APPENDIX E
GROUNDWATER IMPACT ASSESSMENT




RPS Aquaterra

MOOLARBEN COAL COMPLEX STAGE 2 PREFERRED PROJECT REPORT GROUNDWATER IMPACT ASSESSMENT NOVEMBER 2011

MOOLARBEN COAL COMPLEX STAGE 2
PREFERRED PROJECT REPORT
GROUNDWATER IMPACT ASSESSMENT
NOVEMBER 2011

Prepared by:

RPS Aquaterra
Suite 902, Level 9 North Tower
1-5 Railway Street, Chatswood NSW 2067
T: 61 2 9412 4630
F: 61 2 9412 4805
E: water@rpsgroup.com.au
W: rpsaquaterra.com.au

Prepared for:

Hansen Bailey
On behalf of Moolarben Coal
PO Box 473, Singleton NSW 2330
T: 61 2 6575 2000
F: 61 2 6575 2001
E: DMunroe@hansenbailey.com.au
W: hansenbailey.com.au

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	Name	Position	Signature	Date
Author	Hugh Middlemis Andrew Fulton	Senior Principal Water Resources Engineer Senior Hydrogeologist	*Hugh Middlemis* *Andrew Fulton*	30 Nov 2011
Reviewer	Peter Dundon	Senior Principal Hydrogeologist	*Peter Dundon*	31 Aug 2011
Reviewer	Noel Merrick	Independent Hydrogeologist	*Noel Merrick*	4 Nov 2011
Reviewer	Craig Schultz	Senior Principal Hydrologist/ Hydrogeologist	*Craig Schultz*	30 Nov 2011

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EXECUTIVE SUMMARY

Background to Assessment

Moolarben Coal Mines Pty Ltd (MCM) is proposing Stage 2 of the Moolarben Coal Complex (MCC) (Stage 2) within Exploration Licence (EL) 6288. The site is located east of the village of Ulan in the Western Coalfields of New South Wales, around 40km north of Mudgee and 25km east of Gulgong. EL6288 is bounded to the west by the existing Ulan Coal Mine and to the east by the existing Wilpinjong Coal Mine.

RPS Aquaterra undertook a groundwater impact assessment for the Stage 2 Environmental Assessment (Stage 2 EA). Subsequent to submission of the Stage 2 EA. The groundwater impact assessment was reviewed by Dr Frans Kalf of Kalf and Associates Pty Ltd at the request of the Department of Planning and Infrastructure (DP&I). Issues raised by Dr Kalf have been addressed in this report.

This revised groundwater impact assessment replaces Appendix 5 of the Stage 2 EA and supports the Preferred Project being prepared by Hansen Bailey Environmental Consultants. The groundwater impact assessment has been updated to account for the Preferred Project and incorporates issues raised following submissions to the Stage 2 EA and the review by Dr Kalf.

Ongoing peer review of the groundwater impact modelling has been provided by Dr Noel Merrick, former Director of the National Centre for Groundwater Management, and is now an independent consultant. This report incorporates his suggestions.

Project Description

The purpose of this assessment is to form part of a Preferred Project Report (PPR) being prepared by Hansen Bailey to support the application for Project Approval under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The application was made to facilitate the development of a 24-year open cut and underground coal mine and associated infrastructure and integration with the existing Stage 1 operations.

Specifically, the Preferred Project will consist of:

- The construction and operation of an open cut (OC) mining operation (OC4) extracting up to 12 million tonnes per annum (Mtpa) Run of Mine (ROM) coal and up to 13Mtpa combined rate with the Stage 1 open cuts;
- The construction and operation of two underground (UG) mining operations (UG1 and UG2) extracting up to 4Mtpa ROM coal cumulative with the Stage 1 underground;
- The construction and operation of the Stage 2 ROM coal facility;
- Extension of the life of the Coal Handling and Preparation Plant (CHPP) to Year 24 of Stage 2 with increased throughput of up to 17Mtpa (13Mtpa open cut and 4Mtpa underground);
- The development of the Northern Out Of Pit (OOP) emplacement area;
- The construction and operation of two conveyors and associated facilities between the Stage 2 ROM coal facility and Stage 1 CHPP;
- The construction and operation of a Mine Access Road;
- The construction and operation of administration, workshop and related facilities;
- The construction and operation of water management infrastructure; and
- The installation of supporting power and communications infrastructure.

Hydrogeological Background

The geology of the MCC area comprises principally an extensive sequence of Permian coal measures, which dips gently (1 to 2 degrees) to the north-east. Coal will be recovered from the Ulan Seam, which is the lowermost and most significant of the coal seams in the Permian Illawarra Coal Measures in the Western Coalfields. The sequence is underlain by the Shoalhaven Group sediments, volcanic and granitic basement rocks, and overlain by Triassic Narrabeen Group sediments. The Triassic sediments, having been eroded and incised by current-day surface drainage, commonly form upland plateaus, and are absent from large parts of the MCC area. Quaternary alluvium associated with current surface drainage is present in some areas. Remnants of a Tertiary palaeodrainage system have also been identified in a few locations.

The MCC will have an impact on the groundwater environment on a local, and to a more limited extent, regional scale. Dewatering will be required to mine UG1 and UG2, with dewatering volumes being used primarily within the MCC for coal washing and dust suppression.

Groundwater investigations have been carried out to develop a thorough understanding of the existing groundwater environment in and around the Project Boundary, and to make an assessment of the potential impacts of the MCC on the groundwater resources and existing groundwater users. An extensive network of over 100 groundwater monitoring bores is now in place. Bore depths range from less than 10m to over 150m.

Baseline monitoring, comprising monthly measurement of water levels and quarterly sampling of groundwater for laboratory analysis of water quality is routinely undertaken at all monitoring sites. A number of surface water sampling sites are also regularly monitored for water quality.

The principal aquifer in the MCC Project Boundary is the Ulan Seam which, along with other parts of the Permian coal measures sequence, in places displays secondary permeability due to fracturing and jointing within the coal seams. The Triassic Narrabeen Group and weathered granite basement also provide some groundwater resource potential.

The Shoalhaven Group sediments, Tertiary palaeochannel deposits and Quaternary alluvium are considered to contain only localised aquifers with minor groundwater potential.

Groundwater levels within the Ulan Seam and Permian coal measures have already been extensively impacted by the pumping of groundwater for dewatering at Ulan Coal Mine to the northwest of the Preferred Project.

Predicted Impacts

Groundwater numerical modelling using MODFLOW SURFACT has assessed both the impact of groundwater inflow and the requirement for dewatering at the Preferred Project cumulatively with Stage 1, Wilpinjong and Ulan coal mines. An assessment of post-mining water level recovery rates over a 100 year period has also been undertaken. Groundwater levels in the Ulan Seam and overlying Permian coal measures will be impacted by MCC operations. Drawdowns in excess of 5m in the Ulan Seam are predicted to extend not more than 16km from the MCC area, and less than 13km in the Permian overburden.

Total predicted mine inflows at the MCC (plus pumping from the Moolarben Northern Borefield) range from 1381 megalitres per annum (ML/a) in Mine Year 1 up to 1993ML/a in Mine Year 17 (i.e. 3.8ML/d to 5.5ML/d).

Cumulative impacts of the Wilpinjong Coal Mine, Ulan Coal Mine and the MCC were determined using the MODFLOW-SURFACT model. A second simulation was conducted representing only the Wilpinjong and Ulan Coal Mines. This was compared to the simulation that included the MMC in order to determine the impact of the MCC proposals only.

Minimal drawdowns due to the MCC are predicted in the Triassic formations in proximity to the MCC mining areas (less than 2m in the lower Triassic and less than 1m in the upper Triassic). However, measurable drawdowns are predicted to occur in the Triassic above the Ulan Coal Mine underground mine due to the MCC – up to more than 10m drawdown in the lower Triassic and more than 2m in the upper Triassic. This is believed to be due to the increased vertical hydraulic conductivity in the overburden above Ulan Coal Mine’s 400m wide longwall panels as a result of subsidence, providing a more permeable leakage pathway for downward leakage from the Triassic to the Ulan goaf. So even after mining at the Ulan Coal Mine is completed, ongoing drawdown effects are expected to be seen in the Triassic above Ulan Coal Mine, as long as the MCC dewatering continues.

Drawdowns due to the MCC are predicted to be localised and of limited magnitude in the surficial groundwater systems. Drawdowns exceeding 2m are predicted to extend up to 700m downstream from the pit edge of OC4 and OC1 into the Wilpinjong Creek and Moolarben Creek valleys respectively.

In general, the predicted impact of the MCC on groundwater sources (private bores, wells, springs, soaks, and groundwater-fed dams) in the vicinity (up to 5km) of MCC can be summarised as follows:

- Bores installed in the Permian will be either mined out or are already dry;
- No impact is predicted for sources in the alluvium, with the exception of a number of dams and soaks which will be mined out by the OC4 development; and
- Small water level impacts will be seen in some Triassic bores by the end of mining in Year 24, with the maximum impact being 0.6m. The magnitude of impact is not expected to affect the performance of any bore. The water levels are expected to have substantially recovered by the end of the 100 years recovery period.

Since the drawdown in alluvium is predicted to be minimal, the impact on GDEs is expected to be minor as well.

At the end of the 100 year recovery period, predicted water levels in all the main hydrogeological units have recovered to at least, and often higher than, the levels prevailing at the start of mining of Stage 2 of the MCC.

Groundwater across the MCC area is broadly of the same chemical type, although both pH and salinity are variable. Total dissolved solids (TDS) concentrations range from less than 500mg/L to over 8000mg/L, with the higher salinities associated with shallow groundwater-fed dams and creeks, and also to some sites in the Permian coal measures and Ulan Seam. The pH values typically range between 5.5 and 8.5; however some sites, particularly those in the south of the development area, record baseline pH values of less than 5. The groundwater quality of inflows to UG1, UG2, and OC4 is expected to be variable and at the saline end of the range of measured TDS.

Monitoring and Reporting

The current groundwater and surface water monitoring programs should be continued. Based on the regional groundwater and surface water study undertaken by Aquaterra in 2009 (Aquaterra, 2009b), the current monitoring network provided by all three mines in the region has sufficient groundwater monitoring points to provide good regional spatial coverage. Potential exists to rationalise the monitoring program for the MCC, Ulan and Wilpinjong coal mines by sharing the data at several locations where duplication exists and/or data sharing can provide benefits to the mining operations.

Collated monitoring data from the MCC should be subjected to an annual review by an approved experienced hydrogeologist in order to assess the impacts of the MCC on the groundwater environment, and to compare any observed impacts with those predicted from groundwater modelling.

The approved Water Management Plan (WMP) for the MCC will need to be updated to accommodate the Stage 2 development. It should address and provide for Site water resource monitoring and appropriate trigger levels, response plans and reporting requirements. The amendments will need to include any specific requirements of government agencies, which may arise from the approval process and provision of development consent conditions. Relevant legislation, policies, standards, guidelines and water sharing plans will also be applicable.

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APPENDICES

1. INTRODUCTION

1.1 Background

Moolarben Coal Mines Pty Ltd (MCM) is proposing Stage 2 of the Moolarben Coal Project (Stage 2) within Exploration Licence (EL) 6288. The site is located east of the village of Ulan in the Western Coalfields of New South Wales, around 40km north of Mudgee and 25km east of Gulgong (Figure 1.1). The Project Boundary is located to the northwest portion of A449, the eastern residual area of A428, plus untitled ground between the Ulan Colliery holding and A309.

EL6288 is bounded to the west by the Ulan Coal Mine and to the east by the Wilpinjong Coal Mine.

The Moolarben Coal Complex (MCC) includes four open cut mines and three underground mines. In September 2006, MCM lodged an Environmental Assessment (EA) Report (MCM, 2006) for the proposed development of the Stage 1 of the MCC, incorporating three open cut mines and an underground mine together with a coal preparation plant, coal handling and storage facilities, rail loop, train loading system, and associated mine infrastructure and services. This part of the MCC is referred to as Stage 1. A comprehensive groundwater assessment report was prepared by Peter Dundon and Associates Pty Ltd (PDA, 2006a) for inclusion in the Stage 1 EA. Stage 1 of the MCC was granted approval by the Minister for Planning on 6 September 2007.

A Major Project Application for Stage 2 of the MCC was lodged with the Minister for Planning in May 2008.

RPS Aquaterra undertook a groundwater impact assessment for the Stage 2 Environmental Assessment (Stage 2 EA). Subsequent to submission of the Stage 2 EA, the groundwater impact assessment was reviewed by Dr Frans Kalf by Kalf & Associates Pty Ltd at the request of the Department of Planning and Infrastructure (DP&I). Issues raised by Dr Kalf have been addressed in this report.

RPS Aquaterra was commissioned on behalf of MCM to undertake a revised groundwater impact assessment for Stage 2. The purpose of this assessment is to form part of a Preferred Project Report (PPR) being prepared by Hansen Bailey to support the application for Project Approval under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The application was made to facilitate the development of a 24-year open cut and underground coal mine and associated infrastructure and integration with the existing Stage 1 operations.

Specifically, the Preferred Project will consist of:

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- The construction and operation of two conveyors and associated facilities between the Stage 2 ROM coal facility and Stage 1 CHPP;
- The construction and operation of a Mine Access Road;
- The construction and operation of administration, workshop and related facilities;
- The construction and operation of water management infrastructure; and
- The installation of supporting power and communications infrastructure.

The MCC will operate as an integrated operation comprising both open-cut and underground workings – open-cuts OC1, OC2 and OC3 and underground UG4 (Stage 1), plus open-cut OC4 and undergrounds UG1 and UG2 (Stage 2). The Stage 1 and Stage 2 components will be integrated into a revised mining schedule; incorporating the immediate commencement of OC4 should the Stage 2 approval be granted.

Underground mining would be carried out using longwall mining techniques.

1.2 Mining Proposal for Stage 2

MCM is proposing to operate both open cut and underground mines within the Project Boundary within EL6288, mining coal from the Ulan Seam. The extent of EL6288 is shown in Figure 1.1.

Stage 1 approved the production of up to 10Mtpa of coal from a maximum 12Mtpa ROM. This comprised mining of up to 4Mtpa from UG4 plus an aggregated volume of more than 8Mtpa from OC1, OC2 and OC3.

Stage 2 seeks approval to increase coal production for the MCC to a total of 17Mtpa ROM coal. Approval is sought to produce up to 13Mtpa ROM coal from OC1 to 4, and up to 4Mtpa from UG1, UG2 and UG4.

1.3 Report Objective

The objective of this report is to support the PPR and provide sufficient information on the existing groundwater environment within the MCC area and its immediate surrounds, and to assess the potential impacts on groundwater levels and quality from development of Stage 2 of the MCC, such that any concerns regarding groundwater and surface water resources, groundwater dependant ecosystems (GDEs) and existing groundwater users are addressed to the satisfaction of the Minister for Planning and Infrastructure.

This report also addresses groundwater related issues from the submissions to the public exhibition of the EA and the review by Kalf & Associates Pty Ltd (July, 2009). These issues and where they are addressed in this report are summarised in Table 1.1.

Table 1.1: Kalf Review Recommendations

Recommendation	Sections in Report
Clarify the groundwater model simulation methods used, the sources of hydrogeological information and the issues associated with use of layers in groundwater models.	5.2, 3.3, 3.4
Recalibrate the Moolarben groundwater model against recent monitoring data and groundwater model results for the Ulan Coal Mine.	5.4
Simulate long-term pumping tests to validate the groundwater model.	5.4
Assess existing leakage losses from the Goulburn River due to current mining (i.e. Ulan Coal Mine) and clarify Stage 2 impacts to the Goulburn River.	5.11
Clarify the final watertable depth across the open cuts.	6.2, 6.8
Use residual mass curve (RMC) plots for climate data and Piper and Schoeller diagrams for groundwater quality to better represent current available data and model.	2.7, 2.8
Provide one north-south model section (e.g. between E760 and E764) and three east-west model sections across the area to be mined.	6.3
Provide a conceptual diagram showing why the Drip will not be affected by the MCP.	5.1, Figure 2.5
Include the following in future groundwater modelling and reporting: Updated model parameters consistent with the Ulan Coal Mine groundwater model. Subsidence induced cracking to the ground surface;	 5.3 5.9

Ongoing peer review of the groundwater modelling has been provided by an independent consultant, Dr Noel Merrick through both Stage 1 and Stage 2.

This report is structured as follows:

- Section 2 contains a summary of previous groundwater investigations undertaken in the MCC area prior to September 2007;
- Section 3 details the additional groundwater investigations undertaken, specifically in relation

to Stage 2, between September 2007 and May 2008;

- Section 4 reports on the existing groundwater environment within the Project Boundary;
- Section 5 outlines MCM's mining proposal giving a brief summary of the proposed operations and water supply demands of the MCC;
- Section 6 reports on the groundwater modelling work undertaken to assess the potential impacts of the MCC;
- Section 7 describes the potential groundwater impacts of the MCC on groundwater resources, groundwater quality, GDEs and other groundwater users;
- Section 8 details proposed monitoring, mitigation and management strategies in relation to any identified potential impacts;
- Section 9 provides recommendations for the development of contingency response plans to address any unforeseen adverse impacts on groundwater and/or surface water; and
- Section 10 provides a list of references.

1.4 Environmental Assessment Requirements

In accordance with Section 75F of the EP&A Act, the then Department of Planning, now Department of Planning and Infrastructure (DP&I), has issued the environmental assessment requirements for the preparation of the Environmental Assessment for Stage 2 of the MCC. The requirements relating to groundwater have been addressed within this report as detailed in Table 1.2.

Table 1.2: Environmental Assessment Requirements

Environmental Assessment Requirement	Relevant Section of Report
A description of the existing environment.	Section 3
Assessment of the potential impacts of all stages of the project including any cumulative impacts associated with the concurrent operation of the project with any other existing or approved mining operation, taking into consideration any relevant guidelines, policies, plans and statutory provisions. Assessment of the potential impacts on the quantity, quality and long-term integrity of the groundwater resources.	Sections 5 and 6
Description of the measures that would be implemented to avoid, minimise, mitigate, rehabilitate/remediate, monitor and/or offset the potential impacts of the project including detailed contingency plans for managing any significant risks to the environment.	Sections 7 and 8

1.5 Relevant State Policies and Guidelines

This report has also been prepared with due consideration of relevant state policies and guidelines including:

- NSW Groundwater Policy Framework Document – General;
- Draft NSW Groundwater Quantity Management Policy;
- NSW Groundwater Quality Protection Policy;
- NSW Groundwater Dependant Ecosystem Policy; and
- Guidelines for Fresh and Marine Water Quality (ANZECC).

1.6 Water Licensing

Groundwater licences under Part 5 of the *Water Act 1912* will be required for any of the following activities affecting groundwater in the Permian hard rocks:

- Extraction of water from underground mining;
- Extraction of water from open cut mining;
- Extraction of water from production bores; and
- Installation of production bores (for water supply and/or dewatering) and monitoring piezometers (for the purposes of water quality monitoring and test pumping).

In addition, the extraction of any groundwater from alluvial systems will be subject to conditions and management in accordance with the 'Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009' (HUAWS WSP), as the MCC is located within the area known as the Upper Goulburn River Water Source. This water sharing plan was gazetted in July 2009.

1.7 Project Setting

The MCC is located in the Western Coalfield, which occupies the northwest margin of the Sydney-Gunnedah-Bowen Basin in NSW. The Western Coalfield contains the Illawarra Coal Measures of Middle to Late Permian age. The Permian coal measures contain a number of coal seams, however the Ulan Seam occurring near the base of the Illawarra Coal Measures is the only seam of economic significance, and hence, is the target resource of the MCC. The Permian coal measures lay directly over Carboniferous granites, Rylstone Volcanics or Early Permian Shoalhaven Group formations.

The Permian sequence is overlain by Triassic, and in turn by Jurassic sediments. Overlying the Permian and Triassic/Jurassic sequence, the uppermost geological units comprise unconsolidated Quaternary alluvium and colluvium, and in some localities partially consolidated Tertiary palaeochannel deposits.

Small intrusives and remnant basalt flows of Tertiary, and possibly Jurassic age, have been observed in outcrop in some parts EL6288.

2. PREVIOUS GROUNDWATER INVESTIGATIONS

2.1 Summary of Stage 1 and Stage 2 Groundwater Investigations

Extensive groundwater investigations were carried out in and around EL6288, including:

- Drilling, installation and hydraulic testing of groundwater monitoring bores (piezometers) and test production bores;
- Groundwater level and groundwater quality monitoring;
- Collection of data on registered / licensed and other privately-owned groundwater sources, and natural springs, soaks and seepages;
- Laboratory permeability testing of core samples;
- Review of hydrogeological and other relevant reports produced for the Ulan and Wilpinjong coal mines; and
- Numerical groundwater modelling in order to assess the potential impacts of the MCC.

The results of the Stage 1 investigations were presented in reports produced by Peter Dundon and Associates (2006a, 2006b, 2006c, 2007a and 2007b). Results of the Stage 2 investigations were presented in Aquaterra's report accompanying the 2008 Stage 2 EA (Aquaterra, 2008).

2.2 Piezometer / Monitoring Bore and Test Bore Installation

During the Stage 1 and Stage 2 investigations, over 100 piezometers and 4 test production bores were installed. One of the test production bores has been commissioned as a production bore, and two additional production bores have been drilled and brought into water supply production.

The piezometer sites were distributed across the Project Boundary with the aim of testing, sampling and monitoring groundwater both in the Ulan Seam (the target seam for coal extraction) and the overlying and underlying lithological units. Additional drilling was undertaken in Stage 2 to further investigate the relationship between groundwater in the shallow regolith and in the deeper coal measures, including the recharge-discharge processes.

Piezometers were installed at locations within the coal deposit and proposed mining areas, as well as up dip (southwest), down dip (northeast) and along strike (north-west and south-east) of the proposed mine areas. Many of the piezometers were installed in existing exploration drill-holes. In areas where coal exploration drill-holes were not available, new bores were drilled specifically for piezometer installation.

The number and locations of the piezometers installed is consistent with the NSW Office of Water (NOW) groundwater monitoring guidelines for mine sites in the Hunter catchment (DIPNR, 2003).

All drilling and testing work was carried out with the consent of the relevant landowners and/or landholders, with Part 5A groundwater licence applications granted for all piezometers and test bores. Access Licences are held for the three bores which have been brought into service as water supply bores.

The locations of the piezometers and test bores are shown on Figure 2.1. Bore construction summary details are presented in tables in Appendix A. Construction logs for piezometers and test production bores installed during the Stage 2 investigations are presented in Appendix A. Logs for bores installed during the Stage 1 investigations are not reproduced in this report; they were previously included in the Stage 1 EA groundwater impact assessment report (PDA, 2006a).

2.2.1 Standpipe Piezometers

The majority of groundwater bores were completed as stand-pipe piezometers, forming an extensive monitoring network from which both groundwater level and groundwater quality data are now collected.

Existing coal exploration drillholes converted to standpipe piezometers were drilled at diameters of 100mm or 125mm. New holes, drilled specifically for piezometer installation, were drilled at various diameters from 100mm to 200mm. Most were drilled by air, although mud-rotary techniques were required at some sites due to ground conditions. Each bore was cased with 50mm diameter PVC casing and screened adjacent to the desired monitoring interval. The bore annulus was gravel packed over the target monitoring interval, and a bentonite seal set above and below the screened zone to ensure that the screened section was isolated. The remainder of the annulus above the bentonite seal was then backfilled with cement grout. All piezometers were completed at the ground surface with a concrete block, to prevent ingress of surface runoff or contamination, and secured within a padlocked steel monument.

Construction details of the standpipe piezometers are summarised in tabular form in Appendix A. Construction logs for piezometers installed during the Stage 2 studies are also included in Appendix A.

2.2.2 Murragamba Valley Transects

The main focus of the Stage 2 investigation drilling involved a series of shallow monitoring bores drilled along three roughly east-west orientated transects across the Murragamba Valley as shown on Figure 2.1. At each site, a shallow piezometer was installed, screened across the uppermost (potentially) groundwater bearing zone which was typically either weathered Permian coal measures material, colluvium or, at some sites, alluvium. A second slightly deeper bore was then drilled at each site. In the deeper bore, screens were placed at the interpreted highest water intersection in the underlying weathered Permian coal measures.

The primary purpose of installing these monitoring sites was to collect further hydrogeological information on the nature of the regolith groundwater, and groundwater in either Quaternary or Tertiary sediments as previously reported by Dundon (2007a). Previous coal exploration drilling had also recorded the presence of Tertiary deposits (described as predominantly clayey, quartzose gravels and sands). The drilling of paired bores also provided an ideal set-up for the collection of observation data during subsequent hydraulic testing.

The bore sites along each transect are detailed in Table 2.1. Geological cross-sections based on these transects are presented in Figures 2.2 to 2.4.

Table 2.1: Summary of Murragamba Valley Drilling Transect Sites

Transect	Approximate Northing (m MGA)	Monitoring Bores
1 (Most northerly transect)	6424400	PZ168 to PZ177
2 (Central transect)	6422800	PZ131 to PZ136
		PZ155 to PZ167
		(includes VW piezometer PZ133)
3 (Most southerly transect)	6420400	PZ137 to PZ141
		PZ143 to PZ149
		PZ153 and PZ154

2.2.3 Vibrating Wire Piezometers

A number of multi-level vibrating wire piezometer bores were installed, mostly around the proposed underground mines (UG1, UG2 and UG4), to provide a number of permanent monitoring sites for monitoring of groundwater levels or pressures at various stratigraphic depths.

Vibrating wire piezometers PZ127 and PZ130 were installed above UG1 and UG2. These were installed primarily in order to monitor any depressurisation within the Triassic and upper Permian coal measures; both sites also have a piezometer in the Ulan Seam.

PZ128 and PZ129 are located to the north of UG4, between the mine and ‘The Drip’ (an area of groundwater seeps from Triassic outcrops on the northern side of Goulburn River some 460m to the north of TG14 in UG4). Both have piezometers into the Triassic and upper Permian sediments, and were installed to extend the monitoring network for detection of possible impacts on ‘The Drip’ from UG4. A cross-section in the vicinity of ‘The Drip’ is presented in Figure 2.5. The location of this cross-section (Transect 4) and ‘The Drip’ are shown on Figure 2.1.

PZ133 is located within the Murragamba Valley, adjacent to bores PZ134 and PZ155, and was completed with three piezometers into the Ulan Seam and lower / middle Permian.

PZ179 was installed immediately adjacent to Test Bore TB179, located to the southeast of UG4. This site was completed to the same depth as TB179 with four piezometers installed to monitor changes in water levels within the Ulan Seam, Permian and Triassic strata.

2.2.4 Test/Production Bores

Five test production bores (TB52A, TB52B, TB103, TB105 and TB179) were constructed, at four sites. Three of the test bores (TB52A, TB105 and TB179) are to be retained as production bores to facilitate dewatering (predominantly of UG4), and/or to provide additional make-up water supply for the MCC. TB103 and TB52B are to be retained for monitoring purposes.

At the commencement of site works after approval of Stage 1, bores TB52A and TB179 were brought into service as water supply bores, and a new production water supply bore (TB190) was drilled and brought into service. These were used to supply construction water in the early months of Stage 1 construction.

Groundwater Access Licences 20BL171998, 20BL1712000 and 20BL172300 respectively are held for these three production bores.

2.3 Hydraulic Testing

The hydraulic testing schedule and test results from the Stage 1 and Stage 2 investigations are presented in Tables 2.2 and 2.3. Graphical plots of the test data are presented in Appendix B.

2.3.1 Piezometers

On completion, each piezometer was hydraulically tested, either by a short duration constant rate pumping test with a low capacity sampling pump, or by falling-head slug test, to derive indicative values of aquifer hydraulic conductivity (permeability).

Test durations were typically between 1 and 2 hours, which was the practical limitation of the pumps used. The tests provided sufficient data for determination of site-specific aquifer hydraulic properties, but test durations were too short to evaluate aquifer geometry or regional hydraulic continuity.

Table 2.2: Summary of Hydraulic Testing Schedule and Analysis Results – Piezometers

Aquifer	Transmissivity (m^2/d)		Average Hydraulic Conductivity (m/d)		Average Hydraulic Conductivity (m/s)		Data Points
	Range	Median	Range	Median	Range	Median	
Alluvium (Quaternary / Tertiary)	0.16-9.2	1.5	0.05-3	0.38	5.7 x 10-7-3.5 x 10-5	3.3 x 10-6	6
Regolith / Surficial	1.2	1.2	0.01-0.18	0.1	1.0x10-7-2.1 x 10-6	1.1 x 10-6	5
Upper / Middle Permian	0.2-22	1.7	0.04-7.2	0.32	4.7 x 10-7-8.3x10-5	3.7 x 10-6	22
Lower Permian	0.2-9.6	2	0.0003-14	0.3	3.0 x 10-9-3.5 x 10-4	3.0 x 10-6	12
Shoalhaven Group	-	-	0.19-6.8	3.5	2.2 x 10-6-8 x 10-5	4.1 x 10-5	2
Ulan Seam	3-17	3.7	0.004-11	0.29	4.9 x 10-8-1.2 x 10-4	3.3 x 10-6	12
Marrangaroo Formation	3.3	3.3	0.06-1.1	0.22	7.4 x 10-7-1.3 x 10-5	2.6 x 10-6	3
Ulan Granite	0.8	0.8	0.3	0.3	3.1 x 10-6	3.1 x 10-6	1

Table 2.3: Hydraulic Testing Schedule and Analysis Results – Test Production Bore

Test Bore	Screened Interval (mbgl)	Aquifer	Date of Test	Type of Test	Pumping Rate (kL/d)	Duration (mins)	Transmissivity	Average Hydraulic Conductivity (m/d)	Average Hydraulic Conductivity (m/s)	Comments
TB52A	47 – 53 108 – 114	Lower Permian Ulan Seam	27 February 2006	Constant Rate	345	480	40	3.3	3.9×10^{-5}	Single boundary effect
				Recovery			40	3.3	3.9×10^{-5}	
			3 March 2006	Constant Rate	345	2880	35	2.9	3.4×10^{-5}	Multiple boundary effects
				Recovery			37	3.1	3.6×10^{-5}	
TB52B	31 – 37	Tertiary palaeochannel	22 February 2006	Constant Rate	175	420	6	1.0	1.2×10^{-5}	
				Recovery			6	1.0	1.2×10^{-5}	
TB103R	76 – 79 82 – 85 94 – 97	Lower Permian	24 February 2006	Constant Rate	300	2880	38	4.2	4.9×10^{-5}	Multiple boundary effects
TB105	78 – 84 126 – 132	Lower Permian Ulan Seam	3 March 2006	Constant Rate	345	4320	45	3.8	$5.8. \times 10^{-5}$	Multiple boundary effects and leakage
TB179	Open Hole from 42m	Permian	30 July 2008	Constant Rate	9.9	40	*52*	-	-	Indicative T value only

2.3.2 Test Bores

Three of the Stage 1 test bores were subjected to Constant Rate tests of between 48 and 72 hours, at pumping rates of between 300kL/d and 350kL/d. Bore TB52B was pumped at a rate of 175kL/d for 7 hours.

Hydraulic testing confirmed that sustainable yields of individual production bores would be in the order of 300 to 400kL/d.

In addition to the testing completed by PDA, HLA had previously undertaken independent testing of several privately owned bores (Imrie Bore, Elward Bore and Kearins Bore) intersecting the Triassic sediments in the north of the Project Boundary in work undertaken for Ulan Coal Mines Limited (UCML). The results of these tests were presented in Appendix A of the 2002 UCML Annual Environmental Management Report (UCML, 2003). PDA subsequently re-interpreted the test data reported in that document, the results of which were reported in PDA (2007a).

2.3.3 Laboratory Permeability Testing

Laboratory permeability testing on Triassic core samples was also carried out as part of Stage 1 investigations. The results of this testing were reported in PDA (2007a).

2.4 Census of Existing Groundwater Occurrence and Use

As part of the groundwater investigations, information on registered groundwater users within and close to the proposed Project Boundary were collated through a search of the NOW groundwater bore database. This was supplemented by a field census to inspect registered sites, and identify and record the presence of unregistered groundwater supply sources such as bores, wells, soaks, dams, and any naturally discharging springs.

The NOW groundwater bore database revealed the presence of 130 registered bores and wells within 10km of the Project Boundary. These sites are shown in Figure 2.6. Summary construction details and other information for each registered bore are presented in Appendix C.

The field census involved approaching nearby landholders to determine their current or past use of groundwater, and to collate local first-hand knowledge of other natural expressions of groundwater, such as springs or soaks on their properties.

Each site was visited, sampled and photographed, and construction and other details provided by the landholder were recorded. The location and elevation of each site was determined by GPS. Wherever possible field measurements of groundwater quality (comprising electrical conductivity EC and pH) were also taken and a water sample collected for laboratory analysis.

The locations of most features identified during the census are shown on Figure 2.7. Figure 2.8 shows the elevation of the water level, and the measured EC and pH at the time of census for selected sites in the Stage 2 mine areas.

The complete records for each census site, including survey details, photographs and results of water quality analysis, are presented in Appendix D.

2.5 Groundwater Monitoring Program

A groundwater level and quality monitoring program encompassing all the installed piezometers and bores, as well as selected registered and unregistered groundwater sites, was established. Monitoring commenced in February 2005, and has been maintained to the present time. Data collected represent a baseline monitoring period of 6 years, with data up to 2011 considered in this report.

Groundwater levels are measured monthly in all piezometers and test bores to assess the seasonal fluctuations in groundwater levels, and responses to recharge and natural discharge processes, as well as to detect any impacts from mining which commenced at the MCC in November 2009.

Water samples are collected quarterly from selected piezometers and test bores with all samples subsequently submitted to a NATA-registered laboratory for comprehensive analysis of major cations and anions, nutrients, and heavy metals. Electrical conductivity and pH are measured in the field at the time of sampling.

2.5.1 Surface Water Quality

A network of surface water quality monitoring sites was established during Stage 1. MCM monitors surface water quality and flows at ten monitoring sites on a monthly basis at the following locations: Bora Creek, Murragamba Creek, Lagoons Creek, Moolarben Creek, and the Goulburn River.

Surface water quality is discussed further in Sections 4.9 and 4.11 and throughout Section 6 and 7 where relevant. Surface water monitoring site locations are shown on Figure 3.1.

2.6 Groundwater Modelling

Using the data collected from Stage 1 investigations, a numerical model of the groundwater system was set-up in order to assess the potential impacts of Stage 1 of the MCC on the groundwater environment. An integral part of the modelling work was to identify and assess current groundwater conditions, including any existing impacts to groundwater levels as a result of dewatering operations at the adjacent Ulan Coal Mine.

Modelling was undertaken using a three-dimensional finite difference model based on the MODFLOW numerical groundwater flow modelling package (McDonald and Harbaugh, 1988) with the SURFACT Version 3 module (HydroGeoLogic, 2006), operating under the Processing MODFLOW Pro and the Groundwater Vistas Version 5 graphic interface software packages (IES, 2006; ESI, 2005). The model was set up to simulate groundwater conditions over a 1600km^2 area, to encompass the MCC and the nearby Ulan and Wilpinjong coal mines' zone of potential impact.

During the assessment process, a number of modifications were made to the groundwater model, culminating in the production of model versions MC1.6 and MC1.9, which subsequently formed the basis for the Stage 1 project approval. The results of modelling were reported in a series of reports between September 2006 and July 2007 (PDA, 2006a and b; PDA, 2007a, b and c).

Throughout the model development, review has been provided by Dr Noel Merrick, former Director of the National Centre for Groundwater Management and now an independent consultant.

The same groundwater model, subject to some modifications and recalibration, as detailed in Section 6, has been used to model the potential impacts from the Stage 2 proposal.

2.7 Groundwater Levels

Groundwater levels have been monitored monthly in all piezometers since the first investigation bores were installed in February 2005. Water level hydrographs have been produced for each site and are included for reference in Appendix E. Composite hydrographs are presented as Figures 2.9a and 2.9b. Trends established on these hydrographs are discussed in further detail below.

Groundwater levels are also shown on the geological cross-sections (Figures 2.2, 2.3, 2.4 and 2.5). Marked differences in water levels between the Ulan Seam, overlying Permian coal measures and shallower hydrogeological units are clearly illustrated in each section.

2.7.1 Groundwater Level Trends

Water levels in individual bores range between approximately 335mAHD and 510mAHD.

Bores PZ4 and PZ18, both screened through the Ulan Seam near the outcrop area to the south and west of EL6288 respectively, show sharp rises in water level of several metres in response to rainfall.

Other bores, including PZ39, PZ40B, PZ43A, PZ44, TB52A, PZ72A, PZ105B and C, PZ125 and PZ135 all show an active recharge and discharge pattern, with clear rises in water level following significant rainfall followed by recession until the next rainfall recharge event. Cumulative rainfall residual mass has been included on Figures 2.9a and 2.9b. This list includes bores in the near-surface weathered zone, alluvium and deeper unweathered Permian strata. Several shallow bores within the Murragamba valley (PZ172 to PZ177) were showing a declining trend until the end of 2009, suggesting recession following recharge from some time prior to the commencement of monitoring. The downward trend stopped in the early part of 2010, and by mid-2010, these hydrographs had started on a rising trend suggesting a response to recharge. This pattern is consistent with the rainfall pattern, as represented by the Rainfall Residual Mass curve superimposed on Figure 2.9a and Figure 2.9b. The Rainfall Residual Mass curve indicates whether the rainfall is generally above or below average, with a rising trend indicating extended period of above average rainfall (when recharge is likely to be higher) while a downward trend indicates a period of below average rainfall accumulation (when recharge is likely to be lower). The groundwater levels in this group of bores are generally trending downwards in conformance with the trend on the Rainfall Residual Mass curve, but with a lag time of a few months.

A number of bores completed in the Ulan Seam and lower Permian piezometers show a clear rising trend suggesting a recovery in water levels in response to an apparent reduction in the net dewatering rate at Ulan Coal Mine. Bores showing this pattern include PZ101B, PZ102B, PZ110, PZ103A, PZ104, TB105, PZ156 and PZ157 (all completed within the Ulan Seam), TB103, PZ105A and PZ127-VW112m (all completed in the lower Permian), and PZ102A (completed in the Marrangaroo Formation). Possible explanations for the observed trends may include:

- A gradual northwards shift in the centre of pumping, as the Ulan Coal Mine underground mine has advanced;
- Reduction in the rate of pumping from bores close to the Ulan Coal Mine open cut; or
- Disposal of surplus water into overburden dumps located inside the former open cut voids, leading to localised recharge of the Ulan seam and lower Permian strata.

Bores OB4, PZ3, PZ30, PZ43B, PZ50A and B, PZ52, TB52B, PZ55, PZ58, PZ72C, PZ74, PZ101C, PZ106B, PZ107, PZ108, PZ112A and B, PZ131 and PZ132 show very little change in level with time, suggesting they are not undergoing active recharge and discharge in response to rainfall. This list includes bores in various units, including several within the Tertiary palaeochannel deposits and in shallow alluvium / colluvium material in the Murragamba valley area.

