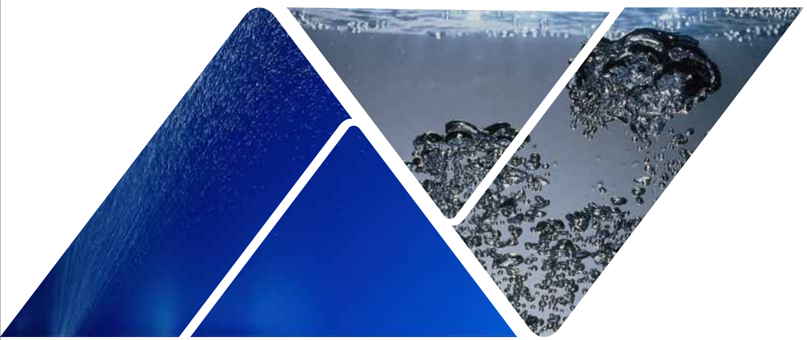
Groundwater Assessment



Appendix 8

CENTENNIAL HUNTER PTY LIMITED

ANVIL HILL PROJECT: GROUNDWATER MANAGEMENT STUDIES

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SUMMARY OF FINDINGS

Centennial Hunter Pty. Limited (Centennial) is seeking consent to undertake open cut mining operations in the Wybong area, NSW. Proposed mining provides for the extraction of up to 10.5 Million tonnes per annum (Mtpa) of ROM coal over a period of 21 years from 3 seams within the Newcastle (formerly known as Wollombi) Coal Measures. Mining will result in depressurisation of groundwater within the coal seams and the adjacent interburden as the pressure wave induced by pit deepening expands outwards. Overburden will be progressively emplaced in the pits as mining progresses and re-saturation in the long term will affect groundwater quality in final voids located in Main Pit and Southern Pit. Detailed groundwater management studies have been conducted for the proposed mining operations in order to address identified groundwater related issues. Findings are summarised.

The hardrock coal measures strata provide limited groundwater storage and transmission capacity. Interburden and overburden lithologies comprising conglomerates, tuffaceous and lithic sandstones, siltstones and shales are noted to possess very low intergranular hydraulic conductivities. Groundwater transmission characteristics are therefore most likely to be governed more by the occurrence and frequency of jointing than by intergranular flow. Water quality in the coal measures is saline with dissolved salts concentrations ranging from 554 to more than 8130 mg/L (853 to 12508 µS/cm).

Proposed mining would access 3 seams – the Great Northern, Fassifern and Upper Pilot seams in four mining areas. Northern Pit and Tailings pits in the east would be either above the regional water table or submerged below the water table in limited areas. Main Pit and Southern Pit in the west and south-west would progressively penetrate the water table in a westerly and down dip direction. This would initiate groundwater depressurisation within the coal seams initially, and subsequently within overlying conglomerates and other strata.

A computer based aquifer model of the region has been developed in order to understand the many complex groundwater flow processes that would evolve during mining. Within the limitations and constraints imposed by numerical modelling, simulation results demonstrate that mining would maintain inward draining hydraulic sinks around the mine pits for a distance of up to 500 m beyond the eastern pits, and distances of about 1.5 km to the west and north of Main Pit. Depressurisation of the rock strata may induce leakage from the alluvium associated with Big Flat Creek and Wybong Creek.

Total seepage entering the mine pits for average rainfall recharge conditions is predicted to rise from a rate of less than 0.5 ML/day during the first year of mining to a maximum rate of about 1.8 ML/day in mining year 10 declining thereafter to a rate of about 0.9 ML/day at the completion of mining in year 21. A sustained wet period may elevate these rates of seepage (through regolith contributions) by between 0.2 to 0.5 ML/day.

Anvil Creek alluvium would be progressively incised as Main Pit is developed in a westerly direction. Hydraulic testing of the alluvial materials supports low hydraulic conductivities consistent with observed silt and clay strata. Seepage contributions are therefore predicted to be low and manageable through the installation of dewatering slots to facilitate gravity drainage during stripping.

Big Flat Creek alluvium may be isolated from Anvil Creek alluvium (depending upon detailed exploration and testing) through the construction of a barrier cut off wall across Anvil Creek at the confluence of these two creeks. Such a wall would inhibit horizontal leakage of saline groundwaters associated with Big Flat Creek alluvium, into Main Pit. However vertical leakage may still occur in a downwards direction via underlying conglomerates and subcropping seams. The rate of this component of leakage is predicted to be low and of the order of 50 to 100 kL/day over an area of about 181 ha. This would be equivalent to a leakage rate of 0.027 to 0.054 L/day per square meter of alluvium in the potentially affected area. Since Big Flat Creek groundwaters are generally saline with no identifiable beneficial use, leakage impacts are considered to be acceptable.

Vertical leakage may also occur from alluvium associated with Wybong Creek. The maximum rate of leakage is also predicted to be low and of the order of 15 to 30 kL/day over an area of about 160 ha. This would be equivalent to a leakage rate of 0.009 to 0.019 L/day per square meter of alluvium within the potentially affected area and would be reduced to a negligible rate when water levels in the final voids equilibrate.

There are only two identified boreholes (GW066620 and GW078502) located within the coal measures that may be 'yield affected' within the predicted cone of depressurisation that would surround the mine pits. Bore GW066620 located a short distance to the north east of Main Pit is decommissioned while bore GW078502 is unequipped and encountered poor yield and poor water quality when constructed through both Wyong Creek alluvium and the underlying coal measures. Wells located within or close to Big Flat Creek alluvium and considered to be at risk include H1W and P2W. Yield at these locations may only be affected if leakage from the alluvium is significant and drought conditions prevail. Otherwise rainfall recharge is expected to maintain yield. Shallow regolith (weathered bedrock) seeps that are accessed by wells in areas north of Big Flat Creek are unlikely to be affected unless specific and as yet unidentified hydraulically transmissive structural features (eg. faults), provide direct conduits to strata within the proposed mine pit(s). In this event, two locations may be at risk – P1W and K1W. Wells and bores located within Wybong Creek alluvium to the west or Sandy Creek alluvium to the south-east, would not be impacted.

Groundwater quality within the coal measures and the alluvial lands would not be impaired by mining operations. Indeed it is possible that in some areas, the slow leakage of saline water from the strata and in particularly the alluvial lands, may lead to partial flushing and replacement by improved quality groundwater in the long term.

At the cessation of mining final voids would be designed as either open water voids in Main and Southern Pit, or partly filled and re-shaped voids supporting densely wooded areas with linkage to a re-instated Anvil Creek. For open void conditions, void water would accumulate from direct rainfall, runoff from areas surrounding the voids, rainfall infiltration through spoils, and groundwater seepage from coal measures strata. A period of more than 50 years would be required for equilibrated systems to re-establish in Main and Southern pits at average elevations of 135 mAHD and 150 mAHD respectively. These equilibrated levels are based on simulation of the recovery processes and represent levels where water influx under wide ranging climatic conditions, is balanced by evaporative losses from the void water surfaces.

Recovery of water levels would re-saturate spoils emplaced within the mine pits and this process is predicted to remobilise salts released by the fragmentation of interburden during mining. An estimate of the final void water quality has been calculated from a salt load estimate generated through leachate trials on interburden core. This load is estimated to range between 0.65 and 1.13 kg per cubic metre of saturated spoils. The lower limit of this range reflects a coarse fragmentation distribution while the upper limit reflects an increased fines content. Void groundwater salinity is calculated to fall in the range 3250 to 5650 mg/L.

Speciation analyses of leachate samples indicate the void groundwater will tend towards a sodium>magnesium>calcium cation distribution and a chloride>bicarbonate>sulphate anion distribution although bicarbonates may be dominant if ion exchange is a major mechanism as suggested by leachate trials. pH in the range 6.5 to 9.0 is predicted to prevail.

Acid forming characteristics of spoils have been examined and all samples (used in leachate trials) have been found to be non acid forming.

In order to update knowledge and understanding in respect of surface/groundwater interactions, an expanded groundwater and surface monitoring programme is recommended. Centennial has committed to maintaining existing groundwater monitoring bore locations and constructing a number of additional bores at new locations beyond the mine pit areas. Monitoring bores will also be constructed in spoils following reshaping to verify and validate water seepage and quality predictions. Monitoring data will be retained in existing databases and data transferred at appropriate reporting intervals to DNR.

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1. INTRODUCTION

Centennial Hunter Pty Limited (Centennial) is seeking consent to undertake mining operations in the Wybong area located in the upper Hunter region about 20 km west of Muswellbrook and 10 km north of Denman. Proposed mining provides for the extraction of up to 10.5 Million tonnes per annum (Mtpa) of ROM coal over a period of 21 years. Mining is planned to commence in several areas east of Anvil Hill and south of Wybong Road, advancing in both easterly and westerly directions for distances of two and three kilometres from the initial box cut(s). Anvil Hill will remain undisturbed.

Mining will extract coal from the Great Northern, Fassifern and Upper Pilot A (UPA) seams at relatively shallow depths when compared to many operations in the Upper Hunter region. Operations in the early years of mining will be above or close to the prevailing regional water table, progressing below the water table with gradual pit deepening in the down dip (westerly) direction. Overburden spoils will be emplaced in the pits as mining progresses.

Mine pit development below the water table will result in depressurisation of the exposed coal seams and interburdens. Such depressurisation may lead to changed groundwater flow directions within the coal measures and any connected aquifers including leakage from surface drainages. Re-saturation within the pits after mining has been completed, may alter the long term 'recovered' water table and the long term groundwater quality in mined areas.

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

- Description of the different aquifer systems including extent, inter-relationships and connectivity to surface water systems and dependent eco systems;
- Description of the potential interaction between hard rock aquifer systems and alluvial systems associated with Big Flat Creek and Anvil Creek that may be connected to Wybong Creek;
- Assessment of the regional groundwater elevations, flow directions, rates of flow and chemical signatures of the groundwaters;
- Details of proposed mine pits and any bore or other water supply works that may intercept the aquifer systems;
- 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 final landform.

Mackie Environmental Research Pty Ltd (MER) was commissioned by Umwelt (Australia) Pty. Limited (Umwelt) on behalf of Centennial in 2004 to undertake groundwater management studies for the Anvil Hill Project and to provide advice in respect of future measurement and monitoring of aquifer conditions. The contained report provides results of those studies and includes groundwater hydrological data for the region, and computer simulations of aquifer systems developed to assess the likely impacts for both mining and post mining scenarios.

3. REGIONAL SETTING

The Project Area is identified on Figure 1.

The physiography comprises undulating hills and grasslands in eastern parts of the region while in western parts, the countryside is interrupted by steep hills bounded by sandstone escarpments (eg. Anvil Hill) with numerous densely wooded areas.

Topographic elevations range from about 140 metres - Australia Height Datum (mAHD) at the confluence of Big Flat Creek and Wybong Creek, to 280 mAHD on Anvil Hill or higher on other hills in the vicinity - see Figures 1 and 2 for general location.

Nearest active mining is located some twelve km east of Anvil Hill where open cut operations at Bengalla Mine access older coal measures than those present within the Project Area.

3.1 Rainfall and evaporation

The climate is temperate and is influenced to some extent by coastal weather patterns. Rainfall averages about 590 mm per annum as measured at Denman which is the nearest long term rain gauging station. Rainfall statistics for Denman are provided in Appendix A - average rainfalls are highest in summer months.

A number of periods during the last decade have witnessed below average annual rainfalls with moderately dry years occurring from 1994 to 1997 and exceptionally dry conditions occurring from 2002 to 2005. The pattern of rainfall during these years has not been conducive to groundwater recharge and has resulted in regional water table declines.

The nearest long term gauging station for evaporation is located at Scone located about 30 km to the north-east where an average of about 1600 mm per annum has been recorded. A review of the historical data indicates evaporation exceeds rainfall for all months of the year, the smallest difference occurring in June where average rainfall (40.3 mm) is similar to average evaporation (48 mm). Hence there is increased potential for recharge during winter months. However this generally depends on the sequence of rainfall events.

3.2 Drainage and groundwater recharge

The Project Area is traversed by four significant creeks - Anvil Creek which flows into Big Flat Creek which then flows into Wybong Creek in the western part of the Project Area (see Figure 2), and Sandy Creek which flows into the Hunter River south of the Project Area. Anvil and Big Flat creek systems are ephemeral and have numerous un-named and often poorly defined tributaries.

Anvil Creek, Big Flat Creek and Wybong Creek fall within the Wybong Creek Water Sharing Plan (WCWSP) as prescribed within the Water Management Act 2000. The plan was invoked in July 2003.

During periods of high rainfall, creek runoff can be exceptionally high with local flooding occurring for short periods, especially around the lower parts of Big Flat Creek catchment near the confluence with Anvil Creek (and Clarks Gully).

Rainfall infiltration and recharge to the alluvium associated with these drainages is expected to be highly variable since the alluvium is often clayey with poor transmission characteristics - perched water tables within the alluvium have been observed. Rainfall infiltration to other shallow groundwater systems including the weathered rock zone or regolith is also expected to be variable. Conglomeritic areas (see below) tend to weather to a mixed gravelly, sandy, silty regolith where the silty zones are likely to exhibit poor transmission characteristics, but the sandy and gravelly areas offer potential for groundwater recharge. The regolith acts as a temporary water store during sustained wet periods and provides a source for recharge to the underlying less permeable coal measures. This differentiation in properties can sometimes result in the presence of springs which are noted in some parts of the area.

3.3 Geology

Regional geology is summarised on the published 1:100,000 Hunter Coalfield Regional Geology Map 1993 (Dept. Mineral Resources) and described by Beckett (1988). Fundamentally the geology in the region comprises Permian age Wollombi Coal Measures with overlying younger Triassic age Narrabeen Group sandstones clearly identifiable as the rocky escarpments (eg. Anvil Hill). In addition to these 'hardrock' strata, drainage channels host much younger Quaternary to Recent unconsolidated alluvial materials.

The Wollombi Coal Measures are located in the upper (younger) part of the Permian (250 million years ago). Exploration at Anvil Hill has demonstrated the close similarity of the Wollombi and Newcastle Coal Measures. This consistency has recently been formally recognised, and Newcastle Coal Measures terminology has now replaced the Wollombi Coal Measures in the Hunter Valley. Centennial has adopted terminology for the latter. Hence the Wollombi Coal Measures are hereinafter referred to as the Newcastle Coal Measures.

Immediately east of the area, the sub cropping Newcastle Coal Measures terminate abruptly against the north-south trending Mt. Ogilvie Fault system which defines a vertical displacement of more than 200 m. Jerrys Plains Subgroup strata belonging to the older Wittingham Coal Measures, are exposed to the east of the fault(s). Figure 3 provides a summary of the stratigraphic succession for the Permian coal measures.

The Newcastle Coal Measures were deposited under conditions ranging from upper deltaic to a progressively drier terrestrial environment. These depositional environments have resulted in an overburden stratigraphy in the Anvil Hill area comprising well cemented conglomerates and conglomeritic sandstones with relatively low to negligible intergranular hydraulic conductivity (permeability) and variable salt content.

The Anvil Hill area was recognised as offering significant potential for resource development by Powercoal Pty. Limited (Powercoal) during the period 1999 to 2002 when numerous exploration holes were drilled. Subsequent exploration by Centennial following acquisition of Powercoal, confirmed coal resource extent and significance with more than 290 cored or open holes being drilled by late 2005. The extensive drilling undertaken to-date together with aeromagnetic survey methods employed to assist in delineating the locations of faults, dykes and sills, has resulted in a reasonably detailed understanding of the local geology.

Centennial proposes to mine coal resources of the Great Northern, Fassifern and Upper Pilot A seams which subcrop at relatively shallow depths in the eastern parts of the Project Area and dip gently to the west. Seam descriptions are as follows:

> ***The Great Northern seam*** is typically about 3 m thick but thins in the south of the proposed open cut area and is deteriorated in the far north-east part of the area. The seam is mostly dull with little or no cleating (J. Brunton pers.comm.). The seam overlies the Awaba Tuff which typically ranges in thickness from 3 to 4 m and thickens to more than 10 m in the south-east of the area.
>
> ***The Fassifern seam*** underlies the Awaba Tuff, is typically about 6 m thick and is characterised by numerous consistent tuffaceous bands. Plies in the upper section of the seam are comprised of high ash, dull coal (occasional bright bands) with little or no cleating. In contrast the middle and lower sections are lower in ash and are mainly interbanded dull and bright coals. Cleating remains infrequent. A siltstone/sandstone split up to 20 m thick develops between the upper and lower sections of the seam in the south of the area.

The Upper Pilot A (UPA) seam is separated from the overlying Fassifern seam by a thin sequence of interbedded carbonaceous mudstones and tuffaceous claystone-siltstone bands usually about 1.7 m thick. The seam is typically 1 m thick and is characterised by a high ash, dull coal upper section grading downwards into lower ash, brighter (interbanded dull and bright) coal. The brighter sections display some cleating. However the seam is generally regarded as weakly cleated.

Figure 4 gives a consolidated geological section for the region with general descriptors. Figures 5 and 6 provide east-west and north-south sections at the locations marked on Figure 2. Reference to these figures shows the extent of the shallow conglomerates which thicken steadily in westward direction, and the relative thickness of the tuffaceous sandstone interburden (Awaba Tuff) between the Great Northern and Fassifern seams.

3.3.1 Structural features

Faulting is both frequent and complex across the region. The history and causative stresses remain largely unresolved but regional east-west compression of the coal measures has contributed to the development of a number of these faults. Several directions have been identified from resource modelling and aeromagnetic analysis. These are shown on Figure 7 and comprise:

- north-south faulting including the Mt. Ogilvie system to the east of the Project Area;
- north-east faulting which may have influenced the location of Big Flat Creek and parts of Wybong Creek;
- north-west faulting which may have influenced the location of Wybong Creek above the confluence with Big Flat Creek;
- east-west faulting

A number of igneous dykes are also noted throughout the area. The most significant and massive of these bisects the coal resource in a north easterly direction as shown on Figure 7. Thickness of this dyke is thought to be in the order of 5 m and is likely to thicken as it passes through the coal seams. A number of smaller dykes have also been identified and are similarly shown on Figure 7. Igneous sills have partially intruded the Great Northern and Fassifern seams in the north-east part of the area.

Jointing has not been mapped but is generally thought to be infrequent based on rock core extracted from exploration boreholes except where localised faulting is known or inferred.

3.4 Existing bores and wells in the region

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

Figure 8 identifies bore/well locations situated in proximity to proposed mining operations. For clarity, this plot excludes registered and temporary observation piezometers installed by Centennial.

Nearest privately owned bores or wells are located in or adjacent to the alluvial lands associated with Big Flat Creek (north and south of Wybong Road) or Anvil Creek. Bores identified as Nos. GW078502, K-bore, GW066620, BM bore, GW023072 and GW066617 are either not in use or abandoned due to failure of equipment, failure of the bore structure, or saline water quality. The well identified as R1W is an old timber lined well currently not in use while wells identified as P1W and H1W are used for stock or domestic purposes depending on water quality.

An increased number of bores are located more than 3 km beyond the proposed pit areas of mining. A number of these are located within Wybong Creek alluvium to the west of the Project Area. Many are located within alluvial lands associated with Sandy Creek to the south-east (see Figure 8).

4. GROUNDWATER HYDROLOGY

4.1 Aquifer systems

The Upper Hunter Region hosts three recognised types of aquifer systems – the coal seams/measures, the shallow weathered zone or regolith, and the alluvial deposits adjacent to major drainages. These systems tend to act in an integrated way in some areas while in other areas they may act in isolation.

The main aquifer systems that have been identified in and around the Project Area include:

- ***coal seam aquifers*** with water storage in coal cleats. These aquifers are generally confined above and below by interburden aquitards (conglomerates, sandstones, siltstones) where intergranular storage dominates. Secondary storage may also be developed within interburden fractures and faults. Groundwater quality is generally brackish to saline;
- ***parts of the overlying weathered zone or regolith*** as intergranular storage. These zones may source springs following periods of high rainfall but most are depleted during extended dry and drought periods. Water quality is variable from fresh to saline;
- ***certain areas within the alluvial lands*** where porosity (storage) and hydraulic conductivity (transmitting capacity) are sufficiently developed to warrant exploitation although high salinity is a significant issue, especially within Big Flat Creek catchment.

Water tables and pressures in the coal measures are sustained by rainfall percolation to sub cropping strata at a generally low rate with estimates of rainfall recharge varying from zero to no more than 2% of annual rainfall based upon previous studies in the Upper Hunter region. The Great Northern and Fassifern seams are likely to exhibit highest rates of direct recharge in areas where they subcrop (see Figure 2). These areas would tend to generate driving pressures in a westward direction down dip.

The coal seams are confined in down dip areas to the west of seam subcrops. Groundwater encountered within a particular seam during drilling in these areas, rises above the seam thereby indicating confinement. Confinement is also indicated by semi continuous water level monitoring at a number of piezometers located in the Fassifern seam where oscillations in the water table of up to 150 mm can be attributed to barometric change. Confined elastic storage is inferred from these movements. Strong confinement is also exhibited at borehole PAHOH08 where artesian conditions have prevailed since the bore was constructed ie. the borehole is free flowing if left uncapped. At this location the water source is within sandstones located beneath the Upper Pilot A seam and is probably associated with bedding shear.

Water tables in the regolith can be isolated from deeper coal measures through the presence of the massive and relatively impermeable conglomerates that overly the coal seams. This isolation is however likely to be interrupted at locations where vertical faulting provides a connecting pathway to deeper strata. These same pathways could also facilitate recharge to deeper strata or vertical mixing of groundwaters.

Alluvial lands in the area would normally be identified as useful aquifers. However in Big Flat Creek and Anvil Creek, the unconsolidated materials are mostly silty and clayey. Indeed hydraulic testing and subsequent monitoring of numerous boreholes at the confluence of both creeks supports low conductivity materials with semi confinement at depth. Perching is also evident with the uppermost two or three metres of alluvium sometimes hosting a separate water table. This very shallow zone generally exhibits high salinity with values ranging from 5000 to more than 20000 µS/cm (Appendix B).

4.2 Groundwater piezometric surface

The groundwater pressure distribution within coal measures has been mapped using a data set which includes routine piezometric monitoring, and spot measurements determined from open exploration holes (prior to grouting). Spot measurements determined from geophysical logging have also been employed.

A total of 53 sites are routinely monitored for water level and basic water quality parameters (pH and EC) at two monthly intervals. Of these, 18 are located with the Fassifern seam (exploration holes), 10 are located in the deeper alluvium near the confluence of Anvil Creek and Big Flat Creek, and 25 are either open to all strata within the coal measures or located within the shallow alluvium or regolith. Automated water level logging apparatus is also installed at 10 piezometer locations. Appendix B, Figure B1 provides site locations and Table B1 gives construction details.

Figure 9 provides a composite piezometric surface based upon regional interpolation of groundwater equipotentials and inference from computer simulation of aquifer systems (Section 5). Reference to this plot indicates a southward or south-westerly gradient in areas north of Big Flat Creek, a westward to north-westerly gradient in the central part of the Project Area, and a flow divide in the southern part of the area. Approximate flow directions are indicated by arrows on Figure 9.

Big Flat Creek alluvium appears to provide a groundwater sink roughly along the axis of the creek although contour control data is relatively sparse to the north of the creek. An hydraulic sink is also inferred along the axis of Wybong Creek. Both ‘sinks’ are probably influenced by faulting within the coal measures underlying the alluvium.

The hydraulic gradient across the proposed mine pits varies from a low of about 1 in 150 to a higher gradient of about 1 in 25. Low gradient areas may indicate the presence of relatively higher strata hydraulic conductivity, perhaps associated with increased cleating within the coal seams. It is also possible that these same areas may be associated with reduced rainfall recharge. Areas supporting higher gradients reflect increased rainfall recharge. The latter may be indicated by elevated groundwater levels bounded by the 180 mAHD equipotentials. These areas are situated on elevated ground in the south and in areas where the Fassifern-UPA seams subcrop in the east.

Also plotted on Figure 9 is the submergence surface for the Fassifern seam. This surface has been generated as the difference between the seam floor and the prevailing piezometric surface. Positive values indicate the seam floor is above the water table (unsaturated) while negative values indicate the seam floor is below the water table (saturated). Clearly there are large areas where the seam is unsaturated or only partially saturated in central parts of the Project Area. Mining in these areas is unlikely to affect the regional water table.

A maximum submergence of the seams occurs at the most westerly limit of proposed mining where about 50 to 60 m head of groundwater would prevail.

4.3 Regional hydraulic properties

Hydraulic properties for coal seams, interburden and alluvium have been measured using various techniques. The most commonly applied method has involved the variable head or slug test where a volume of water in the test hole was displaced and the head response then measured. Testing has been undertaken at 44 locations including installed piezometers and exploration holes before grouting/sealing of those holes. Test methodology, analytical procedures and results are provided in Appendix C. Numerous tests returned relatively high conductivity values consistent with fracturing. A number of these high conductance sites are in proximity to inferred or known faults.

In addition to variable head tests, selected core from six exploration bore sites have been submitted to laboratory determination of hydraulic conductivity (K) and porosity. These analyses are considered to provide accurate estimates of the intergranular conductivity at a small scale – tuffaceous sandstone (Awaba Tuff) and conglomerates were specifically targeted. All core tests returned low conductance values.

All test data has been consolidated into a schedule of hydraulic conductivities considered to be broadly representative of the strata present within the region. Table 1 provides a summary.

Table 1: Representative hydraulic properties from laboratory and field testing

Lithology	Method	K range (m/day)	K rep. (m/day)
alluvium (Anvil Creek and Big Flat Creek)	var. head	1.00E-03 – 6.53E-01	3.69E-02
conglomerate – sandstone above GN seam	core	6.08E-06 – 1.55E-04	3.67E-05
Great Northern seam (inc. structure, cleats)	var. head	8.50E-03 – 9.47E+00	<4.44E-01
Awaba tuff	core	6.97E-07 – 1.38E-04	4.06E-06
Fassifern seam (inc. structure, cleats)	var. head	8.50E-03 – 9.47E+00	<4.44E-01
coal measures (bulk)	var. head	2.20E-05 – 1.11E+01	3.33E-02

K = hydraulic conductivity

4.4 Regional water qualities

Data relating to regional groundwater qualities has been generated by routine monitoring of basic water quality parameters pH and EC, and targeted sampling for laboratory determination of major ions and rare elements and metals.

Summary data is provided in Appendix D. In general, data reflects poor quality brackish to saline waters within the coal measures and within the alluvium of Big Flat and Anvil creeks. There are occasional exceptions where the shallow regolith may host relatively fresh water springs.

Salinity data is represented on Figure 10. EC values range from 117 to 23955 µS/cm with an average of 8425 µS/cm. pH values range from 5.78 to 9.18 with an average of 7.10. Elevated pH at some locations reflects an environment offering buffering (mitigating acid generation) as is observed in most mining areas of the Upper Hunter region.

Established water quality guideline data are summarised in the following Table 2 together with typical groundwaters sampled. Comparison of EC levels suggest groundwaters within the coal measures and many locations sampled within the alluvial deposits, have limited or no beneficial use (high salinity)

Speciated groundwater is shown on the tri-linear plot in Appendix D, Figure D2. This representation facilitates classing of the water types by plotting percentage milli equivalents of the main ions found in water. Speciation for major cations and anions indicates a classing of waters where sodium chloride or primary salinity tends to dominate ie. Na>Mg>Ca and $Cl>HCO_3>SO_4$ when all samples (alluvium, regolith and coal measures) are considered.

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

TDS (mg/L)	Equivalent EC (µS/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
3188	4904	*typical Fassifern Seam groundwater*
8250	12693	*shallow alluvial groundwater*
9371	14417	*deeper alluvial groundwater*
131	202	*regolith spring*

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

5. PREDICTION OF MINING RELATED GROUNDWATER IMPACTS

Mining of coal seams will result in depressurisation of rock strata within and around the proposed mine pits. The extent to which depressurisation will become more ‘regionalised’ depends upon a number of factors including aquifer/aquitard hydraulic properties, variation in stratigraphy, structural features including dykes and faults, and recharge sources. 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.

An aquifer model of the region has been developed in order to assess the likely impacts arising from mining. The model employs a finite difference scheme (ModFlow-Surfact) for solving a set of differential equations known to govern groundwater flow. The simulation method requires dividing the overall area of interest into rectangular cells or blocks, the number of cells in the model grid being determined by the general juxtaposition of proposed mining operations, and the expected hydraulic gradients developed in the course of mining.

The simulation model is a simplified representation of the aquifers. The extent of the regional model is indicated in Appendix E on Figure E1. The model is a variably saturated scheme and comprises six layers with 36000 cells per layer. Total modelled area is 132 sq. km with cell areas varying from 1 ha (100 m x 100 m) to 0.25 ha (50 m x 50 m). Cells have been designed to give increased detail to the proposed pit areas and drainages together with the alluvial aquifers of Big Flat Creek, Sandy Creek and Wybong Creek, and the regional coal measures. The Great Northern and Fassifern/UPA seams have been included as specific layers (3 and 5) throughout the area. Deeper strata in the eastern part of the model (east of the Mt Ogilvie fault system) where the Jerrys Plains Sub Group is present, has been simplified from numerous stratigraphic zones to a single representative zone.

Model layers, stratigraphy and assigned conductivity values are discussed in Appendix E.

5.1 Model properties and boundary conditions

Properties assigned to the model include hydraulic conductivity (permeability), elastic and inelastic storage. Horizontal hydraulic conductivities have been calculated as the log means of measured seam and interburden values summarised in Appendix C. Vertical conductivities have been assigned a value one tenth the horizontal value within coal seams although in many instances this could be much lower due to the frequently observed presence of dull coal layers and impermeable carbonaceous shales. Use of a 10:1 (H:V) ratio also supports conservative (high) estimates of depressurisations since calculation of transverse anisotropy based on core inspections suggests the ratio may be greater than 100:1 as a result of shaley bands. Certain layers have also been upweighted in hydraulic conductivity values to provide for possible jointing and to improve convergence to a solution in the modelling process.

The major north-east trending dyke that separates the proposed mine pits has been included in the model together with a number of smaller and less significant dykes since these features have the potential to compartmentalise groundwater flows. It is assumed that these dykes are relatively impermeable.

In respect of drainages, special model cells that control the groundwater elevation through importation or exportation of surface water, have been assigned to Wybong Creek, Sandy Creek and the Hunter River assuming these drainages maintain flow at all times. Bed elevations have been calculated for separate reaches based on available survey data. Special cells that govern only the exportation of groundwater from the model, have been located over regional ephemeral creeks. Bed elevations for these creeks have been estimated from a digital terrain model with a uniform negative adjustment of 5 m to account for localised drainage profiles and influence of the regolith.

Rainfall recharge has been applied at an average rate of about 1 mm/year in coal measures equivalent to about 0.17% of annual rainfall. A much higher rate of 90 mm/year has been assigned to Wybong Creek and Sandy Creek alluvium (15% of annual rainfall) consistent with previous studies where Hunter River alluvium has been included. In the absence of measured recharge, an arbitrary lower rate of 40 mm/annum has been applied to Big Flat Creek where high silt and clay content is observed in the alluvium and is assumed to impede recharge.

5.2 Open cut strata depressurisation

Estimates of strata depressurisation and pit seepage for the proposed twenty-one year duration of the Project have been simulated. The pit highwall has been progressed at yearly intervals in accordance with strip planning data supplied by Centennial.

Figures 11a and 11b show the simulated piezometric head distributions for the most affected strata (Fassifern-UPA seam) at 5, 10, 15 and 21 years (left plots) together with the loss of water level or drawdown (right plots). These plots illustrate a limited loss of formation pressures/levels in the central part of the planned pit area during the first 5 years of mining. This generally low level of impact is attributed to limited submergence of the coal seams - mining operations are either above the water table or no more than about 10 to 15 m below the water table. This area is also elevated with respect to the major drainages - Big Flat and Anvil Creeks.

Formation depressurisation and dewatering at 10, 15 and 21 years is greatest in the western part of Main Pit with a piezometric surface extending to the west and north of the pit where greatest submergence of the coal seams occurs. Pressure losses in these areas at the completion of mining are predicted to extend some 1.5 km beyond the pit highwall towards and beneath Wybong Creek where about 2 metres loss of pressure (head) is indicated at the Fassifern Seam depth.

Figure 12 shows the calculated pit seepage rates over the mine life as separate pit seepages and as a total for all pits. These influxes represent groundwater that is released from all strata as a resulting of mining (blast fragmentation, highwall, end wall and floor seepage etc.). They do not include direct rainfall captured by the pit, rainfall runoff and infiltration though emplaced spoils within the mine pits.

Model outcomes predict most groundwater influx will be generated within Main Pit. This is largely due to the deeper westward dipping strata and increasing submergence of seams within this pit. Total seepage entering the mine pits for average rainfall recharge conditions is predicted to rise from a rate of less than 0.5 ML/day during the first year of mining to a maximum rate of about 1.8 ML/day in mining year 10 declining thereafter to a rate of about 0.9 ML/day at the completion of mining in year 21. The reducing rate after mining year 10 is attributed to a declining length of highwall in Main Pit as mined strips migrate towards a final void in the southern part of this pit. A sustained wet period may elevate these rates of seepage (through regolith contributions) by between 0.2 and 0.5 ML/day.

Northern, Southern and Tailings pits are all expected to generate relatively low rates of seepage due to small or zero submergence combined with the effects of depressurisation expanding outwards from Main Pit operations.

Figure 13 shows the pressure loss regime at the completion of mining in increased detail. This plot indicates pressure/water level losses for both the Fassifern Seam (in blue) and the shallower conglomerates (in red). As expected, the overall impact regime for the conglomerates is less extensive than the more transmissive coal seam. While not shown, the impact regime for the shallow regolith and Big Flat Creek alluvium is no more than a few hundred metres beyond the pit perimeter. This reduced impact is attributed to rainfall recharge balancing downward leakage to the depressurised hardrock strata..

An estimate of vertical leakage from Big Flat Creek alluvium to the mine pit(s) via the coal seams, has been generated by the numerical model. The rate of this component of leakage is predicted to be low and of the order of 50 to 100 kL/day over an area of about 181 ha adjacent to and north of Main Pit. This would be equivalent to a leakage rate of 0.027 to 0.054 L/day per square meter of alluvium in the potentially affected area.

Vertical leakage may also occur from alluvium associated with Wybong Creek downwards to the coal seams via the conglomerates. The maximum rate of leakage from this alluvium is also predicted by the numerical model to be low and of the order of 15 to 30 kL/day over an area of about 160 ha. This would be equivalent to a leakage rate of 0.009 to 0.019 L/day per square meter of alluvium within the potentially affected area and would be reduced to a negligible rate when water levels in the final voids equilibrate.

