WALLARAH 2 COAL PROJECT
GROUNDWATER MANAGEMENT STUDIES
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ABSTRACT

Groundwater impact assessments have been conducted for the proposed underground operations at the Wallarah 2 Coal Project (W2CP). Studies have included consolidation and assimilation of hydrogeological information including aquifer test and monitoring data generated as part of regional investigations, numerical computer simulation of the proposed mine development, and prediction of mine water seepage and depressurisation impacts on hard rock strata and alluvial lands associated with the Dooralong and Yarramalong valleys.

Three hydrogeological domains have been identified. They are the regional hard rock strata including Triassic non coal strata and the deeper Permian coal measures hosting the Wallarah-Great Northern (WGN) seam, the shallower weathered rock, and the unconsolidated aquifers in valley fill and coastal plain environments.

Within the hard rock aquifer system the WGN coal seam provides limited groundwater storage and transmission capacity while overburden materials comprising sandstones, siltstones and tuffs exhibit extremely low permeabilities with some lithologies hydraulically isolating formations above and below. The range in permeabilities is consistent with reported values at other mining operations to the north.

The shallower hard rocks in topographically elevated areas may offer increased but limited groundwater transmission and storage capacity through weathering of the rock matrix and the presence of de-stressed jointing. These aquifer systems tend to be localised, are rainfall driven and are likely to be perched in many areas.

The alluvial aquifers in proximity to the mine occur within the Dooralong and Yarramalong valleys. Alluvial sediments comprise moderate to low permeability clays, silts, sands and gravels in a mixed assemblage which is typically 5 to 30 m thick. These alluvial systems are rainfall driven and retain a shallow water table 2 to 5 m below ground surface which exhibits a downstream hydraulic grade. Coastal sands to the east of the project area are more permeable and most likely exhibit a seaward hydraulic grade.

Limited measurement of regional aquifer pressures in the hard rock strata suggests an aquifer flow regime consistent with topography where elevated piezometric levels occur in topographically high areas while lower levels occur in low lying areas. A regional flow regime from elevated to low lying areas can be inferred from the observed difference in piezometric levels. Upwards leakage of groundwater from hard rock strata to the valley hosted alluvium can also be inferred. This flow regime may be enhanced in shallower strata by more open joints and fractures as a result of de-stressing over geologic time. Evidence of pressure driven leakage has been demonstrated at two geological exploration bore sites where artesian pressures were encountered at relatively low elevations.

Rates of groundwater flow through the subsurface strata are governed by the prevailing piezometric surface and the hydraulic properties of strata. The velocities of flow within the hard rock system are calculated to be very low and in the range from 1.0E-7 to 1.0E-4 m/day (0.036 to 36 mm/year) based on the hydraulic conductivities used in numerical modelling of these aquifer systems. In contrast to the hard rocks, the alluvial aquifers associated with the Wyong River and Jilliby Jilliby Creek (and other significant drainages) tend to act as much more dynamic flow systems with rainfall recharge penetrating the silty aquifer materials. This infiltration mechanism sustains a groundwater flow regime towards the main drainages where creek bank and river bed seepage eventually discharges groundwater to the river or creek as base flow in a gaining stream environment. Velocities of groundwater flow within the alluvium are calculated to range from 1.0E-4 to more than 1.0E-2 m/day (36 to 3600 mm/year).

Groundwater quality within the hard rock strata is brackish to saline (limited measurement) with an indicative total dissolved solids (TDS) range of 1800 to 4600 mg/l while pH values range from 6.3 to 7.6. Groundwater within the alluvium hosted in the Dooralong and Yarramalong valleys is fresh to saline with an indicative TDS range of 200 to 9100 mg/l while pH values range from 5.2 to 11.8 although the latter may reflect the influence of borehole grouting. Increasing salinity is observed beyond the area of interest in coastal sands to the east.

Proposed coal mining is to be undertaken as longwall operations in the Wallarah-Great Northern seam at depths ranging from about 350 m to more than 600 m. Longwall panels are planned to be 150 m to 250 m wide and would be extracted over distances of 1.4 to 3.4 km passing beneath both hard rock areas and alluvial lands associated with Jilliby Jilliby Creek and Hue Hue Creek catchments, and hard rock areas associated with drainage to the lower reaches of the Wyong River.

Panel extraction will result in dewatering of the deep coal seam and in surrounding strata. Subsidence and associated strata cracking above caved areas will induce depressurisation above the seam and extending through undisturbed overburden. Such depressurisation could potentially induce leakage from groundwater resources from overlying strata including the alluvial lands hosted within the Dooralong and Yarramalong valleys.

Computer based aquifer model simulations of proposed mining operations have been conducted in order to understand the many complex groundwater flow processes that could evolve during extraction of longwall panels in the WGN seam. The basic model design is a finite difference scheme that simulates variably saturated flow in hard rock and alluvial strata over an area of more than 575 square kilometres. Hard rock strata simulated within the model include from top down, the Terrigal Formation, Patonga Claystone, the Tuggerah Formation, Munmorah Conglomerate, Dooralong Shale and the underlying WGN seam. The regolith and weathered rock zone that acts as a receptor for rainwater recharge and probably maintains a perched water table in some areas, is not included in the model due to its limited thickness.

A groundwater numerical model has been developed which represents the expected strata depressurisation case. Conservatism is built into the model where a freely draining connected cracking regime within the subsidence zone, is assumed to attain a height up to 220 m above the seam. This zone is commonly inferred to be less than 150 m at other underground mine locations adopting similar panel widths.

The model has generated predictions of formation depressurisation throughout the rock strata, and seepage to mine workings in the course of time. Since no previous mining has been conducted in the area, it has not been possible to calibrate the model against significant prior groundwater stresses within the hard rock system. However extensive field and laboratory testing has been conducted to establish representative hydraulic conductivities (permeabilities) for the different strata.

Within the limitations and constraints imposed by numerical modelling techniques, simulations of longwall mining predict that panel extraction will depressurise the WGN seam for lateral distances of 1 to 3 kilometres beyond the panels over the proposed period of mining. The depressurisation wave will also expand through overlying strata at a slow rate. A rise in mine water seepage is predicted to occur from a rate of less than 0.1 ML/day at commencement of panel extraction, to a predicted maximum sustained rate of about 2.5 ML/day. This seepage range may be enhanced from time to time by potential dewatering of any unidentified fracture related storage at depth. This may lead to short term increases of perhaps 0.5 ML/day which should dissipate over a period of months.

Pre-mining upwards leakage from the hard rock strata to the valley fill alluvium is currently inferred from regional water level monitoring and from the aquifer simulation models. A reduction in hard rock pore pressures will slightly reduce the rate of upward leakage beneath the alluvium in some areas overlying extracted panels. However the reduction in leakage induced by depressurisation after 38 years of mining is calculated to be less than 2 ml/day per square metre of land surface. This rate is very low compared to a potential rate of rainfall recharge calculated to as high as 130 ml/day per square metre (assuming 4% infiltration). Reduction of leakage induced by deep depressurisation is therefore not predicted to impact in a measurable way upon any shallow groundwater flows, creek flows or existing bores/wells located in the alluvium. On cessation of mining, groundwater levels/pressures within the hard rock strata will be re-established. However the period for significant re-pressurisation is predicted to exceed 200 years.

Subsidence over longwall panels will directly affect the shallow alluvial aquifer systems as a result of transient change in the groundwater storage component of those systems. The change may occur through either filling of temporary shallow crack storage brought about by regional subsidence, or displacement of the aquifer and water table in subsided areas.

Filling of shallow crack storage may lead to very localised short term depletion of alluvial groundwater storage followed by rapid recovery. These adjustments in storage are calculated to be small to negligible and unlikely to have any measurable impacts. Connective cracking to deeper strata is not predicted and hence shallow groundwater resources will not freely drain down to the mined panels.

Subsidence will also induce a fall in the water table elevation as a part of a panel is subsided relative to an adjacent unsubsided area. The process will be a continuum that will include subsequent rebound of the (subsided) water table. The duration of the rebound-recovery process will depend largely upon local unconsolidated alluvial aquifer properties (permeability and storage characteristics), the recharge capacity of local drainages, and the prevailing climate. Impacts of an average 1.3 metres subsidence on alluvium storage have been assessed though development of a number of shallow alluvial aquifer models at a scale more appropriate for this type of analysis than the regional aquifer model. Calculations indicate between 55 and 75% of rebound in the water table could be expected within about 6 months of subsidence occurring (for the expected range in alluvial aquifer hydraulic properties and very low rainfall recharge). The subsided areas would exhibit an increase in overall groundwater storage due to increased saturated thickness. The depth to the water table would be reduced by an amount equivalent to or less than the predicted subsidence at a particular location. The maximum contribution to additional groundwater storage created by the subsidence process is estimated to be about 2100 ML over the mine life. This volumetric requirement would be sourced from regional rainfall recharge, creek and river runoff.

A number of existing bores/wells have been identified that draw water from the alluvium and hard rock strata. The very slow reduction in hard rock pressures will not affect the long term yield at these locations. Similarly the change in water table elevation in subsided areas is unlikely to affect pumping yield. However the subsidence process may affect the mechanical integrity of twelve boreholes located within the subsidence zone. These locations could be repaired or re-drilled if damaged, without loss of yield.

Based upon study results, impacts of mining on shallow groundwater and surface water environments are judged to be low and highly unlikely to affect the water resources of the alluvial lands situated within the Dooralong and Yarramalong valleys. The water table within shallower parts of the Terrigal Formation and the underlying Patonga Claystone may be affected in some areas where perching and rainwater recharge within the regolith and weathered rock are absent. These areas are simulated within the aquifer model as comprising extremely low permeability materials that would not support exploitation for water supply in the future.

Comprehensive groundwater and surface water monitoring will need to be addressed as part of any approvals. Existing groundwater monitoring locations will need to be augmented to comply with NSW Office of Water (NOW) monitoring guidelines and all locations would need to be maintained throughout the mine life. Monitoring data should be retained in an appropriate database and provision made for analysis and transfer at appropriate reporting intervals, to NOW.

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1. INTRODUCTION

Kores Australia Pty Limited is seeking approval to develop longwall mining in an area to the north-west of Wyong. The proposal known as Wallarah 2 Coal Project (W2CP) provides for the mining of coal at a rate of about 8 Million tonnes per annum (Mtpa) over a period of 38 years. Mining will be undertaken as longwall operations in the Wallarah-Great Northern seam at depths greater than 350 m. Longwall panels are planned to be 150 m to 250 m wide and will be extracted over panel lengths of 1.4 to 3.4 km.

Panel extraction will result in depressurisation of groundwater contained within the coal seam and in surrounding strata. Subsidence and associated cracking above caved (goaf) areas will induce depressurisation above the seam which in turn has the potential to induce more widespread depressurisation extending through undisturbed overburden. Such depressurisation could potentially induce leakage from groundwater resources from overlying strata including shallow alluvial lands hosted within the Dooralong and Yarramalong valleys. In addition, potential surface cracking imparted through subsidence could affect shallow-surficial alluvial and hard rock aquifer systems while subsidence is likely to initiate transient shifts in the regional water table.

Mackie Environmental Research Pty. Ltd. (MER) was commissioned by W2CP in 2006 to consolidate existing groundwater studies undertaken by various consultants, in order to assess the likely impacts of mining on groundwater systems and to provide advice in respect of future measurement and monitoring of aquifer conditions. The groundwater assessment has more recently, been designed to comply with the Department of Planning (DoP) Director-General's Requirements for the project, being:

- a description of the existing environment,
- an assessment of the potential impacts of all stages of the project and in particular, potential impacts on the Gosford-Wyong water supply scheme, taking into consideration any relevant policies, guidelines, plans and statutory provisions;
- a description of the measures that would be implemented to avoid, minimise, mitigate and/or offset the potential impacts, including detailed contingency plans for managing any significant risk to the environment.

In this context, key areas of study relating to groundwater have been broadly identified as follows:

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

The contained report provides a summary of information arising from previous studies together with various computer based simulations undertaken by MER to assess the likely impacts arising from proposed mining operations.

1.1 Historical and recent studies of relevance

Two previous groundwater related studies have been conducted in the area of interest.

Coffey Partners International (1998) provides a relatively comprehensive study of groundwater systems in the region. Components of that study include a regional overview, identification of existing bore and well locations, geophysical profiling of parts of the shallow alluvial systems associated with Jilliby Jilliby Creek, installation of piezometers at a number of locations and establishment of a regional groundwater monitoring network. Extensive measurements of hydraulic conductivity (permeability) were also undertaken in exploration boreholes throughout the area using packer-injection techniques. The study is considered to be a 'factual data' study and a pre-cursor to impact assessment.

ERM (2002) consolidated data and findings from the above noted study and includes monitoring data for installed piezometers and preliminary assessments of possible impacts of mining on the regional aquifer systems through development of a simplified groundwater model. Surface water (flood) studies were also included.

In addition to the above, recent overview studies have been conducted by Hydroilex Pty. Ltd. in respect of the shallow zone hydrogeology of the alluvial sediments contained within the Yarramalong and Dooralong valleys.

Findings from the above studies have been incorporated within the current groundwater assessments.

1.2 Independent Expert Panel - Coal Mining in the Wyong LGA

On 5th February 2007 the NSW Government Minister for Planning announced an independent strategic inquiry into potential coal mine developments in the Wyong Local Government Area, including the Dooralong and Yarramalong Valleys. An Independent Expert Panel was appointed to conduct the inquiry and report on:

1. Whether coal mining under the catchment for the Mardi Dam would compromise, in any significant way, the water supply of the Central Coast;
2. Environmental impacts of any underground coal mining, with a particular emphasis on:
    a. surface and groundwater resources, especially on drinking water supply and flooding;
    b. hazards and risks of subsidence impacts; and
    c. the amenity of the community, including dust and noise impacts;
3. Social and economic significance of any underground coal mining to the local community, the region and State; and
4. Areas where mining should not be permitted, or if permitted the conditions under which it may proceed, having regard to the matters listed above and the NSW Government's strategic planning policies that apply to the area.

There were a number of findings and recommendations for future coal mining activities presented in the Strategic Review Report dated July 2008 and released on 15 December 2008. With regard to groundwater and in particular the alluvial aquifer systems hosted within the Dooralong and Yarramalong valleys, the findings of the Inquiry appear to be generally consistent with the impact assessments provided in this report. Relevant clauses in the Strategic Review Report include inter alia:

"Both the WACJV and DPI agree that there are dense, almost impermeable rock strata between the shallow alluvial aquifer and deeper hard rock aquifers of the region. Subsidence cracks in the hard rocks at the base of the alluvium are likely to be limited in number and depth, and to quickly fill with both groundwater and sediment. Accordingly, the Panel concludes that, even if cracks do

occur at the base of the alluvium, they are unlikely to allow significant mixing of water from the hard rock aquifers and the alluvial aquifers.";

"The Panel therefore considers that community concerns about the potential for the Wallarah 2 proposal to significantly impact the shallow alluvial groundwater resources of the Wyong Valleys are unfounded.".

2. REGIONAL SETTING

Abstraction of longwall panels within the Wallarah - Great Northern (WGN) seam is proposed in an area immediately north-west of the township of Wyong. This general area comprises two broad alluvial infill valleys known as the Yarramalong and Dooralong valleys drained by the Wyong River and Jilliby Jilliby Creek respectively. The valleys extend from steep and often rugged hinterland of the Ourimbah and Olney State Forests, south-eastward to the coastal alluvial plain adjacent to Tuggerah Lake as indicated on the locality map provided as Figure 1.

Surface grades within the low lying parts of the main valleys and coastal plains are generally no more than 20 metres in 1 kilometre (2%), with a south-easterly and easterly grade. In contrast, upland areas exhibit high topographic relief with variable but often very steep grades.

Underground mining has not been previously developed in the area. Nearest operations (Centennial Mandalong mine) are located to the north near the township of Morriset while further north are the more extensive underground operations historically associated with the Newcastle coalfield.

W2CP mining operations are proposed within the footprint indicated on Figure 1. Part of this footprint is situated in the Dooralong valley and beneath alluvial aquifer systems associated with Jilliby Jilliby Creek and its tributaries. Part of the footprint also extends southward beneath the Yarramalong Valley but this part does not extend beneath the Wyong River or its associated alluvial aquifer system.

2.1 Climate

The regional climate is temperate and is influenced mostly by coastal weather patterns. Rainfall is summer dominant and averages about 1180mm per annum as measured at Wyong gauging station.

While not accurately measured, rainfall infiltration to groundwater systems is likely to be very limited in elevated hard rock areas (less than 1%) due to the steep slopes (high runoff) and relatively low permeability of shallow and outcropping rock strata. In contrast, rainfall infiltration within the low lying alluvial valleys is likely to be much greater due to the flat lying, predominantly sandy-silty unconsolidated sediments. Infiltration-recharge rates in the range 5 to 10% of annual rainfall could be expected in these alluvial areas.

2.2 Drainage and runoff

The Wyong River and Jilliby Jilliby Creek convey valley runoff in a generally southward or south easterly direction, discharging (as the Wyong River) into Tuggerah Lake. These drainages and the numerous tributaries also provide a source of recharge to the underlying rock strata and stream bed alluvial deposits within the Dooralong and Yarramalong valleys (Figure 1). Rainwater infiltration to the unconsolidated materials and infiltration through stream and creek beds, serve to replenish the underlying aquifers and to elevate the water table during periods of extended rainfall. Following these rainfall periods, the elevated water table provides a driving head to sustain bank seepage and exfiltration of groundwater back to the drainages in the form of baseflow. In drought periods, flow ceases within most tributaries. Groundwater is then assumed to migrate slowly through the porous alluvial materials, intermittently exchanging or interacting with the major drainages and maintaining some sub-surface flow.

2.2.1 Base flow to Jilliby Jilliby Creek

Baseflows during dry and drought periods are sourced from groundwater storage and as such, the duration and magnitude of these flows can be used as a general indicator of aquifer storage. Sustained baseflow normally supports the presence of transmissive, high storage aquifers while a rapid decline in baseflow (after significant rainfall events) generally indicates limited aquifer transmission and contributing storage capacity.

Baseflow to Jilliby Jilliby Creek has been broadly estimated as part of the current study for the purpose of considering groundwater-surface water interactions within the alluvial and hard rock aquifer systems. Baseflow characteristics have also been employed in a general way to constrain numerical modelling of the aquifer system.

Flow data for the period 1973 to 2005 for gauging station 211010 on Jilliby Jilliby Ck (below Little Jilliby Jilliby Creek – see Figure 1) has been processed using a recursive filter technique to generate baseflow contributions to total creek flow with a baseflow index of 0.2. Results are provided in Appendix A as selected flow periods (Figure A1) and as a summary flow duration plot (Figure A3). Creek flows exhibit reasonably rapid flow recession even though the catchment has extensive alluvial deposits. Fairly rapid recessions are especially evident for the period 2000 to 2005 when rainfall events were relatively sparse and drought conditions prevailed from 2002 onwards. Indeed on numerous occasions, Jilliby Jilliby Creek ceased to flow. The calculated recession trends suggest the alluvium (and hard rock) within the Dooralong valley has only moderate storage potential and transmission capacity. Baseflow contributions are especially low during the extended dry periods when flows are typically less than 1 ML/day.

Baseflow estimations for the Wyong River have also been completed at gauging station 211014 at Yarramalong. Results are provided in Appendix A. However flows in this drainage system may be regulated through the Wyong water supply scheme with contributing flows from the Mangrove Creek Dam into the Wyong River catchment via Bunning Creek (Figure 1).

2.3 Geology

Regional geology is summarised on the published 1:100,000 scale Gosford-Lake Macquarie geological map (Geological Survey of NSW, 2003) and the 1:100,000 scale Newcastle Coalfield Geology Map (Dept. Mineral Resources) described by Hawley and Brunton (1995). Fundamentally the hard rock geology comprises south-westerly dipping sedimentary strata that vary in age from about 230 to 250 million years. These rocks are associated with the Clifton Subgroup of the Narrabeen Group of sedimentary rocks. Main units of interest are identified on Figure 2 a generalised stratigraphic column They include in a top-down progression, the Hawkesbury Sandstone, the Terrigal Formation, the Patonga Claystone, the Tuggerah Formation, the Munmorah Conglomerate and the Dooralong Shale. The WGN seam underlies the Dooralong Shale and is situated in the upper part of the Moon Island Beach Subgroup of late Permian coal measures. The Awaba Tuff, the Fassifern Seam and the Boolaroo Subgroup underly the WGN seam. Unconformably overlying these strata are Recent to Quaternary unconsolidated alluvial and other coastal deposits. Detailed descriptions of these stratigraphic units are provided in ERM (2002) and summarised from that document as follows:

> ***The Hawkesbury Sandstone*** (middle Triassic) only outcrops in topographically high areas in far western parts of the study area. The unit comprises a sequence of sandstones with minor siltstones and claystone lenses. Sandstones are massive, coarse to medium grained quartzose, with frequent cross bedding. The depositional environment for this unit was dominantly fluvial. Sandstone areas of high topographic relief are known to exhibit de-stressing with displacements sometimes evident along discrete bedding planes, and opening of near vertical micro fractures or joints. This process imparts a secondary permeability (via the fracture network) that is sometimes exploited for water supply.

The Terrigal Formation (+200 m thickness) is the uppermost unit of the Narrabeen Group (early Triassic) comprising a fluvio-deltaic sequence of sandstones and siltstones with occasional claystones. The formation outcrops over large areas west of Jilliby Jilliby Creek as indicated on Figure 3. The sandstones are coarse to fine grained, quartzose with occasional pebble and conglomeritic bands – a channel braid and splay depositional environment is inferred. In core, the sandstones appear to be well cemented and where tested, exhibit moderate to very high rock strength and very low permeability. Like the Hawkesbury Sandstone, areas of high topographic relief may exhibit de-stressing with displacement of bedding layers and opening of near vertical micro fractures and joints. This joint induced secondary permeability enhancement has been identified through occasional mud and water losses during exploration drilling.

The Patonga Claystone is exposed in coastal cliffs from Wamberal Point to Bateau Bay. The claystone also outcrops as a north westerly line of undulating hills from Wyong in the south east, to Cooranbong in the north and subcrops over much of the area east of Jilliby Jilliby Creek. The unit is not a massive claystone as the name suggests but comprises a variable sequence of grey to green, and red to brown claystones and siltstones with relatively minor occurrences of fine grained sandstones. The sandstones typically fine upwards and occasionally contain basal, pebble and siltstone fragments suggesting an erosive environment. In core, the siltstones exhibit moderate to high rock strength and very low permeability.

The Tuggerah Formation outcrops along the western shore of Tuggerah Lake and along the coast between the Entrance and Toowoon Bay. The formation comprises a variable sequence of sandstones, shales and conglomerates. Sandstones are coarse to fine grained ranging in thickness from about 5 to 15 m. Uren (1977) notes that the lower part of the Tuggerah Formation typically includes medium to coarse sandstones with occasional conglomeritic bands. Interbedded siltstones and claystones are also evident. The upper part of the formation generally comprises well developed sections of medium grained sandstone with occasional thin red-brown and grey to green claystones. The depositional environment is consistent with predominantly fluvial-alluvial fans and braided streams with occasional overbank deposits.

The Munmorah Conglomerate (upper part) outcrops at Norah Head while the lower part is observed around Lake Munmorah and the southern shore of Lake Macquarie. The unit comprises conglomerates, conglomeritic sandstones, sandstones and red, green and grey shales. The conglomerates are light grey to green with well sorted and rounded pebbles or sub rounded clasts (cherts, quartzites, jaspers etc.) ranging from 10 to 20 mm dia. The sandstones are typically medium grained grey to white with cross bedding evident. These conglomerates and sandstones are thought to have been deposited in a braided stream and alluvial fan environment.

The conglomerate attains a maximum thickness of more than 140 m in the Macquarie Syncline, near Lake Munmorah, thinning to the south-west over the Morisset Anticline to approximately 80 m.

The Dooralong Shale is the basal unit of the Narrabeen Group and the Clifton Sub-Group. The shale unit has a maximum thickness of approximately 200 metres and comprises mostly siltstones, claystones and minor sandstones. Siltstone successions are interbedded grey to green, medium to fine grained while sandstones tend to be typically white to grey.

The depositional environment is consistent with lower energy alluvial overbanks in a fresh to brackish water environment. The sediments often display irregular bedding (including coarse to fine grained sandstones) and small scale cross bedding together with carbonaceous laminae. The sandstones commonly exhibit a fining upwards with an erosive base.

Unconfined compressive strength tests (SCT, 1999) indicate a wide variation in both the horizontal and vertical directions associated with the interbedded sequence (10 to 40 Mpa). Core inspections support very low permeability.

The Wallarah Seam is best developed to the north around Catherine Hill Bay. The coal is dull, hard and massive, and constitutes one of the best steam coals of the Newcastle Coalfield. It coalesces with the Great Northern Seam in the Wyong area. The Great Northern Seam is also characteristically hard and dull with higher ash content but relatively few ash bands. The seam is well developed in the northern part of the Newcastle coal field where the type area offers a maximum seam thickness of 7.3 m. The seam thins southward but maintains a thickness of about 6 m in the Wyong area as the Wallarah-Great Northern Seam. It is extensively silled in the Cooranbong area to the north. Moderate to high strength (30 to 80 MPa) rocks comprising shales, siltstones and conglomerates provide the roof to the seam (SCT, 1999).

The Awaba Tuff is overlain by the Bolton Point Conglomerate Member and underlain by the Chain Valley seam. Thickness is reported to vary from 2 to 12 m in the area of interest with a recorded maximum thickness of 24 m (McElroy & Coleman 1961). It is characterised by a greenish chert-like appearance and texture. Core inspection supports a low to very low permeability. SCT (1999) report a rock strength in the range 30 to 70 MPa.

Unconsolidated and variably saturated alluvial sediments occur at the surface within the Dooralong and Yarramalong valleys while dune sands and estuarine deposits prevail in coastal areas to the east. The distribution of unconsolidated sediments is shown on Figure 3. These sediments typically attain thicknesses of 10 to more than 30 m and comprise mixed and variable sequences of sands, silts and clays. Relatively clean permeable sand and gravel zones can occur both at surface and at depth but appear to be sparse in the Dooralong valley. Along the (valley) alluvium perimeter, sheet wash and hill slope runoff undoubtedly contribute colluvial deposits in the form of localised fans and braids that overly a regolith or weathered hard rock zone generally of limited thickness.

Figure 4 provides a SW-NE vertical section (location identified on Figure 3) illustrating the general juxtaposition of strata and the proposed WGN seam extraction interval. Within the proposed mine footprint, the seam occurs at depths varying from about 350m in the north-eastern area to more than 600 metres in areas to the south-west. Structure contours for the floor of the WGN seam are shown on Figure 5 and further illustrate the south-westerly dip. Figure 6 indicates the depth of cover over the seam.

2.4 Structural influences

The horizontal stress field in the area is approximately NNE-SSW and this may have induced jointing in the same direction. Lineaments associated with jointing also support a WNW-ESE influence on some drainages throughout the region. These lineaments can be recognised in the regional topography.

Major regional faults have not been identified by W2CP geologists. Minor faults may be inferred from observed fractures in drill core but these features are generally sparse. Where fractures are observed, it has not been possible to map continuity beyond ‘in-hole’ observation due to the near vertical orientation and variable scale of such features. Typically they are observed to be free of secondary mineral deposition or alteration suggesting they are more consistent with micro cracks that do not enhance or contribute to groundwater flows at depth. Apertures of these cracks are observed to be less than about 100 microns in unconfined core (loupe measurement) and are estimated to be less than 20 to 50 microns when confined.

A number of regional dykes have been identified by W2CP geologists. Known or inferred doleritic dykes identified from airborne magnetic survey, are indicated on Figure 3. These features tend to be variably altered from observations at other underground mines, and are considered to be unlikely to act as flow barriers that might compartmentalise groundwater flows at a regional scale.

3. GROUNDWATER HYDROLOGY

Groundwater occurrence within the region has been mapped as part of the current study. Three principal domains have been identified:

- the unconsolidated alluvial aquifers hosted within the Yarramalong and Dooralong valleys and coastal areas where unconfined conditions prevail,
- the shallow weathered rock zone where unconfined conditions prevail,
- and the more regional sedimentary rocks and coal measures including the WGN seam. This sequence of rocks supports variably confined conditions except in areas where the strata subcrop.

Figure 3 provides a map showing occurrence and approximate boundaries to the unconsolidated alluvial and the coastal aquifer systems together with subcropping geology.

The unconsolidated alluvial deposits act as an inhomogeneous aquifer system exhibiting variable storage and transmission characteristics depending upon location. The underlying Narrabeen Group is regarded as an aquifer only in the shallow weathered zone or in areas where secondary permeability has been introduced through jointing and stress relief at shallower depths, more generally within the Terrigal Formation. For the greater part however, strata within this group of rocks are considered to be aquitards (very poor groundwater transmission characteristics) or aquicludes (impermeable).

3.1 Existing bores and wells in the region

Groundwater resources are occasionally exploited for water supply by bores and wells. In order to determine the locations of existing bores and wells, a records search was conducted on the NSW Office of Water (NOW) database. This database contains all registered structures and includes both pumping bores and wells in use, and exploration/test wells which may have been completed as monitoring bores.

Figure 7 provides the results of the records search and identifies 61 bore/well locations within a 5 kilometre zone of the mine footprint including 12 locations situated within the footprint. More distant bores are located mainly to the south of Yarramalong Road or clustered in the Yarramalong and Forest Park areas. Appendix B provides registration details of 39 bores located within and up to 2km beyond the mine footprint.

An overview of bore construction information indicates most locations draw groundwater from the hard rock areas (Narrabeen Group) rather than the alluvial areas. Yields are variable but generally low, and water qualities vary from fresh to brackish.

3.2 Groundwater occurrence in unconsolidated valley sediments

Groundwater contained within the valley infill and coastal plain sediments occurs within a mixed but typical sequence of gravels, sands, silts and clays. Measurement of groundwater levels at specific alluvial monitoring bores/wells installed some years ago for environmental assessment purposes, has indicated an overall saturated thickness ranging from 2 to more than 30 m. Measurement of water level and water quality parameters has not been possible in recent years due to restricted access to monitoring sites. However standing water levels (in bores) and basic water quality parameters were recorded at monitoring locations over the period February 1998 to December 2001. Appendix C provides a summary of data locations together with graphical plots.

Water level measurements support relatively shallow depths to groundwater of the order of 1 to 5 m with seasonal oscillations evident in all observation bores due to natural rainfall recharge. These depths and seasonal movements (in alluvial lands) are also consistent with observations in the Mandalong Valley to the north of the project area.

Historical pH measurements indicate a range from 5.5 to 7.5 for coastal locations and 5.2 to 11.8 for valley deposits although the high pH of 11.8 probably reflects the influence of grouting in specific boreholes. Salinity measured as total dissolved solids (TDS) supports a fresh to saline quality groundwater in upland areas (200 to 9100 mg/l) and moderately fresh to highly saline quality groundwater in lowland and coastal areas (500 to >20000 mg/l).

Deeper groundwater in the alluvial areas may be more brackish or saline than shallower groundwater as a consequence of slow upward leakage of brackish groundwater from the deeper hard rock aquitards in inland areas. Shallower groundwater may be fresh or weakly brackish in some areas.

More detailed analysis of groundwaters contained within the alluvium has been previously undertaken (CPI 1998, ERM 2002) through speciation of major ions in water samples obtained from installed piezometers. These groundwaters have been characterised through cation and anion occurrences. Results are summarised in Appendix C as Figure C3, a trilinear speciation plot. This type of plot facilitates classing of the groundwaters. Reference to the trilinear plot indicates both alluvial and hard rock water samples plot in a similar domain and can not be easily discriminated from each other. The domain exhibits a dominance in primary salinity with Na>Mg>Ca and $Cl > HCO_3 > SO_4$.

3.2.1 *Hydraulic properties of alluvium*

Hydraulic properties of the unconsolidated alluvial deposits, while sparsely measured due to restricted access to test locations, generally reflect a silty, clayey alluvium with low hydraulic conductivities. Locally these conductivities are likely to exhibit some variance due to the nature of the unconsolidated materials and the depositional environment.

CPI (1999) undertook falling head testing at 12 locations identified in Appendix D. Analysis was based upon the Hvorslev method. Additional analyses were conducted by MER using the KGS method (Butler, 1997). Results are also provided in Appendix D. An overview of results indicates a generally low hydraulic conductivity alluvium consistent with the observed geology – silty and clayey sands and gravels. The average conductivity value assuming a log normal distribution is approximately 1.8E-01m/day while the median value is 2.0E-01 m/day for Hvorslev analyses and 2.4E-01 m/day for KGS analyses. Depth to the water table is shallowest in the area of piezometers DO41 and DO42 at the confluence of Armstrongs Creek with Jilliby Jilliby Creek.

Hydraulic conductivities of shallow sand deposits situated in coastal areas to the east, while untested, are expected to be higher than the alluvial deposits within the Dooralong and Yarramalong valleys. Table 1 provides a general summary of expected properties.

Table 1: Estimates of hydraulic conductivity for shallow unconsolidated aquifers

Material	Hydraulic conductivity (m/day)	Drainable porosity (%)
valley alluvium - gravels	10 - 50	25 - 35
valley alluvium – sands	1 - 20	20 - 35
valley alluvium - silts	0.01 - 5	15 – 30
valley alluvium - clays	<0.0001 – 0.01	1 –10
coastal sands	0.5 - 40	20 – 40
mixed valley infill - sand, silt, clay 9expected)	0.1 - 5	20 - 30

3.3 Groundwater occurrence in hard rock strata

Groundwater within the Narrabeen Group of rocks, occurs predominantly as interstitial (pore space) storage. The groundwater derives from sustained recharge by rainfall infiltration through the shallow weathered zone into the underlying clastic rocks over geologic time.

Recharge in topographically high areas sustains an elevated water table that is constrained mostly by surface drainage systems flanking these high areas. That is, the water table is intercepted by local drainages which act to relieve pressures by either conveying seeped groundwater down slope to the Wyong River and Jilliby Jilliby Creek, or by evapotranspirational losses through vegetation along these same drainages when surface flows subside. As a result, the water table (phreatic surface) tends to be a subdued reflection of topography with flow paths initiated in elevated areas often along topographic divides, and terminating beneath the major drainages or along the coastline.

Groundwater flow rates within the hard rocks are very low due to the low hydraulic conductivities of the strata. Relatively higher rates of flow are expected within sandstones while much lower rates of flow will prevail within claystones and shale strata.

There is potential for groundwater exchange between strata via fractures and micro cracks which introduce secondary permeability if they are connected. However it is extremely difficult to establish the occurrence, frequency and connectivity of these fractures since they are mostly vertical or sub vertical and consequently are less likely to be intersected by exploration boreholes than fractures that occur at shallow angles. Core inspections and borehole permeability testing undertaken as part of the current study suggest the hard rock strata are infrequently fractured and therefore likely to exhibit low secondary permeability. Where observed in core, the fractures are often clean and without alteration or secondary mineralisation implying negligible movement of groundwater along these features.

Groundwater within the hard rock strata may be differentially pressurised through structural features or bedding plays, especially in areas of higher topographic relief. When such conditions are encountered during drilling, groundwater levels may rise and sustain an artesian flow at surface. This phenomena was encountered at exploration boreholes B500V800 and B600V850P for example.

The WGN coal seam like most seams throughout the coalfields, is identified as the main aquifer at depth in so far as it offers enhanced groundwater storage and transmission characteristics through the presence of cleating although the seam is only weakly cleated. Historical mining operations at other locations (eg. Mandalong) have preferentially depressurised and dewatered the seam with loss of pressure extending over significant distances in advance of mining (+1km) and ultimately inducing vertical leakage and pressure losses within overlying and underlying strata.

3.3.1 Hydraulic properties of hard rock strata

There is a reasonable body of information addressing the hydraulic conductivities of the Narrabeen Group and the WGN seam in areas to the north of the project area. Of particular note are measurements reported by Pacific Power International in the Cooranbong area. The following Table 2 provides a concise summary of packer testing results for the main lithologies in that area (Forster et. al., 1997).

Extensive hydraulic testing has been conducted in the hard rock strata within the W2CP project area as part of regional hydrogeological evaluations. Test procedures have comprised conventional packer injection type testing (CPI, 1998) and laboratory measurements on overburden core to establish an expected range in hydraulic conductivities. Other measurements have included porosity, and parameters relating to geomechanical properties - sonic velocity, unconfined compressive strength (UCS), Youngs modulus etc.

Table 2: Estimates of conductivities for consolidated aquifers in the Cooranbong area

Formation	Description	Borehole	Depth int. (m)	Hyd. cond. (m/day)
Patonga Claystone	slickensided joints and some crushed seams	PCGW34	56.9-62.0	2.6E-04
Munmorah Cong.	typical section with massive sandstone and conglomerate	PCGW34	142.3-152.9	4.8E-05
	with siltstone band containing slickensided joints and discontinuities	PCGW36	296.9-307.5	1.7E-06
Dooralong Shale	sandstone band with open vertical fractures	PCGW34	190.9-195.5	8.3E-06
	typical section with sandstone and siltstone, no joints	PCGW34	210.3-220.9	1.3E-05
	typical sandstone/siltstone interbedded sequence	PCGW36	318.9-329.5	1.7E-06
	with porous sandstone band	PCGW36	349.9-360.5	1.7E-06
WGN Seam	coal with near vertical joints and mineral filled cleats	PCGW34	223.1-229.7	1.9E-04
	coal with numerous sub-vertical fractures and joints - fragmented	PCGW36	379.7-386.3	avg. 6.0E-01

after Forster et.al., 1997

Packer testing has been completed at 31 exploration borehole locations within the project area. Testing has generally been conducted using a single packer drill stem assembly with test intervals varying from 3 m to 200 m and averaging about 30 m. Test procedure comprised measurement of the rate of clean water injection to test intervals over a range of injection pressures (CPI, 1998). However it is noted that many tests were conducted at the limit of the equipment and instrumentation; hydraulic conductivities of test intervals were often so low that water injection could not be sustained at a measurable rate. For these tests the analytical results are regarded as upper limit estimates of hydraulic conductivity. Results of testing are provided in Appendix D and summarised in the following Table 3.

Laboratory permeability tests on core were conducted to provide improved estimates of intergranular permeability and to examine/check the ratio of vertical to horizontal permeability (anisotropy). Total porosity was also determined for selected samples. Details are provided in Appendix D and summarised in Table 3. An overview of results supports a generally impermeable hard rock regime similar to that encountered to the north in the Mandalong-Cooranbong area.

Table 3: Summary estimates of conductivities for consolidated aquifers

Stratigraphic Unit	Packer testing		Core testing	
	Median (m/day)	LN-Mean (m/day)	Median (m/day)	LN-Mean (m/day)
Patonga Claystone	< 1.77E-03	< 2.11E-04		
Tuggerah Formation	< 3.21E-05	< 4.61E-05	9.96E-06	2.32E-05
Munmorah Conglomerate	< 1.18E-05	< 3.05E-05	5.20E-06	3.56E-06
Dooralong Shale	< 1.13E-05	< 2.59E-05		1.44E-05
Wallarah/ Great Northern Seam	< 2.24E-05	< 4.56E-05		
Teralba Conglomerate	< 1.46E-05	< 5.15E-05		
Karingal Conglomerate	< 1.46E-05	< 3.04E-05		
Awaba Tuff	< 1.47E-05	< 6.19E-05	4.51E-06	4.51E-06
Fassifern Seam		< 2.71E-03		
Bolton Point Conglomerate		9.12E-06		

LN=mean assuming a log normal distribution

Compressibility and subsequent estimates of elastic storage (as S_s) have been calculated from laboratory measurements of Youngs Modulus undertaken by SCT Operations Limited (SCT - 1999) and measurements of total porosity (Appendix D). Specific storage estimates ranging from 1.0E-06 to 3.0E-06 1/m have been calculated for a modulus range from less than 10 to more than 25 GPa.

3.4 Groundwater quality in hard rock aquifers

Data relating to regional hard rock water qualities has been generated from limited monitoring of simple water quality parameters pH and salinity (TDS) of water samples obtained from piezometers within the project area as part of regional studies conducted between 1998 and 2002. Summary data is provided in Appendix C.

In general, the water quality data reflects fresh to brackish conditions throughout the area. Salinity measured as total dissolved solids (TDS) ranges from 1800 to 7500 mg/l while pH values range from 6.3 to 7.6. Improved quality groundwater may be expected within shallow hard rock systems (<30 m depth) in some areas of elevated topography where stress relief induced by weathering, may have generated secondary aquifers with higher rates of flushing, particularly down joints and fractures, and along bedding shears.

Hydrochemical speciation of hard rock system groundwaters has been conducted on groundwater samples obtained at a number of monitoring bores. Available data derives from ERM (2002) and is provided in Appendix C. Plotting of speciated samples on the trilinear plot (Figure C3) illustrates small differences in water classes between shallow and deep groundwaters.

3.5 Regional piezometric surface

It is not feasible to plot a regional piezometric surface from the very limited database available to the project. Instead an indicative water table plot for both the Narrabeen Group and the alluvial lands (valley fill and coastal systems) has been generated with the assistance of the regional groundwater model discussed in Section 4. Groundwater contours provided in Figure 8 have been generated from steady state aquifer modelling where the hydraulic relationships between rainfall recharge, stream bed elevations and rock permeabilities, have been considered. Predicted water levels have been calibrated against limited measurements of water rest levels within the monitoring bore network (see Appendix E). The generated piezometric surface is a subdued reflection of topography with flow directions generally away from topographic highs and towards the Yarramalong and Dooralong valleys, and subsequently towards the coast.

Rates of groundwater flow are governed by the prevailing piezometric surface and the hydraulic properties of respective strata. The velocities of flow within the hard rock system (Terrigal Fm.) are calculated to be very low and in the range from 1.0E-07 to 1.0E-4 m/day (0.036 to 3.6 mm/year) based on the hydraulic conductivities used in numerical modelling of the aquifer system.

In contrast to the hard rocks, the alluvial aquifers associated with the Wyong River and Jilliby Jilliby Creek (and other significant drainages) act as more dynamic flow systems with rainfall recharge penetrating the sandy and silty aquifer materials. This infiltration mechanism sustains a groundwater flow regime towards the drainage axes where creek bank and river bed seepages eventually discharge groundwater to the river or creeks as base flow. Velocities of groundwater flow within the alluvium are calculated to range from less than 1.0E-4 to about 1.0E-2 m/day (36 to 3600 mm/year).

It is important to note that the regional hard rock groundwater system below the water table is in fact a complex three dimensional flow regime which varies depending upon depth and location of measurement. Appendix E, Figure E9 provides a number of plots that show the likely steady state piezometric surface at different stratigraphic horizons. Reference to this figure illustrates the increasingly subdued geometry of the piezometric surface at depth while still supporting a flow regime from elevated areas towards the low lying major drainages and then to the coast. Highest groundwater elevations are predicted in the Forest Park area where piezometric heads of more than 250 mAHD are calculated in the shallower hard rock system while the deep WGN seam is predicted to exhibit piezometric heads of the order of +160 mAHD in the same area. Downwards flow from the surface through the deeper strata can be inferred from the head difference.

4.0 COMPUTER SIMULATION OF PROPOSED MINING

Proposed mining will extract coal from longwall panels within the WGN seam. Panel extractions will be undertaken deep below the prevailing regional water table and will result in depressurisation of the exposed coal seam and depressurisation of strata above and below the seam. Depressurisation above the seam will be accelerated through caving and subsidence, leading to changed groundwater flow directions within the overlying strata. A pore pressure (loss) wave will propagate beyond the extracted panels at a rate governed by the prevailing hydraulic properties of all strata.

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

A relatively sophisticated computer based mathematical model of the region has been developed in order to understand the likely regional extent of depressurisation and to predict mine water influx. The modelling method employs a numerical finite difference scheme for solving a set of differential equations known to govern groundwater flow.

The modelling method requires dividing the overall area of interest into a large number of separate rectangular cells. The number of cells defined in the model (mesh) has been determined by the proposed mine panel geometry and seam extraction sequence, the spatial variations occurring in strata properties, the prevailing drainage system, and the expected hydraulic gradients that evolve during the simulation period. The constructed model comprises 14 transversely anisotropic layers representing a total area of about 575 sq. km. Cells have been carefully designed to represent the Wyong River, Jilliby Jilliby Creek, other regional drainages, Tuggerah Lake, the alluvial aquifers, and the mine plan.