Bore PZ111 (screened in the Ulan Seam) was showing a steady recovery as described above for the group of bores believed to be responding to a change in net dewatering conditions at Ulan Coal Mine. However, from July 2007 to May 2008, water levels in this bore declined, possibly in response to dewatering / bore pumping at Wilpinjong. Water levels have since recovered. PZ111 is located close to the western edge of the Wilpinjong mine area.

Bores PZ50A and PZ109 both show a pattern of declining water levels suggesting gradual drainage from the bore into extremely low permeability rock.

2.7.2 Vertical Head Differences

A number of monitoring sites comprise piezometers separately screened across two or more different hydrogeological units. These monitoring sites measure the vertical distribution of heads at specific locations. Hydrographs for multi-level piezometers at the same location are plotted as composite plots in Appendix E. Generally, there is a pattern of lower heads in the deeper piezometers (i.e. declining heads with depth); although at some sites the pattern is reversed, with higher heads recorded in the deeper piezometers.

The observed distributions of vertical heads (declining and/or increasing with depth) are a reflection of the topographic elevation in the locations where each unit is recharged (i.e. where it outcrops or subcrops) and historical dewatering of the coal seams in nearby mines.

The Ulan Coal Seam and the lowermost parts of the coal measures overburden outcrop along the Moolarben Creek valley to the west and south-west of the MCC. This is close to the margin of the Sydney Basin. This outcrop area constitutes the primary recharge zone for the Ulan Seam and other permeable parts of the coal measures. From there, the groundwater flows downdip to the north-east within the coal measures. It is clear that the groundwater levels in the Permian coal measures in the vicinity of the Project Boundary are influenced mostly by the elevations of the coal measures at outcrop within the Moolarben Creek valley (the primary recharge zone), and the elevations of the same strata where they outcrop downdip to the north-east (the primary discharge zone).

There are many sites where very large head differences are observed, the most striking being the PZ41A-B site, where the head in the Ulan Seam (425mAHD – PZ41B) is 60m higher than in the underlying Marrangaroo Formation (366mAHD – PZ41A), even though the screened intervals are only 5-10m apart vertically.

In some instances, the head difference with depth is due to dewatering effects from the Ulan Coal Mine, with depressed groundwater levels in the Ulan Seam and the immediately overlying and underlying strata. Much of the overlying coal measures are totally de-saturated and in some locations the Ulan Seam is completely dry.

Groundwater levels in Ulan Seam piezometers within the Project Boundary are up to 90m lower than in the surficial aquifer (e.g. PZ112A and B), but the surficial aquifer shows no sign of downward leakage. Other piezometer pairs showing a large head difference between the Ulan Seam and shallow groundwater are PZ50A/B/C, PZ150/PZ152 and PZ133.

In the southern half of EL6288, including the Murragamba valley area, the Ulan Seam is substantially unsaturated, with water levels up to 60m lower in the Ulan Seam than in the overlying Permian and surficial aquifers. This area is too distant to have been affected by Ulan Coal Mine dewatering, and the first measurements of the low groundwater levels pre-date the commencement of mine dewatering at Wilpinjong Coal Mine, hence they are not due to Wilpinjong Coal Mine either. Hence, the low groundwater heads observed in the Ulan Seam in that area are not due to mining activity, but are a natural feature.

2.7.3 Groundwater Contours

Contour plans of groundwater levels within each of the main hydrogeological units across the MCC are presented in Figures 2.10 to 2.14. The contours have been updated to include the Ulan Coal Mine and Wilpinjong Coal Mine monitoring data, incorporating data available from Annual Environmental Management Reports (UCML, 2008; and Peabody, 2008).

Groundwater levels from the Ulan Seam have been used to construct the contours shown in Figure 2.10. Water levels in the Ulan Seam decrease substantially in the area of the proposed UG4, being impacted by dewatering of the seam and overlying strata for mining activities at the adjacent Ulan Coal Mine. Groundwater levels in the vicinity of Ulan Coal Mine have been drawn down to below 240mAHD. Prior to the influence of mining, water levels within the Ulan Seam in the UG4 area may have been similar to those in overlying and underlying units, based on the earliest water level data available from the Ulan Coal Mine area (Figure 2.15).

The contours in Figure 2.10 also show the area of lower groundwater levels across the Murragamba Valley where the Ulan Seam is substantially unsaturated (as discussed above) and as seen on the cross-sections on Figures 2.2 to 2.4. This area is too distant from Ulan Coal Mine for the water levels in this area to be influenced by Ulan Coal Mine's dewatering, and they pre-date the commencement of operations at Wilpinjong Coal Mine. The lower levels in the Murragamba Valley area are therefore believed to be a reflection of limited recharge in the Ulan Seam outcrop / subcrop area.

Measured groundwater levels in the lower Permian typically range from around 440mAHD in the south of the MCC area, to 360mAHD to the north. Dewatering at UCML has caused drawdown to lower elevations in both the lower and upper/middle Permian formations, as shown by the pattern of groundwater contours in Figures 2.11 and 2.12. Groundwater levels in the lower Permian, and upper / middle Permian, have been drawn down to below 300mAHD and 360mAHD respectively.

In proximity to the Ulan Coal Mine, groundwater levels in the Permian (Figures 2.10 and 2.11) are generally quite different from those in the overlying Triassic (Figure 2.12). Drawdowns have started to be observed in the Triassic since Ulan Coal Mine started mining 400m wide longwall panels, but to date the maximum recorded drawdown outside of the panel areas is around 15m (UCML, 2010).

Groundwater was recorded in Triassic formations only in the northern most part of EL6288. Groundwater levels in that area typically range from 380mAHD to 400mAHD. In some places, such as at the northern end of UG4, the upper Permian and lower Triassic have similar levels, whereas the lower Permian water levels are closer to those in the underlying Ulan Seam.

Groundwater levels of the Tertiary/Quaternary alluvium and regolith units, collectively termed the surficial aquifer system, are much more locally controlled than those of the underlying Permian and Triassic units (Figure 2.14). The contours have been constructed from data available from shallow piezometers in Murragamba Valley, as well as data from spring, bore and soak sites identified during the groundwater census. Groundwater levels typically range between 420mAHD and 520mAHD. The contour pattern shows a general conformance with surface topography, and is disconnected from the groundwater contour pattern in the deeper Permian coal measures. The apparent disconnection is likely to be due to the low inherent vertical hydraulic conductivities of intervening strata.

Groundwater level data from the underlying basement units (granites and volcanics in the west and Shoalhaven Group in the eastern areas) is sparse, but where available indicates limited vertical interconnection with the overlying Permian coal measures.

2.8 Groundwater Quality

Field measurements of pH and EC collected during drilling and bore installation are recorded on the borelogs in Appendix A. Following completion, each bore was purged in accordance with AS5667 (Standards Australia, 1998) prior to the collection of an initial water sample for laboratory analysis of major cations and anions, nutrients and heavy metals. Summary laboratory analysis results from the ongoing monitoring program are provided for information in Appendix F.

A summary of the groundwater chemistry based on sampling from bores in each of the main hydrogeological units is shown in Table 2.4.

To show the distribution of field water quality, salinity (as TDS mg/L) and pH data from July 2008 have been plotted on Figure 2.16.

Table 2.4: Summary of Groundwater Chemistry - Groundwater Monitoring Piezometers

Aquifer Screened	Water Quality				
	TDS (mg/L)		pH		Data Points
	Range	Median	Range	Median	
Alluvium (Quaternary / Tertiary)	110-8400	460	4.4-8.8	5.9	7
Regolith / Surficial	210-11000	5400	5.4-7.2	6.6	7
Lower Triassic	200-370	285	6.6-7.5	7.1	2
Upper / Middle Permian	160-5300	2100	3.5-7.9	6.1	22
Lower Permian	160-3000	525	4.7-9.3	6.6	12
Ulan Seam	220-4300	990	5.6-12.6	6.3	18
Marrangaroo Formation	460-3200	1600	5.4-6.3	5.7	4
Shoalhaven Group	1200-3000	2100	3.7-6.0	4.9	2
Ulan Granite	2400	2400	6.0	6.0	1

3. DESCRIPTION OF THE EXISTING HYDROGEOLOGICAL ENVIRONMENT

3.1 Regional Setting

EL6288 covers approximately 11,000ha (110km^2) and is characterised by substantial topographic relief. The land elevation ranges from approximately 370mAHD in the Goulburn River valley, to 600mAHD on the surrounding ranges. The Great Dividing Range lies just to the west of the MCC area.

The dominant landforms and topographic features of EL6288 comprise forested upland ridges, dissected plateaus, and lowlands consisting of cleared valleys associated with Moolarben, Lagoon, Murragamba, Bora and Wilpinjong Creeks, and their minor tributaries.

On a regional scale, drainage occurs to the east via either Goulburn River or Wilpinjong Creek. Wilpinjong Creek drains the central part of the lease, from its headwaters in the Murragamba Valley and the area east of UG4 (Figure 3.1). Wilpinjong Creek flows east into the Wilpinjong Coal Mine lease area, and then southeast joining Wollar Creek before its confluence with the Goulburn River well to the east of the MCC area. The western margins of EL6288 are drained by the headwaters tributaries of the Goulburn River (Moolarben Creek and Lagoon Creek). The Goulburn River then flows in a northerly direction around the western side of the MCC, and then eastwards through an incised valley to the north of UG4. It eventually joins the Hunter River near Denman well to the east.

The Murragamba Creek catchment lies almost entirely within the MCC area originating in the south and flowing northwards through the area proposed for OC4 before joining Wilpinjong Creek. To the east a smaller tributary ‘Eastern Creek’ follows a similar course through the OC4 area and joins Wilpinjong Creek just downstream of the Murragamba Creek confluence.

The east-west valley immediately south of UG4 contains the surface divide between Goulburn River and Wilpinjong Creek. It contains the minor tributary Bora Creek (flowing westerly through the mine infrastructure area to join the Goulburn River within the drainage diversion channel around Ulan Coal Mine), and the upper part of the east-flowing Wilpinjong Creek.

The major commercial activities of the area are farming and coal mining (underground and open-cut). The valley floors in the region support agricultural activity, including sheep and cattle grazing, Lucerne cultivation and apiaries. Adjoining national parks include the Goulburn River National Park to the northeast and the Munghorn Gap Nature Reserve to the southeast.

3.2 Climate

3.2.1 Rainfall

Based on data collected by the Bureau of Meteorology (BoM) climate monitoring station at Ulan Post Office (Station No. 062036) between 1906 and 2007, and Ulan (Mittaville) (Station No. 062045) between 1960 and 1982, the average annual rainfall of the area is approximately 640millimetres (Table 3.1).

The distribution of the rainfall throughout the year is relatively uniform, but slightly higher during the summer months (October through to March). Rainfall intensity is locally affected by the orographic influence of the Great Dividing Range just west of the Project Boundary.

Table 3.1: Long-term Average Monthly Rainfall at Ulan Post Office, Ulan (Mittaville) and Mudgee (mm)

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Ulan Post Office (1906-2007)	72.8	62.6	52.9	41.3	44.9	46	48.1	47.4	42.4	55.3	57.8	65.5	**639.7**
Ulan (Mittaville) (1960-1982)	84.8	67.6	67.6	30.8	46.5	39.3	37.4	44.1	44.5	70.4	49.8	61.3	**642.4**
Mudgee Airport (1988 – 2011)	69.7	71.8	46	32.2	35.7	41.3	42	39.8	49.8	57.4	81.8	72	**639.5**

3.2.2 Evaporation / Evapotranspiration

The closest BoM climate monitoring station to the MCC area that collates evaporation data is Mumbil (Station No. 062003) approximately 70km southwest of Ulan village. From data collected between 1960 and 1982, the average annual potential evaporation for the area is approximately 1570mm.

Table 3.2: Long-term Average Monthly Potential Evaporation Rates (mm)

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mumbil (1960-1982)	240	198	166	107	63	41	42	61	90	137	187	232	**1569**

A comparison between long-term monthly average rainfall and monthly average potential evaporation indicates that, on average, the area has an excess evaporative capacity over rainfall in all months (except possibly June and July) and can therefore be classified as having a semi-arid climate. There is, however, variability in monthly rainfall totals and there would be periods when rainfall could exceed evaporation rates, particularly during the cooler winter months. The long-term average monthly rainfall and evaporation data are presented graphically in Figure 3.2.

Evapotranspiration (ET) is a function of evaporation transfer from both vegetated and unvegetated land surfaces. It is affected by climate, availability of water and vegetation. The published evapotranspiration map (BoM) shows that the estimated annual evapotranspiration for the MCC area is in the order of 600 mm per year. ET is discussed further in Section 5.2.2.

3.3 Geology

Detailed information from geological core logs associated with the MCC test bores and piezometers are provided in Appendix A. The geology and hydrogeology has also been described as part of the Stage 1 investigations in reports produced by Peter Dundon and Associates (2006a, 2006b, 2006c, 2007a and 2007b) and in Aquaterra's Stage 2 investigations accompanying the 2008 Stage 2 EA (Aquaterra, 2008). This information was used to compile the following descriptions of geology and hydrogeology described in the following sections.

3.3.1 Regional Geology

EL6288 is located in the Western Coalfield, which occupies the northwest margin of the Sydney-Gunnedah-Bowen Basin in NSW. The Western Coalfield contains the Illawarra Coal Measures of Middle to Late Permian age, overlain by Triassic sandstones and conglomerates of the Narrabeen Group. In turn, the Triassic is overlain by Jurassic sediments north of EL6288. The Permian coal measures lie directly over both the Carboniferous Ulan Granite and Rylstone Volcanics in the southwest or Early Permian Shoalhaven Group in the southeast.

The Permian coal measures comprise a well bedded sequence of claystone, mudstone, siltstone, sandstone and coal, however, the Ulan Seam is the only seam of economic significance. This seam occurs near the base of the Illawarra Coal Measures and is considered to be the northern equivalent of the Lidsdale seam (Bayly, 1999), which is mined further south at Lithgow. The Permian sedimentary sequence lies unconformably on the Early Permian or Carboniferous basement and strikes in a northwest direction, with dips of between 1 and 2 degrees to the northeast. Overlying the whole of the Permian and Triassic sequence, the uppermost geological units comprise colluvium and weathered rock, with some unconsolidated Quaternary alluvium in valley areas, and in some areas partially consolidated Tertiary gravel, sand, clay and silt present as Tertiary palaeochannel fill deposits.

3.3.2 Overview of Geology within EL6288

The Permian coal measures within EL6288 comprise a well-bedded sequence of claystone, mudstone, siltstone, sandstone and coal of Permian age (Johnstone, 2007). These sedimentary units unconformably on-lap the Early Permian or Carboniferous basement and strike in a northwest direction with dips of 1 to 2 degrees to the northeast.

In the northern half of EL6288, the Permian coal measures are generally 100 to 120 m thick, and are overlain by up to 60 m of plateau-forming lower Triassic Wollar Sandstone, part of the Narrabeen Group. The typical lithology of the Wollar Sandstone includes pebbly to medium-grained quartz sandstone, red-brown and green mudstone, and lenses of quartz conglomerate (Wilpinjong Coal, 2005). The contact between the Permian and Triassic is marked by an erosional unconformity.

Drilling data indicate that the weathered profile varies in depth from around 4 to 18m, but is generally restricted to depths of less than 10m.

The Permian coal measures within the Project Boundary have variable permeability and storativity. Permeability is generally higher in the coal seams, but there is occasional moderately high permeability in the interburden sediments (generally sandstone, siltstone and mudstone) due to localised fracturing. The Ulan Seam is termed an aquifer by virtue of its relative higher permeability than the interburden sediments. The interburden sandstones, siltstones and mudstones are of significantly lower permeability than the Ulan Seam (by one or more orders of magnitude) and they generally act as aquitards.

The sandstones of the overlying Triassic Narrabeen Group and the underlying Marrangaroo Sandstone and Shoalhaven Group have been shown by the field investigations to have poor aquifer properties, although the Triassic is an important contributor of baseflow to the streams. The basement units (Nile Sub-Group in the eastern parts and granites and volcanics in the western parts) are also relatively impermeable, and constitute a basal aquitard in the groundwater model. Nevertheless, groundwater occurs in all these units, and may form local aquifers where relatively higher permeability exists.

Along the valley floors, in the south and central south parts of EL6288, the coal measures have been eroded by more recent fluvial events. An east-west trending Tertiary palaeochannel has been identified in some areas occupied by the present-day drainage valleys of Murragamba and Wilpinjong Creeks, but not coincident with the present drainage courses. This palaeochannel has been observed to be up to 48m deep. The infill sediments comprise poorly-sorted quartzose sands and gravels semi-consolidated in a clayey matrix. Investigations further to the south and west suggest that this channel may be part of a larger system that originally emanated from the north or west. Exposures of the channel in the Goulburn River diversion, and just north of the Ulan airstrip reveal cross bedding suggestive of a southerly flow direction (Johnstone, 2005).

In places, these palaeodeposits have themselves been eroded and superimposed by more recent weathering and sedimentation associated with the Wilpinjong and Murragamba Creek channels. The Quaternary alluvium occurs in association and connected with the present day streams and rivers, whereas the Tertiary alluvium occurs in a palaeochannel system that is not coincident with the present drainages, and is generally hydraulically separate from them. Limited hydraulic connectivity is considered to exist between the alluvium and the coal measures.

Small intrusives and remnant basalt flows of Tertiary, and possibly Jurassic age, have been observed in outcrop in the Murragamba and Wilpinjong valleys and as elevated plateaus mainly to the north of EL6288. Basalt flows of up to 30m have been intersected in some bores. No significant basalt remnants or other igneous intrusives are believed to be present in the areas in which mining is proposed in Stage 1 or Stage 2 of the MCC.

The basement underlying the Illawarra Permian coal measures is the Carboniferous Ulan Granite, with marine sediments of the Shoalhaven Group (fine-grained silty sandstones) having been intersected in some drill holes in the southern part of EL6288. The Ulan Granite outcrops extensively directly to the west of the MCC area.

3.4 Hydrogeology

3.4.1 Hydrogeological Units

Six main hydrogeological units have been identified within the Project Boundary, viz:

- Quaternary alluvium;
- Tertiary palaeochannel deposits;

- Triassic Narrabeen Group sediments (sandstone and conglomerate);
- Permian coal measures sediments (claystone, mudstone, siltstone, sandstone, coal and tuff), including the Ulan Coal Seam;
- Basal unit comprising variously the Early Permian Marrangaroo Formation, and Nile Sub-Group, or fine grained marine sediments of the Shoalhaven Group; and
- Basement (Ulan Granite and Rylstone Volcanics).

The regional distribution of these hydrogeological units, based largely on the published geological map (Watkins, et al, 1999) is shown on Figure 3.3. Note that the Shoalhaven Group is not depicted on this figure as outcrops of this unit have been rarely recorded.

Relatively higher permeability occurs in the Ulan Seam, some parts of the Permian coal measures, and within some parts of the Tertiary palaeochannel deposits. Minor zones of relatively higher permeability also occur in parts of the Triassic sequence, although the Triassic is only saturated in the northern part of EL6288, and is only partly saturated over the northern part of the proposed UG4. Minor zones of permeability can also occur in the underlying Marrangaroo Formation. All other units possess low permeability.

A number of springs and seepages are observed within the Project Boundary, where low permeability units within the Triassic or the Permian coal measures outcrop or subcrop. In the northern part of EL6288 the springs and seepage zones within the Triassic Narrabeen Group sediments, observed along Goulburn River and in its tributary streams, are the surface expressions of perched aquifers, representing local accumulations of groundwater above less permeable horizons. The most prominent of these is known as ‘The Drip’, and is located to the north of UG4.

Surficial aquifers are mostly poorly developed, and do not generally constitute a useful source for water supply purposes, although they are believed to contribute, in some areas, to supporting Groundwater-Dependent Ecosystems (refer Section 4.12).

The Tertiary palaeochannel deposits have only limited hydraulic connectivity with the present day Murragamba and Wilpinjong Creek drainage systems.

3.4.2 Groundwater Occurrence within EL6288

Groundwater has been recognised as occurring within each of the following regimes:

- Localised aquifers within the unconsolidated Quaternary alluvium associated with the present drainage system;
- Palaeochannel valley-fill deposits within remnants of a Tertiary-age palaeodrainage;
- Localised fracture aquifers within the Triassic Narrabeen Group sediments;
- Localised fracture aquifers within the Permian coal measures, principally the Ulan Seam;
- Localised groundwater in volcanic intrusive / extrusive structures;
- Limited aquifer potential in the Shoalhaven Group sediments, and
- Aquifers in weathered basement granites and volcanics.

In the south-western part of EL6288, where the Permian coal measures outcrop, the Ulan Seam aquifer is unconfined, and in places dry. Minor spring seepages have been observed from, or below, the floor level of the Ulan Seam in low-lying areas. The Ulan Seam is only partially saturated within most of the Murragamba Valley area, with groundwater levels well below the near-surface groundwater levels in the regolith and upper parts of the Permian overburden.

Throughout EL6288, there are two regionally persistent zones where lost circulation has been encountered in drilling (Johnstone, 2005). These relatively more transmissive zones occur at the boundary between the Permian and Triassic, and just above the C marker band of the Ulan Coal Seam.

3.5 Aquifer Parameters – Estimates of Hydraulic Conductivity

Table 3.3 details, for the principal hydrogeological units, the range and mean values of hydraulic conductivity obtained from analysis of the hydraulic test data collected during Stage 1 and Stage 2 investigations.

The hydraulic testing program was discussed in Section 2.3. The results of all tests are presented in Appendix B.

Table 3.3: Major Hydrogeological Units – Hydraulic Conductivity

Unit	No. of Tests	Hydraulic Conductivity (m/d)	
		Range	Median
Quaternary Alluvium/Colluvium/Residual Soil (Regolith)	10	0.05 -3	0.38
Tertiary Palaeochannel alluvium	5	0.01 - 0.18	0.1
Triassic Narrabeen sediments	6	0.04 - 7.2	0.32
Permian coal measures overburden – middle and upper	30	0.0003 -14	0.3
Permian coal measures overburden – lower	18	0.19 - 6.8	3.5
Permian coal measures – Ulan Seam	18	0.004 - 11	0.29
Shoalhaven Group	2	0.06 - 1.1	0.22
Basement – granite, volcanics (one test – atypical)	1	0.3	0.3

3.6 Current Groundwater Use

3.6.1 Census and NOW Registered Sites

The census of local groundwater use on properties around EL6288, conducted in stages between May 2005 and April 2008, identified a small number of bores, wells, a few springs and soaks, and a large number of dams, believed by the landowners to be partly groundwater-fed. The identified water sources are shown on Figure 2.2, and summary details are provided in Appendix D.

A search of the NOW groundwater bore database identified 130 registered bores and wells within approximately 10km of the MCC area. Summary details of these sites are presented in Appendix C.

3.6.2 Ulan Coal Mine

The Ulan Coal Mine is located immediately to the north-west of the MCC area. Groundwater pumping, predominantly for dewatering purposes, began at the Ulan Coal Mine as early as 1924, but it is believed that regular and substantial pumping did not commence until 1957. Around 15ML/d of groundwater inflow is currently extracted in the dewatering operations of the mine (MER, 2010). Approximately 3ML/d of water excess to mine requirements is disposed of by means of irrigation on the Bobbadeen property to the north of Ulan Coal Mine and north-west of EL6288 (UCML, 2008).

A further 0.43ML/d is extracted from a water supply bore PC1C which, according to UCML (2006), is located close to Millers Dam on the eastern side of the Ulan-Cassilis road, and provides potable water, fire water and a supply for other mining requirements. The NOW database does not show any registered bore east of the Ulan-Cassilis road in this area.

A map attached to bore licence 20BL168008 in Appendix 3 of UCML (2004) shows this licensed bore to be located west of the Ulan-Cassilis Road, between the road and Goulburn River. According to the NOW database records, this bore is registered number GW059034, and was drilled in January 1981 to a depth of 89m and is cased to 72m, with stainless steel screens at 41-47m and 60-66m depth. Based on the driller's log, the bore appears to have been completed within the Permian coal measures, possibly including the Ulan Seam.

3.6.3 Wilpinjong Coal Mine

Wilpinjong Coal Mine is located directly to the east of the MCC. Construction of the Wilpinjong mine commenced in February 2006, with approximately 4.9MT of ROM coal being produced by the end of 2007 (Peabody, 2008). During the period January to December 2007, a total of 98ML of groundwater was extracted from five water supply / dewatering bores located adjacent to Wilpinjong Creek to the north of the Wilpinjong mining area just outside the northern boundary of Wilpinjong's ML1573.

3.7 Groundwater Levels and Flow Patterns

Groundwater levels have been routinely monitored across the MCC area since mid-2005, and an extensive baseline dataset now exists. The composite hydrographs presented in Figures 2.9a and 2.9b, and individual hydrographs in Appendix E, show the changes in groundwater levels with time. Groundwater level contours have also been constructed (Figures 2.10 to 2.14) to show spatial regional groundwater level patterns, and an indication of groundwater flow direction.

The contours generated infer that, apart from the area being impacted by Ulan Coal Mines dewatering, groundwater is flowing through the deeper (Permian) hydrogeological units in a north-easterly direction, in the direction of dip. This flow pattern would be influenced by the recharge process which occurs predominantly in areas where each unit outcrops. The Permian units outcrop near the basin margin, in the Moolarben Creek valley area to the west of the MCC's OC1 to OC3. The top of the Great Dividing Range occurs just west of this area, and forms the western surface catchment divide for the study area.

Groundwater flow in the surficial water-table aquifers (alluvium, colluvium, weathered bedrock) generally follows the local topography, mirroring the local surface drainage pattern, with higher groundwater levels in areas of elevated terrain and lower levels in the valleys.

Within the main hydrogeological units, groundwater levels vary from at, or near, surface in zones of recharge, to more than 200m below surface within the Ulan Seam where impacted by Ulan Coal Mine dewatering. Dewatering at Ulan Coal Mine has produced an area of drawdown which has impacted groundwater levels throughout the Permian, and locally within the overlying Triassic formations. Although significant impacts to Triassic groundwater levels have only occurred since Ulan Coal Mine increased the width of their longwall panel from around 200m to 400m (early 2007). These more significant impacts are still quite localised in the immediate vicinity of the wider panels.

The impacts on the Permian units extend into the MCC area, and it is interpreted that drawdowns of 40-60m have already occurred in the Ulan Seam, and parts of the lower Permian, along the western side of UG4 (Figures 2.6 and 2.11). As a consequence, the groundwater flow direction in the northern part of EL6288 has been altered and is now mainly toward the west and northwest.

Groundwater levels within the study area for each main hydrogeological unit are discussed in more detail below.

3.7.1 Quaternary Alluvium/Colluvium/Weathered Bedrock (Regolith Layer)

Groundwater levels in the surficial (near-surface) groundwater system range between 520mAHD in the south and 420mAHD in the north, but are closely related to surface topography rather than being a regional flow system, as shown by the groundwater contours in Figure 2.14. Groundwater within this layer is derived from local infiltration of rainfall into the near-surface alluvium, colluvium and/or highly weathered bedrock zone, with down-gradient flow towards topographic lows, generally the valley floor. Groundwater flow patterns within the shallow groundwater system are believed to be unrelated to flow systems in the deeper Permian sediments.

Groundwater flow generally follows the surface drainage systems, with similar flow directions and flow patterns to surface runoff. Groundwater discharges locally via upslope springs or seepage zones or as base-flow to the stream systems. As the groundwater table is typically shallow, losses also occur via evapotranspiration with negligible percolation to the underlying unweathered hard rock units of the Triassic and Permian.

3.7.2 Tertiary Palaeochannel Deposits

Tertiary palaeochannel deposits have been recorded at a number of sites. The interpreted extent of the palaeochannel deposits is shown in Figure 3.3. The deposits are believed to form part of a remnant palaeodrainage system. Drilling investigations completed as part of Stage 1 and Stage 2, supplemented by the results of exploration drilling, have confirmed the presence of palaeochannel deposits within the area between UG1 and UG4 and extending eastwards towards Wilpinjong. Tributaries are believed to extend into the Murragamba and Eastern Valleys (Figure 3.1). A smaller area of Tertiary palaeochannel deposits was reported in Stage 1 within the Moolarben Creek catchment.

In the main east-west palaeochannel, groundwater flow direction is believed to be toward the east, occurring at depth below the present day drainage. In the tributary channels, groundwater flow is likely to be to the north-northeast towards the main channel.

Groundwater levels within the palaeochannel deposits are shallow, typically ranging from 2m to 13m depth below surface. However, immediately south of UG4, the palaeochannel is dry. Several other bores drilled to investigate the presence of palaeochannel deposits in the Murragamba and Eastern Valleys were also dry. Where present, groundwater levels in the palaeochannel within the area of OC4 appear to be similar to the base level of Murragamba Creek and Wilpinjong Creek. However, bores PZ182 and PZ185 were dry, and the deposits were only partially saturated in the remaining bores. The palaeochannel is not coincident with the present creek system, and there is believed to be only limited hydraulic connection with, and therefore limited baseflow contribution to, the present creek system.

3.7.3 Triassic Sandstone

Triassic strata are present across a significant portion of the MCC area, however much of the area, including the Preferred Project mining areas of OC4, UG1 and UG2, is unsaturated. In the area above UG4 the lower Triassic strata are only partially saturated. The upper Triassic is totally unsaturated over the entire MCC area.

The Triassic is partially or fully saturated over the northern parts of the Ulan Coal Mine.

Within the MCC area groundwater derived from the Triassic is believed to be the main baseflow contributor to the Goulburn River. This contribution must originate predominantly from the northern side of the river, as the Triassic is largely unsaturated to the south.

Groundwater discharging from the upper Triassic at ‘The Drip’, a local sandstone outcrop, and similar seeps along Goulburn River, is derived from perched aquifer zones recharged from local infiltration of rainfall. Hence groundwater in the upper Triassic in this area does not have a significant influence on a regional scale, and only contributes to more localised drainages.

Groundwater contours for the Triassic (Figure 2.13) show groundwater levels within the upper and lower Triassic to typically range between 380mAHD and 400mAHD where present within the MCC, with the groundwater flow direction generally towards the Goulburn River.

3.7.4 Permian Coal Measures Including Ulan Seam

Permian coal measures are present ubiquitously across the MCC area. Regional groundwater flow in these units is generally to the north-northeast, but has been strongly influenced locally by the impact of dewatering at Ulan Coal Mine. The contours of groundwater levels for the Ulan Seam, lower Permian and upper / middle Permian coal measures are shown on Figures 2.10, 2.11 and 2.12 respectively.

Across the MCC area, groundwater levels in the upper and middle Permian typically range between 420mAHD and 500mAHD, except to the north where levels have been drawn down to around 360mAHD, as a result of Ulan Coal Mine dewatering, although the drawdown is less than in the lower Permian strata.

The earliest available water levels (from Ulan Coal Mine piezometers) date from January 1982. Bores PB2 and PB3 are located just west of the Ulan-Cassilis road, adjacent to the northern half of UG4, and PB5 and PP9 are about 1 km west of UG4, between Ulan Coal Mine’s open cut and underground mines (Figure 2.15). These bores provide a good early record of the impacts of mine dewatering on groundwater levels. PB2 and PB3 are screened in the Permian coal measures above the Ulan Seam, while PB5 and PP9 are completed in both the Ulan Seam and the coal measures above.

These bores reported water levels between 390mAHD and 400mAHD in January 1982 (Figure 2.11). By 2004, the water levels in PB5 and PP9, screened in the Ulan Seam, had fallen to around 350mAHD, a decline of around 45m. Water levels in PB2 and PB3, screened only in the overlying Permian coal measures, also fell considerably between the start of records (1982) and 2004 to around 360-365mAHD, a decline of around 30m. Since 2005, water levels in all of these bores have shown partial recovery trend with levels now typically between 3m and 7m higher than in

2004. This partial recovery in groundwater levels is believed to be due to the main area of Ulan Coal Mine dewatering shifting further to the north, or possibly a recharge effect from mine water disposal into overburden dumps in former Ulan Coal Mine open cut areas.

Water level data from several other Ulan Coal Mine piezometers also show significant drawdown. The hydrograph for PZ04, located just east of Ulan Coal Mine's underground operations, shows that between mid-2001 and mid-2007, water levels were drawn down 60m, from around 330mAHD to approximately 270mAHD. Relating these data to the baseline water levels recorded for the Ulan Seam in PB5 and PP9 suggests local drawdown in water levels of as much as 120m.

Groundwater level data from Wilpinjong Coal Mine's monitoring network provide further information on groundwater levels within the Ulan Seam and lower Permian strata. Records began in January 2007 and to date show no discernable overall change in water levels within the Permian coal measures.

3.8 Recharge and Discharge

3.8.1 Recharge

Recharge occurs by direct infiltration of rainfall and local runoff into the unconsolidated surficial material, comprising alluvium/colluvium in low-lying areas, and into the weathered zone of the bedrock (regolith layer) in more elevated areas. Water percolates downwards until reaching a zone of reduced permeability (top of bedrock beneath the alluvium / colluvium, or the base of weathering in other areas), and then flows laterally above the less permeable aquitard layer. Recharge rates are a function of rainfall intensity, evaporation, vegetation coverage and density, topography and soil properties of the surficial aquifer material.

A water-table aquifer may form as either a localised perched aquifer, or more extensive unconfined aquifer, within surficial unconsolidated material.

The Permian and Triassic aquifers of the MCC area are primarily recharged at outcrop. Where the Triassic and/or Permian is overlain by alluvium, colluvium or highly weathered bedrock, recharge may also occur to the permeable parts of the hard rocks that subcrop beneath the unconsolidated surficial material, supplementing the primary recharge derived from direct infiltration of rainfall into the rock in areas of outcrop up-gradient. Water that may flow into a permeable zone beneath the alluvium would then flow predominantly down-gradient along that permeable horizon, but there may also be a very small component of continuing downward percolation through the coal measures to deeper aquifers.

Substantial recharge could occur into the weathered zone of the Permian or Triassic, but due to the low permeability of most of the unweathered rock below the weathered zone, perched aquifers commonly form above fresh bedrock. The layering of mudstones and siltstones within the Permian coal measures restricts the vertical movement of water within the coal measures, and this formation is considered to have a low overall rate of recharge, since recharge is limited to those areas where the Ulan Seam and other relatively more permeable layers outcrop or subcrop.

Groundwater levels within the Permian and Triassic generally show there to be an apparent downward hydraulic gradient, but this is more a consequence of the fact that stratigraphically higher layers outcrop (and are thus recharged) at higher topographic elevations, rather than necessarily suggesting a downward flow path through the Triassic and into the Permian strata. It is in these outcrop areas where recharge predominantly takes place. The apparent downward gradient is well illustrated in the hydrographs of the PZ133 piezometer (a multilevel vibrating wire piezometer bore) with discrete monitoring intervals in the Ulan Seam and in various levels within the overlying Permian strata (Figure 3.4).

3.8.2 Discharge

Natural groundwater discharge occurs through evapotranspiration, seepage and spring flow where the water-table intersects the ground surface and through baseflow contributions to creeks and rivers, including discharge to the alluvium in some locations. Local discharges may take place wherever an aquifer unit within the Permian sediments crops out, such as on hillsides or the flanks of creeks and gullies, if the water level in that unit is higher than the ground surface.

Baseflow contributions to river and stream features are also a primary natural groundwater discharge process with relative contribution rates proportionately increasing during the recession period of surface runoff after a rainfall event. The creeks in the MCC area are considered to be generally "gaining", in the sense that groundwater drains from the aquifer into the creeks. Ephemeral creeks (e.g. Murragamba Creek, Moolarben Creek and Wilpinjong Creek) occur where baseflow is either absent, or where the storage characteristics of minor local aquifers are insufficient to maintain permanent creek flow during drier periods.

3.9 Groundwater Quality

Groundwater quality across the Stage 2 MCC area is variable, both in terms of key field parameters such as salinity and pH, and also in terms of major and minor hydrochemical constituents. Where relevant, comparison of results has been made to the ANZECC (2000) guideline values for freshwater ecosystem protection.

Figures 3.5 and Figures 3.6 show the distribution of pH and salinity (as TDS (mg/L)) respectively. A summary of the laboratory analysis results for each site are provided in Appendix F.

3.9.1 Salinity

The salinity of groundwater across the Stage 2 MCC area varies considerably, with recorded values of Total Dissolved Solids (TDS) ranging from less than 200mg/L to more than 11,000mg/L.

In general, salinities are higher in the surficial groundwater than in the underlying Permian. Several of the highest salinity values correspond to shallow groundwater-fed dams and creeks for example SP88 and SP103, but also to some bores drilled through Permian strata (such as PZ50b, PZ131, PZ155 and PZ173) and into the Ulan Coal Seam (PZ150). The most elevated salinities in the surficial groundwater system are recorded near the downstream end of Murragamba Creek and are believed to be due to the shallow depth to the water-table, and the concentration effects associated with evapotranspiration; average salinity values in the shallow bores across the northernmost cross-section (Transect Line 3) are as follows:

- PZ172 (screened 6-9m) – TDS 7300mg/L;
- PZ174 (screened 9-12m) – TDS 9200mg/L; and
- PZ177 (screened 4-7m) – TDS 5000mg/L.

Sites in the southwest of the Murragamba Valley area (Figure 3.8) generally have a wider range of salinity combined with a tendency for lower chloride ion content probably reflecting their usually shorter groundwater residence time and the mineral composition of local lithologies.

Groundwater from some of the less permeable zones within the Permian coal measures is often more saline than groundwater from within coal seams (Ulan Seam and shallower seams) and is believed to be related to lack of proximity to recharge and lower permeability.

Generally, the Ulan Seam has low to moderate salinity. However, significant local variations have been noted, most clearly in PZ150 and PZ151. Both are screened in the Ulan Seam at depths of 70-80m below surface, and they are only 500m apart, but they report average TDS readings of 3200mg/L and 390mg/L respectively. The shallow piezometer adjacent to PZ150 (PZ152 – screened at 8-14m) also reports high salinity, with a TDS of 4200mg/L, similar to that in the Ulan Seam at the same site.

Groundwater in the Tertiary palaeochannel deposits within Murragamba Valley is moderately saline to saline, with TDS values ranging from 2300 to 6700mg/L, viz:

- PZ158 (screened 12-15m) – TDS 3700mg/L;
- PZ166 (screened 6-9m) – TDS 3500mg/L;
- PZ167 (screened 10-16m) – TDS 6700mg/L;
- PZ177 (screened 4-7m) – TDS 5000mg/L;
- PZ180 (screened 11-14m) – Dry;
- PZ182 (screened 11-14m) – Dry;

- PZ184 (screened 6-9m) – TDS 2300mg/L; and
- PZ185 (screened 11-14m) – Dry.

Monitoring data from Wilpinjong Coal Mine show similar high salinities in the alluvium, with reported TDS values of ~400 to 9000mg/L (ECs of 600µS/cm to 13,000µS/cm) TDS), and 630mg/L to 3400mg/L (EC from 900µS/cm to 4800µS/cm) from bores installed into the coal measures (Peabody, 2008).

3.9.2 pH

Recorded pH values indicate the majority of groundwaters to be mildly acidic with pH values typically around 5 to 6. Across the MCC area the general pH range is 5.0 to 8.5.

