ULAN COAL MINES LTD.

ASSESSMENT OF GROUNDWATER RELATED IMPACTS ARISING FROM MODIFICATIONS TO THE ULAN WEST MINE PLAN

JANUARY 2015

Mackie Environmental Research

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SUMMARY

Ulan Coal Mines Limited (UCML) is currently extracting coal from longwall operations at Underground 3 and at Ulan West mine. Open cut operations are also continuing in the Boxcut-West Pit area.

UCML is seeking approval to modify the currently approved mine plan for Ulan West underground mine by extending longwall panels LW6 to LW12 southward. The proposal allows for the continued mining of coal from all operations at rate of up to 20 Million tonnes per annum (Mtpa) over a period of 15 years or more.

Coal extraction under a modified Ulan West mine plan would continue to depressurise groundwater contained within the mined coal seam and in surrounding Permian strata. Subsidence and associated cracking would also continue to induce depressurisation and downwards leakage of groundwater contained within Triassic sandstones that overly the Permian strata, to the coal seam and goaves.

The expected long term behaviour of the groundwater systems impacted by mining at Ulan West has been assessed by amending the existing UCML groundwater flow model for the region. Those amendments include both a re-sequencing of longwall panels at Underground 3 (Approved operations model) and the proposed southward extension of longwall panels at Ulan West (Modified Ulan West model). The model for approved operations has been recalibrated using available groundwater monitoring data and historical estimates of groundwater seepage to underground operations. This model has then been adjusted to incorporate the extended panels. It has also been used to regenerate a pre-mining estimate of the regional water table and to determine probable groundwater flow path lines within the various strata. Model outcomes continue to support a pre-mining flow system that has been recharged by rainfall over a long period of time. The recharge sustains groundwater mounding in Triassic sandstone subcrop areas to the south southwest of Ulan West mining operations. Predicted flow paths support the presence of a groundwater flow divide that is located up to 6 kms west of the topographic Great Divide. Flow paths west of the groundwater divide are generally westerly down the Talbragar River catchment (Murray Darling Basin) while flow paths east of the divide support easterly flow down the Goulburn River catchment (Sydney Basin).

Simulation of modified and approved mining operations continues to predict sustained depressurisation of the Ulan seam to distances of 10 to 20 km beyond the longwall panel footprint at the end of mining in 2029. Permian interburden is predicted to depressurise to distances of 5 to 15 km while Triassic strata are likely to depressurise generally to distances of about 4 to 6 km.

Groundwater seepage to Ulan West (modified mine plan) is predicted to peak in 2022 at about 12.5 ML/day during the extraction of panel LW8. The rate is then predicted to decline as the remaining panels LW9 to LW12 are extracted. Seepage inflows for the approved mine plan are expected to be almost identical for longwalls LW1 to LW6 and lower for subsequent panels (due to the shorter panel lengths) with a peak rate of 11.3 ML/day predicted in 2021-2022.

Total volumes of groundwater reporting to Ulan West over the mine life are estimated to be 52.3 GL for the modified mine plan and 51.2 GL for the approved mine plan. The difference of 1.1 GL represents about 2.1% increase in mine water reporting to the water management system. This groundwater is drawn almost entirely from Permian strata overlying the Ulan seam since Triassic strata in the area of extended longwall panels are either unsaturated or partially saturated with only a few metres submergence.

Groundwater within the coal measures both during and post mining, is expected to exhibit a hydrochemical signature (cations and anions) consistent with the range of water qualities currently encountered in exploration holes and observation piezometers - a sodium-magnesium bicarbonate-chloride water. Hydrochemical signatures associated with a modified mine plan mining are not likely to change measurably from the approved mine plan.

Groundwater quality sourced from overburden and reporting to the mining operations, is expected to exhibit a total dissolved solids (TDS)>900 mg/L and a speciation signature with Mg or Na cations, and HCO_3 or Cl anions dominating (over Ca and SO_4). Mixing with coal seam water during mining may elevate the TDS.

Predicted impacts on baseflows for the Talbragar River system are similar to previously assessed impacts. These impacts are attributed to predicted long term loss of pore pressures in shallow Triassic strata resulting from vertically downwards leakage to the Ulan seam. Analysis of baseflow impacts indicates losses of 0.185 ML/day for the modified mine plan and 0.183 ML/day for the approved mine plan with the highest contribution attributed to Mona Creek catchment.

All groundwater reporting to the water management system requires licenced allocations constrained by Water Sharing Plans. Two plans are relevant to UCML operations:

- The Hunter Unregulated and Alluvial system east of the Great Divide (Goulburn Extraction Management Unit) applicable to surface water sources and connected alluvial systems. A WSP for hardrock systems (Permian, Triassic and younger) east of the Great Divide is not enacted at this time. Until the WSP is enacted, water take from these systems is required to be licenced under the Water Act (1912);
- The Murray Darling Basin (MDB) Porous Rock Groundwater system west of the divide, the prescribed water source being the Sydney Basin. The area of the Sydney Basin water source impacted by UCML operations lies within an area defined as the 'Other' zone.

Volumetric estimates of annual water take for licencing purposes have been assessed as 7660ML for the MDB water source and 6570 ML for the Goulburn River catchment (Water Act).

Simulation of the recovery of groundwater levels indicates more than 300 years will pass before groundwater levels and pressures within the depressurised strata, substantially rebound. A long term decline in water table elevations is predicted in southern parts of Ulan West as a result of changed hydraulic properties (due to subsidence related cracking) in Permian and Triassic strata. A long term (+300 years) decline in the water table of 5 metres or more is predicted over most of Ulan West mining footprint. The area associated with this decline is approximately 105 sq km and is identical for both the modified and approved mine plans. A difference in impacts generated by the modified mine plan is predicted mostly over a relatively small area of 4 sq km located at the southern end of longwalls LW6 to LW12. There are no water supply structures within or in close proximity to this area.

The Drip is recognised as an important natural feature which hosts localised groundwater dependent ecosystems. It is a perched groundwater system sustained by surficial and relatively shallow groundwater storage which is governed mostly by short term rainfall events that surcharge the regolith, weathered rock and vertical joints in the area. Rainfall recharge and downwards percolation is intercepted at horizontal bedding planes which then transmit the groundwater to the exposed rock faces along the Goulburn River gorge, where it emanates as seeps and drips. During dry periods some seeps may cease to flow. Depressurisation and partial dewatering of Triassic strata in the area of the Drip has already occurred as a result of historical mining operations at UCML and no impacts have been measured on the perched groundwater system that supplies the Drip. No future impacts are predicted on the perched system from the proposed modified mine plan for Ulan West.

The following Table A provides a comparative summary of groundwater related impacts associated with the proposed modifications to the Ulan West mine plan.

Table A: Comparative summary of outcomes for Approved and Modified mine plans

Issue	**Approved mine plan outcome**	**Modified mine plan outcome**
Dewatering of groundwater systems	Peak dewatering rate of 11.3 ML/day in 2021-2022	Peak dewatering rate of 12.5 ML/day in 2022
Baseflow losses – Goulburn River catchment	0.039 ML/day at the close of mining in 2029	No difference to approved mine plan
Baseflow losses – Talbragar River catchment	0.183 ML/day at the close of mining in 2029	0.185 ML/day at the close of mining in 2029
Groundwater quality	Change in groundwater chemistry associated with Permian and Triassic strata	No difference to approved mine plan
Recovery and re-equilibration	More than 300 years with residual drawdown present at the southern end of longwalls	No difference to approved mine plan
Cumulative impacts	Cumulative impacts drawdown analysis indicates significant contributions associated with other UCML operations but negligible influence associated with Moolarben operations	No difference to approved mine plan
Aquifer interference policy (AIP)	Ulan West mine plan was approved in 2010 before introduction of the AIP.	No difference to approved mine plan in terms of impacts on other water users
Water allocations and licensing	Allocations and licencing will fall within two water sharing plans: The Hunter Unregulated system east of the Great Divide - Goulburn Extraction Management Unit (not enacted at) and the MDB Porous Rock Groundwater system (Sydney Basin) west of the divide	Increase in MDB allocation required
Management and mitigation measures	Management of impacts by licencing in perpetuity.	No difference to approved mine plan
The Drip	No impact	No difference to approved mine plan

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1. INTRODUCTION

Ulan Coal Mines Limited (UCML) is seeking approval to modify the currently approved mine plan for Ulan West underground mine by extending longwall panels LW6 to LW12 southward as indicated on Figure 1. The proposal provides for the continued mining of coal from all operations at rate of up to 20 Million tonnes per annum (Mtpa) over a period of 15 years or more.

Coal extraction at Ulan West will continue to depressurise groundwater contained within the mined coal seam and in surrounding Permian strata. Subsidence and associated cracking will also continue to induce depressurisation and downwards leakage of groundwater contained within Triassic sandstones that overly the Permian strata. The overall long term behavior of the groundwater systems impacted by mining at Ulan West is expected to be similar to observed behavior of these same systems at adjacent Ulan Underground 3.

Mackie Environmental Research Pty. Ltd. (MER) has been commissioned by UCML to assess the likely groundwater related impacts arising from the proposed Modification at Ulan West. Impact studies have utilised the knowledge base established as part of the approvals process for Ulan West in 2009 (MER, 2009) and subsequent monitoring. These studies have included:

- a description of the regional setting and the existing groundwater systems and the likely flow regimes that prevailed before mining activity commenced;
- an assessment of the groundwater related impacts of all stages of the approved UCML mining operations including any cumulative impacts associated with Underground 3 and open cut operations, and neighbouring mining operations at Moolarben Coal;
- an assessment of the potential additional groundwater related impacts resulting from the proposed modification to the Ulan West mine plan;
- a description of the measures that would be implemented to avoid, minimise, mitigate and/or offset the potential impacts.

The contained report provides a summary of findings.

1.1 Government legislation and policies

Government legislation, policy and guidelines applicable to and considered as part of the groundwater impact assessment, include:

The Water Act (1912): which for mining, focuses on the licencing of water extraction from the surface and groundwater resources including borehole water supply and water seepage to mining operations. Parts of the Water Act have been superseded by the Water Management Act (2000).

The Water Management Act (2000) has as its objective, the sustainable and integrated management of NSW water resources. This is achieved through prescribed water management principles, certain harvestable rights and water extraction approvals which may include water works and controlled activity approvals, or aquifer interference approvals. These are constrained by Water Sharing Plans (WSP) which are implemented through the establishment of rules for sharing water between the environment and water users.

Aquifer Interference Policy. The Aquifer Interference Policy (AIP) addresses requirements for obtaining water licences for aquifer interference activities, and establishes a framework for the assessment of impacts associated with a mining project and whether more than minimal harm might occur to a water asset. In order to comply with water sharing plans the water take must be licenced under either the Water Act 1912, or the Water Management Act 2000.

NSW Office of Water (NOW) is required to assess any major (and State significant) mining proposal against specified minimal harm criteria which are set out in Table 1 of the policy. There are two levels of minimal impact specified - if the predicted impacts are less than Level 1, they will be considered as acceptable, but if the impacts are greater than Level 1 then groundwater assessments need to demonstrate that the impacts are acceptable. Study findings have been considered with regard to the AIP.

The NSW State Groundwater Policy – Framework Document: has as its primary goal, the management of the States groundwater resources in order to sustain 'environmental, social and economic uses for the people of NSW. The Policy was a pre-cursor to the Water Management Act and basically sets out fundamental objectives to improve the management and sustainability of groundwater resources. Supporting Policy documents include the NSW Groundwater Quality Protection Policy and the NSW State Groundwater Dependent Ecosystems Policy.

Australian Groundwater Modelling Guidelines aims to promote a consistent and sound approach to the development of groundwater flow models. The guidelines address conceptualisation, design and development of a model, calibration and prediction of impacts including sensitivity analyses. Development of the regional groundwater flow model for the project has been generally in accordance with these guidelines.

2. REGIONAL SETTING

MER (2009) provides an overview of the regional setting which is represented herein for completeness.

2.1 Drainage catchments

At a regional scale, Ulan West and Underground 3 mine footprints straddle the Great Divide separating the Hunter-Goulburn River catchment to the east, from the Murray Darling Basin catchment which includes the Talbragar River, to the west (see Figure 1). At a local scale, the drainage catchments in proximity to UCML operations include Ulan Creek, Bobadeen Creek and several unnamed creeks that drain to the Goulburn River, and Mona Creek, Cockabutta and other creeks that drain to the Talbragar River.

The tributaries of the Goulburn River upstream of the township of Ulan are considered historically to be intermittent or ephemeral, becoming perennial at some point downstream of the confluence of the Goulburn River and Murrumbline Creek. The Talbragar River is probably ephemeral upstream of the confluence with Turee Creek and intermittent as far downstream as the confluence with Cockabutta Creek[1]. All other drainages are considered to be naturally ephemeral; they cease to flow in dry spells.

2.2 Geology

The mapped geology of the area according to the Western Coalfields Geology Map, (NSW Geological Survey, 1998) is shown on Figure 2. A stratigraphic column showing increased detail for the coal resources is provided as Figure 3. The main lithologies in stratigraphic order (youngest to oldest) include the following:

Recent-Quaternary alluvial sediments of limited extent are associated with some of the creeks in the general project area including Mona Creek, Ulan Creek, Bobadeen Creek and an unnamed tributary of Cockabutta Creek. The alluvium-colluvium tends to be present in relatively discontinuous stringer deposits along the valley floors and generally consists of fine to coarse grained sands and gravels within a silt/clay matrix. Thicker sequences of alluvium are present at the confluence of Ulan Creek and the Goulburn River and to the northwest in areas adjacent to the Talbragar River. Identified or interpolated alluvium distributions are shown on Figures 1 and 2 and are based on air photo interpretations supported by topographic gradient assessments[2] using GIS systems.

[1] Based on discussions with hydrology specialists
[2] Topographic grades less than 1 degree and adjacent to a drainage channel are assumed to correlate to alluvial deposits.

The distribution shown on Figure 1 is considered to be the most representative.

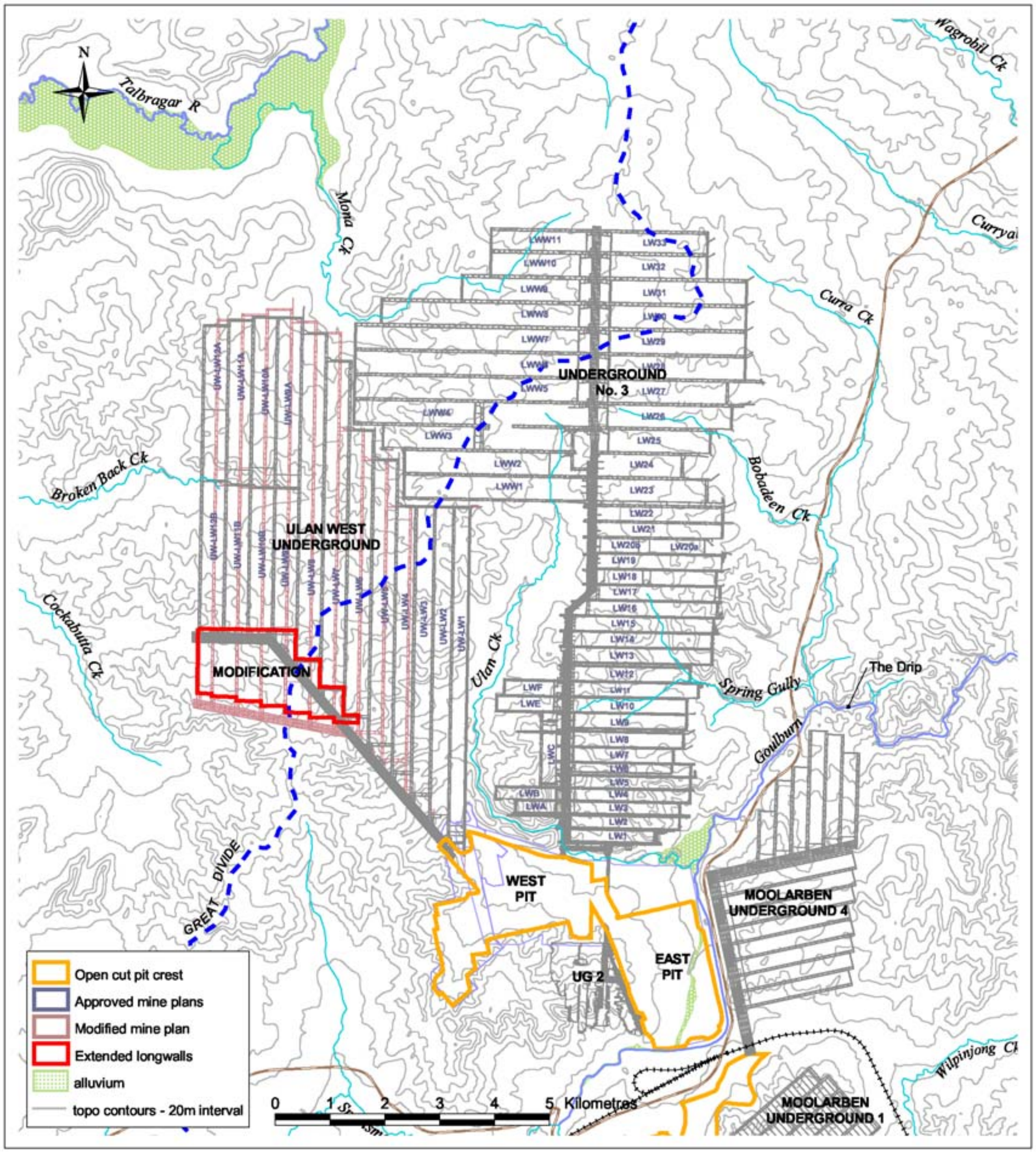

Figure 1: Regional locality plan showing approved longwalls (grey) and the proposed Modification with changed gate road locations (pink).

Tertiary volcanics are associated with an area of volcanic activity centered on the Liverpool Ranges to the northeast. The rocks comprise grey amygdaloidal, and alkaline olivine, basalts and have intruded strata as plugs and sills.

Jurassic rocks are classified into the following units:

> ***Pilliga Sandstone**:* also known as the Munmurra Sandstone, this unit consists of cross-bedded, coarse, quartzose sandstone (commonly ferruginous) with some conglomerate, minor claystone and shale. It has been reported as a soft, porous quartz sandstone with occasional conglomeritic beds which is often an excellent aquifer (Merriwa town water supply is obtained from this aquifer). This sandstone is not present in the area of interest.
>
> ***Purlewaugh Siltstone***: comprises grey siltstone and mudstone with interbedded fine to medium grained, grey lithic sandstone in some areas. Observations and measurements of

permeability of core from UCML exploratory drill holes (MER, 2009) suggest this unit may act as an aquitard inhibiting rainfall recharge through these rocks to underlying Triassic rocks.

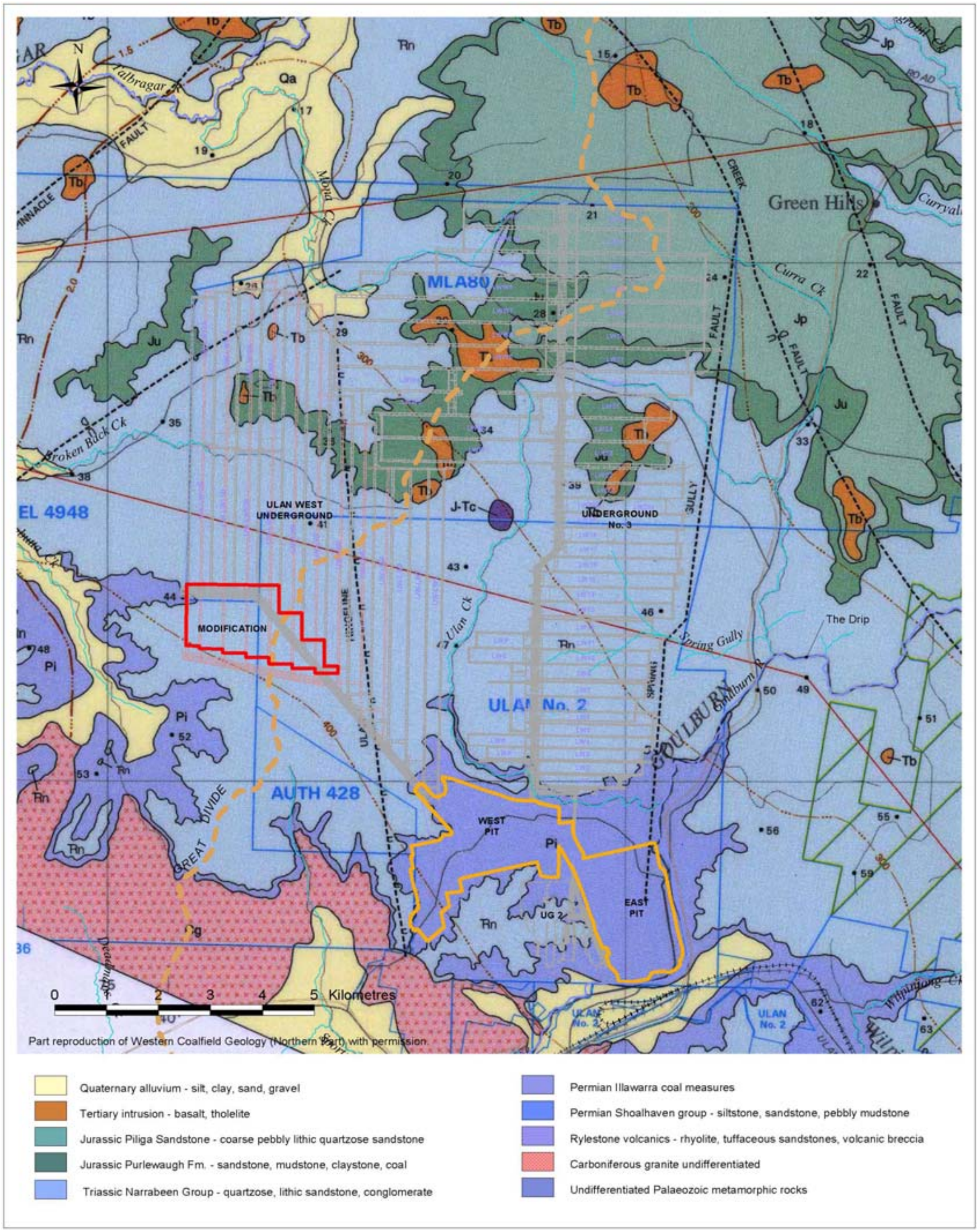

Figure 2: Published geology map showing approved longwalls and proposed longwall modification

Triassic rocks are represented by the *Wollar Sandstone* which is distinguished from other rocks in the region by the associated rough and sometimes steeply incised terrain. This sandstone is equivalent to the Narrabeen Group in other parts of the Sydney Basin and has an average thickness of around 120 m within the general area of mining. In the area of the Modification identified on Figure 2, the thickness varies from 10 to about 100 m. The sandstone consists of two main facies which are identified as either quartzose or lithic sandstones.

The ***quartzose facies*** comprises a cream to yellow, cross-bedded porous sandstone with well-rounded quartz pebbles (conglomeritic in parts). The average thickness of this unit in the area is about 85-90 m.

The ***lithic facies*** underlies the quartzose facies and comprises a light grey/green, poorly sorted sandstone. It contains acid volcanic pebbles (15% to 20%) and grey/green chert pebbles (20% to 25%) typically to +5mm diameter. The average thickness of this unit is about 35 m.

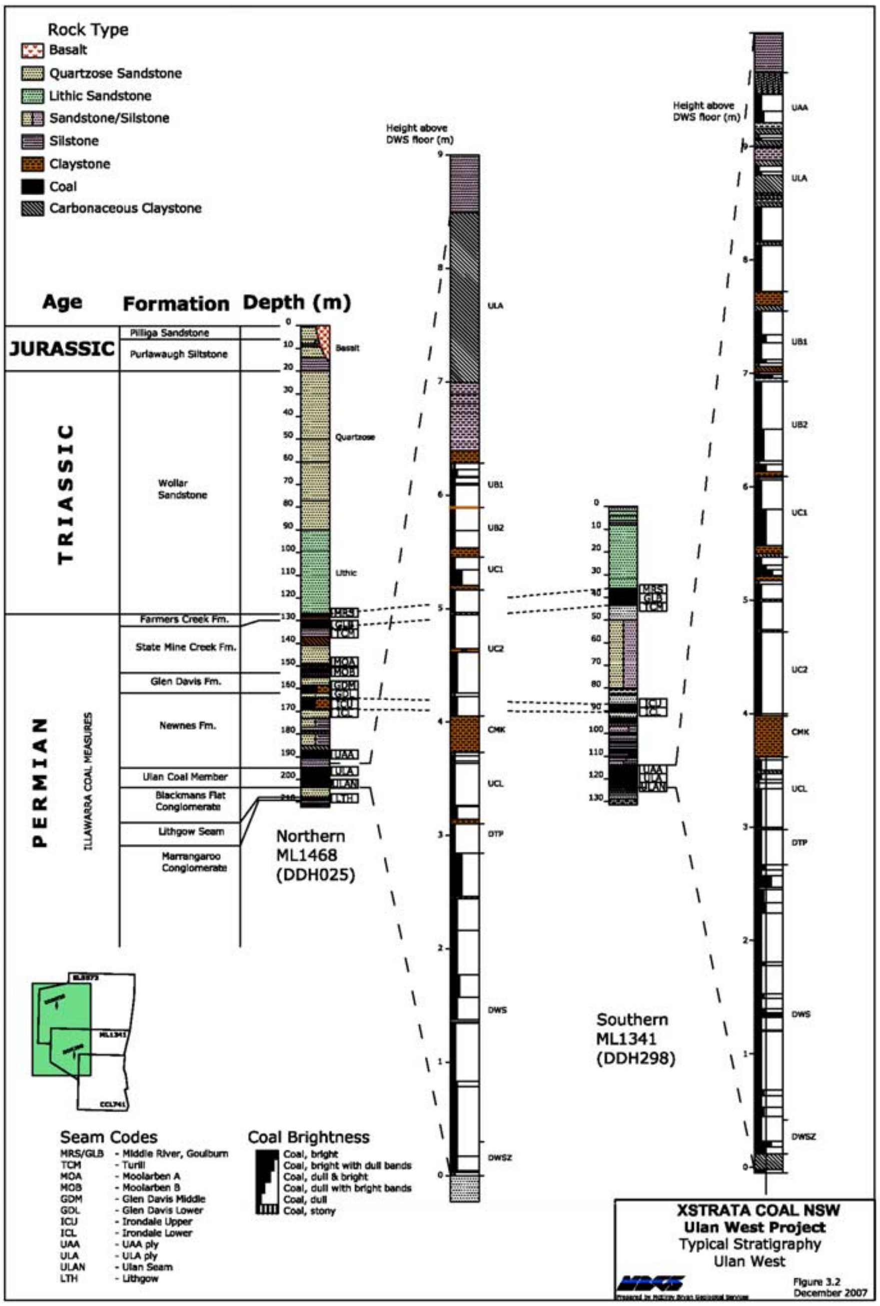

Figure 3: Typical stratigraphic column at Ulan West

Permian rocks are represented by the Illawarra Coal measures and have an average thickness of approximately 145 m. The Triassic/Permian contact is conformable and occurs at the top of the Permian Middle River-Goulburn coal seams.

Permian Coal Measures (PCM) comprise an interbedded sequence of claystones, siltstones, sandstones and coal seams. Claystones may be carbonaceous in parts while siltstones and sandstones vary from fine to coarse grained, commonly well cemented and often with carbonaceous laminations. Coal seams include the Middle River, Moolarben, Glen Davis, Irondale and Ulan seams which are all generally dull with minor bright bands and moderately to weakly cleated (see Figure 3).

The Ulan seam is about 10m thick. The base of the Ulan D Seam working section (the mined section in underground operations) is an average of about 90m below the base of Triassic strata.

Marrangaroo Conglomerate: Underlies the Ulan seam. It is a reasonably permeable, weakly cemented, massive rock unit with granular to pebbly phases. This unit cannot be readily correlated across the project area and appears to grade to a medium to coarse-grained sandstone in some areas.

Carboniferous rocks occur in the west of the region and form the eastern limit of the Lachlan Fold Belt which borders the sedimentary sequence of the Gunnedah Basin. These rocks consist mostly of intrusive igneous bodies and associated volcanics.

2.3 Bedding and structural features

Permian and younger strata dip to the north-east at a shallow angle (less than 2 degrees) as indicated by the structure contour mapping for the Ulan seam floor shown on Figure 4.

A number of near vertical faults have been identified that displace the strata. A major fault zone known as the Spring Gully Fault is located in the eastern portion of the UCML area (Figure 4) and has been observed in the East Pit open cut highwall. It trends north-south and exhibits a displacement of up to 8m. The fault is a barrier to mining due to associated rock weakness but is only a partial barrier to groundwater flow.

A number of other major faults are identified on the regional geological map (Figure 2) and are also indicated on Figure 4. Very little is known about these faults. However for current hydrogeological assessments they are assumed to be similar to the Spring Gully Fault insofar as they probably act as partial barriers to groundwater flow.

A number of volcanic plugs have also been identified. These features may enhance groundwater storage around their perimeters as a result of alteration, fracturing or seam cindering.

3. GROUNDWATER HYDROLOGY

Groundwater occurrence within the region has been mapped over many years. Three domains have been identified. They are:

- the shallow regolith and weathered rock zone that may host perched groundwater storage systems during extended wet periods;
- the unconsolidated alluvial materials associated with the major drainages that host unconfined groundwater systems;
- the regional sedimentary rocks that host both unconfined and confined groundwater systems.

3.1 Groundwater occurrence in unconsolidated sediments

Alluvial sediments can be broadly classified as either Quaternary shallow valley fill sediments that are substantive along the Talbragar River and relatively minor along other drainages west of the Great Divide, or the deeper and older Tertiary sediments noted particularly in the Moolarben area east of the divide.

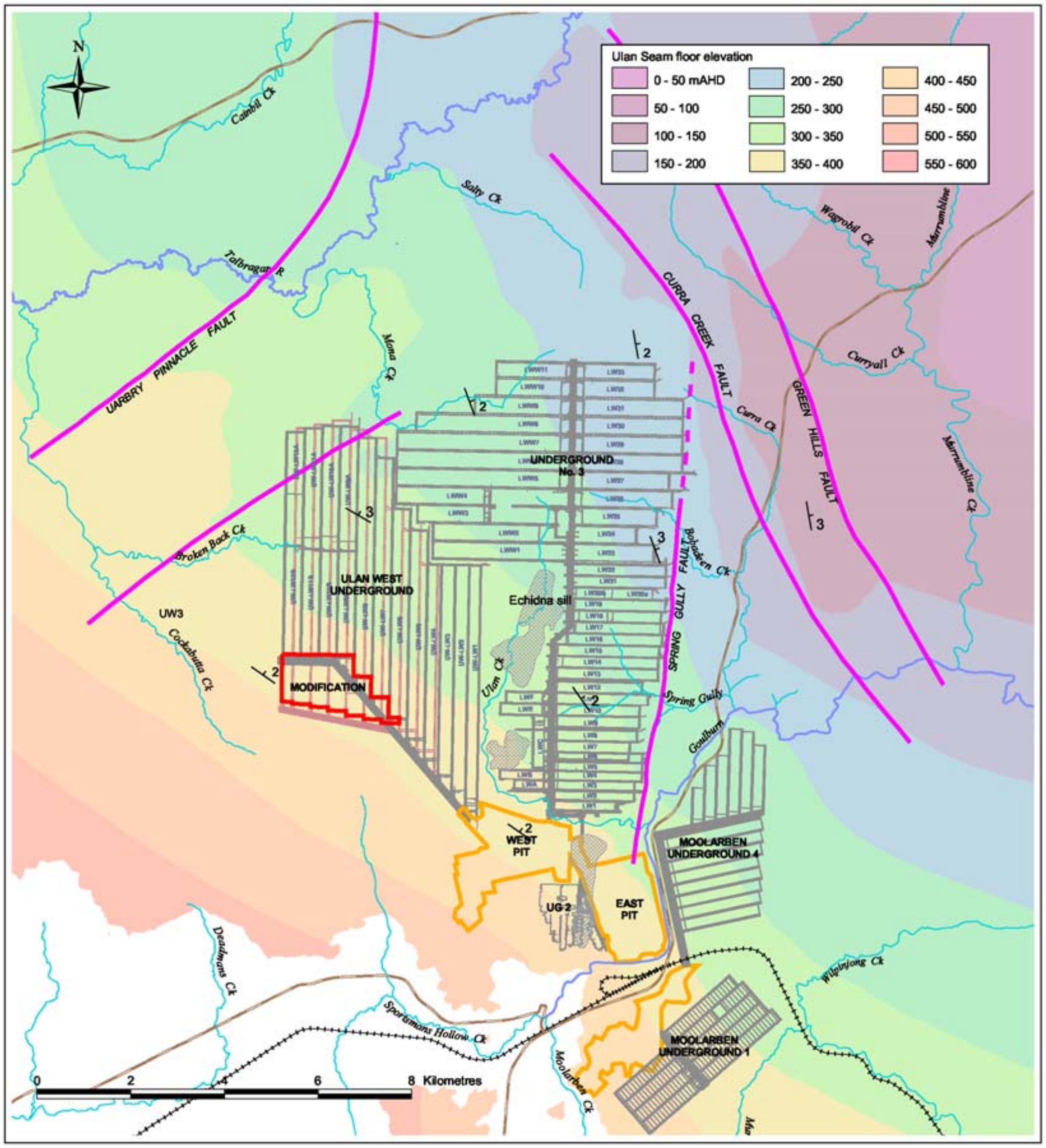

Figure 4: Ulan seam floor and major fault locations

Quaternary (and Recent) alluvium east of the divide is more localised and comprised of sands, silts and clays. Groundwater contained within these sediments occurs at depths of about 5 to 10m with estimated saturated thicknesses (of alluvium) in the range 10 to 20m. Minor occurrences of alluvium in the upper reaches of Mona Creek and Broken Back Creek were identified in late 2008 and piezometers were installed in shallow exploration boreholes as part of the UCML regional groundwater monitoring program. Alluvium at these locations is commonly less than 5m thick and comprised of sandy, silty deposits with limited saturated thickness. Most test holes were found to be damp or dry.

Alluvial deposits (now removed) that was originally located along the Goulburn River course before the river was diverted around the East Pit, is shown on Figure 1. These deposits comprised interbedded clays, sandy clays, sands and sandy gravels. The 'northern alluvium' that occurs at the confluence of Ulan Creek and the Goulburn River comprises silty sands at the surface, underlain by sands and clayey sands, with sands and gravels towards the base. Deposits along Moolarben Creek appear to be similar in character to sediments identified in the northern alluvium.

Tertiary paleochannels identified in the central and southern part of the Moolarben project area are reported to host infill sediments up to 48m thick which are comprised of poorly sorted quartzose sediments partly consolidated within a clayey matrix.

3.1.1 Hydraulic properties of alluvium

Hydraulic properties of the alluvial deposits along the Talbragar River have not been measured due to their relative remoteness from UCML operations. Since the materials comprise a mixed assemblage of clays, silts, sands and gravels, the horizontal hydraulic conductivity is expected to range from 0.01 to 10 m/day. The vertical conductivity range is expected to be lower by an order of magnitude or more. Effective porosity is likely to range from 1% to perhaps 10%.

Measured hydraulic conductivities of alluvium associated with the Goulburn River range from 0.01 to 10 m/day while measured conductivities of alluvium in the Moolarben project area are reported to range from 0.05 to 3 m/day.

3.2 Groundwater occurrence in rock strata

Groundwater within the Jurassic, Triassic and Permian strata in the UCML area is held predominantly as interstitial (pore space) storage. This storage is a result of rainfall recharge through the shallow weathered rock zone into the underlying rocks, over geologic time.

Groundwater flow rates within the hard rock strata while not measured, are likely to vary significantly. Higher rates of flow are expected within the Triassic sandstones which are porous and permeable, while much lower rates of flow are expected within Permian sandstones, siltstones and claystones which are relatively impermeable.

There is potential for vertical groundwater flow between strata via fractures and micro cracks which introduce secondary permeability if they form a connected network. However it is extremely difficult to establish the occurrence, frequency and extent of these fractures since they are mostly vertical or sub-vertical and consequently are less likely to be intersected by exploration boreholes than fractures that might occur at shallow angles. Core inspections and borehole permeability testing undertaken as part of the 2009 EA suggested fracturing in hard rock strata at depth is relatively limited and therefore lacking connectivity. In contrast, shallow strata exhibited increased fracturing (jointing) and these strata are therefore expected to exhibit fracture dominated flow. This shallow zone is considered to be of little importance in governing groundwater flows in deeper strata.

The Ulan coal seam is identified as the main water bearing zone in the Permian strata insofar as it offers enhanced groundwater transmission characteristics (through cleats) when compared to non coal strata. Historical mining operations at UCML have depressurised the seam for distances of more than 10 km beyond mined areas. This seam depressurisation has induced some vertical leakage and pressure losses within adjacent strata in these distant areas. However non-coal strata between the Goulburn and Irondale seams (see Figure 3) appear to act as an aquitard, effectively inhibiting downwards leakage[3].

3.2.1 Hydraulic properties of hard rock strata

Hydraulic testing to assess rock mass permeabilities, has previously been undertaken as part of regional hydrogeological evaluations. Test procedures have comprised conventional packer

[3] See hydrographs for monitoring bore TAL1 – Appendix D

injection type testing and test pumping. Laboratory measurements on strata core have also been conducted (MER, 2009) to establish an expected range in matrix hydraulic conductivities together with bulk and effective porosities. Other measurements that have contributed to the hydraulic properties knowledge base include parameters relating to geomechanical properties - sonic velocity, unconfined compressive strength (UCS) and Youngs modulus.

Figure 5 shows selected wireline logs for borehole DDH242 together with stratigraphy and calculated strata conductivities (from the wireline logs)[4].

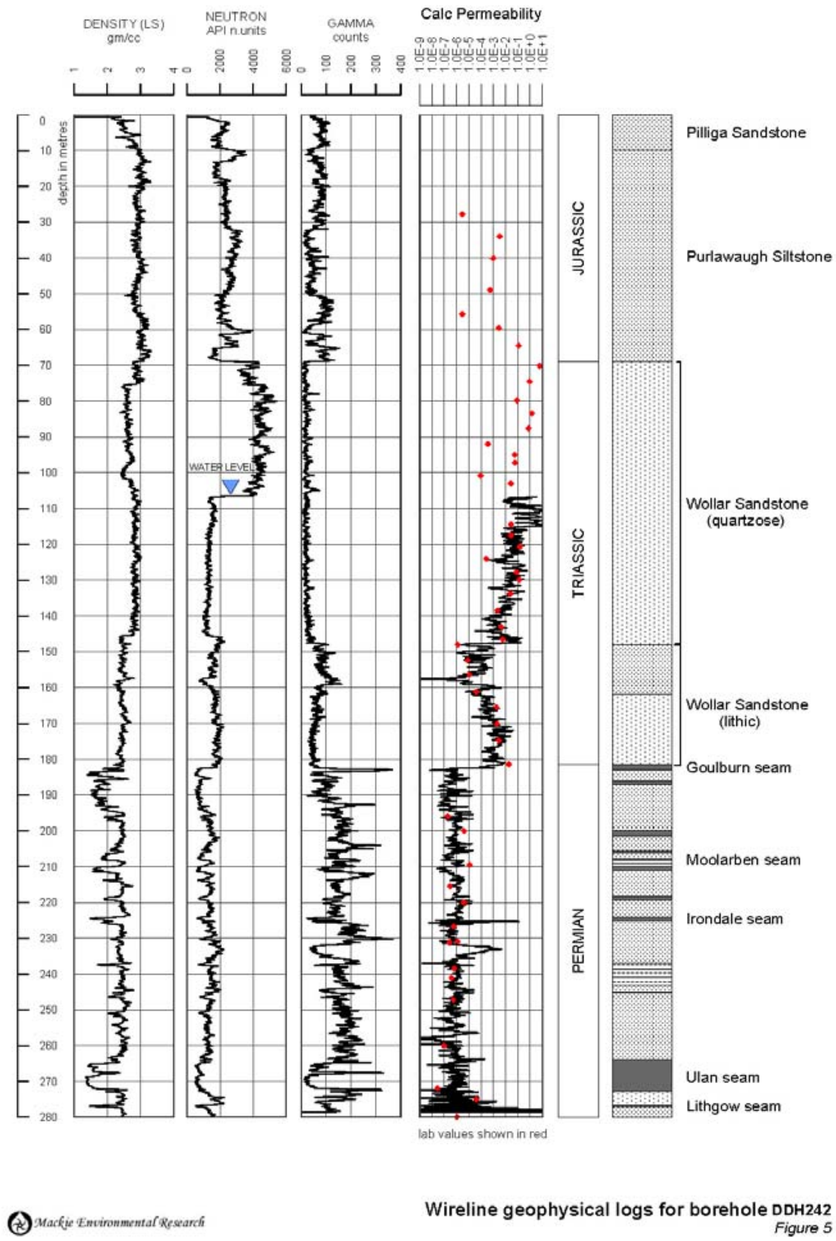

Figure 5: Wireline geophysical logs and hydraulic conductivities determined from core tests

Processing of logs for this borehole and numerous other boreholes reveals that:

[4] see Mackie, 2012 for an expanded description of the technique used to generate semi continuous vertical logs.

- Jurassic strata tend to exhibit variable but lower conductivities and higher anisotropies than the underlying Triassic quartzose sandstones;
- most of the Triassic quartzose samples submitted for laboratory analyses exhibit relatively high conductivities (near to or above 1.0E-02 m/day) consistent with a medium grained porous and sometimes friable sandstone. Calculated conductivities from wireline logs correlate closely to measured conductivities;
- Triassic lithic sandstones are evidently less permeable than the Triassic quartzose sandstones with the upper 10 to 15 m exhibiting quite low conductivities;
- Permian non-coal strata are the least conductive rocks being mostly below 1.0E-5 m/day for sandstone-siltstone core samples.

Figure 6 explores the relationship between effective porosity and conductivity for selected sandstone core samples (MER, 2009). While the data is limited, a useful relationship is clearly apparent – high effective porosity equates to high conductivity, and low porosity equates to low conductivity. The relationship implies that Triassic quartzose sandstones exhibit the highest drainable storage while Permian non coal strata exhibit the lowest.

Specific storage estimates ranging from 1.69E-06 to 5.13E-06 1/m have been calculated for a modulus range from 3.1 to 17.7 GPa. Higher specific storage values may be associated with weaker porous Triassic sandstones and the coal seams.

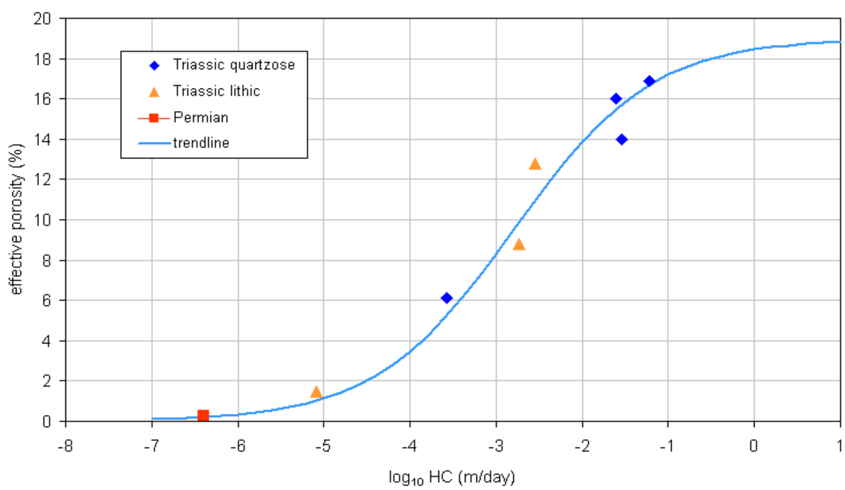

Figure 6: Relationship between hydraulic conductivity and effective porosity

3.3 Groundwater monitoring

The regional groundwater monitoring network currently comprises standpipe and pore pressure transducer piezometers installed at more than 45 locations (see Appendix D, Figure D1 for locations. The network is augmented from time to time with 3 additional locations currently scheduled during 2014-2015. Historical monitoring data is provided in Appendix D.

3.3.1 Potentiometric surfaces and groundwater flows

The water table or phreatic surface within the hard rock system resides in the Triassic strata over most of the UCML operations footprint but migrates into Jurassic strata to the north east (down dip). The interpolated phreatic surface at January 2014 is shown on Figure 7. Contours above extracted panels reflect dewatering within the subsidence zone while elsewhere the contours support a north-easterly groundwater flow direction which tends easterly near the northern end of UG3 then south-easterly under the influence of the Goulburn River drainage system. These regional flow directions infer recharge to the Triassic strata where it outcrops to the southwest of Ulan West mine. In this area there is minimal or no overlying Jurassic strata present. The Great Divide is also plotted to illustrate an apparently weak influence from the Talbragar River – the groundwater divide lies to the west of the topographic divide.

Figure 8 shows the interpolated potentiometric surface for the Ulan Seam at January 2014. This surface differs markedly from the water table shown in Figure 7 and illustrates the regional impact of mining operations where extracted panels have dewatered strata to the floor of the Ulan seam and attracted flow from all directions as expected.

3.3.2 Groundwater Quality

Groundwater sampling data collected over the last 10 years but particularly over the annual water quality monitoring period, reveal distinctive water types for the Jurassic, Triassic, and Permian strata, and the Ulan seam with respect to basic water quality parameters electrical conductivity (EC) and pH while ionic speciation suggests broader similarities.

Parameters EC and pH for 104 groundwater samples collected between 2002 and 2013, are summarised in Table 1. Results indicate that overall, the groundwater salinity (as EC) of the Triassic (Wollar) Sandstone is typically around half the salinity of Permian strata and less than one fifth the salinity of Jurassic strata. pH measurements support a weakly alkaline signature for Permian groundwaters, a neutral signature for Triassic groundwaters and a weakly acidic signature for the Ulan seam. It is also noted that the EC of groundwater within the quartzose strata of the Wollar Sandstone, is comparable to the EC of Goulburn River surface water and is significantly lower than the average EC value for surface water of the Talbragar River at Elong Elong.

