Wallarah 2
COAL PROJECT

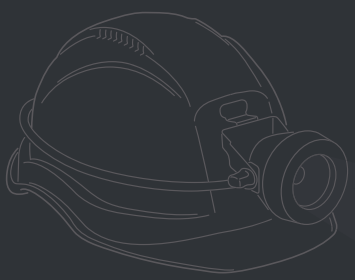
# Wallarah 2 Coal Project

## Environmental Impact Statement

April 2013

## Appendix I

Groundwater Impact Assessment



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# WALLARAH 2 COAL PROJECT
# GROUNDWATER IMPACT ASSESSMENT
# FEBRUARY 2013

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## ABSTRACT

Groundwater impact assessments have been conducted for the proposed underground operations at the Wallarah 2 Coal Project (the Project). Studies have included collation and assimilation of hydrogeological information including 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 (1) the regional hard rock strata including Triassic non coal strata and the deeper Permian coal measures hosting the Wallarah-Great Northern (WGN) coal seam, (2) the unconsolidated groundwater systems in valley fill and coastal plain environments and (3) the shallow weathered rock.

Within the hard rock strata 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 likely to hydraulically isolate formations above and below. The range in permeabilities is consistent with reported values at other mining operations to the north.

The alluvial groundwater systems in proximity to the proposed 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 typically at depths of 1 to 5 m below ground surface. Coastal sands to the east of the project area are more permeable and most likely host groundwater flows towards the sea.

The shallow 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 flow systems tend to be localised, are rainfall driven and are likely to be perched.

Limited measurement of regional groundwater pressures in the deep hard rock strata suggests a groundwater 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 alluvium can also be inferred. Evidence of this pressure driven leakage has been demonstrated at several 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 groundwater systems. In contrast to the hard rocks, the alluvial materials 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 alluvial sediments. This infiltration mechanism sustains a shallow 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 7500mg/L while pH values range from 6.3 to 7.6. Groundwater quality within the alluvium 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. Increasing salinity has been 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.

Mining operations will result in dewatering of the deep coal seam and depressurisation of surrounding strata. Subsidence and associated caved areas will also induce depressurisation above the seam, extending upwards through undisturbed overburden.

Computer based groundwater model simulations of proposed mining operations have been conducted in order to understand the many complex subsurface flow processes that could evolve during extraction of longwall panels. 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 and variable distribution.

The current groundwater model is identified as W3. The model differs from earlier (2010) models W1 and W2 insofar as the ground surface and stream boundary conditions have been adjusted in some areas based on high resolution digital terrain data. Predicted underground seepage reporting to the mine has also been calculated using an improved algorithm.

In addition to model W3, an alternate model W4 has been developed which introduces a randomisation of the hydraulic conductivities within the subsidence zone over the interval 180 to 220 m height above the WGN seam. This approach is considered to more realistically address the variable nature of crack connectivity and bed separation that might influence leakage from the alluvial lands.

The models have generated predictions of formation depressurisation throughout the rock strata, and estimates of 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 flow model against significant prior groundwater stresses within the hard rock system. Calibration has therefore focused on the alluvial systems and the water table response to rainfall. With regard to hardrock systems, extensive field and laboratory testing has been conducted in order 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 up to 3 km beyond the panels over the proposed period of mining. The depressurisation wave will also expand through overlying strata at a slow rate. Mine water seepage is predicted to rise from a rate of less than 0.1 ML/day at commencement of mining (during development), to a predicted peak rate of about 2.5 ML/day. This seepage may be enhanced from time to time by potential dewatering of localised fractures at depth. This may lead to short term increases of perhaps 0.5 ML/day which should dissipate over a period of weeks to a few 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 hardrock pore pressures will reduce the rate of upward leakage beneath the alluvium and induce downwards leakage. However the leakage induced by depressurisation after a potential 38 years of mining is calculated to be less than 2 millilitres/day per square metre of land surface or about 0.02 ML/day for an alluvial lands area (within the mine footprint) of about 9.3 sq.km.. This rate is very low compared to a potential rainfall recharge rate calculated to be as high as 130 millilitres/day per square metre. Leakage induced by deep strata 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.

Subsidence over longwall panels will directly affect the shallow alluvial groundwater systems as a result of transient change in the groundwater storage component of those systems. The change may occur through filling of temporary shallow crack storage in hardrock immediately beneath the alluvium and brought about by regional subsidence. Filling of shallow crack storage may lead to very localised 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 on the alluvial groundwater system.

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 sediment properties (permeability and storage characteristics), the recharge capacity of local landforms, and the prevailing climate. Impacts of an average 1.4 metres subsidence on alluvium storage have been assessed though development of a generic groundwater model representing the alluvial sediments at a scale more appropriate for this type of analysis than the regional groundwater model. Calculations indicate between 55 and 75% of rebound in the water table could be expected within about 6 months of subsidence occurring assuming very low rainfall recharge. In areas where the water table currently rises and falls within a few metres of surface and where subsidence is of the order of 1 m or more, the water table is expected to temporarily reside closer to surface until re-equilibration is complete.

A number of existing bores/wells have been identified that draw water from the alluvium and hard rock strata. Boreholes located beyond the subsidence footprint are unlikely to be affected. However 12 boreholes have been identified within the subsidence footprint which may be affected by either loss of pressure head or loss of structural integrity. These boreholes/wells in the alluvium and shallow bedrock could be repaired or re-drilled if damaged, without loss of yield.

It is unlikely that any measurable change in groundwater quality will be observed in deep hard rock strata as pore pressures decline. Localised change in salinity may be observed in deep caved zones as groundwater contained within different stratigraphic horizons mixes with fragmented materials in goaf. This water will be captured by, and treated within the mine water system. Similarly, it is unlikely that any measurable change in water quality will be observed in the shallow unconsolidated alluvial groundwater system post mining since subsided areas are likely to reflect unsubsided conditions with respect to aquifer material properties and surface drainage systems.

There will be a change in water quality within the seam workings as a result of the storage of salt waste product from the surface water treatment plant(s). This waste will comprise a near solid salt product and a liquid brine. The solid waste will be stored and sealed in special development headings located to the east of longwall LW1 for the first 11 years of operation. Subsequently, brine will be emplaced in goaves. With re-saturation of the coal seam and overlying strata post mining, the stored salts-brines are expected to remain immobile due to the very slow rate of recovery of the hardrock groundwater system. Groundwater levels and pressures are predicted to take at least 500 years to achieve about 50% recovery of water levels in the workings – a groundwater sink will prevail for the foreseeable future. The higher density of brine will also contribute to immobility; brine will favour the deepest areas of the workings and recovering water column.

Within the shallow hardrock domain, there are a number of naturally occurring ephemeral ferruginous springs that have been identified in the upper reaches of Jilliby Jilliby and Little Jilliby Jilliby Creeks. These springs have resulted in the presence of localised iron staining and bacterially mediated matting for short distances along the downstream drainage channels. The presence of iron is attributed largely to the occurrence of siderite (iron carbonate) in the Terrigal Formation. Marcasite and pyrite may also be present but inspections and core analyses suggest these minerals are minor.

It is likely that surface cracking of hard rock strata resulting from subsidence will initiate localised redirection of runoff into new cracks with the potential for new ferruginous springs to develop. Candidate locations cannot be identified since neither the local mineralogy nor the precise location, aperture, extent or connectivity of surface cracks can be predicted with any certainty. Aquatic ecosystems are present within some ephemeral channels. Impacts on these surface water ecosystems have been considered elsewhere by ecological studies.

Groundwater dependent ecosystems are located along and adjacent to both major and minor surface drainage channels. They comprise Paperbark, Coachwood, Blackbutt and other species that rely on the shallow water table or upon soil moisture in the unsaturated zone. Potential impacts upon these systems relate to displacement of the water table as a result of subsidence. Groundwater flow modelling of the displacements associated with subsidence in the alluvial lands indicate minimal impact on the water table due to the relatively low permeability of alluvial materials. Rainfall is expected to rapidly recharge the system (as evidenced by historical water table monitoring) with minimal impact and restoration of conditions that are expected to be similar to pre-mining conditions, after the completion of mining. In elevated terrain and forested areas, the water table is generally predicted to be deep. In these areas the ecosystems rely upon soil moisture within the unsaturated zone which is sustained by rainfall and runoff. These conditions are not expected to change post-subsidence and as such, the identified groundwater dependent ecosystems are not expected to be impacted by mining.

Comprehensive groundwater and surface water monitoring will need to be included 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 will need to be retained in an appropriate database and provision made for analysis and transfer to NOW at appropriate reporting intervals.

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# 1. INTRODUCTION

Wyong Areas Coal Joint Venture (WACJV) is seeking approval to develop longwall mining in an area to the north-west of Wyong. The proposal known as Wallarah 2 Coal Project (the Project) provides for the mining of coal at a rate of up to 5 Million tonnes per annum (Mtpa) over a period of 28 years. Mining will be undertaken as longwall operations in the Wallarah-Great Northern (WGN) 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 shallower overlying strata including the 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 groundwater systems while subsidence is likely to initiate transient shifts in the regional water table.

Mackie Environmental Research Pty. Ltd. (MER) was commissioned by WACJV in 2012 to re-assess and collate existing groundwater studies undertaken by various consultants, in order to confirm the likely impacts of mining on groundwater systems and to provide advice in respect of future measurement and monitoring of groundwater conditions.

The groundwater re-assessment has more recently, been designed to comply with the Department of Planning and Infrastructure (DP&I) Director-General's Requirements (DGRs) for the Project, and to address relevant statutory policies and guidelines. Accordingly, the following key elements of study have included:

- a description of the existing environment;
- an assessment of the potential impacts of all stages of the Project and in particular, potential impacts on groundwater systems that might be associated with the Gosford-Wyong water supply scheme;
- a description of the measures that would be implemented to avoid, minimise, mitigate and/or offset the potential impacts, including 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 groundwater systems including extent, inter-relationships and connectivity to surface water systems and any groundwater dependent ecosystems;
- description of the interaction between hard rock groundwater 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 groundwater 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 gathered by various consultants together with computer based groundwater flow systems simulations undertaken by MER to assess the likely impacts arising from proposed mining operations.

## 1.1 Government legislation and policies

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

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

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

Two WSP's are relevant to the project area:

> ***Water Sharing Plan for the Jilliby Jilliby Creek Water Source 2003*** which took effect from 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 strata underlying this water source.
>
> ***Water Sharing Plan for the Central Coast Unregulated Water Sources 2009*** which took effect from 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 groundwater system.

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

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

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

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

## 1.2 Historical studies of relevance

Two previous significant groundwater 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. 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 groundwater systems through development of a simplified groundwater model. Surface water (flood) studies were also included.

In addition to the above, 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. L. Cook and Associates also supervised and reported on the installation and testing of multi level piezometers installed at five locations in the Dooralong valley alluvial lands[1].

SCT Operations has assessed the geomechanical impacts and fracture regimes associated with subsidence using numerical modelling methods for a number of vertical sections considered to be generally representative of field conditions. MSEC have assessed the impacts of subsidence on surface features within the proposed mine footprint.

Marine Pollution Research has assessed surface drainage channels in respect of aquatic ecosystems.

EcoEngineers has assessed the likelihood of iron staining arising from siderite or marcasite in potentially redirected stream flows within the area of subsidence.

MER has formulated a conceptual hydrogeological model based on the accumulated knowledge base and then developed a regional groundwater flow model for the assessment of groundwater related impacts. Where relevant, findings from the above noted studies have been incorporated within the current groundwater assessments.

# 2. REGIONAL SETTING

Extraction of longwall panels within the 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 m in 1 km (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 mining operations are located to the north near the township of Morriset (Centennial Mandalong mine).

The proposed mining operations are within the footprint indicated on Figure 1. Part of this footprint is situated in the Dooralong valley beneath alluvial groundwater systems associated with

[1] Piezometers were installed in March 2010 on a property known as Honeysuckle Park near the confluence of Little Jilliby Creek with Jilliby Jilliby Creek.

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.

## 2.1 Climate

The regional climate is temperate and is influenced mostly by coastal weather patterns. Rainfall is summer dominant and averages about 1200 mm per annum.

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, loamy-silty unconsolidated sediments. Long term minimum infiltration-recharge rates in the range 5 to 10% of annual rainfall could be expected in these alluvial areas.

Appendix A provides summary rainfall statistics.

## 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, serves to replenish the underlying groundwater system and to elevate the water table during periods of extended rainfall. Indeed sustained surface saturation is commonly observed throughout much of the Dooralong Valley following significant rainfall periods due to the presence of a relatively shallow water table. Following these rainfall periods, the elevated water table provides a driving head to sustain migration of groundwater to the main drainages where it contributes to 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.

## 2.3 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). Local (project related) geology has been provided by WACJV. 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 which shows 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 underlie 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 low permeability. Like the Hawkesbury Sandstone, areas of high topographic relief may exhibit de-stressing with localised displacement of some bedding evident, and opening of near vertical micro fractures and joints in some areas. Joint induced secondary permeability enhancement has been identified 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 pebble and siltstone fragments suggesting an erosive environment. In core, the siltstones exhibit moderate 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 present. The upper part of the formation generally comprises well developed sections of medium grained sandstone with thinner beds of red-brown and grey-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 m 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 suggest 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 variably mixed 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 alluvium (valley) 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 southwest to northeast vertical section (location identified on Figure 3) illustrating the general juxtaposition of strata and the proposed WGN seam extraction interval. The seam occurs at depths varying from about 350m in the north-eastern area to more than 600 m in areas to the south-west within the proposed mine footprint.

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

No major regional faults have been identified by WACJV geologists[2] that transect the mine footprint. 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 (core) observation due to the near vertical orientation and variable scale of such features. Typically the fractures 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 regional groundwater flows at depth. Apertures of these cracks are typically observed to be less than about 100 microns in unconfined core (loupe measurement) and are estimated to be less than 50 microns when confined.

There are a number of known or inferred doleritic dykes identified from airborne magnetic survey. These features are indicated on Figure 3. They trend in a northwest to southeast direction and tend to be variably altered from observations at other underground mines. They are considered to be unlikely to act as flow barriers that might compartmentalise groundwater flows at a regional scale and are not recognised as groundwater conduits.

[2] See WACJV 2013 for geological and structural elements descriptions.

# 3. GROUNDWATER HYDROLOGY

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

- the unconsolidated alluvial groundwater system hosted within the Yarramalong and Dooralong valleys and coastal areas where unconfined conditions prevail;
- 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;
- the shallow weathered rock zone where unconfined conditions and generally perched systems prevail.

Figure 3 provides a map showing occurrence and approximate boundaries to the unconsolidated valley fill and coastal 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 adjacent and underlying Narrabeen Group is regarded as a potential aquifer only in the shallow weathered zone or in areas where secondary permeability has been introduced through jointing and stress relief, notably within the Terrigal Formation in steeper hilly terrain. For the greater part however, strata within the Narrabeen Group are considered to be aquitards with very poor groundwater transmission characteristics.

## 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 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 km zone of the mine footprint including 12 locations situated within the footprint. More distant bores beyond the mine footprint 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 2 km beyond the proposed 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 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 monitoring locations together with graphical plots of recorded water levels.

Water level measurements support relatively shallow depths to the water table of the order of 1 to 5 m with seasonal water level variations 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.

### 3.2.1 Alluvial lands hydraulic properties

Hydraulic properties of the unconsolidated alluvial deposits 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. Test analyses were based upon the Hvorslev method. Additional analyses were conducted by MER using the KGS method (Butler, 1997) and these results are also provided in Appendix D. Kores also installed piezometers at 5 locations (HP1 to HP5) near the confluence of Jilliby Jilliby Creek and Little Jilliby Creek in 2010. These piezometers were subjected to rising head tests (L. Cook and Associates) and generated estimates of conductivities in the range 5.8E-03 to 6.4E-01. An overview of all results indicates a generally low hydraulic conductivity consistent with the observed alluvial materials – 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 about 2.2E-01 m/day.

Hydraulic conductivities of shallow sand deposits situated in coastal areas to the east, while untested, are expected to exhibit a generally higher range 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 sediments***

| Material | Hydraulic conductivity (m/day) | Drainable porosity (%) |
|---|---|---|
| valley alluvium – sands (if relatively silt free) | 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 (expected) | 0.1 – 5 | 20 – 30 |

### 3.2.2 Alluvial lands groundwater chemistry

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 +9000 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 can be fresh or weakly brackish in some areas.

More detailed analyses of groundwaters contained within the alluvium have been previously undertaken (CPI 1998, ERM 2002) through speciation of major ions in water samples obtained from installed piezometers. These groundwaters have been characterised from major cations and anions. Results are summarised in Appendix C as Figure C4, a trilinear speciation plot which facilitates classing of the groundwaters. Reference to the trilinear plot indicates both alluvial and hard rock water samples plot in a similar domain and cannot be easily discriminated from each other. The domain exhibits a dominance in primary salinity with Na>Mg>Ca and Cl>$HCO_3$>$SO_4$.

## 3.3 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 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 pore 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 or 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 calculated to be 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 weak connectivity and low secondary permeability. Where observed in core, the fractures are often clean and without alteration or secondary mineralisation implying negligible movement of groundwater along fractures.

The WGN coal seam is identified as the main water bearing strata at depth in so far as it offers enhanced groundwater storage and transmission characteristics through the presence of cleating. 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*

Extensive hydraulic testing has been conducted in the hard rock strata within the 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.

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 2.

Laboratory permeability tests have been conducted on core in order to provide improved estimates of intergranular (matrix) permeability. Porosity was also determined for selected samples. Details are provided in Appendix D and summarised in Table 2. An overview of results supports a practically impermeable hard rock regime.

*Table 2: Summary estimates of conductivities for consolidated strata*

| 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

There is also a reasonable body of information addressing the permeabilities 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 3 provides a concise summary of packer testing results for the main lithologies in that area (Forster et. al., 1997).

*Table 3: Estimates of conductivities for consolidated strata 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

Compressibility and 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 GPa to more than 25 GPa.

### 3.3.2 Groundwater quality in hard rock strata

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.

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 C4) illustrates similar water classes for shallow and deep groundwaters.

In general, the water quality data reflects fresh to brackish conditions throughout the area. Salinity 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 localised secondary groundwater systems with higher rates of flushing, particularly along joints and fractures and along bedding shears. These same areas may also host ferruginous springs. The presence of iron in spring waters is largely attributed to the dissolution of siderite which is a naturally occurring iron carbonate mineral identified in parts of the Terrigal Formation. Appendix C, Table C2 provides a summary of X-ray diffraction (XRD) mineralogical assessments which have been undertaken to promote a more comprehensive understanding of probable outcomes of water-rock interactions. These assessments support the widespread presence of siderite.

## 3.4 Regional piezometric surface

It is not possible to plot a regional piezometric surface from the database available to the project area. 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 equipotential contours provided in Figure 8 have been generated from steady state groundwater flow 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 potentiometric 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.

In contrast to the hard rocks, the alluvial groundwater systems associated with the Wyong River and Jilliby Jilliby Creek (and other significant drainages) act as much more dynamic flow systems with rainfall recharging the sandy and silty sediments. This infiltration mechanism sustains a groundwater flow regime towards the drainage channels where stream bank and river bed seepages eventually discharge groundwater to the river or creeks as baseflow. Velocities of groundwater flow within the alluvium are calculated to range from less than 1.0E-4 m/day 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 E11 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 Wyong State Forest/Jilliby SCA area where piezometric heads of more than 150mAHD are calculated in the shallower hard rock system.

## 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 model of the region has been developed in order to understand the likely regional extent of depressurisation and to predict future 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 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 groundwater system, 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 subsidence zone above longwall panels. 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 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, the Munmorah Conglomerate, Dooralong Shale and the WGN seam. The geometry of each unit has been carefully defined from structure contour information supplied by WACJV 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 previous models W1 and W2[3] which were developed in 2009 and 2010 respectively, have been superseded by models W3 and W4 which include minor changes to the hydraulic conductivity distributions and changes to the way the subsidence zone is represented. The revised model W3 represents the conservative case and is based upon a hard rock permeability distribution derived from measured hydraulic conductivities. A fourth model W4 has also been developed which includes stochastic representation of the subsidence zone as a randomised connectivity of cracks and randomised bedding plane separations imposed on model W3 regional hydraulic properties. It represents a less conservative and possibly more realistic case.

[3] Model W2 introduced randomised hydraulic conductivities within the subsidence zone to model W1.

## 4.1 Model properties, boundary conditions and pre-mining water levels

Properties assigned to the model which govern groundwater flow include hydraulic conductivity, compressive (elastic) storage and specific yield. Hydraulic conductivity distributions for individual model layers, have been calculated using three exploration boreholes as type profiles or sections. Geologic logs for each of the boreholes have been used in assigning 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 adopted in strata above extracted longwall panels. Basically four disturbed zones are commonly associated with the subsidence process, the first three being included in the groundwater model. The zones are characterised as follows and are more fully described in Appendix E and illustrated in Figure E5:

- ***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 to a certain height. 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 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 has been defined by geomechanical studies to be of the order of 200 m beneath the alluvial lands. It is noted however that this zone progressively decreases in drainability with increasing height (above seam) as the zone width and the frequency and connectivity of cracks, diminishes (see Appendix E, Figure E5). For modelling purposes a zone width equivalent to panel width has been adopted to a height of about 220 m.

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 plus underground 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 and transient calibrations of the model. Steady state calibration was undertaken by adjusting net recharge (recharge after evapotranspirative losses) 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 rate of recharge determined by this process has then been 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.

Transient calibration was subsequently completed by conducting model simulations using measured rainfalls for the periods from 1998 to 2001 and from 2010 to early 2012 and further adjusting the alluvium material properties until an acceptable match was achieved between measured water table fluctuations (due to rainfall) and simulated water table fluctuations. Calibration results are provided in Appendix E.

## 4.2 Model W3 - Mining induced depressurisation of rock strata

The W3 groundwater flow 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 maximum period of 38 years or 10 years beyond the proposed approval period of 28 years.

Figures E12 to E16 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 migrate upwards via the simulated subsidence zone and after 28 (and 38) years, zero pore pressures are predicted to impact the lower part of the Tuggerah Formation.

Figure 9 provides a plot of the simulated depressurisation in the deep WGN seam after 38 years of mining. Reference to this figure illustrates the drawdowns that are predicted to surround the mine workings. Lateral (in-seam) extent of WGN depressurisation is greatest in the area of the pit bottom. Here the impacts of depressurisation extend more than 2 km beyond the mine footprint as defined by the 2 m head loss contour. 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 groundwater system after 38 years. The only identifiable drawdown impacts 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 will not be affected. The reasons for negligible drawdown impact in these alluvial areas relate to the low permeability of the underlying Patonga Claystone and Tuggerah Formation which act as aquitards, and the high storage capacity and sustained rainfall recharge prevailing within the shallow alluvium. Storage and rainfall recharge is able to accommodate 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 hard rock groundwater 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 millilitres/day per square metre of alluvial land surface - see Appendix E, Table E4).

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 E20). 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 determined by modelling assumes no contributions from localised fracture related storage that might be encountered by mining - the location, extent and hydraulic properties of this type of storage remain unknown. Occasional fracture zones can be identified in drill core but inspections suggest they are generally infrequent, often with little 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. Even though the occurrence of localised fractures may be sparse, it would not be unreasonable to expect up to 0.5 ML/day increase in mine water seepage over periods of weeks to months if fracture network storage is encountered and drained.

## 4.3 Model W4 – Mining induced depressurisation with random permeabilities

Model W4 is an alternative simulation to model W3 which introduces randomness to the assignment of permeabilities within the subsidence zone at heights above 180 m. The process has involved randomly scaling the horizontal conductivity values between 100 and 500 times the undisturbed values. This reflects the dominance of bed separation at heights above 180 m. The vertical conductivity has been scaled between 1 and 10 times to reflect the near absence of vertical cracking at these heights[4]. Shallower layers have also been scaled in a randomised manner with respect to horizontal conductivity (see Appendix E).

Simulations have yielded nearly identical drawdown results to model W3 and the calculated daily influx rate is expected to rise from 0.1 ML/day to a maximum influx of about 2.4 ML/day. Leakage from the alluvial aquifer system is also similar to model W3.

## 4.4 Recovery of hard rock groundwater pressures post mining

At the completion of mining, regional groundwater 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 5%. Figure E26 in Appendix E shows the predicted drawdown distribution after 500 years with seam depressurisation during the recovery process predicted to extend more than 6 km beyond the mine footprint. Pore pressures would continue to decline in the Tuggerah Formation and Patonga Claystone strata to a point where unsaturated flow may prevail beneath the alluvial lands. Leakage would still continue from the alluvial lands at the same rate as predicted at the cessation of mining although it is possible that some reduction may occur due to variably saturated conditions[5].

In addition, complete depressurisation of strata in the Terrigal Formation that hosts the regional water table (model layer 1), is predicted in some parts of area within the mine footprint. In reality this is unlikely to occur since these areas are expected to be actively recharged from the shallow regolith-weather rock zone which is more conducive to increased rates of rainfall infiltration. This zone of elevated rainfall recharge is not included in the groundwater flow model.

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 goaves, 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.

## 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 and is expected to occur in two distinct phases:

[4] See SCT, 2011 for geomechanical assessments
[5] For variably saturated conditions, the unsaturated conductivity is generally lower than the fully saturated conductivity.

- 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 a longwall 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 the surface. Soil structure, runoff and other conditions may lead to infilling of the aperture by unconsolidated fine materials before closure is induced by the migrating subsidence wave.

Crack length could vary from less than a metre to more than 10 m with a variable aperture possibly ranging from a few mm to 50mm or more 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 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 fractures are 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 groundwater storage (in the hardrock) 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 10 m. The subsidence report (MSEC (2013) Figures 5.2 to 5.5 provides plots of the total strains for vertical 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 horizontal 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 shallow rock may absorb strain energies within the porous matrix resulting in very limited cracking. An estimate of groundwater losses has been generated by 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. This yields a cumulative crack/fissure water storage of about 0.9 kL/m of panel. 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 within 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 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 some 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 will occur as a result of subsidence. The change will depend upon location and prevailing hydrological factors. A maximum subsidence of the order of 2.4 m is predicted in areas of elevated hardrock terrain which are predominantly areas of State forest while in alluvial areas, a maximum subsidence of the order of 1.4 m is predicted.

In the elevated hard rock areas, the groundwater gradients are only likely to change in a relatively minor way since topographic slope is much greater than the impact of subsidence ie. relative changes in water table elevation 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 the same magnitude as subsidence. Groundwater levels in the shallow weathered rock zone will continue to fluctuate in response to rainfall recharge.

Alluvial areas affected by subsidence are identified on Figure 11 and are delimited by subsidence zones at 0.5m intervals. In areas with slopes of less than 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 lowering the water table in the unsubsided area and raising the water table in the subsided area.

This 'continuum' will result in a temporary 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 considered using groundwater flow modelling techniques.

### *5.2.1 Shallow alluvial systems modelling relating to subsidence*

A separate generic groundwater flow 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 a means of considering various geometric relationships between subsided panels and an unsubsided drainage line or creek. Appendix F provides a summary of model design.

Alluvial materials encountered within the Dooralong Valley are expected to exhibit inhomogeneous hydraulic properties distributions. Consequently the analytical approach adopted to assess changes in the water table, 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 10 m/day consistent with the planned coal face progression in a panel. Four different hydraulic conductivities ranging from 0.1m/day to 5m/day have been applied to the alluvial sediments in separate modelling scenarios.

Results of simulations are provided in Appendix F. These results indicate that within a subsided panel, the water table (which is displaced downwards relative to an unsubsided area) will rebound more slowly for the lowest hydraulic conductivity with about 55% rebound observed after 200 days[6] for a conductivity of 0.1m/day. Approximately 75% rebound after 200 days is predicted for a conductivity of 0.5m/day. It is noted that these simulations are conservative and assume very low rates of rainfall recharge to the area (less than 1 mm/year or 0.1% of annual rainfall) consistent with dry weather or drought conditions. Recent monitoring of water table fluctuations attributed to rainfall, indicates response times of just a few days.

[6] 200 days is a reasonable estimate of the time taken for the next longwall panel to be extracted in areas beneath the Dooralong valley alluvial lands

The effect of subsidence on creek flows will vary in space and time. Essentially, contributions from groundwater migration from unsubsided to subsided areas, rainfall runoff (percolation) and leakage from surface drainage channels will need to recharge subsided parts of the groundwater system by an amount less than or equal to the porous storage displaced vertically downwards, until quasi-equilibrium is achieved whereby movements in the water table are in response to rainfall recharge. Equilibrium is expected to be restored when an adjacent panel is subsided.

The potential temporary increases in alluvial groundwater storage have been calculated from subsided panel areas (shown on Figure 11) and are summarised in Table 4 based on the proposed schedule of panel extractions and an average sediment drainable porosity of 20%. The maximum storage increase and hence maximum demand on recharge from rainfall and surface drainages is expected during extraction of panel LW9N when 181 ML is estimated to fully replenish the subsided panel area over a period of 8 to 10 months before the adjacent panel LW10N is subsided. The actual storage increase will depend upon the permeability and effective porosity of the alluvial materials at a specific location - the lower the permeability and porosity, the smaller will be the temporary increase in groundwater storage.

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

| Panel | Mine year | Mine year | ML storage | Drainage catchment |
|---|---|---|---|---|
| **LW1N** | 3.0 | 3.5 | 11 | Hue Hue Ck |
| **LW2N** | 3.5 | 4.0 | 4 | Hue Hue Ck |
| **LW3N** | 4.1 | 4.6 | 2 | Hue Hue Ck |
| **LW4N** | 4.9 | 5.5 | 0 | Hue Hue Ck + Jilliby Jilliby Ck |
| **LW5N** | 5.6 | 6.3 | 29 | Hue Hue Ck + Jilliby Jilliby Ck |
| **LW6N** | 6.5 | 7.2 | 55 | Jilliby Jilliby Ck |
| **LW7N** | 7.3 | 8.2 | 92 | Jilliby Jilliby Ck |
| **LW8N** | 8.4 | 9.2 | 136 | Jilliby Jilliby Ck |
| **LW9N** | 9.3 | 10.1 | 181 | Jilliby Jilliby Ck |
| **LW10N** | 10.2 | 11.0 | 173 | Jilliby Jilliby Ck |
| **LW11N** | 11.1 | 12.0 | 163 | Jilliby Jilliby Ck + Little Jilliby Ck |
| **LW1S** | 12.1 | 12.5 | 83 | Jilliby Jilliby Ck |
| **LW2S** | 12.5 | 13.2 | 119 | Jilliby Jilliby Ck + Armstrongs Ck |
| **LW3S** | 13.3 | 14.0 | 92 | Jilliby Jilliby Ck + Armstrongs Ck |
| **LW4S** | 14.1 | 14.8 | 62 | Jilliby Jilliby Ck + Armstrongs Ck |
| **LW5S** | 14.9 | 15.6 | 37 | Armstrongs Ck |
| **LW6S** | 15.7 | 16.3 | 19 | Armstrongs Ck |
| **LW7S** | 16.4 | 17.0 | 24 | Armstrongs Ck |
| **LW8S** | 17.1 | 17.7 | 12 | Armstrongs Ck |
| **LW9S** | 17.8 | 18.3 | 0 | Armstrongs Ck |
| **LW10S** | 18.4 | 19.0 | 5 | Armstrongs Ck |
| **LW1SW** | 19.1 | 19.8 | 7 | Little Jilliby Ck + Wyong R |
| **LW2SW** | 19.8 | 20.5 | 5 | Little Jilliby Ck + Wyong R |
| **LW3SW** | 20.6 | 21.2 | 5 | Little Jilliby Ck + Wyong R |
| **LW4SW** | 21.3 | 21.9 | 5 | Little Jilliby Ck + Wyong R |
| **LW5SW** | 22.0 | 22.6 | 6 | Little Jilliby Ck + Wyong R |
| **LW6SW** | 22.7 | 23.2 | 8 | Little Jilliby Ck + Wyong R |
| **LW12N** | 23.3 | 24.2 | 114 | Jilliby Jilliby Ck + Little Jilliby Ck |
| **LW13N** | 24.3 | 25.1 | 116 | Jilliby Jilliby Ck + Little Jilliby Ck |
| **LW14N** | 25.2 | 26.0 | 88 | Jilliby Jilliby Ck + Little Jilliby Ck |
| **LW15N** | 26.2 | 26.9 | 44 | Jilliby Jilliby Ck + Little Jilliby Ck |
| **LW16N** | 27.0 | 27.8 | 5 | Jilliby Jilliby Ck + Little Jilliby Ck |
| **LW17N** | 27.9 | 28.6 | 0 | Jilliby Jilliby Ck + Little Jilliby Ck |
| **LW18N** | 28.7 | 29.4 | 0 | Jilliby Jilliby Ck + Little Jilliby Ck |
| **LW19N** | 29.5 | 30.2 | 0 | Little Jilliby Ck |
| **LW20N** | 30.4 | 31.0 | 0 | Little Jilliby Ck |
| **LW21N** | 31.2 | 31.9 | 0 | Little Jilliby Ck |
| **LW22N** | 32.0 | 32.7 | 0 | Little Jilliby Ck |
| **LW23N** | 32.8 | 33.4 | 0 | Little Jilliby Ck |
| **LW24N** | 33.6 | 34.2 | 0 | Little Jilliby Ck |
| **LW25N** | 34.3 | 35.0 | 0 | Little Jilliby Ck |
| **LW26N** | 35.2 | 35.9 | 0 | Little Jilliby Ck |

| | | | | |
|---|---|---|---|---|
| **LW7SW** | 36.0 | 36.5 | 0 | Little Jilliby Ck + Wyong R |
| **LW8SW** | 36.6 | 37.1 | 0 | Little Jilliby Ck + Wyong R |
| **LW9SW** | 37.2 | 37.7 | 0 | Little Jilliby Ck + Wyong R |
| **LW10SW** | 37.8 | 38.1 | 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 proposed development include:

- Reduction in regional hard rock groundwater pressures;
- Leakage of groundwater from shallow alluvial sediments 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 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. The pressure loss regime has been assessed using groundwater flow modelling techniques described in Section 4 above and in Appendix E. Zero pore pressure is predicted to migrate upwards from extracted panels, potentially to the lower part of the Tuggerah Formation about 220 m above the coal seam during mining . This will in turn generate pressure gradients within the remaining part of the Tuggerah Formation and in parts of the overlying Patonga Claystone. These gradients will be sustained by downwards leakage from the alluvial lands or from hardrock systems beyond the alluvial lands.

The overall pressure loss envelope is predicted to generate seepage to the mine workings and to goaf. The seepage rate is predicted to rise from about 0.1 ML/day during initial development, to approximately 2.5 ML/day during mining. It is possible that pre-mining discrete fracture networks may be intercepted from time to time within the subsidence zone. These networks could lead to short term increases in groundwater seepage that may persist for periods of several weeks to months at rates possibly as high as 0.5 ML/day but as storage in the fractures is depleted, seepage rates are expected to decline.

## 6.2 Leakage of groundwater from shallow groundwater systems

In respect of subsidence induced fracturing, SCT (1999 and 2011) have conducted simulations of the subsidence regime and determined that cracking above goafed zones would not exhibit connectivity from seam to surface. Instead, a significant zone of at least 100 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. This constrained zone has been represented in the groundwater models

The potential downwards leakage from shallow alluvial aquifer systems through the constrained zone, has been assessed by modelling, to be less than 2 millilitres/day per square metre of land surface – a rate that is small and easily balanced by recharge from rainfall which is estimated at 130 millilitres/day per square metre assuming a minimum 4% of annual rainfall. The approximate alluvial area subjected to this leakage loss is estimated to be about 9.3 sq.km. Hence the total leakage loss from the alluvial lands is calculated to be about 0.02 ML/day at the end of mining.

## 6.3 Change in shallow groundwater system storage induced by subsidence

A change in shallow groundwater storage will result from subsidence. The change is likely to be transient and would occur through either temporary filling of tensile cracking storage 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, recovery of local water levels within the unconsolidated strata would exhibit a variable impact depending upon location.

Subsided alluvial areas will exhibit a temporary increase in groundwater storage as each panel is displaced downwards and groundwater migrates from the unsubsided area to the subsided area. This will result in a potential for the water table to decline (locally) in parts of the unsubsided panel and to rise in the subsided panel. The rate of recovery will depend largely upon climatic conditions with slower rebound occurring during drought periods. Under drought conditions, calculations indicate between 55 and 75% of rebound could be expected within about 6 months of subsidence occurring. Measured water table responses suggest rapid recovery is likely to occur during normal and above average rainfall periods. Yarramalong Valley sediments are predicted to remain generally unaffected except in areas immediately south-west of longwalls LW11S to LW18S where the alluvium is in proximity to the panel footprint. In these areas the storage related impacts is expected to be minor since alluvial lands subsidence is predicted to be minor.

## 6.4 Loss of groundwater yield at existing bore locations

There are 12 boreholes located within the area of subsidence that may exhibit some 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 1.4 m (alluvium subsidence) but 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) | Groundwater intercept + yield (L/s) | Water depth (m) | Water quality | Bore Geology |
|---|---|---|---|---|---|---|---|
| | E | N | | | | | |
| GW028035<br>20BL021424<br>P | 348750 | 6318275 | 30.5 | 19.8-<br>25.2m/1.26 | 7.60 | good | 0.0-4.8 clay<br>4.8-6.7 s/s<br>6.7-18.3 clay<br>18.3-20.4 s/s<br>20.4-24.4 sh<br>24.4-30.5 s/s |
| GW033297<br>20BL026199<br>W,D | 348930 | 6321110 | 19.8 | 17.6-<br>19.7m/0.25 | 4.60 | nil | 0.0-10.66 clay<br>10.66-11.88 s/s<br>11.88-17.67 sh<br>17.67-19.81 s/s |
| GW051560<br>20BL111424<br>F,S | 348160 | 6322940 | 33.0 | 28.0m/5.0 | 13.0 | nil | 0.0-19.0 clay<br>19.0-33.0 s/s |
| GW056521<br>20BL122843<br>D,S | 345687 | 6321210 | 45.0 | nil | nil | nil | 0.0-8.0 clay<br>8.0-25.0 s/s<br>8.0-25.0 sh<br>25.0-44.0 s/s<br>44.0-45.0 sh |
| GW058390<br>20BL127954<br>D | 345575 | 6321050 | 0.00 | nil | nil | nil | nil |
| GW059092<br>20BL135236<br>D,S | 349070 | 6320630 | 38.0 | 24.0-<br>25.0m/1.26 | 15.0 | salty | 0.0-16.0 clay<br>16.0-38.0 sh s/s |

| Bore | Coordinates (AMG) | | Depth (m) | Groundwater intercept + yield (L/s) | Water depth (m) | Water quality | Bore Geology |
|---|---|---|---|---|---|---|---|
| | E | N | | | | | |
| GW078221<br>20BL166822<br>I | 349022 | 6319270 | 60.0 | 28.9-30.0m/0.13 | 26.0 | fresh | 0.0-16.5 clay<br>16.5-28.9 mud<br>28.9-42.6 cong<br>42.6-53.0 mud<br>53.0-60.0 cong |
| GW080608<br>20BL169008<br>D,S | 349520 | 6321281 | 48.0 | 41.0-45.0m/0.40 | 3.20 | nil | 0.0-36.0 sands<br>36.0-48.0 sh |
| GW078609<br>D | 348866 | 6323656 | 32.0 | nil | nil | nil | 0.0-6.0 soil/clay<br>6.0-30.0 s/s<br>30.0-32.0 mudstone |
| GW200505<br>D,S | 350914 | 6322022 | 54.0 | 26.4-26.9m<br>48.5-49.3m | nil | fresh | 0.4-4.9 clay<br>4.9-6.5 gravel<br>6.5-26.4 clay<br>26.4-26.9 clayey gravel<br>26.9-31.4 clay<br>31.4-49.3 cong<br>49.3-50.1 clay<br>50.1-54.0 cong |
| GW058391<br>D | 345728 | 6321244 | nil | nil | nil | nil | nil |
| GW058392<br>D | 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 water quality will be observed in the shallow unconsolidated alluvial groundwater system post mining since subsided areas will essentially reflect unsubsided conditions with respect to aquifer material properties and surface drainage systems when mining is completed in a panel.

However within the shallow weathered zone in consolidated hardrock areas beyond the alluvial lands), a number of naturally occurring ferruginous springs have been identified. The locations of these springs in the upper catchment reaches of Jilliby Jilliby and Little Jilliby Jilliby Creeks, are shown on Figure 12 as sites A1, C1, C2, I and J (Marine Pollution Research, 2013). The occurrence of iron in surface waters is largely attributed to the dissolution of the mineral siderite (iron carbonate) which has been identified in parts of the Terrigal Formation. The mineral marcasite-pyrite (iron sulfide) may also be present at some locations (eg. Site A1) but core sample analyses suggest their presence is relatively minor based on X-ray diffraction (see Appendix C, Table C2).

Observed channel staining downstream of the ferruginous springs is attributed to dissolved iron reacting rapidly with oxygenated water and leading to bacterially mediated precipitation of iron (as oxy-hydroxides). Since these flow systems are commonly ephemeral, the iron staining and bacterial matting will dissipate during dry periods when flow ceases. During wet periods, the matting and dissolved phases of iron, may be transported downstream.

It is likely that subsidence induced surface cracking of hard rock strata will initiate re-direction of surface flows into some related cracks at some locations thereby promoting new water-rock hydrochemical interactions with the potential for new ferruginous springs to develop. Candidate locations cannot be identified since neither the mineralogy nor the precise location, extent persistence or connectivity of surface cracks can be predicted with any certainty.

### 6.5.1 Storage of brine in underground operations

A detailed water balance has been undertaken for the Project as part of a surface water impact assessment. The water management strategy provides for the treatment of mine water and surface water sourced from hardstand and stockpile areas in a combined reverse osmosis (RO) water treatment plant and brine treatment plant. The clean treated water output will be suitable for mine related uses for the project and available for licensed discharge to Wallarah Creek to supplement environmental flows.

The water management assessment (WRM, 2013)[7] considered the case of a combined RO and brine treatment plant to provide a near-solid salt waste product and a concentrated brine waste product. The WACJV propose to emplace the near solid waste for the first 11 years of operation, in dedicated development headings located to the east of longwall LW1 as shown on Figure 13. These compartments would be sealed when filled. Subsequently, the brine would be emplaced in goaves.

The stored salt waste (solids and brine) is expected to remain relatively immobile as re-saturation of the coal seam and surrounding strata occurs post mining. Immobility is attributed to the exceptionally slow rate of recovery of water levels and pore pressures post mining; after more than 500 years, water levels in the workings are predicted to have recovered (up dip) about 110 m from an initial minimum elevation of about –480 mAHD to about -370 mAHD. This elevation is above the deepest goaves hosting the brine, but still below the elevation of the stored solid waste. The mine is therefore predicted to act as a groundwater sink for the foreseeable future with sustained inward flow of groundwater inhibiting migration of brines as indicated by the drawdown distribution shown on Figure E26, Appendix E. In addition, the much higher density of the waste salt-brine when compared to formation groundwater, is expected to promote salinity stratification with the higher density brines residing at the base of the recovering water column and formation groundwater residing at the top of the column. These densities are summarised in the following Table 6.

***Table 6: Salinities and densities of formation and waste waters from the surface facilities***

| | Salinity (mg/L) | Density (gm/cc) 25°C |
|---|---|---|
| Coal seam groundwater | 7500 | 1.003 |
| Hyper saline (solid) waste salt (first 11 years) | 707500 | 1697.0 |
| Brine (after 11 years) | 290500 | 1237.6 |

## 6.6 Impact on groundwater dependent ecosystems

Groundwater dependent ecosystems have been identified by Cumberland Ecology and are shown on Figure 12. These systems are located along and adjacent to both major and minor surface drainage channels. The identified flora comprise Paperbark, Coachwood, Blackbutt and other species that rely on the shallow water table or upon soil moisture in the unsaturated zone. Potential impacts upon these systems relate to displacement of the water table as a result of subsidence.

Calculations and generic groundwater flow modelling of the displacements associated with subsidence in the alluvial lands (Appendix F) indicate minimal impact on the water table due to the relatively low permeability of alluvial materials. That is, as one area is subsided relative to an adjacent area, the groundwater will migrate slowly from the unsubsided area to the subsided area with highest rates of flow occurring in the zone of maximum tilt. Rainfall is expected to rapidly recharge the system (as evidenced by historical water table monitoring) with restoration of conditions that are expected to be very similar to pre-mining conditions.

[7] WRM, 2013 see Section 3.4

In elevated terrain and forested areas, the permanent water table is generally predicted to be deeper than the weathered rock and regolith. In these areas the trees and plants are unlikely to draw moisture from this deep water table. Instead they probably rely upon soil moisture within the unsaturated zone which is sustained by rainfall and runoff. Conditions in this shallow zone are not expected to change significantly post-subsidence and as such the identified groundwater dependent ecosystems are not expected to be impacted by mining related changes to the groundwater systems in the long term.

## 7. WATER SHARING PLANS

Groundwaters are not part of the water resources that are defined within the Water Sharing Plans applicable to the area. However it is possible that subsidence in the alluvial lands may induce temporary leakage from surface drainage systems to subsided panels as the groundwater table re-equilibrates. This scenario is most likely in alluvial areas adjacent to Jilliby Jilliby Creek or its tributaries while in areas more distant from the creek(s), groundwater movement and rainfall runoff infiltration is likely to provide the greatest contribution. The highest groundwater storage increase is associated with LW9N[8] where it is estimated that 181 ML may accrue before the adjacent panel LW10N acts to mitigate the increase.

It is also possible that subsidence associated LW6SW in the Wyong River catchment may initiate a localised increase of approximately 8ML in groundwater storage.