3.9.3 Dissolved Metals

Laboratory analysis of groundwater samples indicate moderately elevated dissolved metals concentrations in groundwater across the MCC area. Analysis includes determination of dissolved concentrations of Aluminium, Arsenic, Boron, Cadmium, Cobalt, Copper, Iron, Lead, Manganese, Mercury, Nickel, Selenium, Silver and Zinc.

Dissolved metal concentrations in bores from the Stage 2 MCC area which exceed ANZECC (2000) guideline values for freshwater ecosystem protection are detailed in Table 3.4.

Most exceedances are not excessive, however, PZ43B and PZ58 report a number of dissolved metal concentrations orders of magnitude higher than the ANZECC guideline values. Zinc concentrations are also well above the ANZECC guideline values in a number of bores.

Table 3.4: Exceedances of ANZECC (2000) Freshwater Ecosystem Protection Guideline Values

Metal	Guideline (mg/L)	Bore	Reported Concentrations	
			Range (mg/L)	Average (mg/L)
Aluminium	0.055	PZ41A	<0.02-0.07	0.04
		PZ41B	<0.02-0.68	0.14
		PZ43A	<0.02-0.12	0.04
		PZ43B	5.2-16.0	9.8
		PZ106A	<0.02-1.6	0.72
		PZ106B	<0.02-0.17	0.07
		PZ107	<0.02 – 0.25	0.11
		PZ135	0.02-0.21	0.11
		PZ181	0.15	-
Arsenic	0.013	PZ43A	<0.001-0.06	0.02
		PZ43B	0.002-0.03	0.01
		PZ131	0.01-0.015	0.01
		PZ183	0.02	-
Cadmium	0.0002	PZ41A	<0.00005-0.0003	0.0003
		PZ43B	0.0014-0.0027	0.0017
		PZ183	0.0016	-
Copper	0.0014	PZ41a	0.006-0.0052	0.0017
		PZ41b	<0.0005-0.0016	0.0011
		PZ43B	0.008-0.03	0.017
		PZ 50b	<0.0005-0.0092	0.0029

Metal	Guideline (mg/L)	Bore	Reported Concentrations	
			Range (mg/L)	Average (mg/L)
Copper		PZ 50c	<0.0005-0.0026	0.0013
		PZ106a	<0.0005-0.004	0.0014
		PZ106b	<0.0005-0.0019	0.0013
		PZ 107	<0.0005-0.002	0.0014
		PZ 112b	0.001-0.0043	0.0025
		PZ 131	0.0017-0.0032	0.0025
		PZ 138	<0.0005-0.0019	0.0019
Lead	0.0034	PZ 40b	<0.00005-0.044	0.0066
		PZ 41a	<0.00005-0.034	0.009
		PZ 41b	<0.00005-0.034	0.0089
		PZ43B	0.012-0.54	0.102
		PZ 50c	0.0004-0.19	0.0244
		PZ 106a	<0.00005-0.013	0.004
		PZ 106b	<0.00005-0.0026	0.0009
		PZ 107	<0.00005-0.018	0.003
		PZ 111	<0.00005-0.009	0.0031
		PZ 112a	0.0061	-
Manganese	1.9	PZ39	0.17-3.80	0.62
		PZ41a	2.80-3.50	3.21
		PZ41b	2.1-4.6	3.62
		PZ 50c	<0.001-13.00	1.23
		PZ 134	3.00-3.2	3.13
		PZ 135	2.0-3.1	2.63
		PZ 136	1.5-2.4	2.07
Nickel	0.011	PZ39	<0.001-0.070	0.0082
		PZ41A	0.028-0.350	0.22
		PZ41B	0.009-0.220	0.126
		PZ43A	0.004-0.042	0.011
		PZ43B	0.24-0.87	0.55
		PZ50B	<0.0001-0.0001	0.0001
		PZ106A	0.001-0.067	0.012
		PZ106B	0.023-0.047	0.032
		PZ107	0.006-0.084	0.018
		PZ111	0.003-0.062	0.024
		PZ112A	0.039	-
		PZ135	0.046-0.110	0.083
		PZ137	0.025-0.039	0.031
		PZ138	0.12-0.17	0.15
		PZ139	0.003-0.082	0.03

Metal	**Guideline (mg/L)**	**Bore**	**Reported Concentrations**	
			Range (mg/L)	**Average (mg/L)**
Nickel		TB179	0.38	-
		PZ183	0.36	-
Zinc	0.008	All bores recorded zinc levels above the ANZECC guideline. Concentrations in the majority of bores were <0.05 on average. Bores with the highest concentration ie averages ≥0.05 are:		
		PZ39	0.006-0.65	0.093
		PZ41A	0.02-0.71	0.39
		PZ41B	0.029-0.77	0.215
		PZ43B	1.5-3.5	2.76
		PZ50A	0.018-0.29	0.111
		PZ50B	<0.005-0.19	0.07
		PZ106A	0.007-0.13	0.046
		PZ106B	0.009-0.13	0.05
		PZ107	0.006-0.29	0.058
		PZ112a	0.41	-
		TB179	0.17	-
		PZ181	0.065	-
		PZ183	0.74	-

3.9.4 Nutrients (Ammonia and Nitrate)

Ammonia concentrations are generally below the 0.9mg/L ANZECC (2000) guideline value for freshwater ecosystem protection. Minor exceedances of this value are reported from bores PZ41A (average 1.3mg/L), PZ41B (average 1.4mg/L), PZ50c (average 1.9mg/L), PZ134 (average 1.0mg/L) and PZ135 (average 1.0mg/L). Elevated ammonia concentrations (>3mg/L) have historically also been recorded at OB03 but recent sample data from this site are all below the ANZECC guideline value.

Nitrate concentrations are also generally below the ANZECC (2000) ecosystem guideline value of 0.7mg/L. Minor exceedances are reported from PZ43B (average 1.0mg/L), PZ112B (average 0.8mg/L), OB03 (average 1.0mg/L) and PZ173 (average 1.0mg/L). Higher concentrations were reported for PZ50C (average 2.3mg/L), PZ165 (average 2.8mg/L) and PZ167 (average 9.3mg/L). Reasons for these higher concentrations were not established as part of the scope of work for this study.

3.9.5 Major Ion Composition

Laboratory analysis results for major ion composition have been assessed with the aid of Piper trilinear plots shown in Figure 3.7, Figure 3.8 and Figure 3.9.

These plots allow each water analysis to be plotted as a unique point based on the relative concentrations of the major cations (calcium, magnesium, sodium and potassium) and major anions (carbonate, bicarbonate, sulphate and chloride). Such plots allow the assessment of differences in water chemistry applying to different areas and/or different hydrogeological units; and the relative components of groundwater derived as mixtures of waters from one or more different sources. Interpretation can be made as to the influence of recharge and discharge processes as well as the mixing of waters from different sources.

In addition to displaying the relative ionic composition, these plots have also been prepared to provide a broad indication of groundwater salinity, with the plotted symbols sized according to representative salinity ranges.

Figures 3.7 to 3.9 show data from both census (unregistered) and drilled bore sites across the area of proposed UG1, UG2 and OC4, the main development areas of MCC Stage 2. Data show that, in general, groundwater across the area is of a broadly similar type being typically dominated by sodium plus potassium cations, and a combination of carbonate / bicarbonate and chloride anions.

3.10 Surface Water Quality

The results of monthly surface water quality analysis are reported within the Surface Water Management Strategy report prepared for Stage 2 (Worley-Parsons, 2010), and hence are not repeated in full herein, however a brief discussion of salinity levels is included below.

Salinity can be used as a general indicator of water quality, and is an important parameter in the assessment of environmental value, particularly in relation to ecological communities and, therefore, the development and distribution of GDEs, and surface-groundwater relationships.

The recorded salinity as Electrical Conductivity (µS/cm) and TDS (mg/L) at sites SW1 to SW9 is plotted in Figure 3.10. Average salinity at each site shows considerable variation ranging from just under 300µS/cm EC (200mg/L TDS) at SW6, Ryan's Creek, to over 4,000µS/cm EC (~2500mg/L TDS) at SW7 (Lagoon Creek), and both SW8 and SW9 located along Moolarben Creek. The results show that waters with elevated salinity are present across much of the MCC area, particularly in the upland areas, where they are believed to reflect the presence of naturally saline soils and/or saline bedrock groundwater seepages. With the exception of SW6, all sites consistently show salinity levels over the ANZECC Aquatic Ecosystems upper guideline level (for Upland Rivers) of 350µS/cm EC.

3.11 Groundwater-Surface Water Interaction

There is abundant evidence in the large number of springs and seeps that groundwater discharges to the surface within the MCC area. However, with few exceptions, the volumes of individual spring and seep discharges are very small. Many seeps are only visible as patches of dampness or lush grass. The flow rate of the largest spring flow observed within the study area is estimated at less than 1L/s, with most being well below 0.1L/s. Nevertheless, the accumulation of groundwater discharges, together with bank storage from recent runoff, is sufficient to maintain semi-perennial flow in the major tributaries (such as Lagoon and Moolarben Creeks) and virtually permanent flow in Goulburn River (either visible flow or flow within the sandy stream bed). Land owners report that a number of spring-fed dams are able to maintain some permanent water through most extended dry periods due to groundwater seepage.

Groundwater baseflow comprised a significant component of total streamflow during the early period of baseline monitoring. This is reflected by a close relationship in the water salinity and major ion chemistry between the groundwater and the surface water during periods of lower rainfall (PDA, 2006a). The comparison of recorded surface water salinity values (as mg/L TDS), with salinity records from monitoring bores across the MCC area illustrates this well – refer Figure 3.10.

3.11.1 Moolarben Creek – Lagoon Creek

In the Moolarben Creek – Lagoon Creek catchment, the surface water quality (monitored at SW8 and SW9) is generally saline to a similar extent to that of the groundwater from that area (Figure 3.10), illustrating that groundwater baseflow is a significant fraction of total stream flow.

3.11.2 Murragamba Creek

Throughout the Murragamba Valley, comparable water chemistry data are recorded at both surface water monitoring (SW3 and SW4) and groundwater monitoring sites (Figure 3.10). Bores in the area directly to the east and south of Murragamba Creek show groundwater levels to be similar to the elevation of the creek-bed and it is likely that discharge from the shallow alluvium/colluvium and weathered rock are contributing on a seasonal basis to baseflow. The very deep groundwater levels in the Ulan Seam beneath Murragamba and Eastern Creek valleys mean that there would be no contribution to baseflow from the deeper parts of the Permian within the Project Boundary.

3.11.3 Goulburn River

The water quality in the Goulburn River is much less saline than that in the Moolarben Creek – Lagoon Creek system indicating that the River probably derives most of its baseflow from other tributaries, such as Ryan's Creek and Sportsman's Hollow Creek which drain granitic catchments to the west of the Permian basin margin, and in which the groundwater is presumably of better quality.

To the north, groundwater levels in the Permian Coal Measures in bores close to Goulburn River are below the present-day riverbed level (possibly due to Ulan Coal Mine dewatering effects). The Permian is thus not locally contributing to baseflow in the Goulburn River itself, although there are small contributions to baseflow of relatively saline Permian groundwater in the upper reaches of Moolarben and Lagoon Creeks.

The Goulburn River is believed to be more closely related to groundwater in the Triassic sediments that outcrop beneath and adjacent to the river. Water discharging at, and in the vicinity of, 'The Drip' is derived from perched groundwater within the Triassic sediments.

3.12 Groundwater Dependant Ecosystems

Groundwater Dependant Ecosystems (GDEs) are defined by ARMCANZ/ANZECC (1996) as ecosystems which have their species composition and their natural ecological processes determined by groundwater. A detailed ecological assessment report, which includes discussion of the occurrence and distribution of GDEs within the MCC area, has been prepared by Ecovision Consulting and Marine Pollution Research (Ecovision, 2008).

4. MINING PROPOSAL

4.1 Mining Proposal

Stage 1 construction commenced in November 2009 with construction of mine infrastructure and removal of overburden initiated. For the purpose of this study and groundwater impact assessment, the mining schedule (coal extraction) for the Preferred Project has been assumed to begin in 2012 but will depend on the final approval date. The Preferred Project has an anticipated mine life of approximately 24 years. In this report, the Mining Schedule has been defined based on January – December calendar years, as shown in Table 4.1.

Table 4.1: Preferred Project Mining Schedule

Mine Year	Calendar Year
0	2011
1	2012
2	2013
3	2014
4	2015
5	2016
6	2017
7	2018
8	2019
9	2020
10	2021
11	2022
12	2023
13	2024
14	2025
15	2026
16	2027
17	2028
18	2029
19	2030
20	2031
21	2032
22	2033
23	2034
24	2035

Stage 2 of the MCC completes at Year 24 (2035). However, under the proposed schedule integrating the Stage 1 and Stage 2 mining operations, UG4 (part of Stage 1) will continue after the completion of OC4 in 2035. UG4 is proposed for completion in 2041.

As the groundwater modelling undertaken to assess the groundwater impacts has to consider both Stage 1 and Stage 2 together, the model has assumed a total mine life of 30 years, with completion of mining in 2041.

MCM proposes to mine from a combination of four open-cut and three underground mines (from Stages 1 and 2). At full production, up to 17Mt of ROM coal per year will produce up to approximately 13Mtpa of product coal.

Mining will be maintained at approximately 13Mtpa ROM from OC1, OC2, OC3 and OC4, and up to 4Mtpa ROM from UG1, UG2 and UG4.

Coal production from the open cuts (for the purpose of this groundwater assessment) has been assumed to commence in Year 1 (2012) from OC1, with OC2, OC3 and OC4 coming on-line over the following 16 years. However Stage 1 has started, with coal extraction from OC1 commencing in 2009. The difference between the modelled and actual extraction start year is negligible for the model outcomes when compared to the overall MCC timeline.

Access for underground operations will also be constructed during the early years of the MCC with development of UG1 due to commence during Year 4 (2015).

The proposed mining schedule for all open cuts and underground mines in the MCC as assumed for the purposes of modelling, combining the Stage 1 and Stage 2 proposals, is illustrated on Figure 4.1.

4.2 Open Cuts OC1 to OC4

Open cut mining will commence at OC1, OC2 and OC4 concurrently in Year 1 (Figure 4.1). The largest open-cut, OC4, will be mined between Years 1 and 20.

Overburden will initially be placed outside the pits, being used for the construction of noise and visibility barriers and other infrastructure works. However, once sufficient void space becomes available, in-pit dumping of waste will occur. Rehabilitation of the mine areas will proceed progressively following mining and waste backfilling. It is expected that a final void extending below the water table will remain in OC1 and another at the south-eastern extremity of OC4. Final voids in OC2 and OC3 are expected to be above the water table.

Limited dewatering will be required in OCs 1 to 4, as the Ulan Seam and overlying sediments are either dry or only partially saturated through most of the area. The Ulan Seam is also already partly dewatered in areas to the north-west of OC1 and OC4, due to the regional effects of dewatering operations at Ulan Coal Mine.

4.3 Underground Mines UG1, UG2 and UG4

UG1 will be accessed by a portal from within OC1, to be constructed in Year 4. UG2 will be accessed through UG1, and will follow UG1 sequentially. The entry to UG4 will be from the northern end of OC1, and mining in UG4 is proposed to commence in Year 14, with development starting in Year 13 (Figure 4.1).

UG1 and UG2 comprise thirteen longwall panels, between 270m and 305m in width, and between 1685m and 2895m in length. The depth of cover varies from around 35m to 165m.

A significant amount of advanced dewatering is anticipated to have occurred in the area of UG4 by the time mining commences in Year 13 (2024), due to make-up water supply pumping from the borefield, and from continuing drawdown impacts associated with dewatering at Ulan Coal Mine.

5. GROUNDWATER MODELLING

5.1 Background

The local and regional impacts of the MCC on the groundwater resources have been assessed with the aid of numerical groundwater flow modelling. Several phases of groundwater modelling have now been completed.

The results of initial modelling using a model denoted MC1 were reported by PDA (2006a). This report was included as part of the Stage 1 EA (MCM, 2006a). During the Stage 1 review and approval process, a number of modifications were made to the model, and further modelling was reported in a series of supplementary reports issued between December 2006 and July 2007. The final modelling runs (denoted MC1.6 and MC1.9) on which the Stage 1 project approval was based are reported in PDA (2007a and 2007b).

To support the Environmental Assessment for the Stage 2 MCC (MCM, 2008), the model was further developed, taking account of data from additional hydrogeological investigations, and additional monitoring data from the nearby Ulan and Wilpinjong coal mines. The model version used for the Stage 2 studies was referred to as MC2.1.

The principal modifications incorporated into the MC2.1 model included (Aquaterra, 2008):

- Extension of the model area a further 15km to the north and 10km to the west, to accommodate simulation of future extensions of the Ulan Coal Mine with sufficient distance to the model boundaries;
- Adjustment to the layer configuration in some areas to allow each layer to represent a uniform hydrogeological unit;
- Inclusion of a new Layer 1 to represent the regolith (weathered rock, colluvium, alluvium and Tertiary palaeochannel deposits where present); and
- Modifications to some parameter values, based on additional information obtained since Stage 1.

The Stage 2 modelling (MC2.1) originally allowed for no water sharing between neighbouring mines, and included pumping from bores at both the MCC and Wilpinjong Coal Mine for periods when the model-predicted groundwater inflows at those projects were insufficient to meet their respective water demands. The model was subsequently used to assess the inflows to each of the three mining operations (the MCC, Ulan Coal Mine and Wilpinjong Coal Mine), but allowing for optimum water sharing between the mines, and with revised mine plans reflecting changes since the initial Stage 2 modelling was carried out. At this stage, the model was recalibrated, with some minor changes in parameters such as specific yield, and horizontal and vertical hydraulic conductivity particularly in the Ulan Coal Mine area. The recalibrated model used for the water sharing simulations was termed MC2.2, and was described in Aquaterra (2009b).

The calibration period utilised in the MC2.1 model was maintained but the parameters listed above were changed to improve calibration of groundwater inflows against the most recent estimates of groundwater inflows to the Ulan Coal Mine underground mine. The Ulan Coal Mine inflow rates have been poorly understood in the past.

The modifications made included some reference to parameter values used by MER (2009) in predictive modelling for the Ulan Completion of Mining EA. However, some of the MER parameters are not consistent with the hydraulic testing results from the MCC area, so the parameter changes were mostly limited to the model in the Ulan Coal Mine area, on the western side of the Spring Gully Fault. It is understood that the Ulan Coal Mine model is currently being re-calibrated to account for higher than anticipated inflows to the underground workings during recent months.

The MC2.2 model has been used in the current impact assessment, and it adopts the mine plan and schedule which was provided in March 2011 by MCM, including subsequent minor adjustments. This mine plan and schedule includes the mining from both Stage 1 and Stage 2 and is depicted in plan on Figure 4.1. Model refinement also incorporates modified mine plans for the Ulan and Wilpinjong coal mines, using the most recent publicly available reports.

Background information on the model fundamentals (e.g. regional aquifer conceptualisation, layer elevations, surface-groundwater interaction features), model refinements and benchmarking undertaken between 2006 has been documented comprehensively in previous reports by Aquaterra (2006a, 2006b, 2007a, 2007b, 2008, 2009a and 2009b) and PDA (2006a, 2006b, 2007a and 2007b), and is not repeated herein where the details are unchanged.

5.2 The Groundwater Model

5.2.1 Modelling Software

A 3-Dimensional finite difference model has been built using MODFLOW code (McDonald and Harbaugh, 1988) with flow calculations undertaken utilising MODFLOW SURFACT (Version 3) code to allow for both saturated and unsaturated flow conditions. The modelling has been undertaken using the Groundwater Vistas (Version 5.16) software package (ESI, 2006).

The model was set up to simulate groundwater conditions over a 2750km^2 area, to encompass the area of potential impact of both the MCC and the nearby Ulan and Wilpinjong operations.

The model structure, modelling approach, model calibration, the results of simulations and the assessment of potential impacts to the groundwater environment are discussed in detail in the following sections.

5.2.2 Model Design and Conceptual Hydrogeology

The conceptual model is a simplified representation of the real system, identifying the most important geological units and hydrogeological processes, while acknowledging that the real system is hydrologically and geologically more complex. The conceptual model forms the basis for the computational groundwater flow model. The key conceptual model features of the MCC MC2.2 model are described below, and are graphically illustrated in Figure 5.1. Figure 5.2a shows the model domain, and Figure 5.2b shows a schematic cross section with conceptual groundwater flow patterns and levels.

Geology and Hydrogeology

The geology and hydrogeology of the MCC area has been described in Sections 3.3 and 3.4, respectively.

The hydrogeological units of relevance to the MCC have been incorporated into the groundwater model as separate model layers, viz:

- Regolith and Quaternary/Tertiary alluvium including Tertiary palaeochannel deposits;
- Upper Triassic Narrabeen Group sediments[1] (also includes the Jurassic in the northern extremity of the model area);
- Lower Triassic Narrabeen Group sediments;
- Upper Permian coal measures;
- Middle Permian coal measures;
- Lower Permian coal measures;
- Ulan Coal Seam; and
- Basement units (comprising variously Marrangaroo Formation, Shoalhaven Group, Ulan Granite or Rylstone Volcanics).

Representative aquifer properties of the lithological units in the study area are listed in Table 3.3. These are based on the results of field investigations by Peter Dundon and Associates and Aquaterra, and from reference to studies undertaken by others for the nearby Ulan and Wilpinjong coal mines. Vertical hydraulic conductivities are assumed to be at most one tenth of the horizontal

[1] The terms "upper", "middle" and "lower" used in this report are relative terms used to subdivide the Permian and Triassic units into multiple model layers. They are not geological age terms.

hydraulic conductivity, and in some cases several orders of magnitude lower. This is further substantiated by the outcome of model calibrations discussed in Section 5.4.

Within the coal seams, the groundwater flows predominantly through cleat fractures, with very little evidence of structure-related fracturing. Due to the laminar nature of the coal measures, groundwater flow generally occurs within, or along the boundaries between, stratigraphic layers. This means that effective rock mass vertical permeability can be significantly lower than horizontal permeability.

Most permeability in the Permian coal measures is associated with coal seams. However, there are a number of instances of significant localised permeability in other lithologies in the coal measures sequence.

Groundwater Flow Pattern

The general flow pattern (for shallow groundwater and rivers) is from the west to the east (the indicative flow pattern is shown by green arrows in Figure 5.1); with the top of the Great Dividing Range forming the western catchment divide for the study area. West of this divide, surface and shallow groundwater flows in a westerly and north-westerly direction. This applies in areas to the north and west of the Ulan Coal Mine.

Groundwater flow in the deeper Triassic and the Permian coal measures is not directly related to the local topography, but prior to the commencement of mining at Ulan Coal Mine, had a general flow direction to the north-east, in the direction of the dip of the strata. Thus, the highest groundwater levels occur in the southwest of the model area and the lowest groundwater levels in the north-eastern parts of the model area. This flow pattern has been modified by mine dewatering at Ulan Coal Mine, such that there is now flow towards that mine extending over a fairly wide area, including the northern parts of the MCC project area. The extent of this drawdown is shown on Figure 2.1. There is believed to be a component of lateral groundwater flow out of the model area over the northern, eastern and possibly southern model boundaries.

Surface Drainage

Surface drainage in the vicinity of the MCC and the relationship between surface water and groundwater are described above in Sections 3.1 and 3.8.

The numerical model design incorporates river/aquifer interaction features to enable representation of both baseflow (groundwater discharge to streams) and recharge (from the streams to the groundwater), as well as quantification of the impacts of groundwater pumping on surface water features. It should be noted that the tributary streams in the study are mainly ephemeral because baseflow support is insufficient to sustain continuous flow, and extensive periods of no-flow naturally occur.

Surface drainages have been represented in the model using either the River (RIV) or Drain (DRN) packages of the MODFLOW software.

The river stage elevations were set to 1m below the river bank elevation, and river bed levels set to 0.2m below the stage in the main rivers, while the river stage elevations of the tributary streams have been set to the same level as the stream bed (1m below the river bank elevation). River cells allow flow in both directions between the groundwater and the stream, depending on relative heads.

Where ephemeral streams are present within the area, these have been represented within the model as drain cells. These simply drain water from the model whenever groundwater levels are higher than the drain bed level. With this arrangement, the minor streams, which are ephemeral, act only as baseflow-fed groundwater discharge features in the model, not potential recharge features; whereas the main rivers and streams can act as either groundwater discharge or recharge features, depending upon whether the simulated groundwater level is above or below the specified stage level. Drain cell elevations were set to 1m below the surface elevations. The river conductance parameter was set to 1000m^2/day.

Baseflow

Baseflow contribution to river and stream features represents one of the primary natural groundwater discharge processes (the other main natural discharge process being evapotranspiration). Baseflow is groundwater that discharges into a stream system, and is a continuing process, but with contribution rates often increasing during the recession phase after a rainfall event has recharged the aquifer system, and raised groundwater levels relative to the stream bed level. Goulburn River and the creeks in the area (Murragamba Creek, Wilpinjong Creek North, Wilpinjong Creek, Wollar Creek and their tributaries) are considered to be generally "gaining", i.e. they generally receive baseflow discharges from the groundwater system. This process may be continuous where baseflow is present or intermittent where creeks are ephemeral. Ephemeral creek characteristics are apparent where the baseflow is insufficient to maintain permanent (perennial) creek flow.

In areas where the groundwater levels may be lower than the creek system, the creeks may be "losing" streams i.e. they may lose water by seepage to adjacent or underlying aquifers. It is possible for larger river/creek systems to provide some recharge to the aquifer under natural conditions at least at some times, when river and creek levels may be temporarily higher than the groundwater following heavy rainfall events. Under current conditions, where groundwater levels in some units have been lowered due to coal mine dewatering at the Ulan Coal Mine, then the lowered groundwater levels may have locally changed the rivers/streams from "gaining" to "losing".

The MC2.2 model is designed to allow both processes (i.e. baseflow discharge and groundwater recharge) to occur.

Recharge

Recharge processes in the MCC area are discussed in Section 3.8. Average long-term monthly rainfall data for the area are presented in Section 3.2.

Five rainfall recharge zones were defined in the model. The percentage values of rainfall that recharge the water table vary depending on the type and extent of surficial outcrop, and local topography. For the steady-state (long term average) modelling with the MC2.2 model, the annual average recharge rate has been modelled by applying a spatially-variable effective rainfall percentage recharge rate to different lithologies and specific areas.

The same percentage recharge rates have been carried forward to the transient (time-varying) calibration ("history match") model, but applying the actual monthly rainfalls recorded at the Ulan Post Office gauge during the 21-year calibration period to June 2008, rather than a uniform average rainfall rate. For the forward predictions of mine dewatering, the adopted recharge rates have again been applied to the annual average rainfall.

Discharge/Evapotranspiration

Evapotranspiration has been included in the model using the Evapotranspiration (EVT) package of MODFLOW. The EVT parameter values adopted were a constant rate of 600mm/yr and an extinction depth of 5m, meaning that evapotranspiration in the model will occur predominantly in areas of shallow depth to the water table, which is mostly in valleys of the Goulburn River and Wilpinjong Creek and their tributaries.

Fracture Zone Changes to Permeability

Conceptually, there are a number of physical hydrogeological effects that are expected to occur throughout the life of the MCC which need to be represented using specific modelling approaches. This includes the simulation of changes to the hydraulic properties of overburden material caused by the caving and subsidence above longwall panels.

Subdividing the overburden into multiple layers allows subsidence caving and fracturing effects to be simulated to various heights above the seam, so that the impact of progressive caving and fracturing associated with the longwall mining of the Ulan Seam in the underground mines could be adequately represented. This is detailed further in Section 5.3.3.

Three 'zones' of subsidence permeability should develop above the coal seam:

- A high permeability, caved zone where there is direct connectivity with the mined goaf. Because of the total fragmentation of the strata immediately above the goaf, both horizontal and vertical permeability are assessed to be much higher than in situ permeability in this zone;
- A zone of 'tortuous cracking' that extends above the 'caved' zone. Within this zone, enhanced permeability occurs due to discrete vertical fractures that connect with horizontal layer separation features, allowing water to travel between and along layer boundaries. The tortuous flow paths that are created along bed layers and down fractures result in a zone where the overall permeability is lower than the caved zone below, but higher than in situ permeability; and
- If there is sufficient cover depth above the mined zone, a 'barrier zone' may exist above the 'tortuous' zone, in which there is minimal change to the in-situ permeability.

5.2.3 Model Domain and Boundary Conditions

The domain and boundaries of the model are shown in Figure 5.2a.

The model boundary conditions have been assigned to represent the regional groundwater flow system in a realistic manner, taking into account stratigraphic and topographic controls. The model boundary condition maps for each layer are illustrated in Appendix G.

Model MC2.2 covers an area of 50km x 55km (2 750km^2), with a variable grid size ranging from 100m x 100m in the MCC area, and increasing gradually up to 500m x 500m near the outer model boundaries. This gives a grid mesh of 434 rows and 336 columns, a total of 145 824 cells per layer, or 1 166 592 cells for the full 8-layer model.

The non-uniform grid size in MC2.2 was selected to optimise the model run time and improve the model efficiency, while maintaining the 100m x 100m grid in the vicinity of proposed mining areas to provide the capability for accurate modelling of impacts, particularly stream-aquifer interaction processes in the areas where greatest impacts are expected to occur. The finer grid also allows good resolution of the dipping layer geometry, and the potentially steep gradients in groundwater levels in areas close to proposed mine dewatering operations.

The MC2.2 model contains eight layers, all of which are active except for a minor area at the south eastern corner of the model domain which has been specified as a no-flow boundary in each layer. A general head (or head-dependent flow) boundary was specified in all layers where alluvium is present at the model boundary. General head boundaries were also included in the Permian model layers at the model boundary in the north-eastern and north-western corners of the model (i.e. the downdip areas of the Permian strata). These general head boundaries were included to accommodate the possibility that dewatering effects extend to the model boundary.

5.2.4 Model Layers

Model MC2.2 contains 8 layers, as detailed in Table 5.1.

The top elevation of Layer 1 was specified from the surface topography Digital Elevation Model. The Ulan Coal Seam (Layer 7) top and base elevations were taken from the MCC geological model within the MCC exploration lease, and extended regionally using information from the Wilpinjong and Ulan Coal Mine groundwater models and other regional geological data. The regional structure of the Ulan Coal Seam was also based on spot level and general dip information provided by the 1:100,000 geological map (Watkins, et al, 1999). Layer surface elevation data are presented in Appendix H.

Layer thicknesses in the model tend to vary spatially. Typical thicknesses are around 10m for Layer 1 (Alluvium and Regolith) while Layer 2 is more wedge shaped and starts from zero at its outcrop near to the MCC and reaches up to 400m thick in areas well to the north of the project site. Layer 2 comprises the upper Triassic and as well as the overlying Jurassic lithologies. The thickness of the Layer 3 (Lower Triassic) is typically about 30m. The upper and middle Permian (Layers 4 and 5) have thickness of 25m, whereas the lower Permian (Layer 6) is 50m thick. The thickness of the Ulan Coal Seam (Layer 7) is assumed to be 10m. The basement (Layer 8) has been assumed to have a uniform nominal thickness of 100m.

Table 5.1: Moolarben Coal Complex MC2.2 Model Layers

Layer	Lithology	Aquifer / Aquitard	Comments
1	Quaternary alluvium	Locally minor aquifer	Limited to valley areas of active streams
	Tertiary palaeochannel alluvium	Minor aquifer	Remnants of buried former drainage system
	Weathered bedrock / regolith	Locally minor aquifer	Generally present across the model
2	Triassic (upper)	Minor aquifer	
3	Triassic (lower)	Minor aquifer	
4	Permian (upper)	Aquitard	
5	Permian (middle)	Minor aquifer / aquitard	Moderate permeability in parts of MCC area
6	Permian (lower)	Aquitard	
7	Ulan Seam	Aquifer	Main aquifer
8	Marrangaroo Formation	Aquitard	Basal unit, poorly permeable in MCC area
	Ulan Granite	Aquitard	Outcrops in southwest and south parts of model
	Volcanics	Aquitard	Basal unit

Within the model, Layers 1 to 7 were designated as MODFLOW SURFACT ‘Type 3’ layers, which allows for each to behave as unconfined or confined dependent on water levels relative to layer elevations. Model simulations involved variably-saturated flow conditions using the van Genuchten function as an unsaturated flow modelling option provided by the MODFLOW SURFACT BCF4 package.

5.3 Specific Model Simulation Approaches

The overall objective of the groundwater modelling was to assess the potential impacts of the MCC on the groundwater environment, specifically with regard to:

- Predicted mine inflow (and dewatering) rates;
- Regional changes in groundwater levels during mining and after mine closure;
- Changes in baseflow contributions to surface watercourses; and
- Potential impacts on any existing beneficial groundwater uses, and GDEs.

As well as incorporating the latest available mine plans and schedule for the MCC, the modelling also incorporated available information on the historical and projected future Ulan Coal Mine dewatering operations, and proposed groundwater pumping operations at Wilpinjong Coal Mine, to ensure that the cumulative effects of mining from the MCC and Ulan and Wilpinjong coal mines were assessed.

Two model simulations were run in parallel, one including all three projects – the MCC, Ulan and Wilpinjong coal mines; and the other with only Ulan and Wilpinjong coal mines. The predicted impacts from these two simulations were compared, and the impacts of MCC determined as the difference between the two.

5.3.1 Simulation of Mining

Underground mining and dewatering activity is represented in the MC2.2 model using drain cells in all active areas within the mined coal seams, both development headings and longwall panels, with modelled drain elevations set to 1m above the base of the Ulan Coal seam layer (Layer 7). These drain cells were applied wherever workings occur, and were progressed through annual increments in a transient model set-up in accordance with the mine schedule as detailed on Figure 4.1. The full mine-life simulation has been undertaken as a series of separate sequential transient models (or time slices), rather than as a single simulation. This enables changes in hydraulic parameters in the mine areas to represent changes to the in situ hydraulic parameter values for strata mined out, replaced by waste rock backfill, or altered due to subsidence fracturing above extracted longwall panels. For each new time slice simulation, the output groundwater levels from the previous time slice were adopted as starting heads for the new time slice. This leads to step-wise changes in the representation of the mine layout, so in each 12 month time-slice, drains were activated 6 months in advance and 6 months in arrears, to try to keep the impacts and mining advance close to in unison.

The progression also involved changing the parameters with time in the goaf and overlying fractured zones directly after mining of each longwall panel, whilst maintaining active drain cells in the mined out panels and along all development headings. Drain cells were kept active until such time as access is no longer required to specific underground mine areas, when the drains were switched off for subsequent time slice simulations.

Open-cut mining is represented similarly by specifying drain cell levels at 1m above the base of the appropriate model layer for the period of mining and backfilling, after which the drain cells are progressively de-activated as the void is backfilled. Drain cells remain active within the active mining areas with drain cell footprint reduced to the final void area by the end of mining.

The drain conductance value reflects the resistance to flow between the surrounding material and the void. This is a critical model parameter which determines the simulated seepage inflow into the workings. The drain cell conductance parameter used for both open-cut and underground mines was 1000m^2/d.

5.3.2 Simulation of Water Supply Pumping

Pumping of groundwater will be required at MCC in some years to supplement water supplies from the approved UG4 borefield. This water will supplement groundwater inflows, surface water capture and water sourced from Ulan Coal Mine under the water sharing agreement between MCC and Ulan Coal Mine. Groundwater abstraction from bores is also undertaken by Wilpinjong Coal Mine. The locations and pumping rates of the Wilpinjong bores are based on information from Wilpinjong's 2007 AEMR (Peabody, 2008).

The total amount of water pumped from various sources in each stage of the simulation has been matched to the water demand.

5.3.3 Changes in Model Parameters with Time

In order to simulate the changes that occur during the mining operations, the hydraulic properties of the affected model cells have been progressively changed. For example:

- Open cut mining: Model cells inside the pit area initially have in-situ rock properties, progressively void properties as the pit develops, and then fill material properties as part of, or the entire pit is backfilled. Progressively changing to void properties includes increasing porosity to 99% and hydraulic conductivity to in excess of 100m/d;
- The horizontal and vertical hydraulic conductivity and specific yield for the open cut areas were changed for the Ulan coal seam (Layer 7), and also for the overlying Layers 1 to 6, to represent progressive mining and pit backfilling of the MCC and Wilpinjong Coal Mine open cuts; and
- Underground mining: Models cells for the Ulan Seam initially have coal seam properties, and then progressively void properties in development headings and goaf properties within the longwall panels, as mining develops. Likewise, the material overlying the coal seam (Layers 5 and 6) initially has in-situ rock properties, which change with time as the goaf and overlying subsidence zones develop. The basis for determining maximum height of connective cracking which allows connection with underground goaf areas was based on assessment of pressure responses to mining in overburden layers within and near the Ulan Coal Mine footprint.

In the Base Case model, the horizontal and vertical hydraulic conductivity parameters were changed in Layer 7 (Ulan coal seam), and also in the overlying layers 6 and 5 (the lower and mid-

Permian overburden) to represent the failure zones for both the MCC and Ulan Coal Mine underground mining. This is consistent with previous modelling.

The selection of appropriate permeability values was based on the results of hydraulic testing combined with model calibration for MCC and Ulan Coal Mine. This foundation was used to achieve an adequate history match to Ulan Coal Mine dewatering rates and observed groundwater level impacts. (Note: these calibrated simulations did not require the use of the RAMP function, which is discussed in Section 5.9 in the context of its application in uncertainty analyses).

Data on Ulan Coal Mine dewatering used in MC2.2 were initially sourced from the 2007 Ulan Coal Mine AEMR (UCML, 2008) and reviewed against the 2010 AEMR (UCML, 2010). Historical dewatering was simulated by use of drain features in the MC2.2 model. Use of historical monitoring data and pumping history from Ulan Coal Mine allowed for an additional check on model reliability, by comparing predicted and observed historical dewatering pumping rates, as well as calibration of the model to historical groundwater levels in the area from an active mining operation in the same coal seam under similar conditions (cover depth, overburden geology, panel widths, etc).

For the post-mining recovery model run, aquifer properties of the Ulan coal seam (Layer 7) and the overburden formations above the underground mine workings at the MCC were increased to reflect the enhanced permeability of goaf and subsidence fracture zones. For open cut areas, parameters commensurate with waste rock were assigned to mine cells backfilled with waste. The final pit voids were assigned high permeability and storage parameter values.

Sensitivity modelling has been carried out, in which hydraulic properties were changed for all layers above extracted longwall panels. Increased deformation parameters in terms of fracture height and vertical hydraulic conductivities have also been assessed as part of the uncertainty analysis. This is discussed in Section 5.9.

The version of MODFLOW-SURFACT utilised for this analysis does not allow changing of hydraulic conductivity parameters with time during a single simulation. Therefore, modelling has been undertaken by use of consecutive ‘time-slice’ models of short duration (generally 2 years), which has allowed parameters to be changed between successive time slices in specific areas to represent stepwise progression of mining (open-cut and underground), and the expansion of the subsidence failure zone as underground mining progresses.