5.3 Cut off wall in Anvil Creek alluvium

During years 4 to 5 of mining operations in Main Pit, the highwall would encroach upon the confluence of Big Flat Creek, Clarks Gully and Anvil Creek. The pit end wall would intercept the alluvial materials in this area during the following 6 years with a maximum depth-thickness exposure of the order of 25 m. Since the water table resides at depths of 5 to 8 m there remains a maximum saturated thickness of 17 to 20 m to the base of the alluvium that would contribute seepage (of saline water) to Main Pit.

Hydraulic testing of these alluvial materials supports low hydraulic conductivities consistent with observed silt and clay strata. Seepage contributions are therefore predicted to be low and manageable through the installation of dewatering slots during stripping, to facilitate gravity drainage. However there could be isolated pockets of more permeable sand and gravel materials that may exhibit higher rates of seepage for relatively short periods until contained groundwater storage is depleted.

Big Flat Creek alluvium may be isolated from Anvil Creek alluvium (depending upon detailed exploration and testing) through the construction of a barrier cut off wall across Anvil Creek at the confluence of these two creeks at the location indicated on Figure 13. Such a wall would inhibit horizontal leakage of saline groundwaters associated with Big Flat Creek alluvium, into Main Pit.

The regional numerical simulation model has insufficient resolution to examine the depressurisation of the alluvium close to the mine pit, in detail. Accordingly a seepage face model has been developed to describe likely water level changes within the alluvium and the impacts of seepage mitigation measures.

The model is described in Appendix E and is a vertical section extending across Big Flat Creek orthogonal to the proposed Main Pit end wall. Estimates of seepage arriving at the pit highwall have been generated for a 10 m (width) section and for different saturated depths. Model results indicate the approximate seepage rates given in Table 3. Summating seepage rates in Table 3 for an average saturated alluvium thickness of 10 m over 1.5 km distance aligned immediately north of Main Pit high wall (across Anvil Creek) gives a total seepage estimate of 66 kL/day (0.066 ML/day) without a barrier and 27 kL/day (0.027 ML/day) with a barrier.

It is noted however that Table 3 results include dewatering of the alluvium within a buffer zone between the pit highwall drain and the barrier wall location set back approximately 50 m from the highwall. The component of leakage through the wall location is represented in Table 4 for comparison. These results more clearly indicate the effectiveness of a barrier wall in inhibiting horizontal seepage.

Table 3: Seepage rates from Big Flat Creek alluvium arriving at the mine pit

Saturated alluvium thickness	Seepage per 10 m (no barrier wall)	Seepage per 10 m (with barrier wall)
(m)	(kL/day)	(kL/day)
5	0.31	0.14
10	0.44	0.18
15	0.53	0.21
20	0.58	0.22

Table 4: Seepage rates from Big Flat Creek alluvium through the barrier wall

Saturated alluvium thickness	Seepage per 10 m (no barrier wall)	Seepage per 10 m (with barrier wall)
(m)	(kL/day)	(kL/day)
5	0.26	0.09
10	0.40	0.13
15	0.45	0.15
20	0.48	0.16

5.4 Mine pit seepage quality

The quality of groundwater entering the mine pits is expected to reflect an average of water quality for the coal measures (excluding Big Flat Creek alluvium). The quality is expected to fall in the range 853 to 12508 µS/cm with a likely average value of 4904 µS/cm (3200 mg/L) determined from coal measures water samples. Ionic speciation is expected to be variable with weak domination by primary salinity (as NaCl).

All seeped water will remain within the mine water system as a result of the inward flow regime to the groundwater sink surrounding the mine pits which is predicted to prevail at all times. Mine water would not migrate beyond the pit areas.

5.5 Recovery of aquifer pressures post mining

Regional water levels/pressures will recover following cessation of mining. The rate of recovery will depend upon the remaining water held in storage within the coal measures, the hydraulic properties of spoils, rainfall recharge through spoils, and runoff entering the final void.

An estimate of the rate of recovery of regional pressures/water levels has been made using the aquifer simulation model with the pressure distribution defined in Figure 11b at completion of mining in 2029, as the initial condition for recovery. Model simulations are described in Appendix E.

Spoils emplaced within the pit shell would exhibit different properties to the intact coal measures. A conductivity of 1 m/day and a drainable porosity of 20% have been applied to the emplaced spoils. In addition, contributions via spoils infiltration and percolation have been assigned a rate of 30 mm/year (5% of annual rainfall) based on soil moisture modelling of 105 years of daily rainfall records for Denman.

5.5.1 Final void scenarios

Numerical modelling of the water level recovery process indicates that the void water levels in the mine pits would be slow to recover after cessation mining. The recovery process would result from continuing groundwater seepage (at a declining rate), rainfall directly falling in open void areas, and rainfall runoff infiltrating rehabilitated spoils. A stabilised ‘recovered’ level would occur when these contributions are balanced by losses. Such losses typically occur through evaporation from the void open water surface(s).

Water levels in Main and Southern pits have been designed to stabilise at about 135 mAHD and 150 mAHD respectively. These elevations are 5 to 10 m below inferred high wall ‘spill’ points (beneath spoils) and are equivalent to exposed open void surface water areas of 42 ha and 22 ha respectively, as indicated on Figure 14. At these elevations (and surface areas), average net contributions to the pits from rainfall, runoff and infiltration, are balanced by evaporative losses assuming a rate of 80% of potential evaporation (PE). These evaporative sinks would prevail in the very long term. However the closure design may vary during the years prior to closure depending upon verification of depressurisation impacts, the level of agreement with aquifer model predictions at that time, and monitoring records in relation to groundwater and mine water quality. Alternatives to an evaporative sink may include infilling and reshaping of the final voids without an open water condition, or an open water condition connected to a drainage system where Anvil Creek used to be, that facilitates retention and discharge of surplus void water during periods of extreme rainfall. These scenarios would result in heavily timbered void areas where open water evaporative losses are replaced by tree and grass evapotranspirative losses that would maintain spoils water levels at higher elevations.

Northern pit would be fully spoiled with no open void. Rainfall infiltrating this pit would partially fill depressions below the original water table until a stabilised surface prevails where continuing infiltration is balanced by leakage back into the surrounding coal measures as the water table rebounds. The rate of leakage is estimated to be a maximum 58 ML/annum (159 kL/day) assuming 5% maximum infiltration-percolation. It is likely that a substantial component if not all of the percolated rainfall, would migrate to the south-west into Main Pit through the intact barrier coal seams separating the pits.

The remaining tailings pits are either close to or above the existing regional water table and will be filled with very low permeability tailings and capped. Rainfall infiltration is not expected to be significant.

5.6 Final void groundwater quality

The hydrochemistry of recovering groundwater within the voids would reflect contributions from coal measures seepage, contributions from spoils seepage and contributions from rainfall runoff entering the voids.

Void water is expected to remain largely isolated from the regional coal measures and surficial aquifers through the maintenance of inward hydraulic gradients during the recovery process and an evaporative sink condition that would continue to attract groundwater flow to the voids (at low rates) in the long term.

Estimates of the overall total dissolved solids and ionic speciation characteristics of void water have been made using leachate trials. Representative core samples obtained from 8 exploration holes situated within the proposed mine pits, have been subjected to leach trials to ascertain the likely long term characteristics of groundwater within emplaced spoils. Trials comprised crushing of core, sieving to smaller and more uniform grain size fractions followed by leaching for three months before samples were dispatched for laboratory analyses of major ions. This procedure facilitates reconstruction of fragmentation distributions and improved estimation of leachable salt load. Appendix F summarizes methodologies and calculations.

An average leachable and mobilisable load has been determined for two limiting spoils fragmentation distributions resulting from the mining process. A total mobilisable salt load of between 0.65 and 1.13 kg per cubic metre of spoils has been determined. An estimate of the void water quality has been made by assuming this salt mobilisation rate will prevail throughout all spoils which re-saturate during the recovery period. If a final emplacement bulk spoils porosity of 20% is assumed, then the void water quality is estimated to lie between 3250 and 5650 mg/L (Appendix F) with most leachate generated by rainfall dissolution.

Speciation analyses of leachate samples indicate the void groundwater will tend towards a sodium>magnesium>calcium cation distribution and a chloride>bicarbonate>sulphate anion distribution although bicarbonates may be dominant if ion exchange is a major mechanism as suggested by leachate trials. pH in the range 6.5 to 9.0 is predicted to prevail.

Acid forming characteristics of spoils have been examined and all samples (used in leachate trials) have been found to be non acid forming.

6. POTENTIAL ENVIRONMENTAL IMPACTS

Proposed mining within the Project Area will induce change to the local groundwater and surface water environments. Potential impacts arising from the development will include:

- Loss of coal measures aquifer pressures;
- Leakage of groundwater from shallow alluvial aquifers;
- Potential impacts on water supply bores and wells;
- Change in groundwater quality in coal measures;
- Salinisation in the final void(s) following cessation of mining.

6.1 Loss of coal measures aquifer pressures

Future mining would induce loss of aquifer pressures in the target Great Northern, Fassifern and UPA seams, and in strata between and overlying these seams. The greatest pressure loss envelope is expected to occur within the Fassifern –UPA seams and is predicted to expand beyond Main Pit perimeters in northerly and westerly directions for distances of about 1.5 km. Coal measures pressure losses are not predicted to extend to Sandy Creek alluvium or the Hunter River alluvium in the south east of the area.

Pressure losses would prevail after cessation of mining for a period of more than 50 years. While groundwater levels within the mine pits will recover, the long term water levels would never recover to pre mining levels since the areas of mine development would exhibit different hydraulic properties to the pre mining conditions - spoils permeability is likely to be 3 to 4 orders of magnitude higher than undisturbed coal measures. The net effect of changed properties would be a relatively flat water table over Main and Southern pits at elevations of about 135 and 150 mAHD respectively due to final void(s) design. These levels would maintain an inward hydraulic sink with respect to the regional groundwater system. The influence of this groundwater sink post mining is estimated to extend up to 500 m beyond the mined areas when long term equilibrium is attained. As a result, very long term impacts are considered to be small and acceptable.

6.2 Leakage of groundwater from shallow alluvial aquifers

Loss of coal measures pore pressures may initiate downwards leakage from Big Flat Creek alluvium in the areas near Clarks Gully and Anvil Creek confluence (providing seam losses are transmitted upwards through the overlying conglomerate). The rate of leakage is predicted to be low and of the order of 50 to 100 kL/day over an area of about 181 ha. This would be equivalent to a leakage rate of 0.027 to 0.054 L/day per square meter of alluvium in the potentially affected area. Since Big Flat Creek groundwaters are generally saline with no identifiable beneficial use, leakage impacts are considered to be acceptable.

Vertical leakage may also occur from alluvium associated with Wybong Creek downwards through the underlying conglomerates. The rate of leakage is also predicted to be low and of the order of 15 to 30 kL/day over an area of about 160 ha. This would be equivalent to a leakage rate of 0.009 to 0.019 L/day per square meter of alluvium within the potentially affected area and would be reduced to a negligible rate when water levels in the final voids equilibrate.

6.3 Potential impacts on water supply bores and wells

There are only two identified boreholes located beyond the mine pit perimeters that may be 'yield affected' by the predicted cone of depressurisation. These include bore GW066620 located a short distance to the north east of Main Pit which is decommissioned and bore GW078502 which remains unequipped and encountered poor yield and poor water quality when constructed through Wybong Creek alluvium and the underlying coal measures.

Wells located within or close to Big Flat Creek alluvium and considered to be at risk include Hogan well and Pitman well. Yield at these locations may only be affected if leakage from the alluvium is significant and drought conditions prevail. Otherwise rainfall recharge is expected to maintain yield.

Shallow regolith seeps that are accessed by wells in areas north of Big Flat Creek are unlikely to be affected unless specific and as yet unidentified hydraulically transmissive structural features (eg. faults), provide direct conduits to strata within the proposed mine pit(s). In the event, two locations may be at risk – P1W and K1W. Wells and bores located within Wybong Creek alluvium to the west, or Sandy Creek alluvium to the south-east, are unlikely to be be impacted.

6.4 Change in groundwater quality in coal measures

Groundwater within the coal measures is saline with salinity levels observed to be in the range 853 to 12508 µS/cm (554 to 8130 mg/L) averaging about 4904 µS/cm (3200 mg/L).

Proposed mining is expected to sustain a similar groundwater quality range although periods of high rainfall may lead to a reduction in mine water salinity through shallow flushing within the perimeter regolith zone. It is improbable that regional coal measures groundwaters will exhibit a change in salinity as a result of mining.

6.5 Salinisation in the final voids

Open pit (free standing water) voids are proposed in Main and Southern pits on completion of mining although final design would be subject to detailed assessment approximately 5 years prior to closure. Alternatives could include infilling and reshaping of the final voids without open water condition, or an open water condition connected to a re-instated Anvil Creek drainage system.

Depending upon the final closure plan, the voids may exhibit a salinity higher than existing coal measures groundwater due to leaching of salts from spoils and evaporative processes. However the salinity is predicted to be significantly lower than measured salinities within parts of Big Flat

Creek alluvium. Since an inward hydraulic grade or groundwater sink is likely to prevail as a result of evaporative losses, mixing of surface waters is improbable. Regional water quality impacts are therefore considered to be minimal.

7. DNR LICENSING REQUIREMENTS

Licensing of certain aspects of the mining operations is normally required under the Water Act 1912, and the Water Management Act 2002.

7.1 Water Act 1912

The groundwater in fractured rock aquifers or bedrock in the Wybong area is subject to the Water Act 1912.

The excavation of the mine pits will require bore licences under Part 5 of the Water Act. Separate bore licences would also need to be obtained for any other bores, such as for water monitoring.

7.2 Water Management Act 2002

Wybong Creek catchment is subject to the Wybong Creek Water Sharing Plan. The plan applies to surface water and connected groundwater resources contained within the underlying alluvium. Alluvial lands associated with Anvil Creek and Big Flat Creek therefore fall within the plan under a defined Zone 2 area.

Anvil Creek alluvium will be stripped and removed as part of the mining process thereby removing a subsurface groundwater flow component to Big Flat Creek alluvium. The flow contribution is very low and estimated to be of the order of 2.2 kL/day based upon a measured average hydraulic conductivity 0.037 m/day, a hydraulic grade of about 0.004 and a saturated flow cross sectional area of about 15000 m2. In addition, vertical leakage from Anvil Creek and Big Flat Creek alluvium induced downwards by coal measures depressurisation, has been estimated from aquifer modelling to be of the order of 50 to 100 kL/day maximum. This water is likely to be saline and of no beneficial use.

Coal measures are not identified as part of the Wybong Creek Water Source. They are consolidated rock layers that are essentially disconnected from the alluvial sediments and generally have no beneficial use owing to their brackish or saline water quality and limited yield potential.

Considering all groundwater elements addressed within the current study, the impacts of the proposed mining operations on the water sharing plan, are considered to be relatively low to negligible.

8. IMPACTS 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, 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.

8.1 Groundwater assessment criteria

Impacts in respect of groundwater relate to two key areas:

- physical depressurisation of the rock strata and potential indirect impacts on other aquifer systems like Big Flat Creek and Wybong Creek alluvial deposits, and;
- changes to groundwater hydrochemistry induced by regional depressurisation.

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. Centennial currently monitors groundwater levels at a numerous borehole and well locations. Falling water levels/pressures are currently evident at a number of these locations due to the prevailing dry and drought conditions. However these should stabilise and then rise with the onset of increased and sustained rainfall.

Pressure losses will become evident with the onset of mining activities at many of the piezometers. Pressure losses in piezometers situated beyond the mine pit(s) perimeter may signify an increase in the potential for leakage from the alluvial materials if the expanding pressure loss wave migrates beneath the alluvium.

Groundwater impact assessment should therefore be based on the measured change in regional aquifer systems pressures, flows and hydrochemistry.

Centennial has committed to depressurisation monitoring which will include:

- Construction of additional piezometers to permit shallow coal measures depressurisation measurement in the region west and north of Main Pit and west and south of Southern Pit. Locations for these piezometers would be subject to consultation and agreement with DNR. Permeability testing should be completed on new piezometers in order to facilitate estimation of subsurface flows.
- Construction of piezometers in rehabilitated spoils emplaced within all pits during the course of mining. The purpose of these piezometers would be monitoring of void/spoils water level recovery and water quality post mining.
- Two-monthly monitoring of water levels in all existing piezometers and in new piezometers.
- Daily monitoring of water levels by installed auto recorders at the 10 existing piezometers and in selected new piezometers (shallow zone) in order to discriminate between oscillatory groundwater movements attributed to rainfall recharge, and longer term pressure losses related to mining.

Centennial has committed to undertake groundwater quality monitoring including:

- Two-monthly monitoring of basic water quality parameters pH and EC in all existing and new piezometers.
- Six monthly measurement of total dissolved solids (TDS) and speciation of water samples in 8 piezometers. Speciation should include major ions Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4 (or S) and elements/metals including Al, As, B, Ba, Fe (soluble), Li, Mn, Rb, P, Se, Si, Sr, Zn.
- Graphical plotting of data and identification of trend lines and statistics including mean and standard deviation calculated quarterly. Comparison of trends with rainfall and other identifiable processes that may influence such trends.

Impact analyses will include:

- Two-monthly assessment of departures from identified monitoring or predicted data trends. If consecutive data over a period of 6 months (minimum of three consecutive readings) exhibit an increasing divergence in a negative impact sense from the previous data or from the established or predicted trend then such departures should initiate further action. This could include a need to conduct more intensive monitoring (including installation of additional piezometers) or to invoke impacts re-assessment and/or remedial actions if causality is attributed to mining operations and is assessed to be detrimental to the environment beyond predicted impacts.
- Formal review of depressurisation of coal measures and comparison of responses with aquifer model predictions biennially. Expert review should be undertaken by a suitably qualified hydrogeologist if measured depressurisation in coal measures exceeds predicted depressurisation for the designated period.
- Annual reporting (including all water level and water quality data) to DNR in an agreed format.

In addition to the above and as part of overall quality procedures, the monitoring programme should be subject to review annually by Centennial environmental services group and/or their appointed consultants.

Mackie Environmental Research

May 2006

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IMPORTANT INFORMATION ABOUT YOUR HYDROLOGICAL REPORT

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

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

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

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C. Mackie
CP. No. 113049

0 2000 4000 Metres

Scale 1:60000 (air photo supplied by Centennial Coal)

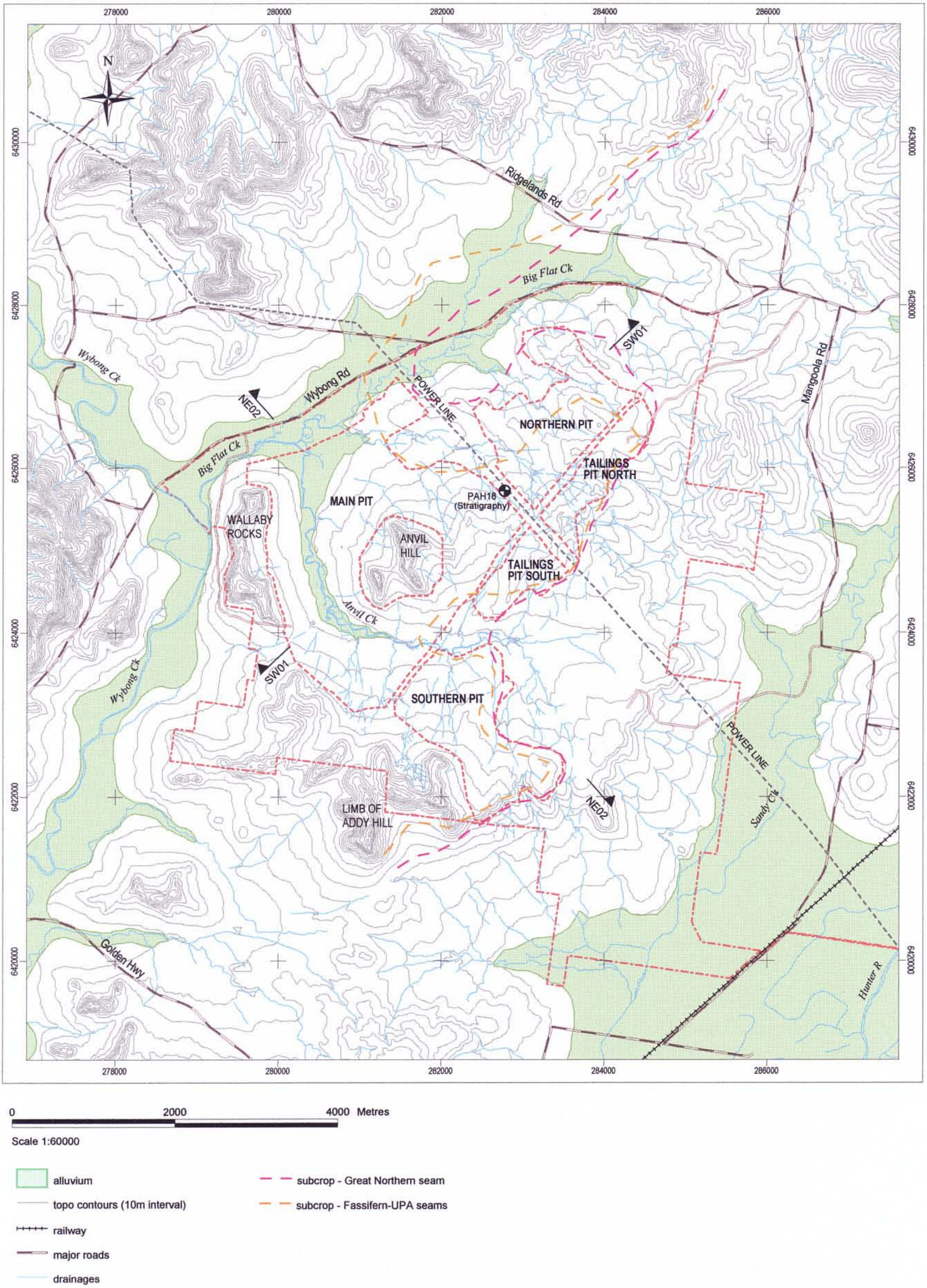
- proposed mining area boundary
- railway
- dirt roads
- major roads
- drainages
- project application area

ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Regional air photo and project area

Figure 1

Mackie Environmental Research



ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Regional topography and drainage

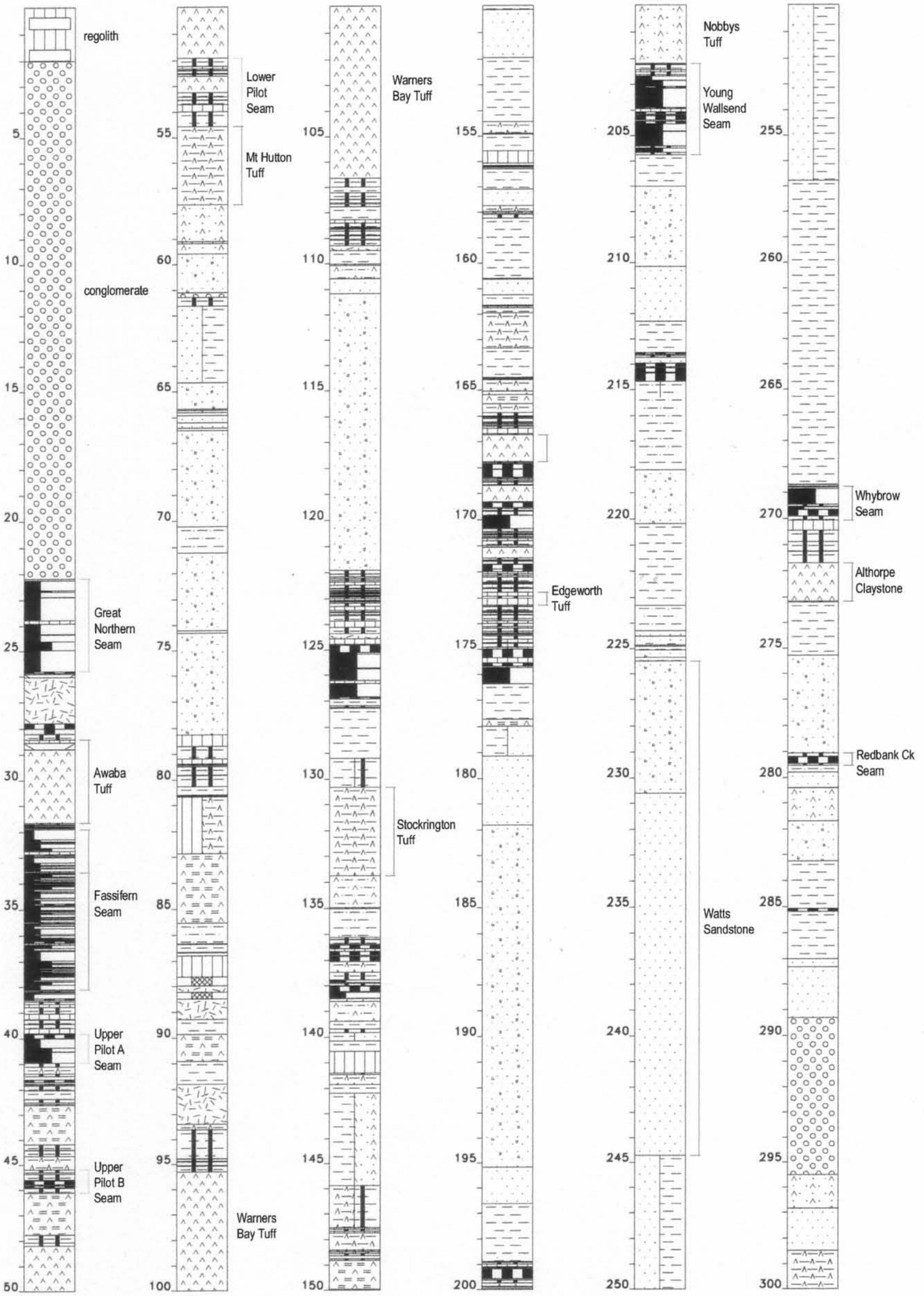
Figure 2

STRATIGRAPHY OF THE UPPER HUNTER COAL MEASURES

SINGLETON SUPER GROUP	NEWCASTLE (WOLLOMBI) COAL MEASURES		MOON ISLAND BEACH FORMATION	VALES POINT SEAM	UD	low sulphur
				WALLARAH SEAM	UD	low sulphur
				GREAT NORTHERN SEAM	UD	low sulphur
			AWABA TUFF (NALLEEN TUFF)		UD	tuffaceous sandstone
			BOOLAROO FORMATION	FASSIFERN SEAM	UD	low sulphur
				UPPER PILOT SEAM	UD	low sulphur
				MT HUTTON TUFF	UD	tuffaceous sandstone
				LOWER PILOT SEAM	UD	low sulphur
				HARTLEY HILL SEAM	UD	low sulphur
			WARNERS BAY TUFF		UD	tuffaceous sandstone
			ADAMSTOWN FORMATION	AUSTRALASIAN SEAM	UD	low sulphur
				STOCKRINGTON TUFF	UD	low sulphur
				MONTROSE SEAM	UD	low sulphur
				WAVE HILL SEAM	UD	low sulphur
				EDGEWORTH TUFF	UD	tuffaceous sandstone
				FERN VALLEY SEAM	UD	low sulphur
				VICTORIA TUNNEL SEAM	UD	low sulphur
			NOBBYS TUFF (MONKEY PLACE CREEK TUFF)		UD	tuffaceous sandstone
			LAMBTON FORMATION	NOBBYS SEAM	UD	low sulphur
				DUDLEY SEAM	UD	low sulphur
				YARD SEAM	LD.UD	low sulphur
				BOREHOLE SEAM	LD	moderate to low sulphur
			WARATAH SANDSTONE (WATTS SANDSTONE)		LD	sandstone, minor congl. marker
	WITTINGHAM COAL MEASURES		DENMAN FORMATION		SM	sandstone, siltstone, laminite
		JERRYS PLAINS SUBGROUP	MT LEONARD FORMATION	WHYBROW SEAM	LD	moderate to low sulphur
			ALTHORP FORMATION		LD	claystone
			MALABAR FORMATION	REDBANK CREEK SEAM	LD	moderate sulphur
				WAMBO SEAM	LD	low sulphur
				WHYNOT SEAM	LD	low sulphur
				BLAKEFIELD SEAM	LD	moderate to low sulphur
				SAXONVALE MBR	LD	moderate sulphur
			MOUNT OGILVIE FORMATION	GLEN MUNRO SEAM	UD.LD	moderate sulphur
				WOODLANDS HILL SEAM	UD	low sulphur
			MILBRODALE FORMATION		UD	claystone
			MOUNT THORLEY FORMATION	ARROWFIELD SEAM	UD	low sulphur
				BOWFIELD SEAM	UD	low sulphur
				WARKWORTH SEAM	UD	low sulphur
			FAIRFORD FORMATION		UD	claystone marker
			BURNAMWOOD FORMATION	MT. ARTHUR SEAM	UD	low sulphur
				PIERCEFIELD SEAM	UD	low sulphur
				VAUX SEAM	LD.UD	low sulphur
				BROONIE SEAM	LD	moderate to high sulphur
				BAYSWATER SEAM inc. RAVENSWORTH	LD	marker seam – low sulphur
			ARCHERFIELD SANDSTONE		MR	lithic sandstone – marker bed
		VANE SUBGROUP	BULGA FORMATION		MT	sandstone, siltstone, laminite
			FOYBROOK FORMATION	LEMINGTON - WYNN SEAM	ULD	moderate to high sulphur
				PIKES GULLY - BENGALLA SEAM	UD	moderate to low sulphur
				ARTIES - EDENGLASSIE SEAM	UD	moderate to low sulphur
				LIDDELL - RAMROD CK. SEAM	LUD	moderate to low sulphur
				BARRETT SEAM	LD	moderate sulphur
				HEBDEN SEAM	LD	moderate to high sulphur
			SALTWATER CK FORMATION		MR	sandstone, siltstone, laminite
MAITLAN D GROUP			MULBRING SILTSTONE		MT	siltstone claystone
			MUREE SANDSTONE		MR	sandstone, siltstone, congl.
			BRANXTON FORMATION		MT	sandstone, siltstone, congl.
	GRETA COAL MEASURES		ROWAN FORMATION	HILLTOP SEAM	UD.LD	low sulphur
				BROUGHAM SEAM	UD	low sulphur
				PUXTREES SEAM	UD	low sulphur
				AYRDALE SANDSTONE	UD	sandstone
				BALMORAL SEAM	LD	moderate sulphur
			SKELETAR FORMATION			rhyolite, chert, claystone

MT=marine transgression MR=marine regression LD=lower deltaic UD=upper deltaic ULD=upper to lower delts LUD=lower to upper delta SM=sub marine