Given a measure of uncertainty in respect of permeability and effective porosity of the alluvium at a local scale, a conservative approach is considered to be appropriate. Accordingly, 300ML per annum could be redirected from runoff and baseflow contributions to temporary storage within the alluvial lands. With respect to the current Water Sharing Plans and future accounting (licencing), this volume of water could be distributed as 270 ML in relation to the Jilliby Jilliby Creek Water Source and 30 ML in relation to the Central Coast Unregulated Water Sources.

## 8. AQUIFER INTERFERENCE AND LICENSING REQUIREMENTS

The AIP identifies two groundwater sources – highly productive systems and less productive systems. The alluvial groundwater systems contained within the Dooralong and Yarramalong valleys are regarded as less productive systems due to the generally low permeability of these materials and the increasing salinity with depth. The less productive nature of the systems is also reflected in the small number of boreholes that have been constructed.

Groundwater related impacts on the alluvial lands have been assessed in respect of minimal harm criteria prescribed in Table 1 of the AIP as follows:

- ***Water table (1)*** *– Impacts to be less than or equal to 10% cumulative variation in the water table and 40 m from any high priority groundwater dependent ecosystem or high priority culturally significant site.* There are no high priority groundwater dependent ecosystems or high priority culturally significant sites identified in the WSP for Jilliby Jilliby Creek or the WSP for the Central Coast Water Supply.
- ***Water table (1)*** *– A maximum of 2 m decline at any water supply work is allowed unless make good provisions apply.* Maximum subsidence is predicted to be 1.4 m which is within the maximum 2 m prescribed range.
- ***Water pressure (1)*** *– A cumulative pressure head decline of not more than 40% (maximum 2 m) of the post water sharing plan pressure head above the base of the water source is allowed.* Maximum subsidence is predicted to be 1.4 m which is within the prescribed 2 m decline. However in subsided areas where the alluvium pinches out along the valley sides the pressure head decline could exceed 40% since the saturated thickness of alluvium

[8] See Table 4

reduces rapidly (with pinch out). The long term viability of the water source in these peripheral areas is not expected to be affected as the system will re-equilibrate.

- ***Water quality (1a)*** - *Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity*. No long term change in water quality is predicted since subsided areas will essentially reflect unsubsided conditions with respect to aquifer material properties, rainfall recharge and surface drainage systems when mining is completed.
- ***Water quality (1b)*** - *Increase in salinity to be less than 1% of the long term average salinity.* No long term change in salinity is predicted since subsided areas will essentially reflect unsubsided conditions with respect to aquifer material properties, rainfall recharge and surface drainage systems when mining is completed.
- ***Water quality (1c)*** - *Mining activity should not be undertaken within 200 m laterally or 100 m vertically of the water source.* While there is no direct mining activity within these prescribed limits, consequential subsidence has direct impact on the alluvial groundwater systems. However the impacts are not likely to affect the long term viability of the water source.

Licensing in respect of groundwater seepage from the hard rock water bearing strata 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 and adjacent strata 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.

Additionally, long term (sustained) leakage losses from shallow groundwater systems are estimated to be about 0.02 ML/day (7.3 ML/day) from the shallow alluvial system and less than 0.08 ML/day (29.2 ML/day) from the hardrock groundwater system.

## 9. GROUNDWATER RESOURCES MONITORING

A comprehensive groundwater monitoring programme should be developed (post approval) 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. All monitoring data 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.

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 Project environmental services group and/or their appointed consultants.

## 9.1 Impacts verification criteria

Groundwaters are not currently monitored beyond Honeysuckle Park due to restricted access to existing monitoring locations. The originally installed 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 groundwater systems associated with the Dooralong and Yarramalong valleys;
- 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 to those predicted by current groundwater flow modelling. This might occur if as yet unidentified major regional faulting was intercepted and was found to provide vertical connectivity between the shallow alluvial systems and mine workings. However, this is considered highly unlikely since extensive geological investigations have not indicated the presence of any major faults in the proposed mining area (see geological report WACJV, 2013). Furthermore, exploratory-gas longhole (horizontal in seam) drilling normally provides a means of detection for such features and mine planning can then accommodate appropriate measures to ensure the resultant subsidence impacts are minimised of eliminated in these areas.

In any event, assessment criteria need to be incorporated within a Groundwater Management Plan for monitoring and verification of any future impacts. Criteria should 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 suitable for monitoring of the first longwall panels. Additional installations will need to be strategically located to assess vertical depressurisation associated with subsequent panels in order to verify and validate regional impacts;
- Additional piezometers will be required to monitor pore pressures after cessation of mining. Transducers will need to be installed from seam elevation to about 50m below surface in order to track recovery of pressure heads within the hardrock system. Salinity monitoring devices may also need to be installed at this time to monitor brine emplacements;
- 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 ventilation humidity and routine monitoring of ROM coal moisture content delivered from the working face in order to more accurately determine the underground water balance.

Water quality monitoring should include:

- Quarterly monitoring of basic water quality parameters pH and EC/TDS in selected piezometers and pumped mine water. Such monitoring may provide early indication of mixing of shallow groundwaters with waters 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 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 programme should be reviewed on an annual basis to determine ongoing suitability and any proposed changes should be discussed in the Annual Review (formerly 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 0.5 ML/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 groundwater model predictions biennially. Expert review should be undertaken by a suitably qualified hydrogeologist or groundwater engineer;
- Annual reporting (including all water level and water quality data) as part of the Annual Review.

## 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 and/or modification of the mine plan.

### 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., (CPI) 1998. Wyong groundwater study. *Report prepared for Coal Operations Australia Ltd.*

EcoEngineers, 2010. Assessment of hydrogeochemical effects of mine subsidence in vertical fractures and claystone bedding planes in upland Terrigal Formation sandstone. *Letter report prepared for Kores, 2010.*

EcoEngineers, 2012. Follow-up baseline surface water quality survey – Wallarah 2 Project – sites A1 and A2. *Letter report prepared for Kores, 2012.*

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. 2009. Modflow-Surfact user manual.

Mackie Environmental Research, 2009. Wallarah 2 Coal Project. Groundwater management studies. *EA report prepared for Kores, October 2009.*

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.*

Marine Pollution Research P/L, 2013. *Wallarah 2 Coal Project, Aquatic Ecology Impact Assessment. Report prepared for WAJCV, June 2013.*

MSEC, 2013. Assessment of mine subsidence impacts on the natural features and surface infrastructure for the Wallarah 2 coal project. *Report MSEC 515, 2013.*

Pitman, W.V., 1973. A mathematical model for generating daily river flows from meteorological data in South Africa. HRU Report 2/76

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

SCT Operations Pty. Ltd., 2011. Wyong western area computer modelling. *Report prepared for Kores Australia, September 2011.*

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

WACJV (2013) – Wallarah 2 Coal Project Geology Report, Wyong Areas Coal Joint Venture, February 2013

WRM (2013) - Wallarah 2 Coal Project Surface Water Impact Assessment, *WRM Water & Environment Pty Ltd Report to Hansen Bailey Environmental Consultants, February 2013.*

**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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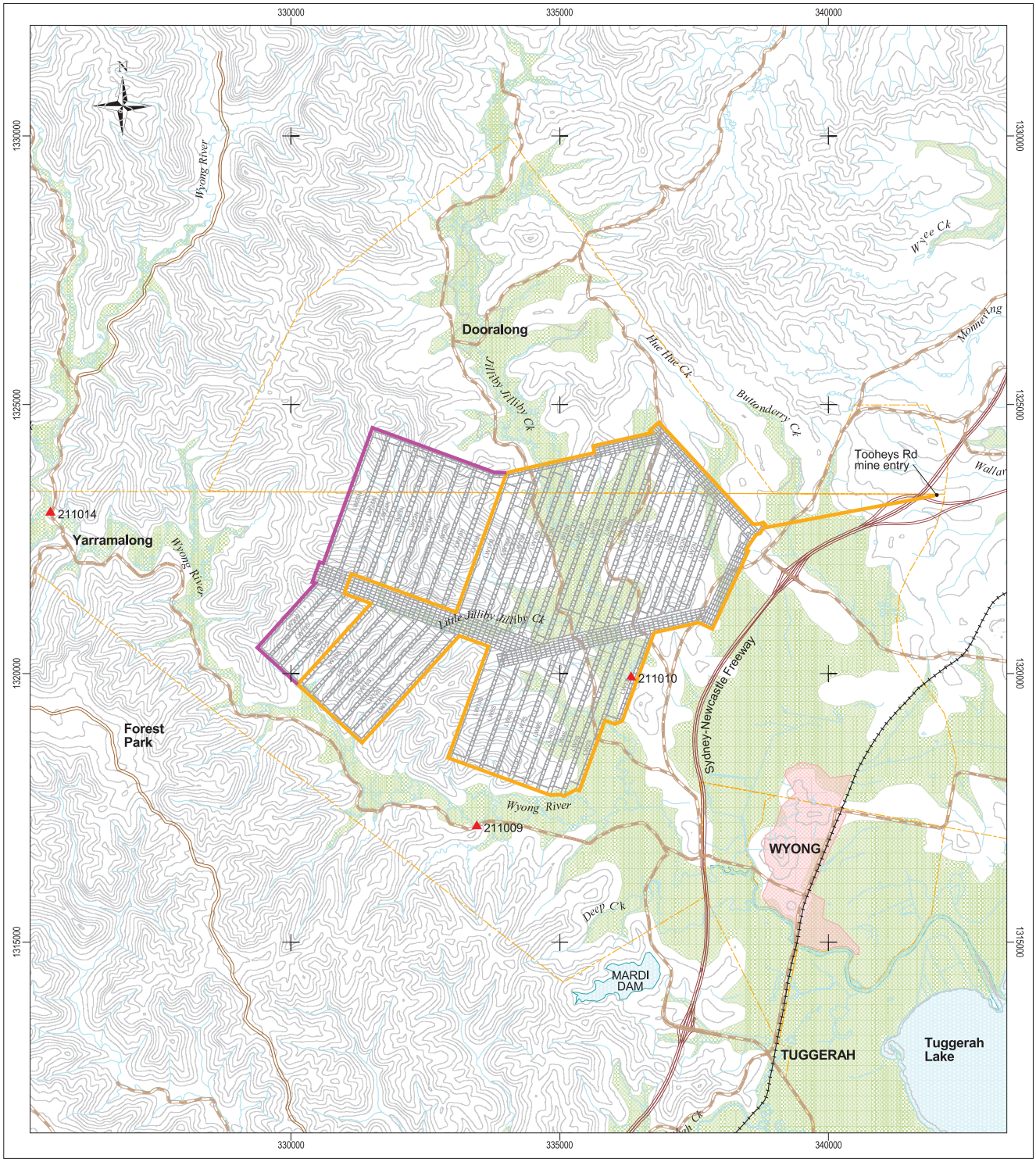
Dr. C. Mackie

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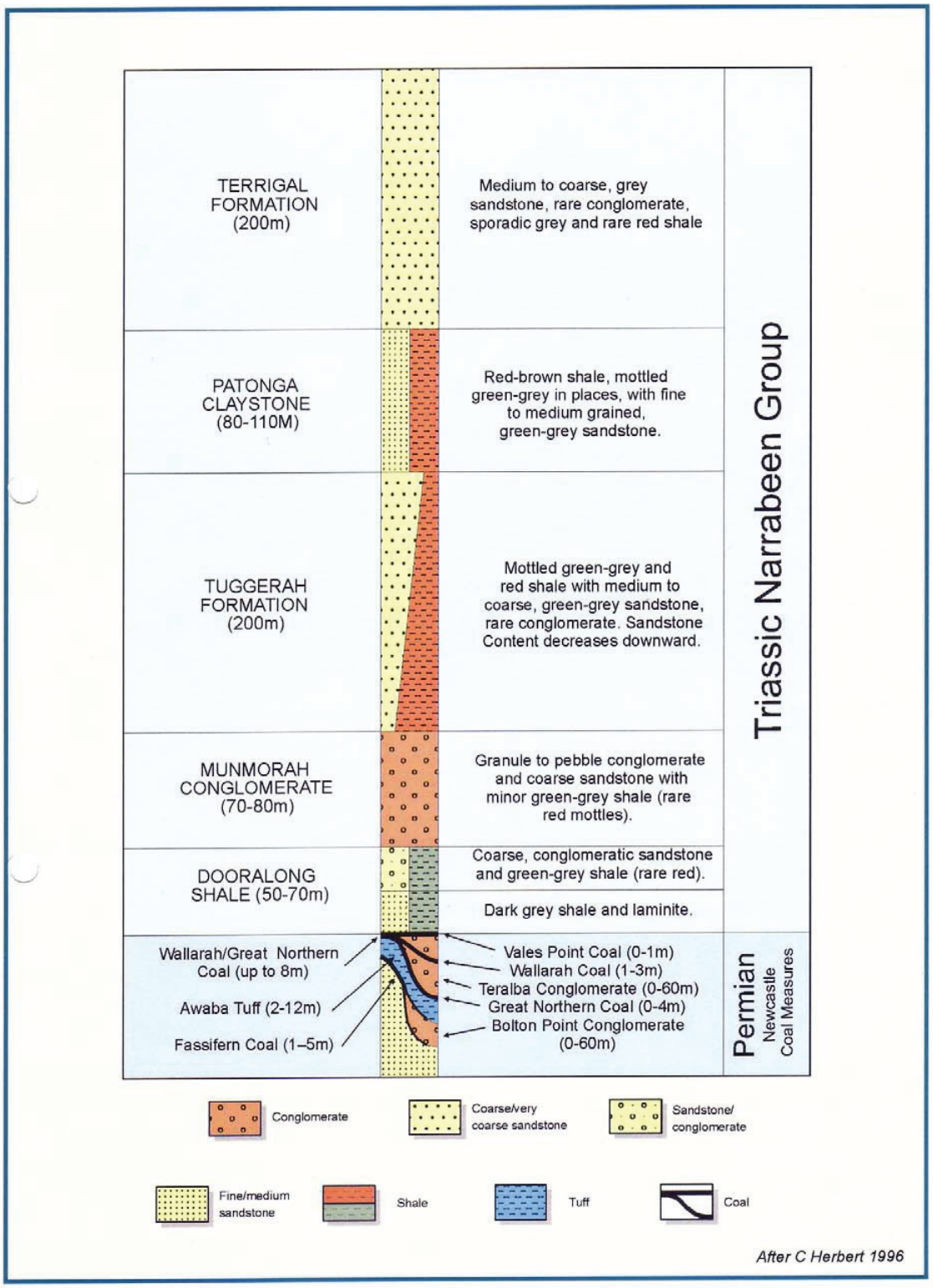
Scale 1:100,000

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

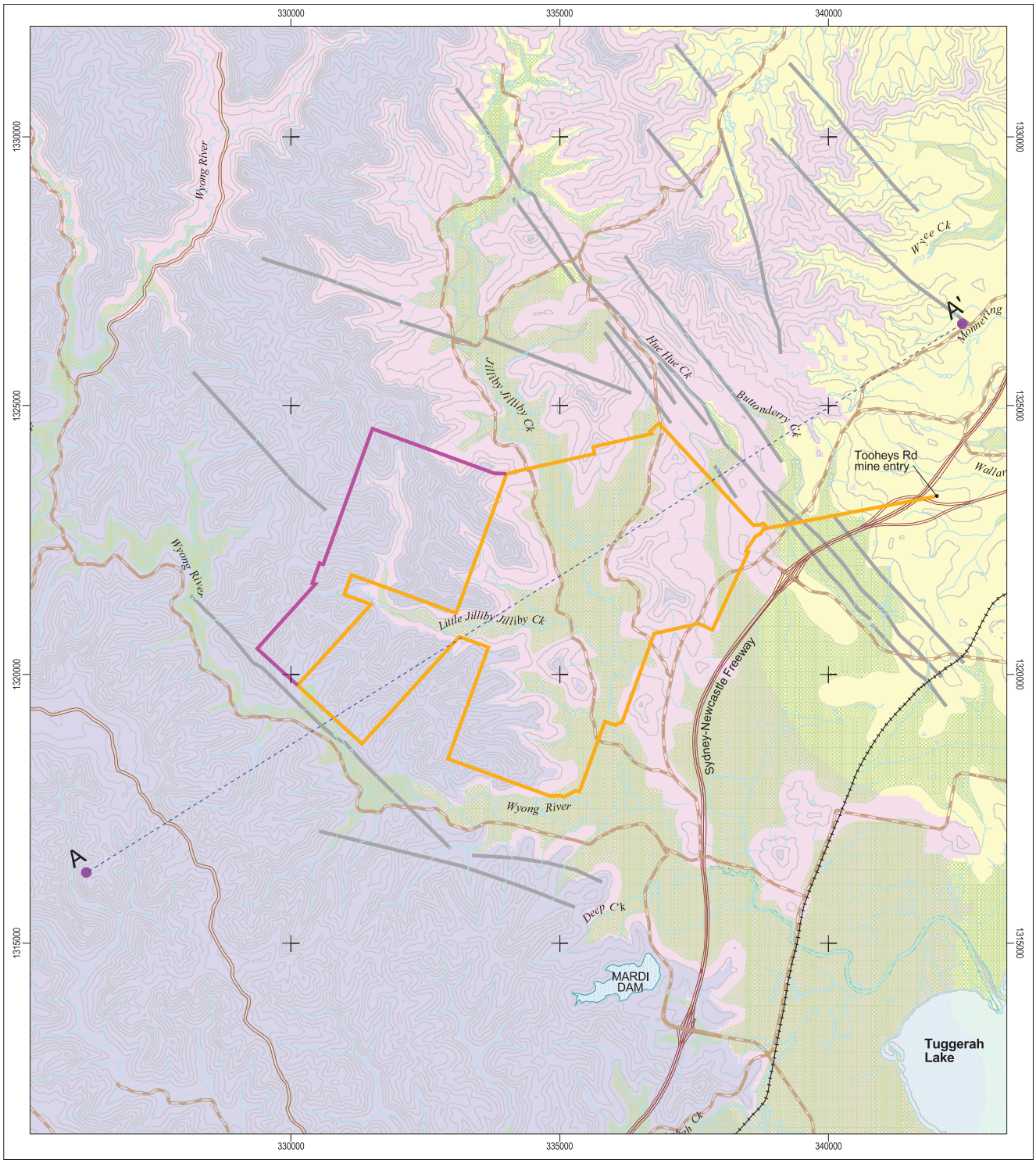
WALLARAH 2 COAL PROJECT

**Regional locality map and proposed mine plan**

*Figure 1*




**Stratigraphic column**
*Figure 2*




0 2000 4000 6000 Metres

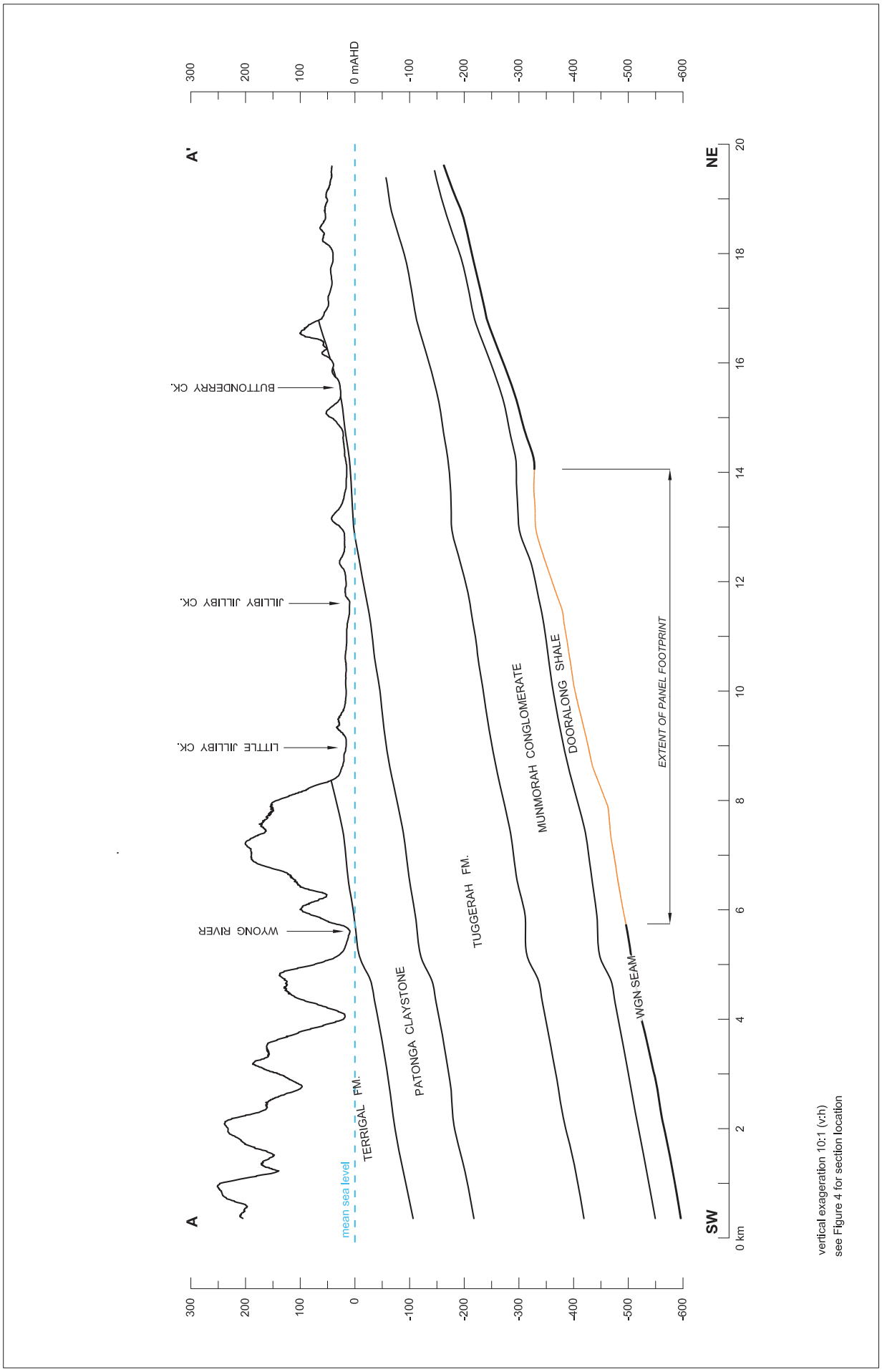
Scale 1:100,000

- creeks
- minor road
- sealed road
- Freeway
- railway
- lease
- Terrigal Fm.
- Patonga Claystone
- Tuggerah Fm.
- alluvium
- 28 years mine footprint
- 38 years mine footprint
- inferred dyke

WALLARAH 2 COAL PROJECT

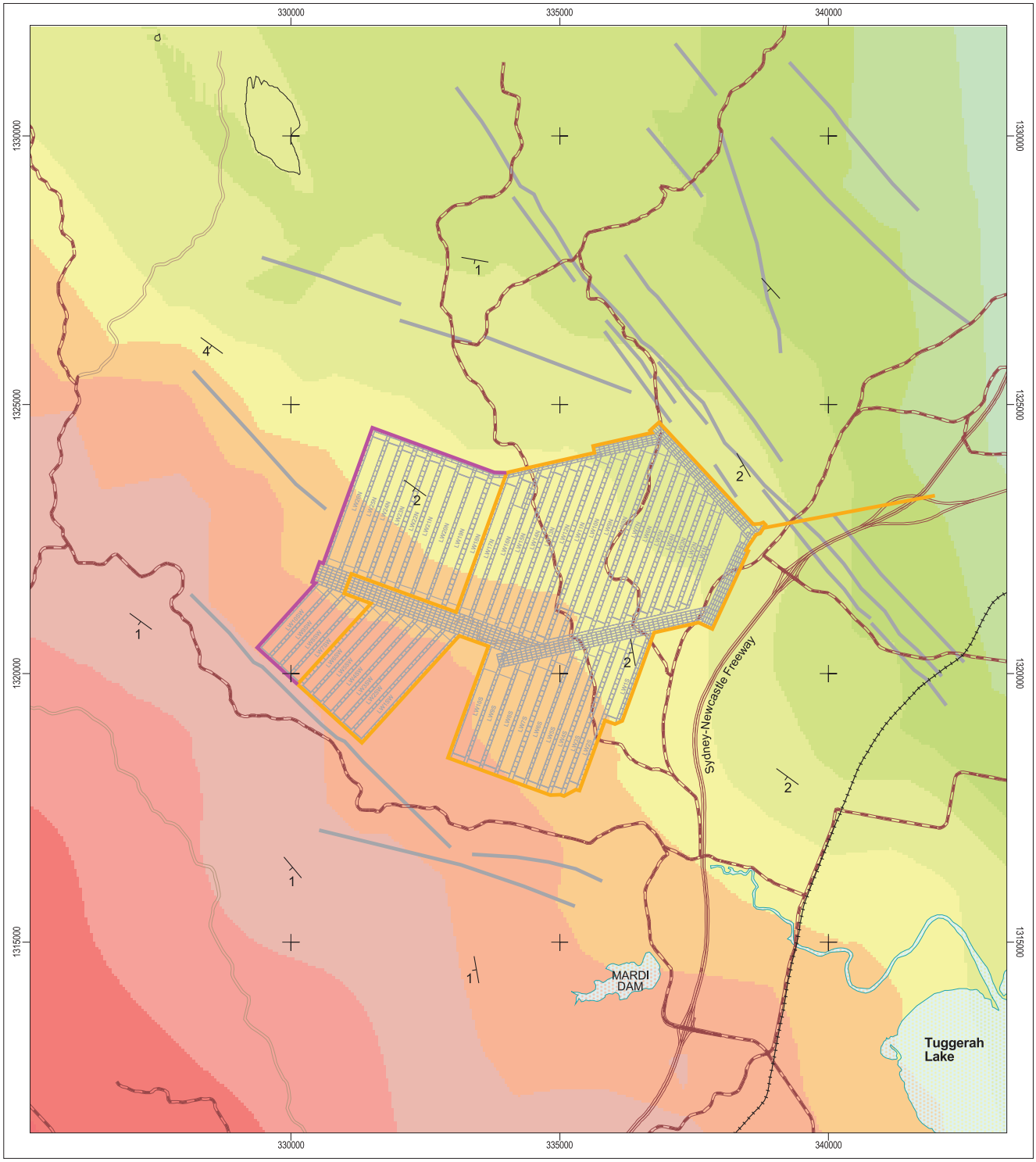
**Regional subcrop geology**

*Figure 3*




**SW-NE Section through proposed mine plan**

*Figure 4*




0 2000 4000 6000 Metres

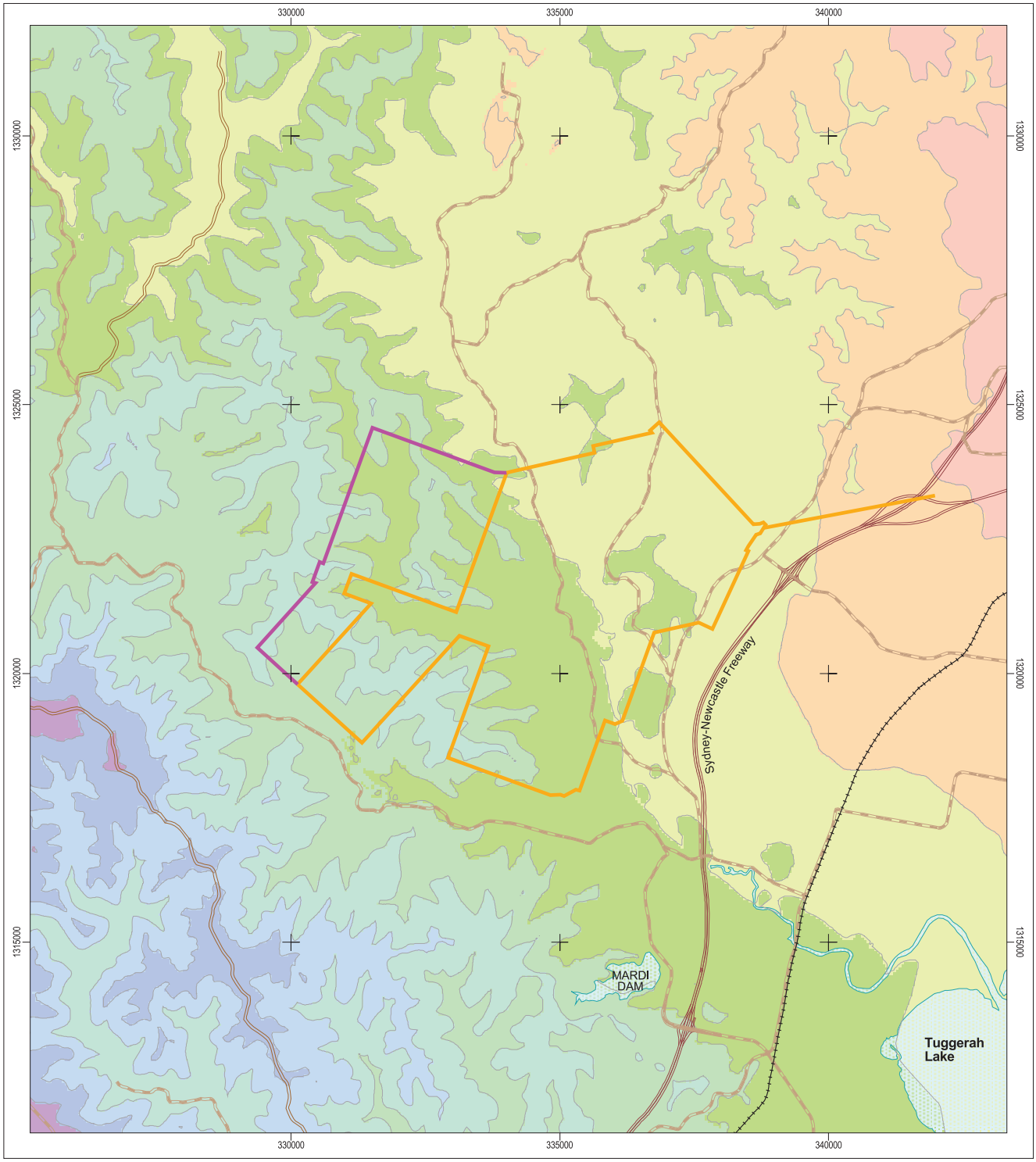
Scale 1:100,000

-700 - -650mAHD
-650 - -600
-600 - -550
-550 - -500
-500 - -450
-450 - -400
-400 - -350
-350 - -300
-300 - -250
-250 - -200
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*




0 2000 4000 6000 Metres

Scale 1:100,000

Depth of cover (m)

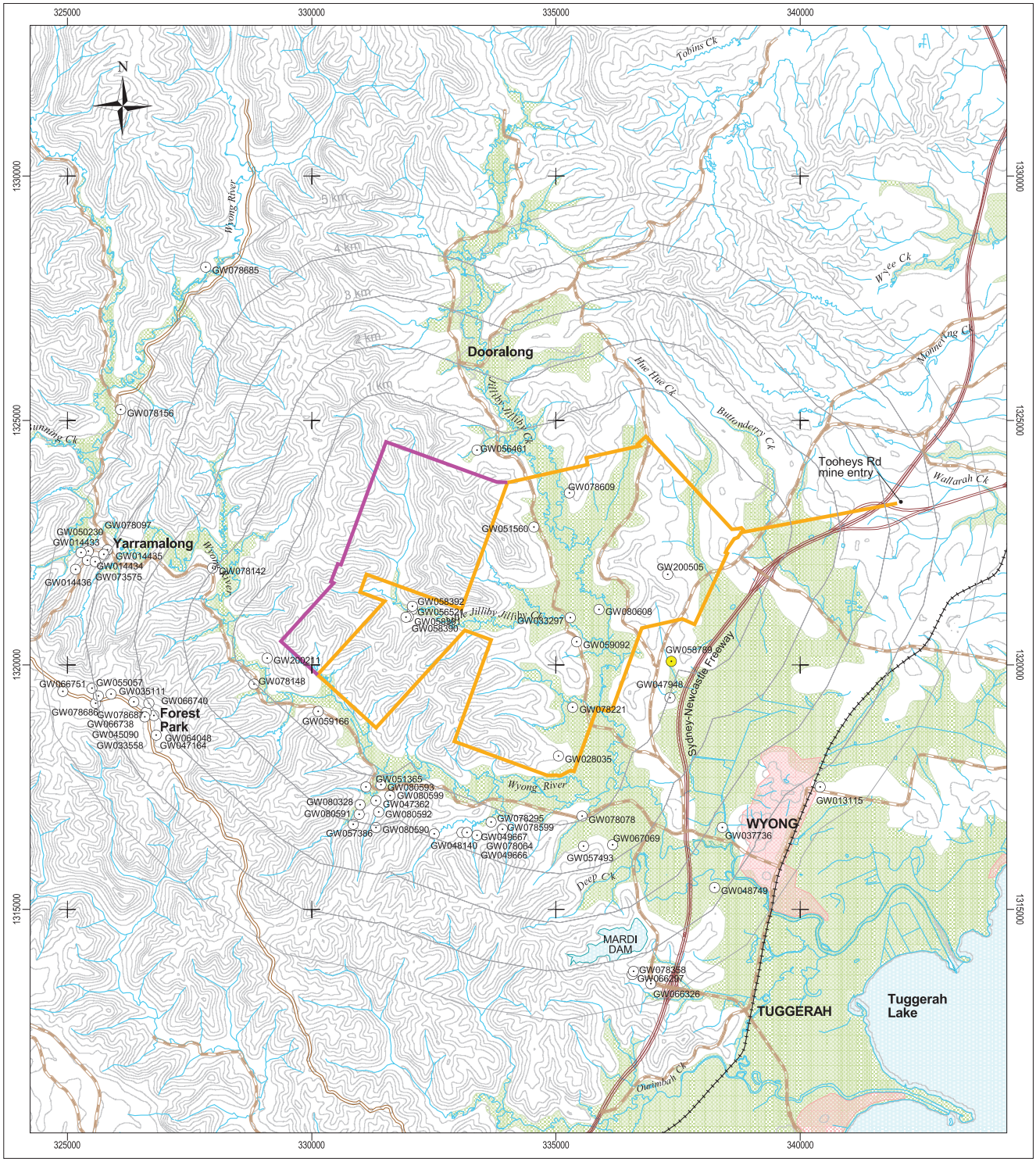
- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1000

- 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*




0 2000 4000 6000 Meters

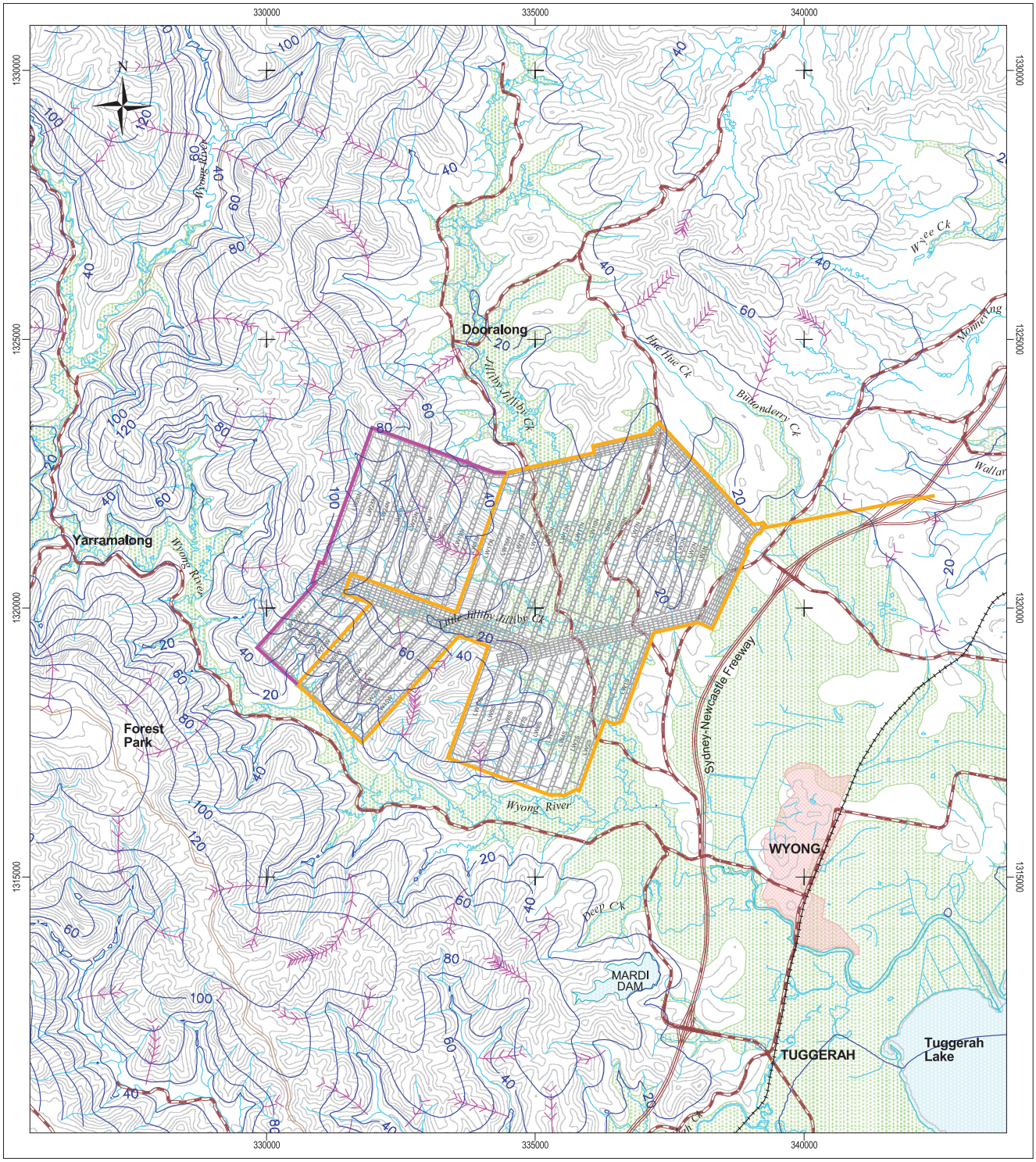
Scale 1:110,000

- creeks
- minor road
- sealed road
- Freeway
- railway
- urban area
- alluvium
- 28 years mine footprint
- 38 years mine footprint
- bore or well

WALLARAH 2 COAL PROJECT

**Locations of registered bores and wells**

*Figure 7*




*Topographic contours at 25m intervals*

0 2000 4000 6000 Metres

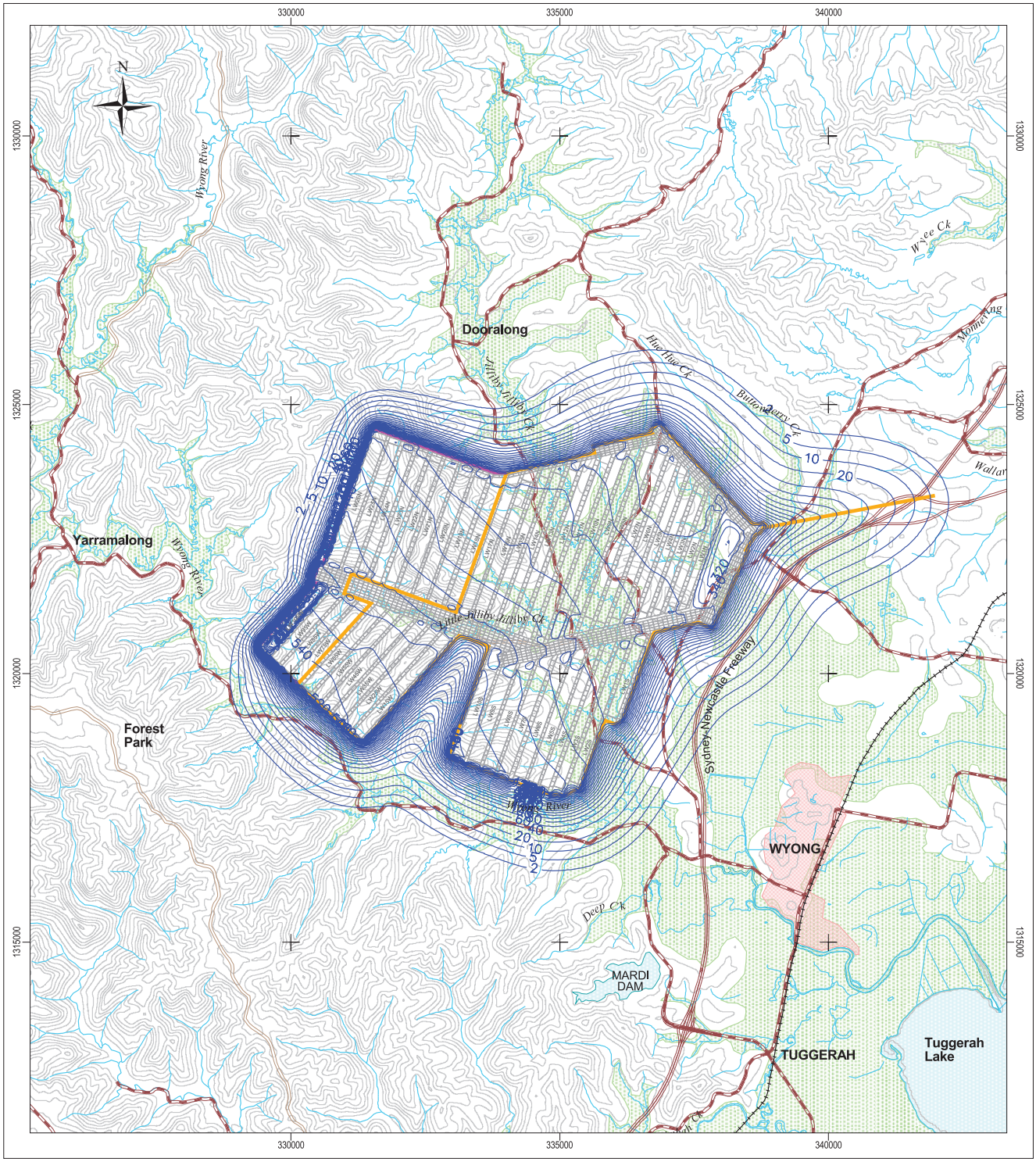
Scale 1:100,000

- urban area
- alluvium
- creeks
- minor road
- sealed road
- Freeway
- railway
- regional water table (mAHD)
- flow path
- 28 years mine footprint
- 38 years mine footprint