Four time slices were used during the model calibration period and two time slices for the period 2008 to 2011 (prior to the development of the MCC), with 17 time slices used to represent simulation of the 30 year MCC mining operation. A final 6-month prediction simulation was run at the end of mining with the final set of active drain cells kept activated, to account for the ongoing impact from the portion of the last mine year’s footprint that was simulated 50% in advance and 50% in arrears. This was stress period 46 (Table 5.2), the output heads from which were then used as starting heads for the post-mining recovery simulation.

5.3.4 Time Scale Selection

Table 5.2 outlines the MC2.2 model stress period set-up for the transient calibration and prediction model runs. A stress period is the timeframe in the model when all hydrological stresses (e.g. recharge, mine dewatering) remain constant.

Mining operations at Wilpinjong Coal Mine have been assumed to start in the 2006-2007 period. It has been assumed that Ulan Coal Mine underground mining started prior to 1990, and will continue until 2029.

Although Stage 1 (OC1) has started with coal extraction in 2009, for the purpose of groundwater assessment and modelling construction the Preferred Project is assumed to commence in Year 0 (2011) with production from OC1 commencing in Year 1 (2012). The difference between the modelled and actual extraction start year is negligible for the model outcomes when compared to the overall MCC timeline. Therefore, the mining schedule (coal extraction) begins in 2012, and the MCC is currently seeking approval for a mine life of approximately 24 years.

Table 5.2: MC2.2 Model Stress Period Setup

<table>
<tr><th colspan="2">Stress Period - Time Slice</th><th>From</th><th>To</th><th>Days</th><th colspan="9">Timing of Operations</th><th>Mine Year</th></tr>
<tr><td rowspan="11">CALIBRATION</td><td>1–1</td><td>1/07/1987</td><td>30/06/1990</td><td>1096</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="33">Ulan Coal Mine underground and open cut</td><td></td><td></td></tr>
<tr><td>2–1</td><td>1/07/1990</td><td>29/06/1992</td><td>730</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3–1</td><td>30/06/1992</td><td>30/06/1994</td><td>731</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4–2</td><td>1/07/1994</td><td>29/06/1996</td><td>730</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5–2</td><td>30/06/1996</td><td>30/06/1998</td><td>731</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6–2</td><td>1/07/1998</td><td>29/06/2000</td><td>730</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7–3</td><td>30/06/2000</td><td>30/06/2002</td><td>731</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8–3</td><td>1/07/2002</td><td>29/06/2004</td><td>730</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>9–3</td><td>30/06/2004</td><td>30/06/2006</td><td>731</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>10–4</td><td>1/07/2006</td><td>30/06/2007</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>11–4</td><td>1/07/2007</td><td>30/06/2008</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="28">PREDICTION</td><td>12–5</td><td>1/07/2008</td><td>30/06/2009</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="19">Wilpinjong Coal Mine open cuts</td><td></td></tr>
<tr><td>13–5</td><td>1/07/2009</td><td>31/12/2009</td><td>183</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>14–6</td><td>1/01/2010</td><td>31/12/2010</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>15–6</td><td>1/01/2011</td><td>31/12/2011</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td></tr>
<tr><td>16–7</td><td>1/01/2012</td><td>31/12/2012</td><td>366</td><td rowspan="3">MCC OC1</td><td rowspan="4">MCC OC2</td><td></td><td rowspan="20">MCC OC4</td><td></td><td></td><td></td><td>1</td></tr>
<tr><td>17–7</td><td>1/01/2013</td><td>31/12/2013</td><td>365</td><td></td><td></td><td></td><td></td><td>2</td></tr>
<tr><td>18–8</td><td>1/01/2014</td><td>31/12/2014</td><td>365</td><td></td><td></td><td></td><td></td><td>3</td></tr>
<tr><td>19–8</td><td>1/01/2015</td><td>31/12/2015</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td>4</td></tr>
<tr><td>20–9</td><td>1/01/2016</td><td>31/12/2016</td><td>366</td><td></td><td></td><td></td><td rowspan="10">MCC UG1</td><td></td><td></td><td>5</td></tr>
<tr><td>21–9</td><td>1/01/2017</td><td>31/12/2017</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td>6</td></tr>
<tr><td>22–10</td><td>1/01/2018</td><td>31/12/2018</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td>7</td></tr>
<tr><td>23–10</td><td>1/01/2019</td><td>31/12/2019</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td>8</td></tr>
<tr><td>24–11</td><td>1/01/2020</td><td>31/12/2020</td><td>366</td><td></td><td></td><td></td><td></td><td></td><td>9</td></tr>
<tr><td>25–11</td><td>1/01/2021</td><td>31/12/2021</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td>10</td></tr>
<tr><td>26–12</td><td>1/01/2022</td><td>31/12/2022</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td>11</td></tr>
<tr><td>27–12</td><td>1/01/2023</td><td>31/12/2023</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td>12</td></tr>
<tr><td>28–13</td><td>1/01/2024</td><td>31/12/2024</td><td>366</td><td></td><td></td><td></td><td></td><td></td><td>13</td></tr>
<tr><td>29–13</td><td>1/01/2025</td><td>31/12/2025</td><td>365</td><td></td><td></td><td></td><td rowspan="4">MCC UG2</td><td></td><td>14</td></tr>
<tr><td>30–14</td><td>1/01/2026</td><td>31/12/2026</td><td>365</td><td></td><td></td><td></td><td></td><td rowspan="10">MCC UG4</td><td>15</td></tr>
<tr><td>31–14</td><td>1/01/2027</td><td>31/12/2027</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td>16</td></tr>
<tr><td>32–15</td><td>1/01/2028</td><td>31/12/2028</td><td>366</td><td></td><td></td><td></td><td></td><td></td><td>17</td></tr>
<tr><td>33–15</td><td>1/01/2029</td><td>31/12/2029</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td>18</td></tr>
<tr><td>34–16</td><td>1/01/2030</td><td>31/12/2030</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>19</td></tr>
<tr><td>35–16</td><td>1/01/2031</td><td>31/12/2031</td><td>365</td><td></td><td></td><td rowspan="5">MCC OC3</td><td></td><td></td><td></td><td></td><td>20</td></tr>
<tr><td>36–17</td><td>1/01/2032</td><td>31/12/2032</td><td>366</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>21</td></tr>
<tr><td>37–17</td><td>1/01/2033</td><td>31/12/2033</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>22</td></tr>
<tr><td>38–18</td><td>1/01/2034</td><td>31/12/2034</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>23</td></tr>
<tr><td>39–18</td><td>1/01/2035</td><td>31/12/2035</td><td>365</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>24</td></tr>
</table>

Stress Period - Time Slice	From	To	Days	Timing of Operations	Mine Year
40–19	1/01/2036	31/12/2036	366		25
41–19	1/01/2037	31/12/2037	365		26
42–20	1/01/2038	31/12/2038	365		27
43–20	1/01/2039	31/12/2039	365		28
44–21	1/01/2040	31/12/2040	366		29
45–21	1/01/2041	31/12/2041	365		30
46-22	1/01/2042	30/06/2042	182	Simulations include a lag time of up to 6 months during which all post-mining subsidence and fracturing should cease (see Section 5.3.3)	
47	1/07/2042	30/06/2143	36525	Post-mining Recovery	

5.4 Model Calibration

Calibration is the process by which the independent variables (parameters and boundary conditions) of a model are adjusted, within realistic limits, to produce the best match between simulated and measured data. The realistic limits on parameter values are constrained by the range of measured values from pumping tests and other hydrogeological investigations.

An initial pseudo steady state calibration was run, using a 5-year transient calibration to simulate the distribution of groundwater heads at 30 June 1987. A true steady state calibration is not possible, as long-term groundwater monitoring records are not available to indicate what pre-Ulan Coal Mine groundwater conditions might have been. Limited groundwater level data are available from the Ulan Coal Mine area from 1982, but transient records are only available from 2001 from a small number of bores initially. Hence, the pseudo-steady state calibration is of only limited value, other than to determine a set of starting groundwater heads for a transient calibration.

A transient calibration has therefore been run for the period July 1987 to June 2008. This includes the period when dewatering pumping increased significantly from the Ulan Coal Mine, and the available groundwater level monitoring data also increased significantly. The available monitoring records from Ulan Coal Mine are invaluable for calibration of the MCC model, as they allow the model to be calibrated against a mining operation that is very similar to that proposed at the MCC. The same coal seam is being mined, similar cover depths are involved in the early years of Ulan Coal Mine, and the Ulan underground mine longwall configuration, prior to 2006, was virtually identical to that proposed for the MCC. Since 2006, Ulan Coal Mine has been mining from wider longwall panels.

Therefore, the targets for the transient history match calibration comprise a snapshot of the groundwater level data between 1987 and 2008 (generally the latter at Moolarben, but sometimes earlier dates in other areas), and the reported 2004 dewatering rate of 10ML/day at Ulan Coal Mine (UCML, 2005). In addition, a limited amount of data available from the NOW database as reported in Wilpinjong Coal Mine's 2007 AEMR (Peabody, 2008) was used.

The overall simulated hydrograph results (Appendix J) coincide very well with the actual hydrographs, confirming the model as a good predictive tool to simulate the complex multi-layer MCC aquifer system. Both the water level response to seasonal recharge, and the drawdown response due to mine dewatering at Ulan and Wilpinjong coal mines, was well replicated.

5.4.1 Steady State Calibration

The overall groundwater balance for the pseudo steady state MC2.2 model is summarised in Table 5.3.

The total inflow is around 249ML/d, comprising rainfall recharge (31%), leakage into the aquifer from the rivers and streams (20%) plus boundary inflow (49%).

The total outflow of the aquifer system (249ML/d) comprises evapotranspiration (35%), discharge from the groundwater into the river (baseflow of 42%) plus dewatering from Ulan open cut mine (<1%) and boundary outflow (22%). The water balance discrepancy between the total inflow and outflow for the pseudo steady state simulation period (pre-1987) was 0.4%.

Table 5.3: Groundwater Budget for the MCC Model Steady State Calibration

Component	Groundwater Inflow (ML/d)	Groundwater Outflow (ML/d)
Rainfall Recharge	75.8	-
Evapotranspiration (EVT)	-	87.8
River- ephemeral creeks and streams	50.5	104.3
Drains- Ulan Open Cut	-	2.1
Head-dependent flow (GHB)	122.5	54.7
Storage	0	0
TOTAL	248.7	249.0

5.4.2 Transient Model Calibration

The aim of the transient calibration was to achieve a history match to the reported dewatering rates and observed groundwater level impacts during the period 1987 to 2008, which included the effects of Ulan and Wilpinjong coal mines dewatering, as well as varying recharge conditions in response to actual rainfall.

An extensive database of baseline water level measurements starting in 2005 are available for bores across the MCC area, and data from these bores were used in the calibration process. Data from several observation bores within the Ulan and Wilpinjong coal mine areas which have a longer period of monitoring, were also used where sufficient data and bore datum information was available. The river stages in the model were not varied at any time during any simulations (calibration or prediction).

The initial conditions in the transient model calibration were based on the heads generated by the pseudo steady state model. The calibration process involved manually changing aquifer parameter values (hydraulic conductivity, unconfined specific yield and confined storage coefficient) within reasonable limits (constrained by available data and hydrogeological knowledge of the area), until reasonable matches were obtained between the observed and simulated hydrographs, and between reported and simulated inflow rates.

The calibrated aquifer hydraulic parameters resulting from the steady and transient model calibration are summarised in Table 5.4. Detailed maps for the hydraulic parameter zones for each layer are presented in Appendix I and the simulated versus observed hydrographs for each of the bores used during calibration are included in Appendix J. The calibrated hydraulic conductivity values for the Permian interburden/overburden (Layers 4 and 6) are somewhat higher than might have been expected, but are supported by higher inflow rates experienced within the Ulan Coal Mine underground operations and relatively high yields from production bores screened within the Permian overburden (e.g.TB103 - Appendix B).

The transient simulation period commenced on 1 July 1987 and ended on 30 June 2008. The transient calibration was divided into 4 time slices to allow for the change of parameters with time to represent progressive formation of goaf and fracture zones at the Ulan Coal Mine underground operations, and the mining and placement of backfill material in open cuts at Wilpinjong Coal Mine.

The first three time slice models (represented by stress periods 1 to 9) were defined on a yearly basis. The last time-slice model (covering stress periods 10 to 11) was set up on a monthly basis and the overall groundwater balance for this time-slice model is summarised in Table 5.5.

Table 5.4: Calibrated MC2.2 Model Aquifer Parameters

Layer	Aquifer/Aquitard	K_h	K_v	Unconfined S_y	Confined S
		(m/d)	(m/d)	(-)	(-)
1	Weathered regolith, palaeochannel and alluvial deposits	0.5 – 3.0	0.001 – 0.075	0.05 - 0.10	n/a
2	Upper Triassic	0.5	0.0001	0.02	0.00005
3	Lower Triassic	0.2	0.00005	0.01	0.00005
4	Upper Permian	0.001 – 0.1	0.000025	0.005	0.00005
5	Middle Permian	0.001 – 0.1	0.000025	0.005	0.00005
6	Lower Permian	0.001 – 0.05	0.00001	0.005	0.00005
7	Ulan Coal Seam	1	0.0005	0.01	0.00005
8	Marrangaroo Formation	0.1	0.00001	0.01	0.00001
8	Granite/volcanics	0.0005	0.00001	0.005	0.00001

Table 5.5: Groundwater Budget for the MCC Model Transient Calibration

Component	Groundwater Inflow	Groundwater Outflow
	(ML/d)	(ML/d)
Rainfall Recharge	81.7	-
Evapotranspiration (EVT)	-	114.2
River - ephemeral creeks and streams	59.7	128.9
Drains - Ulan Coal Mine underground and Wilpinjong Coal Mine Open Cut	-	10.6
Head-dependent flow (GHB)	123.0	54.6
Storage	45.2	1.1
TOTAL	309.6	309.4

5.5 Discussion of Transient Model Calibration

As previously mentioned in Section 5.1, model MC2.2 has also been recalibrated, with some minor changes in parameters such as specific yield, and horizontal and vertical hydraulic conductivity, particularly in the Ulan Coal Mine area. The parameter changes were made to improve calibration of groundwater inflows against the most recent estimates of actual groundwater inflows to the Ulan Coal Mine underground mine.

The calibration performance of the MC2.2 model for the 21 year history match period to June 2008 has been demonstrated in quantitative terms (potentiometric head matches and statistical measures) and qualitative terms (pattern-matching), by:

- Scatter plots of modelled versus measured potentiometric head, and the associated statistical measure of the scaled root mean square (SRMS) value, with maps of the spatial distribution of calibration residuals;
- Hydrographs of modelled and measured potentiometric head; and
- Comparison of the model-predicted dewatering rates from Ulan Coal Mine underground and Wilpinjong Coal Mine open cut to the recorded dewatering rates (derived from the recently available reports).

5.5.1 Scaled RMS

The SRMS value is the major quantitative performance indicator, calculated as the RMS value divided by the range of measured heads across the model. Given uncertainties in the overall water balance volumes (e.g. it is difficult to directly measure evaporation, or baseflow into the creeks), it was considered that a 10% SRMS value on aquifer water levels would be an appropriate target for this project, consistent with the Australian best practice modelling guideline (MDBC, 2001).

The scatter diagram of measured versus modelled potentiometric head targets is plotted in Figure 5.3. It can be clearly seen that most of the calibration head target points (1227 in total) are located along the line of 45°. Based on all 1227 target points (from 145 hydrograph records), the SRMS is around 8.0%, which is well within the target of 10% (Table 5.6).

Table 5.6: Transient Calibration Performance in the MC2.2 Model

Calibration Parameters		Value	
Count	n	1227	-
Scaled Mean Sum of Residuals	SMSR	4.13	%
Root Mean Square	RMS	19.75	m
Scaled RMS	SRMS	8.00	%
Root Mean Fraction Square	RMFS	5.10	%
Scaled RMFS	SRMFS	8.52	%
Coefficient of Determination	CD	0.73	-

5.5.2 Hydrographs

Detailed hydrographs comparing observed and predicted groundwater levels can be seen in Appendix J. They show generally good agreement between predicted and observed levels/pressures.

5.5.3 Match to Ulan Coal Mine and Wilpinjong Coal Mine Dewatering

Throughout the calibration run, the failure zones invoked in the model above Ulan Coal Mine underground mining were progressed with mine development in accordance with the mine plan assumed on the basis of information available in UCML's AEMRs. In summary, and as shown in Appendix K, an acceptable history match was achieved in terms of predicted groundwater inflow/dewatering rates at Ulan and Wilpinjong coal mines, viz:

- Ulan Coal Mine dewatering in 1991 was reportedly about 2.5ML/d – the model predicts 4.2ML/d;
- Ulan Coal Mine dewatering in 2009 was reportedly about 10ML/d – the model predicts 11.2ML/d; and
- Wilpinjong Coal Mine dewatering in 2007 was reportedly about 1.1ML/d – the model predicts 1.1ML/d.

The saw-tooth shape of the plot of predicted Ulan Coal Mine inflows in Figure 5.4, showing initial sharp rises at the start of each time slice, is due to the adoption of new failure zone parameters for the area of active underground mining abruptly at the beginning of each time slice. That is, there is a significant step change in the simulated shape of mine voids at the start of each time slice, whereas in practice the voids would develop more gradually over time. The predicted short term peak rates at the commencement of each time step reflect over-estimates of inflows, as the model adjusts to the new parameter distribution for that time slice.

The predicted inflow rates are plotted for the end of each model stress period, as this is considered to represent the likely long term inflow rate. The data are plotted as raw model output, rather than as average rates, to aid insight into model and aquifer responses.

5.6 Sensitivity Analysis

Sensitivity analysis was carried out to assess the sensitivity of the calibrated model to the assumed input parameters. Extensive sensitivity analysis was completed as part of the Stage 1 modelling, and in discussion with the model reviewer (Dr Noel Merrick) it was agreed that sensitivity analysis for the Stage 2 model would be adequate if limited to assessing the impacts of specific changes to aquifer storativity (specific yield and storage coefficients) and to recharge. Analysis was carried out on all spatial zones within each model layer. Sensitivity multipliers (the factor by which each parameter is altered) are summarised in Table 5.7.

Table 5.7: Sensitivity Analysis - Parameters, Zones and Multipliers

Sensitivity Parameter	Zone	Calibrated Value	Layer	Multiplier
Rainfall Recharge	All	All	Applied to the Highest Active Layer	0.5, 2
Specific Yield	All	All	All	0.5, 2
Storage Coefficient	All	All	All	0.1, 10

MC2.2 sensitivity analysis was undertaken using the last time-slice model from the transient calibration (stress periods 10 and 11). The base SRMS value for this time slice model runs was 8.2%. The sensitivity of the model to each parameter was analysed by first decreasing, and then increasing its value, by the multipliers shown in Table 5.7. Parameters that resulted in a change to the scaled RMS statistics by a significant amount indicate that the model is sensitive to that parameter.

The results for the rainfall recharge and specific yield sensitivity analysis are summarised in Table 5.8. Results show that the model is insensitive to recharge, specific yield and storage coefficient, as modification of each of these parameters has no significant effect on the calculated SRMS value. The slight changes in SRMS obtained during analysis are detailed in Table 5.8.

Table 5.8: Sensitivity Analysis of Recharge, Specific Yield and Storage Coefficient Values

Zone	Calibrated Value	Layer	Multiplier	SRMS (%)
Sensitivity to Recharge				
1, 2, 3, 4, 5	0, 3.1%, 6.8%, 7.4%, 0.51%	Applied to Highest Active Layer	0.5	8.19
			1	8.18
			2	8.18
Sensitivity to Specific Yield				
Zone	**Calibrated Value**	**Layer**	**Multiplier**	**SRMS (%)**
All	All	1 to 8	0.5	8.22
			1	8.18
			2	8.13
Sensitivity to Storage Coefficient				
Zone	**Calibrated Value**	**Layer**	**Multiplier**	**SRMS (%)**
All	All	1 to 8	1	8.18
			10	8.11

5.7 Prediction of Mine Dewatering

Having achieved acceptable calibration of the model, the model was then applied to predictive transient modelling.

Using the groundwater conditions at 2008, derived from results of the transient calibration, as the initial conditions for prediction modelling, MC2.2 was run in a series of consecutive 2-year simulations or “time slices” for the period 2011 to 2041, as shown in the schedule in Table 5.1. The water level conditions for the end of each time slice were specified as the starting conditions for the next time slice model run, and subsidence fracture zone parameters were invoked in areas where underground mining had been completed at the start of each time slice as mining progressed. Hydraulic parameters of back-filled open cut cells were changed as appropriate.

All mine drain cells were deactivated progressively across open cut areas as mining is completed and areas are backfilled. Drain cells are retained as active in all underground mine areas until such time as access to those areas is no longer required.

Following the cessation of mining, all mine drain cells were switched off, and pit void parameters were invoked for the residual open cut areas at the MCC and Wilpinjong Coal Mine.

The predicted mine inflow rates from the predictive scenarios are shown graphically in Figure 5.4 and Figure 5.5, and are summarised in Table 5.9.

During the first thirteen years of mining, as each progressive open-cut area becomes operational, groundwater inflows are predicted to gradually increase from 0.77ML/d (280ML/a) to 2.01ML/d (734ML/a). From Year 14 onwards, as production from UG4 begins, total inflow volumes increase substantially and predictions show inflows in excess of 4.47ML/d (1630ML/a) in Mine Years 29 and 30, the last two years of mining at the MCC.

The water demands of the MCC gradually increase as the area of active open cut mining increases, as dust suppression forms a major component of the water requirement of the MCC. However, the highest water inflows are predicted to occur in the latter years of mining of UG4, the most northerly (down-dip) of the underground mines, especially in the years after completion of open cut mining when the water demands for dust suppression are substantially reduced.

It is proposed to source some of the MCC’s water supply from a borefield located around UG4 and in other parts of the MCC mining lease area. Pumping from the borefield would start in Year 0, and would have the effect of partly dewatering the UG4 area in advance of mining reaching that area. The groundwater inflow rates, particularly to UG4, are very dependent on the rate of pumping from the MCC Northern borefield, as the two will mutually interfere. Hence the total groundwater production comprises both components. The borefield has been assumed in the groundwater modelling simulations to be able to be pumped at up to a maximum of 2400 ML/a (ie 6.57 ML/d).

The combined total for mine inflows and borefield pumping at MCC are predicted to range from 3.78 ML/d (1381ML/a) in Mine Year 1, up to a peak rate of 5.46ML/d (2446ML/a) in Mine Year 17 (Table 5.9).

Table 5.9: Predicted Mine Inflow Rates

Mine Year	Period Ending	Total Ulan Coal Mine Inflows	Total Wilpinjong Coal Mine Dewatering Bores	Water Demand	MCC Mine Inflows							Total MCC Inflows	Modelled Borefield Pumping	Total MCC Inflows+Borefield
					OC1	OC2	OC3	OC4	UG1	UG2	UG4			
		m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d
	Steady State	1252	0	0	0	0	0	0	0	0	0	0		
	30/06/1990	4284	0	0	0	0	0	0	0	0	0	0		
	30/06/1992	4077	0	0	0	0	0	0	0	0	0	0		
	30/06/1994	4036	0	0	0	0	0	0	0	0	0	0		
	30/06/1996	5672	0	0	0	0	0	0	0	0	0	0		
	30/06/1998	5634	0	0	0	0	0	0	0	0	0	0		
	30/06/2000	5621	0	0	0	0	0	0	0	0	0	0		
	30/06/2002	7713	0	0	0	0	0	0	0	0	0	0		
	30/06/2004	9152	0	0	0	0	0	0	0	0	0	0		
	30/06/2006	9850	0	0	0	0	0	0	0	0	0	0		
	30/06/2007	9398	1054	0	0	0	0	0	0	0	0	0		
	30/06/2008	9371	1234	0	0	0	0	0	0	0	0	0		
	30/06/2009	11174	1963	0	0	0	0	0	0	0	0	0		
	31/12/2009	11281	1907	0	0	0	0	0	0	0	0	0		
	31/12/2010	12663	1314	0	0	0	0	0	0	0	0	0		
0	31/12/2011	11566	1148	0	0	0	0	0	0	0	0	0		
1	31/12/2012	12055	2025	4353	220	58	0	490	0	0	0	768	**3016**	**3784**
2	31/12/2013	11118	1690	6841	280	17	0	261	0	0	0	558	**3140**	**3698**
3	31/12/2014	13837	2490	7153	413	24	0	275	0	0	0	711	**2842**	**3554**
4	31/12/2015	12420	777	7463	0	27	0	253	598	0	0	877	**2845**	**3722**
5	31/12/2016	14405	1988	7677	0	0	0	208	799	0	0	1007	**2554**	**3561**
6	31/12/2017	12645	1776	8940	0	0	0	151	829	0	0	980	**2538**	**3517**
7	31/12/2018	15162	2217	9564	0	0	0	786	772	0	0	1558	**2385**	**3943**

Mine Year	Period Ending	Total Ulan Coal Mine Inflows	Total Wilpinjong Coal Mine Dewatering Bores	Water Demand	MCC Mine Inflows							Total MCC Inflows	Modelled Borefield Pumping	Total MCC Inflows+Borefield
					OC1	OC2	OC3	OC4	UG1	UG2	UG4			
		m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d	m^3/d
8	31/12/2019	13406	2175	10096	0	0	0	795	722	0	0	1517	**2316**	**3833**
9	31/12/2020	15178	2668	10151	0	0	0	1252	805	0	0	2056	**2328**	**4384**
10	31/12/2021	13540	2733	10192	0	0	0	1819	628	0	0	2447	**2235**	**4681**
11	31/12/2022	4055	1336	9827	0	0	0	1415	998	0	0	2413	**2549**	**4962**
12	31/12/2023	3588	1062	10164	0	0	0	1143	888	0	0	2031	**2828**	**4859**
13	31/12/2024	5471	1380	10085	0	0	0	1132	881	0	0	2013	**3027**	**5039**
14	31/12/2025	5609	1143	9548	0	0	0	986	786	5	426	2204	**2912**	**5116**
15	31/12/2026	7020	678	9967	0	0	0	880	0	24	753	1657	**3093**	**4750**
16	31/12/2027	6510	454	9485	0	0	0	802	0	18	819	1639	**3110**	**4748**
17	31/12/2028	7365	52	9537	0	0	0	1357	0	7	988	2352	**3111**	**5463**
18	31/12/2029	6742	0	9773	0	0	0	1077	0	0	1042	2119	**3047**	**5166**
19	31/12/2030	0	0	10468	0	0	0	847	0	0	1216	2063	**3015**	**5078**
20	31/12/2031	0	0	10490	0	0	4	1171	0	0	1203	2378	**3033**	**5411**
21	31/12/2032	0	0	10323	0	0	93	0	0	0	1397	1491	**3110**	**4601**
22	31/12/2033	0	0	9959	0	0	80	0	0	0	1883	1963	**2590**	**4553**
23	31/12/2034	0	0	9162	0	0	190	0	0	0	3223	3413	**751**	**4164**
24	31/12/2035	0	0	8836	0	0	265	0	0	0	2576	2840	**2347**	**5187**
25	31/12/2036	0	0		0	0	0	0	0	0	4254	4254	**0**	**4254**
26	31/12/2037	0	0		0	0	0	0	0	0	4244	4244	**0**	**4244**
27	31/12/2038	0	0		0	0	0	0	0	0	4369	4369	**0**	**4369**
28	31/12/2039	0	0		0	0	0	0	0	0	4365	4365	**0**	**4365**
29	31/12/2040	0	0		0	0	0	0	0	0	4466	4466	**0**	**4466**
30	31/12/2041	0	0		0	0	0	0	0	0	4465	4465	**0**	**4465**

5.8 Predicted Water Level Drawdowns

The model has been run twice, firstly with all three mining projects (MCC and Ulan and Wilpinjong coal mines) to determine cumulative impacts; and secondly with just Ulan and Wilpinjong coal mines to determine impacts without the MCC. The results from these two simulations were then compared, and the impacts due to MCC only were determined by subtracting the “without MCC” impacts from the “with MCC” impacts.

The MCC drawdown impacts are discussed below in Section 6.2. There are some differences from the drawdown impacts predicted in the 2008 Stage 2 groundwater study (Aquaterra, 2008), due partly to different scheduling of the MCC open cut and underground mines, partly to inclusion of Ulan West in the future Ulan Coal Mine schedule, and partly to some minor changes made to parameters to improve the calibration of the model.

5.9 Uncertainty Analysis

Uncertainty analysis is the process by which the impacts on model predictions and model reliability are assessed, due to variations in critical parameters identified as ‘sensitive’. Parameter variations were applied to the MCC underground area and no changes were applied to surrounding mines.

Based on previous modelling studies at Stage 1, it was found that the critical parameters that will most likely affect model reliability are the adopted vertical permeabilities in the goaf and subsidence zones above the underground longwall panels.

For the uncertainty analysis, the model was set up with high hydraulic conductivity in the fracture zones based on the depth of overburden above the mined seam and the degree of subsidence associated with the longwall panel. The fractured zone was simulated with horizontal hydraulic conductivity enhanced by a factor of 2, and with vertical hydraulic conductivity enhanced according to a log-linear monotonic (ramp) function. The Ramp function (Merrick, pers comm) provided a conservative, yet realistic basis for assigning variable permeabilities in the overburden. Permeabilities are altered in relation to varying depths and fracturing due to subsidence of overburden cover. This is preferable to using constant permeability values as in the base case model.

Table 5.10 lists a summary of the parameter changes for the uncertainty analysis, commencing with the base case scenario followed by two other scenarios with differing vertical permeability values.

Specifically, this involved using a simplified single time slice, rather than several time slices, for the period up to the end of UG1 – Mine Year 14. Vertical permeability values for model layers L5 and L6 (subsidence zone) and L7 (the Ulan Seam – goaf zone) were retained at the base case values up to this time. Thereafter the Ramp function was used to derive the MCC underground mining fracture zones from L1 to L7 as well as the underlying Marrangaroo Formation. In a second uncertainty run, the values of vertical permeability were increased for these layers by an order of magnitude.

Table 5.10: Uncertainty Analysis Model Hydraulic Properties

Layer	Aquifer	MEDIAN THICKNESS	Host permeability values		Base Case Model following MCC UG mining		Model using enhancement of overburden Kv according to Ramp Function		Model using enhancement of overburden Kv according to Ramp Function X 10	
		(m)	Kh(m/d)	Kv(m/d)	Kh(m/d)	Kv(m/d)	Kh(m/d)	Kv(m/d)	Kh(m/d)	Kv(m/d)
1	Alluvial	10	3	0.01	no change	no change	6	0.05	6	0.5
1	Regolith	10	0.5	0.001	no change	no change	1	0.005	1	0.05
2	Upper Triassic	1 (thickness of 1m at MCC increases in a wedge shape towards the north)	0.5	0.0001	no change	no change	1	0.0001	1	0.0014
3	Lower Triassic	30	0.2	0.00005	no change	no change	0.4	0.0005	0.4	0.0048
4	Upper Permian	25	0.001	0.000025	no change	no change	0.2	0.0007	0.2	0.0066
5	Middle Permian	25	0.001	0.000025	0.01	0.001	0.2	0.001	0.2	0.01
6	Lower Permian	50	0.001	0.00001	0.01	0.004	0.1	0.001	0.1	0.01
7	Ulan Coal Seam	10	1	0.0005	10	10	10	10	10	100
8	Marrangaroo Formation	100	0.1	0.00001	no change	no change	0.2	0.00003	0.2	0.0003

The simplified approach of running a single time slice model for the uncertainty analysis was done for reasons expediency in modelling and simplicity in comparing and interpreting results. It means that all mining areas are assumed to be active throughout the simulation rather than progressively activated, and leads to a higher rate of inflow compared with the base case model described above in Section 5.7. This occurs because the assumed mine area is much larger, and the enhanced overburden permeabilities are invoked over the full life of mine area from day 1. However, this approach involves a much shorter model run time, and is therefore suitable for doing comparative impact assessment of different scenarios based on changes made to the critical parameters, such as higher or lower subsidence fracture heights or permeabilities.

Figure 5.5 illustrates the predicted dewatering rates with increased vertical hydraulic conductivities in the subsidence zone (L5 and L6) and goaf zone (L7), compared with the base case prediction using a single time slice simulations.

It is seen that the Ulan Coal Mine inflows are predicted by the Base Case 30-time slice model to be around 5ML/d up to 2000, before increasing to a peak rate of around 15ML/d by 2022, when mining of the Ulan North area is completed, thereafter inflows again fall to around 5ML/d. However, with the single time slice model, Base Case Ulan Coal Mine inflows start at around 10ML/d, increase to 19ML/d at 2010, and then decline steadily to around 12ML/d 2023.

However, the two uncertainty model runs using the Ramp Function predicted slightly higher inflow rates overall to the Ulan Coal Mine. The first Ramp Function run predicted inflow rates about 20% higher, but by 2010, inflow rates are similar to the Base Case inflows. The second run, which again uses the Ramp Function, but also assumes vertical permeabilities 10 times higher in the subsidence zone overburden compared with the first uncertainty run, predicted inflows that are initially 50% higher than the Base Case, but they too eventually (by 2013) are similar to those in the Base Case.

The MCC inflows are predicted by the 1-time slice model to be more than double those predicted by the 30-time slice model, but at much lower magnitude than the Ulan Coal Mine inflows. However, the uncertainty analysis runs using the Ramp Function predicted MCC inflow rates that were almost identical to the 1-time slice Base Case prediction.

In summary, the uncertainty analysis modelling has shown that higher fracture heights and higher subsidence fracture zone permeabilities would lead to slightly increased inflows to the Ulan Coal Mine, but have a negligible impact on inflows to the MCC mine workings.

5.10 Recovery Simulation

The post-mining recovery run was conducted using the results from the end of the MCC dewatering predictions, i.e. conditions at the end of Mine Year 30, as the initial conditions. The recovery period was set at 100 years to provide an adequate timeframe that would obtain a meaningful depiction of the long-term post mining recovery situation.

Aquifer parameters representing backfill were applied in the MCC and Wilpinjong Coal Mine open cuts, except for final voids. The MCC open-cuts will mostly be backfilled to above the pre-mining water table, but four small final voids will remain. These are in the central and northern parts of OC1 (where portals to UG1 and UG4 are located), at the eastern end of OC4 (the final location of open cut mining), and at the southern end of OC3, although only the OC1 and OC4 voids are expected to be below the regional groundwater level.

The storage properties adopted for the recovery modelling are listed in Table 5.11.

Goaf and fracture zone parameters above both Ulan Coal Mine and the MCC underground mine areas were retained in the model throughout the recovery simulation. Backfilled open cut parameters were adopted for all open cut mined areas except the final voids, where void properties were adopted.

All mine drain cells were deactivated for both open cut and underground areas in the recovery run.

Table 5.11: Recovery Storage Parameters

Mine	Layer	Open cut areas, and fracture zones above LW panels		Host parameters – outside LW panels and open cuts	
		Confined S	Unconfined Sy	Confined S	Unconfined Sy
MCC UG	7	1.50E-04	0.07	5.00E-05	0.01
MCC UG	6 and 5	1.50E-04	0.03	5.00E-05	0.005
Ulan UG	7 and 3	1.50E-04	0.05	5.00E-05	0.01
Ulan UG	6, 5 and 4	1.50E-04	0.025	5.00E-05	0.005
Backfilled Open Cut	1 to 7	5.00E-05	0.10	5.00E-05	0.01
Open Void	1 to 7	5.00E-05	0.99	5.00E-05	0.01

Hydrographs of predicted water level recovery at key MCC monitoring bore sites are included in Appendix K.

At the end of the 100 year recovery period, water levels in Layer 1 are predicted to be essentially the same as pre-mining levels.

In Layer 2 (upper Triassic), 100 year recovery water levels around the Ulan Coal Mine are predicted to be still several metres lower than pre-mining, while in Layer 3 (lower Triassic) water levels are predicted to substantially recover, in some locations to higher than pre-mining levels. This pattern of response is believed to be the result of subsidence fracturing extending up into the Triassic above the 400m wide longwall panels, effectively connecting the upper and lower Triassic into a single unit in those areas, whereas pre-mining the upper Triassic was generally a perched aquifer with heads higher than those in the lower Triassic.

There are no upper Triassic bores near the MCC, and the hydrographs for the lower Triassic bores near UG4 (Imrie bore, PZ105C, PZ101C, PZ129-35m) all show minimal drawdowns during the mining phase, and full recovery post-mining.

Groundwater levels in the Permian overburden (model Layers 4, 5 and 6) are predicted to recover partially, but not completely, across the areas around OC4, but in areas closer to Ulan Coal Mine, i.e. around OC1-2 and UG4, groundwater levels are predicted to recover to higher than pre-MCC levels, as they were affected by long-term mining at Ulan Coal Mine by the time the MCC commenced.

Groundwater levels in the Ulan Seam (model Layer 7) are predicted to recover partially but not completely in the southern parts of the MCC area around OC4. However, in other parts of the Project Boundary, and around Ulan Coal Mine, groundwater levels are predicted to recover to above pre-MCC levels, as the pre-MCC heads are affected by long-term mining at Ulan Coal Mine.

5.11 Baseflow

The rivers, streams and surface drainage features of the Project Boundary were divided into ‘reaches’ within the MCC groundwater model in order to evaluate the groundwater discharge (baseflow) contributions to the Goulburn River, and the Wilpinjong, Moolarben, Lagoon, Murragamba, and Ulan Creek systems. Figure 5.6 shows the location of these reaches (numbered R101 to R111). Reach R112 and R113 represent the combined total catchments of the Goulburn River (R112) and Wilpinjong Creek (R113).

Tables 5.12 and 5.13 summarise the predicted river/creek baseflow and predicted river leakage volumes at key stages during the mine life and post-mining. Some of the minor tributary creeks which have no baseflow, such as Eastern Creek, are not included in these tables.

In Lagoon Creek and the middle reach of Moolarben Creek, predicted baseflows are in the order of 1365 to 1393m^3/d and 1394 to 1433m^3/d respectively until the end of mining operations and reaching respective values of 1383m^3/d and 1499m^3/d by the end of recovery.

Across the Wilpinjong Creek catchment (Wilpinjong, Wilpinjong North, Murragamba and Wollar Creeks), total predicted baseflow volumes at the start of mining operations are approximately

996m^3/d. Rates decrease to a minimum of 599m^3/d at the end of the MCC before again recovering to rates above initial mining conditions (1015m^3/d) at the end of the recovery period.

Modelling of river / creek flows to groundwater (by leakage) along the various reaches predicts that Lagoon Creek, and both the upper and middle section of Moolarben Creek, lose some of their flows to groundwater, at rates that are predicted to remain relatively stable through the mining and post-mining recovery periods.

Modelling predicted no leakage of river / creek flows to groundwater in the Wilpinjong Creek catchment (i.e. Wilpinjong Creek is a ‘gaining’ watercourse).

