

GROUNDWATER ASSESSMENT (MER, 2009)



APPENDIX 9

**RAVENSWORTH UNDERGROUND MINE
ASSESSMENT OF GROUNDWATER IMPACTS
ASSOCIATED WITH PROPOSED MODIFICATION to DA 104/96
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SUMMARY OF FINDINGS

Ravensworth Underground Mine (RUM) is seeking approval to modify mining operations to facilitate more efficient extraction and processing of coal resources. Particular modifications that may induce change to groundwater flow systems include:

- Realignment of the main headings commencing at longwall panel LW6 and ending at LW10, to improve recovery of resource from LW6 to LW10, and
- Extension of longwall panels LW6 and LW7 to the south-west and extension of panels 6 to 10 to the north-east.

The proposed re-alignment and panel extensions to the north-east are in an area close to Bowmans Creek where there is some potential to impact upon the groundwater resources of the alluvial lands associated with the creek and indirectly, upon creek flows.

The hardrock coal measures strata underlying the alluvium, provide very limited groundwater storage and transmission capacity. Jointing and fracturing are sparse and groundwater flow is more generally governed by matrix permeabilities except in coal seams where cleating and micro fracturing apparently enhance transmission and storage characteristics – the coal seams are commonly regarded as the more permeable strata. Interburden and overburden lithologies comprising sandstones, siltstones and shales are noted to possess very low intergranular hydraulic conductivities from extensive core testing in the region.

Extensive mining in surrounding areas and historical mining in the overlying Ravensworth No.2, Ravensworth South and Narama open cuts has already substantially depressurised and dewatered the coal measures and induced some leakage from Bowmans Creek alluvium.

A computer based aquifer model of the region has been previously developed in order to understand the many complex groundwater flow processes that have evolved to-date and would continue to evolve as part of future mining in the region. This model has been used to assess the impact on groundwater systems associated with the extension of longwall panels LW6 and LW7. The model has also been used as a platform to generate a separate and more localised model aimed specifically at understanding the likely piezometric head and pore pressure distributions arising from re-alignment of the main headings, and the potential changes in leakage from the alluvium associated with Bowmans Creek.

Within the limitations and constraints imposed by numerical modelling, the simulation results demonstrate that extension of longwall panels LW6 and LW7 to the south-west will lead to increased depressurisation-dewatering of coal measures in the vicinity of these panels and beneath Bayswater Creek. Impact on the creek which is a diverted-constructed channel in this area, is predicted to be negligible since strata are already dewatered at depth or will dewater in accordance with the currently approved mine plan.

Re-alignment of the main headings (near Bowmans Creek alluvium) would change pore pressures in the zone above the underground operations with the phreatic surface migrating eastward towards the alluvium. Rainfall recharge through spoils emplaced in the Ravensworth pit shell which overlies RUM operations, would continue to sustain a saturated zone near the base of the pit shell. The calculated increase in leakage from Bowmans Creek alluvium (based on steady state conditions) is of the order of 0.001ML/day. The leakage would be balanced by contributions from rainfall recharge to the alluvium. There would be no measurable change to the baseflow in Bowmans Creek.

Water quality within the coal measures and the alluvium would be unaffected by the proposed changes. There are no identified privately owned boreholes that may be 'yield affected' in proximity to the proposed re-alignment or panel extensions.

Impact in relation to the Hunter Unregulated and Alluvial Water Sources Water Sharing Plan is considered to be negligible.

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1. INTRODUCTION

Ravensworth Underground Mine (RUM) is seeking approval to modify mining operations to facilitate more efficient extraction and processing of coal resources. Particular modifications that may induce change to groundwater flow systems include:

- Realignment of the main headings in the Pikes Gully seam commencing at longwall panel LW6 and ending at LW10, to improve recovery of resource from LW6 to LW10, and
- Extension of longwall panels LW6 and LW7 to the south-west and extension of panels LW6 to LW10 to the north-east.

The proposed re-alignment and panel extensions to the north-east are in an area close to Bowmans Creek where there is some potential to impact upon the groundwater resources of the creek and in the associated alluvial lands. Extension of panels LW6 and LW7 are in proximity to Bayswater Creek diversion.

Mackie Environmental Research Pty Ltd (MER) was commissioned in mid 2009 by GSS Environmental acting on behalf of RUM, to consolidate existing groundwater management and monitoring data and to undertake an assessment of the likely impacts of the proposed modifications. The assessments that have been conducted were designed to comply with typical regulatory requirements in relation to groundwater including:

- a description of the existing environment;
- an assessment of the potential impacts of the modifications including the quantity and quality of groundwater, and taking into consideration any relevant policies, guidelines, plans and statutory provisions.

In this context, the key areas of study have been:

- a description of the relevant aquifer systems including extent, inter-relationships and connectivity to surface water systems and groundwater dependent eco systems;
- a description of the potential interaction between hard rock aquifer systems and the alluvial system associated with Bowmans Creek;
- an assessment of the regional groundwater elevations, flow directions, rates of flow and hydrochemical signatures of the groundwaters;
- details of existing groundwater users likely to be affected by the proposed development and the extent of predicted impacts (water levels and water quality);
- details of any long term impacts on the groundwater regime arising from the proposed modifications.

The contained report provides results of those studies and includes historical groundwater data for the region and computer based simulations of the modifications in order to assess the likely impacts.

2. REGIONAL SETTING

Operations at RUM (previously Nardell Underground Mine) are currently in the Pikes Gully seam and are as shown on Figure 1. These operations are conducted within Mining Lease ML1349 and are directly beneath the old Ravensworth No.2, Ravensworth South and the current Narama open cut pits which extracted coal down to and including the Bayswater seam. These pits constitute a very large pit shell extending some 6.8 km in a north-south direction and 2.5 km in an east-west direction with a pit crest outline as indicated by the boundary on Figure 1. The

shell is now mostly filled with spoils and largely rehabilitated. Narama pit is currently active with the highwall moving in an easterly direction.

Spoils in the northern part of the shell (Ravensworth No.2) host partially recovered pore pressures as a result of fly ash storage. The southern part (Ravensworth South and Narama) is assumed to be mostly dry as a result down dip drainage along the floor of the spoils to Narama pit.

Glendell Mine Pit is situated to the north-east of RUM while Ashton Coal open cut and underground operations are situated to the east and south-east. Ravensworth West open cut pit lies immediately to the west of RUM and west of Bayswater Ck.

Underground operations are accessed via a portal located near the surface facilities (see Figure 1). Longwall panels LW1 to LW3 have been extracted and mining is now underway in LW4.

The proposed re-alignment of the main headings is over a distance of about 1 km as shown on Figure 1. This realignment locates the headings closer to the alluvial lands associated with Bowmans Creek leaving a minimum horizontal buffer of some 30 to 50m and a vertical buffer (depth of cover) of some 135 to 140m as indicated by the vertical section Figure 2.

2.1 Surface drainage and groundwater recharge

The mine is bounded by 3 drainage systems which are:

- Bowmans Creek, located in proximity to the east. This creek drains a catchment area of more than 170 sq.km. The creek exhibited very low flows and almost ceased to flow during the extended drought period from 2002 to 2007 but it is generally regarded as perennial. There are extensive alluvial deposits associated with the creek as indicated on Figure 1. These deposits are recharged by rainfall and runoff, and sustain a relatively shallow water table. The stored waters also undoubtedly contribute to baseflow in the creek;
- Bayswater Creek to the west of RUM flows southward from Lake Liddell to the Hunter River and is often dry or sustains disconnected pools for much of the time unless discharges occur from the lake. The creek has been diverted via an engineered channel around Ravensworth-Narama open cut operations for much of the lower reach. There are now only minor deposits of alluvium along this drainage system in the upper reaches;
- the Hunter River is located about 1 km to the south of the most southerly longwall panel LW15. The river channel in this area hosts significant alluvium which is generally considered to be in hydraulic connection with the river.

Flow and groundwater recharge is sustained by rainfall. Rainfall averages about 640 mm per annum as measured at Jerrys Plains which is the nearest continuous long term rain gauging station located some 10 km to the west of RUM. Calculated rainfall statistics for Jerrys Plains are provided in Appendix A.

2.2 Existing bores and wells in the region

The NSW Office of Water (NOW) retains a database of registered bores and wells in NSW. This database includes exploration/test wells that may not have been completed as permanent structures, observation/monitoring bores, and privately owned bores and wells currently in use or abandoned.

There are no privately owned bores in the project area or within 1 kilometre of the area.

3. GROUNDWATER HYDROLOGY

Regional geology is summarised on the published 1:100,000 Hunter Coalfield Regional Geology Map 1993 (Dept. Mineral Resources) and described by Beckett (1988). The geology in proximity to RUM comprises Permian age coal measures which are basically interbedded coal and non coal strata.

RUM mining operations are located in the flatter part of the Bayswater Syncline whose axis trends north-south and plunges southward; strata dip to the south at a shallow angle of between 2° and 5°. The Pikes Gully seam in which longwall mining is currently being conducted, is identified as a banded dull and bright coal seam which exhibits a moderate degree of cleating.

3.1 Local aquifer systems

The main aquifer systems that have been identified in the area are:

- **coal seam aquifers** with water storage primarily in coal cleats which also tend to be the main seepage zones. These coal seam aquifers are generally confined above and below by interburden non coal aquitards or aquicludes comprising sandstones, siltstones and claystones which do not transmit or release water freely. Interburden strata commonly exhibit intergranular permeabilities and drainable porosities that are very low. Occasional secondary storage may be developed within fractures which tend to be more frequent in areas of bedding flexure (steep dips) or where structural faults occur. These areas may offer higher permeability and porosity. Groundwater quality is generally brackish to saline;
- **the alluvial lands primarily associated with Bowmans Creek and the Hunter River** where porosity and hydraulic conductivity (transmitting capacity) are sometimes sufficiently developed in unconsolidated gravels, sands and silts, to warrant exploitation for stock and domestic supplies by bores and wells. These deposits act as storage for baseflows usually through efficient hydraulic coupling with the creek or river channel. Relatively minor deposits are also evident in the upper reaches of Bayswater Creek. However these are beyond the area of interest

Water tables and pressures in the coal measures have been sustained by rainfall infiltration to sub cropping strata over geologic time. The calculated rate of infiltration to unweathered hardrock is very low with estimates varying from zero to no more than 1% of annual rainfall based upon previous studies in the Upper Hunter region. Extensive regional mining operations have profoundly altered the hard rock water table through induced groundwater flows towards mine pits.

Some coal seams subcrop in or close to the project area but all are progressively confined in areas to the south where they dip below the Hunter River. This increasing 'wedge' of rock undoubtedly provides a measure of isolation between depressurised strata at depth, and the Hunter River. Groundwater encountered within a particular seam during drilling in these areas, rises above the seam thereby indicating sub artesian pressures and confinement. Confinement is also indicated by monitoring at a number of piezometers located in the different seams.

Water tables in the regolith and shallow weathered rock zone while not monitored, are mainly observed as weeps and seeps to open cut mining operations only after lengthy wet periods. They are generally temporary.

3.2 Groundwater piezometric surface

The phreatic surface or water table within the coal measures has been partially mapped using established piezometers at strategic locations. Some 24 sites (considered as part of the Ravensworth Operations (Narama and Ravensworth West) environmental monitoring network) are routinely measured for water level and/or pore pressures and basic water quality parameters. Appendix B, Figure B1 provides site locations and Table B1 gives details.

Figure 3 provides a water table plot based upon regional interpolation of groundwater equipotentials, reported water level data at other mine sites and inference from computer simulation of aquifer systems (MER, 2009) for 2009. Reference to this plot indicates a highly irregular surface which is strongly influenced by mining operations – both open cut and underground operations have generated groundwater sinks that attract flows. A remnant southward flow towards the Hunter River can be inferred in some areas from the equipotentials.

3.3 Regional hydraulic properties

Hydraulic properties of different strata have been assessed from available reports and from an extensive regional database held by MER.

Hydraulic conductivities for the coal seams and interburden in the general area have been measured using various techniques. Extensive airlift testing was undertaken as part of the Ravensworth West Environmental Impact Statement (EIS-MER, 1997). Packer tests have also been completed at numerous sites to the east of RUM (Glendell area) and at borehole RNVW6 (refer Figure 3) to the south.

Interburden hydraulic conductivities have been determined by core sampling and laboratory testing of non coal strata at a number of locations in proximity to the underground operations. In addition, Mackie (2009) provides a useful summary of packer test data for coal seams regionally and this data has been used as an indicator to the likely range in hydraulic conductivities for specific seams in the project area.

Appendix C provides a summary of test results while Table 1 gives an indicative range of hydraulic properties for strata within the project area.

Table 1: Indicative range in matrix hydraulic properties

Lithology	Kxy range (m/day)	Bulk porosity %	Effective porosity %
alluvium (Hunter River – Bowmans Creek)	1.0E-02 – 5.0E+01	1 - 25	1 - 25
Permian sandstones	5.0E-06 – 5.0E-04	1 - 18	.01 - 5
Permian siltstones	5.0E-07 – 1.0E-04	1 - 15	.01 – 1
Permian claystones and shales	5.0E-08 – 1.3E-06	1 - 15	.01 - .1
coal seams – dull	1.0E-04 – 1.0E-01	0.1 - 2	0.1 - 2
coal seams – dull and bright	1.0E-03 – 1.0E-01	0.1 - 3	0.1 - 3

Kxy = horizontal hydraulic conductivity

3.4 Regional water qualities

Regional groundwater qualities within the Xstrata monitoring network are routinely monitored for basic parameters pH and EC. This is supported by targeted sampling for laboratory determination of major ions in accordance with consent conditions for Narama and Ravensworth West open cut operations.

Summary coal seam water quality data is provided in MER (2009) for annual sampling for the 2008-2009 period. This data is represented on Figure 4 – the tri-linear speciation plot which 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 for the coal seams support a water quality which is dominated by primary salinity as is typical of the region generally. Waters may be described by $\text{Na} > \text{Mg} > \text{Ca}$ and $\text{Cl} > \text{SO}_4 > \text{HCO}_3$. Interburden water qualities, while not monitored, often exhibit a greater contribution from bicarbonates due to siderite and dolomite presence.

Total dissolved solids reflect mostly saline groundwaters with an average TDS of about 6100 mg/L (StDev of 2500 mg/L) determined for all seams. Table 2 summarises the general status of these coal seam groundwaters with respect to accepted guidelines. The groundwaters are considered to have no beneficial use.

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

TDS (mg/L)	Equivalent EC ($\mu\text{S}/\text{cm}$)	Beneficial use
1000 ¹	1540	acceptable taste limit for humans
1500	2300	general upper limit based on taste
1300 ²	2000	approx. limit for lucerne on alluvial lands
3000 ²	4600	limit for poultry and pasture/fodder
4000 ²	6100	limit for dairy cattle
32500	50000	sea water
5898	8670	<i>Bayswater seam</i>
6217	7130	<i>Lemington seams</i>
5282	9140	<i>Pikes Gully seams</i>
7128	7770	<i>Liddell seams</i>

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

4. PREDICTION OF GROUNDWATER IMPACTS

The current RUM operations in the Pikes Gully seam have resulted in depressurisation of the coal seam and depressurisation of strata above the seam. The extent to which this has occurred, depends upon a number of factors including variation in stratigraphy, seam and interburden hydraulic properties, structural features including dykes and faults, recharge sources and the depressurisation already induced by surrounding and overlying open cut operations. The spatial distribution and interaction of these various components cannot be evaluated using simple mathematical (analytical) expressions. Rather, computer based numerical modelling must be employed which permits the introduction of spatial and temporal variability.

A regional groundwater model was developed and reported as part of the Ravensworth North Pit Environmental Assessments (MER 2009). That model included historical Ravensworth open cut, Coal & Allied and RUM operations.

The model was not discretised at a sufficiently fine scale to address the strata depressurisation associated with the proposed re-alignment of the main headings and potential interactions with Bowmans creek alluvium. A more localised model has therefore been generated which employs the same finite difference scheme (ModFlow-Surfact, Hydrogeologic 1996) as the regional model. The scheme is based upon the discretisation of the area of interest into rectangular cells or blocks, the number of cells in the model grid being determined by the general juxtaposition of the proposed re-alignment with respect to the alluvium, and the expected hydraulic gradients between the underground operations and the alluvium.

The localised model has been used to generate steady state simulations of the groundwater flow systems for the currently approved headings alignment, and the proposed re-alignment for comparison. Adopting steady state conditions represents a 'worst case' scenario, in effect simulating conditions after a very long period of time when the flow systems have equilibrated.

The model is designed in a manner that facilitates consideration of a vertical section in an east-west direction. It comprises 16 layers with 12500 cells per layer, representing a modelled area of 5 sq. km. Individual cell areas of 0.04 ha (20 m x 20 m) have been adopted.

4.1 Model properties and boundary conditions

Material properties assigned to the model include hydraulic conductivity (permeability), elastic and inelastic storage. Hydraulic conductivities assigned to each model layer are identical to the regional model (MER, 2009) and are summarised in the following Table 3. These conductivities have been calculated by a rigorous process of correlation of measured rock matrix conductivities to geologically logged rock types (from core), followed by consolidation of logged sections of the stratigraphic column into the representative model layers. This process produces what is considered to be a more representative parameterisation. Elastic storage and drainable porosity values have been estimated from regional data (Mackie, 2009).

Table 3: layers and hydraulic properties assigned to regional model

Model Layer	Strata	Kxy (m/day)	Kz (m/day)	Ss (1/m)	Sy
1	regolith	1.0E+00	1.0E+00	1.0E-05	0.05
1	alluvium	1.0E+01	1.0E+01	1.0E-05	0.2
2	PCM	5.0E-03	5.0E-05	2.0E-06	0.001
3	Piercefield	2.0E-02	5.0E-03	4.0E-06	0.02
4	PCM	9.0E-04	3.5E-05	1.0E-06	0.0003
5	PCM	9.0E-04	3.5E-05	1.0E-06	0.0003
6	Bayswater	2.0E-02	1.0E-02	4.0E-06	0.02
7	PCM	9.0E-04	4.5E-05	1.0E-06	0.0003
8	PCM	9.0E-04	4.5E-05	1.0E-06	0.0003
9	PCM	9.0E-04	4.5E-05	1.0E-06	0.0003
10	L Pikes Gully	8.0E-02	1.0E-02	4.0E-06	0.02
11	PCM	1.0E-03	2.0E-05	1.0E-06	0.0003
12	U Liddell	4.0E-02	4.0E-03	4.0E-06	0.02
13	PCM	9.0E-04	4.1E-05	1.0E-06	0.02
14	Barrett	4.0E-02	3.0E-03	4.0E-06	0.009
15	PCM	3.3E-03	3.4E-05	2.0E-06	0.001
16	Saltwater Ck Fm	1.0E-04	1.0E-05	5.0E-06	0.08

Kxy = horiz. conductivity, Kz = vert. conductivity, Ss = specific storage, Sy = drainable porosity, PCM=Permian coal measures

Special model cells that control the groundwater elevation through leakage or seepage of surface water (river cells), have been assigned to Bowmans Creek assuming the creek maintains flow at all times. Model cells known as 'drain' cells that govern only the removal of groundwater from the model (no infiltration), have been located along the ephemeral creek identified as a tributary of Swamp Creek located east of Bowmans Creek. Both creek and river bed elevations have been estimated from a digital terrain model with a uniform negative adjustment of 1 m to account for estimation errors. Figure 5 shows the model mesh and drainage cells.