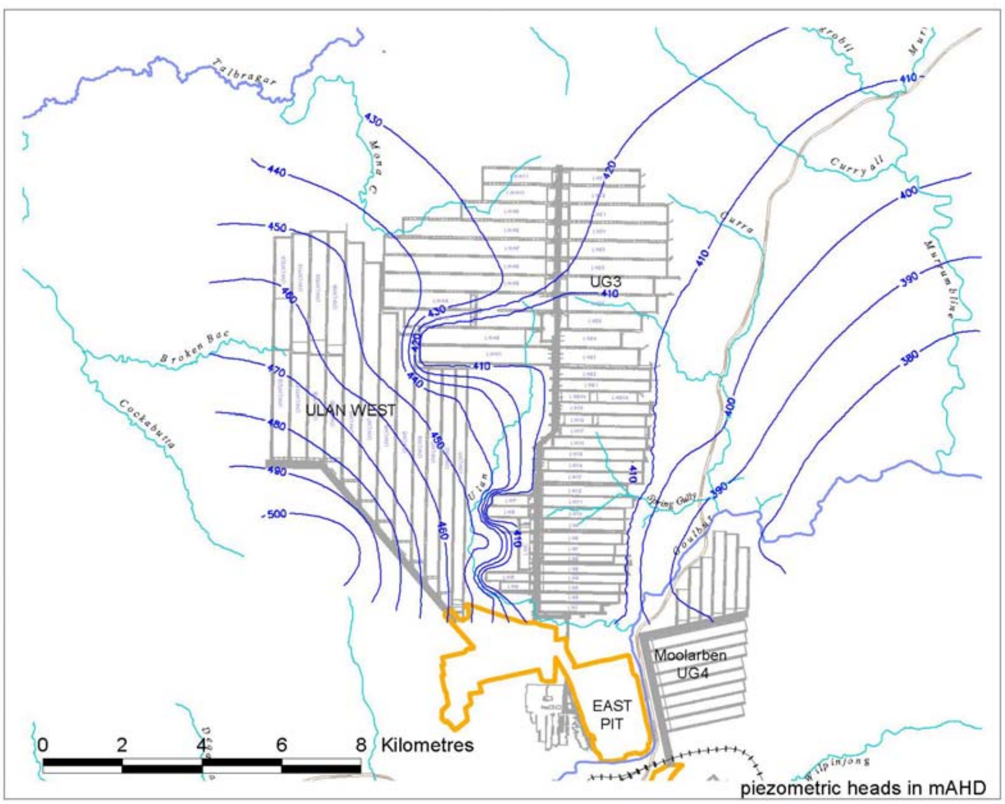

Figure 7: Approximate Triassic sandstone water table – January 2014

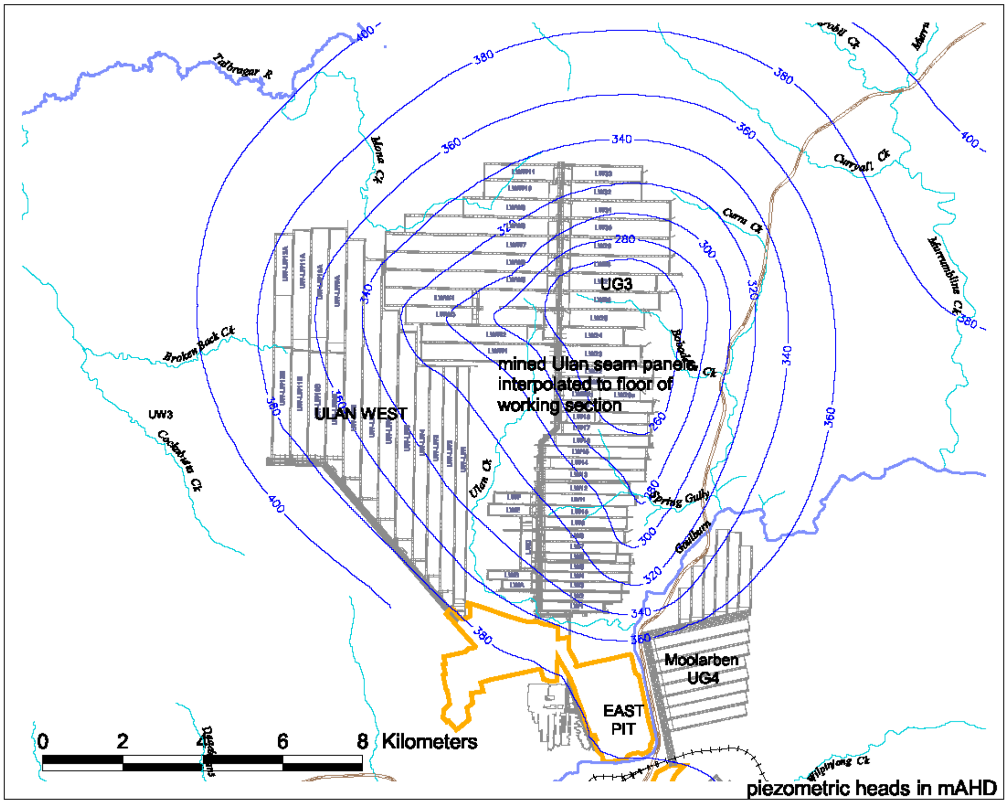

Figure 8: Approximate piezometric surface in the Ulan seam – January 2014

Table 1. EC and pH of undisturbed strata

Unit	No. samples	EC (St.Dev) uS/cm	pH (St.Dev)
Jurassic	9	2554 (1148)	7.61 (1.17)
Triassic	59	471 (326)	7.50 (1.64)
Permian	10	1151 (626)	9.53 (1.62)
Ulan seam	26	1310 (1739)	6.47 (0.31)

Representative water sample data for major ions is provided in Appendix D. A number of samples for the Moolarben project have also been included for completeness. This data set is summarised on the tri-linear speciation plot also known as a Piper diagram – Figure 9. The plot comprises two triangular fields representing cations and anions, and a central diamond field. Individual 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 have been projected into the central diamond field, thereby facilitating a generalised classing of groundwaters and examination of possible mixing trends.

Plotted data is summarised in the following Table 2. The Ulan seam exhibits elevated bicarbonate (as percentage milli-equivalents) when compared to other strata possibly due to the influence of carbonates associated with localised volcanic intrusives. The presence of sodium in Permian coal measures samples (interburden) may be attributed to similar mechanisms observed in the Upper Hunter coalfield where enhanced levels are associated with cation exchange (Na for Ca) relating to the presence of smectite in interburden.

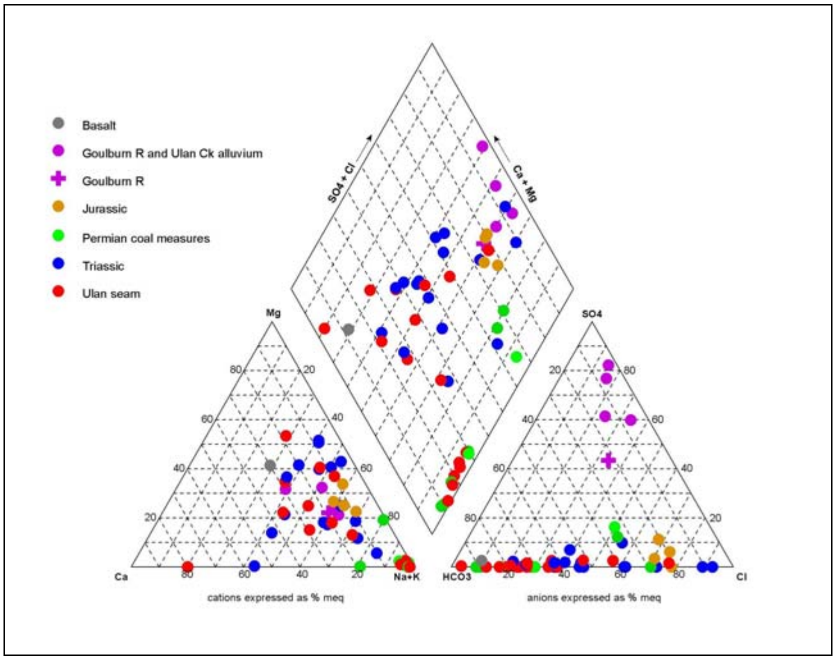

Figure 9: Trilinear plot of major ionic species

Table 2. Ionic species relevance for different stratigraphic units

Unit	Cations	Anions
GR + alluvium (upstream)	Na > Mg > Ca	SO_4 > Cl > HCO_3
Jurassic	Na > Mg > Ca	Cl > HCO_3 >> SO_4
Triassic	Na > Mg, Ca	HCO_3, Cl >>SO_4
Permian	Na > Mg, Ca	HCO_3, Cl >>SO_4
Ulan seam	Na > Mg, Ca	HCO_3 > Cl >>SO_4

3.3.3 Mine water influx

Underground mine water influx has historically comprised contributions from several sources including:

- dewatering of the Ulan seam, goaves and overlying subsided Permian and Triassic strata in Underground 3;
- seepage into the old Underground No.2 (UG2) operations to the south of UG3. This seepage previously migrated northward via the old northern mains. However these roadways have now been intercepted by open cut operations leaving northward flowing mine water to migrate into pit spoils that are emplaced against the headings. Accumulated water in the east pit may be re-entering the old headings on the north side of the interception slot;
- seepage to the East and West pits from rainfall infiltration through spoils. This stored water undoubtedly supports leakage down dip to UG3 via the Ulan seam and possibly the Spring Gully fault;

Water levels in the goaves and discharge volumes from underground dewatering pumps are currently monitored and recorded via an electronic data capture system. This and other site data have been used to generate water balances for underground operations. The balances take into account the volumes of water pumped into and out of underground operations, product coal moisture, estimates of re-circulation from surface stored waters, rainfall and runoff to spoils and numerous other factors which are described in Umwelt, 2013.

Results of water balances over a number of years support a groundwater ingress to underground operational and subsided areas at UG3 of about 8.5 ML/day in January 2008 rising to about 10.5 ML/day in December 2009, 12.2 ML/day in September 2010 and 13.5 ML/day in October 2013.

4.0 COMPUTER SIMULATION OF PROPOSED MODIFICATION

Future mining will continue to extract coal from the Ulan seam in the open cut and underground areas. In underground areas, panel extractions will continue below the prevailing regional water table and will result in further depressurisation of the coal seam and overlying strata including Permian coal measures and Triassic strata. Depressurisation above the seam will continue to be enhanced through caving and subsidence, and a pressure (loss) wave will propagate beyond the extracted panels at a rate governed by the prevailing hydraulic properties of all strata and the drainage characteristics within the subsidence zone.

Evaluation of the pressure loss regime for seam extraction that includes simultaneous evolution of a subsidence zone, is extremely difficult and complex and requires analyses in both space and time. The most appropriate technique to undertake such analyses, is numerical simulation using computer based modelling techniques.

A computer model of the regional groundwater systems has been developed. The model computer code known as Modflow-Surfact (Hydrogeologic, 2010) employs a numerical finite difference scheme for solving a set of differential equations known to govern groundwater flow. The code is reasonably robust in handling steep hydraulic gradients and variably saturated conditions that commonly evolve above subsided panels.

The modelling method requires dividing the overall area of interest into a large number of separate cells defined by an orthogonal mesh which incorporates the proposed mine panel geometry, the seam extraction sequence, the spatial variations occurring in strata hydraulic properties, the prevailing drainage system, and the expected hydraulic gradients that evolve during the simulation period. The model layers adopt a geometry consistent with the known regional stratigraphy but with additional layers included to provide improved representation of strata groundwater pressures.

The model includes Ulan West, Ulan Underground 3, Ulan open cut operations, Moolarben Open Cut 1, Moolarben Underground 1 and 4 to ensure cumulative impacts are included. A summary of the model is provided in Appendix E.

4.1 Groundwater model properties and initial conditions

Properties assigned to the model that govern groundwater flow include hydraulic conductivity, elastic storage and specific yield. Hydraulic conductivities assigned to each model layer below layer 1 were initially informed by core testing (matrix conductivities only) as summarised in Appendices C and E. These values were then adjusted as part of the model initial calibration and subsequent re-calibration process. Resulting values suggest the regional flow system at depth is dominated by matrix intergranular flow rather than fracture flow except for the coal seams where cleating provides a network of flow conduits.

Boundary conditions were also assigned throughout the model. These are numerical conditions that constrain or bound the model domain. Prescribed head *river* cells have been used along the Goulburn River for the reach downstream of the confluence with Bobadeen Creek where river flow is assumed to occur at all times. These conditions enforce seepage from surrounding areas of elevated water table (relative to the river) to the river water level, or seepage from the river to surrounding strata if the water table in those strata is lower than the river level(s). Similar conditions have also been imposed on the Talbragar River in the western part of the model below the confluence with Mona Creek. Prescribed head *drain* cells have been used to represent all other reaches of the rivers and creeks which are assumed to be either intermittent or ephemeral. Assigning these conditions allows the model water table to drain to the creek lines if the elevation of the water table is higher than the creek bed elevations, or to fall below the creek bed without inducing leakage from the creek ie. the creek dries up. Drain cells have also been assigned to open cut areas, and to underground development headings, gate roads and longwall panels at elevations equivalent to the seam working section floor. These cells have been carefully scheduled to attract groundwater seepage in general accordance with the historical and proposed mine plans.

Distributed flux conditions have been employed to represent regional rainfall recharge. This recharge has been applied at differing rates across the model domain depending on the shallow and surficial geology present at particular locations.

Groundwater usage by local landholders for domestic, stock and irrigation purposes has not been included since this usage is small and would not measurably affect the model predictions.

4.2 Model re-calibration for approved mine plan

The assembled groundwater model has been calibrated against measured groundwater levels and historical mining operations. This process has involved both steady state and transient history matching of model predictions to measured water table and pore pressure data.

Steady state calibration aimed to generate a pre-mining water table nominally at January 1986 before open cut operations had advanced significantly below the water table and before any operations at Underground 3 had commenced. The procedure involved adjustment of strata hydraulic properties and regional rainfall recharge rates until a plausible match was achieved between the observed groundwater levels at a number of regional bore locations, and the predicted groundwater levels at those same locations.

The transient calibration process involved further adjustment of strata material properties and other parameters relating to the subsidence zone on a trial and error basis until predicted piezometric elevations and groundwater seepage to UG3 operations plausibly matched observed piezometric elevations and observed water make. Both calibration procedures are discussed in Appendix E.

Figure E5 in Appendix E illustrates the predicted pre-mining water table. This plot establishes a steady state baseline position and provides an understanding of groundwater flow directions and rates of flow. Flow path lines are also shown on Figure E5. These path lines describe individual water particle tracks over a long period of time and are useful in understanding the regional flow systems. The prescribed path lines that transgress the project area, support recharge in an area west and south-west of Ulan West which is partly within the proposed area of extended longwall panels. From this area the path lines describe a route either to the north and north-west in the Talbragar River catchment, or to the north-east and east eventually turning south-eastward and exiting the model down the Goulburn River catchment. The groundwater flow divide defined by these path lines is located up to 5 km west of the topographic Great Divide.

Figure 10 gives the approximate pre-mining submergence or saturated head in overlying Triassic sandstones which has been calculated by subtracting the floor of the Wollar Sandstone (lithic sandstone base) from the pre-mining water table. This plot shows the sandstone was saturated over most of the UG3 area prior to mining with zero saturation located at the southern extremity of the panel footprint. Increasing submergence to more than 100 m head of water, is indicated in north-eastern areas above panels LW29 to LW33 at UG3.

Figure 11 gives the predicted pre-mining submergence of the Ulan seam. This plot shows the seam was saturated over most of the underground and open cut areas prior to mining. Increasing submergence to more than 190 m of fully saturated strata (including Triassic sandstones) is indicated in north-east areas above panels LW29 to LW33 at UG3.

4.3 Mining induced depressurisation for modified mine plan

The groundwater model has been used to simulate depressurisation of the Ulan seam and overlying strata based on the modified mine plan for Ulan West which provides for increased extraction of coal after longwall LW6 (by extending panels southward) when compared to the approved mine plan.

Underground headings, gate roads, longwall panels and open cut strips have all been scheduled in the prediction model according to the mining timetable provided in Table 3. Re-sequencing of mining at UG3 has also been included in this schedule.

Figure 12 shows the extent of predicted depressurisation at the end of mining in 2029 while Figure 13 shows the drawdown relative to premining conditions. Figure 13 indicates complete dewatering of Triassic strata above all mined panels with depressurisation extending some 4 to 5 km beyond the panel footprint. Figures 14 and 15 indicate complete dewatering of the Ulan seam in mined panel areas with depressurisation impacts extending more than 20 km beyond the panel footprint.

Table 3: Panel extraction calendar for modified mine plan

Underground 3			Underground 3		
LW1	07-Dec-86	30-Nov-87	LW27	01-Feb-13	15-Nov-13
LW2	20-Dec-87	15-Oct-88	LW28	15-Jan-14	05-Feb-15
LW3	30-Nov-88	31-Aug-89	LW29	10-Apr-15	25-Mar-16
LW4	05-Dec-89	15-Sep-90	W3	02-May-16	04-Apr-17
LW5	15-Oct-90	04-Jan-92	LW30	11-May-17	02-May-18
A	15-May-92	30-Aug-92	W4	07-Jun-18	22-Jul-19
B	05-Oct-92	28-Feb-93	LW31	27-Aug-19	17-Aug-20
LW6	15-Mar-93	30-Jul-93	W5	22-Sep-20	19-Jan-22
LW7	07-Oct-93	30-May-94	LW32	24-Feb-22	28-Oct-22
LW8	15-Jun-94	15-Feb-95	W6	05-Dec-22	04-Mar-24
LW9	22-Mar-95	26-Oct-95	LW33	09-Apr-24	02-Oct-24
LW10	05-Dec-95	23-Aug-96	W7	07-Nov-24	21-Jan-26
LW11	25-Oct-96	26-Sep-97	W8	26-Feb-26	28-Apr-27
LW12	23-Oct-97	01-Jul-98	W9	03-Jun-27	10-Feb-28
LW13	29-Jul-98	21-Apr-99	W10	17-Mar-28	20-Sep-28
LW14	21-Jul-99	01-Apr-00	W11	26-Oct-28	17-May-29
LW15	31-May-00	22-Feb-01	Ulan West		
LW16	20-Mar-01	08-Oct-01	UW1	20-May-14	10-Apr-15
LW17	06-Nov-01	21-Jul-02	UW2	17-May-15	02-Apr-16
LW18a-b	26-Jul-02	23-Feb-03	UW3	08-May-16	17-Apr-17
LW19	11-Apr-03	03-Nov-03	UW4	23-May-17	30-Mar-18
LW20a-b	10-Dec-03	05-Sep-04	UW5	05-May-18	27-Mar-19
LW21	27-Oct-04	08-Jul-05	UW6	02-May-19	07-Apr-20
LW22	23-Sep-05	13-Jul-06	UW7	13-May-20	15-Jul-21
LW23	25-Oct-06	11-Sep-07	UW8	20-Aug-21	29-Sep-22
LW24	05-Nov-07	20-Mar-08	UW9A	04-Nov-22	09-May-23
W1	26-May-08	12-Feb-09	UW9B	17-Jun-23	21-Feb-24
LW25	01-Apr-09	01-Nov-09	UW10A	30-Mar-24	20-Sep-24
W2	20-Feb-10	12-Dec-10	UW10B	26-Oct-24	07-Jun-25
LW26	01-Jan-11	01-Feb-12	UW11A	15-Jul-25	05-Jan-26
LW-C	15-Feb-12	15-May-12	UW11B	11-Feb-26	10-Oct-26
LW-E	30-May-12	15-Aug-12	UW12A	15-Nov-26	07-Jan-27
LW-F	30-Aug-12	30-Nov-12	UW12B	12-Feb-27	01-Jul-27

Note: Dates indicate start and finish of a particular longwall (subject to change).

4.4 Mining induced depressurisation for approved mine plan

Figures 16, 17, 18 and 19 provide the extent of predicted depressurisation for the approved mine plan at the end of mining in 2029 and the calculated drawdowns. Figure16 has been compared to Figures 12 and the differences in piezometric heads at the end of mining have been calculated. Figure 20 shows these differences which as expected, are confined to the area where longwall panels have been extended southward. This area only exhibits saturation in the Permian strata above the Ulan seam and is expected to drain slowly after cessation of mining. The overlying Triassic strata remain virtually unsaturated as shown on Figure 10. Ultimately these strata are expected to be resaturated post mining.

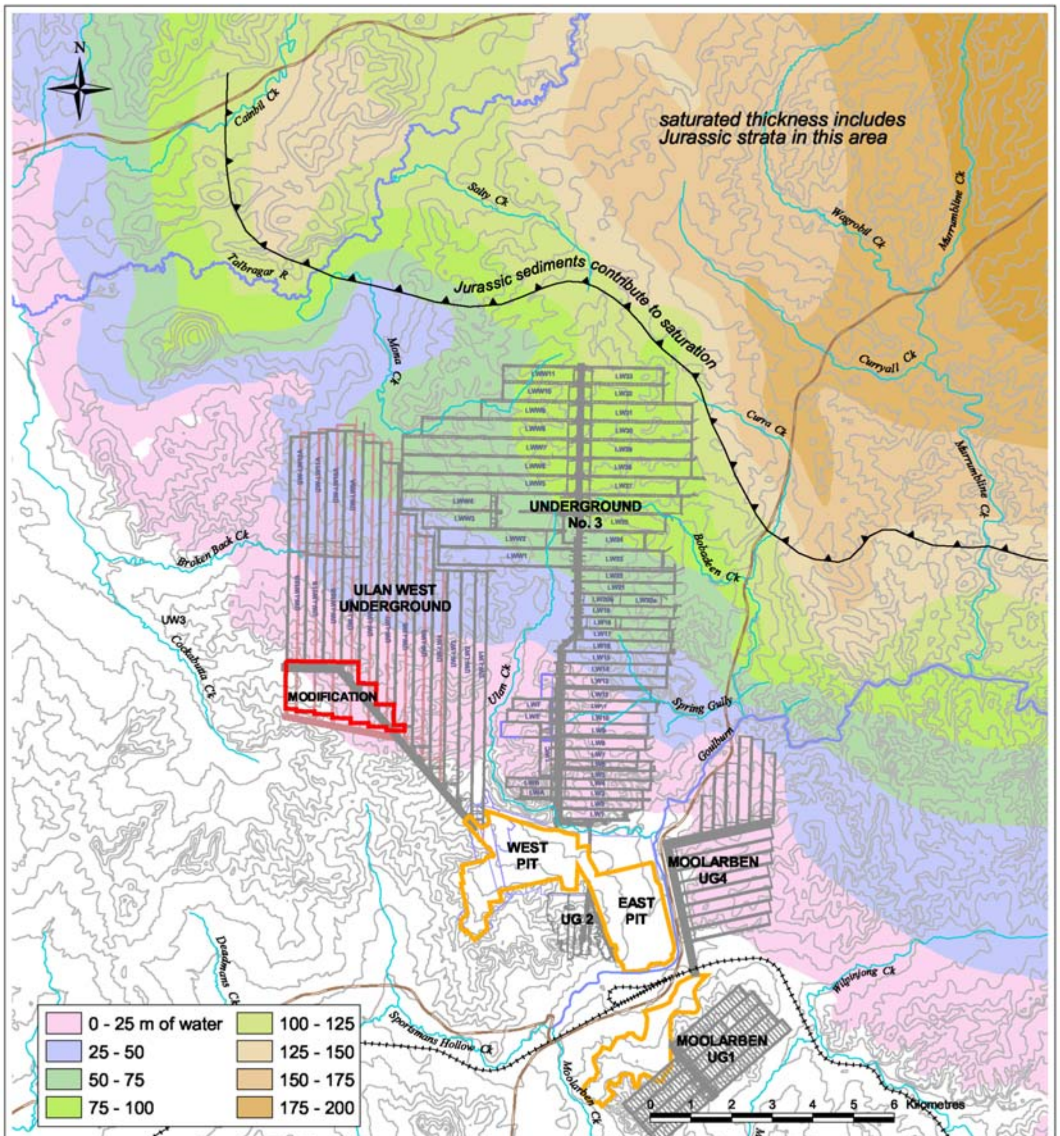

Figure 10: Saturated head of groundwater above the Triassic strata floor before mining

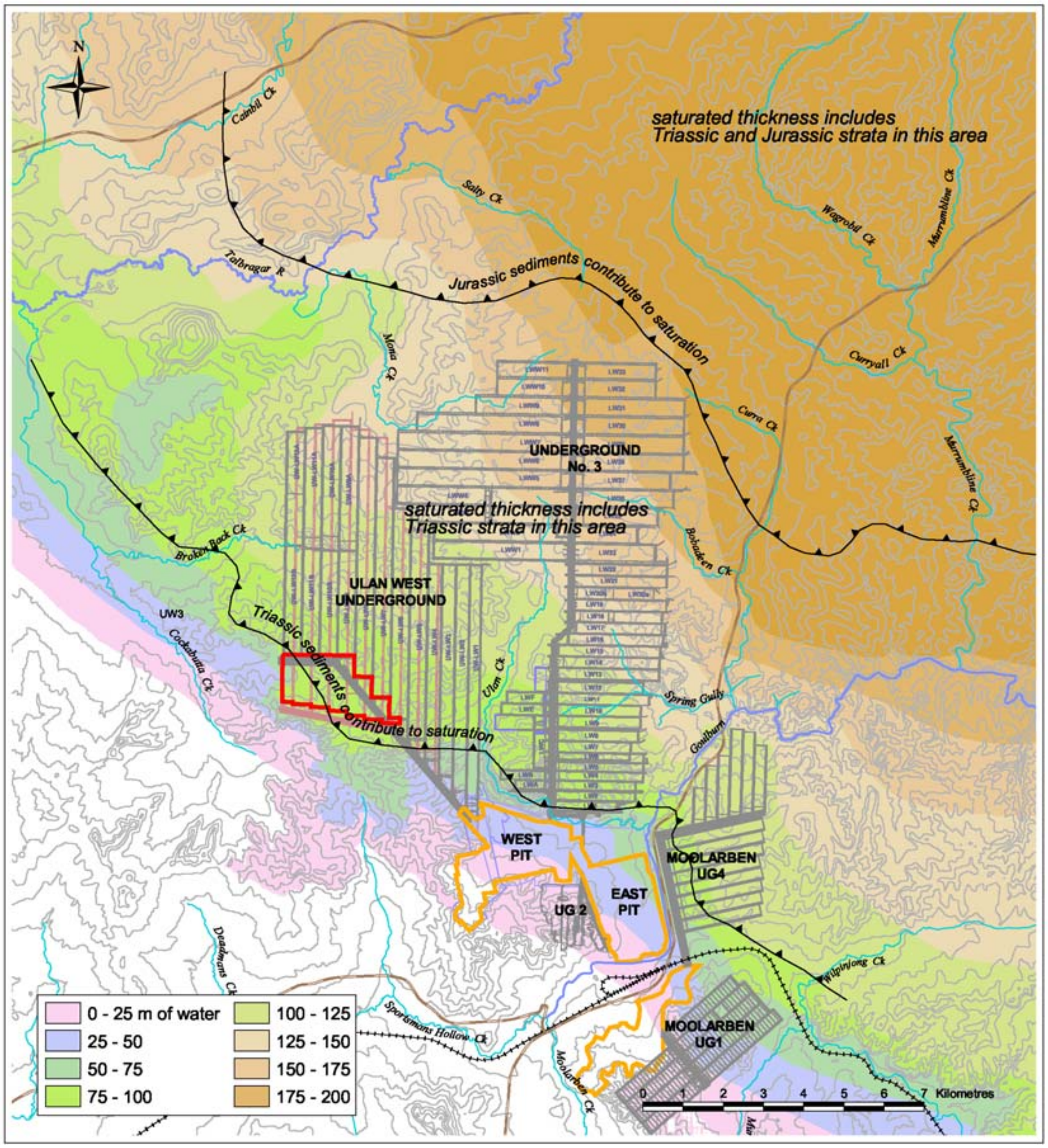

Figure 11: Saturated head of groundwater above the Ulan seam floor before mining

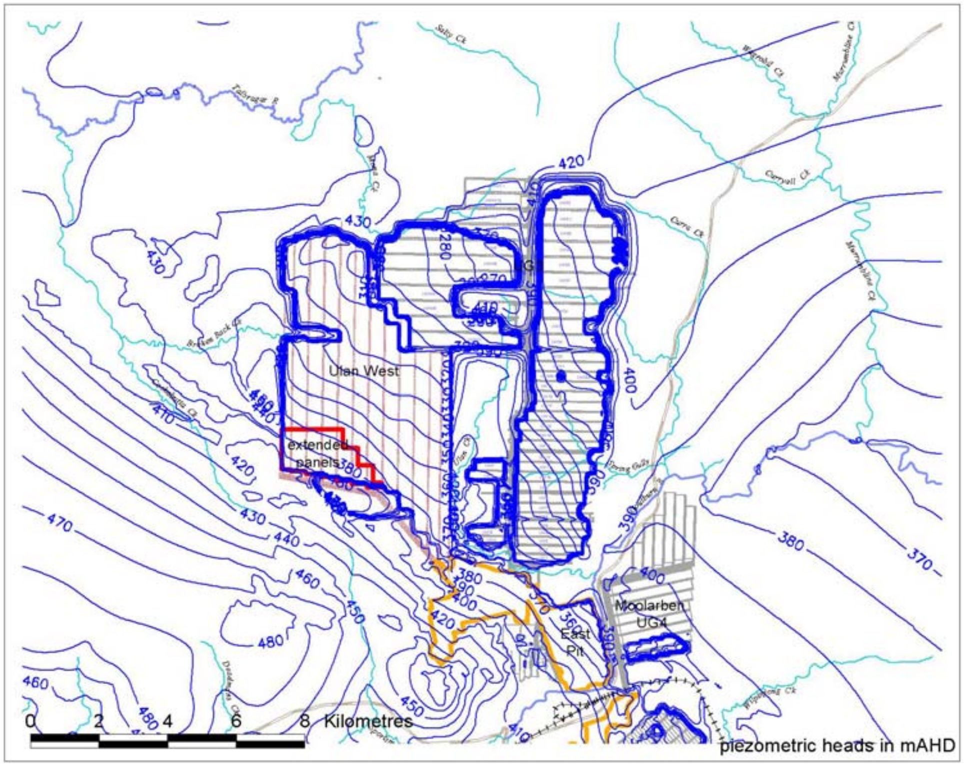

Figure 12: Simulated water table in Triassic strata for modified mine plan - 2029

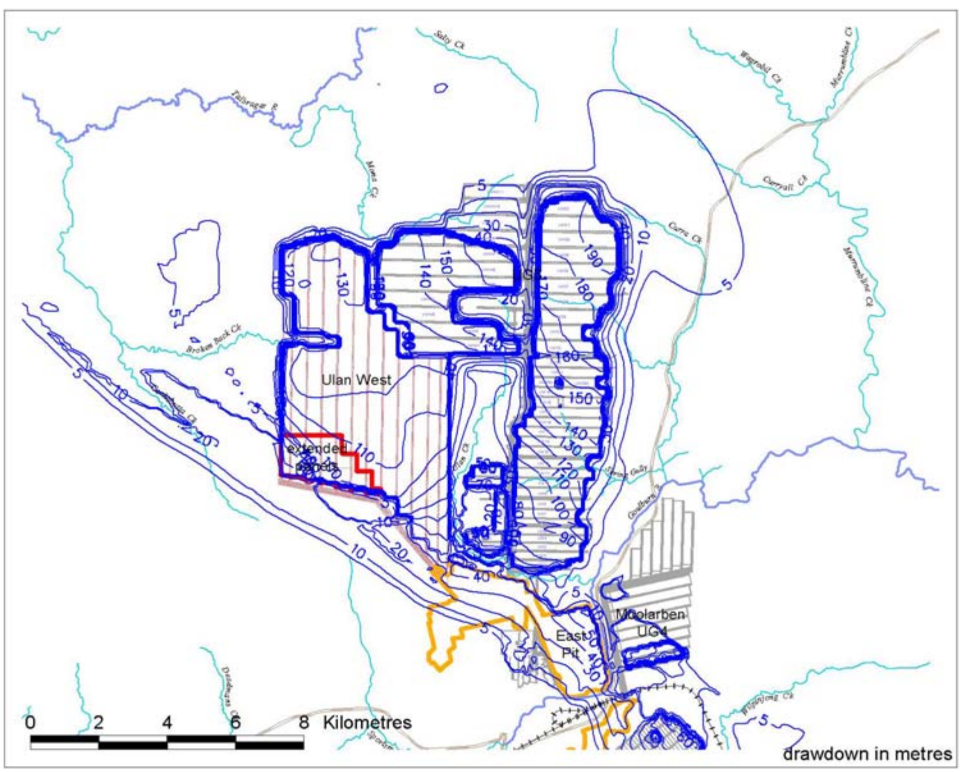

Figure 13: Simulated drawdowns in Triassic strata for modified mine plan - 2029

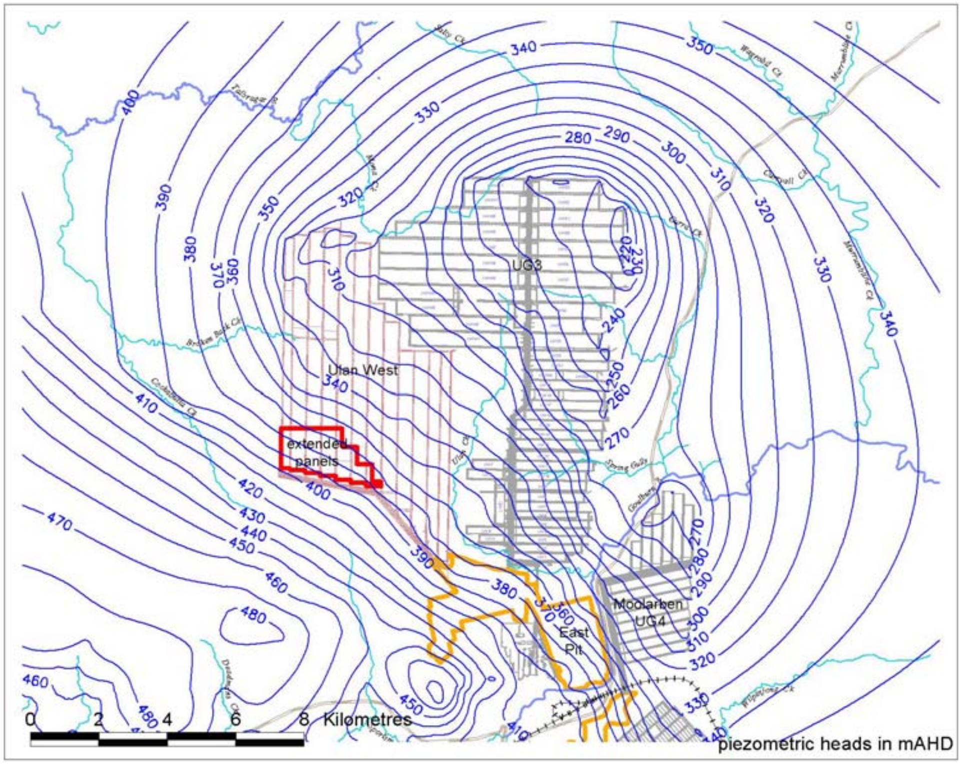

Figure 14: Simulated piezometric surface in the Ulan seam for modified mine plan - 2029

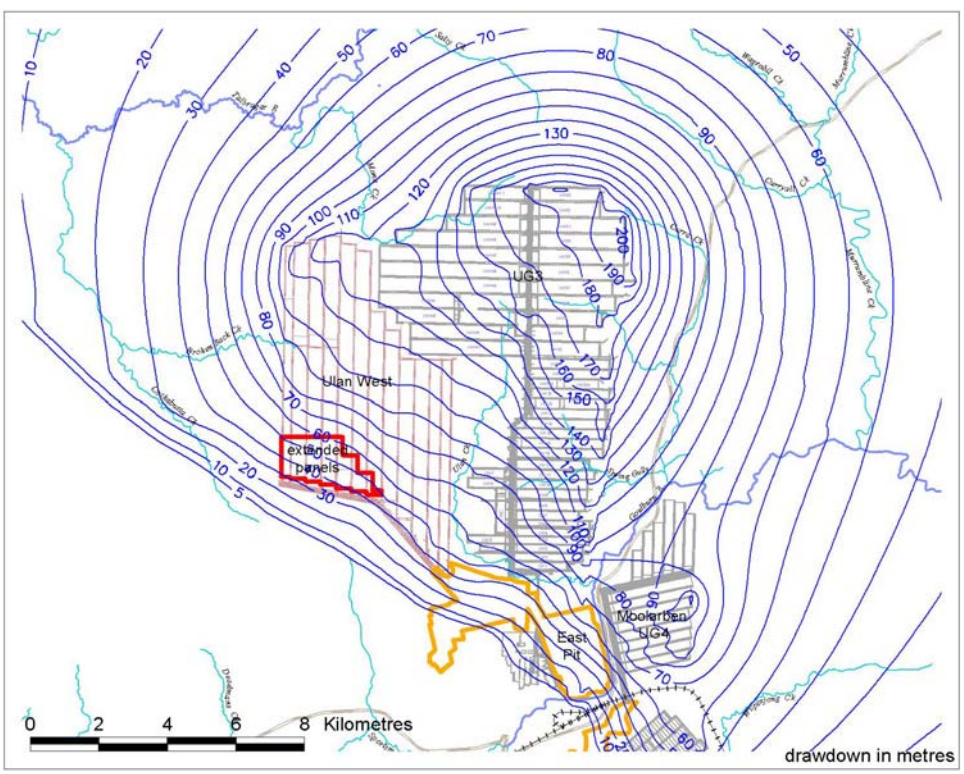

Figure 15: Simulated drawdowns in the Ulan seam for modified mine plan - 2029

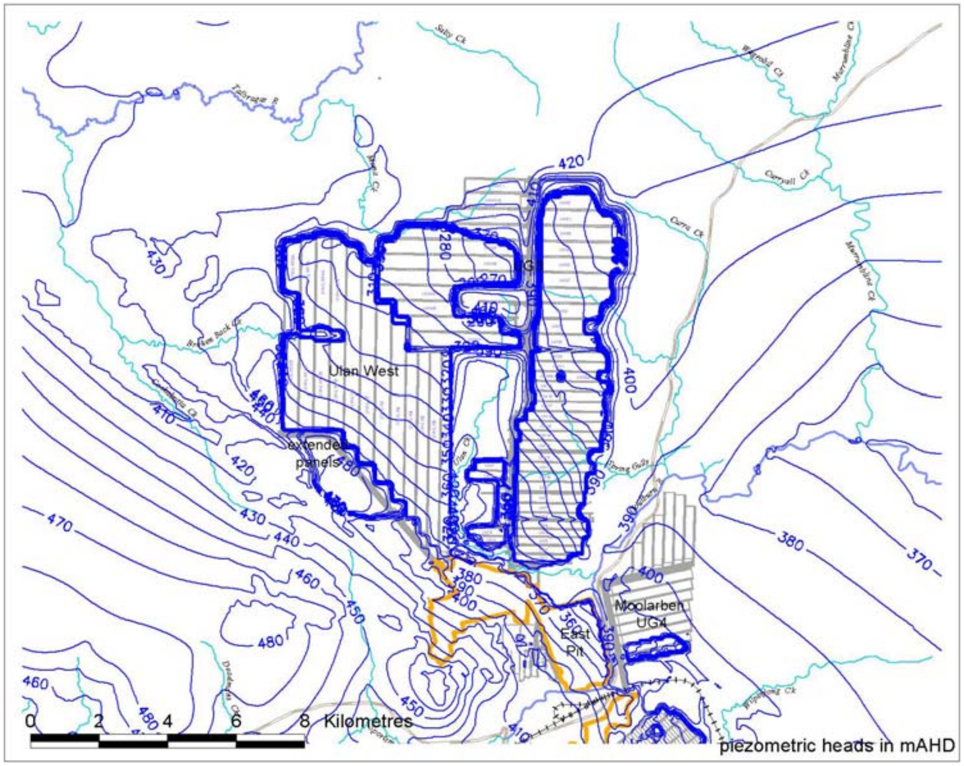

Figure 16: Simulated water table in Triassic strata for approved mine plan - 2029

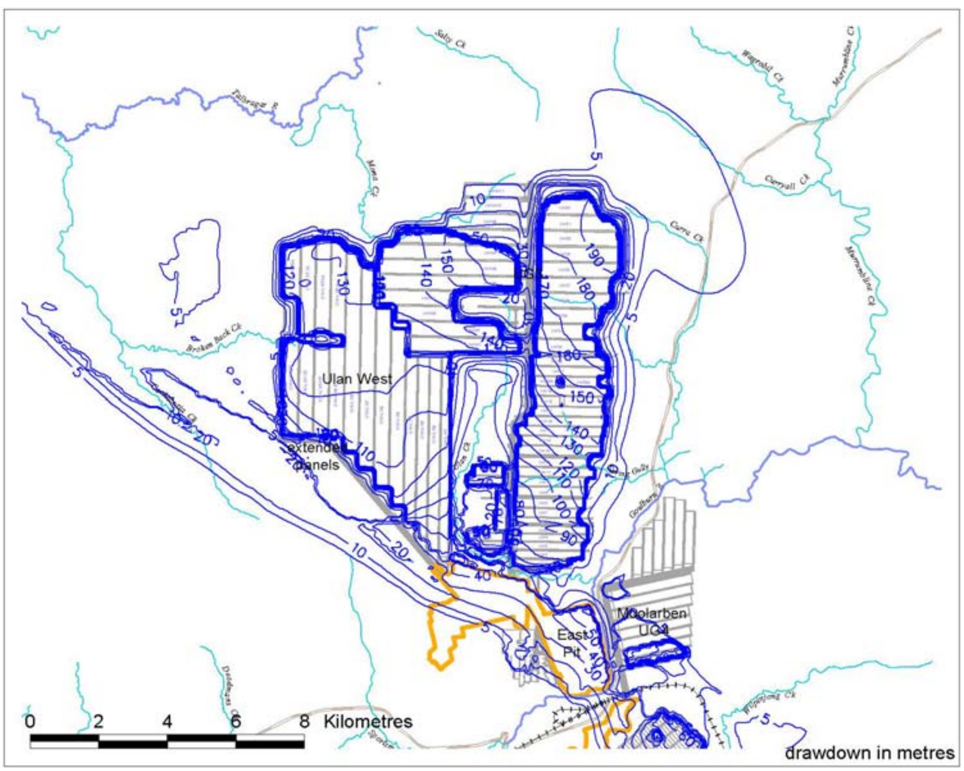

Figure 17: Simulated water table drawdowns in Triassic strata for approved mine plan - 2029

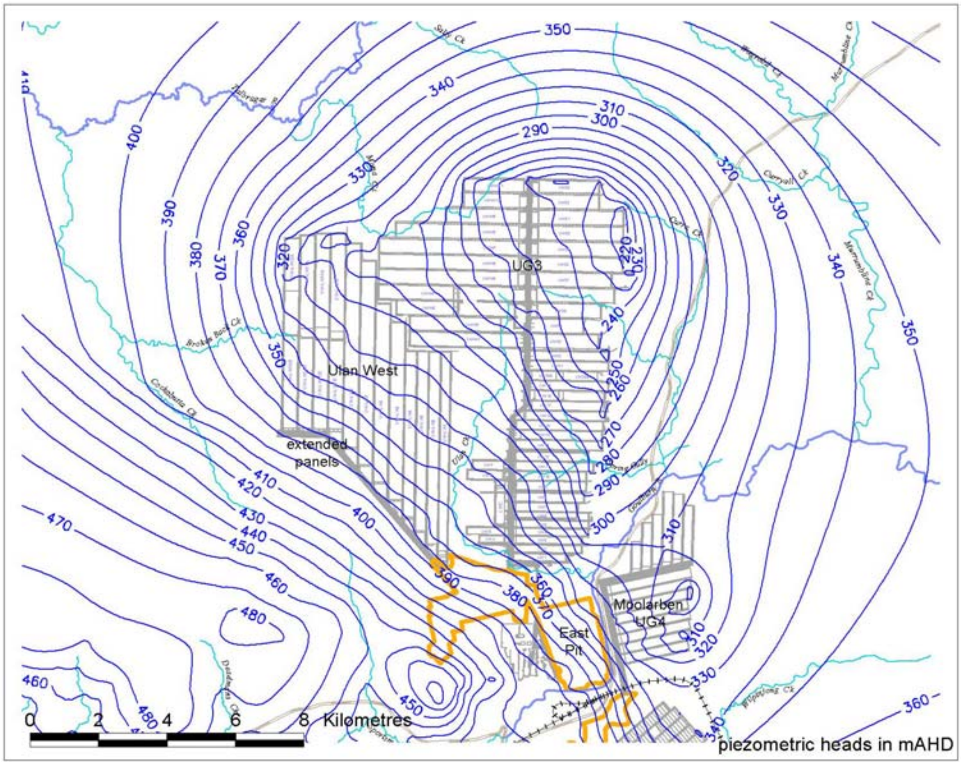

Figure 18: Simulated piezometric surface in the Ulan seam for approved mine plan - 2029

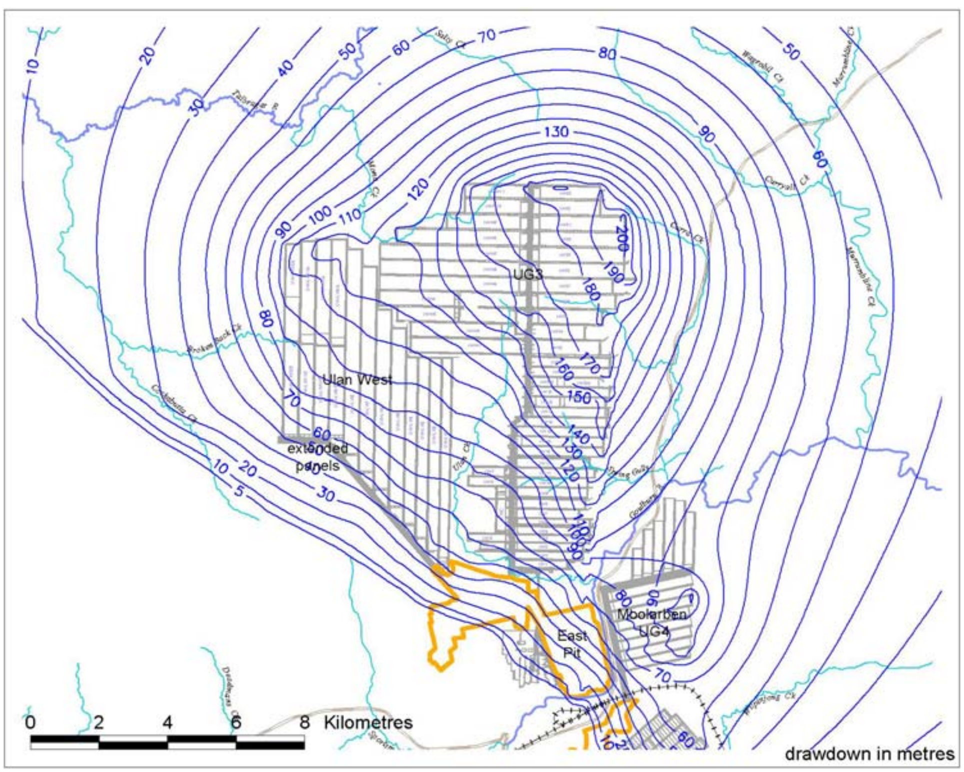

Figure 19: Simulated drawdowns in the Ulan seam for approved mine plan - 2029

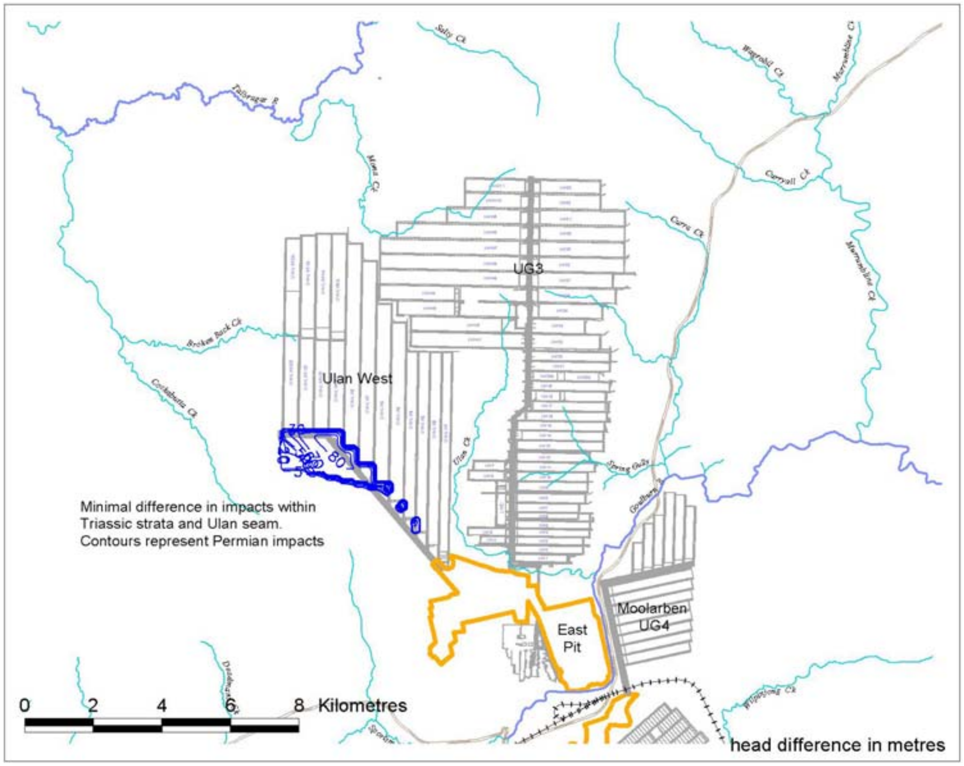

Figure 20: Difference in drawdown (impact) between modified and approved mine plans - 2029

4.5 Predicted seepage to modified underground operations

Specific groundwater inflow budgets have been extracted from both groundwater models on completion of the simulation period. These budgets provide estimates of mine water influx for the modified and approved mine plans. Results are summarised on Figure 21 for Ulan West and Underground 3 operations respectively. Reference to Figure 21 indicates a predicted water make for the modified mine plan at Ulan West which rises from commencement of development in 2012 to about 6 ML/day by 2016 as the first two panels are extracted. The inflow rate peaks in 2022 at about 12.5 ML/day during the extraction of panel LW8. The rate is then predicted to decline as the remaining panels LW9 to LW12 are extracted.