Table 5.12: Predicted Creek/River Baseflow (m^3/d)

Reach	R101	R102	R103	R104	R105	R106	R107	R108	R109	R110	R111	R112*	R113**
	Lagoon Creek	Moolarben Creek Upper	Moolarben Creek Middle	Ulan Creek	Goulburn River West	Goulburn River Tributary	Murragamba Creek	Wilpinjong Creek North	Wilpinjong Creek	Wollar / Cumbo Creek	Goulburn River eastern extent	Goulburn River catchment	Wilpinjong Creek catchment
Start of OC4 (SP15 end of 2011)	1365	701	1433	0	492	0	113	69	116	699	13280	17271	996
Start of UG4 (SP29 end of 2025)	1388	658	1416	0	390	0	0	33	11	710	10972	14825	754
End of OC4 (SP35 end of 2031)	1392	656	1394	0	383	0	0	25	2	622	10254	14079	649
End of mining (SP46 June 2042)	1393	675	1416	0	382	0	2	23	0	576	9288	13154	599
End of Recovery (SP47 end 2142)	1383	650	1499	0	444	0	124	33	60	799	5750	9732	1015

Table 5.13: Predicted Creek/River Leakage to Groundwater (m^3/d)

Reach	R101	R102	R103	R104	R105	R106	R107	R108	R109	R110	R111	R112*	R113**
	Lagoon Creek	Moolarben Creek Upper	Moolarben Creek Middle	Ulan Creek	Goulburn River West	Goulburn River Tributary	Murragamba Creek	Wilpinjong Creek North	Wilpinjong Creek	Wollar / Cumbo Creek	Goulburn River eastern extent	Goulburn River catchment	Wilpinjong Creek catchment
Start of OC4 (SP15 end of 2011)	2269	200	3426	1	1341	0	0	0	0	0	23	7261	0
Start of UG4 (SP29 end of 2025)	2259	200	3421	1	1712	0	0	0	0	0	116	7709	0
End of OC4 (SP35 end of 2031)	2260	200	3424	1	1754	0	0	0	0	0	171	7809	0
End of UG4 (SP46 June 2042)	2259	200	3422	1	1782	0	0	0	0	0	270	7934	0
End of Recovery (SP47 end 2142)	2255	200	3389	0	1613	0	0	0	0	0	469	7925	0

Note: * R112 represents the summation of reaches R101, R102, R103, R104, R105, R106 and R111 ** R113 represents the summation of reaches R107, R108, R109, and R110

6. POTENTIAL GROUNDWATER IMPACTS

6.1 Overview of Potential Impacts on the Groundwater System

Mining activities associated with the operation of the MCC will impact on the groundwater environment on a local scale and, to a more limited extent, regional scale. Potential impacts on the groundwater system may include the following, each of which is discussed in further detail in the following sections:

- Groundwater level impacts (during and post-mining);
- Potential impacts on groundwater and surface water quality;
- Potential impacts on baseflow to Goulburn River (including "The Drip"), Wilpinjong Creek, Murragamba Creek, Moolarben Creek and their associated tributaries;
- Potential impacts on other groundwater users; and
- Potential impacts on GDEs.

In addition this section includes discussion of the potential impacts of subsidence cracking on the hydraulic properties of the strata overlying the underground mines UG1 and UG2. These impacts are based on subsidence predictions by Mine Subsidence Engineering Consultants Pty Ltd (MSEC, 2011).

Finally, the longer-term impacts of the final pit voids are discussed.

The base-case groundwater model was designed to predict the impacts of all three coal mines – Ulan Coal Mine, Wilpinjong Coal Mine and MCC – each operating concurrently in accordance with their respective mine plans. Ulan Coal Mine, Wilpinjong Coal Mine and the MCC are sufficiently close to each other that impacts from each will mutually interfere. The base-case modelling therefore assessed the cumulative impacts of all three mines operating concurrently.

The MCC mine plan and schedule adopted in the modelling are as outlined in Section 5. The forward mine plans and schedules for both Ulan and Wilpinjong coal mines have been assumed on the basis of publicly available information.

6.2 Groundwater Level Impacts

Figures 6.1a to 6.7a show the predicted groundwater levels for each model layer six months after completion of underground mining. This accommodates a half year period of post mine fracturing after year 30 (to end June 2042). It has been assumed in the modelling that the MCC and Wilpinjong Coal Mine would have both ceased production by this time with parts of the mined areas already showing some recovery of residual drawdown impacts prior to the end of mining.

Drawdown contours of the predicted cumulative impact to groundwater levels arising from the MCC and Ulan and Wilpinjong coal mines have also been prepared and are presented, for each layer, in Figures 6.1b to 6.7b. Contours of drawdown impacts due to MCC only are shown in Figures 6.1c to 6.7c.

Large cones of depression centred on the Ulan Coal Mine mining operations are evident in the Ulan Seam and lower Permian (Figures 6.1b and 6.2b), and less pronounced cones of depression in the middle and upper Permian (Figures 6.3b and 6.4b) and lower and upper Triassic (Figures 6.5b and 6.6b). There are only localised drawdowns in the Surficial Aquifer System (Figure 6.7b).

Around the Project Boundary, prominent drawdown cones are predicted in the Ulan Seam and the Permian overburden layers (Figures 6.1b to 6.4b), but very limited local drawdowns in the Triassic layers (Figures 6.5b and 6.6b).

6.2.1 Pre-MCC Groundwater Levels in the Permian Coal Measures

Groundwater levels within the Permian have already been extensively impacted by the dewatering extractions of groundwater at Ulan Coal Mine. Groundwater monitoring records show local water-level drawdown in the Ulan Seam of as much as 120m, with lesser drawdowns throughout the Permian overburden. The impacts from historical Ulan Coal Mine mining operations also extend into the proposed MCC mining areas, particularly UG4, where up to 40m of drawdown has already occurred (within the Ulan Seam) along the western margin of UG4.

Ulan Coal Mine monitoring data indicate that up to the end of 2006, the dewatering of the Ulan Seam and the overlying Permian had resulted in minimal impact on groundwater levels in the Triassic sediments. However, since the beginning of 2006, localised large drawdown impacts have been observed in the lower Triassic, coinciding with the introduction at Ulan Coal Mine of 400m wide longwall panels (longwall panels were previously 208m in width).

6.2.2 Predicted Impacts on Groundwater Levels in the Permian Coal Measures

The most significant impacts to groundwater levels are predicted to occur within the Permian coal measures, specifically within the Ulan Seam, which as the targeted resource requires dewatering prior to mining.

In OC1 to OC4, UG1 and UG2, where the Ulan Seam and the lower Permian coal measures are only partially saturated, limited dewatering may be required. However, in the area of UG4, the Ulan Seam is fully saturated and with up to 80m of confined head, substantial dewatering will be required.

It is proposed to use a borefield located around UG4 to facilitate the required dewatering, in conjunction with natural inflows to the workings. This borefield will also be used to provide make-up water supply, to meet any shortfall between the natural groundwater inflows and the MCC's water demand for dust suppression and coal washing.

In the area south of the Wollar Road and the railway line, which includes the areas for the proposed OC4, UG1 and UG2 mines, the Ulan Seam is only partially saturated. Water levels in the Ulan Seam are up to 90m or more lower than in the overlying sediments (e.g. PZ112A and B; PZ150 and PZ152; PZ133, etc – see Figure 2.1 and hydrographs in Appendix E). Further downdip to the north, where the Ulan Seam is overlain by progressively greater thicknesses of Permian overburden and Triassic and Jurassic sediments, the Ulan Seam becomes fully saturated, and here, apart from where affected by mining-induced impacts from adjacent mines, groundwater levels in the Ulan Seam are broadly similar to those in the overlying Permian and Triassic.

The very low groundwater levels in the Ulan Seam in the southern part of the Project Boundary are not the result of any mining-induced impact. This area is remote from Ulan Coal Mine, and the low groundwater levels were recorded prior to the commencement of groundwater pumping from the Wilpinjong Coal Mine.

Predicted groundwater levels in the Ulan Seam at the completion of MCC mining from the cumulative impacts model are shown in Figure 6.1a. Predicted cumulative drawdowns are shown on Figure 6.1b, and drawdowns due to MCC are shown on Figure 6.1c. Predicted drawdowns of 5m or more due to MCC extend to approximately 16km from the MCC area.

Predicted water levels in the overlying Permian overburden at the completion of the MCC (Mine Year 30 – 2041) are shown on Figure 6.2a, 6.3a and 6.4a (for the lower, middle and upper Permian overburden model layers).

Total predicted drawdowns in these layers due to cumulative impact are shown on Figures 6.2b, 6.3b and 6.4b respectively, while the drawdowns due to the MCC are shown on Figures 6.2c, 6.3c and 6.4c. Drawdowns of 5m or more due to the MCC are predicted to extend to approximately 13km in the lower Permian, and 8-9km in the middle and upper Permian to the north and east of UG4. Note that there is some drawdown impact from the MCC in the vicinity of the Ulan Coal Mine. This is believed to be due to the increase in vertical hydraulic conductivity above the Ulan seam caused by subsidence fracturing at the Ulan Coal Mine. This increased conductivity appears to allow some impact from the MCC to be transmitted across to Ulan Coal Mine via the Ulan Seam, then upwards into the Permian overburden units via the more conductive subsidence zone. Thus the model predicts greater drawdown impacts from the MCC in the Permian overburden units within the footprint of the Ulan Coal Mine underground mine than in areas outside the Ulan Coal Mine footprint.

Modelling of groundwater level recovery (undertaken for a model run time of 100 years after completion of mining at the MCC) shows water levels in the Ulan Seam and overlying Permian formations will recover to at least, and in many cases above, present day levels. Predicted groundwater levels 100 years after completion of the MCC are shown in Figures 6.1d, 6.2d, 6.3d and 6.4d for the Ulan Seam, lower Permian, middle Permian and upper Permian respectively.

6.2.3 Predicted Impacts on Groundwater Levels in the Triassic Narrabeen Group

Predicted groundwater levels in the Triassic Narrabeen Group at the completion of mining at the MCC (Mine Year 30 – 2041) are shown in Figures 6.5a and 6.6a for the lower Triassic and upper Triassic model layers respectively. Cumulative drawdowns are shown in Figures 6.5b and 6.6b, while drawdowns due to MCC only are shown in Figures 6.5c and 6.6c respectively.

Across the majority of the MCC, the Triassic is presently unsaturated. Groundwater is present in the lower Triassic in the very northern end of UG4, but the saturated depth ranges between 0m and about 12m. Above the southern half of UG4 and all of UG1 and UG2, the Triassic is unsaturated.

Figure 6.5b shows predicted cumulative drawdowns in the lower Triassic. MCC only impacts are shown on Figure 6.5c, which shows partial dewatering of the Triassic (i.e. drawdowns of up to 5m maximum) above the UG4 mine, but less than 2m drawdown immediately outside the UG4 mine footprint. However, drawdowns exceeding 10m are predicted to occur above the northern portion of the Ulan Coal Mine underground mine, where 400m wide longwall panels have been assumed in the model, due to the increased vertical hydraulic conductivity resulting from subsidence fracturing above the Ulan goaf.

It is seen that the predicted drawdowns due to the MCC in the lower and upper Triassic model layers are greater above the Ulan Coal Mine underground mine than they are close to the MCC. This is due to the vertical enhancement of permeability above the 400m wide longwall panels of the Ulan Coal Mine underground mine as a result of subsidence fracturing, which provides a more permeable pathway for groundwater flow down from the Triassic into the former Ulan Coal Mine workings, then laterally across to the MCC via the permeable Ulan Seam, than directly across in the Triassic strata themselves.

With 400m wide longwall panels, it has been assumed in the model that hydraulic conductivity would be affected up into the lower Triassic, whereas hydraulic conductivity increases only extend up to the upper Permian model layer above 208m wide longwalls, consistent with observed impacts from pre-2006 mining at Ulan Coal Mine.

As the MCC longwall panels are proposed to be 208m wide, the impacts on the lower Triassic above UG4 will be much less.

The groundwater model (conservatively) predicts partial saturation of the upper Triassic above the northern end of UG4, although drilling has revealed that the upper Triassic is unsaturated across the entire UG4 area, as well as across UG1 and UG2. There is no Triassic in the vicinity of OC4. Predicted groundwater levels for the upper Triassic at the end of MCC mining (Figure 6.6a) show no noticeable cone of depression around the UG4 mine. The plot of predicted drawdown in the upper Triassic due to the MCC (Figure 6.6c) shows less than 1m drawdown across the MCC Project Boundary, but a small area of >2m drawdown above the Ulan Coal Mine 400m wide longwall panels, and again is believed to be due to the increased hydraulic connection between the Ulan Seam and the upper and lower Triassic within the Ulan Coal Mine footprint.

6.2.4 Predicted Impacts on Groundwater Levels in the Quaternary Alluvium

Goulburn River and Wilpinjong Creek catchments

Predicted modelling shows the proposed mining at the MCC to have minimal impact on the alluvium in the Goulburn River and Wilpinjong Creek areas. Drawdowns of more than 2m will occur immediately downstream of OC4, extending a distance of about 700m from the pit boundary. Similarly, drawdowns exceeding 2m are predicted to extend up to 700m from OC1 into the Moolarben Creek valley.

The east-west valley immediately south of UG4 contains the surface divide between Goulburn River and Wilpinjong Creek. It contains the minor tributary Bora Creek (flowing westerly to Goulburn River) and the upper part of the east-flowing Wilpinjong Creek catchment. The valley contains a well-developed Quaternary alluvium up to 10m or more in thickness which elsewhere is generally partly saturated, however, drilling data show this area to be dry, with the water-table situated below the base of the Quaternary alluvium within either the Permian (in the west) or Tertiary deposits (in the east).

Moolarben Creek – Lagoon Creek Catchment

As reported in the Stage 1 groundwater impact assessment (PDA, 2006a), Stage 1 of the MCC will have no significant impact on the alluvium in the Moolarben Creek – Lagoon Creek area, as shown in Figures 6.7a and 6.7b. As the Stage 2 mining activities are further from this catchment, Stage 2 is likewise predicted to have no impact.

The Moolarben Creek - Lagoon Creek system, a tributary of the Goulburn River, lies to the west of the MCC, and in its southern section is contained within a well-defined incised channel, before fanning out across a broad plain approximately level with the northern end of Munghorn Creek Nature Reserve.

Quaternary alluvium has been recorded in both the defined, narrow channel area associated with Moolarben Creek in the south, and with Lagoon Creek further downstream to the north. From drilling results, it is believed that Quaternary alluvium associated with Lagoon Creek has a maximum depth of 10m, but is likely much shallower adjacent to Moolarben Creek. No alluvium has been recorded throughout the central portion of Moolarben Creek.

Murragamba Creek Catchment

Quaternary alluvium is very poorly developed in the Murragamba Creek catchment. The Tertiary palaeochannel deposits within the Murragamba Creek catchment are sporadically saturated, and contain saline groundwater. Within the footprint of OC4, these deposits will be removed by mining. A temporary impact on groundwater levels in the downstream extension of these deposits within the Wilpinjong Creek valley is predicted, but groundwater levels are expected to fully recover post-mining.

The Drip

There is no possibility that high level seepages such as the Drip are derived from groundwater under pressure rising from depth. For that to occur, the recharge zones for that deeper groundwater would need to be at a much higher elevation than the Drip, but the area is close to a regional topographic high, being near the top of the Great Dividing Range. In our assessment, there is no locality at sufficiently high elevation within feasible distance of the MCC to be able to influence deep groundwater to emerge at elevations such as the Drip.

The Drip and other similar seepages visible on the cliffs along Goulburn River to the north of UG4 are derived from perched aquifers situated well above any aquifers hydraulically connected with the proposed underground workings (Figure 2.5), and are also situated outside the area of potential impact from either subsidence or subsurface cracking. They are also located outside the area capable of potential impact from surface cracking (Strata Engineering, 2006).

Consequently, the Drip and other similar seepage zones along Goulburn River will not be affected by either subsidence or mine dewatering associated with the MCC.

6.3 Pressure Head Profiles

Further graphical indication of predicted impacts is provided with pressure head plots illustrated in Figures 6.9 to 6.11. These show pressure heads along four cross-sections – a north-south section along Column 154 of the model, and three east-west sections along Rows 207, 250 and 292 – as shown on Figure 6.8. Figures 6.9a, b, c and d show pressure profiles on the four cross-sections pre-MCC mining. Similarly, Figures 6.10a, b, c and d show pressures at the end of MCC operations; and Figures 6.11a, b, c and d show pressures after 100 years post-mining recovery.

Post mining levels show residual pressures incorporating the impacts of all open cut and underground mining activities. Figure 6.10a shows partial recovery to the north of UG1 and also in the northern part of UG4. A steep drawdown cone is evident to the North of UG4, with groundwater levels/pressures unaffected in the vicinity of 'The Drip'[2]. The Triassic strata remain partly saturated right through the mine life and beyond in the area north of UG4. It should be noted that 'The Drip' has not been represented in the model, as it is supported by local perched aquifers in the Triassic strata, and these local perched aquifers are not sufficiently regional to represent in the model. The perched aquifers supporting 'The Drip' and other seepages are located on the northern side of the Goulburn River.

The sections representing the post-mining recovery pressures (Figures 6.11a to d) show that water levels/pressures are fully restored in almost all areas. In western/central parts of the three East cross-sections, post-mining pressures are higher than pre-mining, as the pre-mining levels include the effects of many years of mining at Ulan Coal Mine.

6.4 Groundwater and Surface Water Quality Impacts

The water quality of mine inflows, both to open-cuts and underground workings, is expected to initially comprise a composite blend of the water derived from each of the aquifers intercepted by each mine. Indicative water quality parameters, based on averaging the water analyses from monitoring bores within the vicinity of each mining area, are provided in Table 6.1.

It is expected that there will be some variation in inflow quality from year to year within each area, and the open-cuts in particular may see broad annual fluctuations about the averages due to the spatial variability in water quality. In the case of OC4, there is likely to be an increase in salinity and a similar accompanying change in some of the other quality parameters, as more saline surficial groundwater is intersected near the northern end of the mine footprint, during Mine Years 8 to 11. Subsequently, salinity may gradually reduce as the mine progresses into the Eastern Creek area, where groundwater quality is expected to be less saline.

In the case of OC2 and OC3, dewatering may slightly reduce the volume of groundwater baseflow, and hence result in a reduction in the proportion of more saline discharges to local creek systems. A corresponding slight improvement in the average water quality of Moolarben Creek and Lagoon Creek, and, therefore, a positive effect on the water quality in the Goulburn River is likely.

Table 6.1: Initial Mine Inflow Water Quality – Indicative Average pH, EC and TDS

Parameter	**Mine Area**						
	OC1	**OC2**	**OC3**	**OC4**	**UG1**	**UG2**	**UG4**
pH	6.0	4.7	5.7	5.9	6.1	5.8	6.7
EC (µS/cm)	830	690	4330	3570	900	3280	1030
TDS (mg/L)	470	500	3080	2540	470	3040	450

6.5 Potential Baseflow Impacts

The predicted baseflow amounts and leakages to groundwater along selected river reaches are summarised in Table 5.12 and Table 5.13 respectively. These selected river reaches are numbered as shown on Figure 5.6. The predicted amounts refer to the combined impacts of the various mining activities in the area. The Murragamba and Eastern creeks are ephemeral systems in which baseflow is insufficient to maintain permanent creek flow within the MCC area. Both creeks flow into Wilpinjong Creek. Eastern Creek is not included in the above mentioned tables as it is usually dry between rainfall events. Although intermittent, the baseflow amounts prior to the commencement of Stage 1, as predicted by the groundwater model, were 113m^3/d in Murragamba Creek (reach 107) and 69m^3/d in Wilpinjong Creek North (reach 108 which is upstream of the Murragamba Creek confluence). These are the main reaches within the drawdown zone of OC4.

Additionally, Table 5.12 and Table 5.13 include other relevant river reaches so that the entire area affected by OC4 and UG4 is presented within the context of the combined drawdown effects of regional mining developments.

[2] 'The Drip' is not shown on the Column 154 section, as it is located a few hundred metres east of the section.

The model therefore predicts baseflow decreases in Wilpinjong Creek, which are not exclusively due to mining at the MCC.

From Table 5.12 it can be seen that post-mining recovery of baseflow amounts will in most cases be less than the those of present (2011) day conditions, however some exceptions occur downstream of the mining areas. For example, the baseflows in the lower reaches of combined Wilpinjong Creek and Wollar Creek near their confluence with the Goulburn River (reach R113) are predicted to recover to levels above pre-MCC baseflow amounts. This does not imply that these recoveries will have reached conditions higher than those under natural circumstances. The pre-MCC baseline condition includes impacts from other mines and therefore natural baseflow conditions may have been higher.

The regional Goulburn River, Moolarben Creek and Lagoon Creek baseflow impacts were addressed in the Stage 1 EA assessment reports (PDA, 2006a and 2007a). No additional baseflow impacts on these streams are predicted in this report to occur as a result of Stage 2.

6.6 Potential Impacts on Groundwater Dependent Ecosystems

GDEs are defined by ARMCANZ/ANZECC (1996) as ecosystems which have their species composition and their natural ecological processes determined by groundwater. The assessment of potential impacts of the MCC on GDEs has been carried out in accordance with the NSW Groundwater Dependent Ecosystems policy (DLWC, 2002), as reported in the Ecological Impact Assessment report prepared by Ecovision Consulting and Marine Pollution Research (Ecovision, 2008).

Groundwater dependant sites, such as springs, dams, soaks and seeps, located within the areas of OC4 are likely to be permanently lost. Table 6.2 provides an inventory of the surface water and groundwater sampling sites within the Preferred Project's open cut mining area. There is also the potential for sites directly overlying underground mining areas to be impacted should subsidence cracking extend to surface, however, this is only likely where the depth of cover is sufficiently low and there is an absence of aquiclude within the overburden sequence.

Based on the predicted subsidence impacts (MSEC, 2011), it is assessed that subsidence above UG1 and UG2 will have a negligible effect on water quality and quantity within any drainage areas that may be affected by subsidence cracking. Where any cracking does occur, the backfilling of cracks is expected to occur relatively quickly after mining, therefore minimising direct infiltration of surface flows to the underlying strata.

Table 6.2: Permian Coal Measures – Surface Water and Groundwater Sites within Open Cut Mine Footprint

Site Description	Site ID
Dam / Soak	SP4, SP10, SP11, SP18, SP50-SP58, SP61 to SP63, SP64, SP74 to SP76, SP104 to SP107, SP109 to SP110, SP113, SP114, SP117, SP119, SP20-SP121, SP125, SP131, SP133-SP135, SP143
Spring / Well	SP20,SP111, SP115
Creek	SP112, SP118, SP127
Bore	SP116, GW024774, GW034640
Seep	SP59
Waterhole	SP122 to SP124, SP126, SP132

6.7 Potential Impacts on Existing Groundwater Users

A number of existing groundwater users have been identified within a 10km radius of the MCC (Aquaterra, 2009a), including:

- Registered groundwater bores and wells; and
- Unregistered bores, wells, springs, seepages and possible groundwater-fed dams or soaks.

The potential impacts on each of these water sources as a result of MCC operations only has been assessed by reference to the predicted drawdowns due to the MCC in Figures 6.1c to 6.7c, and is summarised in Appendix L.

All groundwater features listed in Appendix L, apart from those that have been abandoned due to damage or disrepair, have been considered to be potential water supply sources, even though it is clear that many are not used and are unlikely to ever be used for water supply purposes. The list includes a number of registered Ulan and Wilpinjong coal mine monitoring bores. Many of the others are on land now owned by MCM.

A number of apparently unregistered water supply bores were revealed by the census survey in the Moolarben Creek and Murragamba Creek valleys. These include domestic water supply bores at the Croydon and Fernmount properties (SP7 and SP12); Hay Shed bore (SP39); and Clarkes Gully bore (SP42). All were still in use at the time of the census survey.

A number of abandoned wells or bores were also identified, including unregistered wells SP20, SP27 and SP28 on the Swords property; SP60 (inside Munghorn Gap Nature Reserve); a dry well SP70 on the Simpson property; wells SP111 and SP115, and bores SP116 and SP146 on the Mitchell property; and a well SP138 and spring SP141 on the Powers property.

6.7.1 Potential Impacts on Quaternary Alluvium Sites

It is predicted that none of the Quaternary alluvium water supply sources will be impacted by the MCC (see Appendix L).

6.7.2 Potential Impacts on Sites in Tertiary Palaeochannel Deposits

There are no existing groundwater supplies associated with the Tertiary palaeochannel deposits, (see Appendix L).

6.7.3 Potential Impacts on Sites in the Triassic Narrabeen Group

Five registered bores completed in the Triassic are predicted to undergo small impacts from the MCC. The maximum prediction drawdown due to the MCC is 0.6m, while all other impacts are predicted to be less than 0.4m.

Bore GW078317 (Williams) is predicted to undergo drawdown impact of 0.6m by the completion of the MCC, and to have a residual drawdown of 0.4m at the completion of the 100 year recovery period.

Maximum drawdowns of 0.1-0.2m are predicted at four other registered bores (GW064580 – 0.2m; GW05378 – 0.1m; GW030361 – 0.2m; GW034454 – 0.2m), all of which are predicted to fully recover post-mining. Bores at UCML's Bobadeen irrigation area are predicted to experience drawdowns of up to 0.4m, with post mining residual drawdowns of up to 0.2m.

These predicted drawdown impacts are not considered large enough to affect the performance of any of the bores.

6.8 Final Pit Voids

Four final pit voids will remain at the completion of the MCC – two in OC1 (where the portals to UG1 and UG4 are located), one at the southern end of OC3 (where mining ceases) and another at the far eastern extremity of OC4 (completion of open cut mining).

Groundwater levels are predicted to rise above the void floor levels in the OC1 and OC4 voids, but the OC3 void is expected to be at or above final equilibrium groundwater level.

7. MONITORING AND MANAGEMENT

7.1 Impacts of Groundwater Extraction / Dewatering

It is recommended that the groundwater environment is monitored closely through the life of MCC. This would include:

- The volume and quality of water discharged from the mine (from each open cut and underground mine, as well as total inflows);
- The volume and quality of water pumped from dewatering and water supply bores;
- The regular measurement of groundwater levels in all pumping bores; and
- The current baseline monitoring program (of groundwater quality and water level measurement) be continued.

Regional groundwater and surface water monitoring network rationalisation was undertaken by Aquaterra in 2009 (Aquaterra, 2009b), and the report concluded that all three mines have sufficient groundwater monitoring network to provide good regional spatial coverage. However, there is potential to rationalize the monitoring program for the MCC and Ulan Coal Mine by sharing the data at several locations where duplication exists and/or data sharing can provide benefits to the mining operations.

Data collected will enable the MCC to establish, and continually assess, the impact mining activities have on other groundwater users and the groundwater environment. Collection of these data will also enable continual periodic review of any observed impacts against those predicted during numerical modelling, and will allow further refinement of Model MC2.2 if necessary as the mine develops.

It is recommended that the MCC monitoring program includes recording of the following along with and in addition to the licensing conditions as specified in licensing requirements required by NOW:

- Groundwater extraction volumes – weekly totals from each pumping bore, and weekly totals from each underground pumping station and open cut sump;
- Groundwater pumping from sumps and underground pumping stations;
- Quarterly sampling from all pumping bores, sumps and underground pumping stations for comprehensive hydrochemical analysis as detailed in Table 7.1;
- Monthly manual monitoring, or continuous automated monitoring, of water levels from the network of monitoring bores; and
- Annual sampling of representative monitoring bores for laboratory analysis (as outlined in Table 7.1).

Table 7.1: Recommended Laboratory Analysis Suite for Groundwater

Class	Parameter
Physical parameters	EC, TDS, TSS and pH
Major cations	calcium, magnesium, sodium and potassium
Major anions	carbonate, bicarbonate, sulphate and chloride
Dissolved metals	aluminium, arsenic, boron, cobalt, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, selenium, zinc
Nutrients	ammonia, nitrate, phosphorus, reactive phosphorus
Others	Fluoride, cyanide

7.2 Subsidence Impact Monitoring

A comprehensive monitoring program was recommended to investigate the subsidence impacts above UG4 (PDA, 2006a) due to its proximity to the Goulburn River. A similar program is not required above UG1 or UG2, as the Triassic and surficial sediments are unsaturated in those areas and due to their comparative remoteness from the Goulburn River. Although the Triassic is dry in this area, monitoring bores (multi-level vibrating wire piezometers) are in place to enable ongoing monitoring.

7.3 Review and Reporting

Collated monitoring data should be subjected to an annual review by an approved experienced hydrogeologist in order to assess the impacts of the MCC on the groundwater environment, and to compare any observed impacts with those predicted from groundwater modelling.

It is also recommended that, in accordance with industry best-practice (MDBC, 2001), two years after commencement of coal production a modelling post-audit be carried out. Following this review, if necessary, Model MC2.2 should be re-calibrated and confirmatory forward impact predictions made and reported against in the Annual Review. Further post-audits should be carried out five-yearly through the remainder of the life of the MCC.

Should any review or post-audit indicate a significant variance from the model predictions with respect to water quality or groundwater levels, then the implications of such variance should be assessed, and appropriate response actions implemented in consultation with NOW, DP&I and OEH as appropriate.

It is strongly recommended that the integrated monitoring program involving MCM attempting to form a partnership and data-sharing among the MCC, Ulan and Wilpinjong coal mines as described in Aquaterra (2009b) be implemented.

8. CONTINGENCY RESPONSE PLANS

8.1 Recommendation for Development of Response Plans

It is recommended that a response program be adopted for implementation in the event of unforeseen adverse impacts on the groundwater environment from the MCC. The response plans would be in accordance with those outlined in the revised Water Management Plan (incorporating Groundwater) developed for the approved Stage 1, with specific consideration, where required, of issues relating to Stage 2 operations.

The sections below detail the proposed approach for the management of groundwater levels and water quality outlining the criteria by which each would be assessed in order to determine the need to implement mitigation actions as outlined in the response plans. It should be noted that as groundwater levels and quality will naturally vary over time that the setting of ANZECC (2000) specific trigger-levels, for either quality parameters or water-levels, is not considered practical. For example, water levels will vary considerably across the MCC in response to natural climatic variations and recharge patterns, and due to the impacts of borefield pumping and mine dewatering associated with the MCC and adjacent mining. Likewise seasonal variations in water quality as a result of varying rates of recharge will occur.

It is recommended that the assessment is made based on the variation of levels and quality parameters from their recorded baseline range, combined with the recorded variation from predicted impacts (for those bores within the zone of influence of dewatering and borefield pumping).

Trigger levels will be set, for selected sites, to be applied during the initial stage of mine construction and Mining Years 1 to 3, after which time all trigger levels will be reviewed with reference to the baseline data records available at that time, and revised as appropriate through consultation with NOW. Table 8.1 shows the recommended locations for setting triggers and relates to bores installed in Triassic, alluvium and Tertiary palaeochannel aquifers. The site specific triggers will be defined in the site Water Management Plan and will relate to percentage of saturated thickness.

Table 8.1: Selected Trigger Level Monitoring Points

Bore ID	Formation	Screened Interval (mbgl)	Monitoring commenced	Notes
PZ158	Surficial	11.5-14.5	March 2008	
PZ52	Tertiary Palaeochannel	24-30	August 2005	
TB52B	Tertiary Palaeochannel	31-37	January 2006	
PZ181	Tertiary Palaeochannel	21-24	March 2008	
PZ184	Tertiary Palaeochannel	6-9	July 2008	
PZ150	Regolith / Surficial	10-13	January 2008	Shallow piezometer at paired piezometer site
PZ165	Surficial	2.5-5.5	March 2008	
PZ173	Regolith / Surficial	6-9	March 2008	
PZ177	Regolith / Surficial	4-7	March 2008	
PZ179	Triassic	28m	July 2008	Multi-level vibrating wire piezometer bore

8.2 Water Levels

In the event that observed groundwater level drawdowns are greater than predicted drawdowns by 20% or more for any consecutive three month period, the monitoring data should immediately be referred to a suitably qualified and experienced hydrogeologist for review. The reviewer should assess the data to establish the reasons for the variance and should recommend an appropriate response action plan for implementation in consultation with the NOW and other relevant government agencies. The response action may involve one or more of the following:

- Reduction in pumping rate from a particular pumping bore or bores;
- Cessation of pumping from a particular pumping bore or bores;
- Modification to the mining plan, if appropriate;
- Continuation of pumping and dewatering, with closer monitoring; and
- No change to the operations.

In the event that an existing private water supply is adversely affected by any exceedance in drawdowns, the response action could involve provision of a replacement water supply, possibly from diversion of part of the dewatering discharge, subject to water quality being suitable for the purpose.

8.3 Preservation of Baseflow

In the event that creek baseflows, in that part of Wilpinjong Creek extending from just upstream of the Murragamba Creek confluence to downstream to the Wollar Creek confluence, are adversely affected, due particularly to the loss of groundwater from alluvial aquifers, the response action could involve provision of a supplementary water supply, possibly from diversion of part of the dewatering discharge, from storage in the proposed Splitters Creek Dam, or via the provision of a supplementary supply from bores intercepting Permian aquifers. Any such diversions or supplementary supplies would be made subject to water quality being suitable for the purpose.

8.4 Groundwater Quality

Should the water quality of the mine inflows or dewatering discharge indicate an increase in salinity of more than 50% from the averages listed in Appendix F and Table 6.1, it is recommended that the nature of the exceedance, and all relevant monitoring data, be provided to an approved experienced hydrogeologist for review and assessment of the impact of such exceedances on other users or the environment. If remedial action is recommended by the reviewer on the basis of the water quality exceedance, the recommended action will be implemented in consultation with NOW, DP&I and OEH as appropriate.

It is envisaged that the remedial action may include one or more of the following:

- Re-location of dewatering pumping location(s);
- Cessation of pumping from one or more bores;
- Increase in rate of pumping from one or more bores; and
- Continuation of pumping and dewatering, with closer monitoring.

The appropriate action will be recommended by a suitably qualified and approved hydrogeologist, and as specified in the Water Management Plan.

In the event that an existing water supply is adversely affected by changes in groundwater quality, then as deemed appropriate at the time, part of the dewatering extraction could be diverted, or an alternative water supply provided from a suitable source such as a replacement water supply bore.

