-03	1.0E-05	1.0E-03
12	coal + interburden to RCK	variable	8.6E-04	8.6E-04	1.3E-05	5.0E-06	1.0E-04
13	Maitland Group +	100	1.0E-05	1.0E-05	1.0E-06	1.0E-05	1.0E-04
>>	dolerite sill-dyke	3	5.0E-05	5.0E-05	5.0E-05	1.0E-06	1.0E-04
>>	subsidence cracking	variable	-	-	variable	-	-
>>	faulting	-	1.0E-01	1.0E-01	1.0E-01	1.0E-05	5.0E-02

Kxy = horiz. conductivity, Kz = vert. conductivity, Ss = specific storage, Sy = drainable porosity

Compressibility and subsequent estimates of specific storage (S_s) for interburden have been calculated from laboratory measurements of Young's Modulus (SCT, 2006a). Estimates of S_s range from $1.0\text{E-}05$ to $3.2\text{E-}06$ for a modulus range from 1 to 30 GPa. Interburden strata have been assigned a uniform S_s of $5.0\text{E-}06$ assuming relatively constant compressibility of the strata. Drainable porosities as S_y range from 0.01% to 5%. Model layer properties are summarised in Table F2.

F1.3 Model boundary conditions

Boundary conditions assigned to an aquifer model are those conditions that constrain or bound the model domain mathematically. Such conditions have been applied to the physical outer boundary of the model and throughout internal parts of the model. They include constant groundwater levels (1st type condition) along the Hunter River and Sandy Creek, and drain nodes (constrained 1st type) along ephemeral creeks and in longwall panel areas and open cut pits. Utilisation of 1st type constant groundwater levels along the Hunter River enforces seepage from surrounding areas of elevated water table to the river, or seepage from the river to surrounding strata via the alluvial materials if the piezometric elevations in that strata are lower than river levels.

Distributed elemental flux conditions have been employed to represent regional rainfall recharge. This recharge has been applied at a constant rate of less than 2 mm/annum over hardrock areas. The rate has been determined from a number of steady state simulation trials where recharge was progressively increased until model water levels broadly matched the regional piezometric surface. Since the model is fundamentally a forward model based on rigorous estimation of prevailing hydraulic conductivities, and since those conductivities are extremely low, the actual rainfall recharge is relatively insensitive in respect of the simulated depressurisation process. It basically generates a water store within the regolith but has little impact on seepage to deeper strata or to longwall panels within the timeframe of mining.

Recharge at a rate of 90 mm/annum has been applied over alluvial lands where sandy soils and sands tend to facilitate rapid infiltration during sustained rainfall periods. Infiltration could vary over short distances but the use of an average figure provides a simplification and is considered adequate for planning purposes. Because the rate for the alluvium is much higher than for hardrock areas, it is also a relatively insensitive boundary condition in respect of deeper hardrock depressurisation.

As noted, drain nodes have been assigned along identified creeks and set 5 m below the digital terrain model (topographic) elevation to constrain rising water tables. This depth arbitrarily accounts for error in the terrain model. Drain nodes have also been assigned to underground longwall panels 0.5 m above floor elevations in each seam. All finite elements at the different seam levels have been carefully programmed to apply timewise depressurisation in accordance with planned panel extraction. Drain nodes have been similarly assigned to the floor of open cut operations at Mt Arthur Coal in accordance with EIS modelling for the open cut pit (MER, 2000). Smaller open cuts (McDonalds, Belmont and Saddlers pits) have not been included as they were considered to have penetrated the water table to relatively shallow depths, or their impacts on the piezometric surface would be generally consumed in the pressure losses that evolve from the proposed underground operations.

Groundwater extraction from the alluvium by local landholders for domestic, stock and irrigation purposes, has not been included. Since the alluvial lands are in a sense isolated from the coal measures by much more significant recharge to a relatively high hydraulic conductivity alluvial regime, absence of pumpage in the model is unlikely to affect model outcomes in terms of seepage attraction by the deep longwall panels. Assessment of impact on the alluvial aquifers has however been undertaken through evaluation of model predicted leakage from the alluvium to underlying depressurised hardrock strata.

F1.4 Model calibration

It is not possible to calibrate the aquifer model to a high level of accuracy without a significant stress in the system. That is, without physically depressurising the strata and recording loss of pressure, it is not possible to compare and verify model estimates of depressurisation. Accuracy in model representation is therefore dependent upon the assignment of formation hydraulic properties as determined by packer and core tests, and upon the steady state or initial piezometric surface.

Approximate calibration has been conducted by adjusting rainfall recharge to the system and comparing the resulting head distribution to monitored piezometric levels in the area and levels that prevailed before any mining commenced (pre MAN open cut). Figure F5 provides a plot of the model generated piezometric surface for the shallow regolith/rock zone which can be compared with the regionally interpolated composite surface provided as Figure 6 within the main text. While there are many areas where differences of 10 or more metres occur between the two surfaces, the comparison is considered to be broadly acceptable especially since any significant change in rainfall recharge is noted to take more than 10 years (from model sensitivity simulations) to equilibrate through deeper parts of the system. This long period of equilibration is directly attributed to the very low hydraulic conductivities throughout the region.

Figure F6 provides a correlation plot for piezometers within and around the project area. Measured data (ordinate axis) reflects the influence of the relatively shallow depths assigned to boundary conditions along the multitude of surface drainages where the drainage control (eg. root zone) has been set uniformly at 5 m below ground level. This contributes to numerous points plotting above the 45° correlation trend line suggesting that the predicted steady state water table (for long term average conditions) is higher than the currently measured water table which is influenced by the prevailing drought conditions over the last 5 years.

Figure F7 illustrates groundwater flow paths within the shallow coal measures generated using particle tracking. Pathways support flow from elevated areas of regolith and coal measures, towards the major drainages as expected.

F1.5 Sensitivity analysis

Limited sensitivity analyses have been conducted. These have been restricted to simulations of development of the Woodlands Hill seam since full model simulations require approximately 3 weeks run time. The purpose of sensitivity analyses has been simply to identify those parameters that have a significant effect on model outcomes. Findings indicate:

- model depressurisation (regional impacts extent) is more sensitive to hydraulic conductivity than any other parameter. The second ranked parameter is compressible storage (Ss). These sensitivities are consistent with expectation;
- model depressurisation vertically through strata exhibits highest sensitivity to the transient vertical conductance above extracted panels;
- Rainfall recharge is relatively insensitive to layers beneath the regolith. The regolith zone (layer 1) incorporates the rainfall driven circuits that provide the water store for recharging deeper strata. Reducing or increasing the rainfall, does not significantly affect depressurisation of deeper strata within the mining time frame.

F1.6 Simulation of mining

Simulation of the proposed mine plan has been conducted with the inclusion of Mt Arthur North open cut operations for cumulative assessment purposes. Model simulations commence in January 2002 and progress to January 2007 for open cut operations alone. Underground development in the Woodlands Hill seam including the proposed exploration adit on the southern side of panel WH LW102 (Figure C2, Appendix C), has been programmed to commence at this time. Thus 5 years of

open cut mining are simulated before any underground mining simulations commence. Development of gate roads adjacent to longwall panels WH LW101 and WH LW102 follow the exploration adit and are completed in the Woodlands Hill seam by July 2009 (model year = 7.5).

Modelling has then proceeded by assigning incremental panel extraction to the Woodlands Hill seam according to the planned extraction schedule. This extraction has been followed by the proposed extraction in the shallower Glen Munro and the deeper Arrowfield, Bowfield and Piercefield seams as shown by panel layouts on Figure F8.

The hydraulic conductivity of subsided interburden has been modified during the simulation process. This procedure has required simplification of predictions of cumulative strains, displacements and rock mass hydraulic conductivities (SCT, 2006) into a zone extending above each seam where interburden vertical conductivity overlying extracted panels has been increased by 1 to 2 orders of magnitude (10 to 100 times). This zone effectively connects coal seams or connects the shallowest seams to the regolith. Preliminary trials indicated the resulting depressurisation halo and seepage to the extracted panels, was similar over the range of conductivities tested, with relatively free drainage of strata to goaf. Subsidence zone hydraulic conductivity changes have been applied in the aquifer simulation model in accordance with the progressive extraction of panels over the mining period of 21 years.

The effects of displacement of the water table in subsided areas have not been simulated since gross changes in aquifer geometry cannot easily be accommodated within the Feflow code. These displacements are predicted to be between 0 and 6 m (MSEC, 2007) and would be mostly absorbed by the more significant losses attributed to formation depressurisation within and adjacent to the subsidence zone.

F1.7 Strata depressurisation

Figure F9 illustrates the initial groundwater piezometric surfaces generated by the model prior to commencement of any mining operations in the area. These surfaces vary from layer to layer as a result of the complex flow and pressure distributions established by recharge from the regolith zone (layer 1) downwards. The shallowest layer (1) is a subdued reflection of topography with piezometric highs occurring in areas associated with the topographic highs of Mt. Arthur and Mt. Ogilvie. Piezometric lows are situated beneath the Hunter River and beneath Saddlers Creek as expected. Deeper surfaces associated with the target coal seams are progressively more subdued reflections of topography with slightly lower piezometric surfaces at increasing depth. The reduction in piezometric elevations with depth reflects the 'top down' recharge mechanism.

Figure F10 illustrates the drawdown surfaces generated by the model following completion of panel extraction in the Woodlands Hill seam in mining year 8 (Woodlands Hill seam panels are shown on all plots for reference). Drawdowns have been calculated by subtraction of the piezometric surfaces from pre-mining surfaces shown on Figure F9.

Reference to these plots shows a steep sided depressurisation about the open cut operations (included by summation) in the north-east, and relatively steep depressurisation surrounding the extracted panels in the Woodlands Hill seam. Significant depressurisation is also observed in the overlying Glen Munro seam where head losses are attributed to rapid drainage within the subsidence zone. Some depressurisation associated with development in the Glen Munro seam is observed to the north of the main zone over the extracted panels. Depressurisation also extends downwards to the Bowfield seam with weak losses observed in the deeper Piercefield seam. Very localised and limited drawdown is observed in the regolith due to the higher (unconfined) storage properties and the sustained but low rate of rainfall recharge to this zone.