Rainfall recharge has been applied at a rate of 1.0 mm/year in coal measures which is equivalent to about 0.16% of annual rainfall. A rate of 65 mm/year (about 10% of annual rainfall) has been assigned to the alluvium associated with Bowmans Creek.

4.2 Strata depressurisation induced by mains re-alignment

Strata depressurisation resulting from the current mine plan and current headings alignment has been simulated by scheduling complete dewatering of the Pikes Gully. Depressurisation within the subsidence zone overlying extracted panels has been imitated assuming a more permeable and variably connected fracture network which promotes accelerated dewatering when compared to unsubsidised strata.

The overlying Ravensworth South pit shell in the simulated area is assumed to be in a relatively dry state for the foreseeable future. Rainfall recharge through spoils is therefore assumed to percolate down to the pit shell floor where it migrates down dip and out of the area of interest. It is noted that RUM tailings and water recovery dams are located within the pit shell. However any leakage from these facilities is assumed to migrate down dip without allowing any significant build up in saturation head.

Figure 6a (upper plot) illustrates the predicted pore pressure distribution for a west-east section through the model and through the main headings. The alignment of this section (Figure 1) shows Bowmans Creek and the associated alluvium at their shortest distance from the underground mining operations. Figure 6a indicates pore pressures are sustained beneath the alluvium to the full depth of the model although there has clearly been some depressurisation as a result of open cut and underground mining (non hydrostatic conditions evident). Above the Pikes Gully seam the subsidence zone is dewatered to a height of more than 120m while a thin wedge of saturation is evident at the floor of the overlying open cut pit shell extending westward from the alluvium into the Ravensworth South pit area.

Figure 6b (lower plot) illustrates the predicted pore pressure distribution for the re-aligned main headings and extended panel extractions model. The changed conditions lead to a migration of the dewatered zone defined by the zero pressure contour, eastward towards the alluvium. However the general geometry of the contours on Figure 6b remains very similar to that shown on Figure 6a.

The rate of leakage from Bowmans Creek alluvium has been assessed for each model by examining the internal flow budgets of the model. These budgets are summarised in the following Table 4 in terms of impact on leakage from the alluvium to underlying strata, and impact on baseflow in Bowmans Creek (defined by flow from the alluvium to the creek). Results indicate a very small to negligible increase in leakage from the alluvium to deeper strata and no measurable change to baseflow in Bowmans Creek. This is attributed to the presence of sustained (average) rainfall recharge to the alluvium.

Table 4: Flow budgets for Bowmans Creek and associated alluvium

Case	Current mains ML/day	Re-aligned mains ML/day	Change ML/day
Leakage from alluvium	0.130	<0.131	<0.001
Baseflow in Bowmans Ck	0.004	0.004	0.000

4.3 Strata depressurisation induced by extension of panels LW6 and LW7

Strata depressurisation resulting from the extension of the start line of longwall panels LW6 and LW7 nearer to Bayswater Creek diversion, has been assessed using the regional model employed for Ravensworth Open Cut operations (MER 2009). Simulations have been conducted for both the current longwall layout, and the extended panels for steady state conditions just after the completion of longwall LW7. Results are presented as vertical sections shown on Figure 7 which illustrate predicted pore pressures.

Figure 7a (upper plot) shows dewatered strata beneath the creek for the currently approved mine plan. This dewatering will be brought about by the cumulative effects of Ravensworth No.2, Ravensworth South and Ravensworth West open cuts, and the advancing depressurisation-dewatering effects in deeper strata, induced by RUM operations. There is also some influence

from Cumnock underground mine. Bayswater Ck is assumed to be ephemeral and any water contained in it likely to be perched.

Figure 7b (lower plot) shows the predicted pore pressure distribution for the extended panel scenario. Strata remain dewatered and Bayswater Creek conditions are predicted to be essentially the same.

5. POTENTIAL ENVIRONMENTAL IMPACTS

Proposed re-alignment of the main headings and extension of longwall panels LW6 and LW7 to the south-east have the potential to induce change to the local groundwater and surface water environments. Potential impacts arising from the development will include:

- leakage of groundwater from shallow alluvial aquifers;
- impacts on water supply bores and wells;
- change in groundwater quality in coal measures.

5.1 Leakage of groundwater from shallow alluvial aquifers

Simulation of mains re-alignment indicates a slight redistribution of pore pressures within the Permian coal measures. There would be no obvious change in pore pressures within the alluvium associated with Bowmans Creek [N1] and negligible change in the leakage from the alluvium to the underlying strata, estimated to be less than 0.001ML/day. There would be no significant change to baseflow in Bowmans Creek.

Simulation of the extension of longwall panels LW6 and LW7 indicates a redistribution of pore pressures beneath Bayswater Creek diversion. However the creek remains perched and any leakage would remain the same as for the currently approved conditions. There is no alluvium associated with Bayswater Creek diversion in the area of interest.

5.2 Potential impacts on water supply bores and wells

There are no identified private boreholes within or near the proposed changes (to the mine plan) that are likely to be affected.

5.3 Change in groundwater quality in coal measures

Groundwater within the coal measures is dominated by primary salinity as is typical of the region. Salinity levels exhibit an average TDS of about 6100 mg/L. Waters may be described by $\text{Na} > \text{Mg} > \text{Ca}$ and $\text{Cl} > \text{SO}_4 > \text{HCO}_3$.

Proposed modifications to the mine plan are unlikely to affect groundwater qualities.

6. WATER SHARING PLANS

Water Sharing Plans (WSP) are an integral part of the *Water Management Act 2000*, the objective of which is the sustainable and integrated management of NSW water resources. The WSP's support the long-term health of rivers and aquifers by making water available specifically for the environment. This is achieved through the establishment of rules for sharing water between the environment and water users. One WSP is relevant to the proposed changes:

The Hunter Unregulated and Alluvial Water Sources 2009 which took effect from 1st August 2009. Relevant waters which apply to this water source are defined within the 'Jerrys Water Source' and include waters contained in Bowmans and Bayswater creeks and any connected alluvium. Groundwater contained in the coal measures is excluded.

Since the predicted impact on leakage from the creeks or the alluvium is negligible, the impact on the WSP is also considered to be negligible.

7. LICENSING REQUIREMENTS

Licensing in respect of groundwater seepage into mining operations is already established under Part 5 of the Water Act (1912) for current mining activity.

8. IMPACT ASSESSMENT CRITERIA

The establishment of impact assessment criteria is an important element of future monitoring of both the groundwater and surface water regimes. The criteria should establish a series of benchmarks against which the impacts can be measured, alert protocols developed and mitigative actions initiated. While these criteria (and impacts) can be relatively easily established for surface waters, significant difficulties arise in respect of groundwater since aquifer and aquitard flows in both a regional and local context, are difficult to quantify.

Impacts in respect of groundwater relate mainly to physical depressurisation of the rock strata and potential indirect impacts on the alluvial aquifer system of Bowmans Creek.

Depressurisation can be calculated by regular measurement of prevailing groundwater levels in the rock strata and comparing these levels with those measured prior to mining impacts. Xstrata currently monitors groundwater levels at a numerous borehole and well locations throughout the region. Consideration of the regional network suggests a number of additional piezometers are warranted in areas to the east in the vicinity of Bowmans Creek. Approximate locations are indicated on Figure 8 and include:

- two standpipe completions in Bowmans Creek alluvium to facilitate water level monitoring and water sampling. These completions should extend to the base of the alluvium and with deeper standpipe or pore pressure transducer installed at least 30m below the base of the alluvium in order to monitor pore pressure in the coal measures;
- two pore pressure monitoring boreholes comprising vertical arrays of transducers at 7 or more nominated depths distributed down to the Barrett seam.

Consideration should also be given to future data sharing with Ashton Coal where numerous piezometers are located in Bowmans Creek alluvium in areas nearer the Hunter River.

In addition to the above and as part of overall quality procedures, the monitoring programme should be subject to review annually.

References:

Beckett, J., 1988. The Hunter Coalfield – Notes to accompany the 1:100000 Hunter Coalfield geology map.

Hydrogeologic Inc. 1996. Modflow-Surfact User manual.

Mackie, C.D. 2009. Hydrogeological characterisation of coal measures and overview of impacts of coal mining on groundwater systems in the Upper Hunter Valley of NSW. UTS, 2009.

Mackie Environmental Research (MER), 1997. Ravensworth West Extension groundwater study. Prepared for Peabody Resources, May 1997 for EIS.

Mackie Environmental Research (MER), 2009. Ravensworth Operations Pty Limited – Groundwater management studies: Ravensworth Operations Project. Specialist EA report prepared on behalf of Ravensworth Operations, November 2009.

IMPORTANT INFORMATION ABOUT YOUR HYDROLOGICAL REPORT

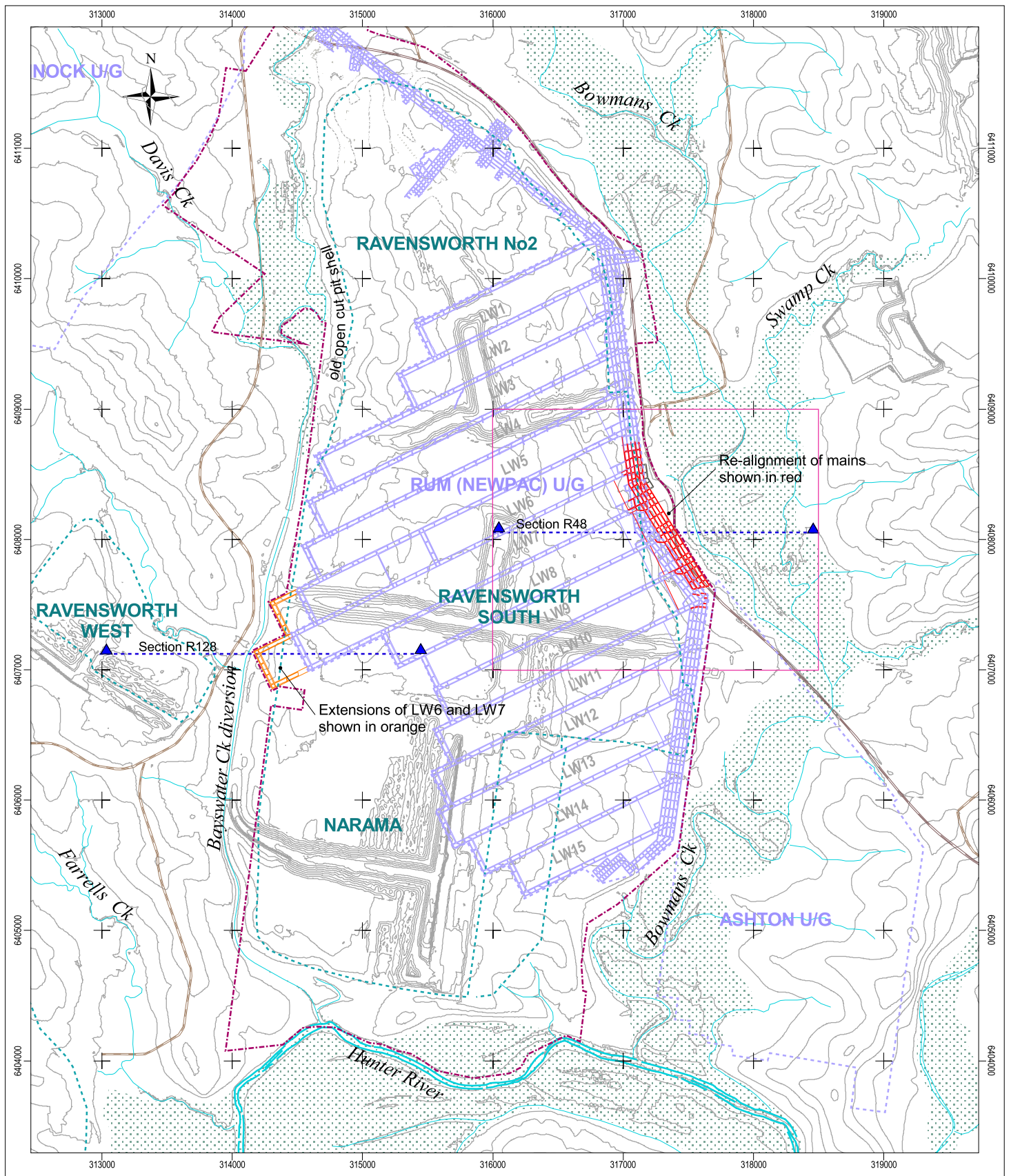
Mackie Environmental Research (MER) has applied skills and standards appropriate for a Chartered Professional (AusIMM) in the preparation of this report, the content of which is governed by the scope of the study and the database utilised in generating outcomes.

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

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

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Dr. C. Mackie
CP. (Env)



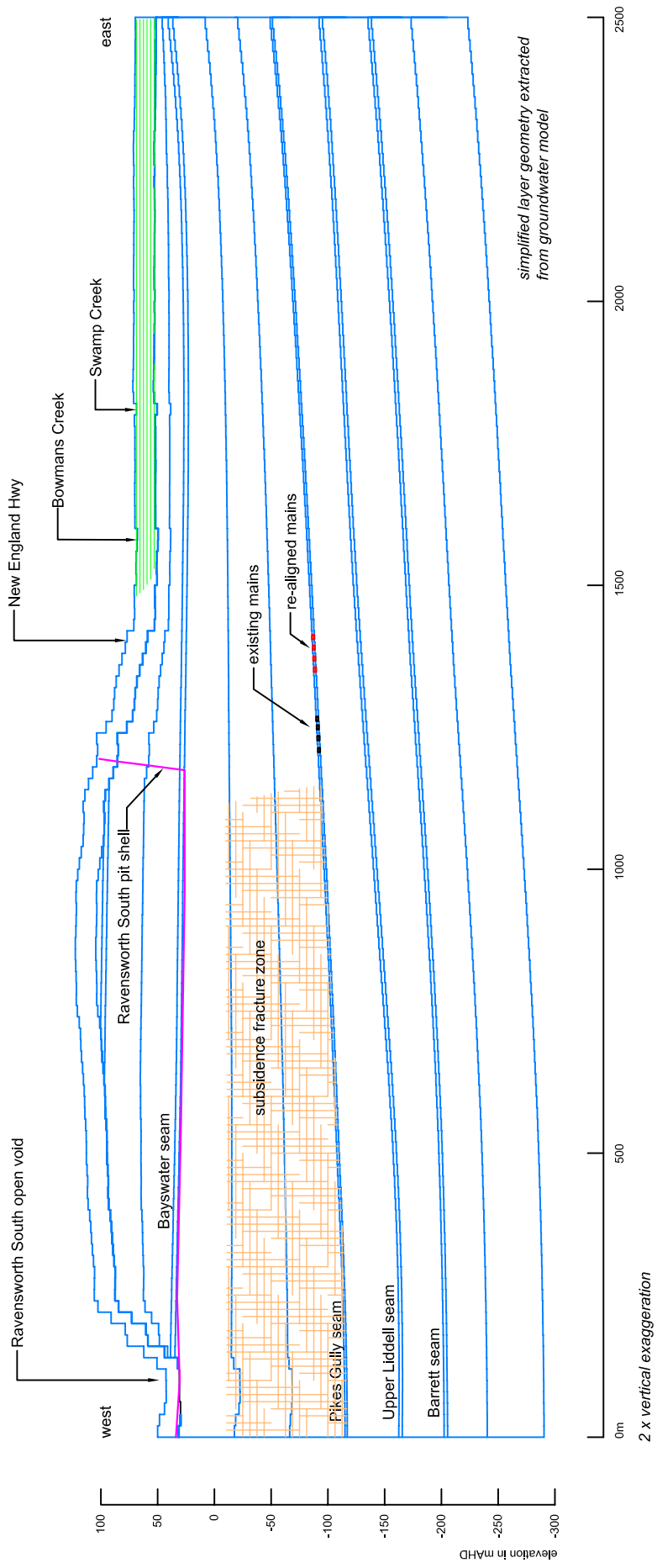
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- - - open cut pit shell
- - - underground workings perimeter
- alluvium
- perimeter of local groundwater model