WALLARAH 2 COAL PROJECT

**Regionally interpolated shallow water table**

*Figure 8*




0 2000 4000 6000 Metres

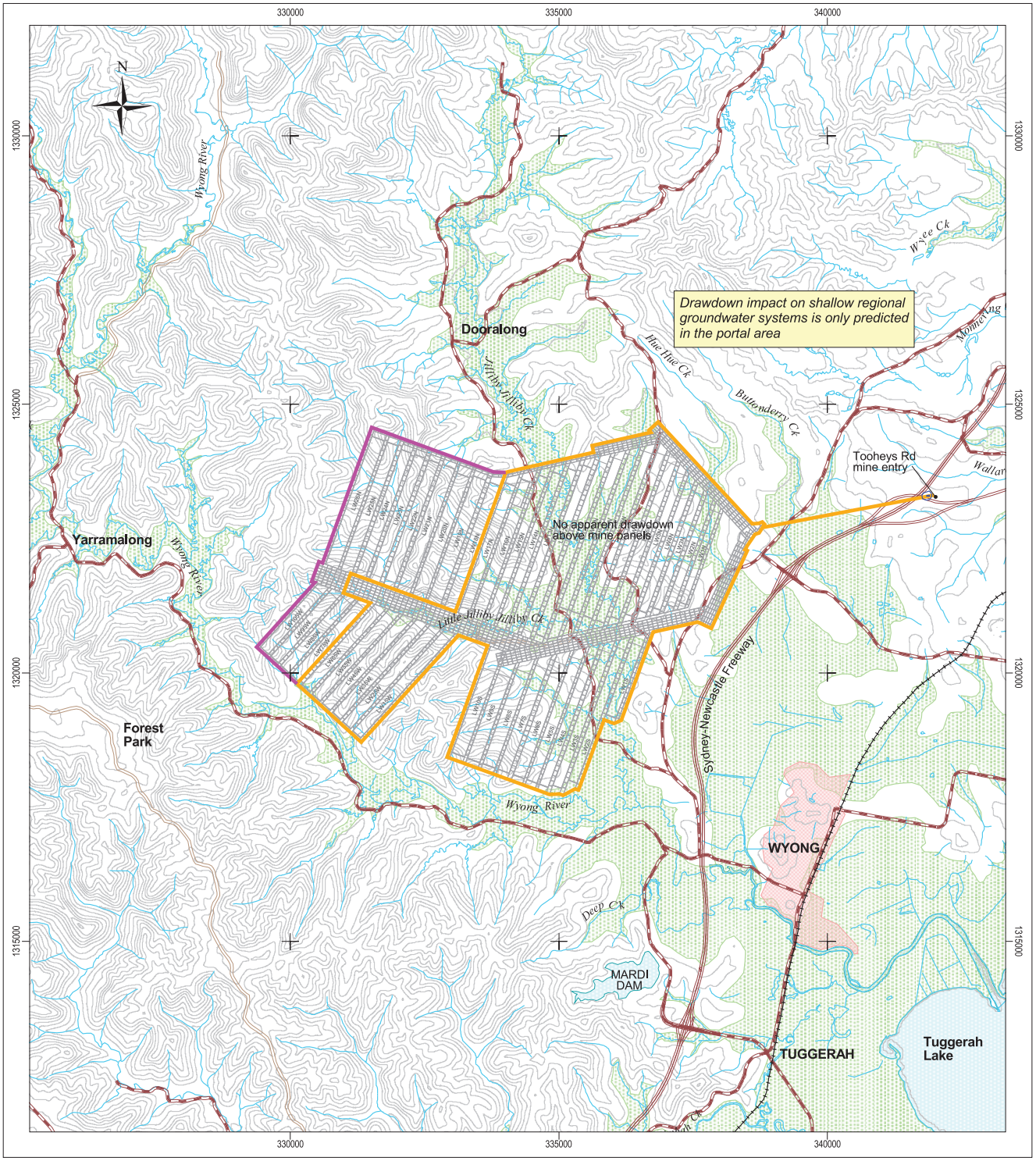
Scale 1:100,000

- 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

**Predicted WGN seam depressurisation after 38 years**

*Figure 9*




*Topographic contours at 25m intervals*

0 2000 4000 6000 Metres

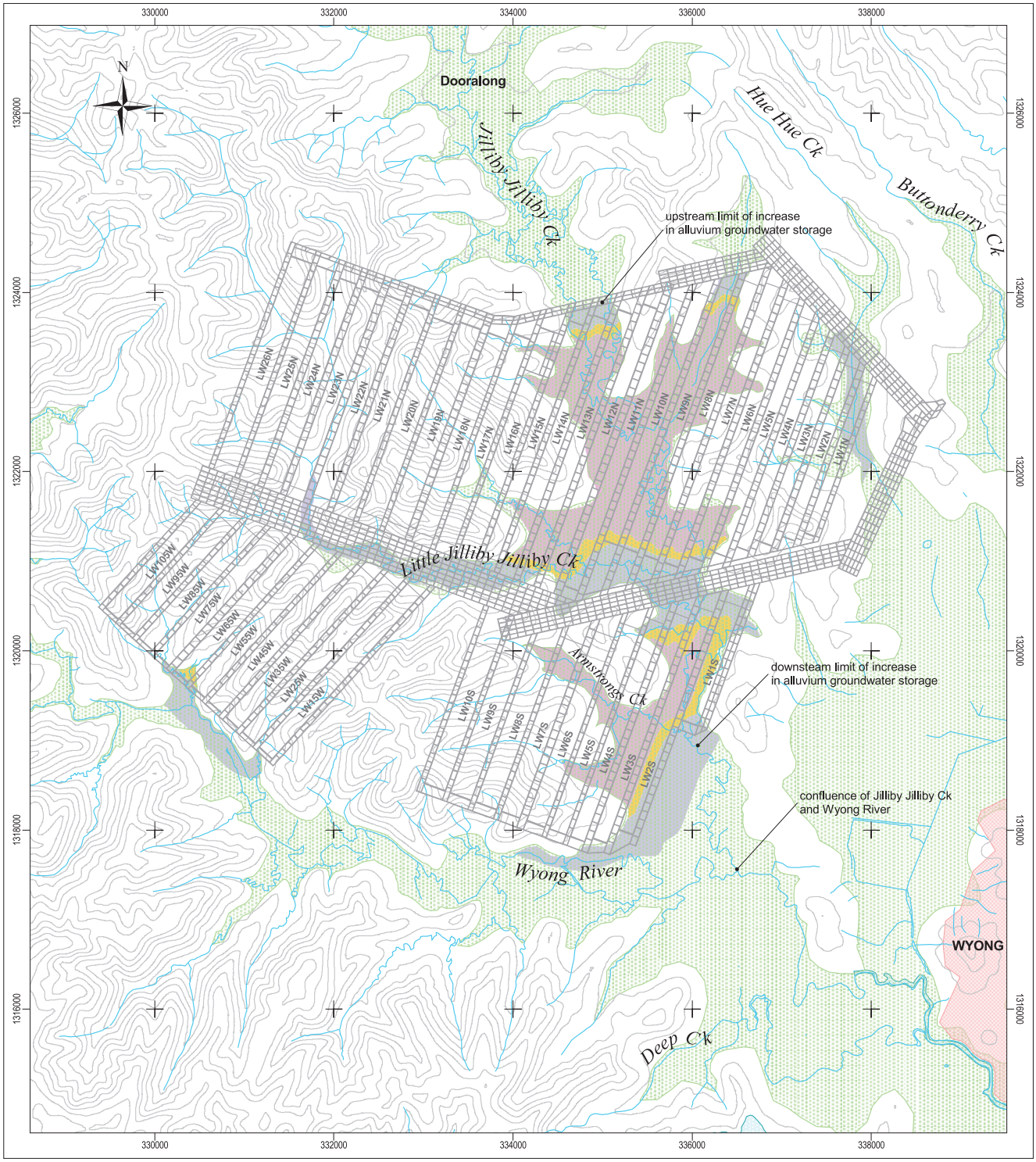
Scale 1:100,000

- 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 W2: Water table drawdown after 38 years**

*Figure 10*




0 1000 2000 3000 Metres

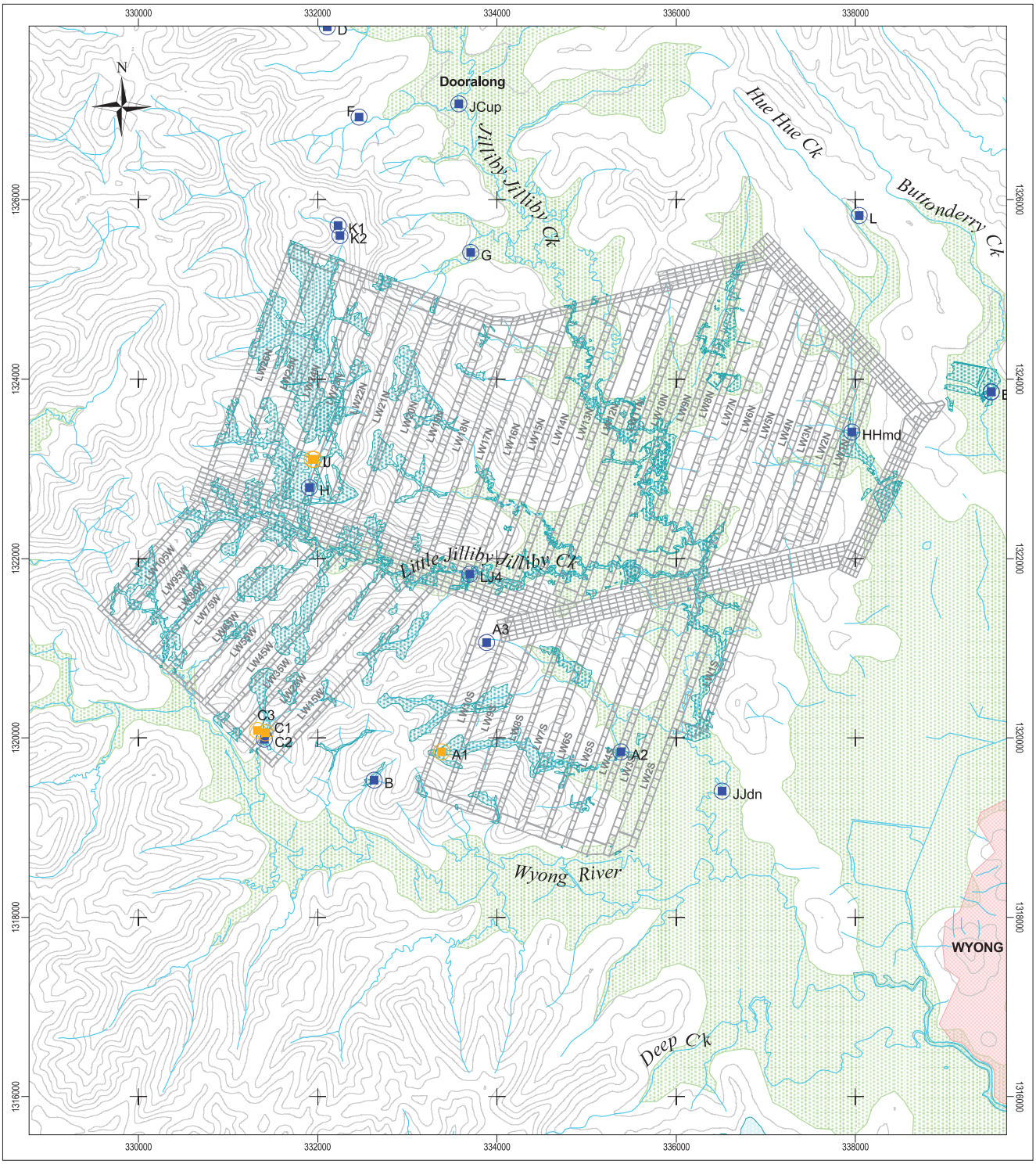
Scale 1:60,000

- creeks
- minor road
- sealed road
- Freeway
- railway
- topographic contours (25m intervals)
- urban area
- alluvium (unsubsided)
- 1.0 to 1.4m subsidence
- 0.5 to 1.0m subsidence
- 0.02 to 0.5m subsidence

WALLARAH 2 COAL PROJECT

**Subsidence affected areas within alluvial lands**

*Figure 11*




0 2000 4000 6000 Metres

Scale 1:60,000

urban area

alluvium

surface water ecology site

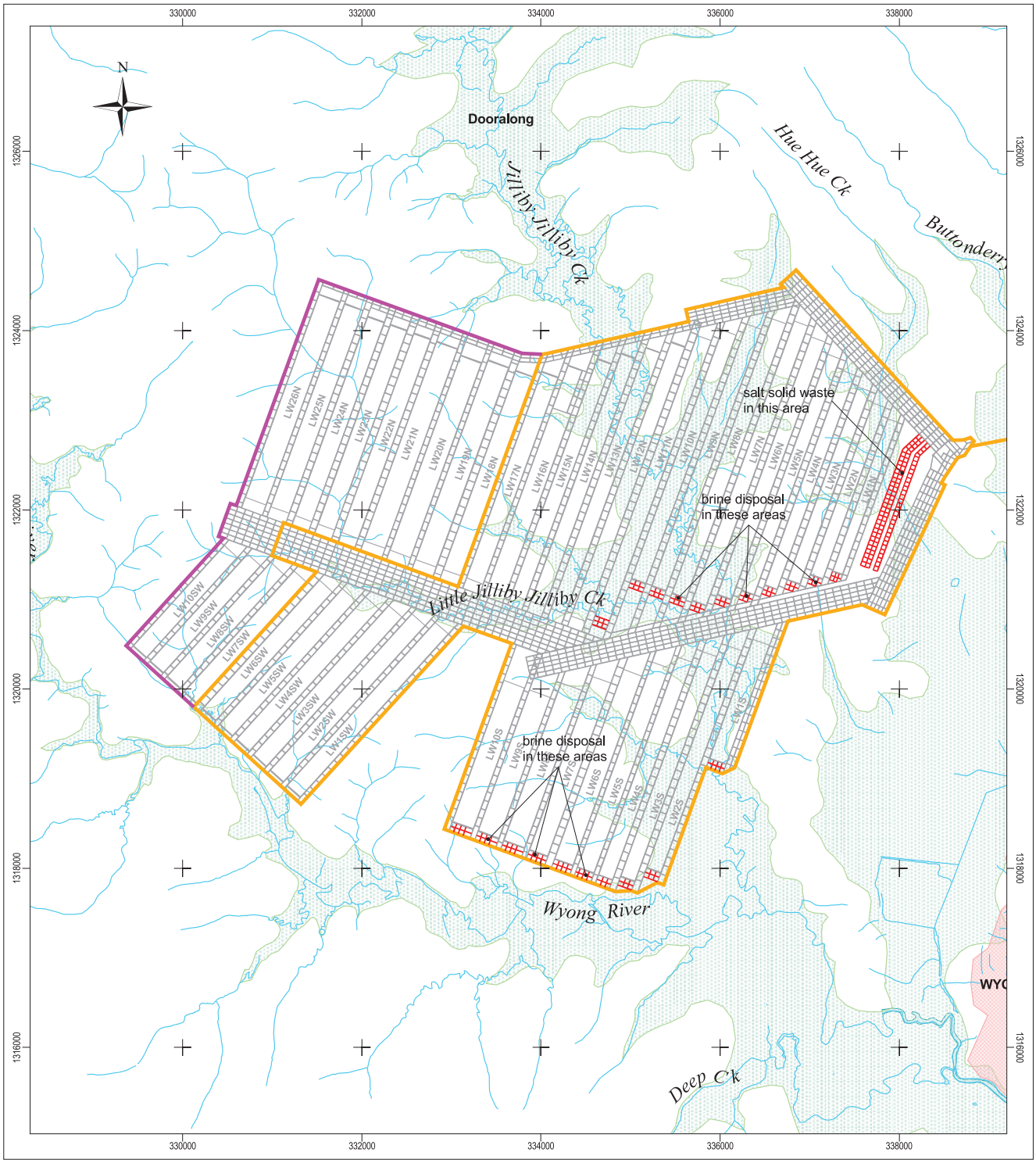
Ferruginous spring surface water ecology site

groundwater dependent ecosystem

WALLARAH 2 COAL PROJECT

**Groundwater dependent ecosystems and monitored aquatic ecosystems**

*Figure 12*




0 2000 4000 6000 Metres

Scale 1:60,000

urban area

alluvium

28 years mine footprint

38 years mine footprint

WALLARAH 2 COAL PROJECT

**Salt and brine emplacement areas**

*Figure 13*

## APPENDIX A: RAINFALL DATA

Rainfall data for Wyee Gauge 061082 provides the nearest long term record to the project area. The long term annual average for this gauge is about 1198mm.

Daily rainfall data has been processed to generate recurrence intervals and average exceedance probabilities for periods up to 30 days. Durations statistics are based on screening of daily rainfall data within each year of available records from 1900 to 2011 - a log normal distribution is assumed. The following Table A1 provides a summary.

***Table A1: Longer term intensity, frequency, duration statistics for 112 years of data.***

| ARI | AEP % | 1 day | 2 day | 3 day | 4 day | 5 day | 6 day | 8 day | 10 day | 15 day | 20 day | 30 day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| once in 1 year | 63.2 | 87 | 119 | 136 | 149 | 158 | 165 | 176 | 188 | 216 | 238 | 277 |
| once in 2 years | 39.3 | 111 | 154 | 176 | 193 | 204 | 213 | 229 | 245 | 279 | 306 | 352 |
| once in 5 years | 18.1 | 143 | 201 | 231 | 252 | 267 | 279 | 302 | 323 | 364 | 398 | 452 |
| once in 10 years | 9.5 | 167 | 238 | 273 | 298 | 315 | 330 | 359 | 384 | 430 | 469 | 528 |
| once in 20 years | 4.9 | 192 | 274 | 316 | 345 | 363 | 382 | 416 | 447 | 496 | 540 | 604 |
| once in 50 years | 2.0 | 225 | 324 | 374 | 408 | 429 | 452 | 495 | 531 | 586 | 636 | 705 |
| once in 100 years | 1.0 | 251 | 363 | 419 | 458 | 481 | 507 | 557 | 598 | 657 | 711 | 785 |

Values are mm of rainfall.

ARI (Average Recurrence Interval) means – the average or expected value for the periods between exceedances of a given rainfall accumulated over a given duration. For example, a rainfall total of 245 mm over 10 days has an average recurrence interval of 2 years.

AEP (Average Exceedance Probability) means – the probability that a specified total rainfall accumulated over a given period, will be exceeded in any one year. For example, a rainfall total of 245 mm over a period of 10 days has a 39.3% probability of being equalled or exceeded in any one year.

Figure A1 provides a rainfall residual mass plot for Wyee Gauge monthly rainfall data since 1900. Negative slopes on this plot reflect periods of below average rainfall while positive slopes reflect above average rainfall. For example, the period from 1931 to 1949 was a sustained dry and drought period.

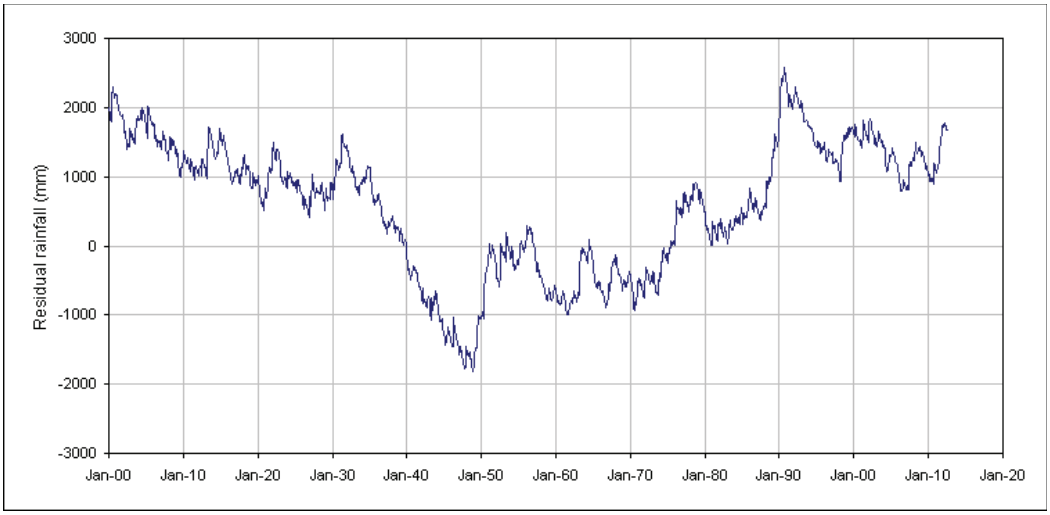



***Figure A1: Rainfall residual mass plot for Wyee Gauge 061082 from 1900***

# APPENDIX B: NOW REGISTERED BORES AND WELLS

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

| Bore | Coordinates (AMG) | | Depth (m) | Groundwater Type | Year Drilled | Groundwater yield (L/s) | Water level (m) | Water quality | Bore Geology |
|---|---|---|---|---|---|---|---|---|---|
| | E | N | | | | | | | |
| GW028035<br>20BL021424<br>P | 348750 | 6318275 | 30.5 | Hard rock | 1968 | 19.8-25.2m/1.26 | 7.60 | good | 0.0-4.8 Clay<br>4.8-6.7 S/S<br>6.7-18.3 Clay<br>18.3-20.4 S/S<br>20.4-24.4 Sh<br>24.4-30.5 S/S |
| GW033297<br>20BL026199<br>W,D | 348930 | 6321110 | 19.8 | Hard rock | 1971 | 17.6-19.7/0.25 | 4.60 | nil | 0.0-10.66 Clay<br>10.66-11.88 S/S<br>11.88-17.67 Sh<br>17.67-19.81 S/S |
| GW047362<br>20BL129128<br>D,S | 345025 | 6317300 | 38.0 | Hard rock | 1979 | 20.0/0.38<br>29.6/2.0 | 8.50 | good | 0.0-7.6 Clay<br>7.6-9.1 Sh<br>9.1-38.0 S/S |
| GW047948<br>20BL136073<br>D | 351005 | 6319500 | 8.0 | Hard rock | 1981 | nil | nil | nil | 0.0-8.0 Rock |
| GW048140<br>20BL106872<br>D,S | 346225 | 6316625 | 38.0 | Hard rock | 1977 | 28.4/4.0<br>35.4/6.8 | 16.8 | good | 0.0-7.6 Clay<br>7.6-28.4 S/S<br>28.4-37.0 Sh<br>37.0-38.0 S/S |
| GW049666<br>20BL109445<br>D,S | 347125 | 6316600 | 45.8 | Hard rock | 1979 | 32.4-32.6/3.8<br>35.6-35.8/1.26 | 13.7 | good | 0.0-27.4 Clay<br>27.4-45.8-Sh |
| GW051560<br>20BL111424<br>F,S | 348160 | 6322940 | 33.0 | Hard rock | 1980 | 28.0/5.0 | 13.0 | nil | 0.0-19.0 Clay<br>19.0-33.0 S/S |
| GW056461<br>20BL122630<br>D,S | 346962 | 6324487 | 17.0 | Hard rock | 1982 | 22.0-23.0/2.52 | 9.0 | nil | 0.0-17.0 Clay |
| GW056521<br>20BL122843<br>D,S | 345687 | 6321210 | 45.0 | Hard rock | 1982 | nil | nil | nil | 0.0-8.0 Clay<br>8.0-25.0 S/S<br>8.0-25.0 Sh<br>25.0-44.0 S/S<br>44.0-45.0 Sh |
| GW057386<br>20BL125307<br>D,F,S | 344567 | 6316775 | 26.0 | Hard rock | 1983 | 16.0-23.0/0.44 | 6.0 | good | 0.0-12.0 Clay<br>12.0-26.0 Sh |
| GW057493<br>20BL125665<br>D | 349290 | 6316420 | 30.0 | Hard rock | 1983 | 18.0-24.0/0.44 | 6.0 | nil | 0.00-12.0 Clay<br>12.0-30.0 Sh |
| GW058390<br>20BL127954<br>D | 345575 | 6321050 | 0.00 | ? | 1982 | nil | nil | nil | nil |
| GW058789<br>20BL125583<br>D,S | 351025 | 6320240 | 29.0 | Hard rock | 1983 | 15.0-15.5/nil<br>23.0-23.5/nil | nil | salty | 0.0-15.0 Clay<br>15.0-29.0 S/S |
| GW059092<br>20BL135236<br>D,S | 349070 | 6320630 | 38.0 | Hard rock | 1981 | 24.0-25.0/1.26 | 15.0 | salty | 0.0-16.0 Clay<br>16.0-38.0 Sh S/S |
| GW059166<br>20BL121663<br>D,I,S | 343820 | 6319100 | 0.00 | ? | 1982 | nil | nil | nil | nil |
| GW067069<br>20BL142928<br>D,S | 349877 | 6316475 | nil | ? | nil | nil | nil | nil | nil |
| GW078064<br>20BL166821<br>D,S | 346872 | 6316669 | 29.0 | Hard rock | 1998 | 15.5-18.0/0.40<br>26.5-27.3/0.80 | 12.9 | 0.25 – 120.00<br>0.50 – 288.00 | 0.0-15.5 Clay<br>15.5-18.0 Sand<br>18.0-26.5 Clay |
| GW078078<br>20BL166653<br>D | 349222 | 6317044 | 36.0 | Hard rock | 1996 | 33.0-33.5/1.0 | 10.0 | fresh | 0.0-25.0 Clay<br>25.0-36.0 S/S |
| GW078142<br>20BL166744<br>D,S | 341557 | 6321975 | 49.0 | Hard rock | 1998 | 22.0-22.8/0.15<br>45.0-46.0/5.0 | 15.0<br>18.0 | fresh | 0.0-11.5 Clay<br>11.5-22.8 S/S<br>22.8-29.5 Mud<br>29.5-49.0 S/S |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| GW078148<br>20BL166707<br>D,S | 342450 | 6319617 | 40.0 | Hard rock | 1998 | 27.0-29.9/0.19<br>33.5-35.0/16.0 | 12.0 | fresh | 0.0-8.8 Clay<br>8.8-29.9 S/S<br>29.9-33.5 Mud<br>33.5-40.0 S/S |
| GW078221<br>20BL166822<br>I | 349022 | 6319270 | 60.0 | Hard rock | 1998 | 28.9-30.0/0.13 | 26.0 | fresh | 0.0-16.5 Clay<br>16.5-28.9 Mud<br>28.9-42.6 Cong<br>42.6-53.0 Mud<br>53.0-60.0 Cong |
| GW078295<br>20BL155229<br>D | 347360 | 6316892 | 32.0 | Hard rock | 1995 | 20.0-29.0/1.26 | nil | good | 0.0-15.0 Clay<br>15.0-20.0 Gravel<br>20.0-32.0 S/S |
| GW078356<br>20BL166558<br>D | 341372 | 6319926 | 140.0 | Hard rock | 1997 | 131.0-131.5/0.2 | 95.0 | fresh | 0.0-5.0 Clay<br>5.0-36.0 S/S<br>36.0-36.5 Sh<br>36.5-97.0 S/S<br>97.0-99.0 Sh<br>99.0-115.0 S/S<br>115.0-117.0 Iron<br>117.0-128.0 S/S<br>128.0-131.0 Cong<br>131.0-133.0 S/S<br>133.0-140.0 Sh |
| GW078599<br>20BL166842<br>D,S | 347596 | 6316742 | 48.0 | Hard rock | 1998 | 44.4-47.0/3.0 | 21.0 | 1.00 -<br>900.00 | 0.0-5.3 Clay<br>5.3-9.0 S/S<br>9.0-11.5 Clay<br>11.5-12.8 S/S<br>12.8-14.2 Clay<br>14.2-15.6 Ironstone<br>15.6-19.5 S/S |
| GW080328<br>20BL168517<br>D,S | 344706 | 6317188 | 12.0 | Alluvial | 2004 | nil | nil | nil | nil |
| GW080555<br>20WA202827<br>D,S | 341552 | 6321690 | 41.0 | Hard rock | 2004 | 33.0-34.0/3.0 | 17.0 | nil | 0.0-8.0 Clay<br>8.0-36.0 S/S<br>36.0-41.0 Sh |
| GW080590<br>20BL169063<br>D,S | 345045 | 6316735 | 42.0 | Hard rock | 2004 | 24.0-30.0/0.50 | 13.0 | nil | 0.0-17.0 Clay<br>17.0-42.0 S/S |
| GW080591<br>20BL169064<br>D, S | 344694 | 6317000 | 48.0 | Hard rock | 2004 | 39.0-42.0/0.83 | 20.0 | nil | 0.0-0.5 Soil<br>0.5-3.0 Clay<br>3.0-40.0 S/S<br>40.0-48.0 Sh |
| GW080592<br>20BL169065<br>D | 345090 | 6317054 | 48.0 | Hard rock | 2004 | 41.0-42.0/1.0 | 20.0 | 2.00 –<br>0.47 | 0.0-4.0 Clay<br>4.0-48.0 S/S |
| GW080593<br>20BL169100<br>F,I | 345127 | 6317608 | 27.0 | Hard rock | 2003 | 18.0-21.0/2.0 | 7.0 | nil | 0.0-9.0 Clay<br>9.0-27.0 S/S |
| GW080599<br>20BL169105<br>C,F,I | 345324 | 6317390 | 30.0 | Hard rock | 1964 | nil | nil | nil | nil |
| GW080608<br>20BL169008<br>D,S | 349520 | 6321281 | 48.0 | Hard rock | 2004 | 41.0-45.0/0.40 | 3.20 | nil | 0.0-36.0 Sands<br>36.0-48.0 Sh |
| GW200211<br>20BL169166<br>D,F,S | 342753.3<br>5 | 6320157.4<br>9 | 72.0 | Hard rock | 2006 | nil | nil | nil | nil |
| GW058391<br>20BL127955<br>D | 345635 | 6321040 | 27.6 | - | 1982 | - | - | - | - |
| GW058392<br>20BL127956<br>D | 345685 | 6321280 | 29.0 | - | 1982 | - | - | - | - |
| GW049667<br>20BL109446<br>D,S | 346800 | 6316675 | 45.8 | hard rock | 1979 | 32.0-32.3/1.89 | 6.0 | good | 0.0-1.0 soil<br>1.0-26.0 clay<br>26.0-46.0 shale |
| GW051365<br>20BL111075<br>D,I,S | 344825 | 6317550 | 44.0 | hard rock | 1979 | 32.0-34.0/0.3 | - | good to<br>brackish | 0.0-3.0 soil<br>3.0-18.0 clay<br>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 | No. | TDS | pH | EC | Ca | Mg | Na | K | HCO3 | SO4 | Cl |
|---|---|---|---|---|---|---|---|---|---|---|---|
| YP11 | 1 | 2483 | 6.9 | 4660 | 27 | 108 | 776 | 8 | 6 | 38 | 1520 |
| YP12a | 2 | 364 | 6.4 | 741 | 4 | 10 | 120 | 3 | 9 | 21 | 197 |
| YO13 | 3 | 526 | 6.3 | 1100 | 10 | 21 | 162 | 5 | 2 | 7 | 319 |
| DP31 | 4 | 1013 | 8.1 | 1670 | 13 | 23 | 315 | 3 | 193 | 33 | 433 |
| DO31a | 5 | 338 | 6.4 | 618 | 5 | 18 | 87 | 2 | 51 | 1 | 174 |
| DO33 | 6 | 666 | 6.4 | 1190 | 9 | 25 | 202 | 3 | 50 | 15 | 362 |
| CMW1 | 7 | 38241 | | | 460 | 1580 | 11300 | 482 | 229 | 3390 | 20800 |
| CMW2 | 8 | 170 | | | 6 | 8 | 38 | 4 | 33 | 21 | 60 |
| CMW3 | 9 | 15944 | | | 335 | 628 | 4620 | 169 | 680 | 662 | 8850 |
| CMW4 | 10 | 10197 | | | 296 | 517 | 2330 | 72 | 362 | 4660 | 1960 |
| CMW5 | 11 | 808 | | | 5 | 13 | 265 | 3 | 10 | 263 | 249 |
| D591JR | 12 | 745 | 6.1 | 993 | 4 | 12 | 240 | 2 | 209 | 41 | 238 |
| DO12 | 13 | 6276 | 5.4 | 11860 | 21 | 200 | 1960 | 10 | 6 | 319 | 3760 |
| DO21 | 14 | 2692 | 6.3 | 4991 | 28 | 90 | 780 | 7 | 228 | 98 | 1460 |
| DO31A | 15 | 276 | 6.1 | 423 | 3 | 11 | 52 | 1 | 137 | 5 | 67 |
| DO31B | 16 | 983 | 6.3 | 1474 | 15 | 31 | 250 | 3 | 218 | 25 | 441 |
| DO33 | 17 | 723 | 6.1 | 1416 | 20 | 36 | 205 | 3 | 102 | 19 | 337 |
| DO41A | 18 | 5467 | 5.8 | 10820 | 36 | 180 | 1760 | 10 | 116 | 305 | 3060 |
| DO41B | 19 | 4763 | 6.5 | 8726 | 57 | 160 | 1690 | 10 | 492 | 201 | 2153 |
| DO42 | 20 | 1723 | 5.4 | 3314 | 15 | 56 | 610 | 5 | 150 | 13 | 874 |
| DUP | 21 | 170 | | | 6 | 8 | 38 | 4 | 33 | 20 | 61 |
| DUP01 | 22 | 37007 | | | 448 | 1440 | 11200 | 532 | 237 | 3050 | 20100 |
| GW057386 | 23 | 1521 | 6.3 | 3423 | 9 | 4 | 535 | 5 | 123 | 68 | 777 |
| GW058789 | 24 | 7538 | 6.5 | 13310 | 83 | 261 | 2320 | 15 | 536 | 333 | 3990 |
| MMW1 | 25 | 427 | | | 50 | 10 | 72 | 3 | 128 | 10 | 154 |
| MMW2 | 26 | 28958 | | | 418 | 1580 | 7850 | 281 | 289 | 3640 | 14900 |
| YO11A | 27 | 498 | 6.0 | 1159 | 6 | 19 | 135 | 2 | 6 | 39 | 291 |
| YO12A | 28 | 252 | 6.0 | 808 | 2 | 6 | 68 | 2 | 21 | 14 | 139 |
| YO12B | 29 | 352 | 6.1 | 527 | 5 | 9 | 100 | 2 | 6 | 16 | 214 |
| YO13 | 30 | 205 | 5.3 | 368 | 2 | 9 | 48 | 2 | 6 | 5 | 132 |
| B400X000 | 31 | 6150 | 6.3 | 11270 | 96 | 410 | 2130 | 15 | 615 | 130 | 3053 |
| B500V800 | 32 | 4700 | 5.7 | 8895 | 80 | 210 | 1250 | 20 | 117 | 176 | 2875 |
| B500W250 | 33 | 5310 | | | 8 | 6 | 2270 | 22 | 5478 | 7 | 414 |
| B500W300 | 34 | 1850 | 7.6 | 3540 | 36 | 51 | 465 | 12 | 520 | 94 | 841 |
| B600V800 | 35 | 9080 | | | 10 | 6 | 1410 | 6 | 852 | 1 | 1870 |
| B600V850 | 36 | 3410 | | | 30 | 35 | 1230 | 9 | 748 | 1 | 1600 |
| B800W000 | 37 | 8800 | 6.6 | 15680 | 74 | 270 | 2830 | 17 | 456 | 575 | 4900 |
| B900W600 | 38 | 2620 | | | 1 | 1 | 367 | 3 | 199 | 34 | 328 |
| C200V900 | 39 | 4200 | 8.1 | 8922 | 115 | 42 | 1450 | 11 | 181 | 15 | 2280 |
| DLWC-3 | 40 | 440 | 5.9 | 1533 | 3 | 9 | 115 | 3 | 21 | 51 | 171 |
| GW047362 | 41 | 825 | 5.0 | 785 | 32 | 25 | 205 | 5 | 178 | 26 | 327 |
| HP1A | 42 | 1999 | 7.6 | 3010 | 27 | 28 | 595 | 9 | 450 | 50 | 840 |
| HP1B | 43 | 979 | 5.9 | 1540 | 13 | 52 | 270 | 3 | 130 | 91 | 420 |
| HP2A | 44 | 3004 | 7.5 | 4240 | 38 | 55 | 915 | 6 | 600 | 20 | 1370 |
| HP2B | 45 | 1288 | 5.3 | 2120 | 20 | 58 | 360 | 4 | 26 | 160 | 660 |
| HP3A | 46 | 3488 | 7.4 | 5400 | 66 | 90 | 1000 | 7 | 680 | 65 | 1580 |
| HP3B | 47 | 1303 | 5.4 | 2000 | 23 | 52 | 400 | 5 | 24 | 49 | 750 |
| HP3C | 48 | 584 | 6.4 | 875 | 42 | 13 | 125 | 1 | 180 | 33 | 190 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **HP4A** | 49 | 3008 | 7.2 | 4160 | 44 | 68 | 910 | 5 | 610 | 51 | 1320 |
| **HP5A** | 50 | 1860 | 7.3 | 2550 | 23 | 28 | 560 | 4 | 510 | 95 | 640 |
| **HP5B** | 51 | 899 | 6.5 | 1390 | 7 | 14 | 290 | 2 | 160 | 86 | 340 |
| **HP5C** | 52 | 554 | 5.8 | 825 | 5 | 8 | 180 | 4 | 61 | 56 | 240 |

## C2 Mineralogical assessment of the Terrigal Formation

The powder X-ray diffraction (XRD) technique is an established methodology for the detection of minerals in a rock sample. It involves illumination of a powdered rock sample by X-rays which generate diffraction peaks that can be associated with particular mineral assemblages (crystal structures) by comparing phase angle peaks to known peaks for specific minerals.

A total of 37 HQ size core sections (63mm diameter) were selected from available cores held by WACJV. Samples were carefully inspected and selected by EcoEngineers and MER.

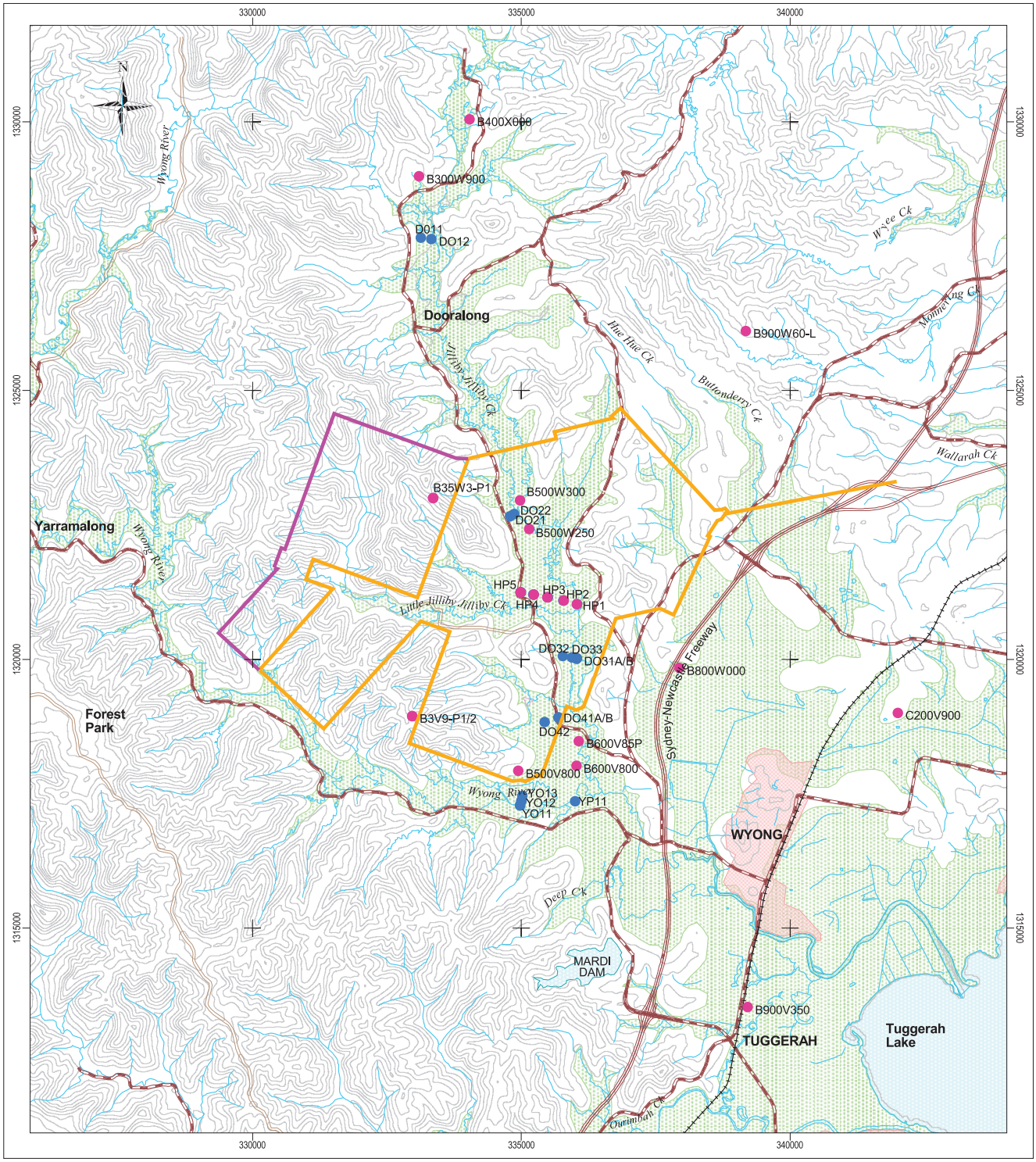
Assessments were conducted by Sietronics Pty. Ltd. XRD patterns were produced using a Bruker-AXS D4 XRD with copper radiation at 40 kV and 30 mA, over a range of 1.3 to 70$^{o}$2θ, with a 0.02 degree step and a 2 second per step count time. A graphite monochromator was used in the diffracted beam. The search/match was carried out with the aid of the Bruker Diffrac$^{plus}$ Search/Match software and the ICDD PDF-2 database. The quantitative phase analysis was performed using the Siroquant version 3 software. Results of all analyses are provided in the following Table C2.