Figure F11 shows the drawdown surfaces generated by the model following completion of panel extraction in the Glen Munro seam in mining year 11 (Glen Munro seam panels are shown on all plots for reference). Reference to these plots shows convergence of depressurisation around these panels with head losses induced by prior extraction in the Woodlands Hill seam. Head losses also extend downwards to the Bowfield seam and upwards to the regolith zone. It is noted however that

regolith zone losses may be over stated due to the design of the aquifer model which incorporates a single layer representing coal measures between the regolith and the Glen Munro seam. This single layer which is of the order of 60 m to more than 200 m thick above the panels, has been assigned an enhanced vertical hydraulic conductivity within the subsidence zone over the entire thickness. In reality, the assigned conductivity may only prevail over thicknesses of 40 m to 100 m or so. Losses in the Piercefield seam attributed to earlier extraction of the Woodlands Hill seam panels, continue to expand.

Figure F12 illustrates the drawdown surfaces generated by the model following completion of panel extraction in the Arrowfield seam in mining year 14. Reference to these plots shows sustained depressurisation of the regolith resulting from prior Glen Munro seam extraction. Clearly defined depressurisation in the Arrowfield seam is conveyed both upwards to the Woodlands Hill seam, and downwards to the Bowfield and (weakly) to the Piercefield seams. Drawdown is also observed to preferentially migrate within the monocline zone in a south-westerly direction. This occurs as a result of the higher conductivity assigned within this zone.

Figure F13 illustrates the drawdown surfaces generated by the model following completion of panel extraction in the Bowfield seam in mining year 16. Reference to these plots shows general convergence of the depressurisation surface with a steep sided surface evolving about the Bowfield seam panels. Drawdown is also maintained within the monocline zone.

Figure F14 shows the drawdown surfaces generated by the model following completion of panel extraction in the Piercefield seam at the end of mining in year 21. Reference to these plots shows continuing convergence of the depressurisation surface in seams above the Piercefield, with a steep sided surface developed about the Piercefield seam panels. The maximum drawdown impact at this time occurs in the Arrowfield and Piercefield seams where depressurisation in these deeper seams extends northwards close to the boundary of the alluvial lands and southwards beneath Saddlers Creek. Drawdown in an easterly direction extends to subcrop or converges with drawdown induced by open cut operations while in a westerly direction it extends 2 to 3 km beyond the overall panel footprint. Drawdown in the regolith is confined mostly to an area centred over the Glen Munro extracted panels.

F1.8 Groundwater seepage to mining operations

On completion of simulations, the model flux balances have been reviewed and specific zone budgets extracted to provide mine water influx estimates. Results are provided on Figure F15 as separate estimates of mine water seepage for each seam and totalised seepage over the mine life based on summation of individual seams. Reference to Figure F15 indicates greatest influx occurs to the Glen Munro and Piercefield seams. These may be over estimates that can be attributed to simplified model design where the thickness of failed overburden exhibiting enhanced vertical conductance, is greater than will actually occur.

These results also include a nominal provision for short term nuisance seepage of 0.5 ML/day added to the total seepage estimate. This seepage component may derive from localised storage intercepted in discrete fracture/fault zones or sills displaying increased conductivity, or from rainfall infiltration through subsided strata during sustained wet periods. This influx would be short term of the order of days to weeks and would be expected to subside when localised storage or rainfall infiltration is depleted.

F1.9 Groundwater seepage to or from alluvial lands

It is noted from simulation results and the various drawdown plots presented as Figures F10 through F14, that depressurisation does not extend northward beneath the Hunter River alluvial lands and hence these areas are not impacted. Depressurisation does however extend southward beneath Saddlers Creek (alluvium) and the vertical flux regime will therefore be affected to some extent in that area. Considering the alluvial deposits within Saddlers Creek that overly a depressurised area

of about 3.5 sq.km., model results predict an upward flux of about 0.34 ML/day or about 0.1 L/day/sq.m. of surface area for pre-mining conditions. That is, groundwater seeps vertically from the underlying coal measures to the alluvium at this rate for the assigned model boundary conditions. Seepage fluxes determined at the cessation of mining indicate the net upward flux would reduce to 0.26 ML/day – a loss of 0.08 ML/day in upward seepage over the 3.5 sq.km. There is no apparent reversal to downward leakage from the alluvium to the coal measures.

However there is a theoretical loss within Saddlers Creek catchment which is related to the manner in which drainage lines are simulated within the groundwater model. The pre mining piezometric surface is generated by continuous rainfall recharging the modelled rock strata. Where the strata are transgressed by a creek line, model nodes are assigned an elevation that acts to constrain the piezometric surface to that elevation (Section F1.3) – nodes are activated and remove groundwater from the model only if the water table exceeds the assigned elevation thereby crudely simulating runoff. In reality, rainfall and runoff are infrequent. The steady state pre mining model indicates a net continuous removal of water of the order of 1 ML/day from creeks connected to the alluvium reach discussed above and indicated on Figure F7. During the course of mining, the rate of removal is predicted to decline to about 0.1 ML/day as a result of falling groundwater levels at higher elevations within the mine footprint. This could be viewed as a reduction in base flow runoff to the considered reach of Saddlers Creek. However, the model does not address hydraulics relating to creek bank storage or base flow regime in detail due to scaling issues. Accordingly, the estimated loss of 0.9ML/day should be viewed with some caution – actual loss may be negligible.

F1.10 Recovery of aquifer pressures post mining

On cessation of mining, the groundwater system will re-pressurise through natural seepage from storage and from rainfall recharge.

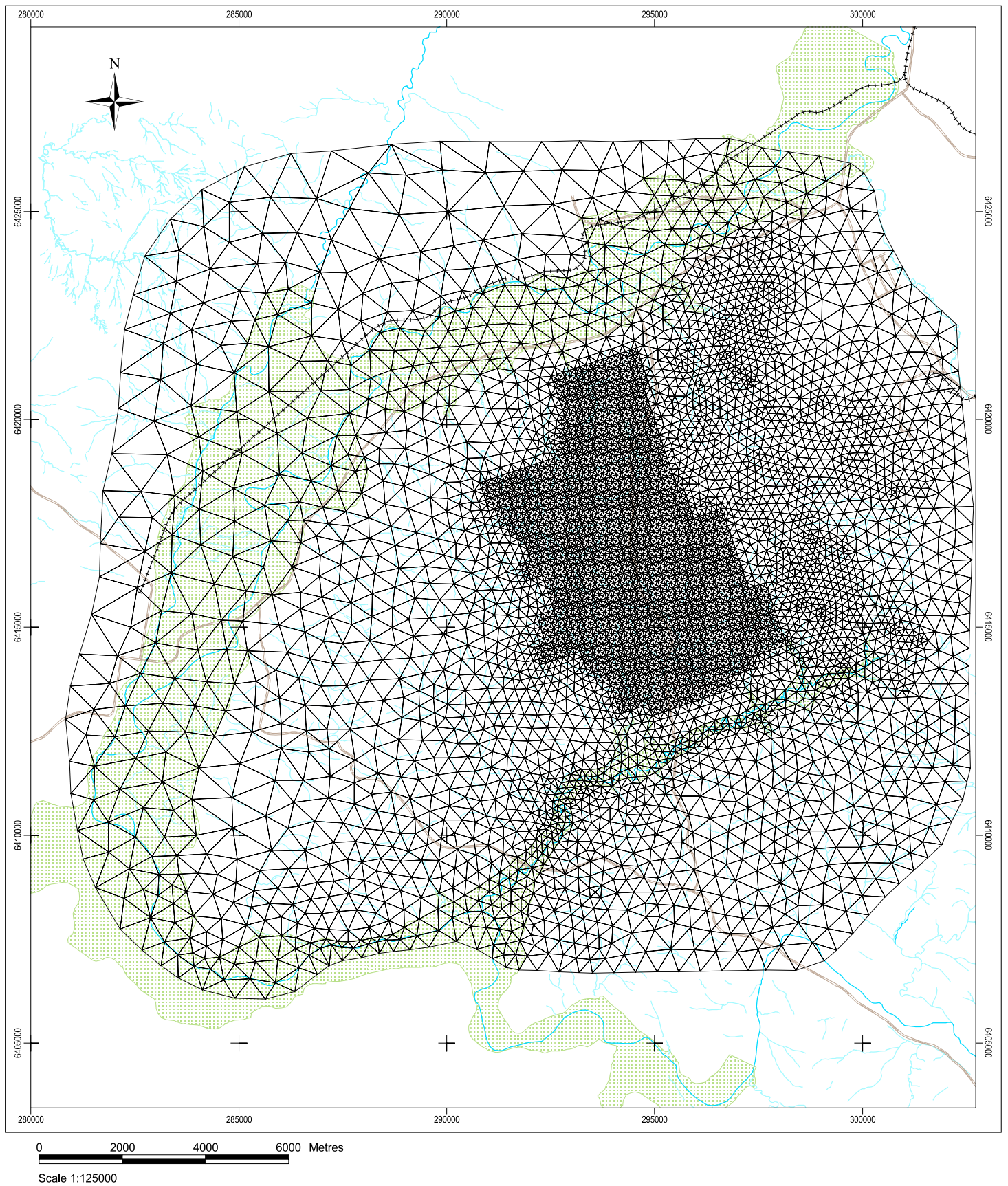
An estimate of the rate of recovery of formation pressures has been made by assigning piezometric surfaces generated by the aquifer model at the completion of mining, as initial conditions for simulation of the recovery process. The open cut operations are also assumed to cease at this time.

Recovery was simulated for a period of 100 years with pressure distributions being calculated at 10, 20, 50, and 100 years post mining. Modelling predicts the system could substantially rebound within 50 years assuming average climatic conditions.