Individual model layers adopt a geometry consistent with the known stratigraphy but with additional layers included to provide improved representation of strata piezometric heads and pore pressures, and to represent the caved subsidence zone. Layer 1 includes the alluvial infill deposits associated with the Dooralong and Yarramalong valleys, the coastal alluvium and the Terrigal Formation above a surface defined at about 30 mAHD (model properties have been varied accordingly). This allows layer 1 to be assigned a slightly higher permeability associated with de-stressing of the hard rock strata in elevated areas when compared to deeper strata. Layers 2 and 3 represent the intermediate and deeper parts of the Terrigal Formation. Deeper layers represent the Patonga Claystone, and the underlying Tuggerah Formation, Munmorah Conglomerate, Dooralong Shale and the WGN seam. The geometry of each unit has been carefully defined from structure contour information supplied by WCP2 and interpolated regionally. The base of the model has been defined as a surface uniformly 100 m deeper than the WGN seam floor. Model details are provided in Appendix E.

The model identified as W1 represents the expected case and is based upon a hard rock permeability distribution derived from measured hydraulic conductivities.

4.1 Model properties, initial conditions and transient changes

Properties assigned to the model which govern groundwater flow include hydraulic conductivity, compressive storage and specific yield. Hydraulic conductivity distributions have been calculated using three exploration boreholes as type profiles or sections as described in Appendix E. Geologic logs for each of the boreholes have been used in assigning broadly representative hydraulic conductivities to each logged section, then consolidating the distribution into equivalent vertical and horizontal conductivities for each stratigraphic layer.

In addition to strata conductivities, enhanced vertical conductivities representing connected and free draining cracking regimes within the subsidence zone, have been imitated in zones above mine panels. Basically four disturbed zones are often associated with the subsidence process, the first three being included in the model at depth. The fourth (shallow vertical cracking) is relatively small scale and has been addressed by simple calculation. The zones are characterised as follows and are more fully described in Appendix E:

- ***completely caved goaf***: the extracted coal seam which is identified as being highly permeable detached-collapsed roof material. ;
- ***highly connected cracking:*** a zone situated above goaf and within the subsidence zone, extending upwards through overburden. This zone exhibits highly connected cracking and promotes relatively free drainage of groundwater from the cracked strata;
- ***weakly connected cracking:*** a zone surrounding the highly connected cracking zone that is not free draining – pore pressures are intermediate between zero and hydrostatic;
- ***shallow vertical cracking:*** a zone of typically 10 to 20 metres depth dominated by tensile failure associated with the subsidence process. The zone is predicted to be disconnected from deeper failure regimes due to the depth of mining. Under these conditions, temporary changes in groundwater movement and storage in the shallow zone are associated with subsidence.

The most important zone for redistributing pore pressure losses regionally is usually the highly connected cracking zone since it initiates a fairly rapid rate of depressurisation and would be essentially free draining downwards to the WGN seam. The maximum height of this zone above the WGN seam has been defined by geomechanical studies (SCT, 2006) to be of the order of 160 m or less for sub-critical conditions, and up to 200 m for super-critical conditions. It is noted however that this zone progressively decreases in drainability with height (above seam) as the frequency and connectivity of cracks, reduces (see Appendix E Figure E6). A reasonably conservative zone of about 220 m height has been adopted in the model.

Boundary conditions applied to the model are mathematical constraints that govern groundwater heads and flows and include bed elevations of ephemeral and perennial creeks and rivers, Tuggerah Lake, and the Pacific Ocean. These conditions have been assigned from available topographic data supported by other survey information. Boundary conditions have also been used to represent the drift entry from surface, roadway development and panel extractions.

Regional rainfall recharge to the alluvium and deeper hard rock system has been determined through a trial and error process of steady state model simulations. Net recharge (recharge after evapotranspirative losses) has been adjusted until the regional piezometric surface broadly correlated to the measured surface at a number of control points that included exploration and monitoring boreholes scattered throughout the region. The net rate of recharge determined by this process has then been uniformly applied across the area at 4% to 8% of annual rainfall for the alluvial valleys and coastal areas, and less than 0.5% of annual rainfall for hard rock areas.

4.2 Mining induced depressurisation of rock strata

The aquifer model has been used to simulate depressurisation of the WGN seam and overlying strata based on the proposed mine plan which provides for extraction of coal (longwall panels) over a period of 38 years or 10 years beyond the proposed approval period of 28 years.

Figures E10 to E14 in Appendix E provide a detailed summary of the extent of predicted depressurisation at 7, 14, 21, 28 and 38 years of mining for different layers throughout the model. Reference to these plots shows the progressive expansion of the pressure loss envelope outwards and upwards from the WGN seam workings. Losses are accelerated upwards via the failure regime and after 38 years, zero pore pressures are predicted to impact the lower part of the Tuggerah Formation inducing pressure loss gradients within this formation and the overlying Patonga Claystone.

Figure 9 provides a detailed plot of the simulated depressurisation in the deep WGN seam after 38 years of mining. Reference to Figure 9 illustrates the substantial drawdowns that are predicted to surround the mine workings at seam depths of 350m or more. Lateral in-seam extent of depressurisation is greatest in the area of the access drift and roadways that would be constructed during the first year of mining. Here the impacts of depressurisation extend about 2 km (defined by the 2 m head loss contour) beyond the mine footprint. In contrast, the last panels extracted in the western area exhibit impacts extending about 400 m beyond the footprint. This difference in impacts demonstrates the steady but slow outward propagation of the pressure loss wave due to the low permeability of the coal seam; propagation distance is greatest in areas first mined.

Figure 10 provides a plot of predicted depressurisation of the water table within the shallow aquifer system after 38 years. The only drawdown impacts predicted to occur are located around the mine entry or portal area of the drift located near Tooheys Road and are likely to be less than a few metres. Alluvial lands within the Dooralong and Yarramalong valleys are unaffected. The reason for negligible drawdown impact in these alluvial areas are twofold and relate to the low permeability of the underlying Patonga Claystone which acts as an aquiclude, and the high storage capacity and sustained rainfall recharge prevailing within the shallow strata – storage and rainfall recharge would be able to accommodate any downwards leakage to deeper hard rock strata without measurable impacts on water levels. This leakage has been assessed within the model in terms of loss of baseflow from the alluvial and hardrock aquifer systems to the local creek catchments. The calculated losses are noted to be negligible, especially when considered on a unit area basis with respect to the alluvial lands associated with each catchment (less than 2 ml/day per square metre of alluvial land surface - see Appendix E, Table E3).

On completion of the 38 years simulation period, specific zone budgets were extracted from the groundwater model in order to provide estimates of mine water influx. Results are given in Appendix E (Figure E16). A total water make of about 26500 ML is predicted over the mine life. The calculated daily rate is expected to rise from 0.1 ML/day to a maximum influx of about 2.5 ML/day.

The mine water influx assumes no contributions from localised fracture related storage that might be intercepted by mining; the location, extent and hydraulic properties of this type of storage remain unknown. Occasional fractures can be identified in drill core but inspections suggest they are generally discrete or moderately clustered with little or no evidence of groundwater movement within the fractures. They are therefore assumed to be micro cracks with hydraulic apertures less than about 50 microns in situ. However it would not be unreasonable to expect up to 0.5 ML/day increase in mine water seepage over short periods of weeks to months if as yet unidentified deep fracture network storage is encountered and drained.

4.3 Recovery of aquifer pressures post mining

Mining is expected to cease after 38 years of longwall extraction. After this time regional aquifer pressures will begin to rebound. The rate of rebound will be dependent upon the remaining water held in storage within the hard rock strata, the hydraulic properties of goaf, and the sustained gravity drainage of strata above extracted panels.

Recovery of strata pressures has been simulated by adopting pressure distributions at 38 years of mining, as initial conditions for a recovery model. Goaf storage has been enhanced to an average 15%. Figure E17 in Appendix E shows drawdown the predicted distribution 200 years – seam depressurisation during the recovery process is predicted to extend more than 4 km beyond the mine footprint. In addition, dewatering of exposed Terrigal Formation strata of up to 10 m is evident in more elevated parts of area. In reality this may not occur as local recharge to the shallow weathered rock zone most likely acts as water store to surcharge deeper strata. This very shallow zone is not included in the model.

Much longer time frames are expected for complete re-pressurisation of strata unless artificial recharge to the underground workings, is promoted following cessation of mining. The very long time frames for recovery are attributed to the creation of much higher storage as a result of development (roadways, cut throughs etc.) and goaf, combined with the very low rates of groundwater seepage to the workings due to the very low hydraulic conductivities of the surrounding hard rock strata.

5.0 SHALLOW STORAGE CHANGES ARISING FROM SUBSIDENCE

A change in the shallow system groundwater storage will accompany the subsidence process. The change may occur through groundwater filling of induced crack type storage in the shallow hard rock strata (including strata beneath alluvial lands), or re-adjustment of groundwater levels brought about by subsidence above mine panels.

5.1 Transient and long term shallow crack storage

Shallow cracking of hard rock strata will occur in certain areas associated with the longwall panel geometry. This cracking has the potential to extend into the overlying weathered rock, soil and alluvial sediments.

Cracking is expected to occur in two distinct phases:

- transient tensile cracking associated with a migrating subsidence wave in the direction of panel extraction;
- perimeter tensile cracking adjacent to chain pillars bounding each panel.

Transient tensile cracking is predominantly represented by tensile fissuring across the panel as caving proceeds along the panel. Cracks are expected to open and close within a relatively short period of days to weeks and may not become evident at surface. Soil structure, climatic and other conditions may lead to premature infilling of the aperture by unconsolidated fine materials before closure is induced by the migrating subsidence wave.

Crack length may vary from less than a metre to more than 10 metres with a variable aperture typically ranging from a few millimetres to fifty millimetres or more, exposed for a short period (depending on surface strains). This mode of cracking would induce leakage from connected groundwater contained within any shallow adjacent or overlying unconsolidated alluvial deposits. The groundwater would fill the crack and any impact on the water table above the crack would tend to equilibrate with surrounding groundwater levels. With closure, the water may be expelled from the crack or forced into other shallow or adjacent strata. The residual storage generated within these cracks is expected to be low to negligible.

Semi permanent tensile cracking adjacent to and along the chain pillars may offer similar crack geometry to the above but crack dilation is more likely to be sustained. Crack infilling in the saturated shallow alluvium may take the form of slumping of unconsolidated materials, while in the shallow hard rock zone, open fracture storage is expected to prevail. Under these conditions there is potential for a measurable impact upon shallow storage as groundwater infills these cracks.

An estimate of the transient change in rock-groundwater storage has been made by mathematically integrating the systematic strain responses for panels extracted beneath alluvial lands and calculating the equivalent storage for cracking to a depth of 10m. MSEC (2007) Figures 7.1 to 7.4 provides plots of the total strains for sections orthogonal to longwall panels. Section 2 intercepts panels LW2S through LW10S. Maximum (extensional) strains within the alluvial lands peak at about 1.3 mm/m and are predicted above panels LW2S and LW3S in Armstrongs Creek catchment. Adopting a conservative approach and integrating the calculated strains for all positive values without provision for a limiting minimum strain below which cracking would not occur, gives a potential average displacement of the order of 0.13 m over each panel along the line of section. This displacement may occur as a few isolated cracks, or as a multitude of hairline cracks or indeed the alluvium and shallow rock may mostly absorb strain energies within the porous matrix resulting in very limited cracking. Multiplying this displacement by an affected depth of cracking of 10 m (to zero displacement) with allowance for an average 3 m depth to the water table, yields a cumulative fissure water storage of about 0.9 kL/m of panel length. This gradually evolving storage would be filled by contributions from adjacent saturated porous materials resulting in a localised temporary decline in groundwater levels until recharged by rainfall runoff. Storage in undisturbed alluvium in the same area is calculated to be 1560 kL/m assuming a panel width of 250 m and an average saturated depth of 25 m for the alluvium. Hence the change in storage attributed to cracking is considered to be very small (about 0.05%).

Cracking in non alluvial elevated hard rock areas may lead to localised redirection of groundwater flow paths in some areas. Fissures that transect drainages in these areas may infill from sediment load during periods of surface runoff, or may remain as localised conduits redirecting flows down slope (including underflows). It is not possible to predict with accuracy, the location and hydraulic connectivity of such cracking. Hence it is possible that parts of a drainage line may exhibit localised loss of runoff which would most likely be returned to the drainage system, downstream.

5.2 Change in storage due to subsidence

A change in water table elevation is likely to occur as a result of subsidence. The change would depend upon location and prevailing hydrological factors.

A maximum alluvium subsidence of the order of 1.4 m is predicted in areas associated with Jilliby Jilliby and Little Jilliby Jilliby creeks while a maximum subsidence of the order of 2.4m is predicted in areas of elevated topography which are predominantly areas of state forest. The displacement that occurs with subsidence will affect both hard rock and unconsolidated aquifer systems.

In elevated hard rock areas, the groundwater levels and gradients are only likely to change in a relatively minor way since topographic slope is much greater than the impact of subsidence – water table elevation changes will not significantly affect groundwater hydraulic gradients. Following subsidence, the water table is likely to have a similar regional geometry as pre-subsidence conditions (elevated levels beneath topographic highs) but with a reduction in elevation of about the same magnitude as subsidence. Groundwater levels would continue to fluctuate in response to rainfall recharge in the shallow weathered rock zone.

In alluvial areas with slopes of only a few degrees, surface drainages and groundwater levels will initially fall as part of a panel is subsided relative to an adjacent unsubsided area. The relative change in groundwater levels from unsubsided to subsided areas will establish localised hydraulic gradients towards the subsided area. Groundwater will migrate towards the subsided area thereby reducing the water table in the unsubsided area and inducing rebound in the subsided area All areas will continue to be recharged from rainfall and from surface drainages, resulting in a general increase in groundwater storage within any subsided alluvial lands. Since this process is likely to represent the most significant impact on shallow groundwater resources, the transient change relating to subsidence has been assessed using an alternative aquifer simulation model in a generic way.

5.3 Shallow aquifer model simulations relating to subsidence

A separate generic aquifer modelling approach has been employed to assess the likely rebound of the water table within alluvial materials in subsided areas. This type of model offers an appropriate means of considering various geometric relationships between subsidence and a drainage line or creek. Appendix F provides a summary of model design.

The alluvial materials are expected to exhibit inhomogeneous hydraulic properties distributions. Consequently the analytical approach adopted is sensitivity based – a number of model simulations have been conducted in order to frame the solution domain and generate an understanding of the limits to groundwater related impacts arising from subsidence displacements. Model simulations represent a situation where a panel is first subsided more than 1.5 km distant from a flowing creek. A subsidence wave then migrates towards the creek at a rate of about 10m/day consistent with planned coal face retreat in a panel. Four different hydraulic conductivities ranging from 0.1m/day to 5m/day have been applied to the alluvial aquifer in separate modelling scenarios.

Results of simulations are provided in Appendix F. Models based on 0.1m/day and 0.5m/day alluvium hydraulic conductivity values indicate limited drawdown impacts beyond the subsided area of a single panel with 0.1m drawdown of the water table extending up to 150m beyond the subsidence zone. This range of conductivities includes the mean and median values of alluvial materials determined from field testing (CPI, 1998) and calculated as 0.17 m/day and 0.2m/day respectively. Within the subsidence zone the water table rebounds more slowly for the lowest hydraulic conductivity with about 55% rebound observed after 200 days for a conductivity of 0.1m/day while 75% rebound is observed for a conductivity of 0.5m/day in the vicinity of the panel commencement. It is noted that these simulations are conservative and assume very low rates of rainfall recharge to the area (less than 1mm/year or 0.1% of annual rainfall). An expected higher rate of recharge to the alluvium would generate more rapid rebound. Higher conductivity models exhibit more rapid rebound in the water table but with an increasing impact zone beyond the subsided area. However this impact is generally expected to be less than 0.5m drawdown. Ultimately the water table within subsided areas would rise and equilibrate across all (subsided) panels to a new and shallower steady state elevation.

The effect of subsidence on creek flows will vary in space and time. Essentially, contributions from rainfall and surface flows will need to recharge subsided parts of the aquifer by an amount equal to the porous storage displaced vertically downwards, until equilibrium is achieved. Affected areas are delimited on Figure 13 by subsidence zones at 0.5m intervals. Purple shaded zones equate to maximum subsidence of alluvial lands (averaging 1.3m) and hence maximum fall and rebound in the water table. Orange (averaging 0.8m) and blue (averaging 0.25m) shaded zones equate to progressively smaller subsidence and rebound movements. These same zones illustrate potential increases in groundwater storage and reduced depth to groundwater as the regional water table re-equilibrates to post subsidence geomorphological conditions.

The potential increases in alluvial groundwater storage have been calculated from subsided panel areas shown on Figure 13 and are summarised in the following Table 4 based on the proposed schedule of panel extractions and an average aquifer drainable porosity of 25%. Maximum storage increase and hence maximum demand on recharge from rainfall and surface drainages, is expected during extraction of panel LW9N when 226 ML is estimated to fully replenish the subsided panel area over a period of 10 months.

The total volumetric increase in alluvial groundwater storage in subsided areas (assuming maximum replenishment) is calculated to be 2127 ML over the 38 years period of mining. In reality, geomorphological adjustments over time in subsided creek beds are likely to result in a smaller increase in storage.

Table 4: Calculated maximum recharge contributions to groundwater storage post subsidence

Panel	Start date	End date	ML storage	Drainage catchment
LW1N	3-Apr-2012	24-Sep-2012	13	Hue Hue Ck
LW2N	20-Oct-2012	15-Apr-2013	5	Hue Hue Ck
LW3N	14-May-2013	26-Nov-2013	3	Hue Hue Ck
LW4N	24-Feb-2014	29-Sep-2014	0	Hue Hue Ck + Jilliby Jilliby Ck
LW5N	28-Oct-2014	6-Jul-2015	36	Hue Hue Ck + Jilliby Jilliby Ck
LW6N	24-Sep-2015	3-Jul-2016	69	Jilliby Jilliby Ck
LW7N	4-Aug-2016	8-Jun-2017	115	Jilliby Jilliby Ck
LW8N	16-Aug-2017	17-Jun-2018	171	Jilliby Jilliby Ck
LW9N	19-Jul-2018	18-May-2019	226	Jilliby Jilliby Ck
LW10N	14-Jun-2019	25-Mar-2020	216	Jilliby Jilliby Ck
LW11N	26-Apr-2020	26-Mar-2021	204	Jilliby Jilliby Ck + Little Jilliby Ck
LW1S	29-Apr-2021	20-Sep-2021	104	Jilliby Jilliby Ck
LW2S	21-Oct-2021	22-Jun-2022	148	Jilliby Jilliby Ck + Armstrongs Ck
LW3S	24-Jul-2022	14-Apr-2023	114	Jilliby Jilliby Ck + Armstrongs Ck
LW4S	12-May-2023	21-Jan-2024	78	Jilliby Jilliby Ck + Armstrongs Ck
LW5S	25-Feb-2024	1-Nov-2024	46	Armstrongs Ck
LW6S	4-Dec-2024	1-Aug-2025	24	Armstrongs Ck
LW7S	2-Sep-2025	17-Apr-2026	30	Armstrongs Ck
LW8S	22-May-2026	18-Dec-2026	15	Armstrongs Ck
LW9S	29-Jan-2027	4-Aug-2027	0	Armstrongs Ck
LW10S	8-Sep-2027	22-Mar-2028	6	Armstrongs Ck
LW11S	26-Apr-2028	2-Jan-2029	9	Little Jilliby Ck + Wyong R
LW12S	6-Feb-2029	1-Oct-2029	6	Little Jilliby Ck + Wyong R
LW13S	6-Nov-2029	29-Jun-2030	7	Little Jilliby Ck + Wyong R
LW14S	28-Jul-2030	26-Feb-2031	7	Little Jilliby Ck + Wyong R
LW15S	6-Apr-2031	23-Oct-2031	8	Little Jilliby Ck + Wyong R
LW16S	1-Dec-2031	13-Jun-2032	11	Little Jilliby Ck + Wyong R
LW12N	6-Aug-2032	9-Jun-2033	142	Jilliby Jilliby Ck + Little Jilliby Ck
LW13N	20-Jul-2033	13-May-2034	145	Jilliby Jilliby Ck + Little Jilliby Ck
LW14N	20-Jun-2034	26-Mar-2035	110	Jilliby Jilliby Ck + Little Jilliby Ck
LW15N	29-May-2035	14-Feb-2036	55	Jilliby Jilliby Ck + Little Jilliby Ck
LW16N	2-Apr-2036	23-Jan-2037	6	Jilliby Jilliby Ck + Little Jilliby Ck
LW17N	15-Mar-2037	10-Nov-2037	0	Jilliby Jilliby Ck + Little Jilliby Ck
LW18N	30-Dec-2037	23-Aug-2038	0	Jilliby Jilliby Ck + Little Jilliby Ck
LW19N	15-Oct-2038	26-Jun-2039	0	Little Jilliby Ck
LW20N	17-Aug-2039	19-Apr-2040	0	Little Jilliby Ck
LW21N	16-Jun-2040	25-Feb-2041	0	Little Jilliby Ck
LW22N	15-Apr-2041	2-Dec-2041	0	Little Jilliby Ck
LW23N	19-Jan-2042	8-Sep-2042	0	Little Jilliby Ck
LW24N	26-Oct-2042	20-Jun-2043	0	Little Jilliby Ck
LW25N	9-Aug-2043	10-Apr-2044	0	Little Jilliby Ck
LW26N	6-Jun-2044	20-Feb-2045	0	Little Jilliby Ck
LW17S	13-Apr-2045	15-Oct-2045	0	Little Jilliby Ck + Wyong R
LW18S	20-Nov-2045	18-May-2046	0	Little Jilliby Ck + Wyong R
LW19S	22-Jun-2046	5-Dec-2046	0	Little Jilliby Ck + Wyong R
LW20S	11-Jan-2047	23-May-2047	0	Little Jilliby Ck + Wyong R

6. POTENTIAL ENVIRONMENTAL IMPACTS

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

- Reduction in regional hard rock aquifer pressures
- Leakage of groundwater from shallow alluvial aquifer systems to deeper systems
- Change in shallow aquifer system storage induced by subsidence
- Loss of groundwater yield at existing bore locations
- Change in groundwater quality
- Impact on groundwater dependent ecosystems

6.1 Reduction in regional hard rock pressures

Proposed longwall mining in the WGN seam will generate a pressure loss regime within the deep rock strata. Coal panel extraction will initially depressurise the seam and goaf. This depressurisation will then migrate upwards through overburden strata via subsidence induced cracking or bedding parting and via pore spaces in the hard rock matrix. This pressure loss regime has been assessed using aquifer numerical modelling techniques described in Section 4 above. Zero pore pressures are predicted to migrate above extracted panels, to the lower part of the Tuggerah Formation about 220 m above the coal seam. This will in turn generate pressure loss gradients within the remaining part of the Tuggerah Formation and in parts of the overlying Patonga Claystone. Since the hard rocks are basically stratified aquicludes or aquitards, there are no identifiable adverse impacts within the hard rock system.

The pressure loss envelope will generate seepage to the mine workings and to goaf. The seepage rate is predicted to rise from about 0.1 ML/day during initial decline construction, to approximately 2.5 ML/day during mining. The predicted seepage to mining operations is considered to be low and manageable.

6.2 Leakage of groundwater from shallow unconsolidated aquifers

Loss of pressure within the hard rock strata has the potential to induce leakage from shallower alluvial systems in the long term. This leakage could occur via intergranular permeability or via induced vertical fracturing arising from subsidence.

In respect of intergranular permeability, the potential downwards leakage flux from shallow aquifer systems has been calculated to be less than 2 ml/day per square metre of land surface – a rate that is small and easily balanced by recharge from rainfall which is estimated at 130 ml/day per square metre assuming 4% of annual rainfall. Loss of storage in shallow aquifers through this mechanism is therefore considered to be negligible.

In respect of subsidence induced fracturing, SCT (1999) have conducted simulations of the failure regime and determined that cracking above goafed zones would not exhibit continuity to surface. Instead, a significant zone of 100 to 400 m thickness would remain devoid of connected cracking and tend to isolate any shallow and surficial subsidence cracking from the deeper cracked and caved zones. Under these conditions the calculated leakage rates noted above are unlikely to rise. Loss of storage attributed to connective cracking is therefore expected to be negligible.

6.3 Change in shallow aquifer system storage induced by subsidence

A change in shallow aquifer storage would result from subsidence. The change would be of a transient nature and would occur through either temporary filling of tensile cracking storage that would be mainly located around the perimeter of longwall panels (at the surface), or re-adjustment of groundwater levels to changed surface geomorphology brought about by subsidence.

Adjustment due to filling of crack storage is predicted to be relatively minor. However, re-equilibration of local water levels within the unconsolidated strata would exhibit a variable impact depending upon location. The Yarramalong Valley sediments are predicted to remain generally unaffected except in areas immediately south-west of longwalls LW11S to LW16S where the alluvium is in proximity to the panel footprint. In contrast, the Dooralong and Hue Hue valley sediments are located above panels scheduled for extraction over the mine life and as such, local aquifers and contained water tables would undergo a more substantial fall in elevation as areas subside. However a rebound in the water table would then occur as subsided areas re-equilibrate to adjacent unsubsided areas. The rate of recovery would depend largely upon climatic conditions with slower rebound occurring during drought periods when local tributaries exhibit low or no flow, and a more rapid rebound occurring during wet periods.

Calculations indicate between 55 and 75% of rebound could be expected within about 6 months of subsidence occurring (for the expected range in alluvial aquifer hydraulic properties and very low rainfall recharge). The subsided alluvial areas would retain an increase in overall groundwater storage as a result of the increased saturated thickness. The depth to the water table would reduce by an amount equivalent to or less than the average subsidence in a given area.

6.4 Loss of groundwater yield at existing bore locations

Loss of pressures induced by mining within the deep hard rock strata is not predicted to affect the yield of any existing boreholes due to the very low leakage fluxes that are estimated by numerical modelling of the aquifer systems.

There are 12 bores located within the subsidence zone that may exhibit a minor loss of yield as groundwater levels initially fall then rebound as a result of subsidence induced strata displacements. Groundwater levels may fall by up to 1.3m but for average conditions, 55% to 75% recovery is expected to occur within 6 months. Such displacement is unlikely to affect borehole yield in a measurable way. However these same locations could be susceptible to mechanical damage (through subsidence) and may need to be repaired or re-drilled if damaged.

Vulnerable bores are identified in the following Table 5 and their locations are shown on Figure 7.

Table 5: Summary details of NOW registered bores/wells within mine footprint

Bore	Coordinates (AMG)		Depth (m)	Aquifers/ yield (L/s)	Water depth (m)	Water quality	Bore Geology
	E	N					
GW028035 20BL021424 P	348750	6318275	30.5	19.8-25.2m/1.26	7.60	good	0.0-4.8 clay 4.8-6.7 s/s 6.7-18.3 clay 18.3-20.4 s/s 20.4-24.4 sh 24.4-30.5 s/s
GW033297 20BL026199 W,D	348930	6321110	19.8	17.6-19.7/0.25	4.60	nil	0.0-10.66 clay 10.66-11.88 s/s 11.88-17.67 sh 17.67-19.81 s/s
GW051560 20BL111424 F,S	348160	6322940	33.0	28.0/5.0	13.0	nil	0.0-19.0 clay 19.0-33.0 s/s
GW056521 20BL122843 D,S	345687	6321210	45.0	nil	nil	nil	0.0-8.0 clay 8.0-25.0 s/s 8.0-25.0 sh 25.0-44.0 s/s 44.0-45.0 sh
GW058390 20BL127954 D	345575	6321050	0.00	nil	nil	nil	nil

Bore	Coordinates (AMG)		Depth (m)	Aquifers/ yield (L/s)	Water depth (m)	Water quality	Bore Geology
	E	N					
GW059092 20BL135236 D,S	349070	6320630	38.0	24.0-25.0/1.26	15.0	salty	0.0-16.0 clay 16.0-38.0 sh s/s
GW078221 20BL166822 I	349022	6319270	60.0	28.9-30.0/0.13	26.0	fresh	0.0-16.5 clay 16.5-28.9 mud 28.9-42.6 cong 42.6-53.0 mud 53.0-60.0 cong
GW080608 20BL169008 D,S	349520	6321281	48.0	41.0-45.0/0.40	3.20	nil	0.0-36.0 sands 36.0-48.0 sh
GW078609	348866	6323656	32.0	nil	nil	nil	0.0-6.0 soil/clay 6.0-30.0 s/s 30.0-32.0 mudstone
GW200505 D,S	350914	6322022	54.0	26.4-26.9 48.5-49.3	nil	fresh	0.4-4.9 clay 4.9-6.5 gravel 6.5-26.4 clay 26.4-26.9 clayey gravel 26.9-31.4 clay 31.4-49.3 cong 49.3-50.1 clay 50.1-54.0 cong
GW058391 D	345728	6321244	nil	nil	nil	nil	nil
GW058392	345802	6321461	nil	nil	nil	nil	nil

'nil' = no recorded data, s/s = sandstone, sh = shale/claystone, cong = conglomerate
D, S, F, I, W, P denotes authorised purpose: Domestic, Stock, Farm, Irrigation, Waste disposal, Poultry

6.5 Change in groundwater quality

It is unlikely that any measurable change in groundwater quality will be observed in hard rock strata as pressures decline. Localised change in salinity, may be observed in deep caved zones as groundwaters contained within different stratigraphic horizons mix with fragmented materials in goaf. This mine water will be treated within the mine water management system.

Similarly, it is unlikely that any measurable change in water quality will be observed in the shallow unconsolidated alluvial aquifer systems. Subsided areas will retain a shallower water table that will be replenished from drainage systems and rainfall recharge. The depth to the water is predicted to remain generally more than 2m. Active flushing of salts by recharge processes will continue.

It is possible that surface cracking of hardrock strata in elevated areas may initiate localised redirection of surface flows in some drainages leading to fresh water-rock hydrochemical interactions and the potential for ferruginous staining downstream of the cracking. This process is observed in some subsided drainages within Hawkesbury Sandstone areas of the southern coalfields (south of Sydney). Candidate drainages within the W2CP project area include the upper reaches of Little Jilliby Jilliby Creek. The Terrigal Formation hosting these drainages is not known to have historically generated natural iron springs and the potential is therefore considered to be low (pers.comm. W2CP geologist).

6.6 Impact on groundwater dependent ecosystems

There are no identified groundwater dependent ecosystems that are likely to be impacted by the proposed mining operations.

7. WATER SHARING PLANS

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

> ***Water Sharing Plan for the Jilliby Jilliby Creek Water Source 2003*** which took effect from 1st July 2004. Waters which apply to this water source include Jilliby Jilliby Creek and its catchment tributaries (including Little Jilliby Jilliby Creek) and all lakes and wetlands in the prescribed area. The plan specifically excludes all groundwater contained within the aquifers underlying this water source.
>
> ***Water Sharing Plan for the Central Coast Unregulated Water Sources 2009*** which took effect from 1st August 2009. Relevant waters which apply to this water source include the Wyong River and its catchment tributaries and all lakes and wetlands in the prescribed area. The plan specifically excludes all groundwater contained within alluvial sediments, coastal sands and fractured or basement rock aquifers.

Groundwater issues arising from the proposed mining operations are deemed not to be constrained by the WSP's.

8. LICENSING REQUIREMENTS

Licensing in respect of groundwater seepage into mining operations will be required under Part 5 of the Water Act (1912). An estimate of seepage has been made through the use of computer based numerical modelling. Seepage is predicted to rise from about 0.1 ML/day during initial development to 2.5 ML/day after 18 years of mining. This volume is drawn largely from storage within the coal seam with minor contributions from overburden depressurisation. Allowing 0.5 Ml/day short term contributions from localised storage from as yet unidentified fracture networks, the maximum rate may be up to 3.0 ML/day.

9. GROUNDWATER RESOURCES MONITORING

A comprehensive groundwater monitoring programme should be developed and maintained as part of the overall mine environmental monitoring plan. The programme should include the existing monitoring bore network, private bores and wells in potentially affected areas, new boreholes designed to monitor vertical pressure distributions during development and mining, and monitoring of mine water seepage during the mine life. Information should be used to validate and verify the predicted seepage and depressurisation. All data should be reviewed regularly as part of compliance procedures and alert protocols. A detailed groundwater monitoring plan should be developed following approval and consultation with Government agencies.

Water management monitoring should include:

- measurement of groundwater levels, pore pressures and water quality within the existing regional network of monitoring bores and an expanded network;

- measurement of rates of groundwater seepage and groundwater quality within the mine water system;
- compliance monitoring and measurement of any water discharges including quality monitoring of major ions and specific rare elements;
- adoption of data transfer protocols to convey monitoring data from the mine to the relevant Regulatory Authorities;
- annual reporting as part of approvals and licensing conditions.

In addition to the above, the monitoring programme should be subject to review annually by the environmental services group of W2CP and/or their appointed consultants.

9.1 Impacts verification criteria

As previously noted, groundwaters are not currently monitored by W2CP due to restricted access to existing (or potentially new) locations. The monitoring network should be re-instated for the purpose of assessing local and regional impacts relating to proposed underground operations. Such impacts are broadly defined as:

- physical depressurisation of the shallow coal measures rock strata and potential indirect impacts on alluvial aquifer systems associated with the Dooralong and Yarramalong valleys;
- and changes to shallow groundwater storage induced by subsidence.

An accelerated decline in formation pressures in shallow strata underlying the valley alluvium could signal a change in seepage rates. Future impacts assessment criteria should therefore address the pressure regime within shallow strata near and beneath the alluvial lands. Leakage can be estimated by interpolation of the pressure/water table hydraulic gradients and calculation of the leakage flux from measured rock permeabilities. This estimate can also be reconciled with the volume of mine water pumped from proposed underground operations. In order to establish both the strata hydraulic gradients and the rock mass permeabilities it will be necessary to expand the groundwater monitoring network. The following recommendations are provided.

Depressurisation monitoring should include:

- Construction of at least 20 standpipe piezometers to augment measurement of pressures/water levels in shallow alluvium and underlying strata to a depth of 50 m As a minimum, the design should allow for isolation of bottom hole strata from mid hole and alluvial strata utilising combined standpipe and pore pressure transducer completions;
- Installation of vertical arrays of pore pressure transducers distributed within the Narrabeen Group of rocks (overburden) at a minimum of 8 locations;
- Strata hydraulic conductivity measurement on rock core obtained at some of the above noted locations. Such measurement should comprise testing for matrix permeability and insitu testing for permeability over the piezometric intervals;
- Quarterly monitoring of water levels in all existing piezometers and in new piezometers;
- Daily monitoring of water levels by installed auto recorders in selected existing piezometers and in new piezometers in order to discriminate between oscillatory groundwater movements attributed to rainfall recharge, and longer term pressure losses related to mining.

Mine water seepage monitoring should include:

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

Water quality monitoring should include:

- Quarterly monitoring of basic water quality parameters pH and EC in selected piezometers and pumped mine water. Such monitoring may provide early indication of mixing of shallow groundwaters with groundwaters in deeper strata. While this process is expected within the subsidence zone, it may not be evident within the wider piezometer network at the leakage levels predicted by groundwater monitoring;
- Six monthly measurement of total dissolved solids (TDS) and speciation of water samples in selected piezometers to support identification of mixing of groundwater types. Speciation should include as a minimum - major ions Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4 and elements including Al, As, B, Ba, F, Fe (total), Li, Mn, P, Se, Si, Sr, Zn;
- Graphical plotting of basic water quality parameters and identification of trend lines and statistics including mean and standard deviation calculated quarterly. Comparison of trends with rainfall and any other identifiable processes that may influence such trends.

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

Impact verification analyses could include:

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

9.2 Impact mitigation measures

Mitigative measures for any identified negative impacts beyond those predicted, may include replacement of water supply or relinquishment of groundwater or surface water allocations in order to account for leakage losses from the alluvial aquifers.

Mackie Environmental Research
October 2009

References:

ANZECC, 2000, Australian water quality guidelines for fresh and marine waters. *Aust & New Zealand Env. Conservation Council.*

Butler, J., 1997. The design, performance and analysis of slug tests. *Lewis publishers.*

Coffey Partners International P/L., 1998. Wyong groundwater study. *Report prepared for Coal Operations Australia Ltd.*

Eckhardt, K, 2005. How to construct recursive digital filters for baseflow separation. Hydrological Processes, Vol.19, 2005

ERM, 2002. Summary of field measurements and monitoring for Wyong Coal Project. *Draft report prepared for Hunter Valley Energy Coal.*

Forster, I, B. 1995. Impact of underground mining on the hydrogeological regime, Central Coast NSW. *AGS, 1995.*

Forster, I, B. Wall and L. Karabesinis, March 1997. Cooranbong Colliery life extension project, overburden strata groundwater study. *Pacific Power International, Power Engineering Civil and Project Services, Rpt GEO100.*

Harbaugh, A.W., E.R. Banta, M.C. Hill and M.G. McDonald, 2000. The U.S. Geological Survey Modular Groundwater Model: user guide to modularisation concepts and the groundwater flow process. US Geological Survey Open file Report 00-92.

Hawley, S.P. and J.S. Brunton, 1995. Newcastle coalfield – Notes to accompany the Newcastle coalfield geology map. *Mineral Resources Pub. GS 1995/256.*

Hydrogeologic Inc. 1996. Modflow-Surfact user manual.

Long J.C., J.S. Remer, C.R. Wilson, P.A. Witherspoon, 1982. Porous media equivalents for networks of discontinuous fractures. *Water Resources Research, Vol.18-3*

McElroy C.T. and M.B. Coleman, 1961. Some aspects of the geology of the Teralba district. *Technical Report, N.S.W. Dept. of Mines.*

SCT Operations Pty. Ltd., 1999. Geotechnical Feasibility Study for Wyong Lease. *Report prepared for Coal Operations Australia Limited.*

Uren R.E. 1977. The geology and low cost extractive resources of the Gosford – Lake Macquarie area. *Mineral Resources Pub. GS1977/431.*

IMPORTANT INFORMATION ABOUT YOUR HYDROLOGICAL REPORT

Mackie Environmental Research (MER) has applied skills, standards and workmanship expected of Chartered Professionals in the preparation of this report, the content of which is governed by the scope of the study and the database utilised in generating outcomes.