Inflows for the approved mine plan are shown for comparison. As expected, the rate is almost identical for longwalls LW1 to LW6 and lower for subsequent panels (due to the shorter panel lengths) with a peak inflow rate of 11.3 ML/day predicted in 2021-2022.

Total volumes of groundwater reporting to Ulan West over the mine life are calculated to be 52.3 GL for the Modified mine plan and 51.2 GL for the approved mine plan. The difference of 1.1 GL represents about 2.1% increase in dewatering. This groundwater is drawn almost entirely from Permian strata overlying the Ulan seam since Triassic strata in the area of extended longwall panels are either unsaturated or partially saturated with only a few metres submergence (see Figure 10).

Figure 22 provides a predicted water make in Underground 3 and the total water make for UG3 and Ulan West. The rate of influx at UG3 rises to 16 ML/day in 2016 and then broadly plateaus to 2020. After that time the seepage rate increases to about 20 ML/day as a consequence of longer panels W5 to W8 being mined (increased rate of coal extraction) together with greater contributions from the Triassic strata due to increasing submergence. The total water make is estimated to peak at about 28 ML/day in 2023.

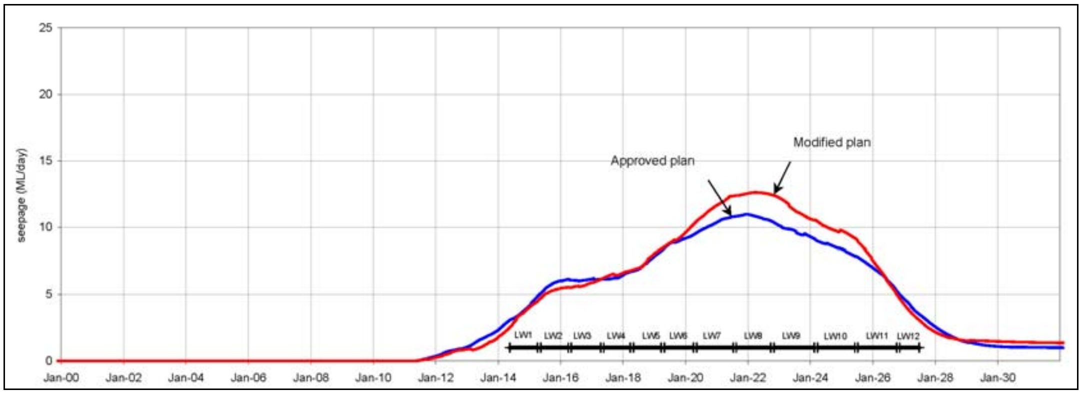

Figure 21: Predicted groundwater seepage reporting to the water management system at Ulan West

The predicted groundwater inflows are based upon the schedule of panel extractions given in Table 3. Any delays in this schedule are likely to reflect as reductions in peak daily inflows.

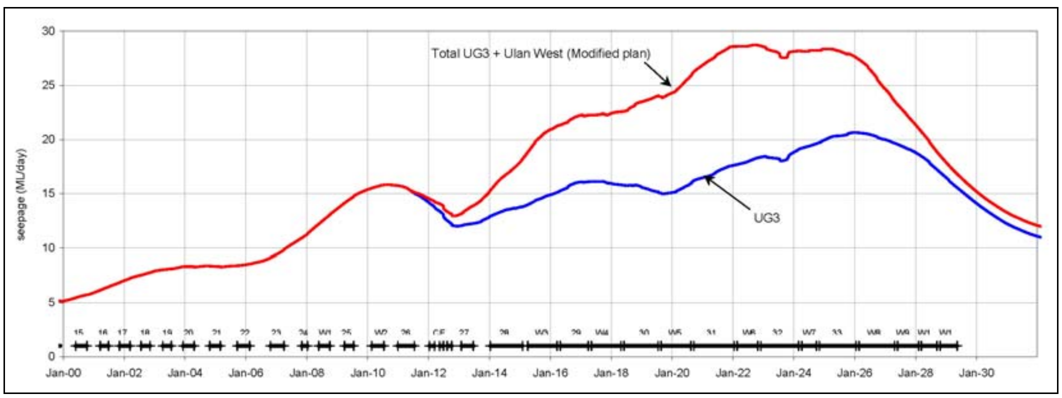

Figure 22: Predicted groundwater seepage reporting to the water management system at UG3

4.6 Baseflow losses to regional rivers and creeks

The impact of shallow depressurisation on groundwater baseflows from the deep hardrock strata to the regional drainage systems has also been extracted from the simulation model. Results demonstrate almost complete loss of baseflow to Ulan Creek and parts of Bobadeen Creek (including Spring Gully) catchments, by 2020. Losses to the Goulburn River tributaries above Ulan township are negligible while losses over the reach from Ulan township to the confluence with Bobadeen Creek are predicted to be sustained over the entire mining period. Summation of losses for the Goulburn River catchment indicate a decline over the cumulative mining period (1986-2029) of less than 0.15 ML/day for the total drainage system extending to the eastern extremity of the model.

It is noted that these flows represent only part of total baseflows. They do not include the more commonly recognised contributions from unconsolidated stream bank (and regolith) systems which are often perched and respond to rainfall and stream flows which are event based (eg. Mona Creek alluvium). The localised scale of these processes and their changes in storage due to rainfall events, precludes their inclusion in the groundwater model. Table 4 provides a summary of losses associated with the deeper hardrock system.

Mona Creek catchment is the most affected catchment providing baseflow to the Talbragar River but sustained losses are also noted in Cockabutta Creek catchment. Summation of losses for the Talbragar River catchment indicate a decline over the mine life of 0.185 ML/day for the Modified mine plan. This is a very small increase of 0.002 ML/day when compared to the Approved mine plan (0.183 ML/day).

Table 4: Estimated baseflow losses for approved and modified plans – recalibrated model

Period	Approved plan		Modified plan	
	Goulburn R. (ML/day)	Talbragar R. (ML/day)	Goulburn R. (ML/day)	Talbragar R. (ML/day)
1986 to 2010	0.082	0.059	0.082	0.059
2010 to 2029 – end of mining	0.039	0.183	0.039	0.185

4.7 Recovery of groundwater pressures post mining

Mining is expected to cease at Ulan West in 2027-2028 following extraction of panel LW12B. Mining is also expected to cease at Underground 3 in 2029 following extraction of panel W11. After this time regional groundwater pressures and the water table will begin to adjust and rebound towards a long term equilibrated state. The rate of rebound will be dependent upon numerous factors including:

- the potentiometric head distributions of groundwater held in storage within the surrounding hard rock strata at the cessation of mining;
- the hydraulic properties of goaves and the overlying fractured (subsided) zone;
- the ongoing gravity drainage of strata above mined panels until piezometric heads equilibrate;
- potentially changed rates of subsurface recharge from rainfall runoff as a result of connective cracking above goaves;
- and the final landform for rehabilitated open cut areas.

Recovery of strata pore pressures has been simulated by adopting the groundwater pressure distributions at 2029 as initial conditions for a transient recovery model. This distribution assumes that all goaves (Ulan West and Underground 3) will be maintained in a fully dewatered state until mining ceases. After that time the operations are simply left to recover without further pumping from underground or open cut voids.

The predicted long term steady state water table for the modified mine plan, is shown on Figure 23. It resides mostly in Triassic sandstone strata with full re-saturation of underlying strata. The geometry of this water table differs from the pre-mining water table due to changed hydraulic properties of the strata and changed rainfall runoff and recharge in open cut areas. Hydraulic properties changes include underground roadways which have been assigned high permeability and maximum (100%) porosity, caved zones and overlying subsided zones which retain the same permeability as adopted in the impact prediction modelling. Emplaced spoils in open cut areas have also been assigned elevated hydraulic properties as summarised in the following Table 5. Rainfall recharge via surface cracking has been maintained at pre-mining rates above goaves but enhanced rates have been applied in rehabilitated spoils areas.

The difference between the water table shown on Figure 23 and the pre-mining water table (see Figure E5, Appendix E) is provided on Figure 24 as the long term residual drawdown impact for the modified mine plan.

Table 5: Material properties assigned to the recovery model

Area	Kxy (m/day)	Kz (m/day)	Ss (1/l)	Sy
underground roadways	4.0E+02	4.0E+02	1.0E-05	1.0E+00
goaves	1.0E+02	1.0E+02	1.0E-05	1.0E-01
fractured subsidence zone	5.0E-02	8.0E-03	1E-05	7.5E-02
spoils	1.0E+00	1.0E+00	1.0e-05	1.0e+00

Figure 25 shows the long term difference in drawdown impacts between the modified and approved mine plans. These figures demonstrate the following:

- ultimate recovery above mine panels is likely to generate a depressed water table towards the southern end of longwalls at Ulan West as a result of reduced depth of cover and enhanced hydraulic conductivities from cracking within the subsidence zone;
- a relatively flat lying water table over the remaining areas of Ulan West and most of Underground 3;
- long term impacts associated with the modified and approved mine plans are generally restricted to the areas of changed geometry or extension of longwall panels (see Figure 25). Most of the difference in impacts is attributed to an area of about 4 sq.km at the southern ends of longwalls LW6 to LW12 – where panel extensions are proposed. Localised impact areas are also noted at the northern ends of longwalls LW7 to LW12 associated with a westward offset of panels, from the approved mine plan. Beyond these areas the regional impacts are identical.

The time taken to achieve a steady state is predicted to be in excess of 300 years.

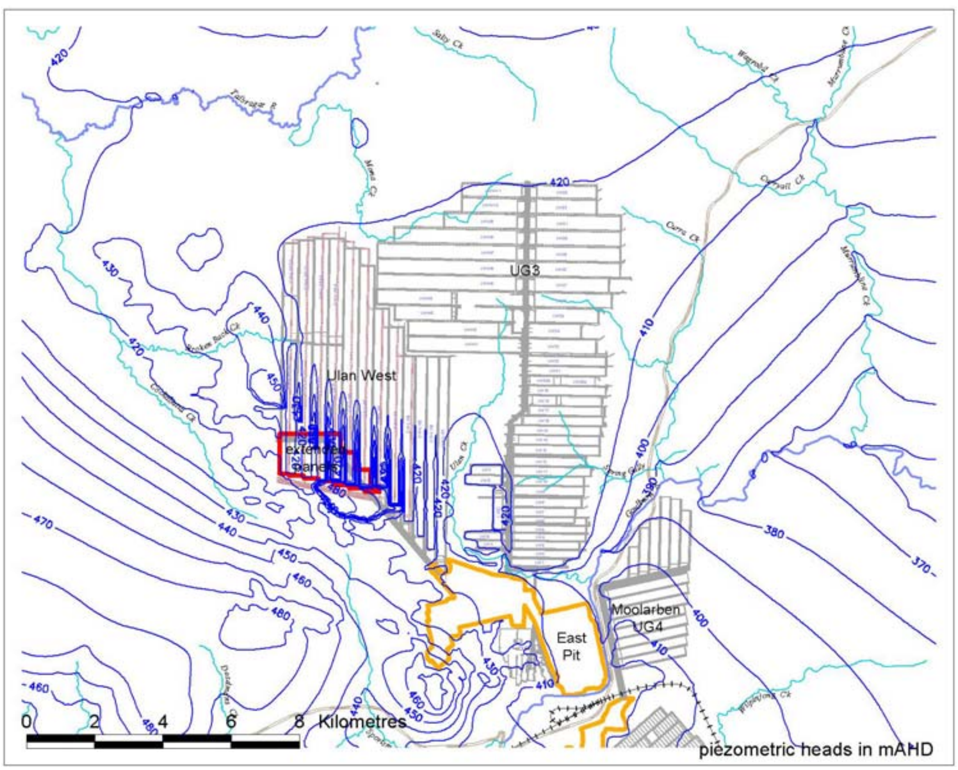

Figure 23: Long term steady state water table for modified mine plan

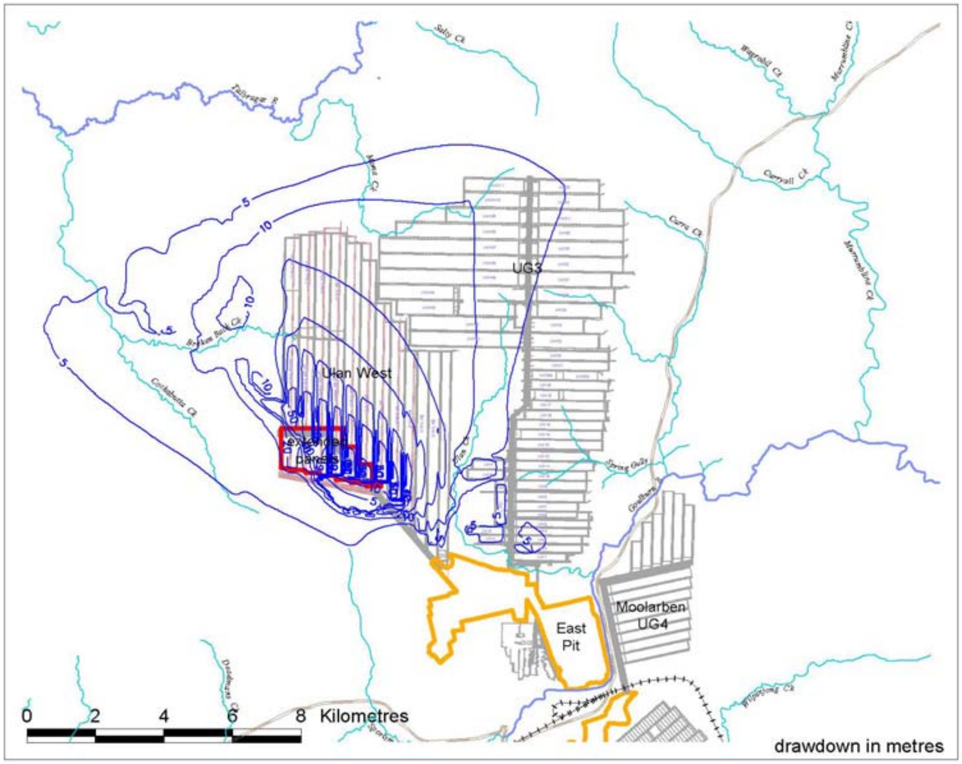

Figure 24: Long term steady state residual drawdown for modified mine plan

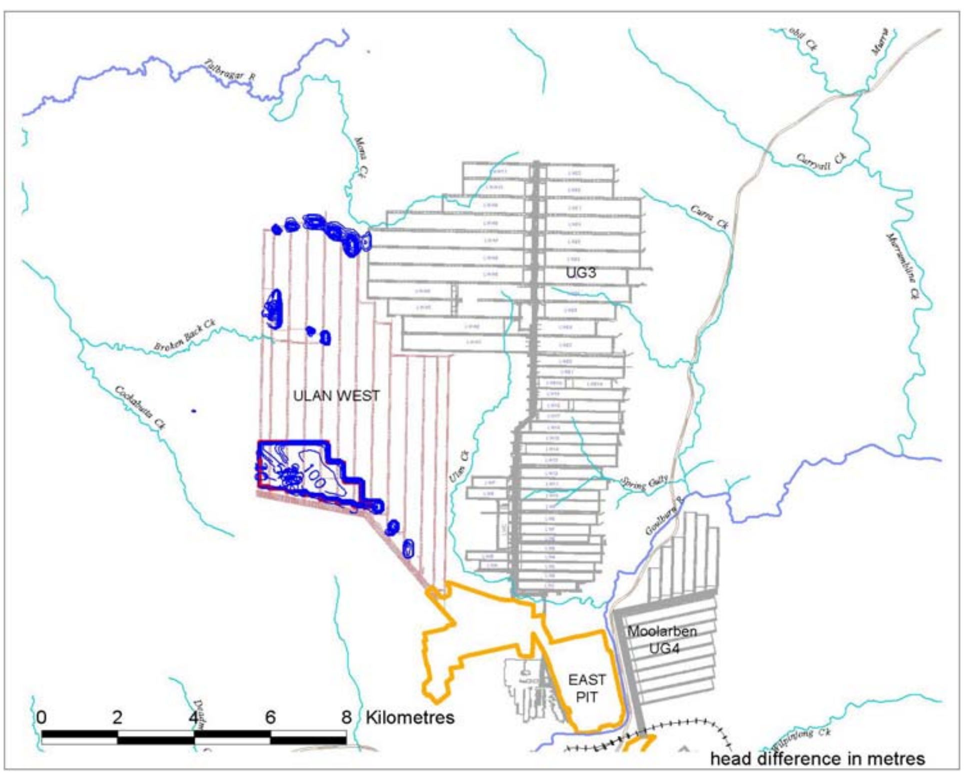

Figure 25: Difference in residual drawdowns between approved and modified mine plans

5. POTENTIAL ENVIRONMENTAL IMPACTS

The proposed modification of the mine plan for Ulan West would induce additional change to the local groundwater environment when compared to the approved mine plan. Potential impacts arising from the Modification include:

- Sustained reduction in regional hard rock aquifer pressures;
- Loss of groundwater yield at some existing bore locations;
- Change in groundwater quality in the strata;
- Impact on groundwater dependent ecosystems.

5.1 Reduction in regional hard rock pressures and baseflow impacts

Continued mining of the Ulan seam will sustain a pressure loss regime in the regional hardrock strata. This pressure loss regime has been assessed using groundwater modelling techniques described in Section 4 above. Strata depressurisation and dewatering is predicted to migrate upwards from extracted longwall panels, through the subsidence zone to the Triassic (Wollar) sandstones where near complete drainage is expected (over the longwall panel footprint). Reductions in potentiometric head in these sandstones are also predicted to extend some 3 to 4 km beyond the panel footprint except in the Moolarben area where the impact of dewatering and depressurisation due to MCM open cut and underground mining will extend the regional pressure reductions further to the east and south-east beyond the extents of the UCML model. Groundwater pressure reductions in the Ulan seam are more widespread than the shallower Triassic strata in the UCML project area and are predicted to migrate distances of more than 20 km beyond the panel footprint in the long term before receding as the system recovers after cessation of mining.

Groundwater seepage to Ulan West operations associated with the Approved mine plan is predicted to rise steadily to a peak inflow rate of about 11.3 ML/day in 2022 while seepage associated with the Modified mine plan is predicted to peak at about 12.5 ML/day in 2023.

The total volume of groundwater reporting to the proposed Modification is estimated to be 52.3 GL compared to a total volume of 51.2 GL for the Approved mine plan. This represents an increase of about 2.1% which is considered to be minor. The additional groundwater will be drawn almost entirely from Permian strata. Groundwater quality is expected to exhibit a TDS>900 mg/L and a speciation signature Mg,Na>Ca and HCO3,Cl>SO4. Mixing with coal seam water during mining may elevate the TDS. Since the Permian strata also exhibit low hydraulic conductivities and porosities, they are considered to have low utility value for groundwater supply purposes.

The reduction in groundwater system pressures caused by Ulan West and UG3 operations is predicted to have an impact on baseflow seepage to surface drainage systems within the catchments. At the close of mining it is predicted that losses to the Goulburn River catchment may be of the order of 0.183 ML/day while losses to the Talbragar River catchment may be of the order of 0.039 ML/day. Losses attributed to the proposed modification are negligible.

The Drip is recognised as a an important natural feature located to the east of Underground 3 which sustains groundwater dependent ecosystems. It is sustained by surficial and relatively shallow perched groundwater storage which is governed mostly by short term rainfall events that surcharge the shallow strata in the manner described above. Rainfall recharge and downwards percolation is intercepted at horizontal bedding planes which then transmit the groundwater to the unconfined rock faces along the Goulburn River gorge where it emanates as seeps and drips. During dry periods some seeps may cease to flow. Seepage that migrates past this shallow perched system, sustains the deeper water table and from numerical modelling, is calculated to be less than 5 mm/year or less than 1% of annual average rainfall. Depressurisation of Triassic strata in the area of the Drip has already occurred as a result of historical mining operations at UCML and no impacts on the perched groundwater system have been observed to date. No impacts on the perched system are likely as a result of future UCML operations which are moving northward and westward away from the Drip.

5.2 Loss of groundwater yield at existing bore locations

Relatively shallow groundwater resources have been accessed by the construction of bores and wells throughout the region by local landholders. The locations of existing water supply structures have been determined from a records search on the NOW database. This database contains all registered structures and includes both pumping bores and wells, and exploration/test bores which have been completed as monitoring structures. Appendix B provides a summary of known locations of bores and wells.

Figure B1 in Appendix B identifies bores located within a zone extending some 8 km or more beyond the longwall panel footprint for UG3 and Ulan West Modified mine plan. There are no boreholes located within or in proximity to the proposed Modification area that could be affected by mining induced drawdowns.

5.3 Change in groundwater quality

It is unlikely that any regional change in groundwater quality will be observed in hard rock strata as groundwater pressures decline above and adjacent to mined panels within the modified mine plan. Localised change in salinity at depth may be observed as groundwaters contained within different stratigraphic horizons mix, as is already evident from historical monitoring of groundwater migrating through goaves at UG3.

Similarly, it is unlikely that any measurable change in water quality will be observed in the shallow unconsolidated alluvial aquifer systems (eg Talbragar River alluvium) since these are either remote from the Modification and/or they are frequently recharged by rainfall.

However, on cessation of mining, significant dilution of Permian strata and mine water salinity is expected as Triassic groundwaters continue to migrate downwards through the subsidence zone to goaves and through to existing roadways and headings. Mine waters are expected to reflect a TDS range of 1000 to 2000 mg/l with increasing sulphate presence up dip. Triassic groundwaters typically range from 300 to 600 mg/l and with sustained contributions from these waters during recovery post mining, mine waters in underground operations are expected to progressively dilute with a long term groundwater salinity calculated to lie somewhere in the range 700 to 1300 mg/l.

5.4 Impacts on groundwater dependent ecosystems

There are no identified groundwater dependent ecosystems within the Modification area. However any as yet unidentified local spring systems that might be present within the subsidence footprint, may be affected if cracking of the subsurface occurs in proximity to such features.

5.5. Aquifer Interference Policy

The Aquifer Interference Policy (AIP) identifies two groundwater sources – highly productive systems and less productive systems. The groundwater systems contained within Permian coal measures and Triassic strata within and in proximity to the proposed Modification area, are regarded as less productive systems due to the generally low groundwater transmission properties of these materials. The less productive nature of the Permian strata is also reflected in an absence of water supply boreholes drawing groundwater from these same strata.

Groundwater related impacts (identified in Figure 20) have been assessed in respect of minimal harm criteria prescribed in Table 1 of the AIP as follows:

- ***Water table (1)*** – *Impacts to be less than or equal to 10% cumulative variation in the water table and 40 m from any high priority groundwater dependent ecosystem or high priority culturally significant site.* There are no high priority groundwater dependent ecosystems or high priority culturally significant sites identified in the impact area.

- ***Water table (1)** – A maximum of 2 m decline at any water supply work is allowed unless make good provisions apply.* There are no water supply works within or in proximity to the Modification area.
- ***Water pressure (1)** – A cumulative pressure head decline of not more than 40% (maximum 2 m) of the post water sharing plan pressure head above the base of the water source is allowed.* A pressure head decline will exceed 40% in the Triassic sandstones which are variably saturated with a pre-mining saturated head estimated to vary from zero to about 3 m. Permian strata will be dewatered. However, there are no water supply works within or in proximity to the area that will be affected.
- ***Water quality (1a) -** Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity*. No long adverse water quality is predicted since subsided areas will essentially reflect unsubsided conditions with respect to aquifer material properties and rainfall recharge.
- ***Water quality (1b) -** Increase in salinity to be less than 1% of the long term average salinity.* No long term adverse change in salinity is predicted since subsided areas will essentially reflect unsubsided conditions with respect to aquifer material properties and rainfall recharge.
- ***Water quality (1c) -** Mining activity should not be undertaken within 200 m laterally or 100 m vertically of a highly connected alluvial aquifer water source.* There are no highly connected water sources within or in proximity to the area that will be affected.

6. LICENSING REQUIREMENTS

UCML operations are located across the Great Divide which separates the Murray Darling Basin (MDB) surface water catchment to the west, from the Goulburn-Hunter River catchment to the east (see Figure 1). With the introduction of the Water Management Act (2000), NSW Office of Water developed water sharing plans (WSP) to promote the sustainability of water resources across the state. A central part of these plans requires the licencing of any groundwater take from defined water sources.

Two WSP's are relevant to UCML operations:

1. The Hunter Unregulated and Alluvial system east of the Great Divide (Goulburn Extraction Management Unit) applicable to surface water sources and connected alluvial systems. A WSP for hardrock systems (Permian, Triassic and younger) east of the Great Divide is not enacted at this time. Until the WSP is enacted, water take from these systems is required to be licenced under the Water Act (1912);
2. The MDB Porous Rock Groundwater system west of the divide. The relevant water source for the MDB Porous Rock Groundwater system is the Sydney Basin. The area of the Sydney Basin water source impacted by UCML operations lies within two management zones defined under Clause 5.1 (b) of the WSP as (i) the 'Macquarie-Oxley' zone which includes all porous water bearing strata excluding Permian and Triassic rocks which have been relegated to the 'Other' zone, and (ii) the Other zone which includes Permian and Triassic age rocks (see Figure 26).

The groundwater take from the three management areas has been determined using the groundwater model for the modified mine plan. Mine seepage flows have then been accumulated into the MDB 'Other' zone for areas west of the Great Divide or the Goulburn River catchment 'Water Act' zone east of the divide. The highest daily rate is associated with the Sydney Basin Other management unit west of the divide which peaks at about 21 ML/day in 2022-2023. A lower rate of 18 ML/day has been determined for the Goulburn River catchment where the Water Act applies. Table 6 provides a summary estimate of future licencing volumes.

Table 6: Inflow to UCML operations and calculated licence volumes for the life of the mine

Management area	Peak daily flow (ML)	Peak annual flow (ML)	Annual Licence req'd (ML)
Goulburn R. catchment	18 (2017)	6570	6570
MDB Sydney Basin Other	21 (2020)	7660	7660
MDB Macquarie Oxley*	0.0	0	0

* impact on non Permian-Triassic strata is negligible.

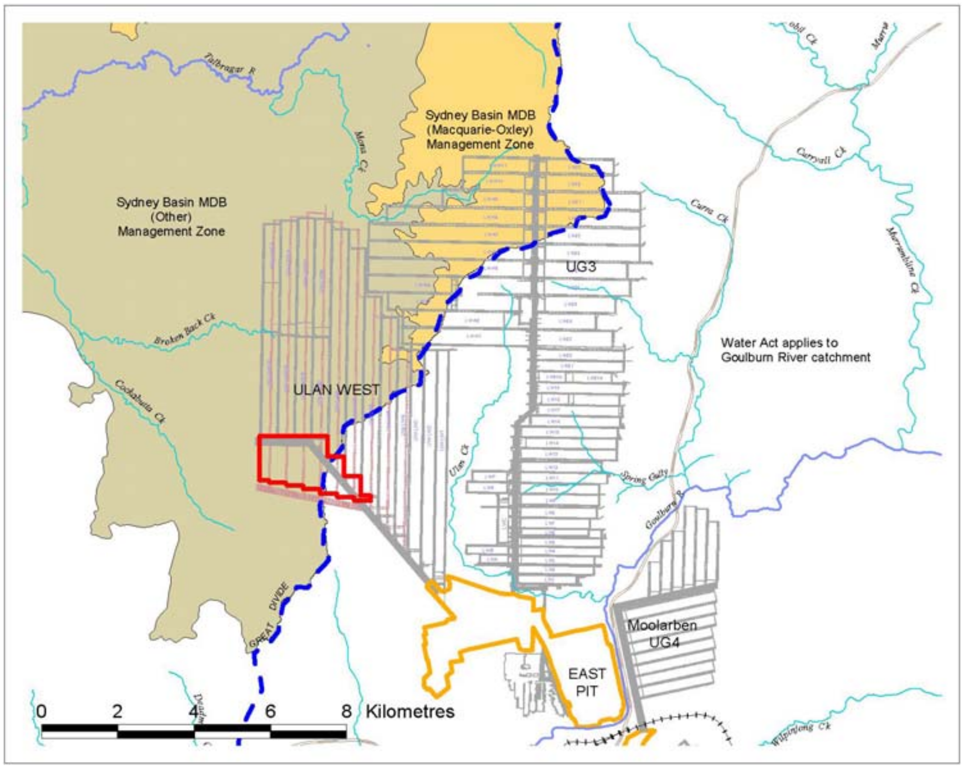

Figure 26: Prescribed water sources (Water Sharing Plans) associated with UCML operations

7. IMPACTS VERIFICATION

The established groundwater monitoring networks must be maintained and augmented as mining operations expand to the west. Information should be used to validate and verify model predicted depressurisation of strata and predicted seepage to the underground workings.

Future groundwater monitoring should include:

- continued measurement of groundwater levels, pressures and water quality (EC, pH and major ion speciation) within the existing regional network of standpipe monitoring bores and any expanded network;
- continued measurement of groundwater seepages and water qualities (EC and pH) within the mine water systems for Ulan West and other UCML operations;
- compliance monitoring and measurement of any surface water discharges including quality monitoring of major ions and specific rare elements.

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IMPORTANT INFORMATION ABOUT YOUR HYDROLOGICAL REPORT

Mackie Environmental Research (MER) has applied skills, standards and workmanship expected of Chartered Professionals 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 underpinning the study, MER notes that 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 contained in the original data 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 or depths. 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.

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APPENDIX A: RAINFALL ANALYSES

Rainfall data for Gulgong 062013 provides the nearest long term record to the project area. The long term annual average for this gauge is about 650mm.

Daily rainfall data has been processed to generate recurrence intervals and average exceedance probabilities for periods up to 30 days. Durations statistics are based on screening of daily rainfall data within each year of available records from 1900 to 2014 - a log normal distribution is assumed. The following Table A1 provides a summary.

Table A1: Longer term intensity, frequency, duration statistics for 112 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	30 day
once in 1 year	63.2	50	63	69	73	77	81	87	92	104	116	137
once in 2 years	39.3	61	77	85	90	95	99	107	113	129	143	169
once in 5 years	18.1	76	96	106	113	120	124	133	141	162	179	211
once in 10 years	9.5	86	110	121	130	138	142	152	162	187	206	242
once in 20 years	4.9	97	124	137	147	155	160	171	183	210	233	273
once in 50 years	2.0	111	142	156	169	179	184	196	210	242	268	313
once in 100 years	1.0	122	156	172	186	197	202	215	231	267	295	344

Values are mm of rainfall.

ARI (Average Recurrence Interval) means – the average or expected value for the periods between exceedances of a given rainfall accumulated over a given duration. For example, a rainfall total of 113 mm over 10 days has an average recurrence interval of 2 years.

AEP (Average Exceedance Probability) means – the probability that a specified total rainfall accumulated over a given period, will be exceeded in any one year. For example, a rainfall total of 155 mm over a period of 5 days has a 4.9% probability of being equalled or exceeded in any one year.

Figure A1 provides a rainfall residual mass plot for Gulgong monthly rainfall data since 1900. Negative slopes on this plot reflect periods of below average rainfall while positive slopes reflect above average rainfall. The period from 1900 to 1950 was a sustained dry and drought period which abruptly terminated in1950.

Figure A1: Rainfall residual mass plot for Gulgong from 1900

APPENDIX B: REGISTERED BORES AND WELLS

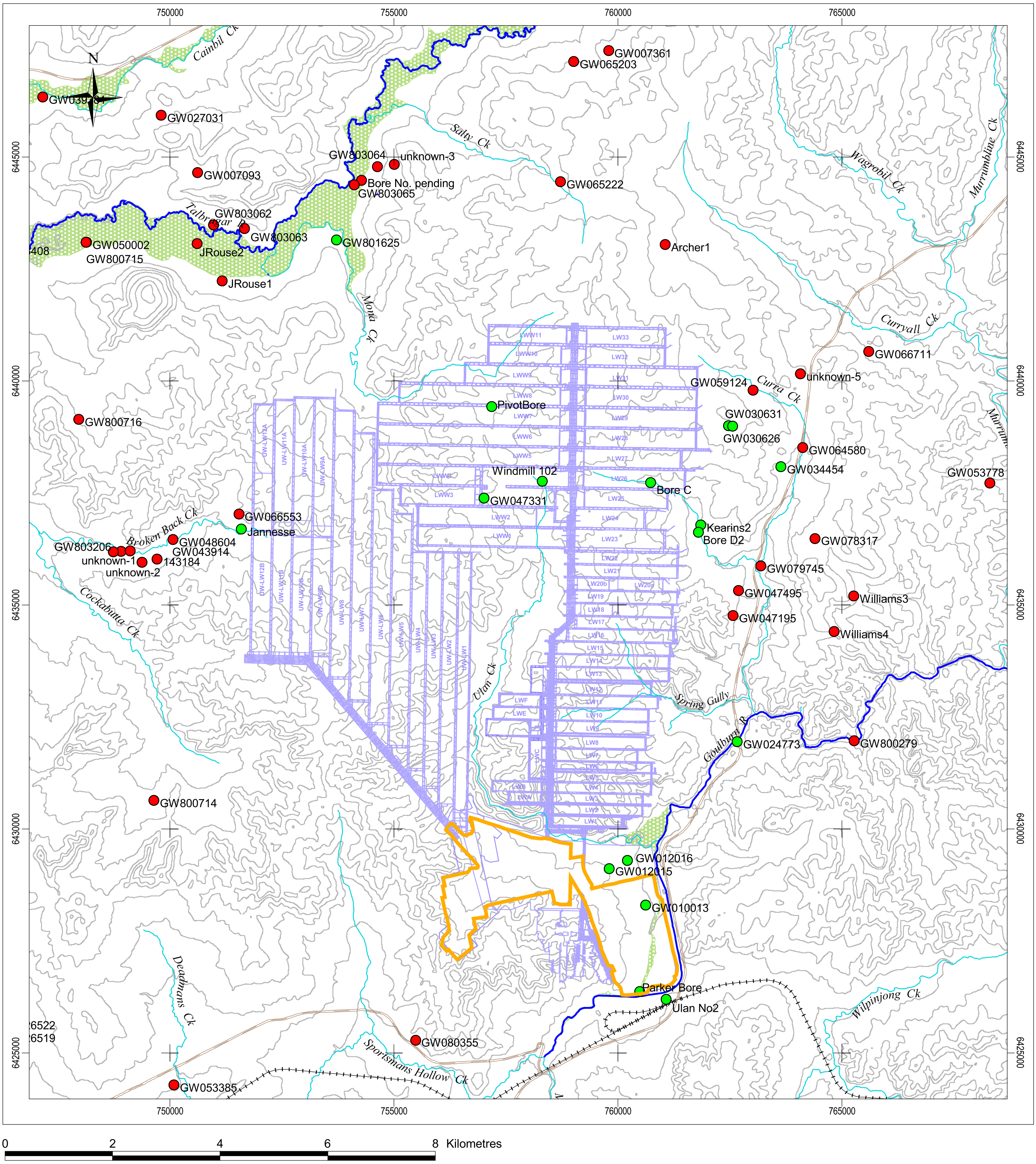
The following Table B1 has been compiled from a search on the NOW bore and well database, and from a review of existing data including regional UCML census data gathered over a number of years. While locations are considered to be reasonably accurate through GPS co-ordination, a number of identified bore structures are not accessible for water level determinations or water sampling.

Table B1: Schedule of bores and wells in proximity to mining operations

Number	Bore Name	Easting (MGA)	Northing (MGA)	Reported Depth (m)	Intended or Licensed Purpose	Date Drilled	Casing Type	Casing Depth	Screen From (m)	Screen To (m)	Land Owner	Bore User / Owner
GW030631		762457	6438996	122	Stock & Domestic	1-Jun-72	Threaded Steel	32.6	Open hole		UCML	
GW034454		763630	6438083	61	Stock	1-Jan-20					UCML	Larry Nott
GW038408	Redhill	745900	6442959	16	Stock	1-Jan-40	Threaded Steel				Birkalla Pty Ltd (Richard Rouse)	Lou Armstrong
GW043914		748909	6436184	26	Domestic	1-Aug-74	Threaded Steel	25.6	12.1	25.6	Jamie Spinks	Jamie Spinks
GW047495	Elward North	762685	6435318	149	Stock & Domestic	1-Apr-79	Welded Steel	14.6	Open hole		Edwin Elward	Edwin Elward
GW048604		750066	6436450	25	Stock & Domestic	1-Sep-78	Welded Steel	18	10	18	Searle & Catrina Page	Searle Page
GW050002	RRouse1	748130	6443090	17	Stock	1-Nov-79	Threaded Steel	16.5	15	16	Birkalla Pty Ltd (Richard Rouse)	Lou Armstrong
GW059124		763013	6439784	32	Stock, Domestic, Irrigation	1-Nov-83					State Government	NSW Government
GW064580		764120	6438504	70	Stock & Domestic	1-Jan-88	PVC	70.1	63.6	70.1	Mervyn Cundy	Mervyn Cundy
GW065222		758716	6444442	37	Stock & Domestic	24-Aug-89	PVC 130mm	36.5	30	36.5	William Hensley	William Hensley
GW066553		751533	6437024	70	Stock & Domestic	2-Feb-89	PVC	70		70		
GW066711		765593	6440649	91	Domestic		PVC	91.4		91.4	Robert Brown	
GW078317	Williams1	764392	6436478		Stock & Domestic		PVC				John Williams	Andrew Williams
GW079745	Williams2	763183	6435861	34	Stock		Steel	34.3		34.3	John Williams	Andrew Williams
GW800279		765270	6431962	24	Stock & Domestic	27-Nov-95	PVC Class 9	21.03	9.1	21.03	Collin & Julia Imrie	Julia Imrie
GW800714		749638	6430634	63	Stock & Domestic	11-Sep-95	PVC Class 9	30	Open hole		Peter & Ellen Panagis	
GW800715	RRouse2	748124	6443092	18	Stock & Domestic	30-Oct-94	Steel	18.3	15	18	Birkalla Pty Ltd (Richard Rouse)	Lou Armstrong
GW800716		747963	6439134	73	Stock & Domestic	28-Jan-95	PVC Class 9	73	68	73	Julie Sanderson	Julie Sanderson
GW801625		753709	6443147	39	Stock & Domestic	21-Sep-96	PVC Class 9	24	Open hole		Alan & Esmae Etheridge	Michael Etheridge
Unknown	Archer1	761051	6443035								Morrie Archer	Morrie Archer
Unknown	Jannesse1	751584	6436682		Domestic		Steel				UCML	
Unknown	JRouse1	751158	6442224		Stock		Steel 130mm				Jonathan & Jane Rouse	John Rouse
Unknown	JRouse2	750601	6443060	18	Stock		PVC 130mm				Jonathan & Jane Rouse	John Rouse
Unknown	Kearins2	761841	6436782	46	Stock						UCML	
Unknown	KearinsD2	761787	6436612		Stock						UCML	
Unknown	PivotBore	757172	6439420								UCML	
Unknown	Ulan No2	761073	6426190	31	Coal Exploration						UCML	
Unknown	Williams4	764817	6434399								John Williams	Andrew Williams
Unknown	Windmill 102	758303	6437754				Steel					

GW010013		760610	6428289	92	Coal Exploration	1-Oct-51	Threaded steel	39.6	Open hole		UCML	
GW012015		759801	6429108	76	Industrial	1-Oct-56	NA	NA	NA	NA	UCML	
GW012016		760206	6429292	76	Industrial	1-Oct-56					UCML	
GW024773	JDP Ulan DDH1	762653	6431944	126	Coal Exploration	1-Mar-75	Steel		Open hole			
GW030626		762553	6438985	105	Stock & Domestic	1-May-72	NA	NA	NA	NA	UMCL	
GW047195	Elward South	762563	6434759	107	Stock & Domestic	1-Apr-79	Welded Steel	8.8	Open hole		Edwin Elward	Edwin Elward
GW047331		757005	6437377	61	Stock, Domestic, Irrigation	1-May-79					UCML	
Unknown	Kearins1	760728	6437723		Stock						UCML	
Unknown	Parker	760478	6426359	31							UCML	
Unknown	Williams3	765258	6435195				Steel 130mm				John Williams	Andrew Williams
GW000919		771324	6447429	68	Stock	1-Mar-22	Threaded Steel	0				
GW007093		750598	6444633	55	Stock	1-Jul-45	Threaded Steel	19.1			Ian Eric Hynes	
GW007361		759793	6447380	34	Stock & Domestic	1-Feb-47	Threaded Steel	5.7				
GW011154		767381	6449215	91	Stock	1-Nov-54	Threaded Steel	10.5				
GW016372		744675	6432611	2	Stock		Timber	1.5				
GW027031		749792	6445923	2	Stock						Maurice, Ian, Betty	
GW031422		767402	6448608	76	Stock		Threaded Steel					
GW043432	Davies Well	763230	6423189		Stock & Domenstic	1-Jan-56	Timber				Collin Davies	
GW049542		758105	6425091	31	Domestic	1-Jun-79	Welded Steel	14.6				
GW052802	Willow Park	756363	6423609	46	Irrigation	1-Jul-80	Steel	17.1				
GW055472		767088	6440723	92	Stock &Domestic	1-Sep-81	Threaded Steel	24.1			Allyson & Patricia	
GW055850		758638	6449184	37	Stock & Domestic	1-Nov-82	PVC	36.5	24	34		
GW059683		757763	6423644	62	Stock & Domestic	1-Aug-84	PVC	2.5				
GW065203		759008	6447119	97	Stock & Domestic	10-Mar-88	PVC	97	90	97		
GW073385		742256	6436728	61	Stock & Domestic	30-Nov-94	Steel	40				
GW073549		756470	6424017	53	Test Bore	24-Nov-94	Steel	18.2	15	18		
GW073550		755731	6423558	53	Test Bore	24-Nov-94	Steel	24.7	18	24		
GW078174		757584	6423654	84	Stock & Domestic	25-Jun-93	PVC Class 6	2.7				
GW080135		767004	6440831	20			PVC	20			Allyson & Patricia	
GW080350		758300	6425102		Domestic	28-Nov-02						
GW080355		755513	6425498		Stock & Domestic	29-Nov-02						
Unknown	McMasters											
GW803206		748728	6436179	66	Stock & Domestic	5-Dec-06					McCaffrey	McCaffrey

		749112	6436196	18	Stock & Domestic						Loughrey & Vallis	Loughrey & Vallis
143184		749711	6436013	153 ft	Stock & Domestic						Marg Hansen	Marg Hansen
		749369	6435945	55	Stock & Domestic	Approx 2004					Michael Bottyan	Michael Bottyan
GW080355		755475	6425279		Stock & Domestic						Werner Cap	Werner Cap
GW803064		754623	6444780	22	Stock & Domestic						Ian Haynes	Ian Haynes
		755002	6444829	30	Stock & Domestic						Ian Haynes	Ian Haynes
Bore No. Pending		754273	6444472	40	Stock & Domestic	30-Jun-05					Ian Haynes	Ian Haynes
GW803065		754112	6444373	30	Stock & Domestic						Ian Haynes	Ian Haynes
GW803062		750965	6443472	27	Stock & Domestic						Ian Haynes	Ian Haynes
GW803063		751657	6443395	20	Stock & Domestic						Ian Haynes	Ian Haynes
GW073385		742070	6436332	50	Stock & Domestic	1994					Colin Seis	Colin Seis
		742531	647362	Unknown	Stock & Domestic						Colin Seis	Colin Seis
		764066	6440151	70	Stock & Domestic	14/05/1991					Mathew McDonald	Mathew McDonald
GW053385		Does Not Exist								Michelle Hyland		



- private (non UCML) bores
- bores owned by UCML
- major roads
- railway
- mainstream drainages
- alluvium
- open cut pit crest

ULAN COAL MINES LIMITED - ULAN WEST MODIFICATION

Private bore locations from NOW database and census

Mackie Environmental Research

Figure B1

APPENDIX C: STRATA HYDRAULIC PROPERTIES

Aquifer testing provides a means of estimating the bulk groundwater transmission and storage characteristics of a geological formation. Various procedures can be employed depending upon the saturated aquifer thickness, regional extent, transmission properties and bore completions. Procedures used at UCML include the following.