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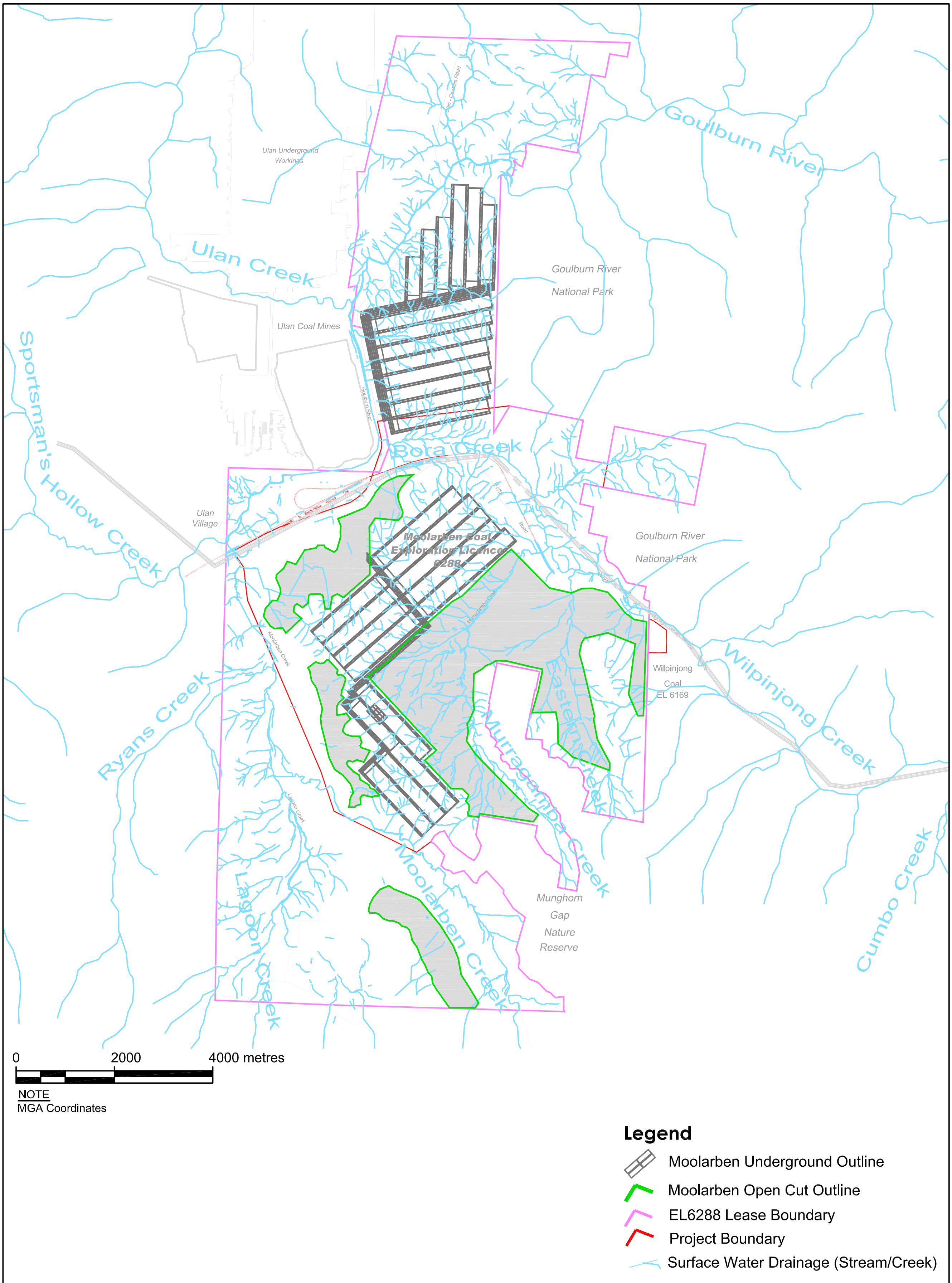
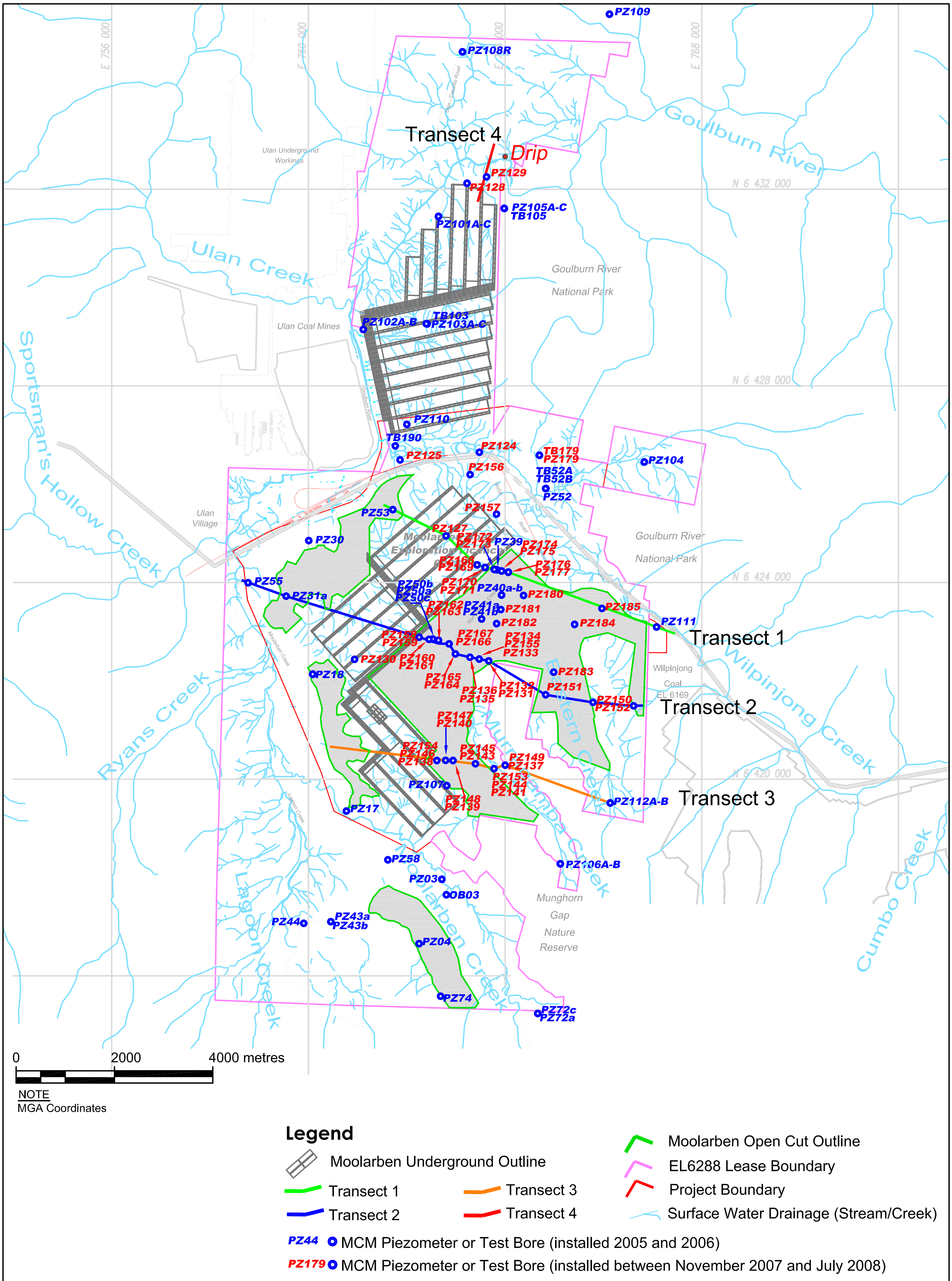
FIGURES



Date: 22 June 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Project Location**
Drawing No: S06I-003	Rev: A	
RPS Aquaterra		**Figure 1.1**



Date: 19 August 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Location of Piezometers and Test Bores Stage 1 and Stage 2 Investigations**
Drawing No: S06l-003b	Rev: B	
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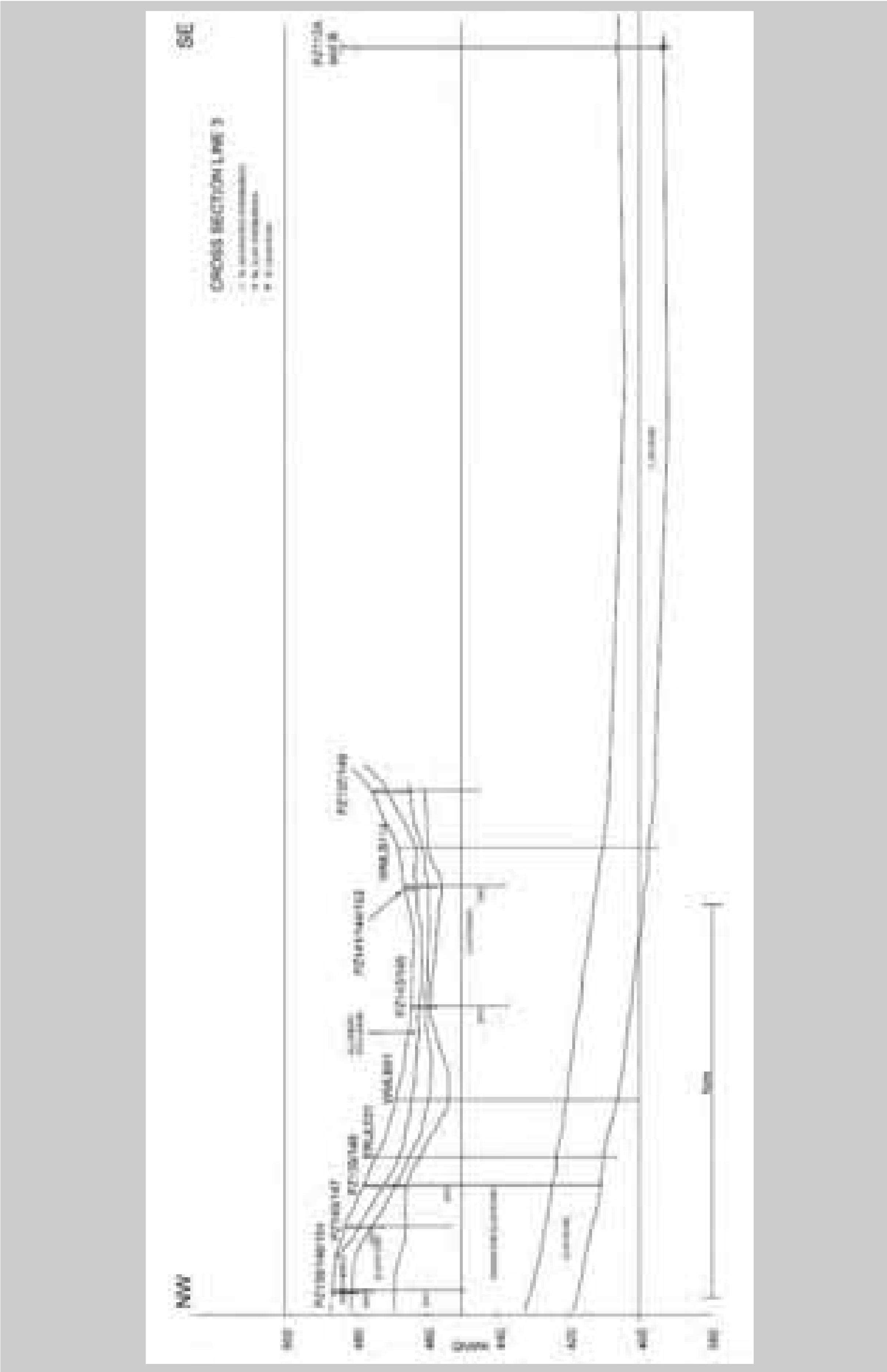
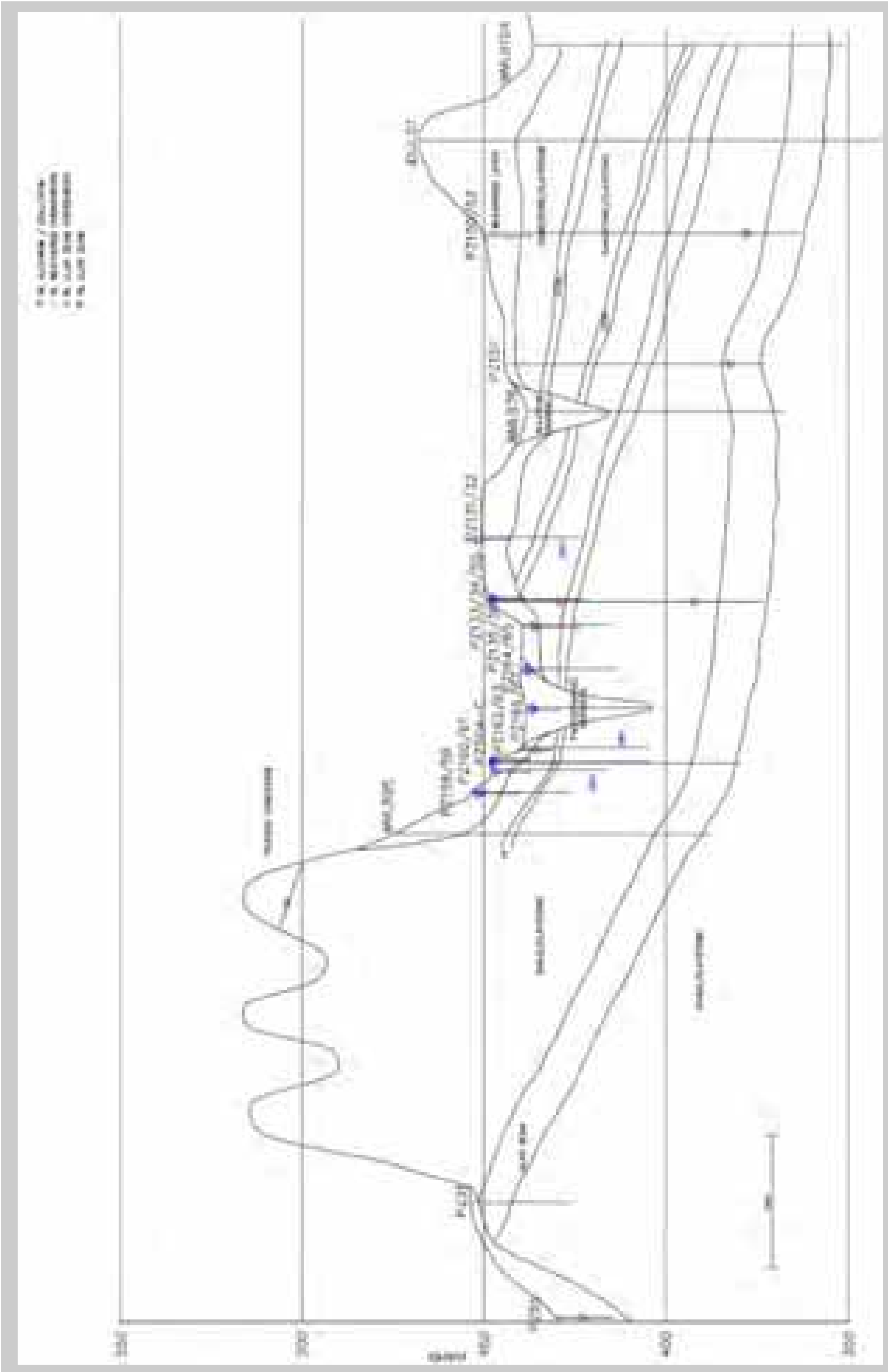
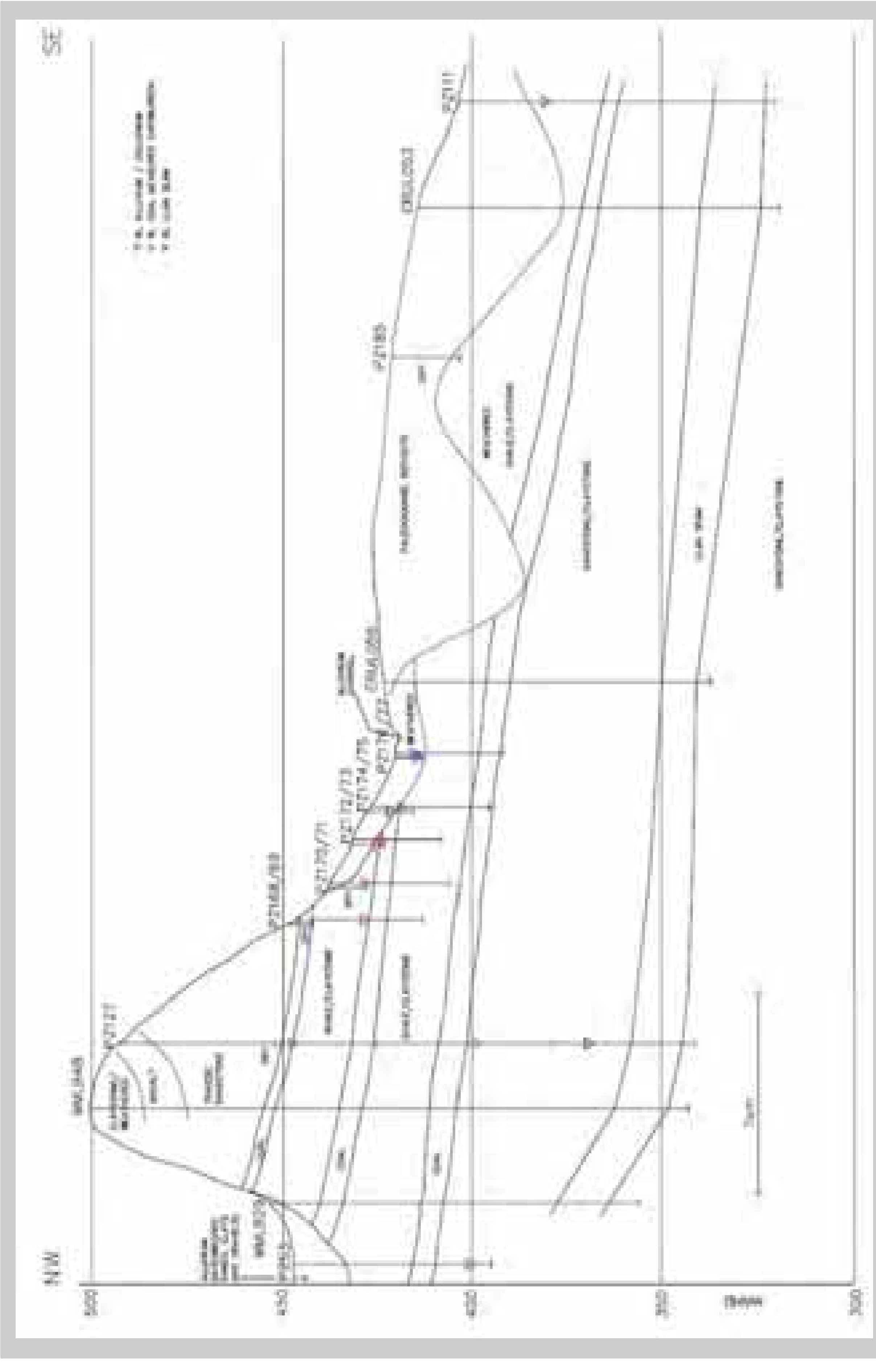


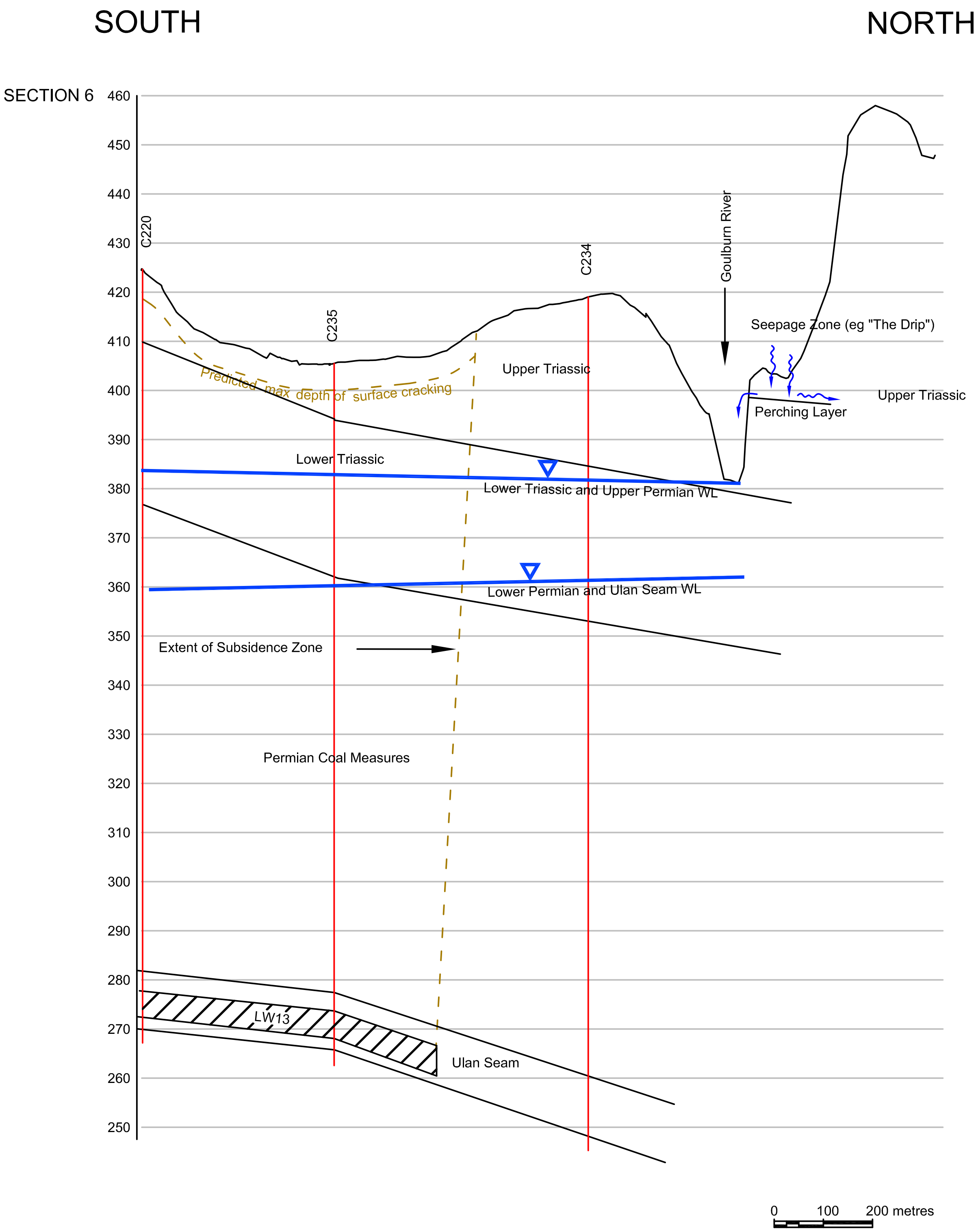
CROSS-SECTION AT TRANSECT 3 FIGURE 2.2



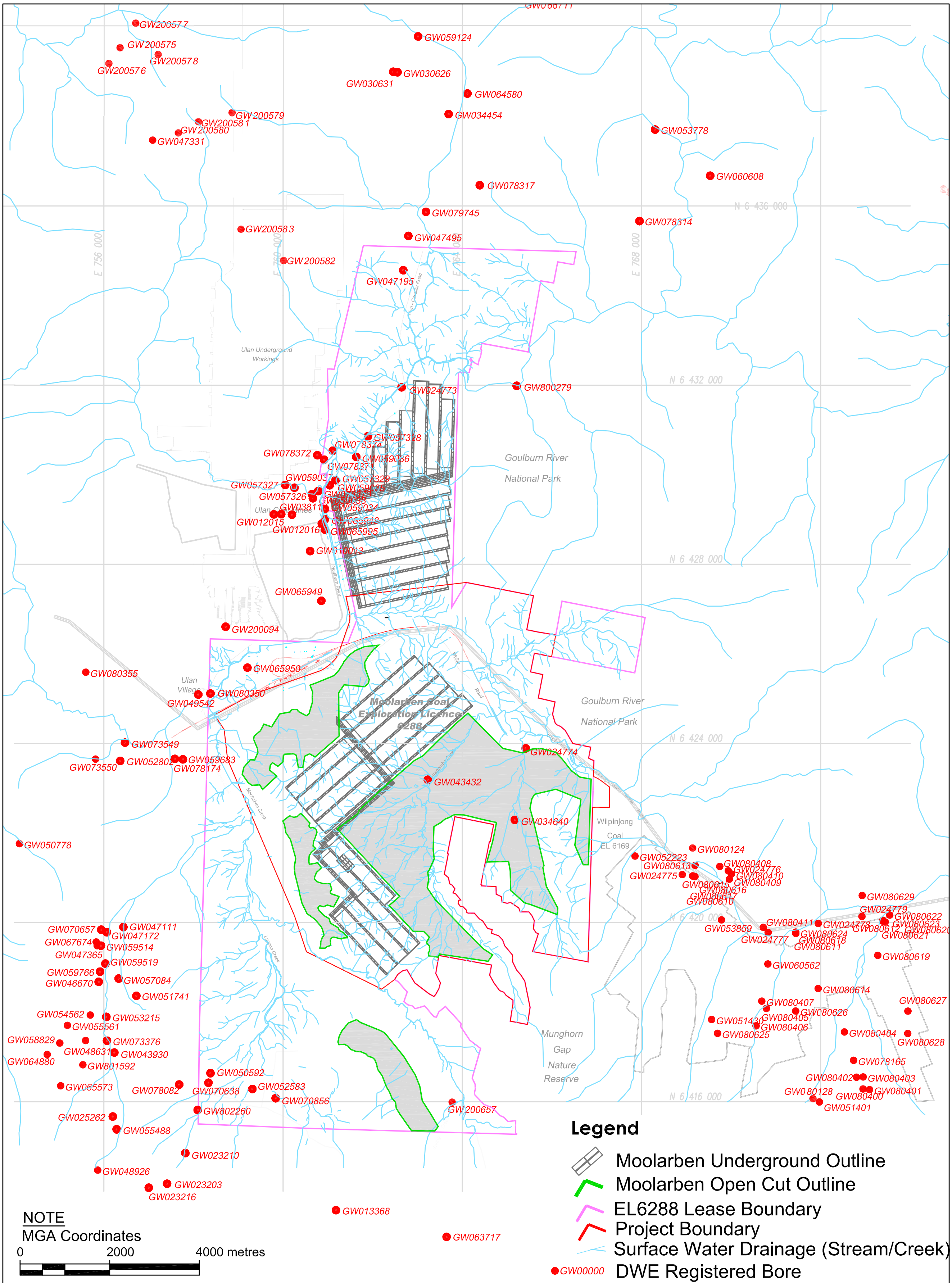
CROSS-SECTION AT TRANSECT 2 FIGURE 2.3



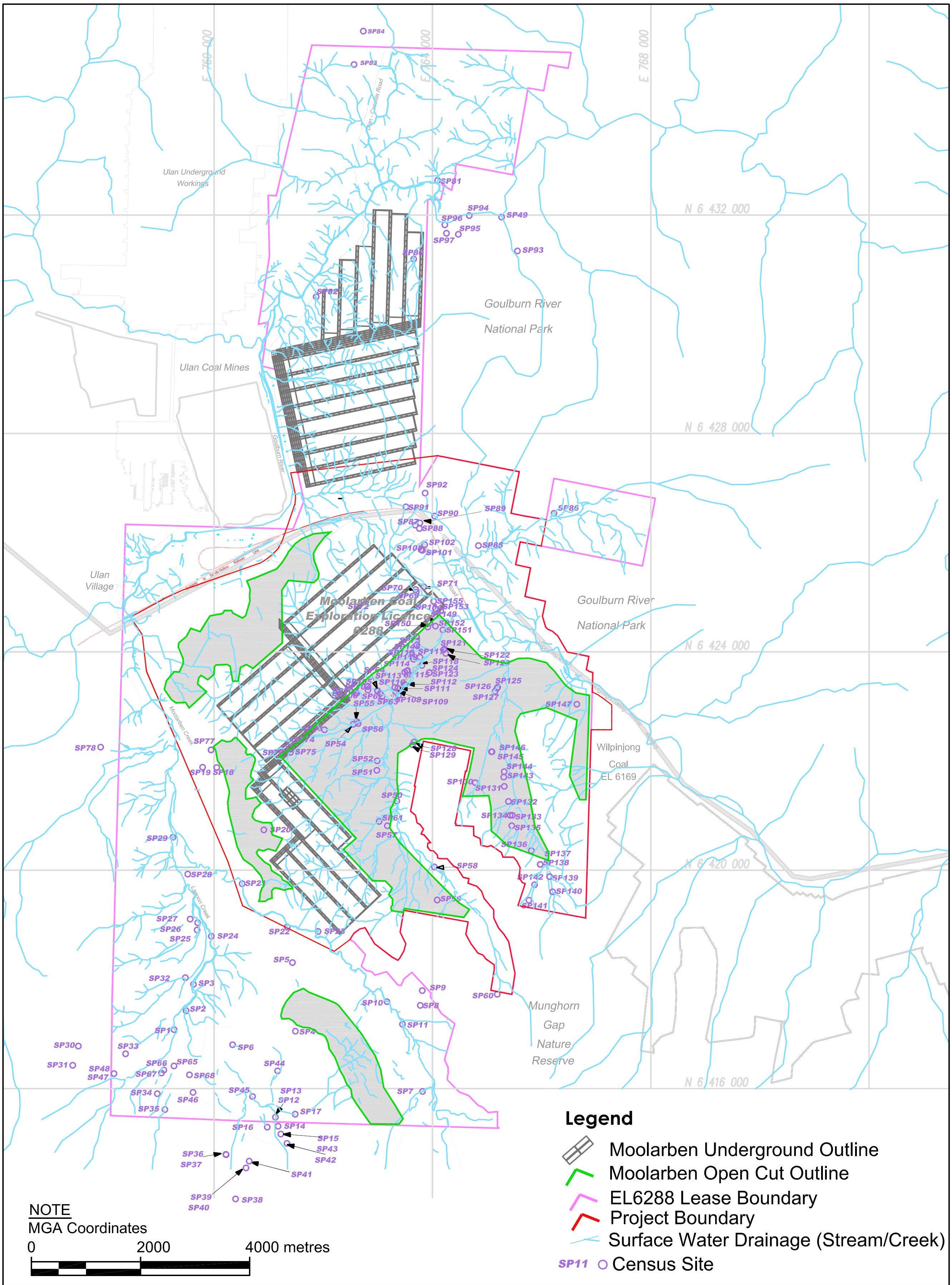
CROSS SECTION AT TRANSECT 1 FIGURE 2.4



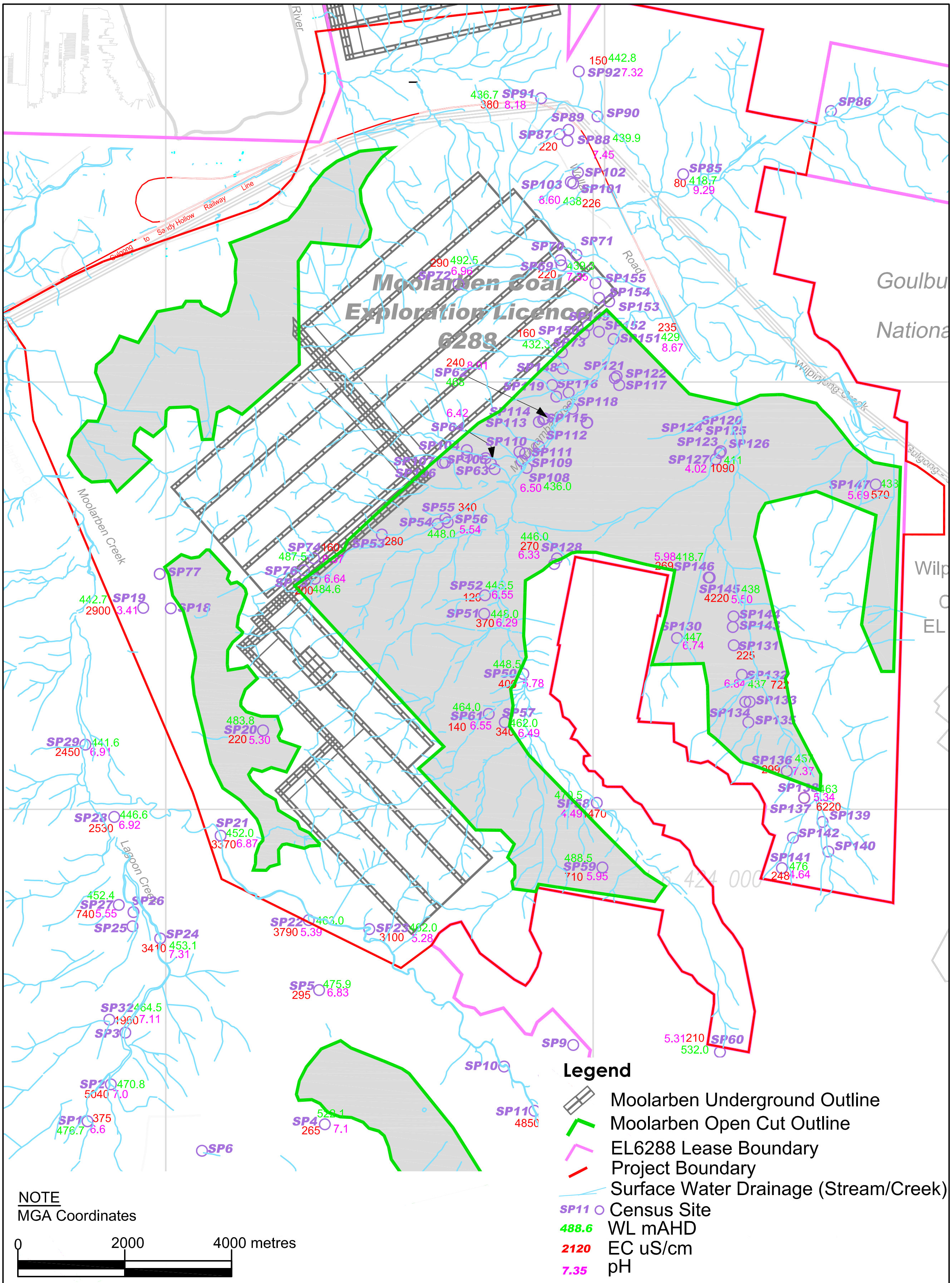
CROSS SECTION AT TRANSECT 4 FIGURE 2.5



Date: 22 June 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Locations of NOW Registered Bores**
Drawing No: S06l-004a	Rev: A	
RPS Aquaterra		**Figure 2.6**



Date: 02 May 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: TL	Job No: S06L	**Locations of Groundwater Census Sites**
Drawing No: S06l-005a	Rev: A	
RPS Aquaterra		**Figure 2.7**



Date: 02 May 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: TL	Job No: S06I	**Moolarben Stage 2 Groundwater Census Sites Water Level, EC and pH**
Drawing No: S06I-006a	Rev: A	
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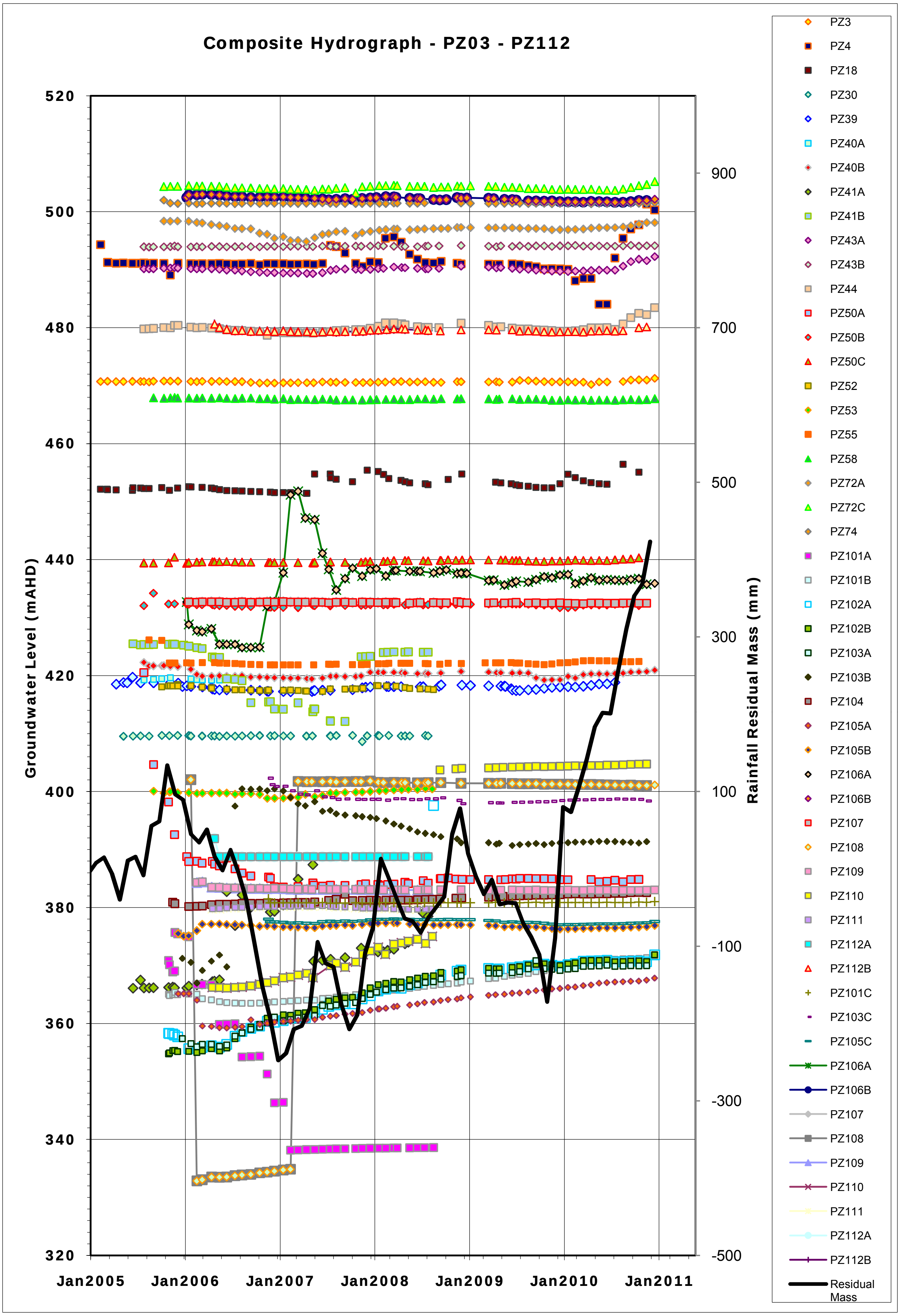

RPS Aquaterra

COMPOSITE HYDROGRAPH PZ3 - PZ112 FIGURE 2.9a

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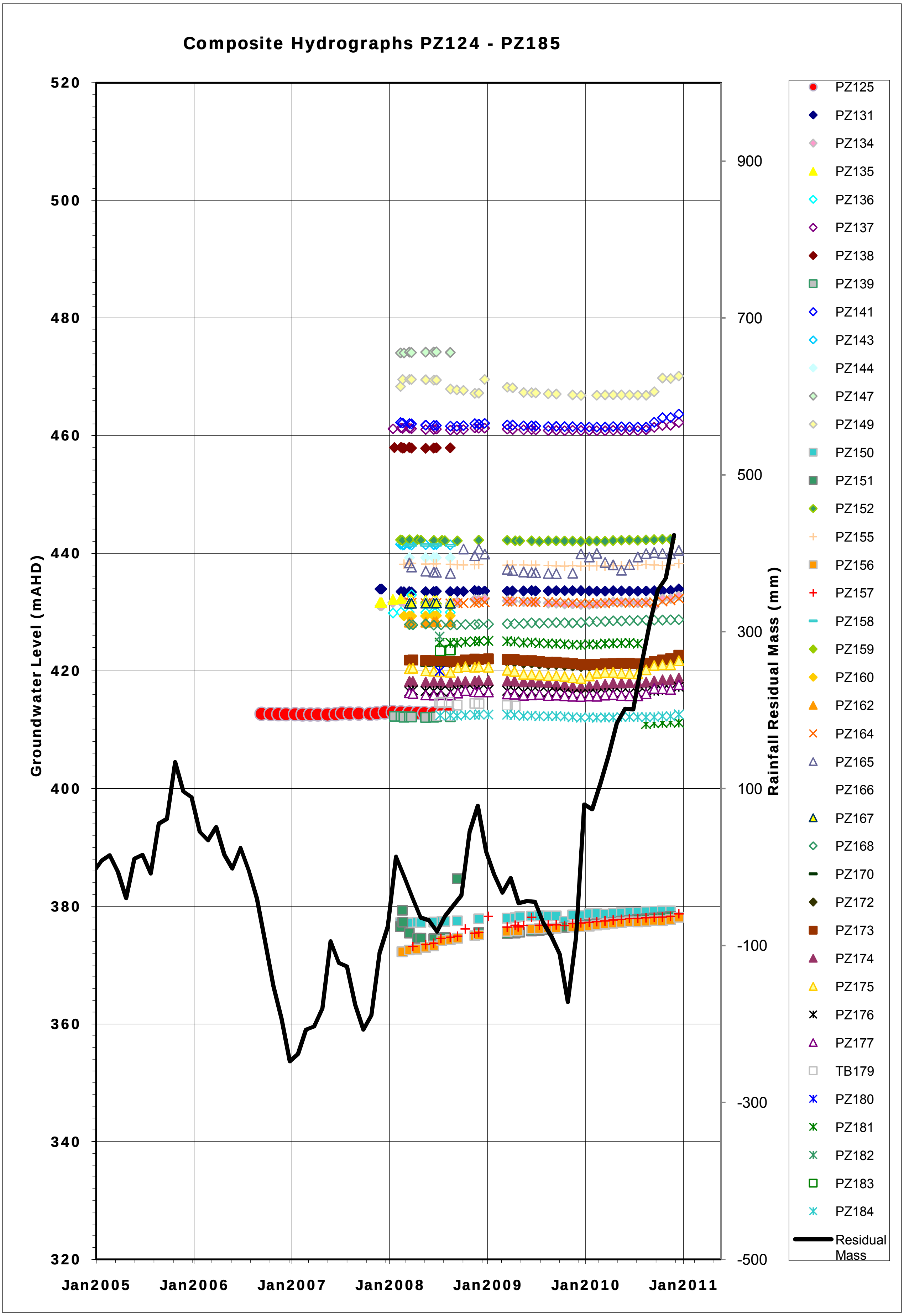
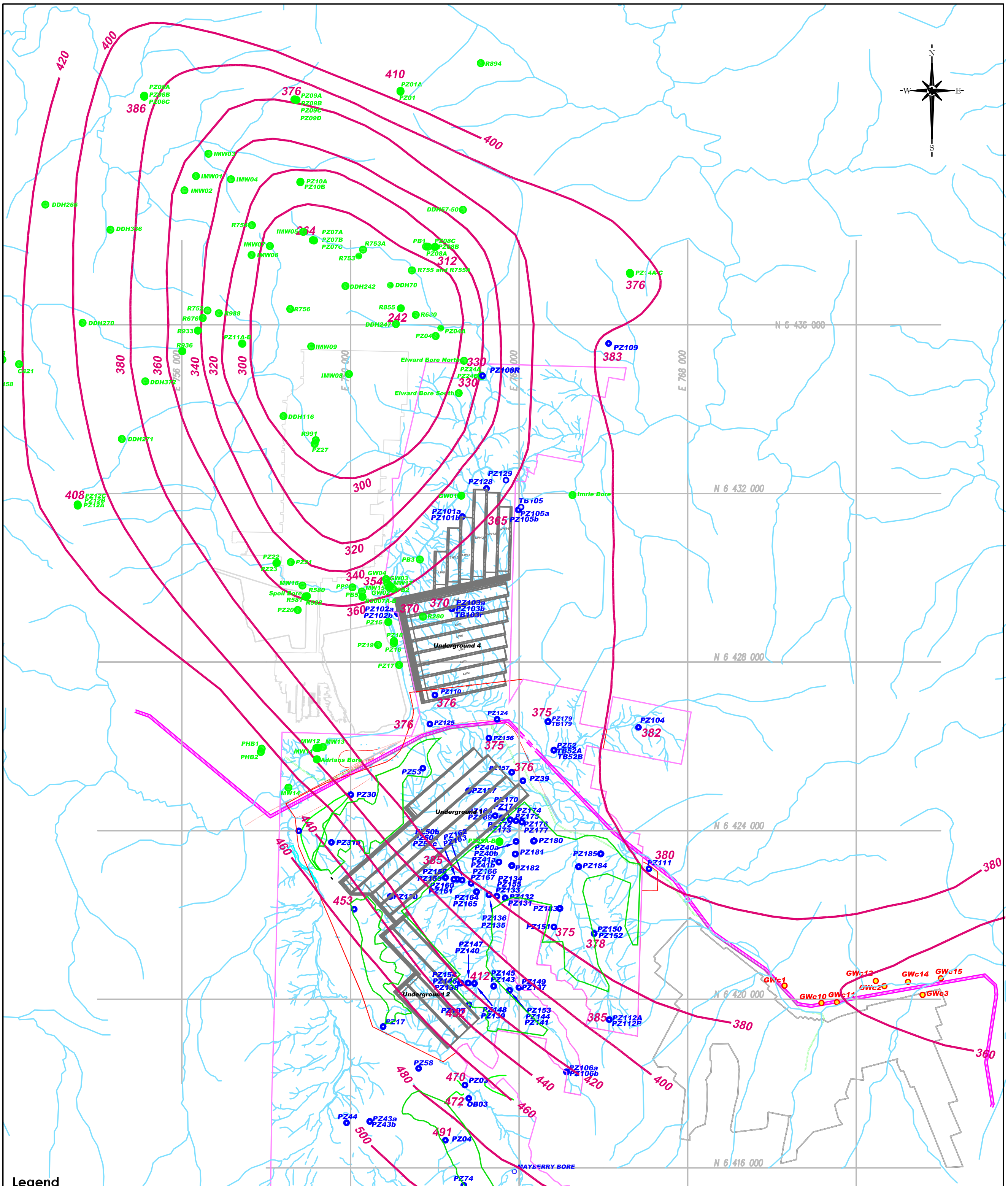