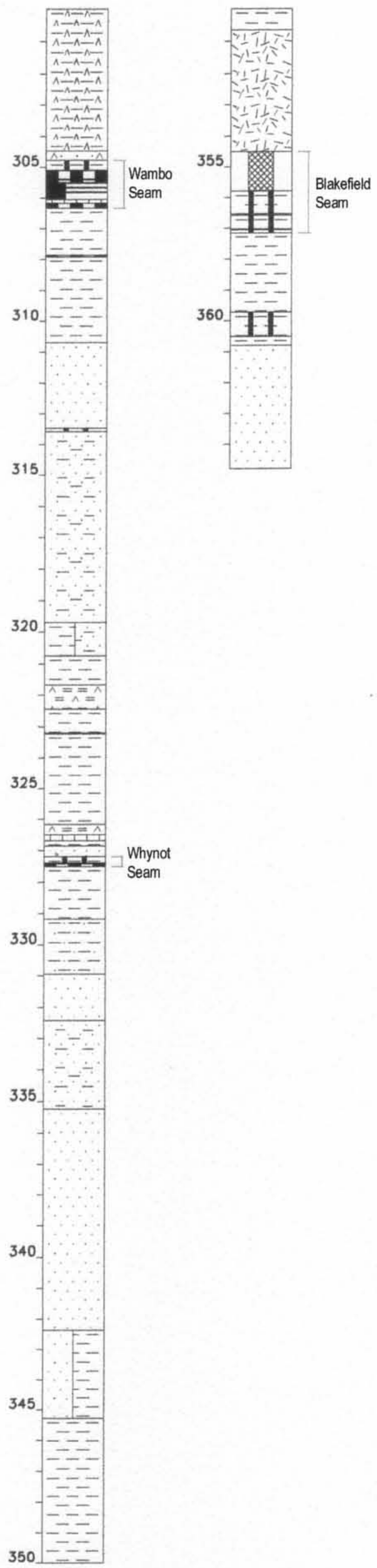
Figure 3



Stratigraphic log for borehole PAH18

stratigraphic detail provided by Centennial

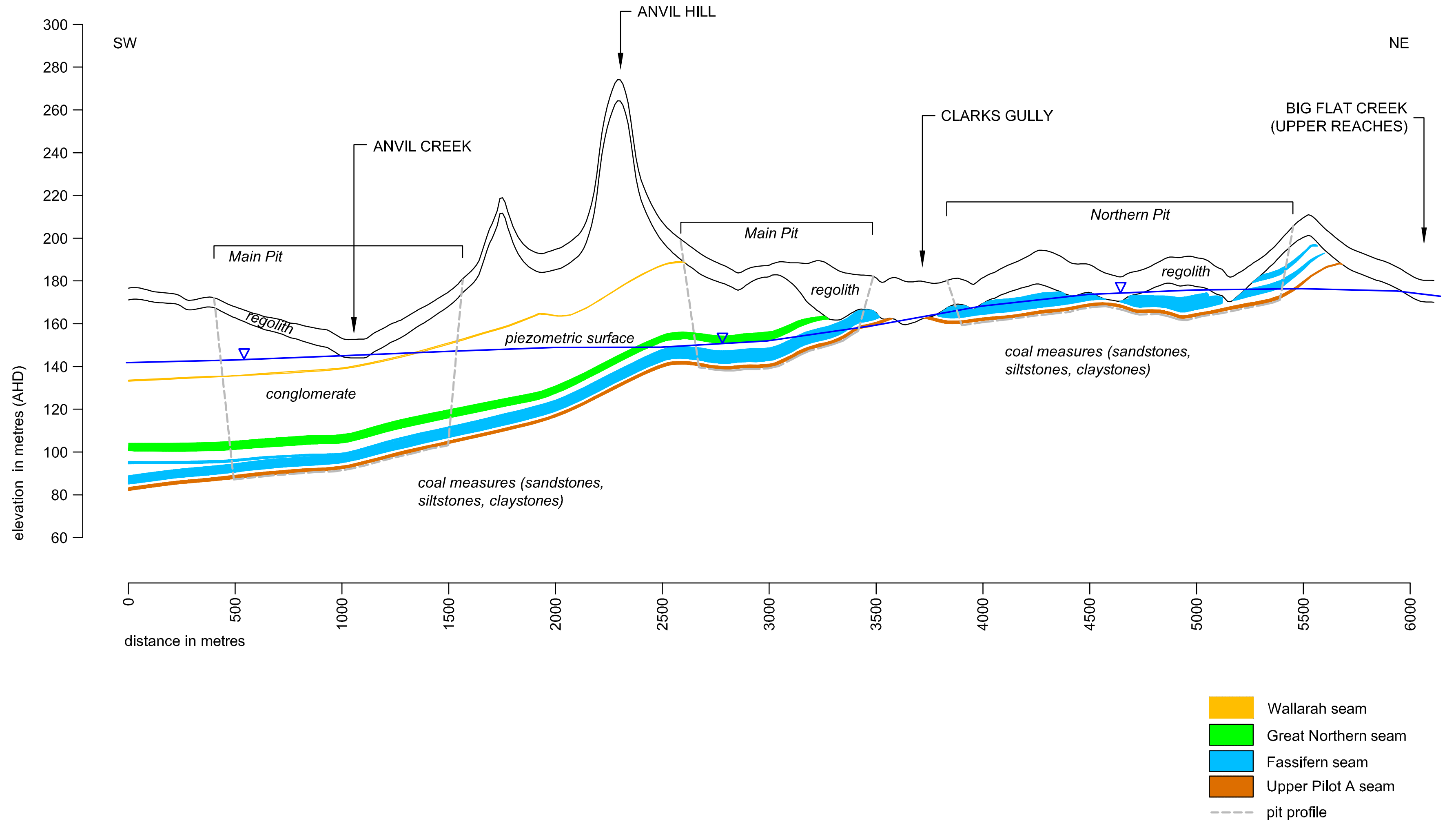
Figure 4



Stratigraphic log for borehole PAH18

stratigraphic detail provided by Centennial

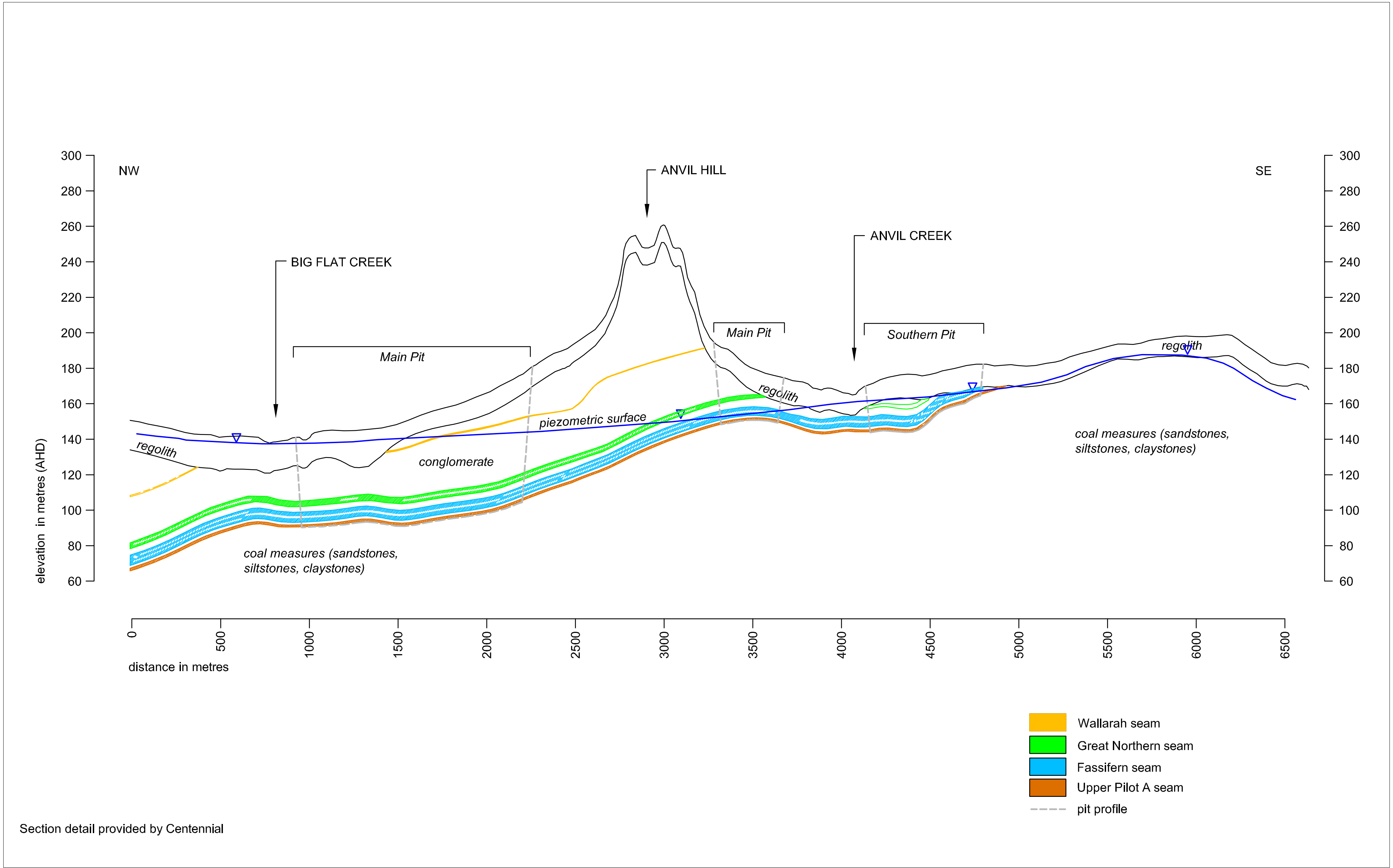
Figure 4 ct'd



Section detail provided by Centennial

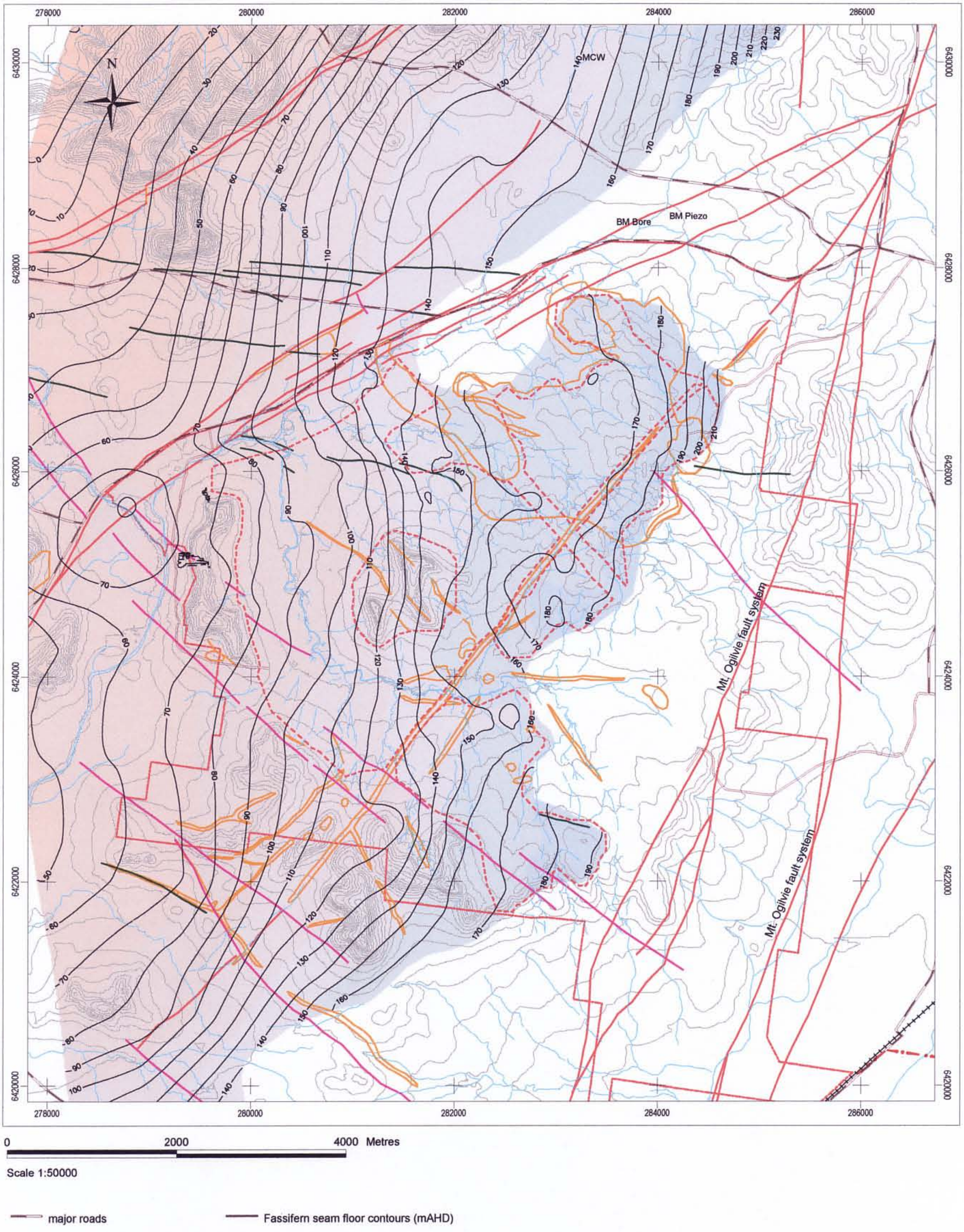
Vertical section SW01 - Southwest to northeast

Figure 5



Vertical section NE02 - North-west to south-east

Figure 6



ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Fassifern seam floor, faults and dykes

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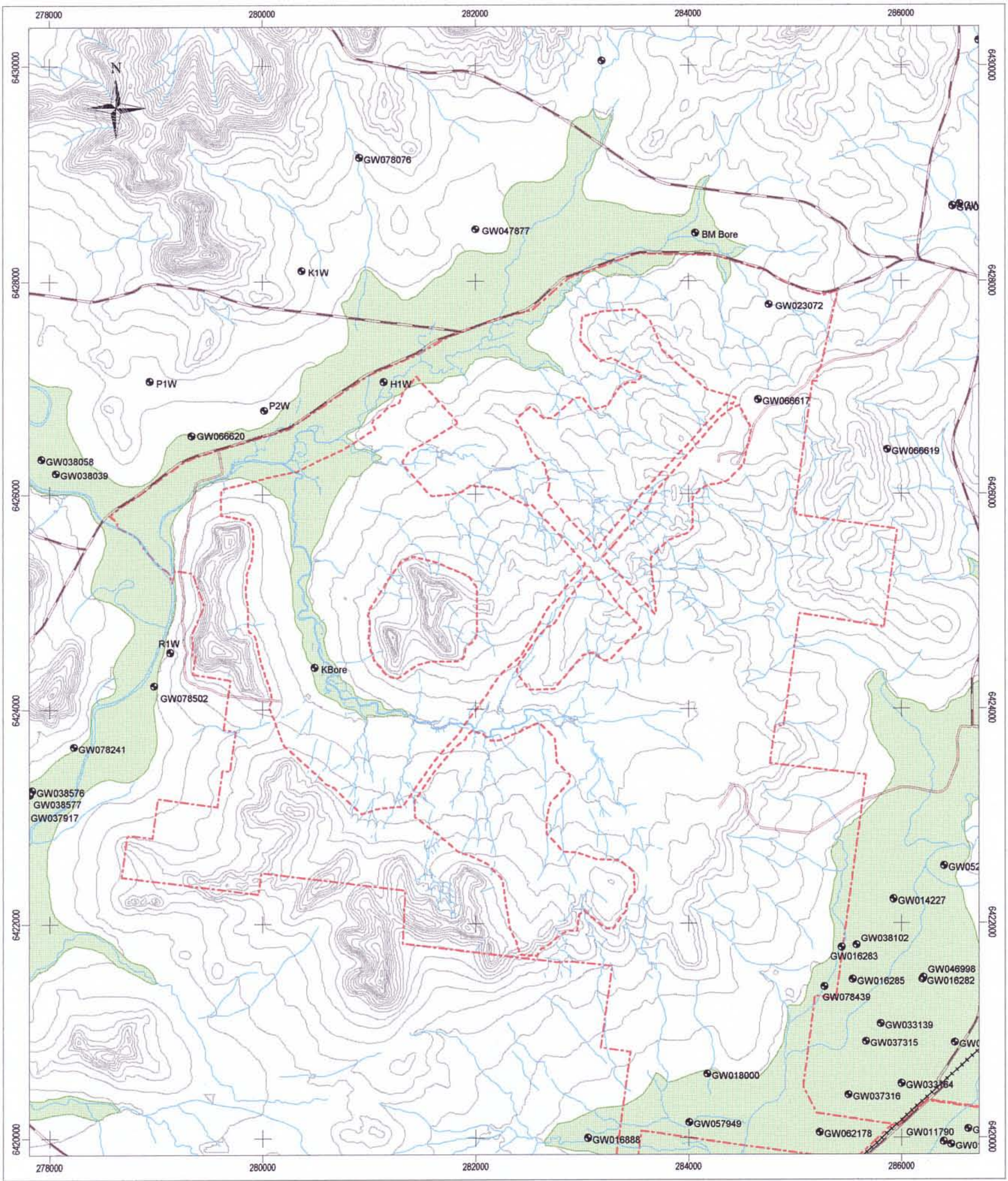
Figure 7



0 2000 4000 Metres

Scale 1:50000

Some private bore locations may be subject to location error

- alluvium
- topo contours (10m interval)
- railway
- major roads
- drainages
- project application area
- private bores and wells
- proposed mining area boundary

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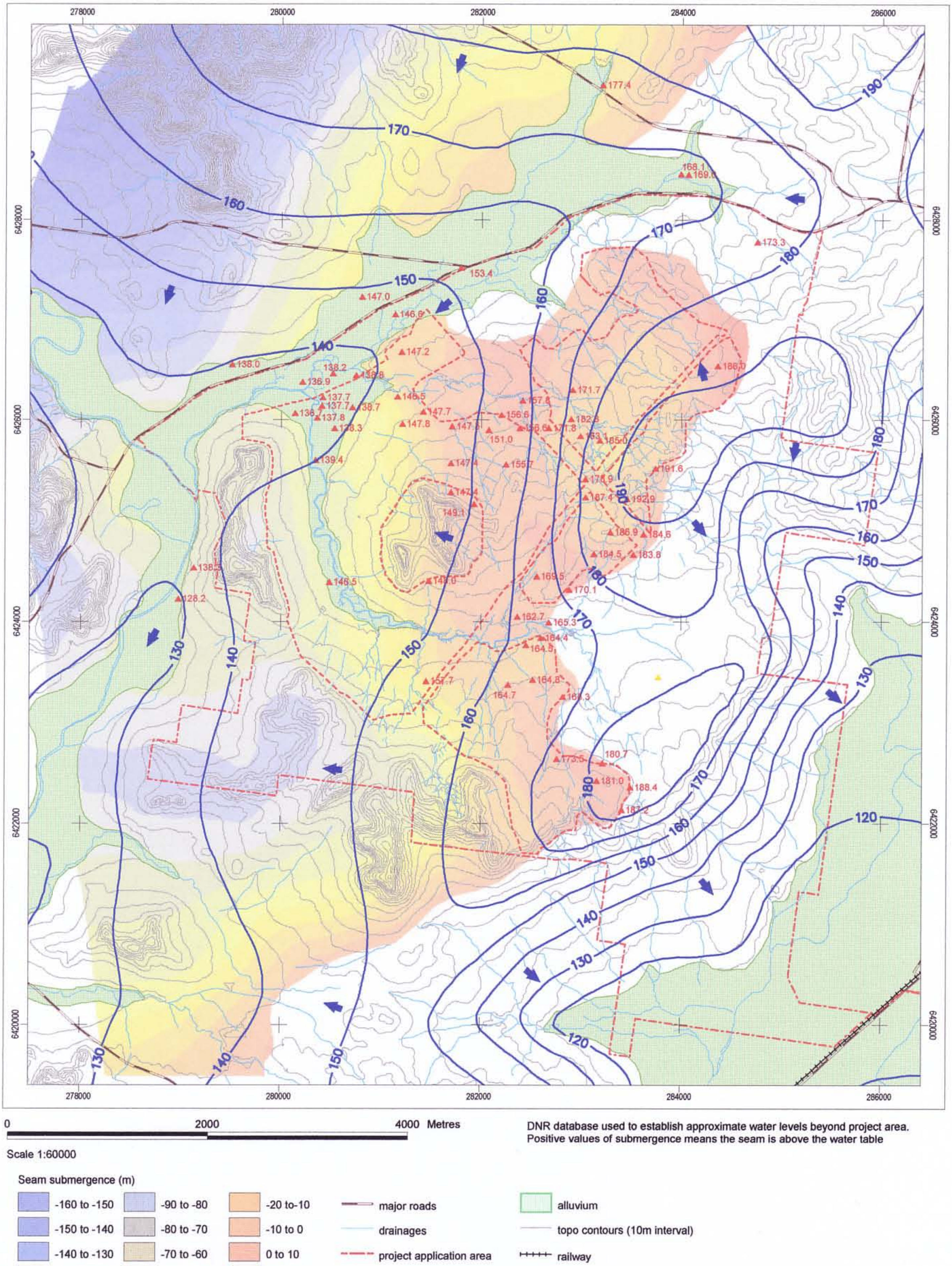
ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

DNR registered private bores, wells excluding monitoring piezometers

Figure 8



DNR database used to establish approximate water levels beyond project area.
Positive values of submergence means the seam is above the water table

ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Composite piezometric surface (Oct. 2005) and Fassifern seam submergence

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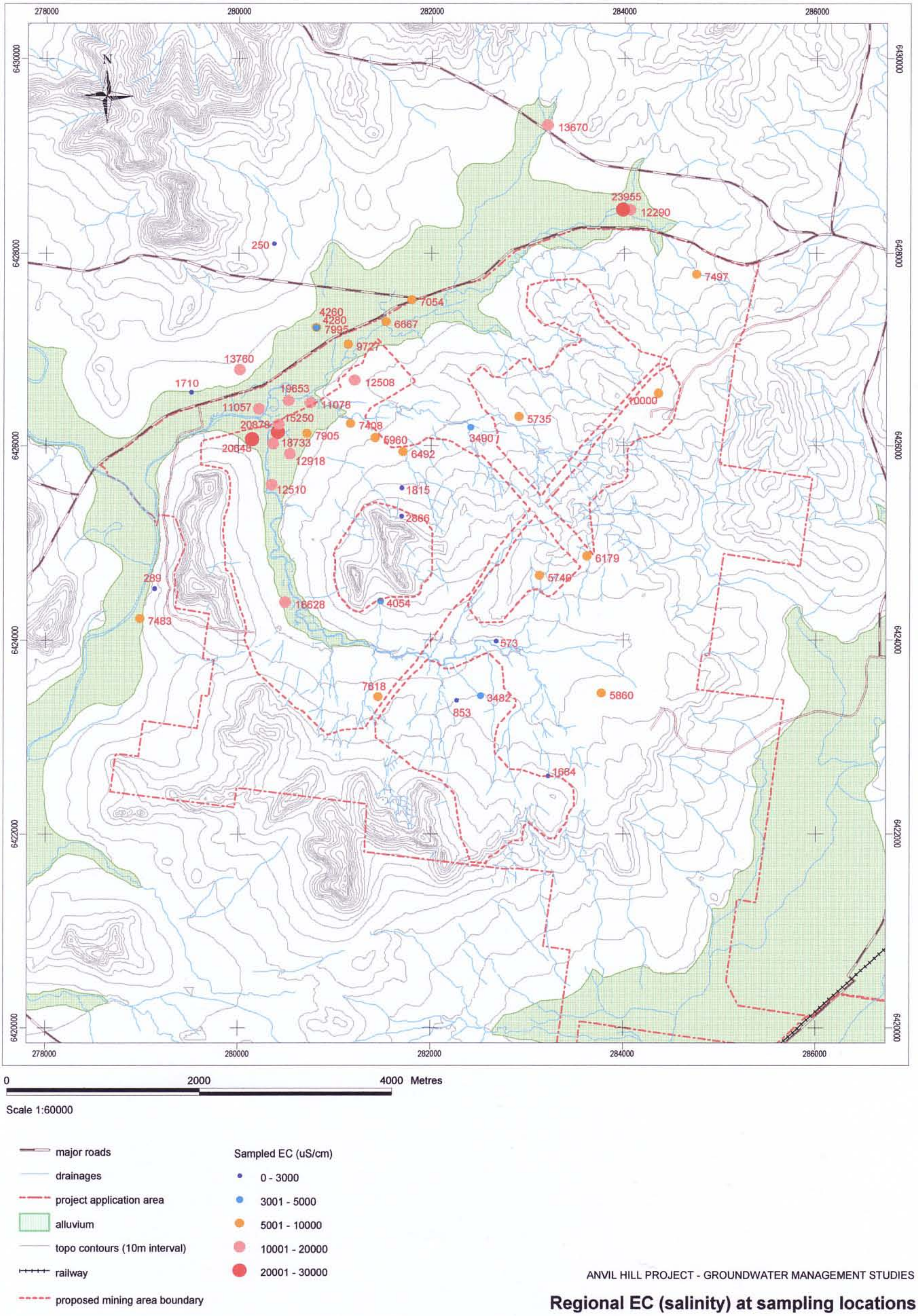
Figure 9



ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Regional EC (salinity) at sampling locations

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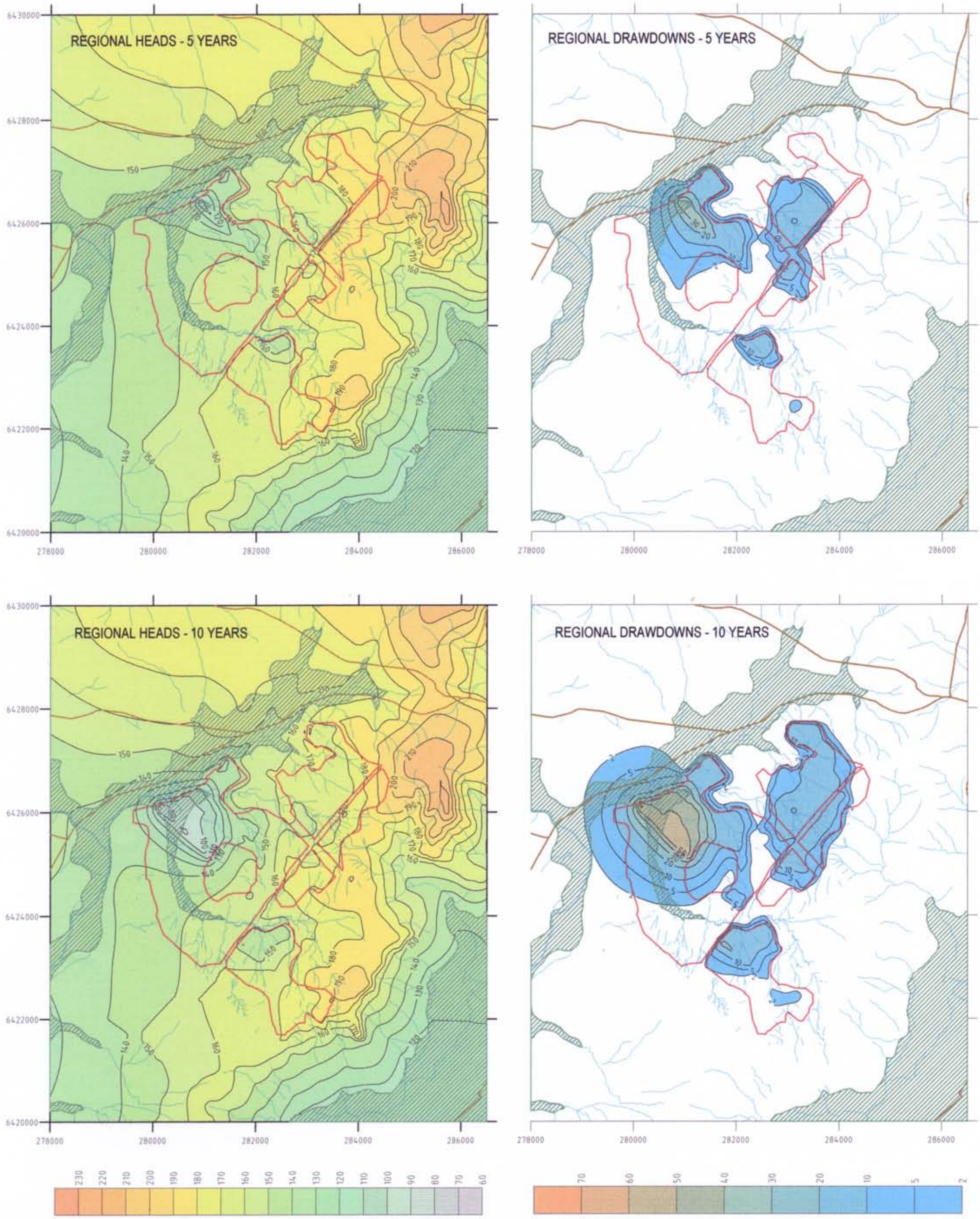
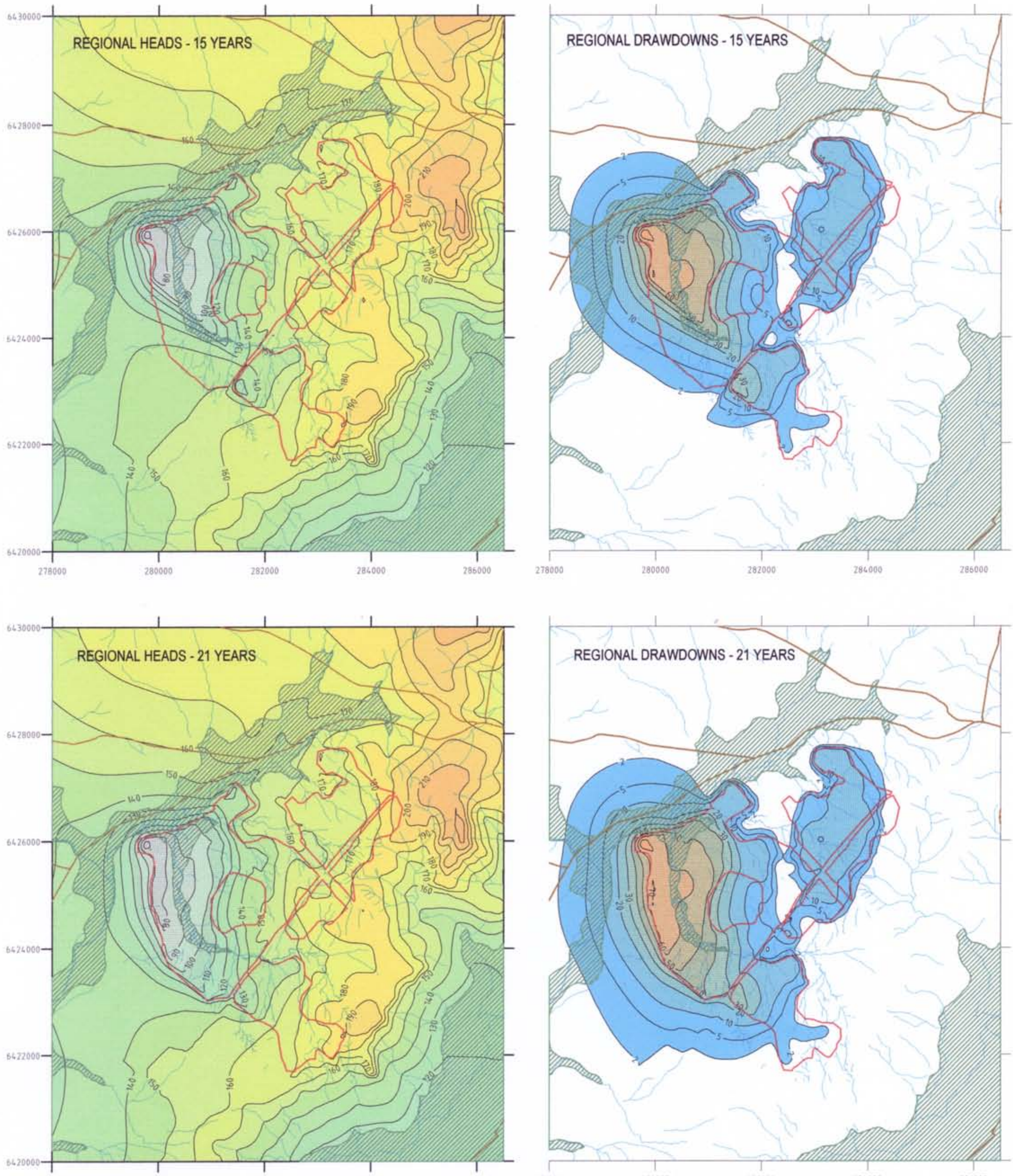
Figure 10



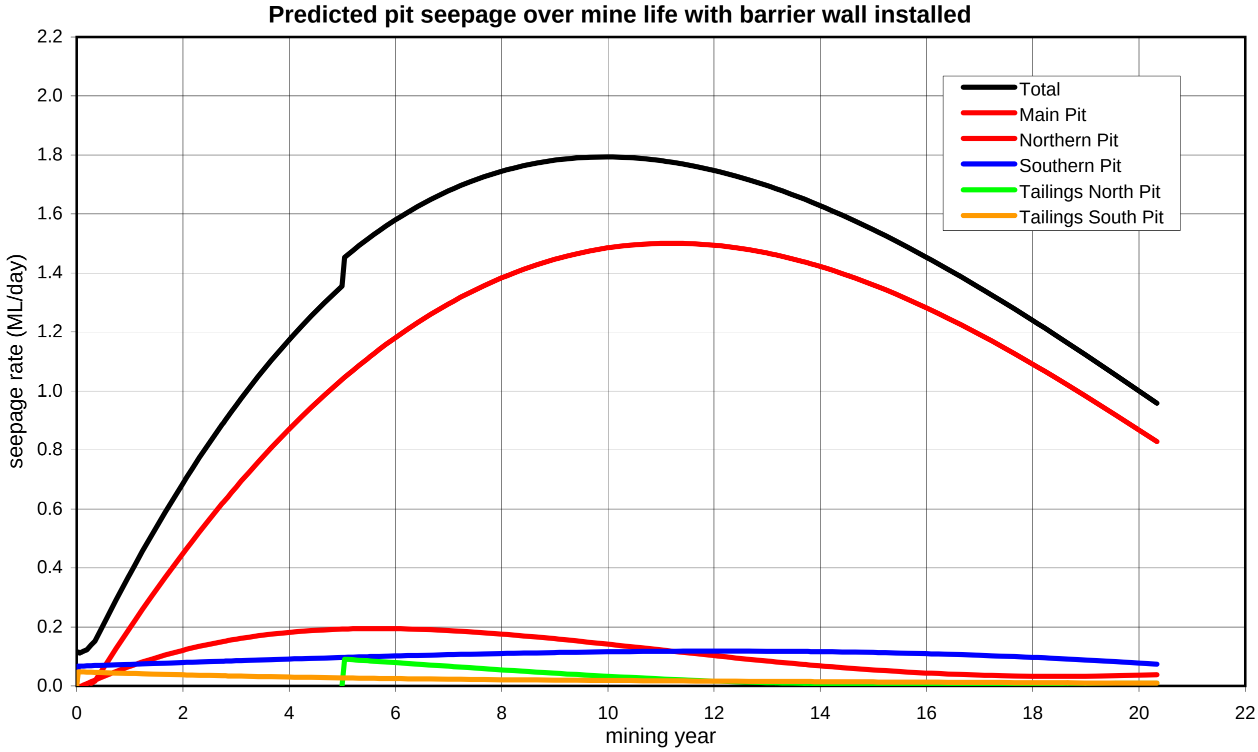
Regional pressure heads and drawdowns (Fassifern-UP-A seam)

Figure 11a

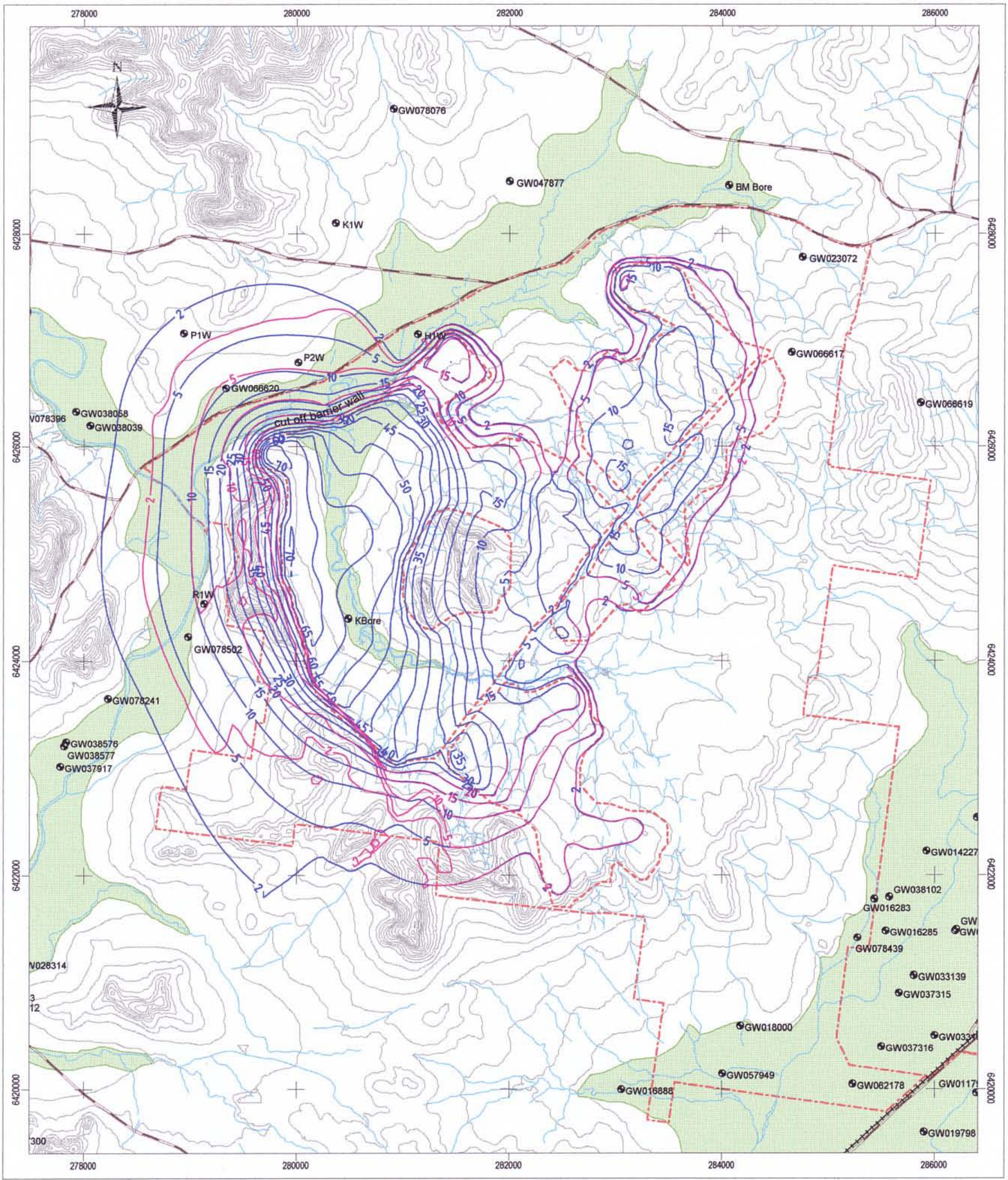


Regional pressure heads and drawdowns (Fassifern-UP-A) seam

Figure 11b



Predicted daily seepage rates to each mine pit. Note that Main Pit generates the highest contribution due to the large pit area and increasing submergence below the water table in a westerly direction. Seepage peaks in mining year 11 then declines steadily as the rate of exposure of highwall in Main Pit progressively reduces towards the final void.