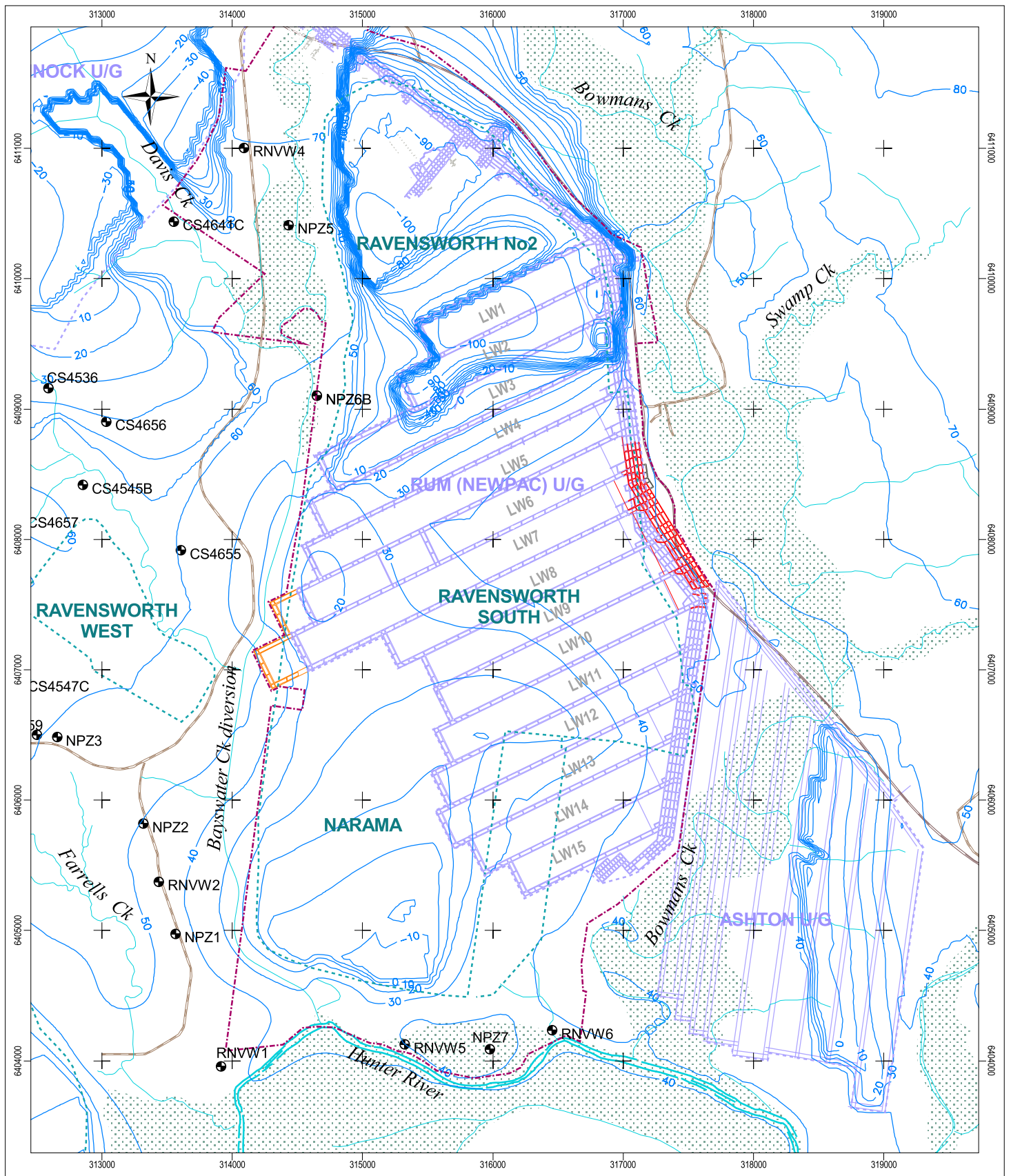
RAVENSWORTH UNDERGROUND MINE MODIFICATIONS

Adjacent open cut and underground operations



Section R48: Hydrogeologic elements

Figure 2



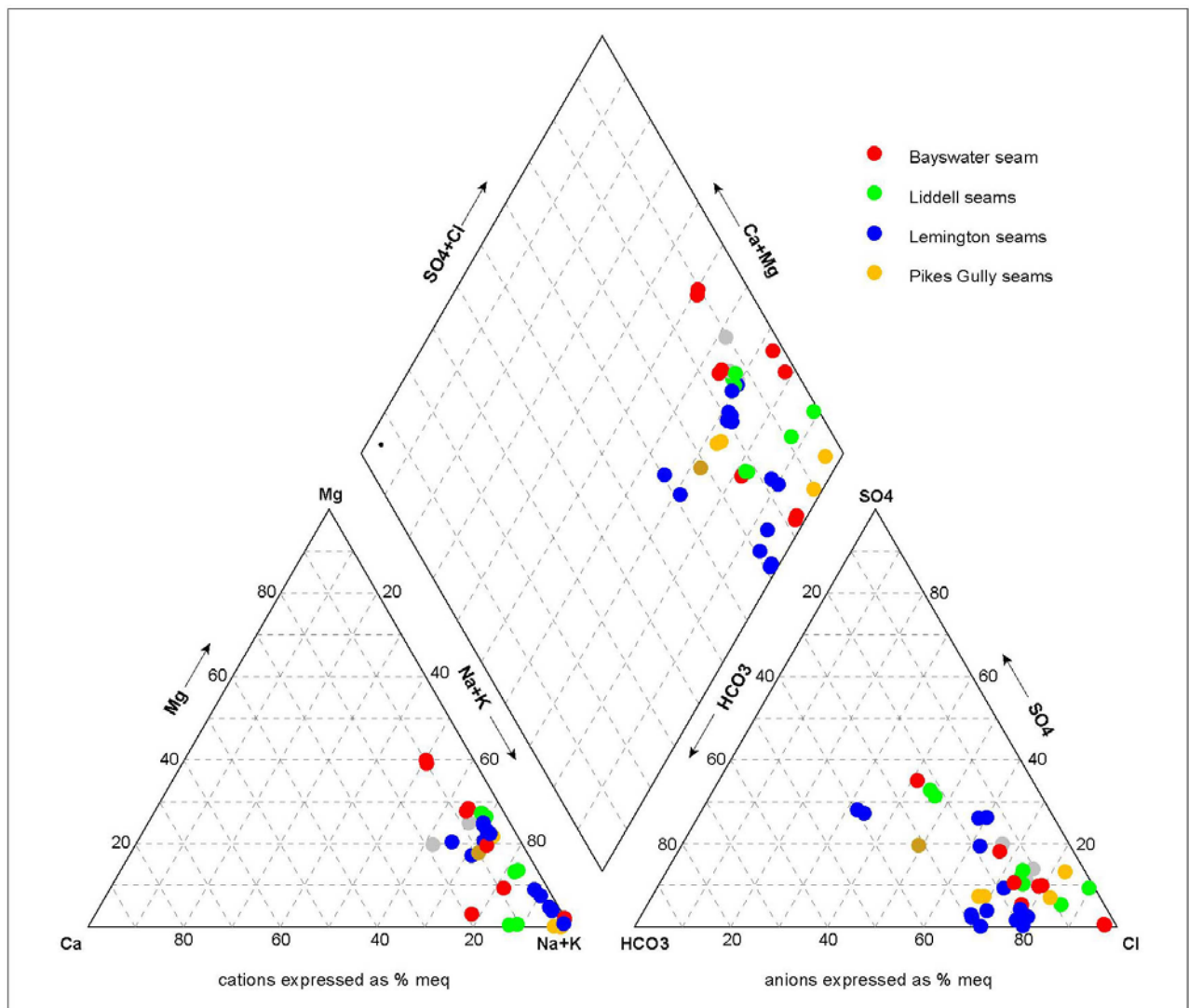
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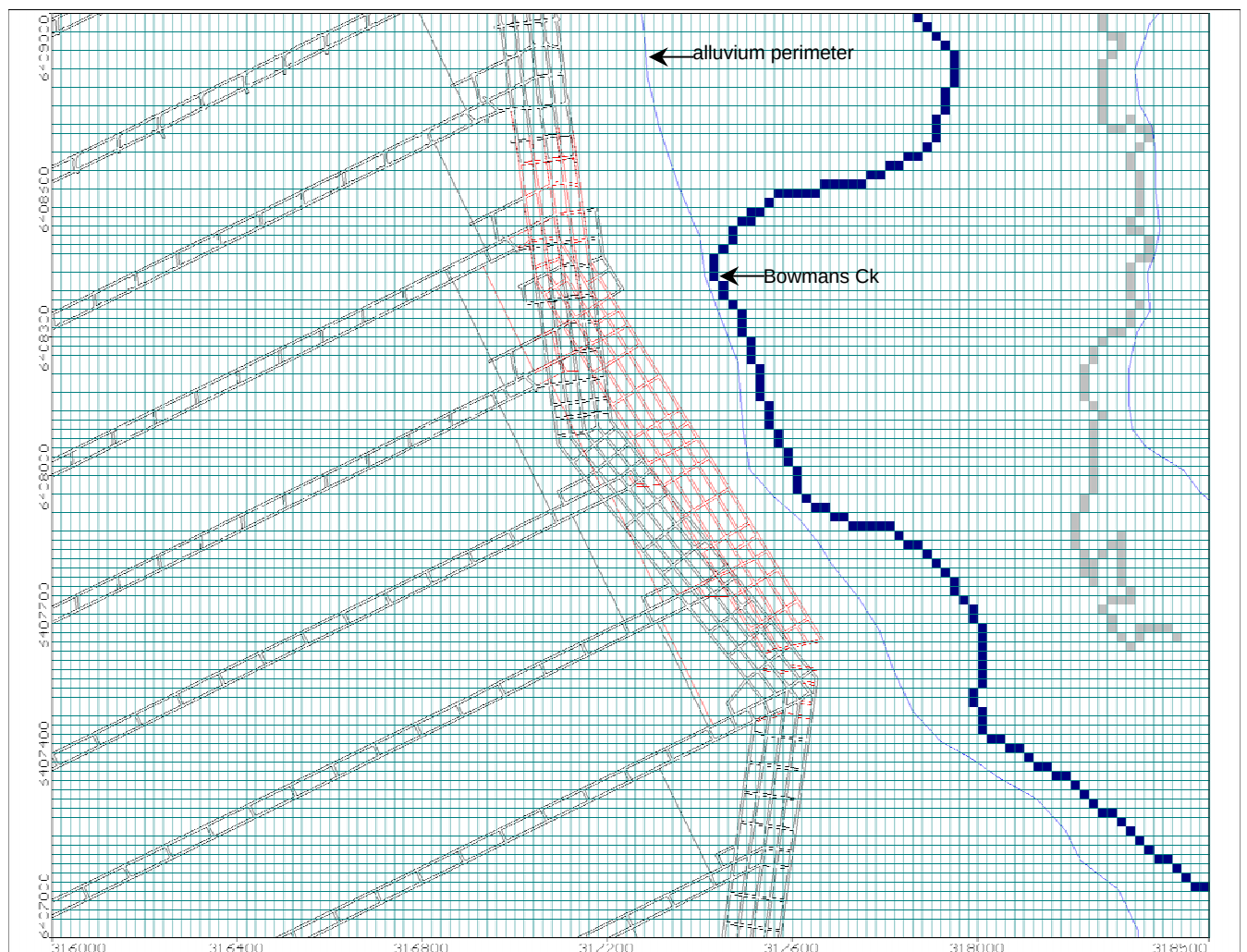
- RUM project area
- open cut pit shell
- underground workings perimeter
- alluvium
- piezometer
- piezometric level (mAHd)

RAVENSWORTH UNDERGROUND MINE MODIFICATIONS

Approximate regional water table and monitoring boreholes



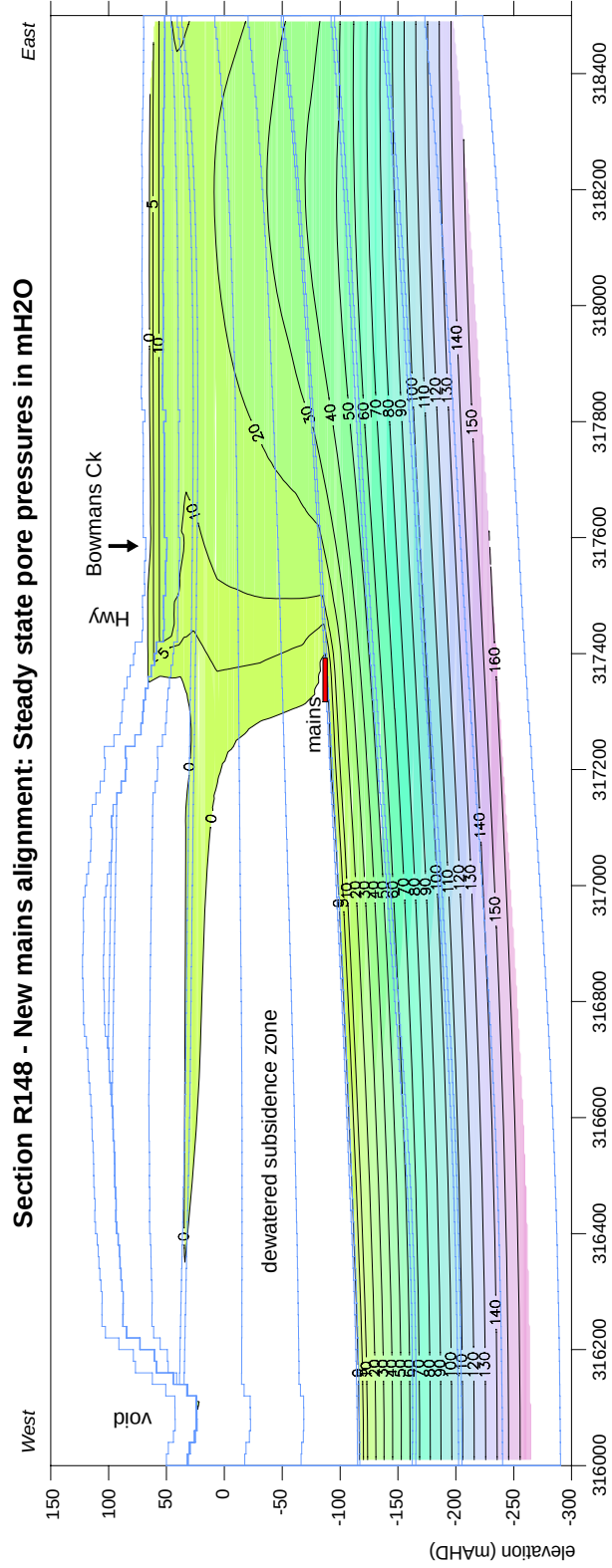
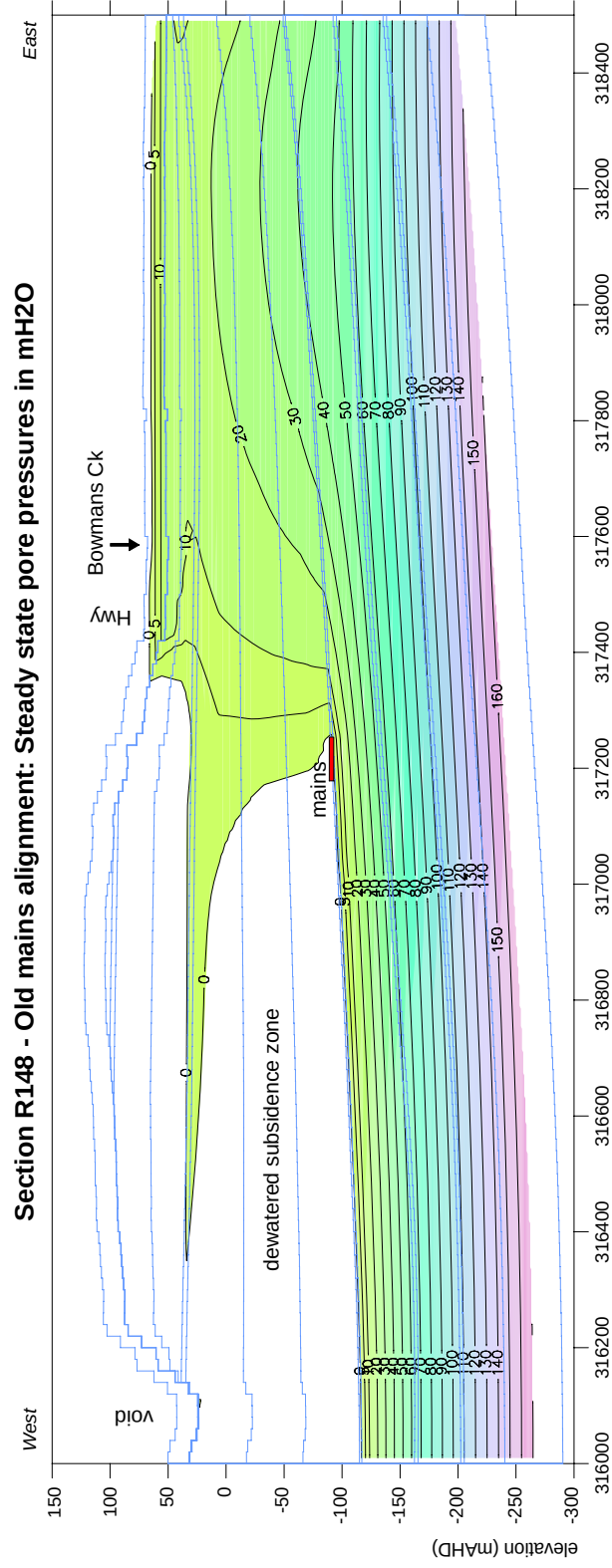
Characterisation of coal seam groundwaters