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

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

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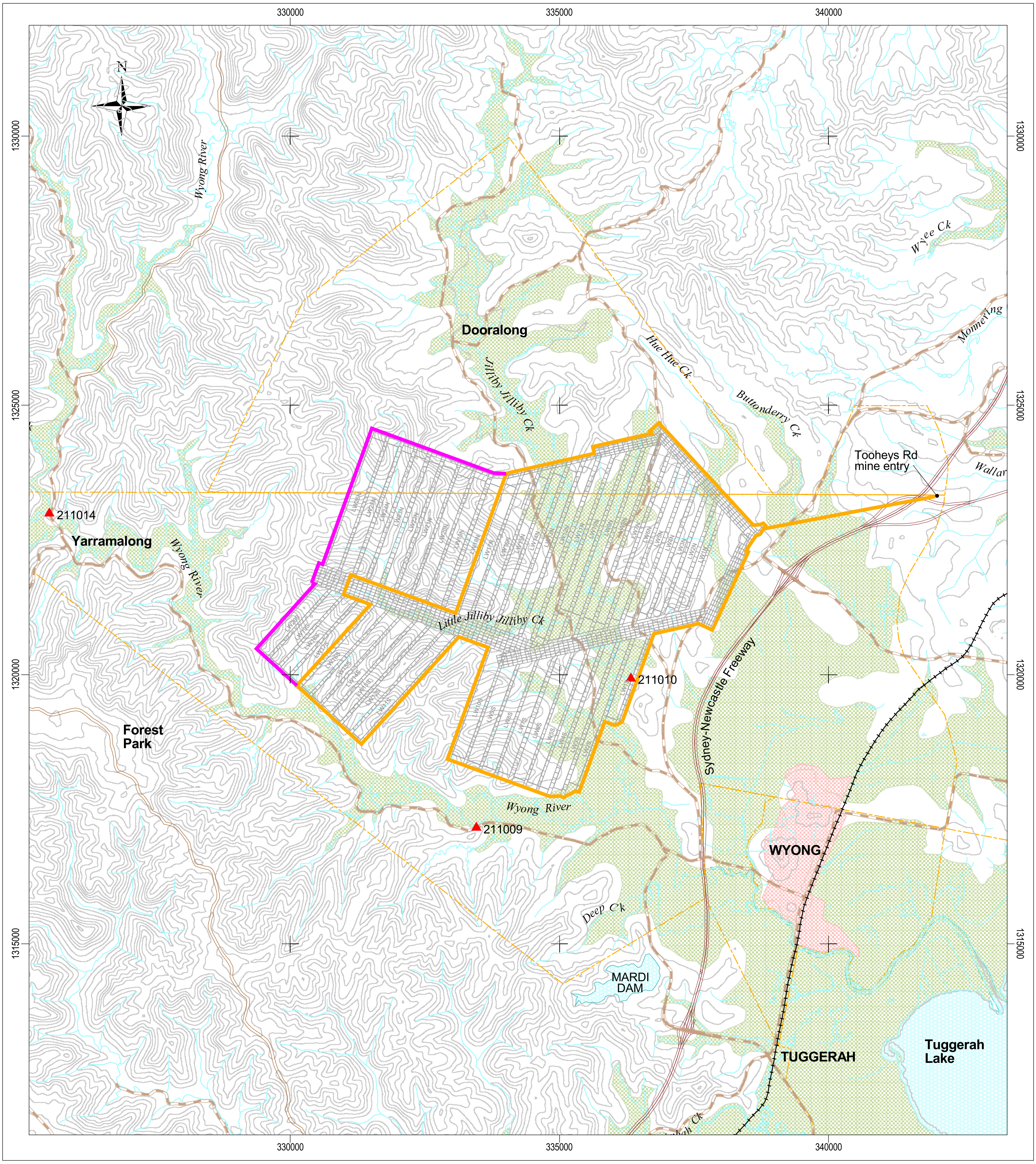
Dr. C. Mackie
CP. Env (AusIMM)



0 2000 4000 6000 Metres

Scale 1:100,000

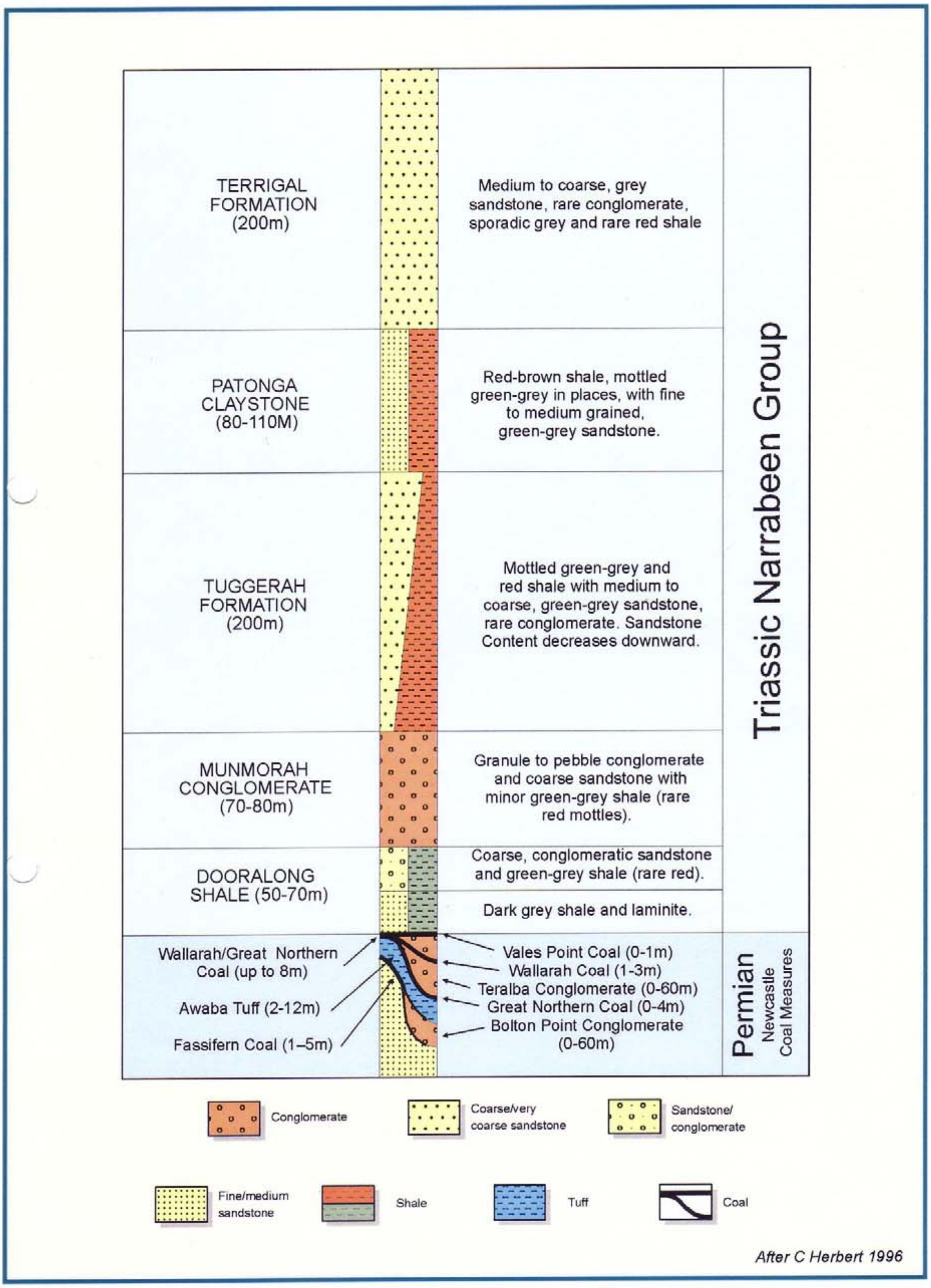
- DWE flow gauge
- creeks
- minor road
- sealed road
- Freeway
- railway
- lease
- urban area
- alluvium
- 28 years mine footprint
- 38 years mine footprint
- mine plan

WALLARAH 2 COAL PROJECT

Regional locality map and proposed mine plan

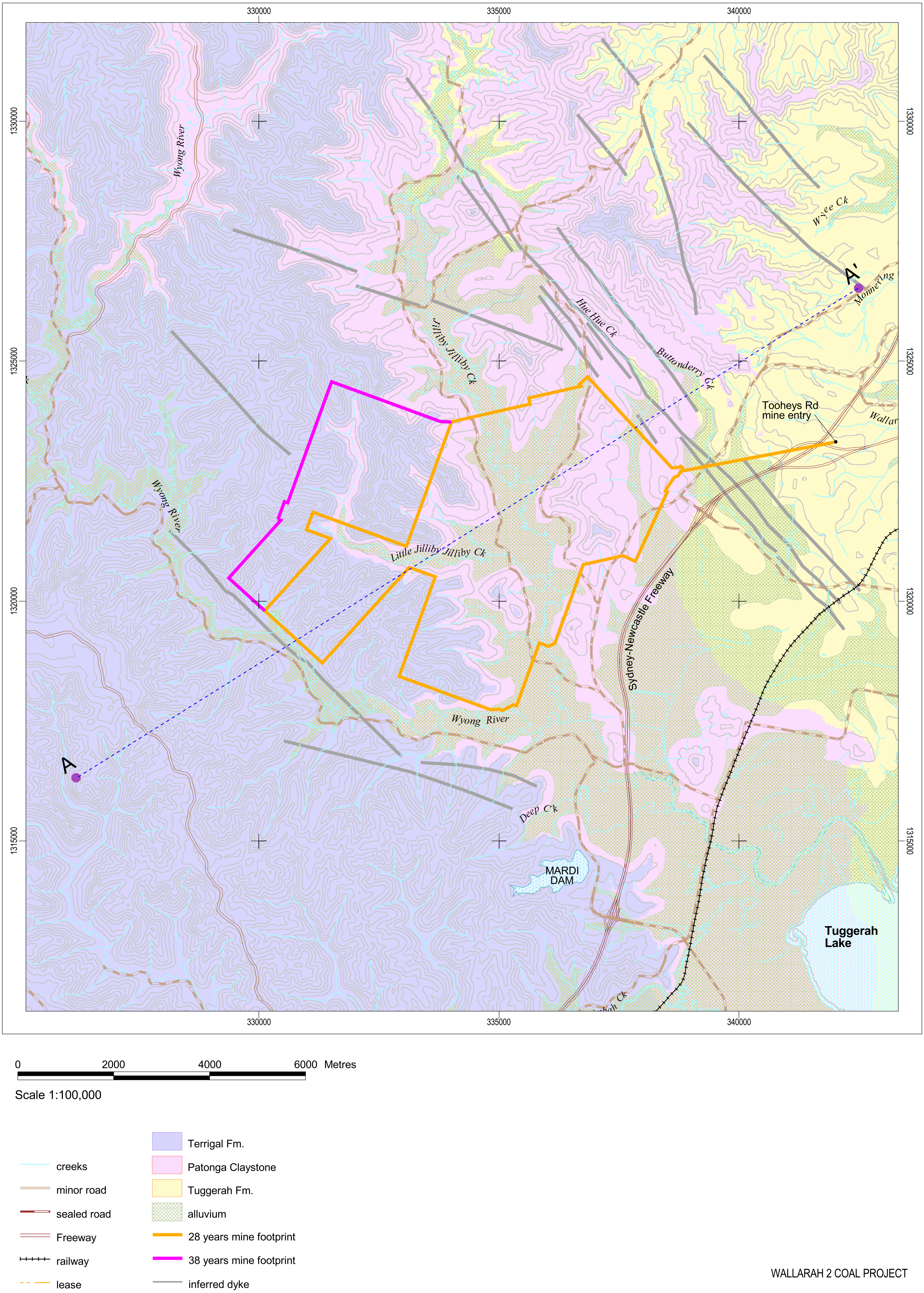
Figure 1

Mackie Environmental Research



Stratigraphic column

Figure 2

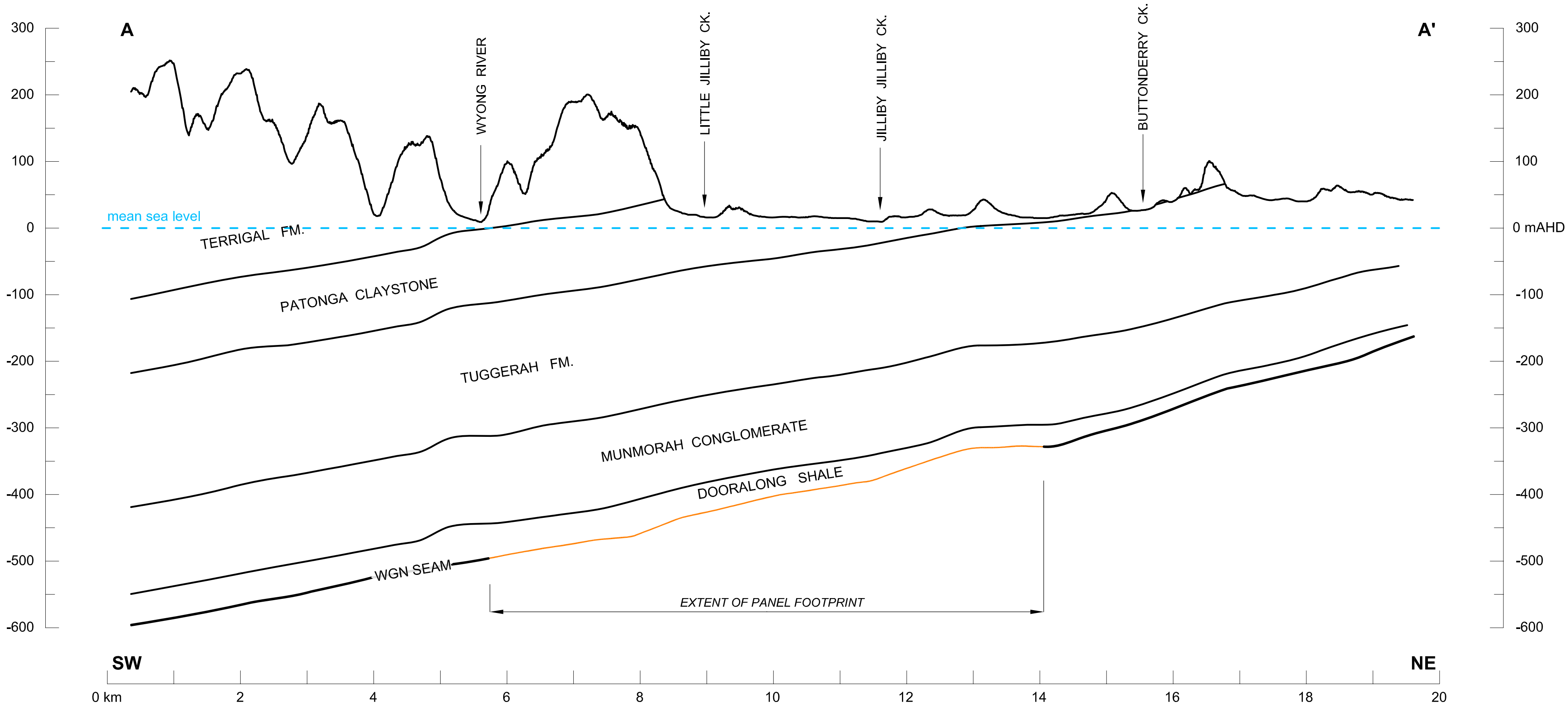


WALLARAH 2 COAL PROJECT

Regional subcrop geology

Figure 3

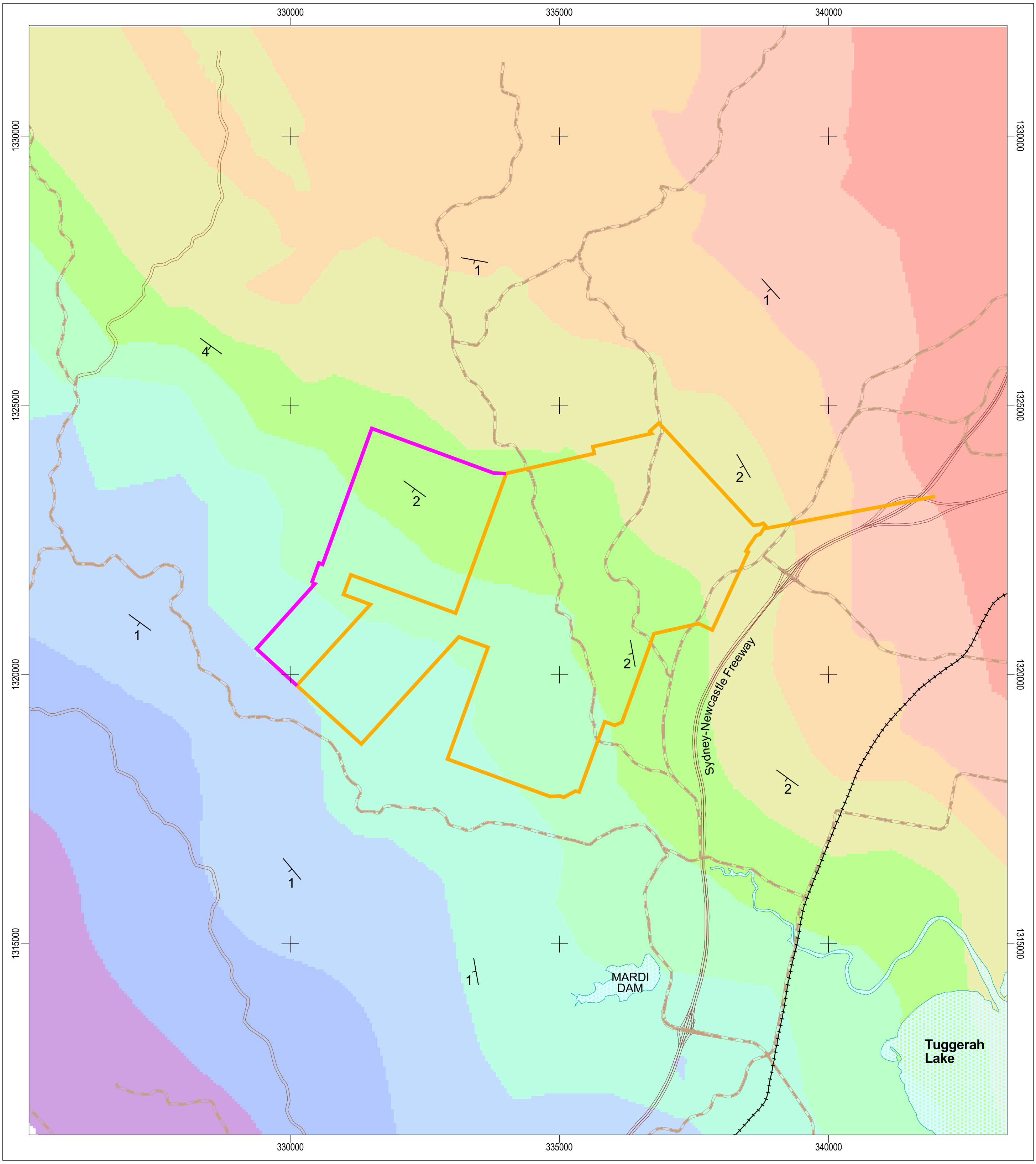
Mackie Environmental Research



vertical exageration 10:1 (v:h)
see Figure 4 for section location

SW-NE Section through proposed mine plan

Figure 4



0 2000 4000 6000 Metres

Scale 1:100,000

Structure contours (mAHD)

- -650 - -600
- -600 - -550
- -550 - -500
- -500 - -450
- -450 - -400
- -400 - -350
- -350 - -300
- -300 - -250
- -250 - -200
- -200 - -100

- creeks
- minor road
- sealed road
- Freeway
- railway

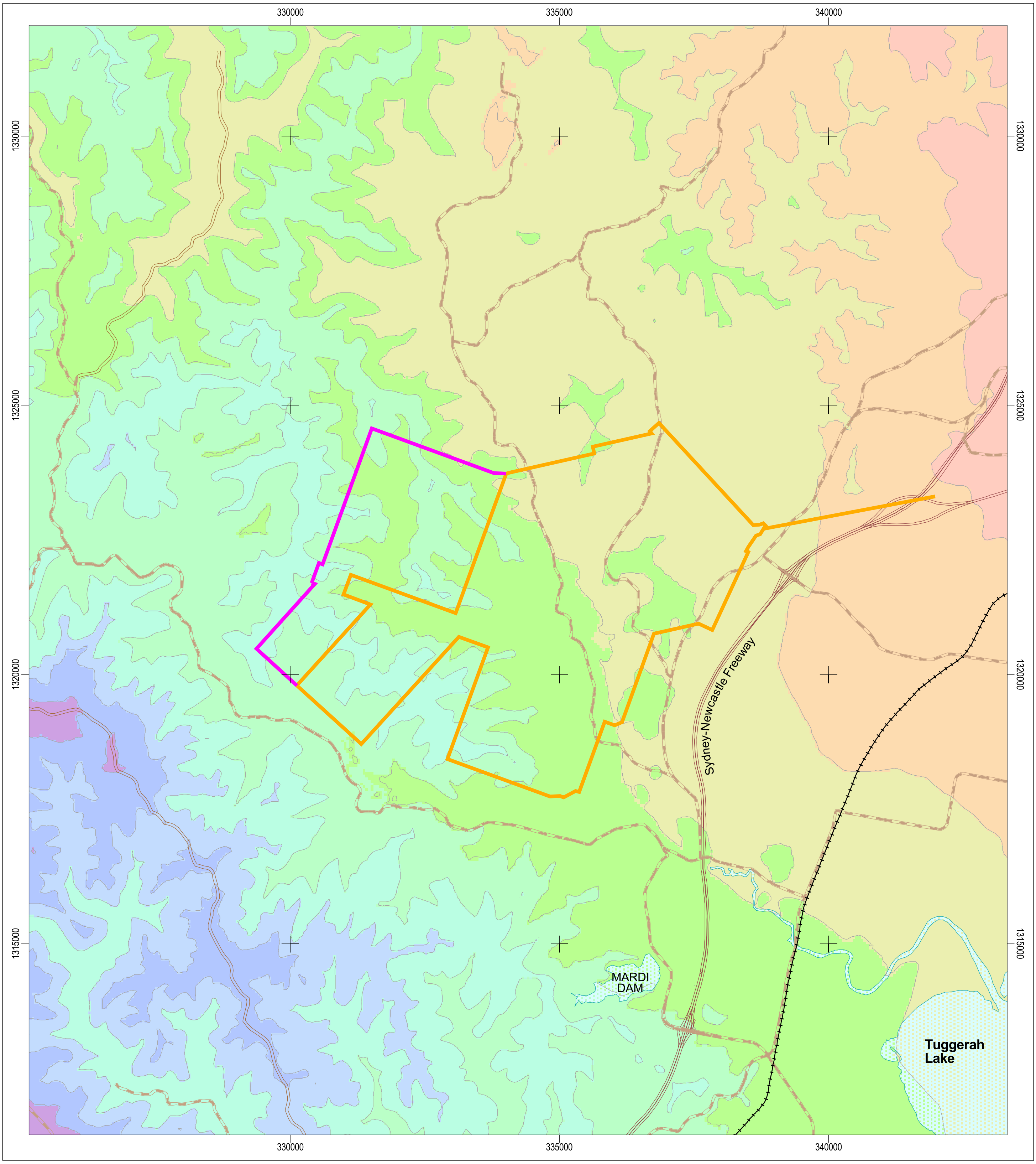
- approx. strike and dip of strata
- inferred dykes
- 28 years mine footprint
- 38 years mine footprint

WALLARAH 2 COAL PROJECT

WGN seam roof structure contours

Figure 5

Mackie Environmental Research



0 2000 4000 6000 Metres

Scale 1:100,000

Depth of cover (m)

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000

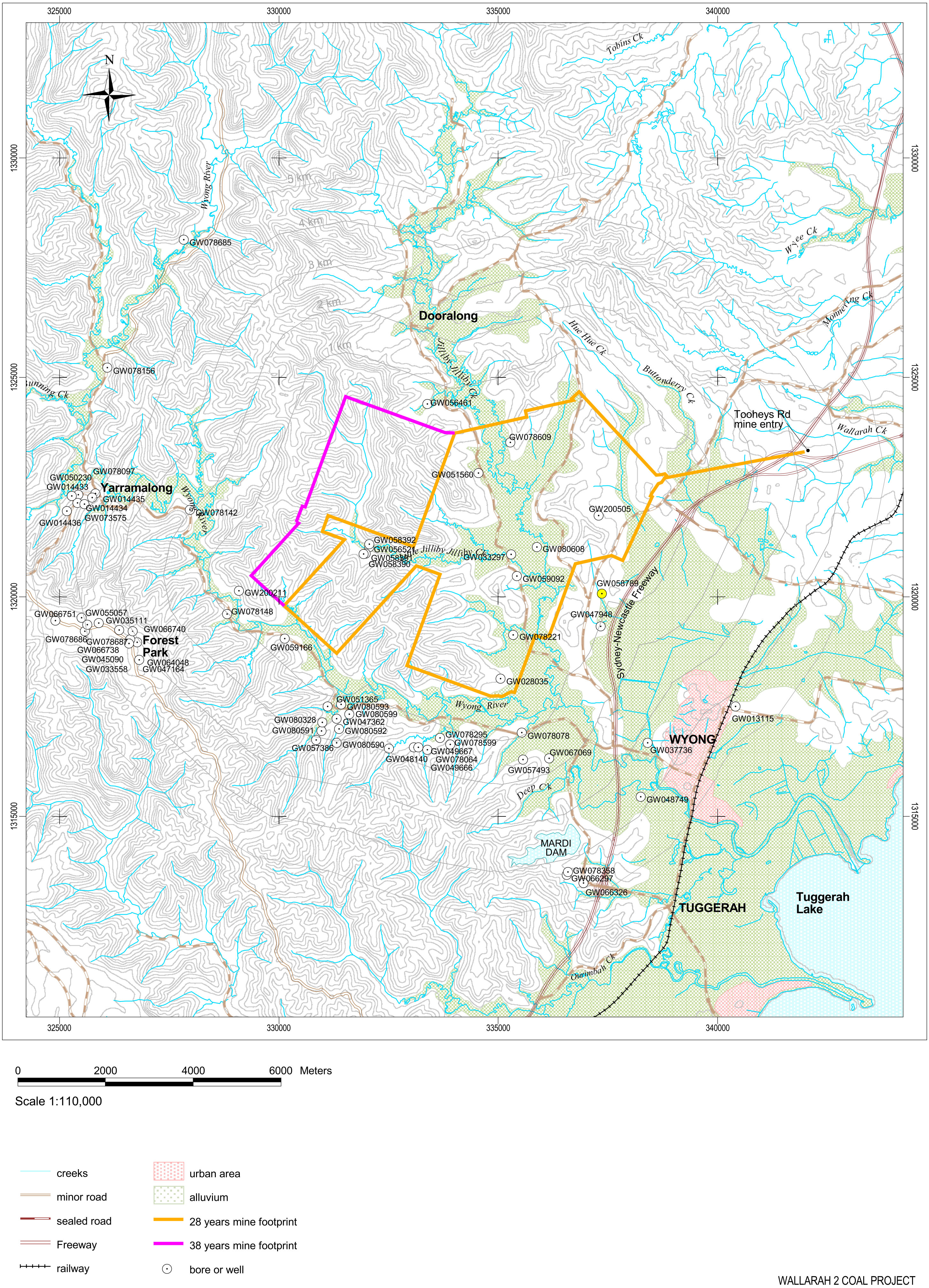
- creeks
- minor road
- sealed road
- Freeway
- railway
- 28 years mine footprint
- 38 years mine footprint

WALLARAH 2 COAL PROJECT

WGN seam depth of cover

Figure 6

Mackie Environmental Research

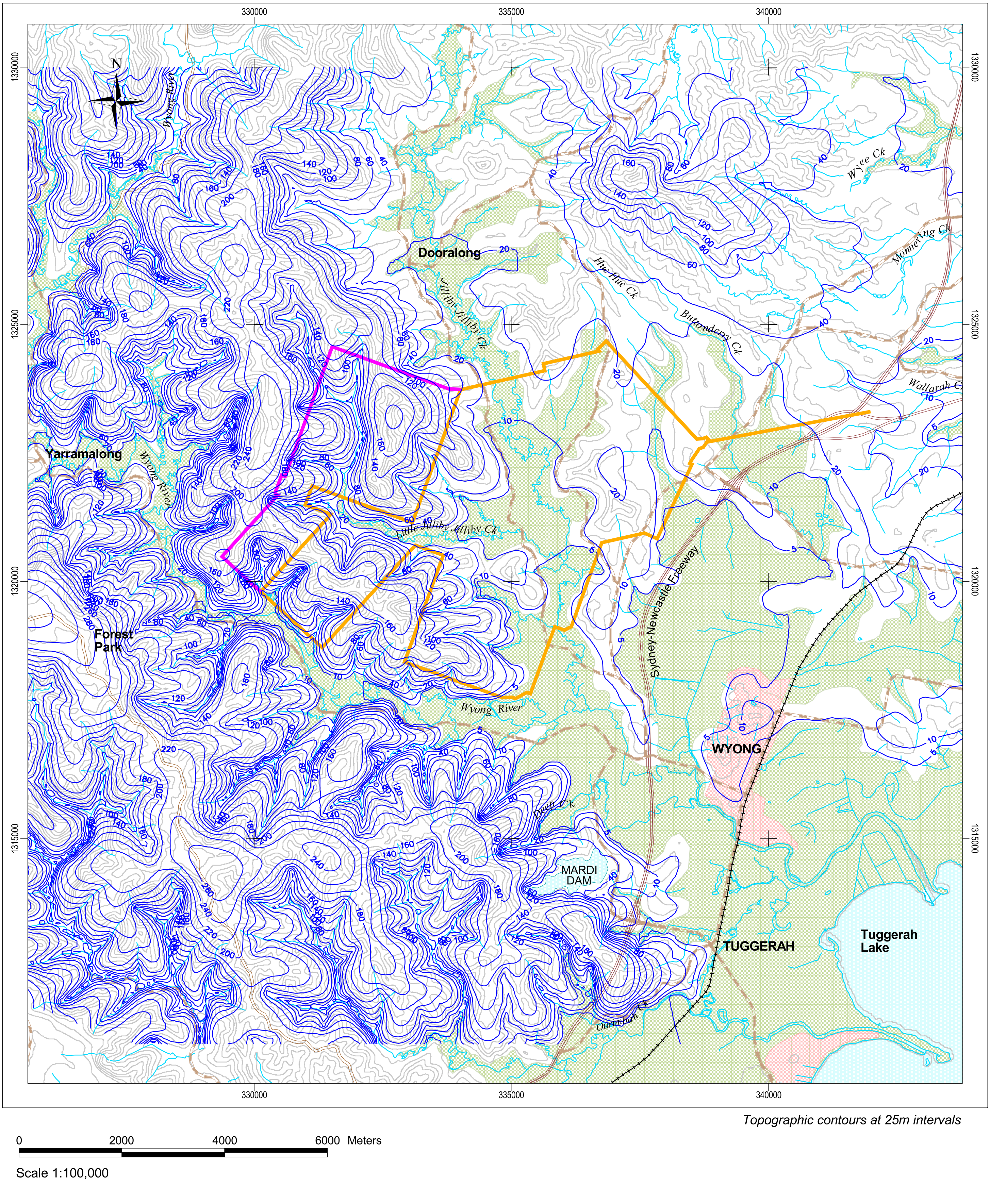


WALLARAH 2 COAL PROJECT

Locations of registered bores and wells

Figure 7

Mackie Environmental Research

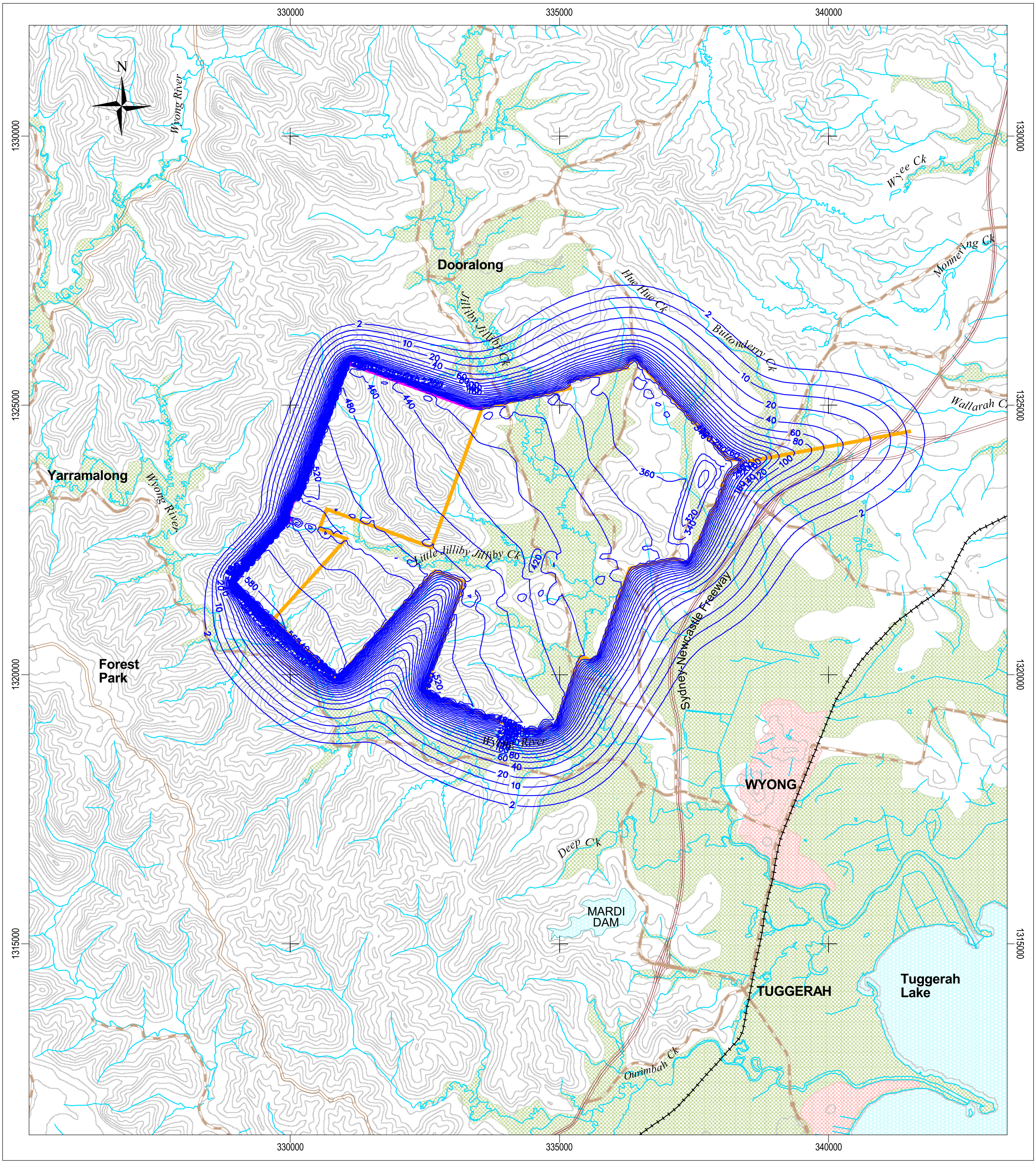


WALLARAH 2 COAL PROJECT

Regionally interpolated shallow water table

Figure 8

Mackie Environmental Research



Topographic contours at 25m intervals

0 2000 4000 6000 Meters

Scale 1:100,000

- creeks
- minor road
- sealed road
- Freeway
- railway
- lease
- urban area
- alluvium
- depressurisation (metres head of water)
- 28 years mine footprint
- 38 years mine footprint
- mine plan

WALLARAH 2 COAL PROJECT

Model W1: Predicted WGN seam depressurisation after 38 years

Figure 9

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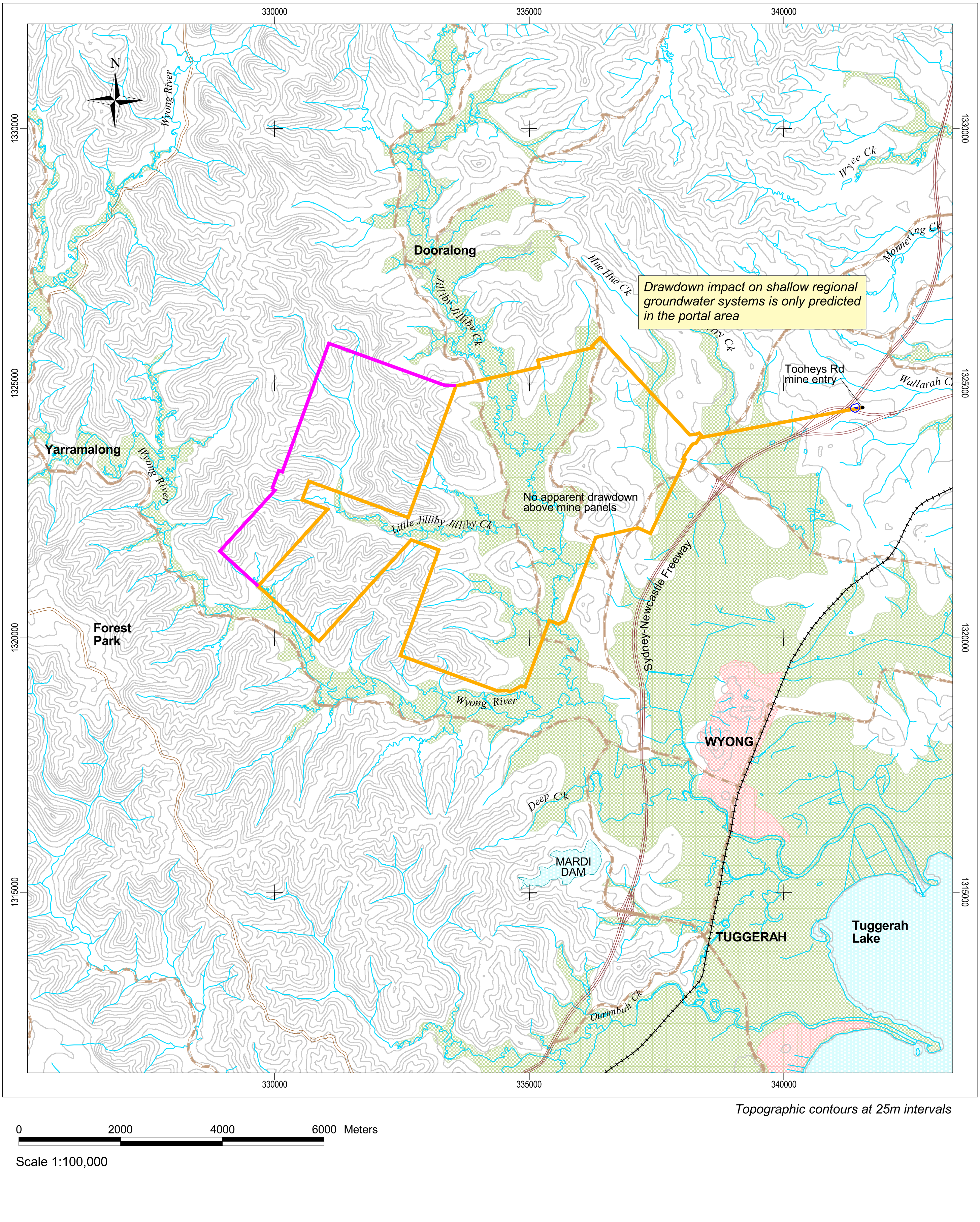
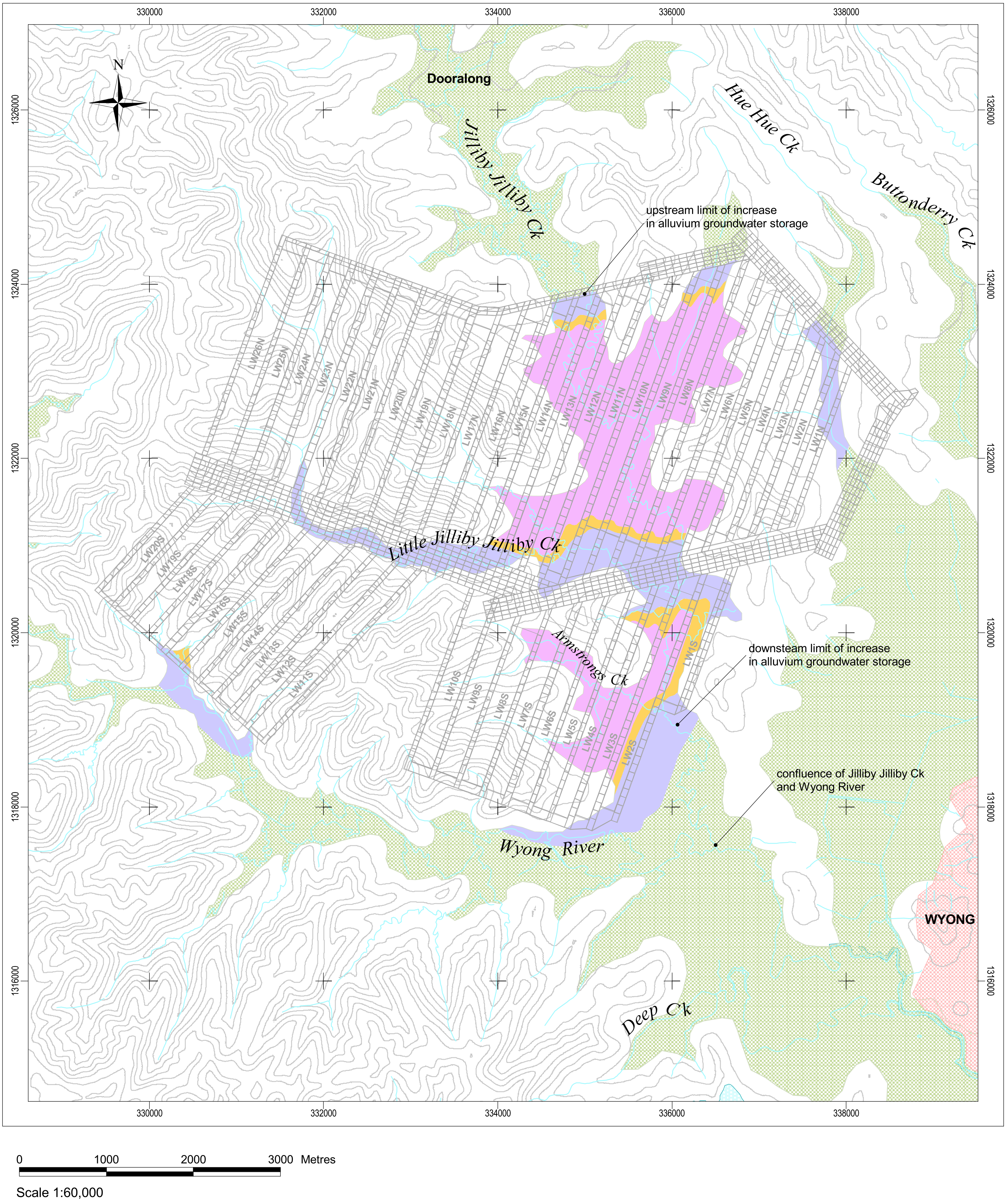


WALLARAH 2 COAL PROJECT

Model W1: Water table drawdown after 38 years

Figure 10

Mackie Environmental Research



WALLARAH 2 COAL PROJECT

Subsidence affected areas within alluvial lands

Figure 11

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APPENDIX A: BASEFLOW ANALYSES

Stream flow can be represented by two contributing flows – surface runoff (quick flow) during and following rainfall events, and baseflow represented in the subsequent recession of flow which is derived from groundwater. Storage that supports baseflow results from slow rainfall infiltration to porous aquifer materials and subsequent migration of groundwater within those materials towards stream channel(s) after rainfall has ceased. Hence baseflow can be associated with shallow aquifer systems within a catchment.

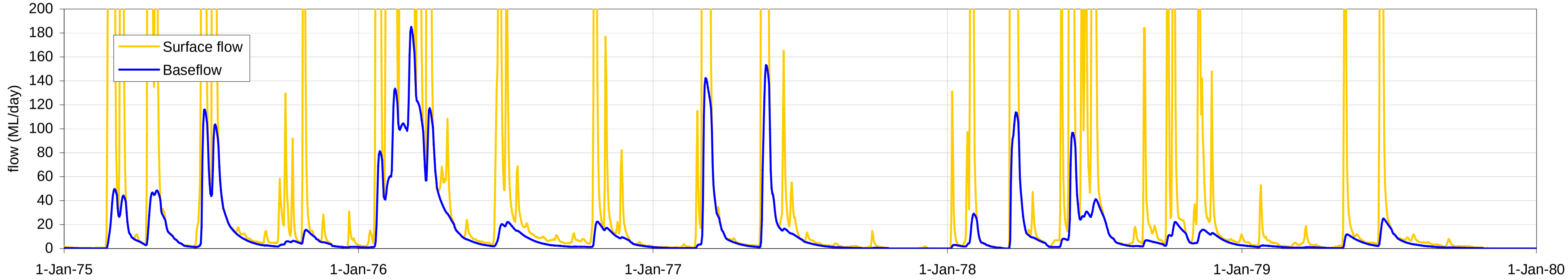
A catchment hosting a substantial porous and permeable alluvial aquifer system will tend to exhibit a slow baseflow recession with stream flow sustained for long periods of time after contributions from rainfall and runoff have ceased. In contrast, a relatively impermeable alluvial system or a hard rock catchment comprised of generally imperveous rocks, will tend to exhibit a fast recession with stream flow sustained for short periods of time.

There are a number of methods that can be used to separate baseflows from the measured surface flows within a stream flow hydrographic record. One method known as the recursive filter technique (Eckhardt, 2005) has been adopted herein. Flow data for gauging stations 211010 (Jilliby Jilliby Ck above Wyong River) and 211014 (Wyong River at Yarramalong) have been processed assuming baseflow indices of 0.2 and 0.3 respectively. Results for selected parts of the hydrographic record are provided as Figures A1 and A2 and summarised on the flow duration plots provided as Figure A3.

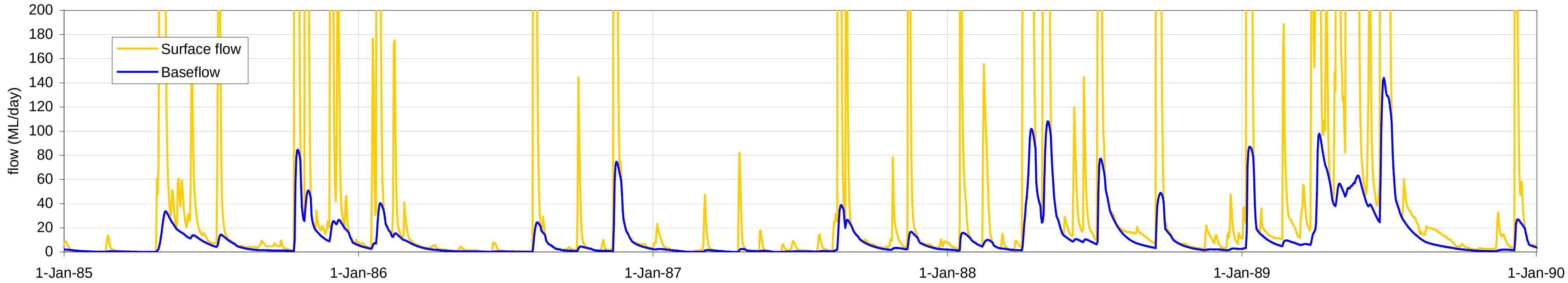
Figure A1 for Jilliby Jilliby Creek exhibits moderately rapid baseflow recession even though the catchment has extensive alluvial deposits. This is especially evident during the period 2000 to 2005 when rainfall events were relatively sparse and drought conditions prevailed from 2002 onwards. The recession trends support useful storage within the alluvium with creek bank storage probably contributing during the first part of the observed recessional trends. Minor contributions to baseflows from deeper hard rock systems (as upwards leakage) may be evident during extended dry periods when flows are typically less than 1ML/day. On numerous occasions, Jilliby Jilliby Creek ceased to flow. These conditions are reflected in the flow duration plot Figure A3 where no measurable flow occurs for 9% of the record.

Figure A2 (Wyong River) also exhibits reasonably rapid baseflow recession reflecting the generally hard rock nature of the catchment above Yarramalong. However the recessions are complicated by the presence of regulated flows (from Bunning Creek) as part of the Wyong LGA water supply scheme.