0 1000 2000 3000 Metres

Scale 1:50000

- alluvium
- topo contours (10m interval)
- railway
- major roads
- drainages
- project application area
- DNR bore search
- proposed mining area boundary
- drawdown in Fassifern seam (m)
- drawdown in conglomerates (m)

ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Model predicted drawdowns at the completion of mining

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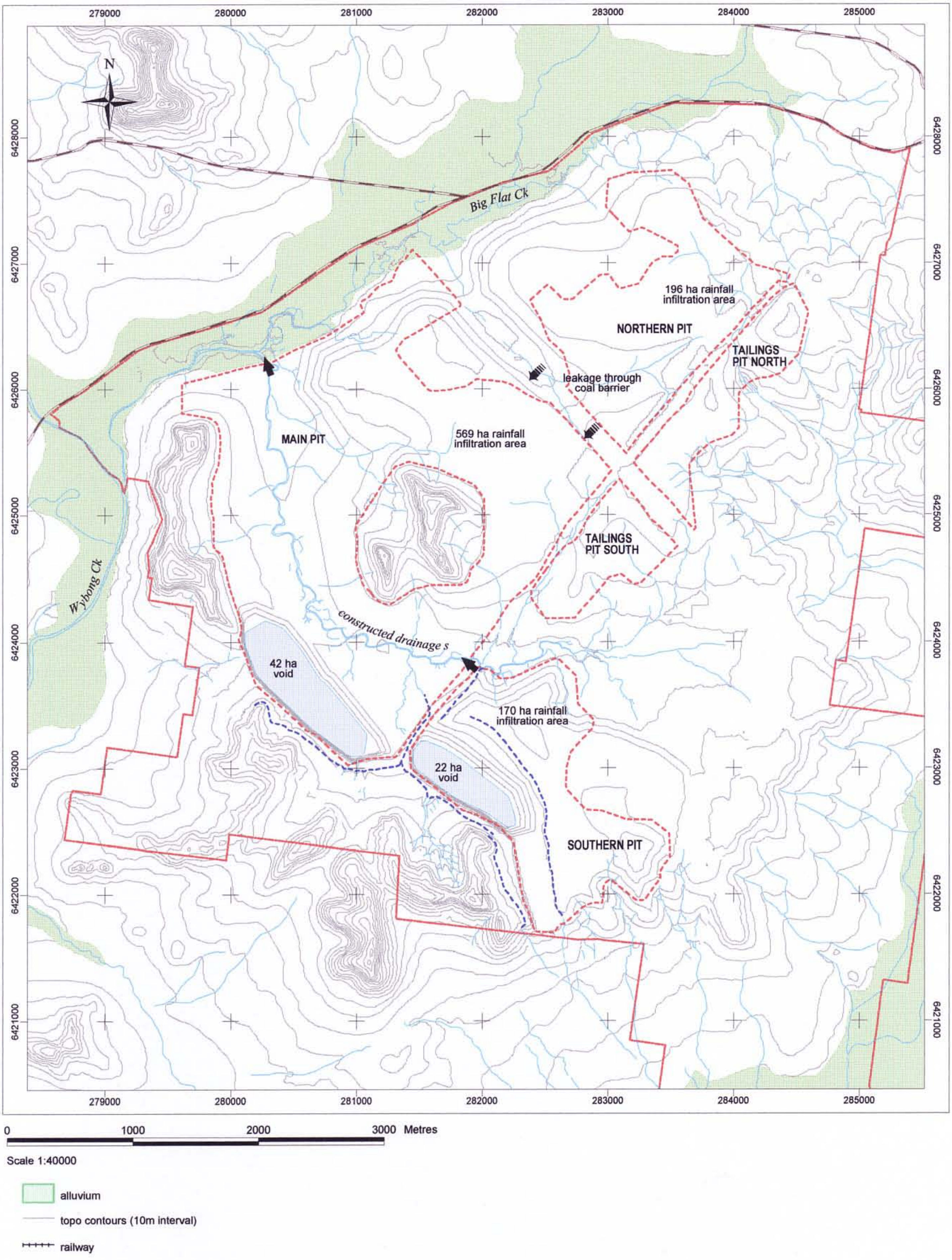
Figure 13



ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Final voids in Main and Southern pits

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Figure 14

APPENDIX A: CLIMATE DATA

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

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

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

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

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

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

ARI (Average Recurrence Interval) 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 90 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 90 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)and rainfall in mm - Scone.

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

APPENDIX B: PIEZOMETRIC SURFACE MONITORING DATA

A substantial network of monitoring bores has been established within the Project Area and surrounding areas. This network includes piezometers constructed in the Fassifern seam and the coal measures generally (includes interburden), piezometers constructed in the alluvial lands associated with Big Flat and Anvil Creeks, and dual-multi piezometer completions to examine vertical pressure distributions. A number of existing bores and wells are also monitored. The following Table B1 provides completion details while Figure B1 provides monitoring locations.

The commencement of monitoring varies across the piezometer network due to the staged completion of piezometers (based upon exploration drilling). In general the approach adopted for nominating a piezometer location was to regularly review geological exploration drill hole results and to install a piezometer if an increased understanding of groundwater pressures at a local scale was required (eg. Big Flat Creek alluvium).

Water level monitoring data is summarised in the plots provided as Figures B2 to B6. Reference to these plots supports the following:

- Piezometric levels in shallow alluvium piezometers have been generally stable over the monitoring period from the third quarter of 2004 (eg. CALM and BM piezometers). These piezometers are located within a few metres of surface;
- Piezometric levels in deeper alluvium in the vicinity of the confluence of Big Flat and Anvil creeks, are generally stable over the relatively short period of monitoring. Weak rising or falling trends are attributed to equilibration with the low permeability silty-clayey alluvial materials;
- Piezometric levels in the Fassifern seam have fallen by a metre or more since mid 2003 with a slowing in the rate of decline since mid 2004. The steady loss of pressure is attributed to reduced recharge in sub crop areas situated in the eastern part of the area . Levels are expected to rise with the future onset of increased rainfall.

B1.1 Semi continuous water level measurements

In addition to bi-monthly monitoring, ten of the piezometers are equipped with automated water level loggers capturing levels at 8 hour intervals (below Nyquist frequency for daily oscillation). These locations are distributed across the area in order to provide information in respect of rainfall recharge, barometric efficiencies and other processes.

Figures B7 and B8 provide results of monitoring. Inspection of these plots supports the following:

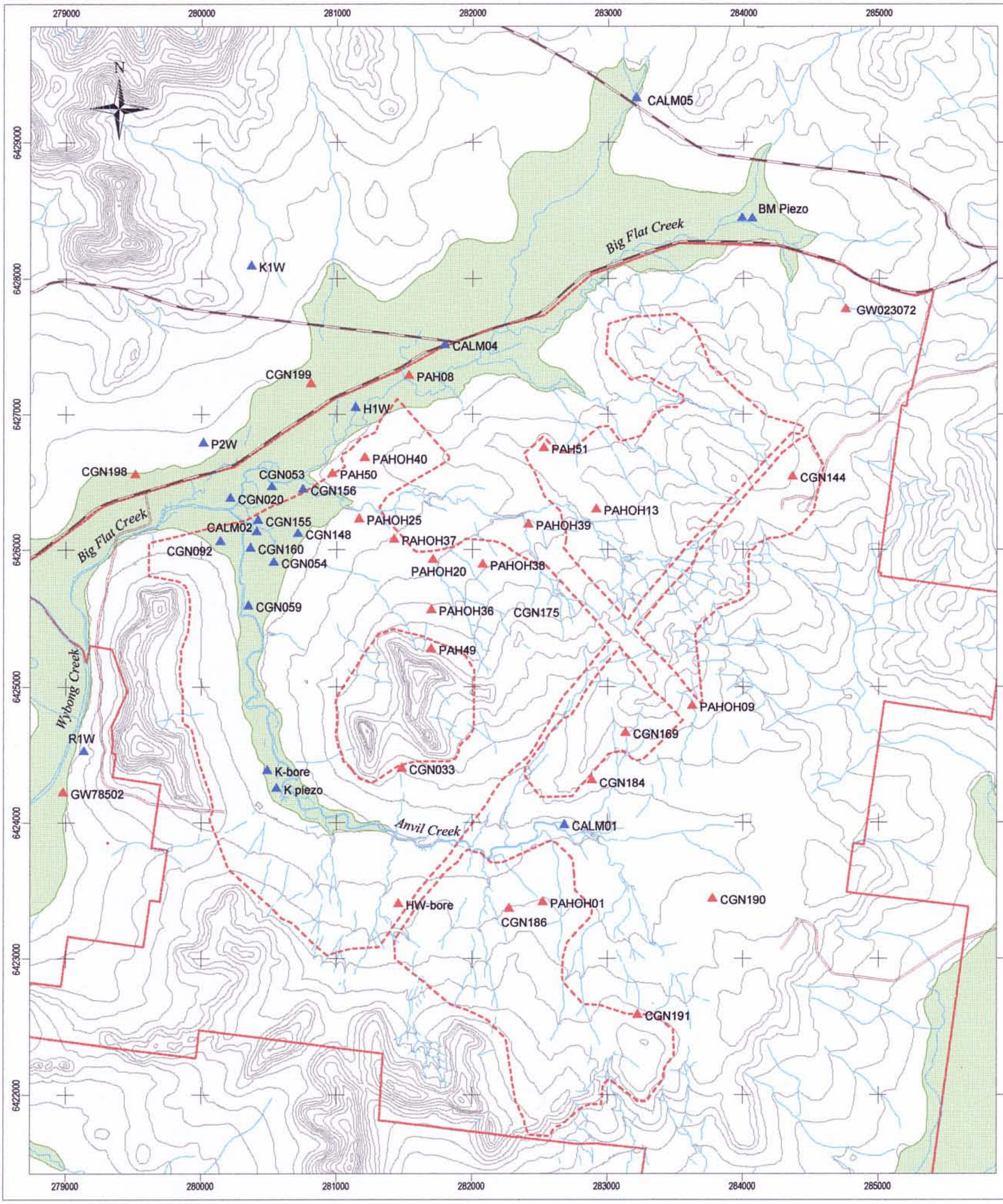
- Effective rainfall recharge is not evident over the period of monitoring (generally dry or drought conditions prevailed);
- Barometric oscillations of several millimetres are evident in most piezometers suggesting semi confined to confined storage conditions (including Big Flat Creek and Anvil Creek alluvium. Figure B9 provides a stacked plot for comparative purposes.

Table B1: Active monitoring locations

Bore	**Stratigraphy**	**Depth (mbGL)**	**Comment**	**Frequency**
BM bore	Big Flat Ck alluvium	6.71	steel cased in alluvial flats	2 months
BM (deep piezo)	Big Flat Ck alluvium	3.80	PVC 40mm piezo	2 months
BM (shallow piezo)	Big Flat Ck alluvium	2.38	PVC 40mm piezo	2 months
CALM01	Anvil Ck alluvium	3.94	PVC 40mm piezo in creek bed	2 months
CALM02	Anvil Ck alluvium	7.91	PVC 40mm piezo	2 months
CALM04 (deep)	Big Flat Ck alluvium	5.03	PVC 40mm piezo	2 months

Bore	Stratigraphy	Depth (mbGL)	Comment	Frequency
CALM04 (shallow)	Big Flat Ck alluvium	3.03	PVC 40mm piezo	2 months
CGN020	Big Flat Ck alluvium	24.70	PVC 65mm piezo	logger
CGN033	Fassifern seam	49.10	PVC 50mm piezo	logger
CGN053	Big Flat Ck alluvium	21.80	PVC 65mm piezo	2 months
CGN054	Anvil Ck alluvium	26.80	PVC 65mm piezo	2 months
CGN059	Anvil Ck alluvium	20.80	PVC 65mm piezo	logger
CGN092	Anvil Ck alluvium	14.80	PVC 65mm piezo	2 months
CGN144	coal measures	100.2	PVC 25mm piezo	2 months
CGN148	Anvil Ck alluvium	27.80	PVC 65mm piezo	logger
CGN155	Anvil Ck alluvium	24.70	PVC 65mm piezo	2 months
CGN156	Anvil Ck alluvium	23.80	PVC 65mm piezo	2 months
CGN160	Anvil Ck alluvium	20.80	PVC 65mm piezo	2 months
CGN169	Fassifern seam	26.6	PVC 50mm piezo	Logger
CGN184 deep	Fassifern seam		PVC 25mm multi piezo	2 months
CGN184 shallow	conglomerate		PVC 25mm multi piezo	2 months
CGN186	Fassifern seam		PVC 25mm piezo	2 months
CGN190	coal measures		PVC 25mm piezo	2 months
CGN191	Fassifern seam		PVC 50mm piezo	2 months
CGN198	Big Flat Creek alluvium	88.00	PVC 25mm piezo	2 months
CGN199-A1	Big Flat Creek alluvium		PVC 25mm multi piezo	2 months
CGN199-A2	Big Flat Creek alluvium	32.00	PVC 25mm multi piezo	2 months
CGN199-P1	Fassifern seam	32.00	PVC 25mm multi piezo	2 months
CGN199-P2		32.00	PVC 25mm multi piezo	2 months
GW023072	coal measures	50.00	not in use	2 months
GW078502	coal measures	58.00	steel cased bore - not in use	2 months
H1W well	Big Flat Creek alluvium	< 5	well - stock supply	2 months
HW-bore	coal measures	32.50	steel cased bore - not in use	2 months
K piezo	Anvil Ck alluvium	< 5	PVC 40mm collapsed - dry	2 months
K-bore	Anvil Ck alluvium	< 15.0	depth estimate (pump in hole)	2 months
K1W well	regolith	< 5	flowing spring-well	2 months
PAH08	interburden	76.70	artesian - steel cased and capped	2 months
PAH49	Fassifern seam	73.00	PVC 50mm piezo	2 months
PAH50	Fassifern seam	48.00	PVC 50mm piezo	2 months
PAH51	Fassifern seam	22.00	PVC 50mm collapsed at 22m	2 months
PAHOH01	Fassifern seam	26.60	PVC 50mm piezo	logger
PAHOH09	Fassifern seam	22.00	PVC 50mm piezo	logger
PAHOH13	Fassifern seam	20.60	PVC 50mm piezo	logger
PAHOH20	Fassifern seam	30.80	PVC 50mm piezo	Logger
PAHOH25	Fassifern seam	81.00	PVC 50mm piezo	2 months
PAHOH36	Fassifern seam	58.40	PVC 50mm piezo	2 months
PAHOH37	Fassifern seam	27.00	PVC 50mm piezo	2 months
PAHOH38	Fassifern seam	30.44	PVC 50mm piezo	2 months
PAHOH39	Fassifern seam	64.30	PVC 50mm piezo	2 months
PAHOH40	Fassifern seam	20.80	PVC 50mm piezo	logger
P2W well	Big Flat Creek alluvium	11.0	well	2 months
R1W well	regolith	<3.00	collapsing old wood lined well on hillside	

mbgl = metres below ground level



0 1000 2000 Metres

Scale 1:40000

- alluvium
- topo contours (10m interval)
- railway
- major roads
- drainages
- project application area
- proposed mining area boundary
- alluvium-regolith monitoring location
- hardrock monitoring location
- observed spring

ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Piezometer locations

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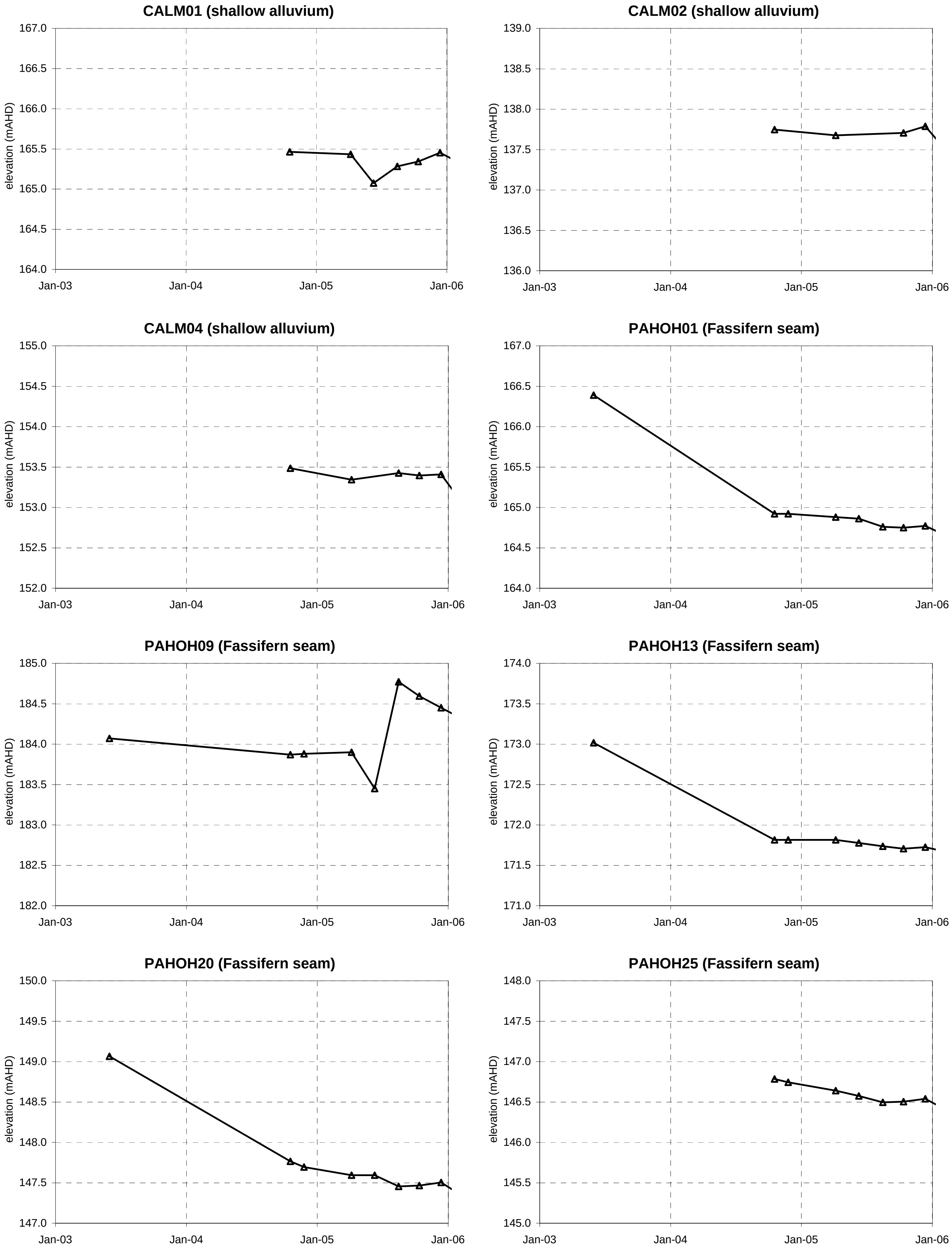
Figure B1



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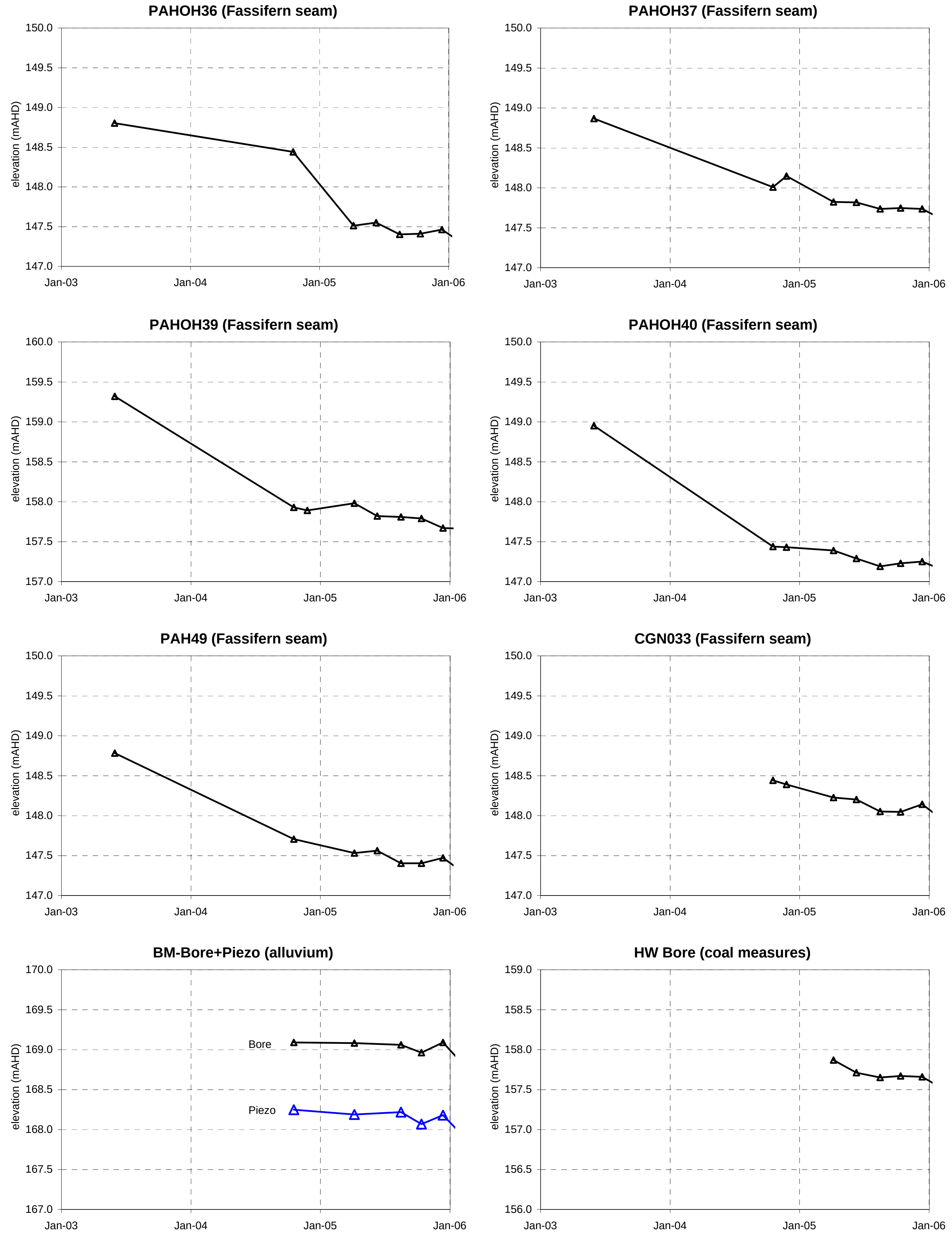
Historical piezometric levels

Figure B2

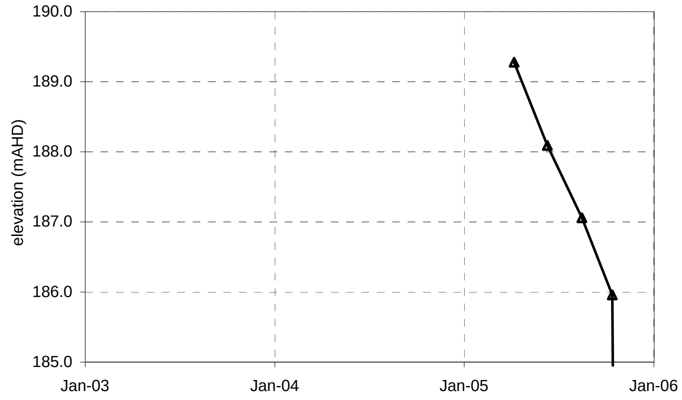


Mackie Environmental Research

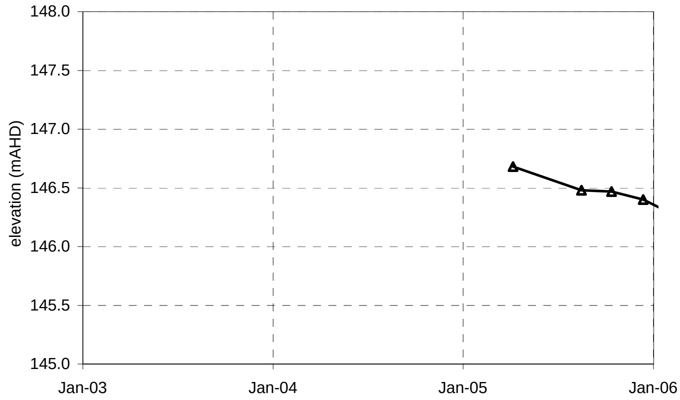
Historical piezometric levels

Figure B3

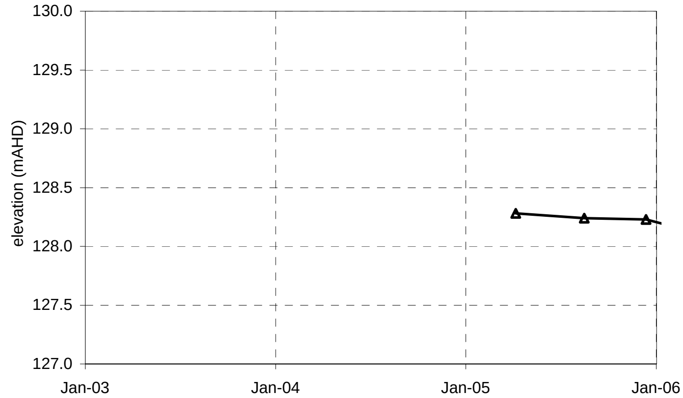
CGN144 (coal measures)



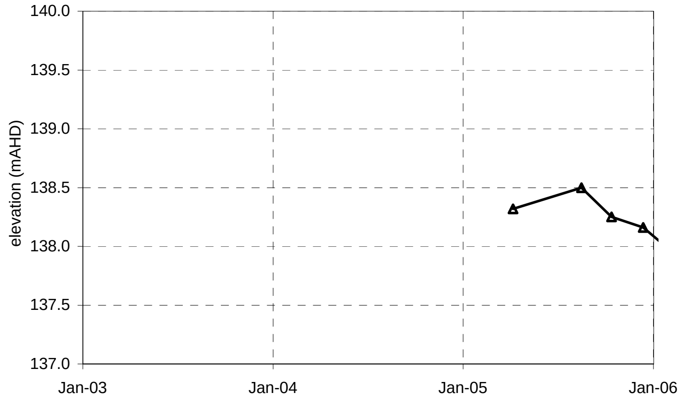
K Bore (alluvium)



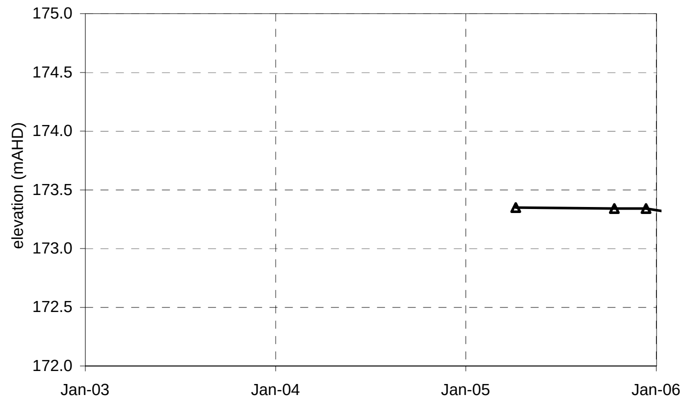
GW078502 - (coal measures)



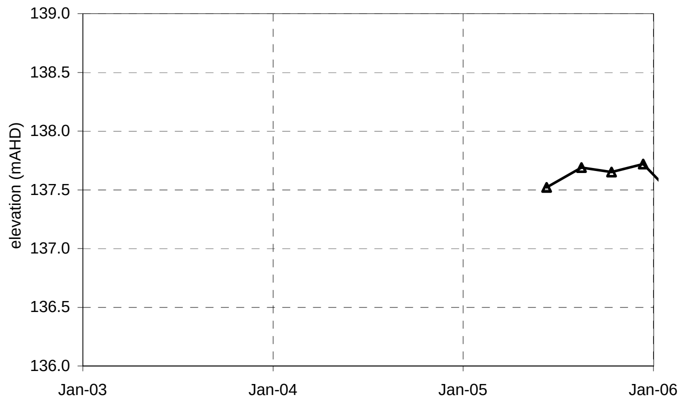
R1W (regolith)



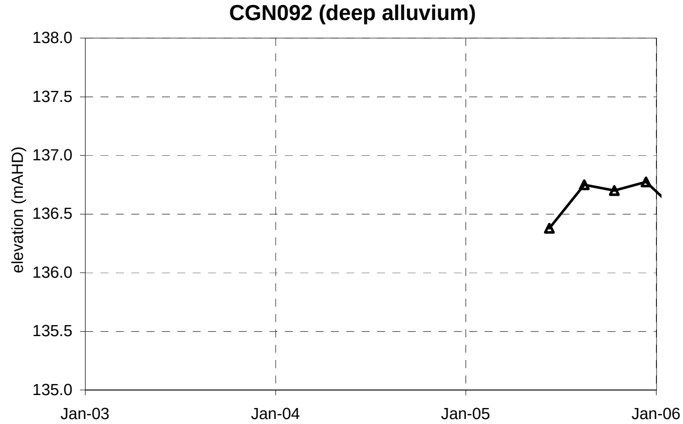
GW023072 (coal measures)



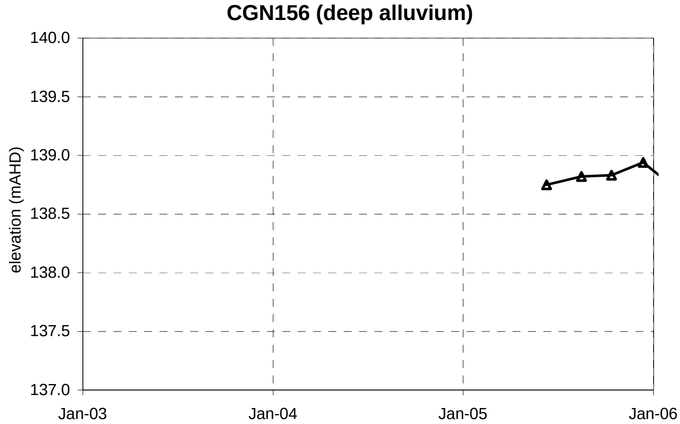
CGN155 (deep alluvium)



CGN092 (deep alluvium)

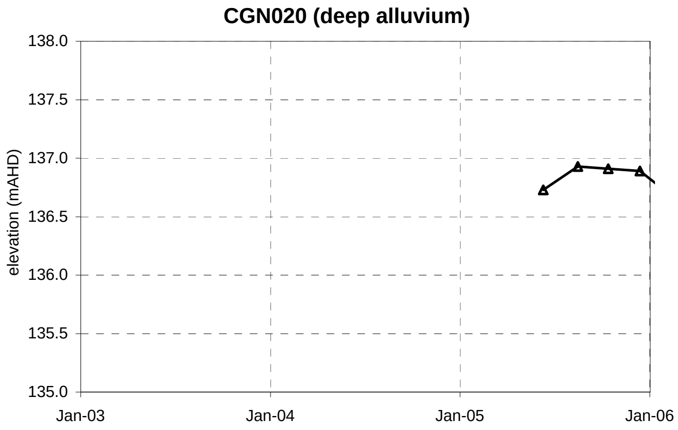


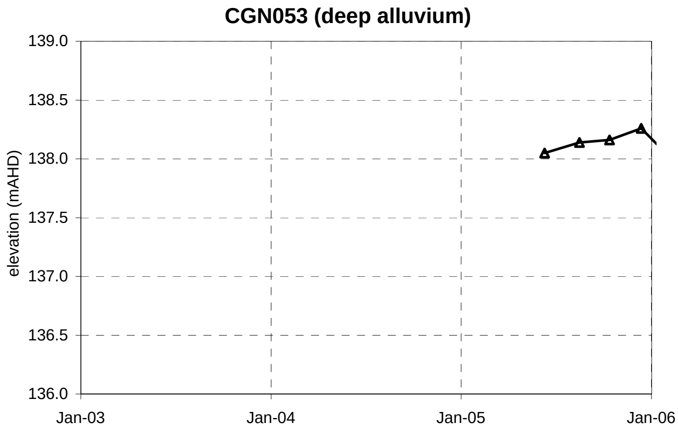
CGN156 (deep alluvium)