C1. Packer injection test analyses

Some 85 packer tests have been conducted at 19 exploration bore locations in order to establish estimates of hydraulic conductivity for different strata. Testing was conducted using either single packer assembly or straddle packers; a number of these tests exhibited potential packer leakage, strata dilation or equilibration (constant injection) difficulties due to equipment limitations. Hydraulic conductivity estimates for all known tests are provided in Table C1.

Figure C1 provides a plan of borehole locations where testing has been conducted and where test results are considered to be most representative of strata in the project area. Figure C2 provides a summary of all packer testing as histograms for the different formations.

C2. Laboratory core tests

Primary HQ size cores were inspected in archived core trays and representative samples were taken for testing from sections displaying relatively uniform properties over a reasonable depth section. Mudstones and claystones were not selected since this rock type tends to fail during cutting of smaller test slugs from the primary core. Consequently, there is a sampling bias towards conglomerates, sandstones, siltstones and laminites. Mudstones and claystones while not sampled, are likely to exhibit a matrix conductivity orders of magnitude lower than tested siltstones and laminites. In addition to hydraulic conductivity, a reduced number of samples were subjected to measurement of bulk porosity and effective porosity (by centrifuge).

Laboratory testing of core was conducted on 39 formation samples extracted at two borehole locations DDH242 and DDH340 located in the UG3 and Ulan West areas respectively. The laboratory procedure facilitates measurement of hydraulic conductivity at a scale representative of the lithology. Conductivity has been determined in either the horizontal or vertical directions by extracting smaller directional core from the borehole (HQ size) core sample, thereby enabling an estimate to be made of the prevailing 'micro' anisotropy within a specific rock type.

Results are summarised in the following Table C2. Figure C3 provides a summary of all testing as histograms. Comparison of results with packer tests indicates core based results exhibit a generally lower. A small number of cores were also subjected to conductivity measurement under different confining pressures to assess the need for adjusting numerical model conductivities with depth (Appendix E). Results are provided on Figure C4 and generally indicate only slight change in conductivity with depth.

Table C1: Hydraulic conductivity estimates from packer tests at 5 exploration bore sites

BoreID	Depth (mbgl)	Interval (mbgl) from	to	K (m/day)	Stratum
DDH84	66.0	51.0	81.0	7.42E-03	Triassic
DDH84	98.5	81.0	116.0	1.91E-03	Permian
DDH84	113.5	111.0	116.0	3.12E-03	Permian
DDH84	131.5	116.0	147.0	1.29E-04	Permian
DDH84	144.5	142.0	147.0	3.56E-02	Ulan seam
DDH84	166.0	156.0	176.0	3.90E-04	sub-seam
DDH59	9.3	7.5	11.0	2.12E-01	Permian
DDH59	14.8	12.8	16.8	1.37E-01	Permian
DDH59	20.7	17.1	24.3	5.00E-01	Permian
DDH59	27.5	26.0	29.0	1.19E+00	Ulan seam
DDH59	32.3	28.7	35.9	6.18E-01	Ulan seam
DDH59	36.4	28.7	44.0	5.33E-01	Ulan seam
DDH62	14.8	12.7	16.9	2.47E-01	Permian
DDH62	26.0	23.0	29.0	8.43E-04	Permian
DDH62	32.0	29.0	35.0	5.30E-03	Permian
DDH62	37.4	33.7	41.0	7.62E-02	Ulan seam
DDH62	40.4	33.7	47.0	4.18E-02	Ulan seam
DDH62	50.6	48.7	52.5	1.32E-03	Sub-Seam
DDH69	21.2	9.2	33.1	6.65E-02	Ulan seam
DDH69	23.6	14.0	33.1	4.65E-02	Ulan seam
DDH71	11.8	4.3	19.3	1.48E-01	Ulan seam
DDH72	19.4	6.7	32.0	1.81E-02	Ulan seam
DDH72	21.2	10.4	32.0	2.11E-02	Ulan seam
DDH146	89.3	83.4	95.2	3.14E-03	boundary
DDH146	138.0	132.3	143.6	2.51E-03	Permian
C417	233.0	226.9	239.2	4.00E-05	sub-seam
DDH116	147.5	141.1	153.9	5.66E-04	Permian
DDH116	160.3	153.9	166.7	4.76E-05	Permian
DDH116	173.1	166.7	179.5	4.25E-03	Ulan seam
DDH116	184.9	180.5	189.3	2.36E-04	sub-seam
DDH117	152.2	145.8	158.6	7.43E-04	Permian
DDH117	160.9	154.5	167.3	4.24E-05	Permian
DDH117	173.1	166.7	179.5	5.22E-03	Ulan seam
DDH117	184.9	180.5	189.3	1.79E-03	sub-seam
DDH123	243.4	237.0	249.8	3.01E-05	Permian
DDH123	251.1	244.7	257.5	1.94E-05	Permian
DDH123	263.3	256.9	269.7	3.48E-04	Ulan seam
DDH123	275.0	270.7	279.2	1.19E-04	sub-seam
R4	6.6	4.9	8.4	5.62E-01	Permian
R6	9.7	8.0	11.4	1.90E-01	Permian
R6	12.2	8.0	16.4	5.18E-02	Permian
UW717	165.5	162.3	168.6	2.59E-05	Permian
UW717	160.0	158.0	162.0	2.93E-05	Permian
DDH266A	37.5	29.0	46.0	2.59E-04	Triassic
DDH266A	54.8	48.0	64.0	1.49E-03	Triassic
DDH266A	72.8	64.0	82.0	1.39E-04	Triassic
DDH266A	78.8	76.0	82.0	4.23E-04	Triassic
DDH270	31.4	23.0	40.0	8.52E-04	Triassic
DDH270	49.0	40.0	58.0	3.04E-04	Triassic
DDH270	67.0	58.0	76.0	4.66E-04	Triassic

BoreID	Depth (mbgl)	Interval (mbgl) from	to	K (m/day)	Stratum
DDH271	36.0	30.0	42.0	8.25E-04	Triassic
DDH271	50.9	42.0	60.0	5.38E-03	Triassic
DDH271	56.9	54.0	60.0	8.28E-05	Triassic
R894	124.9	121.5	126.2	5.47E-03	Jurassic
R894	110.5	107.3	113.7	5.27E-03	Jurassic
R894	102.5	99.3	105.7	5.44E-03	Jurassic
DDH242	12.2	11.1	13.2	1.04E-01	Jurassic
DDH242	15.3	11.4	19.2	2.51E-02	Jurassic
DDH242	33.9	30.5	37.2	6.65E-02	Jurassic
DDH242	39.9	36.5	43.2	1.99E-02	Jurassic
DDH242	45.9	42.5	49.2	4.84E-03	Jurassic
DDH242	51.9	48.5	55.2	3.46E-02	Jurassic
DDH242	57.9	54.5	61.2	1.21E-02	Jurassic
DDH242	63.7	60.5	66.9	1.47E-02	Jurassic
DDH242	69.8	66.4	73.2	2.07E-02	Jurassic
DDH242	75.9	72.5	79.2	3.20E-02	Triassic
DDH242	81.9	78.5	85.2	1.30E-02	Triassic
DDH242	87.9	84.5	91.2	2.42E-02	Triassic
DDH242	99.9	96.5	103.2	4.06E-02	Triassic
DDH242	129.9	126.5	133.2	5.79E-03	Triassic
DDH242	141.7	138.5	144.8	1.56E-03	Triassic
DDH242	159.9	156.5	163.2	4.49E-04	Triassic
DDH242	171.9	168.5	175.2	1.90E-03	Triassic
DDH242	177.9	174.5	181.2	1.47E-03	Triassic
DDH242	183.9	180.5	187.2	3.80E-03	Triassic
DDH242	189.9	186.5	193.2	7.86E-04	Triassic
DDH242	195.9	192.5	199.2	3.11E-03	Permian
DDH242	213.9	210.5	217.2	3.37E-03	Permian
DDH242	225.9	222.5	229.2	2.07E-03	Permian
DDH242	231.9	228.5	235.2	1.64E-03	Permian
DDH242	237.9	234.5	241.2	7.43E-04	Permian
DDH242	243.9	240.5	247.2	5.27E-04	Permian
DDH242	255.9	252.5	259.2	2.51E-04	Permian
DDH242	261.9	258.5	265.2	3.72E-03	Permian
DDH242	276.9	273.5	280.2	3.02E-03	Permian

Table C2: Summary of core tests for the determination of hydraulic conductivity and porosity

Code	Depth m	Orientation	Bulk por. %	Eff. Por. %	Hyd. Cond. m/day	Unit	Lithology
DDH242	27.8	Vertical	12.0		2.96E-06	Jurassic	siltstone, grey to cream banded with fine grained sandstone
DDH242	34.0	Vertical	21.0		3.28E-03	Jurassic	sandstone, quartzose, cream to brown, medium grained, moderately cemented, rounded
DDH242	34.0	Horizontal	-		2.00E+00	Jurassic	sandstone, quartzose, cream to brown, medium grained, moderately cemented, rounded
DDH242	40.1	Vertical	16.7		9.96E-04	Jurassic	sandstone, quartzose, cream to brown, fine to medium grained, moderately cemented, rounded
DDH242	48.9	Vertical	17.7		5.55E-04	Jurassic	sandstone, quartzose, cream with brown banding, fine to medium grained, moderately cemented, rounded
DDH242	55.7	Vertical	-		3.01E-06	Jurassic	sandstone, quartzose, cream with brown grey banding, fine grained
DDH242	59.6	Vertical	-		2.85E-03	Jurassic	sandstone, quartzose, white to pink banded, medium grained, sorted, rounded
DDH242	64.5	Vertical	21.8		1.22E-01	Jurassic	sandstone, quartzose, cream to light brown, medium grained, moderately cemented, rounded
DDH242	70.1	Vertical	24.9		6.25E+00	Triassic Qz	sandstone, quartzose, white, very coarse grained, rounded, very weakly cemented
DDH242	74.5	Vertical	23.9		9.22E-01	Triassic Qz	sandstone, quartzose, white, fine to medium grained with pebbles to +5mm, rounded, moderately cemented
DDH242	79.8	Vertical	22.3		8.72E-02	Triassic Qz	sandstone, quartzose, cream, medium grained, rounded
DDH242	83.4	Vertical	24.8		1.45E+00	Triassic Qz	sandstone, quartzose, white, coarse grained, rounded, weakly cemented
DDH242	87.6	Vertical	20.9		7.46E-01	Triassic Qz	sandstone, cream to pink banded, medium to very coarse grained, poorly sorted with pebbles to +10mm
DDH242	87.6	Horizontal	-		6.23E+00	Triassic Qz	sandstone, cream to pink banded, medium to very coarse grained, poorly sorted with pebbles to +10mm
DDH242	92.0	Vertical	14.4		3.66E-04	Triassic Qz	sandstone, quartzose, cream to pink, fine to medium grained with pebbles to +5mm, rounded
DDH242	95.0	Vertical	19.8		5.66E-02	Triassic Qz	sandstone, quartzose, cream to pink, medium to very coarse grained, rounded, poorly sorted
DDH242	97.2	Vertical	20.7	16.9	6.10E-02	Triassic Qz	sandstone, cream to pink banded, medium to very coarse grained, poorly sorted with pebbles to +10mm, rounded
DDH242	100.8	Vertical	12.6		9.55E-05	Triassic Qz	sandstone, cream to pink banded, fine to coarse grained with pebble bands, poorly sorted, rounded
DDH242	103.0	Vertical	20.7		2.72E-02	Triassic Qz	sandstone, quartzose, cream to pink, fine to medium grained with pebbles to +5mm, rounded
DDH242	107.6	Vertical	27.7		3.73E-01	Triassic Qz	sandstone, quartzose, cream to pink, medium grained with pebbles to +10mm, rounded
DDH242	114.4	Vertical	19.1	14.0	2.86E-02	Triassic Qz	sandstone, quartzose, brown, medium to very coarse grained, weakly cemented, rounded
DDH242	117.4	Vertical	22.2		2.78E-02	Triassic Qz	sandstone, cream, coarse to very coarse grained with pebbles to +5mm, moderately cemented
DDH242	120.7	Vertical	23.0		1.49E-01	Triassic Qz	sandstone, cream, coarse to very coarse grained with pebbles to +7mm, moderately cemented
DDH242	124.0	Vertical	13.9	6.1	2.69E-04	Triassic Qz	sandstone, quartzose, cream, fine grained, rounded, moderately cemented
DDH242	124.0	Horizontal	-		6.46E-04	Triassic Qz	sandstone, quartzose, cream, fine grained, rounded, moderately cemented
DDH242	127.8	Vertical	19.5		7.87E-02	Triassic Qz	sandstone, quartzose, cream to white, coarse grained with pebbles to +5mm,weakly cemented, rounded
DDH242	129.9	Vertical	22.1		1.35E-01	Triassic Qz	sandstone, quartzose, cream to white, very coarse grained with pebbles to +5mm, rounded
DDH242	133.7	Vertical	22.7	16.0	2.50E-02	Triassic Qz	conglomerate-sandstone, cream very coarse grained with pebbles to +10mm, moderately cemented
DDH242	138.5	Vertical	18.5		2.18E-03	Triassic Qz	sandstone conglomerate, cream to light brown, with pebbles to +10mm, moderately cemented
DDH242	143.1	Vertical	18.9		4.52E-03	Triassic Qz	conglomerate, cream to pink with pebbles to +10mm, green, grey, moderately cemented
DDH242	146.5	Vertical	19.7		5.94E-03	Triassic Qz	sandstone, quartzose, white to pink banded, medium to coarse grained, rounded
DDH242	148.0	Vertical	10.6		1.25E-06	Triassic Lithic	sandstone cream to light grey, medium to very coarse grained with clasts to +20mm, rounded

Code	Depth m	Orientation	Bulk por. %	Eff. Por. %	Hyd. Cond. m/day	Unit	Lithology
DDH242	152.4	Vertical	14.5	1.5	8.25E-06	Triassic Lithic	sandstone, cream lithic, coarse to very coarse grained to +5mm, rounded
DDH242	152.4	Horizontal	-		3.42E-05	Triassic Lithic	sandstone, cream lithic, coarse to very coarse grained to +5mm, rounded
DDH242	156.4	Vertical	14.9		1.13E-05	Triassic Lithic	sandstone, quartzose cream mottled, medium to very coarse grained, rounded
DDH242	161.2	Vertical	16.9		4.11E-05	Triassic Lithic	sandstone cream to grey medium to coarse grained with pebbles to +5mm, rounded
DDH242	165.5	Vertical	19.4	8.8	1.83E-03	Triassic Lithic	sandstone cream to light grey, coarse to very coarse grained, rounded
DDH242	170.1	Vertical	16.4		1.99E-03	Triassic Lithic	conglomerate (lithic) with pebbles to +20mm, green, grey, moderate to well cemented
DDH242	174.8	Vertical	20.6	12.8	2.84E-03	Triassic Lithic	sandstone, quartzose, cream, coarse to very coarse grained with pebbles to +5mm, moderately cemented
DDH242	174.8	Horizontal	-		1.14E-02	Triassic Lithic	sandstone, quartzose, cream, coarse to very coarse grained with pebbles to +5mm, moderately cemented
DDH242	181.5	Vertical	21.8		1.88E-02	Triassic Lithic	sandstone conglomerate (lithic) with pebbles to +15mm, green, grey, moderate to well cemented
DDH242	196.0	Vertical	-		1.98E-07	Permian	shale, carbonaceous, dark grey to black with coal bands
DDH242	200.0	Vertical	16.6		4.02E-06	Permian	sandstone, quartzose, grey with thin carbonaceous bands, fine to medium grained
DDH242	205.0	Vertical	-		1.98E-07	Permian	shale, carbonaceous, grey to black
DDH242	209.5	Vertical	17.6		1.22E-05	Permian	sandstone, quartzose, white, fine to medium grained, rounded, moderate to well cemented
DDH242	215.5	Vertical	-		3.01E-07	Permian	siltstone, grey to dark grey banded tending to carbonaceous
DDH242	220.0	Vertical	-		4.03E-06	Permian	sandstone, quartzose, grey with carbonaceous? bands, fine to very fine grained rounded, well cemented
DDH242	226.7	Vertical	-		5.99E-07	Permian	siltstone, grey to cream banded
DDH242	230.9	Vertical	12.2		1.25E-06	Permian	siltstone, grey to cream banded with medium to very fine grained sandstone
DDH242	231.2	Vertical	-		2.74E-07	Permian	siltstone, grey banded with very fine grained cream coloured sandstone
DDH242	238.5	Vertical	12.4		6.39E-07	Permian	sandstone, quartzose, cream to grey, fine grained rounded, moderate to well cemented, sorted
DDH242	241.1	Vertical	11.7	0.3	4.02E-07	Permian	sandstone, quartzose, light grey, fine grained rounded, moderate to well cemented, sorted
DDH242	241.1	Horizontal	-		4.77E-06	Permian	sandstone, quartzose, light grey, fine grained rounded, moderate to well cemented, sorted
DDH242	247.2	Vertical	-		5.46E-07	Permian	sandstone, quartzose, grey with silty carbonaceous bands, fine to medium grained
DDH242	260.0	Vertical	-		9.80E-08	Permian	siltstone, grey to light grey banded
DDH242	271.9	Vertical	-		2.95E-08	Permian	siltstone, grey to brown banded
DDH242	275.0	Vertical	14.0		4.17E-05	Permian	sandstone, lithic, grey, medium grained, rounded to sub angular, moderate to well cemented
DDH242	279.9	Vertical	-		1.14E-06	Permian	sandstone, quartzose, grey, medium grained with thin carbonaceous bands, rounded, moderate to well cemented
DDH340	9.7	Vertical			2.80E+00	Jurassic	sandstone, quartzose, cream to brown, medium grained, moderately cemented, rounded, well sorted
DDH340	14.9	Vertical			4.17E-01	Jurassic	sandstone, quartzose, white to grey, medium grained, moderately cemented, rounded, well sorted
DDH340	25.3	Vertical			4.47E-07	Jurassic	sandstone, quartzose, dark grey, medium grained, moderately cemented, rounded
DDH340	47.1	Vertical			3.88E-03	Triassic Qz	sandstone, quartzose, white, medium grained, moderately cemented, rounded
DDH340	77.3	Vertical			4.67E-01	Triassic Qz	sandstone, quartzose, white, medium to very coarse grained, poorly cemented, rounded
DDH340	77.3	Horizontal			1.38E+00	Triassic Qz	sandstone, quartzose, white, medium to very coarse grained, poorly cemented, rounded
DDH340	84.4	Vertical			4.18E-02	Triassic Qz	sandstone, quartzose, white, fine to medium grained, rounded
DDH340	92.9	Vertical			5.87E+00	Triassic Qz	sandstone, quartzose, cream, very coarse grained, rounded, poorly sorted, weakly cemented

Code	Depth m	Orientation	Bulk por. %	Eff. Por. %	Hyd. Cond. m/day	Unit	Lithology
DDH340	100.9	Vertical			7.76E-01	Triassic Qz	sandstone, quartzose, cream, very coarse grained, sub-rounded, poorly sorted, weakly cemented
DDH340	100.9	Horizontal			1.00E+00	Triassic Qz	sandstone, quartzose, cream, very coarse grained, sub-rounded, poorly sorted, weakly cemented
DDH340	108.2	Vertical			5.30E-05	Triassic Lithic	sandstone, quartzose, cream, medium grained matrix with clasts to +10mm, sub-rounded, poorly sorted, cemented
DDH340	108.2	Horizontal			4.33E-04	Triassic Lithic	sandstone, quartzose, cream, medium grained matrix with clasts to +10mm, sub-rounded, poorly sorted, cemented
DDH340	117.4	Vertical			1.17E-04	Triassic Lithic	conglomerate, with sandstone matrix with pebbles-clasts (inc. cherts) to +8mm
DDH340	123.7	Vertical			1.91E-04	Triassic Lithic	conglomerate, with sandstone matrix with pebbles-clasts (inc. cherts) to +8mm
DDH340	127.8	Vertical			3.67E-03	Triassic Lithic	sandstone-conglomerate, quartzose, cream, coarse grained matrix with clasts to +5mm, sub-rounded, poorly sorted
DDH340	135.6	Vertical			1.37E-02	Triassic Lithic	sandstone, lithic, cream, very coarse to coarse grained, rounded,
DDH340	135.6	Horizontal			1.95E-02	Triassic Lithic	sandstone, lithic, cream, very coarse to coarse grained, rounded,
DDH340	140.0	Vertical			3.78E-04	Triassic Lithic	sandstone-conglomerate, quartzose, cream, fine grained matrix with clasts to +10mm, rounded, poorly sorted
DDH340	153.2	Vertical			9.38E-08	Permian	sandstone-siltstone interbedded, quartzose, grey, fine grained, well cemented
DDH340	155.1	Vertical			1.13E-06	Permian	sandstone, quartzose, grey, medium grained, well cemented
DDH340	155.1	Horizontal			1.02E-05	Permian	sandstone, quartzose, grey, medium grained, well cemented
DDH340	160.4	Vertical			1.58E-06	Permian	sandstone, quartzose, grey, fine grained, rounded, well cemented
DDH340	168.6	Vertical			2.15E-04	Permian	sandstone, quartzose, grey, medium grained, rounded, well cemented
DDH340	168.6	Horizontal			9.38E-04	Permian	sandstone, quartzose, grey, medium grained, rounded, well cemented
DDH340	180.9	Vertical			2.59E-01	Permian	sandstone, quartzose, grey, very coarse grained, rounded, well cemented
DDH340	195.0	Vertical			4.09E-02	Permian	sandstone, quartzose, grey, coarse grained, rounded, well cemented
DDH340	195.0	Horizontal			4.95E-02	Permian	sandstone, quartzose, grey, coarse grained, rounded, well cemented
DDH340	201.2	Vertical			5.02E-07	Permian	sandstone-siltstone interbedded, quartzose, grey, fine grained, well cemented
DDH340	210.7	Vertical			3.31E-07	Permian	siltstone-shale interbedded, grey to black (carbonaceous)
DDH340	230.0	Vertical			1.43E-05	Permian	siltstone, grey to light grey with minor quartz fragments
DDH340	230.0	Horizontal			3.73E-05	Permian	siltstone, grey to light grey with minor quartz fragments
DDH340	246.2	Vertical			1.18E-06	Permian	sandstone, tuffaceous, grey fine grained with clasts to +12mm
DDH340	250.5	Vertical			4.16E-07	Permian	conglomerate, grey to black sandstone-siltstone matrix with clasts to +12mm

Table C3: Summary of core conductivity measurements by formation

Strata	Kv (LN) M/day	Kv/Kh	Kh M/day
Jurassic sandstones	2.15E-03	5.00	1.08E-02
Triassic quartzose sandstones	5.62E-02	5.00	2.81E-01
Triassic lithic sandstones	2.66E-04	2.00	5.32E-04
Permian sandstones	8.03E-06	50.00	4.01E-04
Permian siltstones	4.13E-07	50.00	2.06E-05
Permian shales	1.98E-07	50.00	9.88E-06

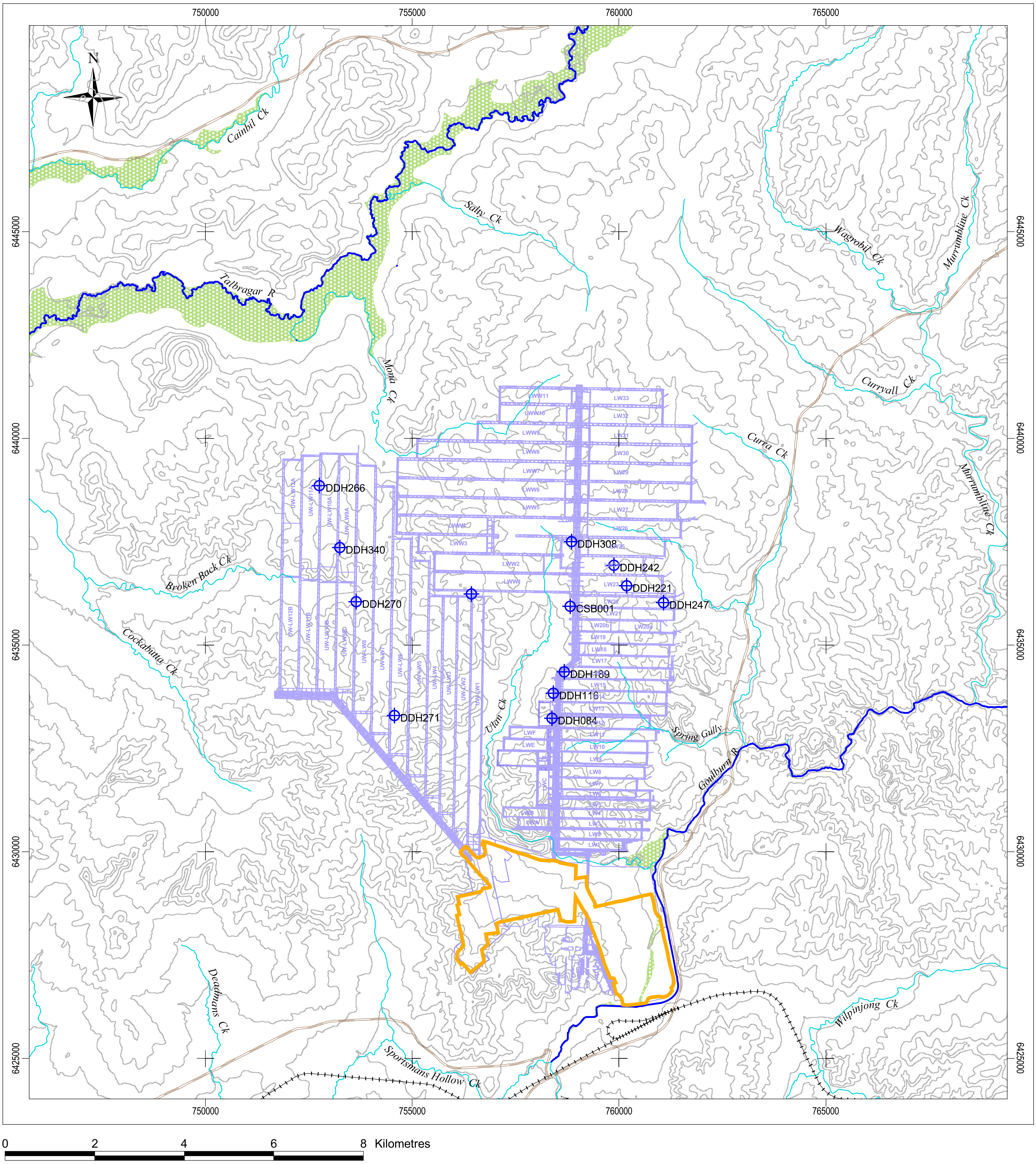
LN = mean for log normal distribution

C3. Rock core mechanical properties

SCT (2007a) provides a summary of core tests on samples taken from borehole DDH242, to determine various rock mechanical properties. Measurements of moduli, have been used to calculate values for compressible storage (S_s). Table C4 provides results.

Table C4: Rock properties after SCT (2007a) and calculated specific storage

Borehole	From m	To m	Depth m	E GPa	Density g/cc	UCS Mpa	Ss 1/m	Lithology
DDH242	83.9	84.2	84.1	17.7	2.25	32.6	1.69E-06	sandstone quartzose
DDH242	141.4	141.8	141.6	8.6	2.29	15.5	3.33E-06	conglomerate quartzose
DDH242	155.5	155.8	155.6	7.9	2.44	22.2	3.85E-06	sandstone lithic
DDH242	178.9	179.2	179.0	17.3	2.25	15.0	1.72E-06	sandstone lithic
DDH242	249.0	249.3	249.2	10.6	2.45	46.6	2.93E-06	interbedded
DDH242	257.0	257.3	257.1	12.8	2.38	50.8	2.39E-06	siltstone
DDH242	260.9	261.1	261.0	16.3	2.41	55.0	1.95E-06	siltstone
DDH243	247.5	247.7	247.6	9.9	2.45	53.4	3.12E-06	siltstone
DDH243	257.7	259.0	258.4	11.4	2.53	45.2	2.83E-06	siltstone
DDH243	261.6	261.8	261.7	13.3	2.32	73.4	2.25E-06	claystone
DDH243	263.1	263.3	263.2	4.4	1.53	23.5	4.22E-06	coal
DDH243	265.2	265.5	265.3	5.4	1.64	55.4	3.71E-06	coal
DDH243	267.2	267.5	267.3	3.1	1.32	20.4	5.13E-06	coal
DDH243	269.1	269.3	269.2	5.1	1.70	39.4	4.07E-06	coal
DDH243	269.4	269.5	269.4	8.1	2.13	24.3	3.27E-06	claystone
DDH243	270.3	270.5	270.4	5.4	2.25	10.0	5.10E-06	conglomerate



Permeability (packer) test holes

major roads

railway

mainstream drainages

topographic contours - 20m interval

alluvium

open cut pit crest

approved mine plans

modified mine plan

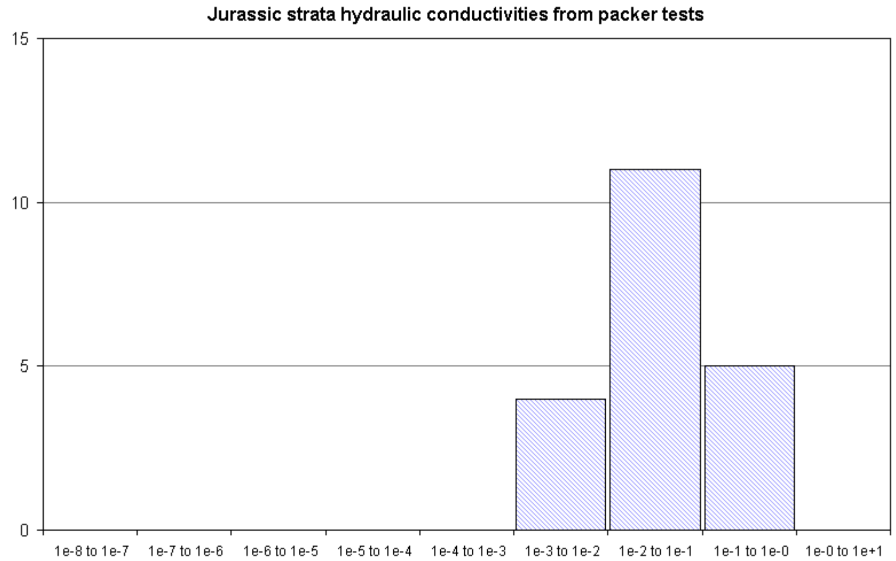
extended longwall area for modification mine plan

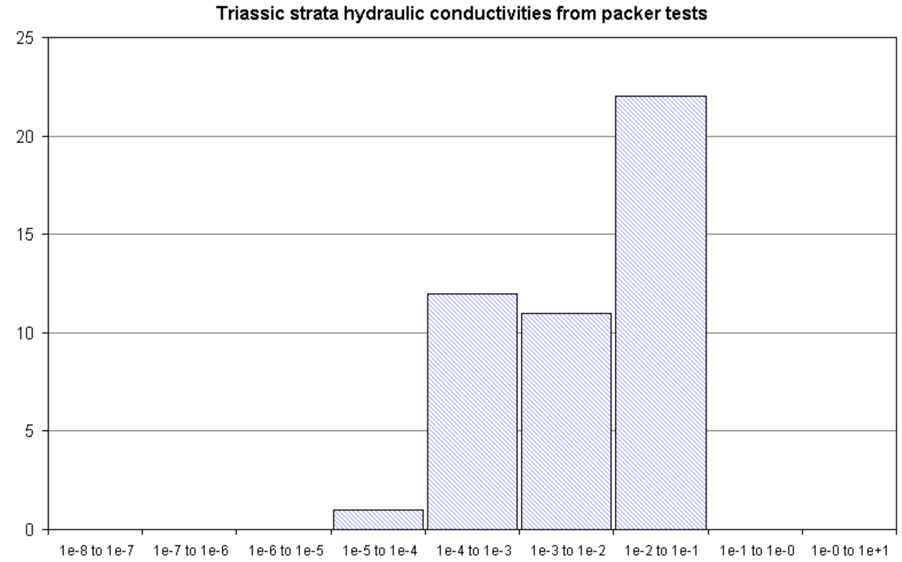
ULAN COAL MINES LIMITED - ULAN WEST MODIFICATION

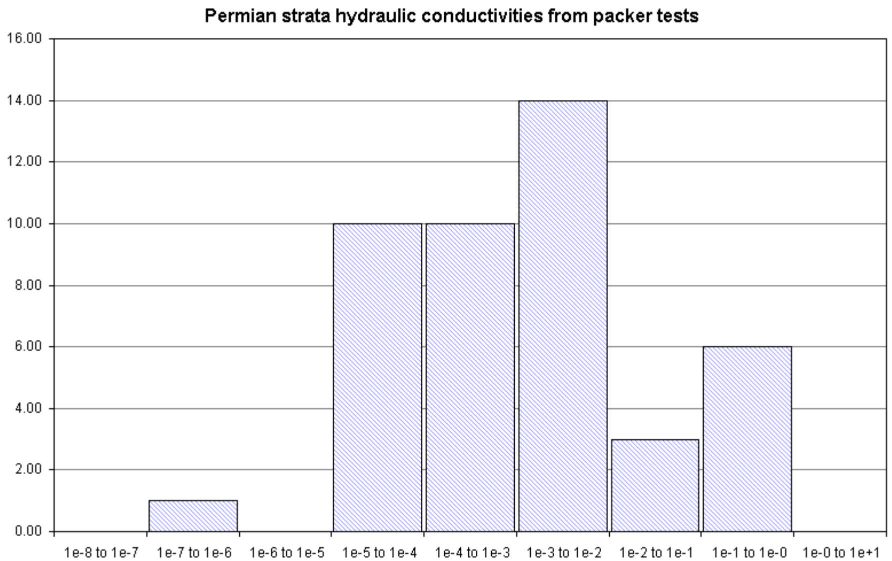
Permeability test hole locations

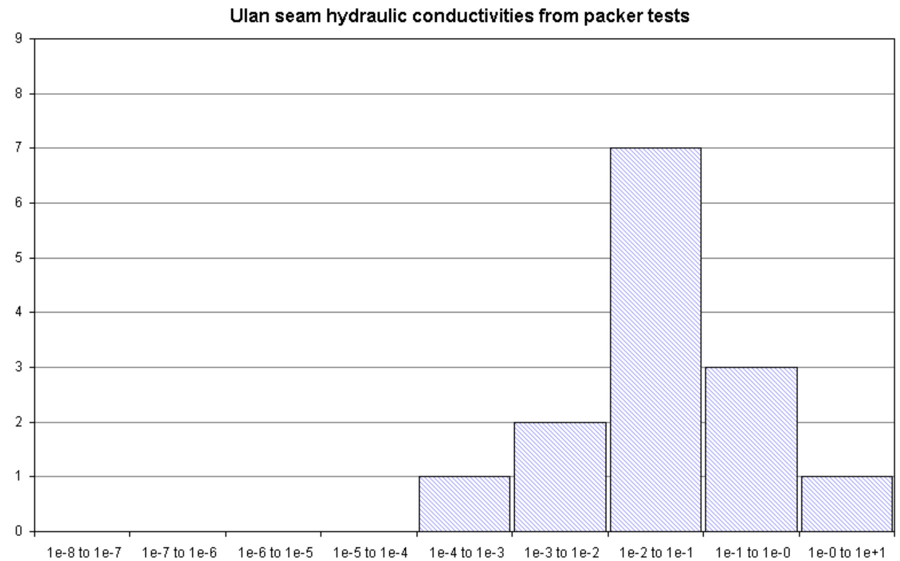
Mackie Environmental Research

Figure C1





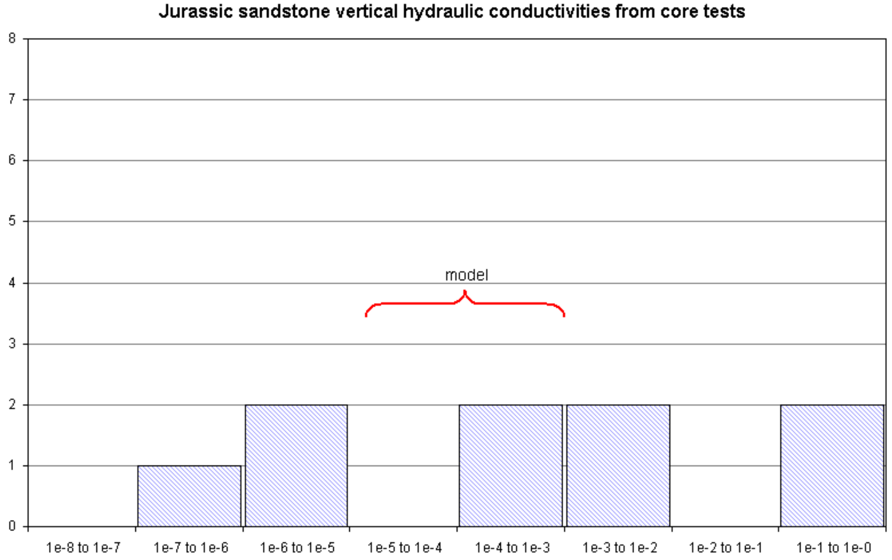


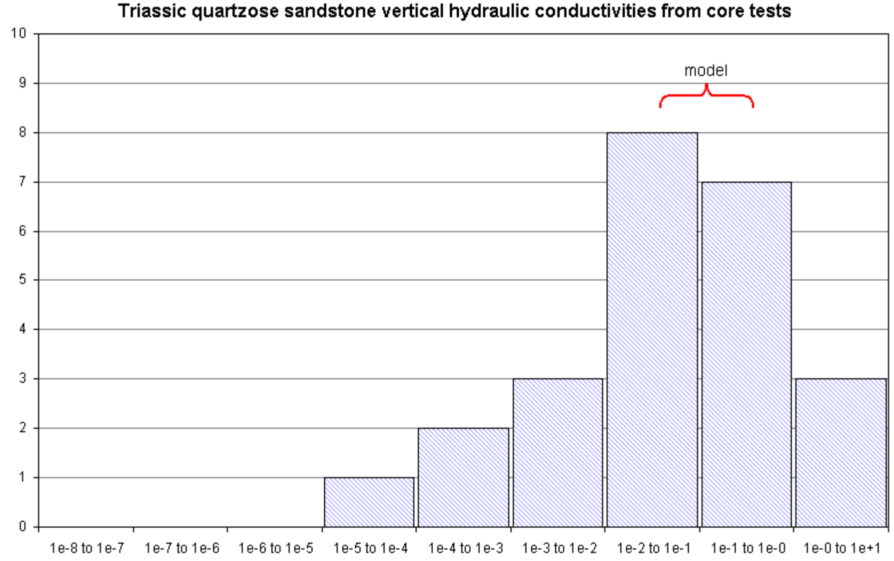


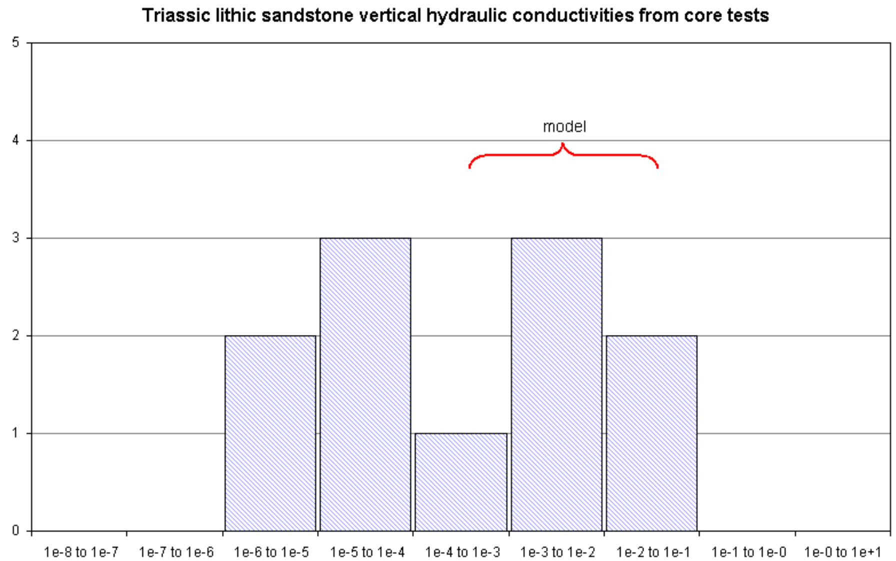
Packer test histograms

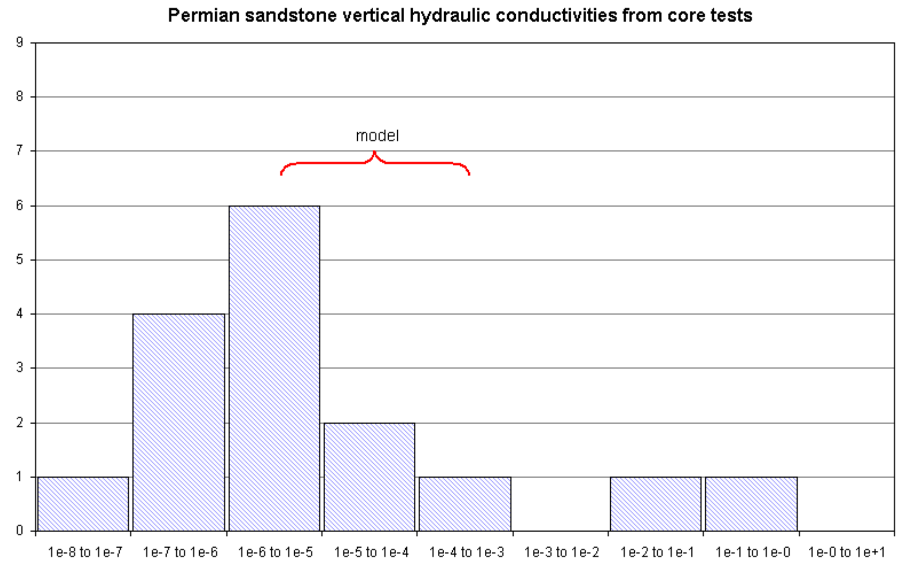
Figure C2

Mackie Environmental Research









Core test histograms

Figure C3

APPENDIX D: GROUNDWATER MONITORING

Coffey (2008a) provides a comprehensive summary of the groundwater monitoring networks installed at UCML. These include:

- the **North Monitoring Network (NMN)** which supports regional scale monitoring of the impacts of mining on groundwater systems. This network includes piezometers associated with geotechnical studies relating to the subsidence zone;
- the **Bobadeen Monitoring Network (BMN)** to assess the impacts of irrigation of mine water on shallow groundwater levels and groundwater quality of unconsolidated sediments within the upper catchments of Mona Creek, Ulan Creek, and Spring Gully Creek;
- the **Intermittent Monitoring Network (IMN)** comprises bores or piezometers that either have been installed for specific purposes, and/or have extensive screens (and so measure a depth-averaged or composite hydraulic head). The network is monitored intermittently for groundwater levels and quality to provide additional data to complement the NMN monitoring data;
- The **Goulburn River and Ulan Creek Alluvium Monitoring Network (AMN)** consists of at 9 locations which are generally screened throughout the thickness of alluvium associated with the Goulburn River or Ulan Creek. The piezometers are monitored intermittently for groundwater levels and quality to provide additional data for ongoing projects;
- The **Goulburn River Diversion Baseline Assessment Monitoring Network (GRDBAMN**) network was installed in 2006 as part of an assessment of the Goulburn River Diversion. It consists of 5 piezometers at 4 locations in the East Pit and together with piezometers in the AMN, is monitored to provide groundwater level data for the alluvium, Permian Coal Measures, and East Pit spoil associated with the Goulburn River.