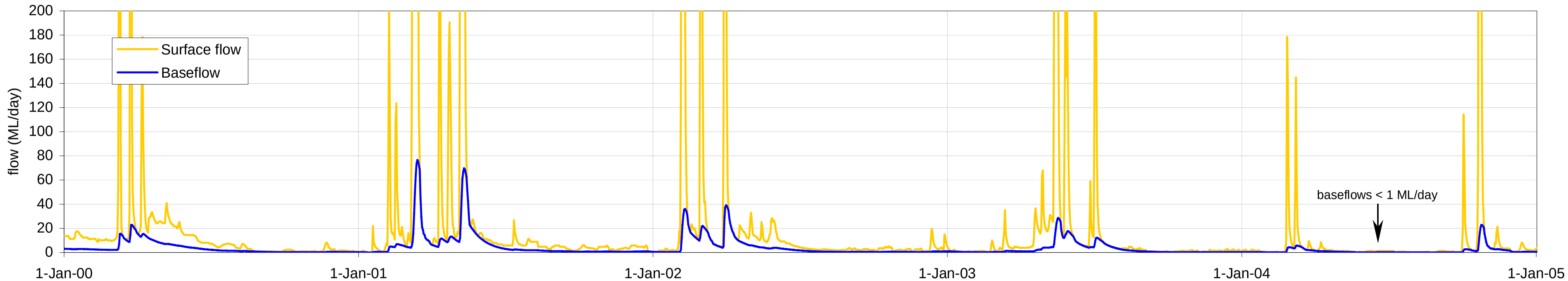
Jilliby Jilliby Creek u/s of Wyong River - Gauge 211010



Jilliby Jilliby Creek u/s of Wyong River (Gauge 211010)



Jilliby Jilliby Creek u/s of Wyong River (Gauge 211010)



Eckhardt filter: a=0.95, BFImax=0.2

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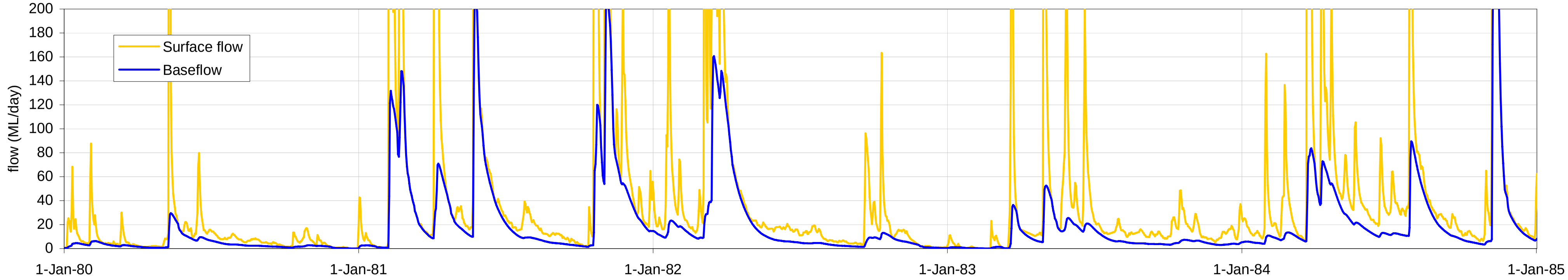
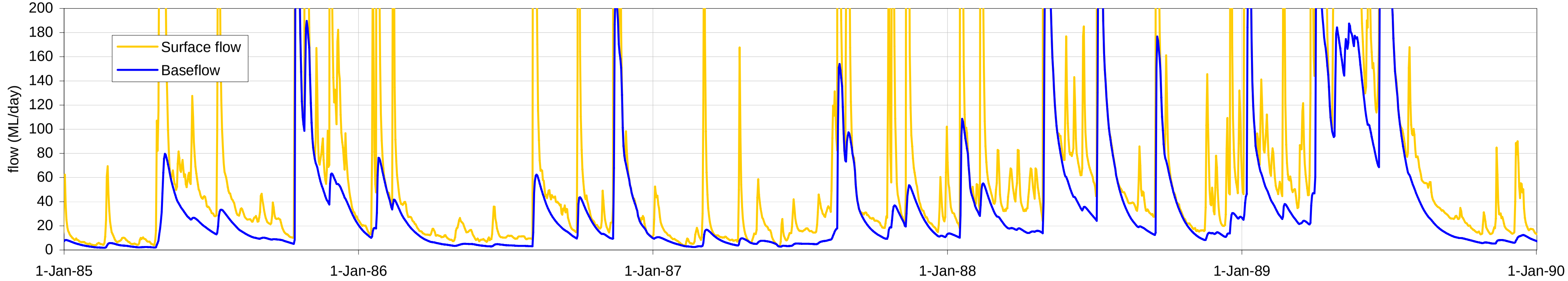
Calculated baseflows from Jilliby Jilliby Ck flow records

Figure A1

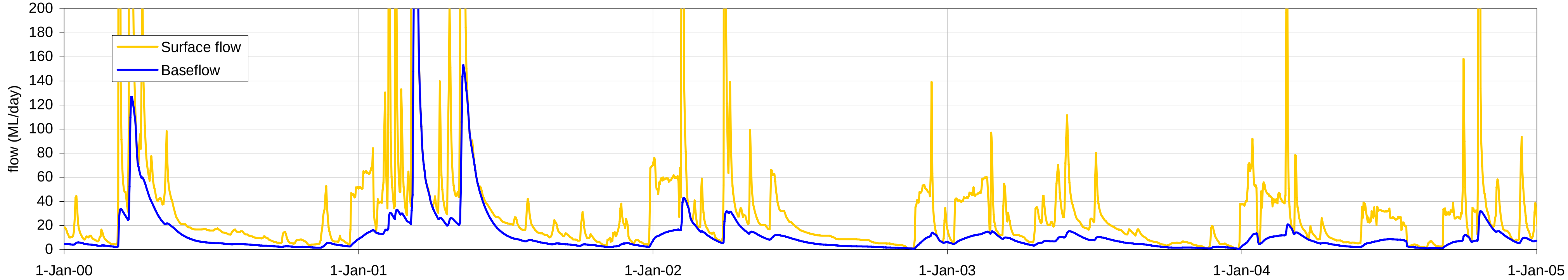
Wyong River at Yarramalong - Gauge 211014



Wyong River at Yarramalong - Gauge 211014



Wyong River at Yarramalong - Gauge 211014

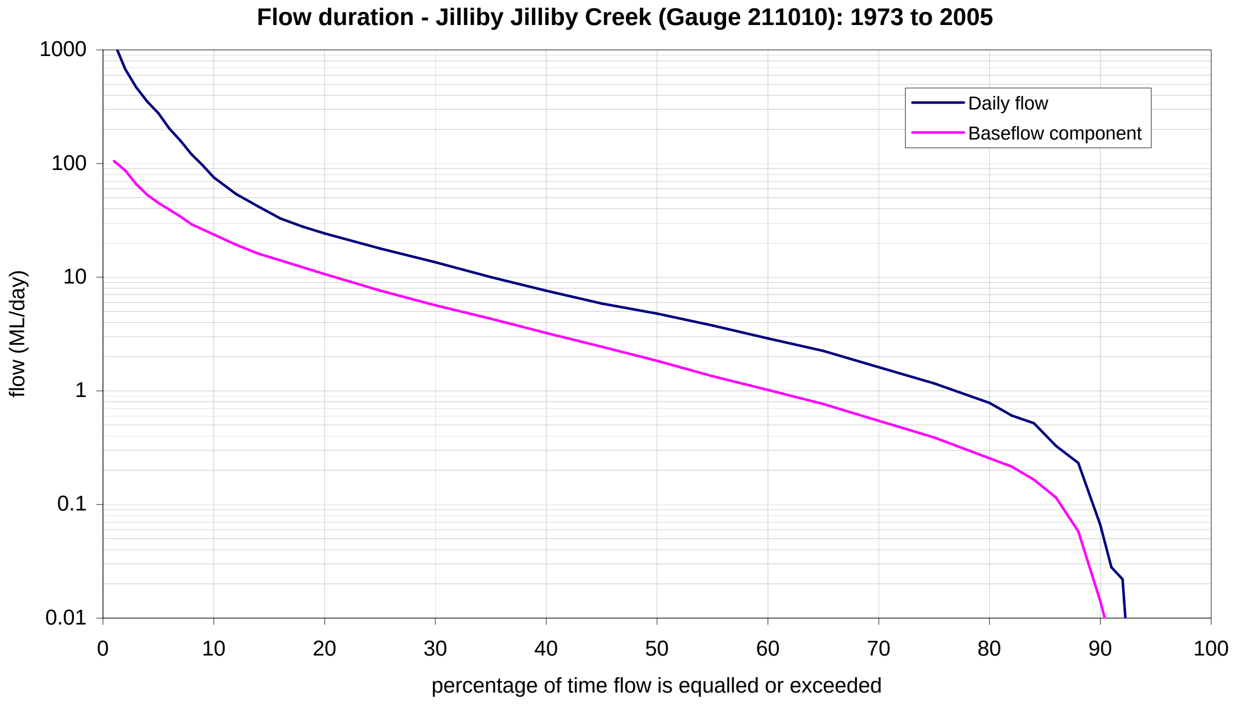


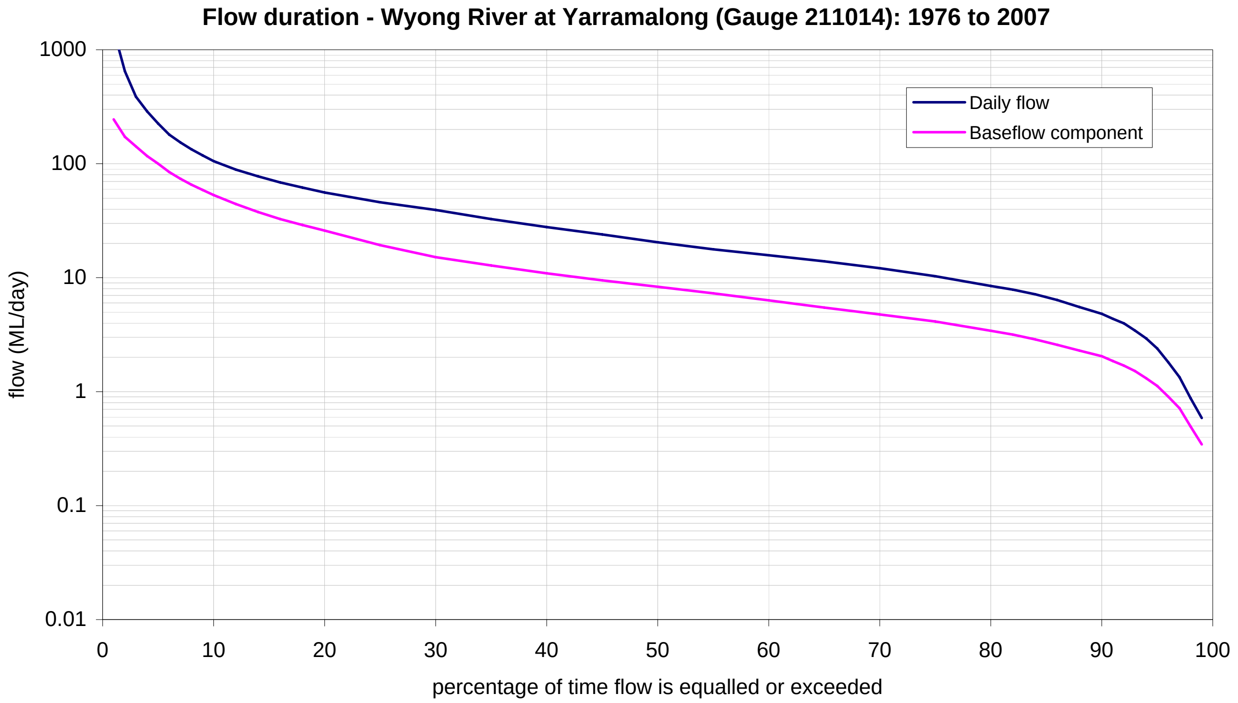
Eckhardt filter: a=0.95, BFImax=0.30

Mackie Environmental Research

Calculated baseflows from Wyong River flow records

Figure A2





Flow exceedance probability plots

Figure A3

APPENDIX B: DWE REGISTERED BORES AND WELLS

Table B1: Summary of NOW registered bores within 2km of proposed mine plan footprint

Bore	Coordinates (AMG)		Depth (m)	Aquifer Type	Year Drilled	Aquifers/ yield (L/s)	Water level (m)	Water quality	Bore Geology
	E	N							
GW028035 20BL021424 P	348750	6318275	30.5	Hard rock	1968	19.8-25.2m/1.26	7.60	good	0.0-4.8 Clay 4.8-6.7 S/S 6.7-18.3 Clay 18.3-20.4 S/S 20.4-24.4 Sh 24.4-30.5 S/S
GW033297 20BL026199 W,D	348930	6321110	19.8	Hard rock	1971	17.6-19.7/0.25	4.60	nil	0.0-10.66 Clay 10.66-11.88 S/S 11.88-17.67 Sh 17.67-19.81 S/S
GW047362 20BL129128 D,S	345025	6317300	38.0	Hard rock	1979	20.0/0.38 29.6/2.0	8.50	good	0.0-7.6 Clay 7.6-9.1 Sh 9.1-38.0 S/S
GW047948 20BL136073 D	351005	6319500	8.0	Hard rock	1981	nil	nil	nil	0.0-8.0 Rock
GW048140 20BL106872 D,S	346225	6316625	38.0	Hard rock	1977	28.4/4.0 35.4/6.8	16.8	good	0.0-7.6 Clay 7.6-28.4 S/S 28.4-37.0 Sh 37.0-38.0 S/S
GW049666 20BL109445 D,S	347125	6316600	45.8	Hard rock	1979	32.4-32.6/3.8 35.6-35.8/1.26	13.7	good	0.0-27.4 Clay 27.4-45.8-Sh
GW051560 20BL111424 F,S	348160	6322940	33.0	Hard rock	1980	28.0/5.0	13.0	nil	0.0-19.0 Clay 19.0-33.0 S/S
GW056461 20BL122630 D,S	346962	6324487	17.0	Hard rock	1982	22.0-23.0/2.52	9.0	nil	0.0-17.0 Clay
GW056521 20BL122843 D,S	345687	6321210	45.0	Hard rock	1982	nil	nil	nil	0.0-8.0 Clay 8.0-25.0 S/S 8.0-25.0 Sh 25.0-44.0 S/S 44.0-45.0 Sh
GW057386 20BL125307 D,F,S	344567	6316775	26.0	Hard rock	1983	16.0-23.0/0.44	6.0	good	0.0-12.0 Clay 12.0-26.0 Sh
GW057493 20BL125665 D	349290	6316420	30.0	Hard rock	1983	18.0-24.0/0.44	6.0	nil	0.00-12.0 Clay 12.0-30.0 Sh
GW058390 20BL127954 D	345575	6321050	0.00	?	1982	nil	nil	nil	nil
GW058789 20BL125583 D,S	351025	6320240	29.0	Hard rock	1983	15.0-15.5/nil 23.0-23.5/nil	nil	salty	0.0-15.0 Clay 15.0-29.0 S/S
GW059092 20BL135236 D,S	349070	6320630	38.0	Hard rock	1981	24.0-25.0/1.26	15.0	salty	0.0-16.0 Clay 16.0-38.0 Sh S/S
GW059166 20BL121663 D,I,S	343820	6319100	0.00	?	1982	nil	nil	nil	nil
GW067069 20BL142928 D,S	349877	6316475	nil	?	nil	nil	nil	nil	nil
GW078064 20BL166821 D,S	346872	6316669	29.0	Hard rock	1998	15.5-18.0/0.40 26.5-27.3/0.80	12.9	0.25 – 120.00 0.50 – 288.00	0.0-15.5 Clay 15.5-18.0 Sand 18.0-26.5 Clay

GW078078 20BL166653 D	349222	6317044	36.0	Hard rock	1996	33.0-33.5/1.0	10.0	fresh	0.0-25.0 Clay 25.0-36.0 S/S
GW078142 20BL166744 D,S	341557	6321975	49.0	Hard rock	1998	22.0-22.8/0.15 45.0-46.0/5.0	15.0 18.0	fresh	0.0-11.5 Clay 11.5-22.8 S/S 22.8-29.5 Mud 29.5-49.0 S/S
GW078148 20BL166707 D,S	342450	6319617	40.0	Hard rock	1998	27.0-29.9/0.19 33.5-35.0/16.0	12.0	fresh	0.0-8.8 Clay 8.8-29.9 S/S 29.9-33.5 Mud 33.5-40.0 S/S
GW078221 20BL166822 I	349022	6319270	60.0	Hard rock	1998	28.9-30.0/0.13	26.0	fresh	0.0-16.5 Clay 16.5-28.9 Mud 28.9-42.6 Cong 42.6-53.0 Mud 53.0-60.0 Cong
GW078295 20BL155229 D	347360	6316892	32.0	Hard rock	1995	20.0-29.0/1.26	nil	good	0.0-15.0 Clay 15.0-20.0 Gravel 20.0-32.0 S/S
GW078356 20BL166558 D	341372	6319926	140.0	Hard rock	1997	131.0-131.5/0.2	95.0	fresh	0.0-5.0 Clay 5.0-36.0 S/S 36.0-36.5 Sh 36.5-97.0 S/S 97.0-99.0 Sh 99.0-115.0 S/S 115.0-117.0 Iron 117.0-128.0 S/S 128.0-131.0 Cong 131.0-133.0 S/S 133.0-140.0 Sh
GW078599 20BL166842 D,S	347596	6316742	48.0	Hard rock	1998	44.4-47.0/3.0	21.0	1.00 - 900.00	0.0-5.3 Clay 5.3-9.0 S/S 9.0-11.5 Clay 11.5-12.8 S/S 12.8-14.2 Clay 14.2-15.6 Ironstone 15.6-19.5 S/S
GW080328 20BL168517 D,S	344706	6317188	12.0	Alluvial	2004	nil	nil	nil	nil
GW080555 20WA202827 D,S	341552	6321690	41.0	Hard rock	2004	33.0-34.0/3.0	17.0	nil	0.0-8.0 Clay 8.0-36.0 S/S 36.0-41.0 Sh
GW080590 20BL169063 D,S	345045	6316735	42.0	Hard rock	2004	24.0-30.0/0.50	13.0	nil	0.0-17.0 Clay 17.0-42.0 S/S
GW080591 20BL169064 D, S	344694	6317000	48.0	Hard rock	2004	39.0-42.0/0.83	20.0	nil	0.0-0.5 Soil 0.5-3.0 Clay 3.0-40.0 S/S 40.0-48.0 Sh
GW080592 20BL169065 D	345090	6317054	48.0	Hard rock	2004	41.0-42.0/1.0	20.0	2.00 – 0.47	0.0-4.0 Clay 4.0-48.0 S/S
GW080593 20BL169100 F,I	345127	6317608	27.0	Hard rock	2003	18.0-21.0/2.0	7.0	nil	0.0-9.0 Clay 9.0-27.0 S/S
GW080599 20BL169105 C,F,I	345324	6317390	30.0	Hard rock	1964	nil	nil	nil	nil
GW080608 20BL169008 D,S	349520	6321281	48.0	Hard rock	2004	41.0-45.0/0.40	3.20	nil	0.0-36.0 Sands 36.0-48.0 Sh
GW200211 20BL169166 D,F,S	342753.3 5	6320157.4 9	72.0	Hard rock	2006	nil	nil	nil	nil
GW058391 20BL127955 D	345635	6321040	27.6	-	1982	-	-	-	-

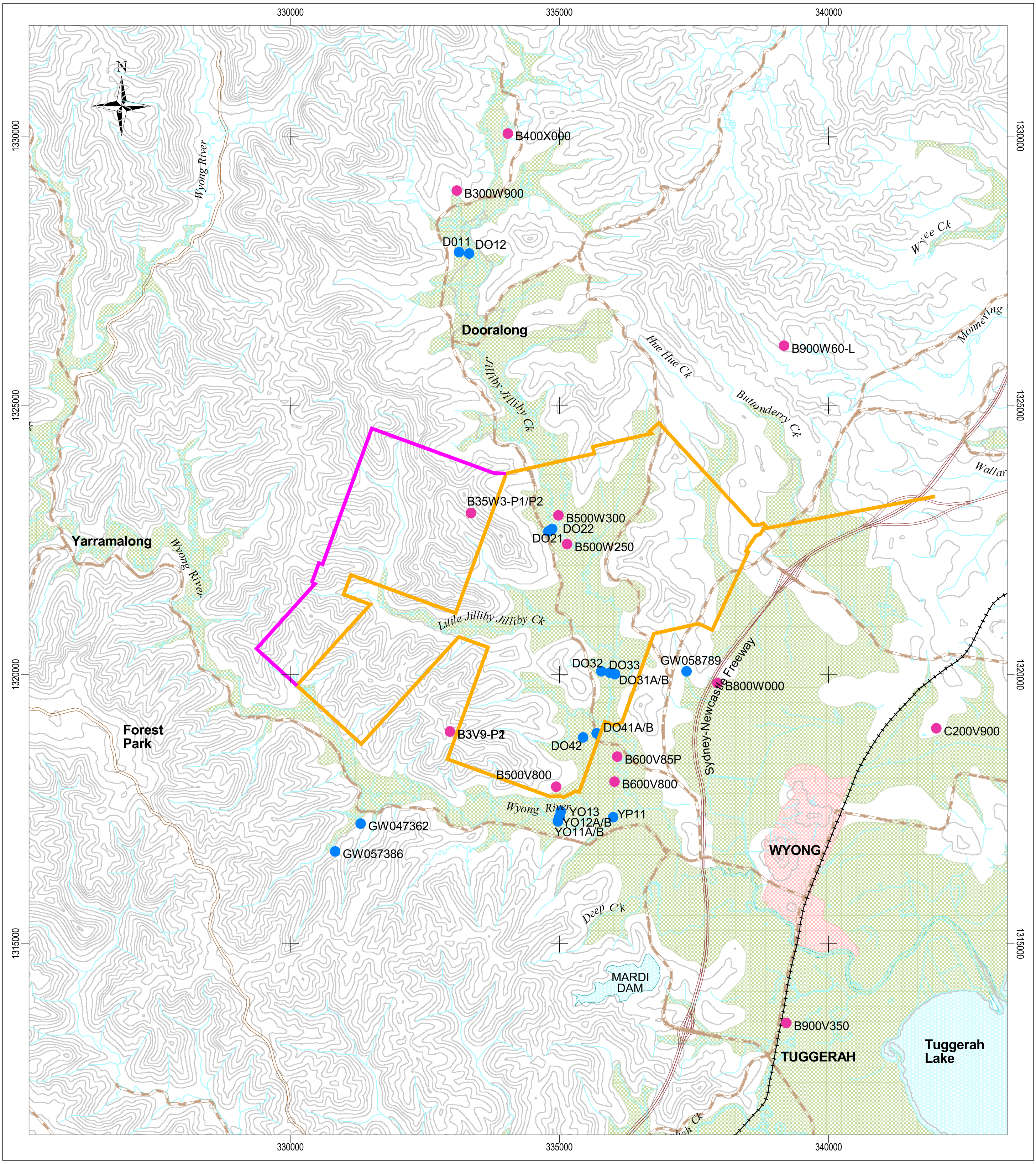
GW058392 20BL127956 D	345685	6321280	29.0	-	1982	-	-	-	-
GW049667 20BL109446 D,S	346800	6316675	45.8	hard rock	1979	32.0-32.3/1.89	6.0	good	0.0-1.0 soil 1.0-26.0 clay 26.0-46.0 shale
GW051365 20BL111075 D,I,S	344825	6317550	44.0	hard rock	1979	32.0-34.0/0.3	-	good to brackish	0.0-3.0 soil 3.0-18.0 clay 18.0-44.0 shale

'nil' = no recorded data, S/S = sandstone, Sh = shale/claystone, Cong = conglomerate
D, S, F, I, W, P denotes authorised purpose: Domestic, Stock, Farm, Irrigation, Waste disposal, Poultry

APPENDIX C: GROUNDWATER MONITORING

Table C1: Summary of speciated groundwater samples

Bore	Strata	TDS	EC	pH	Ca	Mg	Na	K	HCO3	SO4	Cl
		mg/l	uS/cm		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
B400X000	alluvium	6150	11270	6.3	96	410	2130	15	615	130	3053
B500V800	Patonga	4700	8294	5.8	80	210	1250	20	117	176	2875
B500W250	alluvium	5310			8	6	2270	22	5478	7	414
B500W300	alluvium	1850	3540	7.6	36	51	465	12	520	94	841
B600V800	Tuggerah	9080			10	6	1410	6	852	1	1870
B600V850	Tuggerah	3410			30	35	1230	9	748	1	1600
B800W000	Patonga	8800	15680	6.6	74	270	2830	17	456	575	4900
B900W600	Patonga	2620	2124	11.8	1	1	367	3	199	34	328
C200V900	Patonga	4200	8922	8.2	115	42	1450	11	181	15	2280
DO12	alluvium	6276	11930	5.6	21	200	1960	10	6	319	3760
DO21	alluvium	2692	4480	6.3	28	90	780	7	228	98	1460
DP31	alluvium	1013			13	23	315	3	193	33	433
DO31A	alluvium	276	551	6.4	3	11	52	1	137	5	67
DO31B	alluvium	983	1474	6.3	15	31	250	3	218	25	441
DO33	alluvium	723	1416	6.1	20	36	205	3	102	19	337
DO41A	alluvium	5467	7897	6.5	36	180	1760	10	116	305	3060
DO41B	alluvium	4763	8706	6.7	57	160	1690	10	492	201	2153
DO42	alluvium	1723	2976	5.8	15	56	610	5	150	13	874
GW047362	Terrigal	825	780	5.2	32	25	205	5	178	26	327
GW057386	Terrigal	1521	2170	6.9	9	4	535	5	123	68	777
GW058789	Patonga	7538	13310	6.5	83	261	2320	15	536	333	3990
YP11	alluvium	2483			27	108	776	8	6	38	1520
YO11A	alluvium	498	1159	6.0	6	19	135	2	6	39	291
YO12A	alluvium	252	581	6.0	2	6	68	2	21	14	139
YO12B	alluvium	352	527	6.1	5	9	100	2	6	16	214
YO13	alluvium	526	368	5.3	10	21	162	5	2	7	319



0 2000 4000 6000 Metres

Scale 1:100,000

creeks	urban area
minor road	alluvium
sealed road	alluvium monitoring bore
Freeway	hardrock monitoring bore
railway	28 years mine footprint
	38 years mine footprint

WALLARAH 2 COAL PROJECT

Groundwater monitoring bore locations

Figure C1

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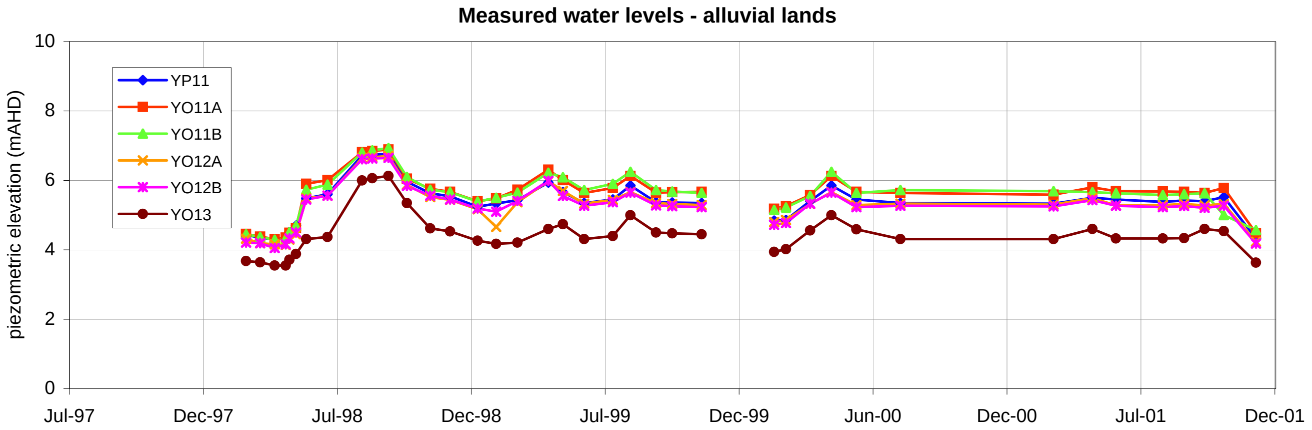
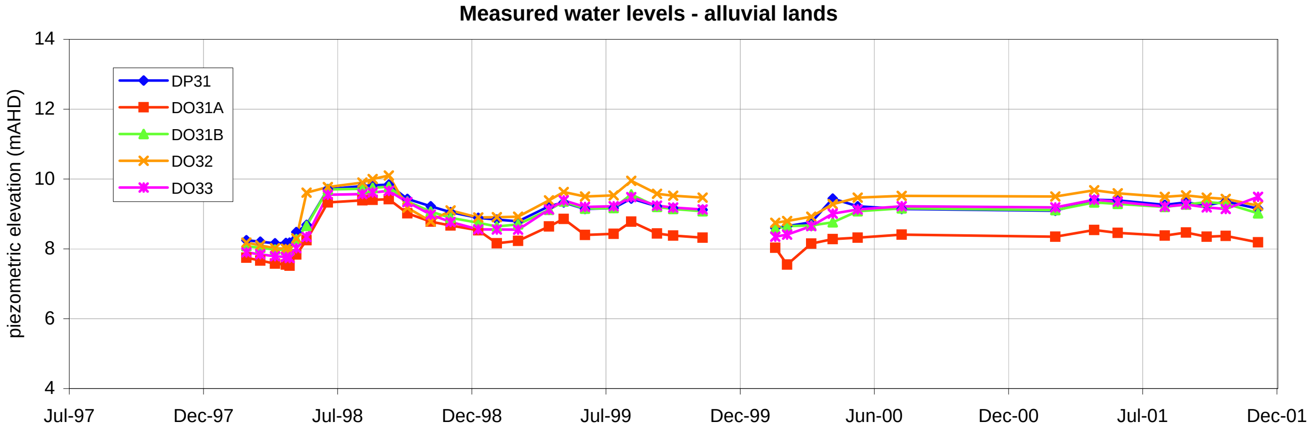
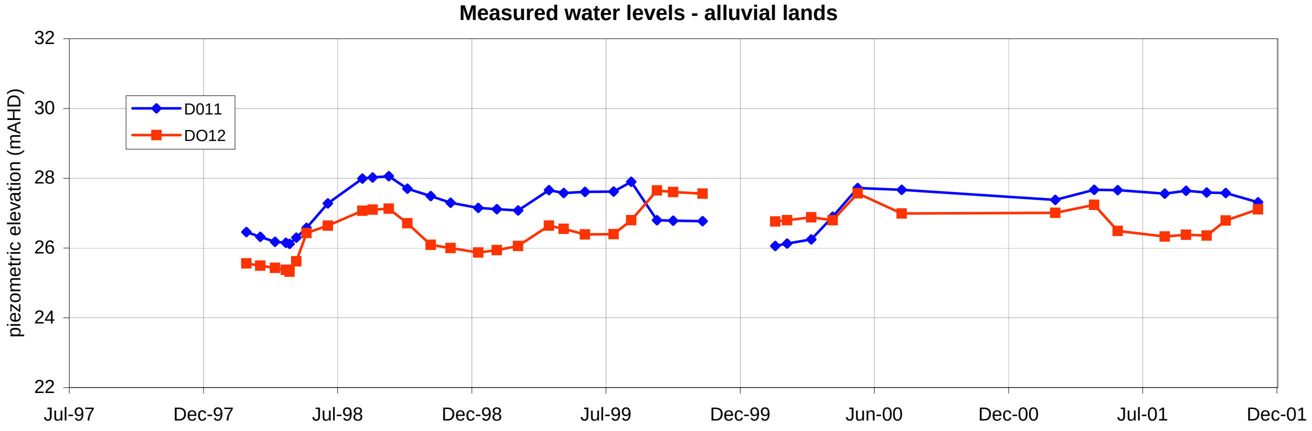
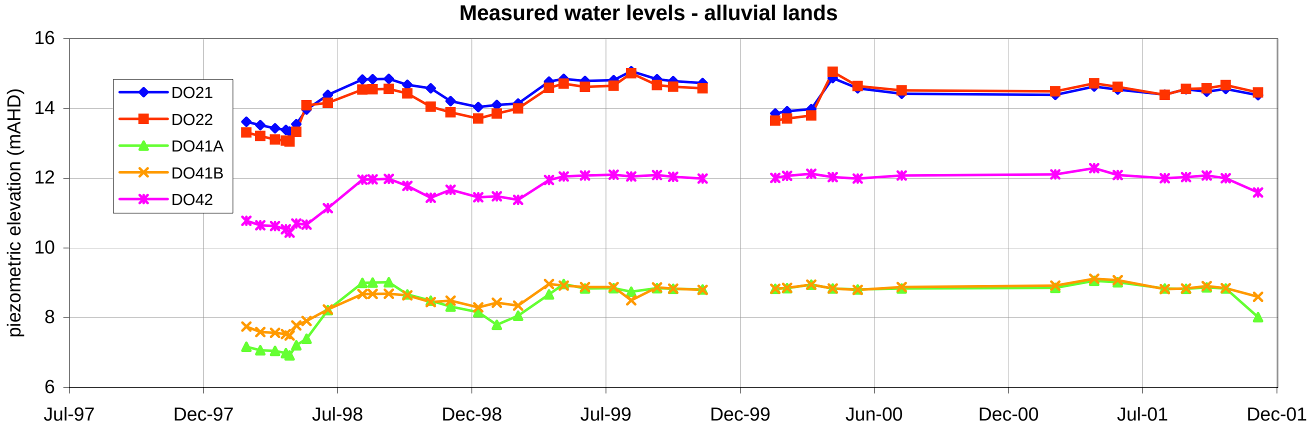


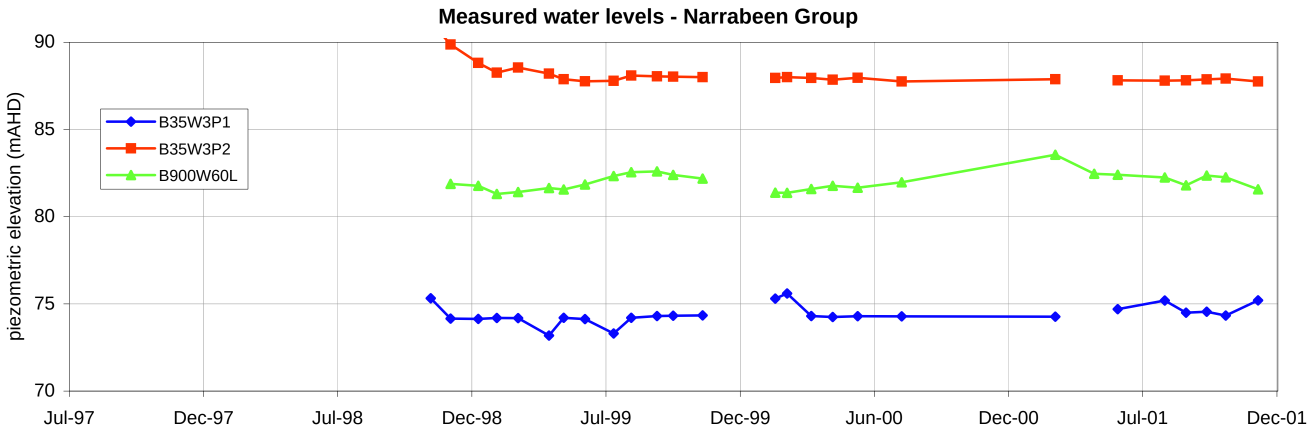


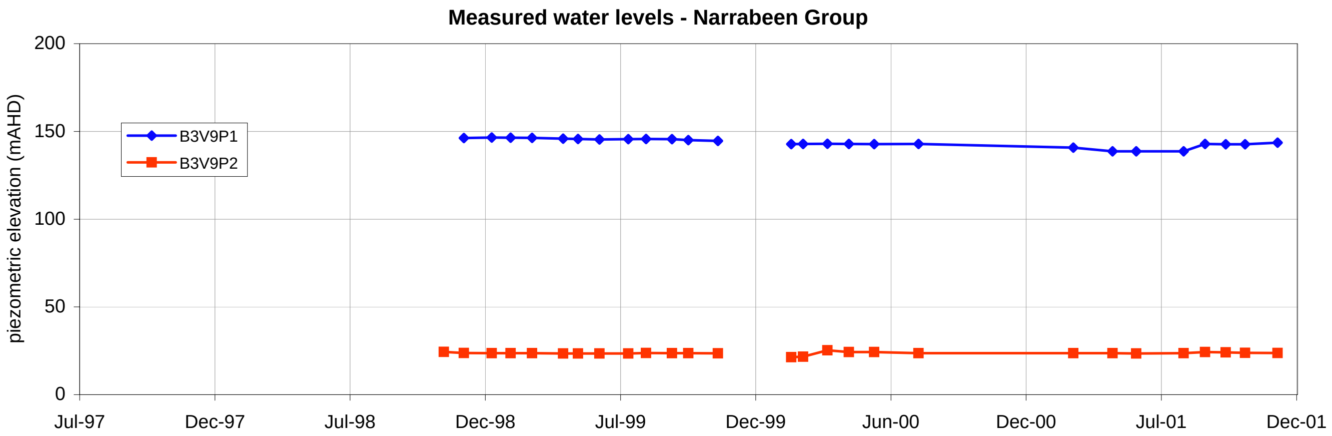


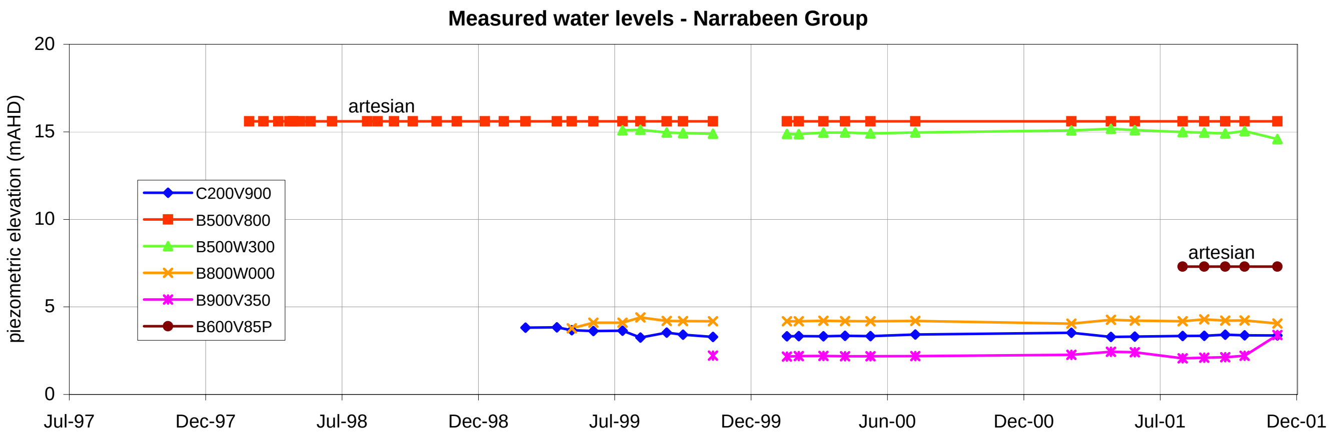


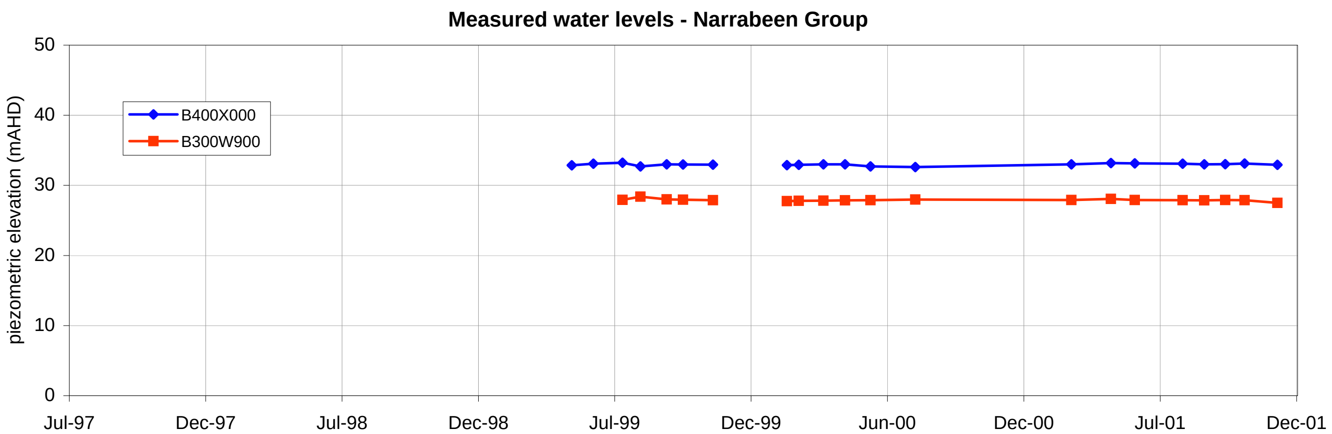
Water level monitoring data - alluvial lands

Figure C2



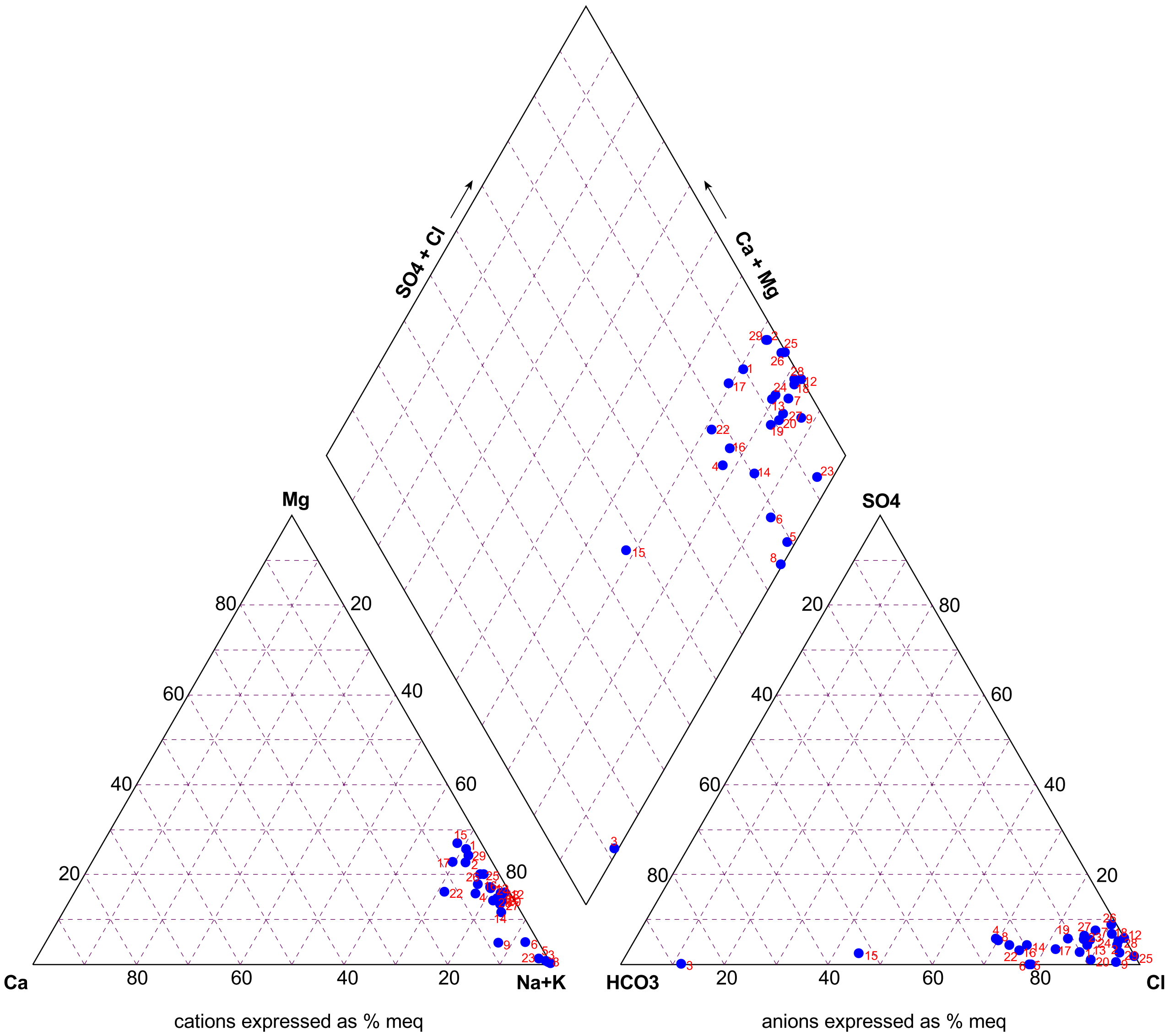






Water level monitoring data - Narrabeen Group

Figure C2 ct'd



ID	Bore	TDS mg/l	EC uS/cm	pH	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO3 mg/	SO4 mg/l	Cl mg/l
1	B400X000	6150	11270	6.3	96	410	2130	15	615	130	3053
2	B500V800	4700	8294	5.8	80	210	1250	20	117	176	2875
3	B500W250	5310			8	6	2270	22	5478	7	414
4	B500W300	1850	3540	7.6	36	51	465	12	520	94	841
5	B600V800	9080			10	6	1410	6	852	1	1870
6	B600V850	3410			30	35	1230	9	748	1	1600
7	B800W000	8800	15680	6.6	74	270	2830	17	456	575	4900
8	B900W600	2620	2124	11.8	1	1	367	3	199	34	328
9	C200V900	4200	8922	8.2	115	42	1450	11	181	15	2280
10	DO12	6276	11930	5.6	21	200	1960	10	6	319	3760
11	DO21	2692	4480	6.3	28	90	780	7	228	98	1460
12	DP31	1013			13	23	315	3	193	33	433
13	DO31A	276	551	6.4	3	11	52	1	137	5	67
14	DO31B	983	1474	6.3	15	31	250	3	218	25	441
15	DO33	723	1416	6.1	20	36	205	3	102	19	337
16	DO41A	5467	7897	6.5	36	180	1760	10	116	305	3060
17	DO41B	4763	8706	6.7	57	160	1690	10	492	201	2153
18	DO42	1723	2976	5.8	15	56	610	5	150	13	874
19	GW047362	825	780	5.2	32	25	205	5	178	26	327
20	GW057386	1521	2170	6.9	9	4	535	5	123	68	777
21	GW058789	7538	13310	6.5	83	261	2320	15	536	333	3990
22	YP11	2483			27	108	776	8	6	38	1520
23	YO11A	498	1159	6.0	6	19	135	2	6	39	291
24	YO12A	252	581	6.0	2	6	68	2	21	14	139
25	YO12B	352	527	6.1	5	9	100	2	6	16	214
26	YO13	526	368	5.3	10	21	162	5	2	7	319

WALLARAH 2 COAL PROJECT

Piper plot of major ions in groundwaters

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Figure C3

APPENDIX D: HYDRAULIC PROPERTIES

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

Hydraulic properties assessments conducted as part of the current study have focused on the hard rock strata via packer (injection) testing in numerous exploration boreholes, and laboratory testing of core from three boreholes. Figure D1 provides a plan of all locations where hydraulic properties estimates have been derived (hard rock and alluvium).