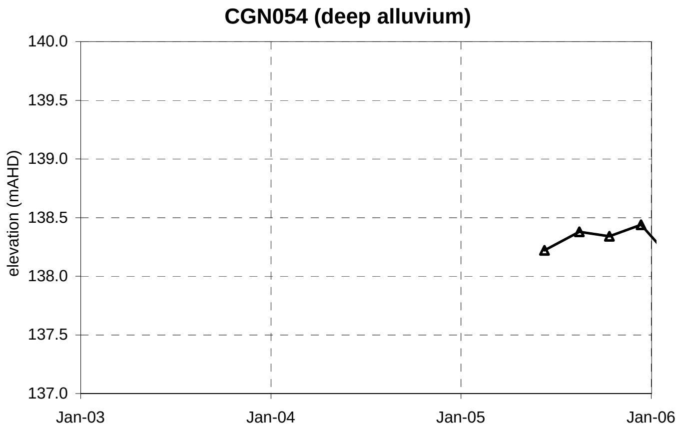


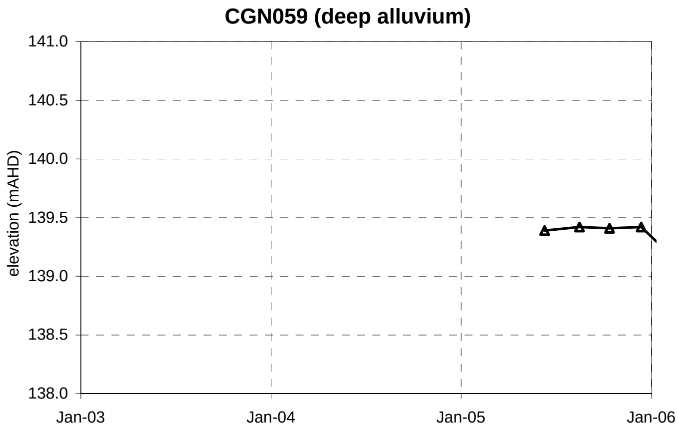
Historical piezometric levels

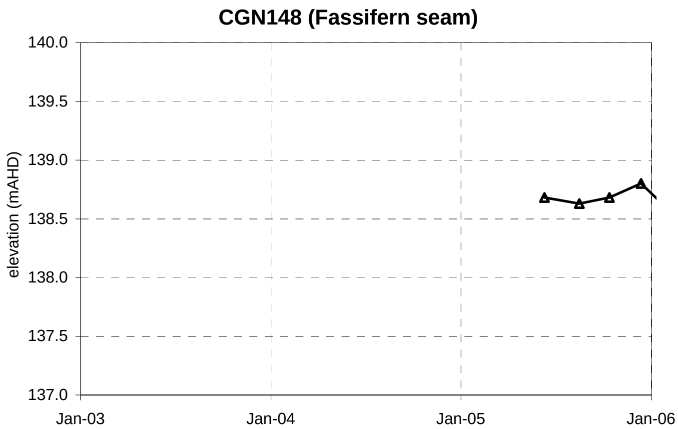
Figure B4

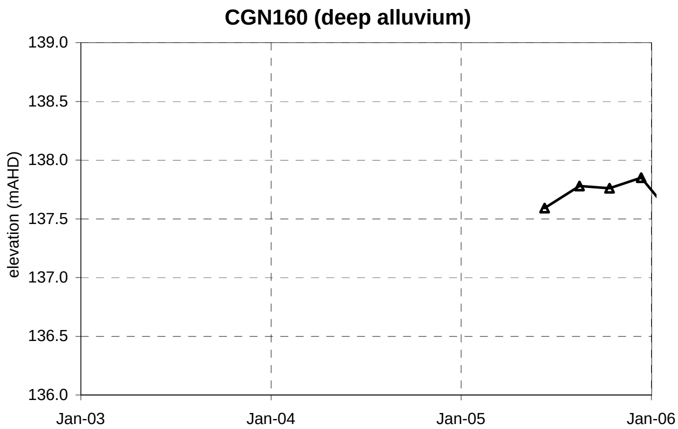


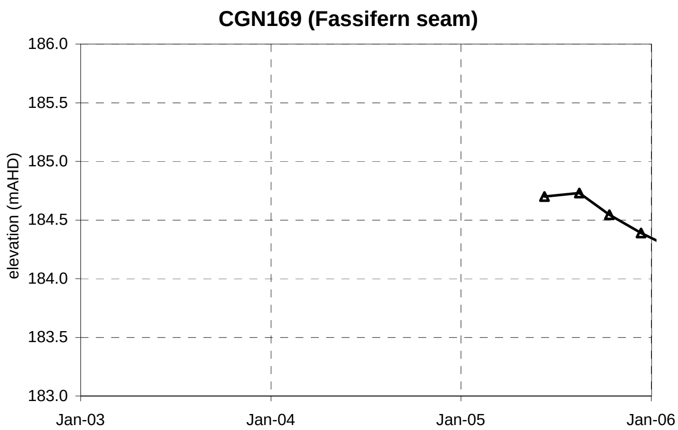


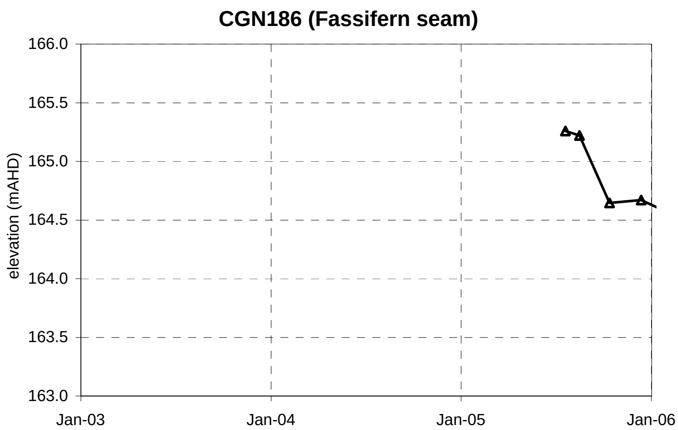






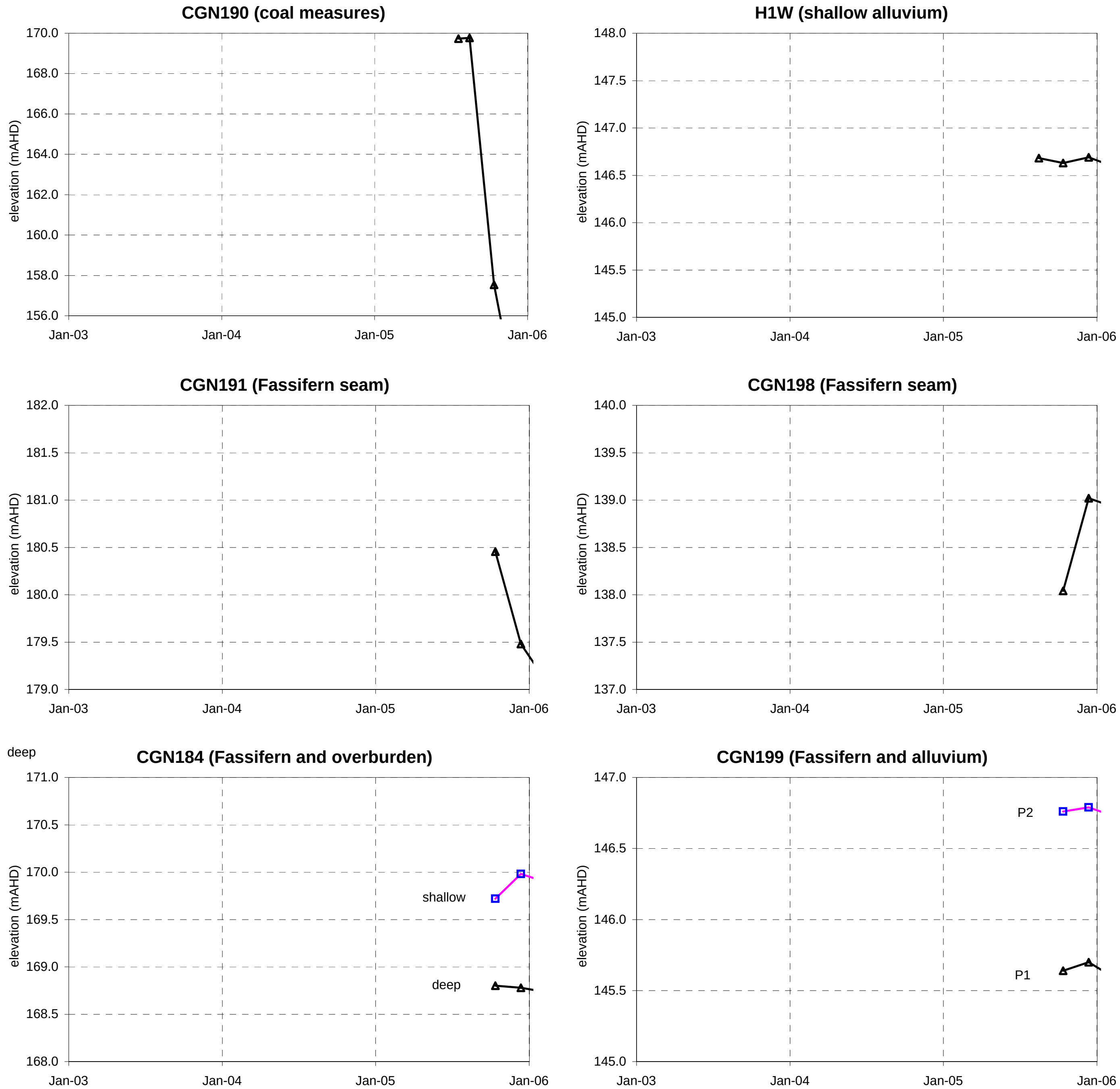






Historical piezometric levels

Figure B5



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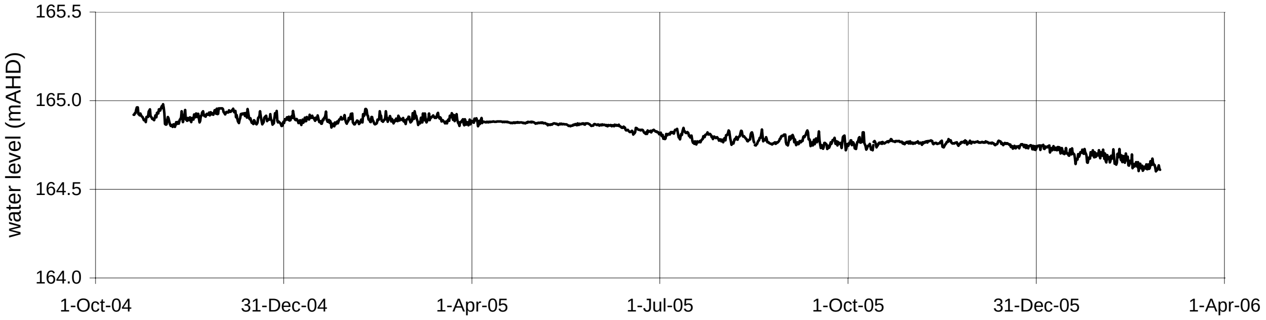
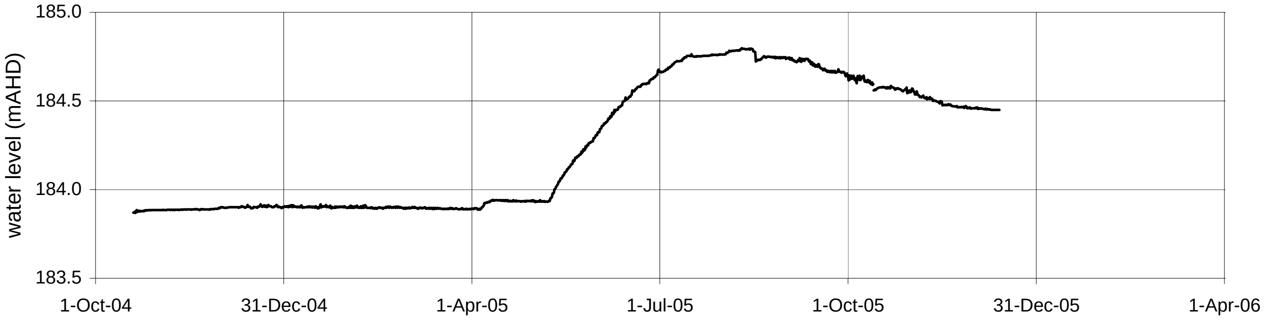
Historical piezometric levels

Figure B6

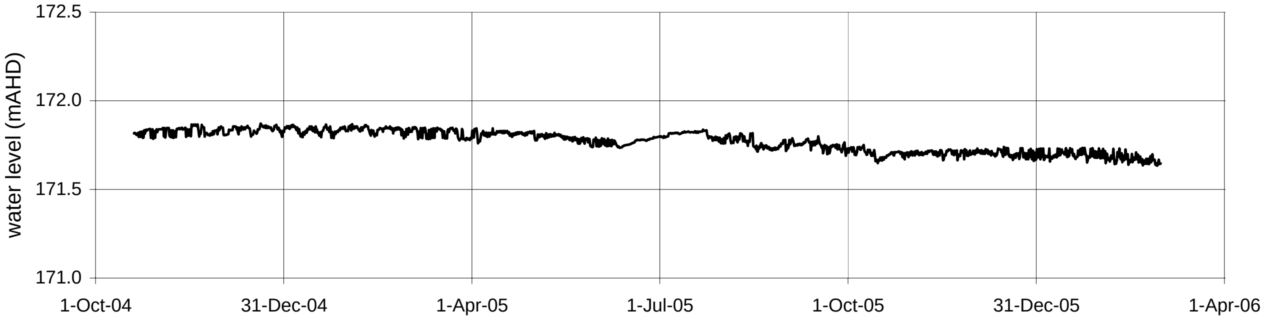
Logger data for PAHOH01 - Fassifern seam



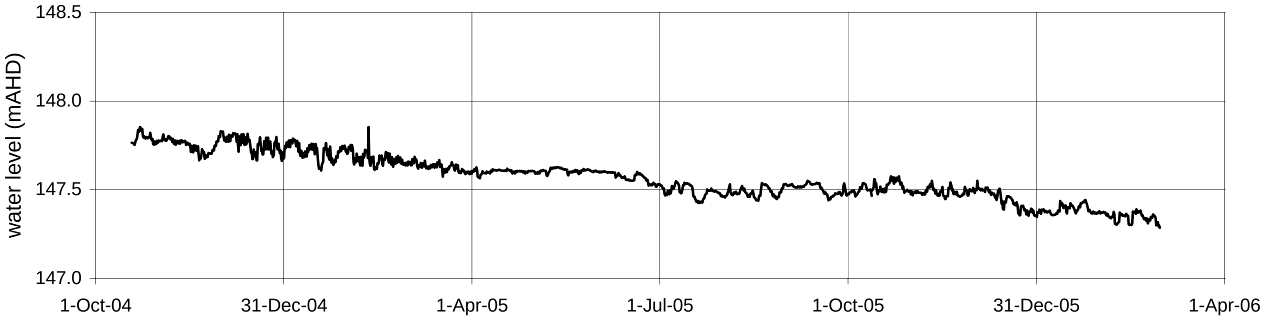
Logger data for PAHOH09 - Fassifern seam



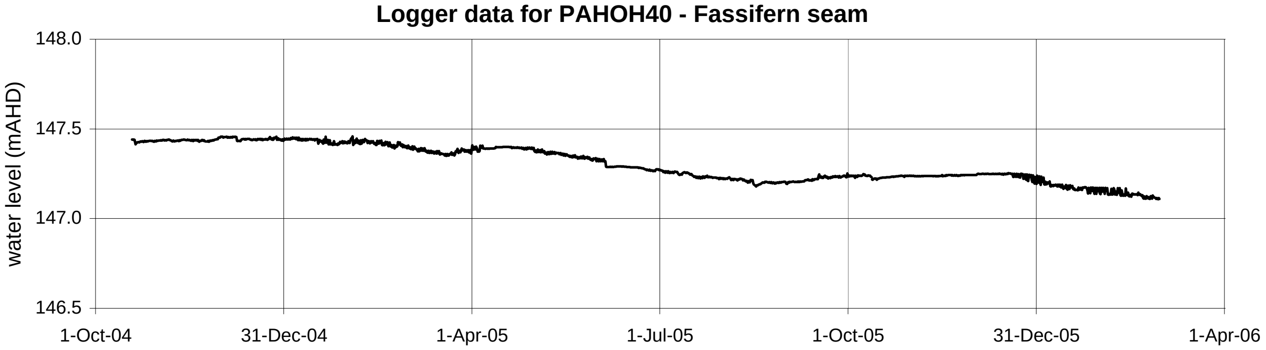
Logger data for PAHOH13 - Fassifern seam



Logger data for PAHOH20 - Fassifern seam

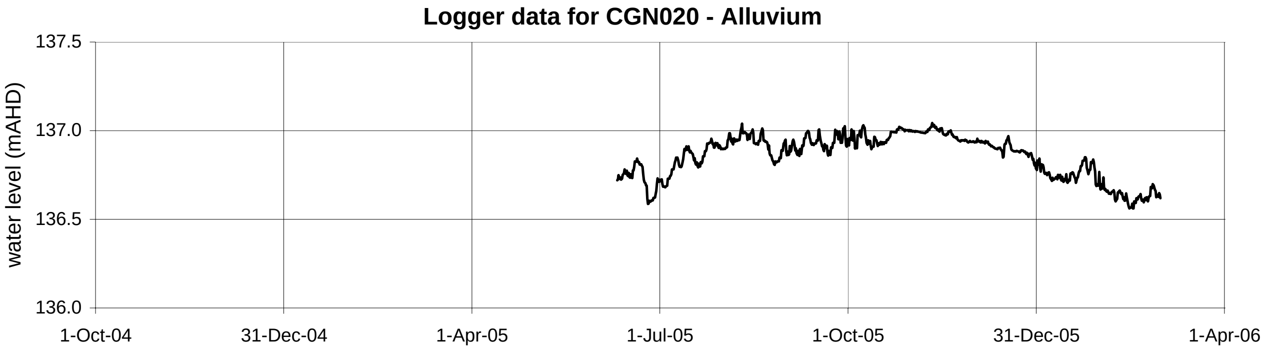


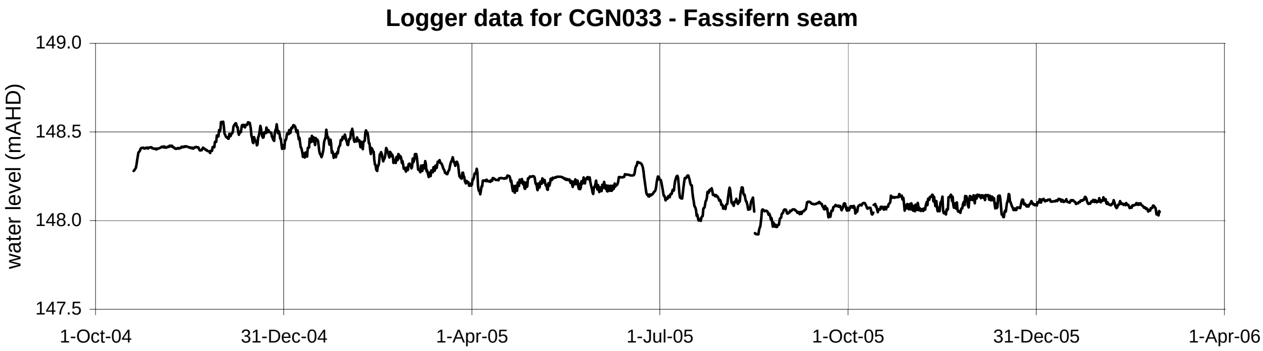
Logger data for PAHOH40 - Fassifern seam

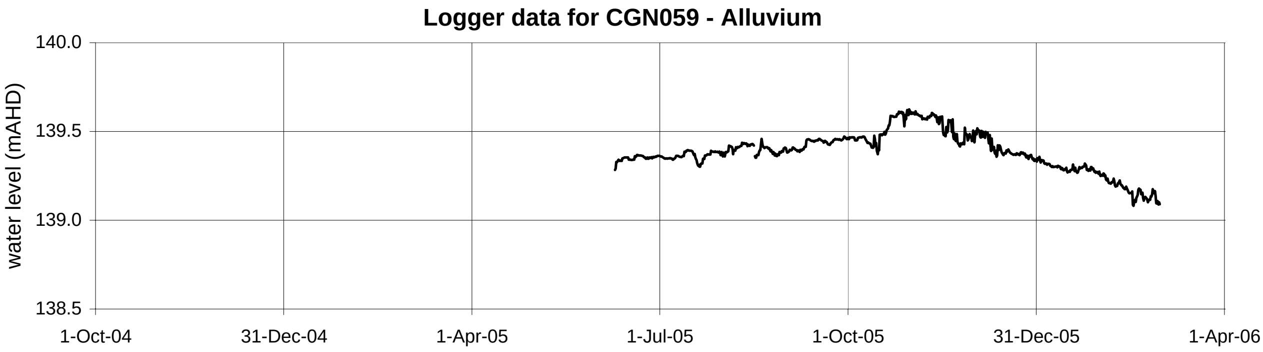


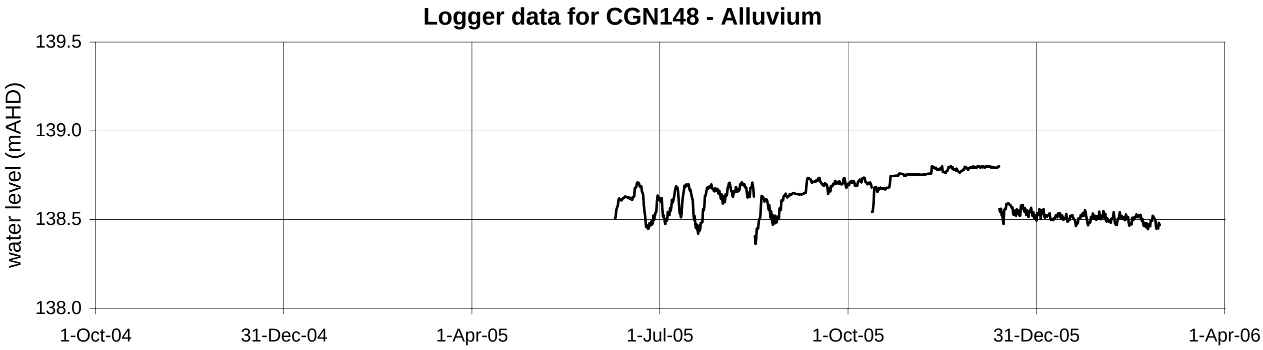
Semi continuous water level monitoring

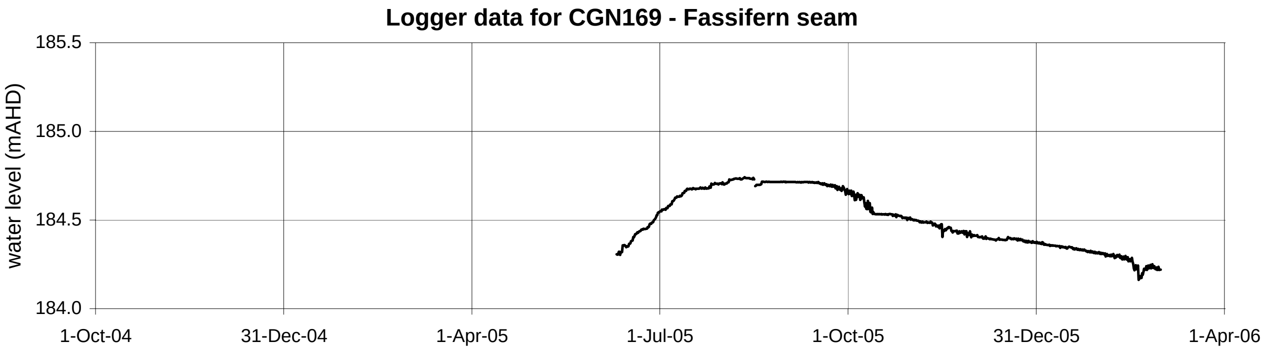
Figure B7





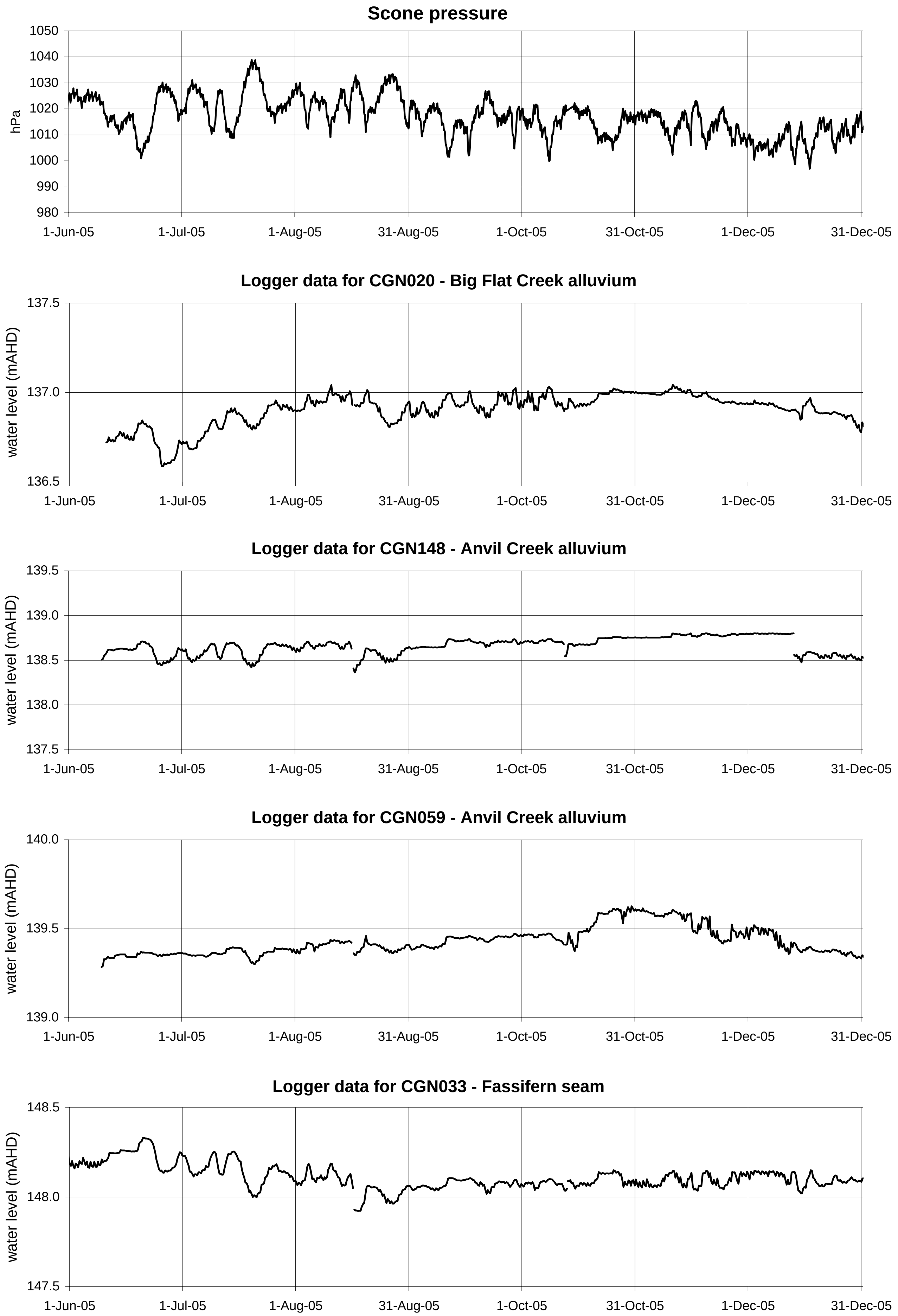






Semi continuous water level monitoring

Figure B8



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Comparison of logger responses and atmospheric pressures

Figure B9

APPENDIX C: AQUIFER HYDRAULIC PROPERTIES

Aquifer testing provides a means of estimating the 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 have included pump out and slug testing in piezometers and open holes, and laboratory core testing of interburden (see Figure C1 for locations).

C1.1 Variable head testing

The variable head or slug test comprises introduction or removal of a volume of water within the test borehole, and monitoring of the subsequent change in water level.

The test procedure adopted at all locations comprised insertion of a calibrated pressure transducer into the borehole in order to monitor water levels continuously. A slug tube was then lowered into the borehole and a volume of water instantaneously displaced. The water level was then monitored initially at 0.5 second intervals expanding to 10 or 20 second intervals depending on the rate of change of the water level. Using the displacement technique it was possible on those holes exhibiting rapid responses to monitor both falling and rising heads in order to obtain improved estimates of hydraulic conductivity.

The Hvorslev method was initially applied to the analysis of data. This analytical procedure is considered to be suitable for generating a first estimate of hydraulic conductivity since it assumes no aquifer storage (analogous to incompressible soil and fluid matrix). Subsequent analysis was then undertaken using numerical modelling techniques and prior Hvorslev analysis as a seed value to generate improved estimates of conductivity and specific storage. Skin effects (if present) have not been included in the analyses.

Holes tested as completed piezometers comprise either piezometers specifically completed within the Fassifern seam or piezometers completed in the alluvial materials beneath Big Flat Creek or Anvil Creek. Tests on open exploration holes without piezometer installations were conducted before these holes were grouted. Conductivity values determined at these locations include coal seams and interburden in the exposed saturated bore wall, and are therefore regarded as bulk or composite conductivity estimates. Table C1 summarises results.

C1.2 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.

Core from 6 exploration boreholes (see Figure C1) was inspected and representative samples taken from sections displaying relatively uniform properties in respect of rock type, grain size and other properties. These samples comprised conglomerates, sandstones, siltstones and tuffs.

All core samples were tested by Core Laboratories Australia at a confining pressure of 5.5 Mpa. The test method employed helium gas as the test ‘fluid’ and generated an estimate of Klinkenberg permeability (K_{inf}). Conversion has provided a measure of the saturated hydraulic conductivity at 20^{o}C. Porosity was also determined. Results are summarised in the following Table C2.

In addition to conductivity tests on core, mechanical properties tests on a number of interburden cores indicate an expected range in Modulus from 6 to 13 Gpa.

Table C1: Hydraulic conductivity estimates from variable head tests

Bore	Completion	Depth (m)	Sat thick (m)	Kxy (m/day)	Ss (1/m)	Stratigraphy
CGN054PZ	piezometer	26.8	19.7	6.53E-01	2.41E-06	Anvil Creek alluvium
CGN059PZ	piezometer	20.7	14.1	1.30E-01	3.00E-01	Anvil Creek alluvium
CGN148PZ	piezometer	27.8	20.1	6.58E-02	4.02E-02	Anvil Creek alluvium
CGN160PZ	piezometer	20.8	13.5	1.67E-02	1.60E-02	Anvil Creek alluvium
CGN020PZ	piezometer	24.6	19.5	4.30E-01	3.52E-02	Big Flat Creek alluvium
CGN053PZ	piezometer	24.9	17.9	1.25E-02	3.79E-02	Big Flat Creek alluvium
CGN092PZ	piezometer	14.8	7.1	1.02E-03	2.20E-01	Big Flat Creek alluvium
CGN155PZ	piezometer	24.7	18.4	2.46E-01	1.70E-06	Big Flat Creek alluvium
CGN156PZ	piezometer	23.8	15.3	1.00E-03	3.00E-01	Big Flat Creek alluvium
CGN117	open hole	51.8	19.3	1.60E-01	1.00E-03	coal measures
CGN129	open hole	37.0	24.5	2.80E-01	1.00E-03	coal measures
CGN131	open hole	42.6	27.3	7.00E-02	1.00E-03	coal measures
CGN165	open hole	25.1	45.1	1.60E-01	1.00E-03	coal measures
CGN169	open hole	26.6	1.0	3.70E-01	1.00E-03	coal measures
CGN175	open hole	51.1	7.3	1.00E-02	1.00E-04	coal measures
CGN181	open hole	31.0	14.9	5.00E-02	1.00E-03	coal measures
CGN182	open hole	30.0	3.3	8.50E-03	1.00E-04	coal measures
CGN183	open hole	31.0	12.7	9.00E-02	1.00E-03	coal measures
CGN184	open hole	30.0	16.2	2.40E-04	5.00E-04	coal measures
CGN185	open hole	30.0	7.3	2.00E-04	1.00E-03	coal measures
CGN190	open hole	100.0	91.0	2.00E-02	1.00E-04	coal measures
CGN191	open hole	26.0	21.9	8.00E-03	1.00E-04	coal measures
CGN192	open hole	31.6	7.8	1.00E-04	1.00E-04	coal measures
CGN195	open hole	18.8	4.4	1.50E-03	1.00E-03	coal measures
CGN196	open hole	36.0	26.8	1.50E-01	1.00E-03	coal measures
CGN197	open hole	68.0	11.7	4.00E-02	1.00E-03	coal measures
CGN119	open hole	56.2	22.0	2.00E+00	1.03E+00	coal measures - permeable (joints)
CGN123	open hole	46.2	27.6	2.10E+00	1.00E-03	coal measures - permeable (joints)
CGN167	open hole	52.1	15.5	2.00E+00	1.00E-03	coal measures - permeable (joints)
CGN186	open hole	37.1	21.3	1.20E+01	1.00E-03	coal measures - permeable (joints)
CGN188	open hole	30.0	24.7	1.50E+01	1.00E-03	coal measures - permeable (joints)
CGN189	open hole	30.0	24.9	2.00E+01	1.00E-03	coal measures - permeable (joints)
CGN193	open hole	45.0	9.1	6.50E+00	1.00E-04	coal measures - permeable (joints)
CGN128	open hole	44.1	24.8	3.00E+01	1.00E-03	fault - coal measures
PAHOH20	piezometer	30.8	11.0	1.05E+00	1.00E-04	Fass. permeable (faults/joints ?)
PAHOH38	piezometer	88.5	15.0	6.00E-03	8.77E-04	Fass. representative dull-bright
PAHOH39	piezometer	64.3	11.0	9.00E-03	1.00E-03	Fass. representative dull-bright
CGN033	piezometer	55.3	5.0	7.06E-03	1.03E-04	Fass. representative dull-bright
PAHOH01	piezometer	58.7	8.0	3.00E+00	1.00E-04	Fass. very permeable (joints ?)
PAHOH09	piezometer	37.0	17.0	1.80E+00	1.00E-04	Fass. very permeable (joints ?)
PAHOH13	piezometer	82.6	19.0	2.30E+00	1.00E-04	Fass. very permeable (joints ?)
PAHOH25	piezometer	81.0	12.0	1.10E+00	1.00E-04	Fass. very permeable (joints ?)
PAHOH37	piezometer	28.5	14.0	9.00E-01	1.00E-04	Fass. very permeable (joints ?)
PAHOH40	piezometer	70.1	11.0	2.00E+01	1.00E-04	Fass. very permeable (joints ?)