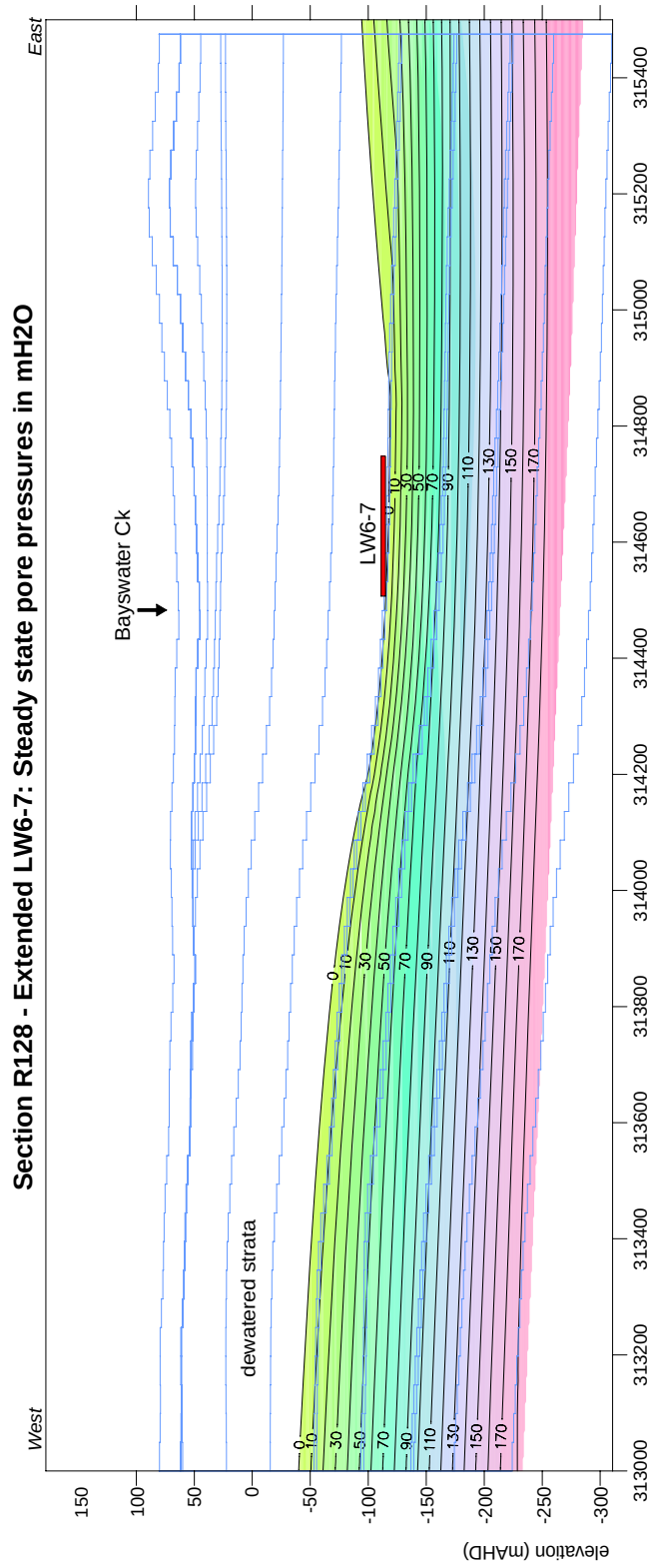
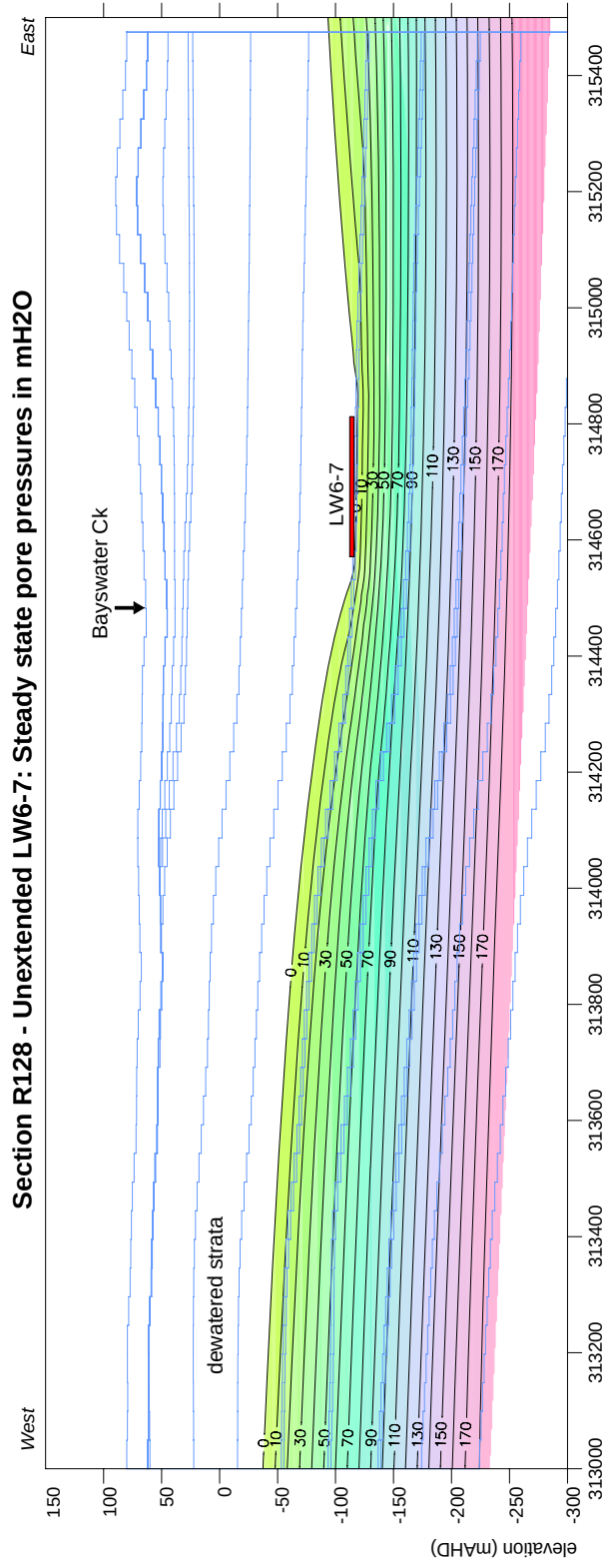
Mesh extents: 2.5km x 2km
 Cell dimensions uniformly 20m x 20m
 16 model layers
 Model hydraulic properties taken from regional model for Ravensworth North pit

Localised model mesh and drainage cells

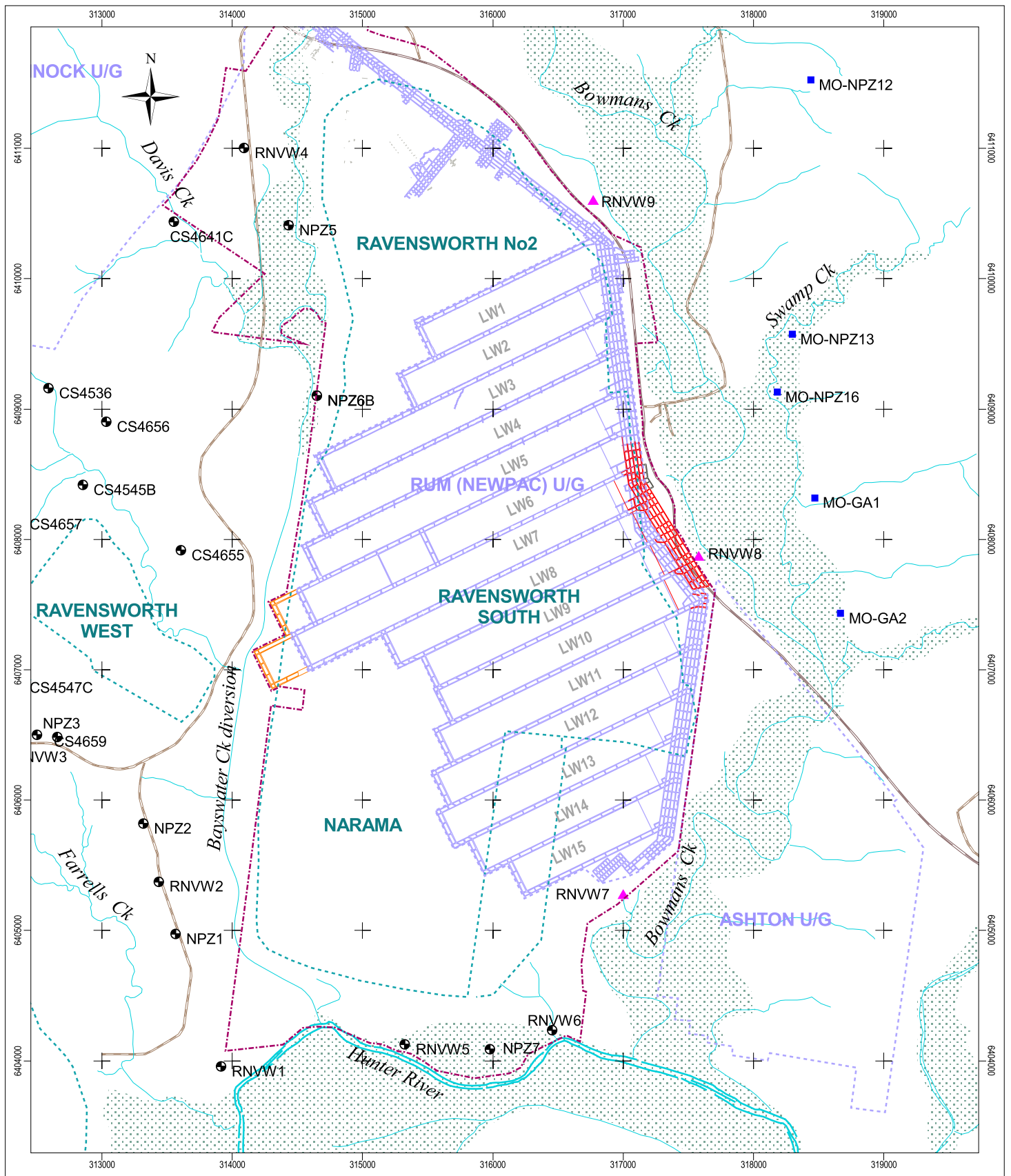




vertical exaggeration 2 times
model layers shown in blue



vertical exaggeration 2 times
model layers shown in blue



RAVENSWORTH UNDERGROUND MINE MODIFICATIONS

Monitoring boreholes and proposed additional locations

APPENDIX A: CLIMATE DATA

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

Long term data for Jerrys Plains has been used in void water management simulations where testing has been conducted against the historical record. In addition, data has been processed to generate recurrence intervals and average exceedance probabilities for specified rainfall durations up to 20 days. The following Table A1 provides a summary.

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

Table A1: Longer term intensity, frequency, duration statistics for 118 years of data.

ARI	AEP %	1 day	2 day	3 day	4 day	5 day	6 day	8 day	10 day	15 day	20 day
once in 1 years	63.2	50	65	72	77	81	85	91	98	114	126
once in 2 years	39.3	63	84	93	100	104	109	117	124	143	158
once in 5 years	18.1	80	110	122	131	137	141	151	159	182	199
once in 10 years	9.5	93	130	144	155	161	166	178	186	211	230
once in 20 years	4.9	106	150	167	179	186	191	204	213	240	261
once in 50 years	2.0	123	177	198	212	220	225	240	249	279	302
once in 100 years	1.0	137	198	222	238	247	251	268	277	309	333

Durations are based on screening of daily Jerrys Plains data within each year of available records from 1890 to 2007 - a log normal distribution is assumed. The long term annual average is 642mm.

ARI (Average Recurrence Interval) means – the average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration. For example, a continuous rainfall event total of 98 mm over 10 days has an average recurrence interval of 1 year.

AEP (Average Exceedance Probability) means – the probability that a given rainfall total accumulated over a given duration will be exceeded in any one year. For example, a continuous rainfall event total of 98 mm over 10 days has a 63.2% probability of being equaled or exceeded in any one year.

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

	Jan	Feb	Mar	Apl	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec
Daily evaporation	7.1	6.2	5.0	3.5	2.2	1.6	1.8	2.8	3.9	5.1	6.1	7.3
Monthly evaporation	220.1	173.6	155.0	105.0	68.2	48.0	55.8	86.8	117.0	158.1	183.0	226.3
Monthly rainfall	76.9	72.5	59.1	44.1	40.4	47.6	43.5	36.7	41.7	52.2	59.9	67.6

APPENDIX B: PIEZOMETRIC MONITORING DATA

A network of monitoring bores exists within the project area and surrounding areas including areas near the Hunter River. The current network includes both standpipe and pore pressures piezometers constructed in the coal measures. The network includes:

- nine locations equipped with vertical arrays of vibrating wire transducers that monitor formation pore pressures in the coal measures (Bayswater, Lemington, Pikes Gully, Arties, Liddell and Barrett seams or interburden) to depths of more than 300m;
- twelve locations equipped with standpipes installed in the coal measures that facilitate dipping of the piezometric level(s) and water sampling;
- eight pit top holes located around the Cumnock coal preparation plant to monitor shallow groundwater levels and any potential impacts that may have arisen from the operations.

The following Table B1 provides details while Figure B1 shows monitoring locations.

B1.1 Piezometric elevations

Umwelt (2008) provides a detailed summary of the monitoring network and water quality information. That data together with more recent water level and pore pressure sampling is summarised on the following Figures B2 to B6. Reference to these plots supports the following:

- Figure B2 – dipped water levels indicate the most significant influences are the Cumnock underground workings and the adjacent Ravensworth No.2-Ravensworth South open cuts and the Narama open cut further to the south. Cumnock operations have lead to extensive depressurisation of the coal seams which in turn have induced flows and leakage from overlying strata. Interestingly the uppermost plot (a) indicates a common piezometric elevation of 67 to 68 mAHD for the currently monitored boreholes even though these bores are widely separated. The reason for this is unclear and may simply be coincidental. Recovering trends are evident in some piezometers from about 2006 onwards, while others are static or continue to drawdown.
- Figure B2 - NPZ1, NPZ2, NPZ3, and NPZ4 are located well to the south of the Cumnock underground. Data trends for these piezometers reflect the influence of recent Ravensworth West open cut operations and Narama open cut which both mine seams down to and including the Bayswater seam. Plots indicate piezometric levels in strata monitored below the Bayswater seam have not yet been drawn down to seam level (excluding NPZ2-Lem), suggesting that interburden are not particularly transmissive in the vertical direction ie. low vertical hydraulic conductivity.
- Figure B3 – Pore pressure installations provide a valuable insight to the vertical distribution of piezometric heads. CS4655 illustrates the Bayswater seam supporting a water table while deeper strata are depressurising in a uniform way. This response suggests hydraulic connection between the deeper transducers in the Lemington F seam to the Barrett seam either possibly through the presence of a vertical fault or other structural feature. CS4656 CS4657 and CS4658 exhibit preferential loss of pressure in the Liddell seams, and recovering pressures in the Pikes Gully and Barrett seams. These trends are seemingly attributable to Cumnock ie. RUM operations would be expected to pull piezometric levels down rather than initiate recovery.
- Figure B3 – RNVW1, RNVW2 and RNVW3 all suggest vertically downwards leakage flows to the Liddell-Barrett seams although the overall loss of piezometric head remains well above the seams and probably within 20 to 30m of the hydrostatic conditions that prevailed prior to commencement of mining in the region. RNVW4 is significantly impacted and reflects pressure losses induced by both Cumnock underground and

Ravensthorpe open cut operations. The nearly hydrostatic conditions (8 to 18mAHD) suggest complete depressurisation to the Lemington seam(s) below the Bayswater seam.

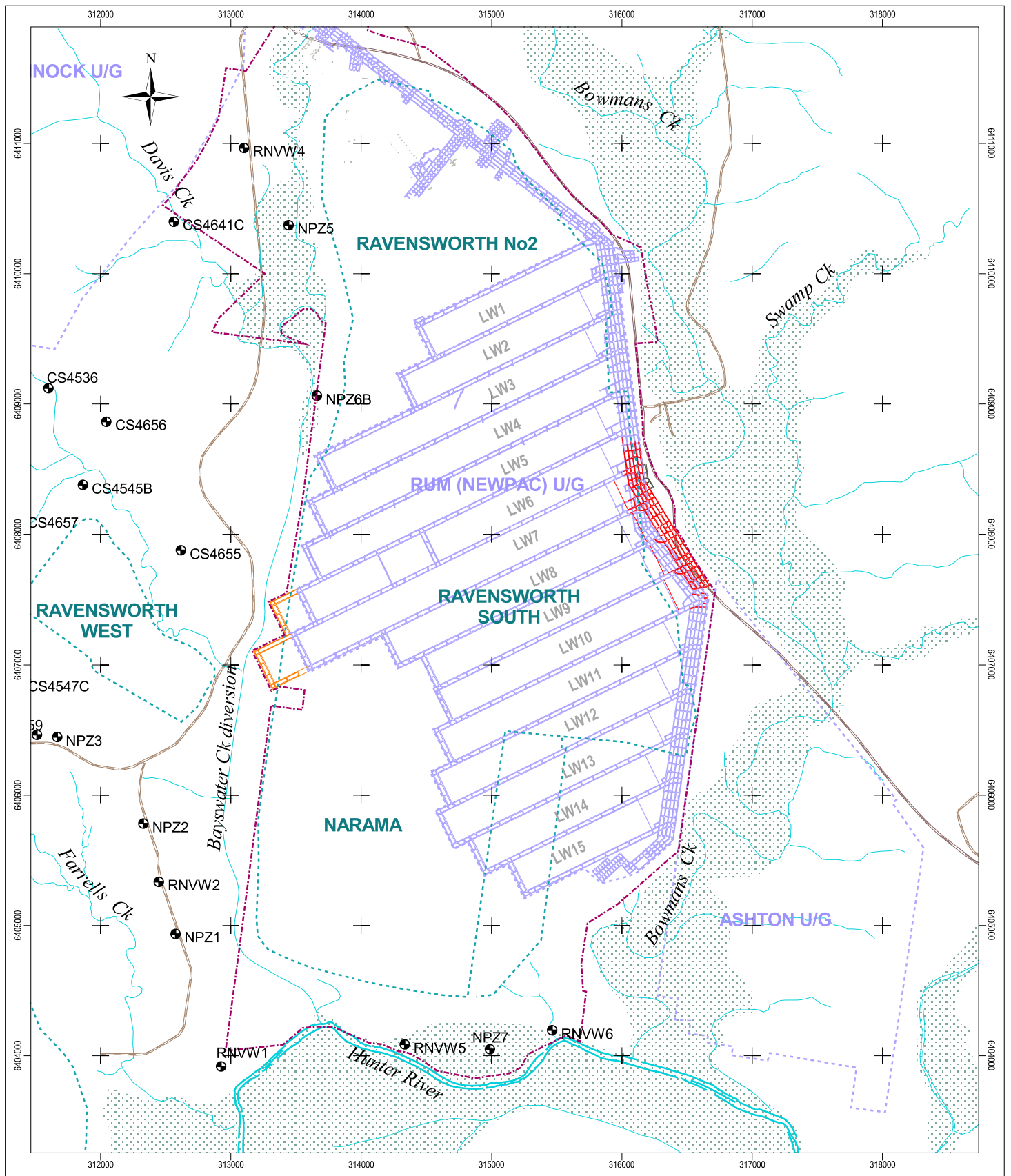
- RNVW5 and RNVW6 located near the Hunter River both suggest the presence of a weak vertical (leakage) gradient although data is quite limited due to recent installation of these transducers. A pre-mining hydrostatic level of about 48 to 50 m would be expected.

B1.2 Groundwater quality

Groundwater speciation is conducted annually. Samples are collected from the piezometer monitoring network and analysed for major cations and anions plus a suite of heavy metals. Umwelt 2008 provides a useful summary from which the coal seam water quality data in Table B1, is represented.