F1.11 Modification to Woodlands Hill panel layout

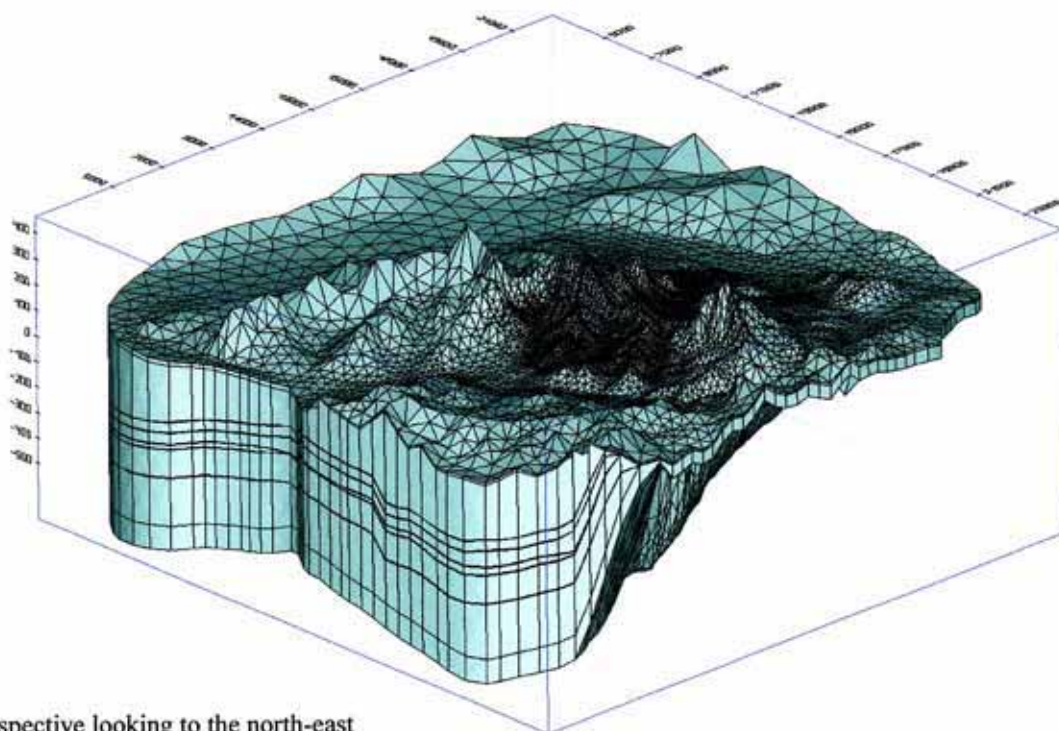
A modification to the mine panel layout is proposed in order to accommodate existing surface infrastructure in the area. This modification includes rotation of all proposed panels in a counter clockwise direction by about 1 degree and adjustment of panel lengths while retaining panels within the overall footprint. Most panels have been shortened in their westward extent and some have been lengthened in their eastward extent as indicated on Figure F16.

The modified panel layout has not been simulated by numerical aquifer modelling since the changes are considered sufficiently minor as to have very limited impact on depressurisation. Rotation would have negligible impact while shortening of panels (westward) would reduce the depressurisation footprint. Eastward extension of panels would have negligible impact since this area will be depressurised by the cumulative impacts of development headings and open cut pits. In addition, subsequent extraction of the deeper Piercefield seam would assimilate the depressurisation envelope by the end of mining.

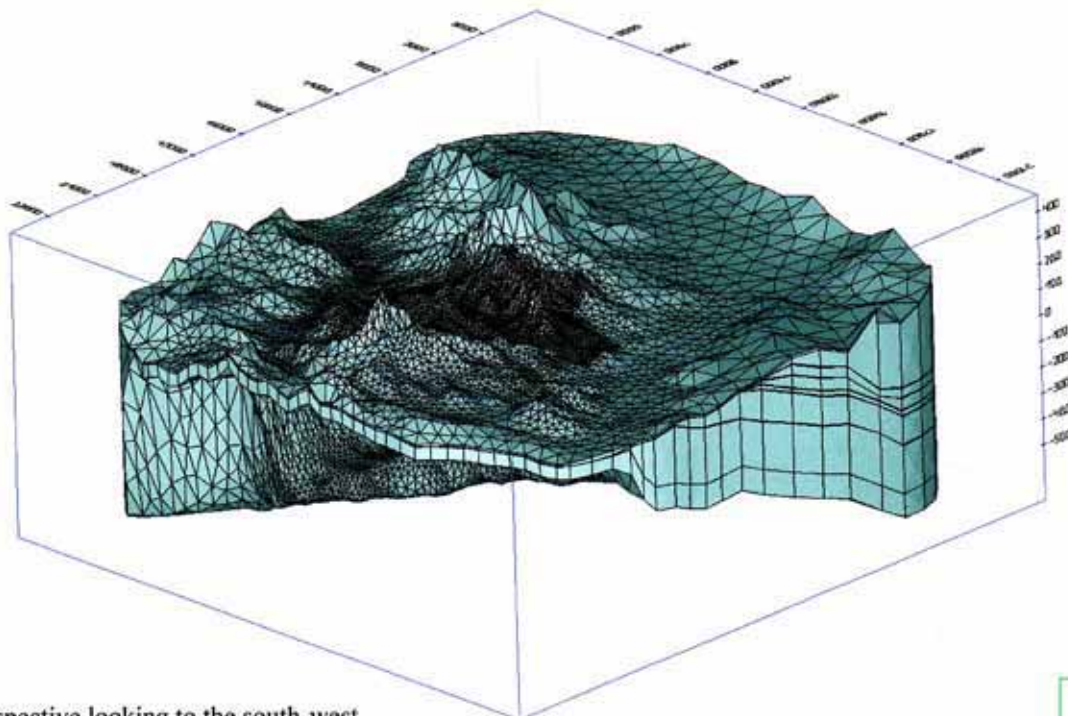
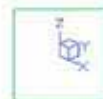


MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

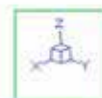
Groundwater model - finite element mesh



Perspective looking to the north-east

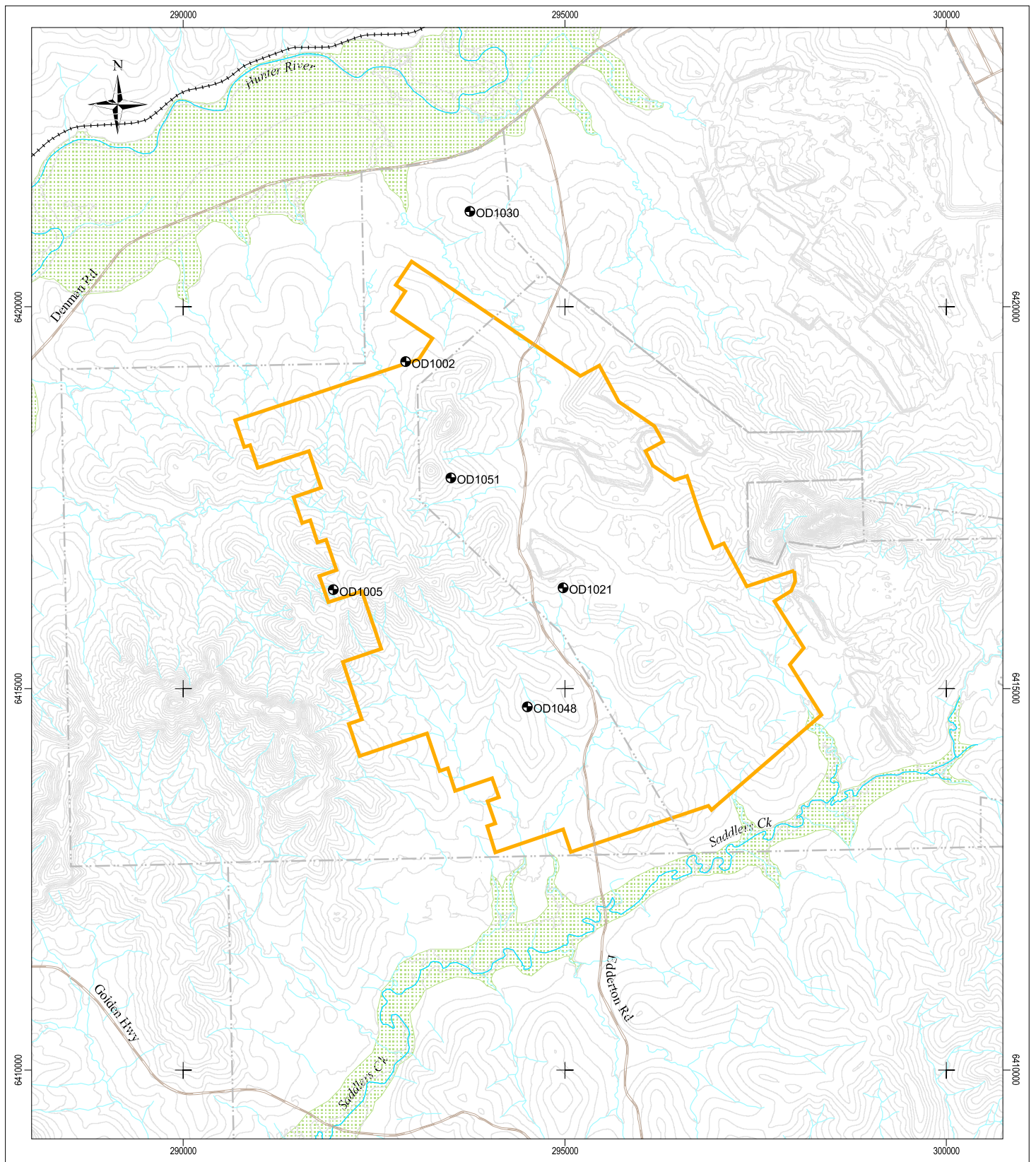


Perspective looking to the south-west



MT ARTHUR COAL UNDERGROUND PROJECT – GROUNDWATER STUDIES

Groundwater model - perspectives



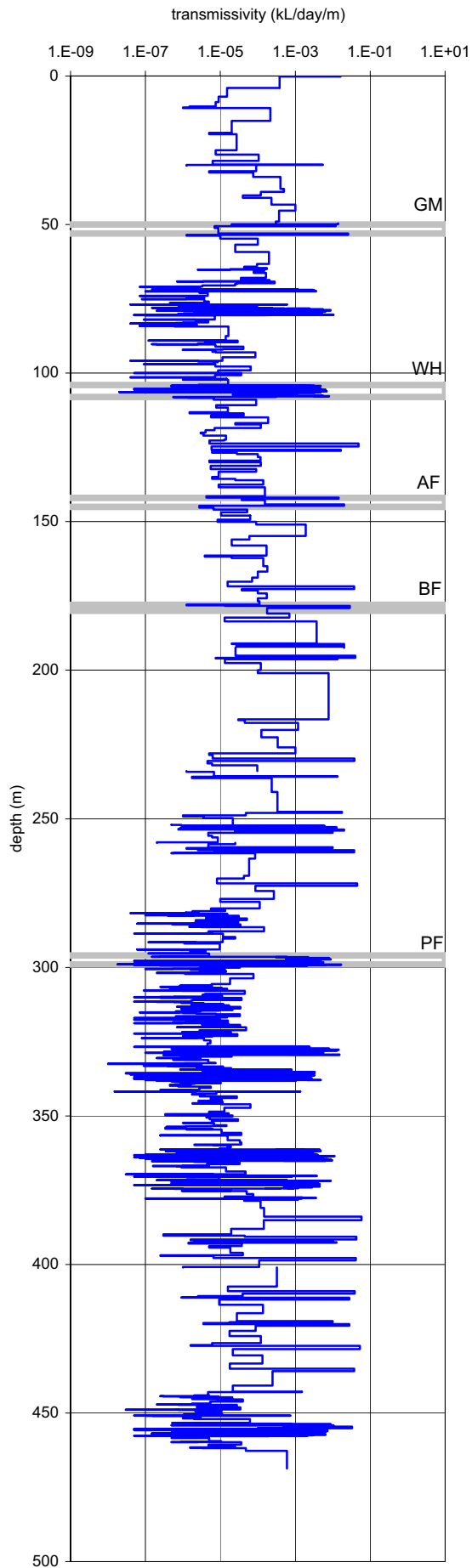
0 2000 4000 6000 Metres
Scale 1:70000

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHD - 10m interval)
- type bore location (hydraulic properties)
- alluvial aquifer

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

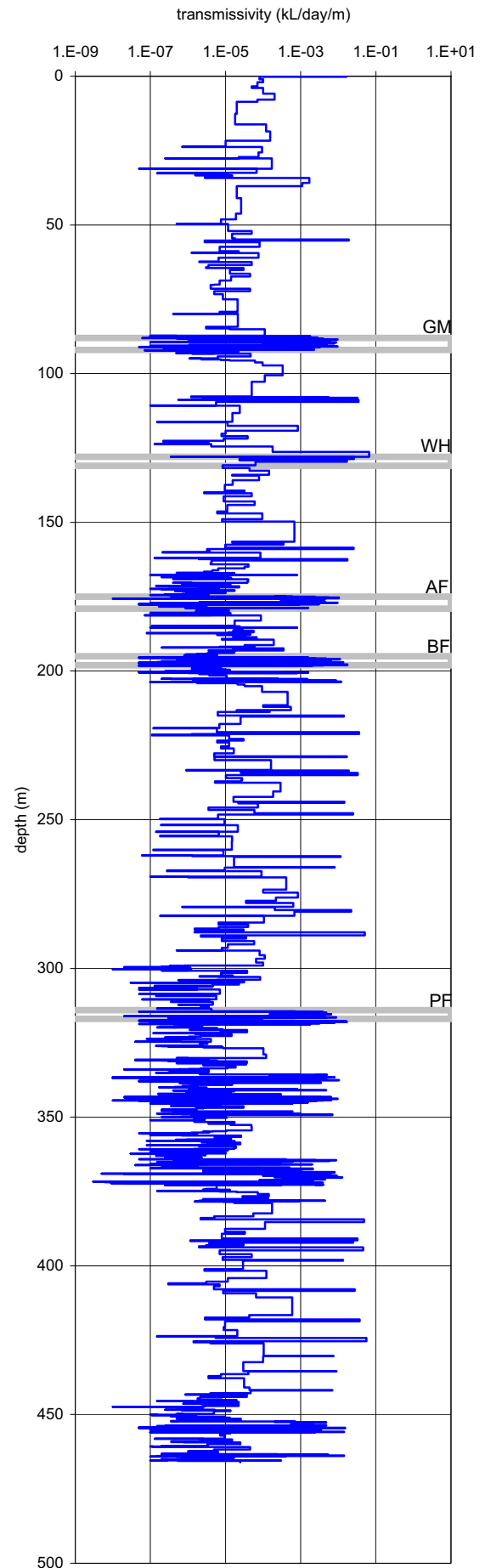
Type bore locations for model hydraulic properties

OD1048 Transmissivity (Kxy*d)



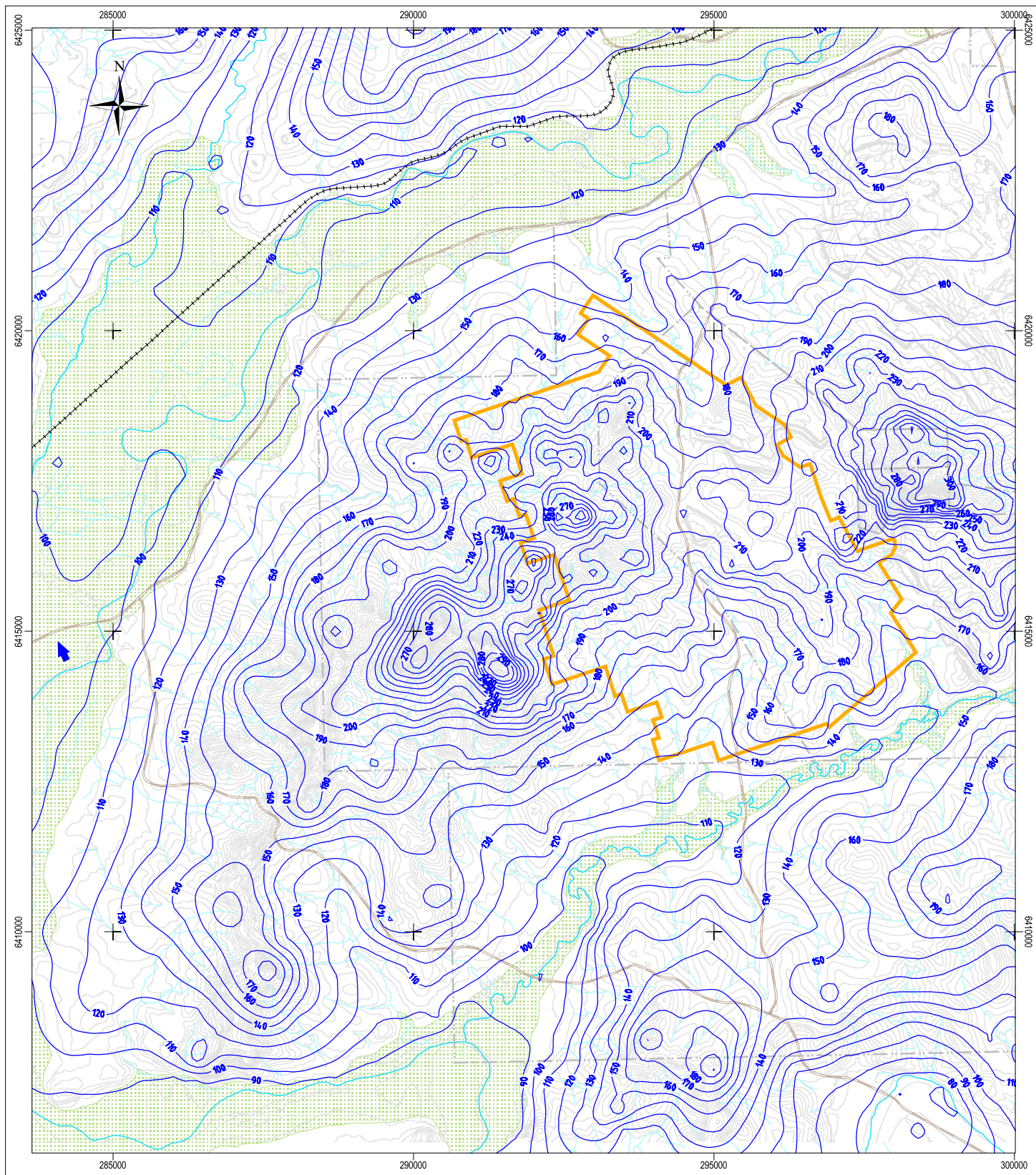
seam working sections shown

OD1051 Transmissivity (Kxy*d)



Typical vertical profiles of transmissivity

Figure F4



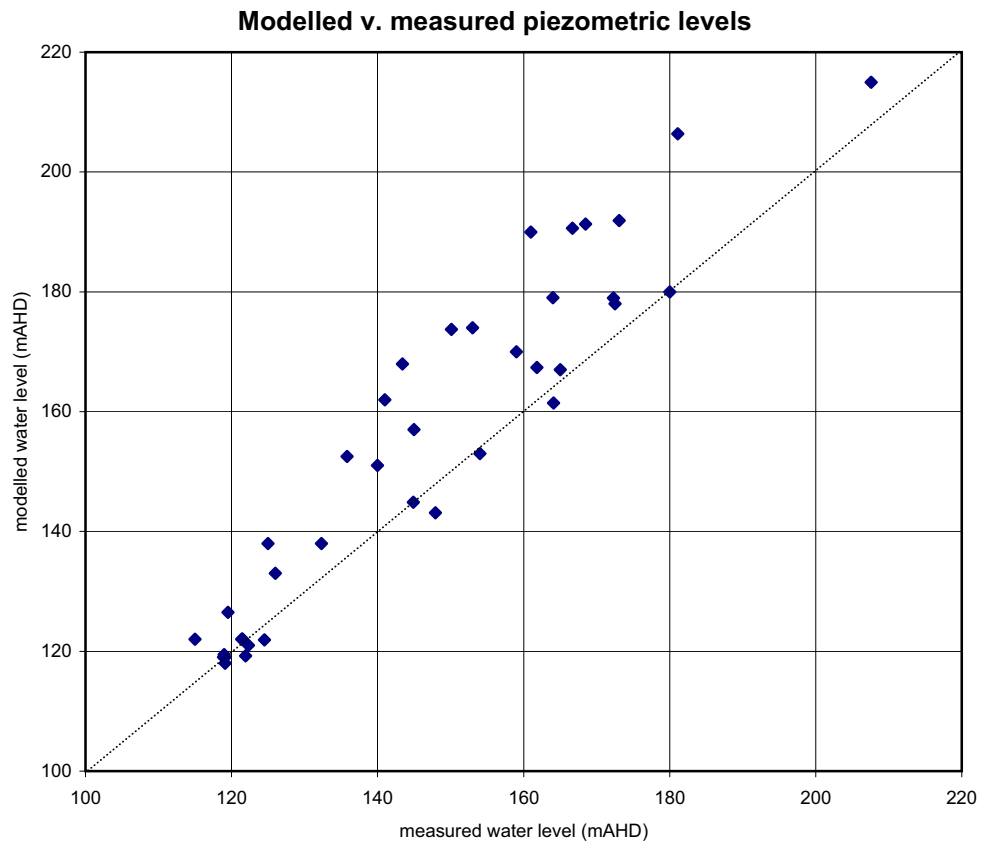
Layer 1 regolith (node slice 2)