The main networks of relevance to regional monitoring are the NMN and the GRDBAMN. Figure D1 provides bore locations for these networks while Figures D2 to D6 provide historical piezometric level data plots. Survey information is summarised in Table D1 (Moolarben Coal bores are prefixed with ‘M’).

A summary of ion speciated water samples is provided in Table D2. These samples are considered representative of locations based on sampling conducted over a number of years.

Table D1: Northern monitoring network including geotechnical bores for subsidence zone monitoring

Piezometer	Easting	Northing	Casing RL (mAHD)	Ground RL (mAHD)	Total Depth (mbgl)	Screen depth (mbgl)		Screened Stratum	Construction Details
						From	To		
PZ06A	755106	6441412		449.690	169	161	169	Conglomerate	
PZ06B	755109	6441425		449.778	159	147	159	Ulan	
PZ06C	755105	6441437		449.700	71	58	71	Triassic	
PZ07A	759136	6438002		502.390	247	262	274	Conglomerate	
PZ07B	759122	6438005		502.122	255	240	255	Ulan	
PZ07C	759105	6438009		501.877	121	102	121	Triassic	
PB01	761793	6437858		478.593	263	162	263	Permian	
PZ08A	761839	6437854		478.402	263	166	263	Permian	
PZ08B	761995	6437847		481.092	265	170	265	Permian	
PZ08C	762011	6437848		482.002	130	90	130	Triassic	
PZ09A	758720	6441337		541.835	330	314	330	Conglomerate	
PZ09B	758702	6441339		541.556	310	290	310	Ulan	
PZ09C	758683	6441343		541.042	165	150	165	Triassic	
PZ09D	758668	6441348		540.591	80	50	80	Jurassic	
PZ10A	758812	6439393		513.795	165	150	165	Triassic	
PZ10B	758808	6439383		514.100	46	26	46	Jurassic	
PZ11A	757426	6435557		476.733	175	160	175	Ulan	
PZ11B	757434	6435550		476.458	82	68	82	Triassic	
PZ12A	753529	6431711		571.338	187	176	187	Conglomerate	
PZ12B	753528	6431725		571.303	172	158	172	Ulan	
PZ12C	753526	6431739		570.597	75	55	75	Triassic	
PZ13A	749207	6440479		445.752	73	65	73	Ulan	
PZ14A	766630	6437232	453.801	453.371	328	294	328	Ulan	Site P
PZ14B	766633	6437221	454.099	453.669	182	140	182	Triassic	

Piezometer	Easting	Northing	Casing RL (mAHD)	Ground RL (mAHD)	Total Depth (mbgl)	Screen depth (mbgl)		Screened	Construction
						From	To	Stratum	Details
PZ14C	766637	6437208	454.559	454.199	56	32	56	Jurassic	
PZ24A	763109	6434793	421.124	420.784	236	208	236	Ulan	Site N
PZ24B	763107	6434783	420.945	420.585	74	44	74	Triassic	
PZ25A	763535	6423746	431.153	430.753	86	78	86	Marrangaroo	
PZ25B	763533	6423732	430.982	430.652	78	60	78	Ulan	
PZ26A	759629	6448988	448.720	448.250	263	248	263	Marrangaroo	Site 0
PZ26B	759621	6448966	448.667	448.207	243	222	243	Ulan	
PZ26C	759613	6448943	448.334	447.919	130	76	130	Triassic	
PZ26D	759605	6448921	447.968	447.548	22	13	22	Jurassic	
PZ27	759148	6433179		533.316	56	Open Hole		Triassic	
R894	763091	6442209	489.280	487.320		NA	NA	VWP array: Triassic / Jurassic	Site G. grouted
DDH266 (UW60)	752760	6438854		493.500	192	NA	NA	VWP array	grouted
DDH270 (UW54)	753643	6436046		518.434	173	NA	NA	VWP array	grouted
DDH271 (UW46)	754611	6433313		507.083	156	NA	NA	VWP array	grouted
DDH242	759879	6436920	522.6	522.6		NA	NA	VWP array	grouted
DDH247	761078	6436019	465.8	465.8		NA	NA	VWP array	grouted
DDH933	756380	6435863	544.56	544.56		NA	NA	VWP array	grouted
DDH936	756010	6435376	533.00	533.00		NA	NA	VWP array	grouted
DDH988	656876	6436275	527.5	527.5		NA	NA	VWP array	grouted
DDH991	759176	6433263	530.00	530.00		NA	NA	VWP array	grouted
GW01	762626	6431948	390.190		6.5	2	6.5	Goulburn R. Alluvium	
GW02	760910	6429778	397.850		5.1	2.1	5.1	Goulburn R. / Ulan Ck. Alluvium	
GW03	760872	6429871	397.160		8.8	2.8	8.8	Goulburn R. / Ulan Ck. Alluvium	
GW04	760844	6429968	398.080		5.5	2.5	5.5	Goulburn R. / Ulan Ck. Alluvium	

 D3

Table D2: Summary of speciated groundwater samples (for tri-linear plotting)

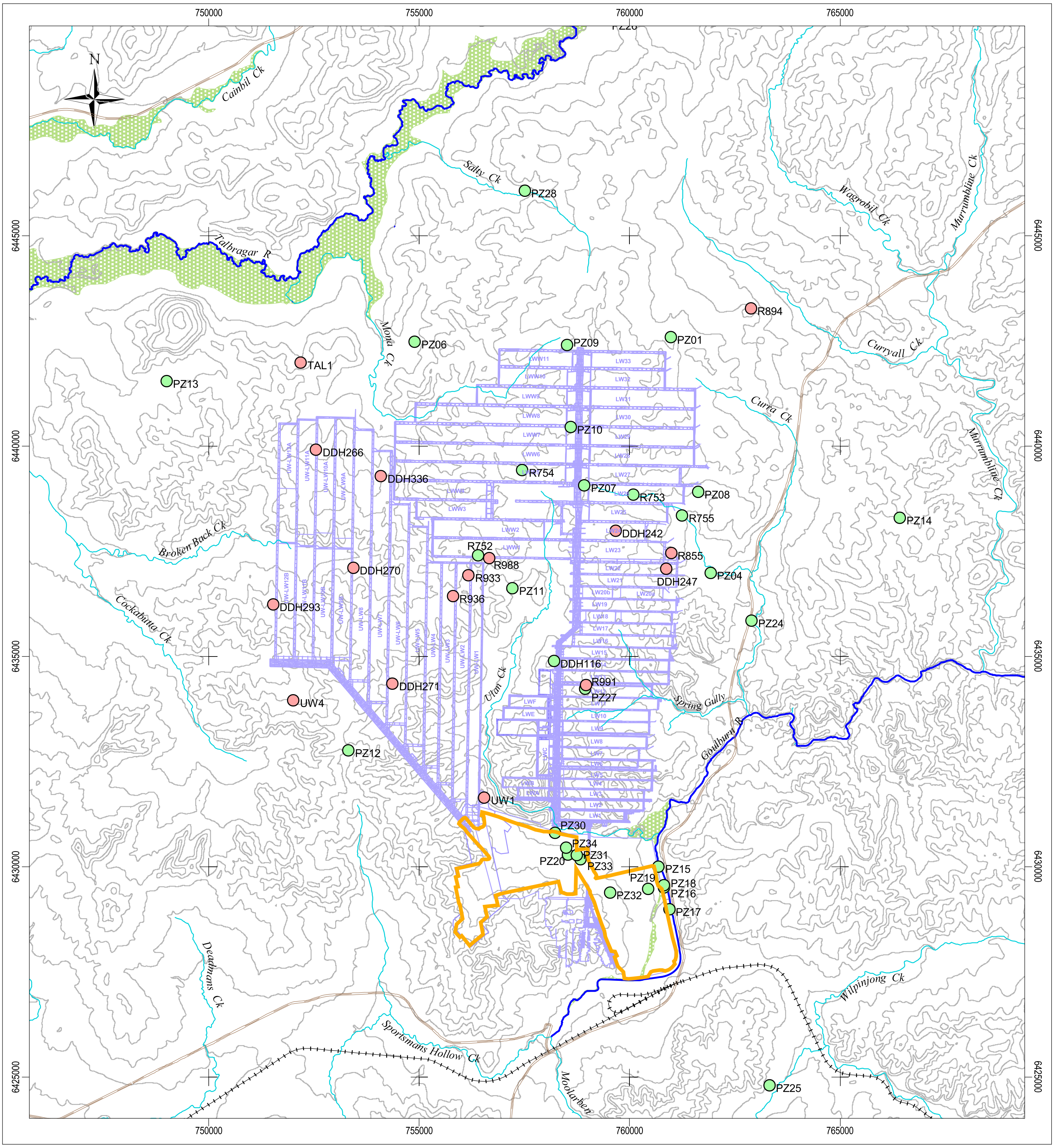
Bore	Date	TDS mg/l	pH	EC uS/cm	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	CO3 mg/l	HCO3 mg/l	SO4 mg/l	Cl mg/l
Goulburn R. at Cassillis Road Bridge	31-Jan-05	425	6.82	708	27	19	91	10	0	98	148	86.1
Goulburn R. at Ulan*	avg	468	6.60	839	22	16	77	5	0	86	52	137
GW01	31-Jan-05	16556	6.99	3040	120	97	537	20	0	146	1100	460
GW02	01-Feb-05	2126	6.53	2290	194	127	274	35	0	61	1270	168
GW03	19-Sep-06	3609	6.9	2440	69	84	244	16	0	102	950	152
GW04	01-Feb-05	4592	7.56	1630	56	52	218	45	0	159	523	151
PZ01	11-Nov-02	292	7.4	500	41	8	46	1.6	0	90	20	85
PZ01A	11-Sep-07	414	6.9	485	43	16	47	26	0	185	5	92
PZ04	31-Jul-01	3477	12.6	5349	655	0.06	80	185	2400	100	4	53
PZ04A	11-Sep-07	138	5.7	245	9.3	4.5	29	1.8	0	37	0	57
PZ06A	18-Oct-05	1673	8.9	1820	3	4.4	470	28	54	1049	0	64
PZ06B	21-Sep-06	888	9	1100	3.3	3.4	225	30	42	506	0	78
PZ06C	11-Sep-07	154	10.1	270	4.2	1.4	21	33	0	49	0	46
PZ07A	12-Sep-07	473	11.3	1090	2.6	1.5	114	50	105	140	0	60
PZ07B	12-Sep-07	567	9.3	730	3.8	1.7	148	23	30	287	0	74
PZ07C	13-Sep-08	261	8.5	415	6.7	19	42	4.8	2.4	122	0	64
PZ08A	19-Oct-05	228	9.7	345	2.4	0.9	58	18	12	55	25	57
PZ08B	19-Oct-05	431	10.1	580	2.5	0.7	108	26	66	171	0	57
PZ08C	13-Sep-07	397	8.6	600	9.1	37	53	4.4	0	151	0	142
PZ09A	11-Sep-07	1049	10.6	1690	9.2	1.6	327	33	195	409	0	74
PZ09B	11-Sep-07	906	8.7	1060	9.3	1.3	239	27	18	512	0	99
PZ09C	13-Sep-08	231	8.9	415	10	18	38	3.2	2.4	82	0	78
PZ10A	13-Sep-08	208	8.7	310	7.6	3.9	37	17	5.4	101	0	36
PZ10B	13-Sep-08	1173	6.2	2130	32	81	259	11	0	227	56	507
PZ11A	20-Sep-06	624	7.6	820	45	14	88	18	0	378	0	81

Bore	Date	TDS mg/l	pH	EC uS/cm	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	CO3 mg/l	HCO3 mg/l	SO4 mg/l	Cl mg/l
PZ11B	13-Sep-08	55	5.8	145	2.9	1.4	7	2.9	0	5	0	36
PZ12A	19-Sep-06	122	6.6	245	0.21	2.7	20	2.2	0	40	0	57
PZ12C	13-Sep-07	99	6.9	260	3.7	3.8	26	1.9	0	11	0	53
PZ13A	13-Sep-08	462	8.1	640	18	9.4	92	11	0	254	0	78
PZ14A	13-Sep-07	1385	9.2	1580	5.4	2.4	382	15	51	824	0	106
PZ14B	13-Sep-07	707	11.8	1260	143	0.5	101	46	252	24	27	113
PZ14C	13-Sep-07	467	9.2	725	13	20	109	10	0	102	0	213
PZ24A	13-Sep-07	718	10.1	970	3	2.2	162	63	72	342	0	74
PZ24B	13-Sep-07	270	8.8	360	9.6	11	49	4.4	0	132	0	64
PZ25A	13-Sep-07	590	11.2	1100	35	0.2	153	37	60	110	46	149
PZ25B	13-Sep-07	840	7.9	865	56	34	118	22	0	451	0	159
PZ26A	10-Sep-07	1644	10	1990	7.8	0.01	390	197	195	787	0	67
PZ26B	10-Sep-07	1255	9.4	1470	3.7	0.01	348	66	90	683	0	64
PZ26C	10-Sep-07	209	9.2	275	4.8	18	24	6.4	15	117	3	21
PZ26D	10-Sep-07	2424	6.8	3520	89	113	504	59	0	622	62	975
PZ28A	11-Sep-07	414	9.1	510	4.4	28	58	13	13.2	242	3	53
PZ28B	11-Sep-07	2071	6.9	3395	100	108	434	27	0	422	179	801
R676	23-Sep-04	508	7.11	715	26	46	45	2	0	317	5	67
R680	22-Sep-04	553	6.72	508	16	38	103	3	0	214	10	169
R752	12-Sep-07	313	6.9	390	25	21	27	0.98	0	220	5	14
R753	22-Sep-04	715	7.18	800	57	43	83	7	0	389	12	124
R753A	12-Sep-07	455	6.7	555	31	26	47	4.4	0	256	5	85
R754	21-Jun-01	438	8.14	673	42	16.1	48	18.8	0	270	1	42
R755	20-Oct-05	324	6.4	440	12	23	47	5.8	0	153	6	78
R755A	12-Sep-07	325	6.7	450	18	23	39	2.7	0	171	4	67
R756	23-Sep-04	177	6.2	281	11	6	39	1	0	39	2	79
M-PZ101A	28-Apr-06	912	8.5	1320	110	26	73	35	0	476	62	130

D5

Bore	Date	TDS mg/l	pH	EC uS/cm	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	CO3 mg/l	HCO3 mg/l	SO4 mg/l	Cl mg/l
M-PZ101B	28-Apr-06	761	8	1030	70	26	76	17	0	475	13	83
M-PZ102A	28-Apr-06	447	8.3	810	33	4	74	18	0	195	68	55
M-PZ102B	28-Apr-06	716	7.9	1200	58	25	100	18	0	305	10	200
M-TB103R	29-Apr-06	368	6.6	650	37	17	34	11	0	183	5	81
M-PZ103A	28-Apr-06	303	8.1	490	25	5.8	32	24	0	159	7	51
M-PZ104	28-Apr-06	434	7.7	710	33	16	58	10	0	220	5	92
M-PZ105	29-May-06	425	6.9	640	29	12	60	13	0	244	1	66
M-PZ105A	28-Apr-06	319	7.8	500	24	7.7	46	7.2	0	171	6	57
M-PZ105B	28-Apr-06	261	7.4	460	23	8	34	6.2	0	107	5	77
M-PZ108R	29-May-06	167	6.7	280	13	4.7	21	5.2	0	88	2	33
M-PZ109	29-May-06	370	9.5	690	6.6	7.7	76	35	28.8	51	65	100
M-PZ110	29-May-06	521	6	1040	39	26	64	21	0	146	15	210

* average value monitored by MCML at Ulan



0 2 4 6 8 Kilometres

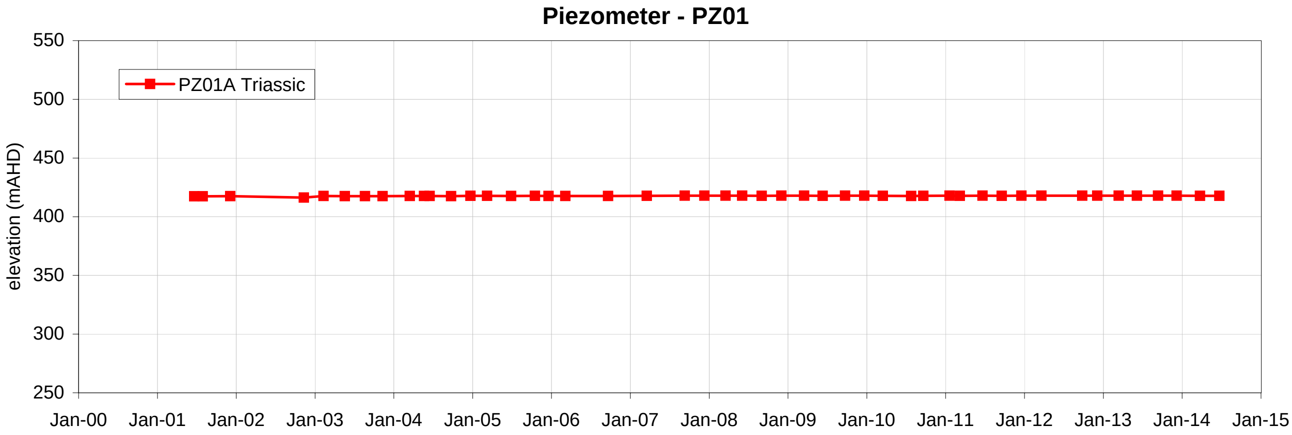
- major roads
- railway
- mainstream drainages
- topographic contours - 20m interval
- alluvium
- standpipes
- pore pressure transducers
- open cut pit crest

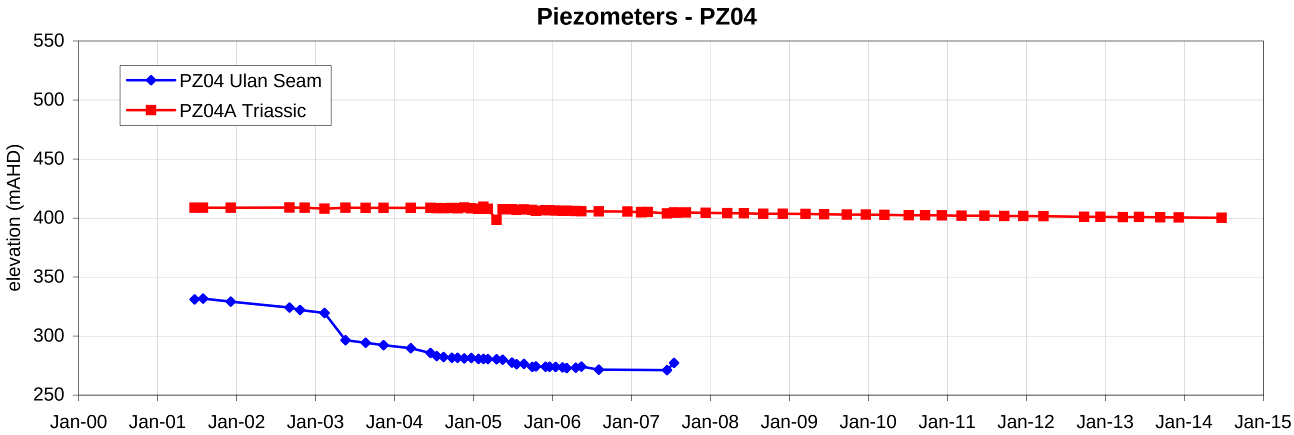
ULAN COAL MINES LIMITED - ULAN WEST MODIFICATION