Table B1: Summary of coal seam groundwater quality – 2008 and 2009

Bore	Date	Seam	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	CO3 mg/l	HCO3 mg/l	SO4 mg/l	Cl mg/l
Coffey	1-Oct-08	Bay	2093	1	8	742	13	127	216	83	903
Coffey	1-Apr-09	Bay	1981	1	6	625	13	133	229	51	923
NPZ1-Mid	1-Oct-08	Bay	9859	328	798	1880	41	0	1118	814	4880
NPZ1-Mid	1-Apr-09	Bay	9462	325	762	1840	47	0	1133	765	4590
NPZ3-Mid	1-Oct-08	Bay	8955	217	482	2100	51	0	1464	751	3890
NPZ3-Mid	1-Apr-09	Bay	9480	199	495	2110	60	0	1476	1380	3760
NPZ4-Mid	1-Oct-08	Bay	4127	128	203	1400	73	0	92	11	2220
NPZ4-Mid	1-Apr-09	Bay	4138	252	24	1170	46	0	106	20	2520
NPZ6-P2	1-Apr-09	Bay	2989	85	52	869	8	0	623	723	629
BoreholeP	1-Oct-08	Ldl	5148	74	121	1420	15	0	1058	1220	1240
BoreholeP	1-Apr-09	Ldl	5438	62	124	1430	19	0	1133	1270	1400
Gully-(EE4)	1-Oct-08	Ldl	9490	125	469	2300	67	0	1415	794	4320
NewGate-S4	1-Oct-08	Ldl	5222	184	6	1770	23	26	34	389	2790
NewGate-S4	1-Apr-09	Ldl	5847	213	5	1720	25	15	532	257	3080
Paddock-HF7	1-Oct-08	Ldl	9640	148	505	2370	38	0	1269	1050	4260
Paddock-HF7	1-Apr-09	Ldl	9112	141	508	2380	46	0	1269	848	3920
NPZ1-Tall	1-Oct-08	Lem	6728	59	111	2080	13	0	1203	222	3040
NPZ1-Tall	1-Apr-09	Lem	7270	52	98	2260	15	0	1269	136	3440
NPZ2-Tall	1-Oct-08	Lem	6882	18	9	2220	12	115	1745	3	2760
NPZ2-Tall	1-Apr-09	Lem	6608	17	9	2210	14	0	1769	139	2450
NPZ3-Tall	1-Oct-08	Lem	7106	40	58	2210	17	0	1720	211	2850
NPZ3-Tall	1-Apr-09	Lem	6720	34	48	2180	18	0	1818	112	2510
NPZ4-Tall	1-Oct-08	Lem	5452	128	203	1400	73	0	1064	14	2570
NPZ4-Tall	1-Apr-09	Lem	5448	131	217	1390	81	0	1091	68	2470
NPZ6	1-Oct-08	Lem	1359	58	50	303	4	0	465	259	220
NPZ6	1-Apr-09	Lem	1643	54	47	368	6	0	566	312	290
Site11-Conveyor	1-Oct-08	Lem	7352	123	304	1860	23	0	1342	1100	2600
Site11-Conveyor	1-Apr-09	Lem	7288	125	313	1810	26	0	1391	533	3090
Site3-Gate	1-Oct-08	Lem	8756	149	409	2150	16	0	1342	1770	2920
Site3-Gate	1-Apr-09	Lem	8434	148	380	2050	17	0	1159	1740	2940
CS4641C	1-Oct-08	PG	3991	24	0	1440	28	59	348	212	1880
CS4641C	1-Apr-09	PG	6578	41	1	1410	31	83	244	848	3920
Hill-S2	1-Oct-08	PG	5106	83	212	1300	23	0	1244	284	1960
Hill-S2	1-Apr-09	PG	5455	83	214	1350	33	0	1293	312	2170
NPZ6-P1	1-Apr-09	reg	2180	66	70	534	11	0	623	305	571



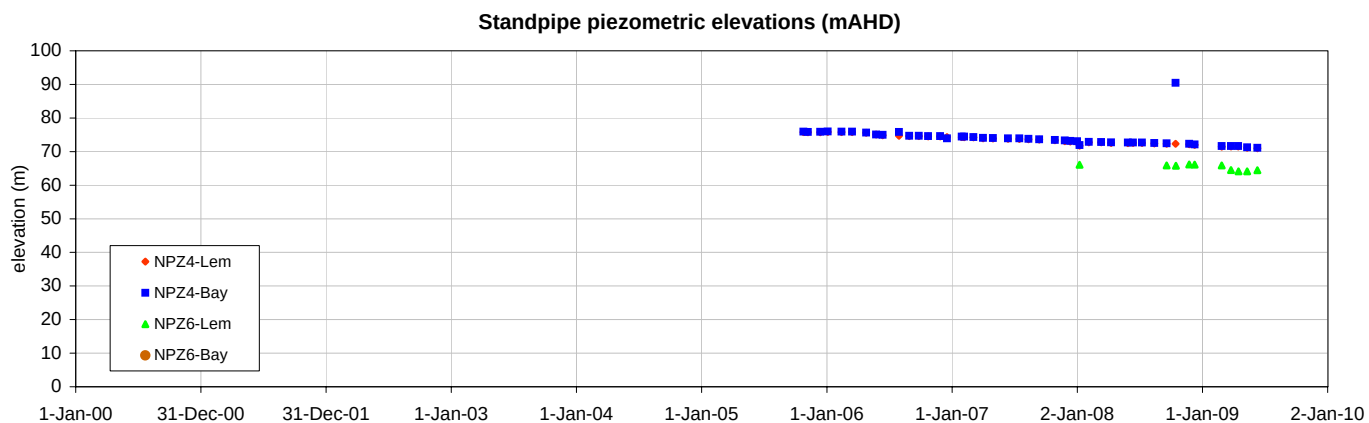
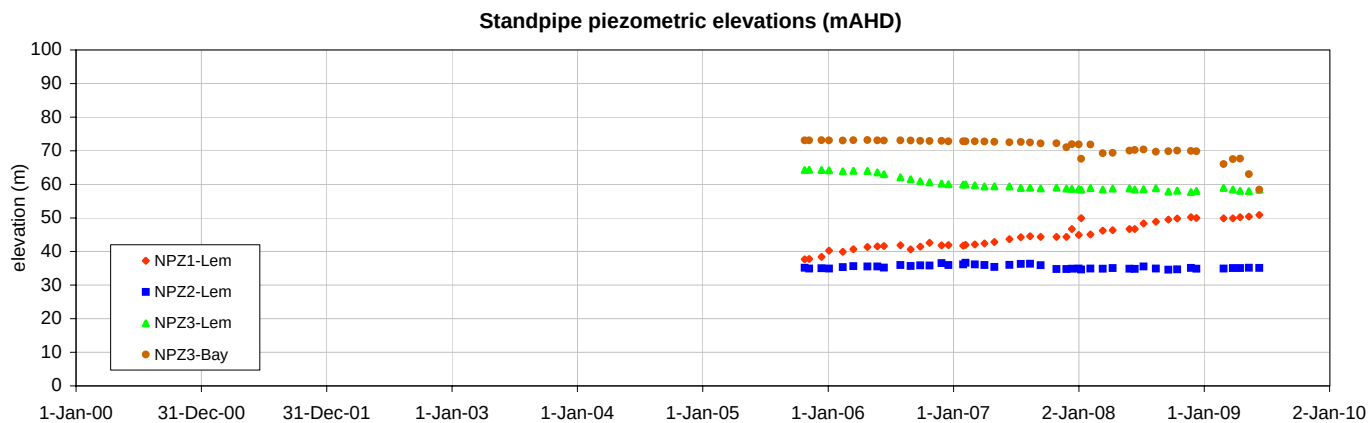
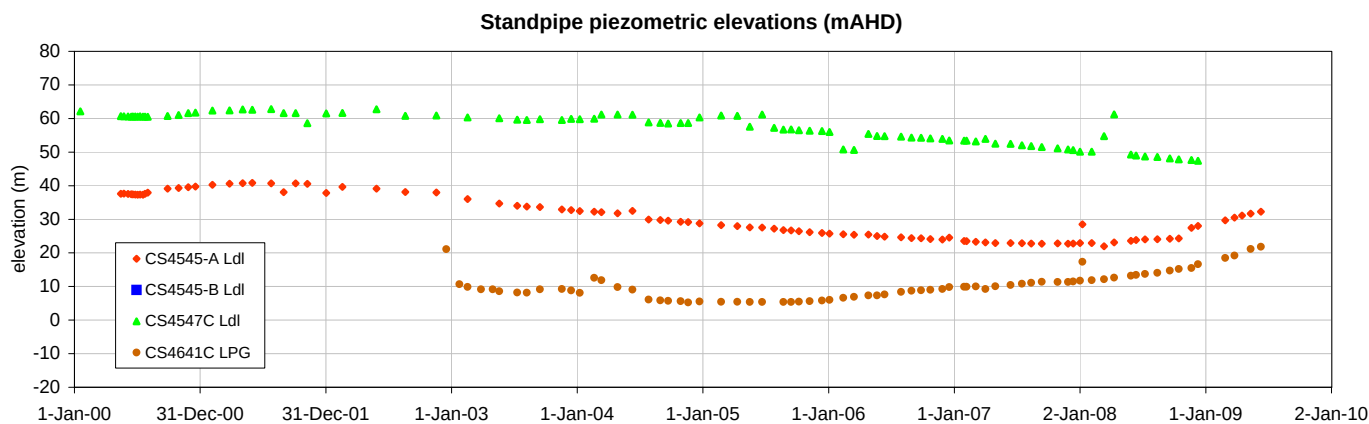
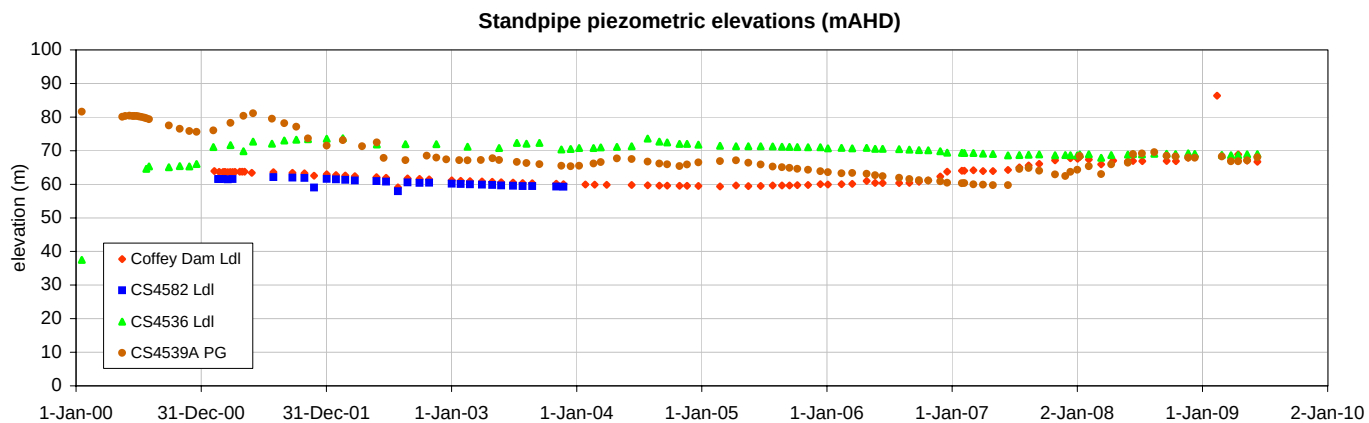
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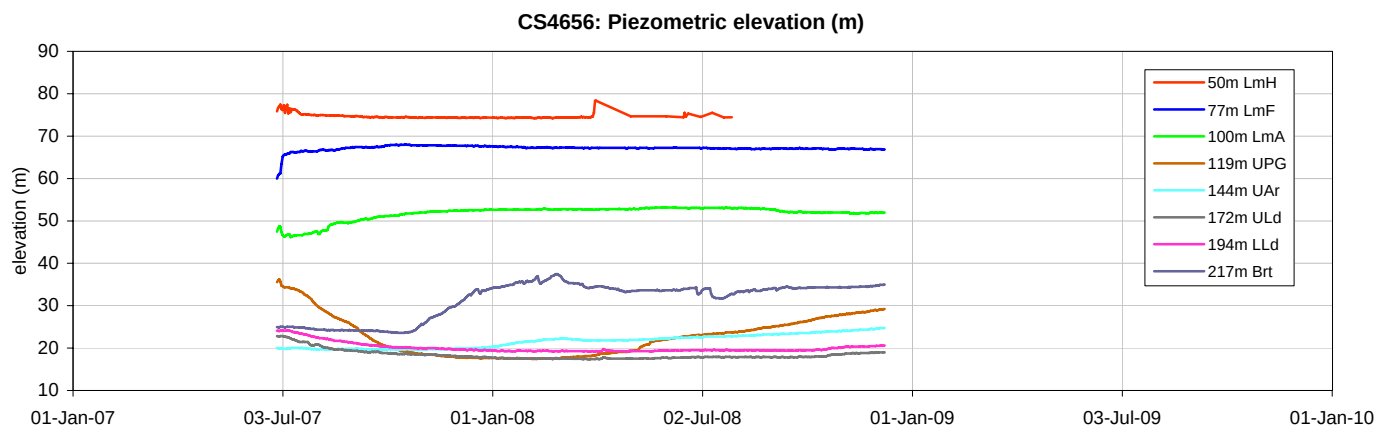
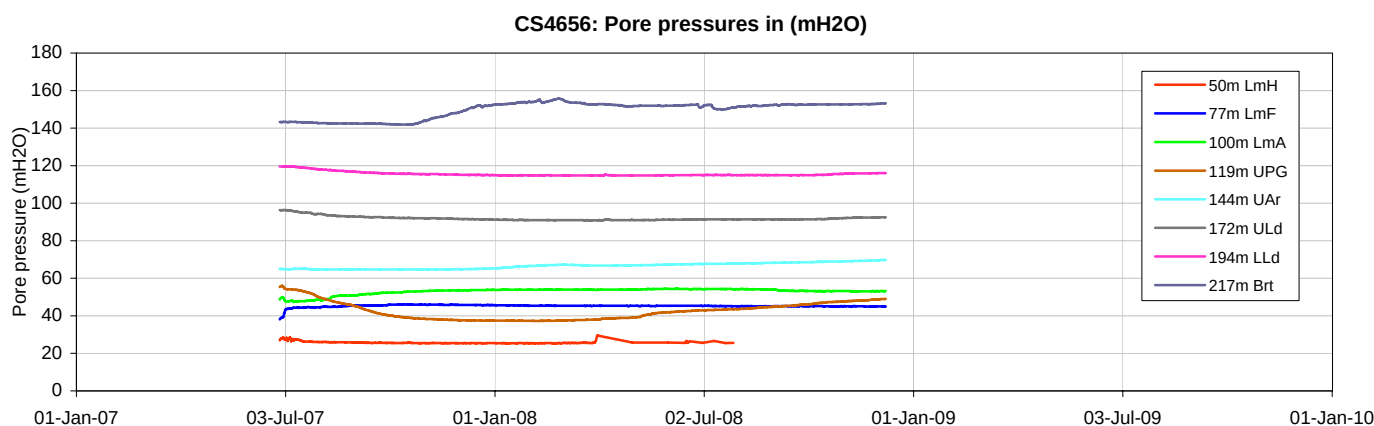
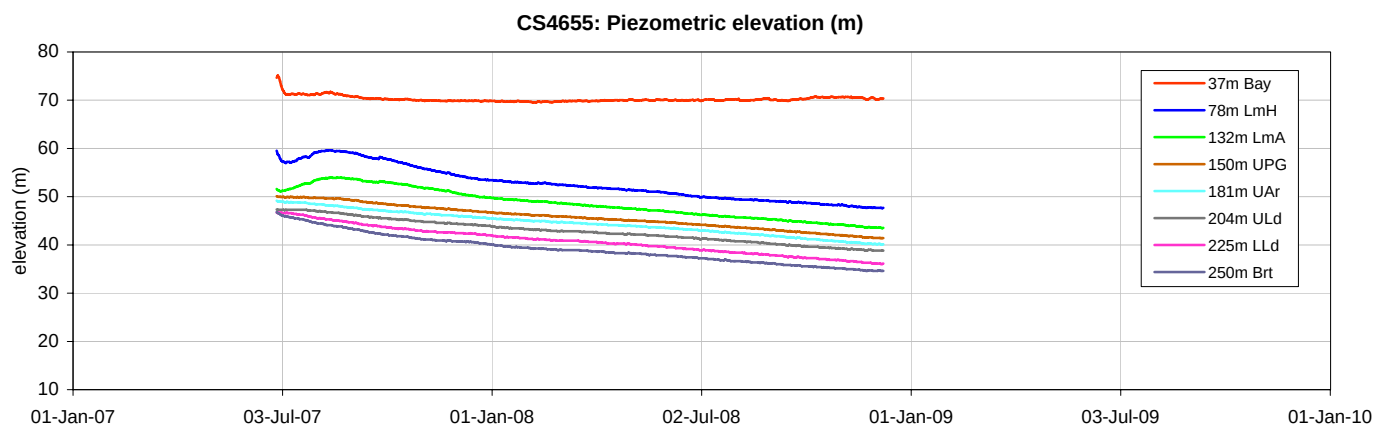
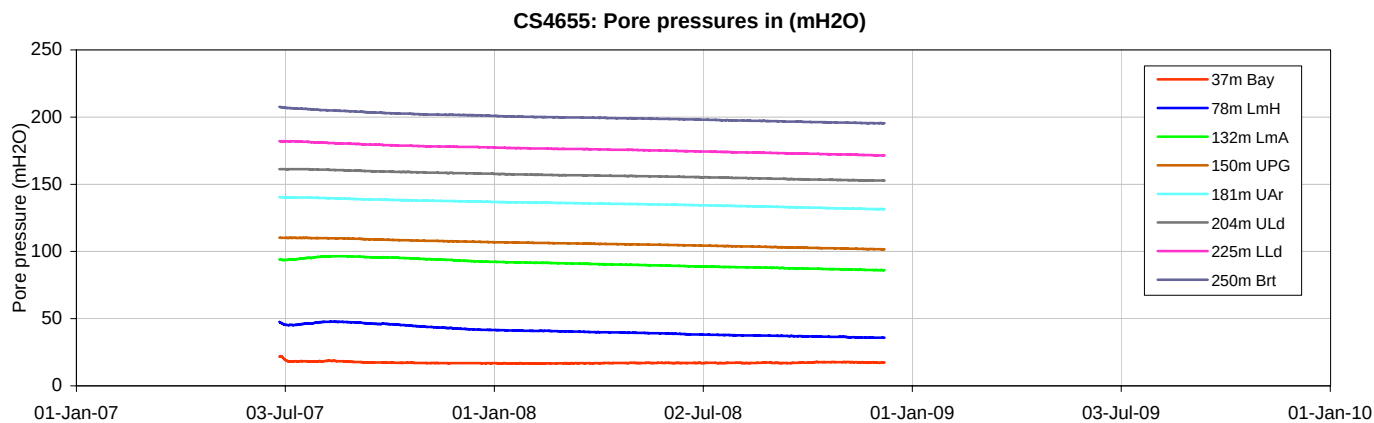
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- - - underground workings perimeter
- alluvium
- piezometer