Table C2: Quantitative analysis of core samples (% by weight) using Siroquant

| Hole ID | Depth | quartz | kaolin | illite | illite-smectite | chlorite | siderite | orthoclase | albite | andesine | anatase | rutile | magnetite | hematite | barite |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B000W100 | 58.5 | 63 | 7 | 8 | | | 11 | 11 | | | <1 | | | | |
| B000W100 | 59.5 | 60 | 8 | 11 | | | 12 | 10 | | | <1 | | | | |
| B000W100 | 61 | 48 | 10 | 15 | | | 16 | 11 | | | <1 | | | | |
| B000W100 | 62.4 | 53 | 8 | 16 | | | 13 | 10 | | | <1 | | | | |
| B000W100 | 69.7 | 72 | 3 | 5 | | | 10 | 7 | | | 2 | | | | |
| B000W100 | 118.1 | 54 | 4 | 7 | | | 17 | 10 | 6 | | | | | | |
| B000W100 | 151.7 | 19 | 1 | 7 | | | 54 | 3 | 3 | | | | | | |
| B250W200 | 24.6 | 83 | 4 | 5 | | | | 7 | | | | | | tr | |
| B250W200 | 32.9 | 53 | 6 | 7 | | | 12 | 9 | | | <1 | | | | |
| B250W200 | 35.1 | 58 | 3 | 8 | | | 24 | 7 | | | | | | tr | |
| B250W200 | 46.2 | 63 | 5 | 8 | | tr | 15 | 10 | tr | | | | | | |
| B250W200 | 47.3 | 43 | 5 | 11 | | | 28 | 7 | 5 | | | | | tr | |
| B250W200 | 62.5 | 53 | 7 | 11 | | | 11 | 10 | 8 | | | | | | |
| B250W200 | 92 | 40 | 12 | 25 | | tr | 14 | <2 | 8 | | | | | | |
| B400V900 | 12.6 | 79 | | | | | 15 | | | | | 1 | | | 5 |
| B400V900 | 14.6 | 82 | 2 | 10 | | | 3 | 3 | | | | | | | |
| B400V900 | 15.1 | 66 | 5 | 8 | | | 11 | 9 | | | <1 | | | | |
| B400V900 | 15.6 | 81 | 3 | 7 | | | 3 | 6 | | | | | | | |
| B400V900 | 16.4 | 79 | 4 | 3 | | tr | 7 | 6 | | | <1 | | | | |
| B400V900 | 19.3 | 59 | 3 | 8 | | | 24 | 6 | | | <1 | | | | |
| B400V900 | 19.6 | 41 | 18 | 28 | | | 6 | 8 | | | | | | | |
| B400V900 | 24.5 | 83 | 2 | 7 | | | 4 | 5 | | | | | | | |
| B400V900 | 27.5 | 70 | 4 | 8 | | tr | 12 | 6 | | | | | | | |
| B400V900 | 28.5 | 85 | 3 | 5 | | | 3 | 5 | | | | tr | | | |
| B400V900 | 31.7 | 62 | 7 | 11 | | | 4 | 8 | 7 | | | 1 | | | |
| B400V900 | 36.1 | 31 | 20 | 29 | | | 3 | 1 | 9 | | | | | | |
| B400V900 | 40.6 | 39 | 19 | 21 | | | 3 | 7 | 7 | | | | | | |
| B400V900 | 41.7 | 42 | 12 | 19 | 7 | | <2 | 10 | 9 | | <1 | | | | |
| B400V900 | 44.7 | 79 | 4 | | | | 8 | 3 | 6 | | | 1 | | | |
| B400V900 | 48.4 | 70 | 5 | 5 | | | 5 | 9 | 7 | | 1 | | | | |
| B400V900 | 48.6 | 51 | 8 | 6 | | <2 | 11 | 8 | 14 | | 1 | | <1 | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B400V900 | 52.4 | 40 | 11 | 16 | | | | | 16 | | | | | 11 | |
| B400W100 | 43 | 46 | 20 | 16 | | | | | | 17 | 2 | | | | |
| B400W100 | 45.7 | 40 | 25 | 20 | | | | | | 15 | 1 | | | | |
| B400W100 | 48.5 | 48 | 18 | 15 | | | | | | 18 | 2 | | | | |
| B400W100 | 56.2 | 41.4 | 21.4 | 15.7 | | | | | | 19.8 | 1.6 | | | | |
| B400W100 | 57 | 44 | 22 | 15 | | | | | | 17 | 1 | | | | |
| B400W100 | 69.4 | 42 | 11 | 14 | | | | | | 31 | 2 | | | | |
| B600W100 | 38.9 | 42.3 | 21.3 | 15.5 | | | | | | 19.5 | 1.3 | | | | |
| B600W100 | 40.9 | 45 | 18 | 16 | | | | | | 19 | 1 | | | | |
| B600W100 | 41.5 | 47 | 17 | 17 | | | | | | 17 | 1 | | | | |
| B600W100 | 56.5 | 46 | 16 | 16 | | | | | | 21 | 2 | | | | |

tr = trace presence




0 2000 4000 6000 Metres

Scale 1:100,000

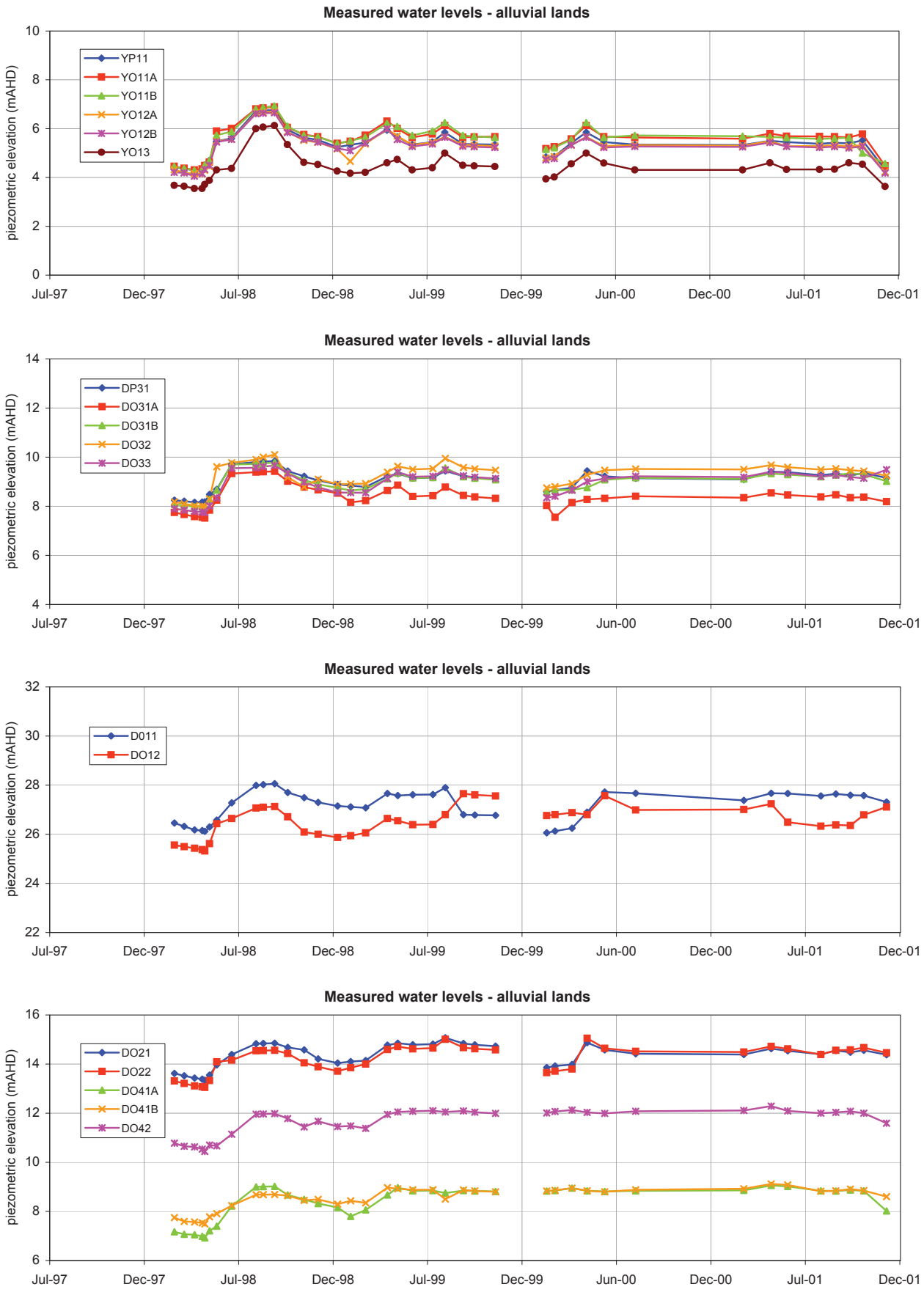
- creeks
- minor road
- sealed road
- Freeway
- railway
- urban area
- alluvium
- alluvium monitoring bore
- hardrock monitoring bore
- 28 years mine footprint
- 38 years mine footprint

WALLARAH 2 COAL PROJECT

**Groundwater monitoring bore locations**

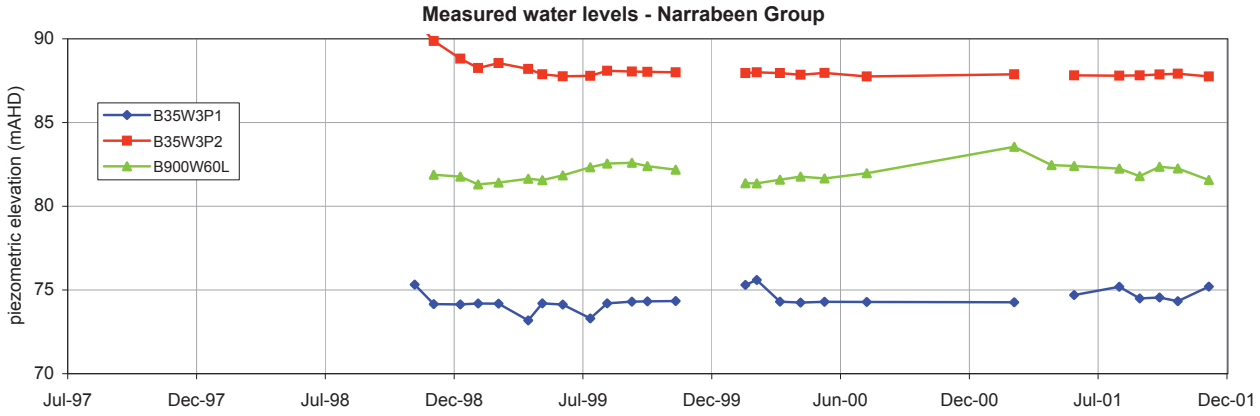
*Figure C1*

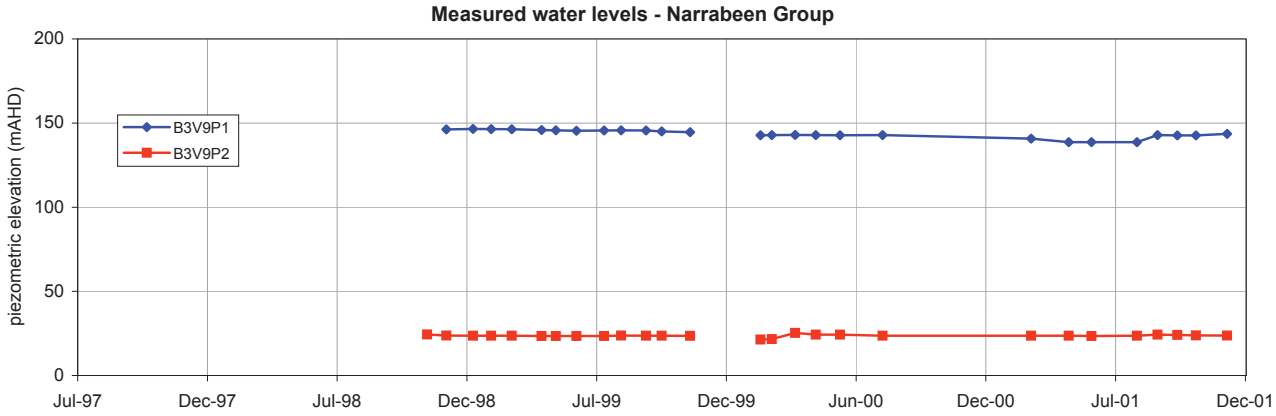
Mackie Environmental Research

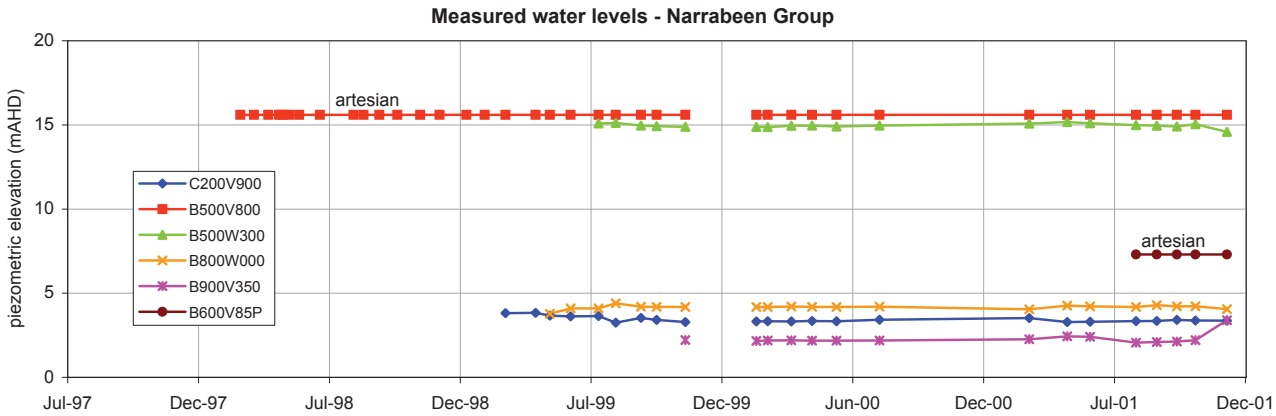


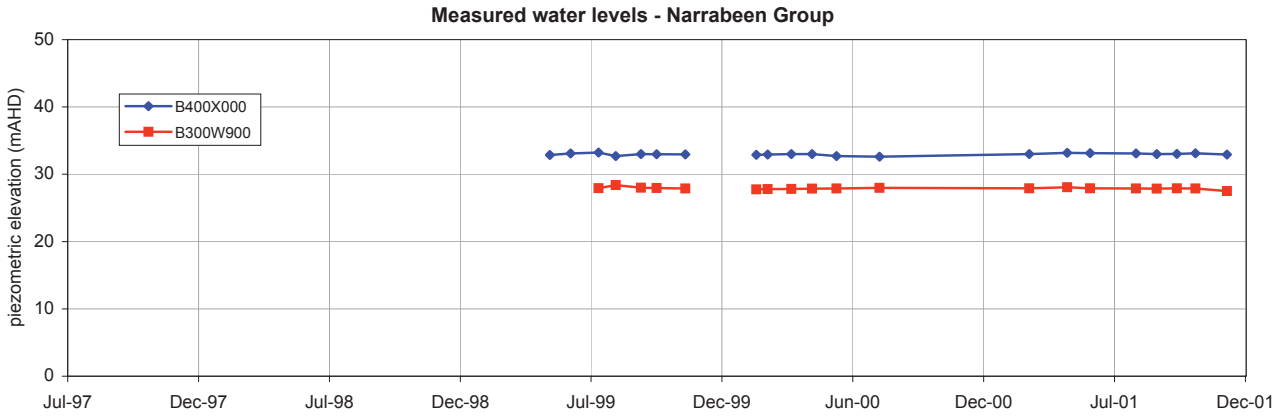

**Water level monitoring data - alluvial lands**

*Figure C2*



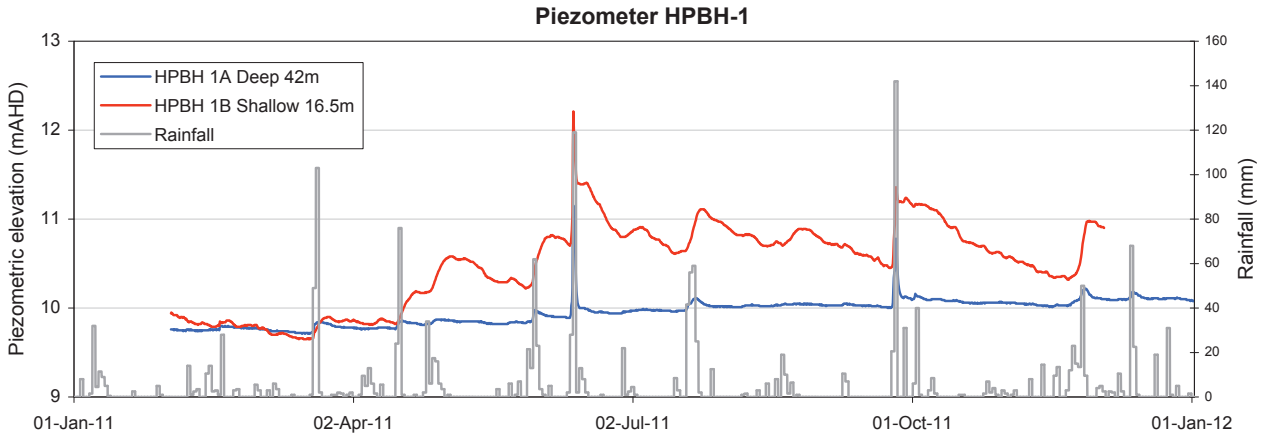



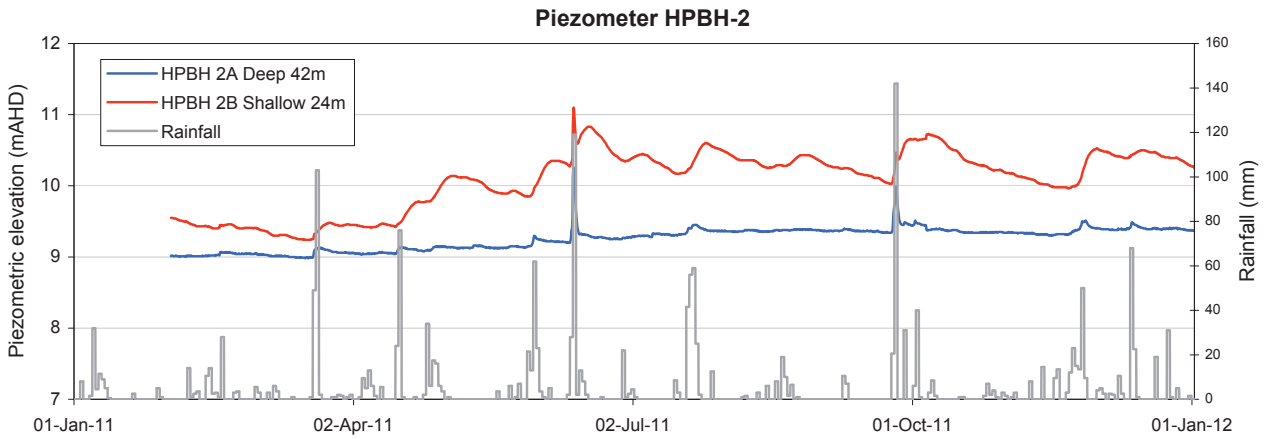



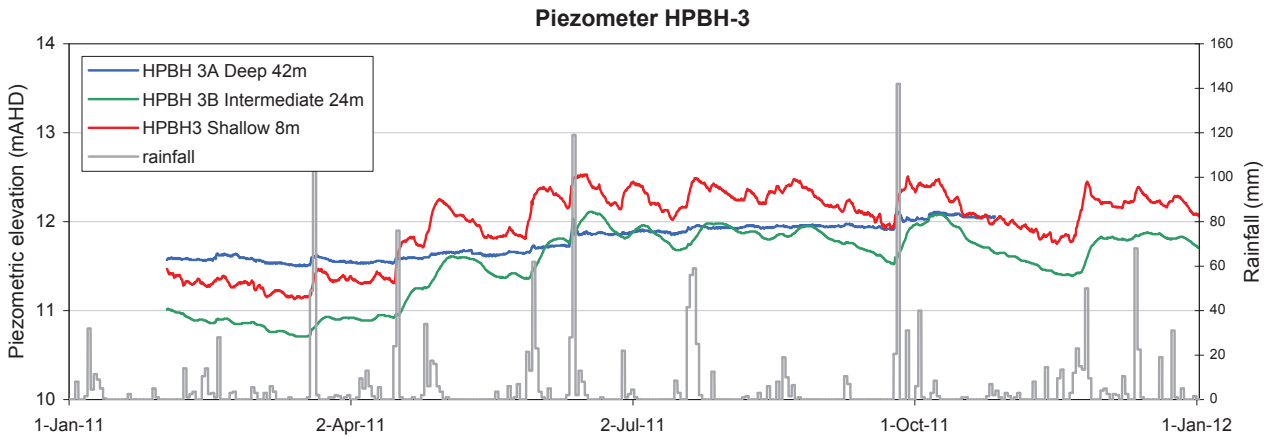



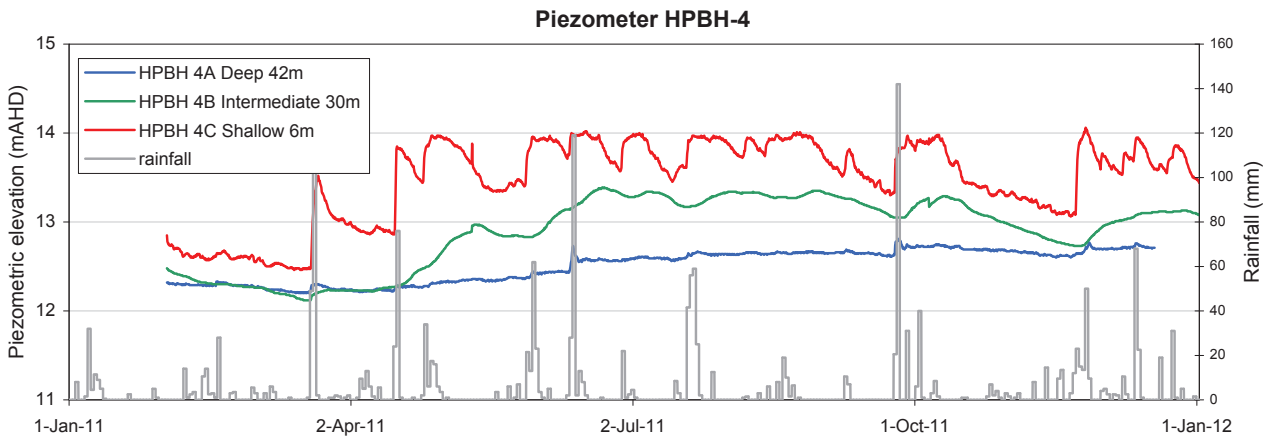

**Water level monitoring data - Narrabeen Group**

*Figure C2 ct'd*

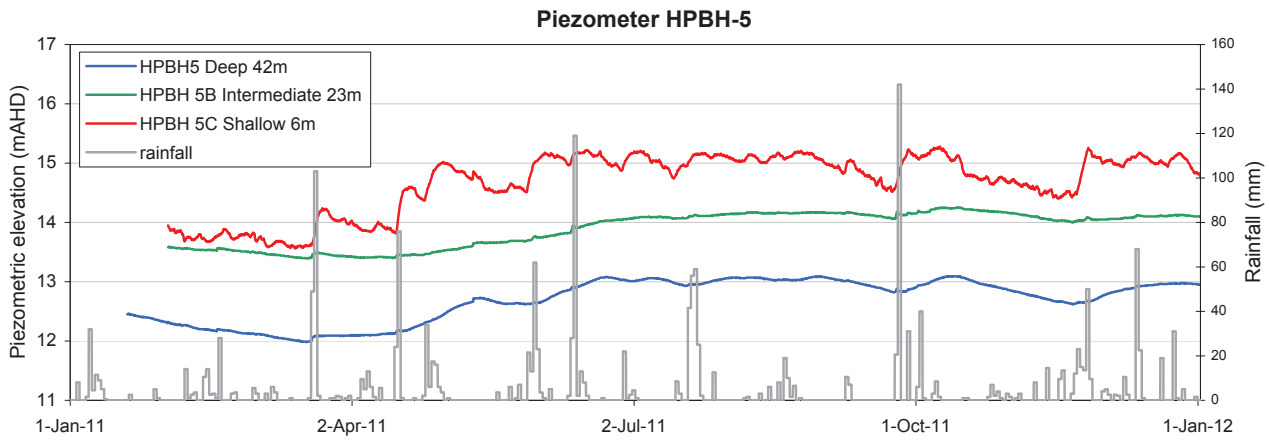


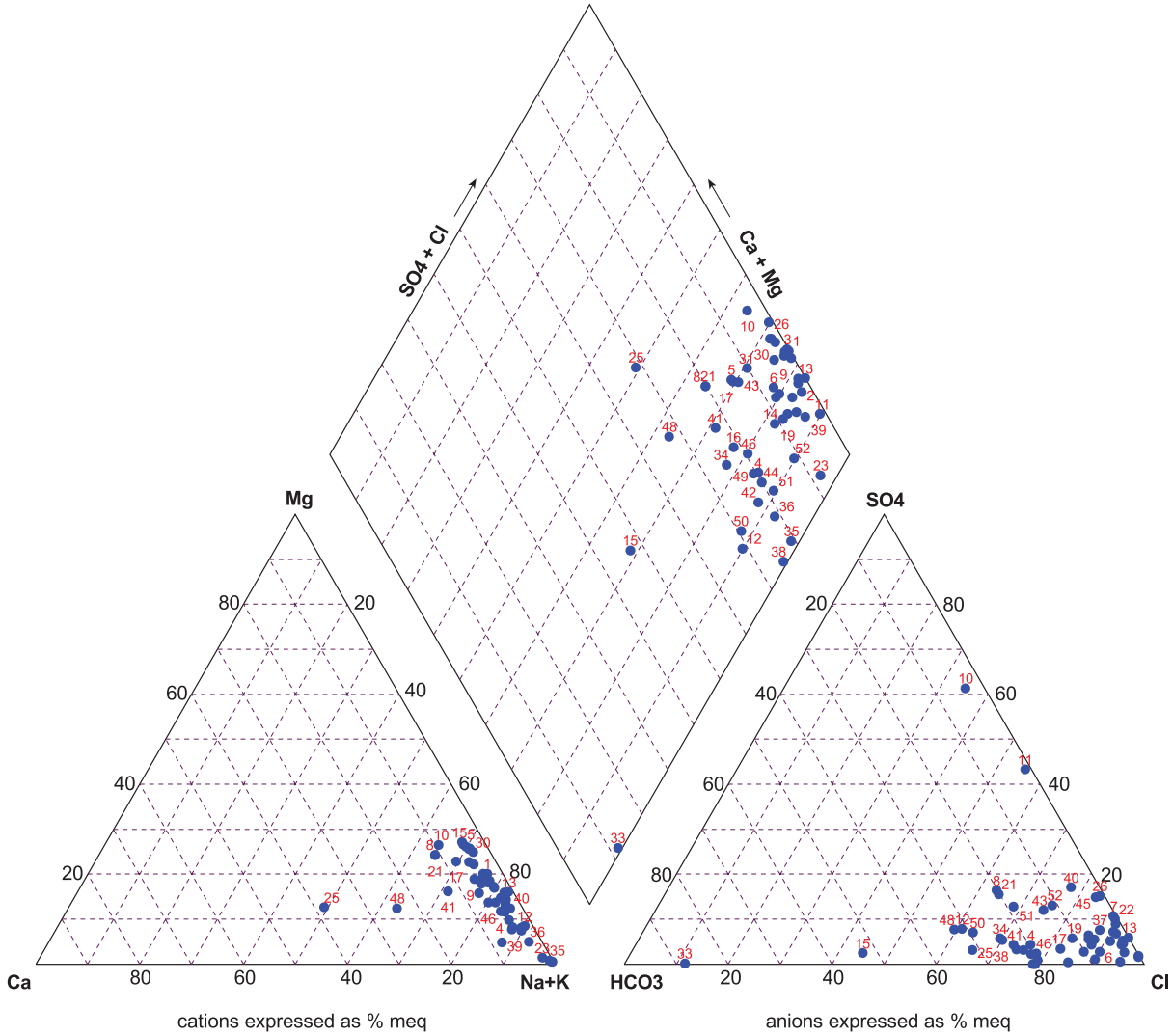




**Honeysuckle Park piezometers**
*Figure C2*




**Honeysuckle Park piezometers**
*Figure C2*




WALLARAH 2 COAL PROJECT

**Piper plot of major ions in groundwaters**

*Figure C3*

# APPENDIX D: HYDRAULIC PROPERTIES

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 in hard rock strata

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. The procedure comprised sealing off the lower portion of an exploration hole and measurement of the rate of clean water injection to the isolated test zone at 3 or 4 injection pressures ranging from 200 kPa to 800 kPa. Numerous tests exhibited potential packer leakage or difficulties in achieving injection equilibration (non constant injection rates) due to equipment limitations.

Hydraulic conductivity estimates are provided in the following summary Table D1. For many tests, a negligible injection rate was observed at all test pressures due to the low conductivity of the 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 m, 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 collated 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 $\log_{10}$ 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 approximately associated with sandstone-conglomerate strata and coal seam(s).

*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 |
| B750W150 | Awaba Tuff/ Fassifern Seam | MS/Coal | 392 | 399 | < 1.01E-04 | 1.44E-05 | bql |

| Bore name | Unit | Lithology | From | To | T | K | comment |
|---|---|---|---|---|---|---|---|
| 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 |
| B400V800 | Patonga Claystone | MS | 18 | 58 | 3.76E-01 | 9.39E-03 | partial fissure clogging and/or onset of turbulent flow |

| Bore name | Unit | Lithology | From | To | T | K | comment |
|---|---|---|---|---|---|---|---|
| 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 |
| B300W100 | Wallarah/ Great Northern Seam | Coal | 447 | 456 | 2.10E-02 | 2.33E-03 | |

| Bore name | Unit | Lithology | From | To | T | K | comment |
|---|---|---|---|---|---|---|---|
| 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 |
| B300V700 | Patonga Claystone | MS/SS | 36 | 115 | 2.86E-01 | 3.62E-03 | |

| Bore name | Unit | Lithology | From | To | T | K | comment |
|---|---|---|---|---|---|---|---|
| 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 ? |
| TUC1 | Tuggerah | SS/MS | 90 | 168 | < 1.88E-04 | 2.41E-06 | bql |

| Bore name | Unit | Lithology | From | To | T | K | comment |
|---|---|---|---|---|---|---|---|
| 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 59 formation samples extracted at five borehole locations B600W300, B800W300, B400V900, B600W100 and B400W100 located in the area scheduled for mining.

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 and siltstones. This bias is considered acceptable for analytical purposes since mudstones and claystones are likely to exhibit a matrix hydraulic conductivities 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 of $\log_{10}$ values 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 core test results with packer tests indicates core based values exhibit a slightly lower range of values than packer test results.

Figure D3 shows (1) a log normal distribution that approximates the core samples data set excluding claystone samples and (2) the expected distribution for the Patonga Claystone (and Tuggerah Formation) if claystone permeabilities were determinable (the existing core is old and fails when sub cores are attempted for testing purposes).

*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 | |
| **B400W100** | 51.3 | sandstone - grey, fine grained, moderate to well cemented | Patonga Claystone | | 1.09E-04 | | |
| **B400W100** | 55.8 | sandstone - grey, very fine grained with silty layers | Patonga Claystone | | 8.88E-07 | | |
| **B400W100** | 61.2 | sandstone - cream, fine to medium grained, well cemented | Patonga Claystone | | 3.88E-05 | | |
| **B400W100** | 68.9 | sandstone/siltstone - grey, fine grained, moderately sorted | Patonga Claystone | | 1.12E-06 | | |
| **B400W100** | 85.8 | sandstone - light grey, fine grained, moderate to well sorted | Tuggerah Fm | | 1.77E-06 | | |
| **B400W100** | 92.7 | siltstone - light grey, medium grained, well cemented | Tuggerah Fm | | 4.38E-07 | | |
| **B400W100** | 102.8 | sandstone - grey, very fine to fine grained, well sorted | Tuggerah Fm | | 2.16E-06 | | |
| **B400W100** | 110.0 | sandstone - light grey, fine grained, moderate to well sorted | Tuggerah Fm | | 1.59E-02 | | |
| **B400W100** | 119.2 | sandstone/siltstone - grey, very fine grained with silty layers | Tuggerah Fm | | 3.66E-07 | | |
| **B400W100** | 131.2 | siltstone/laminite - dark grey, very fine grained | Tuggerah Fm | | 4.64E-07 | | |
| **B400W100** | 143.0 | sandstone - light grey, fine grained, moderate to well sorted | Tuggerah Fm | | 5.83E-07 | | |
| **B600W100** | 42.1 | sandstone/siltstone - light grey, very fine grained | Patonga Claystone | | 2.45E-06 | | |
| **B600W100** | 53.5 | sandstone - light grey, fine grained, moderate to well sorted | Tuggerah Fm | | 1.38E-06 | | |
| **B600W100** | 67.2 | sandstone - light grey, fine grained, moderate to well sorted | Tuggerah Fm | | 8.80E-07 | | |
| **B600W100** | 72.2 | sandstone - cream, fine grained, moderate to well sorted | Tuggerah Fm | | 1.35E-06 | | |
| **B600W100** | 84.1 | sandstone - cream to grey, medium grained | Tuggerah Fm | | 5.21E-03 | | |
| **B600W100** | 90.5 | siltstone - light grey, medium grained, well cemented | Tuggerah Fm | | 1.49E-07 | | |
| **B600W100** | 96.2 | siltstone/laminite - dark grey, very fine grained | Tuggerah Fm | | 5.56E-07 | | |
| **B600W100** | 108.9 | sandstone -grey, medium grained, interbedded silt layers | Tuggerah Fm | | 2.98E-06 | | |
| **B600W100** | 122.7 | sandstone -grey, medium grained, poorly sorted | Tuggerah Fm | | 3.23E-05 | | |

*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-rising 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) which is considered to be more suited to the unconfined alluvial sediments. 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 horizontal 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)*

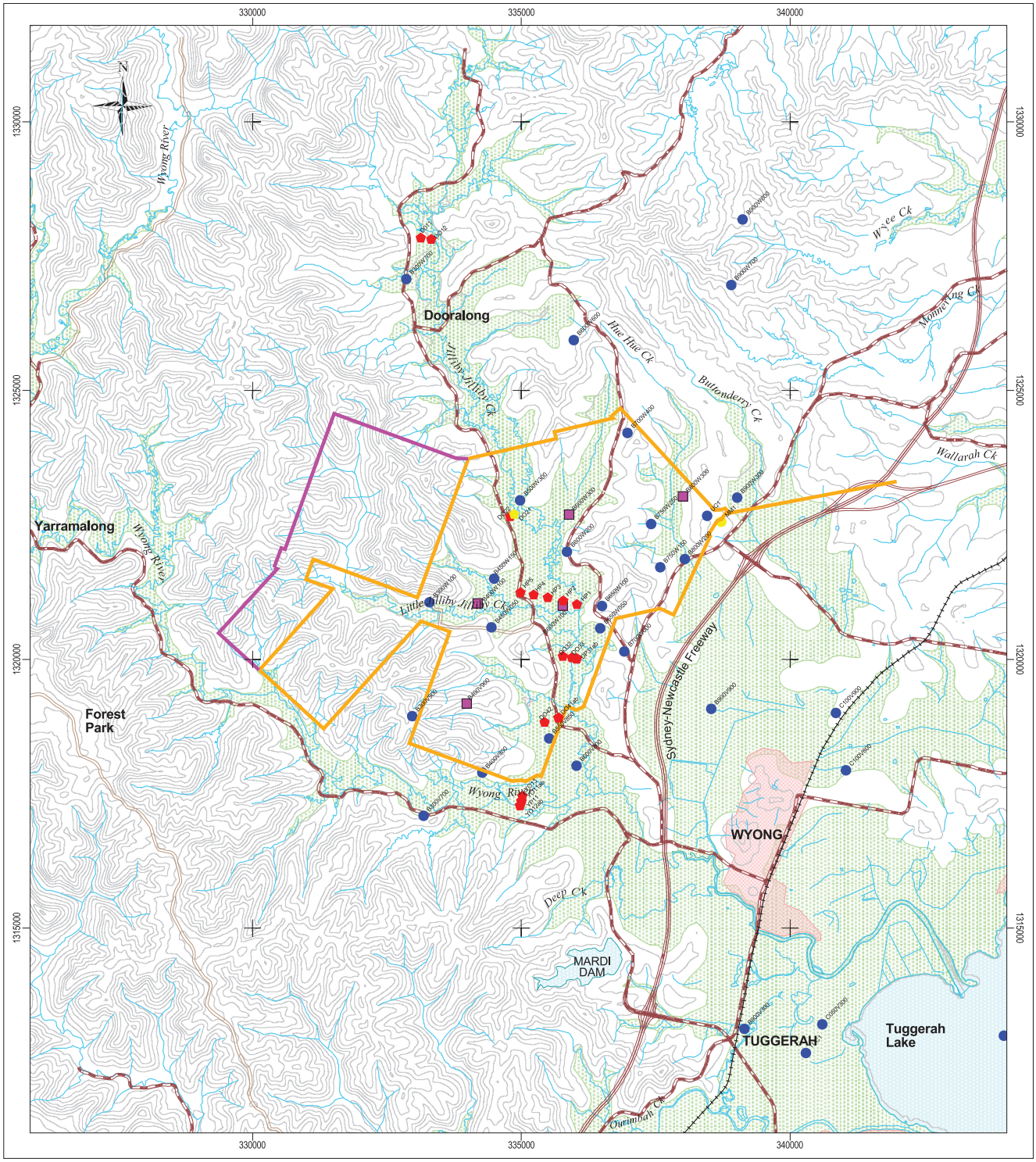
| Bore | Bore depth (m) | Water depth (m) | Test interval (m) | Lithology | Hvorslev K (m/day) | KGS K (m/day) |
|---|---|---|---|---|---|---|
| **DO11** | 24 | 2.6 | | | 2.6E-01 | 4.7E-01 |
| **DO12** | 18 | 3 | 7.5-14.5 | coarse sand | 2.7E-01 | 2.6E-01 |
| **DO21** | 30 | 1.5 | 12.0-22.0 | sandy gravel | 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 |

L. Cook and Associates (2010) installed piezometers and conducted rising head tests at five locations in the alluvial lands at the confluence of Jilliby Jilliby and Little Jilliby creeks[9]. Values for the alluvial materials are summarised in Table D6 and are generally consistent with earlier testing (Table D5).

***Table D6: Rising head (slug) test summary (L.Cook & Assoc, 2010)***

| Bore | Bore depth (m) | Water depth (m) | Test interval (m) | Lithology | Hvorslev K (m/day) | KGS K (m/day) |
|---|---|---|---|---|---|---|
| **HP1A** | 42.0 | 2.6 | 33.0-39.0 | sandstone | 5.4E-02 | 4.5E-02 |
| **HP1B** | 16.5 | 3 | 12.0-15.0 | mixed alluvium | 1.5E+00 | 5.2E-01 |
| **HP2A** | 42.0 | 1.5 | 33.0-39.0 | sandstone | 2.2E-01 | 2.2E-01 |
| **HP2B** | 24.0 | 1.9 | 19.0-21.0 | silty sand | 1.3E+00 | 2.2E-01 |
| **HP3A** | 42.0 | 2.8 | 33.0-39.0 | sandstone | 1.1E-02 | 5.8E-03 |
| **HP3B** | 24.0 | 2.4 | 18.0-21.0 | sand/clay | 1.1E+00 | 6.4E-01 |
| **HP3C** | 8.0 | 1.9 | 5.0-8.0 | peat/clay | 2.8E-02 | 2.5E-02 |
| **HP4A** | 42.0 | 2.9 | 33.0-39.0 | sandstone | 1.1E+00 | 3.9E-01 |
| **HP4B** | 30.0 | 1.2 | 24.0-27.0 | clayey sand | 6.1E-01 | 1.7E-01 |
| **HP5A** | 42.0 | 1.1 | 33.0-39.0 | sandstone | 2.0E-01 | 1.2E-01 |
| **HP5B** | 23.0 | 3.1 | 17.0-20.0 | clay/sand | 1.9E-01 | 4.4E-02 |
| **HP5C** | 6.0 | 4.4 | 3.0-6.0 | silty sand | 4.0E-01 | 5.7E-02 |

[9] Source data provided in spreadsheet format by L. Cook and Associates.




0 2000 4000 6000 Metres

Scale 1:100,000

- creeks
- minor road
- sealed road
- Freeway
- railway
- lease
- urban area
- alluvium
- alluvium test locations
- core test locations
- packer test locations

WALLARAH 2 COAL PROJECT

**Hydraulic conductivity test locations**

*Figure D1*

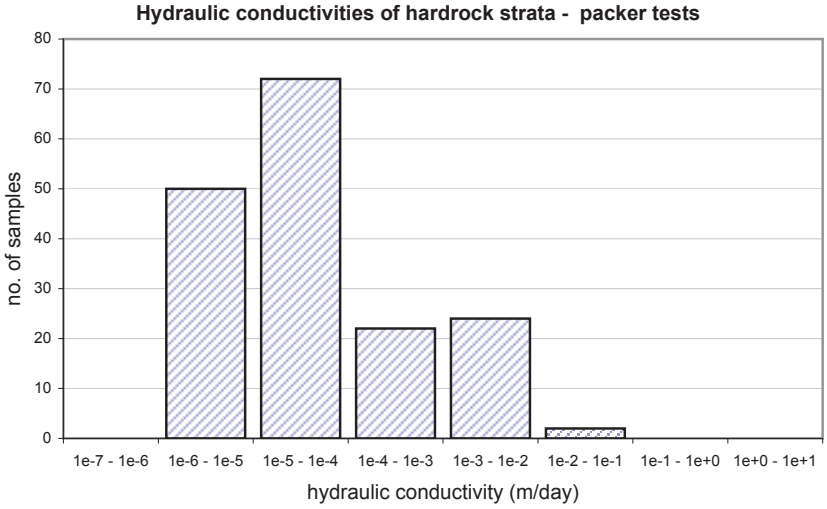



*Figure D2a*

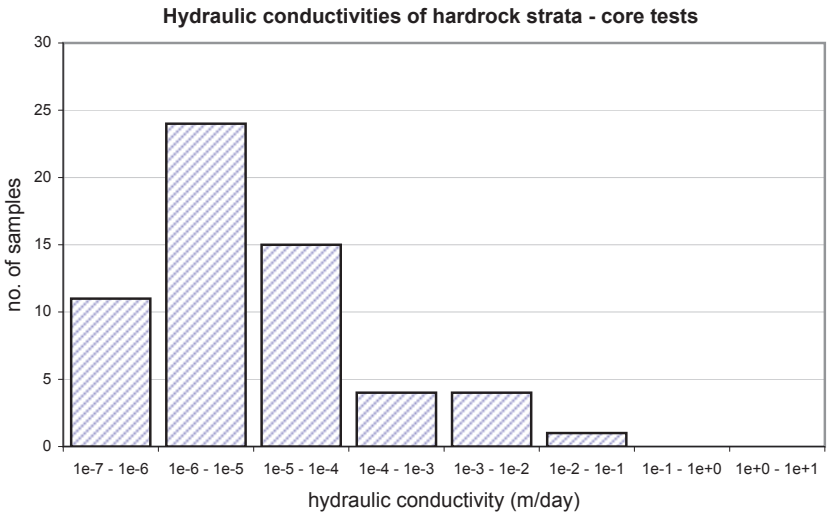



*Figure D2b*

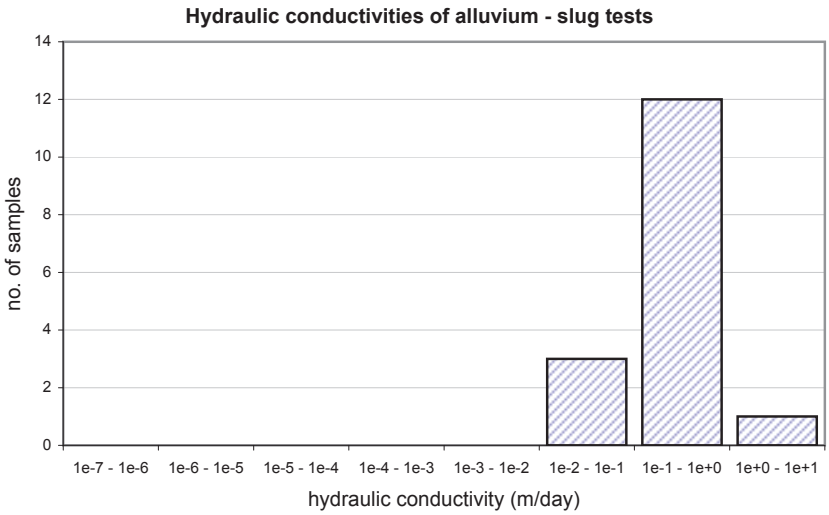
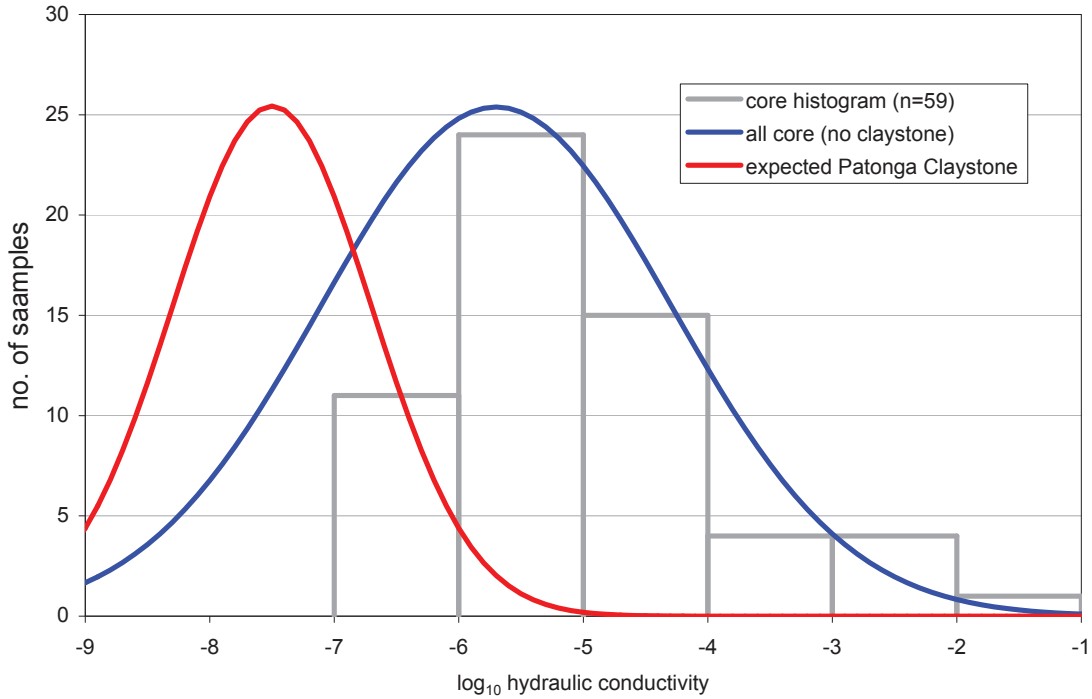



*Figure D2c*

**Summary hydraulic conductivity histograms**
*Figure D2*




The distribution for 'all core samples' (blue line) does not include any claystone samples which constitutes a high proportion of both the Patonga Claystone and Tuggerah Formation. The distribution for the Patonga Claystone (red line) assumes claystone dominance.

**Expected matrix conductivities for Patonga Claystone**
*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 rationalisation of spatially and temporally varying field conditions. The modelling process utilises a system of mathematical equations for water flow through porous media subject to prescribed boundary conditions. The process requires simplification and definition of the groundwater system in respect of geometry, hydraulic properties and applied stresses including rainfall, pumpage, river/creek leakage and underground seepage.

## 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 where the eroded valleys host mixed alluvial deposits which are 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;
- 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. Groundwater flow in the hard rock strata has over a very long period of time, migrated from elevated areas towards the many incised creeks and rivers at lower elevations. Groundwater flow in the alluvium follows a similar pattern but has much shallower hydraulic gradients. 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 hydrogeological system, are the main goals of groundwater flow modelling.

## E2 Numerical model code

In the present study, a finite difference approach has been selected so as to efficiently include a highly variable topographic surface, simulation of the zone of depressurisation and the non-linear response of pressure changes created by the mining process over a large region. The software code Modflow-Surfact (Hydrogeologic, 2009) can simulate variably saturated flow conditions as well as incorporating a range of boundary conditions that can be changed during the simulation. The current model utilises the capability in Modflow-Surfact, to change material properties of the strata during a simulation period. This feature is especially useful for simulation of the subsidence zone. Supporting software coded independently by MER has also been employed for data processing.

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 layout at depth, the spatial variations occurring in strata and sediment properties, the prevailing drainage system, and the expected hydraulic gradients developed in the course of model simulations. Competition between accuracy (at different scales) 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 proposed underground

mining operations 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 layers with 105768 cells per layer. Cell dimensions are a minimum 50 m x 50 m with layer thicknesses of the same order except for the WGN seam. Total model area is about 575 sq. km. with cell areas ranging from 2.5E+03 $m^2$ to 1.0E+04 $m^2$.

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.

## E3. Model geometry

Model layers adopt a geometry consistent with the known stratigraphy of the region but with additional layers included to facilitate representation of the subsidence zone and associated pore pressure distribution. 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 an elevation of 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' and the potentially increased presence of joints and fractures.

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, the Munmorah Conglomerate, Dooralong Shale and the WGN seam. The geometry of each unit has been carefully defined from structure contour information supplied by Kores geologists and interpolated regionally. The base of the model has been defined as 100 m lower than the WGN seam floor. The bottom layer basically represents deeper Newcastle Coal Measures and has been included in order to represent upwards leakage to the WGN seam.

## E4. Model W3 hydraulic properties

The 2012 model is identified as model W3. This model is very similar to the previously reported model W1 (MER, 2010). Modifications include:

- re-interpolation of the model ground surface from high resolution digital terrain data in some areas, and minor adjustment of boundary conditions associated with drainage lines;
- transient calibration of the alluvial groundwater system based upon recent water level monitoring data at new piezometer locations;
- increased hydraulic conductivity of the Terrigal Formation in hilly terrain;
- modification of hydraulic conductivities associated with the subsidence zone;
- improved methodology for the calculation of mine water influx.

### *E4.1 Hard rock hydraulic conductivities*

Hydraulic conductivities assigned to each model layer below layer 1 are 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. Notably, claystones and shales have been assigned values about one order of magnitude lower

than fine grained sandstones. While claystones and shales remain untested for matrix permeability (due to the age of the core) it is more likely that the conductivities are at least 2 orders of magnitude lower than sandstones ie. less than 5.0E-08 m/day.

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.

The process of conversion to hydraulically equivalent layers does not account for the effect of increasing confining stress with depth which logically would tend to reduce hydraulic conductivity. 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 E2 summarises model layer properties.

***Table E1: Adopted matrix 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 |

* 5.0E-07 considered to be the highest value likely to be measured

***Table E2: Hydraulic properties assigned to the groundwater flow model***

| Layer | Lithology | Thickness (m) | Kx m/day | Ky m/day | Kz m/day | Ss 1/m | Sy |
|---|---|---|---|---|---|---|---|
| 1 | valley fill alluvium | avg 30 | 1.3E-01 | 1.3E-01 | 1.3E-01 | 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 | 1.0E-03 | 1.0E-03 | 2.1E-04 | 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 = horizontal conductivity, Kz = vertical conductivity, Ss = specific storage, Sy = drainable porosity

## E4.2 Alluvium hydraulic conductivities

Conductivity values assigned to the alluvial materials are likely to exhibit some variability 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 1.3E-01 m/day (Kxy) has been adopted for modelling purposes based on piezometer testing. Coastal sands have been assigned a value of 1.0E+01 m/day

Since the model is fundamentally a forward model based on 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 system tends to act as a water store with respect to the underlying hard rock strata.