D1. Packer injection test analyses

CPI (1998) carried out 170 packer tests at 31 exploration bore locations in order to establish estimates of hydraulic conductivity for different strata. Testing was conducted using a single packer assembly with test intervals varying from 3 to 200 m and averaging about 30 m. Procedure comprised sealing off the lower portion of an exploration hole and measurement of the rate of clean water injection to the test zone at 3 or 4 injection pressures ranging from 200 kPa to 800 kPa. Numerous tests exhibited potential packer leakage, strata dilation or equilibration (constant injection) difficulties due to equipment limitations. Hydraulic conductivity estimates are provided in the following summary Table D1. At many tests a negligible injection rate was observed at all test pressures due to low conductivity strata. For these tests a likely maximum hydraulic conductivity has been calculated assuming a minimum injection rate of 0.01 litres per minute (10 ml/min) at 600 kPa this being identified as the probable lower limit of the flow measurement apparatus. The calculated conductivity under these conditions for a median test section length of about 23 metres, is about 5.5E-06 m/day. Such tests and properties estimates are indicated by 'bql' (below quantitation limit) in Table D1.

Test results have been consolidated in Table D2 to generate a schedule of bulk hydraulic conductivities based on stratigraphic formations and statistical parameters. It is noted however that due to the highly variable test section lengths these estimates are considered to be approximate. The most applicable estimate is considered to be the mean value based on log normality (LN mean) transformation. While this transformation improves the statistical measure from the highly skewed arithmetic mean (A mean), the resulting distributions still contain some skewness.

Figure D2a provides a summary of all packer testing as a histogram where 85% of the tests returned a hydraulic conductivity less than 1E-03 m/day and 72% of the tests returned a conductivity less than 1E-04 m/day. Higher conductivities appear to be crudely associated with sandstone-conglomerate and coal seam(s).

Figure D3 provides a plot of depth versus hydraulic conductivity. No trend is evident that might relate decreasing conductivity with increasing depth.

Table D1: Hydraulic conductivity estimates from packer tests at 31 exploration bore sites

Bore name	Unit	Lithology	From (m)	To (m)	T (m^2/day)	K (m/day)	comment
B300V900	Patonga Claystone	MS/SS	242	300	< 1.44E-04	2.49E-06	dilation above 600 kPa
B300V900	Tuggerah	MS/SS	360	432	< 1.49E-04	2.06E-06	dilation above 600 kPa
B300V900	Tuggerah	SS/CG	462	492	< 1.31E-04	4.36E-06	recovering pressure
B600V800	Tuggerah	SS	294	310	< 1.18E-04	7.37E-06	bql
B600V800	Tuggerah	SS/MS	310	364	< 1.43E-04	2.64E-06	bql
B600V800	Tuggerah	SS/MS	364	406	2.75E-03	6.55E-05	not properly equilibrated
B600V800	Tuggerah	SS/MS	407	412	< 9.41E-05	1.88E-05	not properly equilibrated - bql
B600V800	Tuggerah	SS/MS	432	441	< 1.06E-04	1.18E-05	not properly equilibrated - bql
B600W200	Tuggerah	SS/MS	190	256	< 1.47E-04	2.22E-06	not properly equilibrated - bql
B600W200	Munmorah Conglomerate	CG/SS	250	270	< 1.22E-04	6.12E-06	not properly equilibrated - bql
B600W200	Munmorah Conglomerate	SS/CG	285	316.3	< 1.32E-04	4.20E-06	not properly equilibrated - bql
B600W200	Munmorah Conglomerate	MS/SS/CG	334	364	< 1.31E-04	4.36E-06	not properly equilibrated - bql
B600W200	Dooralong Shale	MS/SS/CG	364	388	< 1.26E-04	5.26E-06	not properly equilibrated - bql
B600W200	Wallarah/ Great Northern Seam	Coal	404	411	< 1.01E-04	1.45E-05	not properly equilibrated - bql
B700W000	Tuggerah	MS/SS	222	228	< 9.78E-05	1.63E-05	not properly equilibrated - bql
B700W000	Munmorah Conglomerate	SS/CG	246	252	< 9.78E-05	1.63E-05	not properly equilibrated - bql
B700W000	Munmorah Conglomerate	SS/MS	318	330	< 1.12E-04	9.33E-06	not properly equilibrated - bql
B700W000	Dooralong Shale	MS/SS	378	384	< 9.78E-05	1.63E-05	not properly equilibrated - bql
B700W000	Wallarah/ Great Northern Seam	Coal	396	403	< 1.01E-04	1.44E-05	not properly equilibrated - bql
B700W000	Karingal Conglomerate	SS	402	408	5.74E-03	9.57E-04	clogging above 600 kPa
B700W000	Fassifern Seam	Coal/TU	411	415	1.08E-02	2.71E-03	clogging above 600 kPa
B700W400	Munmorah Conglomerate	MS/SS/CG	264	286	6.22E-04	2.83E-05	clogging above 600 kPa
B700W400	Dooralong Shale	SS	339	350	< 1.10E-04	1.00E-05	bql
B700W400	Wallarah/ Great Northern Seam	Coal	349	355.5	< 9.95E-05	1.53E-05	bql
B700W400	Karingal Conglomerate	SS	354	361	< 1.01E-04	1.44E-05	bql
B750W150	Munmorah Conglomerate	SS/CG	228	234	< 9.78E-05	1.63E-05	bql
B750W150	Munmorah Conglomerate	MS/SS	294	306	2.24E-04	1.87E-05	dilated then clogged
B750W150	Wallarah/ Great Northern Seam	Coal	378	384.5	2.98E-03	4.59E-04	clogging above 600 kPa
B750W150	Karingal Conglomerate	SS	384	390	< 9.78E-05	1.63E-05	recovering pressure - not properly equilibrated

Bore name	Unit	Lithology	From	To	T	K	comment
B750W150	Awaba Tuff/ Fassifern Seam	MS/Coal	392	399	< 1.01E-04	1.44E-05	bql
B800W200	Munmorah Conglomerate	SS/CG	186	234	5.19E-03	1.08E-04	clogging above 600 kPa
B800W200	Munmorah Conglomerate	MS/SS/CG	249	282	2.43E-02	7.37E-04	poor data - clogging above 600 kPa
B800W200	Munmorah Conglomerate	SS/CG/MS	282	330	3.37E-03	7.02E-05	dilation and clogging
B800W200	Dooralong Shale	SS/MS	342	352	9.20E-04	9.20E-05	clogging above 600 kPa
B800W200	Wallarah/ Great Northern Seam	Coal	350	355	< 9.41E-05	1.88E-05	bql
B800W200	Karingal Conglomerate	SS	361	372.2	< 1.35E-04	1.21E-05	bql
B900V900	Tuggerah	SS/MS	150	203	4.98E-03	9.40E-05	poor data - not properly equilibrated
B900V900	Munmorah Conglomerate	SS/CG	208	267	8.67E-04	1.47E-05	dilation above 600 kPa
B900V900	Munmorah Conglomerate	MS/SS/CG	267	297	9.15E-04	3.05E-05	
B900W300	Munmorah Conglomerate	SS/MS/CG	210	228	4.81E-04	2.67E-05	not properly equilibrated
B900W300	Dooralong Shale	SS/MS	312	324	5.60E-04	4.67E-05	not properly equilibrated
B900W300	Wallarah/ Great Northern Seam	Coal/SS	330	336	1.96E-04	3.26E-05	not properly equilibrated
B900W300	Teralba Conglomerate	CG	336	345	1.17E-04	1.30E-05	not properly equilibrated
B900W300	Wallarah/ Great Northern Seam	Coal	357	360	< 8.37E-05	2.79E-05	bql
B900W300	Karingal Conglomerate	SS	360	363	3.35E-04	1.12E-04	not properly equilibrated
B900W300	Awaba Tuff	TU	372	376	5.55E-03	1.39E-03	gouge wash out ? Maximum value given
B900W700	Tuggerah	MS/SS	219	261	8.26E-04	1.97E-05	
B900W700	Munmorah Conglomerate	SS/CG	291	333	< 1.38E-04	3.28E-06	not properly equilibrated - bql
B900W700	Dooralong Shale	SS/MS	402	421	< 1.21E-04	6.39E-06	recovering pressure - not properly equilibrated - bql
B900W700	Wallarah/ Great Northern Seam	Coal	422	426	2.69E-04	6.72E-05	dilation above 600 kPa
B900W700	Teralba Conglomerate	CG	426	432	< 9.78E-05	1.63E-05	not properly equilibrated - bql
B900W800	Tuggerah	SS/MS	54	172	1.30E-02	1.10E-04	dilation above 600 kPa
B900W800	Tuggerah	SS/MS/CG	172	268	2.01E-03	2.09E-05	
C100V900	Munmorah Conglomerate	SS/MS/CG	151	214	2.04E-03	3.24E-05	
C100V900	Munmorah Conglomerate	MS/SS/CG	211	266	< 1.43E-04	2.60E-06	recovering pressure - nor properly equilibrated - bql
C100V900	Wallarah/ Great Northern Seam	Coal	278.5	281.9	1.72E-04	5.07E-05	not properly equilibrated - approximate
C100V900	Teralba Conglomerate	CG	283	300	< 1.19E-04	7.01E-06	recovering pressure - nor properly equilibrated
B300W700	Munmorah Conglomerate	SS	186	240	< 1.43E-04	2.64E-06	recovering pressure - nor properly equilibrated
B300W700	Munmorah Conglomerate	SS/MS/CG	240	285	7.92E-03	1.76E-04	not properly equilibrated - poor data
B300W700	Munmorah Conglomerate	SS/MS	285	321	< 1.34E-04	3.73E-06	not properly equilibrated - bql
B300W700	Wallarah/ Great Northern Seam	Coal	342	348	2.25E-03	3.75E-04	not properly equilibrated - poor data
B300W700	Awaba Tuff	TU	348	354	< 9.78E-05	1.63E-05	not properly equilibrated - bql

Bore name	Unit	Lithology	From	To	T	K	comment
B400V800	Patonga Claystone	MS	18	58	3.76E-01	9.39E-03	partial fissure clogging and/or onset of turbulent flow
B400V800	Patonga Claystone	MS/SS	60	100	< 1.37E-04	3.41E-06	bql
B400V800	Tuggerah	SS/MS	100	150	< 1.41E-04	2.82E-06	bql
B400V800	Dooralong Shale	MS/Coal	440	463	6.26E-04	2.72E-05	dilation at 600 kPa - maximum value given
B400V800	Wallarah/ Great Northern Seam	Coal	463	470.46	< 1.02E-04	1.37E-05	bql
B400V800	Karingal Conglomerate	SS	470	477.77	< 1.03E-04	1.33E-05	bql
B600W600	Munmorah Conglomerate	SS/MS/CG	282	318	6.72E-02	1.87E-03	bql
B600W600	Dooralong Shale	SS/MS	318	358	6.23E-02	1.56E-03	fissure clogging
B600W600	Wallarah/ Great Northern Seam	Coal	361	365.5	< 9.20E-05	2.04E-05	bql
C100V800	Tuggerah	SS/MS	100	180	8.85E-02	1.11E-03	recovering pressure - not properly equilibrated
C100V800	Munmorah Conglomerate	SS/CG/MS	220	251	< 1.31E-04	4.24E-06	recovering pressure - not properly equilibrated
C100V800	Dooralong Shale	MS/SS	259	304	< 1.39E-04	3.09E-06	recovering pressure - not properly equilibrated
C100V800	Wallarah/ Great Northern Seam	Coal	304	308	< 8.95E-05	2.24E-05	recovering pressure - not properly equilibrated
B500W300	Tuggerah	MS/SS	156	221	3.34E-01	5.14E-03	fissure clogging above 600 kPa
B500W300	Munmorah Conglomerate	SS/CG	221	249	3.34E-01	1.19E-02	partial fissure clogging and/or onset of turbulent flow
B500W300	Munmorah Conglomerate	SS/MS/CG	249	300	6.50E-02	1.27E-03	partial fissure clogging and/or onset of turbulent flow
B500W300	Munmorah Conglomerate	SS/CG/MS	297	345	6.22E-02	1.30E-03	
B500W300	Dooralong Shale	SS/MS	347	381	2.25E-02	6.61E-04	partial clogging
B500W300	Wallarah/ Great Northern Seam	Coal	393	399	1.08E-03	1.80E-04	not properly equilibrated
C400V300	Munmorah Conglomerate	SS	165	179.5	< 1.56E-04	1.08E-05	not properly equilibrated - bql
C400V300	Munmorah Conglomerate	MS/SS/CG	234	246	1.47E-02	1.22E-03	partial fissure clogging and/or onset of turbulent flow ?
C400V300	Dooralong Shale	MS/SS/CG	276.18	288.18	< 1.12E-04	9.33E-06	not properly equilibrated - bql
C400V300	Wallarah/ Great Northern Seam	Coal	315.18	318.18	< 8.37E-05	2.79E-05	not properly equilibrated - bql
C400V300	Awaba Tuff	TU	324	330	3.38E-02	5.63E-03	dilation followed by clogging
C500V200	Munmorah Conglomerate	SS	145	155.3	4.39E-02	4.26E-03	partial formation clogging
C500V200	Munmorah Conglomerate	MS/SS	192	201	< 1.06E-04	1.18E-05	recovering pressure - not properly equilibrated
C500V200	Munmorah Conglomerate	SS/CG	231	240	< 1.06E-04	1.18E-05	recovering pressure - not properly equilibrated
C500V200	Wallarah/ Great Northern Seam	Coal	306.9	311.3	< 9.15E-05	2.08E-05	recovering pressure - not properly equilibrated
B300W100	Patonga Claystone	MS/SS	48	89	3.60E-03	8.78E-05	recovering pressure - not properly equilibrated
B300W100	Tuggerah	SS/MS	197	269	4.67E-03	6.48E-05	recovering pressure - not properly equilibrated
B300W100	Munmorah Conglomerate	SS/CG	270	312	< 1.75E-04	4.16E-06	recovering pressure - not properly equilibrated
B300W100	Munmorah Conglomerate	SS/CG	366	402	3.67E-02	1.02E-03	dilation over test period - maximum value
B300W100	Dooralong Shale	MS/SS	408	444	2.94E-03	8.16E-05	dilation over test period - maximum value

Bore name	Unit	Lithology	From	To	T	K	comment
B300W100	Wallarah/ Great Northern Seam	Coal	447	456	2.10E-02	2.33E-03	
B300W100	Awaba Tuff	TU/Coal	453	459	< 1.34E-04	2.23E-05	not properly equilibrated - bql
C050V300	Tuggerah	MS/SS	165	190	1.64E-02	6.56E-04	not properly equilibrated - maximum value
C050V300	Tuggerah	MS/SS	190	225	2.12E-02	6.05E-04	not properly equilibrated
C050V300	Tuggerah	SS/CG/MS	225	265	1.30E-02	3.25E-04	recovering pressure - not properly equilibrated - poor data
C050V300	Munmorah Conglomerate	SS/MS/CG	265	318	1.88E-02	3.54E-04	recovering pressure - not properly equilibrated - poor data
C050V300	Munmorah Conglomerate	MS/SS	325	382	1.45E-03	2.55E-05	recovering pressure - not properly equilibrated
C050V300	Teralba Conglomerate	MS/Coal	400	406	3.61E-03	6.01E-04	partial fissure clogging with increasing pressure
C050V300	Wallarah/ Great Northern Seam	Coal	414.4	421.9	< 1.36E-04	1.81E-05	bql
C050V300	Awaba Tuff	TU	422	428	5.25E-04	8.74E-05	recovering pressure + dilation above 600 kPa
B650W050	Tuggerah	SS/MS	190	245	< 1.90E-04	3.46E-06	bql
B650W050	Munmorah Conglomerate	SS/CG	245	294	< 1.86E-04	3.79E-06	not properly equilibrated - bql
B650W050	Munmorah Conglomerate	MS/SS/CG	295	350	< 1.86E-04	3.38E-06	not properly equilibrated - bql
B650W050	Munmorah Conglomerate	SS/MS	350	388	< 1.74E-04	4.57E-06	bql
B650W050	Wallarah/ Great Northern Seam	Coal	399	402	< 1.14E-04	3.81E-05	recovering pressure - not properly equilibrated
B650W050	Karingal Conglomerate	SS/TU	402	412	< 1.48E-04	1.48E-05	not properly equilibrated
B450W050	Munmorah Conglomerate	SS/CG	270	310	4.58E-02	1.14E-03	dilation of fissure
B450W050	Munmorah Conglomerate	SS/MS	310	370	< 1.88E-04	3.13E-06	bql
B900V300	Dooralong Shale	SS/MS	425	448	< 1.67E-04	7.24E-06	bql
B900V300	Dooralong Shale	SS	448	454	< 1.29E-04	2.15E-05	bql
B900V300	Wallarah/ Great Northern Seam	Coal	462	472	< 1.08E-04	1.08E-05	bql
B900V300	Awaba Tuff	SS/TU	472	478	< 9.78E-05	1.63E-05	bql
B650W100	Tuggerah	SS/MS	50	250	4.48E-01	2.24E-03	partial fissure clogging and/or onset of turbulent flow ?
B650W100	Dooralong Shale	SS	390	400	< 1.08E-04	1.08E-05	bql
MM1	Tuggerah	SS/MS	27	57	1.50E-01	5.01E-03	
MM1	Tuggerah	SS/MS	57	123	1.65E-02	2.50E-04	dilation above 400 kPa
MM1	Tuggerah	MS/SS	122	183	< 1.45E-04	2.38E-06	not properly equilibrated - bql
MM1	Tuggerah	SS/MS/CG	183	223	2.87E-02	7.17E-04	
MM1	Munmorah Conglomerate	SS/CG	227	274	3.78E-02	8.04E-04	
MM1	Munmorah Conglomerate	SS/MS	276	336	< 1.45E-04	2.41E-06	not properly equilibrated
MM1	Wallarah/ Great Northern Seam	Coal	357	363	1.66E-02	2.77E-03	
MM1	Teralba Conglomerate	CG	363	375	2.00E-02	1.66E-03	
MM1	Awaba Tuff	TU/Coal	393	402	< 1.30E-04	1.44E-05	not properly equilibrated

Bore name	Unit	Lithology	From	To	T	K	comment
B300V700	Patonga Claystone	MS/SS	36	115	2.86E-01	3.62E-03	
B300V700	Tuggerah	MS/SS	236	324	< 2.08E-04	2.37E-06	not properly equilibrated - bql
B300V700	Munmorah Conglomerate	SS/MS	385	441	3.23E-03	5.76E-05	not properly equilibrated - maximum value
UC1	Patonga Claystone	MS/SS	24	42	6.20E-02	3.45E-03	not properly equilibrated
UC1	Tuggerah	SS/MS	42	102	2.68E-02	4.47E-04	fissure dilation
UC1	Tuggerah	SS/MS	102	162	< 1.49E-04	2.49E-06	not properly equilibrated - poor data
UC1	Tuggerah	SS/MS	162	204	< 1.42E-04	3.37E-06	not properly equilibrated - bql
UC1	Munmorah Conglomerate	SS/CG/MS	204	270	< 1.51E-04	2.29E-06	recovering pressure - not properly equilibrated - bql
UC1	Munmorah Conglomerate	MS/SS/CG	270	294	< 1.30E-04	5.41E-06	recovering pressure - not properly equilibrated - bql
UC1	Munmorah Conglomerate	SS/CG	294	342	< 1.45E-04	3.01E-06	recovering pressure - not properly equilibrated - bql
UC1	Dooralong Shale	SS	342	366	< 1.29E-04	5.36E-06	fissure dilation
UC1	Dooralong Shale	MS/Coal	366	375	1.47E-02	1.63E-03	not properly equilibrated - maximum value
UC1	Teralba Conglomerate	CG	375	387	< 1.51E-04	1.26E-05	not properly equilibrated - bql
UC1	Karingal Conglomerate	SS/Coal	387	399	< 1.46E-04	1.22E-05	not properly equilibrated - bql
UC1	Awaba Tuff	TU/Coal	399	414	< 1.52E-04	1.01E-05	bql
B450W150	Tuggerah	SS/MS	222	232	< 1.08E-04	1.08E-05	bql
B450W150	Munmorah Conglomerate	CG	267	279	< 1.12E-04	9.33E-06	bql
B450W150	Munmorah Conglomerate	MS	336	345	< 1.31E-04	1.46E-05	bql
B450W150	Munmorah Conglomerate	SS/MS	390	411	< 1.66E-04	7.91E-06	bql
B450W150	Wallarah/ Great Northern Seam	Coal	419.6	426.1	< 1.34E-04	2.06E-05	bql
B450W150	Awaba Tuff	TU	426.1	432.1	< 1.35E-04	2.25E-05	bql
B750W250	Tuggerah	SS	168	178	4.33E-04	4.33E-05	bql
B750W250	Munmorah Conglomerate	SS/CG/MS	230	252	< 1.58E-04	7.17E-06	bql
B750W250	Munmorah Conglomerate	CG/SS/MS	298	312	< 1.45E-04	1.03E-05	bql
B750W250	Dooralong Shale	SS	340	352	< 1.42E-04	1.18E-05	bql
B550V850	Tuggerah	SS/MS	70	120	1.12E-01	2.24E-03	bql
B550V850	Tuggerah	SS/MS	120	145	< 1.67E-04	6.69E-06	bql
B550V850	Tuggerah	MS/SS	145	174	1.37E-03	4.74E-05	fissure clogging above 600 kPa
B550V850	Tuggerah	MS/SS	174	222	8.70E-03	1.81E-04	
B550V850	Tuggerah	SS/MS	222	267	4.61E-03	1.02E-04	
B550V850	Munmorah Conglomerate	SS	267	324	4.77E-01	8.37E-03	recovering pressure - nor properly equilibrated
B550V850	Munmorah Conglomerate	MS	324	360	4.27E-03	1.19E-04	recovering pressure - nor properly equilibrated + dilation
TUC1	Tuggerah	SS/MS	36	96	6.83E-01	1.14E-02	partial fissure clogging and/or onset of turbulent flow ?

Bore name	Unit	Lithology	From	To	T	K	comment
TUC1	Tuggerah	SS/MS	90	168	< 1.88E-04	2.41E-06	bql
TUC1	Tuggerah	MS/SS	170	249	< 2.05E-04	2.60E-06	recovering pressure - nor properly equilibrated - bql
TUC1	Munmorah Conglomerate	SS/CG	240	294	5.85E-04	1.08E-05	fissure dilation above 400 kPa
TUC1	Munmorah Conglomerate	SS/CG	294	317	< 1.71E-04	7.44E-06	bql
TUC1	Munmorah Conglomerate	MS/SS	317	371	< 1.95E-04	3.61E-06	bql
TUC1	Dooralong Shale	SS/CG	372	393	< 1.68E-04	8.02E-06	bql
TUC1	Dooralong Shale	SS/MS/Coal	393	413	< 1.67E-04	8.36E-06	bql
TUC1	Wallarah/ Great Northern Seam	Coal/SS/TU	413	438	< 1.73E-04	6.93E-06	bql
TUC1	Bolton Point Conglomerate	CG	438	456	< 1.64E-04	9.12E-06	bql

SS = sandstone, MS = mudstone, CG = conglomerate, TU = tuff, bql = below quantitation limit

Table D2: Summary of packer test hydraulic conductivity estimates by formation

	Number of tests	A-Mean (m/day)	St-Dev	Median (m/day)	LN-Mean (m/day)
Patonga Claystone	6	2.76E-03	3.67E-03	1.77E-03	2.11E-04
Tuggerah Fm	40	7.74E-04	2.09E-03	3.21E-05	4.61E-05
Munmorah Conglomerate	55	6.40E-04	2.02E-03	1.18E-05	3.05E-05
Dooralong Shale	20	2.11E-04	4.95E-04	1.13E-05	2.59E-05
Wallarah/ Great Northern Seam	23	2.85E-04	7.28E-04	2.24E-05	4.56E-05
Awaba Tuff	9	8.01E-04	1.87E-03	1.47E-05	6.19E-05
Teralba Conglomerate	6	3.85E-04	6.69E-04	1.46E-05	5.15E-05
Bolton Point Conglomerate	1	9.12E-06			9.12E-06
Fassifern Seam	1	2.71E-03			2.71E-03
Karingal Conglomerate	8	1.44E-04	3.30E-04	1.46E-05	3.04E-05

D2. Laboratory core tests

Laboratory testing of core has been conducted on 39 formation samples extracted at three borehole locations B600W300, B800W300 and B400V900 located in the area scheduled for mining.

The laboratory procedure facilitates measurement of hydraulic conductivity at a scale representative of the lithology. The method employs gas (helium) as the test 'fluid' and generates an estimate of the Klinkenberg permeability (K_{inf}). Conversion leads to a measure of the saturated hydraulic conductivity. Conductivity can be determined in both the horizontal and vertical directions by extracting smaller directional core from the borehole (HQ size) core sample, thereby enabling an estimate of the prevailing 'micro' anisotropy within a specific rock type. In addition, total porosity can be measured.

Primary HQ size cores were inspected in archived core trays and representative samples for testing were taken from sections displaying relatively uniform properties over a reasonable depth section. Mudstones and claystones were not selected since this rock type tends to fail during cutting of smaller test slugs from the primary core. Consequently, there is a sampling bias towards conglomerates, sandstones, siltstones and laminites. This bias is considered acceptable for analytical purposes since mudstones and claystones are likely to exhibit a matrix hydraulic conductivity at least an order of magnitude lower than siltstones or sandstones.

All core samples were tested by Core Laboratories Australia. Results are summarised in the following Table D3. Statistical overview of the results is presented in Table D4. Figure D2b provides a summary of all testing as a histogram where 92% of the tests returned a conductivity less than 1E-03 m/day and 85% of the tests returned a conductivity less than 1E-04 m/day. Comparison of results with packer tests indicates core based values exhibit a slightly lower range of values than packer test results.

Table D3: Summary of core tests for the determination of hydraulic conductivity and total porosity

Bore ID	Depth m	Material	Formation	Kxy (m/day)	Kz (m/day)	Kxy/Kz	Total porosity %
B600W300	36.1	sandstone - dark grey, very fine grained	Tuggerah Fm	5.81E-06	1.66E-06	3.50	9.7
B600W300	67.1	sandstone - light grey, very fine grained	Tuggerah Fm	9.96E-06	6.64E-06	1.50	13.1
B600W300	96.8	sandstone - light grey, very fine grained	Tuggerah Fm	3.98E-04			15
B600W300	156.6	siltstone/laminite - dark grey, very fine grained	Tuggerah Fm	3.32E-06			7.1
B600W300	184.3	sandstone - white, quartzose, medium grained	Tuggerah Fm	4.98E-06			8.1
B600W300	234.2	conglomeritic sandstone - light grey	Munmorah Conglomerate	4.15E-06			9
B600W300	261.1	conglomeritic sandstone - light grey	Munmorah Conglomerate	1.16E-05			
B600W300	296.6	siltstone/laminite - dark grey, very fine grained	Munmorah Conglomerate	2.48E-07			
B600W300	307.3	conglomerate - light grey	Munmorah Conglomerate	1.66E-06	1.66E-06	1.00	7
B600W300	346	sandstone - light grey, medium grained	Dooralong Shale	5.81E-06	3.32E-06	1.75	9.7
B800W300	35.8	sandstone - dark grey, medium to fine grained	Tuggerah Fm	2.71E-05	3.79E-05	0.72	12.4
B800W300	65.2	sandstone - light grey, medium to fine grained	Tuggerah Fm	3.43E-03			16.7
B800W300	91	sandstone - dark grey, fine grained	Tuggerah Fm	3.38E-06			9.2
B800W300	145.1	sandstone - dark grey, fine grained	Tuggerah Fm	9.96E-06			
B800W300	170.1	sandstone - light grey, medium grained	Tuggerah Fm	3.72E-05			16.4
B800W300	224.7	conglomerate - light grey	Munmorah Conglomerate	1.18E-05			
B800W300	250.4	sandstone - light grey to cream, medium grained	Munmorah Conglomerate	6.24E-06			9.4
B800W300	280.4	siltstone/laminite - dark grey, very fine grained	Munmorah Conglomerate	5.55E-07			
B800W300	304.4	conglomerate - light grey	Munmorah Conglomerate	3.15E-05	1.29E-05	2.44	
B800W300	333.3	sandstone - light grey, medium grained	Dooralong Shale	3.56E-05	7.12E-06	5.00	11.8
B800W300	371.3	sandstone - dark grey, medium grained	Awaba Tuff (floor)	4.51E-06	2.72E-04	0.02	3.3
B400V900	22.0	sandstone - light grey, medium to fine grained	Terrigal Fm		3.65E-05		
B400V900	44.6	sandstone - light grey, medium to fine grained	Terrigal Fm	3.31E-03	3.83E-03	0.87	
B400V900	76.6	sandstone – light grey to grey, fine grained, bedded	Patonga Claystone		1.81E-06		
B400V900	96.2	sandstone - grey, fine grained	Patonga Claystone	1.47E-03	8.88E-04	1.65	
B400V900	119.9	sandstone - grey, fine grained, finely bedded	Patonga Claystone		3.59E-06		
B400V900	149.4	sandstone - grey, fine grained, finely bedded	Patonga Claystone		1.24E-06		
B400V900	178.0	sandstone - grey, fine grained, sorted	Tuggerah Fm		5.30E-05		
B400V900	241.8	sandstone - grey, fine grained, sorted	Tuggerah Fm		2.65E-05		
B400V900	282.8	siltstone – grey to dark grey, laminated	Tuggerah Fm		6.61E-07		
B400V900	309.4	sandstone - light grey to white, medium to coarse grained	Tuggerah Fm	6.73E-04	7.12E-04	0.94	

B400V900	333.2	sandstone - light grey to white, medium to coarse grained	Tuggerah Fm		1.41E-04		
B400V900	357.5	sandstone – conglomeritic, coarse grained matrix	Munmorah Conglomerate		5.17E-05		
B400V900	373.3	sandstone - light to dark grey, medium to fine grained	Munmorah Conglomerate		2.31E-06		
B400V900	399.3	sandstone – conglomeritic, coarse grained matrix	Munmorah Conglomerate		1.24E-05		
B400V900	425.1	sandstone – conglomeritic, coarse grained matrix	Munmorah Conglomerate	1.36E-05	4.46E-06	3.05	
B400V900	462.2	conglomerate – frags to +10mm in ss matrix	Munmorah Conglomerate		3.59E-05		
B400V900	489.9	sandstone – white to light grey, medium to fine grained	Dooralong Shale		2.16E-06		
B400V900	516.3	sandstone – white to grey, fine grained, bedded	Dooralong Shale	5.85E-06	1.00E-06	5.82	

Table D4: Summary of core conductivity measurements by formation

	Kxy LN-mean (m/day)	Kz LN-mean (m/day)
Terrigal Fm (2 samples)	3.31E-03	3.74E-04
Patonga Claystone (sandstones)	1.47E-03	9.19E-06
Tuggerah Fm	3.31E-05	2.11E-05
Munmorah Conglomerate	4.13E-06	9.07E-06
Dooralong Shale	1.07E-05	2.68E-06
Awaba Tuff (1 sample)	4.51E-06	2.72E-04

LN mean = log normal mean

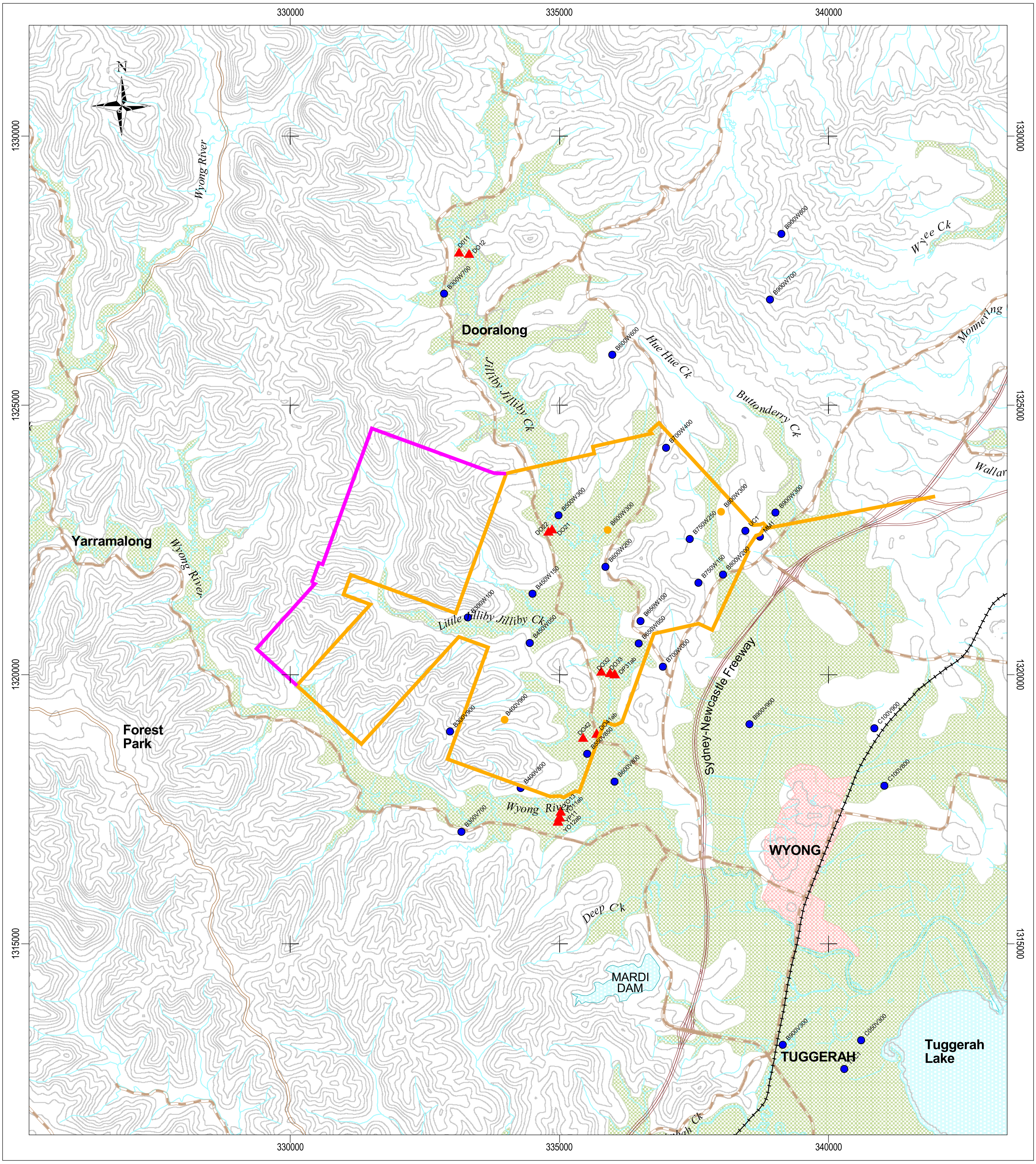
D3. Falling head testing in alluvial piezometers

CPI (1998) undertook falling head tests to estimate hydraulic conductivities in 16 piezometers installed at 12 locations throughout the region including 4 dual piezometer installations (see Figure D1 for locations). Findings are represented in the following Table D5. Analysis was based upon the Hvorslev method. Additional analyses have been conducted by MER using the KGS method (Butler, 1997). Results are also provided in Table D5.

An overview of results supports a generally low conductivity alluvium consistent with the observed geology – silty and clayey sands and gravels in a mixed assemblage. The average conductivity value assuming log normality is approximately 1.8E-01m/day while the median value is 2.0E-01 m/day for Hvorslev analyses and 2.4E-01 m/day for KGS analyses.

Table D5: Falling head (slug) test summary after CPI (1998)

Bore	Bore depth (m)	Water depth (m)	Test interval (m)	Lithology	Hvorslev K (m/day)	KGS K (m/day)
DO11	24	2.6			2.6E-01	4.7E-01
DO12	18	3	7.5-14.5	coarse sand	2.7E-01	2.6E-01
DO21	30	1.5	12.0-22.0	sandy gravel	1.7E-02	9.0E-04
DO22	30	1.9	10.0-21.0	sand/peat	1.6E-01	1.3E-01
DO31A	17.9	2.8	12.0-17.9	peat/sand	1.3E-01	1.5E-01
DO31B	36	2.4	9.0-29.0	sand/clay	1.8E-01	4.0E-01
DO32	32	1.9	12.0-30.0	peat/clay	4.3E-02	4.2E-02
DO33	29.6	2.9	17.6-29.6	clay/gravel	2.2E-01	2.6E-01
DO41A	15	1.2	9.0-15.0	clayey sand	5.9E-02	5.0E-02
DO41B	38.5	1	18.5-24.5	clayey sand	3.1E+00	5.5E+00
DO42	42.9	1.1	18.9-24.9	clay/gravel	1.5E-01	1.5E-01
YO11A	17.9	3.1	11.0-17.9	clay/gravel	2.2E-01	3.2E-01
YO11b	41.9	3.2	18.0-36.0	peat/gravel	1.6E-01	2.2E-01
YO12A	17.9	3.4	12.0-18.0	gravel/clay	4.0E-01	7.5E-01
YO12B	41.6	3.4	11.6-41.6	gravel/clay	2.6E-01	1.5E-01
YO13	30	4.4	18.0-30.0	gravel	2.2E-01	2.6E-01



0 2000 4000 6000 Metres

Scale 1:100,000

creeks		urban area	
minor road		alluvium	
sealed road		packer test hole	
Freeway		falling head test hole	
railway		laboratory core tests	
lease		28 years mine footprint	
		38 years mine footprint	

WALLARAH 2 COAL PROJECT

Hydraulic conductivity test locations

Figure D1

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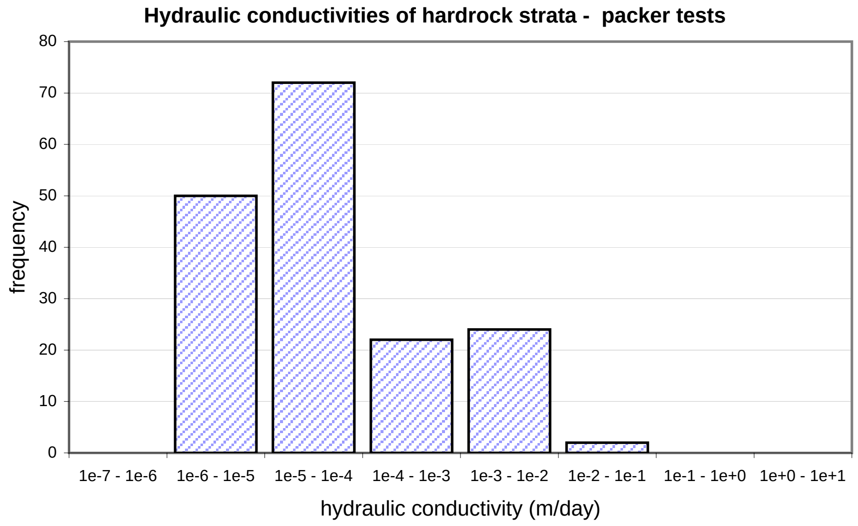
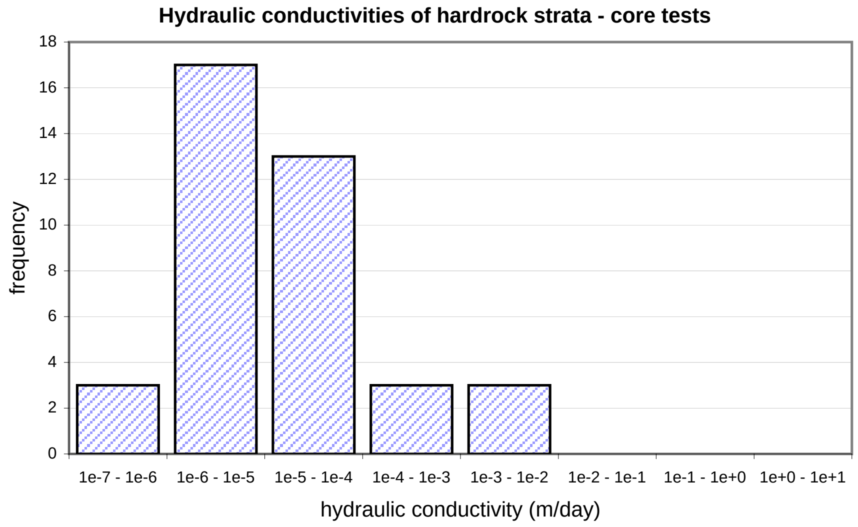
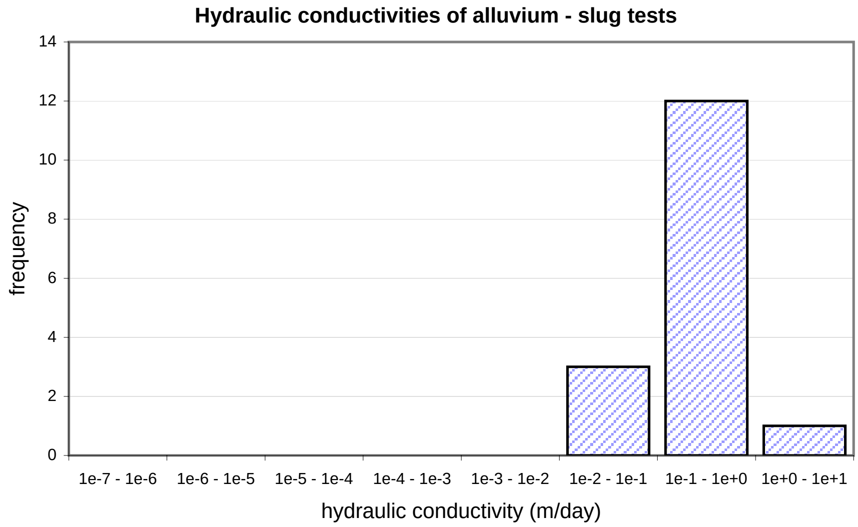
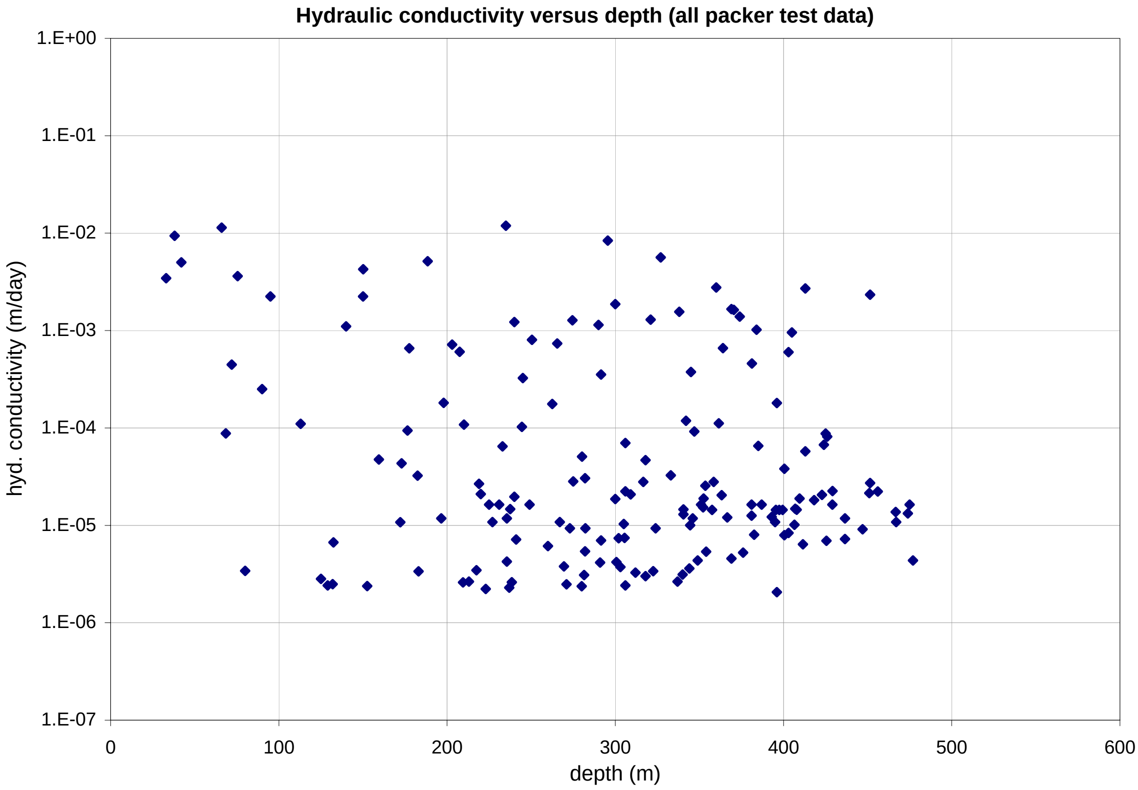






Summary hydraulic conductivity histograms

Figure D2



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Packer test hydraulic conductivity-depth plot
Figure D3

APPENDIX E: REGIONAL GROUNDWATER MODEL

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

E1 Conceptualisation

Figure E1a provides a simple conceptualisation of the groundwater systems of the region. Fundamentally, the layered sedimentary rock strata dip to the southwest. Over geologic time these strata have weathered and eroded to generate the present landscape. The eroded valleys host mixed alluvial deposits which become increasingly sandy towards the coast. Three groundwater domains are identified – the hard rock system in which flows are very slow, the unconsolidated surficial regolith-weathered bedrock, and the valley/coastal alluvial system in which groundwater flows are relatively more rapid.