RAVENSWORTH UNDERGROUND MINE MODIFICATIONS

Piezometer locations

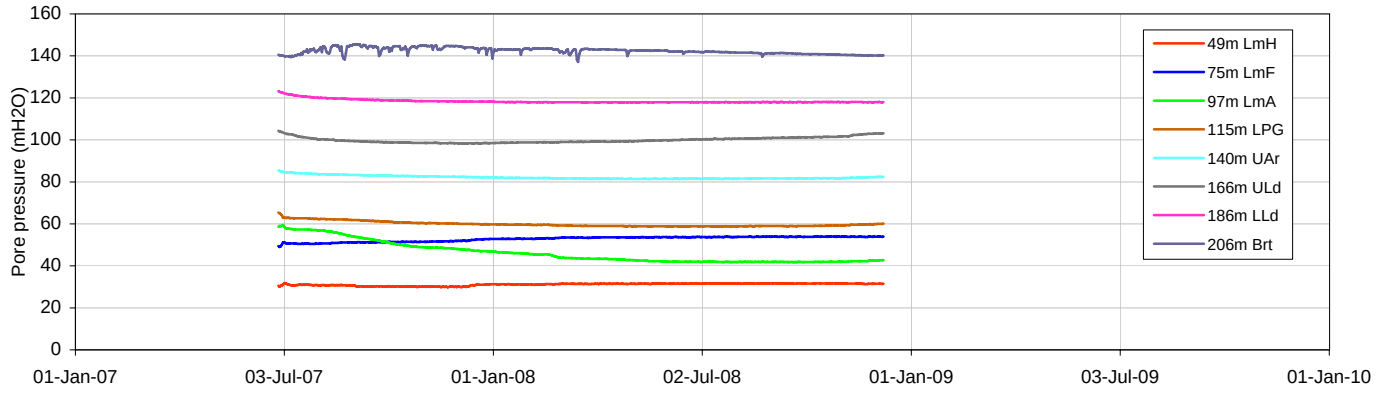


Pore pressures and piezometric elevations
Figure B2

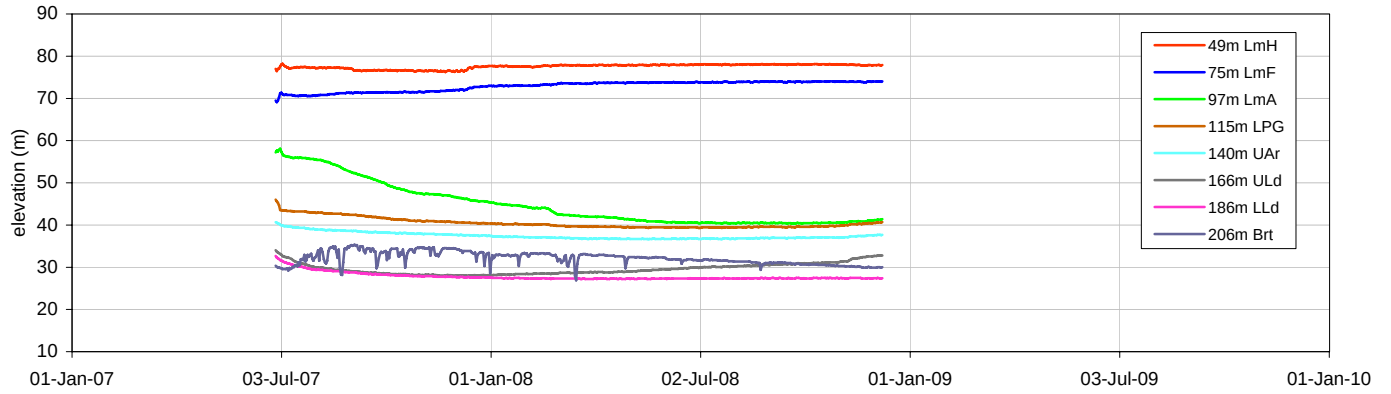


Pore pressures and piezometric elevations
Figure 3a

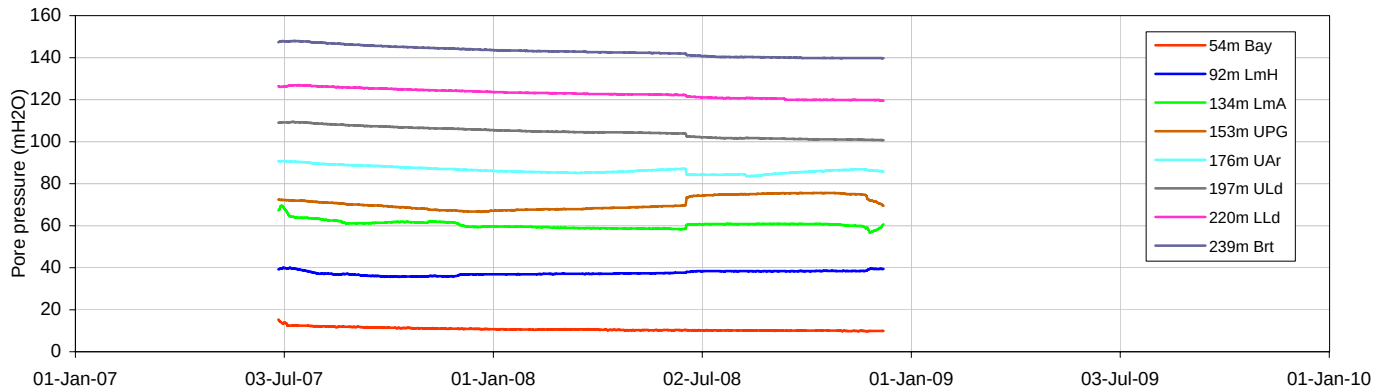
CS4657: Pore pressures in (mH2O)



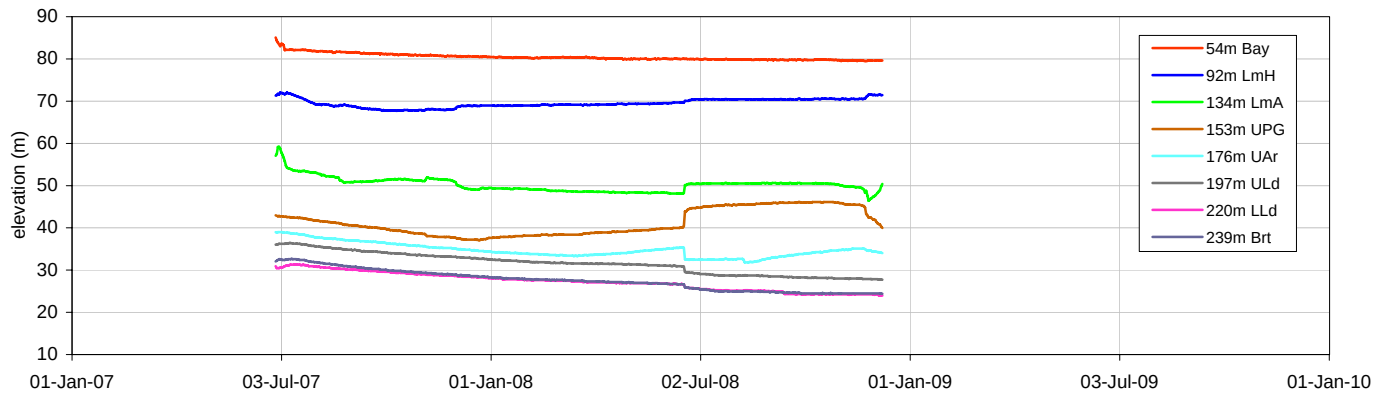
CS4657: Piezometric elevation (m)

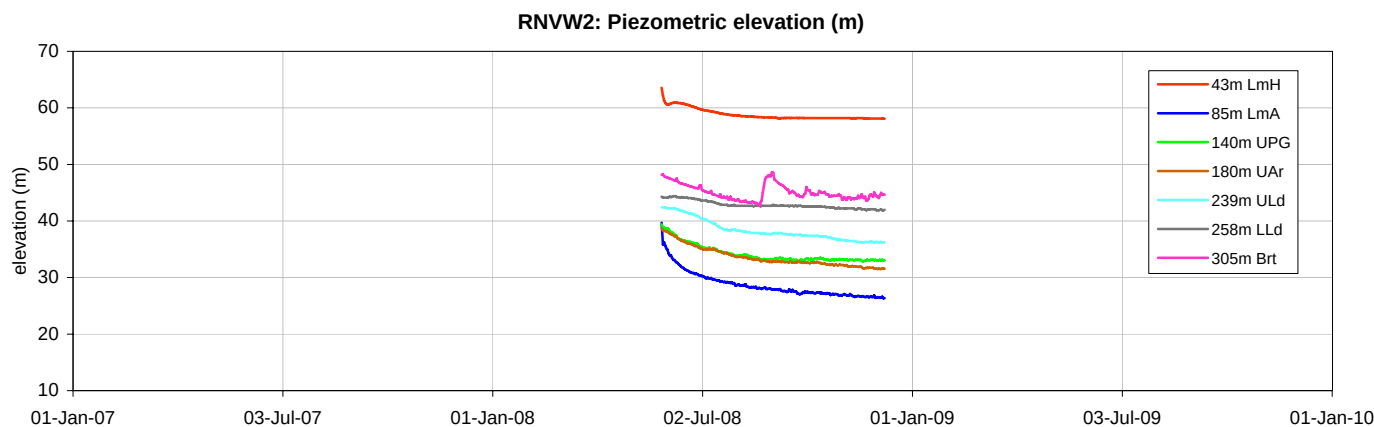
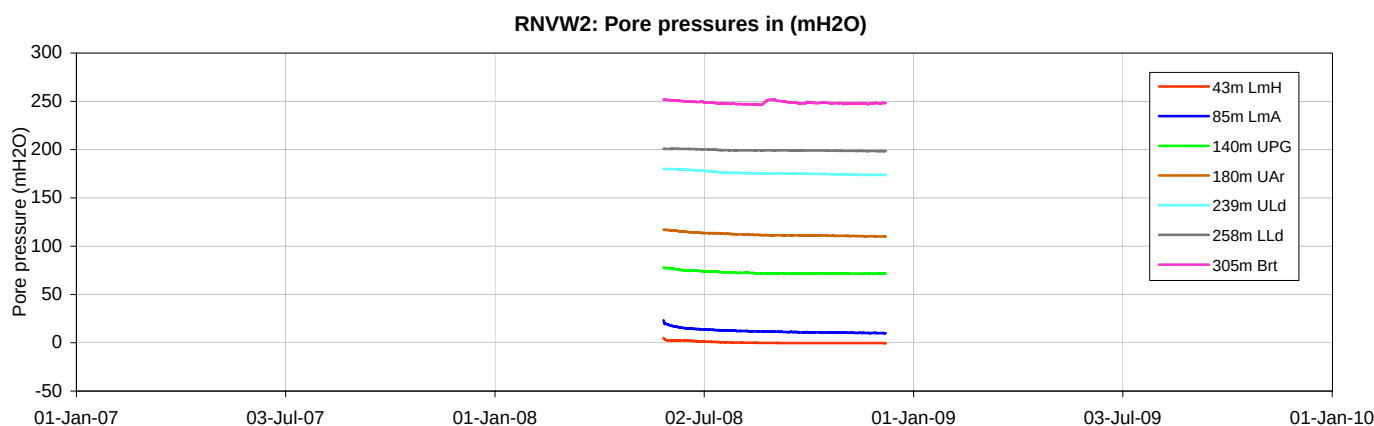
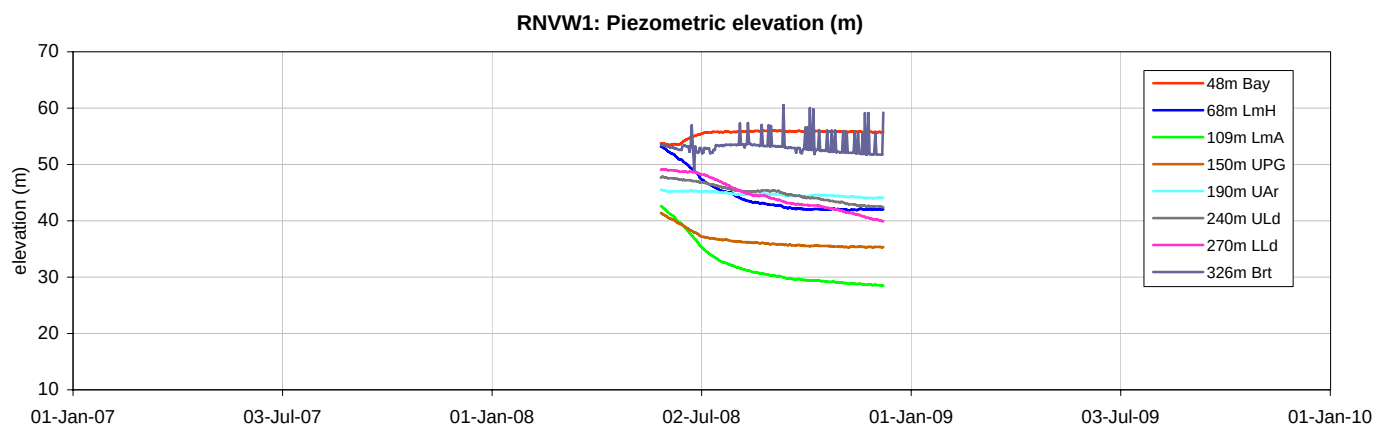
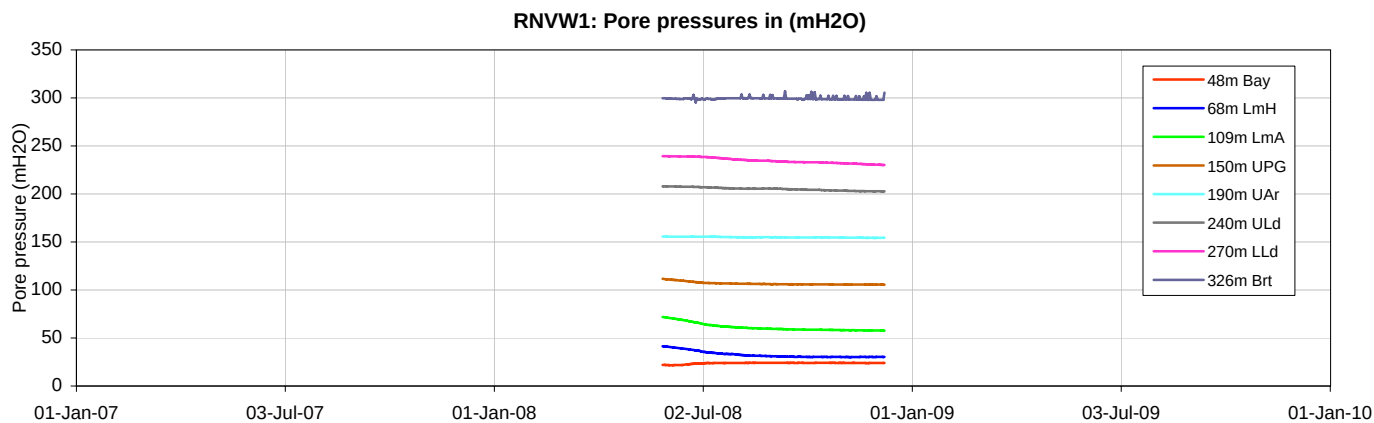


CS4658: Pore pressures in (mH2O)