### E4.3 Subsidence zone hydraulic conductivities

Enhanced vertical conductivities representing connected and relatively free draining cracking regimes within the subsidence zone, have been simulated above the WGN seam.

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 E5 and are 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 of 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;
- ***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 sometimes referred to as the *constrained zone* and is dominated by bedding shear with infrequent vertical cracking;
- ***shallow surface cracking:*** a zone of typically 10 to 20 metres depth dominated by tensile failure. Surficial cracking may exhibit apertures sometimes exceeding 50 mm but characteristics of cracks depend upon the bedding geometry, 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.

Parameter scaling adopted for model W3 is summarised in Table E3 based on an interpretation of 2D geomechanical modelling of fracture enhancement and connectivity (SCT 1999, 2011). Enhanced connectivity was invoked in Modflow-Surfact using the time varying material property (TMP) package with a relatively short ramp time of 0.5 days for properties to change to the increased value. This scaling establishes complete depressurisation of strata in a relatively short period of time.

*Table E3: Summary of conductivity enhancements for model W4*

| Layer | Lithology | Approx. thick. | Scaling x Kv | Scaling x Kh |
|---|---|---|---|---|
| 1 | Alluvium & elevated Terrigal Fm. | variable | 1 | 1 |
| 2 | Terrigal Formation | variable | 1 | 1 |
| 3 | Terrigal Formation | avg.50 | 1 | 1 |
| 4 | Patonga Claystone | avg.50 | 1 | 10 |
| 5 | Patonga Claystone | avg.50 | 1 | 20 |
| 6 | Tuggerah Formation | avg.60 | 1.1 | 60 |
| 7 | Tuggerah Formation | avg.60 | 2 | 100 |
| 8 | Tuggerah Formation | avg.60 | 10 | 600 |
| 9 | Munmorah Conglomerate | avg.60 | 100 | 1000 |
| 10 | Munmorah Conglomerate | avg.60 | 1000 | 6000 |
| 11 | Dooralong Shale | avg.35 | 90000 | 148000 |
| 12 | WGN seam | avg.5 | 5.0E-04 | 8000 |
| 13 | deep coal measures | avg.50 | 1.0E-06 | 1.0E-06 |
| 14 | deep coal measures | avg.50 | 1.0E-06 | 1.0E-06 |

K = hydraulic conductivity, Kv = vertical conductivity

### E4.4 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 calculated modulus range of 10 to 25 GPa.

Average drainable porosities (specific yields) of 0.1% for hard rock strata and 20% for unconfined alluvium, have been adopted.

## E5. Model boundary conditions

Boundary conditions assigned to a groundwater 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*[10] along parts of the Wyong River below Yarramalong, *general head nodes*[11] along the shoreline of Tuggerah Lake, and *drain nodes*[12] 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 assigned constraining heads. River and drain conductance terms have been set to a high value of 1000 $m^2$/day to ensure a high level of connectivity for water transfer.

Distributed flux conditions have been employed to represent regional rainfall recharge. Transient calibration of the W3 model utilised a variable rainfall recharge rate based upon measured rainfall (see Section E6.2 below) while fixed (average) recharge rates were used in long term simulations. For hard rock areas the average rate varies from 0.20 to 18 mm/annum. Recharge at a conservative rate of 90mm/annum has been applied over coastal

[10] River nodes are constrained head and flux nodes allowing water to exit or enter the model at a rate governed by the potentiometric elevation relative to the assigned river elevation, and a conductance term. There is a limit to the water entering the model.
[11] General head nodes are similar to river nodes but there is no limit to water entering the model. Used to simulate the average seawater level.
[12] Drain nodes allow water to exit the model only. The rate is governed by the potentiometric elevation relative to the assigned drain elevation and a conductance term.

sands while an average 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).

Groundwater abstraction by local landholders for domestic, stock and irrigation purposes, has not been included. Since the alluvial lands are for all practical purposes, isolated from the coal measures by much more significant recharge to a relatively high hydraulic conductivity alluvial system, absence of pumpage in the model is unlikely to affect model outcomes in terms of seepage induced by the deep longwall panels. Impact of strata depressurisation on the alluvial groundwater system 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

It is not possible to calibrate the hard rock systems within the model without a significant hydraulic stress[13] in the system and without a comprehensive monitoring system. Model representation of the hard rock systems is therefore dependent upon the measurement and assignment of formation hydraulic properties as determined by packer and core tests, and upon the steady state hydrostatic piezometric surfaces.

### *E6.1 Steady state calibration*

Steady state calibration of the prevailing shallow piezometric surface has been conducted by adjusting rainfall recharge and hydraulic conductivity, and comparing the resulting head distribution to measured or estimated piezometric elevations at a number of 'control' bores identified on Figure E6. Measured elevations are available at existing monitoring wells (mostly within the alluvial lands) while estimated elevations have been generated at a number of sites from inspection of geophysical wireline logs.

Figure E6 also provides a plot of the model generated piezometric surface for the shallow alluvium/rock zone (layer 1). Figure E6a provides a correlation plot for all control piezometers. A measure of the correlation can be described by the normalised root mean square (NRMS) error which is calculated to be 7.5%. This error is considered acceptable for a model of this regional scale but it is noted that by invoking the concept of equivalence it is possible to find many combinations of rainfall recharge and hydraulic conductivity that will provide similar correlations.

Groundwater flow pathways are also shown on Figure E6. These are pathways that a groundwater particle would follow over a very long period of time[14]. Flows are from elevated areas of hard rock strata (Terrigal Formation), towards the major drainages at lower elevations. 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.

### *E6.2 Transient calibration*

The transient calibration process has involved simulation of groundwater system reaction to a transient stimulus which in the absence of any deep strata depressurisation associated with mining activity, has focused on movement of the water table in response to rainfall recharge.

Transient water level data has been sourced from discrete water level monitoring collected over the period 1998 to 2001 (hand dipped measurements) and more recent continuous data stored on dedicated data loggers associated with the five piezometers installed in the Dooralong Valley (Honeysuckle Park) alluvial lands in 2010.

[13] Hydraulic stress means a mechanism that imposes a significant change in observed piezometric elevations.
[14] Flow paths are not restricted to a plane. They are a 3 dimensional representation in plan view.

Water level data for the five piezometers is provided in Appendix C[15] while rainfall data comprised daily data for Wyee rain gauge 061082 to April 2010 supplemented by data for Honeysuckle Park thereafter.

### E6.2.1 Pre-processing rainfall data to derive infiltration recharge estimates

A catchment simulator model based on Pitman 1973[16] has been employed for the purpose of generating estimates of rainfall recharge to the alluvial lands. Fundamentally the model calculates and accumulates surface runoff based on daily rainfall and evaporation, infiltration and percolation to the water table. Evaporative processes apply within the soil store. However once moisture has departed the shallow storage zone, evaporative processes no longer apply and the infiltrated volume is then assigned as recharge to groundwater storage. It is the percolation component that has been used in preparing recharge input to the groundwater flow model for calibration purposes.

Simplification of daily recharge (ie. output from the catchment simulator) to longer periods of constant recharge that represent stress periods in the groundwater flow model, has been based on a maximum likelihood segmentation technique (MLS)[17]. Figure E7 illustrates results for the rainfall calibration sub-set period from 1998 to 2003. Rainfall received during this period reflects close to average conditions. That is the cumulative rainfalls for 1 to 30 day periods are generally consistent with a once in 1 year average recurrence interval (ARI) based on long term statistics for Wyee rainfall data (see Appendix A). Figure E7a upper plot illustrates the recorded rainfall and the calculated rainfall infiltration-percolation from the catchment simulator, while Figure E7b lower plot shows the segmented recharge used in groundwater flow modelling after MLS processing.

Rainfall received during the later calibration period from 2010 to 2012 (for Honeysuckle Park piezometers) reflects above average conditions where cumulative rainfalls for 1 to 30 day periods are generally consistent with a once in 2 years ARI (see Appendix A).

### E6.2.2 Calibration simulations

Transient calibrations have involved repeated simulations using the segmented historical rainfall records, and comparison of model predicted groundwater levels to measured water levels.

Figures E8a to E8c provide plots for piezometers that were monitored during the period 1998 to 2001. These plots exhibit generally good correlation with respect to both the higher frequency component exhibited in water level variations, and the low frequency component close to the average level. Departures are related to a number of factors including piezometer construction, water table perching, model simplification, and complex runoff routing at a localised (paddock or smaller) scale within the Dooralong Valley alluvial lands. For example, calculated water levels at piezometer DO11 are displaced about 2 m lower than field measured values.

Figures E9a to E9c provide plots for piezometers that have been monitored during the period 2010 to 2011. These plots exhibit good high frequency correlations but average levels are displaced. These displacements could be reduced by varying the rainfall recharge. However this requires an understanding of runoff and ponding at a very localised 'paddock' scale which is considered to be impractical.

Results of the transient calibrations confirm the generally low hydraulic conductivity of alluvial sediments. Water levels in deeper piezometers installed in the underlying hard rock strata which is typically either Patonga Claystone or Tuggerah formation, are not influenced

[15] Source data provided in spreadsheet format by L. Cook and Associates.
[16] The Pitman model is a deterministic model which has been modified by MER to facilitate representation of multiple catchments and percolation via the soil profile.
[17] Automated processing of rainfall recharge ensures all events are treated in a routine and repeatable manner. Maximum likelihood processing seeks to identify periods of time over which the recharge rate can be held constant while maintaining a volumetric balance with respect to infiltrated rainfall. Boundaries between these periods are identified by a process involving recharge (signal) smoothing and Kalman filtering.

by specific rainfall events. The lack of any high frequency component confirms the much lower conductivity of these strata at depth compared to the alluvium.

## E7. Simulation of mining

Simulations of proposed mining operations have been conducted over a period of 38 years (10 years more than the 28 years approval period sought). Simulations over the first 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 E10.

The subsidence zone has been simulated by invoking changes to the hydraulic conductivities of strata above each mined panel in accordance with the proposed panel extraction schedule and as described in Section E4.3 above.

### *E7.1. Strata depressurisation and alluvial system leakage*

Figure E11 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 shows a subdued reflection of topography with potentiometric surface 'highs' occurring in areas associated with topographic higher elevations.

Potentiometric 'lows' prevail along the Wyong River and along Jilliby Jilliby Creek as expected. Hence groundwater is induced to flow from the areas of high potentiometric heads, to areas of low potentiometric heads.

Figure E12 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 E11. Reference to Figure E12 shows no drawdown in the water table (layer 1) while drawdown on slices 3 and 5 would be restricted to the Tooheys Road mine entry (portal) area. In contrast, layer 10 in the lower part of Tuggerah Formation 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 (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 E13 illustrates the drawdown in potentiometric 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 shows an 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 E14, E15 and E16 illustrate changes in the formation pressures at 21, 28 and 38 years of mining respectively. Advancement of the pressure loss front 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 Formation 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. 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 E17 and E18 provide vertical sections through the model illustrating pore pressure distributions prior to mining and at the cessation of mining (section locations are shown on Figure E2). Both show complete depressurisation and variable dewatering from the WGN seam up to the lower part of the Tuggerah Formation some 220 m above seam. Pore pressures are reduced but sustained in the remaining zone to ground surface. Figure E17 also shows the retardation in drainage in the western extracted panels with residual saturation clearly evident above pillars but slowly receding upwards; saturation above eastern pillars has virtually dissipated. Figure E18 is orthogonal to Figure E17 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 groundwater system and connected systems. The reasons for this are the retardation of losses within the Patonga Claystone and parts of the underlying Tuggerah Formation, and the higher storage capacities and higher hydraulic conductivities prevailing within the shallow groundwater system – storage is able to accommodate any small downwards leakage to deeper hard rock strata without measurable impacts on water levels.

On completion of the maximum 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 E19 as the calculated daily influx rate. Also indicated on Figure E19 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 approximately 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.

Leakage from alluvial sources has been assessed within the model in terms of loss of baseflow from the alluvial and hard rock groundwater systems to the local creek catchments. Figure E20 illustrates graphed baseflow zone budgets over the mine life while the following Table E4 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 of the order of 0.002 L/day/sq.m. or 2 millilitres/day/sq.m.

***Table E4: Summary of impacts on baseflows to local catchments***

| Catchment | Reduction ML/day | Alluv. Area. sq.km | Unit Area Leak. mL/sq.m./day |
|---|---|---|---|
| Hue Hue Ck | <0.001 | 0.635 | <1.57 |
| J.J. Ck above Little J.J. Ck | <0.001 | 4.356 | <0.23 |
| Little J.J. Ck | <0.001 | 2.063 | <0.47 |
| J.J. Ck below Little J.J. Ck | <0.001 | 2.121 | <0.47 |
| Wyong River tributaries | <0.001 | na | 0 |

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

### E7.2 Stochastic simulation – Model W4

Models W1 and W3 are considered to reflect conservative conditions with respect to the subsidence zone where a freely draining height of about 220 m has been adopted[18].

An alternative scenario which includes randomised hydraulic conductivity distributions has been developed. This approach attempts to reflect the variable and random connectivity of the crack network within the subsidence zone, and the consequent variability in horizontal and vertical drainage predicted by geomechanical modelling (SCT, 1999 and 2011). This alternative model is identified as W4.

Layer 8 for example which is in the uppermost part of the highly connected crack zone (above 180 m height above seam) has been modified from model W3 uniformly free draining conditions, by randomly scaling the horizontal conductivity values[19] between 100 and 500 times the undisturbed values. This attempts to reflect the dominance of bed separation. The vertical conductivity has been scaled between 1 and 10 times to reflect the diminishing effect of induced vertical cracking.

Layers 2 to 7 have also been scaled in a randomised manner with respect to conductivity. Figure E21 illustrates the distribution applied to layer 7.

Simulations of panel extractions for Model W4 are summarised on the piezometric head distributions in Figures E22 and E23 for 28 and 38 years of mining respectively. Comparison of these plots with Figures E15 and E16 indicates minor differences.

Figures E24 and E25 show the predicted pore pressure distributions at the cessation of mining. Comparison of these plots with Figures E17 and E18 indicates very minor differences.

Figure E19 compares mine water seepage rates for all models. Models W1, W2 and W3 exhibit very similar rates over the 38 years of mining while W4 indicates marginally lower rates. The reduction is attributed to the introduction of randomised hydraulic conductivities in layer 7.

### E7.3 Recovery of groundwater pressures post mining

On completion of mining, regional groundwater 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 material properties and pressure head distributions at 38 years of mining, as initial conditions for a recovery model based on Model W3. Mine storage (porosity) has been enhanced to reflect open roadways and goaves. Figure E26 shows the predicted drawdown distribution after 500 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 10 m or more is evident in certain elevated parts of area. In reality this may not be as extensive as indicated, due to the long term (ongoing) presence of rainfall recharge via the shallow weathered rock zone. This weathered rock zone has not been included in the model due to the perched nature of these systems, unknown and variable material properties, and the absence of monitoring.

### E7.4 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, across different modelled scenarios where a particular property is changed. Significant variation in the NRMS error is normally associated with highest sensitivity parameters.

[18] Freely draining conditions were initiated by enhancing conductivities in model layers 8 through 12.
[19] Randomisation employed a uniform deviate over the nominated scaling range – see Table E4.

In the current situation where no mining has been conducted and hence no significant stresses have been applied to the deep groundwater systems, sensitivity analysis has only limited value. However it is important to identify the parameters which are most likely to 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 hydraulic conductivity (Kz) in the subsidence fracture zone (free draining connected cracking).
- the rate of leakage from the alluvial lands will be governed almost entirely by the hydraulic conductivity of the constrained zone which is comprised of Patonga Claystone and Tuggerah Formation. These parameters are considered in more detail in Section 7.4.1;
- Rainfall recharge is relatively insensitive to layers beneath layer 1. Reducing or increasing the rainfall over a sensible range does not significantly affect deep strata depressurisation during the period of mining.

### E7.4.1 Vertical conductivity of the constrained zone

In addition to the above noted generalised sensitivities, an assessment of the nominated vertical hydraulic conductivity in the constrained zone (see Figure E5) has been conducted by considering the equivalent conductivity that might prevail for a randomised distribution (of conductivities) within a 1 Ha surface area rock mass extending to a depth of 120 m. This block of material has been represented in an alternate flow model which is discretised into 5 x 5 x 5 m blocks of variable conductivity. The overall height of 120 m is considered to be the minimum likely height of the constrained zone while a 5 m discretisation attempts to simulate the potential variability in material properties with combinations of vertical and horizontal conductivities potentially providing an enhanced vertical flow pathway through the column.

A log normal distribution has been adopted for the variable hydraulic conductivity distributions to reflect a tendency towards a central value with the mean and variance specified in Table 5. This distribution means for example that values for the horizontal and vertical conductivities will have a high probability of being near their respective mean values but extreme values can also occur albeit with lower frequency.

***Table E5: Statistical parameters for log normal distributions (m/day)***

| | Mean value | $Log_{10}$ Mean | Variance |
|---|---|---|---|
| Horizontal conductivity Kh | 1.0E-02 | -2.0 | 4 |
| Vertical conductivity Kv | 1.0E-05 | -5.0 | 4 |

Figure E27a shows histograms for a typical horizontal and vertical conductivity data set while parametric ranges are summarised in Table E6 as the 5$^{th}$ and 95$^{th}$ percentiles.

***Table E6: Typical range in values (m/day)***

| | 5% | 50% | 95% |
|---|---|---|---|
| Horizontal conductivity Kh | 4.90E-06 | 1.02E-02 | 2.14E+01 |
| Vertical conductivity Kv | 4.57E-09 | 9.89E-06 | 1.74E-02 |

% = percentile probability

Figure E27b illustrates the distributions for both horizontal and vertical permeabilities in the vertical column model. This column has been numerically modelled to derive the equivalent saturated conductivity of a single rock mass of 1 Ha area and 120 m thick. The process has been repeated 100 times to generate a central estimate which has been compared to the regional groundwater models. Results yield a mean vertical conductivity of 4.16E-06 m/day and a standard deviation of 2.48E-07. This 'disturbed' conductivity is very close to the values adopted in the regional groundwater flow model for the Patonga Claystone (3.8E-06 m/day) in an undisturbed state.

The analyses indicate that it is possible to increase the mean horizontal conductivity by several orders of magnitude in a randomised environment with some areas up to 6 orders of magnitude higher than the adopted values in the regional flow model, without significantly affecting the vertical conductivity. Basically the horizontal conductivity is relatively insensitive when compared to the vertical conductivity in controlling vertical leakage through the constrained zone. Similarly, by introducing randomness to vertical conductivities it is possible to increase the mean value without affecting the bulk conductivity of the column.

## E8. Constraints to modelling

It is not possible to completely represent groundwater 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 groundwater 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. Nevertheless 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 drill hole core where fractured zones are observed to be infrequent. While such zones (where identified) are considered to be locally transmissive, they are expected to be poorly connected and 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 for 0.5 ML/day short term increase in the mine water seepage is suggested if they are encountered.
2. Boundary conditions applied to the model drainage network are head-flux conditions (mostly drain type boundaries). Regionally 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 not measurably affect the shallow groundwater system.
3. The failure regime beneath the important alluvial aquifer system is based on connective vertical cracking to a heights of more than 200 m above seam. This zone is predicted to narrow above each panel (see Figure E6). Model discretisation does not lend itself to simulation of a narrowing zone with discrete cracks. A simplified and conservative approach has therefore been adopted that assumes connected and relatively free draining cracking over full panel width to maximum height. As a result,

simulated depressurisation of overburden strata especially beneath the alluvium, is more widespread than may 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 hydraulic conductivity have not been included in the model. The predicted extent of depressurisation at a given time may therefore be greater in some areas, than would be measured under field conditions.

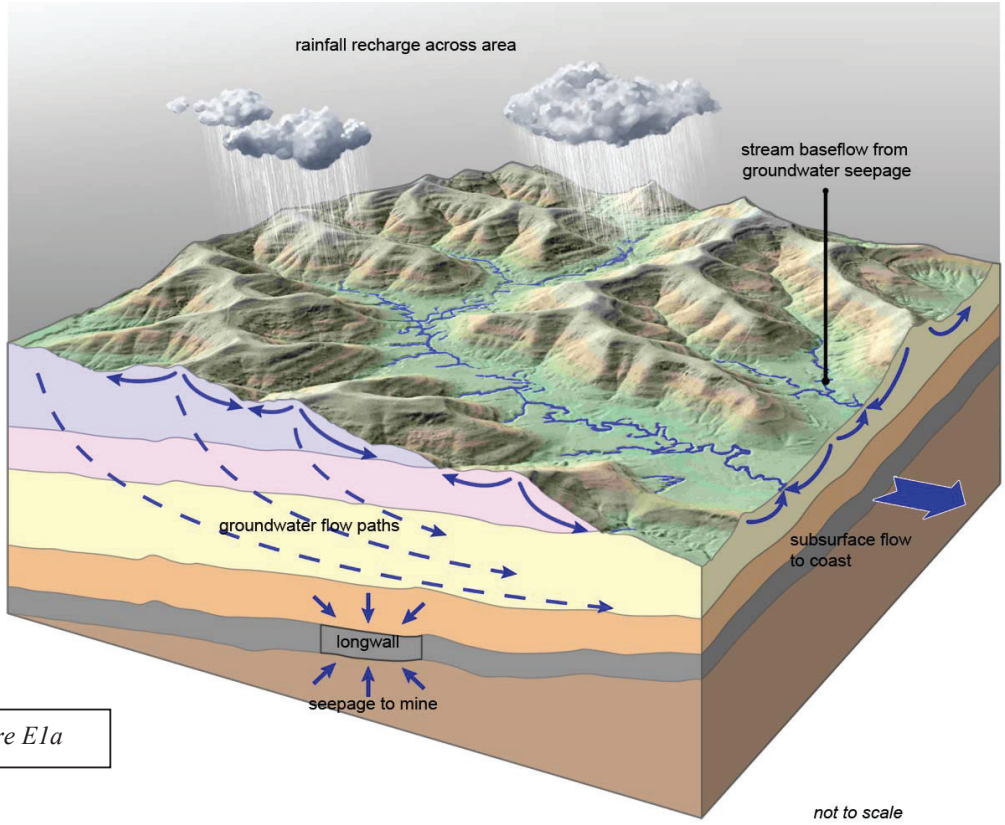



*Figure E1a*

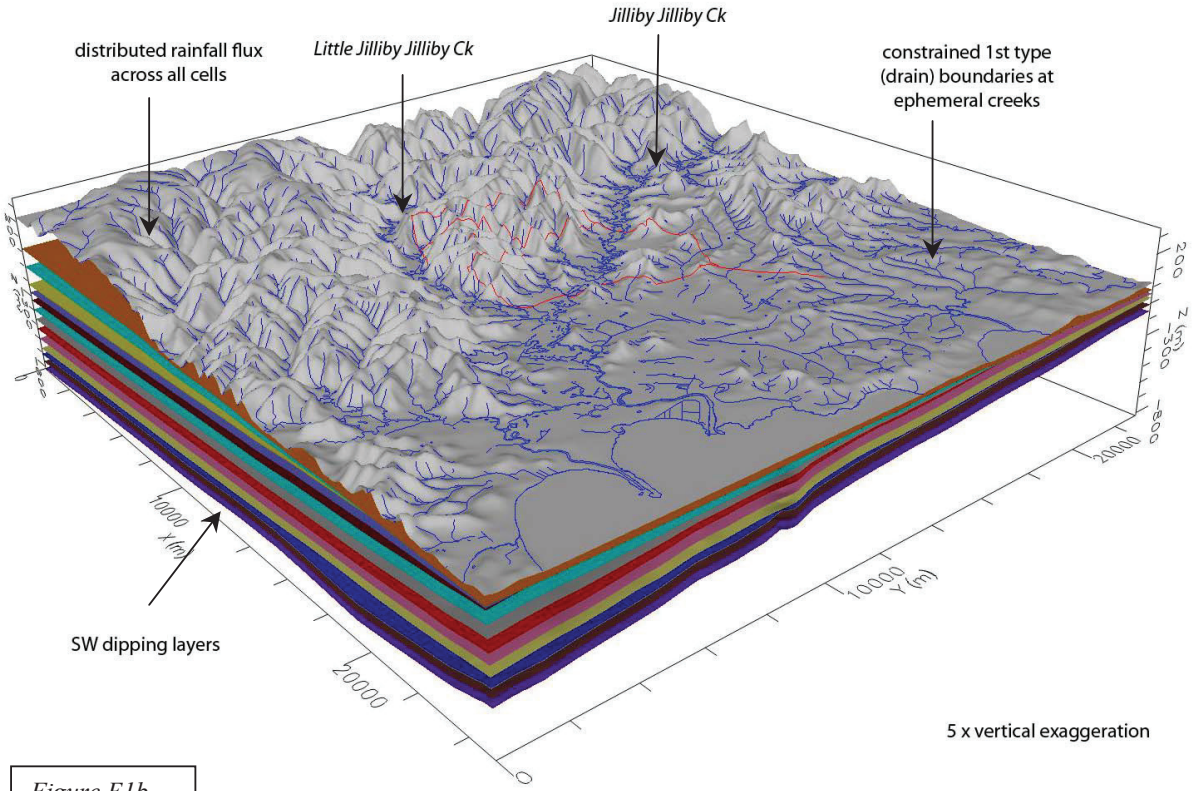
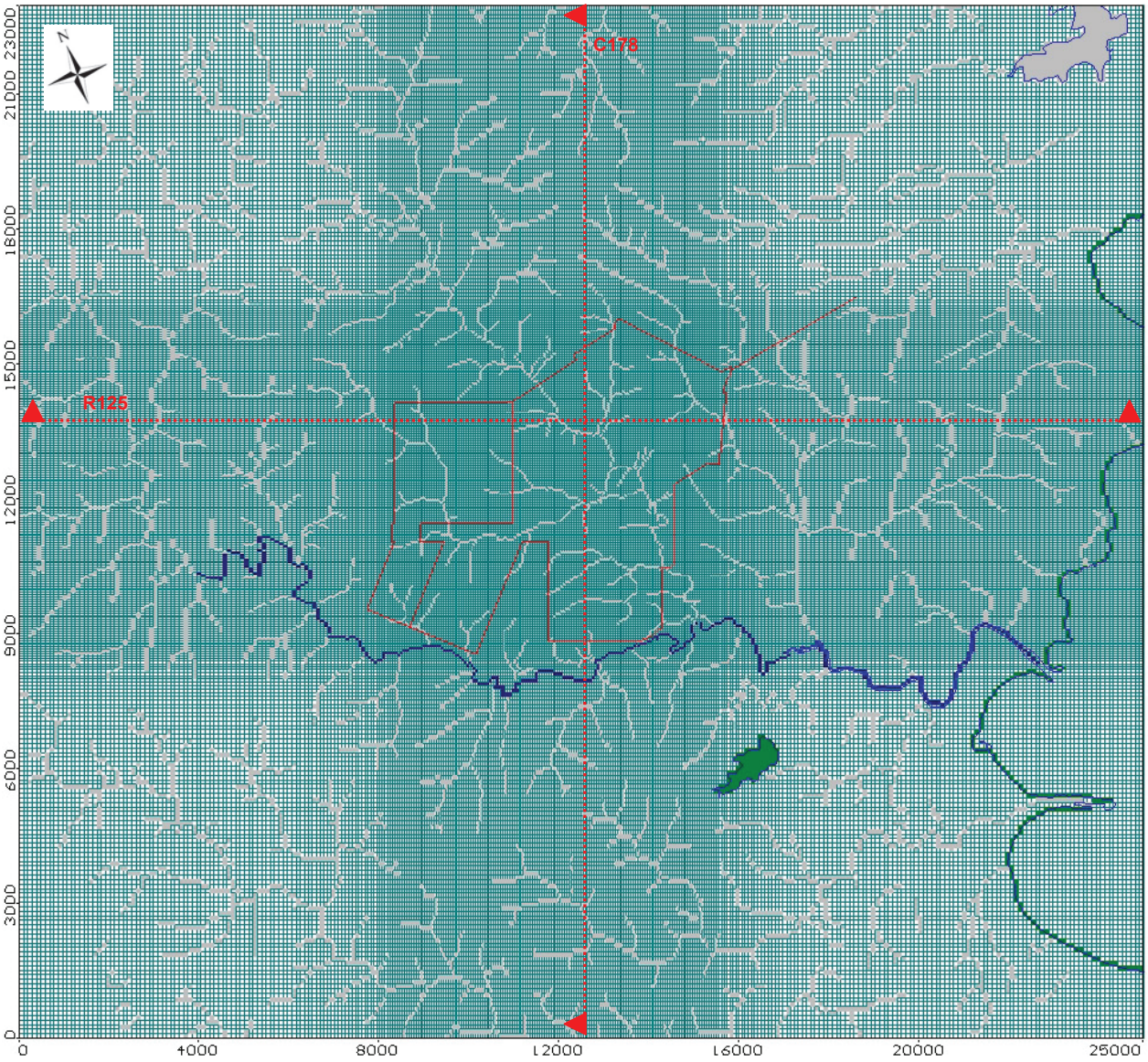



*Figure E1b*

**Conceptualisation of flow system and model realisation**

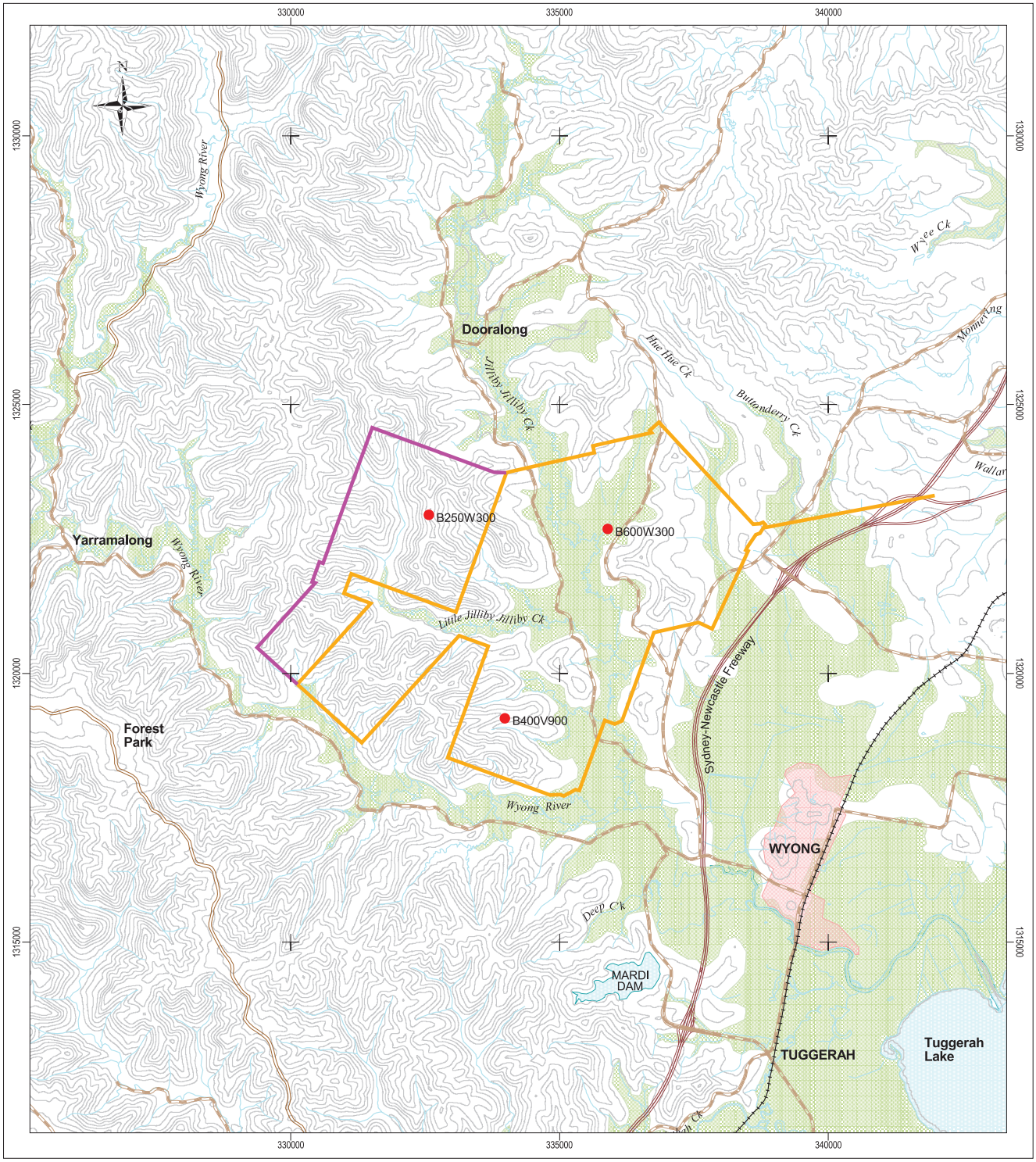
*Figure E1*




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*




0 2000 4000 6000 Metres

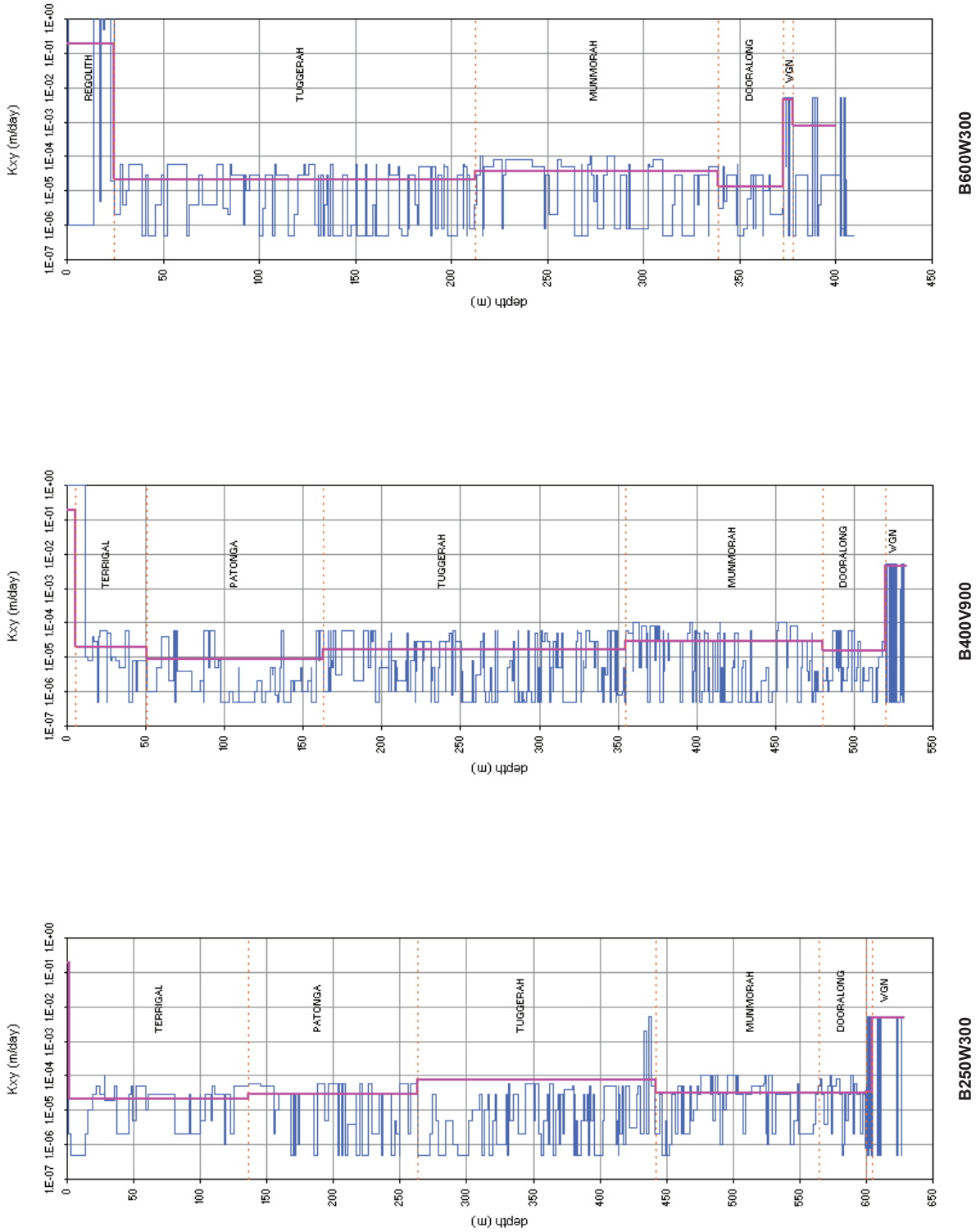
Scale 1:100,000

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

WALLARAH 2 COAL PROJECT

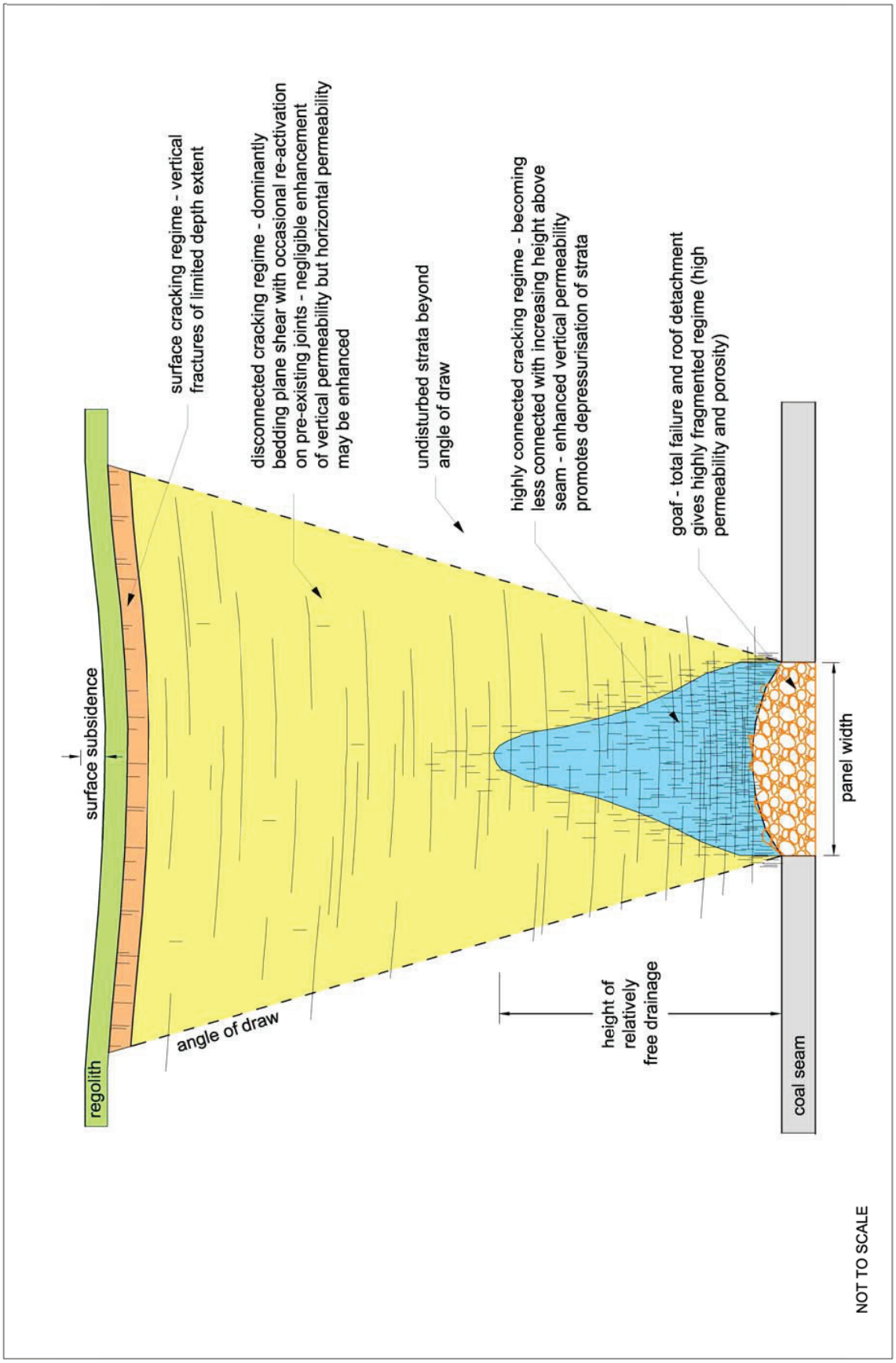
**Hydraulic conductivity 'type' bore locations**

*Figure E3*

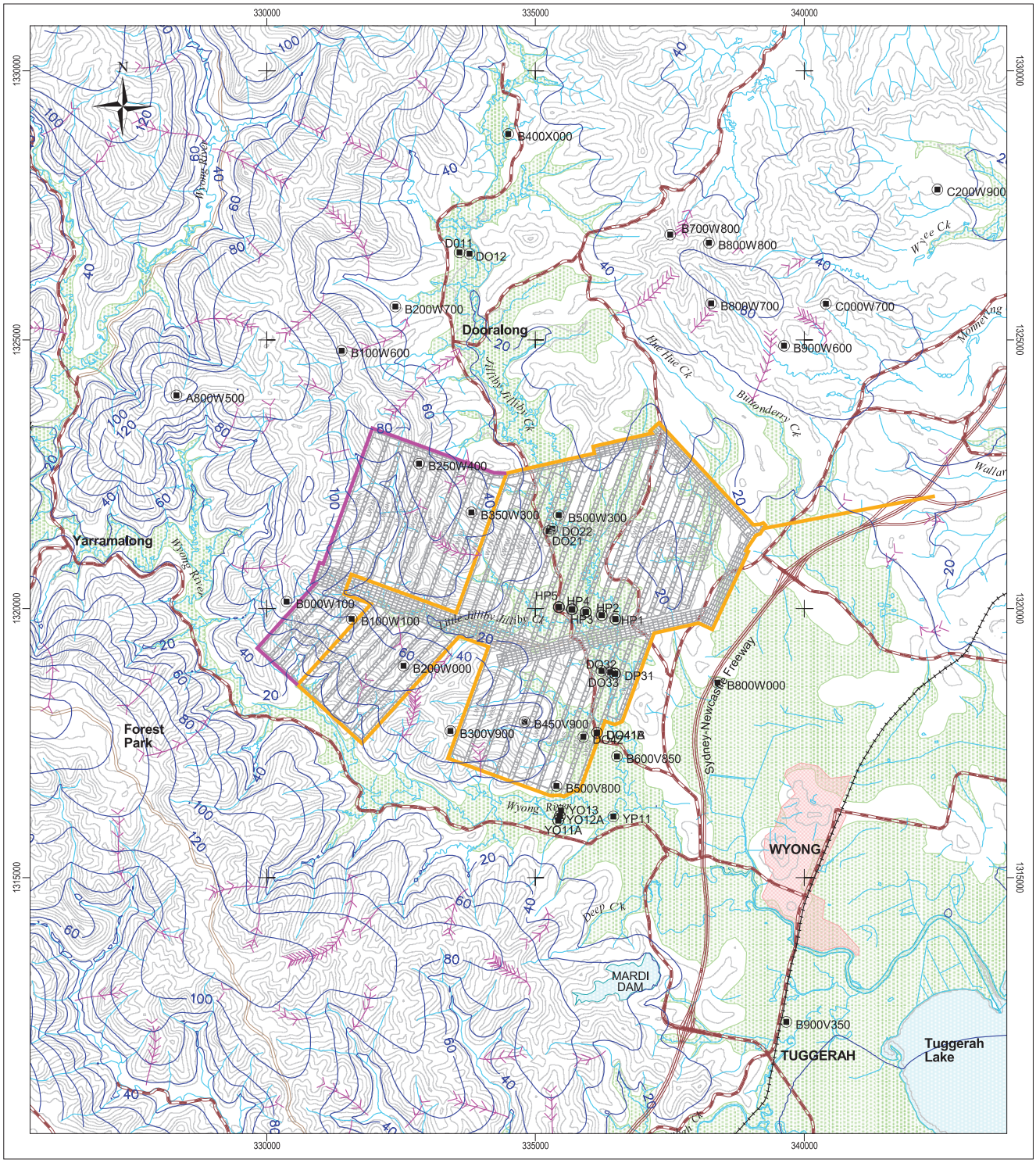



**Interpreted hydraulic conductivity profiles at type bores**

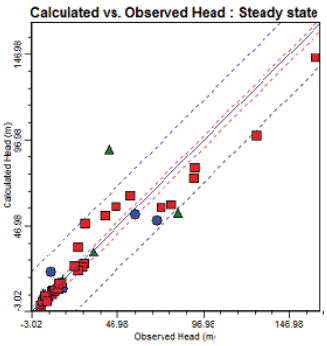
*Figure E4*




**Subsidence zone conceptualisation**
*Figure 5*




*Topographic contours at 25m intervals*




Max. Residual: 49.691 (m) at B100W600/A
Min. Residual: -0.09 (m) at DO32/A
Residual Mean : -0.812 (m)
Abs. Residual Mean : 6.689 (m)