Rainfall provides recharge to the shallow regolith and weathered bedrock zone which in turn acts as a partial water store which surcharges the underlying rock strata. Over geologic time flow in the hard rock strata has migrated from elevated areas towards creeks and rivers at lower elevations, and ultimately to the coast. Flow in the valley infill alluvial systems has followed a similar pattern but with much shallower hydraulic grades. All flow systems are assumed to be in a state of quasi equilibrium. That is, piezometric levels move within a relatively narrow and predictable range.

Development of deep longwall mining operations will induce changes in hard rock groundwater flow directions which will variably depressurise the overlying strata. The prediction of these changes and the resulting impacts throughout the hydrogeologic system, are the main goals of numerical modelling.

E2 Model code

In the present study, a finite difference approach has been utilized due to the large area of interest, the highly variable topography and extensive drainage systems, the potential extent of the depressurisation halo that will evolve at depth during the course of multi seam extraction, and the non-linear nature of the problem. The specific software code is known as Modflow Surfact which can simulate variably saturated flow conditions (Hydrogeologic, 1996). Supporting software coded by MER has also been employed.

The finite difference method requires division of the overall area of interest (the hydrogeologic domain) into a large number of separate rectangular cells. The number of cells defined in the model mesh has been determined by the proposed mine panel geometry at depth, the spatial variations occurring in aquifer properties, the prevailing drainage system, and the expected hydraulic gradients developed in the course of model simulations. Competition between accuracy and computing efficiency affects the overall number of cells contained within a numerical model and consequently the fineness of the model mesh has been varied from small cells within and around the longwall panels where detail is desired, to larger cells in areas more distant from the mine panels.

The basic model design is a variably saturated scheme and comprises 14 transversely anisotropic layers with 105768 cells per layer. Figure E1b provides a perspective showing model layer geometry looking towards the north-west.

The overall model extents are indicated on Figure E2 which shows the model mesh and the mine footprint in plan, and the simulated regional drainage system. Total model area is about 575 sq. km. with cell areas ranging from 2.5E+03 m^2 to 1.0E+04 m^2.

E3. Model geometry

Model layers adopt a geometry consistent with the known stratigraphy but with additional layers included to facilitate representation of the subsidence zone and pressure loss regime within strata. Layer 1 represents the alluvial infill deposits associated with the Dooralong and Yarramalong valleys, the coastal alluvium and the Terrigal Formation above a surface defined at about 30 mAHD. This allows Layer 1 to be assigned a higher hydraulic conductivity in elevated hard rock areas, (relative to deeper strata) which might be associated with regional 'de-stressing' of strata and the potentially increased presence of joints and fractures. The surficial regolith and weathered bedrock domain is considered to be highly localised and not amenable to regional scale groundwater modelling.

Layers 2 and 3 represent the remainder of the Terrigal Formation above the Patonga Claystone. Deeper layers represent the Patonga Claystone, the underlying Tuggerah Formation, Munmorah Conglomerate, Dooralong Shale and the WGN seam. The geometry of each unit has been carefully defined from structure contour information interpolated regionally. The base of the model has been defined as 100 m lower than the WGN seam floor. The bottom layers basically represent deeper Newcastle Coal Measures and have been included to provide for upwards leakage to the WGN seam.

E4. Model W1 hydraulic properties

E4.1 Hard rock hydraulic conductivities

Extensive core inspections suggest micro fractures or joints that might enhance strata hydraulic conductivities, are generally sparse at depth. Hydraulic conductivities assigned to each model layer below layer 1 are therefore based on the logged stratigraphy at three boreholes designated as 'type' boreholes. These bores are B250W300, B400V900 and B600W300 and their locations are shown on Figure E3.

The methodology comprised:

1. **Generation of a lithology-conductivity look up table based broadly upon conductivity tests on core.** This table is provided as Table E1 below and provides estimated conductivities for a wide range of logged rock types. The table assumes that a coarse grained sandstone is more conductive than a fine grained sandstone which is more conductive than a siltstone which is more conductive than a claystone.
2. **Assignment of conductivities to logged stratigraphy.** Exploration bore logs were used to develop full vertical profiles for each type borehole based on detailed geological logging of all core for strata ranging in thickness from 10 mm to more than 5 m (logged originally by BHP geologists). Figure E4abc shows detailed conductivity profiles for each borehole. These profiles reflect the prevalence (and influence) of low conductivity siltstones and claystones throughout the stratigraphic column.
3. **Reduction of conductivity profiles to hydraulically equivalent conductivities** in both horizontal and vertical directions for the main litho-stratigraphic sections in each borehole as indicated on Figures E4abc. This procedure uses established equations and addresses the influence of low conductivity claystone beds on vertical conductivities (ratio of anisotropy) in a logical rather than conjectural manner.

4. **Model conductivity values were subsequently calculated** as an average from the three type boreholes (assuming a log normal distribution), and assigned to individual layers within the model.

It is noted that hard rock conductivities depend on the pore matrix and cementation characteristics of a particular sample and as such it is possible for a fine grained sandstone to exhibit a higher conductivity than a coarse grained sandstone. Under these circumstances the calculated bulk conductivities for stratigraphic sections may vary. However this is considered to more the exception than the rule.

The process of consolidation to hydraulically equivalent layers does not account for the effect of increasing confining stress with depth which logically would tend to reduce hydraulic conductivity with increasing depth. In the absence of specific and reliable criteria, uniform conditions are assumed throughout the depth section(s). That is, hydraulic conductivities have not been adjusted downwards with increasing depth.

Table E1: Adopted hydraulic conductivities for different lithologies

Lithology	Kxy-m/day
clay	1.0E-06
silt	5.0E-03
sand - coarse grained with clay	2.0E+00
sand - coarse to medium grained	4.0E+01
sand- fine to medium grained	2.0E+01
sand - very fine grained	5.0E+00
sandy clay - fine grained	5.0E-06
conglomeritic sandstone - coarse grained	1.0E-04
conglomeritic sandstone - medium coarse grained	8.0E-05
conglomerate-pebble clasts	1.0E-04
conglomerate-medium to coarse grained sandstone	8.0E-05
conglomeritic sandstone	5.0E-05
sandstone	1.0E-05
sandstone - medium to coarse grained to conglomeritic	5.0E-05
sandstone - medium to coarse grained and siltstone	4.0E-05
sandstone with pebble bands	4.0E-05
sandstone - coarse grained	5.0E-05
sandstone - medium to coarse grained	3.0E-05
sandstone - medium grained	8.0E-06
sandstone - fine to medium grained	6.0E-05
sandstone - fine grained	5.0E-06
sandstone -very fine grained	4.0E-06
sandstone - claystone	2.0E-06
sandstone - very fine grained and laminite	2.0E-06
sandstone - siltstone	2.0E-06
siltstone	1.0E-06
siltstone- sandy	2.0E-06
siltstone - shale	6.0E-07
siltstone - fine grained sandstone	2.0E-06
siltstone - medium grained sandstone	4.0E-06
claystone	5.0E-07
claystone - sandy	5.0E-07
shale	5.0E-07
laminite	5.0E-07
laminite - sandy	5.0E-07
laminite - sandy interbedded mudstone	5.0E-07
laminite - silty	5.0E-07

laminite - very fine grained sandstone	5.0E-07
carbonaceous shale	8.0E-07
coal-claystone interbedded	5.0E-05
coal - undifferentiated	5.0E-03
coal	5.0E-03
coal - stoney	1.0E-03

Table E2: Hydraulic properties assigned to the aquifer model

Layer	Lithology	Thickness (m)	Kx m/day	Ky m/day	Kz m/day	Ss 1/m	Sy
1	valley fill alluvium	avg 30	5.0E-00	5E-00	5.0E-00	1.0E-04	2.0E-01
1	coastal sands	avg 30	1.0E+1	1.0E+1	1.0E+1	1.0E-04	2.0E-01
1	Hawkesbury + Terrigal Fm.	variable	2.1E-04	2.1E-04	2.1E-05	1.0E-05	2.0E-02
2	Terrigal Formation	variable	2.1E-05	2.1E-05	3.6E-06	2.0E-06	1.0E-02
3	Terrigal Formation	avg.50	2.1E-05	2.1E-05	3.6E-06	2.0E-06	1.0E-02
4	Patonga Claystone	avg.50	1.8E-05	1.8E-05	3.8E-06	2.0E-06	1.0E-03
5	Patonga Claystone	avg.50	1.8E-05	1.8E-05	3.8E-06	2.0E-06	1.0E-03
6	Tuggerah Formation	avg.60	3.1E-05	3.1E-05	1.5E-06	2.0E-06	3.0E-03
7	Tuggerah Formation	avg.60	3.1E-05	3.1E-05	1.5E-06	2.0E-06	3.0E-03
8	Tuggerah Formation	avg.60	3.1E-05	3.1E-05	1.5E-06	2.0E-06	3.0E-03
9	Munmorah Conglomerate	avg.60	3.4E-05	3.4E-05	2.3E-06	2.0E-06	2.0E-03
10	Munmorah Conglomerate	avg.60	3.4E-05	3.4E-05	2.3E-06	2.0E-06	2.0E-03
11	Dooralong Shale	avg.35	2.0E-05	2.0E-05	2.7E-06	2.0E-06	2.0E-04
12	WGN seam	5	5.0E-04	5.0E-04	5.0E-04	1.0E-05	1.5E-02
13	deep coal measures	50	1.0E-05	1.0E-05	1.0E-06	2.0E-06	5.0E-03
14	deep coal measures	50	1.0E-05	1.0E-05	1.0E-06	2.0E-06	5.0E-03

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

E4.2 Alluvium hydraulic conductivities

Conductivity values assigned to the alluvial materials distributed throughout the model, differ depending upon location. Alluvium within the Dooralong and Yarramalong valleys has been identified as generally mixed sandy, silty clayey material exhibiting conductivity values ranging from less than 1.0E-03 m/day up to 5.5E+00 m/day. A uniform value of 5.0E+00 m/day (Kxyz) has been adopted for modelling purposes. Coastal sands have been assigned a value of 1.0E+01 m/day

Since the model is fundamentally a forward model based on fairly rigorous estimation of prevailing hydraulic conductivities for hard rock strata, and since those conductivities are extremely low when compared to the alluvial materials, the actual conductivity assigned to shallow alluvial systems is relatively insensitive - the alluvial systems tend to act as water stores.

E4.3 Subsidence zone hydraulic conductivities

Enhanced vertical conductivities representing connected and relatively free draining cracking regimes within the subsidence zone (layers 8 to 12), have been imitated to a conservative height of about 220 m above the WGN seam. This height is more than three times previously reported conditions (Forster, 1995) in the region and is considered to be conservative.

Basically 4 disturbed zones are commonly identified, the first three being included in the model. The fourth (shallow vertical cracking) is relatively small scale and has not been addressed in the model. The zones are illustrated on Figure E6 and characterised as follows:

- ***goaf*****:** a zone within and above the extracted coal seam which is identified as being highly permeable and exhibiting a fragmentation drainable porosity 5% or more, after subsidence. This zone would typically contain remnants of the coal seam, stoney coal and other detached roof strata compressed under the weight of overlying (subsided) strata. Height of the zone depends upon stratigraphy, geomechanical properties of the strata and detached roof material, and the geometry of longwall panels;
- ***highly connected cracking:*** a zone situated above goaf and within the subsidence zone, extending upwards through overburden to a height which is often approximated to be equivalent to panel width and has been reported to be 40 to 63 m in height at other locations in the central coast coalfield (Forster, 1995). This zone exhibits highly connected cracking immediately above goaf and facilitates free drainage of groundwater leading to zero or very low pore pressures. Hydraulic connection is generated predominantly by combinations of bedding shear, tensile failure of bedding, and shear or tensile reactivation of pre-existing fractures or joints. Connectivity of cracks declines with increasing height above goaf and hence drainability and pore pressure losses also decline. Cracking regime permeabilities have been considered using computer generated randomized networks (Long et al., 1982);
- ***disconnected cracking:*** a zone surrounding the highly connected cracking zone that is not free draining – pore pressures are intermediate between zero and hydrostatic. This zone is dominated by bedding shear with infrequent vertical cracking. Strain related changes in groundwater storage may be observed;
- ***shallow surface cracking:*** a zone of typically 10 to 20 metres depth dominated by tensile failure associated with the subsidence process. Surficial cracking may exhibit apertures sometimes exceeding 50 mm but characteristics of cracks depend upon the bedding geometry and strata mechanical properties, and any pre-existing joints. The zone may be disconnected from deeper failure regimes if mining is sufficiently deep. Under these conditions, temporary changes in groundwater movement and storage are associated with subsidence.

E4.3 Storativity parameters

Compressibility and subsequent estimates of storativity (as S_s) have been calculated from laboratory measurements of Youngs Modulus undertaken by SCT Operations Limited (SCT - 1999) and measurements of total porosity (Appendix D). A uniform specific storage estimate of 2.0E-06 has been assigned from a modulus range of 10 to 25 GPa. Average drainable porosities (specific yields) of 0.001% for hard rock strata and 20% for unconfined alluvium, have been adopted.

E5. Model boundary conditions

Boundary conditions assigned to an aquifer model are those conditions that constrain or bound the model domain mathematically. Such conditions have been applied to the physical outer boundary of the model and throughout internal parts of the model. They include river nodes (1st type constrained conditions) along parts of the Wyong River below Yarramalong, general head nodes along the shoreline of Tuggerah Lake, and drain nodes along Jilliby Jilliby Creek and all other creeks, and in coal seam extraction areas including the drift from surface to the underground operations. Utilisation of river conditions along parts of the Wyong River enforces seepage from surrounding areas of elevated water table to these cells, or seepage from these cells to surrounding strata if the piezometric elevations in those strata are lower than the boundary constraining levels.

Distributed elemental flux conditions have been employed to represent regional rainfall recharge. This recharge has been applied at a constant rate of 0.15 mm/annum over hard rock areas. The rate has been determined from a number of steady state simulation trials where recharge was progressively increased until model water levels broadly matched a very limited number of groundwater elevations at borehole locations, or more generally reflected a reasonable estimate of the regional piezometric surface in elevated terrain.

Recharge at a conservative rate of 90 mm/annum has been applied over coastal sands while a reduced and probably highly conservative rate of 50 mm/annum has been applied to valley fill alluvial materials in the Dooralong and Yarramalong valleys where lower conductivity silty facies prevail (see Table D5 and Table E2). Recharge to hard rock strata is very low (0.15 mm/annum) owing to the low conductivity of the strata. In reality, there will be numerous active very shallow higher conductivity weathered rock systems that may be perched in the more elevated parts of the area. These systems will tend to be governed by jointing, facilitating higher rainfall recharge that probably supports localised seeps after rainfall. They are poorly mapped and are assumed to be isolated from the deeper hard rock systems. They have not been included in the numerical modelling effort after a number of preliminary model trials indicated negligible impacts on shallow groundwater systems.

Groundwater abstraction by local landholders for domestic, stock and irrigation purposes, has not been included. Since the alluvial lands are in a sense isolated from the coal measures by much more significant recharge to a relatively high hydraulic conductivity alluvial regime, absence of pumpage in the model is unlikely to affect model outcomes in terms of seepage attraction by the deep longwall panels. Impact of strata depressurisation on the alluvial aquifers has however been assessed by quantifying the model predicted vertical leakage from the alluvium to underlying hard rock strata using zone budgeting within the model.

E6. Model calibration – steady state

It is not possible to calibrate the aquifer model to a high level of accuracy without a significant hydraulic stress in the system and without a comprehensive monitoring system. Accuracy in model representation is therefore dependent upon the assignment of formation hydraulic properties as determined by packer and core tests, and upon the steady state or initial piezometric surface.

Approximate calibration of the prevailing shallow piezometric surface has been conducted by adjusting rainfall recharge to the system and comparing the resulting head distribution to measured or estimated piezometric elevations in the area at a number of 'control' bores identified on Figure E7. Measured elevations are available at existing monitoring wells while estimated elevations have also been generated at a number of sites from inspection of geophysical wireline logs noting that these are open hole conditions.

Figure E7 provides a plot of the model generated piezometric surface for the shallow alluvium/rock zone (layer 1). Figure E7 also provides a correlation plot for these piezometers. A measure of the correlation can be described by the normalised root mean square (NRMS) error which is calculated to be 7.4% for the control points. The error is considered acceptable for a model of this regional scale and depth. The error could be reduced further by applying localised variability to rainfall recharge but this would in effect represent a forcing of the model in the uppermost layer 1 without knowledge of local scale hydraulic conductivities or recharge. It is also possible to increase both the hydraulic conductivities and the applied rainfall recharge rates in layer 1 and achieve a similar calibration.

Groundwater flow pathways are likely to be generally orthogonal to the piezometric contours shown on Figure E7. These pathways flow from elevated areas of hard rock strata (Terrigal Formation), towards the major drainages. Velocities of flow are however exceptionally low for the hard rock strata being of the order of 1.0E-07 to 1.0E-04 m/day while within the alluvium velocities range from 1.0E-04 to 1.0E-02 m/day.

E7. Simulation of mining

Model simulations commence in January 2012 and progress to January 2050 representing 38 years of mining (10 years more than the 28 years approval period). Simulations over the first 2-3 years include construction of the access drift, development headings and gate roads for the first two panels (LWN01 and LWN02). Modelling has then proceeded by simultaneously advancing headings and gate roads ahead of mining while commencing panel extraction according to the planned extraction schedule indicated by panel numbering on Figure E8.

E7.1. Strata depressurisation and alluvial system leakage

Figure E9 illustrates the initial steady state groundwater piezometric head distributions generated by the model prior to commencement of any mining operations in the area. These distributions are reported for selected model layers that generally dip to the south-west (see Figure E1b for the geometry of model layers).

The geometry exhibited by the head distributions at different horizons within the model varies from layer to layer but detail reduces with depth as the effects of surface topography on the groundwater flow regime, are dissipated. The shallowest horizon is the water table which exhibits a subdued reflection of topography with piezometric ‘highs’ occurring in areas associated with topographic highs. Piezometric ‘lows’ prevail along the Wyong River and along Jilliby Jilliby Creek as expected. Hence groundwater is induced to flow from the areas of high piezometric heads, to areas of low piezometric heads.

Figure E10 illustrates the drawdown in piezometric surfaces generated by the model after 7 years of development and mining Drawdowns have been calculated by subtraction of the mining affected piezometric heads at 7 years from pre-mining heads shown on Figure E9. Reference to Figure E10 shows no drawdown in the water table (layer 1) while drawdown in slices 3 and 5 would be restricted to the Tooheys Rd. mine entry (portal) area. In contrast, layer 10 in the lower part of Tuggerah Fm. exhibits complete dewatering above extracted panels as a result of free drainage of strata within the subsidence zone that has evolved. The influence of drainage to the drift is also evident. Layer 12 in the WGN seam exhibits maximum drawdown in the model – zero pore pressures prevail in goaf and in development areas in advance of panel extraction. At this (seam) level, the pressure losses extend about 1 km beyond the first extracted panel LWN01.

Figure E11 illustrates the drawdown in piezometric surfaces generated by the model after 14 years of mining Reference to this plot shows no drawdown in the water table (slice 1) while drawdown effects in layers 3 and 5 remain similar to those observed at 7 years. Layer 8 exhibits expanded dewatering associated with extracted panels in the southern area. Further influence of drainage to the drift is also evident. Layer 10 in the lower part of the Munmorah Conglomerate also exhibits complete dewatering within the panel extraction area plus a zone of depressurisation associated with development, extending a few panels further west than layer 8 (southern panels). Retarded depressurisation above pillars is also evident. Zero pore pressures prevail in goaf and in development areas of layer 12. At seam level, the pressure losses (drawdowns) extend about 1 km beyond extracted panels.

Figures E12, E13 and E14 illustrate changes in the formation pressures at 21, 28 and 38 years of mining respectively. Advancement of the pressure loss wave, and dewatering within the subsidence zone are consistent with the processes observed at 7 and 14 years. At 38 years, zero pore pressure (maximum drawdown) prevails within the WGN seam over the entire mine plan area. Zero pore pressures are also predicted to extend to the lower part the Tuggerah Fm as a result of gravity drainage within the subsidence failure regime. Some loss of formation head/pressure is indicated in the lower part of the Patonga Claystone (layer 5) where +10 m is noted above extracted southern panels. Remnant effects of this pressure loss regime are also evident near the base of the Terrigal Formation (layer 3) where up to 2 m head loss is noted. Regional depressurisation of deeper strata at 38 years extends approximately 2 km beyond the first extracted panels in the vicinity of the drift while losses extend about 500m from last extracted panels.

Figures E15a and E15b provide vertical sections through the model illustrating pore pressure distributions at the end of mining (Section locations shown on Figure E2). Both show complete depressurisation and dewatering from the WGN seam up to the lower part of the Tuggerah Fm. some 220 m above seam. Pore pressure are reduced but sustained in the remaining 150 to +300 m zone to surface. Figure E15a also shows the retardation in drainage in the western and more recently extracted panels with residual saturation clearly evident above pillars but slowly receding upwards; saturation above eastern pillars has virtually dissipated. Figure E15b is orthogonal to Figure E15a and does not intercept pillars. However pore pressures are evidently sustained above the main headings which separate northern and southern panels.

While pressure losses are noted in deeper hard rock strata, negligible losses are evident in the shallow water table within the alluvial aquifer and connected systems. The reasons for this are the retardation of losses within the Patonga Claystone, and the higher storage capacities and higher hydraulic conductivities prevailing within the shallow aquifer system – storage is able to accommodate any downwards leakage to deeper hard rock strata without measurable impacts on water levels. Leakage from alluvial sources has been assessed within the model in terms of loss of baseflow from the alluvial and hardrock aquifer systems to the local creek catchments. Figure E16 illustrates graphed baseflow zone budgets over the mine life while the following Table E3 provides a summary. The calculated losses are noted to be negligible, especially when considered on a unit area basis with respect to the alluvial lands associated with each catchment. Constant (unimpacted) conditions are evident outside the mine footprint at distances of about 1 km or more. The flux changes induced as a result of mining are extremely low, being generally less than 0.002 L/day/sq.m. or 2 ml/day/sq.m. This flux is equivalent to about one third a teaspoon of water distributed over one square metre per day.

Table E3: Summary of impacts on baseflows to local catchments

Catchment	Pre-mining ML/day	Post mining ML/day	Reduction ML/day	Alluv. Area. sq.km	Unit Area Leak. mL/sq.m./day
Hue Hue Ck	0.107	0.106	0.001	0.635	1.57
J.J. Ck above Little J.J. Ck	0.750	0.743	0.007	4.356	1.61
Little J.J. Ck	0.124	0.123	0.001	2.063	0.48
J.J. Ck below Little J.J. Ck	0.724	0.720	0.004	2.121	1.89
Wyong River tributaries	0.124	0.124	0.000	na	0

J.J. = Jilliby Jilliby, mL = millilitre, na=no alluvium

On completion of the 38 years simulation period, specific model zone budgets were also extracted in order to provide estimates of mine water influx. Results are given on Figure E16 as the calculated day rate. Also indicated on Figure 18 is the estimated minimum rate based on an analysis of mass balances generated by the modelling scheme. The calculated day rate is observed to rise over the first 18 years to a maximum influx of about 2.5 ML/day. The predicted cumulative seepage over the mine life is 26500 ML.

The mine seepage rate assumes no contributions from localised fracture related storage since the extent and hydraulic properties of this type of storage remain unknown. However it would not be unreasonable to expect up to 0.5 ML/day increase in mine water seepage over short periods of days to weeks if significant and as yet unidentified fracture network storage is encountered and drained.

E7.2 Recovery of aquifer pressures post mining

Mining is expected to cease after 38 years of longwall extraction. After this time regional aquifer pressures will begin to rebound. The rate of rebound will be dependent upon the remaining water held in storage within the hard rock strata, the hydraulic properties of goaf, and the sustained gravity drainage of strata above extracted panels.

Recovery of strata pressures has been simulated by adopting pressure distributions at 38 years of mining, as initial conditions for a recovery model. Goaf storage has been enhanced to an average 15%. Figure E17 shows drawdown the predicted distribution 200 years – seam depressurisation during the recovery process is predicted to extend more than 4 km beyond the mine footprint. In addition, dewatering of exposed Terrigal Formation strata of up to 10 m is evident in more elevated parts of area. In reality this may not occur as local recharge to the shallow weathered rock zone most likely acts as water store to surcharge deeper strata. This very shallow zone is not included in the model.

E7.3 Sensitivity analyses

Sensitivity analyses are normally conducted to establish parameter sensitivity where calibration is undertaken against prevailing stressors within a system. That is, specific parameters like hydraulic conductivity or storativity are adjusted and the influence of those adjustments on the calibration, is measured by comparing the NRMS error described in Section E6, for different scenarios. Significant change in this measure is normally associated with highest sensitivity parameters.

In the current situation where no mining has been conducted and hence no significant stressors prevail within the deep aquifer systems, sensitivity analysis applied to the calibrated model which is based upon sparse field measurements of groundwater levels, has only limited value. However it is important to identify the parameters which are likely to most affect the prediction of depressurisation that would result from longwall mining.

In general:

- the regional extent of model depressurisation will be more sensitive to hydraulic conductivity (Kxyz) than any other parameter. The second ranked parameter will be compressible storage (Ss);
- model depressurisation vertically through strata will exhibit highest sensitivity to the vertical conductance (Kz) and the subsidence failure regime (free draining connected cracking);
- Rainfall recharge is relatively insensitive to layers beneath layer 1 mainly because layer 1 incorporates the rainfall driven circuits that provide the water store for recharging deeper strata. Reducing or increasing the rainfall over a sensible range, does not significantly affect deep strata depressurisation within the mining time frame.

E8. Constraints to regional finite element modelling

It is not possible to completely represent aquifer systems using numerical modelling methods due to the many complexities associated with natural processes, the discrete sampling of rock material properties that govern groundwater flow, and the limitations imposed by numerical modelling methods. A simplified representation of the aquifer systems is therefore required. While this has been undertaken in a measured and structured way in the current study, it is always possible that unidentified features of a system may affect predictions either more favourably or more adversely, at some future time. For this reason, the numerical modelling effort has been designed to account for conditions that are considered to be either representative or conservative where doubt exists. Never the less the following constraints are considered to be noteworthy:

1. Adopted model conductivities for hard rock strata are very low and reflect core and packer testing results with the assumption that conductivities are matrix dominated rather than fracture dominated. This is consistent with observations of drillhole core where fractured zones are observed to be infrequent. While such zones (where identified) are considered to be locally transmissive, they are expected to offer limited storage and transmission capacity. These zones have not been included in the model

due to their relatively small scale. Instead, a provision of 0.5 ML/day short term increase in the mine water seepage is suggested.

2. Boundary conditions applied to the model drainage network are 1st type fixed head (mostly constrained to simulate drain type boundaries). Assigned heads are derived from a 25m grid digital terrain model. Where drainages are incised and the drainage axis does not coincide with the digital terrain grid, the topographic data commonly fails to reflect stream bed elevations and hence assigned heads can be in error by as much as 5 m or more depending upon the terrain and the interpolating algorithm. These heads ultimately govern the 'calibrated' steady state water table which may not agree with field measured conditions. Since the error cannot be determined at each location, it is retained within the modelling process. However the consequences are considered to be minor or negligible since depressurisation associated with mining, will mostly affect the deep hard rock strata.

3. The failure regime associated with panel extraction assumes connective vertical cracking to about 200 m above seam (SCT, 1998). This zone is predicted to narrow above each panel from maximum width at the seam to about 10% to 20% of panel width at a height of 200 m (see Figure E6). Model discretisation does not lend itself to simulation of a narrowing zone. A simplified and conservative approach has therefore been adopted that assumes connected and relatively free draining cracking over full panel width to about 220 m height above seam. As a result, simulated depressurisation of overburden strata is likely to be more widespread than would ultimately be observed under field conditions.

4. Hydraulic conductivities are known to reduce with increasing effective stress which will result from strata depressurisation. Reductions in conductivity have not been included in the model due limitations of the model code. The model predicted extent of depressurisation at a given time may therefore be greater in some areas, than would be measured under field conditions.

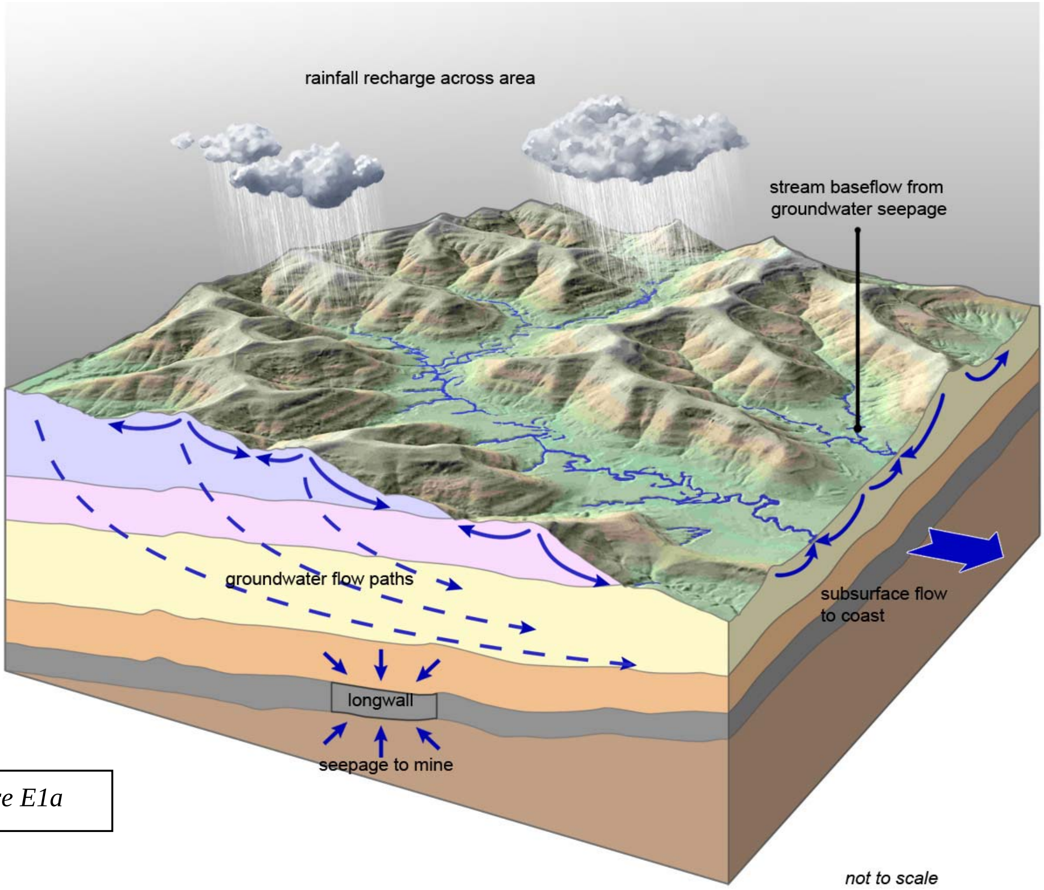


Figure E1a

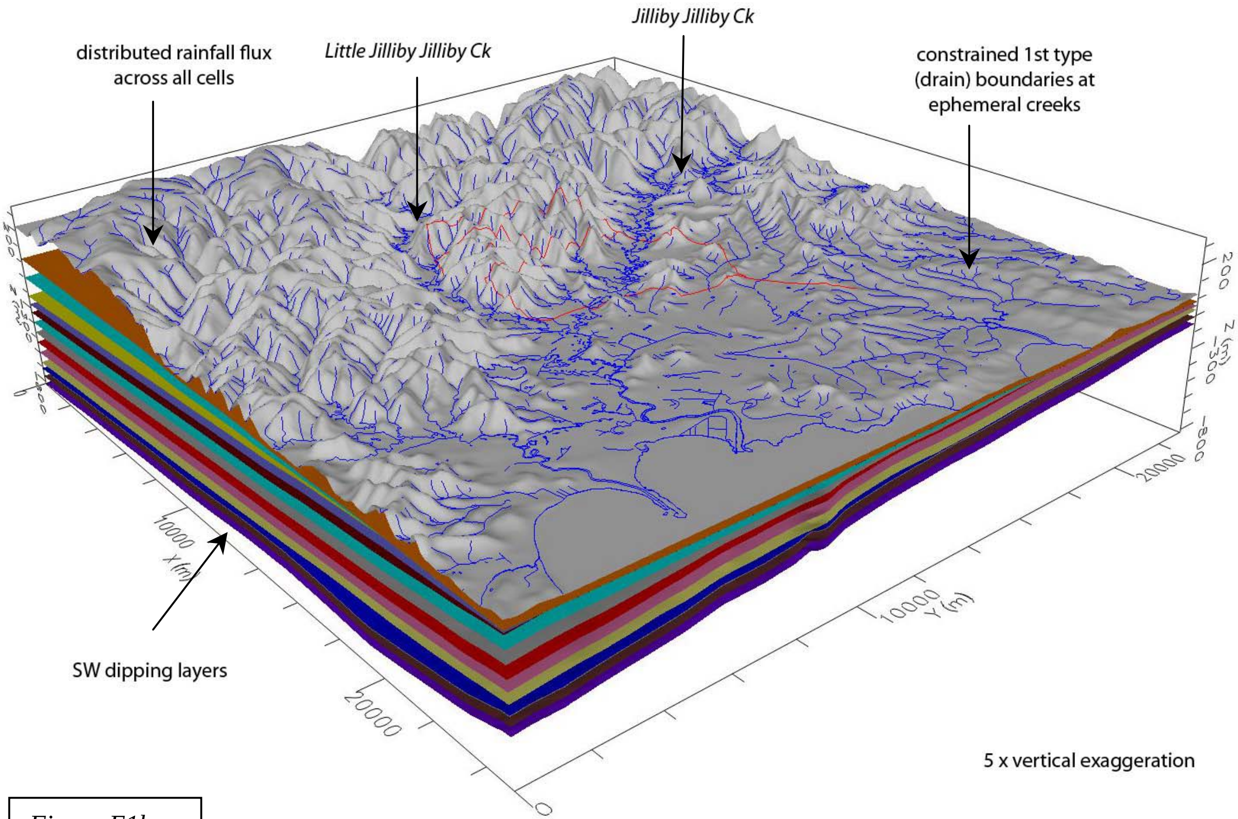
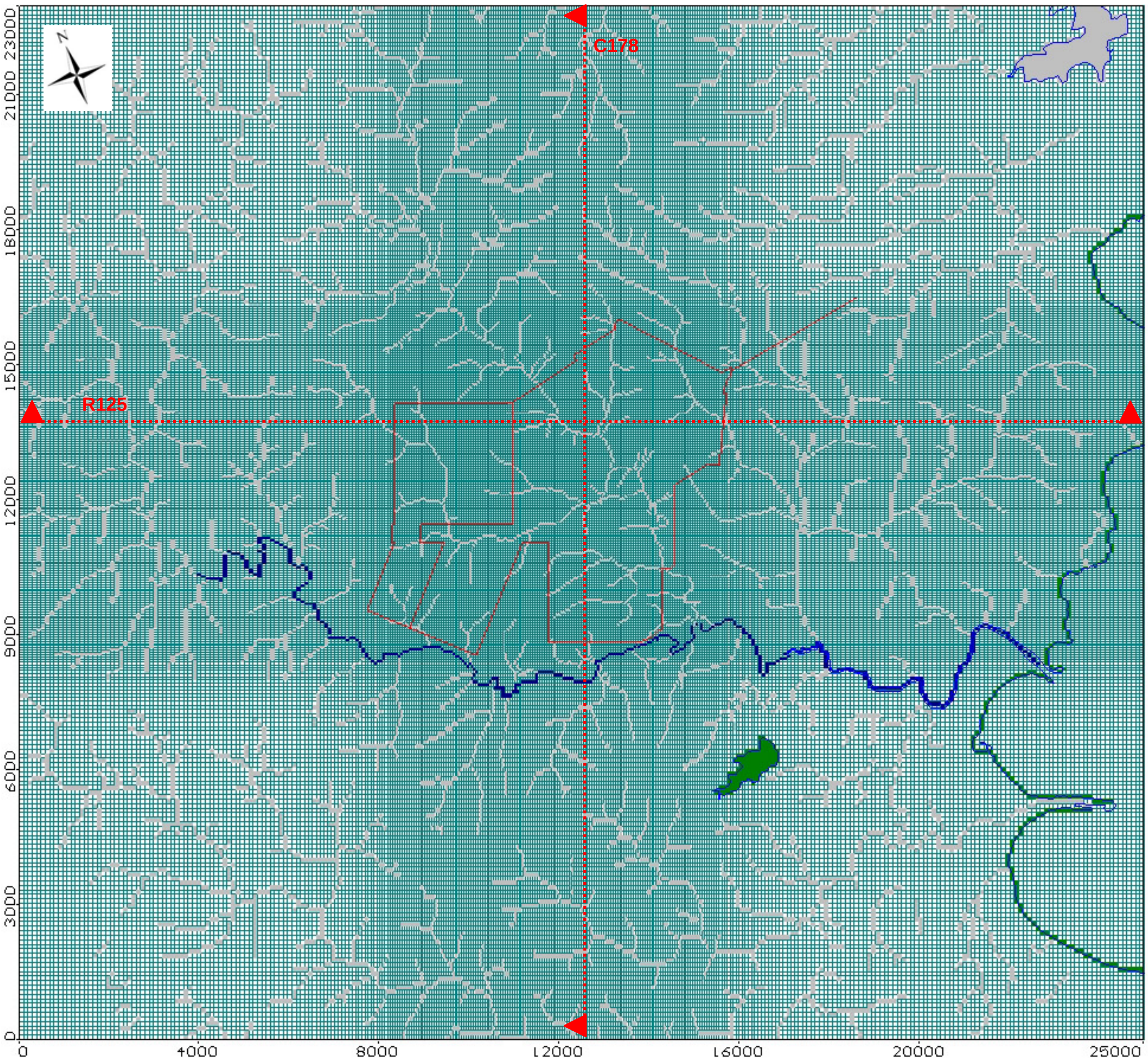


Figure E1b

Conceptualisation of flow system and model realisation

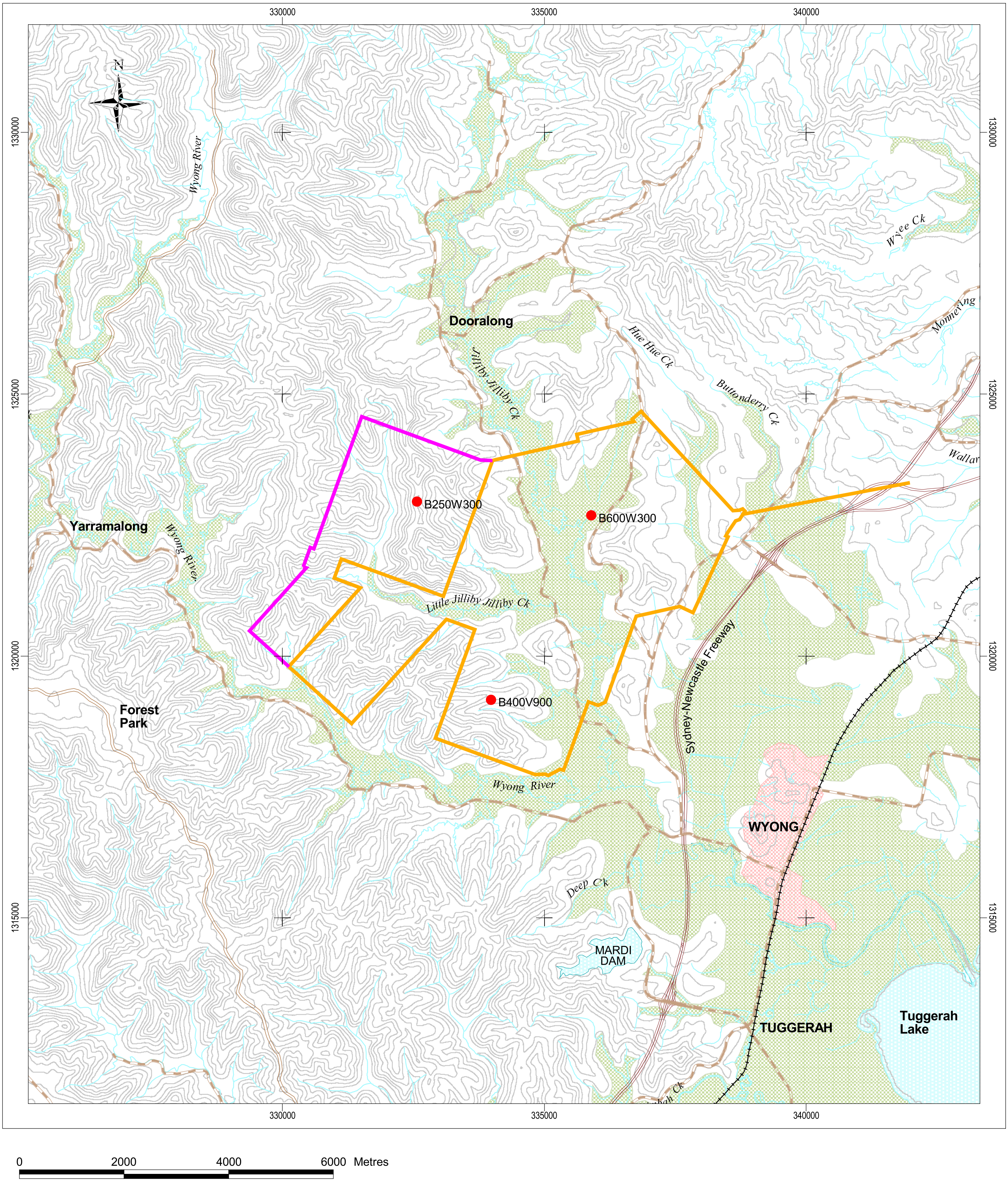
Figure E1



1. Model mesh is rotated –20° from true north: model co-ordinate system shown
2. Creeks are defined by 'drain' type boundary condition (grey)
3. River is defined by 'river' type boundary condition (blue)
4. Coastline is defined by 'general head' boundary condition (green)

Model mesh and drainage lines

Figure E2



Scale 1:100,000

creeks		urban area	
minor road		alluvium	
sealed road		type bore (hydraulic conductivity)	
Freeway		28 years mine footprint	
railway		38 years mine footprint	