Kxy = horzontal hydraulic conductivity, Ss = specific storage, Fass. = Fassifern seam

Table C2: Hydraulic conductivity estimates for interburden from core laboratory tests

Bore	Depth (m)	Core	Stratigraphic location	Kxy (m/day)	Porosity (%)
CGN050	26.0	sandstone – mg with coal frags.	Awaba Tuff	1.38E-04	21.7
CGN052	20.3	conglomerate – fg sandstone matrix pebbles to 14mm dia.	above Great Northern seam	7.76E-05	10.7
CGN084	23.0	sandstone – cream, mg/fg with coal frags.	above Great Northern seam	1.62E-05	16.3
CGN084	42.0	tuffaceous sandstone – cream, fg (with smectite)	Awaba Tuff	1.16E-06	16.7
CGN089	32.9	conglomerate – fg sandstone matrix pebbles to 20mm dia.	above Great Northern seam	1.55E-04	13.1
CGN089	44.4	sandstone – cream with minor pebbles (to 6mm dia.)	above Great Northern seam	6.63E-05	18.9
CGN089	64.7	intercalated mfg sandstone and siltstone (grey)	between Fassifern and Great Northern	6.97E-07	10.3
CGN092	30.3	conglomerate – fg sandstone matrix pebbles to 10mm dia.	above Great Northern seam	6.04E-05	13.6
CGN092	44.1	conglomerate – fg sandstone matrix pebbles to 15mm dia.	above Great Northern seam	1.44E-04	15.8
CGN098	26.1	sandstone – cream with minor pebbles (to 6mm dia.)	above Great Northern seam	1.32E-05	11.8
CGN098	43.0	conglomerate – fg sandstone matrix pebbles to 15mm dia.	above Great Northern seam	1.35E-05	12.7
CGN098	62.0	conglomerate – fg sandstone matrix pebbles to 25mm dia.	above Great Northern seam	6.08E-06	11.5
CGN098	71.5	tuffaceous sandstone – cream, fg (with smectite)	Awaba Tuff	2.44E-06	19.2

C1.3 Summary of hydraulic parameters

Test results support a wide range in hydraulic conductivity and specific storage for different strata and test situations.

Core tests are considered to provide the most accurate estimates of hydraulic conductivity for rock mass unaffected by fractures and joints since these tests are applied to specific core samples and are highly controlled. Values determined from core testing are within the expected range.

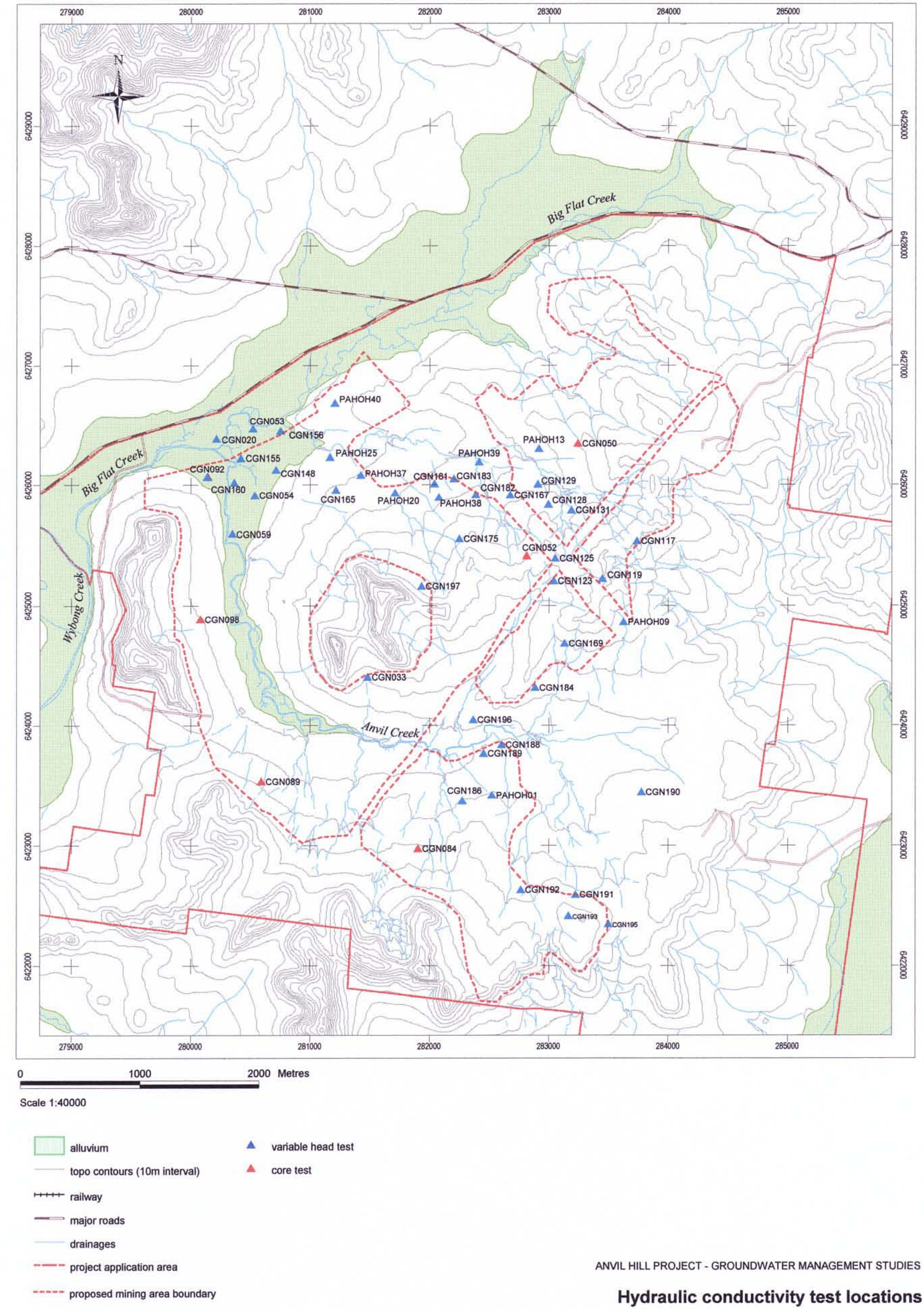
Variable head tests are considered to be less accurate than core tests but give an indication of the magnitude of hydraulic conductivities at a large scale including possible effects of cleating (in coal), jointing, and fractures associated with bedding flexure or faulting. Results summarised in Table C1 exhibit conductivity values that are generally several orders of magnitude higher than values given in Table C2 for core tests. This is partly attributed to the presence of coal seams in the test sections where cleating has probably enhanced the transmission characteristics of the test section and partly attributed to higher conductivities associated with shallower strata or fracturing. Several holes are also in proximity to fault structures (CGN 169 and others).

Summary values for the various lithologies encountered within the Project Area, are prescribed in Table C3 Note that means are calculated assuming a log normal distribution. It is assumed that the Great Northern and Fassifern seams exhibit similar properties. It is noted that the highest value determined for the Fassifern seam (2.00E+01 m/day) probably reflects the effects of localised structure.

Table C3: Summary hydraulic properties from laboratory and field testing

Lithology	Method	K range (m/day)	K mean (m/day)	Spec. stor (1/m)
alluvium (Anvil Creek and Big Flat Creek)	var. head	1.00E-03 – 6.53E-01	3.69E-02	7.44E-03
conglomerate – sandstone above GN seam	core	6.08E-06 – 1.55E-04	3.67E-05	*
Awaba tuff	core	6.97E-07 – 1.38E-04	4.06E-06	*
Fassifern seam (weakly cleated)	var. head	6.00E-03 – 9.00E-03	3.79E-02	4.49E-04
Fassifern seam (strongly cleated)	var. head	9.00E-01 – 3.00E+00	2.41E+00	1.00E-04
Fassifern seam (all tests)	var. head	6.00E-03 – 2.00E+01	3.97E-01	1.57E-04
coal measures (bulk)	var. head	1.00E-04 – 3.70E-01	1.65E-02	4.88E-04

* = not determined by laboratory tests



ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Hydraulic conductivity test locations

Mackie Environmental Research

Figure C1

APPENDIX D: HYDROCHEMICAL DATA

Characterisation of groundwaters within the Project Area has been conducted by obtaining groundwater samples, routinely determining pH and EC, and submitting samples to laboratory analysis for major ions, selected metals and rare elements. In addition a number of 'spot' samples have been obtained (springs, creek pool). All sites where basic water quality parameters have been determined, or ionic speciation undertaken, are shown on Figure D1.

D1.1 Water quality parameters pH and EC

pH and EC parameters determined from water samples collected at the routine monitoring locations exhibit reasonable stability over the period of measurement. Table D1 provides a summary of routine and spot measurements.

pH values determined from routine monitoring range from 5.78 to 9.18 with an average of 7.10. EC values range from 117 to 35955 µS/cm with an average of 8425 µS/cm. K1W well and R1W well are sites that illustrate the occasional presence of regolith driven water sources offering potable water quality. Ranch spring may also fall into this category. The surface dam above BM bore was sampled shortly after a rainfall event and illustrates the quality of run off water that is perched above a saline alluvial aquifer system characterised by high salinity at BM bore and BM piezo.

Table D1: Summary of pH and EC water quality monitoring

BoreID	Average EC (µS/cm)	StDev (EC) (µS/cm)	Average pH -	StDev (pH) -
BM Bore	12290	210	9.11	0.16
BM Piezo deep	23955	706	7.39	0.20
CALM01	573	231	6.95	0.16
CALM02	20878	8278	6.88	0.09
CALM04 - deep	7054	234	7.96	0.28
CALM04 - shallow	13598	2314	7.31	0.06
CGN020	11057	234	6.74	0.01
CGN033	4054	49	6.74	0.07
CGN053	19653	862	6.87	0.09
CGN054	12918	960	6.70	0.17
CGN059	12510	1570	7.06	0.16
CGN092	20648	2532	7.08	0.18
CGN144	10000	3820	7.02	0.55
CGN148	7905	770	6.29	0.08
CGN155	15250	2171	6.93	0.15
CGN156	11078	1714	7.36	0.19
CGN160	18733	2951	6.74	0.27
CGN169	5740	736	6.38	0.03
CGN186	853	*	7.17	*
CGN190	5860	*	7.09	*
CGN191	1684	157	6.82	*
CGN198	1710	*	7.88	*
CGN199 A2	7995	134	7.17	0.01
CGN199 P1	4280	42	7.68	0.06
CGN199 P2	4260	283	7.68	0.08
GW023072	7497	217	6.95	0.13
GW078502	7483	253	6.66	0.06
H1W well	9727	283	7.31	0.02

BoreID	Average EC (µS/cm)	StDev (EC) (µS/cm)	Average pH -	StDev (pH) -
HW Bore	7618	41	6.98	0.02
K Bore	16628	531	6.90	0.12
K1W well-spring	201	*	7.46	*
CALM05 (Mc)	13670	*	7.47	*
PAH08 artesian	6667	204	7.24	0.07
PAH49	2866	43	6.90	0.05
PAHOH01	3482	235	6.35	0.06
PAHOH09	6179	92	5.78	0.08
PAHOH13	5735	77	6.45	0.05
PAHOH20	6492	216	6.38	0.10
PAHOH25	7408	97	7.13	0.30
PAHOH36	1815	250	6.81	0.06
PAHOH37	5960	176	6.70	0.31
PAHOH39	3490	486	6.80	0.18
PAHOH40	12508	1486	6.79	0.30
P2W well	2606	*	8.31	*
Pool in Big Flat Ck below CGN053	21040	*	9.18	*
Ranch Spring	117	*	6.95	*
R1W well	289	13	6.87	0.22
surface dam above BM bore	405	*	7.46	*

StDev=standard deviation, * single measurement

D1.2 Regional groundwater speciation

Laboratory analyses for regional groundwater samples are provided in Table D2. Data for major ions has been reviewed and summarized on the tri linear speciation plot also known as a Piper diagram – Figure D2. This plot comprises two triangular fields representing cations and anions, and a central diamond field. Samples are represented as percentage milli equivalents within the lower triangular fields where each apex represents 100% of the nominated ion. Plotted positions within the triangular fields are then projected into the central diamond field, thereby facilitating a generalised classing of groundwaters and examination of possible mixing trends.

Reference to Figure D2 indicates a classing of waters where sodium chloride (primary salinity) dominates. Magnesium contributions are probably derived from exchange processes relating to the ubiquitous presence of smectite (tuffaceous sandstones) and/or volcanic clasts within the conglomerates.

Table D2: Summary laboratory analyses – regional water samples

ELEMENTS >>>	Al	As	B	Ba	Be	CO3	Ca	Cd	Cl	Co	Cr	Cs	Cu	EC	Fe-Sol	HCO3	Hg	K
UNITS	mg/L	mg/L	mg/L	µg/L	µg/L	mgCaCO3/L	mg/L	µg/L	mg/L	mg/L	mg/L	µg/L	mg/L	mS/cm	mg/L	mgCaCO3/L	µg/L	mg/L
DETECTION	0.1	0.001	0.1	0.5	1	5	0.1	0.2	5	0.001	0.1	0.01	0.1	0.01	0.1	5	1	1
METHOD	/OES	/MS	/OES	/MS	/MS	/VOL	/OES	/MS	/VOL	/MS	/OES	/MS	/OES	/METER	/OES	/VOL	/MS	/OES
CGN020	0.2	0.012	0.1	159.6	X	X	135.4	0.4	3179	0.003	X	0.42	2	10.69	X	1023	X	26
PAH49	0.6	0.002	0.2	2569.3	X	X	105.7	X	568	X	X	2.16	X	2.8	0.8	670	X	10
K Bore	0.2	0.022	X	52.9	X	X	190.9	0.2	5577	X	X	0.53	X	16.95	0.6	523	X	77
PAHOH25	0.1	0.007	0.3	305.9	X	X	105.8	0.4	1883	X	X	3.16	X	7.4	X	1038	X	24
BM Piezo	0.1	0.025	X	148.6	X	X	468.3	0.2	8458	0.001	X	0.17	X	24	X	540	X	75
PAHOH01	0.2	0.001	X	265.6	X	X	254	0.3	817	X	X	1.84	X	3.45	0.7	385	X	15
CGN059	X	0.015	0.1	567	X	X	190.7	X	3996	0.011	X	0.31	X	12.92	0.4	1065	X	54
CGN190	0.2	0.005	0.2	116.8	X	X	66.8	X	1439	0.001	X	5.22	X	5.8	0.6	425	X	11
GW078502	0.1	0.007	X	83.8	X	X	215.4	X	2116	X	X	3.5	X	7.6	0.3	723	X	24
CGN053	0.2	0.023	X	581.3	X	X	125.8	X	6358	0.015	X	0.18	X	19.27	0.2	1400	X	39
PAHOH13	0.4	0.002	X	325	X	X	383.6	X	1581	0.003	X	0.45	X	5.64	0.8	528	X	21
PAH08	0.2	0.003	0.5	1656.4	X	X	31.1	X	1341	X	X	4.78	X	6.53	X	1625	X	19
CGN169	0.2	0.004	0.1	370.7	X	X	358.1	X	1572	0.008	X	0.28	X	5.73	X	621	X	16
PAHOH20	0.2	0.004	0.1	350.1	X	X	237.6	X	1741	X	X	4.91	X	6.46	0.5	458	X	30
CGN033	0.1	0.002	0.3	3281.5	X	X	194.8	X	977	X	X	1.71	X	4.05	0.2	650	X	17

ELEMENTS>>>	Li	Mg	Mn	Na	Ni	OH	P	Pb	pH	Rb	S	SO4	Se	Si	Sr	TDSEva	TotAlk	Zn
UNITS	µg/L	mg/L	mg/L	mg/L	mg/L	mgCaCO3/L	mg/L	mg/L	NONE	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/kg	mgCaCO3/L	mg/L
DETECTION	0.5	0.1	0.1	1	0.1	5	1	0.005	0.1	0.2	1	3	0.005	0.5	0.1	20	5	0.1
METHOD	/MS	/OES	/OES	/OES	/OES	/VOL	/OES	/MS	/METER	/MS	/OES	/CALC	/MS	/OES	/OES	/GRAV	/CALC	/OES
CGN020	47.4	329.8	0.3	1916	X	X	3	X	7.4	24	85	255	0.037	14.9	4.2	6339	1023	0.2
PAH49	25.1	75.2	X	458	X	X	1	X	7.1	37.4	7	21	X	9.3	2.9	1593	670	X
K Bore	37.5	585.5	X	3166	X	X	3	X	7.2	62.9	237	711	0.102	12.1	2.6	11011	523	X
PAHOH25	54.8	155.6	X	1392	0.1	X	4	X	7.5	60	37	110	0.023	10.3	2.5	4254	1038	X
BM Piezo	32.2	700.5	X	5162	X	X	X	X	7.6	38.8	313	939	0.09	8	17.5	16556	540	X
PAHOH01	80.4	111.6	0.7	341	X	X	1	X	6.7	32.3	61	183	0.006	9.8	3.1	2126	385	0.4
CGN059	77.6	633.6	3.2	2107	0.2	X	X	X	7.2	38.2	203	609	0.049	14.4	0.2	8512	1065	X
CGN190	85.9	53.7	0.3	1194	0.1	X	X	X	7.3	21.3	186	558	0.01	5.5	3.7	3609	425	0.3
GW078502	81.6	309.9	0.2	1131	X	X	3	X	7	58.9	98	295	0.028	11.9	1.3	4592	723	X
CGN053	48.9	609.6	2.5	4241	X	X	X	X	7.2	19.4	114	341	0.08	7.3	3.9	12456	1400	X
PAHOH13	12.9	312.8	2.9	503	0.2	X	3	X	6.8	21.4	112	336	0.011	11.8	3.1	3964	528	0.2
PAH08	54.4	38.6	X	1571	0.2	X	2	0.006	7.5	50.3	X	X	0.014	8.2	2.5	3881	1625	X
CGN169	59.3	313.8	5.2	543	0.1	X	2	X	7	10.6	80	238	0.017	14	7.8	3861	621	X
PAHOH20	37.4	337.5	0.9	822	0.1	X	2	X	6.7	77.3	215	643	0.015	12.3	6.4	4330	458	X
CGN033	40.5	121.8	0.3	567	0.1	X	5	X	7.1	49.8	10	30	0.009	8.1	4.9	2321	650	X

X = below detection limit

ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Water quality sampling locations

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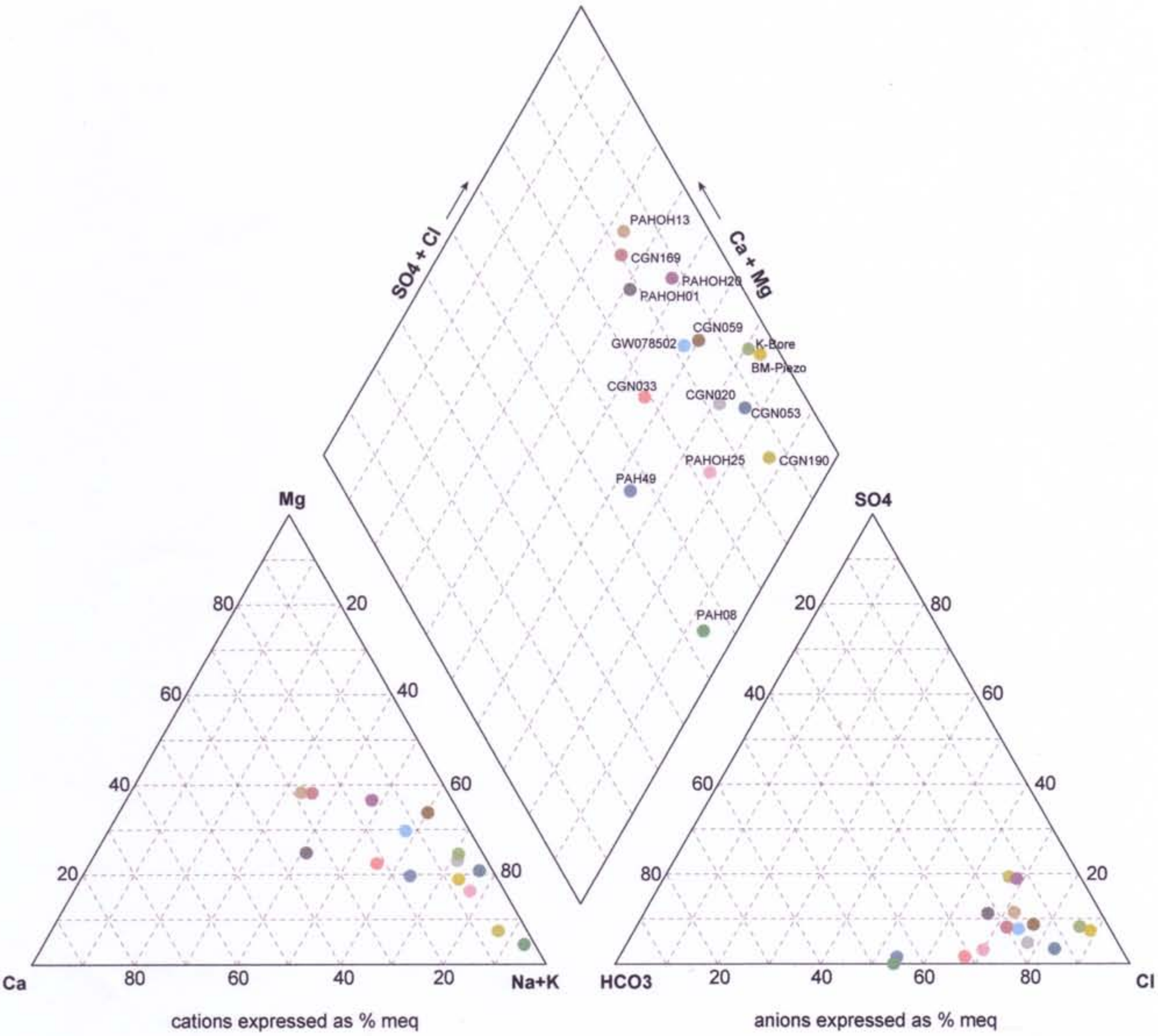
Figure D1



Bore	pH	EC uS/cm	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO3 mg/l	SO4 mg/l	Cl mg/l
BM piezo	7.6	24000	16556	468	701	5162	75	659	939	8458
CGN020	7.4	10690	6339	135	330	1916	26	1248	255	3179
CGN033	7.1	4050	2321	195	122	567	17	793	30	977
CGN053	7.2	19270	12456	126	610	4241	39	1708	341	6358
CGN059	7.2	12920	8512	191	634	2107	54	1299	609	3996
CGN169	7.0	5730	3861	358	314	543	16	758	238	1572
CGN190	7.3	5800	3609	67	54	1194	11	519	558	1439
GW078502	7.0	7600	4592	215	310	1131	24	882	295	2116
K Bore	7.2	16950	11011	191	586	3166	77	638	711	5577
PAH08	7.5	6530	3881	31	39	1571	19	1983	0	1341
PAH49	7.1	2800	1593	106	75	458	10	817	21	568
PAHOH01	6.7	3450	2126	254	112	341	15	470	183	817
PAHOH13	6.8	5640	3964	384	313	503	21	644	336	1581
PAHOH20	6.7	6460	4330	238	338	822	30	559	643	1741
PAHOH25	7.5	7400	4254	106	156	1392	24	1266	110	1883

ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Speciation of major ions for groundwaters

Figure D2

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APPENDIX E: AQUIFER NUMERICAL MODEL DEVELOPMENT

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 definition of the aquifer system in respect of geometry, hydraulic properties and applied stresses including rainfall, pumpage, creek and alluvium leakage and pit seepage.

In the present study, a finite difference approach (ModFlow-Surfact) has been utilized due to the large area, variable topography, numerous drainage systems and the extent of the depressurisation halo that will evolve with continued mining. The method requires dividing the overall area of interest (domain) into a large number of separate cells defined by a nodal point at the centre of each cell. The number of cells defined in the model mesh has been determined by the prevailing drainage system, the mine pit geometry and the expected hydraulic gradients developed in the course of modelling.

The regional model is a variably saturated scheme and comprises six transversely anisotropic layers with 36000 cells per layer. Total modelled area is 132 sq. km. (Figure E1) with cell areas varying from 1 ha (100 m x 100 m) to 0.25 ha (50 m x 50 m). Cells have been designed to give increased detail to the proposed pit areas and regional drainages together with the alluvial aquifers (Big Flat Creek, Sandy Creek, Wybong Creek) and the regional coal measures. The Great Northern and Fassifern/Upper Pilot seams have been included as specific layers throughout the area. Deeper strata in the eastern part of the model (east of the Ogilvie fault system) where the Jerrys Plains Sub Group is present, has been simplified from numerous stratigraphic zones to a single representative zone.

The model does not address potential reductions in hydraulic conductivities due to increasing effective stress as a result of areas within and surrounding the mine pits being depressurised. Nor does it address strain related changes in specific storage. As a result, a measure of conservatism (over estimation of strata depressurisation) is considered to be ‘inbuilt’.

Four variations on the model have been utilised to represent

- ***steady state conditions*** for the period before mining activity commences – basic model properties distribution;
- ***Scenario 1*** - transient simulation during the 21 year project life – basic model properties distribution to assess impacts;
- ***Scenario 2*** **-** transient simulation during the 21 year project life – introduction of a cut off wall emplaced across Anvil Creek;
- ***post mining recovery*** with final voids located in Main pit and South pit.

E1. Regional model geometry

Layer 1 represents a number of stratigraphic zones that include the regional regolith and the alluvial deposits associated with Big Flat Creek, Wybong Creek and Sandy Creek. The base of layer 1 beneath the alluvial lands has been interpolated to reflect a generalised grade downstream based on detailed terrain mapping in areas near the current mining operations and a thickness of alluvium of up to 20 m graded to pinch out along the alluvial boundaries. Measured depths of alluvium were utilised where exploration data was available. Elsewhere layer 1 represents the regolith which attains a thickness of 9 m based on exploration borehole observations.

Layer 2 represents unweathered conglomerates and the overlying Narrabeen sandstones where present.

Layers 3, 4 and 5 represent the Great Northern seam, the Awaba Tuff and the Fassifern (including Upper Pilot A) seam respectively. Bounding surfaces are derived directly from exploration mapping.

Layer 6 is nominally assigned 100 m thickness and represents underlying coal measures.

E2. Regional model hydraulic properties

Model layers, stratigraphy and assigned conductivity values are provided in the following Table E1. Conductivities have been adopted from mean values determined from field testing (Table C3). Some values have been upweighted to accommodate weathering and occasional fracturing (eg. conglomerate), or to improve model convergence to a solution. Such upweighting implies the model predicted regional impacts are more extensive than may otherwise be the case.

Vertical hydraulic conductivities have been assigned at one tenth the horizontal value within coal seams although in many instances this ratio is calculated to be much lower due to the frequently observed presence of dull coal layers and interbedded carbonaceous shales.

The major north-east trending dyke that bisects the mining area has been included as a semi impermeable membrane with a thickness of 10 m. Other significant dykes in the vicinity of this major dyke, have also been included since these may act to 'compartmentalise' the aquifer system. The dykes have been assigned to all layers below layer 1 on the assumption that the regolith zone (layer 1), is completely weathered.

Table E1: Basic model layer-stratigraphy and assigned hydraulic properties

Layer	Stratigraphic boundary zones	Horizontal K (m/day)	Ss-conf. (1/m)	Sy-unconf.
1	Alluvium: Big Flat Creek	4.0E-02	n/a	3.0E-01
1	Alluvium: Wybong Creek and Sandy Creek	5.0E+00	n/a	3.0E-01
1	Regolith over conglomerate	5.0E-03	n/a	2.0E-01
1	Narrabeen sandstones	5.0E-05	1.0E-05	2.0E-02
2	conglomerate	1.0E-04	1.0E-05	2.0E-02
3	Great Northern seam	5.0E-02	1.0E-05	3.0E-02
4	Awaba Tuff	1.0E-03	1.0E-05	1.0E-02
5	Fassifern + Upper Pilot seams	5.0E-02	1.0E-05	3.0E-02
6	sandstones siltstones shales (coal measures)	1.0E-05	1.0E-05	5.0E-02
	dyke features	1.1E-04	1.0E-05	1.0E-03

K = hydraulic conductivity (permeability), unconf = unconfined, conf = confined

E3. Boundary conditions

Boundary conditions assigned to an aquifer model are those conditions that constrain or bound the model domain mathematically. The conditions are applied to the physical outer boundary of the model and throughout internal parts of the model. They include

Modflow *river* type cells (1^{st} type – conductance limiting) along Wybong Creek, Sandy Creek and the Hunter River, Modflow *drain* cells (flux constrained 1^{st} type) along ephemeral creeks (eg. Big Flat Creek) and in pit areas, and distributed flux conditions applies to all cells to represent regional rainfall recharge. Utilisation of river type conditions along Wybong Creek enforces seepage from surrounding areas of elevated water table to the creek, or seepage from the creek to surrounding strata if piezometric heads in those strata are lower than river levels. Drain nodes have been assigned to pit floor elevations in accordance with the proposed mining schedule.

Rainfall recharge has been applied at a constant rate of 0.8 mm/annum over hardrock areas. This rate has been determined through a number of steady state simulation trials for the basic model where recharge was progressively increased until model water levels broadly matched the regional measured piezometric surface. Since the model is fundamentally a forward model based on determination of prevailing conductivities, rainfall recharge is essentially a conductivity dependent variable. That is, reducing the model conductivities requires a reduction in rainfall recharge in order to achieve the same water table distribution.

Recharge at a rate of 90 mm/annum has been applied over alluvial lands associated with Wybong and Sandy creeks where sandy soils are known to facilitate rapid infiltration during sustained rainfall periods. Recharge at a rate of 40 mm/annum has been applied over alluvial lands associated with Big Flat Creek where silts and clays are suspected to inhibit recharge. Infiltration could vary over short distances but the use of averaged figures provides a simplification and is considered adequate for planning purposes. Because the rate for the alluvium is much higher than for hardrock areas, it is also a relatively insensitive boundary condition in respect of deeper hardrock depressurisation where vertical hydraulic conductivities and vertical leakage rates, are low.

E4. Calibration

All simulations have utilised an adaptive time stepping for the iterative process in meeting a specified solution error margin. Pseudo steady state (equilibrated) simulations were initially conducted to generate approximate piezometric surfaces for the coal measures. These were examined and compared to the measured-interpolated piezometric surface and adjustments made in the applied rainfall recharge rather than the hydraulic properties of the various strata in order to achieve a reasonable match. The reason for this preference in adjusting rainfall rests with the large number of measurements of hydraulic conductivity compared to no measurements of rainfall recharge. Model outputs were examined and checked for acceptable volumetric balances.

Figure E2 provides a plot of the prevailing head distribution from model output. While not exact, the general geometry of the piezometric surface compares reasonably with the measured/interpolated surface (Figure 9 of the main text). In addition, nineteen calibration piezometers were selected to give wide coverage. Figure E3 provides a plot of calculated versus measured water levels at these locations for the calibrated model. While there is scatter in this plot, the general correlation is considered acceptable for the prevailing knowledge base. It is noted however that the calibrated model is non unique ie. the adopted model parameters generate a particular piezometric surface that lies within a 'solution domain'. Other similar water tables could be generated by reducing hydraulic conductivities and increasing rainfall recharge within a limited range.

E5. Simulation of strata depressurisation and pit seepage

Simulation of the mine plan has been conducted for a period of 21 years. The adopted final model includes a barrier cut off wall constructed across Anvil Creek (Scenario 2). Extent of depressurisation (drawdown) impact within the the shallower conglomerates at 21 years (layer 2) is provided as Figure E4. Extent of depressurisation (drawdown) impact within the Fassifern Seam at 21 years (layer 5) is provided as Figure E5.

On completion of all model simulations (Scenarios 1, 2 and 3), flux balances were reviewed and specific zone budgets extracted to provide mine water influx estimates for each pit. Pit results indicate more than 70% of seepage is generated within Main Pit. Total seepages (all pits) are summarised in Table E4. These estimates do not include provision for evaporative losses in pit. Nor do they include direct rainfall to the pit(s) or rainfall infiltration/percolation through spoils.

Results generated in Table E4 indicate negligible differences between model scenarios 1 and 2. It might be concluded from these results that the introduction of a seepage cut off wall across Anvil Creek has negligible effect on mine pit seepage. However the similarity in predicted seepage rates is partly attributed to the scale of the model and the low vertical and horizontal hydraulic conductivities assigned to alluvium within Big Flat and Anvil creek catchments, and the relative magnitude of such seepage compared to water derived from the coal seams.

Potential horizontal leakage from Big Flat Creek alluvium to the mine pit has been more closely examined using a vertical section model (see Section E7 below).

Table E4: Model predicted total seepage rates to mine pit(s)

Year (end)	Pit year (end)	Scenario 1 – basic model (ML/day	Scenario 2 – cut off wall on Anvil Ck (ML/day
2008	1	0.38	0.38
2009	2	0.69	0.69
2010	3	0.95	0.95
2012	5	0.69	0.63
2014	7	1.35	1.34
2016	9	1.68	1.67
2018	11	1.78	1.77
2020	13	1.78	1.78
2022	15	1.55	1.55
2024	17	1.35	1.35
2026	19	1.13	1.13
2028	21	0.88	0.88

E6. Sectional model through Big Flat Creek alluvium

The need for a cutoff wall isolating mining operations from Big Flat Creek alluvium, has been considered using a strip model to examine the likely water table geometry, seepage rates and pore pressures in the vicinity of a constructed wall. Specifically the model explores the time required for decay of the water table adjacent to the proposed mine pit – without and with a barrier wall. Model design is illustrated in Figure E6a.