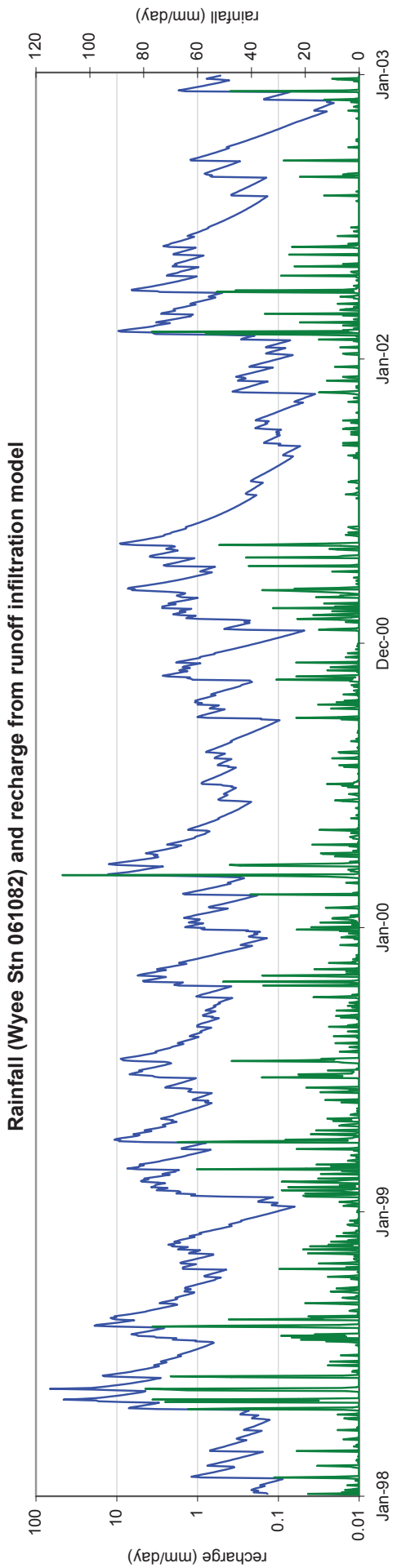
Num. of Data Points : 48
Standard Error of the Estimate : 1.744 (m)
Root Mean Squared : 11.981 (m)
Normalized RMS : 7.493 ( % )
Correlation Coefficent : 0.941

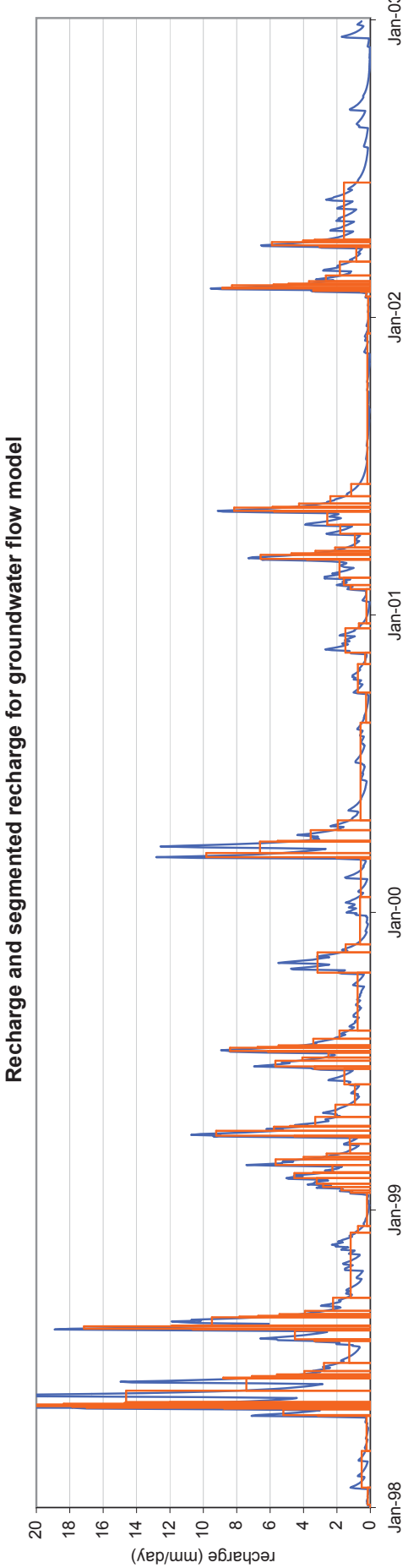
regional water table (mAHD)
flow path
28 years mine footprint
38 years mine footprint

WALLARAH 2 COAL PROJECT

**Regionally calibrated shallow water table**

*Figure E6*




**Rainfall-recharge adopted for model calibration**
*Figure E7*

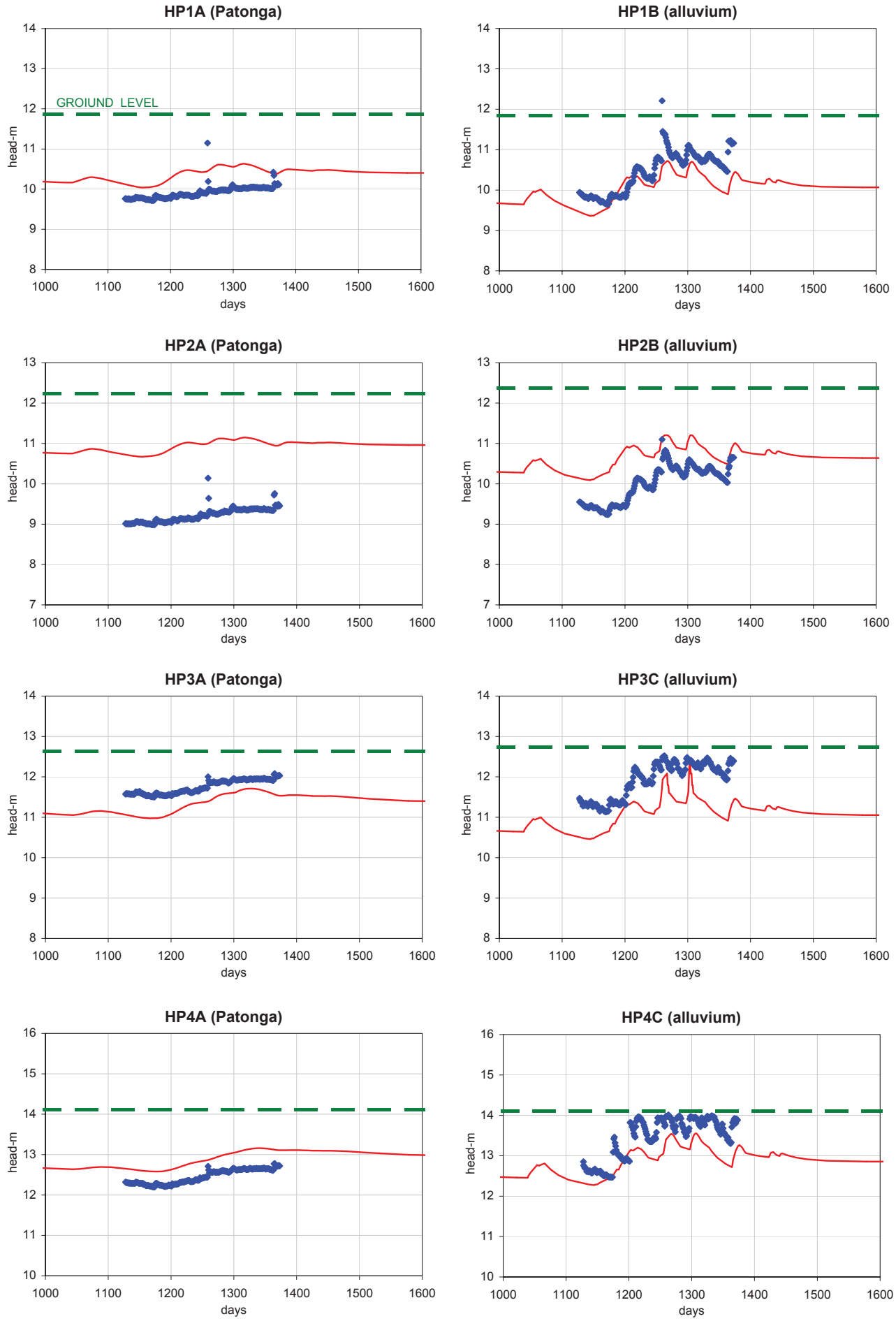

HP1A (Patonga)
GROIUND LEVEL
HP1B (alluvium)
HP2A (Patonga)
HP2B (alluvium)
HP3A (Patonga)
HP3C (alluvium)
HP4A (Patonga)
HP4C (alluvium)
head-m
days

*Figure E8*

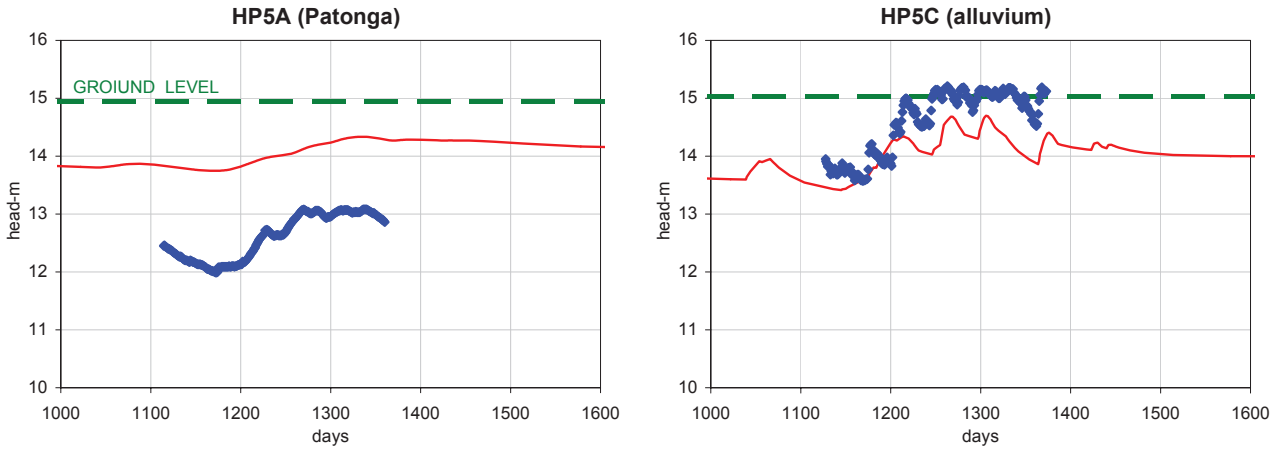

HP5A (Patonga)
GROIUND LEVEL
head-m
days
16
15
14
13
12
11
10
1000
1100
1200
1300
1400
1500
1600
HP5C (alluvium)
head-m
days

*Figure E8*

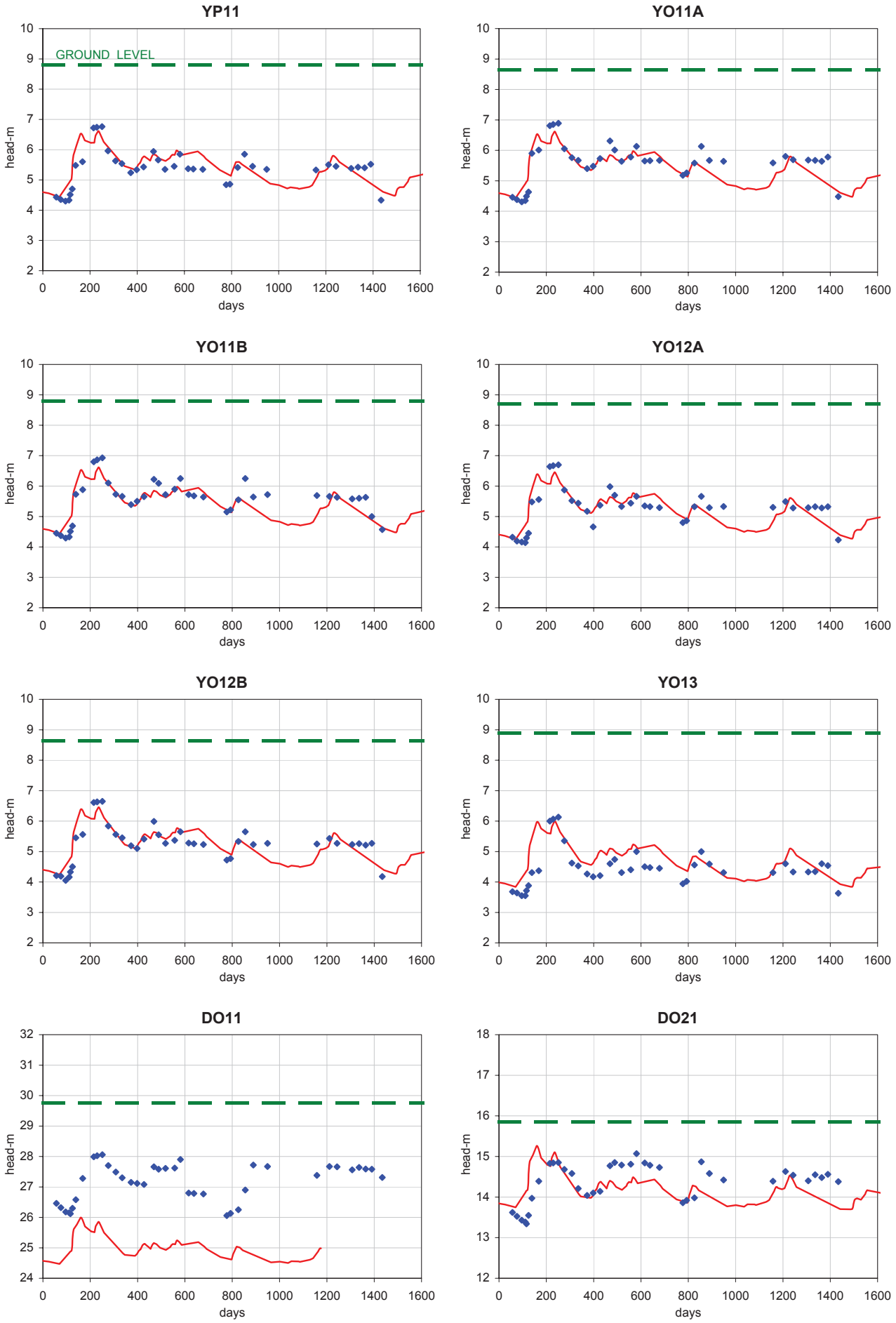

YP11
GROUND LEVEL
YO11A
YO11B
YO12A
YO12B
YO13
DO11
DO21
head-m
days

*Figure E9*

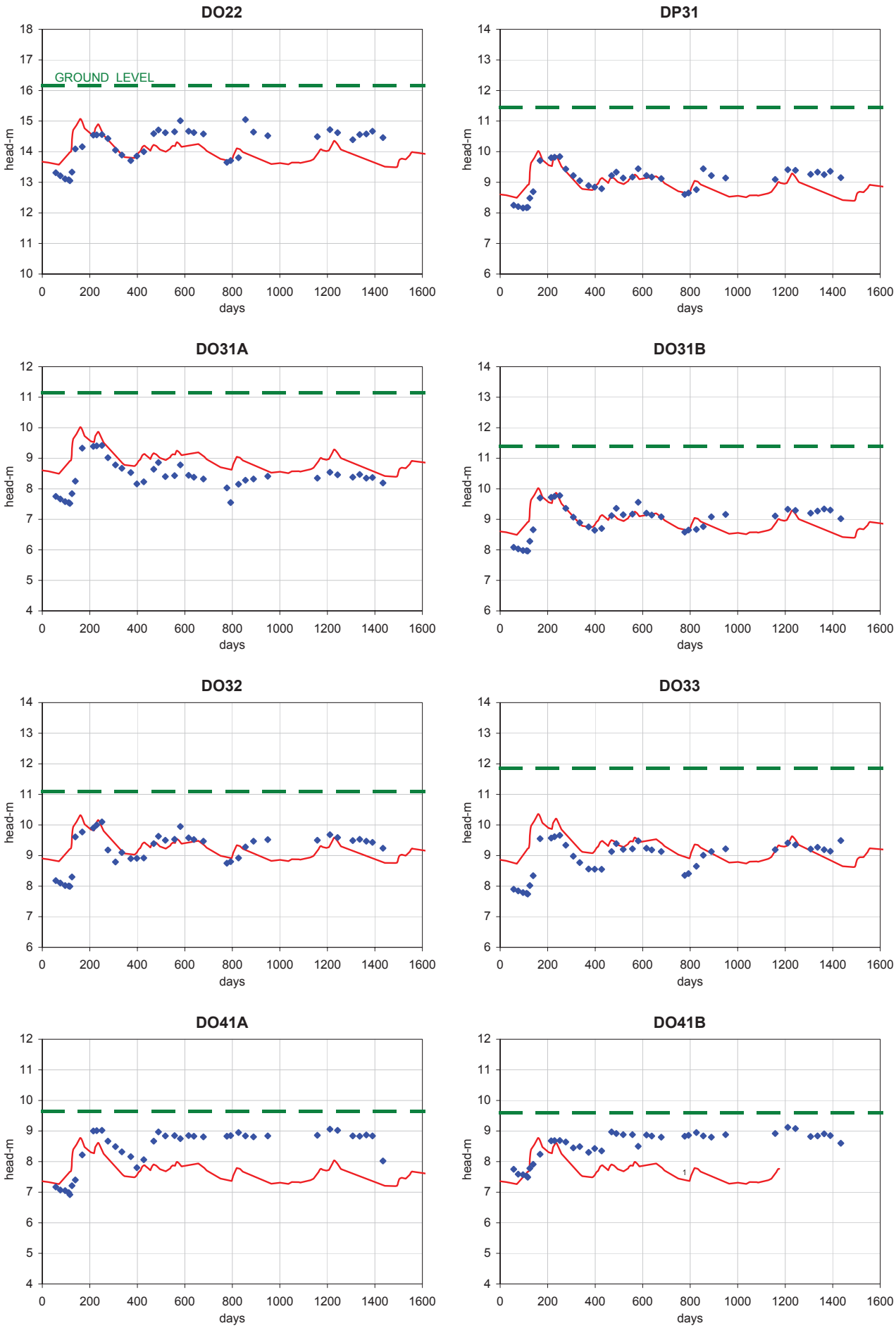

DO22
GROUND LEVEL
head-m
days
DP31
DO31A
DO31B
DO32
DO33
DO41A
DO41B

*Figure E9*

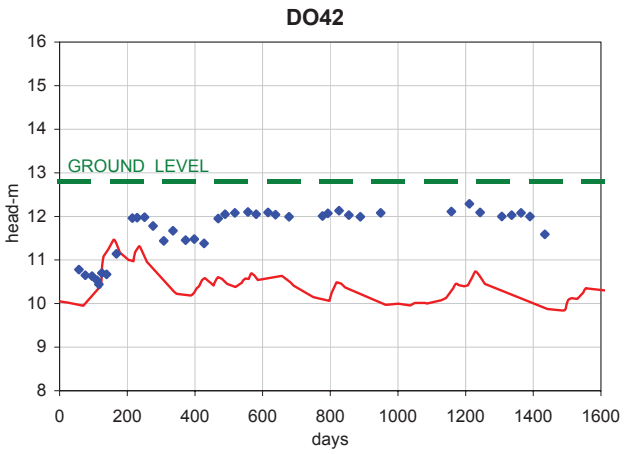
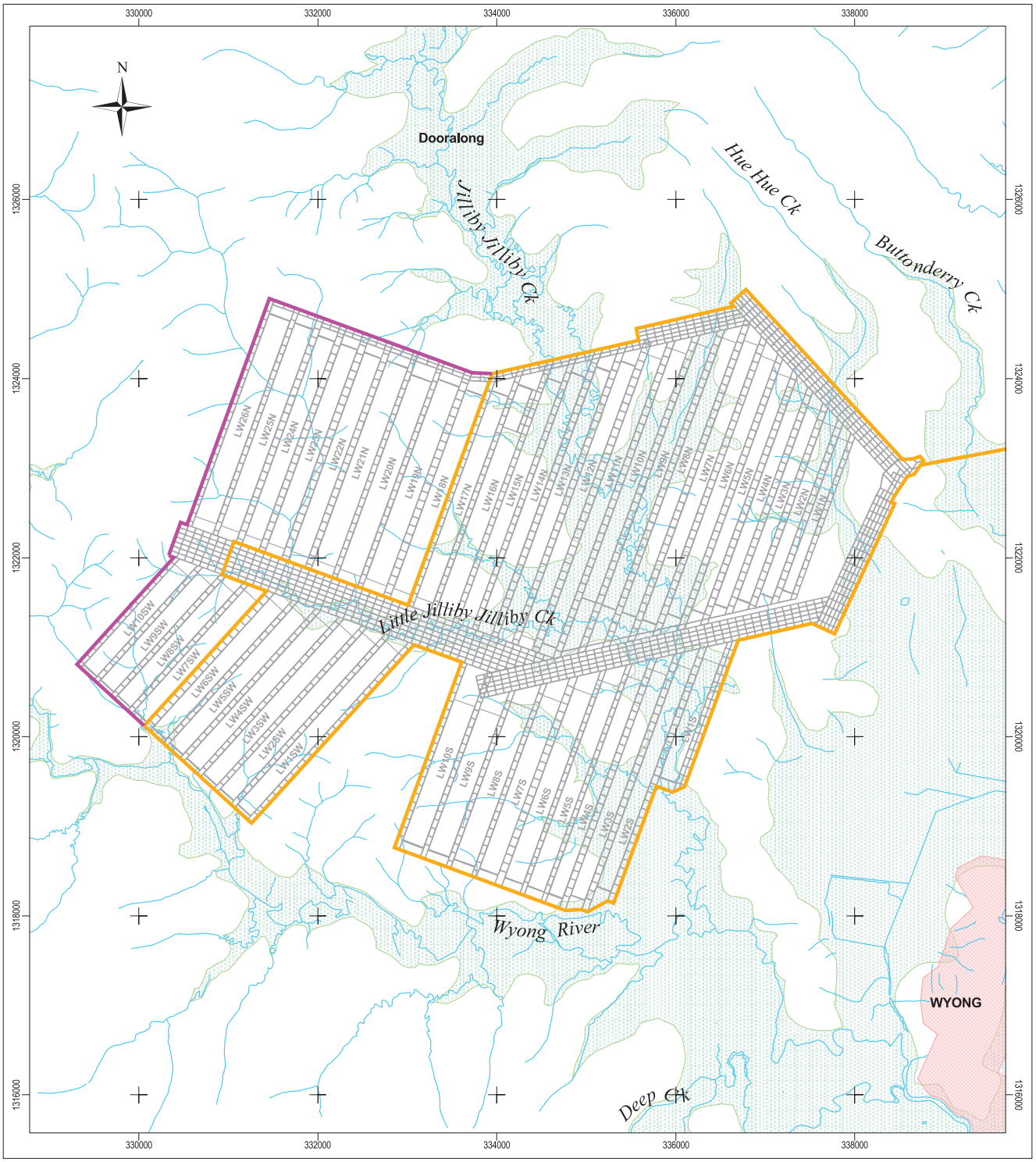

DO42
GROUND LEVEL
head-m
days
16
15
14
13
12
11
10
9
8
0
200
400
600
800
1000
1200
1400
1600

*Figure E9*




0 2000 4000 6000 Metres

Scale 1:60,000

urban area

alluvium

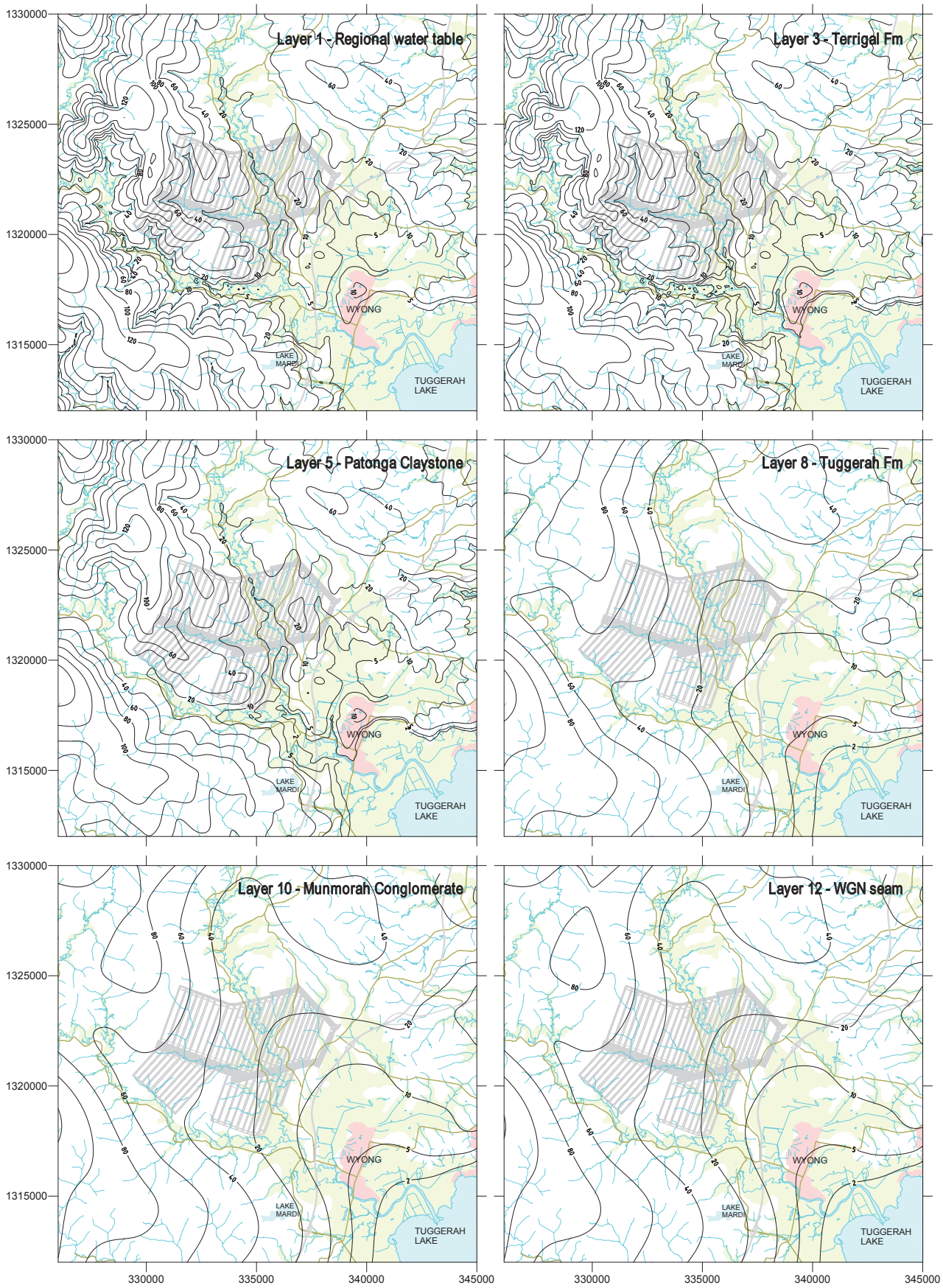
28 years mine footprint

38 years mine footprint

WALLARAH 2 COAL PROJECT

**Longwall panel identification**

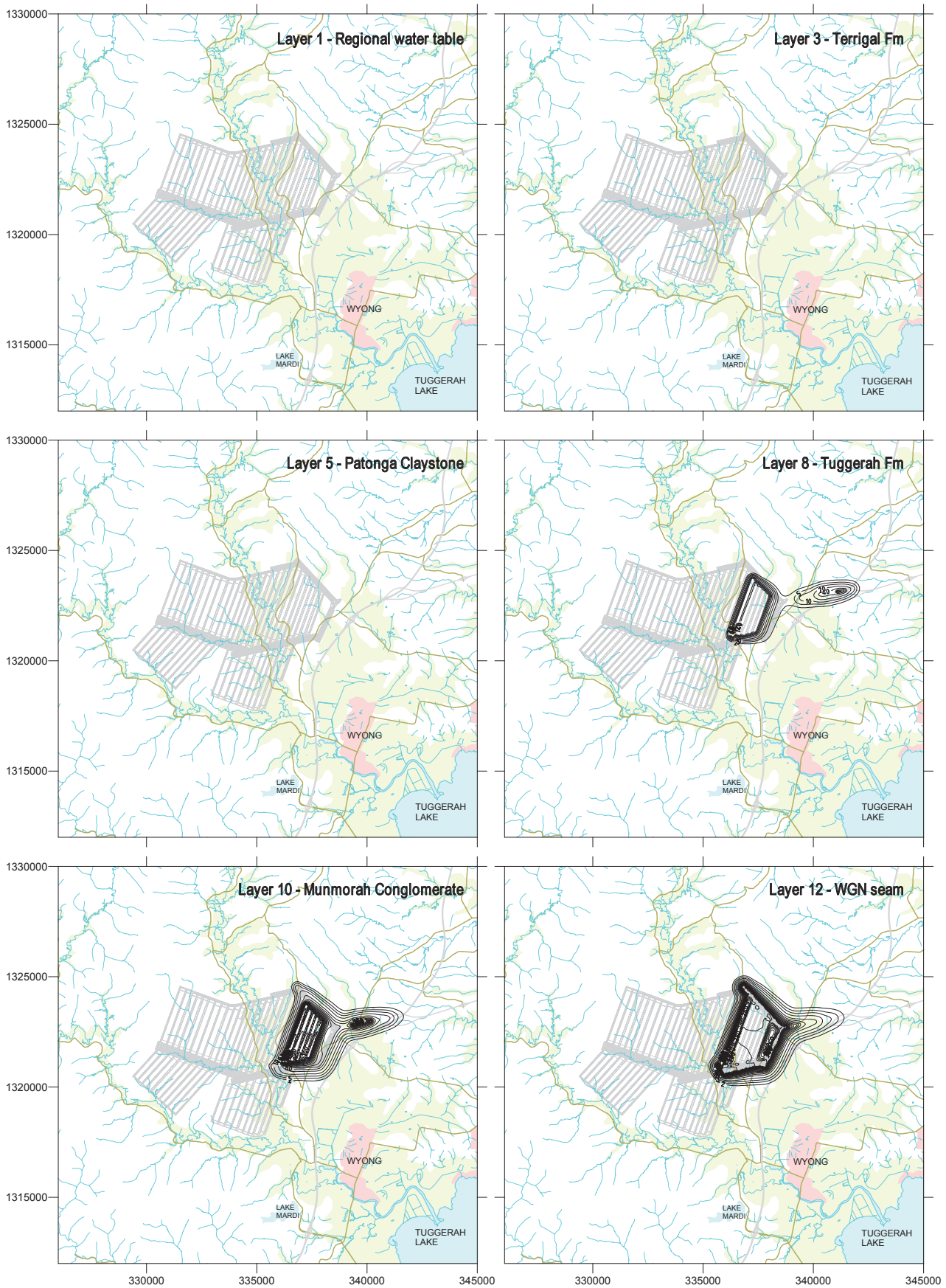
*Figure E10*




Piezometric contours in metres AHD

**Model W3: Pre-mining piezometric surfaces (Year 0)**

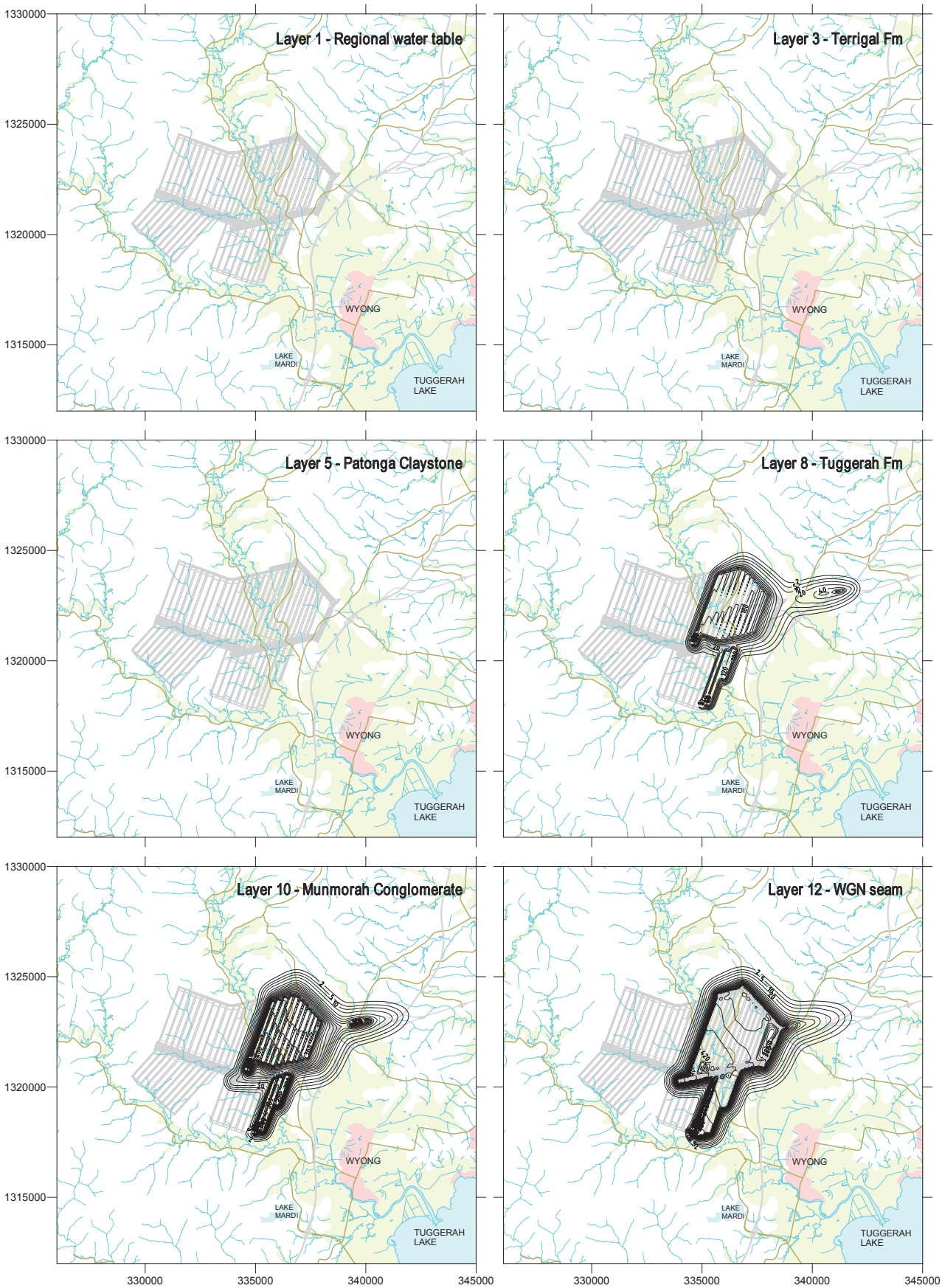
*Figure E11*




Drawdown contours in metres

**Model W3: Piezometric drawdown at Year 7**

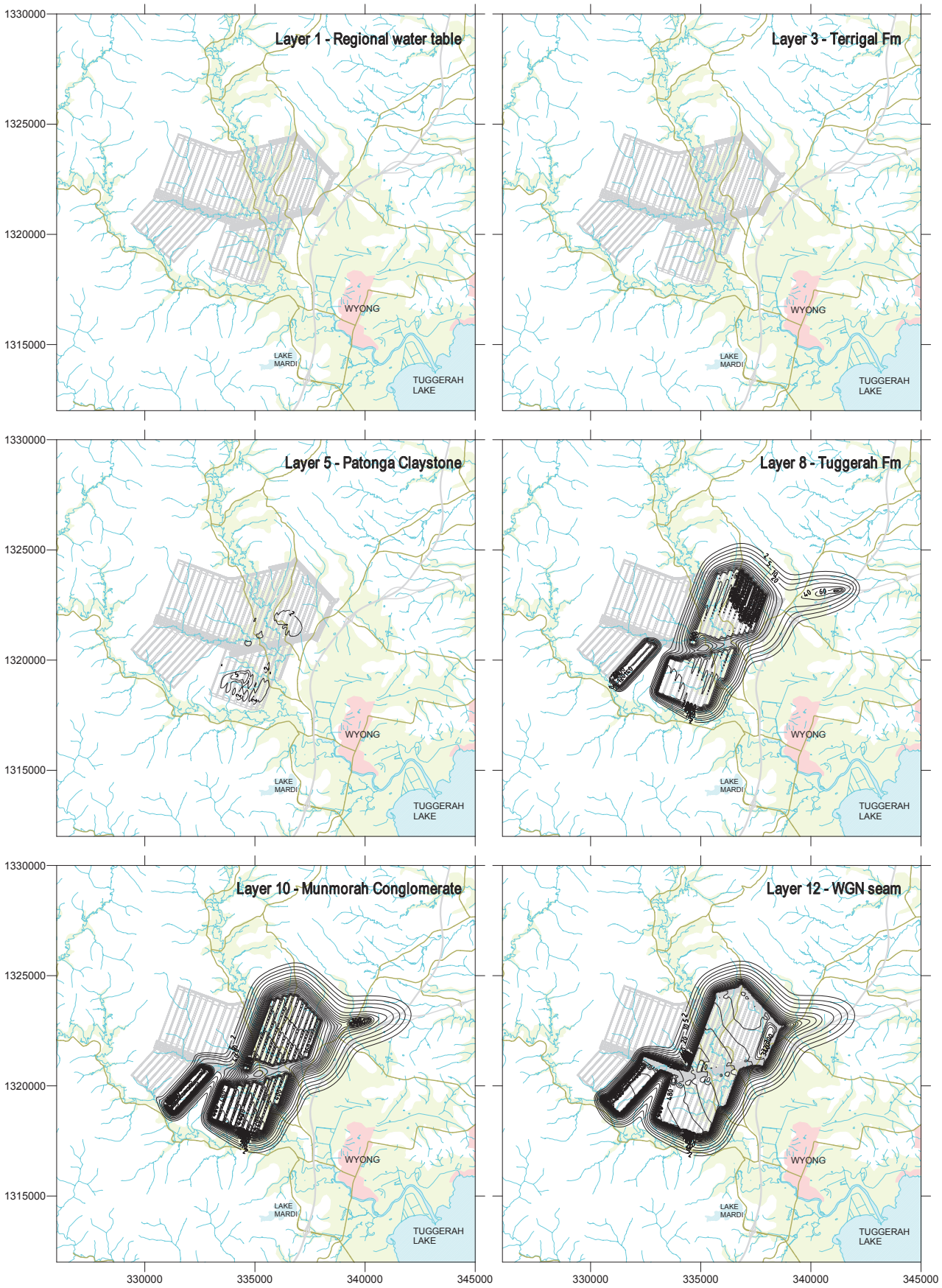
*Figure E12*




Drawdown contours in metres

**Model W3: Piezometric drawdown at Year 14**

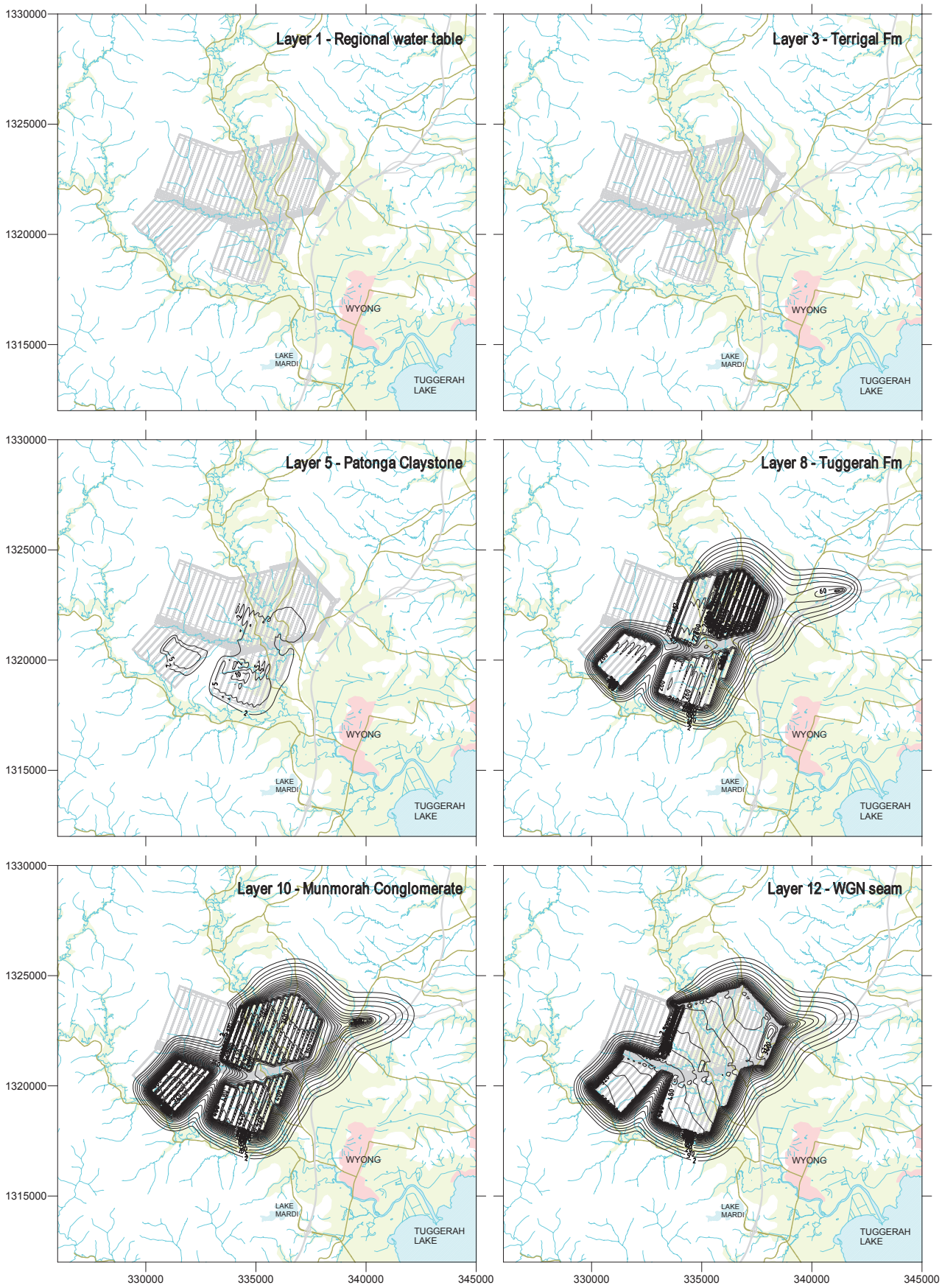
*Figure E13*




Drawdown contours in metres

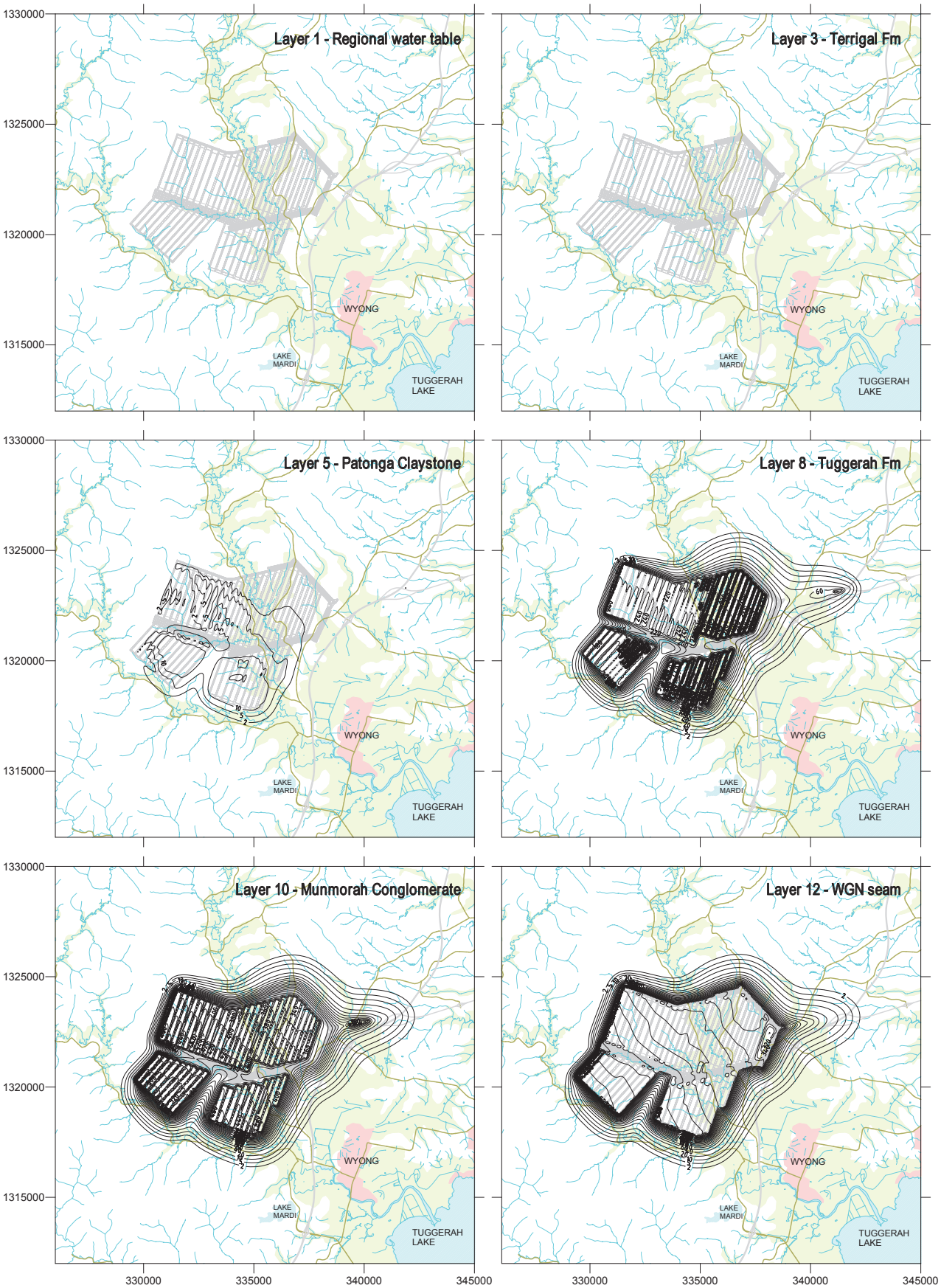
**Model W3: Piezometric drawdown at Year 21**