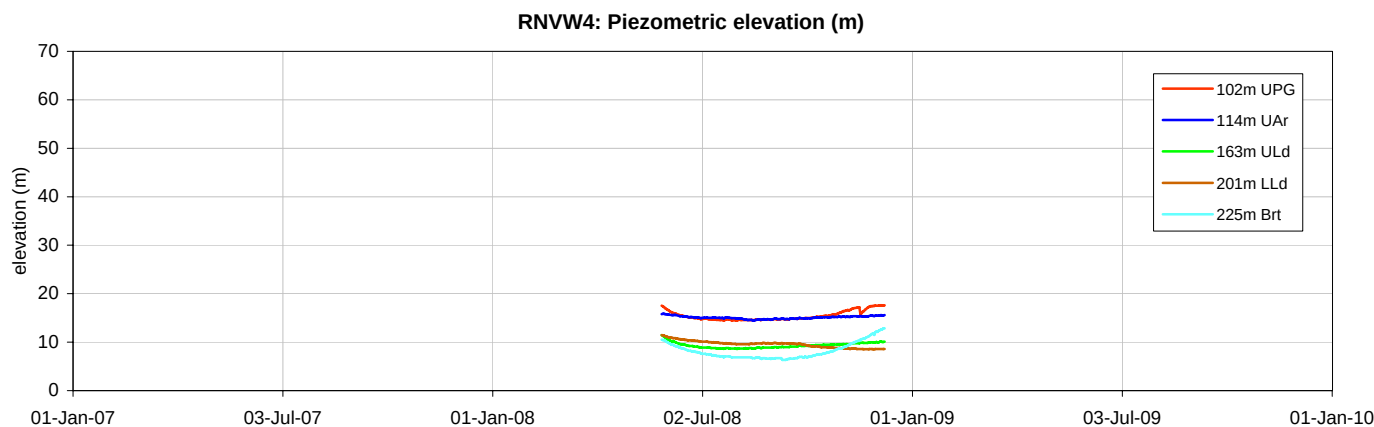
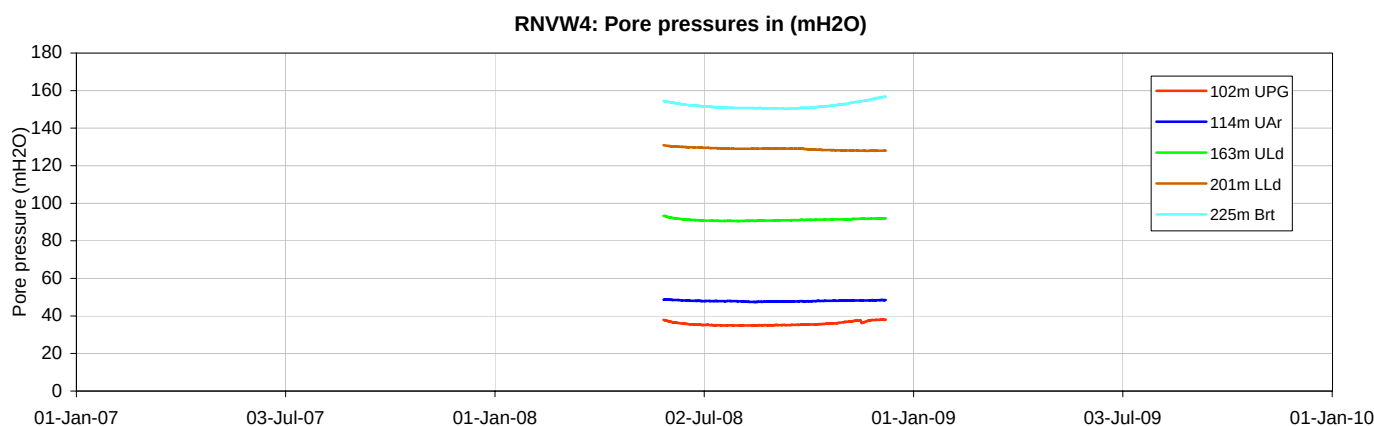
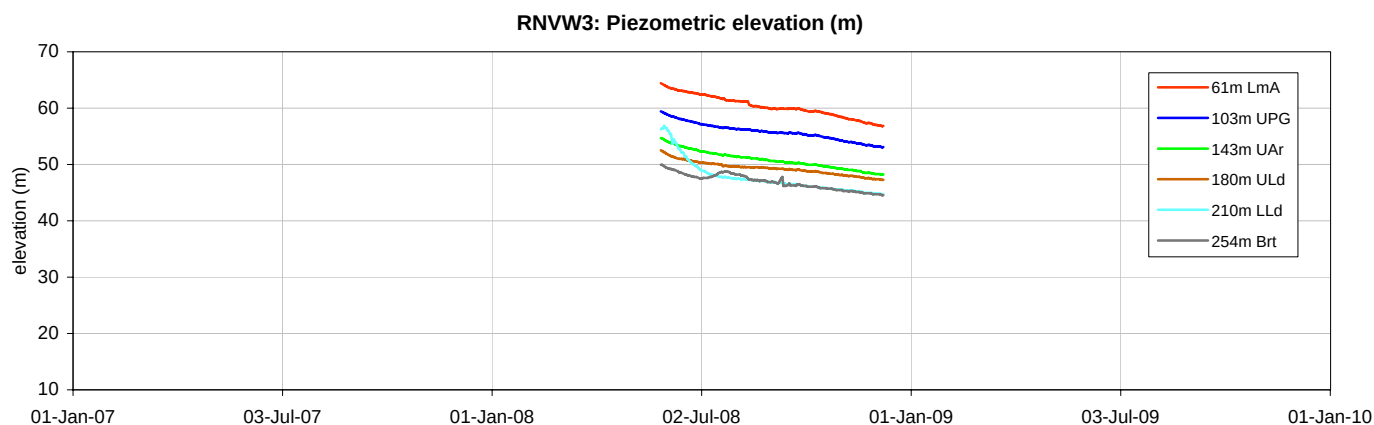
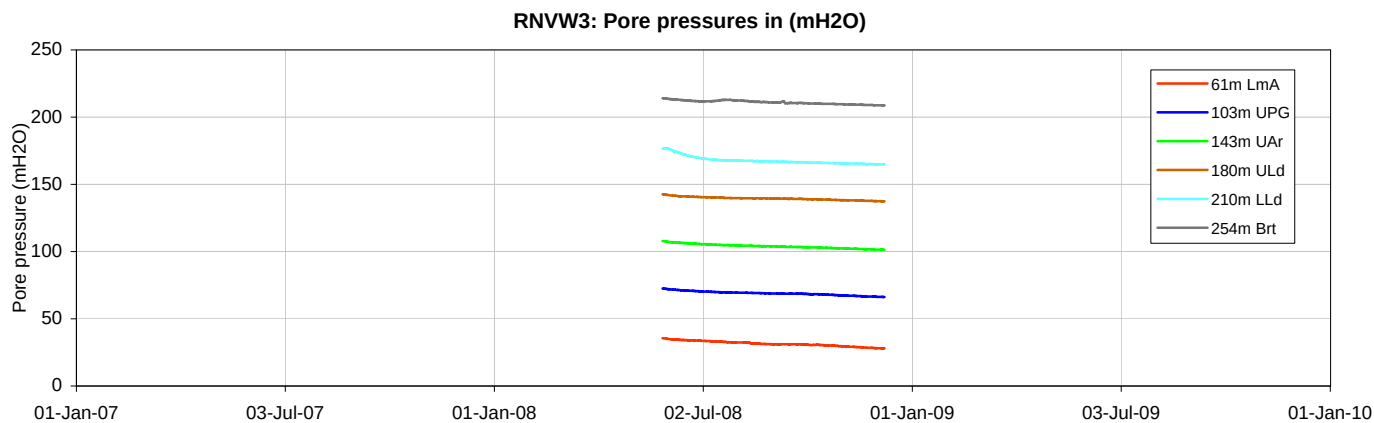


CS4658: Piezometric elevation (m)

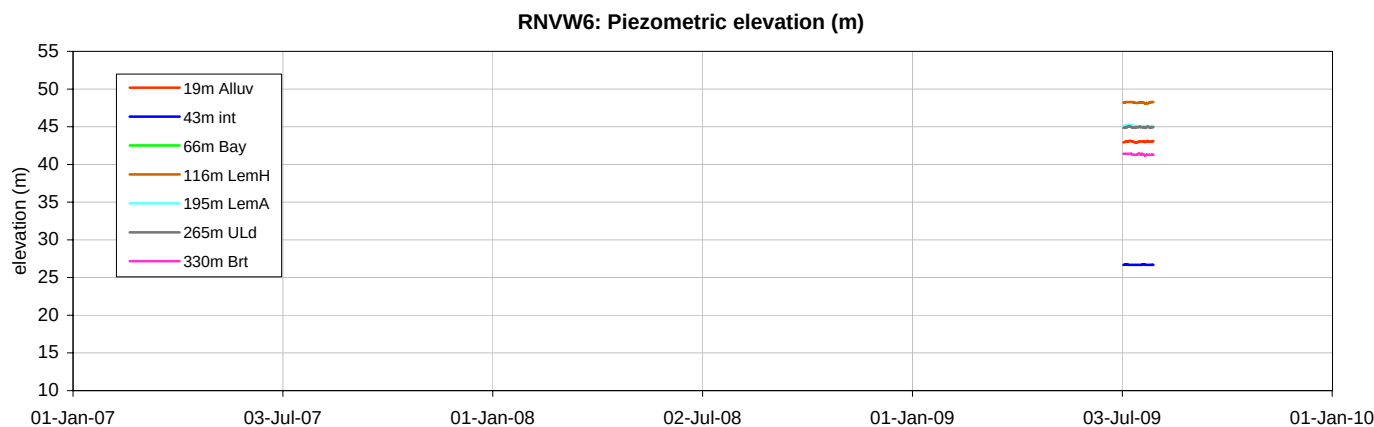
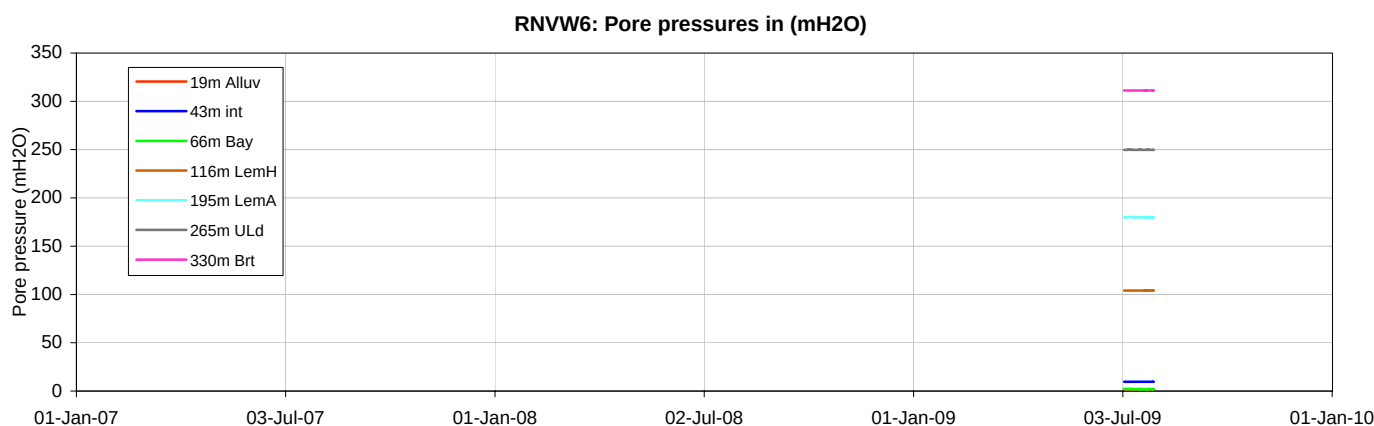
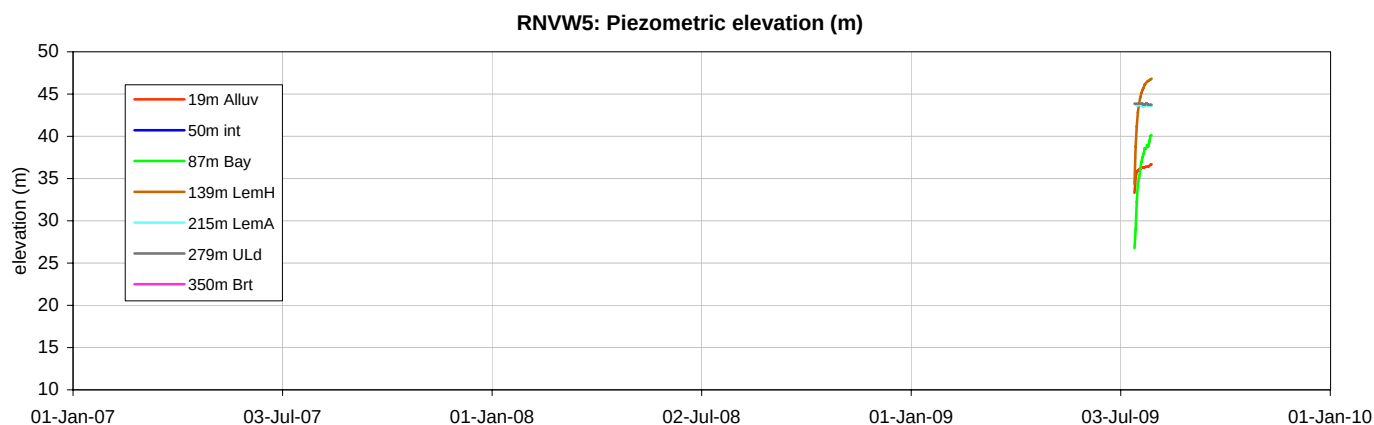
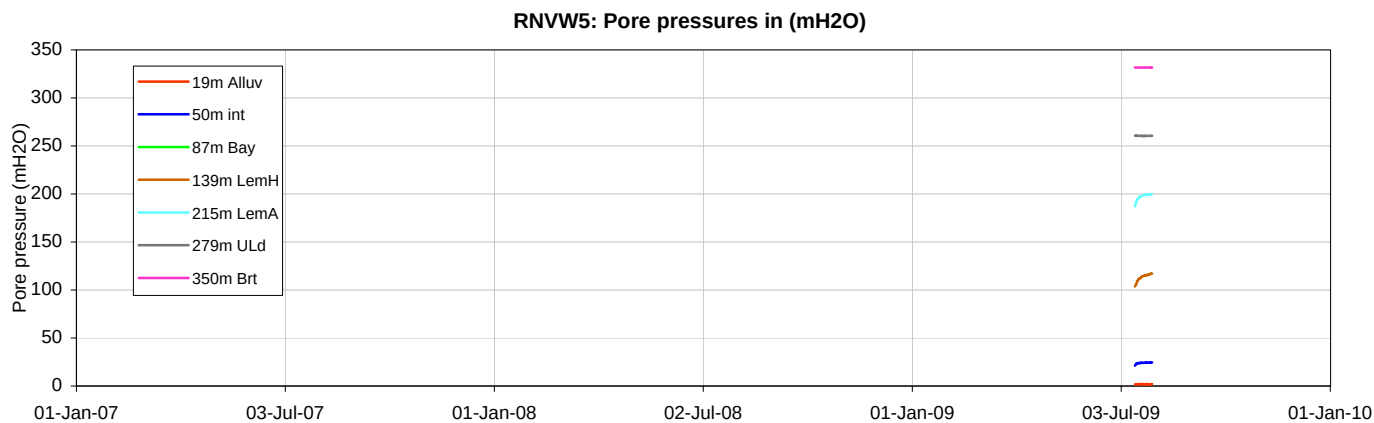




Pore pressures and piezometric elevations
Figure 3c



Pore pressures and piezometric elevations
Figure 3d



Pore pressures and piezometric elevations
Figure 3e

APPENDIX C: STRATA HYDRAULIC PROPERTIES

Aquifer testing provides a means of estimating the groundwater transmission and storage characteristics of the coal measures and shallow alluvium. Various procedures can be employed depending upon the saturated aquifer thickness, regional extent, transmission properties and bore completions. Procedures in the Ravensworth North pit area and surrounding project area have included airlift measurements in exploration holes, packer testing of coal seams and other selected strata, and laboratory core testing of interburden (see Figure C1 for locations).

C1.1 Air lift measurements

MER (1997) reports airlift measurements at numerous bore locations conducted as part of exploration drilling for the Ravensworth West pit. These tests provide a first approximation to the hydraulic conductivity of strata and are generally biased towards the coal seams or to joint and fracture enhancement of permeability since the interburden (sandstones, siltstones etc.) exhibit very low hydraulic conductivities – see Section C1.3 below. Table C1 provides a summary and suggests seam conductivities are in the range 1.0E-04 to 1.0E-01 m/day.

C1.2 Packer testing

Mackie (2009) gives a useful summary of historical packer testing conducted in the region. Table C2 provides a summary of values which support low values for interburden and an expected range of 1.0E-03 to more 4.0E-01 m/day for coal seams. Testing at Cumnock indicates the Barrett seam to be the least permeable while the Lower Pikes Gully and Liddell seams are more permeable. Testing to the east in the Glendell area indicates mixed results.

C1.3 Interburden core tests

Laboratory core testing provides a means of determining the hydraulic conductivity of materials at an intergranular scale consistent with porous media (Darcian) flow. This estimate is typically the lowest conductivity for a specific rock type and is most representative of strata where fracturing and jointing are absent, or where fractures and joints are present but relatively disconnected and unlikely to enhance the bulk permeability of strata.

Core has been previously examined and tested by MER (1997, 2003) at borehole locations identified as RW1536C, RW1540C, RW1543C, RW1547C and EL5423 just west of the project area (see Figure C1). MER (2002) reports similar tests on core extracted in the Mt. Owen area at location MOD662. That data has been included in the current assessments. In addition, core from borehole locations RNVW5 and RNVW6 drilled as part of the current study, was inspected and representative samples taken from sections displaying relatively uniform properties in respect of rock type, grain size and cementation. These samples comprised sandstones, siltstones claystones and shales. The sample locations were specifically chosen to facilitate longer term calculation of potential leakage fluxes from the Hunter River.

All recent core samples were tested by Core Laboratories Australia at a confining pressure of 5.5 Mpa. The test method employed helium gas as the test ‘fluid’ and generated an estimate of Klinkenberg permeability (K_{inf}). Conversion has provided a measure of the saturated hydraulic conductivity at 20°C. Results are summarised in the following Table C3 together with a summary of similar earlier testing in the region. The very low hydraulic conductivities are consistent with results of similar tests conducted at numerous locations throughout the Upper Hunter region.

All data has been used to generate the histograms shown in Figure C2 which are based on results sorted by lithology. A ratio of anisotropy (K_{xy}/K_z) of 2 has been used in order to generate both K_{xy} and K_z estimates.