Scale 1:90000

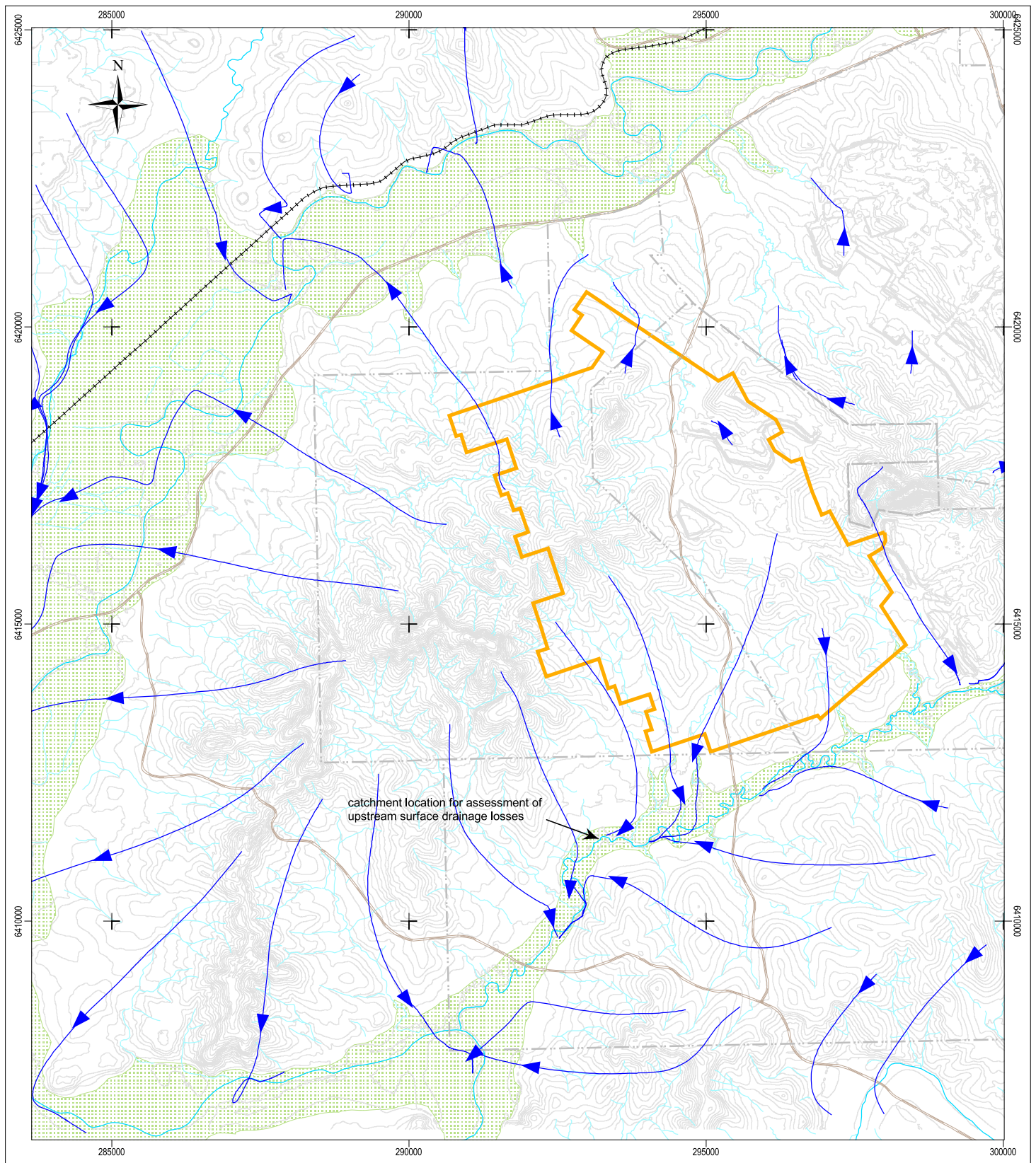
- -- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHd - 10m interval)
- piezometric elevation (mAHd)
- alluvial aquifer

MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Model generated pre mining piezometric surface



Points plotting above the 45° line are influenced by the depth assigned to the water table beneath the multitude of local drainages in elevated areas (as a model boundary condition). This depth has been set to 5 metres below ground level.



0 1000 2000 3000 4000 Metres

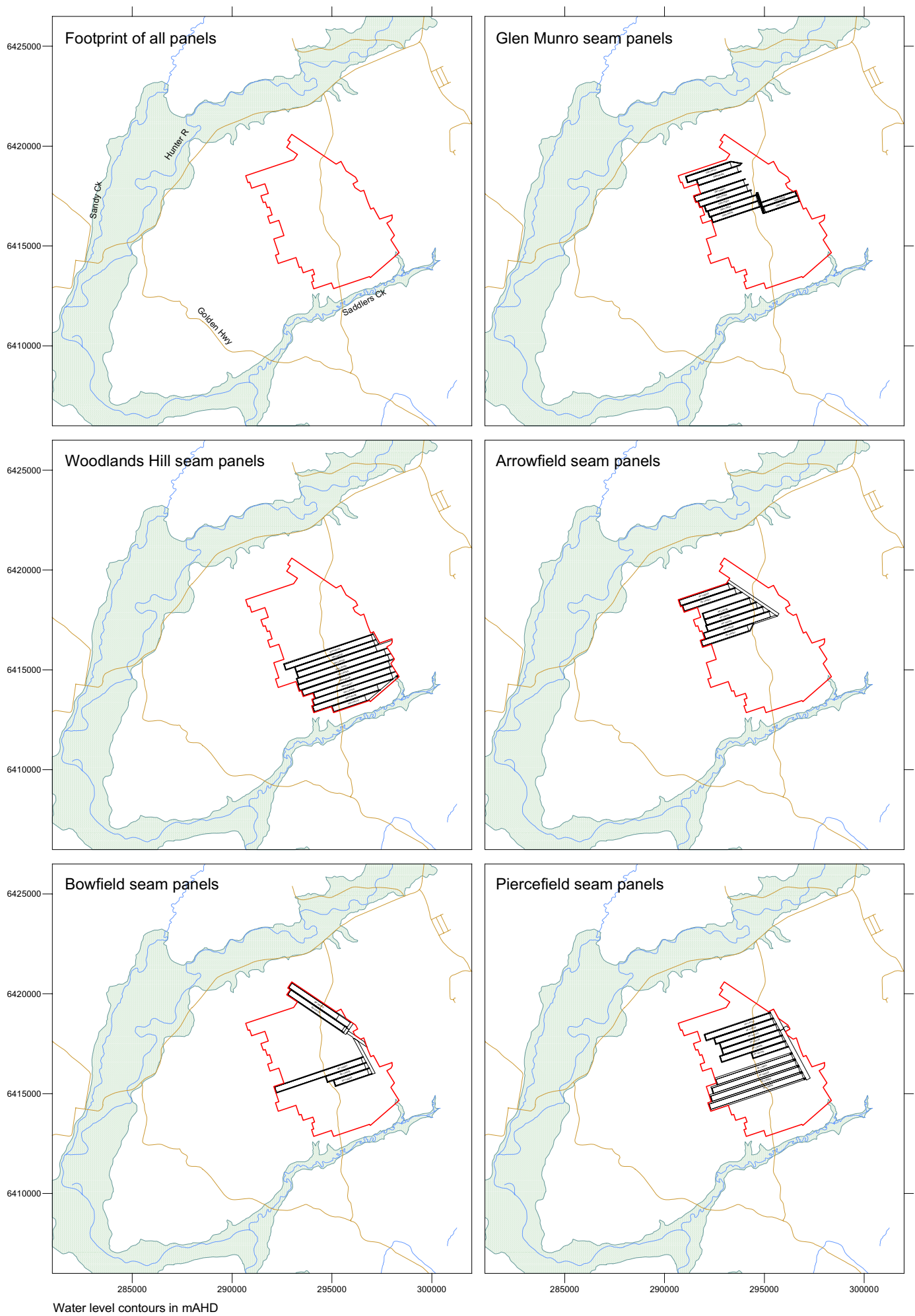
Scale 1:90000

Layer 2 coal measures

- lease boundary
- ++++ railway
- main road
- drainage
- mine panel footprint
- topographic contours (mAHM - 10m interval)
- ▶ particle track
- alluvial aquifer