*Figure E14*




**Model W3: Piezometric drawdown at Year 28**

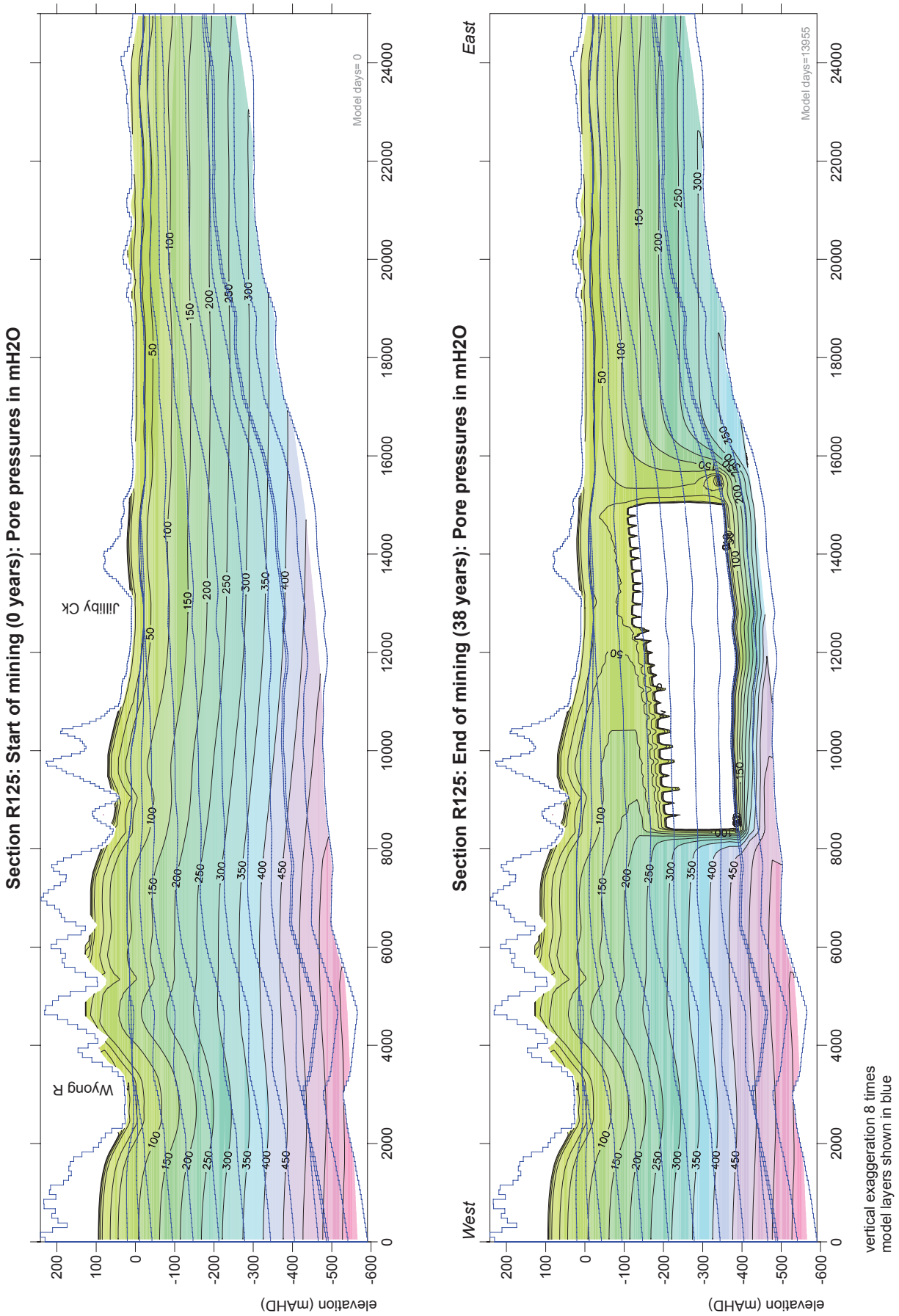
*Figure E15*




Drawdown contours in metres

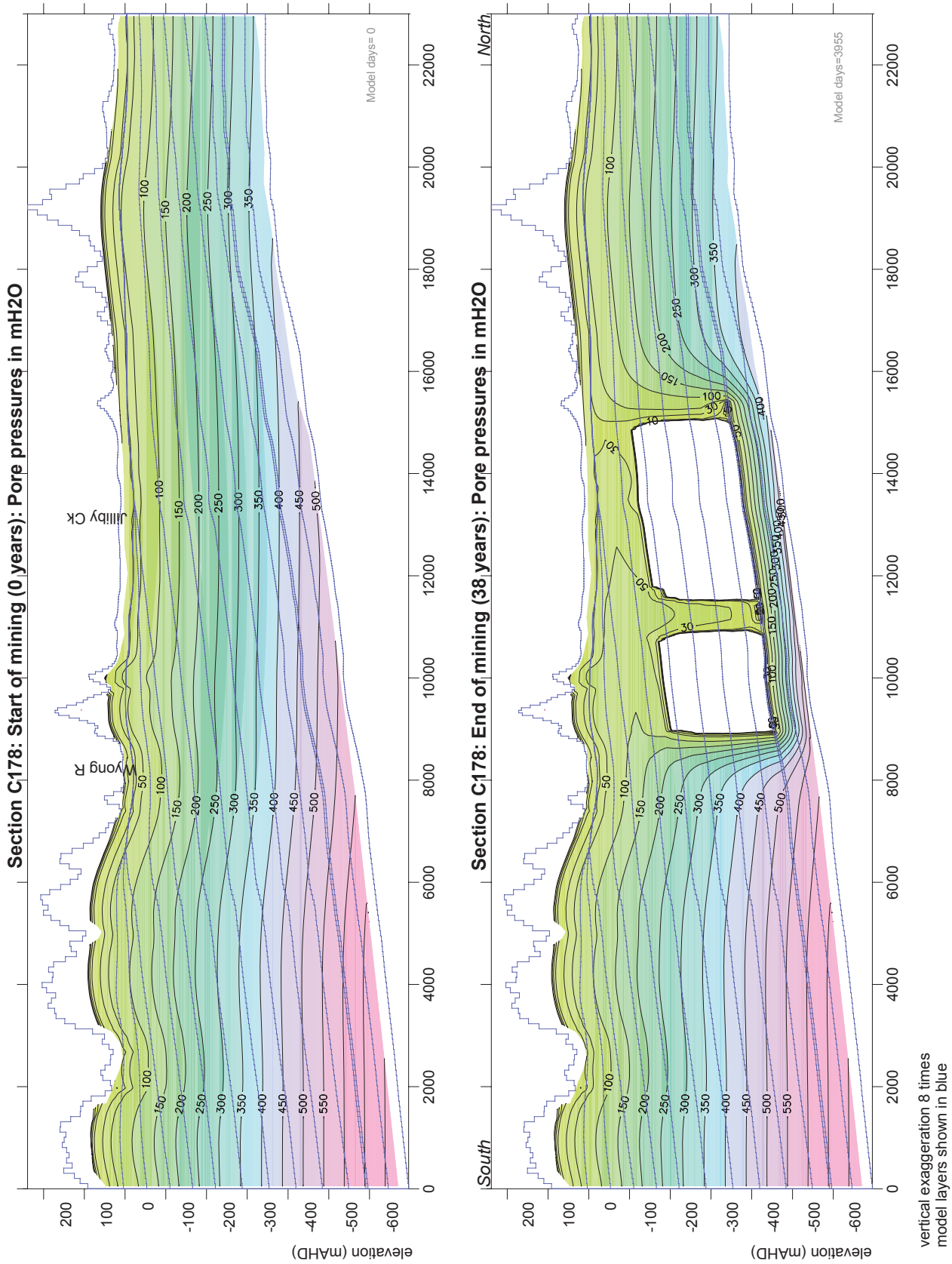
**Model W3: Piezometric drawdown at Year 38**

*Figure E16*




**Model W3 - Pore pressure distributions Section R125**

*Figure E17*




**Model W3 - Pore pressure distributions Section C178**

*Figure E18*

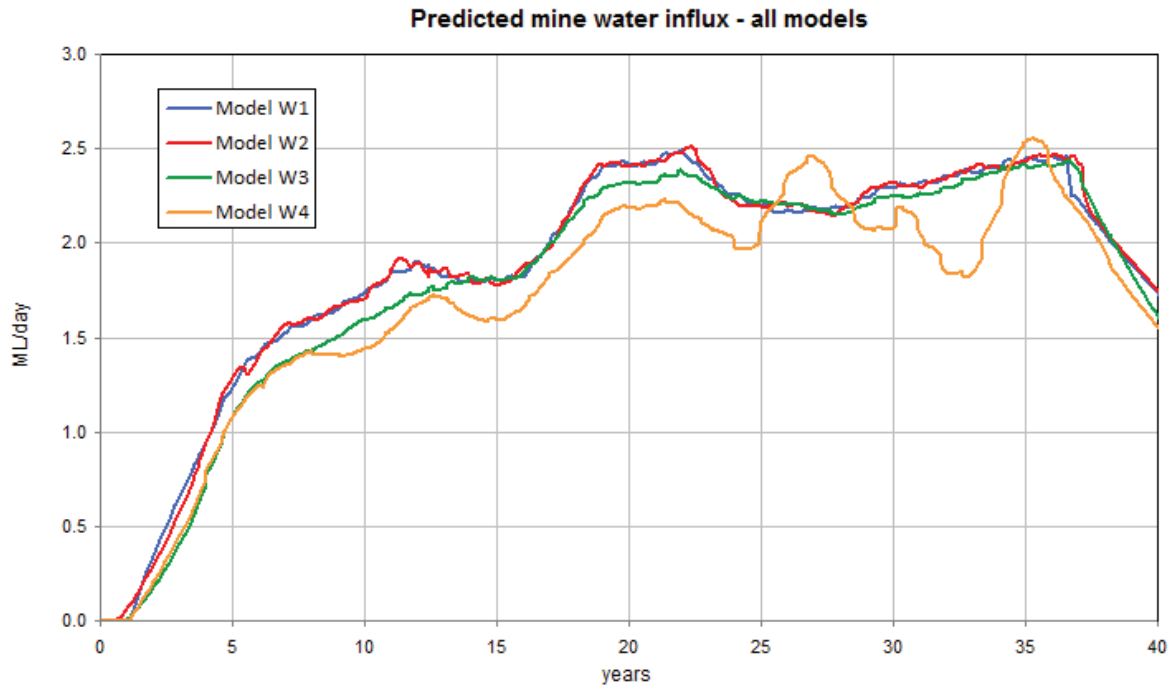



*Figure E19*

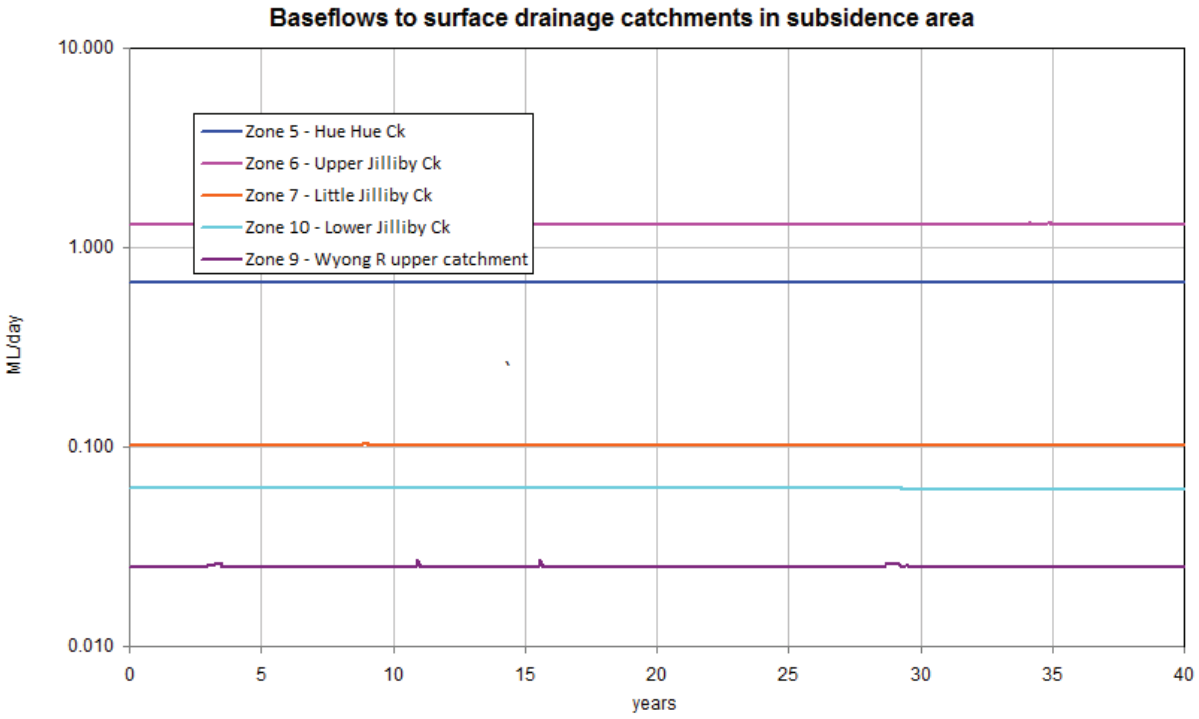
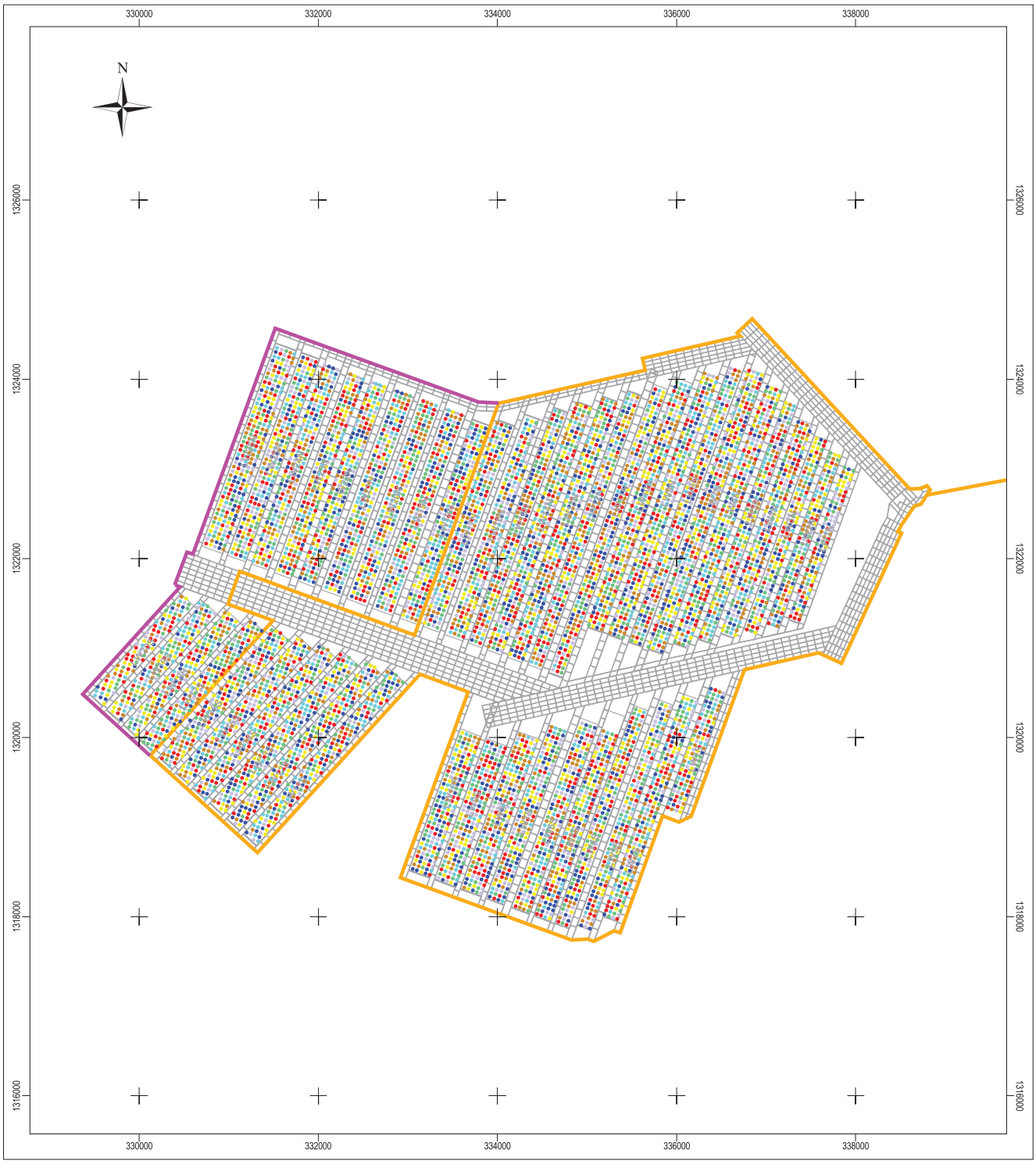



*Figure E20*




0 2000 4000 6000 Metres

Scale 1:50,000

Scaling of conductivity (Kh) employs uniform random deviate to 150 times undisturbed value

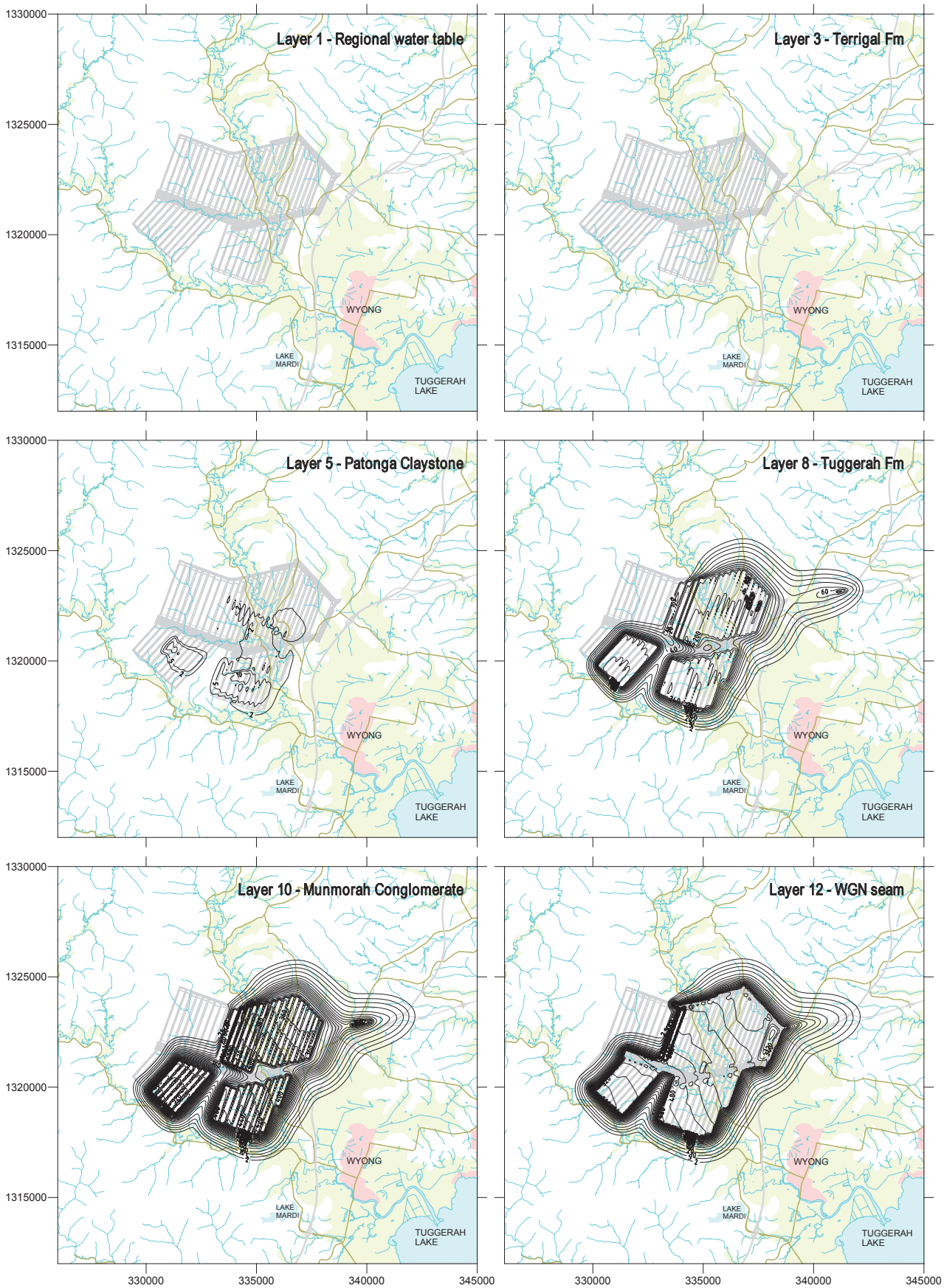
Scaling factors

- 10 - 30
- 30 - 50
- 50 - 70
- 70 - 90
- 90 - 110
- 110 - 130
- 130 - 150

WALLARAH 2 COAL PROJECT

**Constrained zone scaling distribution of Kh - layer 7**

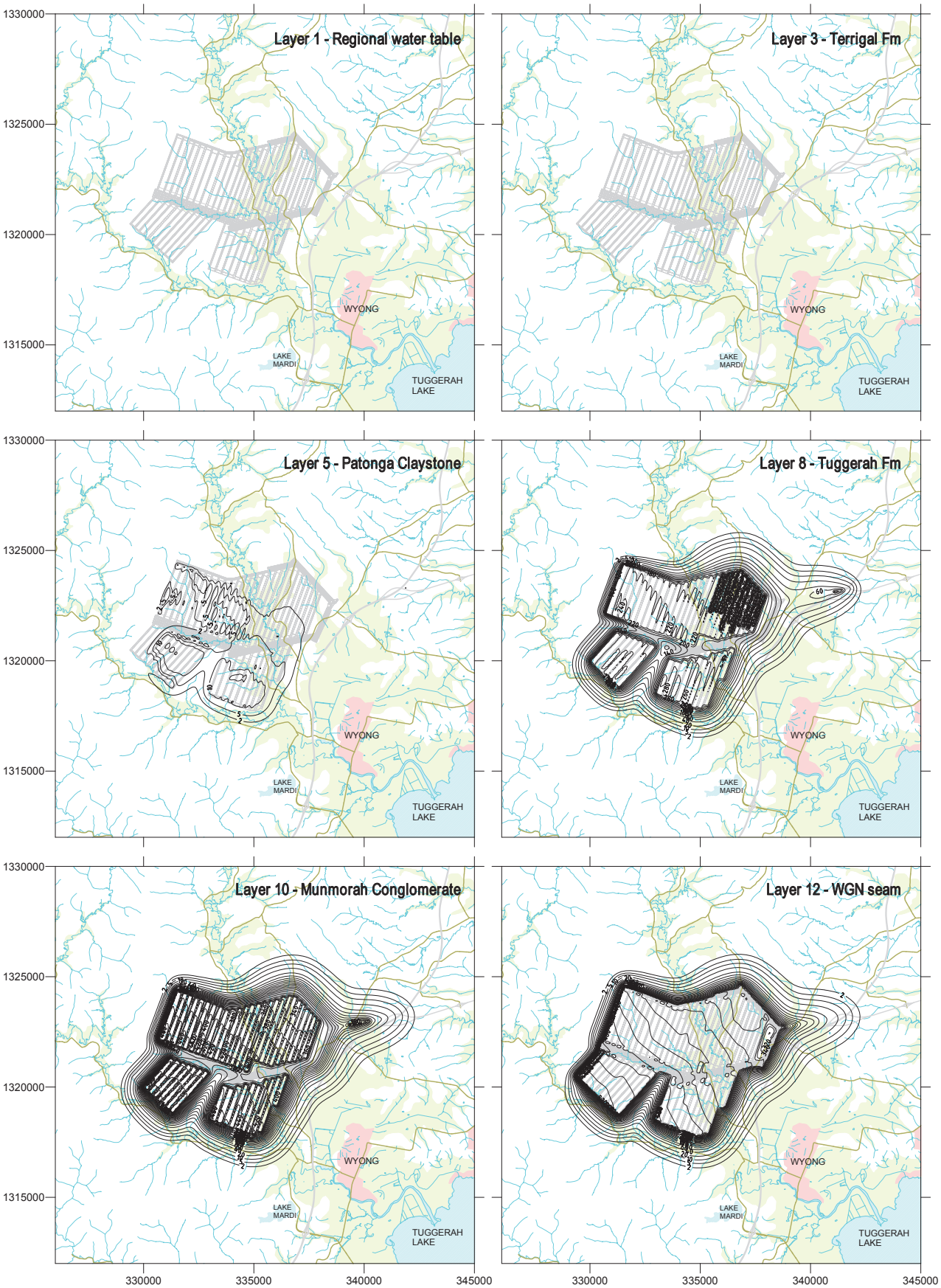
*Figure E21*




Drawdown contours in metres

**Model W4: Piezometric drawdown at Year 28**

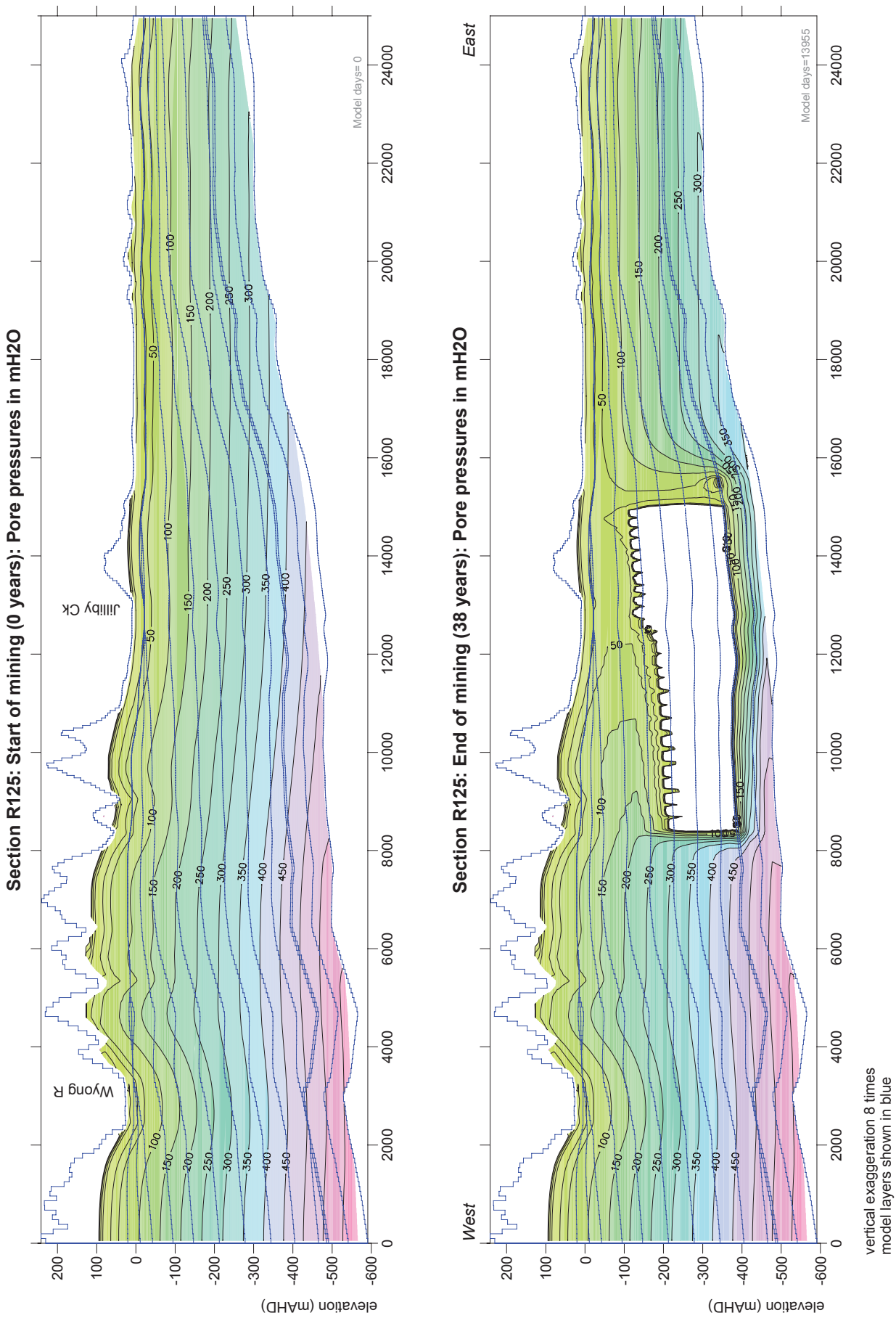
*Figure E22*




Drawdown contours in metres

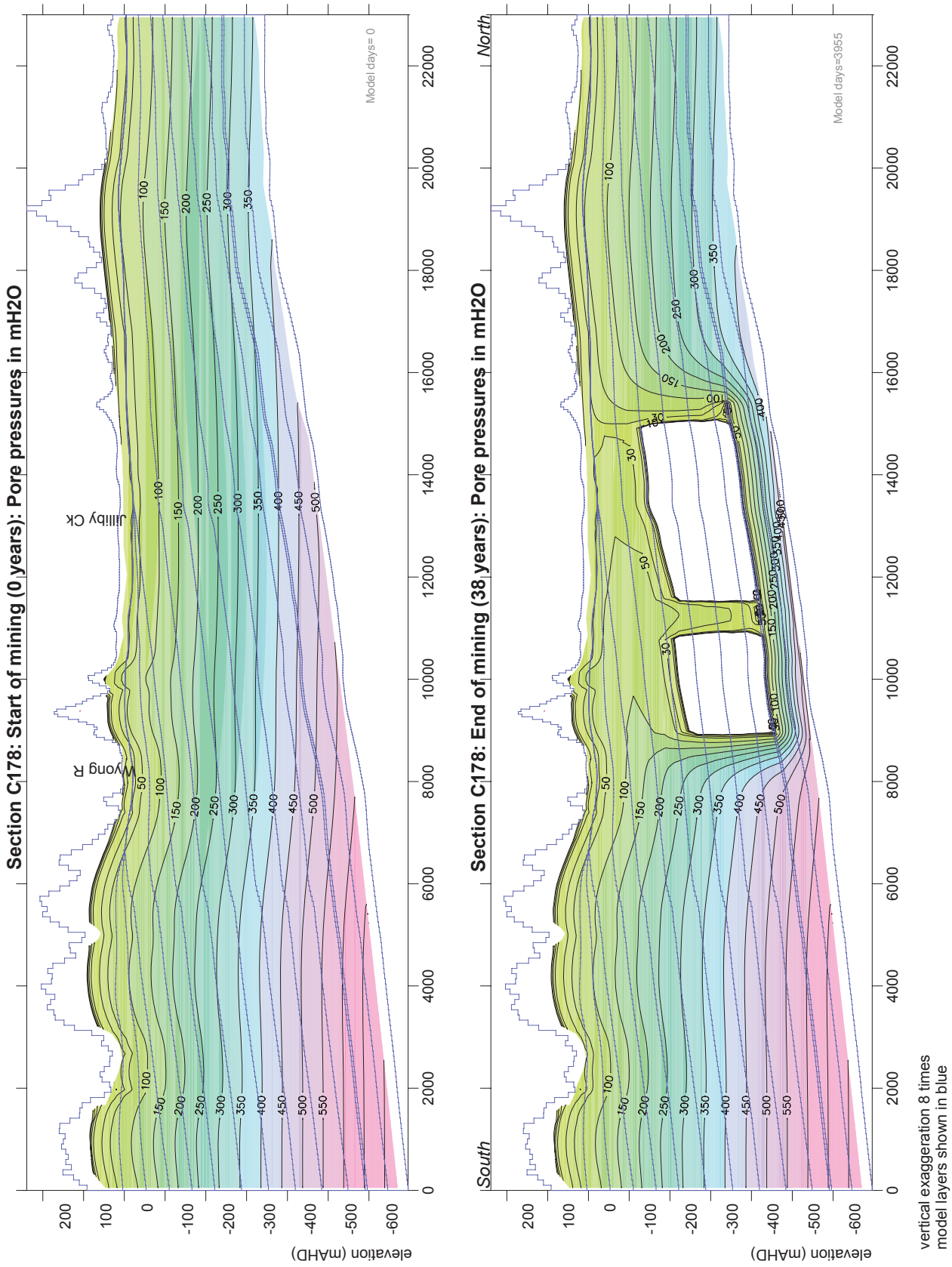
**Model W4: Piezometric drawdown at Year 38**

*Figure E23*



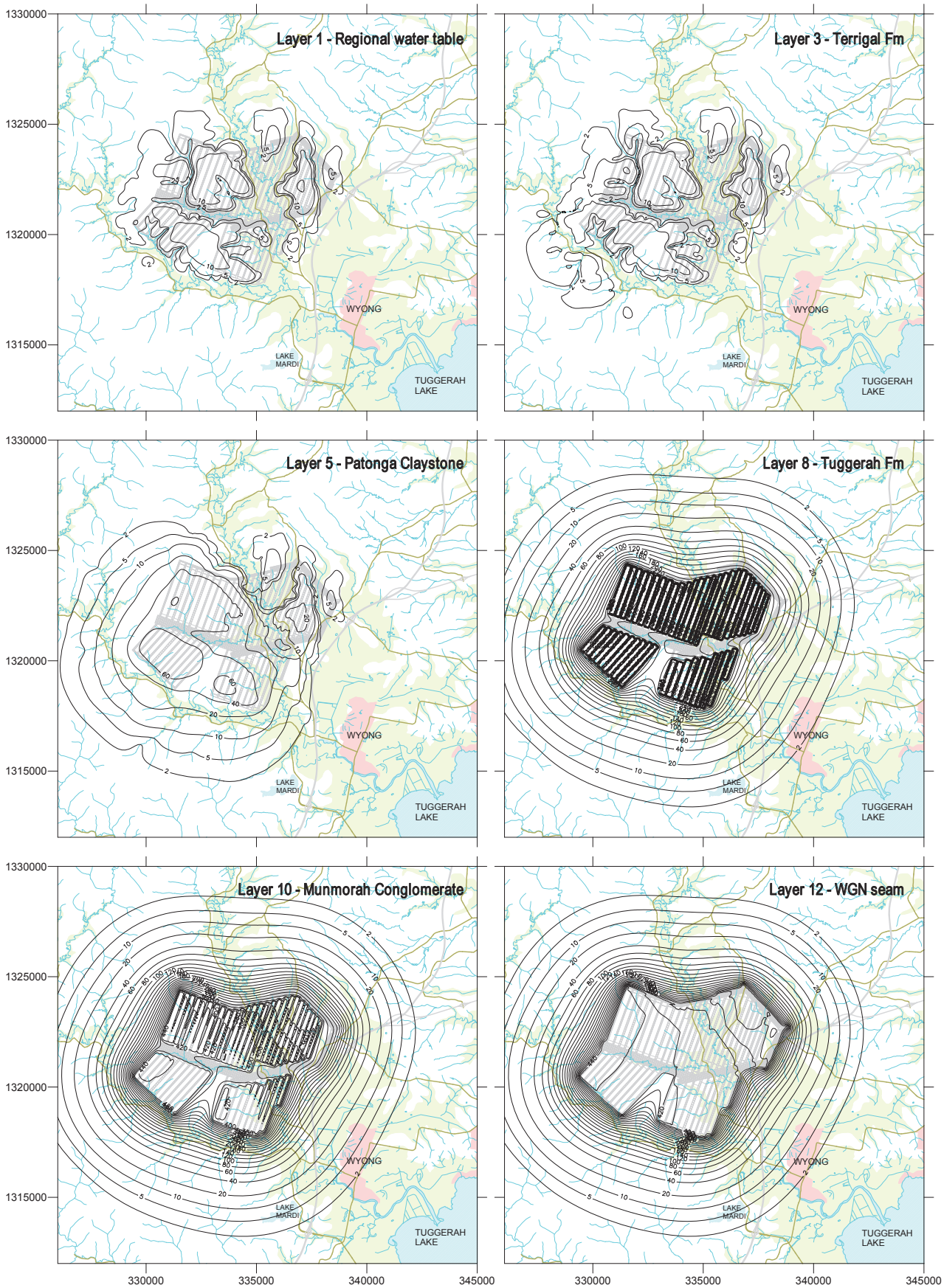

**Model W4 - Pore pressure distributions Section R125**

*Figure E24*




**Model W4 - Pore pressure distributions Section C178**

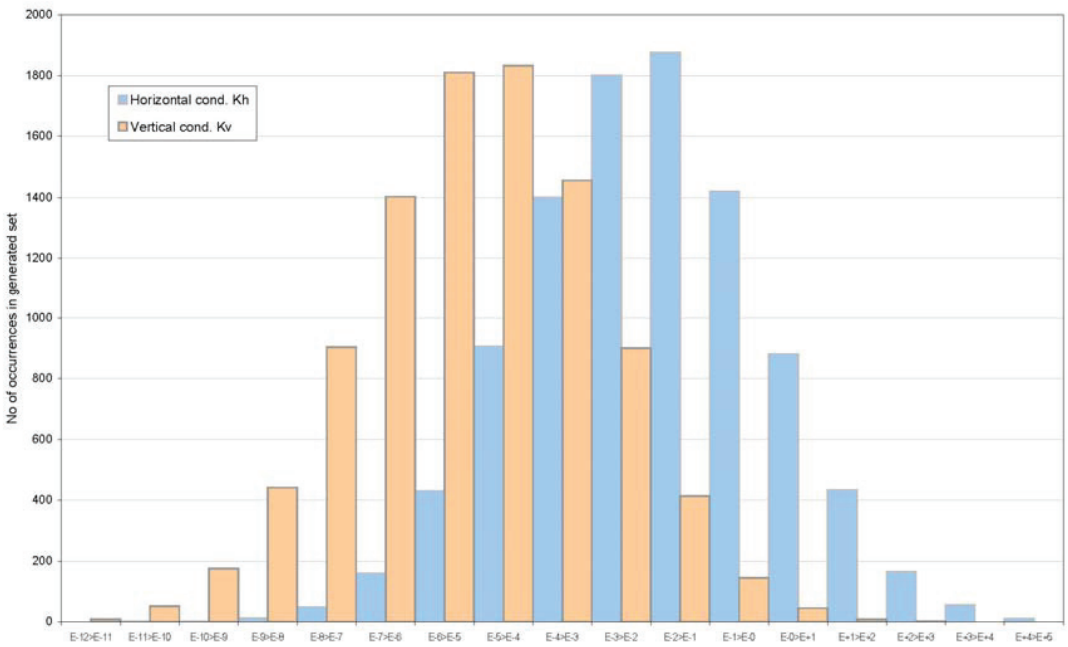
*Figure E25*




Drawdown contours in metres

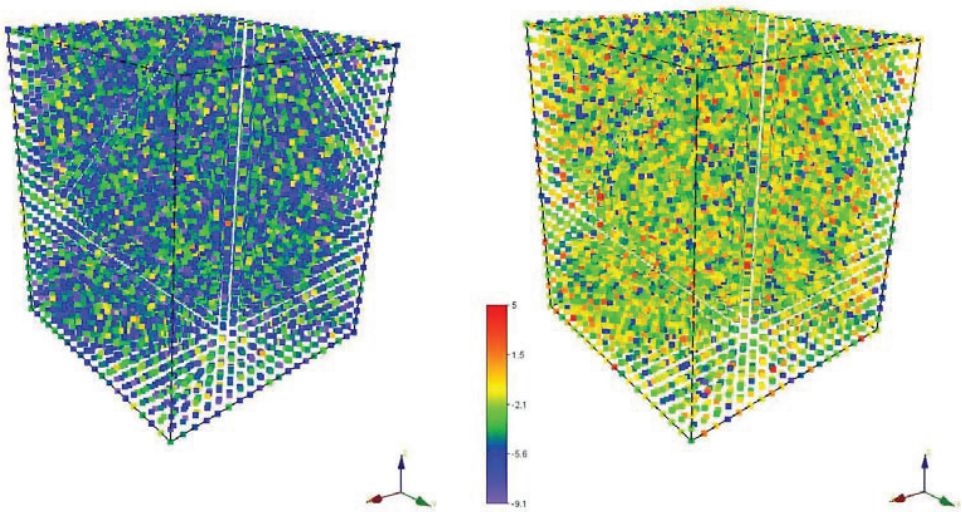
**Model W3: Piezometric drawdown 500 years after closure**

*Figure E26*




Horizontal and vertical conductivity distributions

*Figure E27a*




Vertical conductivity distribution in constrained zone groundwater flow model

Horizontal conductivity distribution in constrained zone groundwater flow model

*Figure E27b*

**Sensitivity of constrained zone hydraulic conductivities**

*Figure E27*

# APPENDIX F: SHALLOW SUBSIDENCE ZONE GROUNDWATER MODEL

A temporary change in shallow alluvial groundwater 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 within the major drainage channels. Temporary filling of shallow crack storage is expected to lead to very localised and short term reduction of groundwater storage within the alluvial sediments followed by recovery.

However subsidence may 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 would be a continuum that would include fall and rebound of the water table in actively subsiding areas. The duration of the rebound-recovery process would depend largely upon the juxtaposition of subsided panels and drainage lines, the recharge capacity of those drainages for prevailing climatic conditions, and local strata properties (hydraulic conductivity and storage characteristics).

In order to understand and assess the probable impacts, a shallow zone simplified (generic) groundwater model has been assembled. The model utilises the same finite difference scheme as used for the regional mining model (Appendix E) but comprises a localised strip model with one layer that represents the 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 a matrix of 200 x 50 m cells.

Figure F1a (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 expansive alluvial sediments with a 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 front 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/day. The subsidence process is replicated by activating drain cells which reduce the water table by 1.3 m instantaneously (1 day duration). In reality a block of strata 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 strata 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). However, in order to understand the likely impacts across a range of conductivities, four values 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 configuration before undertaking transient simulations. The maximum recharge occurs for a conductivity value of 5 m/day and was found to be 10 mm/year. Other rates are summarised in the following Table F1. These rates can be considered as dry weather rates.

*Table F1: Hydraulic properties assigned to the subsidence models*

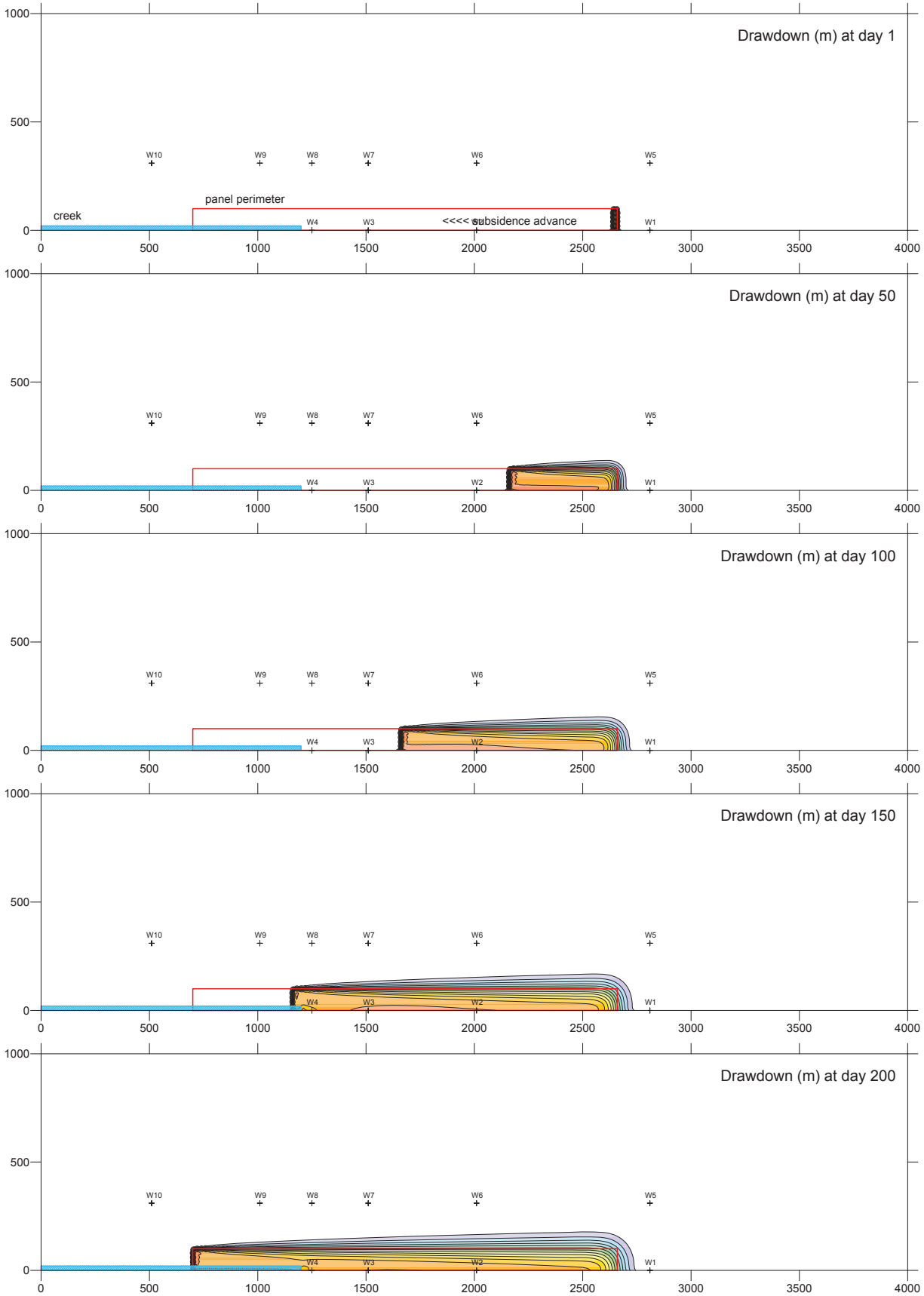
| Model | Hydraulic conduct. (m/day) | Rainfall recharge (mm/year) | Drainable porosity % |
|---|---|---|---|
| **Subside-1** | 0.1 | 0.2 | 25 |
| **Subside-2** | 0.5 | 1.0 | 25 |
| **Subside-3** | 1 | 2.0 | 25 |
| **Subside-4** | 5 | 10.0 | 25 |

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. On the 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 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 that is likely to be significantly exceeded and to lead to a more rapid recovery of the water table. Rapid rise in the water table in response to rainfall events is clearly observed in monitoring locations HP1 to HP5 (see Appendix C for hydrographs).