WALLARAH 2 COAL PROJECT

Hydraulic conductivity 'type' bore locations

Figure E3

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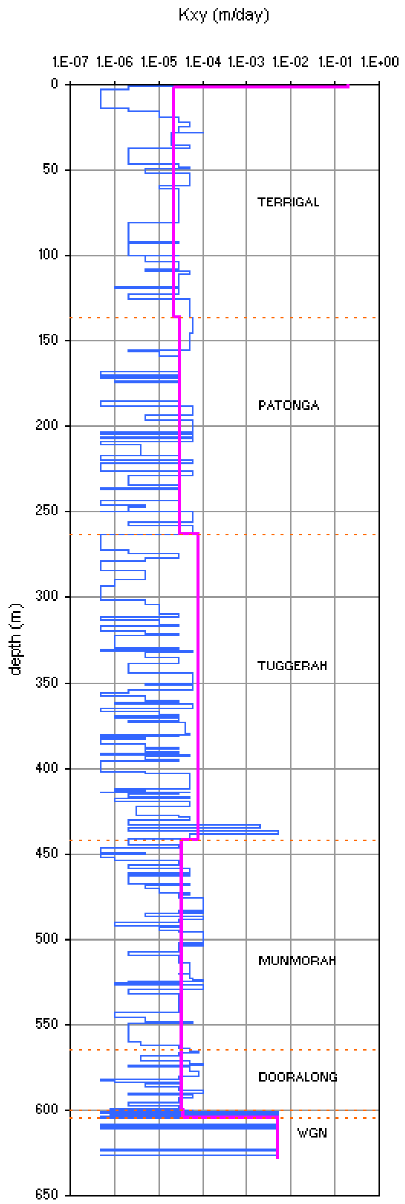
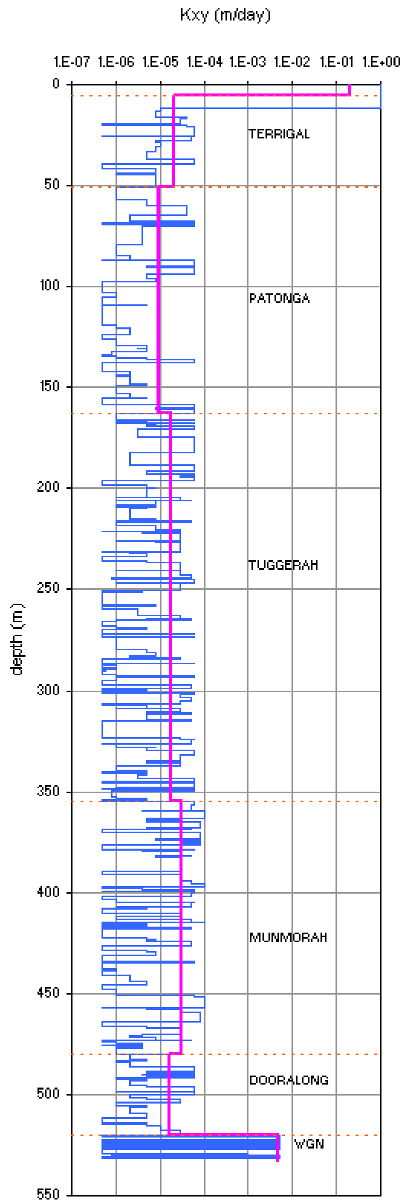
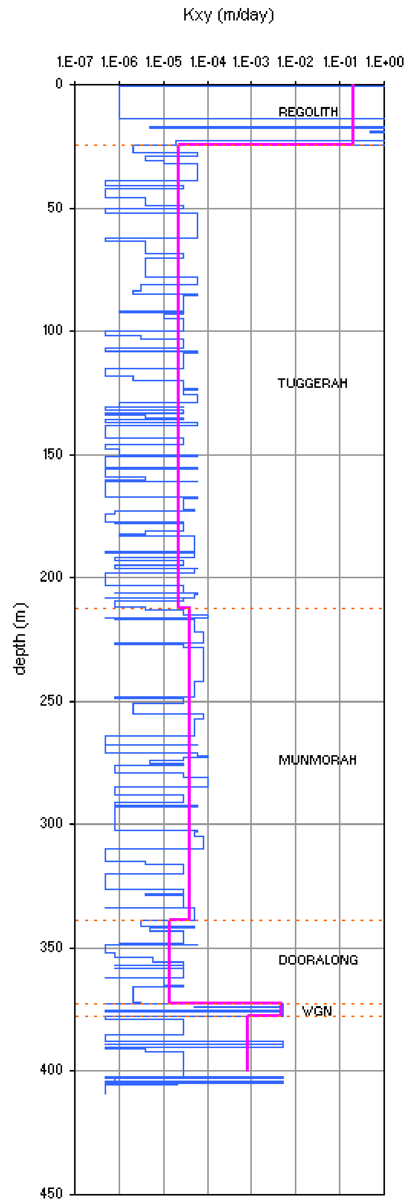


B250W300



B400V900

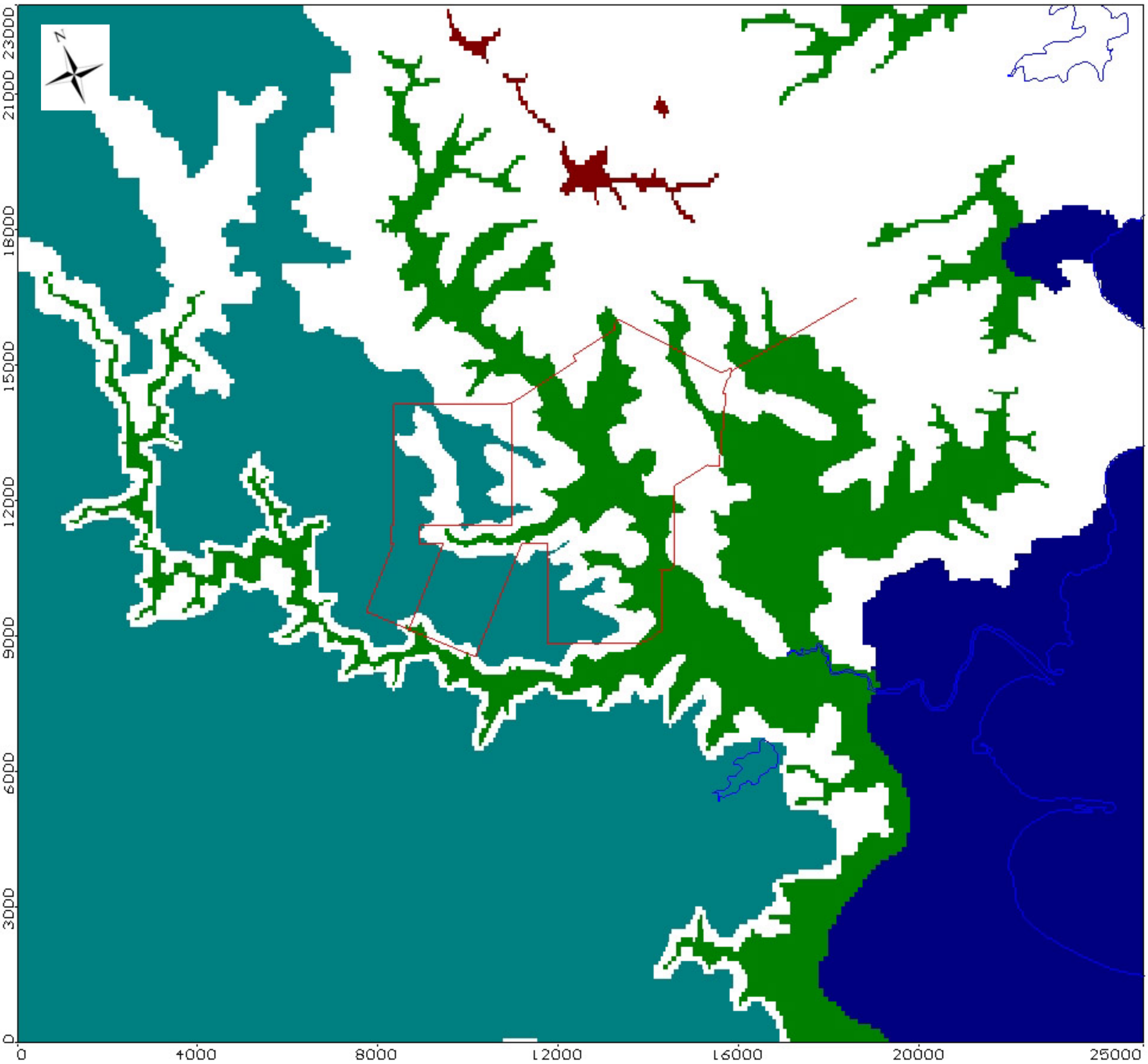


B600W300

Mackie Environmental Research

Interpreted hydraulic conductivity profiles at type bores

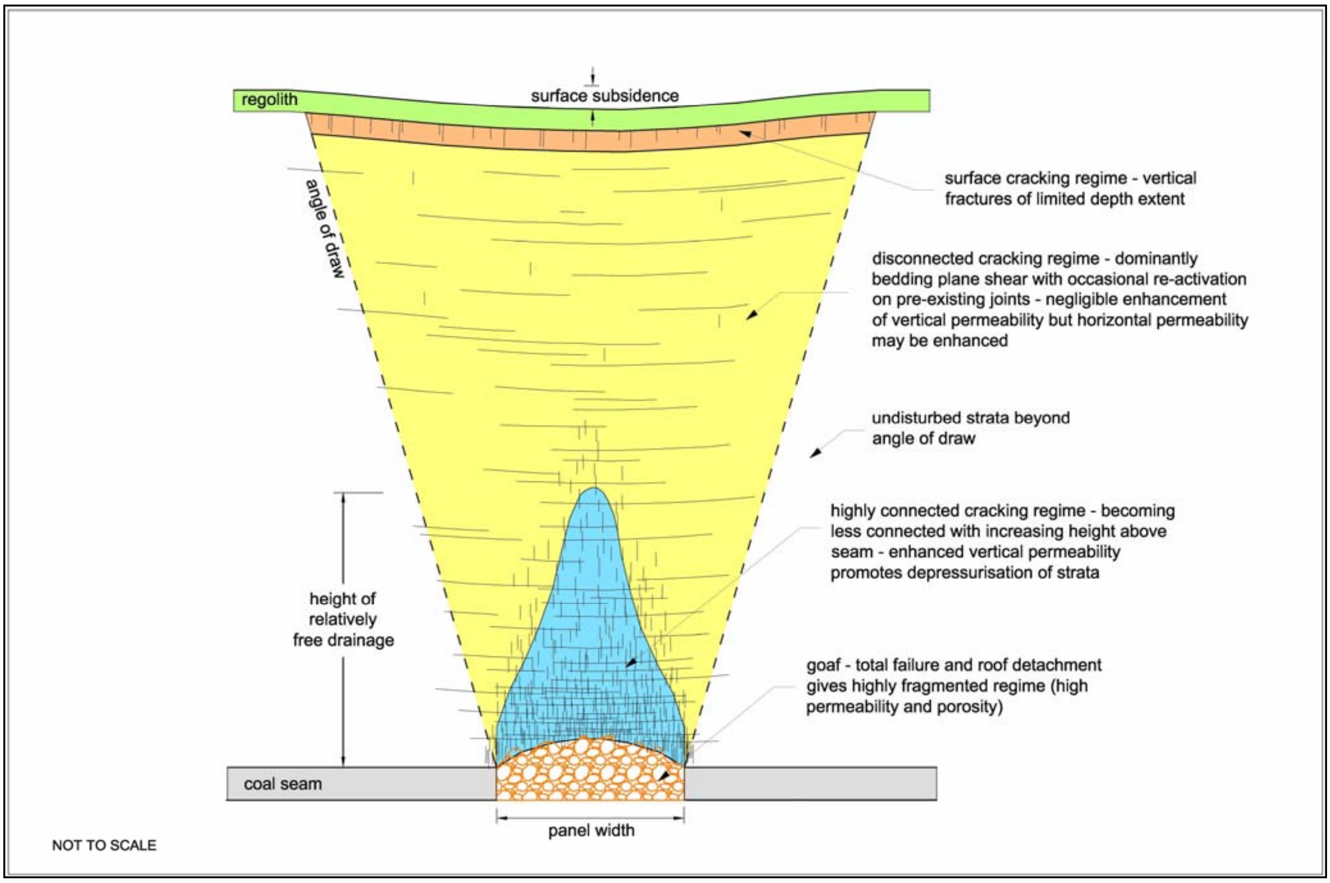
Figure E4



Z		mm/year
1		0.15
2		90
3		50
4		5.5
5		8

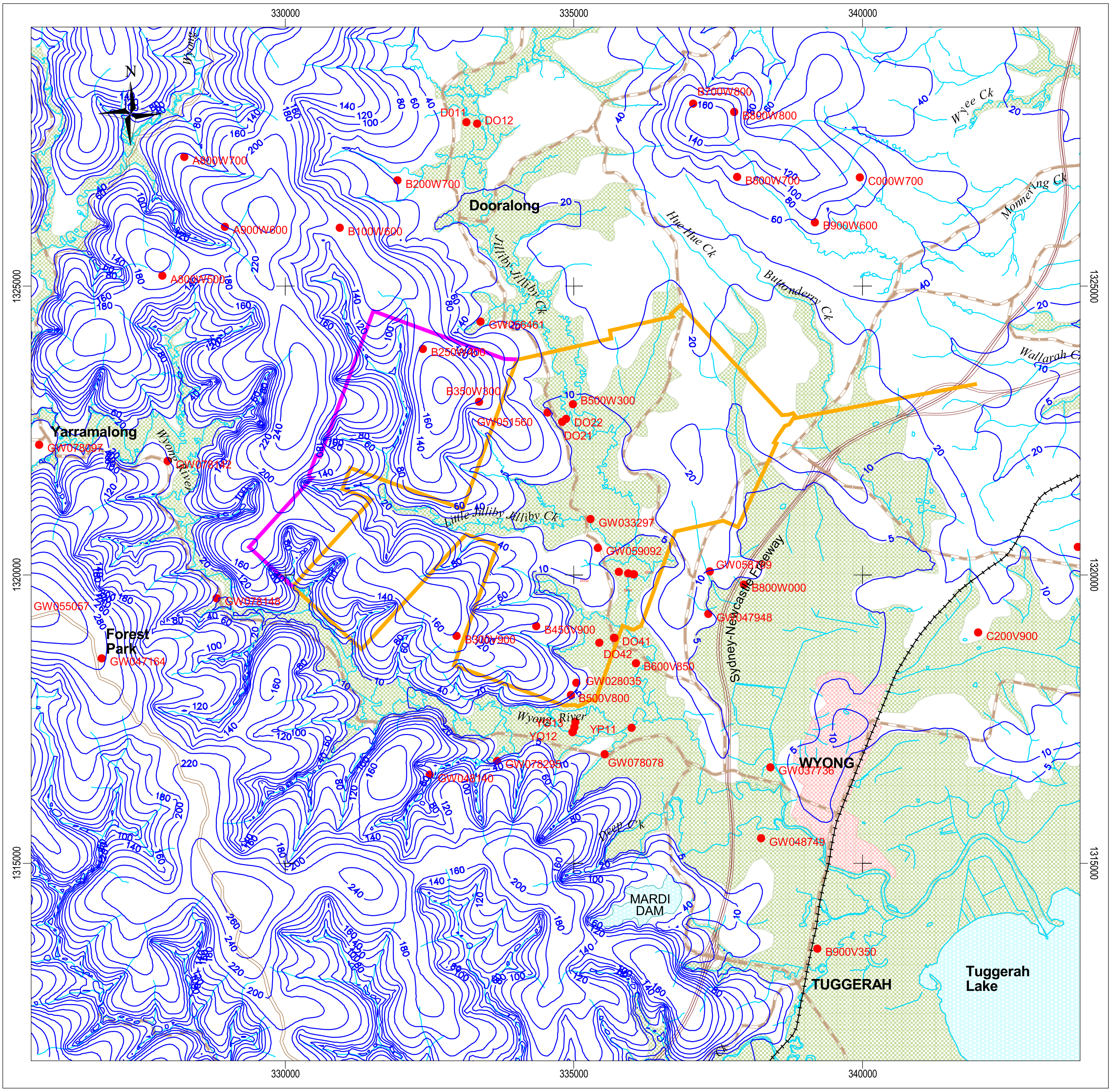
Rainfall recharge distribution in model

Figure E5



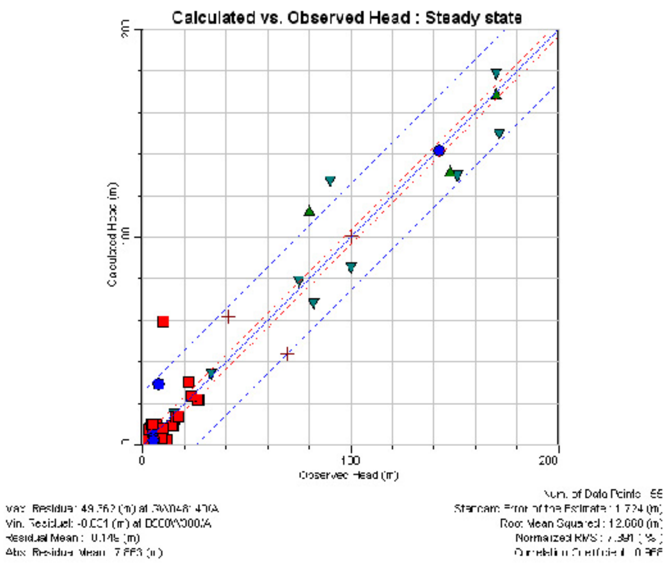
Conceptualisation of subsidence impacts on groundwater flows

Figure E6



0 2000 4000 6000 Meters

Scale 1:100,000



creeks	urban area
minor road	alluvium
sealed road	regional water table (mAHD)
Freeway	28 years mine footprint
railway	38 years mine footprint
	calibration control bore

WALLARAH 2 COAL PROJECT

Regionally interpolated shallow water table

Figure E7

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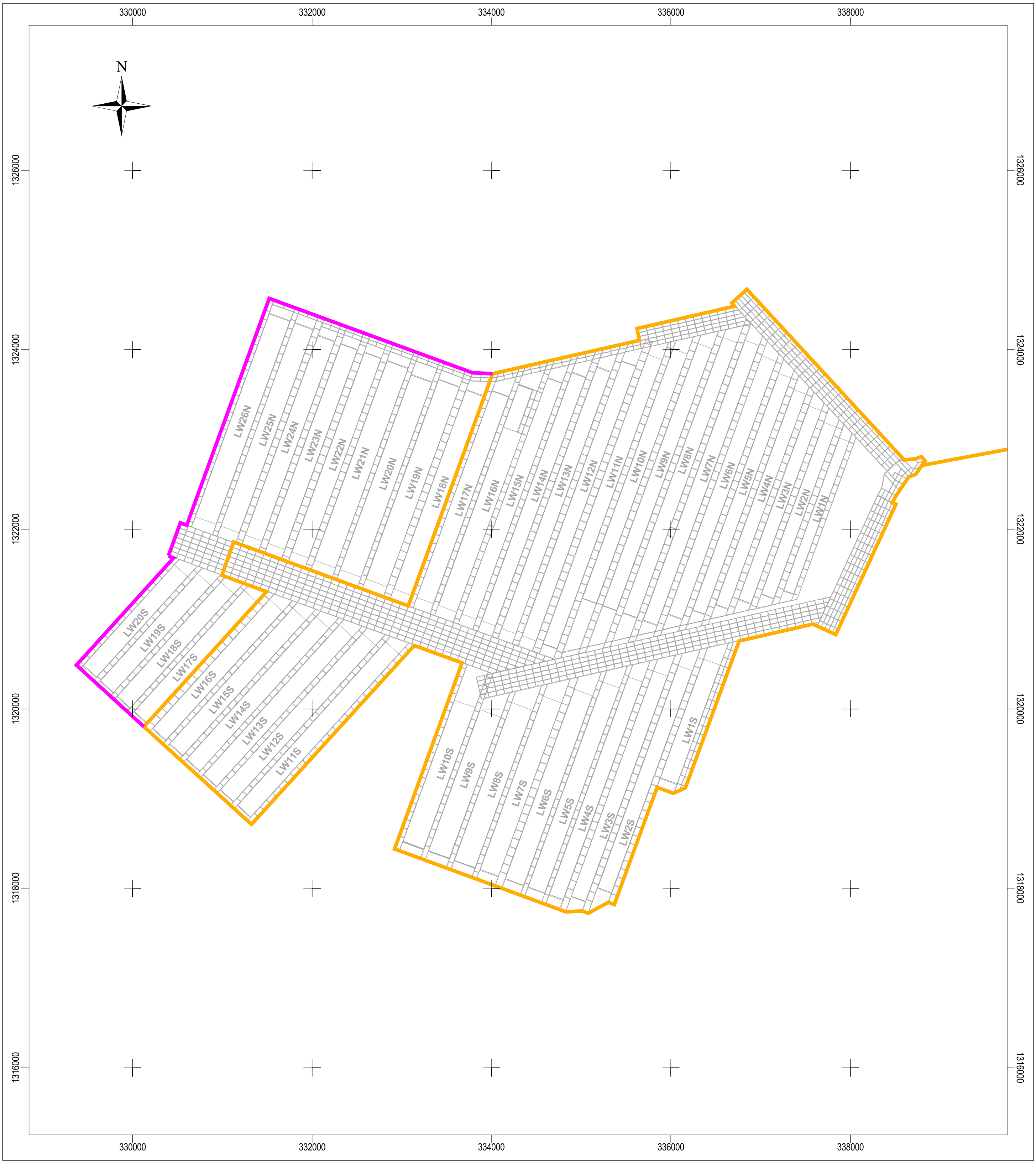

0 1000 2000 3000 Metres

Scale 1:60,000

28 years mine footprint

38 years mine footprint

WALLARAH 2 COAL PROJECT

Panel identification-progression

Figure E8

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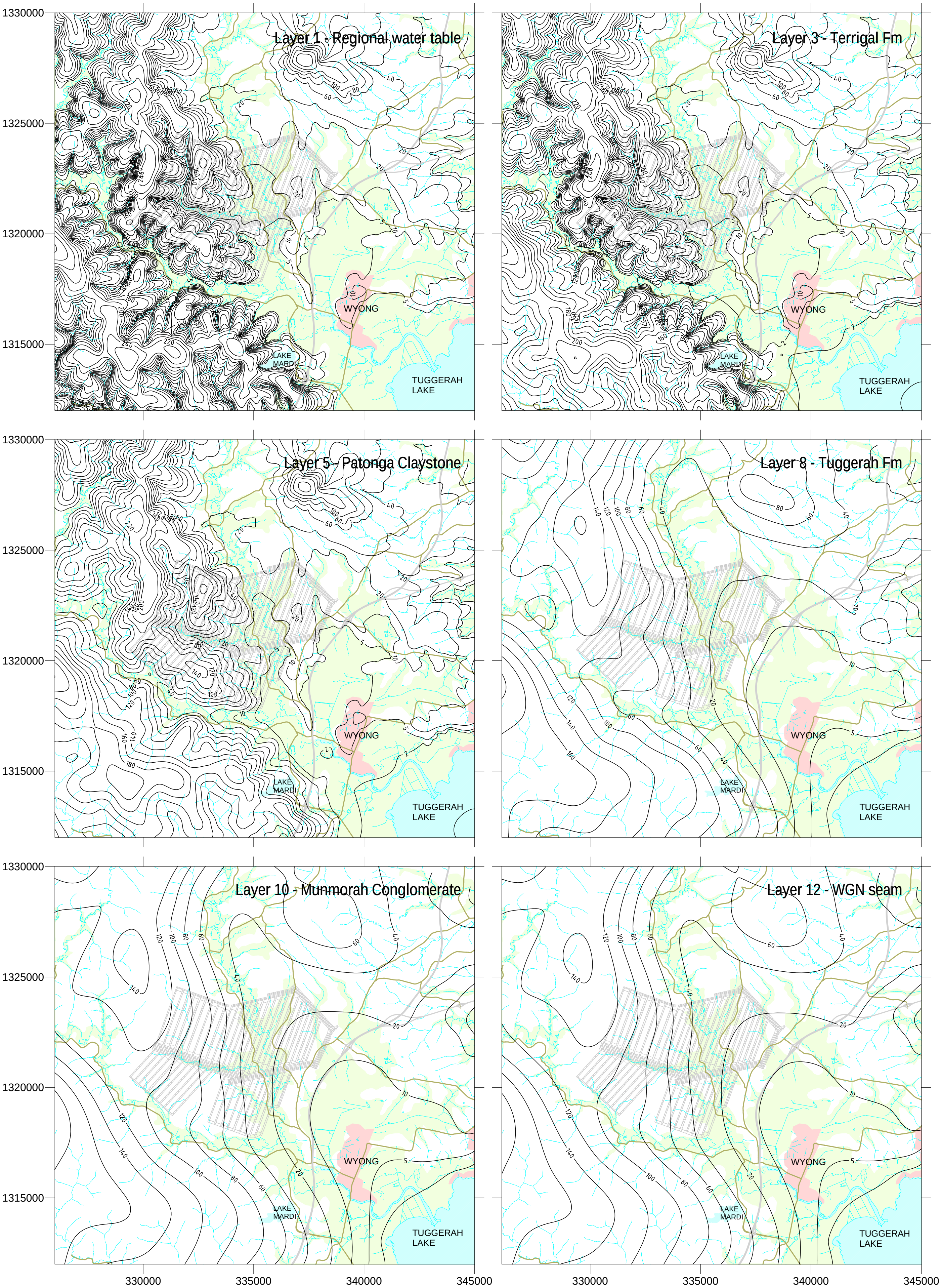
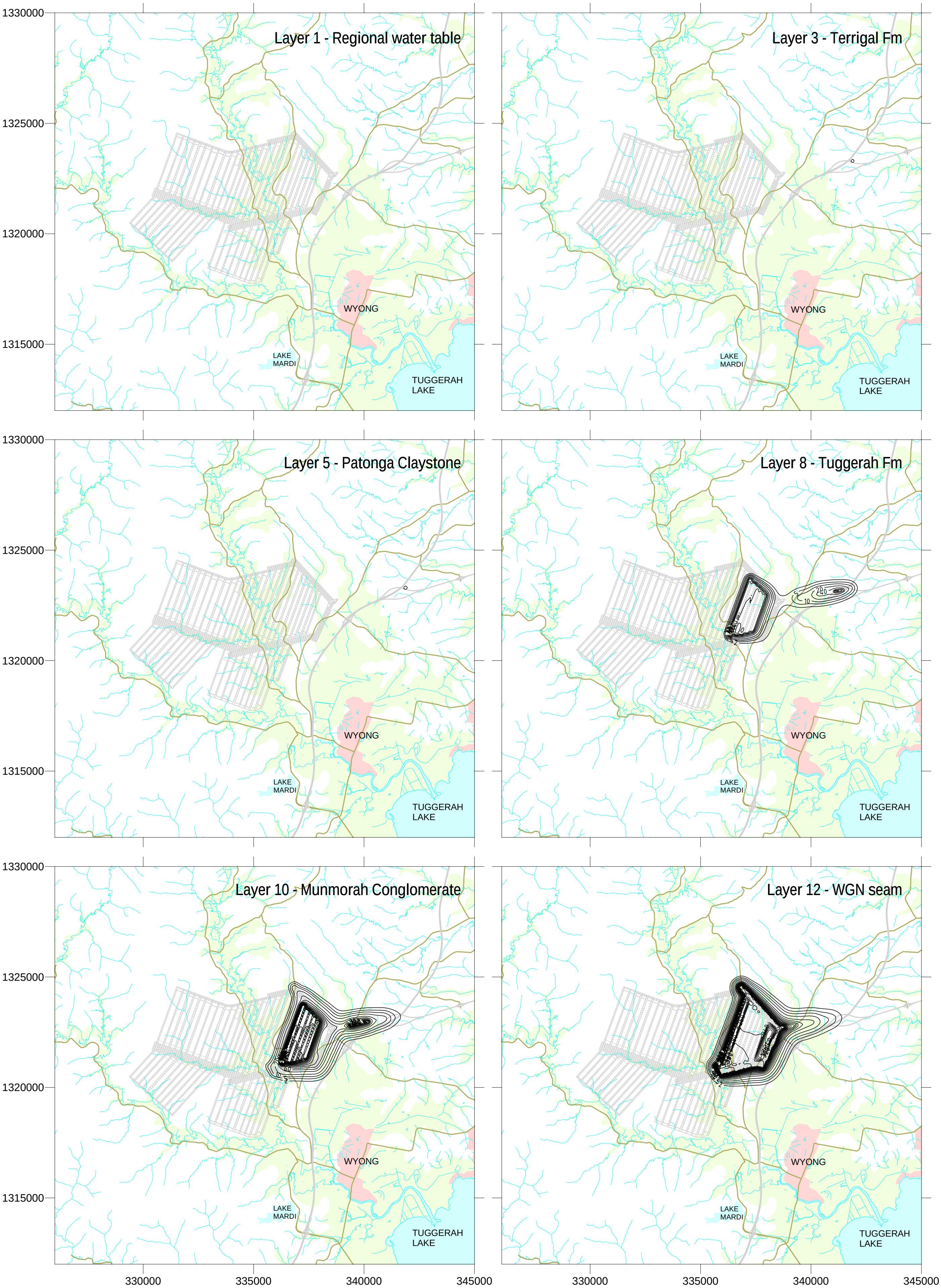


Piezometric contours in metres AHD

Model generated pre-mining piezometric surfaces - Year 0

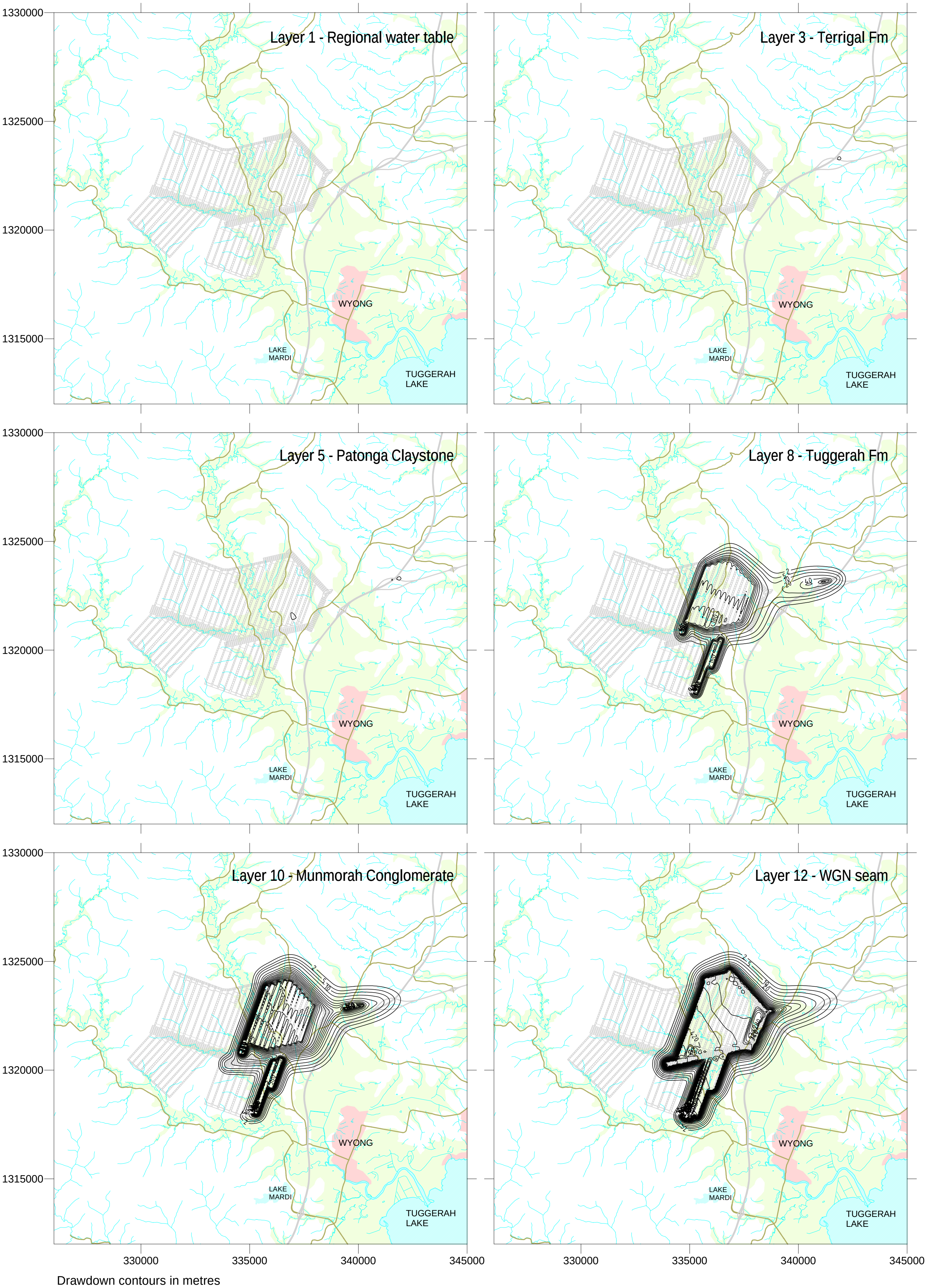
Figure E9



Drawdown contours in metres

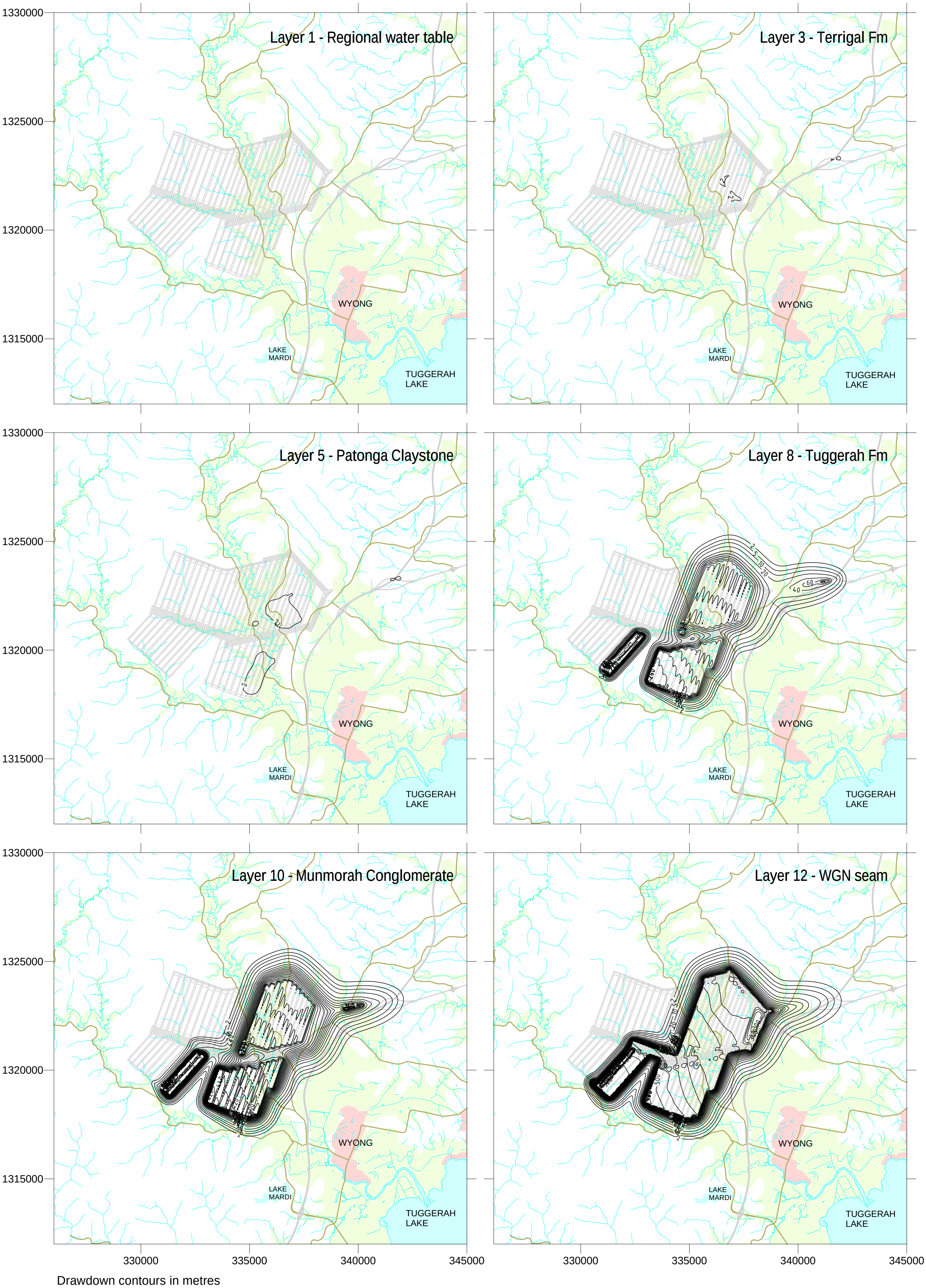
Model W1: Piezometric drawdown during panel extraction - Year 7

Figure E10



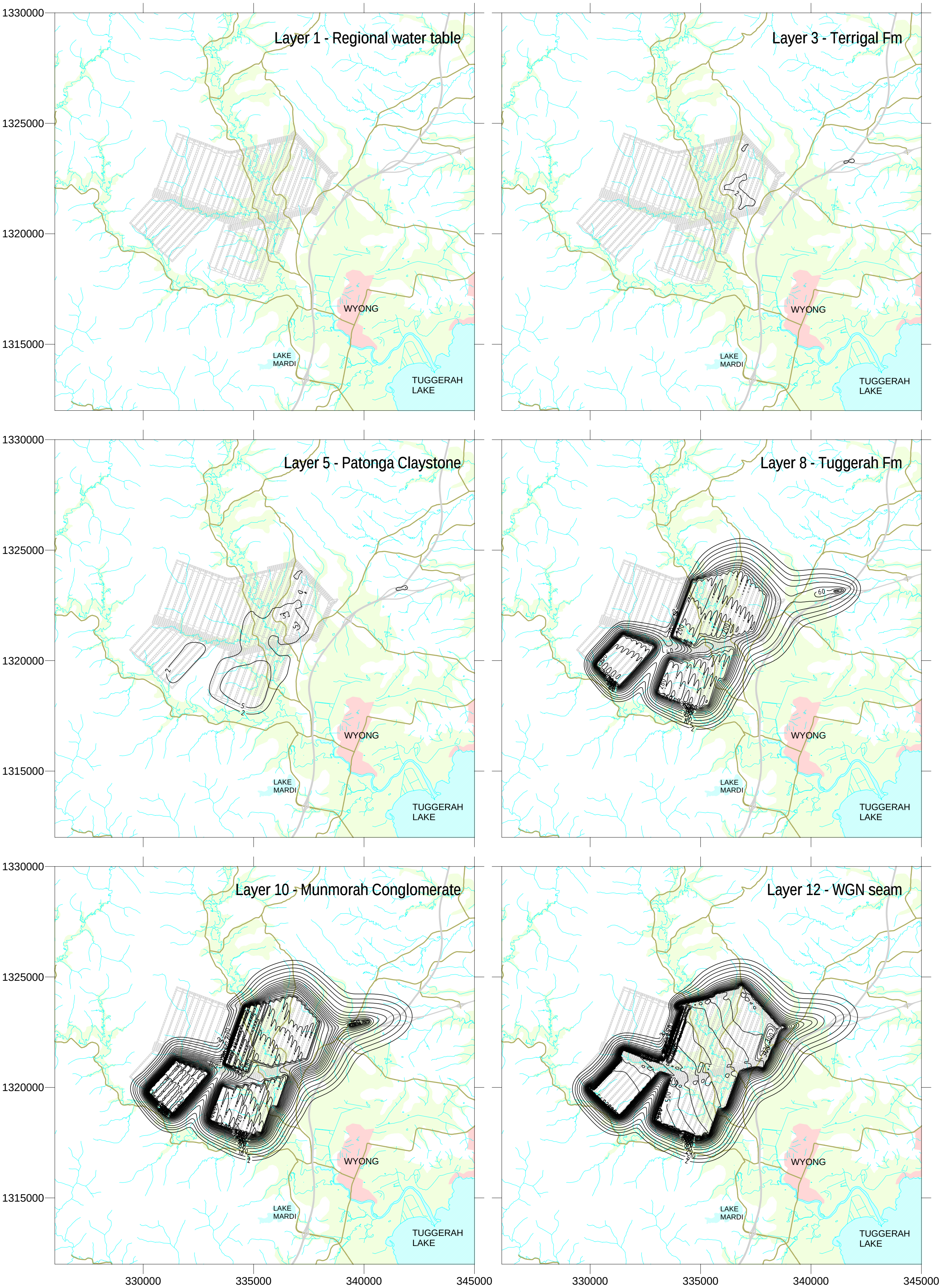
Model W1: Piezometric drawdown during panel extraction - Year 14