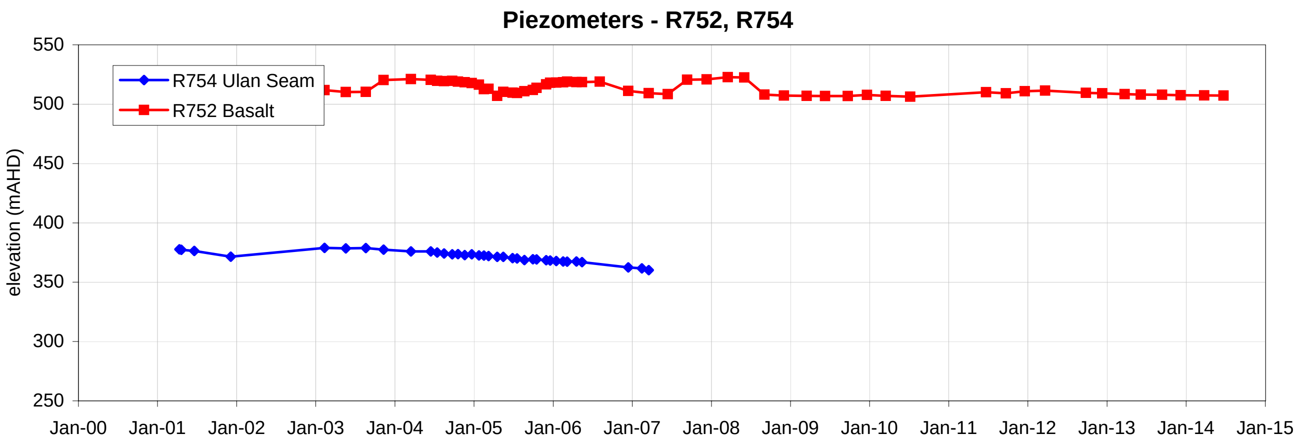
Monitoring piezometer locations

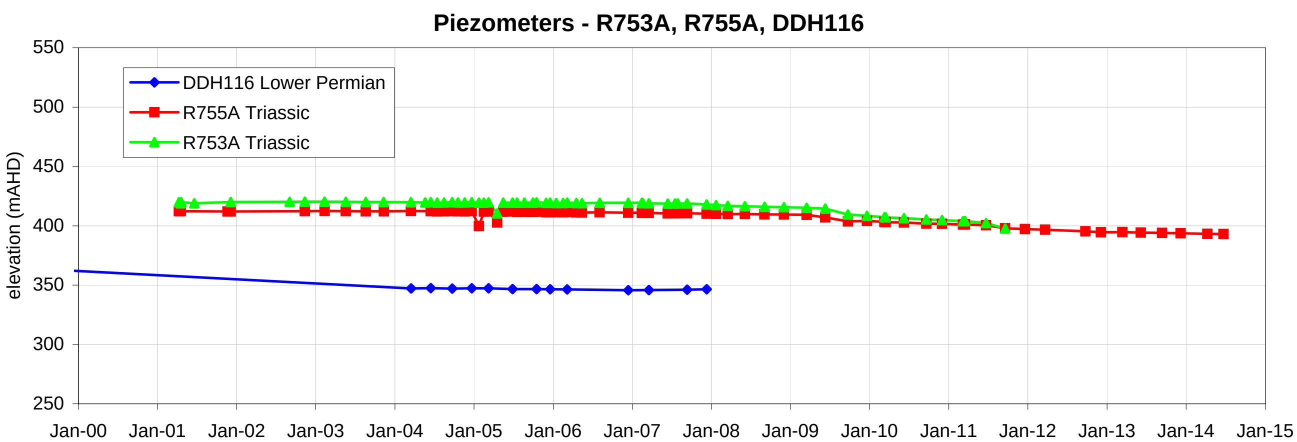
Mackie Environmental Research

Figure D1



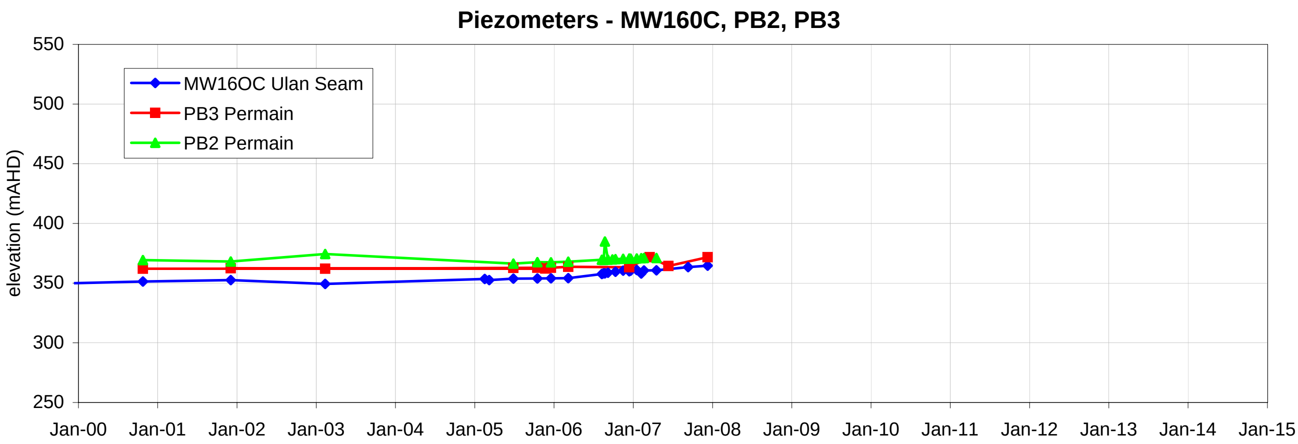


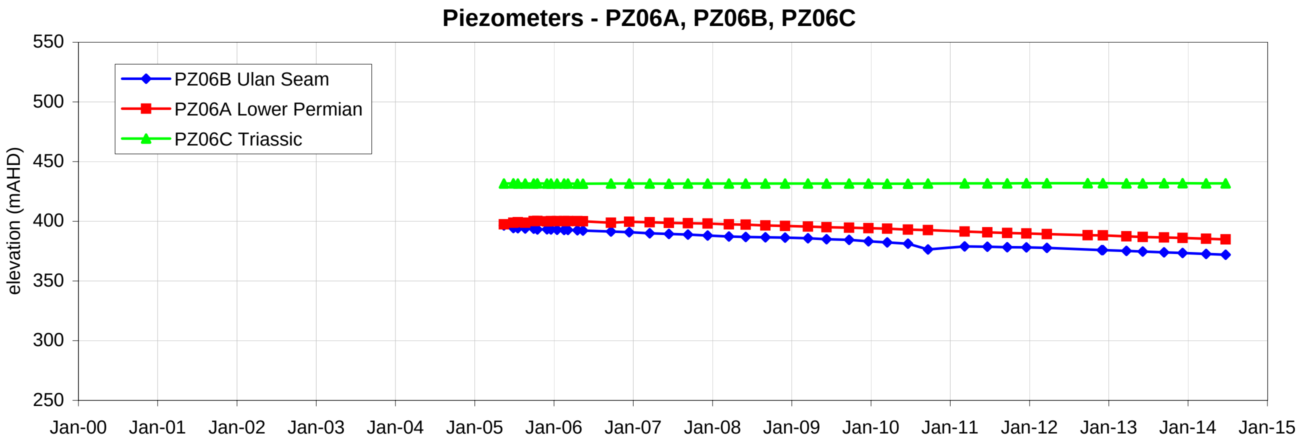


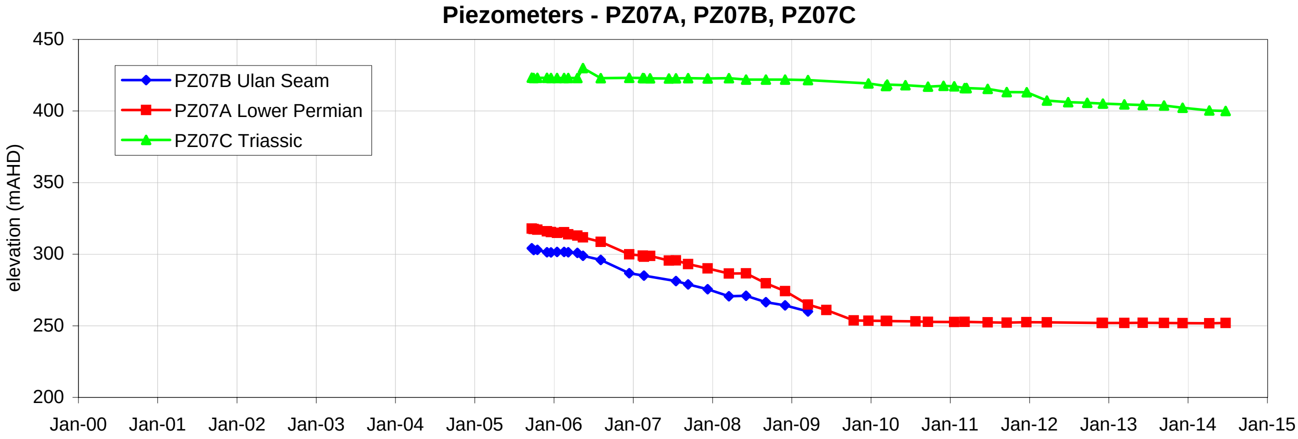


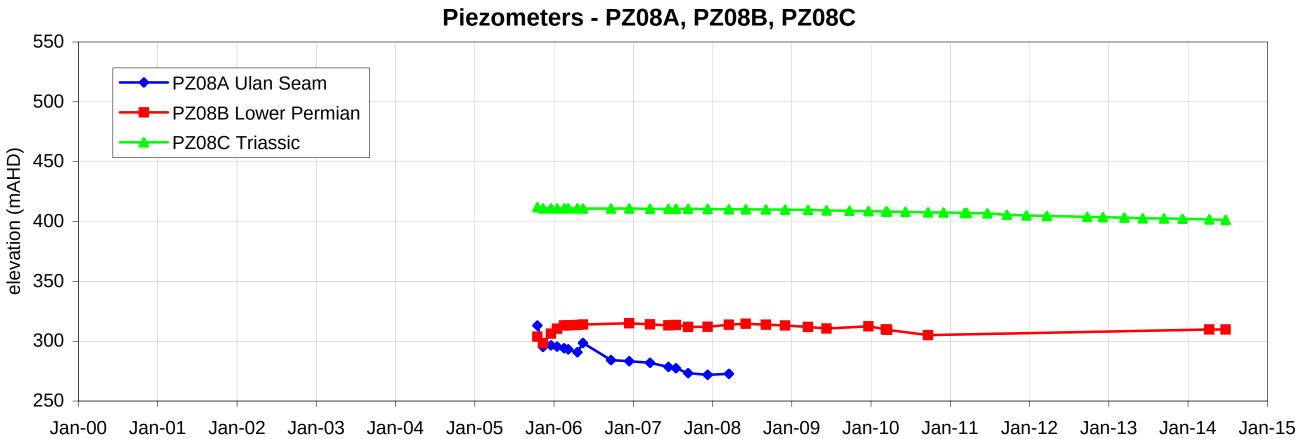
Historical piezometric data

Figure D2



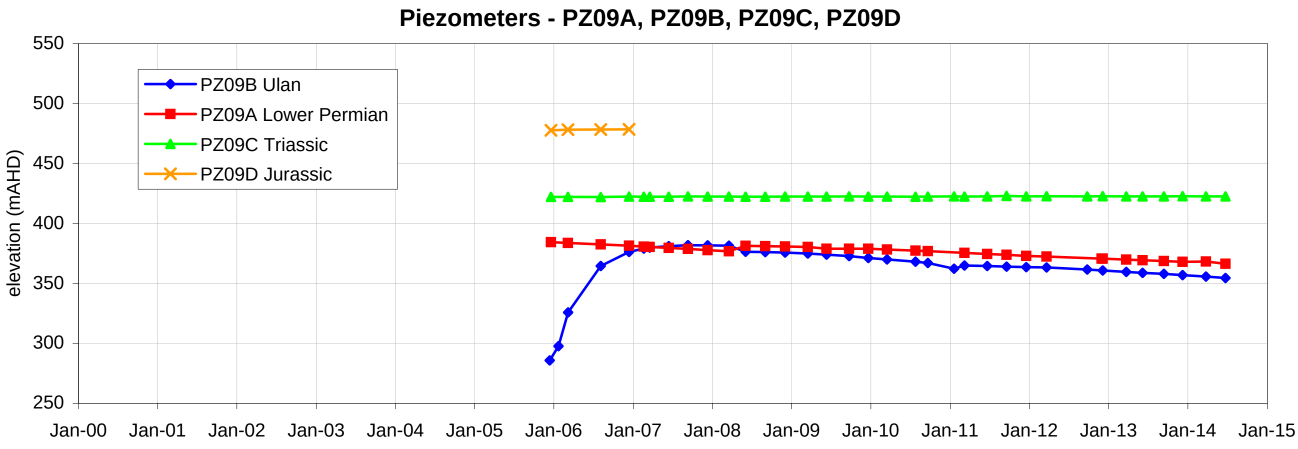


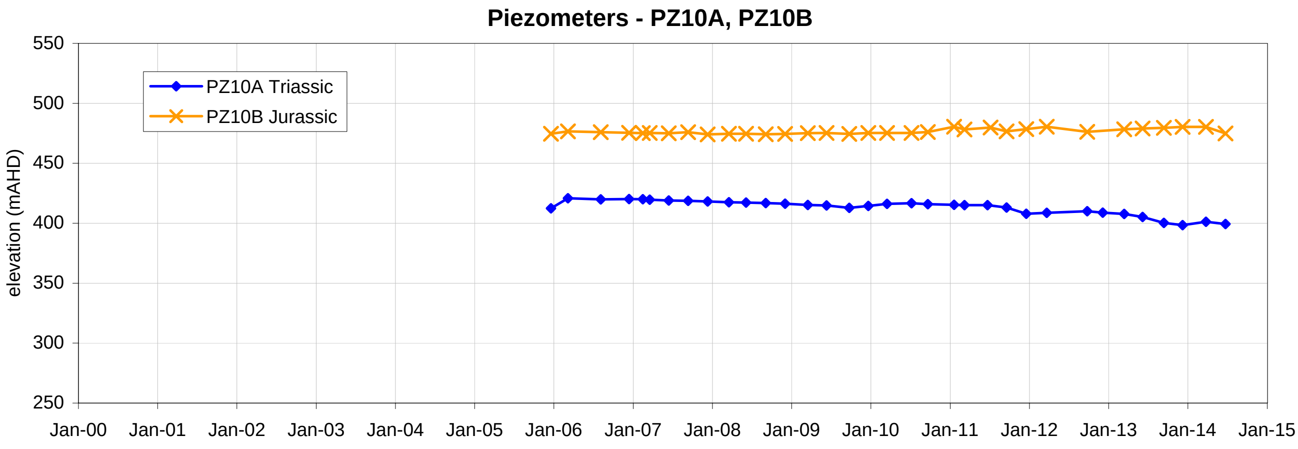


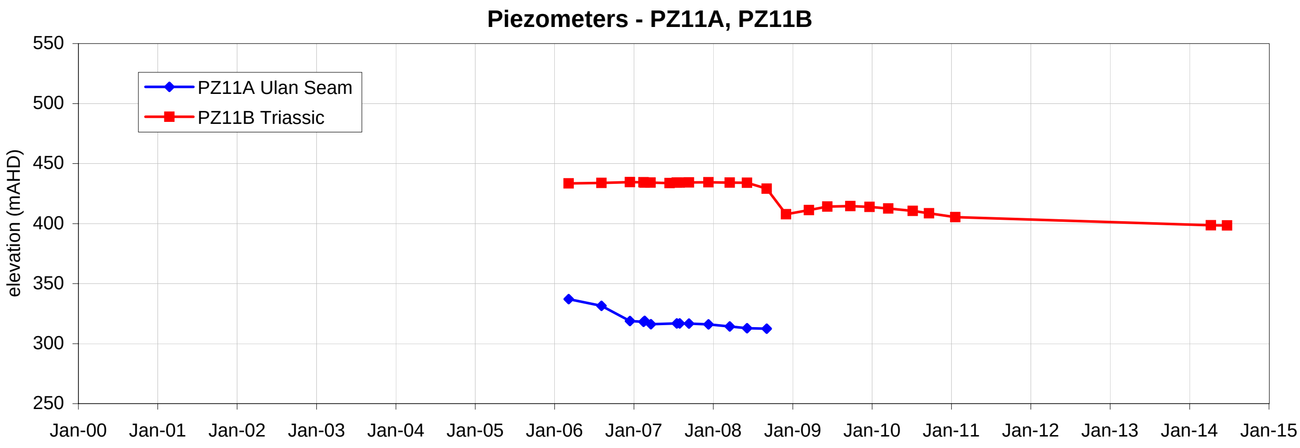


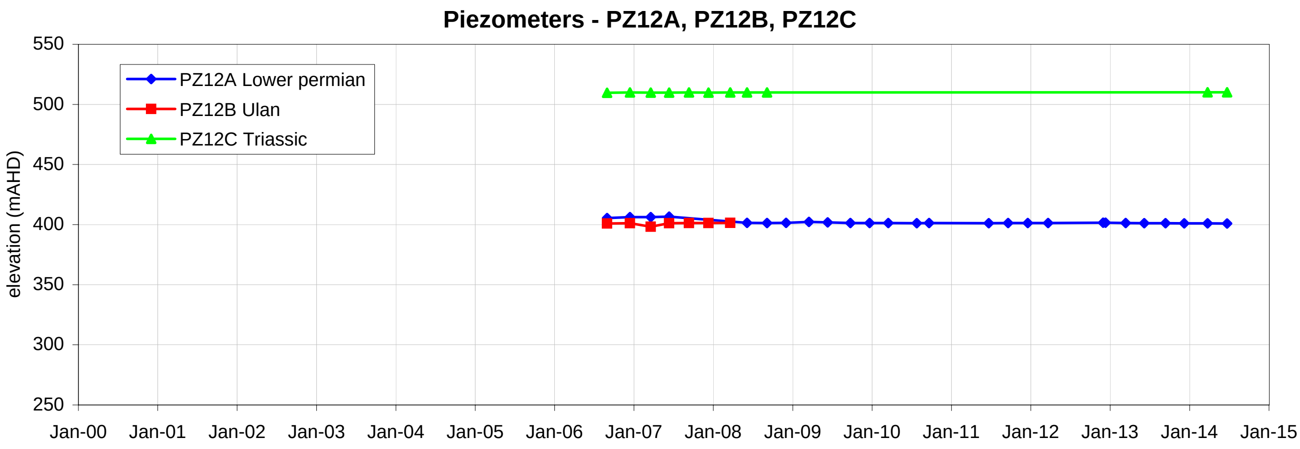
Historical piezometric data

Figure D2



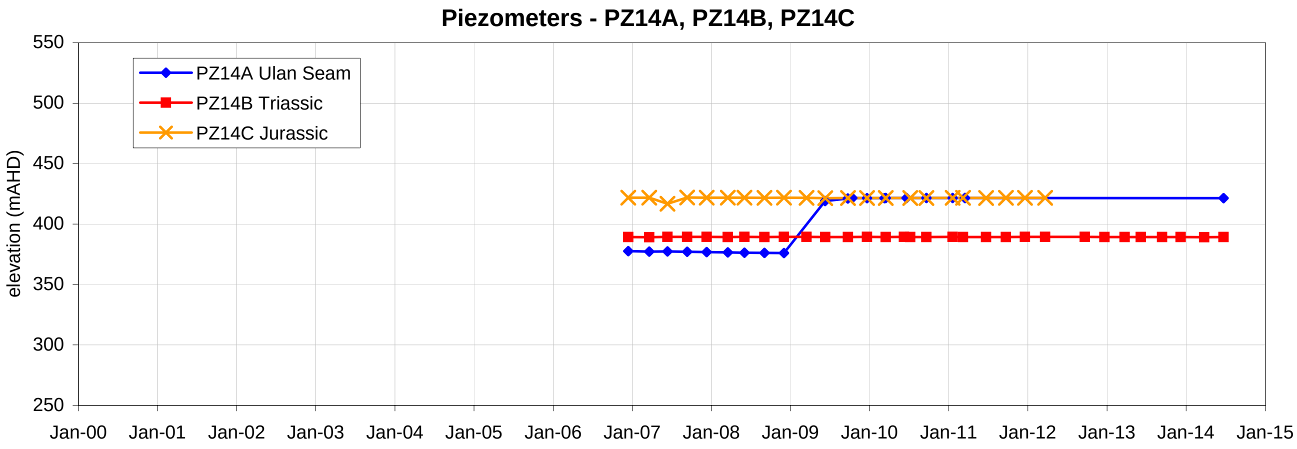


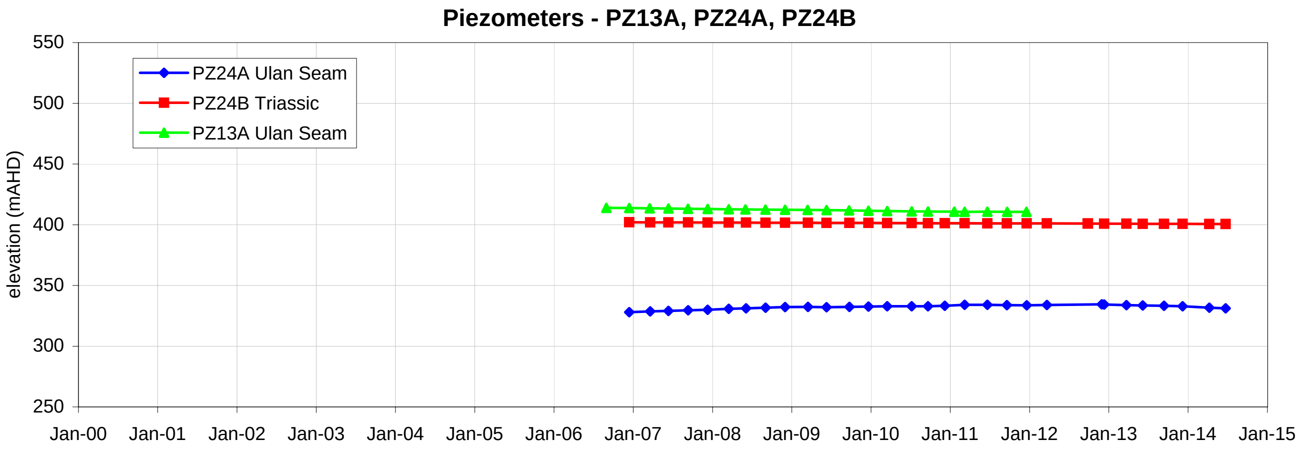


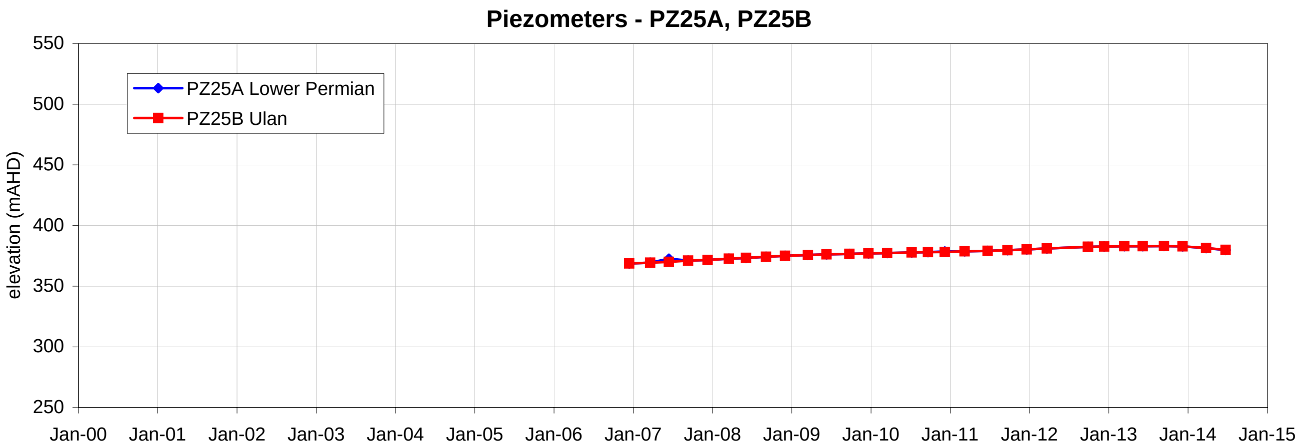


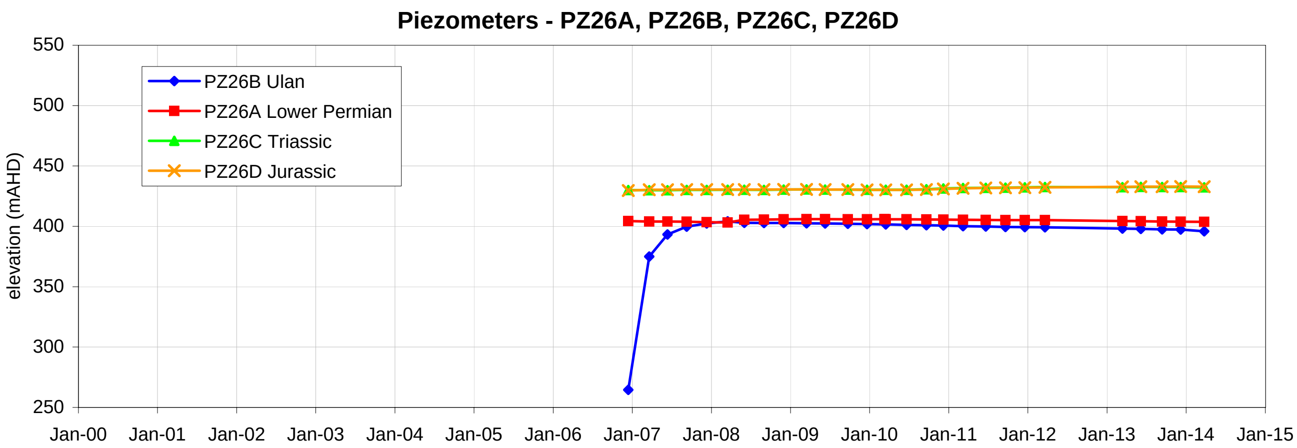
Historical piezometric data

Figure D2



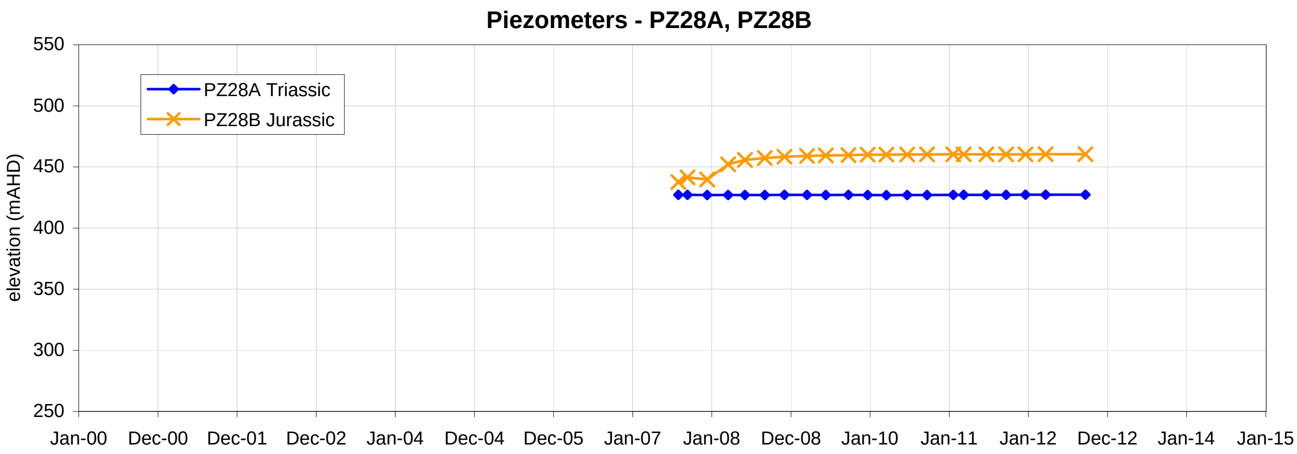






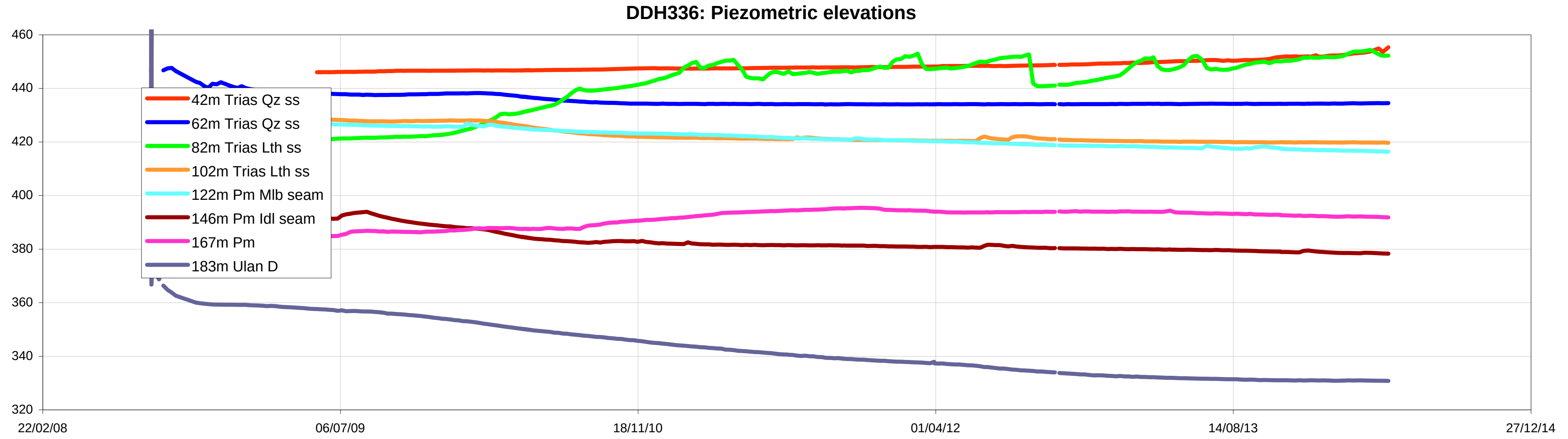
Historical piezometric data

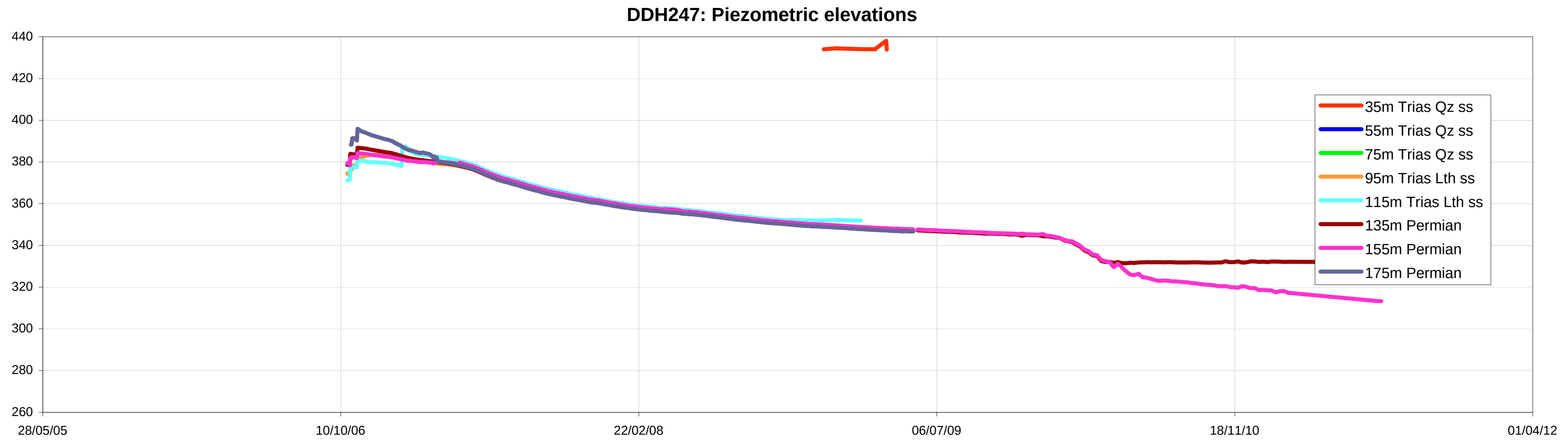
Figure D2

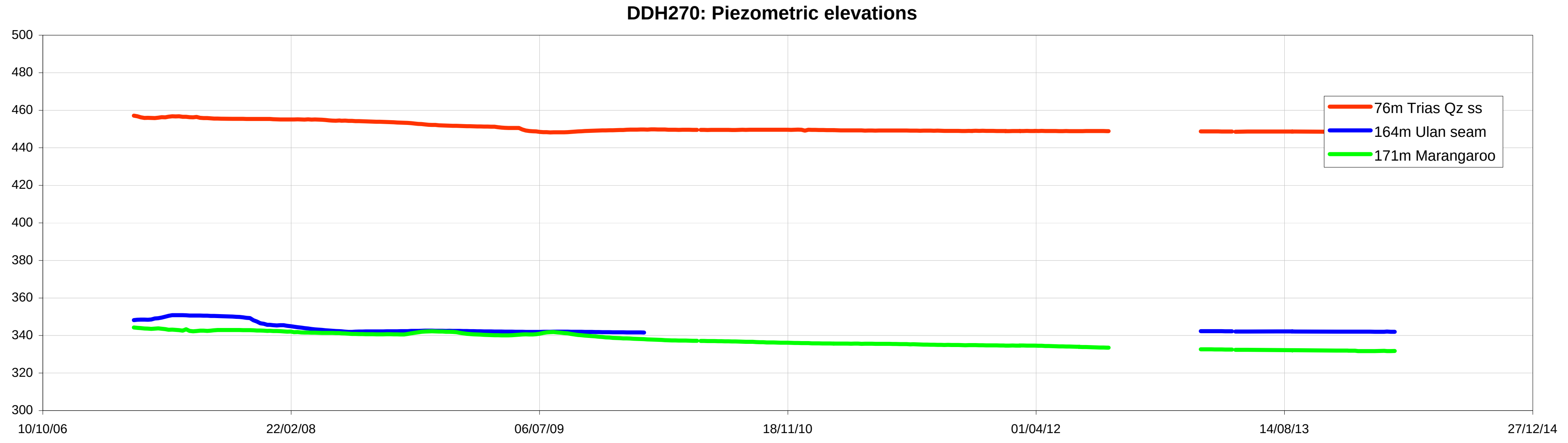


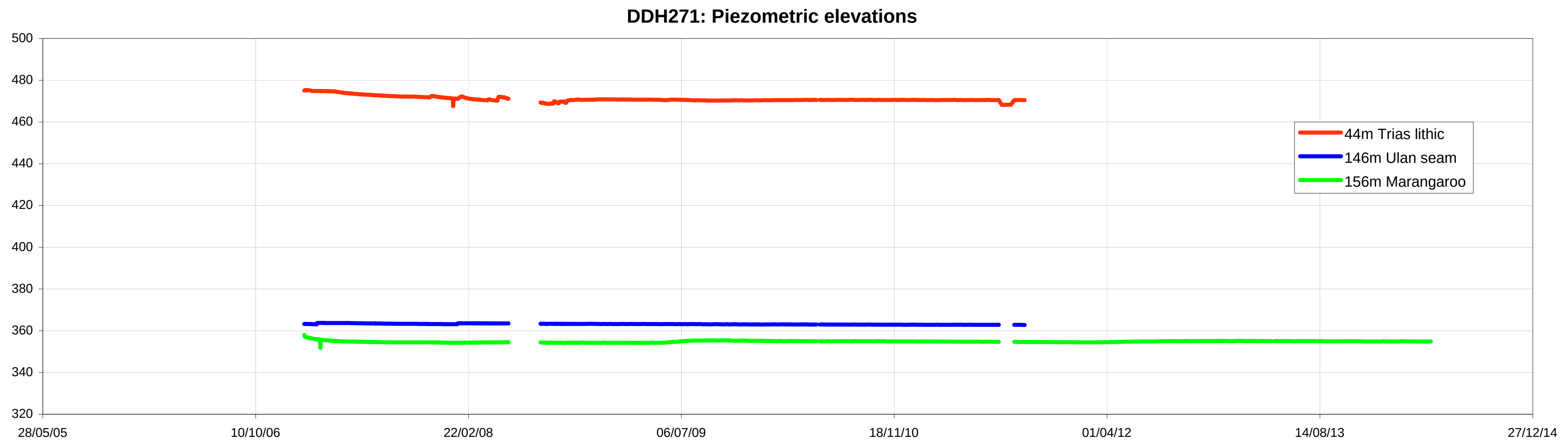
Historical piezometric data

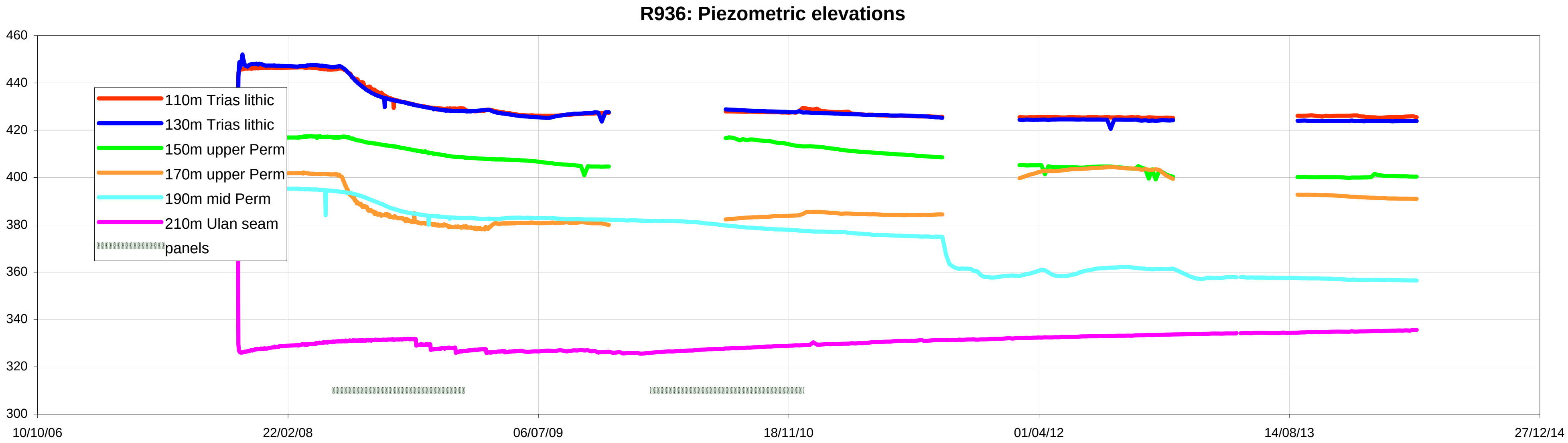
Figure A1

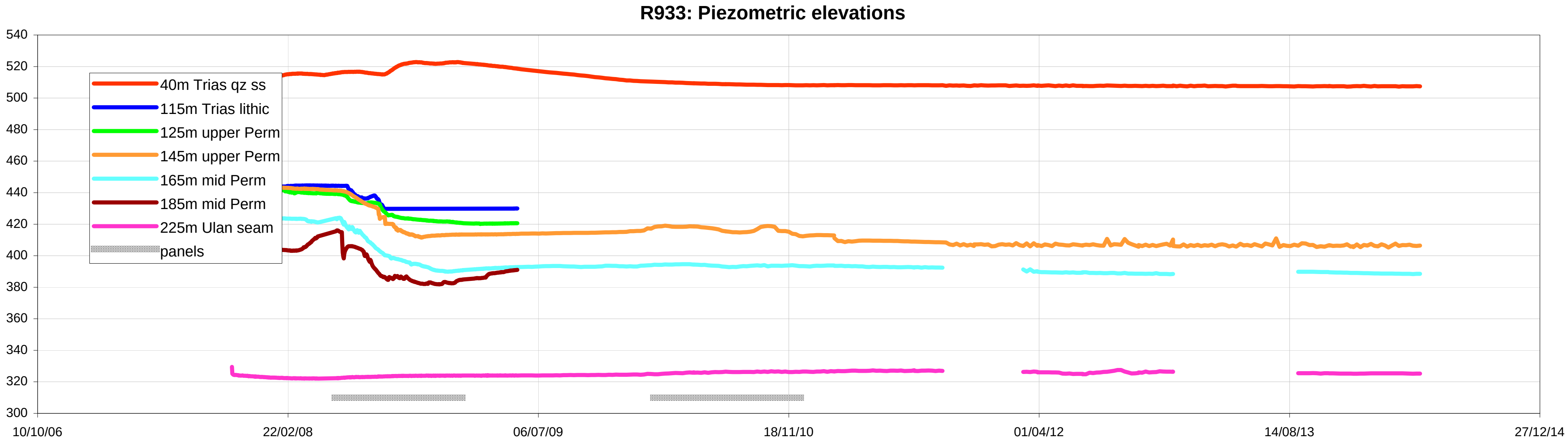

DDH336: Piezometric elevations
460
440
420
400
380
360
340
320
22/02/08
06/07/09
18/11/10
01/04/12
14/08/13
27/12/14
42m Trias Qz ss
62m Trias Qz ss
82m Trias Lth ss
102m Trias Lth ss
122m Pm Mlb seam
146m Pm Idl seam
167m Pm
183m Ulan D

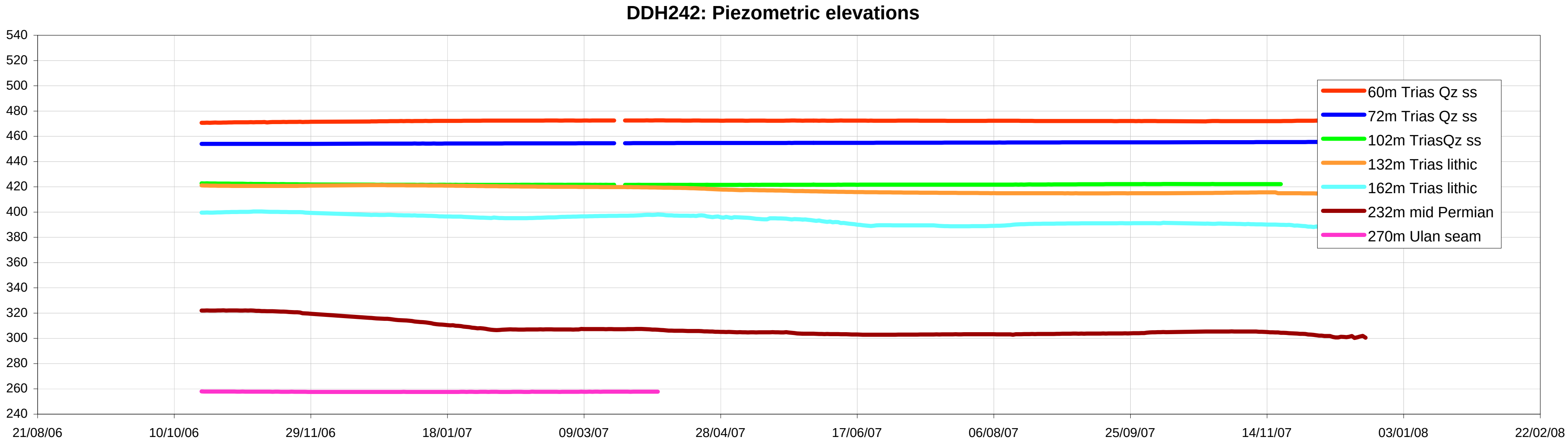

DDH247: Piezometric elevations
440
420
400
380
360
340
320
300
280
260
28/05/05
10/10/06
22/02/08
06/07/09
18/11/10
01/04/12
35m Trias Qz ss
55m Trias Qz ss
75m Trias Qz ss
95m Trias Lth ss
115m Trias Lth ss
135m Permian
155m Permian
175m Permian

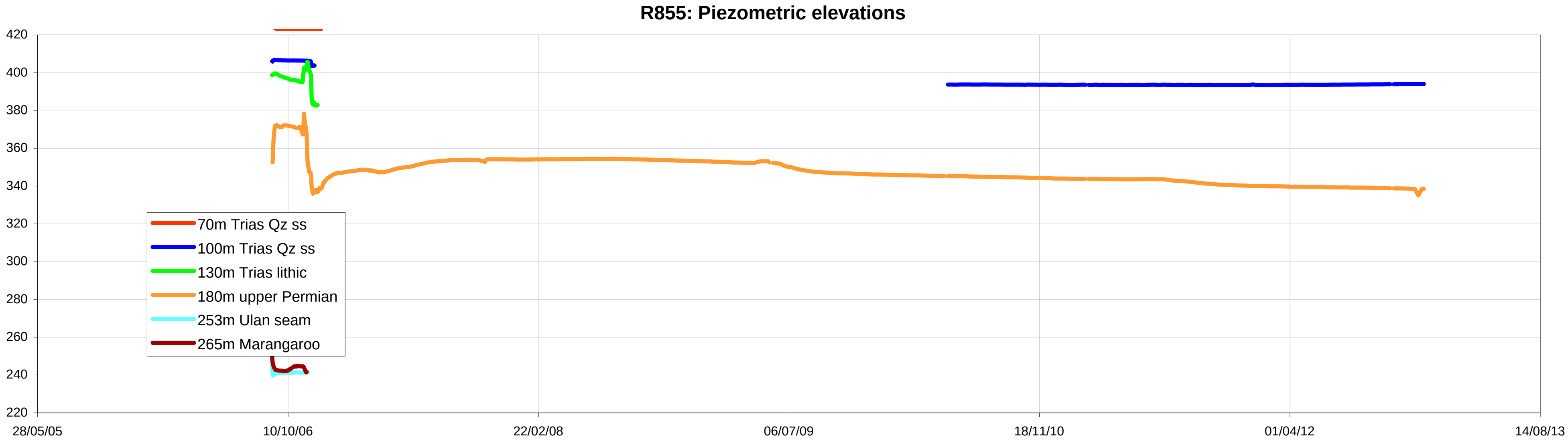

DDH270: Piezometric elevations
500
480
460
440
420
400
380
360
340
320
300
10/10/06
22/02/08
06/07/09
18/11/10
01/04/12
14/08/13
27/12/14
76m Trias Qz ss
164m Ulan seam
171m Marangaroo

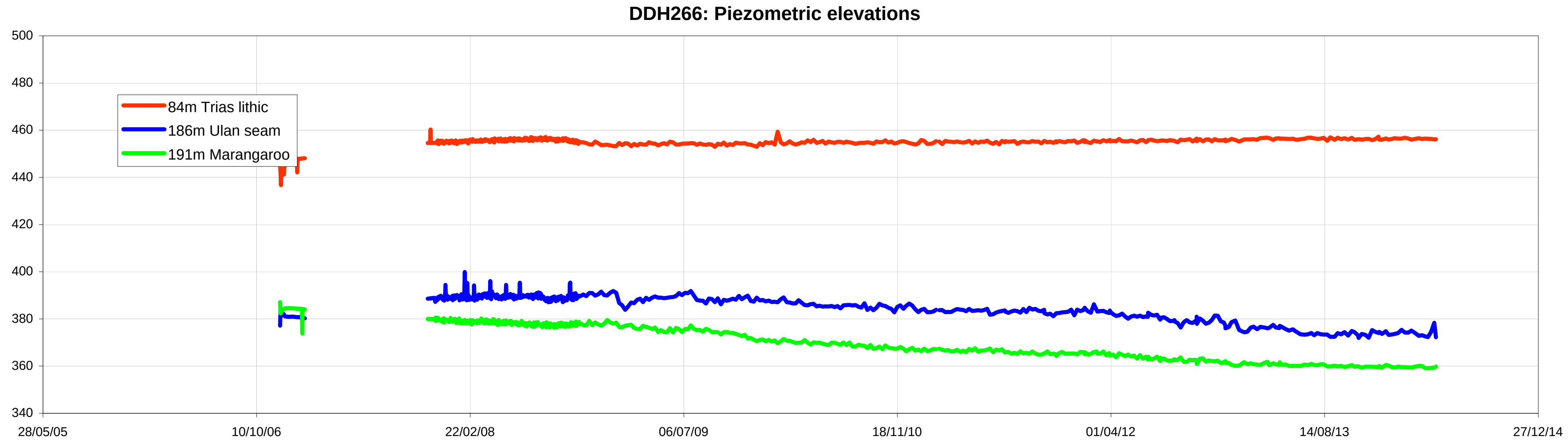

DDH271: Piezometric elevations
500
480
460
440
420
400
380
360
340
320
28/05/05
10/10/06
22/02/08
06/07/09
18/11/10
01/04/12
14/08/13
27/12/14
44m Trias lithic
146m Ulan seam
156m Marangaroo

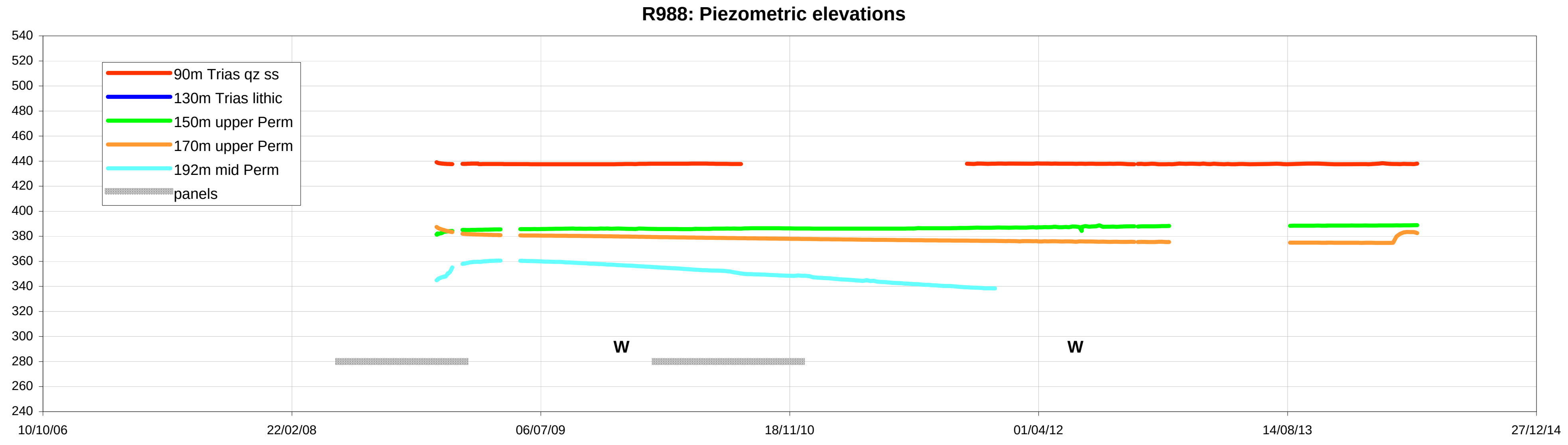

R936: Piezometric elevations
460
440
420
400
380
360
340
320
300
10/10/06
22/02/08
06/07/09
18/11/10
01/04/12
14/08/13
27/12/14
110m Trias lithic
130m Trias lithic
150m upper Perm
170m upper Perm
190m mid Perm
210m Ulan seam
panels

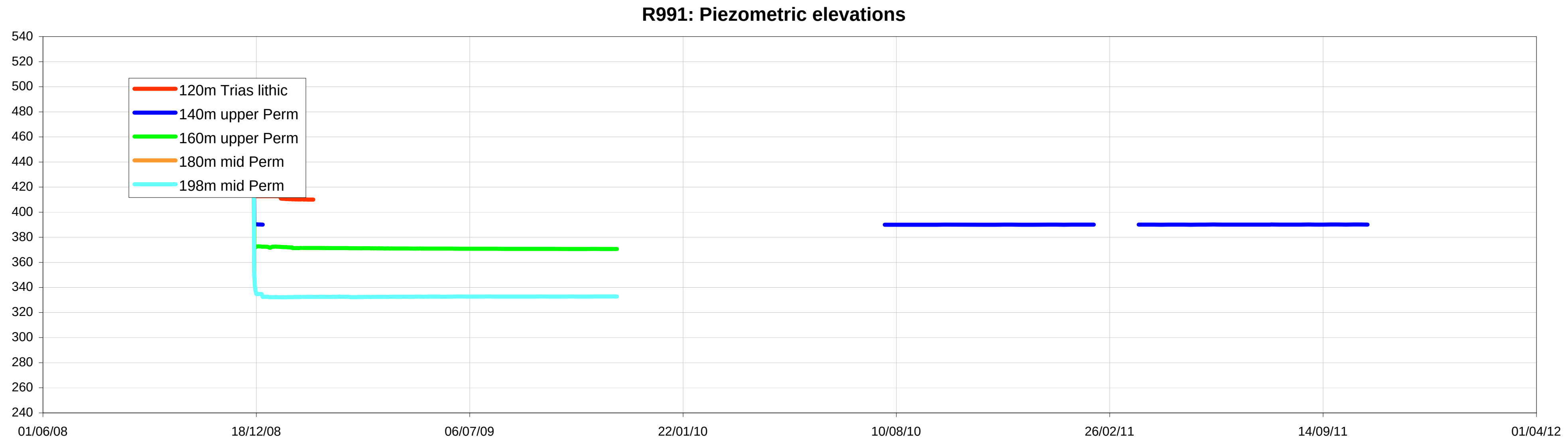

R933: Piezometric elevations
540
520
500
480
460
440
420
400
380
360
340
320
300
10/10/06
22/02/08
06/07/09
18/11/10
01/04/12
14/08/13
27/12/14
40m Trias qz ss
115m Trias lithic
125m upper Perm
145m upper Perm
165m mid Perm
185m mid Perm
225m Ulan seam
panels

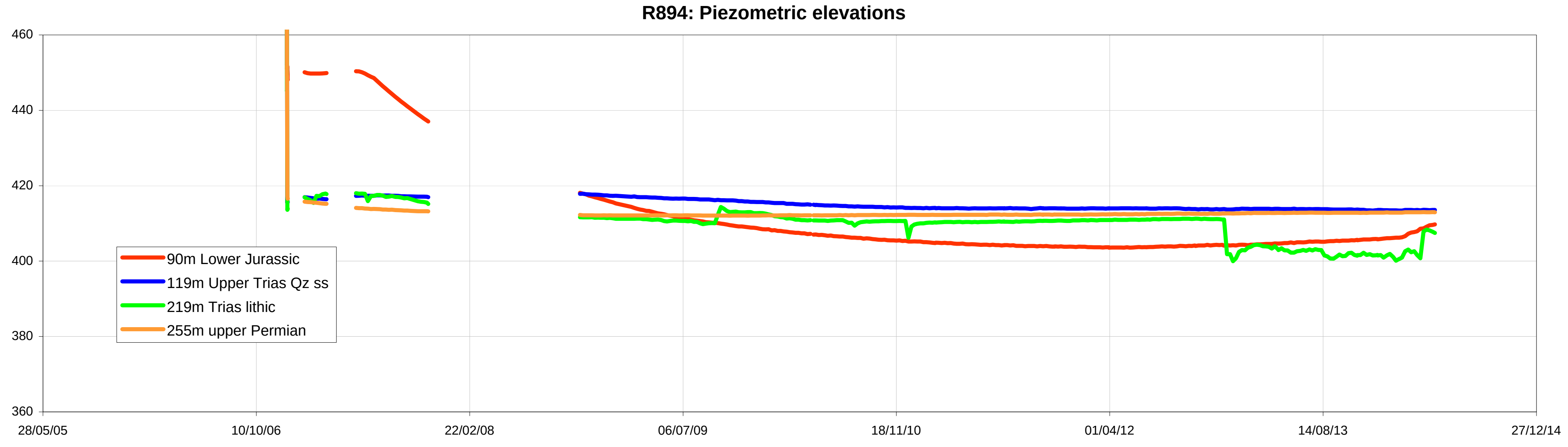

DDH242: Piezometric elevations
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
21/08/06
10/10/06
29/11/06
18/01/07
09/03/07
28/04/07
17/06/07
06/08/07
25/09/07
14/11/07
03/01/08
22/02/08
60m Trias Qz ss
72m Trias Qz ss
102m TriasQz ss
132m Trias lithic
162m Trias lithic
232m mid Permian
270m Ulan seam


R855: Piezometric elevations
420
400
380
360
340
320
300
280
260
240
220
28/05/05
10/10/06
22/02/08
06/07/09
18/11/10
01/04/12
14/08/13
70m Trias Qz ss
100m Trias Qz ss
130m Trias lithic
180m upper Permian
253m Ulan seam
265m Marangaroo



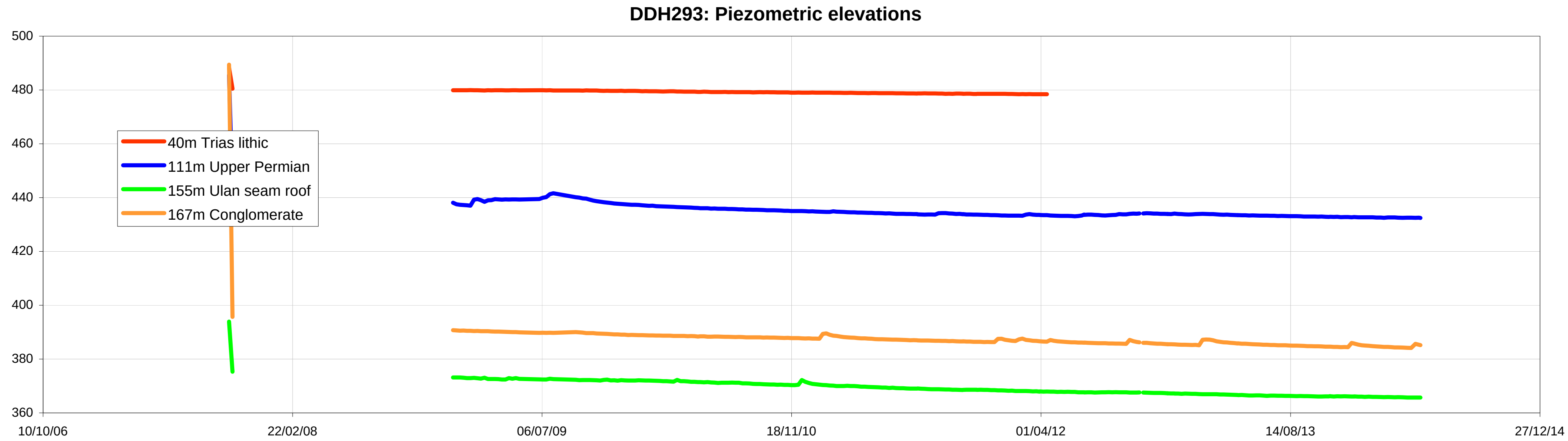


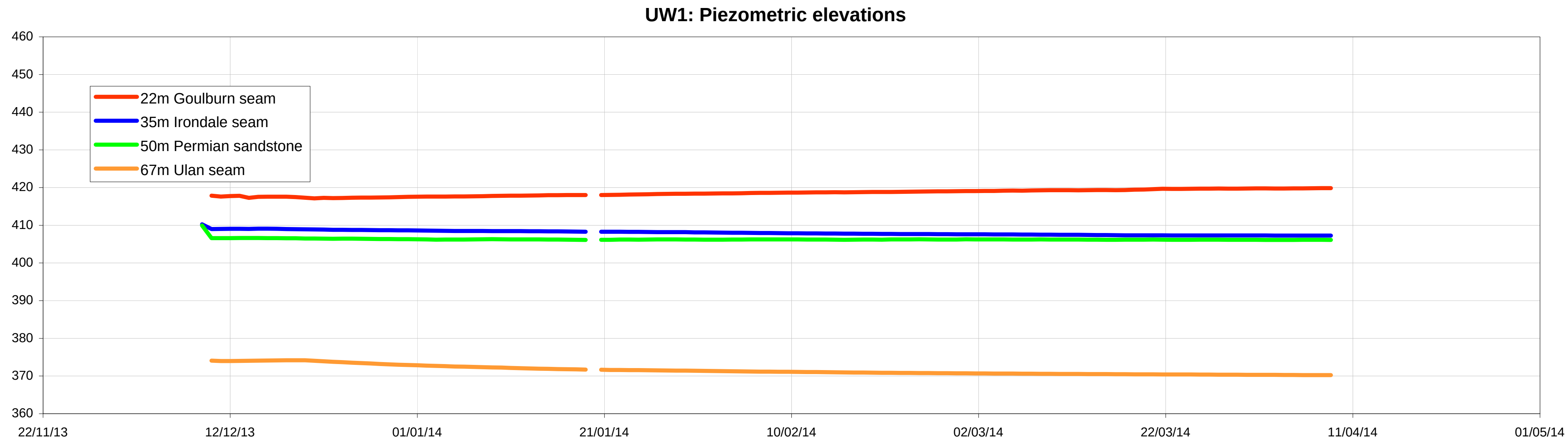


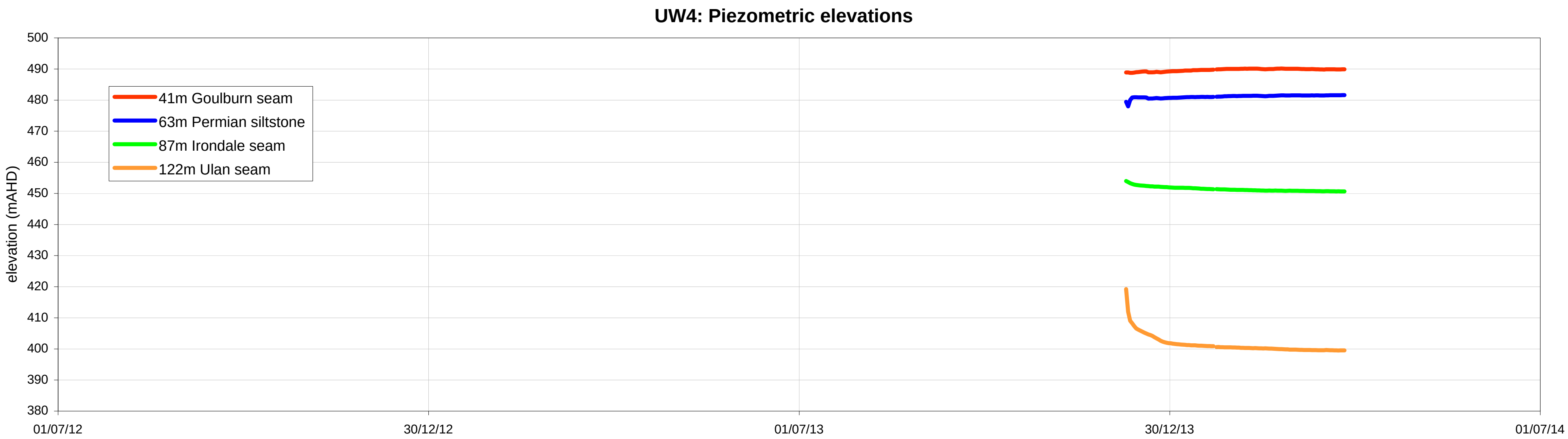


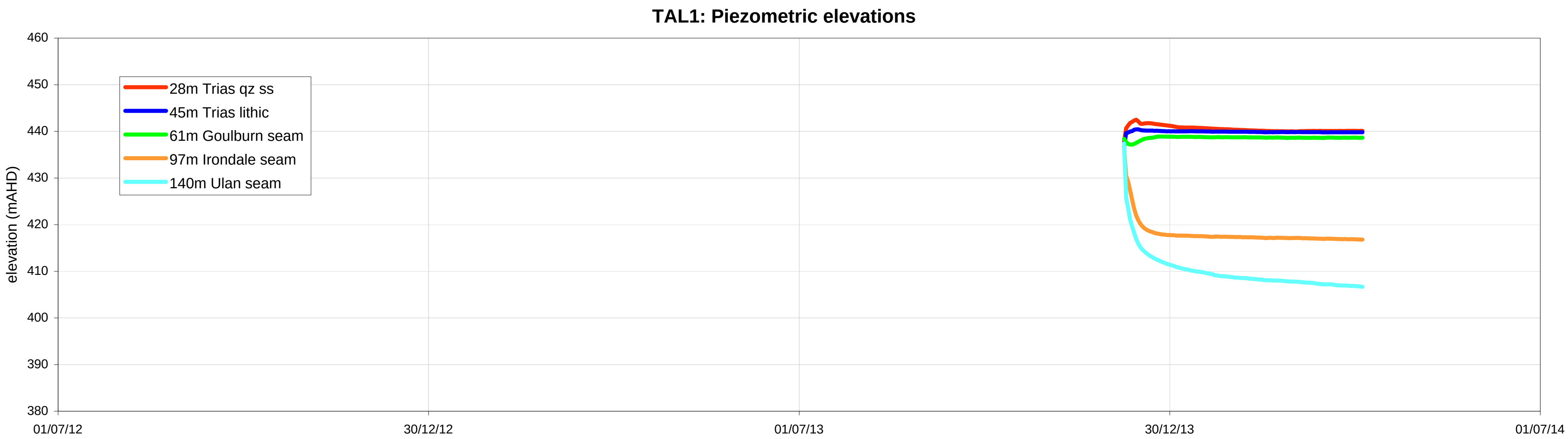
Piezometric elevations

Figure D2


DDH293: Piezometric elevations
500
480
460
440
420
400
380
360
10/10/06
22/02/08
06/07/09
18/11/10
01/04/12
14/08/13
27/12/14
40m Trias lithic
111m Upper Permian
155m Ulan seam roof
167m Conglomerate


UW1: Piezometric elevations
460
450
440
430
420
410
400
390
380
370
360
22/11/13
12/12/13
01/01/14
21/01/14
10/02/14
02/03/14
22/03/14
11/04/14
01/05/14
22m Goulburn seam
35m Irondale seam
50m Permian sandstone
67m Ulan seam


UW4: Piezometric elevations
elevation (mAHD)
500
490
480
470
460
450
440
430
420
410
400
390
380
01/07/12
30/12/12
01/07/13
30/12/13
01/07/14
41m Goulburn seam
63m Permian siltstone
87m Irondale seam
122m Ulan seam


TAL1: Piezometric elevations
elevation (mAHD)
460
450
440
430
420
410
400
390
380
01/07/12
30/12/12
01/07/13
30/12/13
01/07/14
28m Trias qz ss
45m Trias lithic
61m Goulburn seam
97m Irondale seam
140m Ulan seam

APPENDIX E: REGIONAL GROUNDWATER MODEL

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 groundwater system in respect of geometry, hydraulic properties and applied stresses. The simulation of underground mining operations is especially challenging for numerical models due to the prevalence of very steep hydraulic gradients above mine workings, and the presence of at least two zero pore pressure water table (phreatic) surfaces.

E1 Conceptualisation of the flow system

The layered sedimentary rock strata in the project area overly a relatively impermeable (granite) basement. The sedimentary strata dip to the north-east at a shallow angle and over geologic time have weathered and eroded to generate the present landscape which straddles the Great Divide. The Talbragar River valley drains westward and is broad and partly infilled with alluvial and colluvial materials which thicken along the drainage axis. The Goulburn River valley drains eastward and tends to be deeply incised with stringer deposits of alluvium along its course.

The regional sedimentary hard rock system constitutes the primary groundwater flow system. In the current study, groundwater storage and flow in the deeper hardrock strata is considered to be generally associated with the rock matrix rather than with fractures. The exception to this is the Ulan seam where permeability is assumed to be primarily associated with coal cleats (and joints).

Shallow alluvial deposits and the regolith constitute a secondary aquifer system insofar as they are more localised, they comprise unconsolidated materials, and they tend to respond to climatic changes more rapidly.

Over geologic time, flow in the hard rock strata has migrated from topographically elevated areas towards creeks and rivers at lower elevations. Flow in the localised alluvial systems has followed a similar pattern but with much shallower hydraulic grades. Both these flow systems are assumed to have been in a state of quasi equilibrium prior to mining. That is, groundwater levels have moved up and down within a relatively narrow range but flow pathways and flow rates have remained relatively constant in time.

Mining has induced changes in hard rock groundwater flow directions which has depressurised the strata hosting the mining operations and induced depressurisation in adjacent and overlying strata. The simulation of these changes to-date and the prediction of future impacts throughout the hydrogeologic system, have been the main goals of numerical modelling.

E2 Numerical model code

In the present study, a finite difference scheme (Modflow-Surfact, 2010) has been utilized due to the large area of interest, the extent of depressurisation that has evolved due to historical mining in the Ulan seam, and the variably saturated environment that typically prevails with longwall mining below the water table.

The scheme requires division of the overall area of interest (the hydrogeologic domain) into a large number of cells defined by a rectangular model mesh. The number of cells has been determined by the existing and proposed mine pits and longwall panel layouts, the spatial variations occurring in aquifer properties, the geometry of the drainage system, and the steep hydraulic gradients that occur around mined panels. Competition between accuracy and computing efficiency affects the overall number of cells contained within a numerical model and consequently the model discretisation has been varied from small cells within and around the longwall panels and East Pit open cut, to larger cells in areas more distant from the mine.

E3. Model layer geometry

The basic model design comprises 11 transversely anisotropic layers with 94400 cells per layer. The overall model extents are indicated on Figure E2 which also shows the regional drainage network used in the model. Total model surface area is about 1681 sq. km. with individual cell areas ranging from 2.5E+03 m^2 to more than 4.0E+04 m^2. All cells are 'block centered' with model heads calculated at the centroids of individual cells.

Model layers adopt a geometry consistent with the known stratigraphy but with additional layers included to facilitate calculation and interpolation of the pressure head loss regime within strata. The geometry of each layer has been defined from structure contour information supplied by UCML and interpolated regionally. Layer 1 represents the regolith, weathered bedrock and alluvial infill deposits mainly associated with the Talbragar River. It is uniformly defined to a depth below surface of 20 m. Layers 2 and 3 represent the regional Jurassic strata while deeper layers represent the Triassic and Permian strata. The Ulan seam is represented as a separate layer within the Permian strata. The base of the model has been defined approximately 120 m below the Ulan seam floor in deeper basement granites.

Ground surface (top of layer 1) has been determined by direct interpolation from the regional digital terrain model (DTM). This model was generated at 10m pixel resolution over the entire region from original 1:25000 data supplied by the Department of Lands.

Figures E1a and E1b provide perspectives showing model layer geometry looking towards the south-west and south-east respectively with the approved mine plan draped over the topography.

E4. Model hydraulic properties

Hydraulic conductivities assigned to each model layer were initially calculated by correlation to geologically logged rock types (from core) within a particular layer, followed by consolidation of sections of the stratigraphic column into model layers. Subsequent analyses of geophysical wireline logs supported an improved understanding of conductivity distributions, especially in the Triassic sandstones (see Mackie, 2012).

Specific storage (compressible S_s) estimates have been calculated from core laboratory measurements of Youngs Modulus and measurements of porosity (Appendix C). A specific storage range from 1.69E-06 to 5.13E-06 1/m was initially calculated for a modulus range from 3.1 to 17.7 GPa. Values were then adjusted slightly (within an expected range) during the model calibration process.

Specific yield estimates were initially assigned using the conductivity-porosity relationship developed from core tests (see Figure 6 – main text). These values were also adjusted during the calibration process – particularly values assigned to the Triassic quartzose strata.

E5. 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.

River cells have been imposed along the Goulburn River for the reach to the east and downstream of the confluence with Bobadeen Creek where flow is assumed to occur at all times (see Figure E2). These cells enforce seepage from surrounding areas of elevated water table to the river if the water table is above the river, or seepage from the river to surrounding strata if the water table in the strata is lower than the river level(s). River cell conditions have also been imposed on the Talbragar River in the western part of the model below the confluence with Mona Creek.

All river and creek bed levels assigned to specific model cells have been set two metres below the elevation determined by direct interpolation from the regional digital terrain model. The adjustment of two metres is based upon correlation between the regional terrain data and high resolution airborne laser survey of the mine lease conducted by UCML. A uniform cell conductance of 1.0E02 m^2/day has been applied for simplicity. This value governs the rate of removal of groundwater in a specific river cell and ensures relatively rapid model response.

Drain type cells have been used to represent all other drainage lines which are assumed to be ephemeral (see Figure E2). These cells allow the model water table to drain to the drainage lines if the elevation of the water table is higher than the creek bed elevations, or to fall below the creek bed without inducing leakage from the creek. A uniform cell conductance of 1.0E02 m^2/day has been applied for simplicity.