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.

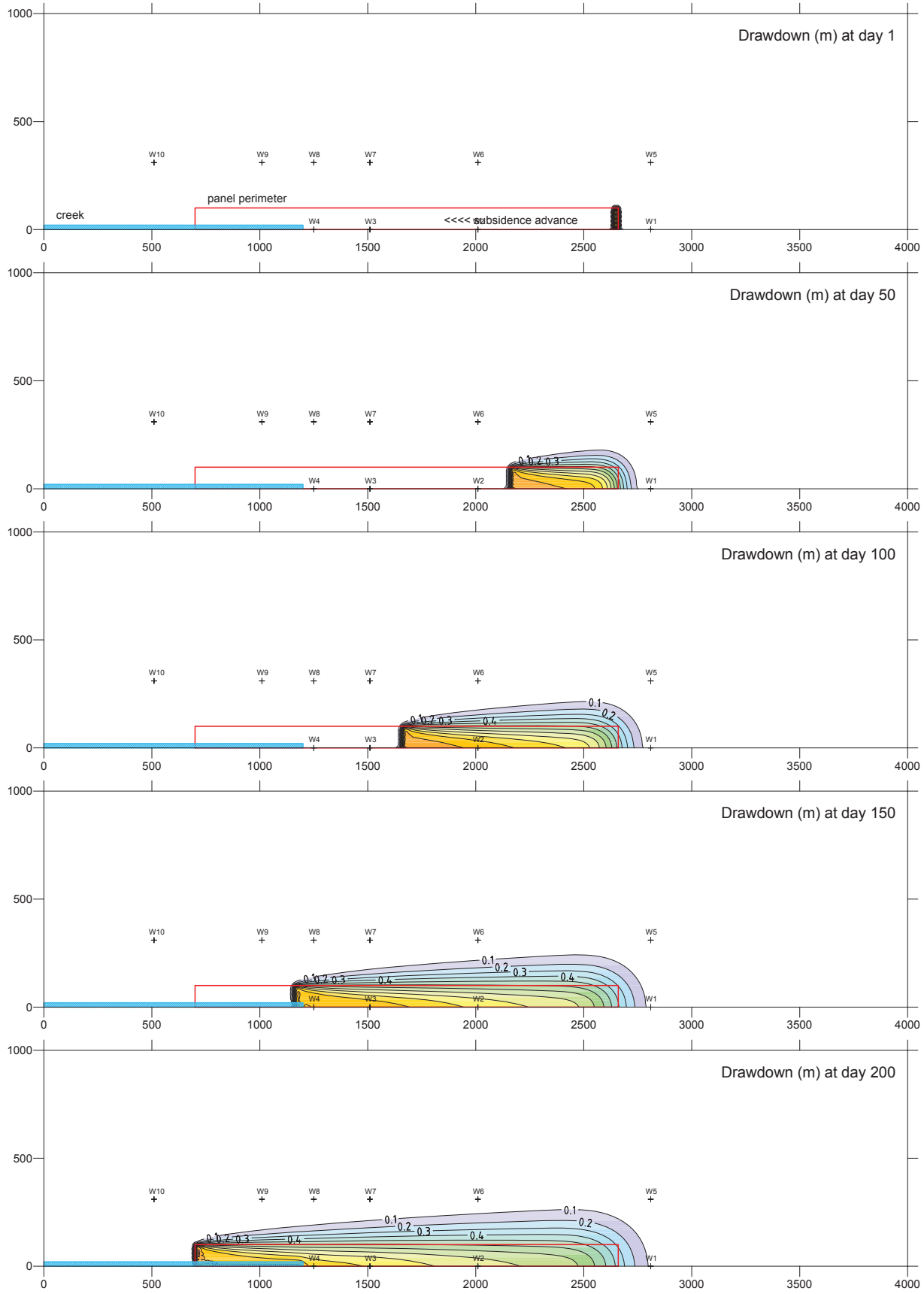
Figure F3 illustrates advancement of the subsidence wave for model Subside 3 (K=1.0 m/day). Initially (day 1) the water table is displaced downwards by 1.3 m and drawdown is restricted to a distance of a few metres beyond the mine panel in much the same manner as the previous models. At 200 days the 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 m/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).



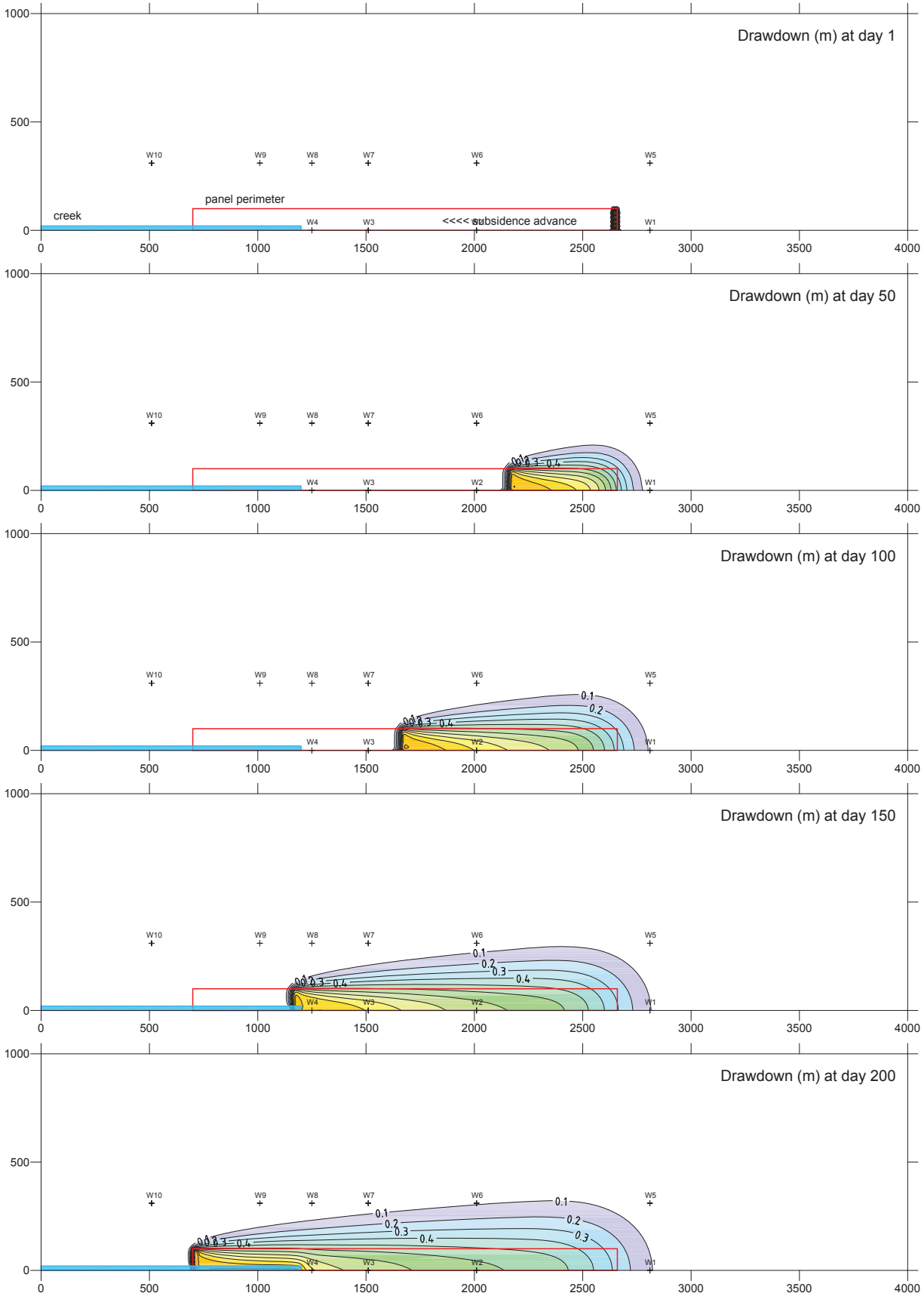

**Subside-1 model output (K=0.1m/day, Sy=25%)**

*Figure F1*



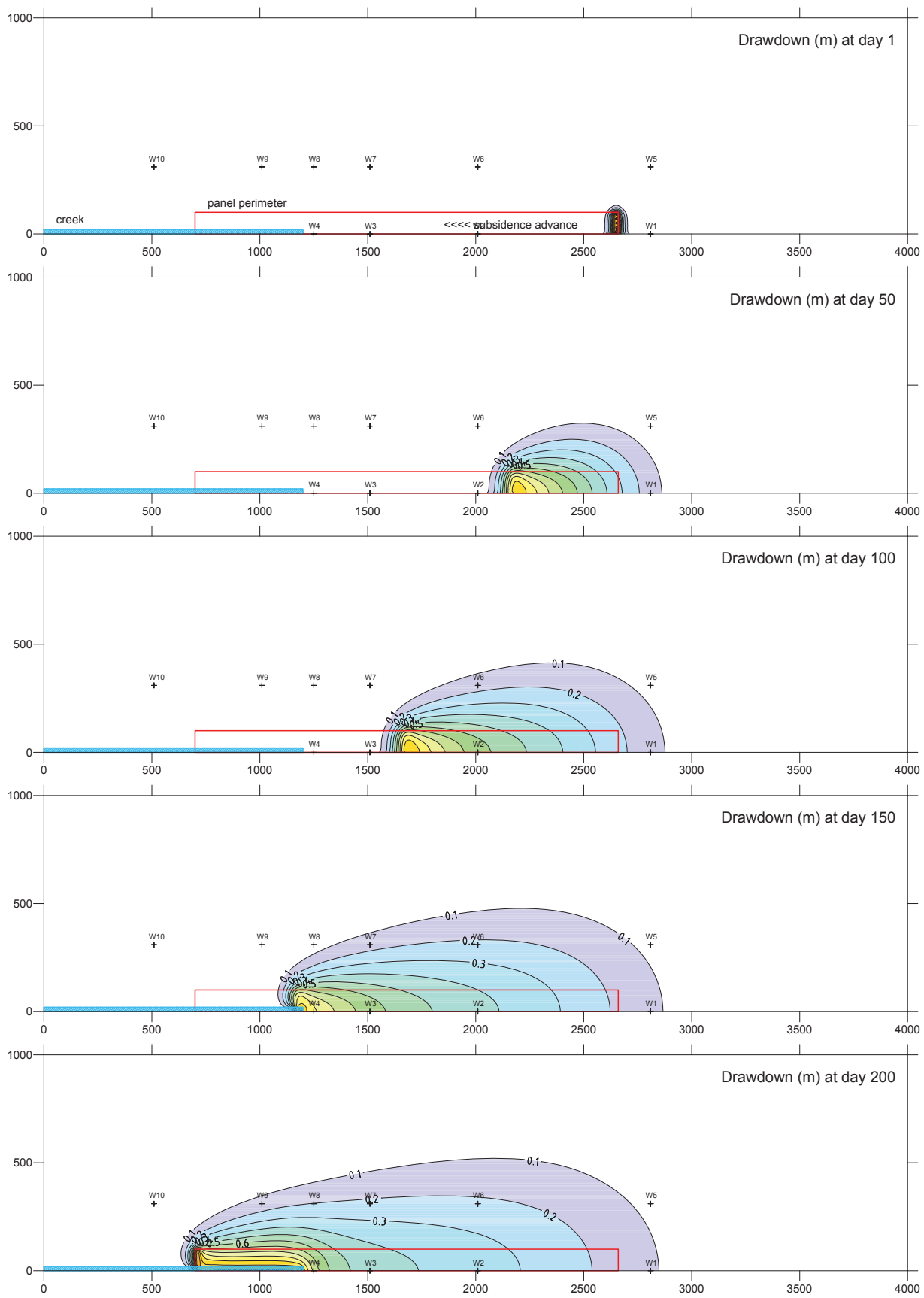

**Subside-2 model output (K=0.5m/day, Sy=25%)**

*Figure F2*



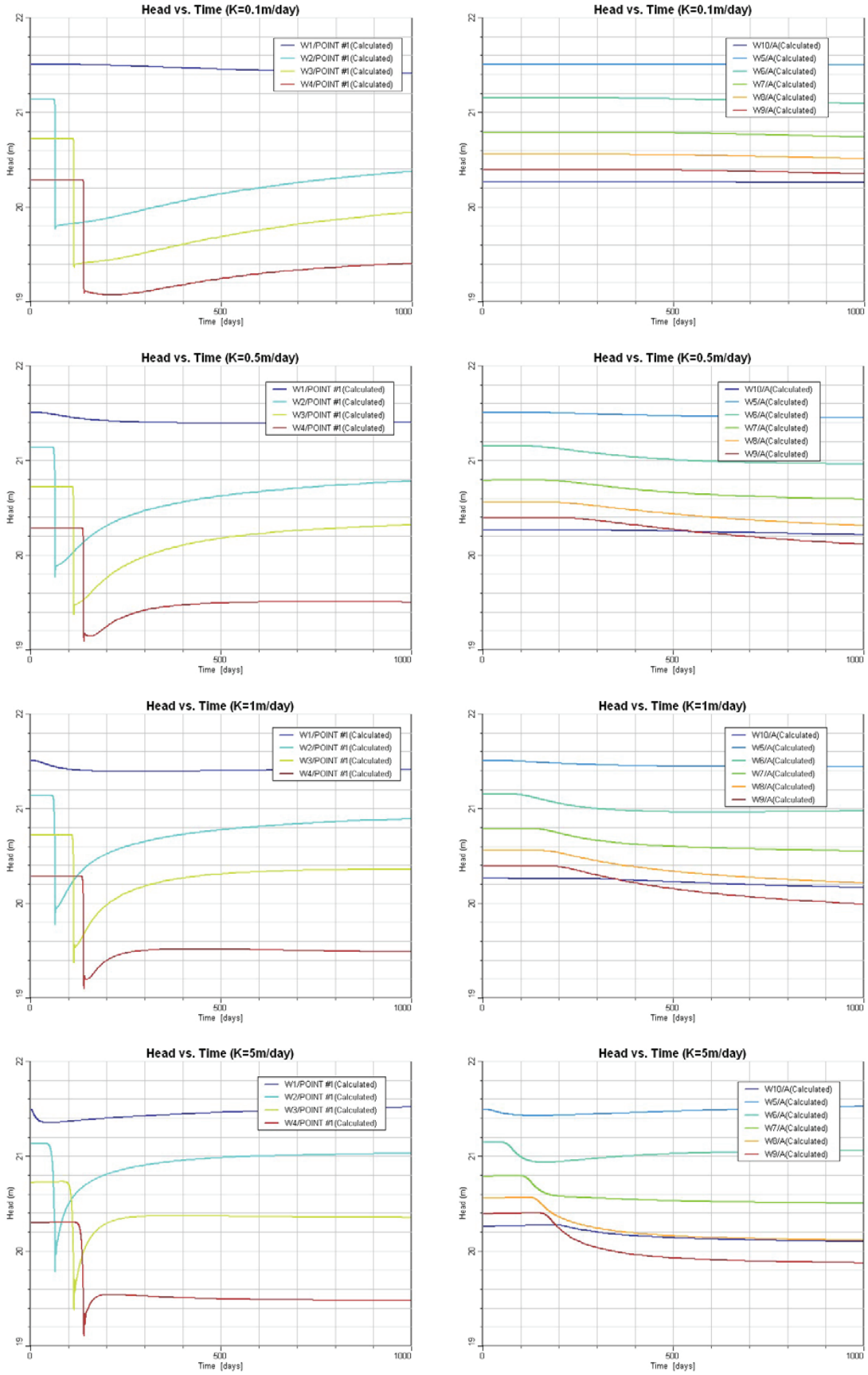

**Subside-3 model output (K=1.0m/day, Sy=25%)**

*Figure F3*




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

*Figure F4*




**Observation well hydrographs subsidence models**
*Figure F5*

# Wallarah 2 Coal Project

# Groundwater Impact Assessment
# Peer Review

KALF AND ASSOCIATES Pty Ltd
Hydrogeological, Numerical Modelling Specialists

# WALLARAH 2 COAL PROJECT

## PEER REVIEW OF MACKIE ENVIRONMENTAL RESEARCH (MER) 2012 HYDROGEOLOGICAL AND GROUNDWATER MODELLING REPORT

Dr F. Kalf
B.Sc. M.App.Sc PhD
26 September 2012

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## Introduction

This report provides a peer review of the recent hydrogeological and groundwater modelling assessment for the Wallarah 2 Coal Project conducted by Mackie Environmental Research (MER 2012).

It is to be noted that no mining has been conducted to date on the Wallarah 2 site and therefore the effects of underground mining are not available for transient model calibration of the hard rock water bearing strata.

## Peer Review Assessment

### *Previous Reviews and MER Modelling Reports*

In 2009 MER completed a modelling report (MER 2009) that was to become part of a previous Environmental Assessment (EA) for the Wallarah 2 coal mining project. That report was peer reviewed by Dr F. Kalf of Kalf and Associates Pty Ltd and included an assessment of comments by both stakeholders, state and local government agencies (KA 2010). Following that review Dr Mackie (MER 2010) conducted additional simulations and made changes to his 2009 report.

Since that time more shallow piezometer water level data has been collected in a part of the site[1] and additional shallow groundwater transient simulation work conducted in accordance with an original request by NOW[2]. The transient model simulation has included analysing watertable variations along an existing shallow piezometer profile in alluvium in response to rainfall events. This work is now part of the more recent 2012 MER report.

In August 2012 KA reviewed an earlier version of the 2012 MER report and suggested some changes to the report's contents and description. The peer review presented herein is for the subsequent updated MER modelling report (MER 2012) that includes many of the recommended changes by KA.

### *Hydrogeological and Modelling Description*

The hydrogeological description of the region and modelling work described in the current MER report (2012) has been completed and presented in a professional manner in my opinion.

The report covers a wide range of topics that include: government legislation and policies; historical studies; regional setting and drainage; geology and structures; groundwater hydrology including existing bores, groundwater occurrence and hydraulic properties of alluvium and hard rock; groundwater quality and regional potentiometric surface.

The simulation of sub-surface mining is covered in detail, introduces stochastic permeability simulation and includes: model properties; initial and transient mining changes; mining induced depressurisation using two different approaches; recovery

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[1] The placement and measurement of a wide distribution of observation/monitoring bores or piezometers has not been possible in recent years due to restricted access in the region.
[2] NOW - NSW Office of Water requested transient analysis be conducted where possible in their original 2010 submission..

of hard rock pressures and water table levels; transient and long-term shallow crack storage; alluvium subsidence storage. A separate section deals with potential environmental impacts. The report concludes with comments on water sharing plans, licensing, groundwater monitoring including verification criteria and mitigation measures.

Groundwater in the hard rock strata is of variable quality with mostly brackish to moderately saline water present with very limited yields due to the very low hydraulic conductivity except in shallow pre-mine in-situ fractured strata. The alluvial sediments also have a low permeability with only fresh to brackish groundwater at shallow depth and more saline and marginal water quality at depth due to upward flow of hard rock higher salinity groundwater. Therefore the groundwater potential in the alluvial sediments and hard rock is limited.

### *Modelling Guidelines*

This review report uses as a basis the new Australian Groundwater Modelling Guidelines (National Water Commission 2012). It should be noted that while these set of guidelines contain relevant procedures and items for the MER modelling work, it does not specifically cover coal mining *per se* and all effects that arise in the groundwater system caused by underground longwall mining of coal seams. Where no guidelines are available specific comments are made regarding the adequacy or otherwise of the approach used for modelling the groundwater system at Wallarah 2 based on the author's experience, previous reviews or available reported field evidence. The completed Peer Review guideline checklists for this modelling work are presented in Appendix A.

### *Model Conceptualisation, Design and Simulation Methods*

The model conceptualisation is more than adequate and described in Appendix E of the MER report. The model comprises 14 model layers representing the various rock strata layers and sub-division of some of these geological layers with associated anisotropic[3] permeability. In addition the model includes the surface topography based on high resolution digital terrain data over an area of 575 square kilometres.

The various creeks and river in the region are also represented and a high conductance value (1000 $m^2$/day) applied to ensure a high hydraulic connectivity between groundwater and surface water channels.

Use in made of an essential variably saturated computer code Modflow-Surfact (MS) to simulate depressurisation caused by longwall panel removal in the sub-surface supported by fracture analysis conducted by a geomechanical consultant. Use of variably saturated code is essential since standard code such as the standard USGS Modflow is a saturated model code that can cause anomalous results when sub-surface depressurisation caused by longwall panel removal is simulated

Boundary conditions have been assigned in the model in a suitable manner.

Highly connected cracking within the subsidence zone above the represented longwall panels has been assigned much higher permeability than pre-mine values to a height of 220m above the mined out seam. Geomechanical modelling for comparison (SCT 1999, 2011) has estimated this 'free draining' zone to be between

[3] Anisotropic permeability. Permeability that is different in the horizontal direction (larger) than in the vertical direction in the oriented plane of the hard rock layer.

160m or less for sub-critical zones and 200m for super-critical conditions above the mined out seam. Hence the method used in the MER model is considered to be conservative.

Of particular note in the MER modelling work (model W4) is the use of stochastic generation of both horizontal and vertical permeability distributions in the subsidence zone in an effort to more closely model the earlier geomechanical fracture/cracking simulations by SCT/MSEC (2010). This is a relatively new approach developed by Dr Mackie (MER 2010) following the KA review (KA 2010). It is considered to be an useful development and allows a comparison to be made of the effects on groundwater pressure changes and inflow caused by either uniform or stochastic permeability assignment of cracking and bed separation in the overburden strata.

### *Calibration, Sensitivity Analysis and Verification*

Steady state calibration has been achieved using earlier sited observation bores water levels throughout the mining area, using topographic surface elevations as a guide and is of sufficient accuracy to provide a suitable starting potentiometric surface for the mining simulation. The scatter diagram indicates that the steady state calibration is satisfactory.

With regard to transient calibration it has only been possible to calibrate (history match) the alluvial watertable variations due to rainfall events within a piezometric alluvial profile. It is not possible to conduct a transient calibration on the hard rock strata given Wallarah 2 is a pre-mine site. The report states (Appendix E section E6):

*" It is not possible to calibrate the hard rock systems within the model without significant hydraulic stress* [i.e. mining] *in the system and without a comprehensive monitoring system. Accuracy in model representation of the hard rock systems is therefore dependent upon the measurement and assignment of formation hydraulic properties as determined by packer and core tests, and upon the steady state hydrostatic piezometric surfaces."*

This reviewer agrees with these comments. Calibration and verification of early time based predictions would be possible once the first set of panels are removed but only if monitoring observations bores/piezometers are available overlying these mined out zones.

Sensitivity analysis has not been conducted for essentially the same reasons as stated in the above quote. However, model parameters chosen are based on a comprehensive data set of hydraulic and core testing. Comparison between using uniform and stochastic permeability distribution is reported to have produced negligible differences in the predicted regional drawdown distribution although the stochastic model produced lower mine inflows. The influence of subsidence cracking on interburden permeability and hence pore pressures can be only be verified once the initial panels in the early stages are mined. The MER report in Section E7.4 does however highlight the parameters which are likely to have the greatest affect on the predicted depressurisation.

### *Prediction, Uncertainty and Model Constraints*

The predictions presented in the report are considered to be reasonable and of sufficient accuracy at this pre-mine stage and the unfortunate current enforced limited monitoring coverage of the Wallarah 2 mine site. Uncertainty is always an aspect in model simulation but use of a model is the only alternative in making an overall assessment of the likely impact in proposed mining projects. The degree of

uncertainty will decrease considerably once the early stages of the mine are in progress and as the model is updated based on collected monitoring water levels.

The MER model constraints are stated explicitly and adequately in section E8 of the report.

*Additional supporting simulations*

Appendix F in the MER report provides additional simulation in order to asses the localised effects of a single panel extraction on the alluvial groundwater system. This provides an interesting adjunct to the main modelling effort.

## Conclusions

This peer review has assessed the adequacy of the hydrogeological data the development of a numerical model for predicting the local and regional effects of longwall mining at the Wallarah 2 site.

There has been no mining to date at the Wallarah site and therefore calibration of mining influences is not possible. It has only been possible to simulate transient effects on the shallow water table in response to rainfall. Also the site assessment is currently hampered by enforced restrictions on placement and recording of monitoring facilities.

Groundwater in the hard rock strata at depth is of variable quality with mostly brackish to moderately saline water present in a low to very low permeable environment with bore yields mainly at shallow depth in pre-mine in-situ fracture zones. The alluvial sediments also have a low permeability with marginal water quality at depth and therefore the groundwater potential in these sediments and hard rock is limited. This situation is quite common in groundwater associated with coal measure strata.

The conceptualisation, model design, simulations and reported have been conducted in a professional manner and in considerable detail despite current limitations.

The predictions provided are considered reasonable based on the available data. The main groundwater impacts are likely to occur at depth with some transient storage effects on the alluvial sediments but limited drawdown effects. There is unlikely to be significant losses of groundwater from the alluvial sediments and any such minor losses would be more than compensated by recharge through rainfall and significant storage buffering within these sediments based on the report findings.

Maximum groundwater inflows to the mine is predicted to be between 2.0 and 2.5 ML/day after 20 to 25 years after mining commences. These results are reasonable in consideration of other similar mining project inflows based on this reviewers experience.

## References

**Kalf and Associates Pty Ltd (KA). 2010** *Wallarah 2 Coal Project. Review of the Mackie Environmental Research Modelling Report, field evidence and stakeholders comments. 27 October.*

**Mackie Environmental Research (MER) 2009** *Wallarah 2 Coal Project. Groundwater Management Studies. October. (EA report prepared for Kores)*

**Mackie Environmental Research (MER) 2010** *Wallarah 2 Coal Project Groundwater Studies: Review by Kalf and Associates Pty Ltd. 13 October. (Comments on KA review by MER)*

**Mackie Environmental Research (MER) 2012** *Wallarah 2 Coal Project Groundwater Management Studies. September. Report No M7589/Rev 3*

**National Water Commission 2012.** Australian Groundwater Modelling Guidelines. SKM and National Centre for Groundwater Research and Training. Waterlines Report Series No 82, June.

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

**Strata Control Technology (SCT) and Mine Subsidence Engineering Consultants (MSEC) 2010.** *Subsidence Impact Assessment . Vol 2 Appendix A. W2CP Environmental Assessment.* [See also KA 2010]

**SCT Operations Pty Ltd 2011.** *Wyong western area computer modelling. Report prepared for Kores Australia, Sept .*

# Appendix A - Peer Review Checklists

## Peer review checklists

NA - Not Applicable

| *Question* | *Yes/No* |
|---|---|
| 1. Are the model objectives and model confidence level classification clearly stated? | Y |
| 2. Are the objectives satisfied? | Y |
| 3. Is the conceptual model consistent with objectives and confidence level classification? | Y |
| 4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer? | Y |
| 5. Does the model design conform to best practice? | Y |
| 6. Is the model calibration satisfactory? | * |
| 7. Are the calibrated parameter values and estimated fluxes plausible? | * |
| 8. Do the model predictions conform to best practice? | Y |
| 9. Is the uncertainty associated with the predictions reported? | Y |
| 10. Is the model fit for purpose? | Y |
| * Calibration is restricted due to it being a pre-mine site. Transient calibration has been conducted on alluvial piezometers. | |

| *Review questions* | *Yes/No* | *Comment* |
|---|---|---|
| **1. Planning** | | |
| 1.1 Are the project objectives stated? | Y | |
| 1.2 Are the model objectives stated? | Y | |
| 1.3 Is it clear how the model will contribute to meeting the project objectives? | Y | |
| 1.4 Is a groundwater model the best option to address the project and model objectives? | Y | |
| 1.5 Is the target model confidence-level classification stated and justified? | N | Class 2 with aspects of Class 3 due to pre-mine site conditions. |
| 1.6 Are the planned limitations and exclusions of the model stated? | ? | |
| **2. Conceptualisation** | | |
| 2.1 Has a literature review been completed, including examination of prior investigations? | Y | Also available in KA 2010 peer review for other mining site experience |
| 2.2 Is the aquifer system adequately described? | Y | |
| 2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...) | Y | |
| 2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds | Y | |
| 2.2.3 aquifer geometry including layer elevations and thicknesses | Y | |
| 2.2.4 confined or unconfined flow and the variation of these conditions in space and time? | Y | |
| 2.3 Have data on groundwater stresses been collected and analysed? | N/A | Pre-mine site |
| 2.3.1 recharge from rainfall, irrigation, floods, lakes | Y | |
| 2.3.2 river or lake stage heights | Y | |
| 2.3.3 groundwater usage (pumping, returns etc) | ? | |
| 2.3.4 evapotranspiration | N | Net recharge applied |
| 2.3.5 other? | - | |

| | | |
|---|---|---|
| 2.4 Have groundwater level observations been collected and analysed? | Y | |
| 2.4.1 selection of representative bore hydrographs | Y | Not complete due to restricted access |
| 2.4.2 comparison of hydrographs | Y | |
| 2.4.3 effect of stresses on hydrographs | Y | Rainfall only possible |
| 2.4.4 watertable maps/piezometric surfaces? | Y | |
| 2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data? | NA | |
| 2.5 Have flow observations been collected and analysed? | N | Pre-mine site |
| 2.5.1 baseflow in rivers | N | |
| 2.5.2 discharge in springs | N | |
| 2.5.3 location of diffuse discharge areas? | N | |
| 2.6 Is the measurement error or data uncertainty reported? | N | |
| 2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows) | N | |
| 2.6.2 spatial variability/heterogeneity of parameters | Y | Stochastic Distribution |
| 2.6.3 interpolation algorithm(s) and uncertainty of gridded data? | N | |
| 2.7 Have consistent data units and geometric datum been used? | Y | |
| 2.8 Is there a clear description of the conceptual model? | Y | |
| 2.8.1 Is there a graphical representation of the conceptual model? | Y | |
| 2.8.2 Is the conceptual model based on all available, relevant data? | Y | |
| 2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification? | Y | |
| 2.9.1 Are the relevant processes identified? | | |
| 2.9.2 Is justification provided for omission or simplification of processes? | Y | |
| 2.10 Have alternative conceptual models been investigated? | N | |
| **3. Design and construction** | | |
| 3.1 Is the design consistent with the conceptual model? | Y | |
| 3.2 Is the choice of numerical method and software appropriate | Y | Modflow-Surfact |
| 3.2.1 Are the numerical and discretisation methods appropriate? | Y | |
| 3.2.2 Is the software reputable? | Y | |
| 3.2.3 Is the software included in the archive or are references to the software provided? | Y | |
| 3.3 Are the spatial domain and discretisation appropriate? | Y | |
| 3.3.1 1D/2D/3D | Y | 3D |
| 3.3.2 lateral extent | Y | |
| 3.3.3 layer geometry? | Y | |
| 3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification? | Y | Very detailed - high resolution |
| 3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction? | Y | |

| | | |
|---|---|---|
| 3.4 Are the temporal domain and discretisation appropriate? | Y | |
| 3.4.1 steady state or transient | Y | Both but transient limited to alluvial water levels |
| 3.4.2 stress periods | Y | |
| 3.4.3 time steps? | Y | |
| 3.5 Are the boundary conditions plausible and sufficiently unrestrictive? | Y | |
| 3.5.1 Is the implementation of boundary conditions consistent with the conceptual model? | Y | |
| 3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained? | Y | |
| 3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level? | Y | |
| 3.5.4 Are lateral boundaries time-invariant? | Y | |
| 3.6 Are the initial conditions appropriate? | Y | Steady State derived. |
| 3.6.1 Are the initial heads based on interpolation or on groundwater modelling? | - | GW modelling steady state |
| 3.6.2 Is the effect of initial conditions on key model outcomes assessed? | N | |
| 3.6.3 How is the initial concentration of solutes obtained (when relevant)? | NA | |
| 3.7 Is the numerical solution of the model adequate? | Y | |
| 3.7.1 Solution method/solver | . | PCG Newton |
| 3.7.2 Convergence criteria | . | 0.001m |
| 3.7.3 Numerical precision | . | Single |
| **4. Calibration and sensitivity** | | |
| 4.1 Are all available types of observations used for calibration? | Y | |
| 4.1.1 Groundwater head data | Y | |
| 4.1.2 Flux observations | N/A | |
| 4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc. | N/A | |
| 4.2 Does the calibration methodology conform to best practice? | Y | Trial and Error only |
| 4.2.1 Parameterisation | . | |
| 4.2.2 Objective function | . | |
| 4.2.3 Identifiability of parameters | . | |
| 4.2.4 Which methodology is used for model calibration? | . | Trial and Error only |
| 4.3 Is a sensitivity of key model outcomes assessed against? | . | |
| 4.3.1 parameters | Y | |
| 4.3.2 boundary conditions | .Y | |
| 4.3.3 initial conditions | .Y | |
| 4.3.4 stresses | .Y | |
| 4.4 Have the calibration results been adequately reported? | Y | |
| 4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale? | Y | |
| 4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model? | NA | |
| 4.4.3 Are calibration statistics reported and illustrated in a reasonable manner? | Y | Limited to alluvium water levels |

| | | |
|---|---|---|
| 4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated? | N | Calibration limited to alluvials |
| 4.5.1 spatially | . | |
| 4.5.2 temporally | Y | |
| 4.6 Are the calibrated parameters plausible? | Y | |
| 4.7 Are the water volumes and fluxes in the water balance realistic? | Y | |
| 4.8 has the model been verified? | N | Not feasible until mining commences |
| **5. Prediction** | | |
| 5.1 Are the model predictions designed in a manner that meets the model objectives? | Y | |
| 5.2 Is predictive uncertainty acknowledged and addressed? | N | |
| 5.3 Are the assumed climatic stresses appropriate? | Y | |
| 5.4 Is a null scenario defined? | . | |
| 5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification? | Y | |
| 5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence? | NA | |
| 5.5.2 Are well losses accounted for when estimating maximum pumping rates per well? | NA | |
| 5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence? | Y | |
| 5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives? | Y | |
| 5.6 Do the prediction results meet the stated objectives? | Y | |
| 5.7 Are the components of the predicted mass balance realistic? | Y | |
| 5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates? | NA | |
| 5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow? | N | |
| 5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)? | N | |
| 5.7.4 Is diffuse recharge from rainfall smaller than rainfall? | Y | |
| 5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge? | N | |
| 5.8 Has particle tracking been considered as an alternative to solute transport modelling? | NA | |
| **6. Uncertainty** | | |
| 6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction? | N | |
| 6.2 Is the model with minimum prediction-error variance chosen for each prediction? | N | |
| 6.3 Are the sources of uncertainty discussed? | N | |
| 6.3.1 measurement of uncertainty of observations and parameters | N | |

| | | |
|---|---|---|
| 6.3.2 structural or model uncertainty | .N | |
| 6.4 Is the approach to estimation of uncertainty described and appropriate? | N | |
| 6.5 Are there useful depictions of uncertainty? | N | |
| **7. Solute transport** | | Not Applicable |
| 7.1 Has all available data on the solute distributions, sources and transport processes been collected and analysed? | | |
| 7.2 Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible? | | |
| 7.3 Is the choice of numerical method and software appropriate? | | |
| 7.4 Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated? | | |
| 7.5 Is there sufficient basis for the description and parameterisation of the solute transport processes? | | |
| 7.6 Are the solver and its parameters appropriate for the problem under consideration? | | |
| 7.7 Has the relative importance of advection, dispersion and diffusion been assessed? | | |
| 7.8 Has an assessment been made of the need to consider variable density conditions? | | |
| 7.9 Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure? | | |
| 7.10 Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses? | | |
| 7.11 Is the calibration based on meaningful metrics? | | |
| 7.12 Has the effect of spatial and temporal discretisation and solution method taken into account in the sensitivity analysis? | | |
| 7.13 Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters? | | |
| 7.14 Does the uncertainty analysis consider the effect of solute transport parameter uncertainty, grid design and solver selection/settings? | | |
| 7.15 Does the report address the role of geologic heterogeneity on solute concentration distributions? | | |
| **8. Surface water–groundwater interaction** | | |
| 8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives? | Y | |
| 8.2 Is the implementation of surface water–groundwater interaction appropriate? | Y | |
| 8.3 Is the groundwater model coupled with a surface water model? | N | |
| 8.3.1 Is the adopted approach appropriate? | Y | |
| 8.3.2 Have appropriate time steps and stress periods been adopted? | Y | |
| 8.3.3 Are the interface fluxes consistent between the groundwater and surface water models? | NA | |

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## Wallarah Coal Project
## KA Review of the updated 2013 MER
## Hydrogeological and Modelling Assessment

This document presents review comments in addition to those previously provided in a full peer review by Dr Kalf (KA 2012). The KA comments herein reference that previous review and are based also on an updated report by MER [1](2013) sent to KA office on the 20 February 2013. The updated MER (2013) hydrogeological and modelling assessment supersedes the MER (2012) assessment report and the update is in response to a letter from DoPI (2012) that includes an Attachment A by NOW that comments on the adequacy of the EIS for public exhibition. In particular, the issues in that Attachment A related to groundwater include the following sections:

Section 2. Aquifer characterisation and groundwater model conceptualisation

Section 3. Subsidence impacts, in particular groundwater/surface water effects and sensitivity of vertical hydraulic conductivity of strata effecting shallow groundwater and stream surface water leakage.

Section 5. Water quality (i.e. ferruginous staining)

Section 6. Baseflow

With regard to Section 2 the comments by NOW state that faulting was not included in the previous model. In particular that *" there is other geological evidence that significant faulting exists"* although they do not refer to the source for such evidence and are not specific about where and to what extent such faulting occurs and whether these structures would be significant water bearing zones or not[2]. The community alleged the presence of a fault in the main drainage valley in 2005 based on the 'Australian Gas Alliance' opposition to 'Sydney Gas' investigations being carried out in the region. Kores subsequently investigated this claim some years ago and had indicated to me in 2010 that they had found no such evidence of faulting based on geophysical survey results or drilling cores. Additional discussion and background on this issue is provided in Section 7.3 of the Geological report

[1] Mackie Environmental Research Pty Ltd.
[2] Comments by NOW in their Section 3 do refer later to a particular underground mine north of Wallarah concerning induced leakage but I understand there are differences of opinion on the relevance and accuracy about the description given by NOW for this example and no further evidence has been provided by them.

(Kores 2013) prepared for the EIS. The inclusion of any major fault in the model was and is therefore considered to be hypothetical and not supported by any evidence. The discussion in section 2.4 in MER (2013) is also relevant. NOW's hydrogeologist Mr J. Williams was asked by Dr Mackie in a recent personal interview to provide the likely conditions and parameters for the fault(s) inclusion in the model based on Williams' concern. This offer however was declined. To satisfy NOW's concern Dr Mackie instead has therefore conducted vertical hydraulic conductivity sensitivity analysis, for the constrained zone, which is considered to be a suitable alternative. The results are provided in Appendix E Section E7.4.1 and Figures E27a and b. The results indicate that the bulk vertical permeability so derived is of the same order of magnitude as that adopted for the regional model.

Regarding KA model conceptualisation omission suggested by NOW the KA report has in it a section clearly titled 'Model Conceptualisation, Design and Simulation Methods' and states *" The model conceptualisation is more than adequate and described in Appendix E of the MER Report".* This comment remains valid.

NOW has also indicated an issue with the conceptual model that includes the accuracy of the model predictions being dependent on the conclusion that the induced goafing fracturing and upward propagation to some extent would not significantly affect the overlying shallow strata. It should be noted that the conceptual model for these predictions is not based on the groundwater model but on the geomechanical model simulations of fracture zone development (SCT 1999, 2010 and 2011). As already noted in the original KA review (KA 2012)[3] although the groundwater model simulations rely on the results of the SCT modelling work, MER as a conservative estimate, has included major fracturing zones (i.e. 'free draining') that are much higher above the goaf than indicated by the SCT modelling work. (See page E5 Section E4.3 - MER 2013).

NOW refers to the land access issue in Section 2 that has resulted in limited spatial coverage of the bore network. This is a valid comment but cannot currently be corrected until such time as Council and landholders grant such access. Increasing the network coverage would certainly be desirable in the longer term and as I understand it would be the company's intention of increasing the network if approval is granted. As noted previously (KA 2012) it will be important to have available water level data both pre-mine and during mining in multi-depth piezometers within the overburden set over the first panel(s) that is/are mined. This will provide initial hydrographs for comparison between the groundwater model predictions and field results. Recommendations on monitoring and verification in this regard are provided in the MER report (2013 - Sections 9.0 and 9.1).

In Section 3 NOW states: *" The mine* [ground] *water influx assumes no contributions from localised fracture related storage that might be intercepted by mining ".* This is not strictly correct. Reference is made to the earlier MER report: (MER 2012 page 22 Section 4.2) *" However, it would not be unreasonable to expect up to 0.5 Ml/day increase in mine water seepage over periods of weeks to months, if fracture network storage is encountered and drained".* The same statement is contained in the current update report MER (2013, page 22 section 4.2 last paragraph and slightly modified, page E10 para 6).

Section 5 refers to water quality and in particular the possibility of ferruginous staining associated with tensile cracking. This is a possibility as indicated in the MER report (Abstract page 4) with evidence of such natural staining locally in some of the seepage zones in the upper reaches of the stream catchments. However, the report by EcoEngineers in 2010 maintain that there is an no potentially iron forming minerals that includes pyrite and

[3] In KA(2012) review it was noted that MER had set the highly connected cracking ('free draining zone') up to 220m above the mined out panels whereas the geomechanical model simulations indicate such a zone extending to 160m or less for sub-critical zones and 200m for super-critical conditions.

marcasite in this formation according to the NOW document. It has been suggested however that siderite is probably responsible for the localised natural spring seepage staining (MER 2013 - Abstract).

With regard to Section 6 in the NOW comments concerning 'Baseflow offsets', tensile fracturing at shallow depths is a possibility. Diversion and re-emergence further downstream of some surface flow has been observed in the Southern Coalfields but this usually occurs where the stream flows across exposed sandstone bedrock. Where there are alluvial sediments overlying claystone bedrock it could be expected that such diversion would be impeded to a large extent because of the filling of these fractures by alluvial clays, silts and sand. The mining and geotechnical monitoring of the first panel(s) will provide further data on this issue. In non alluvial zones there maybe some diversion and re-emergence of surface flows downstream in the upland areas as noted in the MER report.

The new MER (2013) report considers that stored salt waste within the underground at brine concentration and hyper-saline (solid) product will remain essentially immobile during resaturation and final recovery due the very high density. There is agreement with that conclusion.

**Conclusions**

The issues raised above do not change the review previously provided by KA (2012) significantly nor do they change the assessment with regard to the New Modelling Guidelines presented in that report. The sensitivity analysis of the vertical hydraulic conductivity of the interburden above the mined out zone to allow for hypothetical increased induced fracture development toward the surface has indicated that the bulk vertical hydraulic conductivity, that comprises a Gaussian distribution of this parameter, is of the same order of magnitude as adopted in the current MER groundwater model.

I consider that the MER report is suitable for public exhibition.

F. R. Kalf

**References**

**DoPI 2012** *Wallarah 2 Coal Project (SSD-4974). Adequacy of the Environmental Assessment for public exhibition. Nov 29. with Attachment A Additional comment bt NSW Office of Water.*

**Kalf and Associates Pty Ltd (KA). 2010** *Wallarah 2 Coal Project. Review of the Mackie Environmental Research Modelling Report, field evidence and stakeholders comments. 27 October.*

**Kalf and Associates Pty Ltd (KA). 2012** *Wallarah 2 Coal Project. Review of the Mackie Environmental Research Hydrogeological and Modelling Report,*

**Kores 2013.** *Wallarah 2 Coal Project Geological Report. Feb*

**Mackie Environmental Research (MER) 2012** *Wallarah 2 Coal Project Groundwater Management Studies. September. Report No M7589/Rev 3*

**National Water Commission 2012.** *Australian Groundwater Modelling Guidelines. SKM and National Centre for Groundwater Research and Training. Waterlines Report Series No 82, June.*

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

**Strata Control Technology (SCT) and Mine Subsidence Engineering Consultants (MSEC) 2010.** *Subsidence Impact Assessment . Vol 2  Appendix A. W2CP Environmental Assessment.* [See also KA 2010]

**SCT Operations Pty Ltd 2011.** *Wyong western area computer modelling. Report prepared for Kores Australia, Sept .*