Figure E11



Model W1: Piezometric drawdown during panel extraction - Year 21

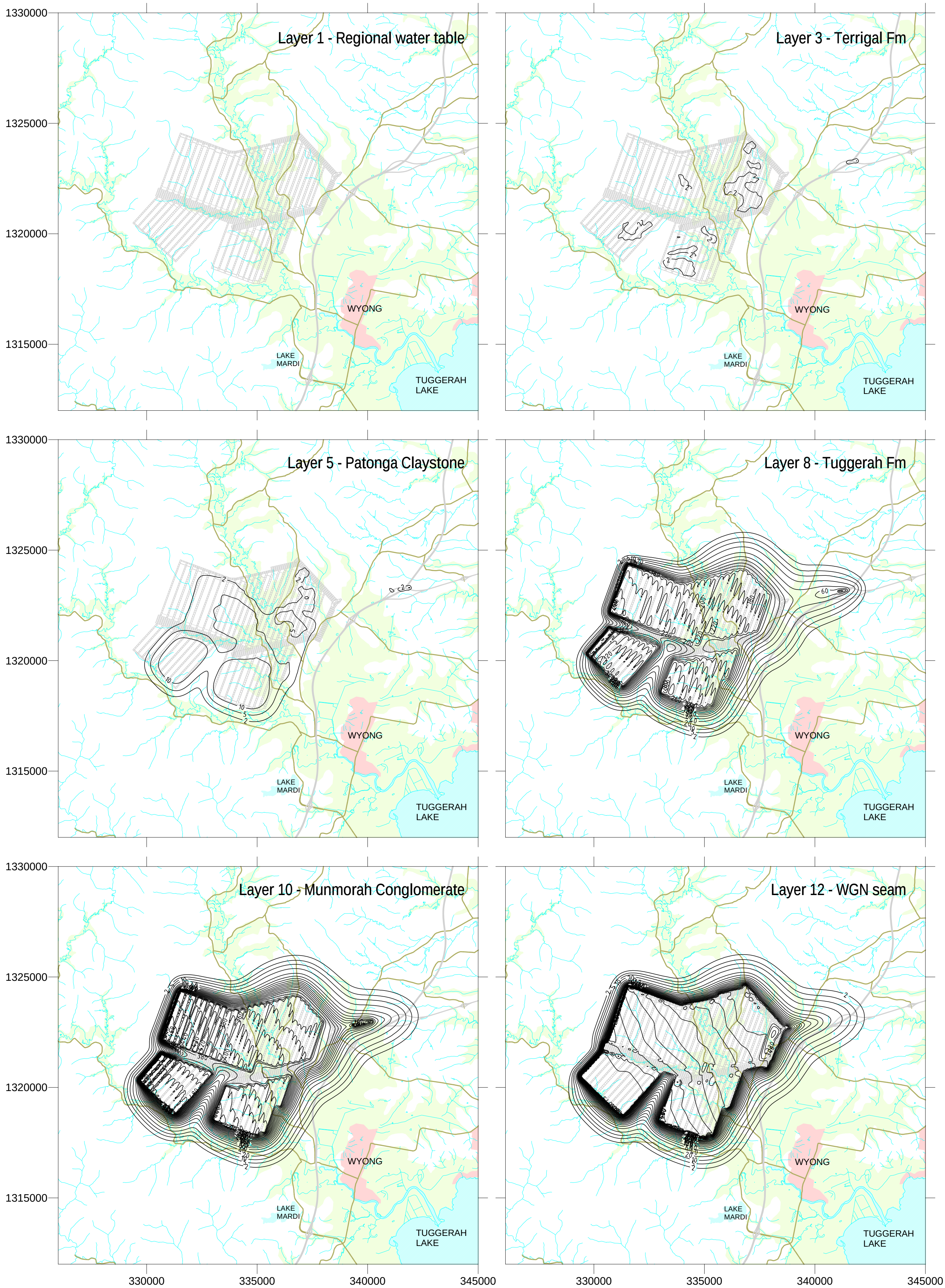
Figure E12



Drawdown contours in metres

Model W1: Piezometric drawdown during panel extraction - Year 28

Figure E13

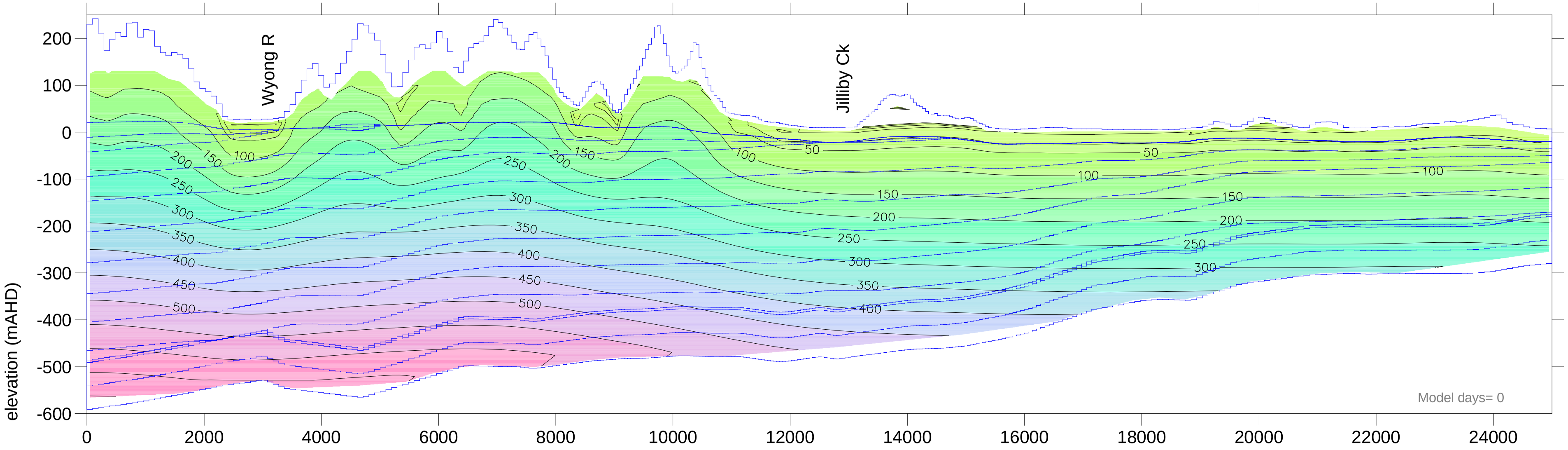


Drawdown contours in metres

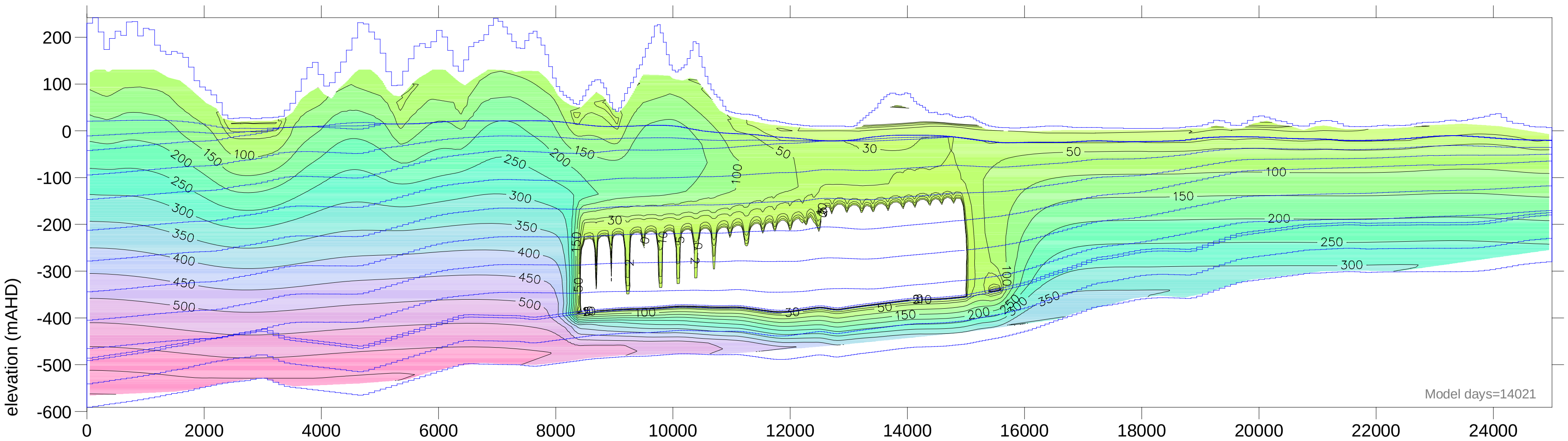
Model W1: Piezometric drawdown during panel extraction - Year 38

Figure E14

Section R125: Start of mining (0 years): Pore pressures in mH2O



Section R125: End of mining (38 years): Pore pressures in mH2O



vertical exaggeration 8 times
model layers shown in blue

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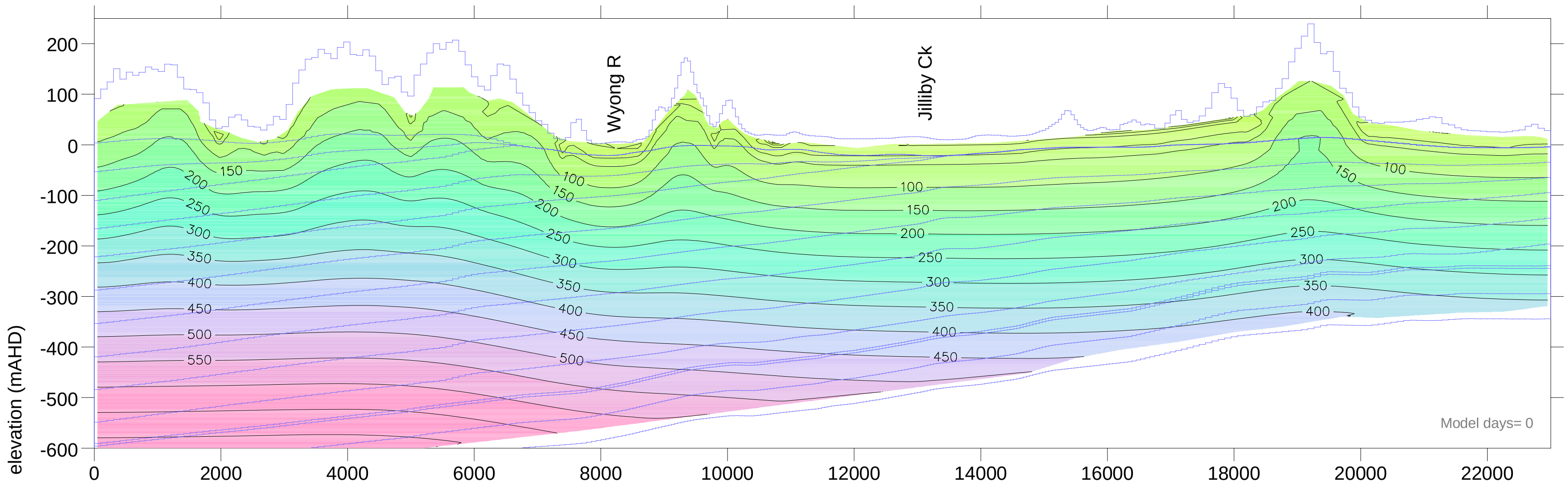
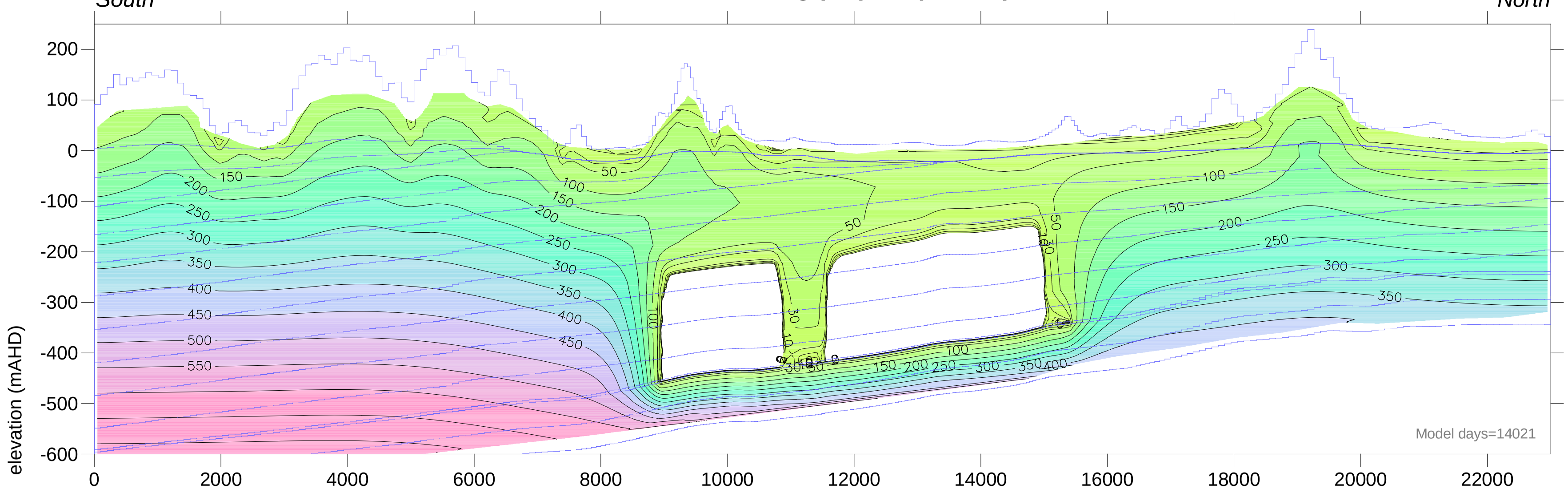
Pore pressure distributions

Figure E15a

Section C178: Start of mining (0 years): Pore pressures in mH2O



Section C178: End of mining (38 years): Pore pressures in mH2O

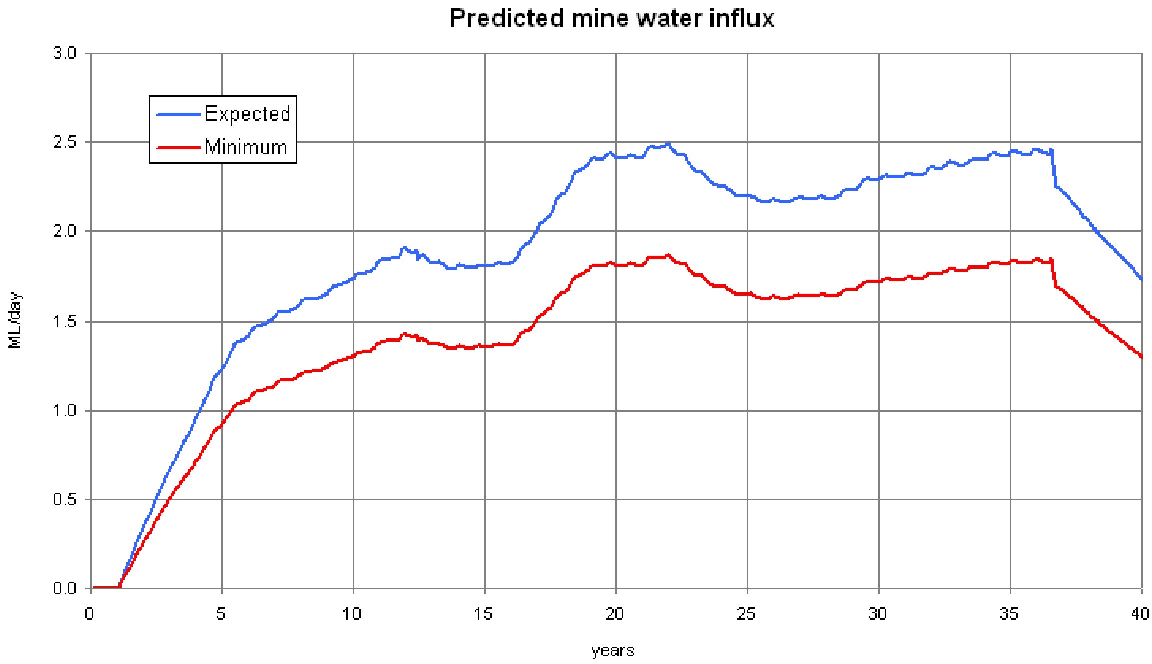


vertical exaggeration 8 times
model layers shown in blue

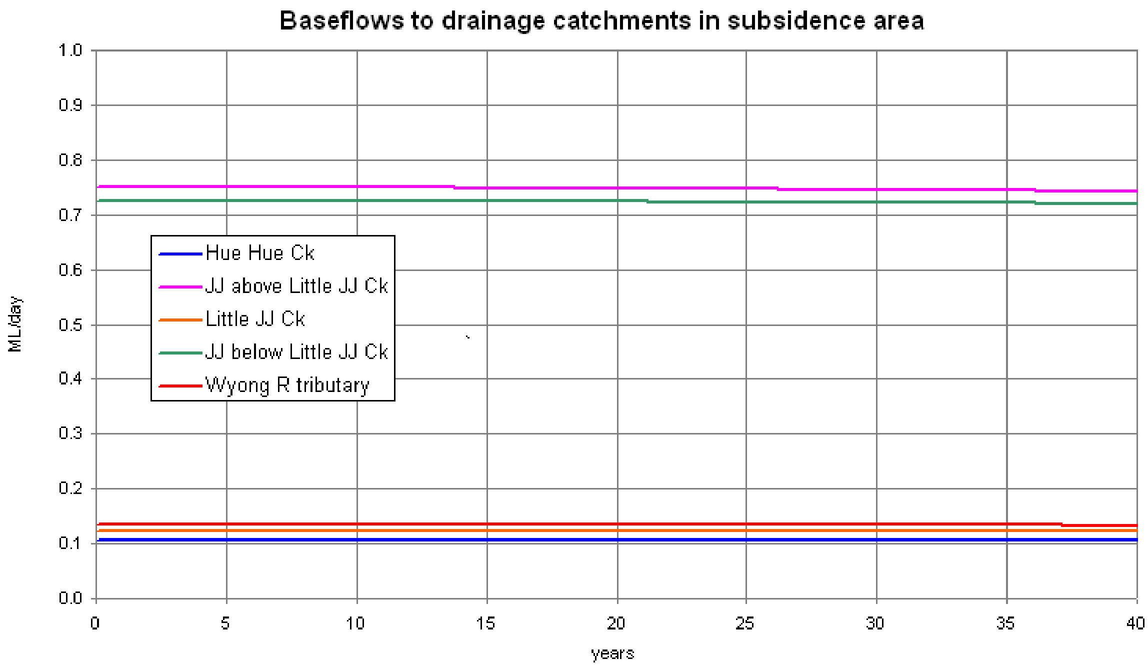
Mackie Environmental Research

Pore pressure distributions

Figure E15b

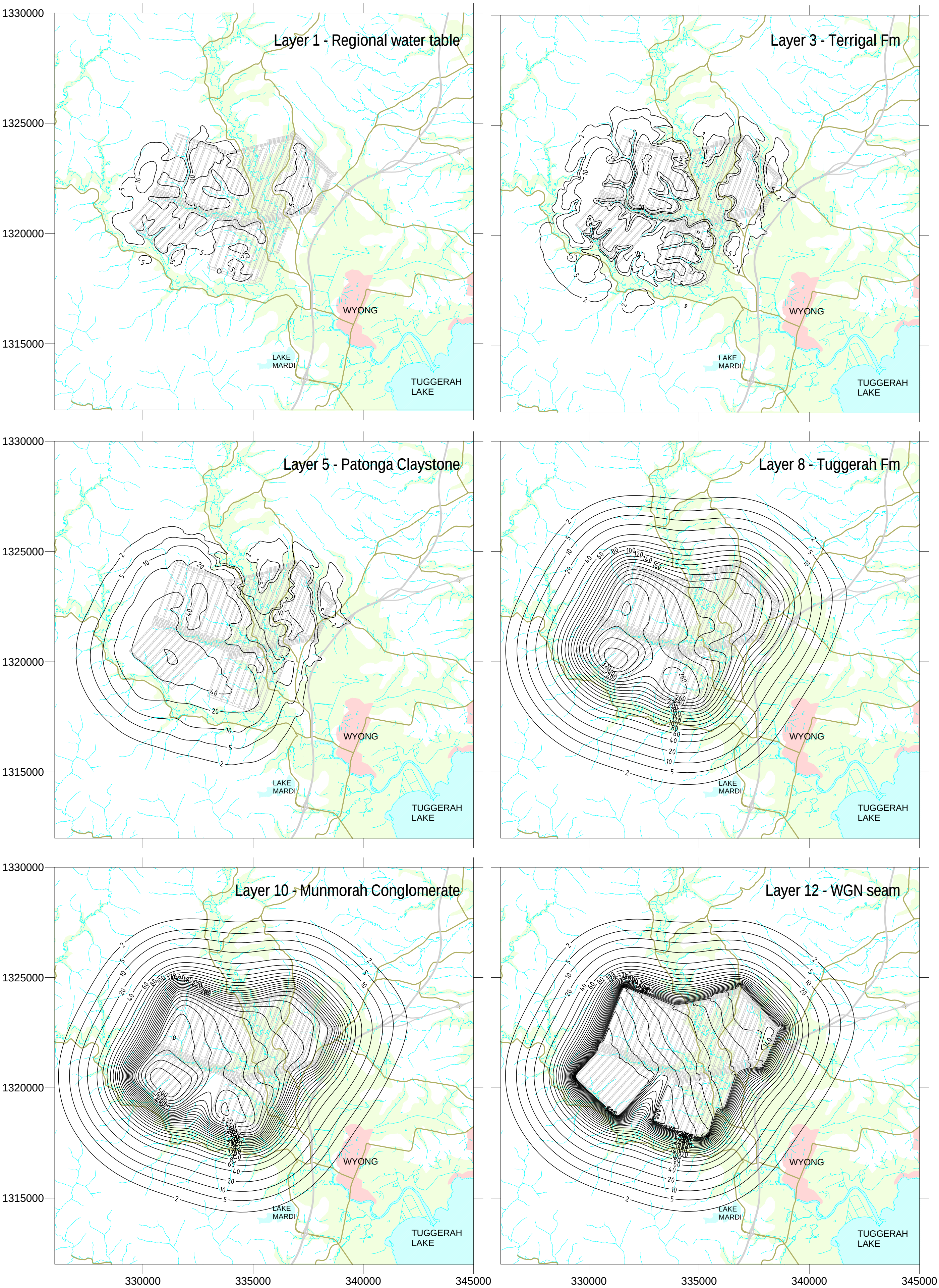


1. The expected mine water influx is based on model output.
2. the minimum influx broadly allows for model simulation mass balance errors.



Mine water seepage and base flow impacts

Figure E16



Drawdown contours in metres

Model W1: Piezometric drawdown 200 years after closure

Figure E17

APPENDIX F: SHALLOW SUBSIDENCE ZONE GROUNDWATER MODEL

A change in shallow alluvial aquifer storage will accompany the subsidence process. The change may occur either through filling of temporary shallow crack storage, or readjustment of groundwater levels to changed surface water levels brought about by regional subsidence. Temporary filling of shallow crack storage is expected to lead to very localised and short term depletion of groundwater storage within the alluvial aquifer(s) followed by recovery.

Subsidence will however, induce a more widespread impact due to a rapid reduction in water table elevation as a part of a panel is subsided relative to an unsubsided area. The process will be a continuum that will include fall and rebound of the subsided water table. The duration of the rebound-recovery process will depend largely upon the juxtaposition of subsided panels and drainage lines, the recharge capacity of those drainages for prevailing climatic conditions, and local aquifer properties (hydraulic conductivity and storage characteristics).

In order to understand and assess probable impacts, a shallow zone simplified (generic) aquifer model has been assembled. The model utilises a finite difference scheme known as Modflow (Harbaugh et.al., 2000) for a single layer representing valley infill alluvium, the goal being to assess typical rebound times at a local scale for basic configurations of panel induced subsidence and drainage. The domain of the model is 4000 m long by 1000 m wide with the area regularly gridded at 20 m intervals thus generating 20 x 20 m cells.

Figure F1 uppermost plot illustrates the arrangement where an axi-symmetric design replicates subsidence generated by a 200 m wide panel (100 m wide in axi-symmetric form). This scenario assumes an expansive alluvial aquifer with sediment (model) thickness of 30 m, and extraction of a single panel which advances a subsidence zone indicated by the red outline, from an area devoid of any creek recharge potential, towards and beneath a single flowing drainage (blue shaded) located a distance of 1500 m from the initial subsidence point. Subsidence ceases 500 m along the drainage thus giving a 2000 m long subsidence zone.

The subsidence wave therefore migrates a distance of 1500 m before intersecting the drainage (in most valley areas, distances between a subsidence zone and the nearest surface drainage are typically less than 1000 m). Subsidence of 1.3 m is imposed at an advancing rate of 10 m per day. The subsidence process is replicated by initiating drainage cells which reduce the water table by 1.3 m instantaneously (1 day duration). In reality a block of aquifer is subsided against an adjacent block in advance of the subsided block but realigned with the previously subsided block. The displacement of the water table in this process is generally less than 10% of the saturated thickness of the aquifer except in transitional areas where alluvial materials may thin out and on lap surrounding more elevated hard rock terrain. Model cells to the north and east of the panel represent unsubsided areas.

A representative alluvium hydraulic conductivity based on test results, is approximately 0.2 m/day (Appendix D). In order to understand the likely impacts, four values of alluvium hydraulic conductivity have been applied to the modelling process – 0.1, 0.5, 1 and 5 m/day. A uniform drainable porosity of 25% is assumed in all models. Rainfall recharge has been applied to the alluvium at a rate which generates an initial hydraulic gradient of approximately 1:1500 towards the creek for all scenarios. Thus for each model, rainfall has been adjusted under steady state conditions to achieve the same water table geometry before undertaking transient simulations. The maximum recharge occurs for a conductivity value of 5 m/day and was found to be 10 mm/year or slightly less than 1% of annual rainfall (1180 mm/year). Other rates are summarised in the following Table F1.

Table F1: Hydraulic properties assigned to the subsidence models

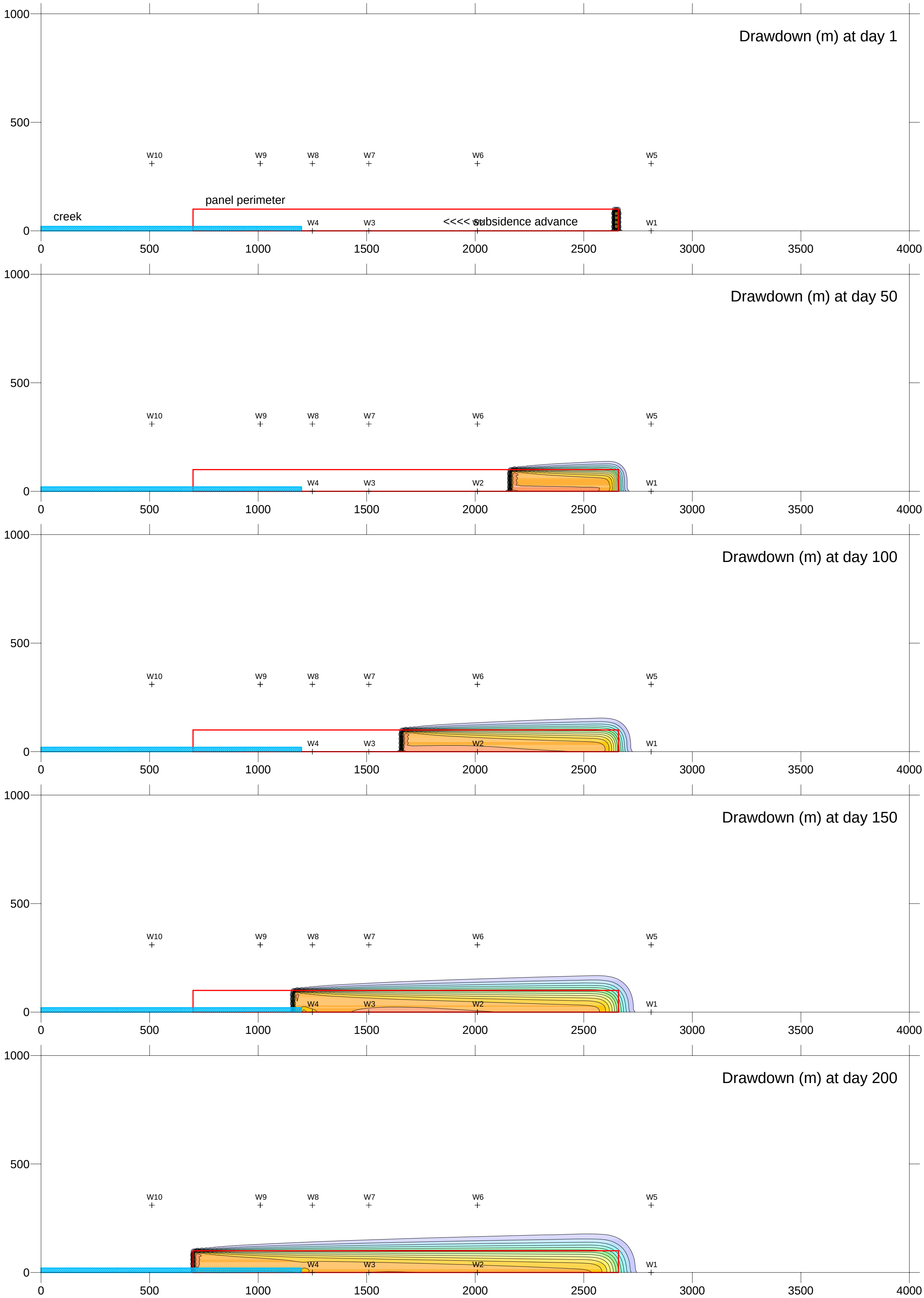
Model	Hydraulic conduct. (m/day)	Rainfall recharge (mm/year)	Drainable porosity %
Subside-1	0.1	0.2	25
Subside-2	0.5	1.0	25
Subside-3	1	2.0	25
Subside-4	5	10.0	25

Figure F1 also illustrates 5 stages of advancement of the subsidence wave as drawdown contours (K=0.1 m/day). These contours illustrate the likely impact on the water table. Initially onthe first day, the water table is displaced downwards by 1.3 m and drawdown is restricted to a distance of a few metres beyond the mine panel. Subsequent progression to 100 days illustrates some recovery of water levels within the subsided zone and a slightly expanded impact zone beyond the panel. A flowing creek is intercepted at about 150 days with no obvious recharge to the drawdown zone since the creek is also displaced downwards. At 200 days, the recovery of the water table near the commencement of the panel continues at a slow rate as indicated by the hydrographs (Figure F5). Thus for this scenario the water table largely remains in a displaced position after 200 days with minimal impact observed in adjacent unsubsided areas. It is noted however that this scenario assumes a very low rate of rainfall recharge (0.2 mm/year or about 0.017% of annual rainfall) that is likely to be significantly exceeded and if so, is likely to lead to a more rapid recovery of the water table.

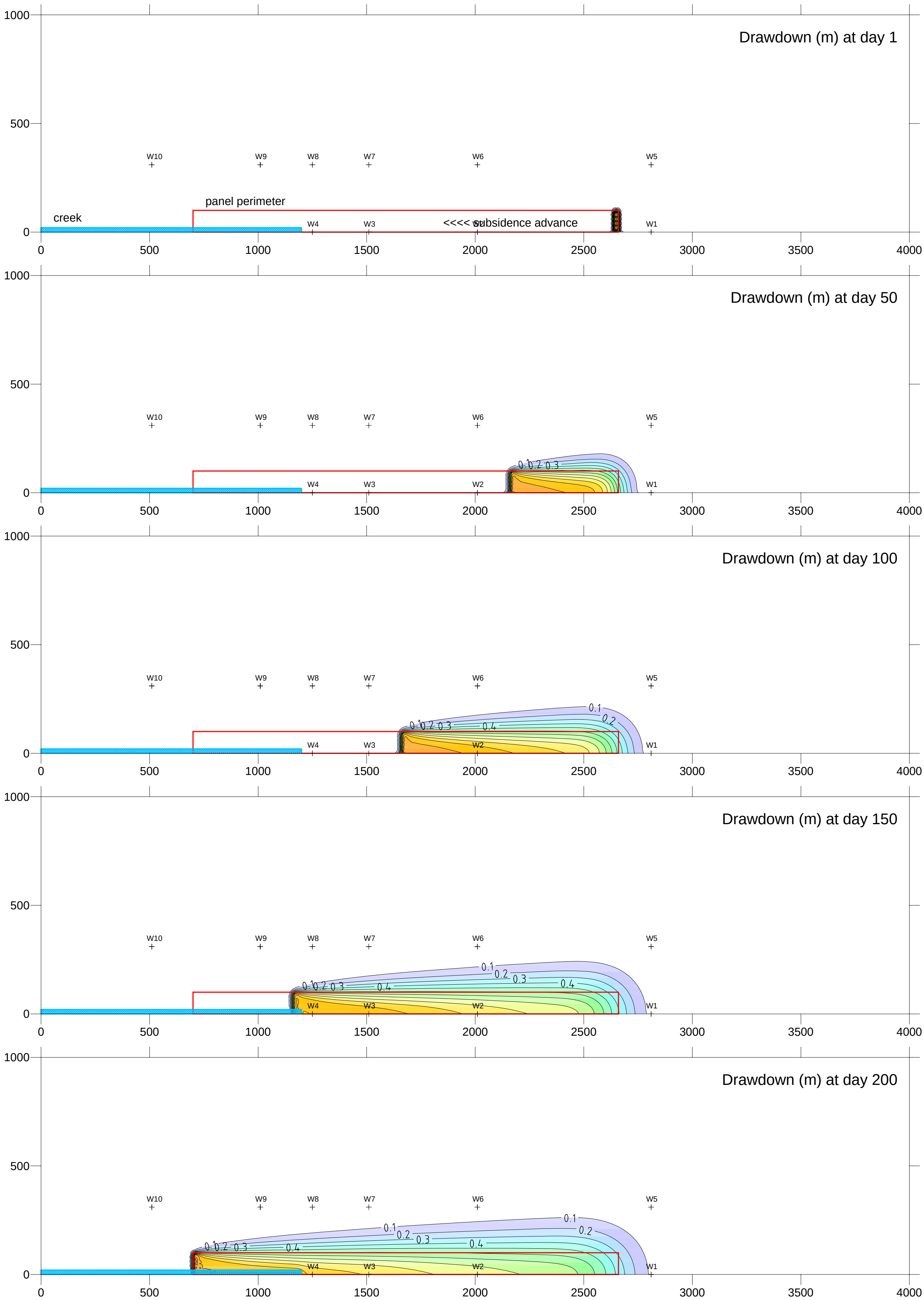
Figure F2 illustrates advancement of the subsidence wave for model Subside 2 (K=0.5 m/day). Initially (day 1) the water table is displaced downwards by 1.3 m and drawdown is restricted to a distance of a few metres beyond the mine panel in much the same manner as the previous model. Subsequent progression to 100 days illustrates partial recovery of water levels within the subsided area. At 200 days the recovery of the water table near the commencement of the panel is about 75% complete as indicated by the drawdown contours and by the hydrographs (Figure F5). The water table remains in a partially displaced position after 200 days with limited impact observed in adjacent areas – 0.1m drawdown has extended about 150 m beyond the panel. As with the previous model this scenario assumes a very low rate of rainfall recharge (1 mm/year or about 0.1% of annual rainfall) that is likely to be significantly exceeded and likely to lead to a more rapid recovery of the water table.

Figure F3 illustrates advancement of the subsidence wave for model Subside 3 (K=1.0 m/day). Initially (day 1) the water table is displaced downwards by 1.3 m and drawdown is restricted to a distance of a few metres beyond the mine panel in much the same manner as the previous models. At 200 days the recovery of the water table near the commencement of the panel is about 81% complete as indicated by the drawdown contours and by the hydrographs (Figure F5). The water table remains in a partially displaced position after 200 days with limited impact observed in adjacent areas – 0.1m drawdown has extended about 220 m beyond the panel. As with the previous models this scenario assumes a low rate of rainfall recharge (2 mm/year or about 0.17% of annual rainfall) that is likely to be significantly exceeded and likely to lead to a more rapid recovery of the water table.

Figure F4 illustrates advancement of the subsidence wave for model Subside 4 (K=5.0 m/day). Initially (day 1) the water table is displaced downwards by 1.3 m and subsidence in then progressed at a rate of 10 metres per day. At 200 days the water table remains in a partially displaced position with increased by quite low impact observed in adjacent areas – 0.1 m drawdown has extended more than 400 m beyond the panel. Recovery of the water table near the commencement of the panel is about 90% complete as indicated by the drawdown contours and by the hydrographs (Figure F5).



Subside-1 model output (K=0.1m/day, Sy=25%)



Subside-2 model output (K=0.5m/day, Sy=25%)

Figure F2

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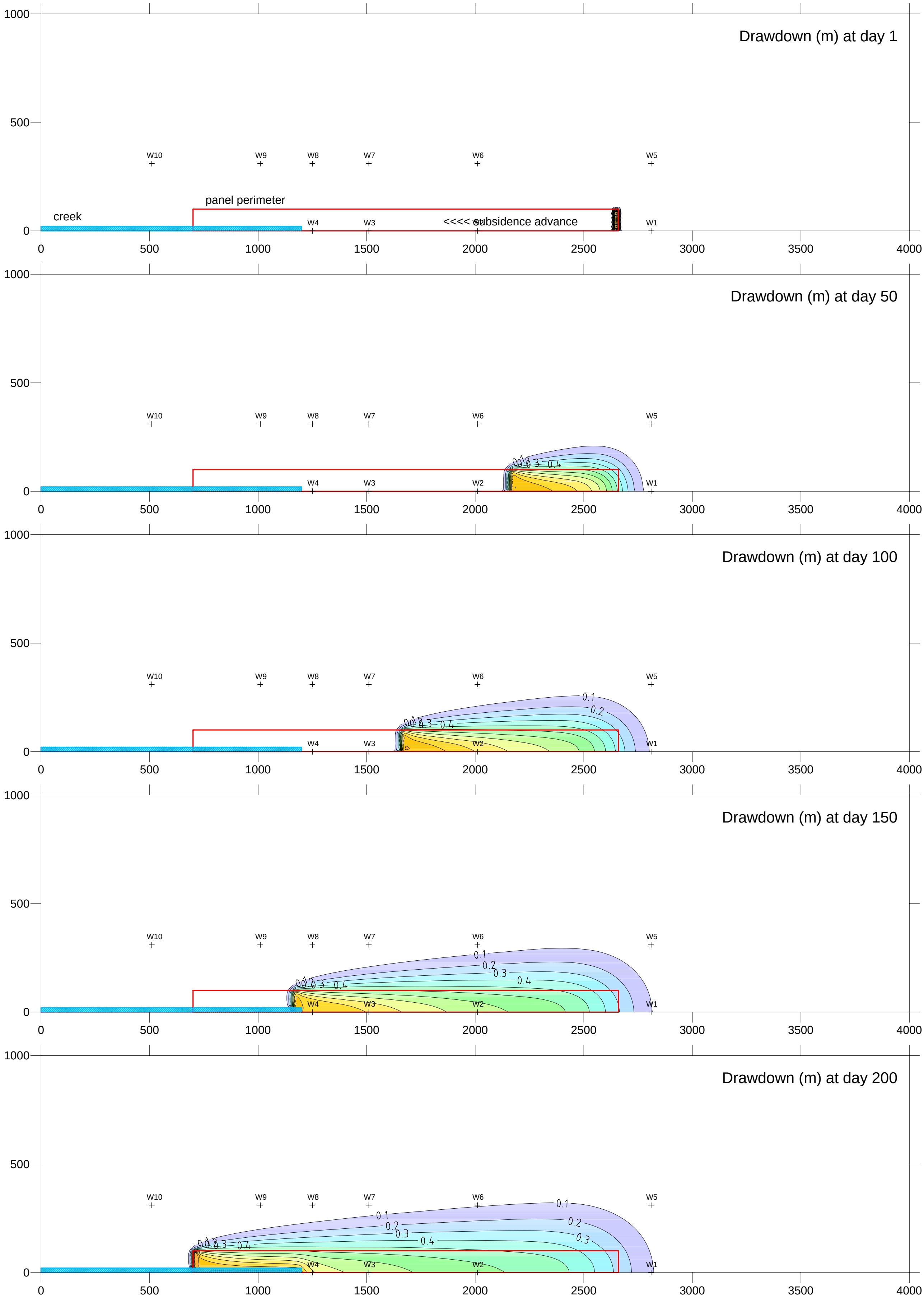
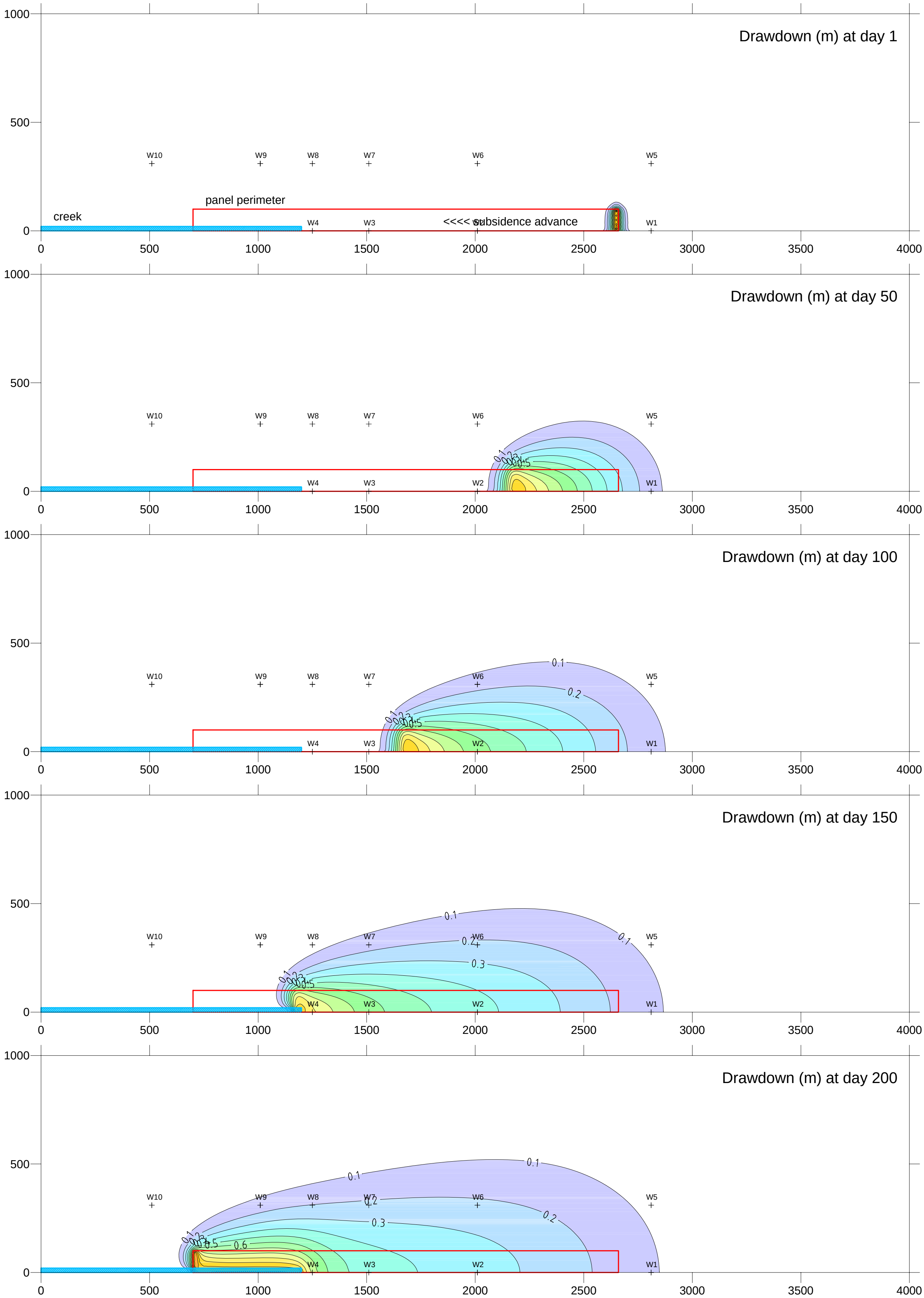


Subside-3 model output (K=1.0m/day, Sy=25%)

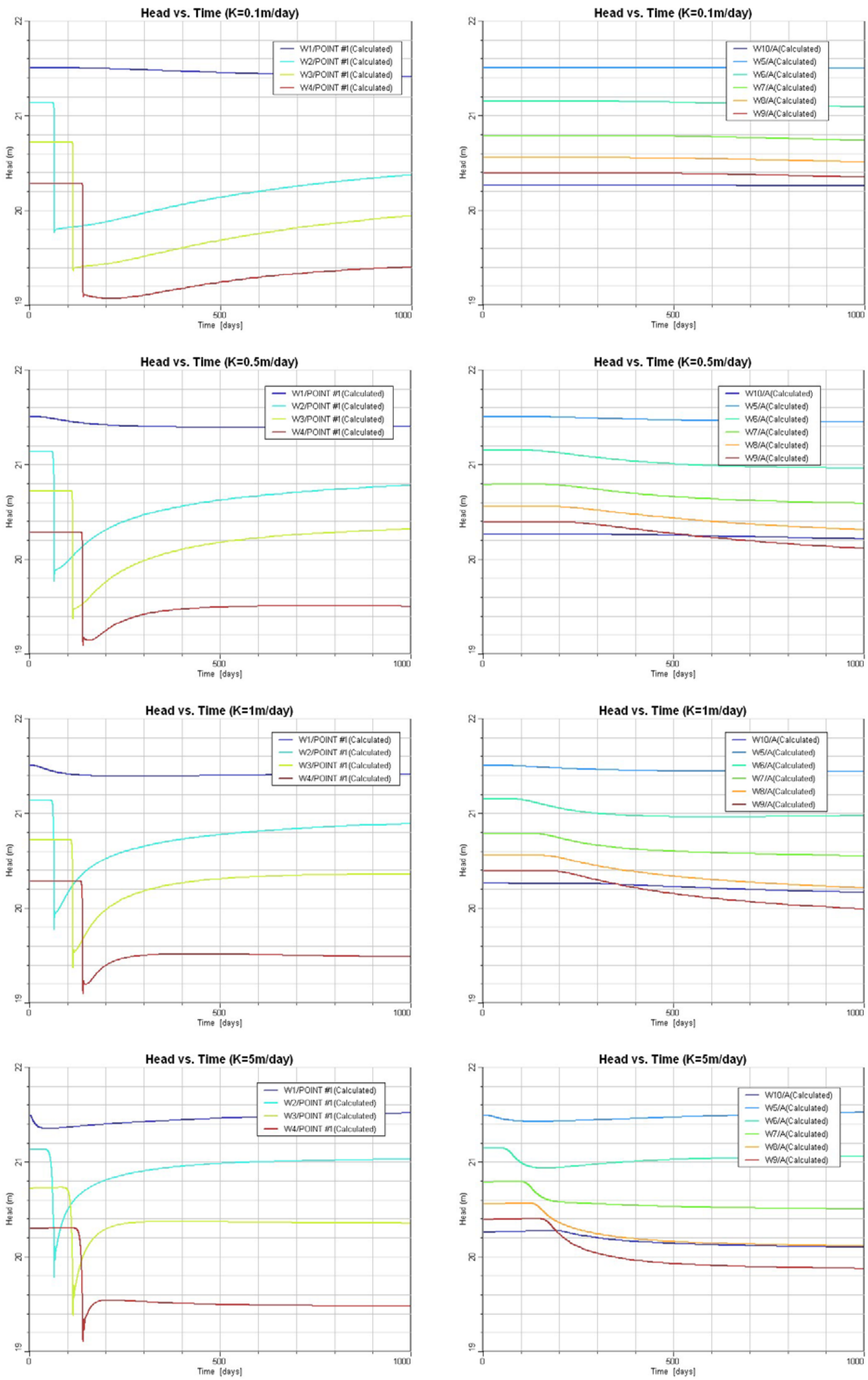
Figure F3

Mackie Environmental Research



Subside-4 model output (K=5.0m/day, Sy=25%)

Figure F4



Observation well hydrographs subsidence models

Figure F5