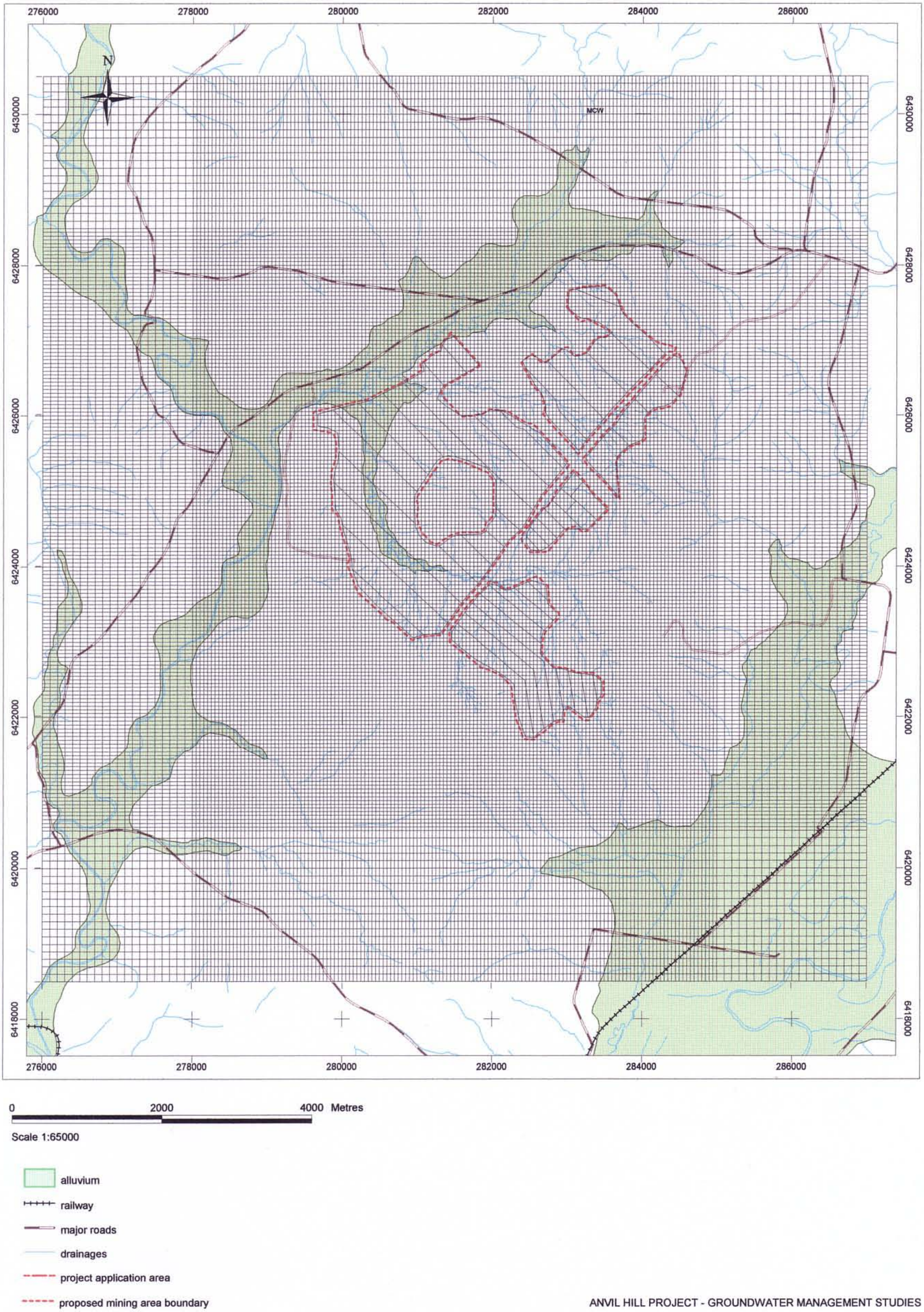
The strip model represents a section through the alluvium orthogonal to the pit face (across Big Flat Creek. The strip is 10 m width and 400 m long with a constant recharge source located 400 m from the pit face in order to generate substantial drawdown profiles. Instantaneous depressurisation at the pit face to the base of the alluvium, initiates groundwater flows.

Two conditions have been considered – (1) seepage without a barrier wall and (2) seepage with a barrier wall. Dewatering profiles for various depths of alluvium are included as Figures E6b and E6c for conditions 1 and 2.

E7. Simulation of recovery of coal measures water table

Recovery of the water table within the coal measures has been simulated by adopting the regional groundwater head distribution at the completion of mining in Year 21, and allowing the aquifer model to recover. The number of model layers has been reduced from 6 to 2 by consolidating the original layers 1 to 5 in order to improve solution convergence and stability in the presence of a large number of ‘dry’ model cells that prevail at the completion of mining. Mine pit boundary conditions have been removed and pit hydraulic properties amended to reflect the presence of spoils where porosity and permeability have been raised to 20% and 1 m/day respectively. The planned void areas have been changed to reflect open storage conditions. All other model boundary conditions remain the same. It is noted that these conditions considerably simplify the complex geology.

The above noted procedure was employed to generate a first estimate of the relationship between pit influx and rebounding head in the mine pit(s). This relationship was then employed in a one dimensional runoff and rainfall infiltration model that utilises 100 years of rainfall daily history to more accurately predict void recovery and evaporative losses using the pit shell and void final landforms.



ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Aquifer model extents and gridded mesh

Figure E1

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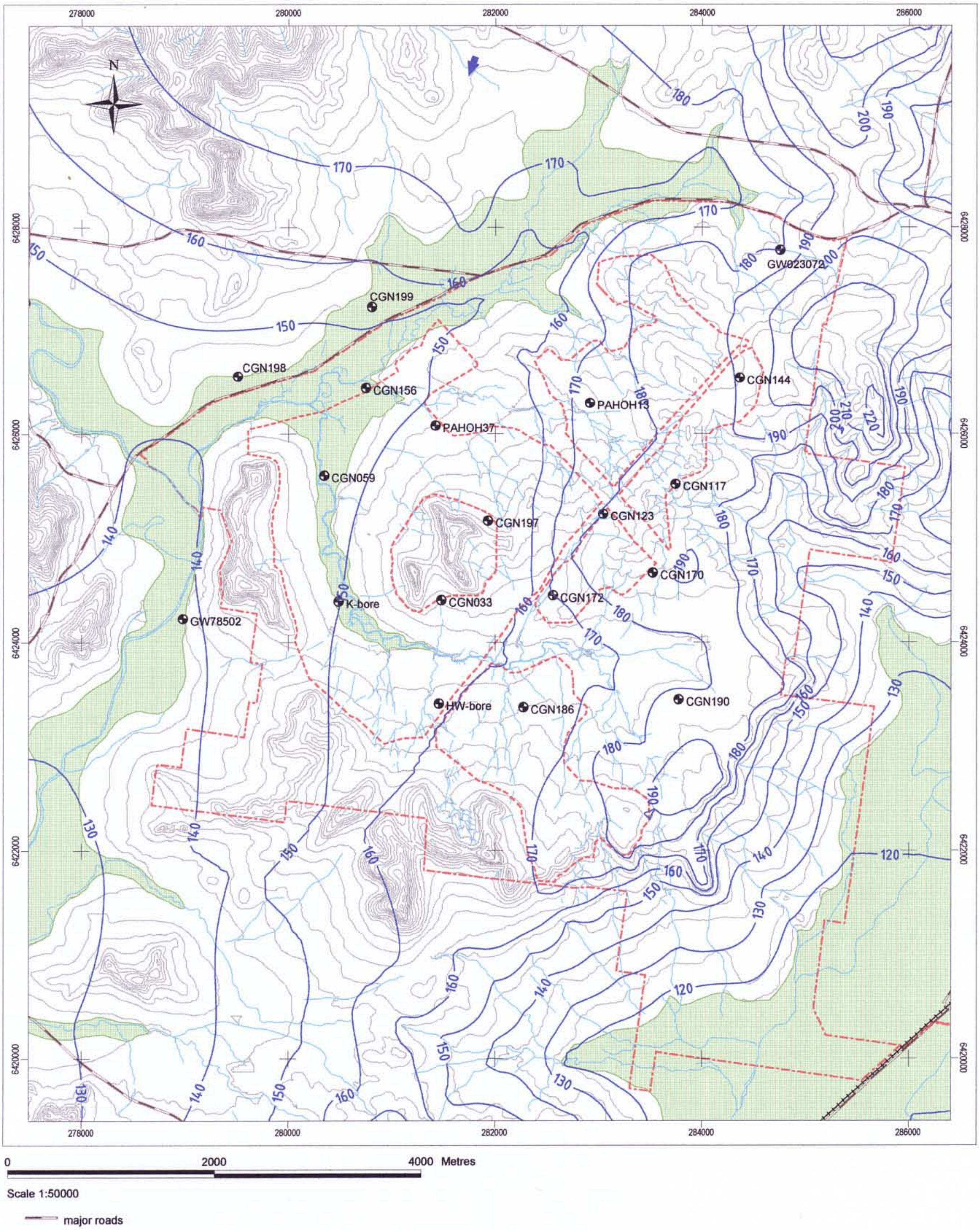

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Piezometric surface generated by aquifer model

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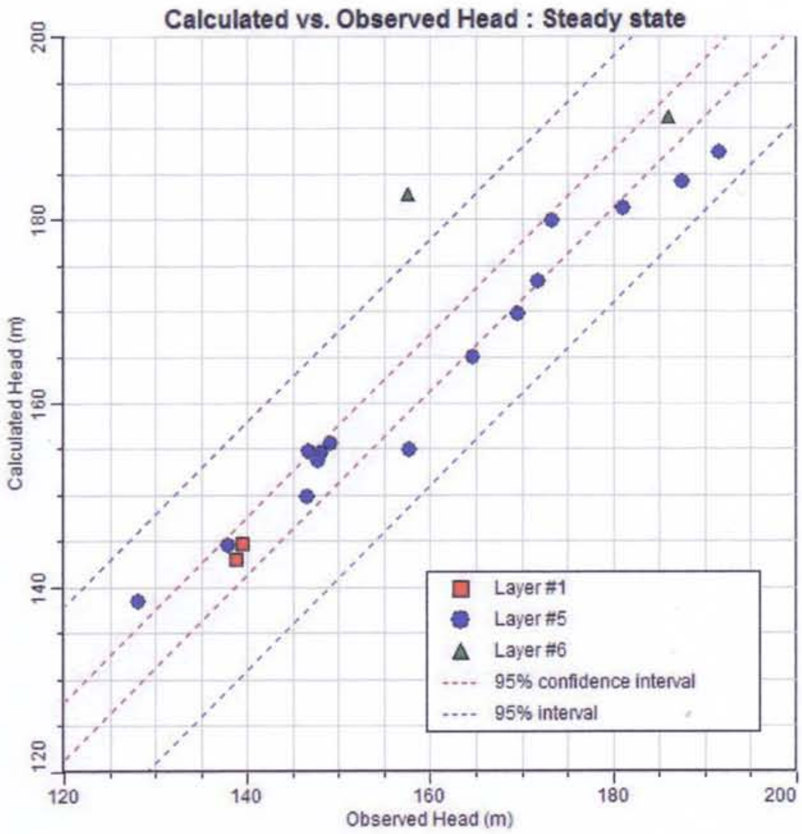
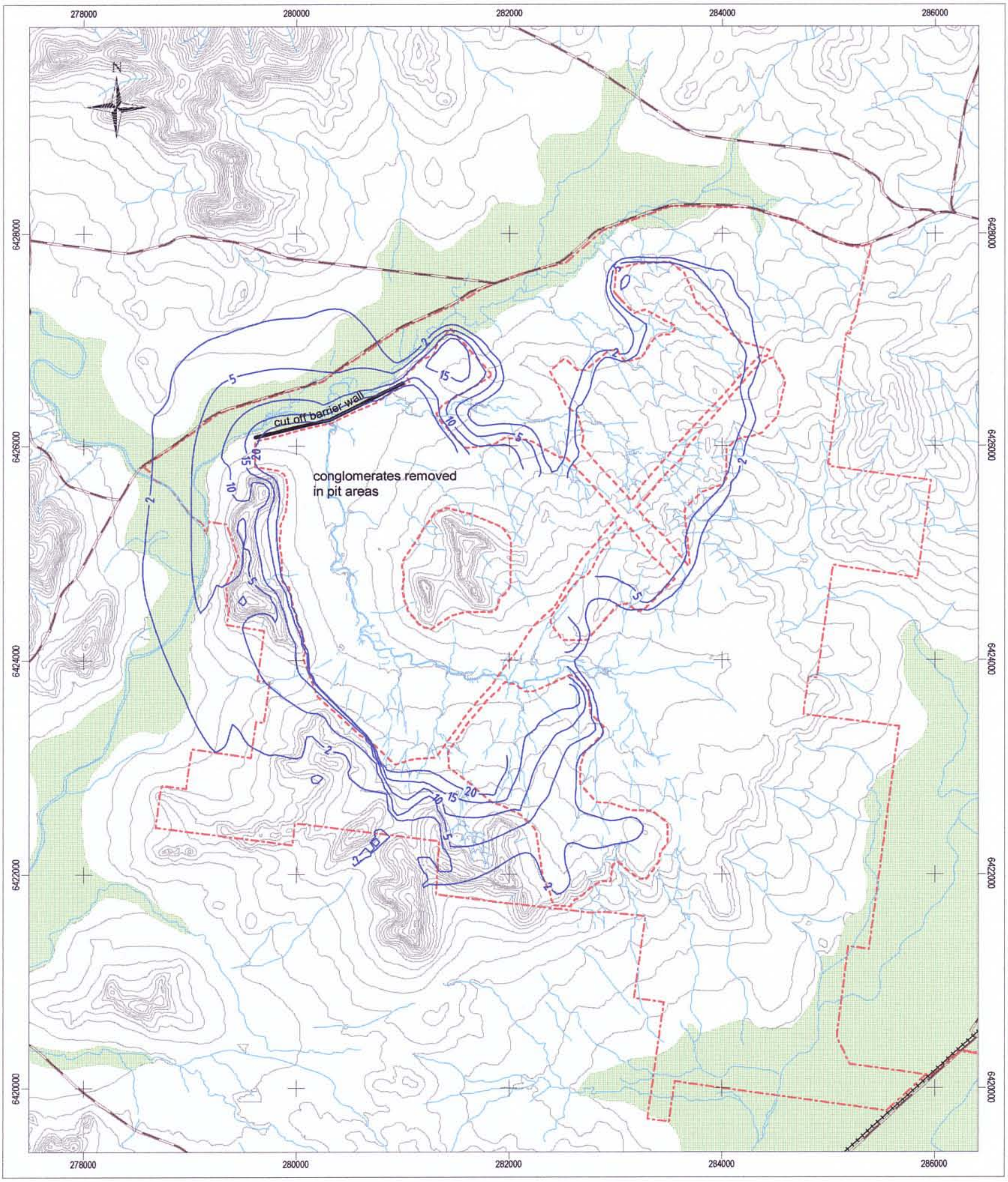
Figure E2



Num. of Data Points : 19
Max. Residual: 25.262 (m) at CGN190/A
Min. Residual: 0.146 (m) at CGN172/A
Residual Mean : 4.483 (m)
Abs. Residual Mean : 5.595 (m)

Standard Error of the Estimate : 1.482 (m)
Root Mean Squared : 7.723 (m)
Normalized RMS : 12.182 (%)
Correlation Coefficient : 0.941

Calculated versus observed head - pre mining
Figure E3



0 1000 2000 3000 Metres

Scale 1:50000

alluvium

topo contours (10m interval)

railway

major roads

drainages

project application area

drawdown in conglomerates (m)

proposed mining area boundary

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Drawdowns in conglomerates at the completion of mining

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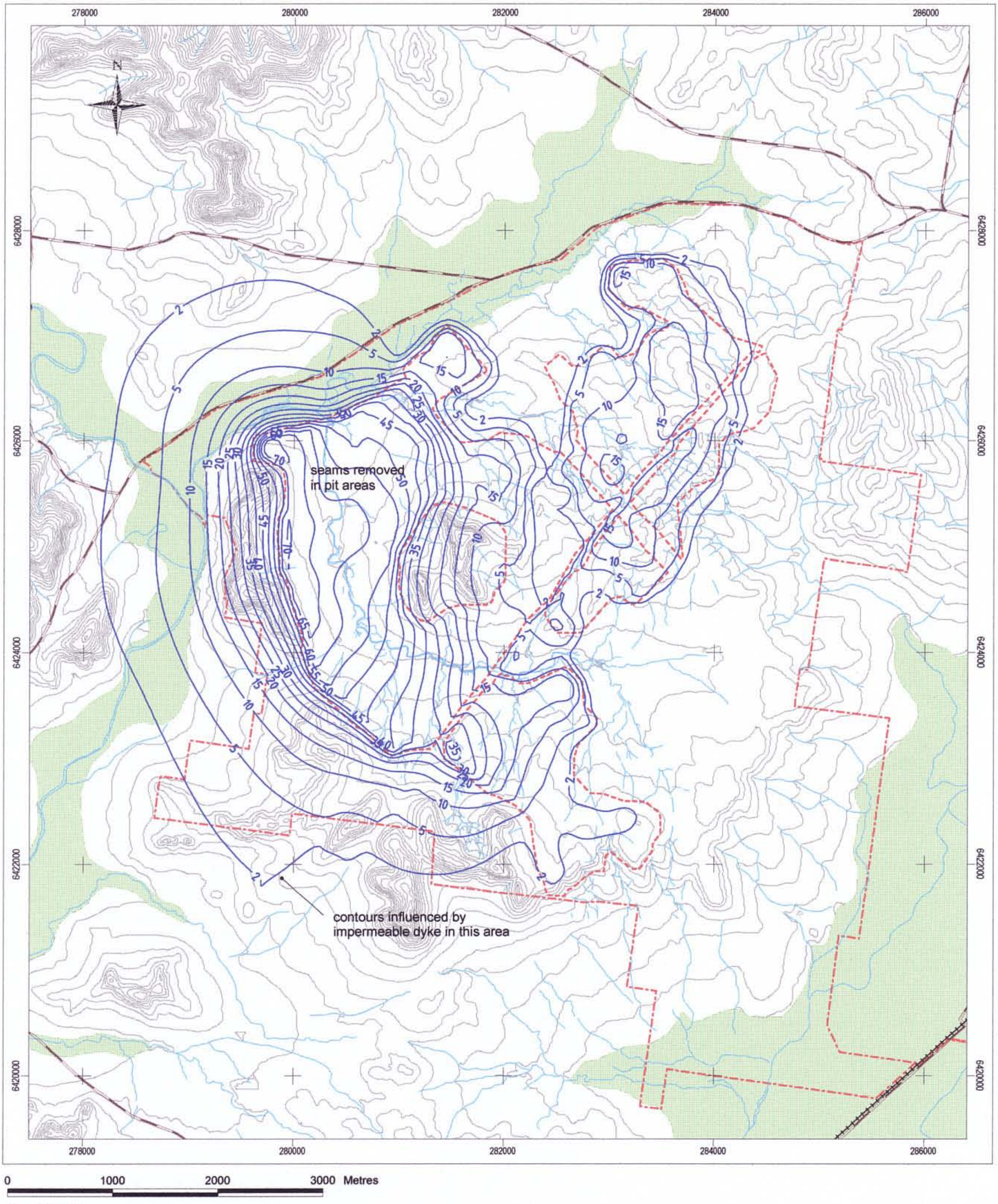
Figure E4



Scale 1:50000

alluvium

topo contours (10m interval)

railway

major roads

drainages

project application area

drawdown in Fassifern-UPA (m)

proposed mining area boundary

ANVIL HILL PROJECT - GROUNDWATER MANAGEMENT STUDIES

Drawdown in Fassifern-UPA seams at the completion of mining

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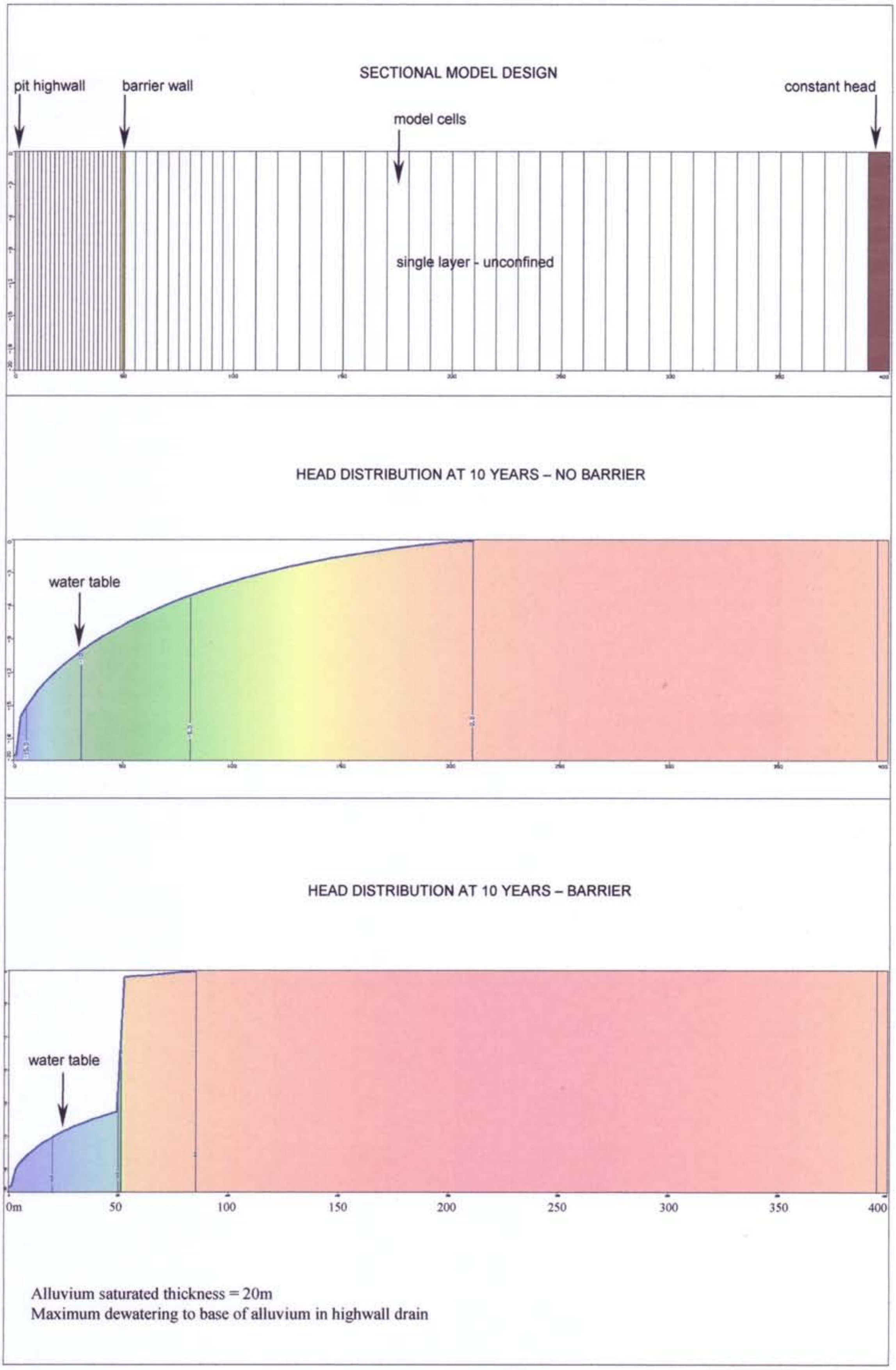
Figure E5



Vertical section model through Big Flat Creek alluvium

Figure E6

APPENDIX F: SPOILS LEACHATE

Interburden spoils have the potential to generate leachate in the long term. The process comprises two phases – leachate generation during mining, and leachate generation after cessation of mining.

During mining, rainfall percolates into mine spoils areas through unshaped, shaped and rehabilitated areas. The rate of infiltration/percolation can vary depending upon ground conditions at a particular location but percolating rainfall below about 5 metres depth (beyond evaporative and root zone influences) is most likely to remain as deep moisture and to migrate to the base of the spoils.

The pathway adopted by infiltrating rainfall is 'preferential' due to the nature of emplacement. That is, highly variable spoils fragmentation from blasting delivers fragments ranging from less than 1 mm to more than 1 metre diameter leaving many open pathways within the dumps. Leaching of salts occurs along these pathways, the efficiency of the leaching process being governed by the fragment size distribution. Large rocks remain essentially impermeable and have poor leaching characteristics while crushed rocks offer improved leaching characteristics due to the reduced grain size and increased surface area per unit volume.

While leachate generation would occur during the 21 year mine period, all leachate during this period would be retained within the mine water system since it would generally emanates at the toe of the mine pit low wall for down dip mining, and would subsequently be used in coal washing, dust suppression and other activities. When mine pit operations cease and rainfall or groundwater begins to accumulate in the final void and beneath the shaped spoils profile, the groundwater quality is expected to reflect a mixture of rainfall directly falling on void areas, runoff from the reshaped areas surrounding the voids, percolating rainfall (through spoils), and regional groundwater seeping from the coal measures.

Since void water level recovery will ultimately fully saturate the spoils emplaced below the (projected) recovered water table, the salt contribution can be estimated by conducting leachate trials on rock samples having a similar grain size distribution to spoils emplaced. Clearly this is not feasible for the entire fragmentation range. The approach adopted herein has been to undertake trials on the fragmentation range from less than 1 mm up to 0.025 m dia and to extrapolate results beyond this range using theoretically predicted fragmentation distributions.

F1. SAMPLE PREPARATION

Fifteen core samples used in leachate trials were selected at differing depths from eight boreholes distributed across the proposed mine pit area (Figure F1). These samples mostly comprised conglomerate, sandstone, siltstone or Awaba Tuff. All core was jaw crushed to minus 25 mm to facilitate fractionation of samples.

The leachate technique adopted was a simple system comprising submergence of samples in de-ionised water (as a surrogate for rainfall) or groundwater. Subsequent routine monitoring of pH and electrical conductivity (EC) was then conducted over a period of 3 months. The groundwater sample was obtained from artesian bore PAHOH08. Since EC is a good indicator of dissolved salts, monitoring over time permitted extrapolation of data trends to equilibrated values.

Prior to commencement of the trials, samples were sieved and different fractions separated. Sieved samples included the following fractions +0.18 to +0.40 mm, +0.9 to +2.1 mm, +4.7 mm to +12.5 mm. Sample weights ranged from 43 to 151 grams with an average weight of 127 grams. Measurement procedure comprised decanting approximately 50 ML of leachate for measurement of parameters. A TPS MC84 meter was used for all EC measurements while a Lutron pH-206 meter was used for all pH measurements. Instruments were calibrated prior to commencement and following completion of routine measurements. All samples were maintained in the temperature range 18 to 21 degrees during the trials.

After 3 months of monitoring, leachate samples for the 4.7 to +12.5 mm range were dispatched for laboratory determination of major ions and certain rare elements (Genalysis Laboratory Services). Analytical results are provided in Table F1.

EC measurements over the monitoring period were converted to represent leachable salts (milligram leached salt per gram of sample) using a conversion factor based on laboratory analyses of leachates. Typical examples of trends over the monitoring period, are provided on Figure F2 for three sample locations using the de-ionised water solute. A fourth plot illustrates water quality change with time for nine samples immersed in the groundwater solute. Inspection of trends for this plot suggests all samples exhibit a declining trend during the latter period of monitoring – loss of salinity is indicated. Declining trends are attributed to ion exchange processes possibly with an initial dominance in chloride ions shifting to bicarbonate dominance. Obvious minerals offering considerable exchange capacity include kaolinite (as sandstone cement matrix in interburden), and montmorillonite within the Awaba Tuff.

Laboratory results have been used to generate a tri-linear speciation plot Figure F3 for the purpose of examining the general classing the leachate and understanding the relationship between leachate chemistry and regional groundwaters. Cations and anions are plotted in the lower left and lower right triangular fields respectively and these points have been projected into the central diamond field. In respect of the de-ionised water solute, all samples plot in an area dominated by sodium and magnesium cations with minor contributions from calcium. There is no dominant anion when all samples are considered. In respect of the groundwater solute, sodium is the dominant cation while chloride and bicarbonate are the dominant anions. The reduced scatter of leachate samples is attributed to the initial chemistry of the groundwater taken from borehole PAH08.

Figure F4 examines various relationships between ionic species:

- Figure F4(a) illustrates Na versus Cl: points plotting close to the line indicate NaCl dissolution is a dominant mechanism;
- Figure F4(b) illustrates Na/Cl versus EC: ion exchange is suggested for values greater than 1 while reverse ion exchange is suggested for values less than 1. Most points plot close to but above a value of 1, supporting the possibility of ion exchange;
- Figures F4(c) and F4(d) explore the possibility of MgCl and CaCl dissolution. The relatively wide scatter suggests influence from other cations and anions associated with Mg or Ca via exchange mechanisms rather than dissolution;
- Figure F4(e). A 1:1 relationship indicates that the dominant process is the dissolution of gypsum, calcite or dolomite. Data plotting below the line supports ion exchange with Ca and Mg being depleted with respect to SO_4 and HCO_3. Most samples plot below the line.
- Figure F4(f). Waters plotting close to zero with respect to the x-axis are not influenced by ion exchange. Most of the data plotting in this area are samples generated by de-ionised water where dissolution is the dominant mechanism. Since samples also plot close to the zero point on the y-axis, dissolution of calcite, dolomite and gypsum is likely to be congruent and ion exchange unlikely. In contrast, groundwater leachate samples plot along the line with a slope of –1 in a distinctly different grouping (lower right). This grouping suggest ion exchange is the dominant mechanism in this group of samples.

Table F1: Summary of laboratory analyses – leachate samples

ELEMENTS	Al	As	B	Ba	Be	CO3	Ca	Cd	Cl	Co	Cr	Cs	Cu	EC	Fe-Sol	HCO3	Hg	K
UNITS	mg/L	µg/L	mg/L	µg/L	µg/L	mgCaCO3/L	mg/L	µg/L	mg/L	µg/L	mg/L	µg/L	mg/L	mS/cm	mg/L	mgCaCO3/L	µg/L	mg/L
DETECTION	0.1	0.1	0.1	0.05	0.1	5	0.1	0.02	5	0.1	0.1	0.001	0.1	0.01	0.1	5	0.1	1
METHOD	/OES	/MS	/OES	/MS	/MS	/VOL	/OES	/MS	/VOL	/MS	/OES	/MS	/OES	/METER	/OES	/VOL	/MS	/OES
CGN098-24.5	X	1.1	X	7.24	X	X	17.7	X	161	0.8	X	0.788	X	1.11	X	137	X	18
CGN050-14.1	3.4	1.5	X	5.87	X	X	0.7	X	28	0.3	X	0.193	X	0.18	1.4	23	X	1
CGN031-11.2	X	1.4	X	3.27	X	X	8.8	X	321	0.2	X	0.017	X	1.15	X	13	X	4
CGN098-62.1	X	4.4	X	8.32	X	X	31.9	X	32	36.5	X	0.593	X	0.65	X	178	X	8
CGN067-30.9	0.2	2.2	0.4	4.06	2.5	X	32	5.19	163	763.6	X	1.805	0.1	1.21	1.6	X	X	13
CGN098-43.0	X	5.4	X	6.99	X	X	23.6	X	94	10.3	X	0.785	X	0.86	X	205	X	11
CGN089-20.1	X	5.4	X	9.12	X	X	24	X	101	9.3	X	0.792	X	0.89	X	205	X	12
CGN084-23.0	X	3.5	X	16.18	X	X	119.2	0.06	78	23.4	X	1.108	X	1.9	X	183	X	15
CGN067-23.2	X	0.7	X	2.14	X	X	5.1	X	140	X	X	0.428	X	0.66	X	20	X	7
CGN092-44.1	X	2.4	X	8.45	X	X	36.5	X	33	14.1	X	0.552	X	0.64	X	227	X	6
CGN084-43.5	3.7	29.7	X	6.28	0.1	10	6.4	X	9	0.3	X	0.901	X	0.32	0.6	93	X	6
CGN052-20.3	X	0.3	X	4.04	X	X	6	X	59	X	X	0.008	X	0.3	X	40	X	2
CGN092-30.3	X	5.6	X	9.45	X	X	26.3	X	129	26.7	X	0.791	X	0.95	X	158	X	9
CGN031-19.3	77.5	1.7	X	18.78	4.1	X	4	0.07	150	2.8	X	10.075	X	0.6	12	20	X	5
CGN050-26.0	0.9	12.7	X	40.13	X	X	14.6	X	X	X	X	0.73	X	0.2	0.5	73	X	8
CGN052SW-20.3	1	6.8	X	21.77	X	X	4.9	X	1376	X	X	0.041	X	5.94	X	1380	X	13
CGN092SW-44.1	0.5	73.9	X	88.53	X	X	12.3	X	1359	12.3	X	2.717	X	6.23	X	1500	X	20
CGN084SW-23.0	1	16.9	X	16.16	X	X	16.5	X	1394	24.1	X	3.219	X	6.83	X	1335	X	29
CGN089SW-20.1	X	5.7	0.1	163.13	X	X	12.5	X	1545	X	X	2.315	X	6.6	X	1485	X	32
CGN067SW-30.9	1.3	14.7	1	70.13	X	X	46.1	0.21	1483	150.1	X	4.818	X	6.67	X	1255	X	26
CGN098SW-62.1	0.8	76.5	X	30.41	X	X	8.2	X	1368	32.6	X	3.261	X	6.24	X	1450	X	22
CGN050SW-14.1	0.2	7.5	0.1	54.12	X	X	36.9	X	1350	0.2	X	0.025	X	5.98	X	1400	X	9
CGN098SW-24.5	2.8	17.8	0.2	38.34	X	X	7.6	X	1501	10.8	X	2.143	X	6.74	X	1515	X	31
PAH08SW	1	5.5	0.3	1338.41	X	35	14.9	X	1421	0.1	X	5.612	X	6.52	X	1573	X	19
CGN084SW-43.5	0.9	12.3	0.1	194.93	X	X	45.9	X	1439	0.6	X	4.189	X	5.08	X	685	X	23

X = below detection limit, samples with SW in the identifier are leachates generated from site water obtained from bore PAHOH08.