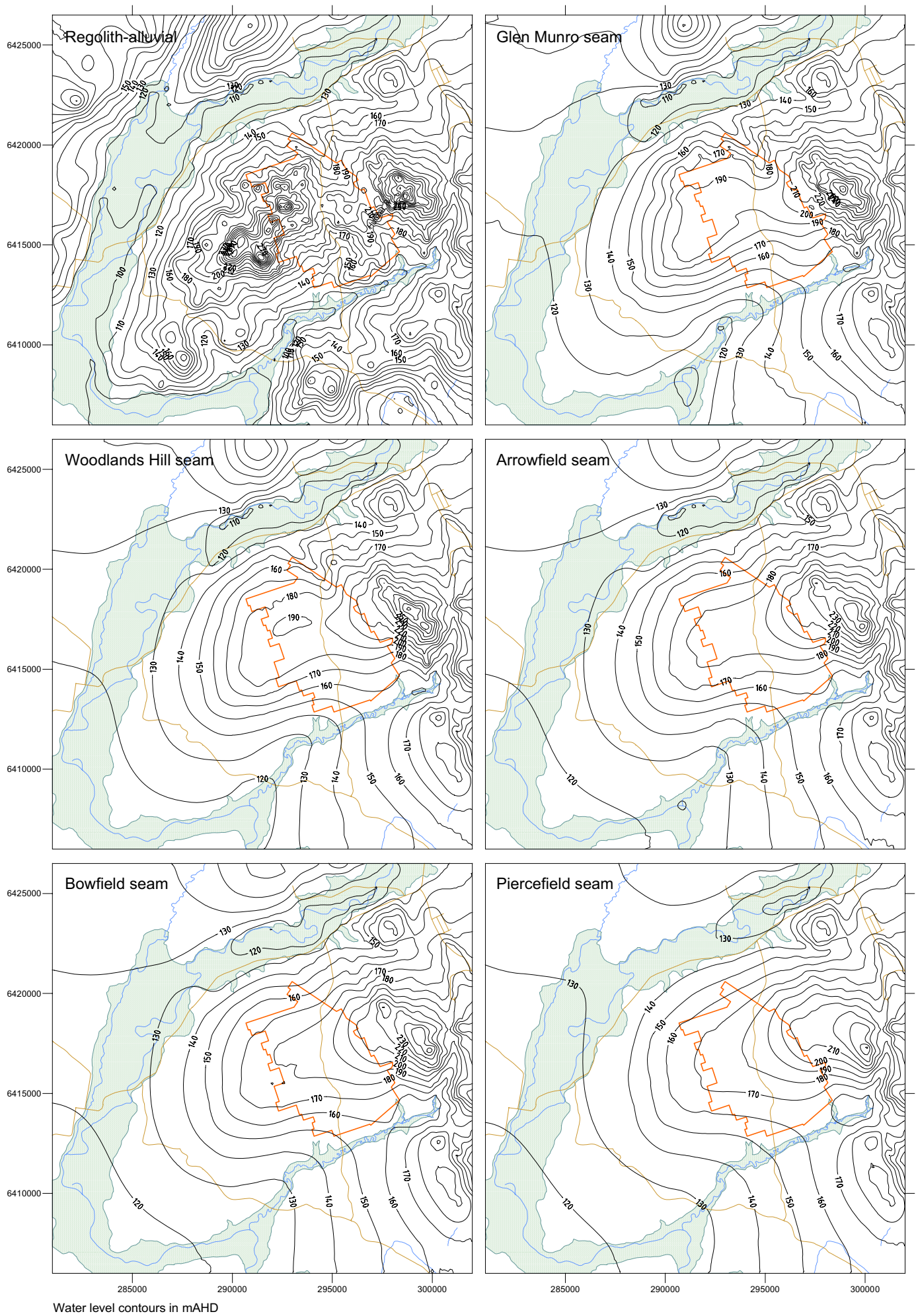
MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