COMPOSITE HYDROGRAPH PZ124 - PZ185 FIGURE 2.9b

F:\Jobs\S6\300 Data\Original Drawings\[Water Hydrographs updated 18Apr2011.xlsx]Fig2.9b

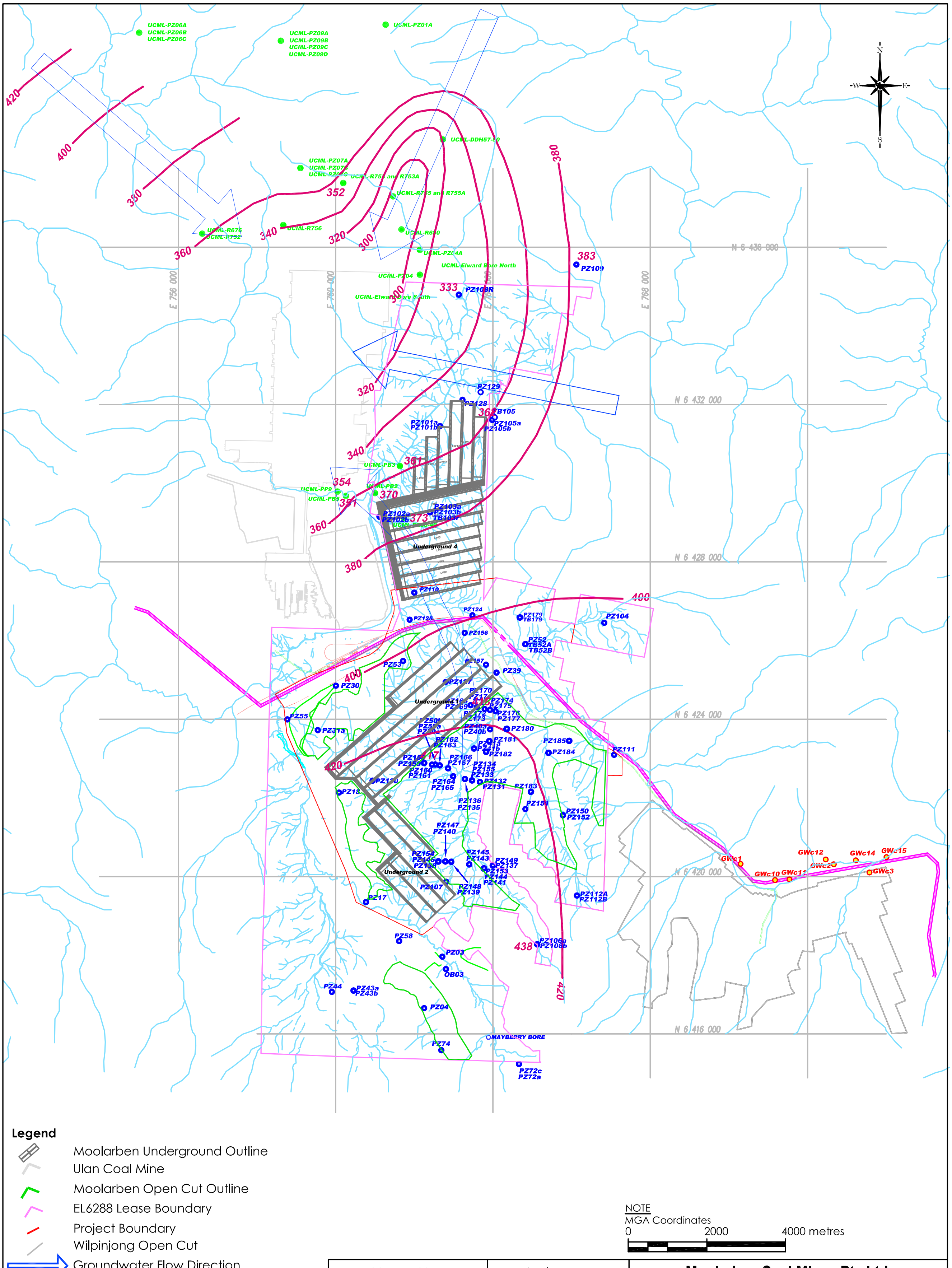


Legend

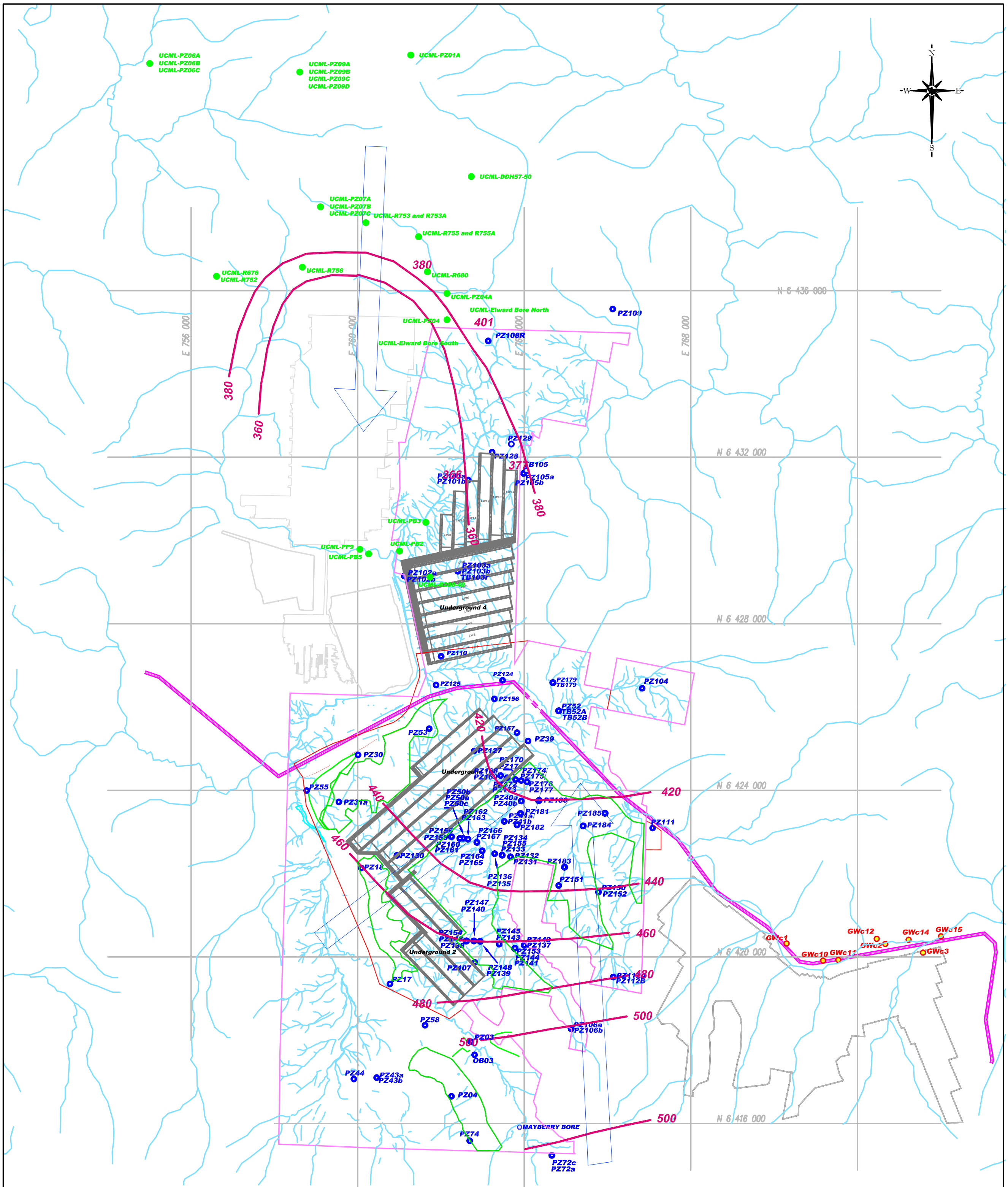
- Moolarben Underground Outline
- Ulan Coal Mine
- Moolarben Open Cut Outline
- EL6288 Lease Boundary
- Project Boundary
- Wilpinjong Open Cut
- Groundwater Contours (mAHD)
- Groundwater Flow Direction
- Surface Water Drainage (Stream/Creek)
- GWc10 Wilpinjong Monitoring Bore
- PZ44 MCM Piezometer or Test Bore
- PZ09B UCML Groundwater Bore

NOTE
MGA Coordinates
0 2000 4000 metres

Date: 02 June 2011	Scale: As shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Ulan Seam Groundwater Contours**
Drawing No: S06I-3.6	Rev: A	
RPS Aquaterra		**Figure 2.10**



Date: 02 May 2011	Scale: As shown	Moolarben Coal Mines Pty Ltd
Initials: HZ	Job No: S06L	Lower Permian Groundwater Contours
Drawing No: S06I-3.7	Rev: A	
RPS Aquaterra		Figure 2.11



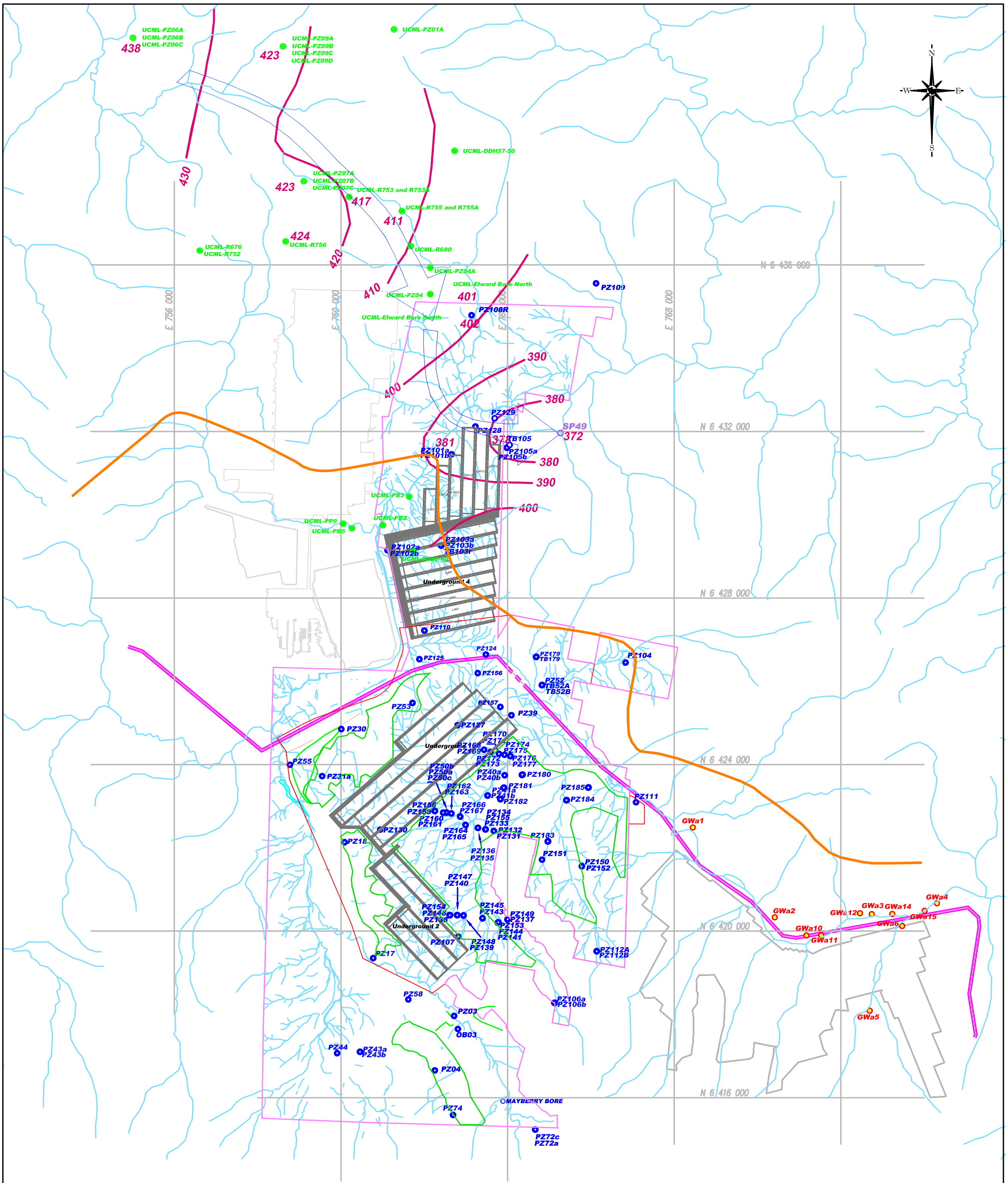
Legend

- Moolarben Underground Outline
- Ulan Coal Mine
- Moolarben Open Cut Outline
- EL6288 Lease Boundary
- Project Boundary
- Wilpinjong Open Cut
- Groundwater Flow Direction
- Surface Water Drainage (Stream/Creek)
- GWc1 Wilpinjong Monitoring Bore
- PZ44 MCM Piezometer or Test Bore
- UCML-PZ09B UCML Groundwater Bore

NOTE
MGA Coordinates

0 2000 4000 metres

Date: 02 May 2011	Scale: As shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Middle and Upper Permian Groundwater Contours**
Drawing No: S06I-3.8	Rev: A	
		Figure 2.12



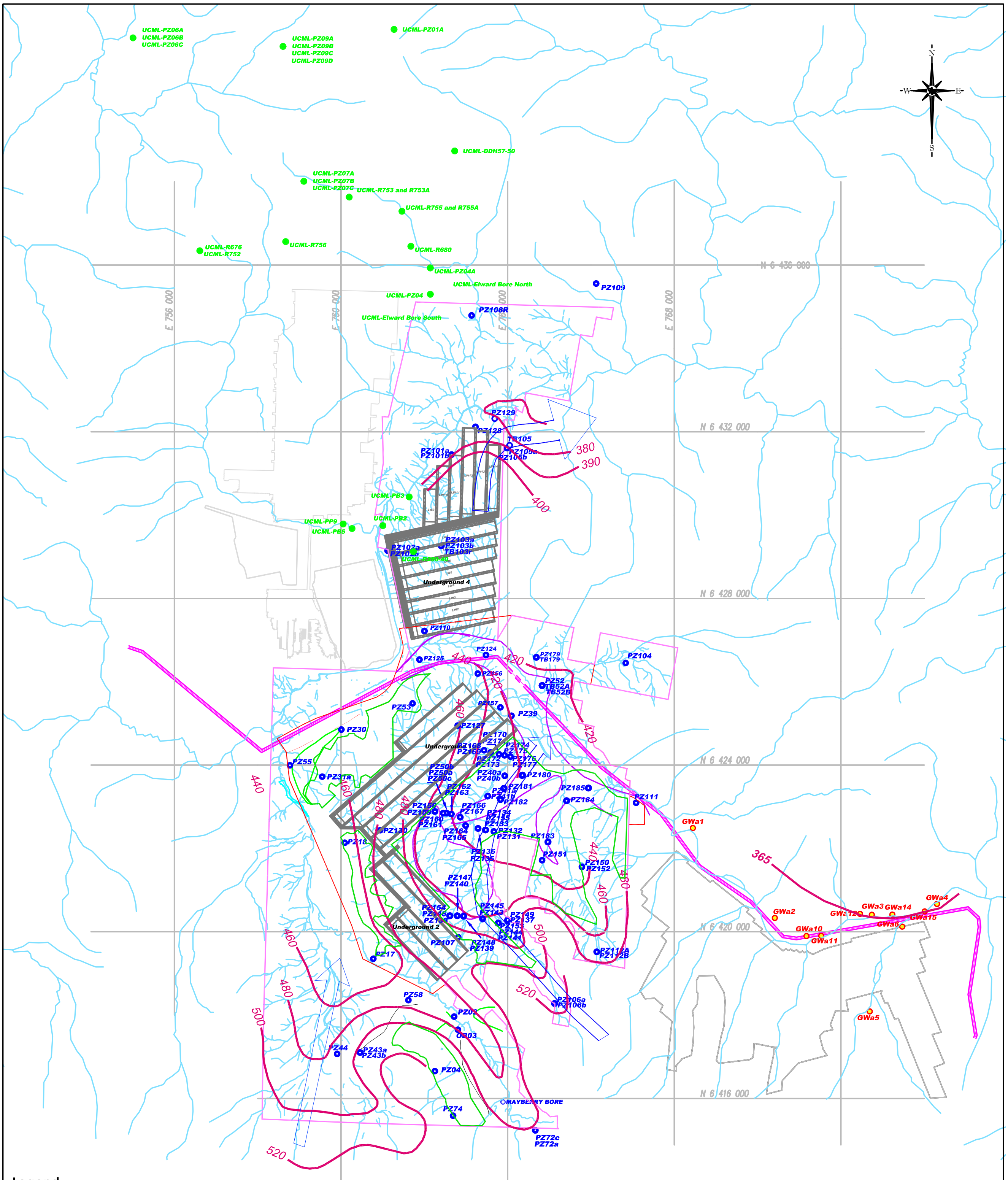
Legend

- Moolarben Underground Outline
- Ulan Coal Mine
- Moolarben Open Cut Outline
- EL6288 Lease Boundary
- Project Boundary
- Wilpinjong Open Cut
- Groundwater Flow Direction
- Surface Water Drainage (Stream/Creek)
- PZ44 Wilpinjong Monitoring Bore
- PZ44 MCM Piezometer or Test Bore
- UCML-PZ09B UCML Groundwater Bore
- Extent of saturated Traissic strata

NOTE
MGA Coordinates

0 2000 4000 metres

Date: 23 August 2011	Scale: As shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Upper and Lower Triassic Groundwater Contours**
Drawing No: S06I-3.9	Rev: A	
RPS Aquaterra		**Figure 2.13**



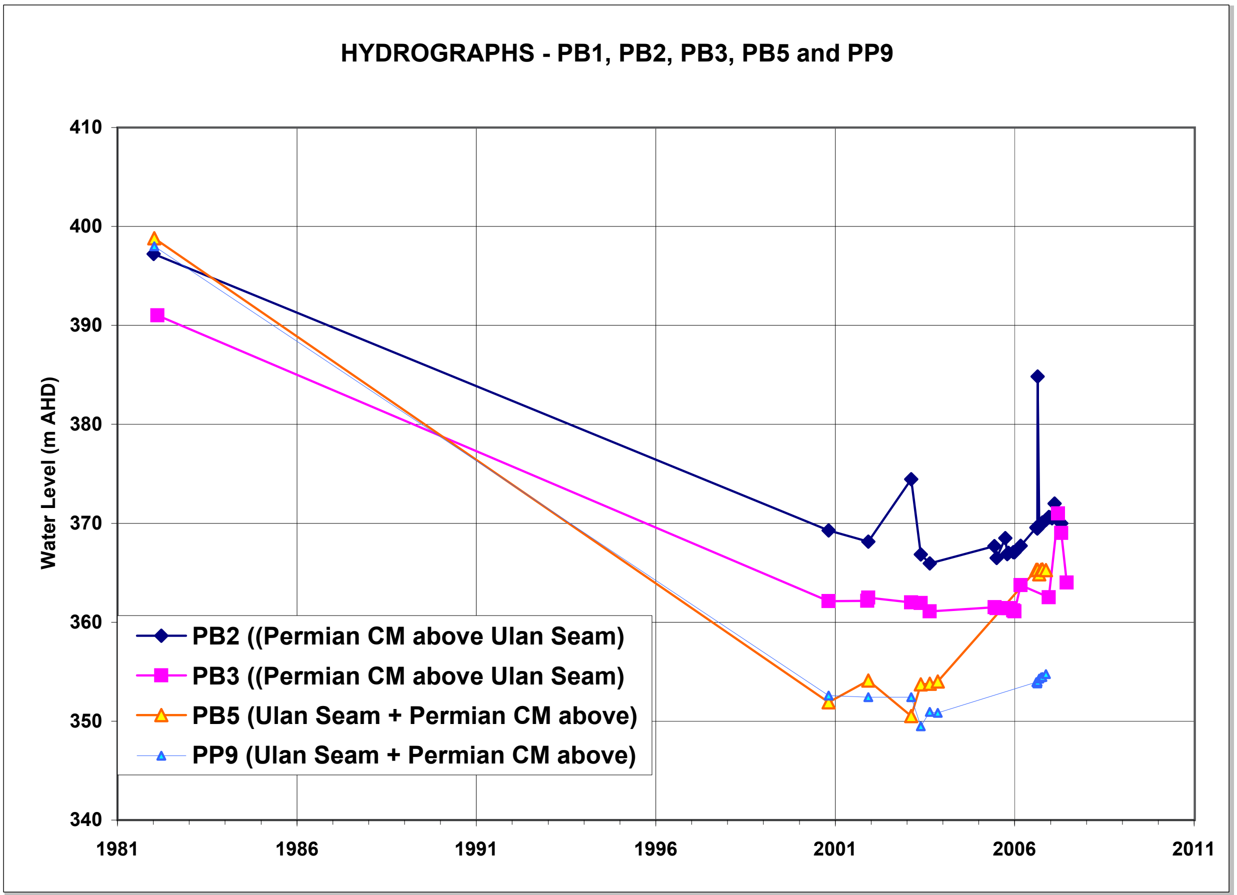
Legend

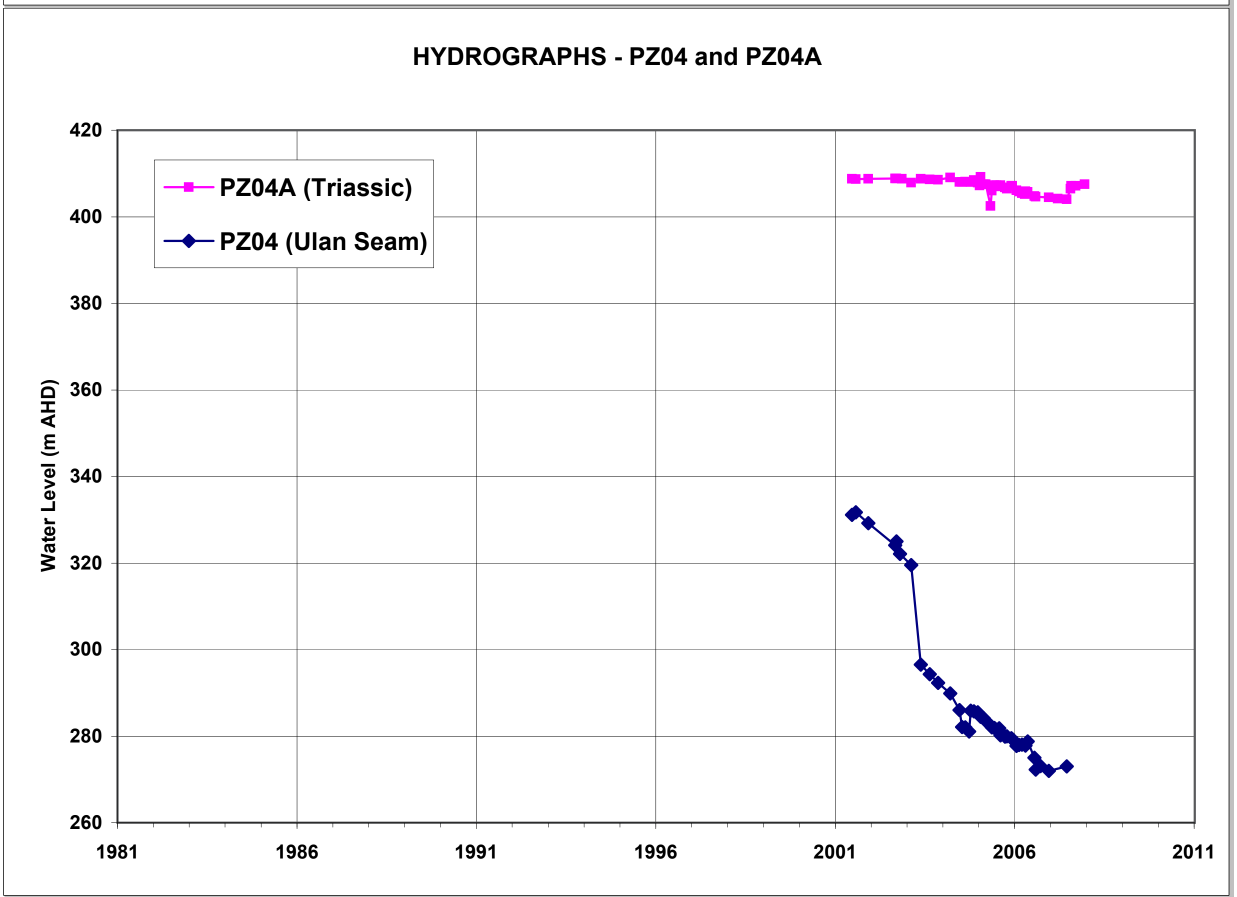
- Moolarben Underground Outline
- Ulan Coal Mine
- Moolarben Open Cut Outline
- EL6288 Lease Boundary
- Project Boundary
- Wilpinjong Open Cut
- Groundwater Contours (mAHD)
- Groundwater Flow Direction
- Surface Water Drainage (Stream/Creek)
- PZ44 Wilpinjong Monitoring Bore
- PZ44 MCM Piezometer or Test Bore
- UCML-PZ09B UCUML Groundwater Bore

NOTE
MGA Coordinates

0 2000 4000 metres

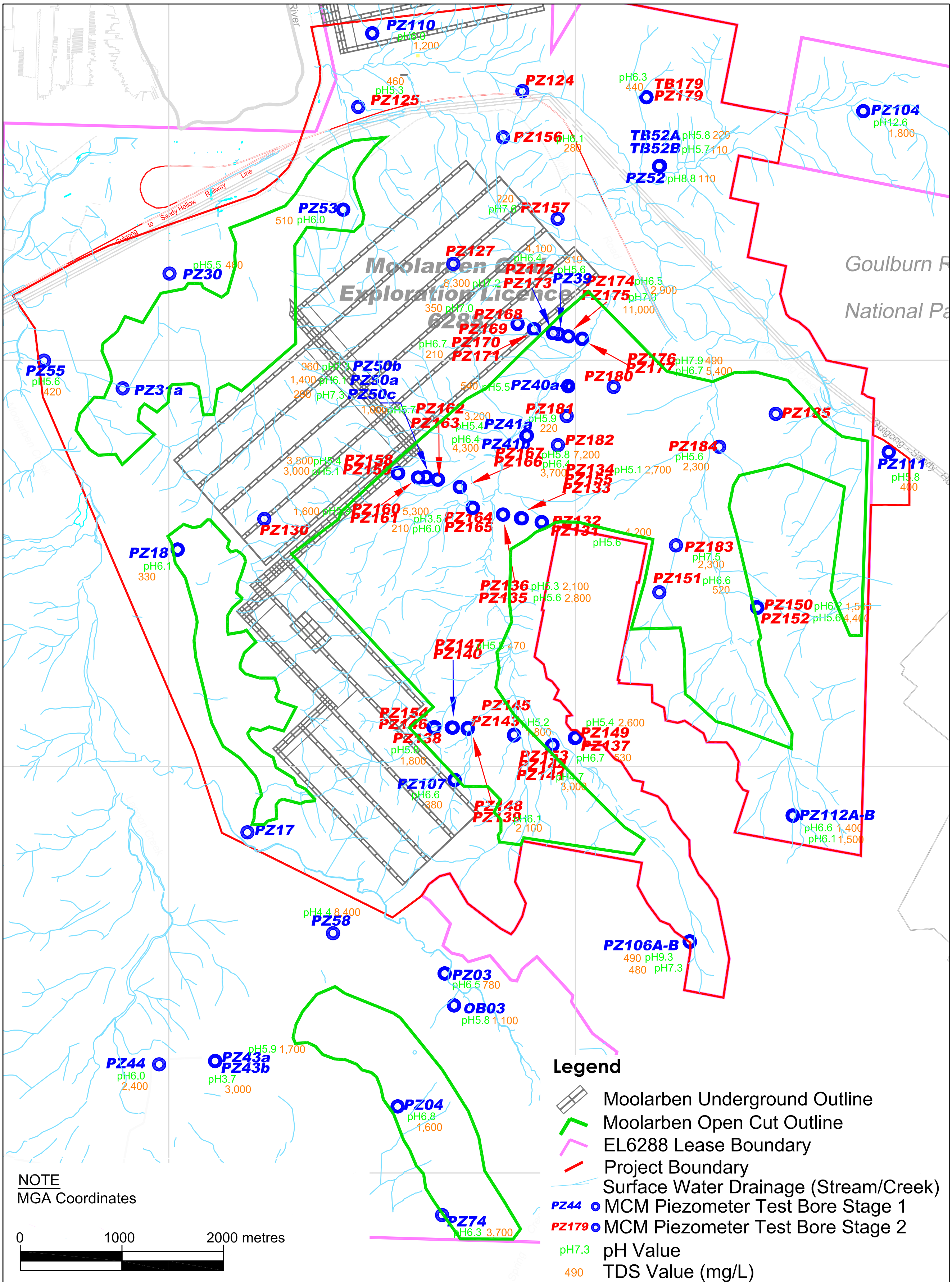
Date: 02 May 2011	Scale: As shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Surficial Aquifer System Groundwater Contours**
Drawing No: S06I-3.10	Rev: A	**Figure 2.14**
RPS Aquaterra		



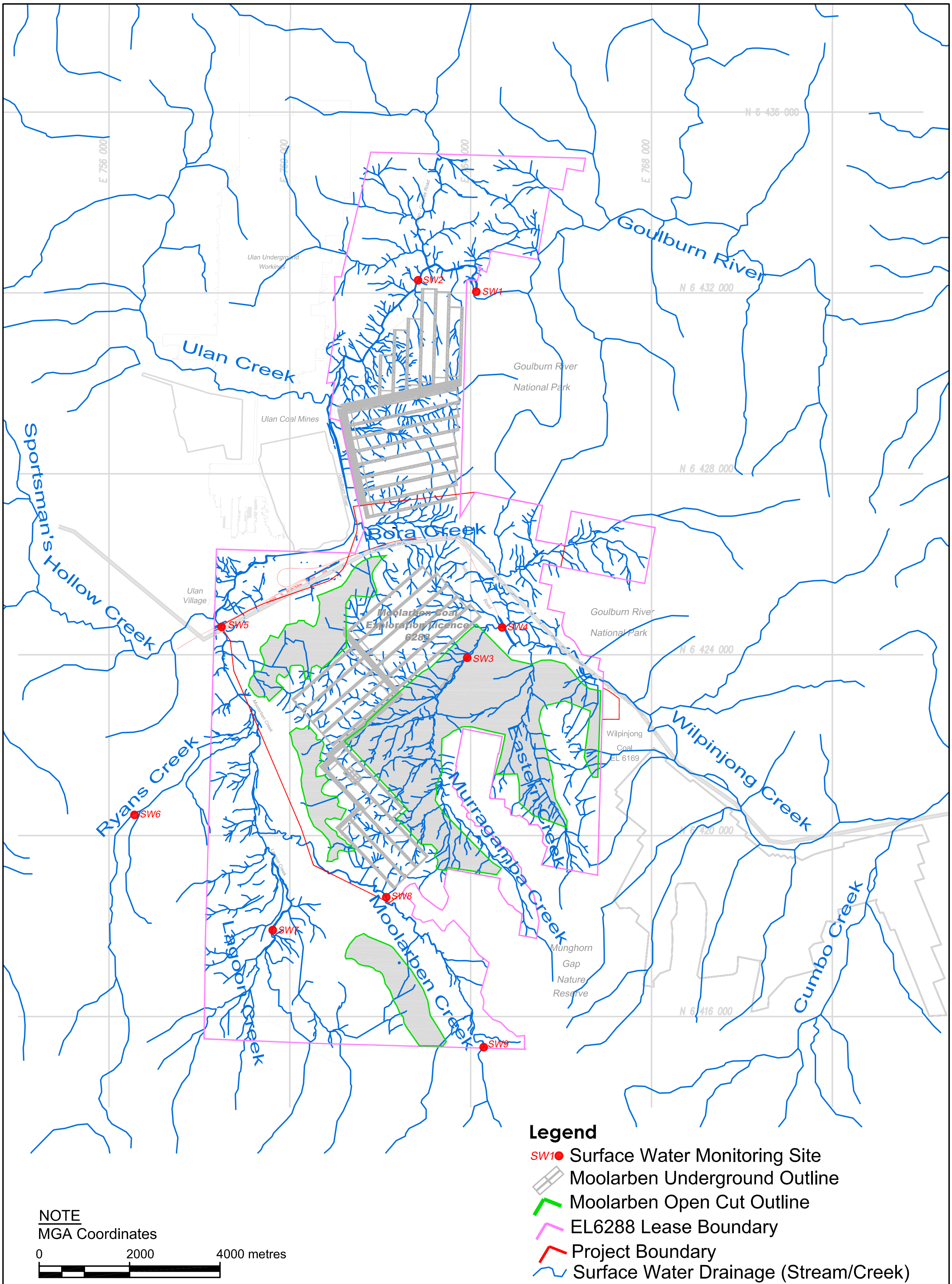


RPS Aquaterra

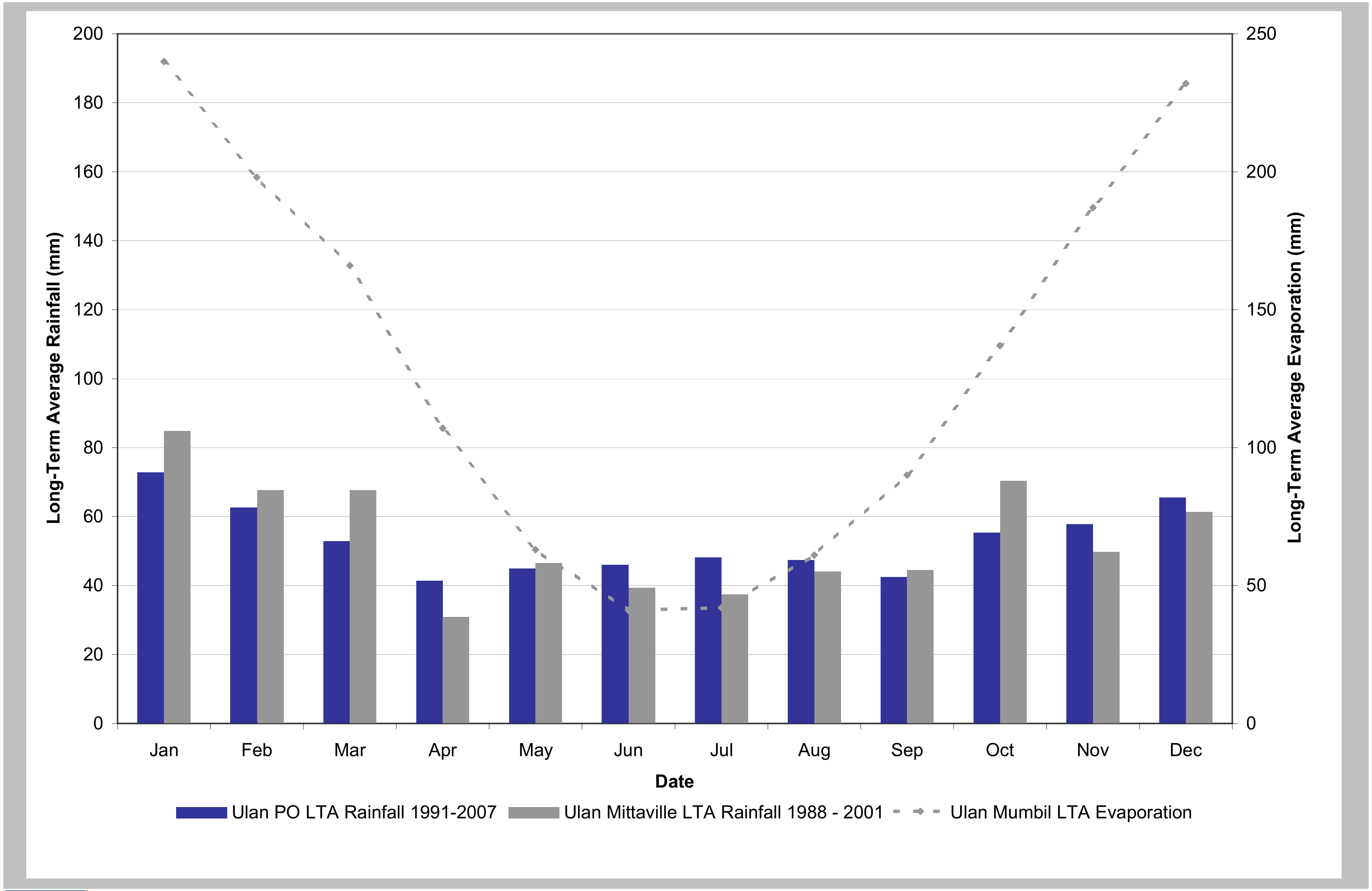
ULAN COAL MINE COMPOSITE HYDROGRAPHS FIGURE 2.15



Date: 02 May 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: TL	Job No: S06L	**Piezometers and Test Bores with pH and TDS data**
Drawing No: S06I-3.12	Rev: A	
RPS Aquaterra		**Figure 2.16**