Drain cells have also been employed to represent open cut areas, underground development headings, gate roads and longwall panels at an elevation equivalent to the seam working section floor. These cells have been scheduled to depressurise and induce groundwater seepage in accordance with the historical and proposed mine plan. A uniform cell conductance of 1.0E02 m^2/day has been applied for simplicity. This value ensures rapid and free drainage only when specific model cells are triggered to impose zero pore pressures consistent with the mining process.

Distributed flux conditions have been employed to represent regional rainfall recharge. This net recharge has been applied at differing rates depending on the shallow and surficial geology. The rates have been determined from numerous steady state simulation trials where recharge was progressively increased until model water levels broadly matched groundwater elevations measured at a number of regional borehole locations (see Section 6 below). Figure E3 shows the distribution of recharge zones within model layer 1. These zones are calculated to align with layers beneath the regolith-weathered zone.

Groundwater pumping by local landholders for domestic, stock and irrigation purposes, has not been included since pumping rates are unlikely to have a measurable impact on the regional groundwater flow system.

E5.1 Treatment of the subsidence zone

Enhanced vertical conductivities representing connected and free draining cracking regimes are normally associated with the subsidence zone above longwall panels. Basically four disturbed zones are commonly identified (see Figure E4):

- ***goaf*****:** a zone within and above the extracted coal seam which is identified as being highly permeable and exhibiting a high fragmentation porosity of 15% or more. This caved zone typically contains remnants of the coal seam, stoney coal and other detached roof strata compressed under the weight of overlying (subsided) strata. Height of the zone depends upon stratigraphy, geomechanical properties of the strata, and the geometry of longwall panels. It is often estimated to be 3 to 10 times the height of mining or approximately 9 to 30 m above the working section floor for UCML operations;
- ***connected cracking:*** a zone situated above extracted panels and extending upwards through overburden to a height which is often approximated to be equivalent to or greater than panel width. At UCML it is predicted to extend upwards through the Permian, Triassic and Jurassic strata (SCT 2007b,c). Hydraulic connection is generated predominantly by combinations of bedding shear, tensile failure of bedding, and shear or tensile reactivation of pre-existing fractures or joints. The zone exhibits highly connected cracking immediately above goaf but connectivity is assumed to decline with increasing height. This cracked regime facilitates relatively free drainage of groundwater from the strata leading to zero pore pressures in the lowermost part of the zone, and low or zero pore pressures extending to the uppermost part of the zone in the course of time as drainage proceeds;
- ***disconnected cracking:*** a zone which is often referred to as the 'constrained zone' and may occur above the connected cracking zone. The zone is characterised by bedding shear with infrequent vertical cracking. The presence and extent of this zone is governed by a

number of factors including depth of cover and subsidence criticality. It is considered to be absent at UCML since longwall panel widths are considered to be of sufficient magnitude to potentially generate cracking to surface (SCT, 2009). Pore pressures may be maintained in some areas in the long term depending on numerous factors including the rate of rainfall or stream bed recharge from above;

- ***shallow surface cracking:*** a zone of typically 10 to 20 m depth comprised of tensile cracking with some re-activation (and closure) on pre-existing joints. Surficial cracking may exhibit apertures sometimes exceeding 100 mm depending on strain energies and how they are dissipated. The zone may be disconnected from deeper failure regimes if mining is sufficiently deep. Under these conditions, temporary changes in shallow groundwater movement and storage are associated with subsidence.

The increased rate of drainage of subsided overburden has been simulated using the TMP1 package (Hydrogeologic, 2010) by assigning elevated vertical and horizontal conductivities to the different strata using scaling factors that were adjusted as part of the model re-calibration process to achieve reasonable agreement between observed and predicted pore pressures and mine water influx. Upscaled conductivities essentially promote an upwards migration of the zero pore pressure surface (atmospheric pressure) from the coal seam while maintaining a pressure continuum throughout the saturated part of the subsidence zone.

E6. Model re-calibration – steady state

Calibration is the process involving adjustment of certain parameters until model generated groundwater flows and piezometric levels reasonably match the measured flows and levels. In adjusting parameters it is important to maintain reasonable correlation between ‘calibrated’ and measured aquifer properties.

Model re-calibration has been undertaken in an iterative manner by first conducting steady state simulations to generate pre-mining piezometric surfaces and flow systems, followed by (transient) simulation of mining operations.

Steady state calibration of the pre-mining piezometric surface has been conducted by adjusting rainfall recharge to the system and comparing the resulting head distribution to piezometric levels that have not been measurably influenced by mining at the present time. Figure E3 shows the locations of control piezometers. A measure of the calibration is based upon the correlation between measured and predicted groundwater levels and is described by the normalised root mean square (NRMS) error at the control bores. This error is calculated to be 9.7% and is considered to be acceptable for a groundwater model of this regional scale and complexity. The error could be reduced further by applying localised variability to rainfall recharge but this would in effect represent a localised forcing of the model without knowledge of local scale hydraulic conductivities or rainfall recharge processes.

Figure E5 provides a plot of the model generated water table for Triassic strata. Groundwater flow path lines (for Triassic strata) are also shown on Figures E5. These path lines describe individual water particle tracks over a long period of time and are useful in understanding the regional flow systems. The path lines support recharge in areas west and south-west of Ulan West mine. From here the path lines describe a route either to the north and north-west to the Talbragar River catchment, or to the north-east and east eventually turning to the south-east and exiting the model down the Goulburn River catchment. The groundwater flow divide defined by these path lines is located up to 5 km west of the topographic Great Divide. Figure E6 provides a plot of the model generated steady state pre-mining piezometric surface in the Ulan seam. Velocities of flow within the hardrock strata are estimated to range from 1.0E-03 to 5.0E-01 m/day.

Pre-mining baseflows have been extracted for the various catchments surrounding the mining operations and are presented in Table E1. These are groundwater flows that are drained from the model via boundary conditions assigned along drainage lines, in order to achieve the piezometric surfaces shown on Figures E5 and E6.

Table E1: Re-calibrated steady state pre-mining groundwater baseflows

Catchment or reach	Status	Baseflow ML/day
Upper Goulburn R above Sportsmans Hollow Ck confluence	ephemeral	0.002
Goulburn R from Sportsmans Hollow Ck to Bobadeen Ck confluence	ephemeral	0.022
Goulburn R from Bobadeen Ck to Murrumbline Ck confluence	intermittent	0.764
Goulburn R below Murrumbline Ck confluence	perennial	0.195
Ulan Ck catchment	ephemeral	0.009
Bobadeen Ck catchment including Spring Gully	ephemeral	0.004
Curryall – Murrumbline Ck catchment	perennial	0.109
Mona Ck catchment	ephemeral	0.077
Cockabutta Ck (lower) catchment	intermittent	0.225
Talbragar R above Mona Ck confluence	perennial	2.029
Talbragar R from Mona Ck to Cockabutta Ck confluence	perennial	0.688
Talbragar R below Cockabutta Ck confluence	perennial	1.669

In general they are lower than the baseflows commonly associated with stream flow recession curves (often defined by baseflow indices) which include larger contributions from rainfall events retained as storage in localised colluvial and alluvial materials. Baseflows have been used as a guide to calibration – low flows (less than say 0.03 ML/day) can reasonably be expected to identify with ephemeral streams. It is noted that the baseflow attributed to the Upper Goulburn River catchment is low due to the limited catchment area included in the groundwater model – areas to the south drained by Moolarben Creek are not fully represented. The values, while of similar magnitude, differ from the 2009 model calibration (MER, 2009) due to adjustments in layer conductivities and rainfall recharge rates.

E7. Model re-calibration – transient state

The transient re-calibration process has involved further adjustment of strata hydraulic properties and subsidence zone parameters on a trial and error basis until predicted piezometric data and mine water seepage inflows plausibly matched observed conditions.

A model generated water table for Triassic strata and a potentiometric surface in the Ulan seam for June 2014 (equivalent to 10393 days of model time) are provided as Figure E7 and Figure E8. Reference to these plots clearly shows the steep hydraulic gradients prevailing around extracted longwall panels, and the regional depressurisation associated with the transmissive Ulan seam. Triassic depressurisation is complete above the longwall panels but is restricted to less than a few kilometres from the panel perimeters. The subsidence zone reflects fully dewatered conditions with a lag of a few years (to complete dewatering) after mining of a specific panel. The lag is governed by the effectivev porosity of the strata and the enhanced hydraulic conductivities assigned to the caved zone and overlying fracture zone. In contrast to the relatively localised impacts in the Triassic sandstones, the Ulan seam induces significant regional depressurisation extending more than 10 kms beyond the footprint.

Table E2 gives a summary of re-calibrated material properties. Table E3 provides a summary of adopted subsidence zone conductivities. It is noted that layers 1, 2, 3 and 4 are unsaturated over most of the mine panel footprint and have therefore been excluded from enhanced drainage within the subsidence zone. Layer 5 only required a minor increase to achieve a (flux) calibrated outcome due to the generally high vertical matrix conductivity that prevails in the Triassic quartzose sandstone strata.

Table E2: Material hydraulic properties assigned to the calibrated model

Layer	Lithology	Thick (m)	Kxy m/day	Kz m/day	Ss 1/m	Sy
1	valley fill alluvium	20	5.0E+01	1E+01	2.0E-06	3.0E-02
1	regolith-weathered rock	20	1.0E-02	1.0E-02	2.0E-06	5.0E-02
2	Jurassic sandstones-siltstones	variable	5.0E-03	1.0E-04	7.0E-06	1.0E-02
3	Jurassic sandstones-siltstones	avg.40	6.0E-03	8.0E-05	7.0E-06	1.0E-03
4	Triassic quartzose sandstones	avg.37	2.0E-02	1.0E-02	3.0E-05	6.2E-02
5	Triassic quartzose sandstones	avg.37	1.5E-02	1.0E-02	3.0E-05	2.8E-02
6	Triassic lithic sandstones	avg.36	8.0E-03	2.0E-04	9.0E-06	2.0E-03
7	upper[5] Permian coal measures	avg.43	1.0E-04	5.0E-06	2.0E-06	8.0E-03
8	middle Permian coal measures	avg.41	4.0E-04	8.0E-06	1.0E-06	3.0E-03
9	Ulan Seam	avg.8	6.0E-01	6.0E-01	7.0E-06	1.0E-02
10	lower Permian coal measures	avg.50	2.0E-03	6.0E-04	6.0E-06	3.0E-03
11	Granite + meta sediments	avg.50	1.0E-05	1.0E-05	2.0E-06	1.0E-03

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

Table E3: Leakance scaling factors assigned to the subsidence zone

Layer	Lithology	Thick (m)	Kxy	Kz
4	Triassic quartzose sandstones	avg.37	2.0E-00	1.3E+01
5	Triassic lithic sandstones	avg.36	1.0E+01	2.0E+01
6	upper Permian coal measures	avg.43	3.5E+01	3.4E+02
7	middle Permian coal measures	avg.41	1.2E+04	2.3E+02
8	Ulan Seam	avg.8	1.5E+04	1.2E+02

Kxy = horiz. conductivity, Kz = vert. conductivity

Figures E9, E10 and E11 provide pore pressures distributions in 2014 at three vertical sections through the model (see Figure E2 for section locations). Complete drainage of the mined Ulan seam is clearly evident in these sections as is the delayed but complete drainage of Permian and Triassic strata.

Figure E12 shows typical model calibration plots at regional piezometers (model days).

E8. Parameter sensitivity

Sensitivity analysis is often conducted in order to 'rank' the relative importance of parameters within a numerical model and to identify which parameters need to be carefully considered during the calibration process. Specific parameters like hydraulic conductivity or storativity are adjusted and the influence of those adjustments on the calibration is measured for different scenarios. However sensitivities vary depending upon the focus of the analysis. For example, steady state

[5] upper and middle Permian refers to strata above the Ulan seam rather than age – lower Permian strata are identified as Permian strata below the Ulan seam.

model calibration for pre-mining conditions demonstrates sensitivities that are unrelated to the mining process; lowest sensitivities are associated with the material properties of the deeper strata within the model while highest sensitivities are associated with material properties in the shallowest layers and the applied rainfall recharge and surface drainage boundary condition parameters. In contrast, transient simulations of UCML longwall mining operations exhibit high sensitivities to material properties assigned to the subsidence zone and boundary conditions associated with mining.

While sensitivity simulations for the model have not been conducted in a rigorous manner it is apparent from the routine adjustments made to the model subsequent to calibration in 2009[6], that:

- the regional extent of model depressurisation induced by mining is more sensitive to hydraulic conductivities (Kxyz) than any other parameter;
- model depressurisation vertically through strata beyond the subsidence zone exhibits the highest sensitivity to the vertical conductivity (Kz);
- within the Ulan seam subsidence zone, model depressurisation exhibits high sensitivity to the scaling factors[7] applied to vertical leakance;
- Mine water make to roadways and goaf is especially sensitive to specific yield.

E9. Factors affecting accuracy of the numerical model

It is not possible to completely represent aquifer systems using numerical modelling methods due to the many complexities associated with natural processes, the discrete sampling of rock material properties that govern groundwater flow, and the limitations imposed by numerical modelling methods. A simplified representation of the aquifer systems is therefore required. While this simplification has been undertaken in a measured and structured way in the current study, it is always possible that unidentified features of a system or properties assigned to a particular part of the system, may affect predictions either more favourably or more adversely, at some future time. Accordingly, the following constraints are noteworthy:

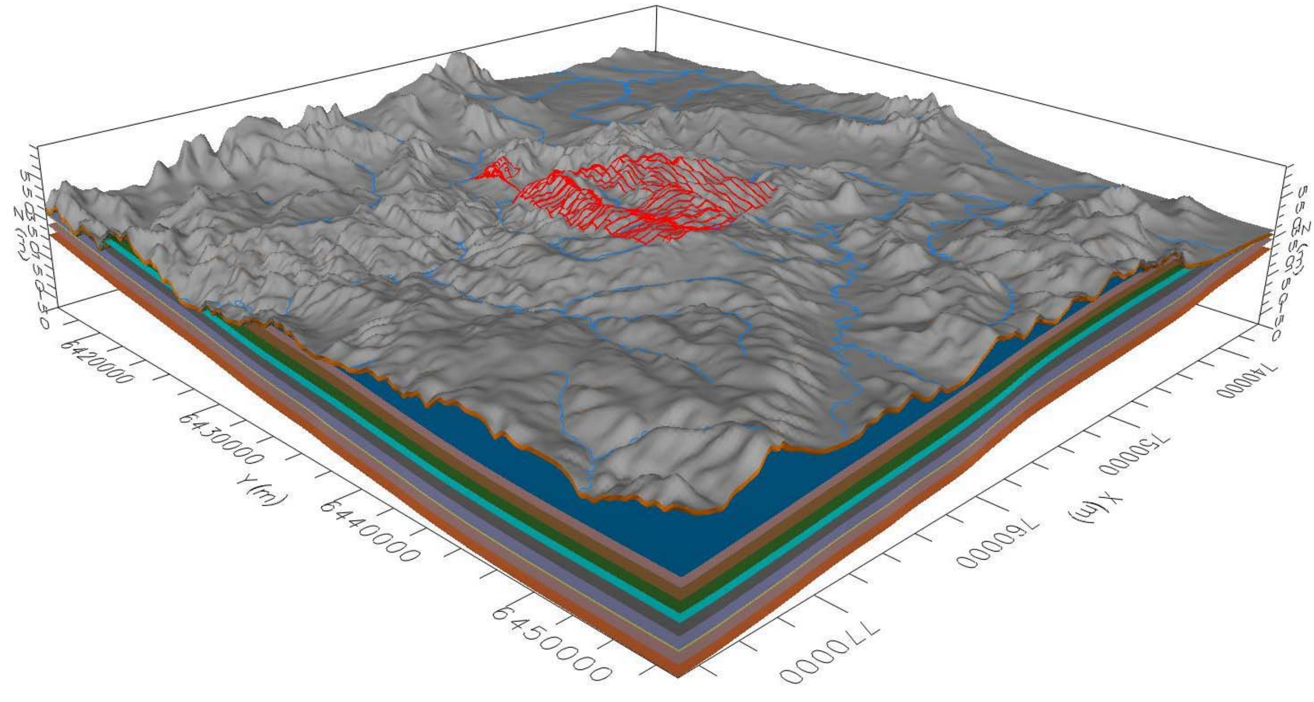
1. Key stratigraphic horizons in the model have been interpolated accurately within the UCML lease area but data beyond this area and especially to the west, north and east, is very limited. In these more distant areas, surface projections supported by hand contouring have been invoked in order to generate stratigraphic horizons. It is possible that these surfaces may affect predictions of groundwater flow and mining related impacts to some extent.
2. Vertical discretisation of the model (as defined by the number and thickness of layers) is the minimum considered necessary for consideration of mining related impacts. Accuracy may be improved by introducing additional layers at some future time but this will inevitably result in longer model run times which are currently more than 20 hours.
3. Adopted model hydraulic conductivities for hard rock strata tend to reflect core measurements rather than packer testing results based on the assumption that conductivities are matrix dominated rather than fracture dominated. This is consistent with observations of drill hole core at Ulan where fractures are observed to be generally infrequent except perhaps at shallower depths where strata are less confined but mostly unsaturated. If fracture flow is the dominant mechanism in a particular (but unidentified) area then piezometric head distributions and groundwater flows may differ from those derived from the current model. This may be the case in areas with limited depth of cover.
4. Hydraulic conductivities are known to reduce with increasing effective stress which will result from strata depressurisation. Such reductions in conductivity have not been included in the model due limitations of the model code. The model predicted extent of

[6] The groundwater model was developed and calibrated in 2009 – see MER, 2009
[7] The Surfact model facilitates modification to material properties during a simulation by scaling using the TMP1 package

depressurisation at a given time may therefore be greater in some areas, than may be measured under future field conditions.

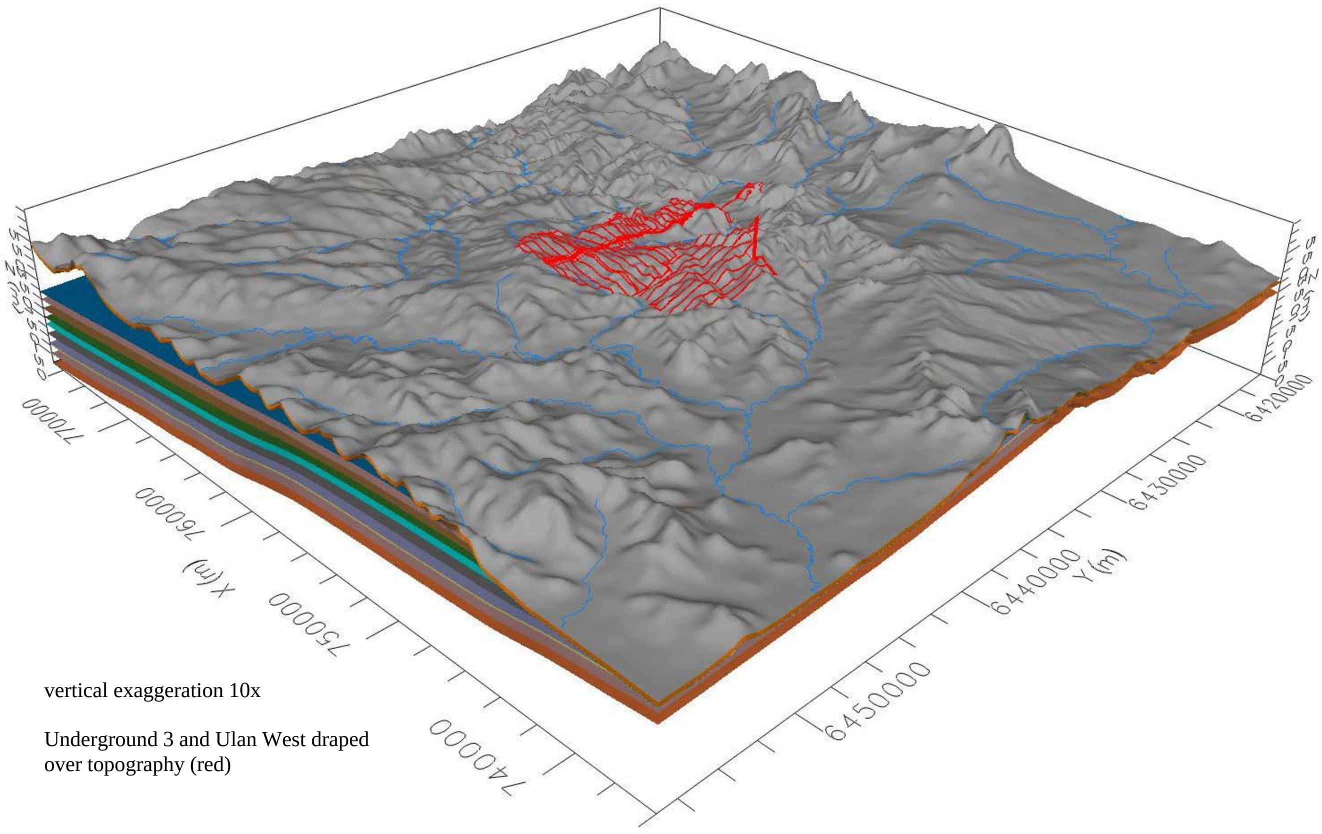
5. Boundary conditions applied to the model drainage network are mixed head-flux boundaries constrained to simulate drain or river type boundaries according to Hydrogeologic, 2010. Assigned heads have been derived from the gridded regional topography data set. Where drainages are incised and the drainage axis does not coincide with the digital terrain grid, the topographic data commonly fails to accurately reflect stream bed elevations and hence assigned heads could be in error by as much as 5 m or more depending upon the terrain and the interpolating algorithm. These heads ultimately govern the model 'calibrated' steady state water table which may not agree with field measured conditions everywhere. Since the error cannot be determined at each location, it is retained within the modelling process. However the consequences are considered to be minor.
6. Model calibration has utilised regional piezometric data and measured groundwater influx to underground operations for the period 2007-2014 with increased weight applied to groundwater inflow from UG3 longwalls LW23 to LW27 that were mined during this period. Calculation of the true rate of inflow is challenging due to the complex interflows that can occur in underground operations. Since model calibration is governed by inflows, any errors in the inflow rates will necessarily be carried through the calibration process

It is important to also note that numerical model predictions are inevitably affected by increasing uncertainty for longer prediction intervals. The prediction error is governed by a multitude of variables associated with all of the elements of model input – the more accurately the inputs reflect field conditions, the more accurate are the output predictions. Model verification therefore becomes an important post analytical procedure and is strongly recommended. The model is currently reviewed biennially.



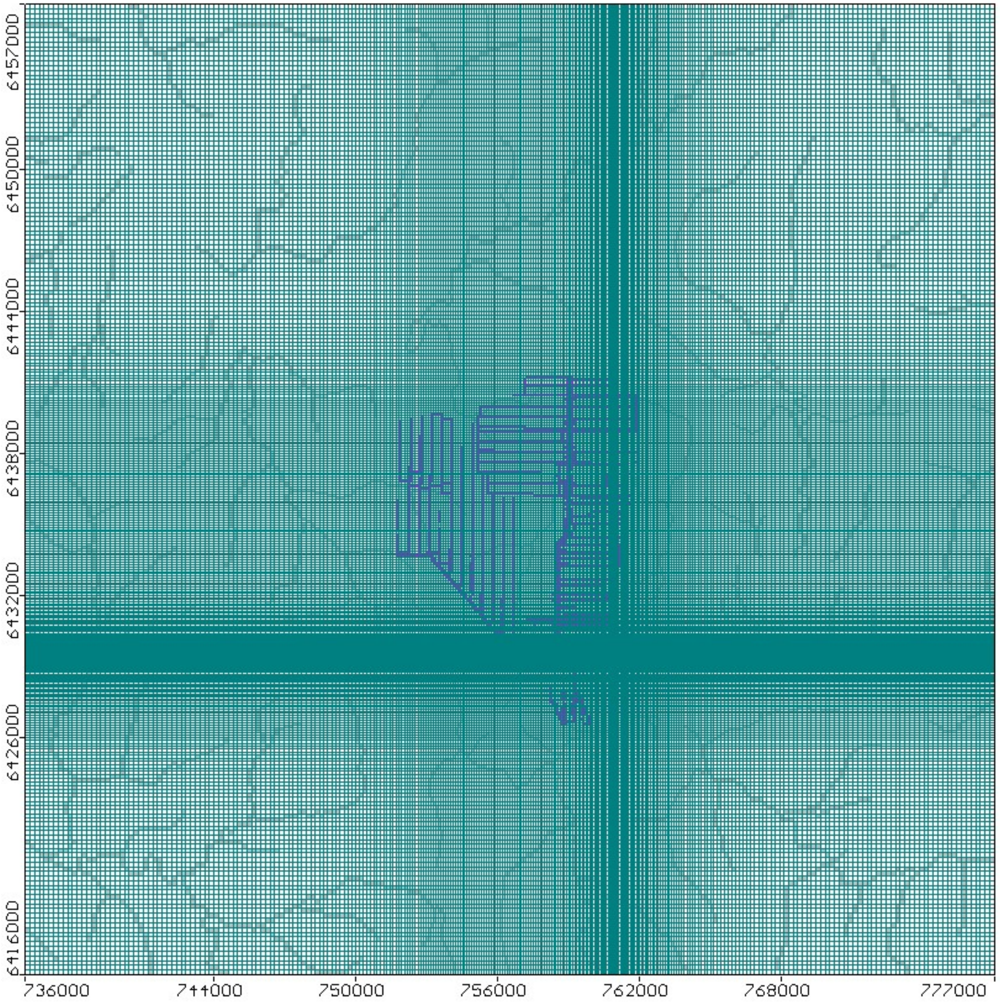
Model layers – looking to the south-west

Figure E1a

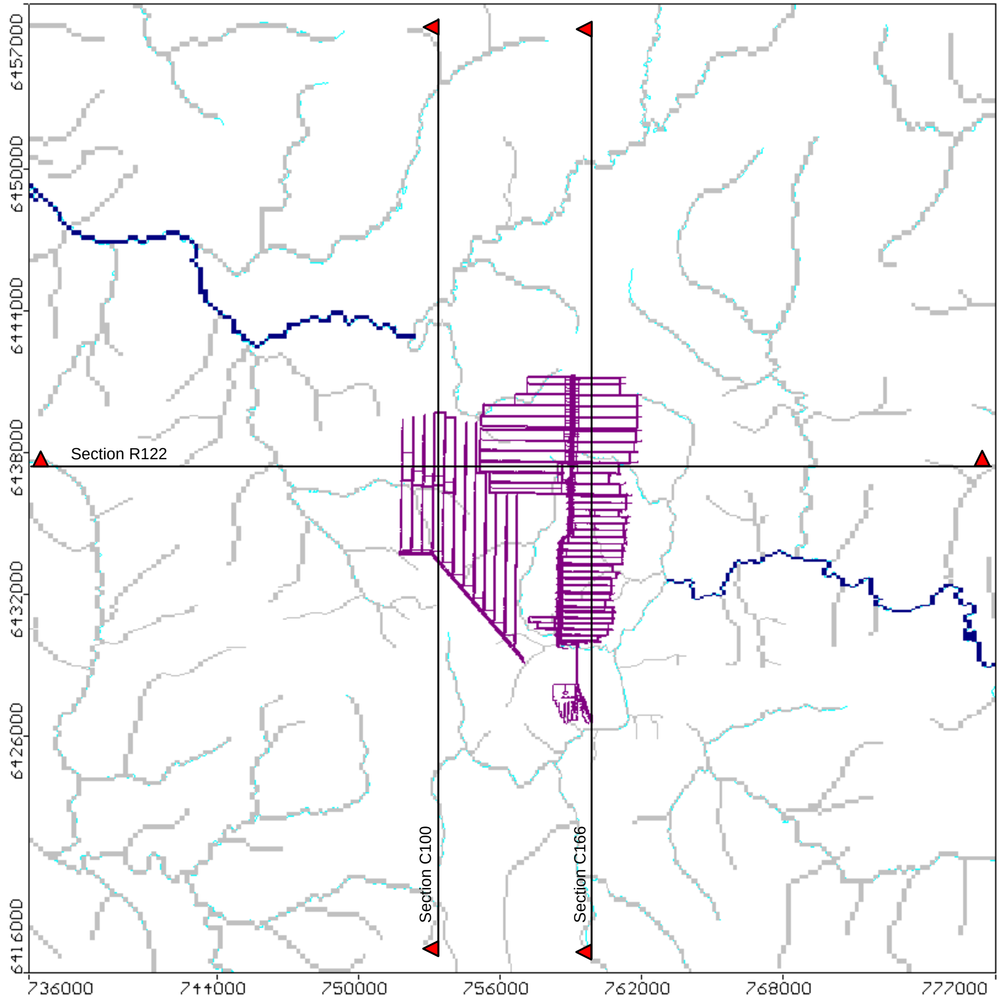


Model layers – looking to the south-east

Figure E1b



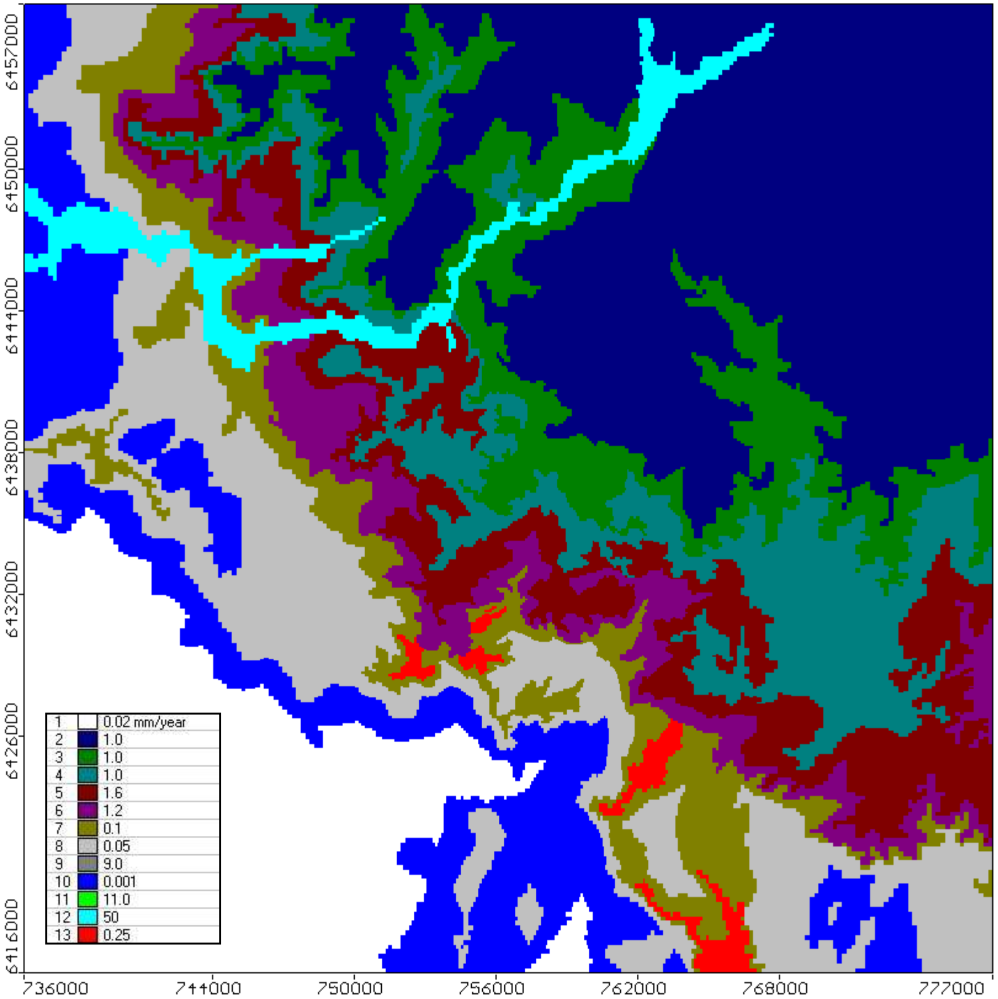
Finite difference model mesh



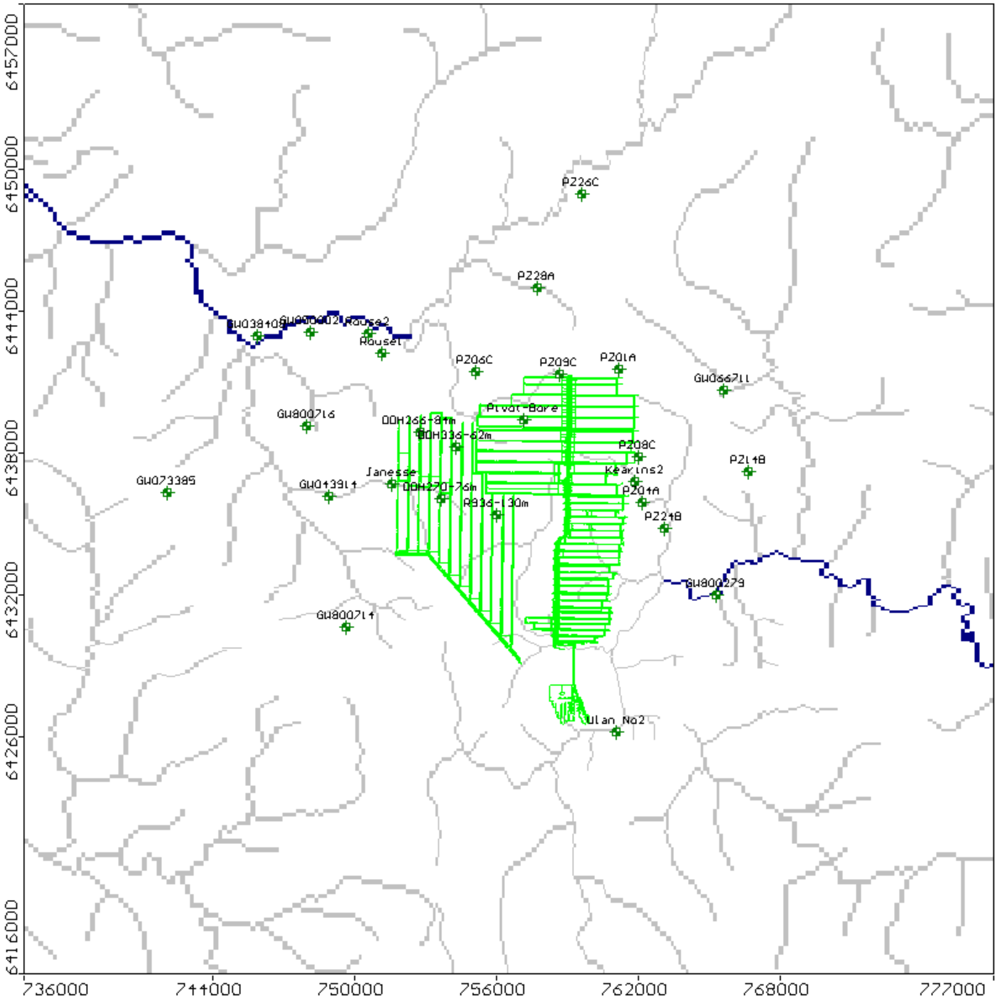
Model drainage network and vertical section locations

Groundwater model mesh and drainage network

Figure E2



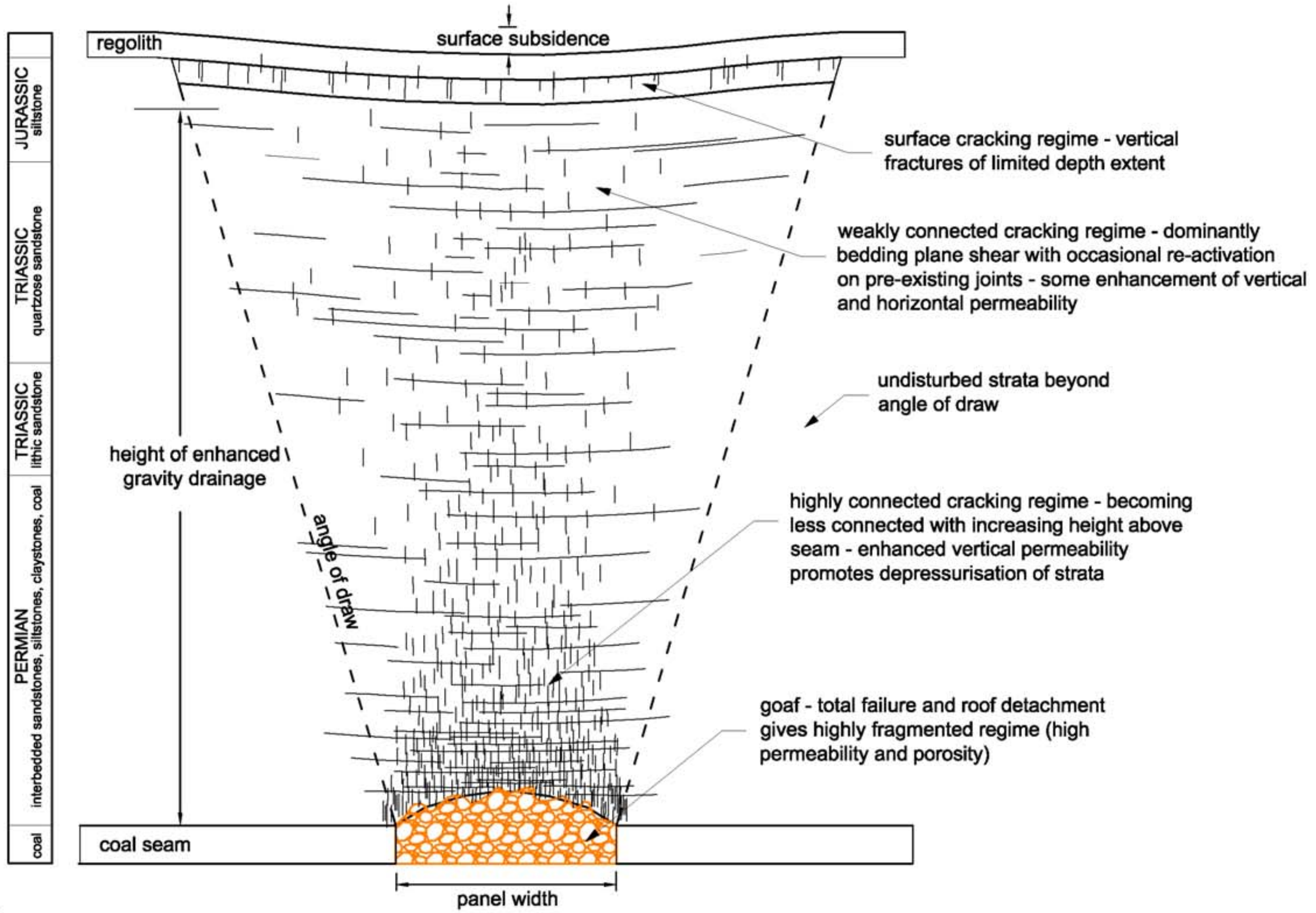
Model rainfall recharge distributions



Model calibration piezometers

Recharge areas and steady state calibration control points

Figure E3

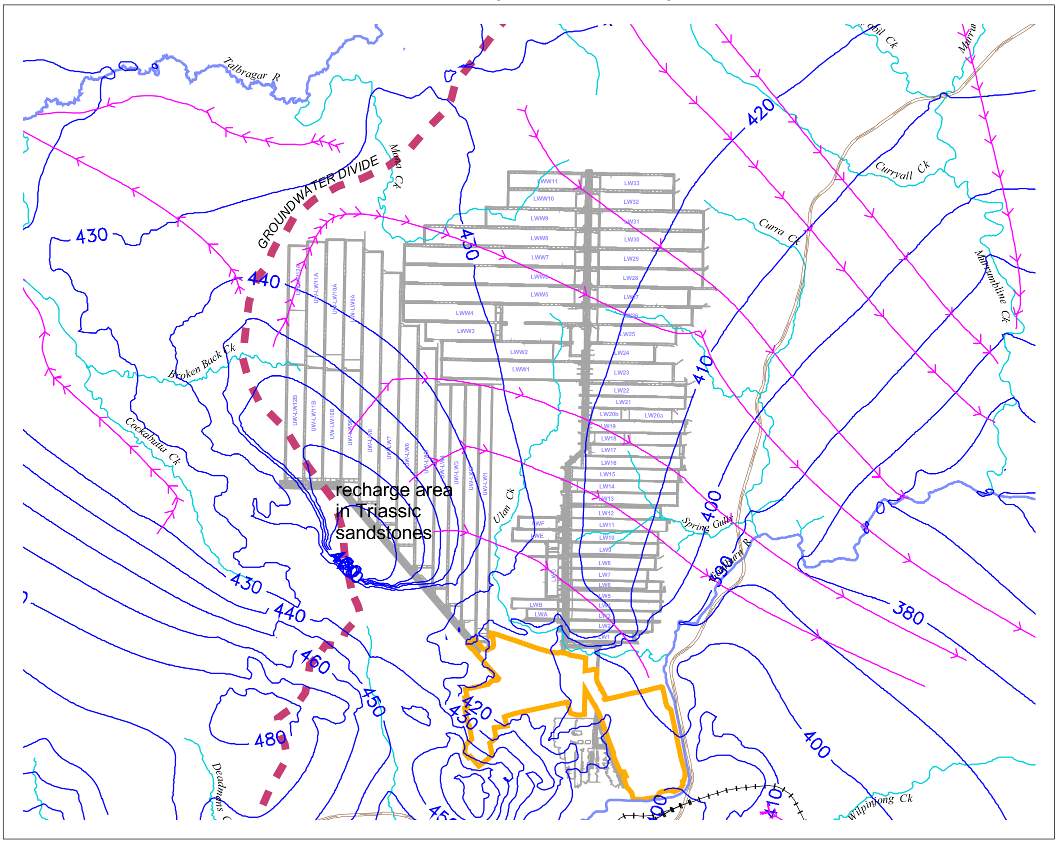


NOT TO SCALE

Conceptual model of subsidence failure regime

Figure E4

UPPER TRIASSIC (WATER TABLE) - PRE MINING



piezometric heads in mAHD

Figure E5

ULAN SEAM PIEZOMETRIC HEADS - PRE MINING

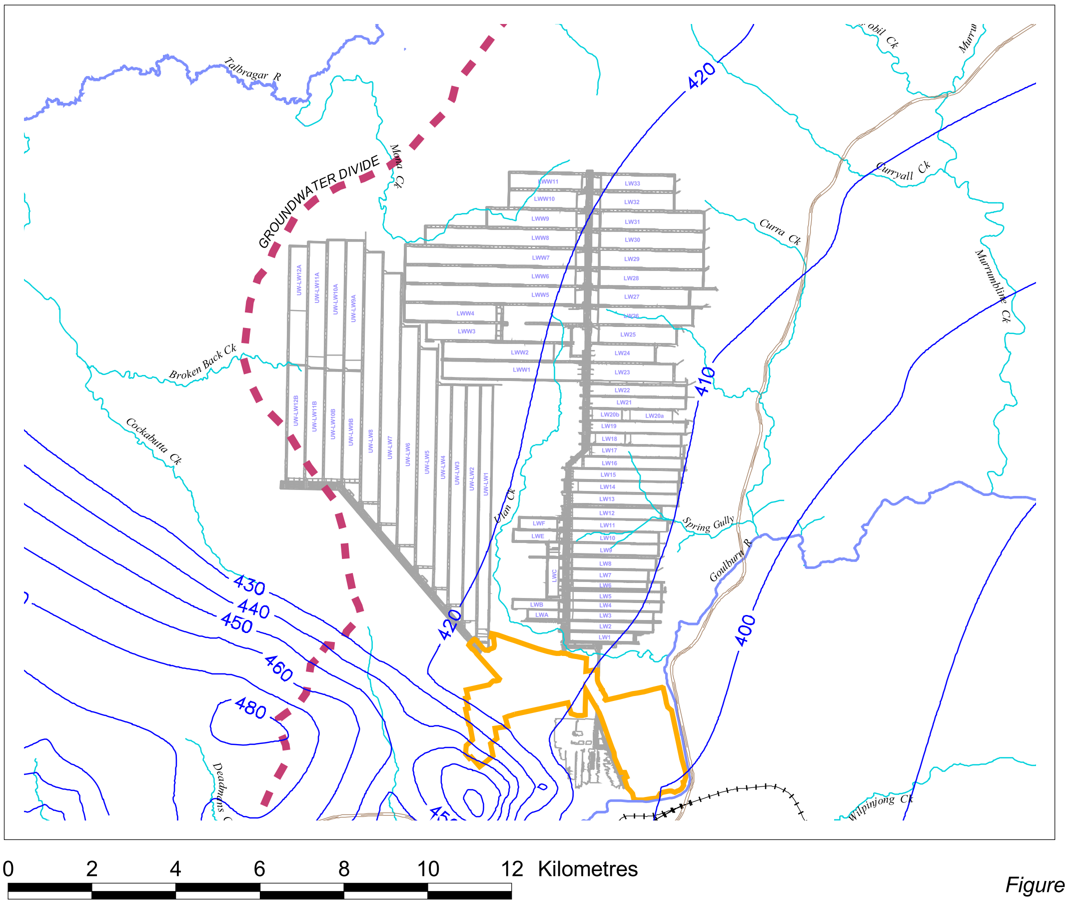


Figure E6

ULAN COAL MINES LIMITED - ULAN WEST MODIFICATION

Interpolated pre-mining groundwater flow systems

Figure E5 and E6

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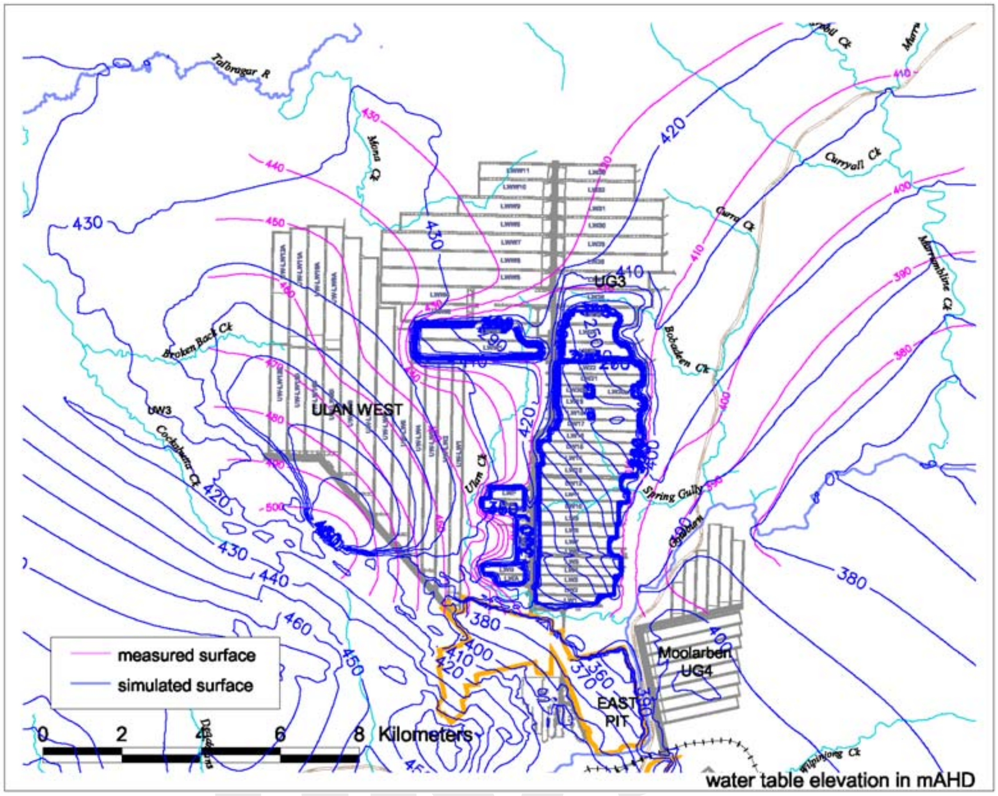