**Model generated groundwater particle flow tracks
in shallow coal measures**



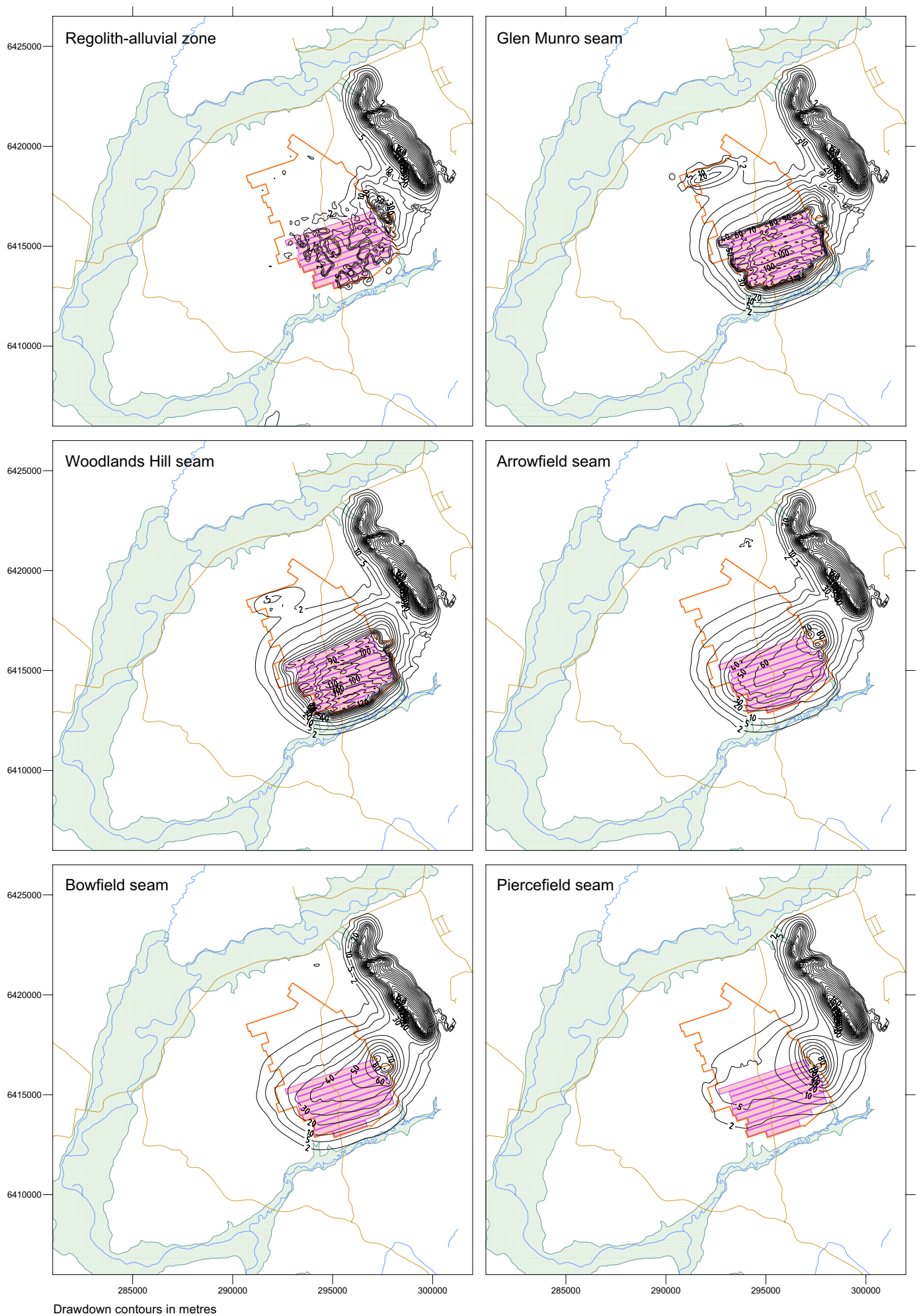
Progression of panel extractions

Figure F8

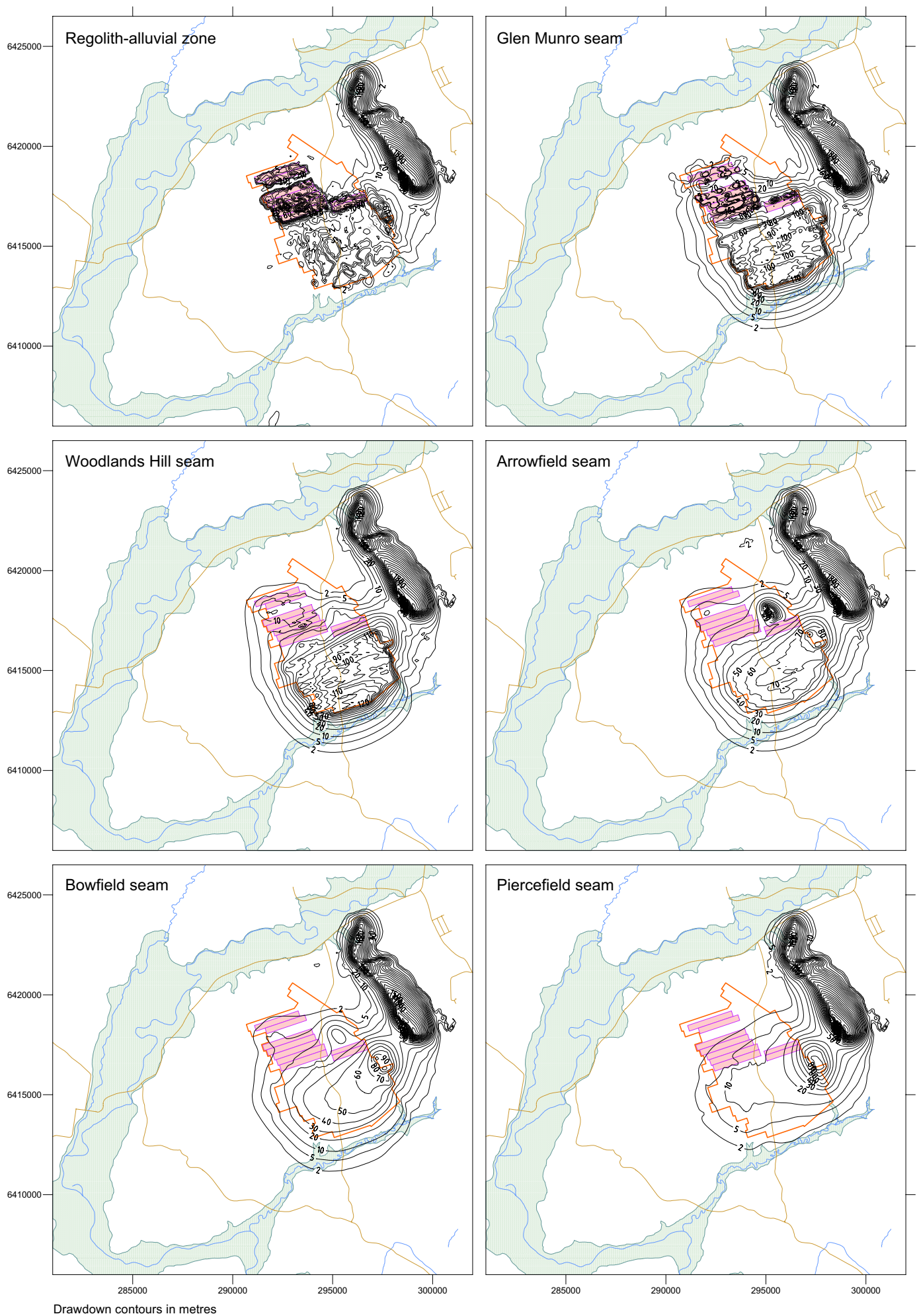


Water level contours in mAHD

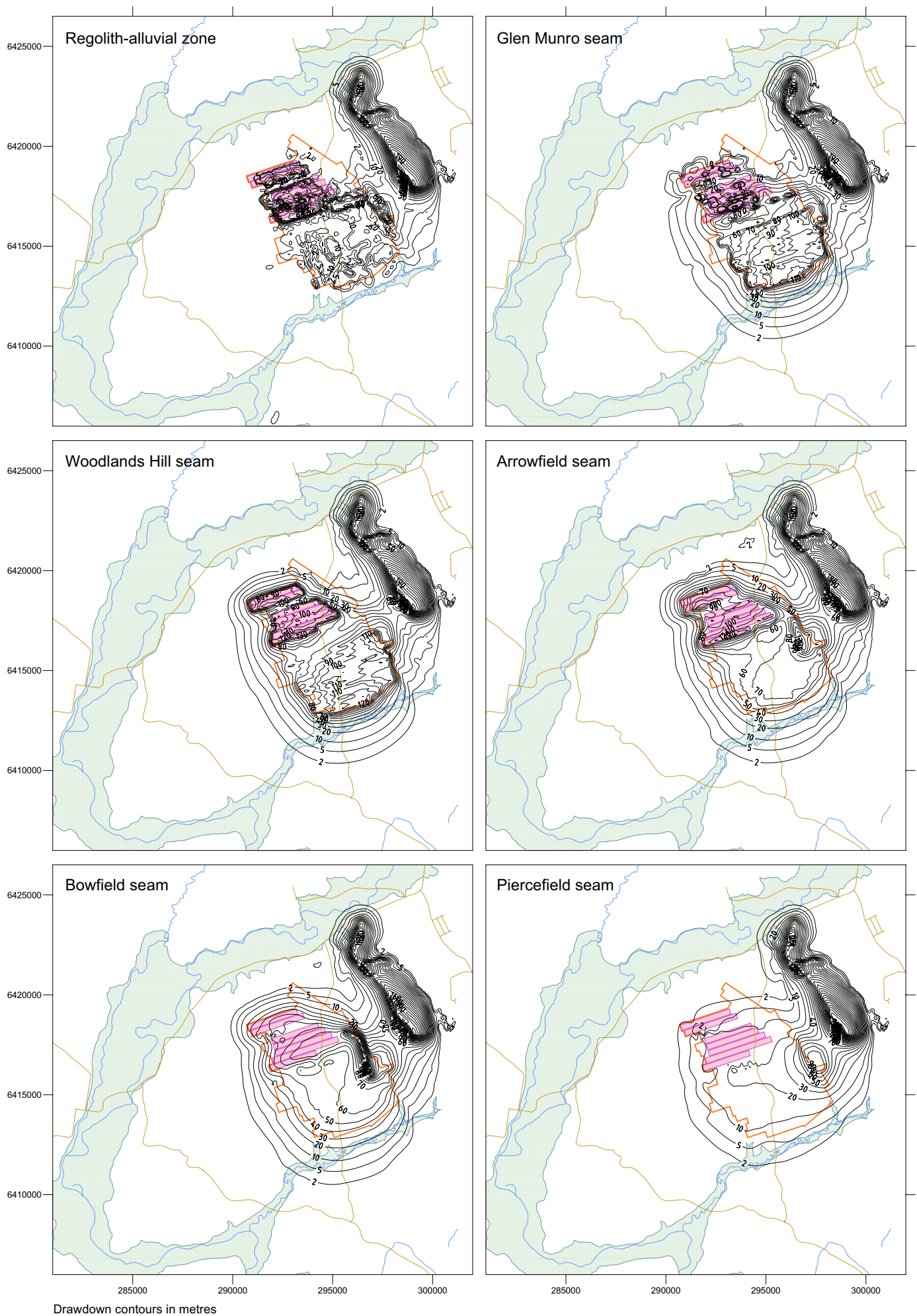
Regional pre-mining piezometric surfaces



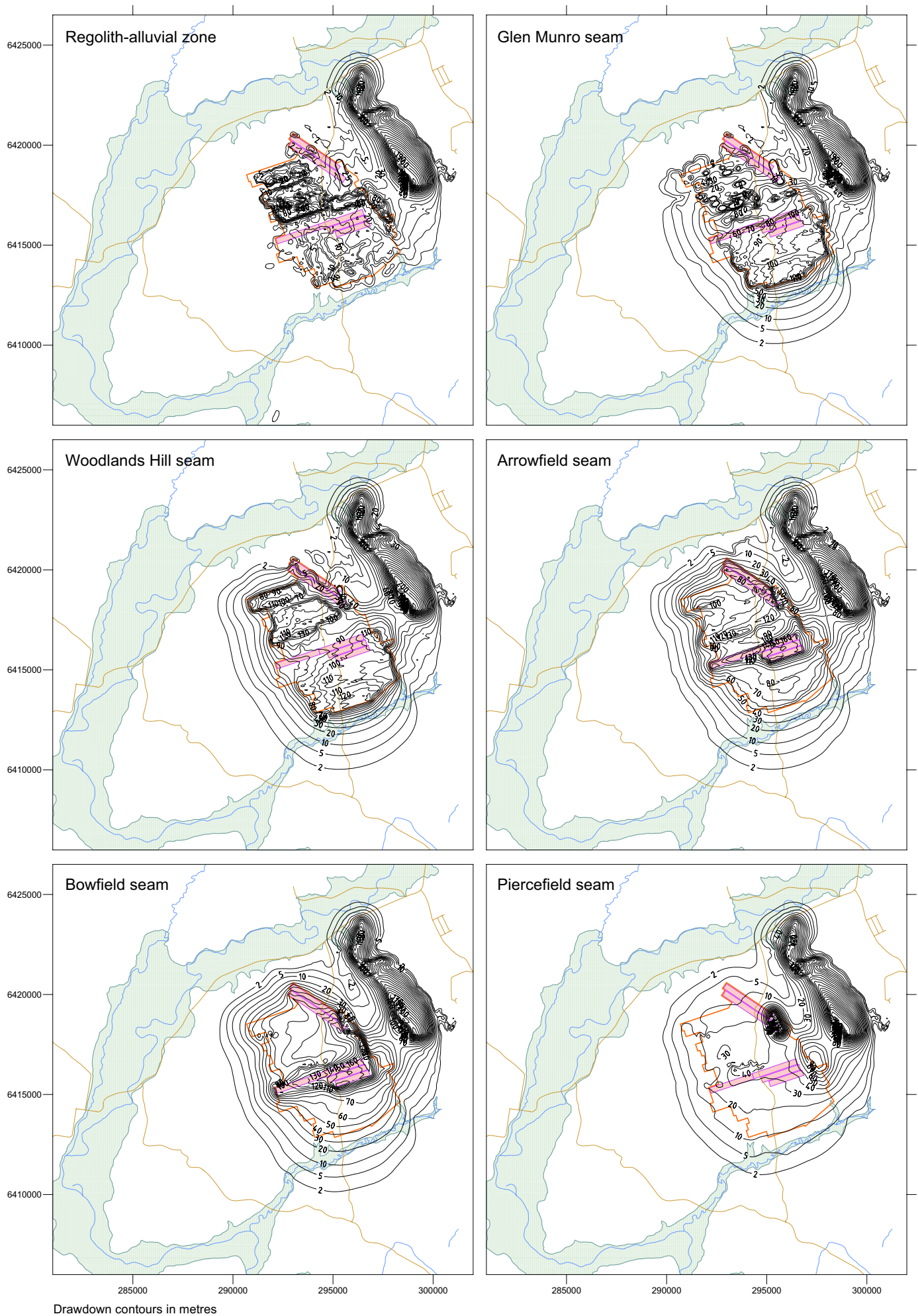
Piezometric drawdown at end of panel extraction in the Woodlands Hill seam - Year 8