Table C1: Hydraulic conductivity estimates from air lift tests

Bore	Q	Drawdown	Kd	K
	L/sec	m	kL/day/m	m/day
RW1501	0.28	46.5	6.3E-01	1.4E-02
RW1502	0.32	35.5	9.5E-01	2.7E-02
RW1503	0.08	31	2.7E-01	8.8E-03
RW1504	0.37	36	1.1E+00	3.0E-02
RW1505	0.37	35.5	1.1E+00	3.1E-02
RW1506	0.22	15.5	1.5E+00	9.7E-02
RW1508	0.04	19.5	2.2E-01	1.1E-02
RW1510	0.14	27.5	5.4E-01	2.0E-02
RW1511	0.04	9	4.7E-01	5.2E-02
RW1513	0.45	24	2.0E+00	8.2E-02
RW1516	0.18	23.5	8.1E-01	3.4E-02
RW1517	0.22	58	4.0E-01	6.9E-03
RW1518	0.45	45	1.1E+00	2.3E-02
RW1519	0.32	35	9.6E-01	2.8E-02
RW1522	0.45	84	5.6E-01	6.7E-03
RW1523	0.08	64	1.3E-01	2.1E-03
RW1525	0.22	65	3.6E-01	5.5E-03
RW1527	0.08	57	1.5E-01	2.6E-03
RW1528	0.02	55	3.8E-02	7.0E-04
RW1530	0.08	80	1.1E-01	1.3E-03
RW1531	1.82	87	2.2E+00	2.5E-02
RW1532	0.24	88	2.9E-01	3.3E-03
RW1533	0.14	91	1.6E-01	1.8E-03
RW1534	0.57	78	7.7E-01	9.9E-03
PC7505	0.04	27	1.6E-01	5.8E-03
PC7506	0.04	12.5	3.4E-01	2.7E-02
PC7507	0.22	20	1.2E+00	5.8E-02
PC7508	0.14	20.5	7.2E-01	3.5E-02
PC7509	0.09	25	3.8E-01	1.5E-02
PC7510	0.22	23	1.0E+00	4.4E-02
PC7513	0.05	31	1.7E-01	5.5E-03
PC7515	0.14	29	5.1E-01	1.8E-02
PC7516	0.14	31.5	4.7E-01	1.5E-02
PC7517	0.08	21	4.0E-01	1.9E-02
PC7518	0.06	19	3.3E-01	1.8E-02
PC7519	0.1	34	3.1E-01	9.1E-03
PC7531	0.2	13.5	1.6E+00	1.2E-01

Table C2: Hydraulic conductivity estimates from packer tests

Bore	Area	Test interval (m)	Lithology	Avg. Kxy (m/day)
DU50	Glendell	133.8 – 140.3	Barrett seam	5.1E-02
DU51	Glendell	70.0 – 76.5	Barrett seam	2.2E-02
DU61	Glendell	13.6 – 17.0	Barrett seam	7.5E-03
		22.7 – 29.2	interburden	2.0E-04
		38 – 41.4	Lemington C seam	9.3E-02
		44.3 – 47.8	Lemington B seam	7.1E-03
		62.9 – 75.7	Lemington A seam	1.0E-03
		91.3 – 97.8	Pikes Gully seam	4.3E-03
		124.2 – 127.6	Arties seam	2.6E-03
		147.1 – 150.5	Upper Liddell seam	1.6E-02
		160.2 – 166.7	Middle Liddell seam	1.0E-03
		174.3 – 177.7	Lower Liddell seam	2.2E-03
		187.1 – 190.5	Lower Liddell seam	1.2E-02
DU64	Glendell	167 – 170.3	Barrett seam	5.5E-03
DU76	Glendell	41.0 – 48.3	Lemington seam	2.1E-03
		65.6 – 69	Pikes Gully seam	1.4E-03
		105.9 – 109.3	Liddell seam	1.0E-02
		124.6 – 130	Liddell seam	1.3E-02
		141.4 – 144.8	Liddell seam	3.8E-01
		147.4 – 153.9	interburden	4.0E-04
		154.1 – 157.6	Liddell seam	2.4E-02
		157.9 – 164.4	interburden	1.0E-04
		170.5 – 173.9	Barrett seam	1.9E-02
		176.7 – 183.2	Barrett seam	4.4E-02
		181.2 – 187.7	Interburden	2.3E-03
		188.1 – 191.1	Hebden seam	9.0E-04
DU83	Glendell	172.2 – 178.7	Barrett seam	1.6E-03
DU85	Glendell	43.0 – 46.4	Pikes Gully seam	8.9E-02
		59.3 – 65.8	interburden	4.0E-04
		80.3 – 86.8	Arties seam	4.9E-02
		96.9 – 103.4	interburden	4.0E-04
		103.4 – 109.9	Liddell seam	7.4E-03
		113.4 – 116.8	interburden	1.0E-05
		117.8 – 124.3	Liddell seam	2.0E-03
		133.8 – 137.2	interburden	7.1E-03
		107.8 – 111.2	Barrett seam	5.0E-03
CS4511C	Cumnock U/G	160.5 – 166	Lower Pikes Gully seam	6.8E-02
		202 – 208	Upper Liddell seam	2.8E-02
		249.8 – 259	Barrett	4.0E-03
CS4512C	Cumnock U/G	97.8 – 103.2	Lower Pikes Gully	1.3E-01
		136.1 – 142.2	Upper Liddell seam	1.8E-01
		184.6 – 195.2	Barrett seam	8.0E-03
CS4513C	Cumnock U/G	100.8 – 109.3	Lower Pikes Gully seam	1.6E-02
		142.7 – 147.9	Upper Liddell seam	2.4E-02
		184.8 – 195.3	Barrett seam	1.5E-03

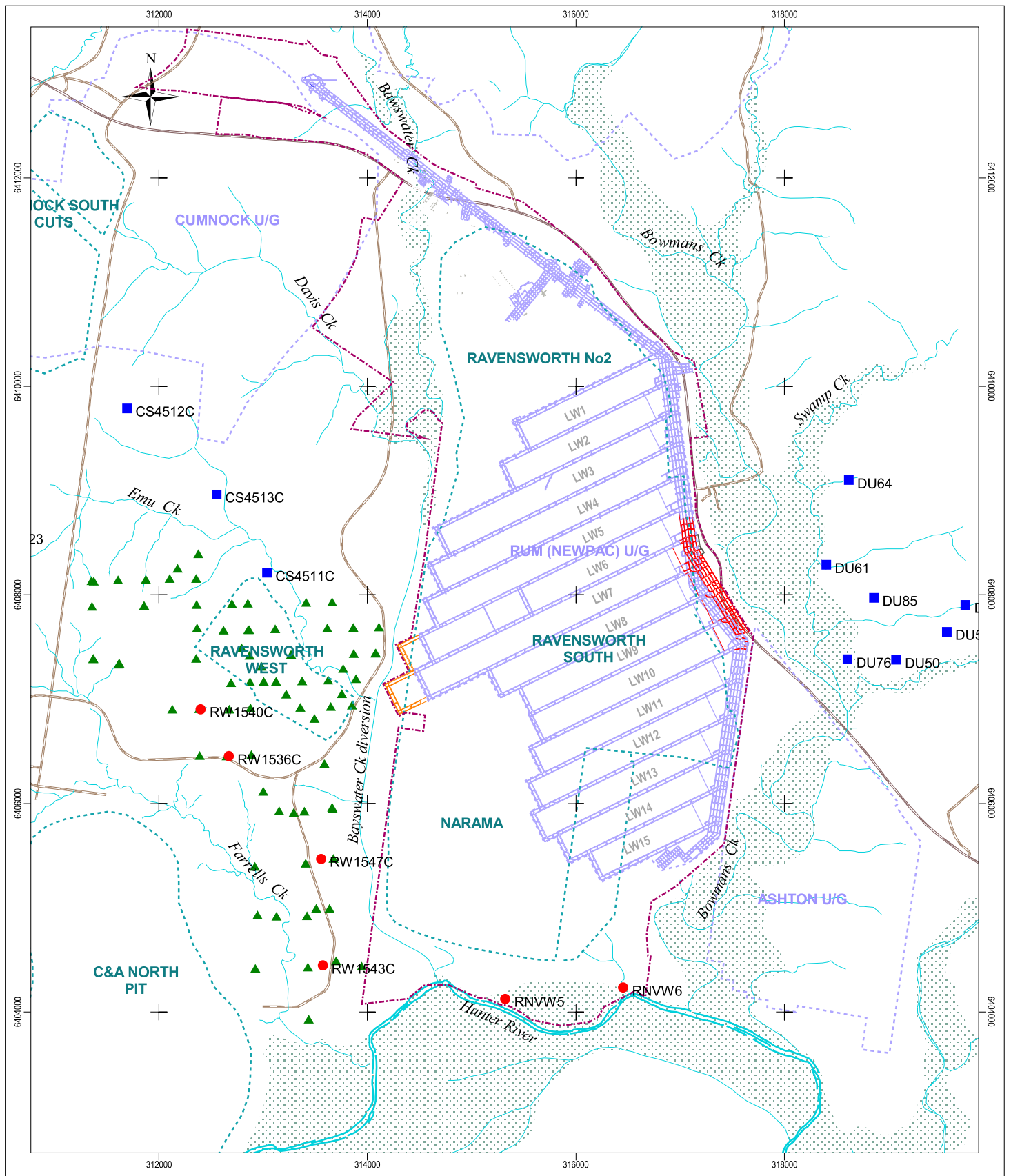
Table C3: Hydraulic conductivity estimates for interburden from core tests

Bore ID	Depth m	Description	Stratigraphic location	Kxy (m/day)	Kz (m/day)
EL5243	13.8	sandstone, fine grained with siltstone bands	between Lemington seams	7.67E-06	6.60E-06
	33.3	sandstone, fine grained with siltstone bands	between Lemington seams	4.92E-06	
	47.6	sandstone, fine grained with siltstone bands	between Lemington seams		2.16E-06
	66.3	sandstone, fine grained	between Pikes Gully seams	1.00E-05	2.57E-06
	77	siltstone with finer silty bands	below Pikes Gully seams		2.03E-06
	86	sandstone, medium to fine grained	above Arties seam		1.20E-05
	101.4	sandstone with silty bands	between Arties seam	1.05E-05	3.74E-06
	115	siltstone, laminated	below Arties seam		8.00E-07
	117.5	sandstone, siltstone interbedded	below Arties seam		1.18E-06
	126.4	sandstone, medium grained	above Liddell seam	4.60E-05	
1536C	145.6	sandstone, medium grained, carb. Lams.	between Liddell seam	2.80E-06	2.46E-06
	166.3	sandstone, medium grained, carb. Lams.	above Barrett seam	2.67E-06	
	178	sandstone, medium grained, carb. lams	below Barrett seam	1.66E-06	1.49E-06
	70.3	sandstone, medium grained	Archerfield sandstone	1.25E-05	1.99E-05
	52.3	siltstone	between Broonie seams	2.49E-06	
1540C	56.5	sandstone, medium grained	between Broonie seams	2.32E-05	1.08E-05
	51.6	sandstone, medium grained	between Broonie seams	3.82E-05	2.82E-05
	97.5	siltstone	above Bayswater seam		8.30E-07
1543C	60.9	sandstone, with siltstone bands	between Broonie seams	8.30E-07	8.30E-07
	90.5	sandstone, medium to fine grained	between Broonie seams		5.93E-06
	91	sandstone, medium grained	between Broonie seams	1.25E-05	7.47E-06
1547C	63	sandstone, medium grained	between Broonie seams		1.58E-05
	59	sandstone, medium grained	between Broonie seams		5.06E-05
	84.1	sandstone, coarse grained	between Broonie seams	1.29E-04	1.11E-04
	88.9	sandstone, medium grained	Archerfield sandstone	8.30E-06	
C87	45	sandstone, medium to fine grained	between Broonie seams	4.76E-04	4.10E-05
F81	34.9	sandstone, with silty bands	above Broonie seam	4.19E-06	3.46E-06
J87	52	sandstone, medium grained	between Broonie seams	4.57E-05	3.02E-05

Bore ID		Depth m	Description	Stratigraphic location	Kxy (m/day)	Kz (m/day)
		62.5	sandstone, medium grained	between Broonie seams	3.15E-04	2.04E-04
ZM81	Carrington O/C	51	sandstone, medium grained	above Bayswater seam		2.13E-05
ZM84	Carrington O/C	33.2	sandstone, medium grained weathered	between Broonie seams	8.07E-03	2.32E-03
		35.8	sandstone, medium grained weathered	between Broonie seams	6.77E-03	2.37E-03
ZW81	Carrington O/C	63	sandstone, medium grained	above Bayswater seam	4.60E-04	5.08E-04
MOD662	Mt Owen	28	sandstone, medium grained quartzitic, carb fleks	between Lemington seams	4.23E-06	1.68E-05
		68	sandstone, medium to fine grained, carb. Fleks	between Lemington seams		3.75E-06
		87	sandstone, medium grained, carb. fleks	between Lemington seams	3.85E-06	
		153.1	sandstone/siltstone interbedded	below Pikes Gully seam	1.27E-06	5.64E-06
		155.3	siltstone with shaley bands	below Pikes Gully seam		6.05E-07
		174.1	sandstone, medium grained	below Pikes Gully seam	1.35E-05	
		203	siltstone/sandstone, fine grained interbedded	above Artes seam	3.40E-07	3.29E-07
		248.2	sandstone, medium grained	between Middle Liddell seams	5.24E-07	
		269	siltstone, fine grained siltstone interbedded	between Middle & Lower Liddell		2.66E-06
		277.9	sandstone, fine grained	between Middle & Lower Liddell	5.97E-07	
		292	siltstone, laminated fine grained	above Barrett seam	5.27E-07	3.77E-07
		324.7	sandstone, medium fine grained	above Upper Hebden seam	4.50E-07	4.02E-07
		351	sandstone, coarse grained	below Upper Hebden seam	2.04E-07	
ID1001	Mt Arthur Nth	77.1	sandstone, coarse to medium grained	below Broonie seam		1.08E-04
		131.7	sandstone, medium grained	above Bengalla seam		5.89E-05
ID1033	Mt Arthur Nth	122.3	sandstone, medium fine grained	below Bengalla seam		1.03E-05
		158	sandstone, fine grained, carb. fleks	between Edenglassie and Ramrod Ck		8.30E-07
		177.1	sandstone, fine grained	below Ramrod Ck seam		8.30E-07
ID1037	Mt Arthur Nth	108.6	sandstone, fine grained	between Edenglassie and Ramrod Ck		1.53E-05
ID1044	Mt Arthur Nth	75.4	sandstone, medium fine grained	above Edenglassie seam		6.14E-05
		101.4	sandstone/siltstone, interbedded	between Edenglassie and Ramrod Ck		8.30E-07
ID1052	Mt Arthur Nth	115.1	sandstone, medium fine grained, carb fleks	below Broonie seam		7.80E-06
		136.6	sandstone, medium grained	above Edderton		1.60E-06
		216.7	sandstone, fine grained, carb fleks	between Edenglassie and Ramrod Ck		8.30E-07
		243.5	sandstone, medium grained, carb fleks	between Ramrod Ck seams		1.24E-06

Bore ID		Depth m	Description	Stratigraphic location	Kxy (m/day)	Kz (m/day)
OD1047	Mt Arthur Sth U/G	280.8	sandstone/siltstone, ss is fine grained, well cemented	between Mt. Arthur and Piercefield seams		6.11E-07
		300.3	sandstone/siltstone, ss is fine grained, well cemented	between Piercefield and Vaux seams		7.25E-07
OD1052	Mt Arthur Sth U/G	267.5	sandstone, fine grained, well sorted	between Mt. Arthur and Piercefield seams	3.92E-07	3.49E-07
		291.3	sandstone, fine grained, well sorted	between Piercefield and Vaux seams		2.04E-07
		305.1	sandstone/siltstone, finely laminated, ss is fine grained	between Piercefield and Vaux seams		2.90E-07
OD1053	Mt Arthur Sth U/G	257.5	sandstone, grey to white, medium grained, well sorted	between Mt. Arthur and Piercefield seams		2.80E-07
		285.3	sandstone, grey to white, fine grained, well sorted	between Piercefield and Vaux seams		3.01E-07
OD1074	Mt Arthur Sth U/G	292.1	sandstone/siltstone - finely laminated, ss is fine gr., cream	between Mt. Arthur and Piercefield seams		3.39E-07
OD1080	Mt Arthur Sth U/G	120	sandstone - white to grey, very coarse to coarse gr.(congl.)	between Warkworth and Mt. Arthur seams		1.52E-02
RNVW5	Ravensworth Ops	20.3	siltstone, grey finely laminated, with carb shale	above Vaux 3 seam		8.25E-07
		21.2	sandstone, white, medium grained, well cemented, lithic, part qz	above Vaux 3 seam		1.24E-06
		22.4	siltstone, grey finely laminated, with carb shale	above Vaux 3 seam		1.33E-07
		23.6	sandstone, white, medium grained, well cemented, lithic, part qz	above Vaux 3 seam	7.84E-07	5.55E-07
		29.5	siltstone, grey finely laminated, with carb shale	above Vaux 3 seam	9.22E-07	4.78E-07
		39.4	sandstone, white to cream, medium grained, well cemented	between Vaux V1 and Broonie RA1		3.85E-06
		44.2	sandstone (fine grained)-siltstone inter bedded, with finer lams	between Vaux V1 and Broonie RA2		4.04E-07
		46	sandstone, white to grey medium grained, well cemented, lithic	between Broonie RA1 and R1	2.05E-07	3.33E-07
		54.8	sandstone, grey medium grained, well cemented, lithic	between Broonie RA1 and R1		7.54E-07
		57.5	sandstone, grey medium grained, well cemented, lithic	between Broonie RA1 and R1		3.62E-07
		63.2	sandstone, grey, fine grained, well cemented quartzose	between Broonie RA1 and R1	4.61E-07	3.11E-07
		67	sandstone, grey, fine to medium grained with occasional pebbles to 2mm	between Broonie RA1 and R1		1.25E-07
		71.2	sandstone, grey, fine to medium grained with occasional pebbles to 2mm	between Broonie R1 and R2		1.54E-07
		75.4	sandstone (fine grained)-siltstone inter bedded, with finer lams	between Broonie R2 and R3		5.18E-07
		93.5	sandstone, grey, fine to medium grained with occasional pebbles to 3mm	between Bayswater and Lemington		1.15E-06
RNVW6	Ravensworth Ops	19.6	sandstone, white, fine to medium grained quartzose, well cemented	between Broonie RA1 and R1	1.23E-07	1.05E-07
		23.3	sandstone, white, fine to medium grained quartzose, well cemented	between Broonie RA1 and R1		1.92E-07
		25.9	sandstone (fine grained)-siltstone inter bedded, with finer lams	between Broonie RA1 and R1	4.48E-07	3.48E-07
		28.5	sandstone (fine grained)-siltstone inter bedded, with finer lams	between Broonie RA1 and R1		1.24E-07
		36.2	sandstone (fine grained)-siltstone inter bedded, with finer lams	between Broonie R2 and R3		1.77E-07
		38.3	sandstone (fine grained)-siltstone inter bedded, with finer lams	between Broonie R2 and R3	4.10E-07	3.46E-07

Bore ID	Depth m	Description	Stratigraphic location	Kxy (m/day)	Kz (m/day)
	42.8	sandstone, grey to white medium grained quartzose, well cemented	between Broonie R4 and Bayswater		1.56E-05
	46.2	conglomerate, white fine grained sandstone matrix, clasts to +10mm	between Broonie R4 and Bayswater		4.74E-06
	48.3	sandstone, white to cream, medium grained, well cemented	between Broonie R4 and Bayswater		2.25E-06
	55.1	conglomerate, white fine grained sandstone matrix, clasts to +10mm	between Broonie R4 and Bayswater		2.32E-06
	59.4	sandstone, white, medium grained, well cemented, lithic, part qz	between Broonie R4 and Bayswater	1.48E-04	3.85E-05
	61.5	sandstone, white to cream, medium grained, well cemented	between Broonie R4 and Bayswater	2.14E-06	1.59E-06
	73.1	sandstone, grey medium grained, well cemented, lithic	between Bayswater and Lemington		1.56E-06



0 1000 2000 3000 Meters

Scale 1:50000

- RUM project area
- open cut pit shell
- underground workings perimeter
- alluvium
- packer test
- ▲ airlift test
- core test

RAVENSWORTH UNDERGROUND MINE MODIFICATIONS
Hydraulic conductivity test locations