Figure E7: Comparison of model generated and measured water table in Triassic sandstones

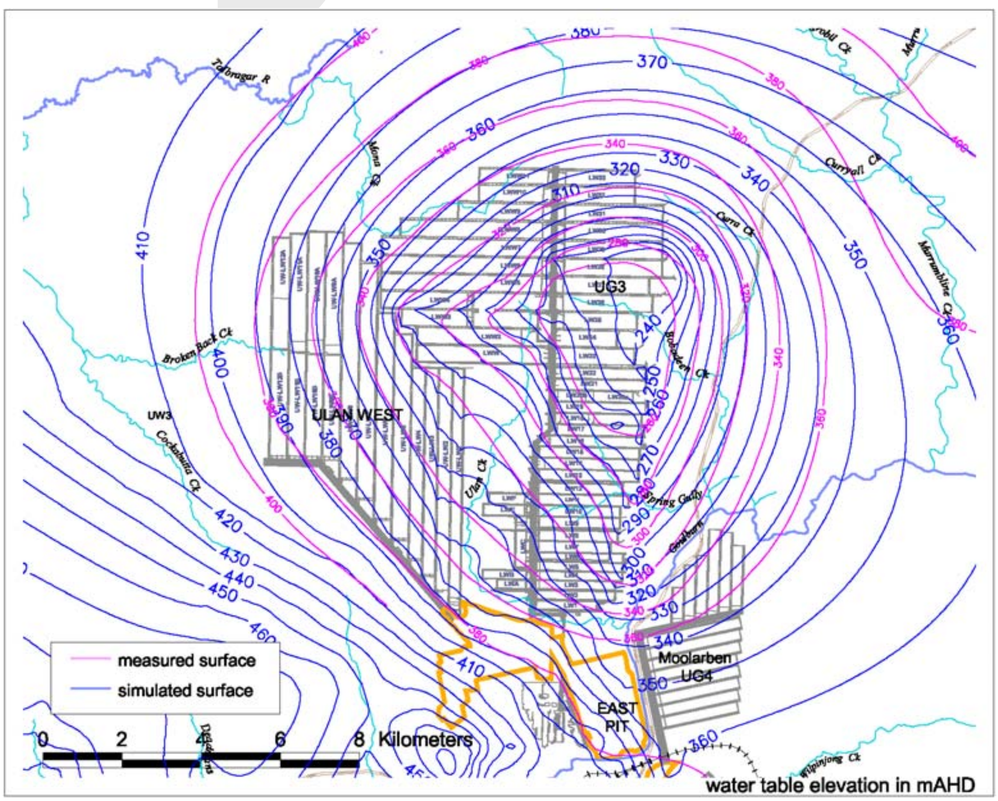
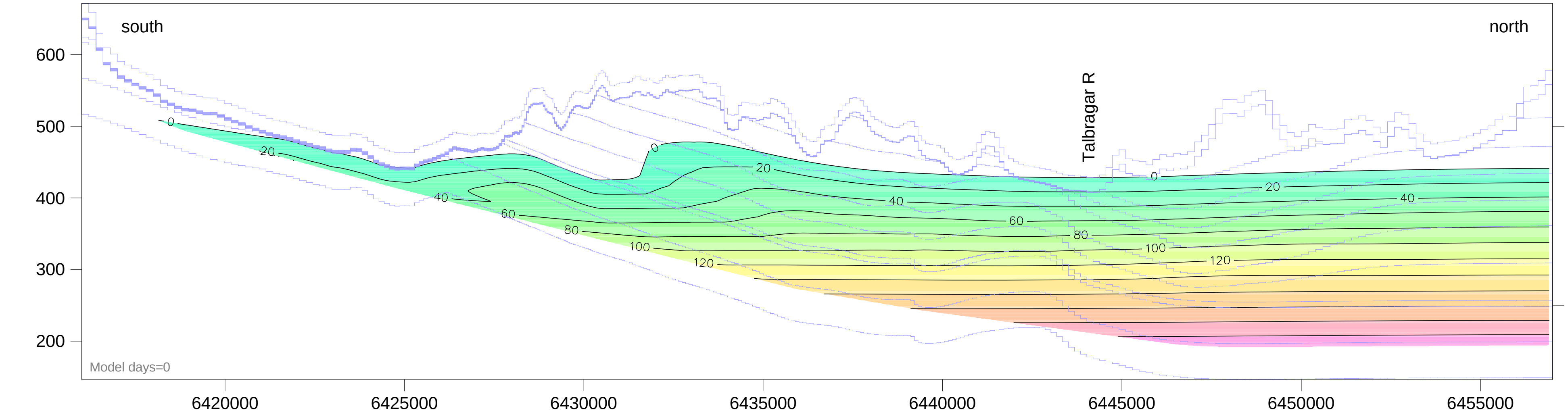
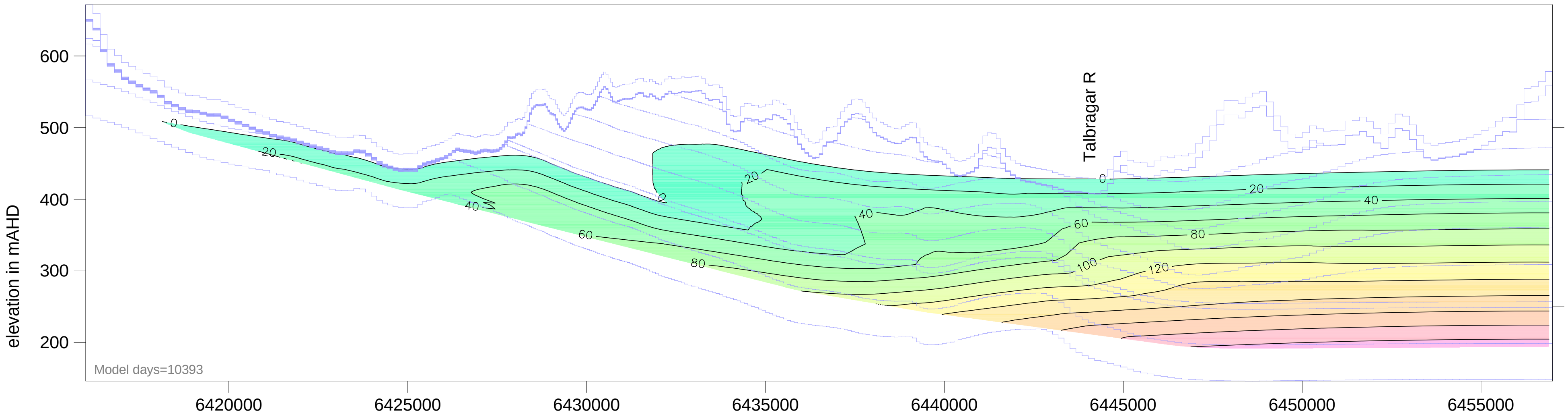


Figure E8: Comparison of model generated and measured potentiometric surface in Ulan seam

Section C100: Start of mining (1986) - Pressure heads in mH2O



Section C100: Ulan West in June 2014 - Pressure heads in mH2O



vertical exaggeration 20 times

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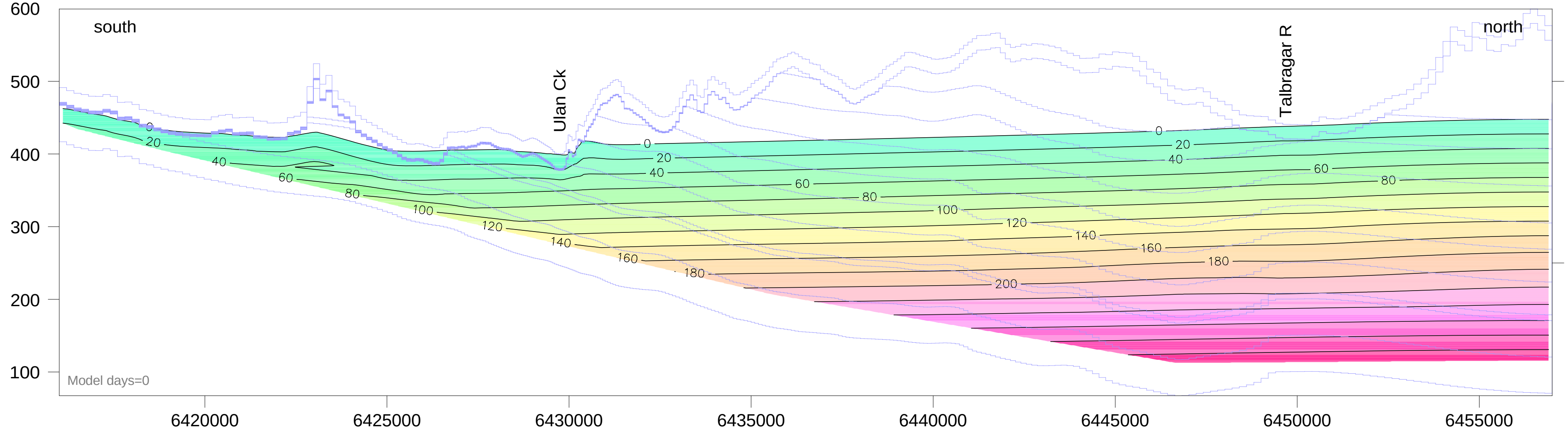
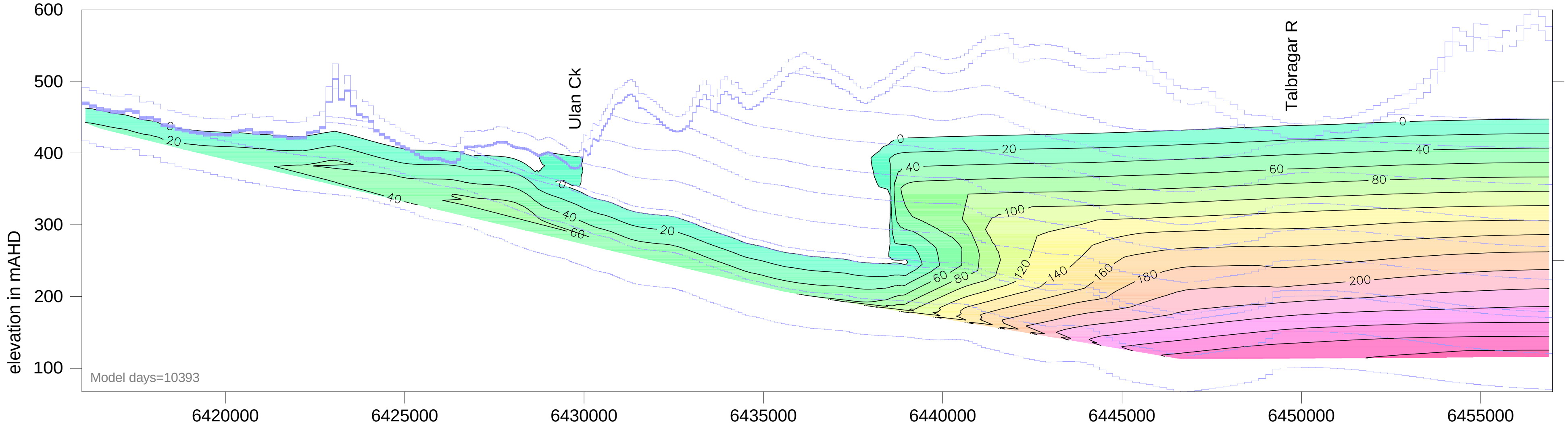
Figure E9

Section C166: Start of mining (1986) - Pressure heads in mH2O



Section C166: LW-27 completed (2014) - Pressure heads in mH2O



vertical exaggeration 20 times

Figure E10

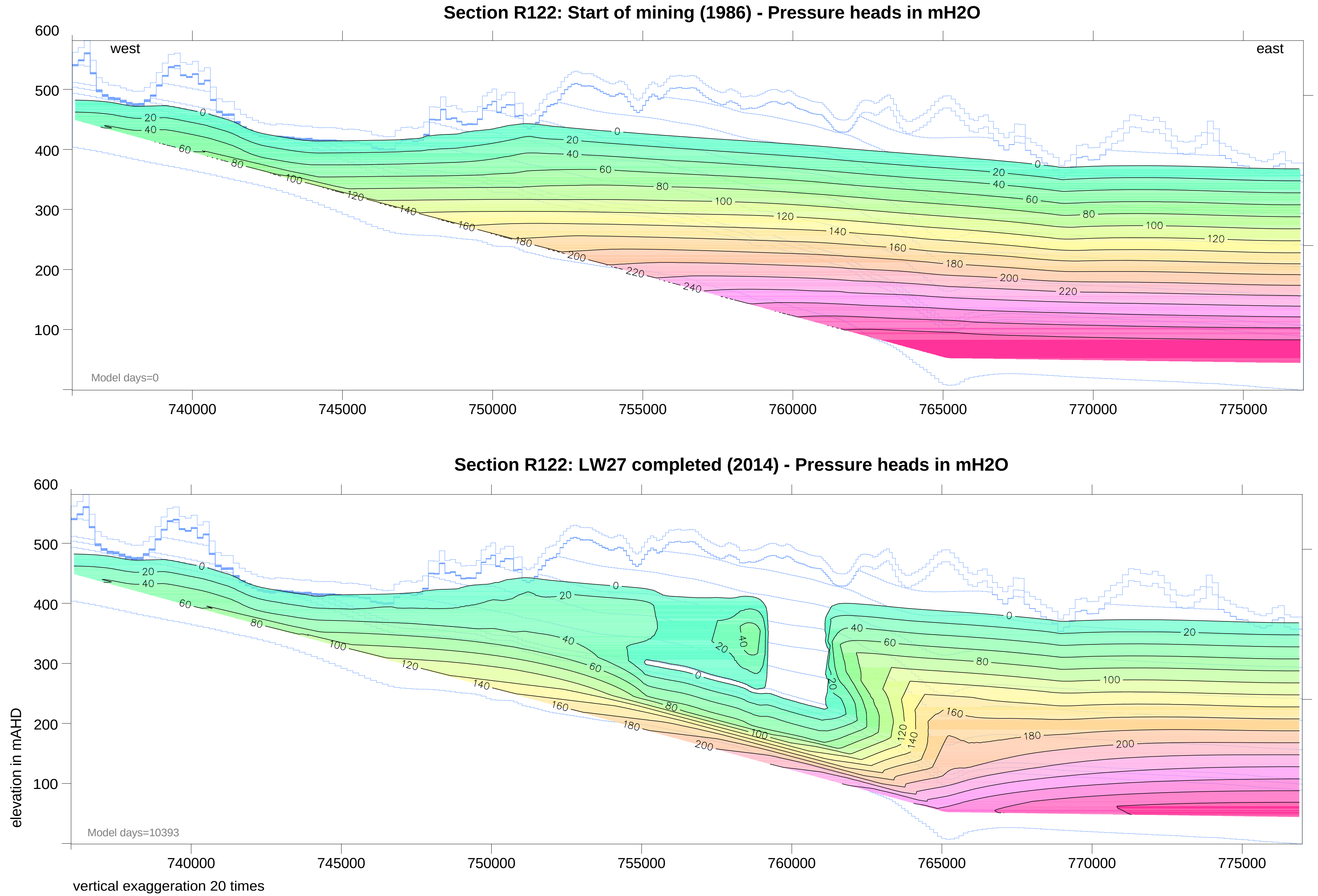


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Figure E11

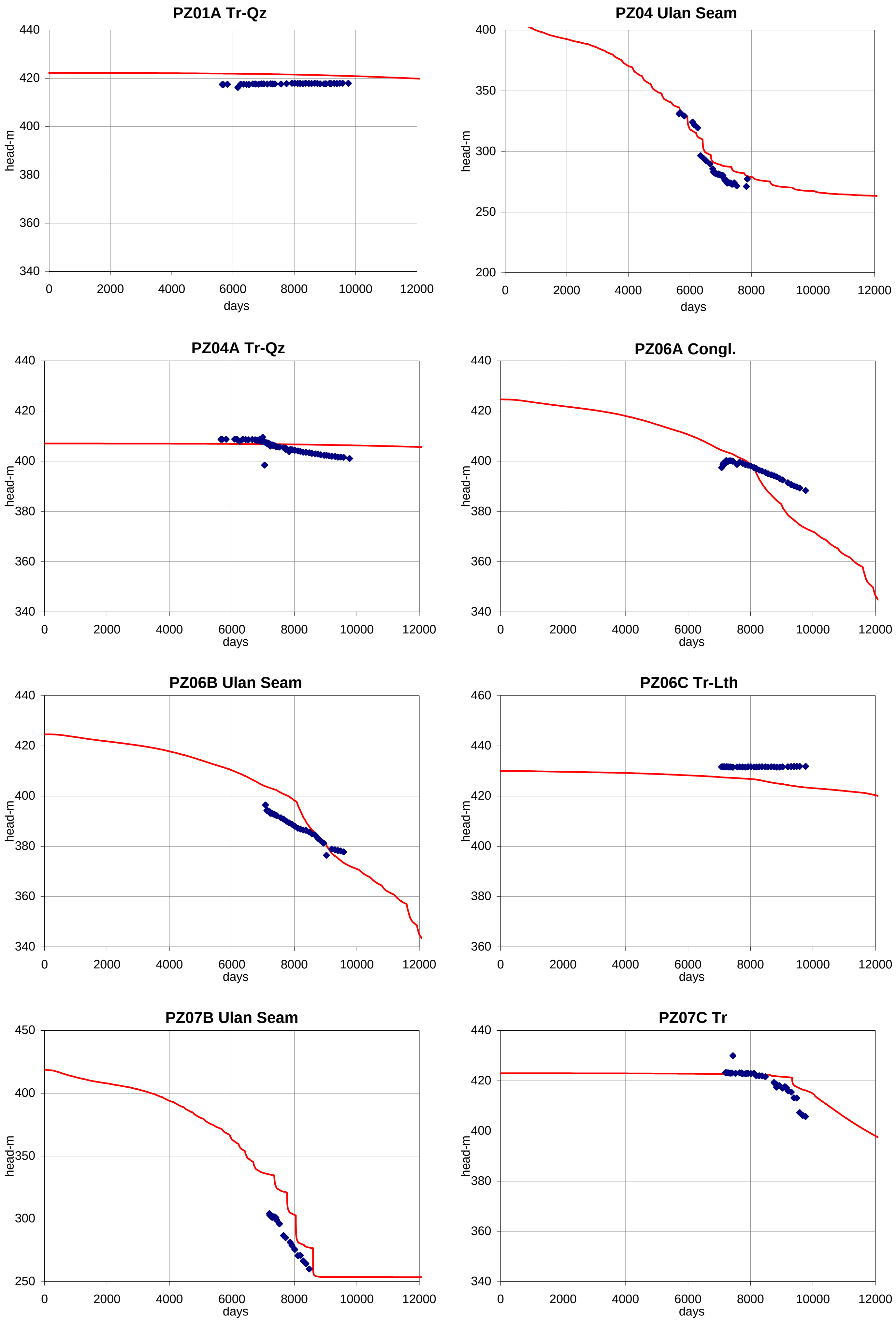
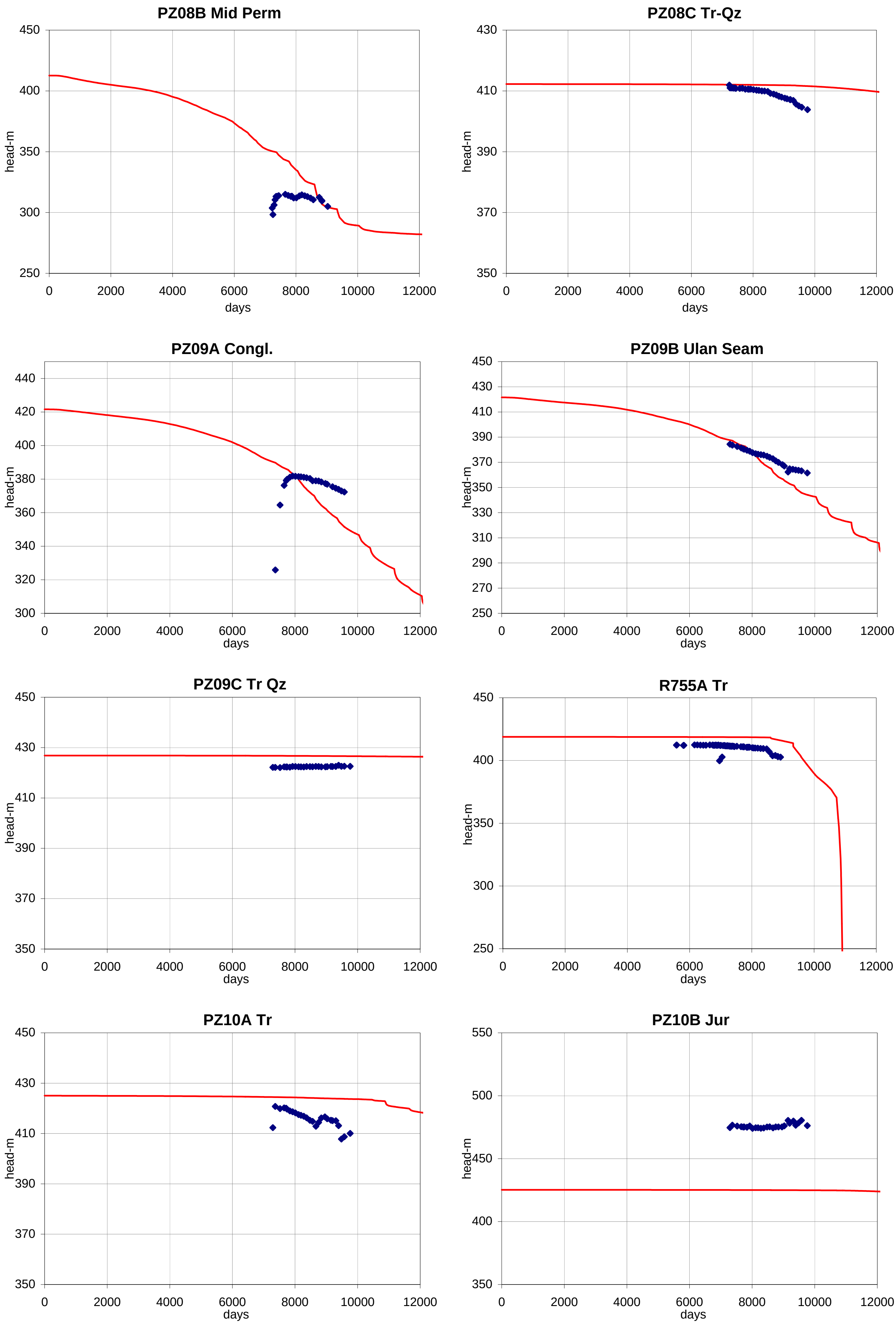

PZ01A Tr-Qz
head-m
days
440
420
400
380
360
340
0
2000
4000
6000
8000
10000
12000
PZ04 Ulan Seam
head-m
days
400
350
300
250
200
0
2000
4000
6000
8000
10000
12000
PZ04A Tr-Qz
head-m
days
440
420
400
380
360
340
0
2000
4000
6000
8000
10000
12000
PZ06A Congl.
head-m
days
440
420
400
380
360
340
0
2000
4000
6000
8000
10000
12000
PZ06B Ulan Seam
head-m
days
440
420
400
380
360
340
0
2000
4000
6000
8000
10000
12000
PZ06C Tr-Lth
head-m
days
460
440
420
400
380
360
0
2000
4000
6000
8000
10000
12000
PZ07B Ulan Seam
head-m
days
450
400
350
300
250
0
2000
4000
6000
8000
10000
12000
PZ07C Tr
head-m
days
440
420
400
380
360
340
0
2000
4000
6000
8000
10000
12000

Figure E12


PZ08B Mid Perm
PZ08C Tr-Qz
PZ09A Congl.
PZ09B Ulan Seam
PZ09C Tr Qz
R755A Tr
PZ10A Tr
PZ10B Jur
head-m
days
0
2000
4000
6000
8000
10000
12000

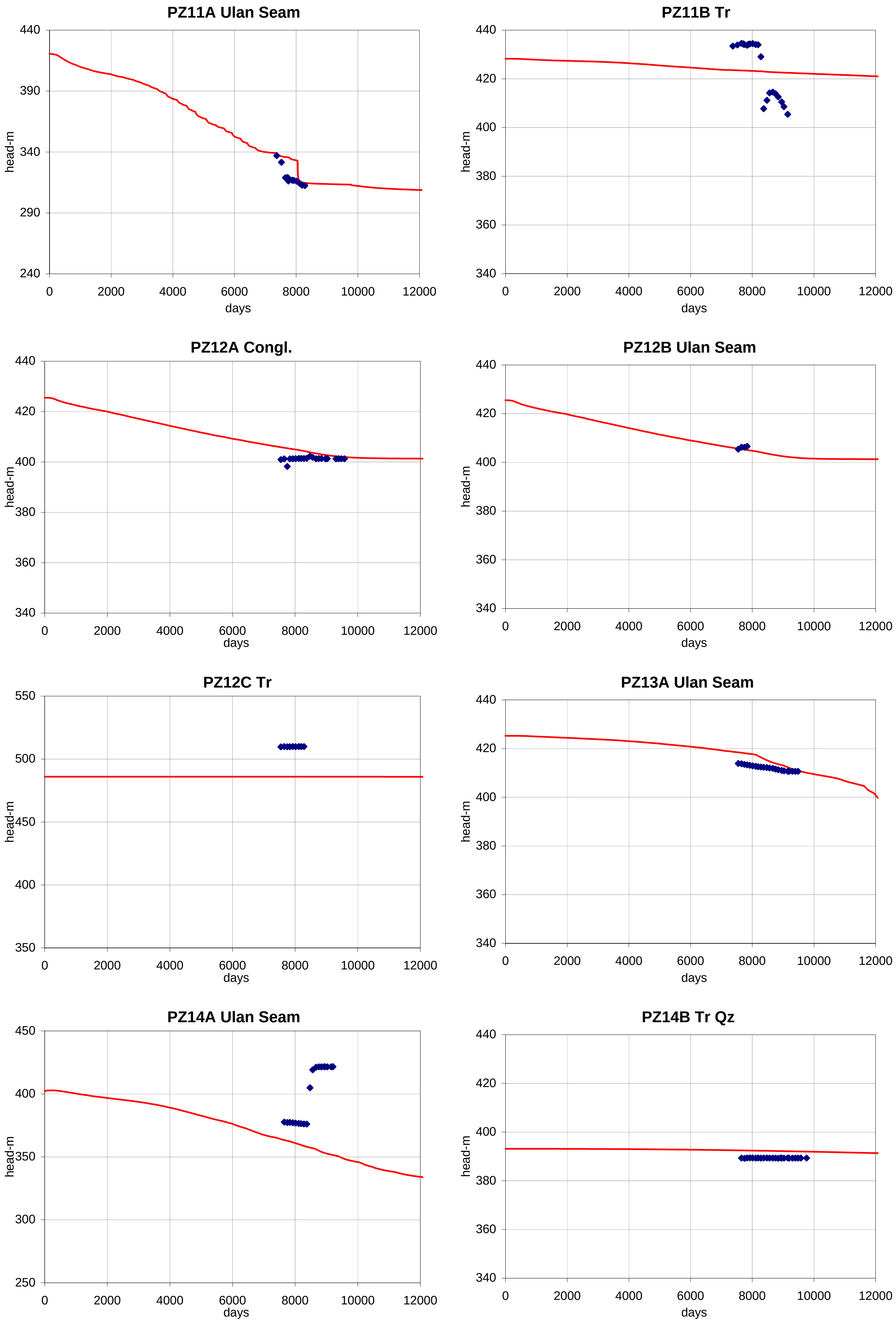


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Figure E12

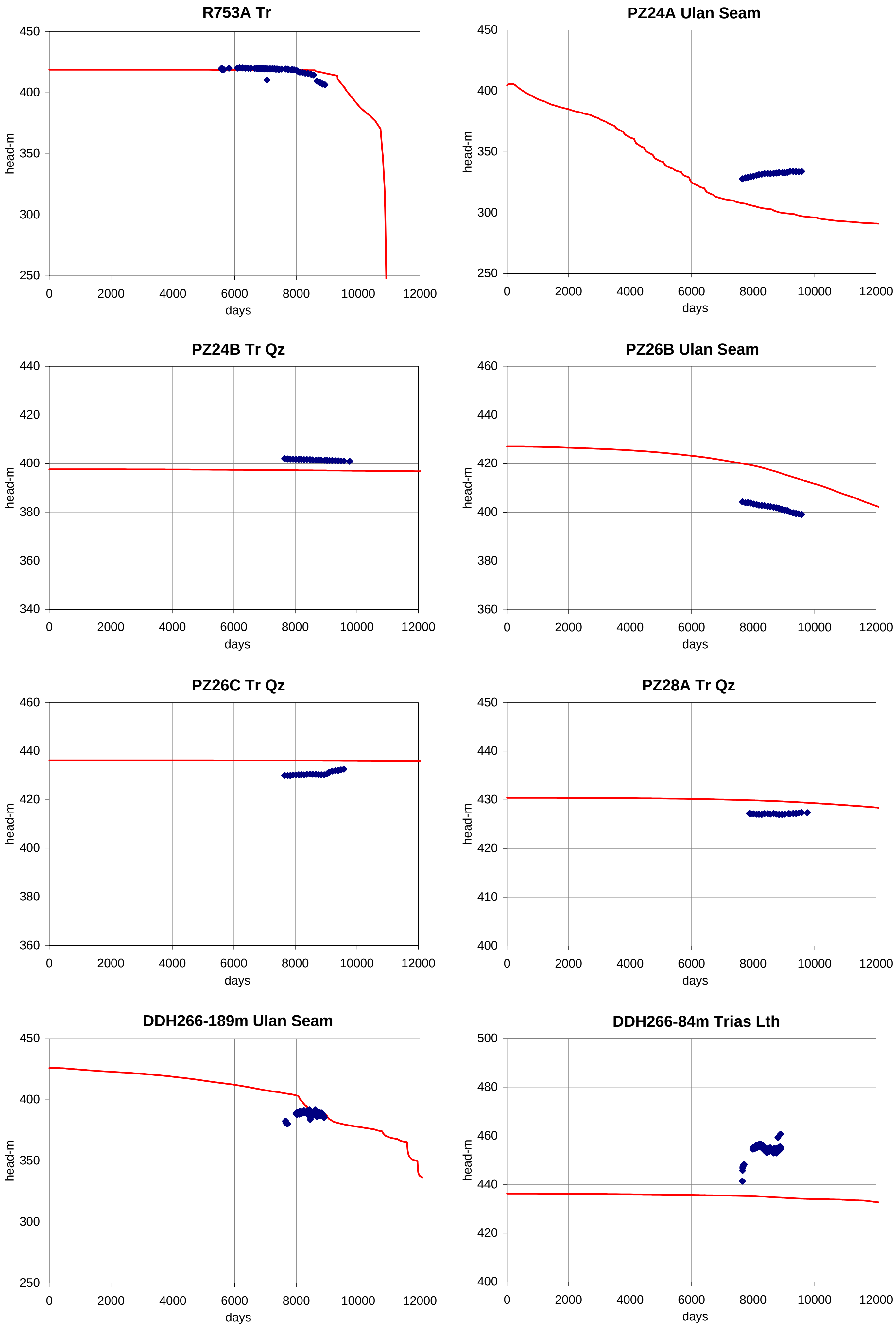
R753A Tr
head-m
450
400
350
300
250
0
2000
4000
6000
8000
10000
12000
days
PZ24A Ulan Seam
head-m
450
400
350
300
250
0
2000
4000
6000
8000
10000
12000
days
PZ24B Tr Qz
head-m
440
420
400
380
360
340
0
2000
4000
6000
8000
10000
12000
days
PZ26B Ulan Seam
head-m
460
440
420
400
380
360
0
2000
4000
6000
8000
10000
12000
days
PZ26C Tr Qz
head-m
460
440
420
400
380
360
0
2000
4000
6000
8000
10000
12000
days
PZ28A Tr Qz
head-m
450
440
430
420
410
400
0
2000
4000
6000
8000
10000
12000
days
DDH266-189m Ulan Seam
head-m
450
400
350
300
250
0
2000
4000
6000
8000
10000
12000
days
DDH266-84m Trias Lth
head-m
500
480
460
440
420
400
0
2000
4000
6000
8000
10000
12000
days

Figure E12

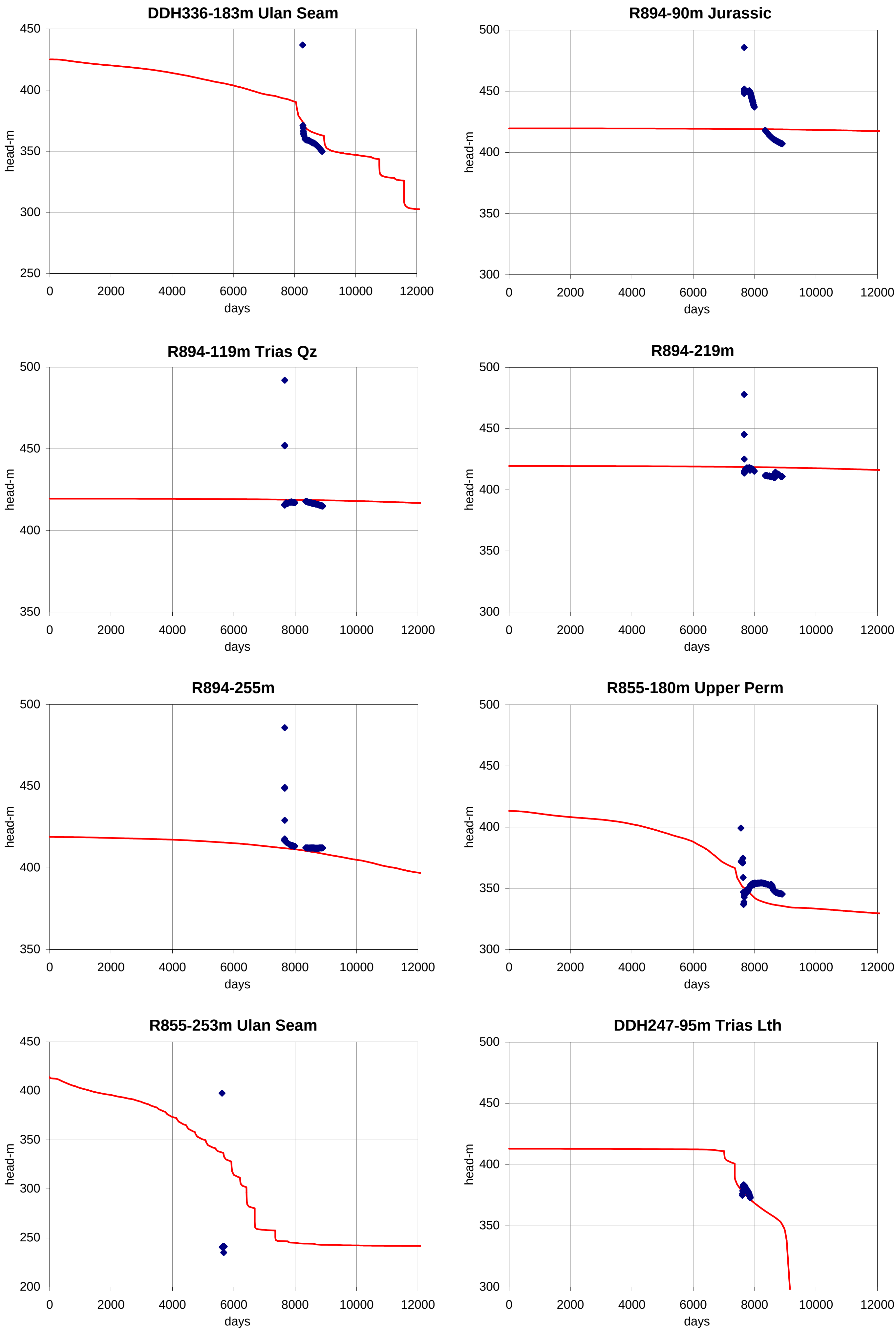
DDH336-183m Ulan Seam
head-m
days
R894-90m Jurassic
head-m
days
R894-119m Trias Qz
head-m
days
R894-219m
head-m
days
R894-255m
head-m
days
R855-180m Upper Perm
head-m
days
R855-253m Ulan Seam
head-m
days
DDH247-95m Trias Lth
head-m
days

Figure E12

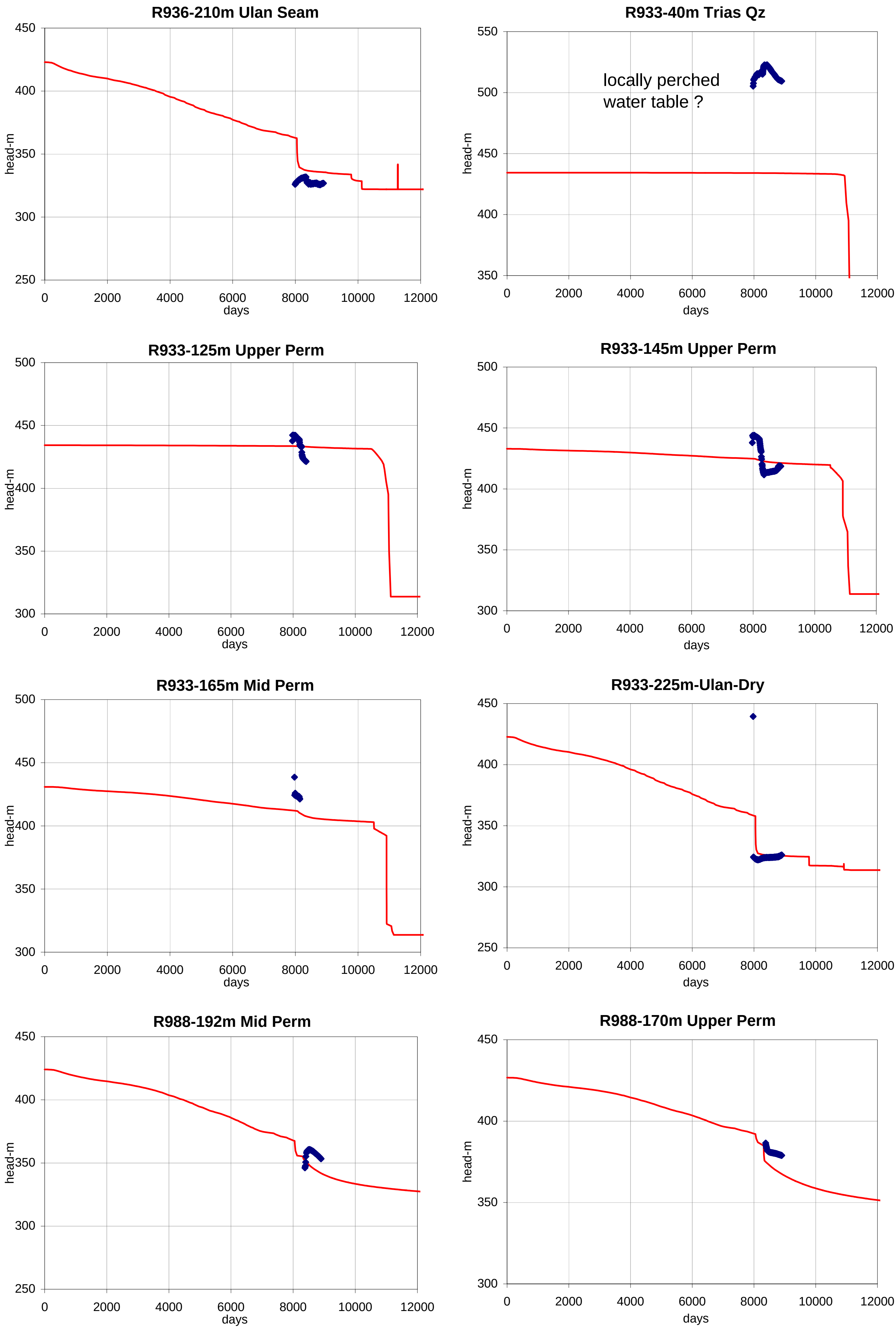
R936-210m Ulan Seam
R933-40m Trias Qz
locally perched
water table ?
R933-125m Upper Perm
R933-145m Upper Perm
R933-165m Mid Perm
R933-225m-Ulan-Dry
R988-192m Mid Perm
R988-170m Upper Perm
head-m
days
0
2000
4000
6000
8000
10000
12000
250
300
350
400
450
500
550

Figure E12

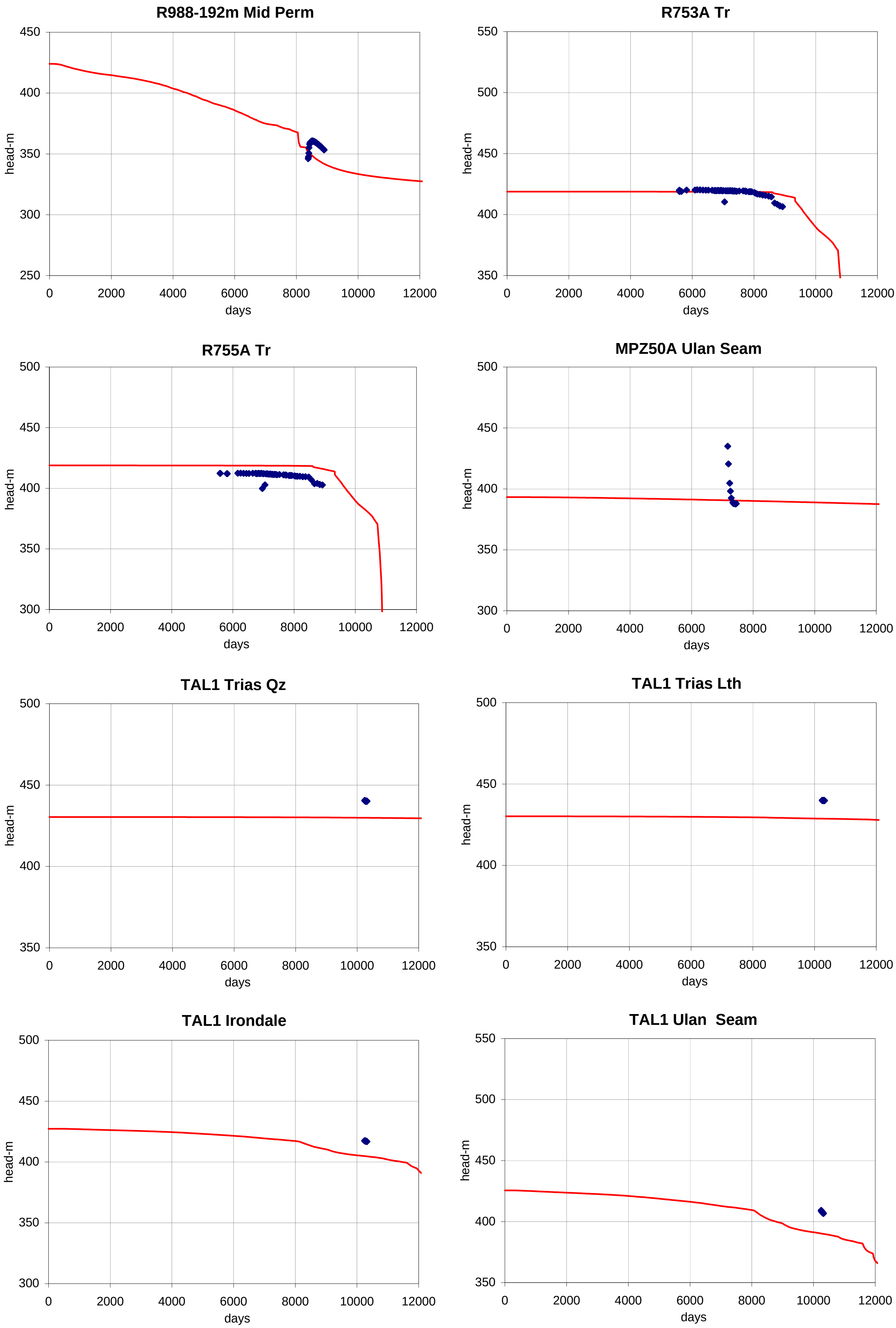
R988-192m Mid Perm
R753A Tr
R755A Tr
MPZ50A Ulan Seam
TAL1 Trias Qz
TAL1 Trias Lth
TAL1 Irondale
TAL1 Ulan Seam
head-m
days
0
2000
4000
6000
8000
10000
12000
250
300
350
400
450
500
550

Figure E12