Table F1: Summary of laboratory analyses – leachate samples (continued)

ELEMENTS	Li	Mg	Mn	Na	Ni	OH	P	Pb	pH	Rb	S	SO4	Se	Si	Sr	TDSEva	TotAlk	Zn
UNITS	µg/L	mg/L	mg/L	mg/L	mg/L	mgCaCO3/L	mg/L	µg/L	NONE	µg/L	mg/L	mg/L	µg/L	mg/L	mg/L	mg/kg	mgCaCO3/L	mg/L
DETECTION	0.05	0.1	0.1	1	0.1	5	1	0.5	0.1	0.02	1	3	0.5	0.5	0.1	20	5	0.1
METHOD	/MS	/OES	/OES	/OES	/OES	/VOL	/OES	/MS	/METER	/MS	/OES	/CALC	/MS	/OES	/OES	/GRAV	/CALC	/OES
CGN098-24.5	72.64	42.1	X	171	X	X	X	X	7.6	25.69	63	188	4.5	2.3	0.2	650	137	X
CGN050-14.1	3.06	1.8	X	38	X	X	1	0.8	7.4	3.14	4	11	0.8	17.8	X	141	23	X
CGN031-11.2	14.05	41.5	X	173	X	X	X	X	6.7	2.62	17	50	4.9	9.3	0.2	728	13	X
CGN098-62.1	18.45	53.6	0.3	45	X	X	X	X	7.6	17.27	43	128	7.4	2.2	0.4	402	178	X
CGN067-30.9	717.41	72.4	5.8	117	3.4	X	X	1.5	5	38.07	128	383	19.5	7	0.3	877	X	1.4
CGN098-43.0	31.51	51.1	0.1	100	X	X	X	0.8	7.6	21.62	35	104	7.7	2.2	0.2	508	205	X
CGN089-20.1	32.63	52.1	0.1	102	X	X	X	1.1	7.6	22.37	38	114	7.4	2.1	0.2	518	205	X
CGN084-23.0	64.08	169.8	0.7	90	0.1	X	X	X	7.2	25.89	279	836	27.6	1.9	0.8	1554	183	X
CGN067-23.2	12.04	13.7	X	109	X	X	X	0.5	7.1	9.17	19	56	2.7	6.7	X	400	20	X
CGN092-44.1	16.1	49.4	0.3	43	X	X	X	0.8	7.7	14.72	24	72	5.3	2.6	0.4	380	227	X
CGN084-43.5	10.99	4.2	X	62	X	X	X	3.4	8.8	9.8	5	15	9.8	10.5	0.5	227	103	X
CGN052-20.3	11.48	9.8	X	44	X	X	X	2	7.7	0.73	3	8	X	5.4	0.1	158	40	X
CGN092-30.3	30.68	46.6	X	122	X	X	X	0.6	7.6	23.05	53	158	12.1	3	0.4	546	158	X
CGN031-19.3	7.03	18.4	X	108	X	X	X	30.2	7.3	25.37	8	24	X	191.8	X	480	20	X
CGN050-26.0	4.91	6.9	X	21	X	X	X	1.1	8.1	17.75	5	16	10.9	5	0.1	60	73	X
CGN052SW-20.3	67.31	78.5	X	1281	X	X	X	X	7.9	5.6	3	9	21.1	8.2	0.1	3576	1380	X
CGN092SW-44.1	67.5	72.5	X	1339	X	X	3	1.1	8.4	53.86	19	57	25.8	5.4	0.5	3822	1500	X
CGN084SW-23.0	109.91	170.1	X	1342	X	X	X	X	8.1	55.96	226	676	46	4	0.4	4484	1335	X
CGN089SW-20.1	69.97	81.6	X	1456	X	X	2	1.1	7.9	34.98	11	34	19.3	7.1	1.3	4062	1485	X
CGN067SW-30.9	1715.99	107	1	1382	0.7	X	1	1.8	8.1	81.15	138	412	43.4	6	1.7	4179	1255	X
CGN098SW-62.1	85.06	80.9	X	1360	X	X	X	X	8.1	61.17	41	124	28.7	4.9	0.3	3900	1450	X
CGN050SW-14.1	46.7	74.8	X	1302	X	X	2	0.6	8.3	1.22	4	13	20.6	10.8	1	3610	1400	X
CGN098SW-24.5	135.48	97.9	X	1443	X	X	1	X	8.3	54.69	58	175	20.2	4.5	0.3	4231	1515	X
PAH08SW	74.05	37.5	X	1489	X	X	X	0.8	8.5	56.05	1	3	14.9	7.7	2.9	3998	1608	X
CGN084SW-43.5	78.55	80.7	X	909	X	X	X	0.5	7.6	47.29	6	18	27.7	4.5	9.2	2910	685	X

X = below detection limit

F2. SALT REMOBILISATION ANALYSIS

F2.1 Spoils salt load estimation

Blasting operations will generally aim to optimise fragmentation towards the larger rock sizes. The resulting distribution can be approximated by the Rosin-Rammler formula shown on Figure F5. Two limiting plots are indicated – the larger size distribution assumes efficient blasting and blocking, while the reduced sizing assumes lower fragmentation efficiency leading to an increase in smaller sized fragments.

Equilibrated end point estimates for the leachate trials have been used to upscale smaller fragment results to a full fragment distribution using an equation that reflects a reducing LSL with increasing particle size. The equation is of the form:

$RR_e = a + b*\log(\text{size})$ where: RR_e = salt leached at equilibrium (gm/kg of sample)

a = 1.50

b = -0.40

size = average (retained sieve) fragment size

Tables F2 and F3 provide summaries of theoretical particle distributions for a 10 tonne sample of spoils together with the calculated salt load based on measured release rates and the above equation, and an estimated cumulative (total) salt load for each of the distributions shown on Figure F5. Assuming an average spoils emplaced density of about 1.9 t/m^3, the equivalent mobilisable salt loads per cubic metre of spoils for the optimal and reduced size distributions are estimayed to be 0.65 kg and 1.13 kg respectively.

Table F2: Calculated mobilisable salt (10t spoils) – large fragmentation size

Screen size (mm)	weight passing (%)	weight retained (gm)	Projected dia. (mm)	calc. salt load (gm)	cum. salt load (gm)
<0.18	3.24E-08	3.24E-01	9.00E-02	6.21E-04	6.21E-04
0.18 to 0.4	160E-07	1.28E+00	2.90E-01	2.19E-03	2.81E-03
0.4 to 0.9	8.10E-07	6.50E+00	6.50E-01	1.02E-02	1.30E-02
0.9 to 2.1	4.41E-06	3.60E+01	1.50E+00	5.15E-02	6.45E-02
2.1 to 5	2.50E-05	2.06E+02	3.50E+00	2.64E-01	3.28E-01
5 to 10	1.00E-04	7.50E+02	7.50E+00	8.62E-01	1.19E+00
10 to 20	4.00E-04	3.00E+03	2.00E+01	2.94E+00	4.13E+00
20 to 50	2.50E-03	2.10E+04	3.50E+01	1.85E+01	2.26E+01
50 to 100	9.95E-03	7.45E+04	7.50E+01	5.59E+01	7.85E+01
100 to 200	3.92E-02	2.93E+05	1.50E+02	1.84E+02	2.63E+02
200 to 500	2.21E-01	1.82E+06	3.50E+02	8.78E+02	1.14E+03
500 to 1000	6.32E-01	4.11E+06	7.50E+02	1.44E+03	2.58E+03
1000 to 2000	9.82E-01	3.50E+06	1.50E+03	8.03E+02	3.38E+03

Table F3: Calculated mobilisable salt (10t spoils) – reduced fragmentation size

Screen size (mm)	weight passing (%)	weight retained (gm)	Projected dia. (mm)	calc. salt load (gm)	cum. salt load (gm)
<0.18	6.00E-04	6.00E+03	9.00E-02	1.15E+01	1.15E+01
0.18 to 0.4	1.30E-03	7.32E+03	2.90E-01	1.26E+01	2.41E+01
0.4 to 0.9	3.00E-03	1.66E+04	6.50E-01	2.61E+01	5.02E+01
0.9 to 2.1	7.00E-03	3.98E+04	1.50E+00	5.69E+01	1.07E+02
2.1 to 5	1.65E-02	9.53E+04	3.50E+00	1.22E+02	2.29E+02
5 to 10	3.27E-02	1.62E+05	7.50E+00	1.86E+02	4.15E+02
10 to 20	6.45E-02	3.18E+05	2.00E+01	3.12E+02	7.27E+02
20 to 50	1.53E-01	8.85E+05	3.50E+01	7.81E+02	15.1E+03
50 to 100	2.83E-01	1.30E+06	7.50E+01	9.75E+02	2.48E+03
100 to 200	4.86E-01	2.03E+06	1.50E+02	1.28E+03	3.76E+03
200 to 500	8.11E-01	3.25E+06	3.50E+02	1.57E+03	5.33E+03
500 to 1000	0.9640	1.53E+06	7.50E+02	5.35E+02	5.86E+03
1000 to 2000	0.9987	3.47E+05	1.50E+03	7.97E+01	5.94E+03

F2.2 Final void water quality

Water qualities in each of the mine pits is expected to be similar since spoils lithologies and fragmentation ranges are likely to be similar. The average water quality has been estimated by calculating the ‘instantaneous’ salt load based upon the projected LSL from spoils without dilutions derived from open void storage (direct rainfall).

Employing estimates of equilibrated LSL of between 0.65 kg and 1.13 kg per cubic metre of spoils and assuming a bulk spoils minimum porosity of 20%, the equivalent water salinity range is 3250 mg/L to 5650 mg/L. This range is consistent with observed water salinities within the undisturbed coal measures.

F3. Spoils acid generating potential

Spoils acidity is generally caused by the presence of sulphide minerals and the exposure of the minerals to the air. Since the spoils would be saturated at depth, oxidation would mainly occur during emplacement and for a short time following emplacement as oxygen present within void spaces, is consumed. Pyrite (FeS_2) is generally the offending mineral in the Upper Hunter region. This mineral which produces sulphuric acid when oxidised and wetted according to the following well known reaction:

$$FeS_2 + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 2H_2SO_4$$

The potential generation of acid can be buffered or neutralised through the presence of carbonates, or through exchange mechanisms or the breakdown of silicates. Hence measurement of various parameters that address both the acid generation potential and the acid neutralising potential of the emplaced materials, permits an overall assessment of the longer term leachate quality. A total of fifteen spoils samples have been subjected to analyses and determination of relevant ‘indicator’ parameters. Table F4 provides a summary of results.

F3.1 Maximum potential acidity - MPA

Measurement of the total sulphur content of a sample (%S) is used to calculate the maximum potential acidity (MPA) on the assumption that all sulphur in a specific sample is represented by pyrite. This assumption is often conservative since some sulphur is bound in other forms like sulphate which is non acid generating. On a stoichiometric basis the MPA of a sample is calculated by multiplying the %S by 30.62 and the result is expressed as equivalent kg of H_2SO_4 (sulphuric acid) per tonne of rejects.

F3.2 Acid neutralising capacity - ANC

Acid buffering capacity within spoils in the Upper Hunter region is most often available through the presence of secondary calcite (in coal seams), dolomite cementation in sandstones and siltstones, and illite-smectite or kaolinite (as ion exchangers). Measurement of the acid neutralising or buffering capacity within a particular sample, is undertaken by adding hydrochloric acid to a sample and then titrating the aliquot with sodium hydroxide to determine the amount of acid initially neutralised. The result is expressed in the same units as the MPA - equivalent kg H_2SO_4 per tonne of spoils.

F3.3 Net acid producing potential - NAPP

The net acid producing potential (NAPP) for a particular sample is simply the difference between the maximum potential acidity and the acid neutralising capacity:

NAPP = MPA –ANC …. in kg H_2SO_4 per tonne

If the NAPP is positive then the sample is a candidate for acid forming conditions subject to other measurements. Conversely if the NAPP is negative then the sample is most likely to be non acid generating.

F3.4 Net acid generation - NAG

In order to more explicitly determine the acid generating potential of a sample, a further test is commonly conducted – the net acid generation (NAG) test. This test is more aggressive than the above noted tests. Hydrogen peroxide is first added to the sample to effectively oxidize any sulphides. The pH of the aliquot is measured after 24 hrs, then the aliquot is boiled and the pH measured after cooling. Acidity is then determined by titration with NaOH to pH 4.5. The result is expressed in equivalent kg H_2SO_4 per tonne of rejects.

Table F4: Summary of acid forming potential of spoils

Sample	Total S	MPA	ANC	NAPP	NAG pH	NAG titr.	Comment
	%	kgH_2SO_4/t	kgH_2SO_4/t	kgH_2SO_4/t	pH	kgH_2SO_4/t	
CGN098-24.5	0.02	0.61	19	-18.39	7.6	0	non acid forming
CGN050-14.1	0.006	0.18	2	-1.82	7.3	0	non acid forming
CGN031-11.2	0.0001	0.00	3	-3.00	6.6	0	non acid forming
CGN098-62.1	0.029	0.89	26	-25.11	8.0	0	non acid forming
CGN067-30.9	0.065	1.99	3	-1.01	5.8	0	non acid forming
CGN098-43.0	0.008	0.25	33	-32.76	7.9	0	non acid forming
CGN089-20.1	0.01	0.31	21	-20.69	7.9	0	non acid forming
CGN084-23.0	0.13	3.98	24	-20.02	8.0	0	non acid forming
CGN067-23.2	0.006	0.18	3	-2.82	7.4	0	non acid forming
CGN092-44.1	0.0001	0.00	26	-26.00	8.0	0	non acid forming
CGN084-43.5	0.0001	0.00	102	-102.00	8.4	0	non acid forming
CGN052-20.3	0.0001	0.00	7	-7.00	8.2	0	non acid forming
CGN092-30.3	0.021	0.64	24	-23.36	8.1	0	non acid forming
CGN031-19.3	0.0001	0.00	6	-6.00	6.5	0	non acid forming
CGN050-26.0	0.005	0.15	88	-87.85	8.5	0	non acid forming

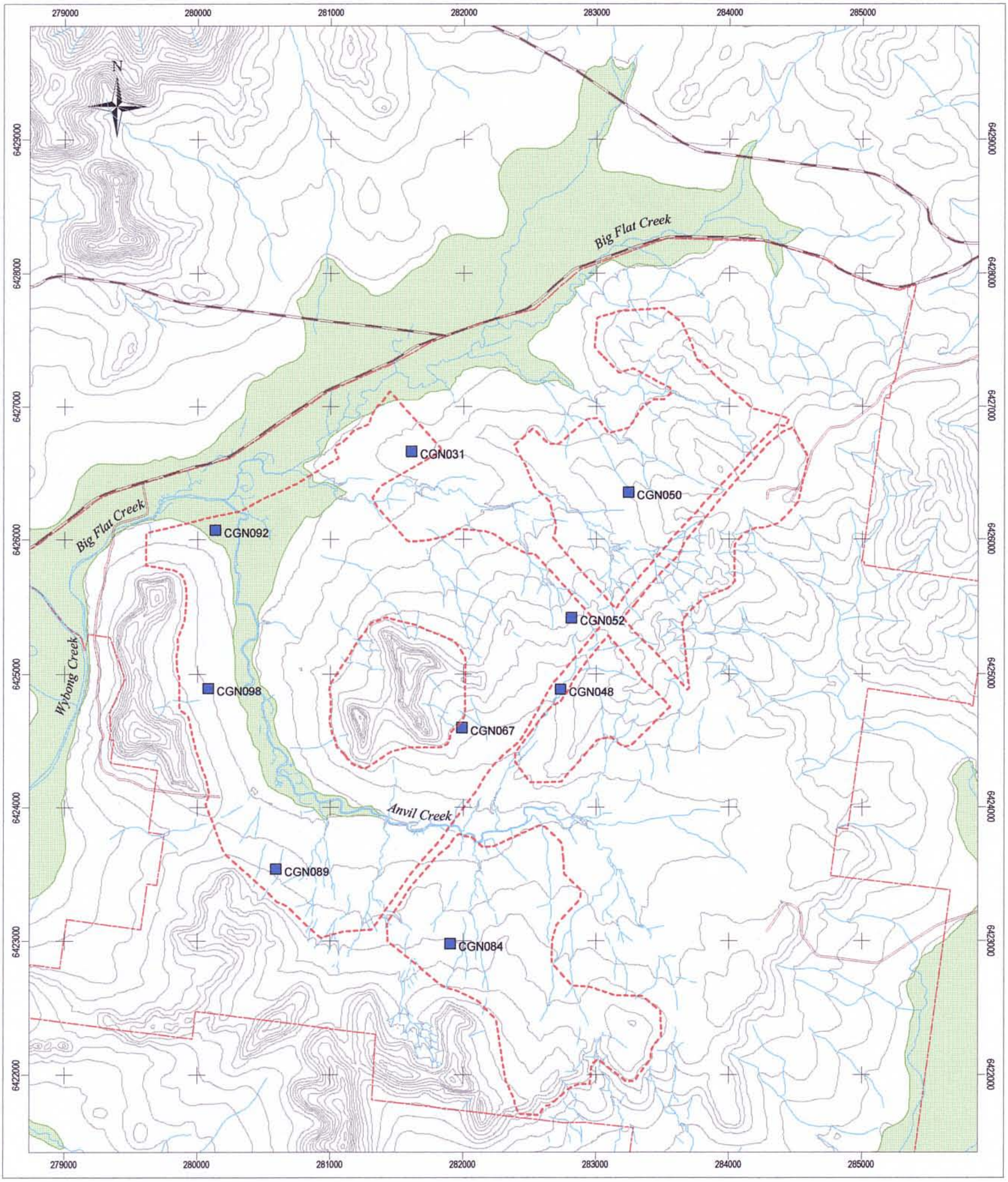
F3.5 Assessment of acid forming potential of emplaced spoils

The acid forming potential of the spoils samples can be classified on the basis of the NAPP and NAG values according to criteria given in the following Table F5. These criteria have been applied to Table F4.

All of the fifteen samples exhibit non acid forming characteristics. That is, the materials have insufficient sulphides present or are capable of buffering and mitigating any tendency to form acid when oxidised. Acid generation within spoils is therefore considered to be highly unlikely.

Table F5: Classification of acid forming potential applied to Table 3

Status	NAPP	NAG	Final NAG pH
Potentially acid forming	> 0	> 5	< 4.5
Weak potential for acid forming	> 0	≤ 5	< 4.5
Non acid forming	≤ 0	0	≥ 4.5
Indeterminate	≤ 0	0	≥ 4.5



0 1000 2000 Metres

Scale 1:40000

- alluvium
- topo contours (10m interval)
- railway
- major roads
- drainages
- project application area
- proposed mining area boundary
- core for leachate trial

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Locations of leachate core samples

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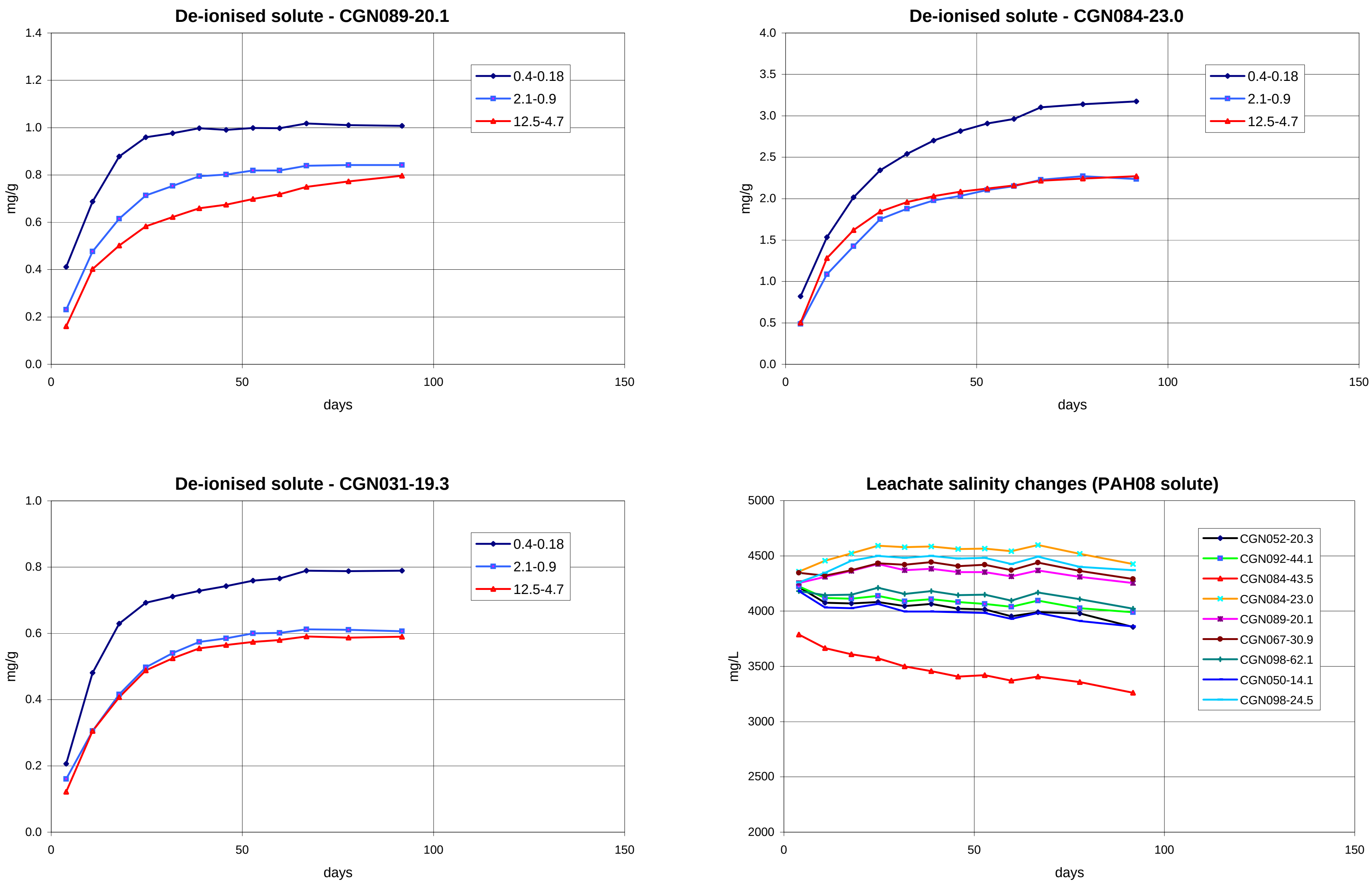
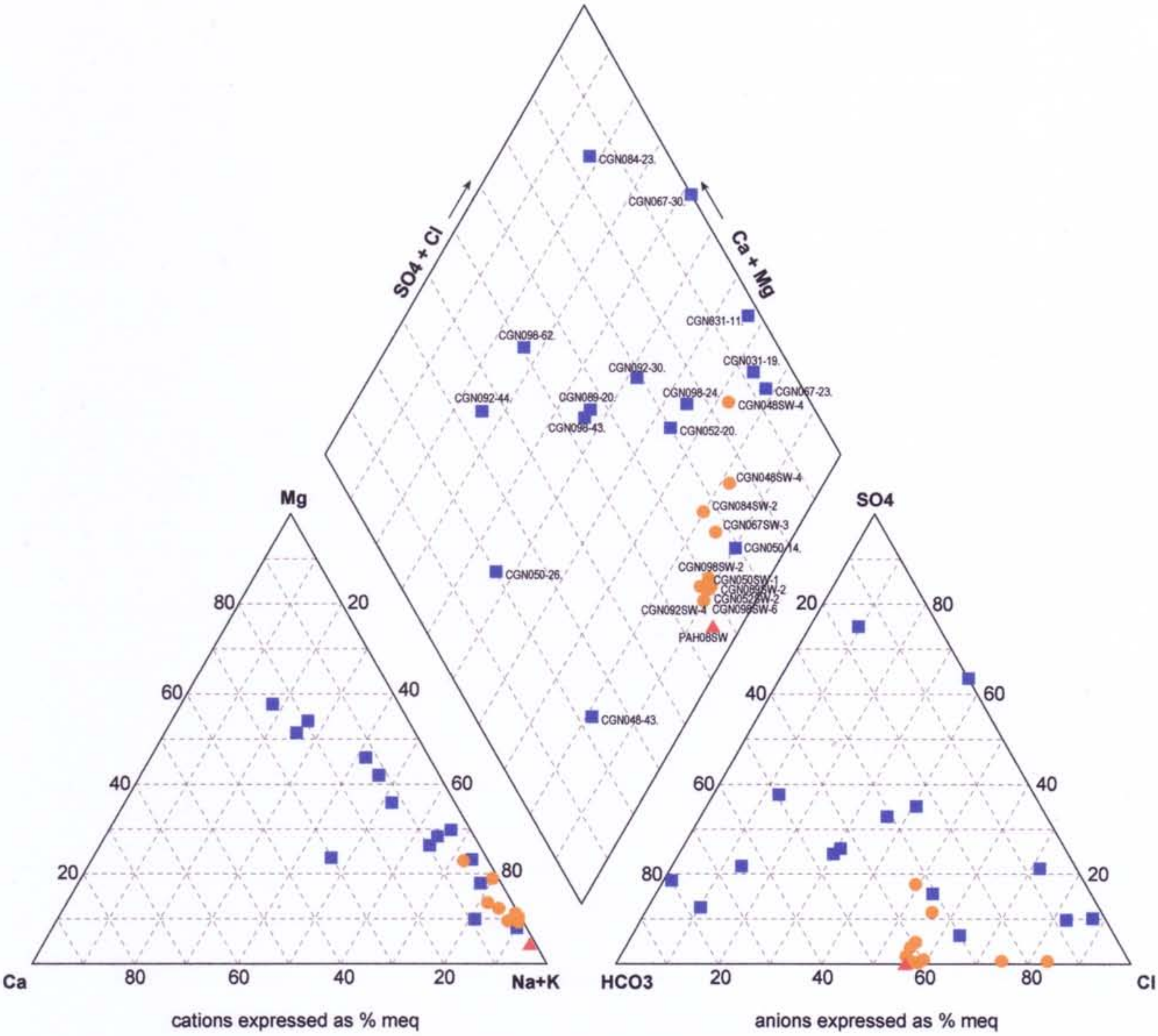
Figure F1



Typical leachate trials using de-ionised water and groundwater solutes

Figure F2



Bore ID	Date	TDS mg/L	pH	EC mS/cm	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L
CGN098-24.5	Oct-05	650	7.6	1.11	18	42	171	18	167	188	161
CGN050-14.1	Oct-05	141	7.4	0.18	1	2	38	1	28	11	28
CGN031-11.2	Oct-05	728	6.7	1.15	9	42	173	4	16	50	321
CGN098-62.1	Oct-05	402	7.6	0.65	32	54	45	8	217	128	32
CGN067-30.9	Oct-05	877	5.0	1.21	32	72	117	13	0	383	163
CGN098-43.0	Oct-05	508	7.6	0.86	24	51	100	11	250	104	94
CGN089-20.1	Oct-05	518	7.6	0.89	24	52	102	12	250	114	101
CGN084-23.0	Oct-05	1554	7.2	1.9	119	170	90	15	223	836	78
CGN067-23.2	Oct-05	400	7.1	0.66	5	14	109	7	24	56	140
CGN092-44.1	Oct-05	380	7.7	0.64	37	49	43	6	277	72	33
CGN084-43.5	Oct-05	227	8.8	0.32	6	4	62	6	113	15	9
CGN052-20.3	Oct-05	158	7.7	0.3	6	10	44	2	49	8	59
CGN092-30.3	Oct-05	546	7.6	0.95	26	47	122	9	193	158	129
CGN031-19.3	Oct-05	480	7.3	0.6	4	18	108	5	24	24	150
CGN050-26.0	Oct-05	60	8.1	0.2	15	7	21	8	89	16	1
CGN052SW-20.3	Oct-05	3576	7.9	5.94	5	79	1281	13	1684	9	1376
CGN092SW-44.1	Oct-05	3822	8.4	6.23	12	73	1339	20	1830	57	1359
CGN084SW-23.0	Oct-05	4484	8.1	6.83	17	170	1342	29	1629	676	1394
CGN089SW-20.1	Oct-05	4062	7.9	6.6	13	82	1456	32	1812	34	1545
CGN067SW-30.9	Oct-05	4179	8.1	6.67	46	107	1382	26	1531	412	1483
CGN098SW-62.1	Oct-05	3900	8.1	6.24	8	81	1360	22	1769	124	1368
CGN050SW-14.1	Oct-05	3610	8.3	5.98	37	75	1302	9	1708	13	1350
CGN098SW-24.5	Oct-05	4231	8.3	6.74	8	98	1443	31	1848	175	1501
CGN048SW-43.5	Oct-05	2910	7.6	5.08	46	81	909	23	836	18	1439
PAH08SW	Oct-05	3998	8.5	6.52	15	38	1489	19	1919	3	1421

Speciation of major ions for spoils leachates

Figure F3

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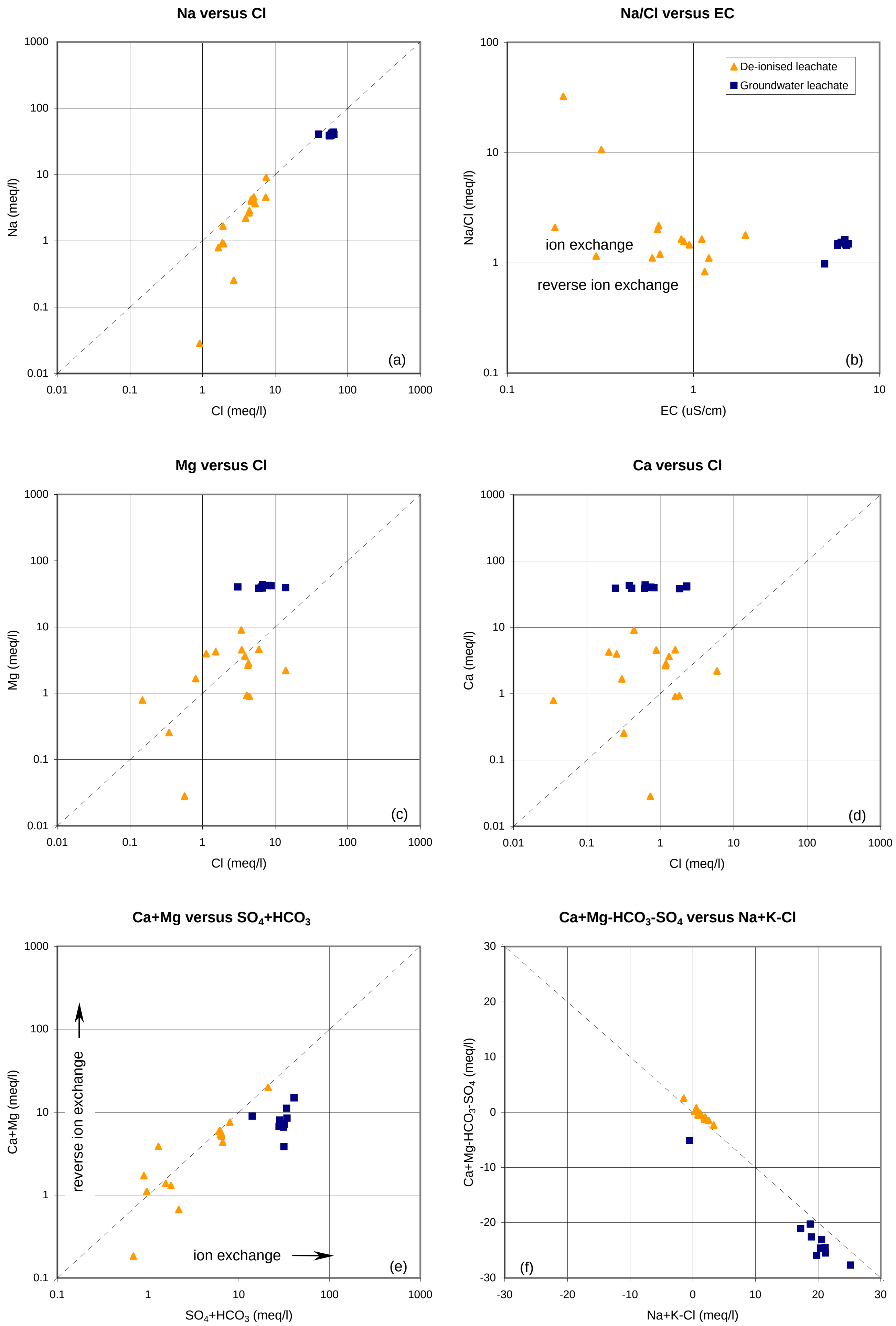

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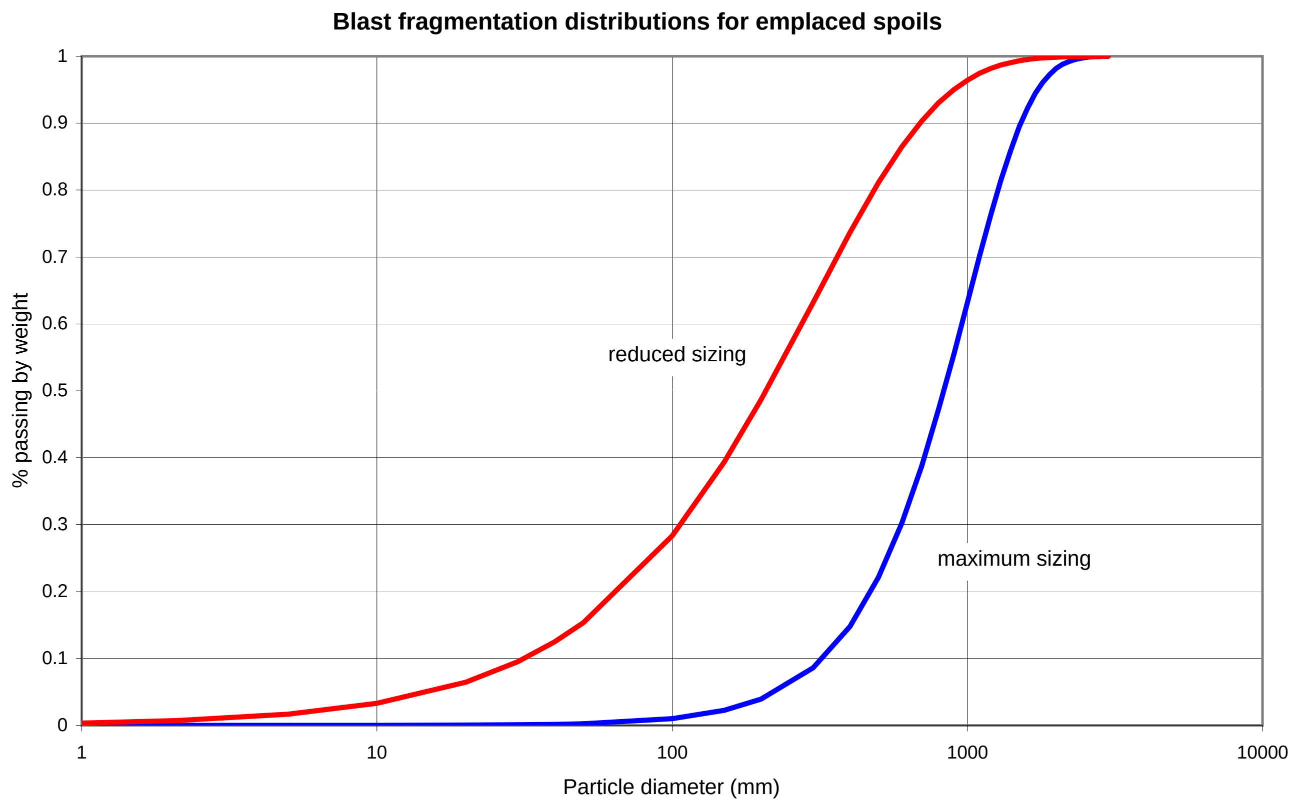
Bivariate plots for speciated leachates

Figure F4



Fragment size distribtions assume Rosin - Rammler equation for blast fragmentation. Reduced sizing red curve generates increased salt load (due to increased content of finer fraction) when compared to the estimated maximum sizing (blue curve). Actual sizing is assumed to lie between these two bounding curves.

Assumed spoils fragmentation distribution

Figure F5

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