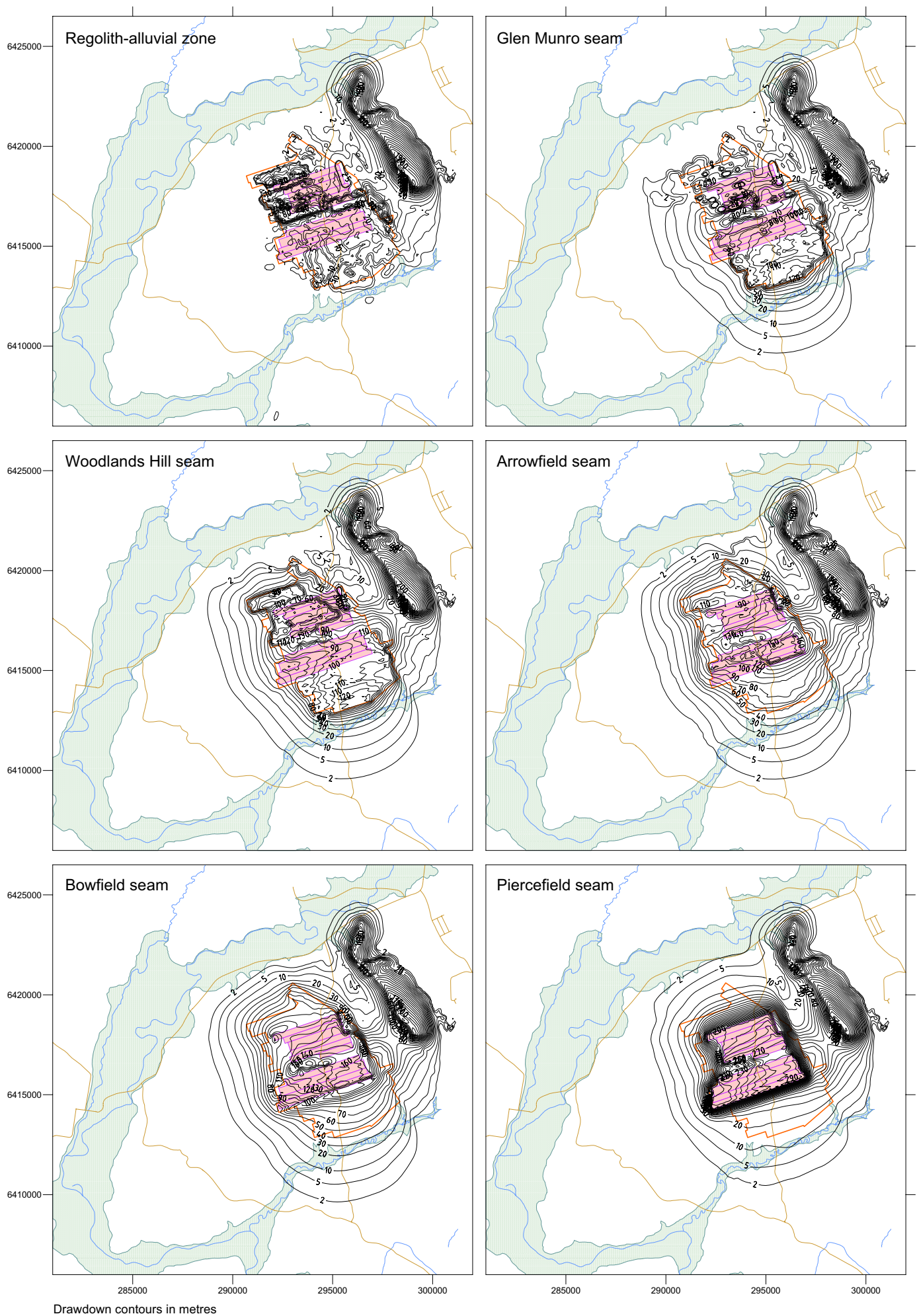
Piezometric drawdown at end of panel extraction in the Glen Munro seam - Year 11



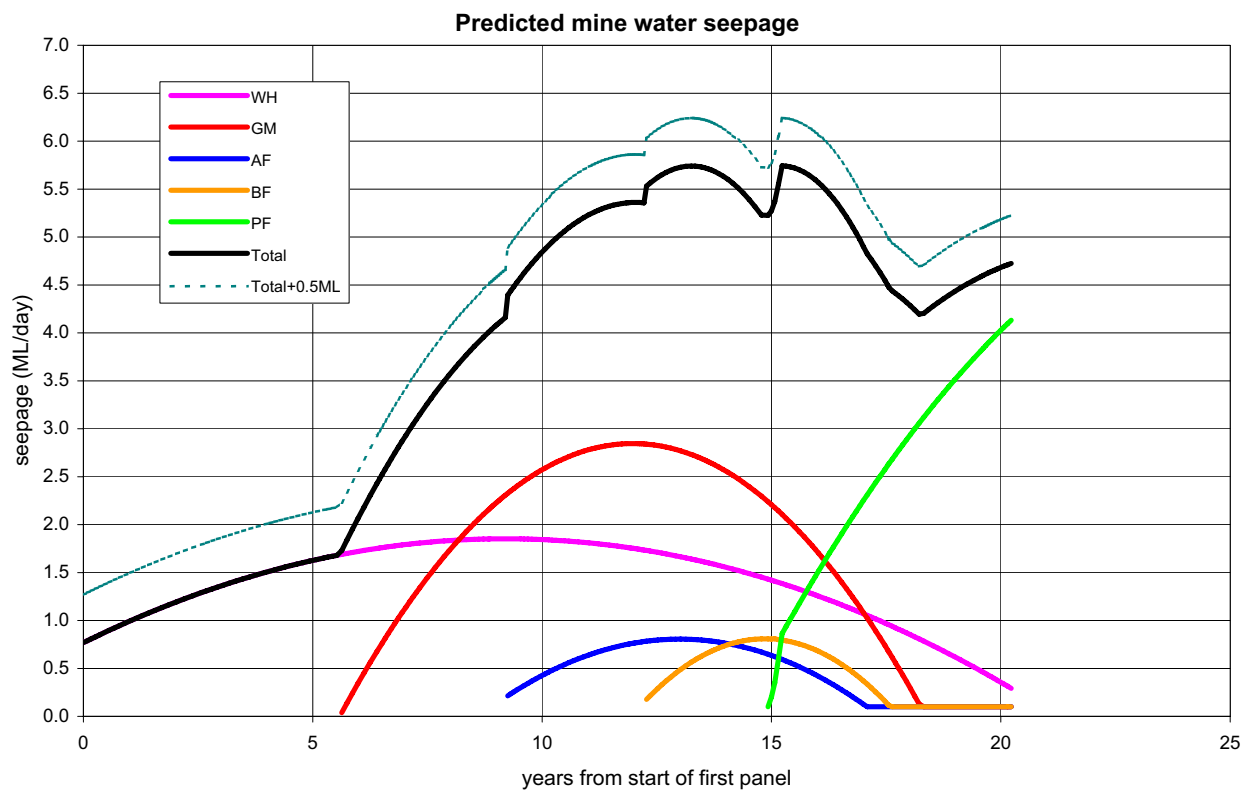
Piezometric drawdown at end of panel extraction in the Arrowfield seam - Year 14



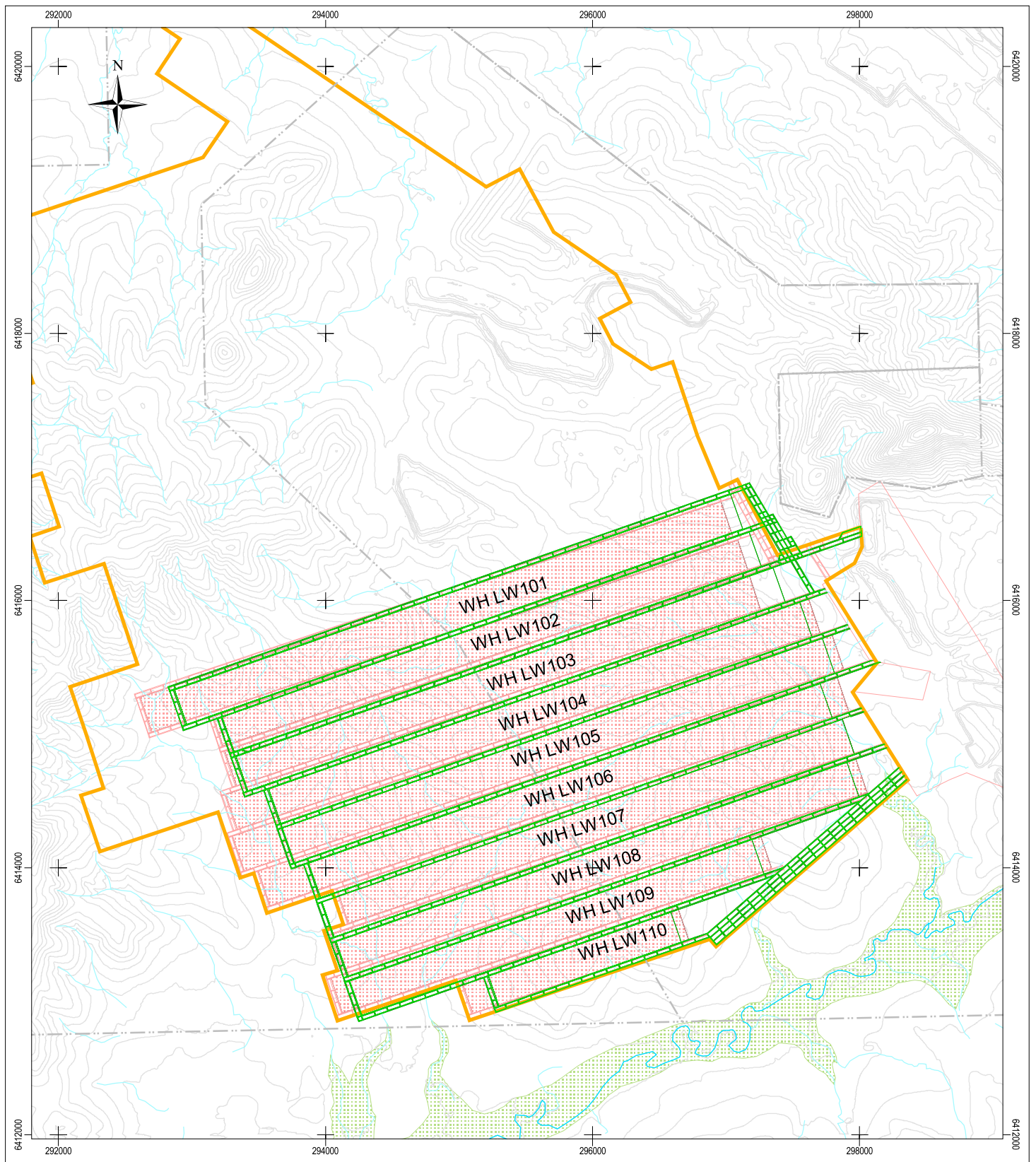
Piezometric drawdown at end of panel extraction in the Bowfield seam - Year 16



Piezometric drawdown at end of panel extraction in the Piercefield seam - Year 21



Plot shows the model predicted seepage for each seam and summation of all seams (total plot). An additional 0.5 ML/day is shown above the total to reflect potential contributions from localised increases in fracture storage and/or rainfall infiltration via the subsidence zone. These contributions may last weeks to months before being depleted.



MT ARTHUR COAL UNDERGROUND PROJECT - GROUNDWATER STUDIES

Amended panels layout in Woodlands Hill seam