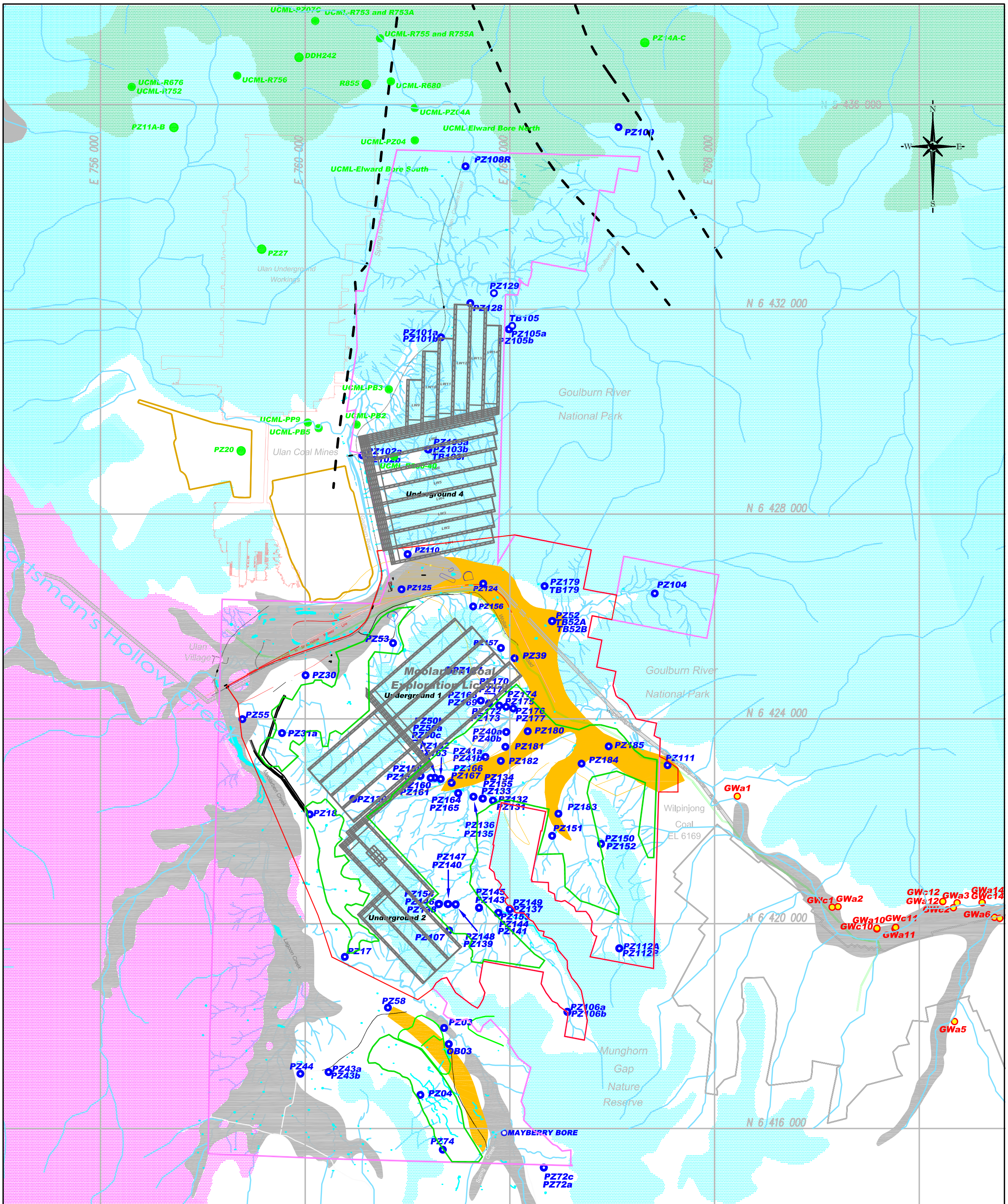


Date: 10 June 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Surface Drainage Features**
Drawing No: S06I-4.1	Rev: A	
RPS Aquaterra		**Figure 3.1**



RPS Aquaterra

LONG-TERM AVERAGE MONTHLY CLIMATE DATA FIGURE 3.2



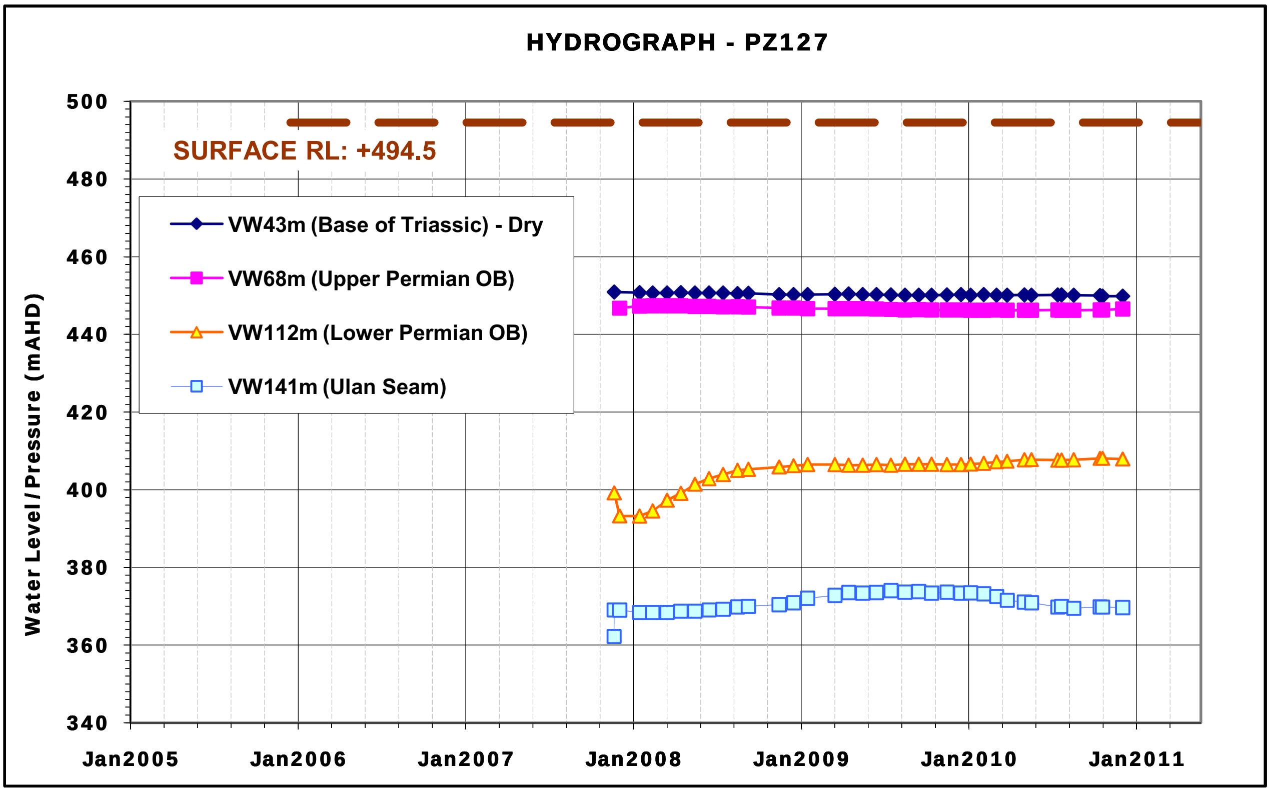
Legend

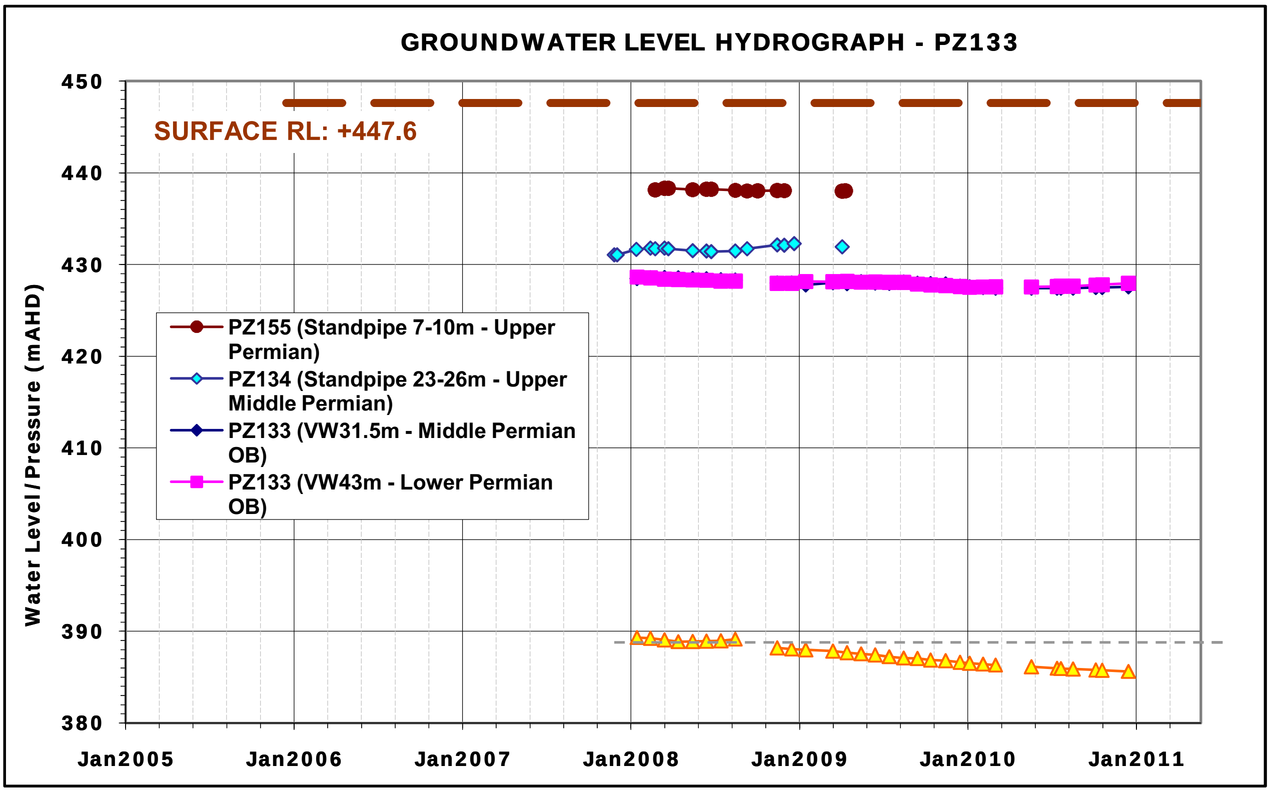
PZ44	MCM Piezometer or Test Bore		Recent Alluvium
UCML-PZ09B	UCML Groundwater Bore		Tertiary Paleochannel Deposite
GWc10	Wilpinjong Monitoring Bore		Jurassic
	EL6288 Lease Boundary		Triassic Narrabeen Group
	Project Boundary		Permian Coal Measures
	Moolarben Open Cut Outline		Granite / Volcanics Basement
	Surface Water Drainage (Stream/Creek)		
	Moolarben Underground Outline		
	Fault		

NOTE
MGA Coordinates

0 2000 4000 metres

Date: 14 May 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Hydrogeological Units**
Drawing No: S06I-4.3	Rev: A	
RPS Aquaterra		**Figure 3.3**





COMPOSITE HYDROGRAPH PZ127 AND PZ133 FIGURE 3.4

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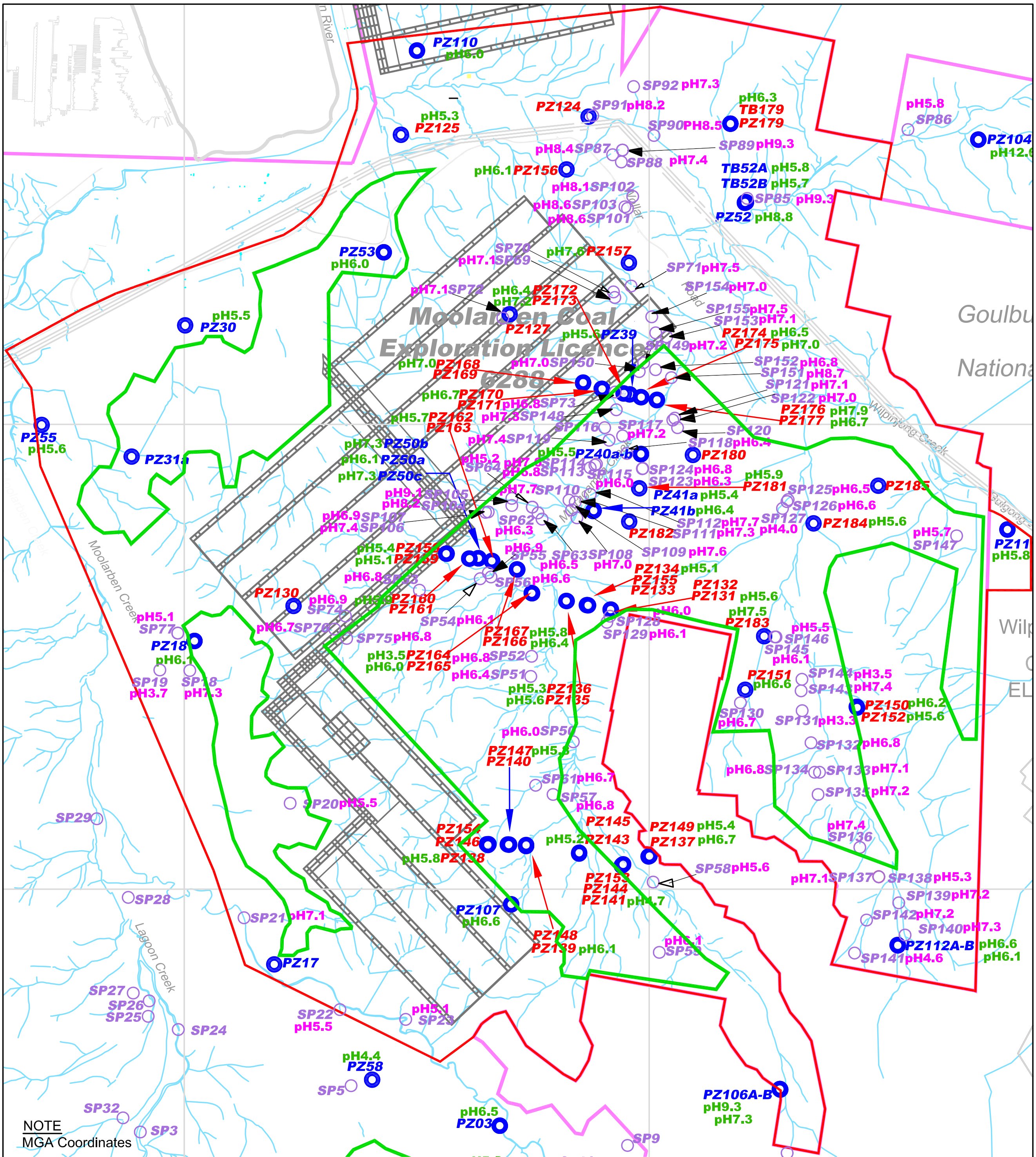
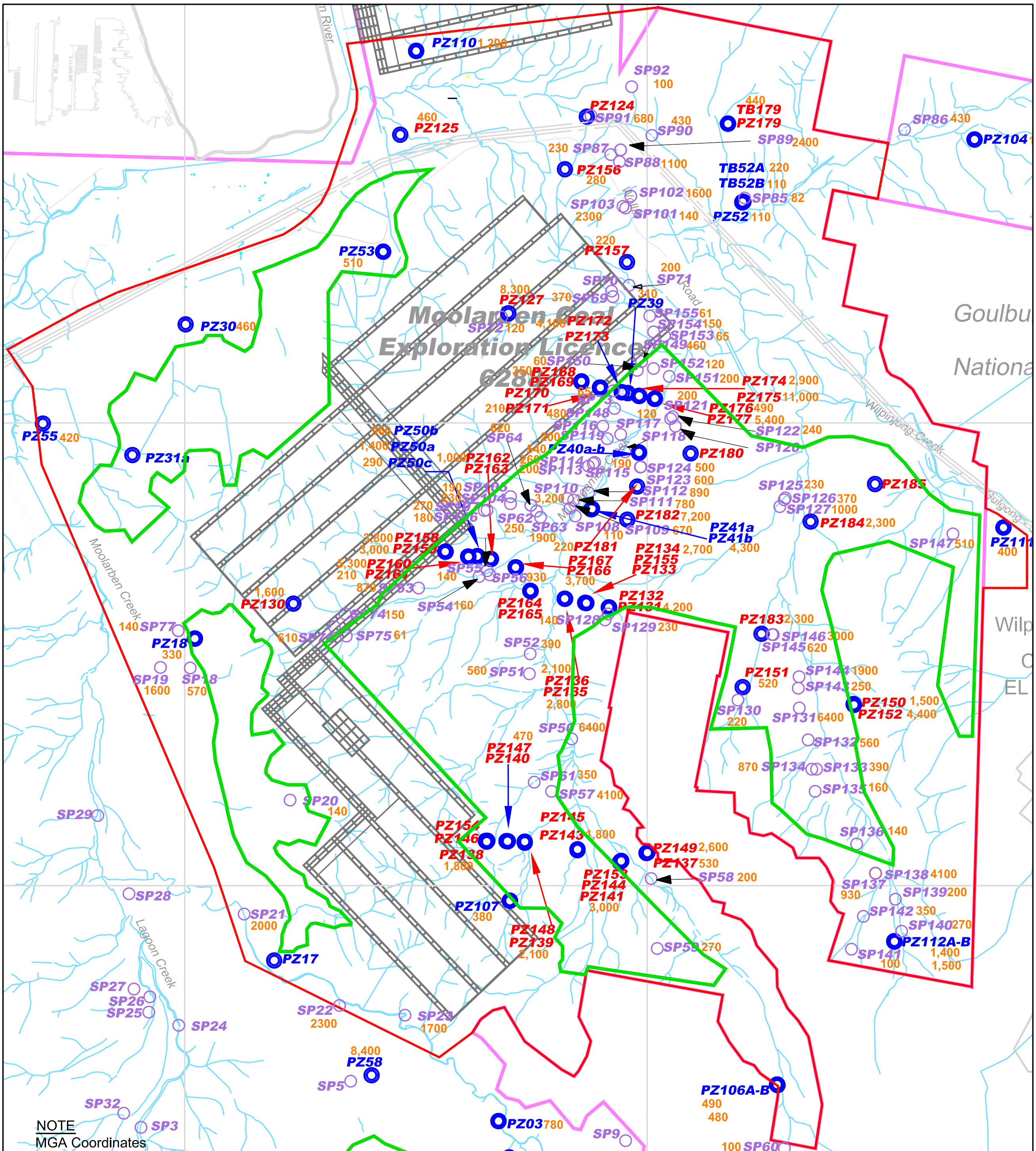


NOTE
MGA Coordinates

Legend

- Moolarben Underground Outline
- Moolarben Open Cut Outline
- EL6288 Lease Boundary
- Project Boundary
- Surface Water Drainage (Stream/Creek)
- SP14 Census Site
- PZ44 MCM Piezometer or Test Bore Stage 1
- PZ179 MCM Piezometer or Test Bore Stage 2
- pH7.3 Bore pH Date
- pH6.1 Census Site pH Date

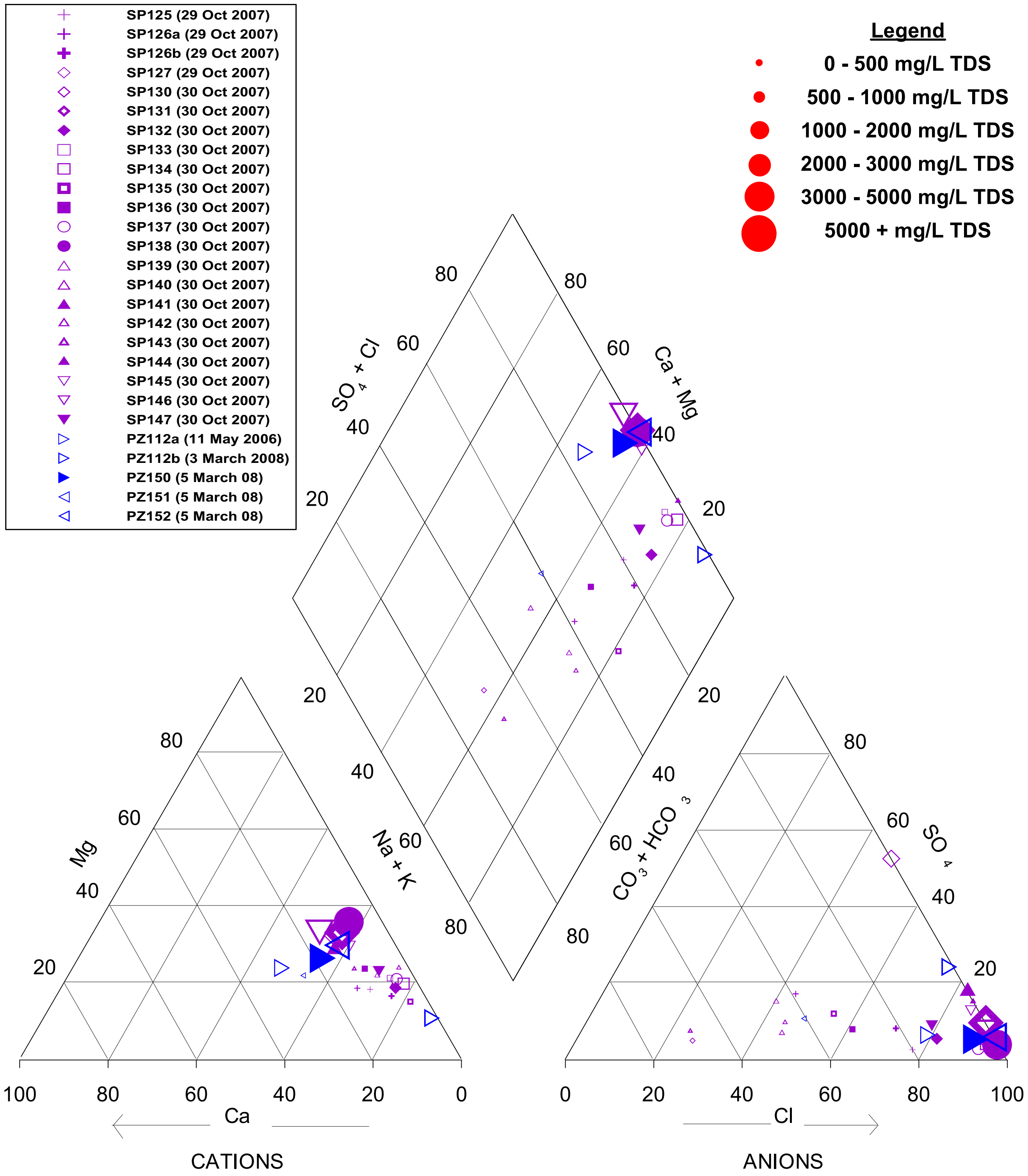
Date: 29 June 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Groundwater pH** **MCC Stage 2 Area**
Drawing No: S06I-4.5	Rev: A	
RPS Aquaterra		**Figure 3.5**



Legend

- Moolarben Underground Outline
- Moolarben Open Cut Outline
- EL6288 Lease Boundary
- Project Boundary
- Surface Water Drainage (Stream/Creek)
- SP14 Census Site
- PZ44 MCM Piezometer or Test Bore Stage 1
- PZ179 MCM Piezometer or Test Bore Stage 2
- 3000 Bore TDS (mgl)

Date: 29 June 2011	Scale: As Shown	**Moolarben Coal Mines Pty Ltd**
Initials: HZ	Job No: S06L	**Groundwater TDS (mg/L)** **MCC Stage 2 Area**
Drawing No: S06I-4.6	Rev: A	
RPS Aquaterra		**Figure 3.6**



CLIENT Moolarben Coal Mines Pty Ltd		PROJECT MOOLARBEN PROJECT
DRAWN SRD	DATE November 2008	TITLE PIPER TRILINEAR DIAGRAM Groundwater Quality In The South Eastern Area of Murragamba Valley
CHECKED NW	DATE November 2008	
SCALE As Shown	A4	PROJECT No S06 — Figure 3.7

RPS Aquaterra

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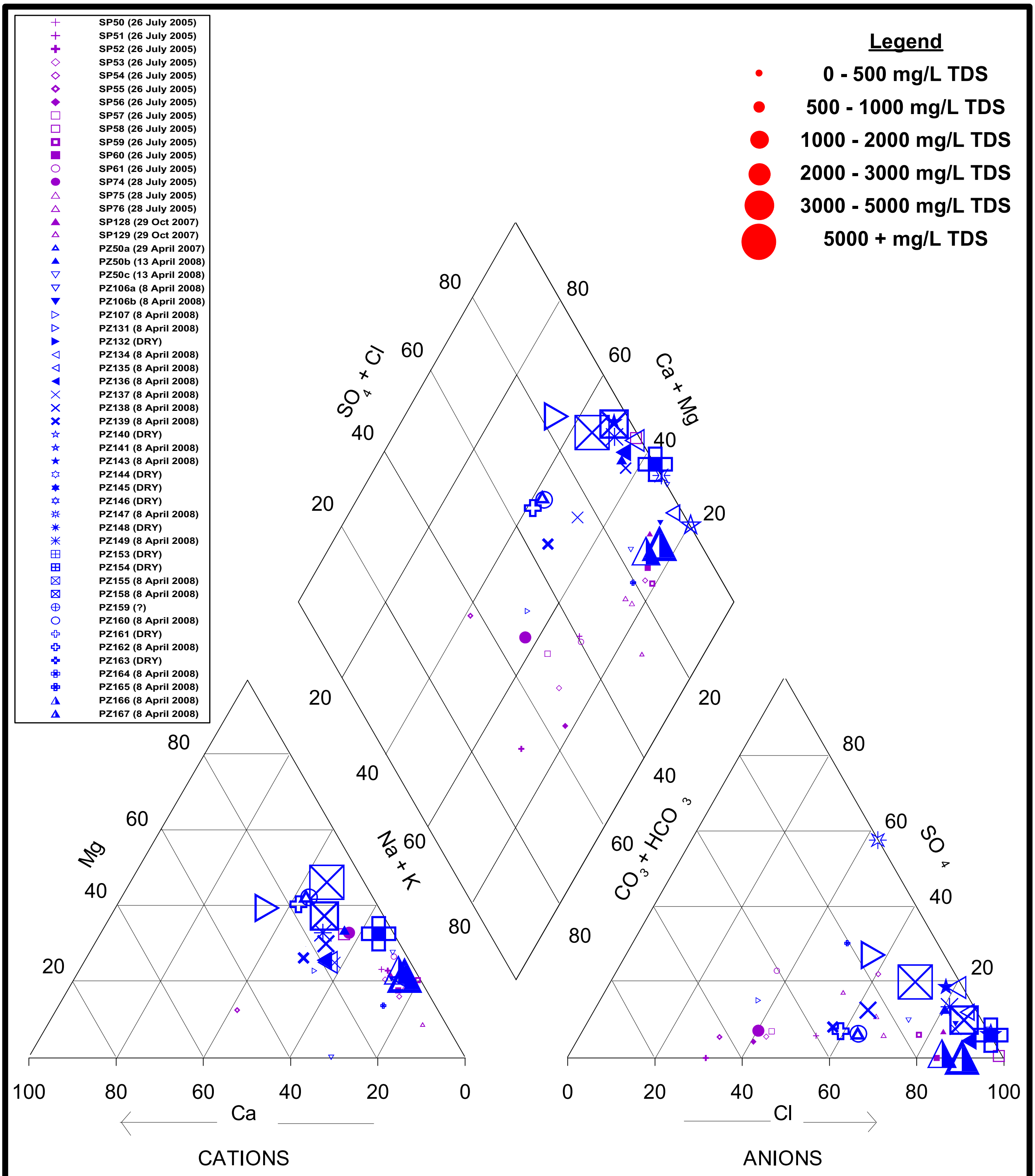

RPS Aquaterra	CLIENT Moolarben Coal Mines Pty Ltd		PROJECT **MOOLARBEN PROJECT**
	DRAWN SRD	DATE November 2008	TITLE **PIPER TRILINEAR DIAGRAM** **Groundwater Quality In The South Western Area Of Murragamba Valley**
	CHECKED NW	DATE November 2008	
	SCALE As Shown	**A4**	PROJECT No **S06** — **Figure 3.8**

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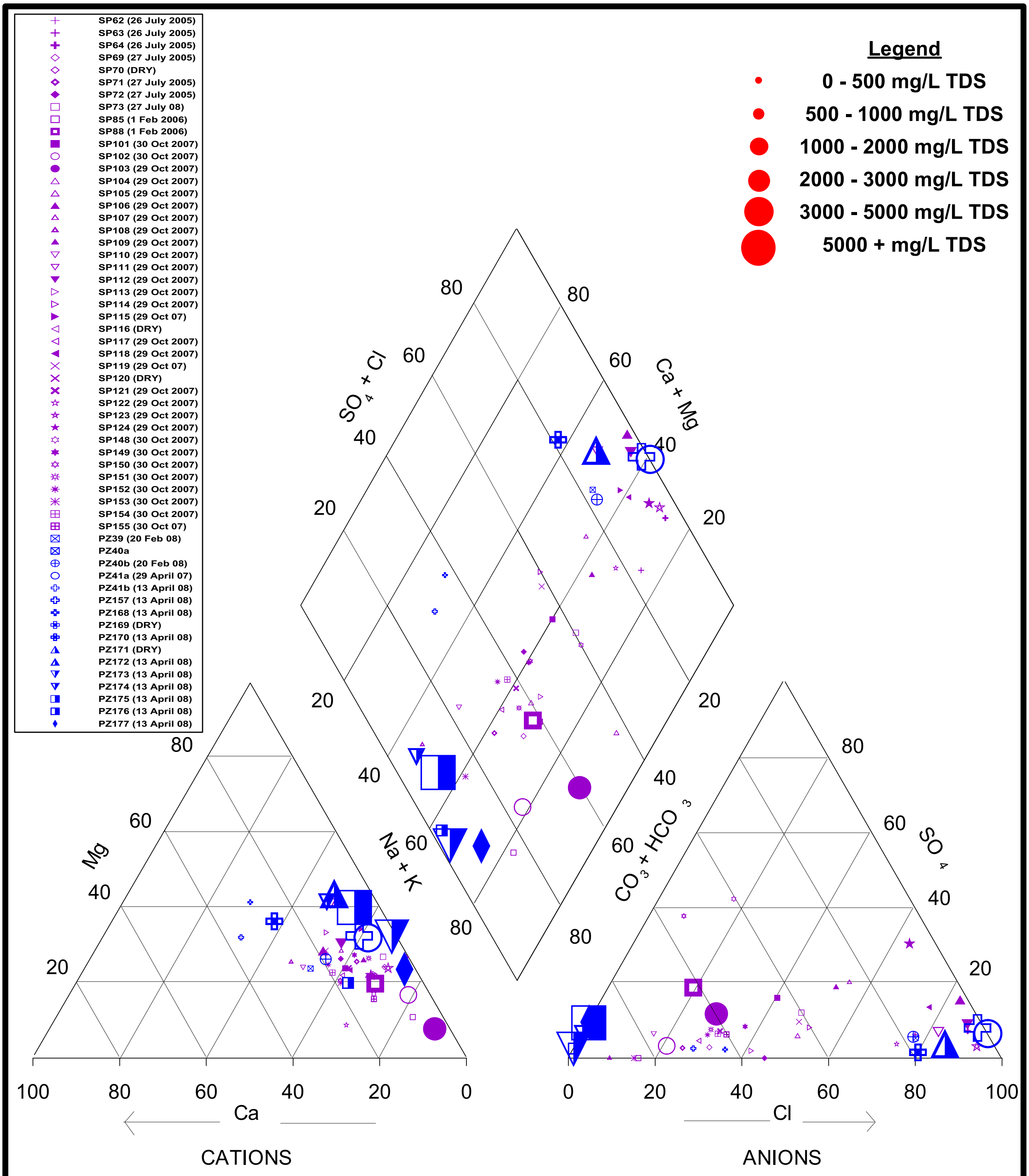

CLIENT Moolarben Coal Mines Pty Ltd

PROJECT **MOOLARBEN PROJECT**

DRAWN SRD | DATE November 2008

CHECKED NW | DATE November 2008

TITLE **PIPER TRILINEAR DIAGRAM**
Groundwater Quality In The Northern End Of Murragamba Valley

SCALE As Shown | A4

PROJECT No **S06** | **Figure 3.9**

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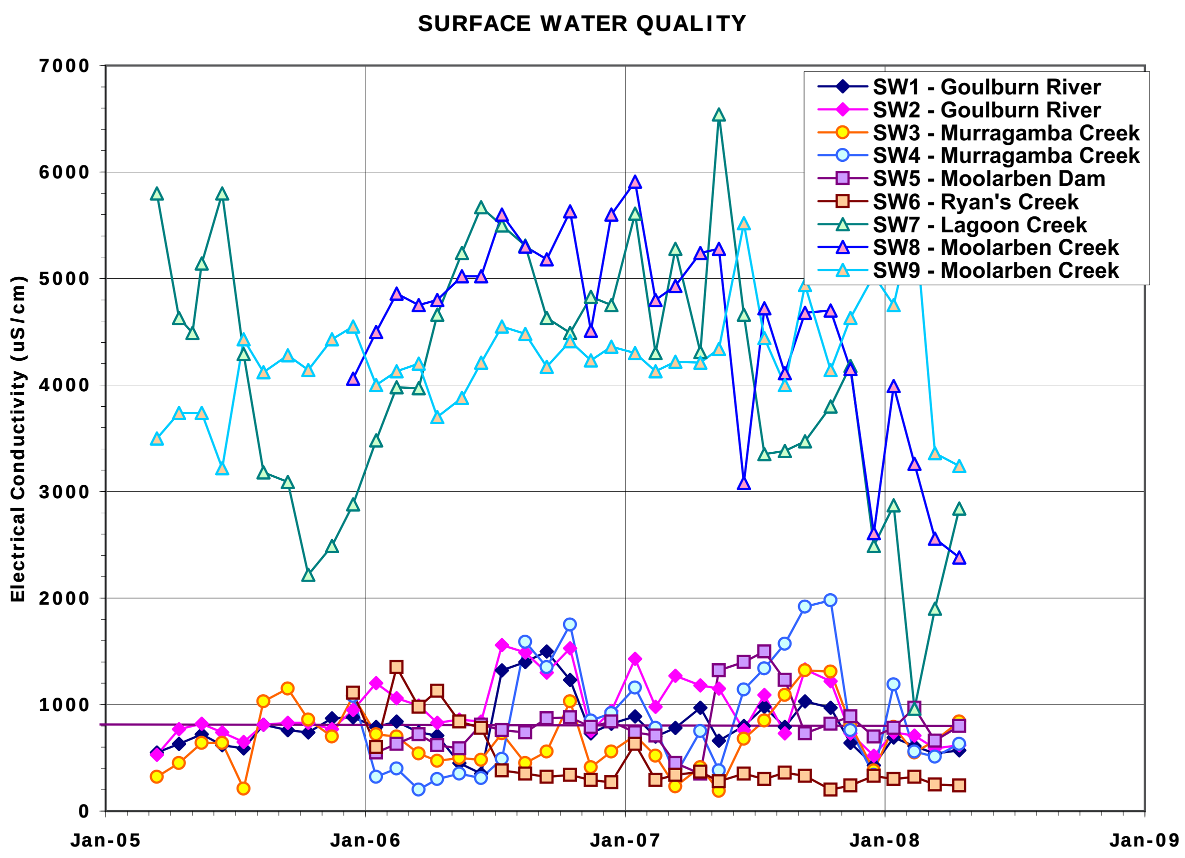
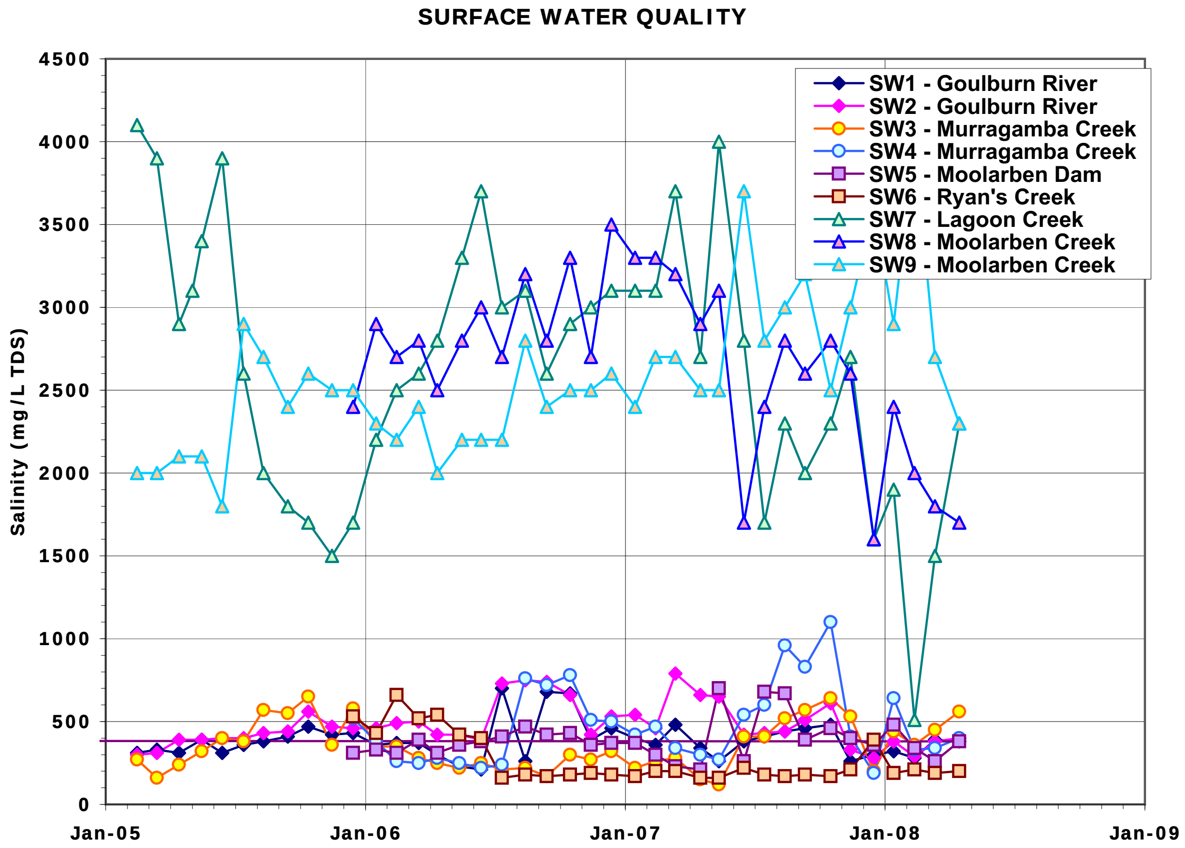
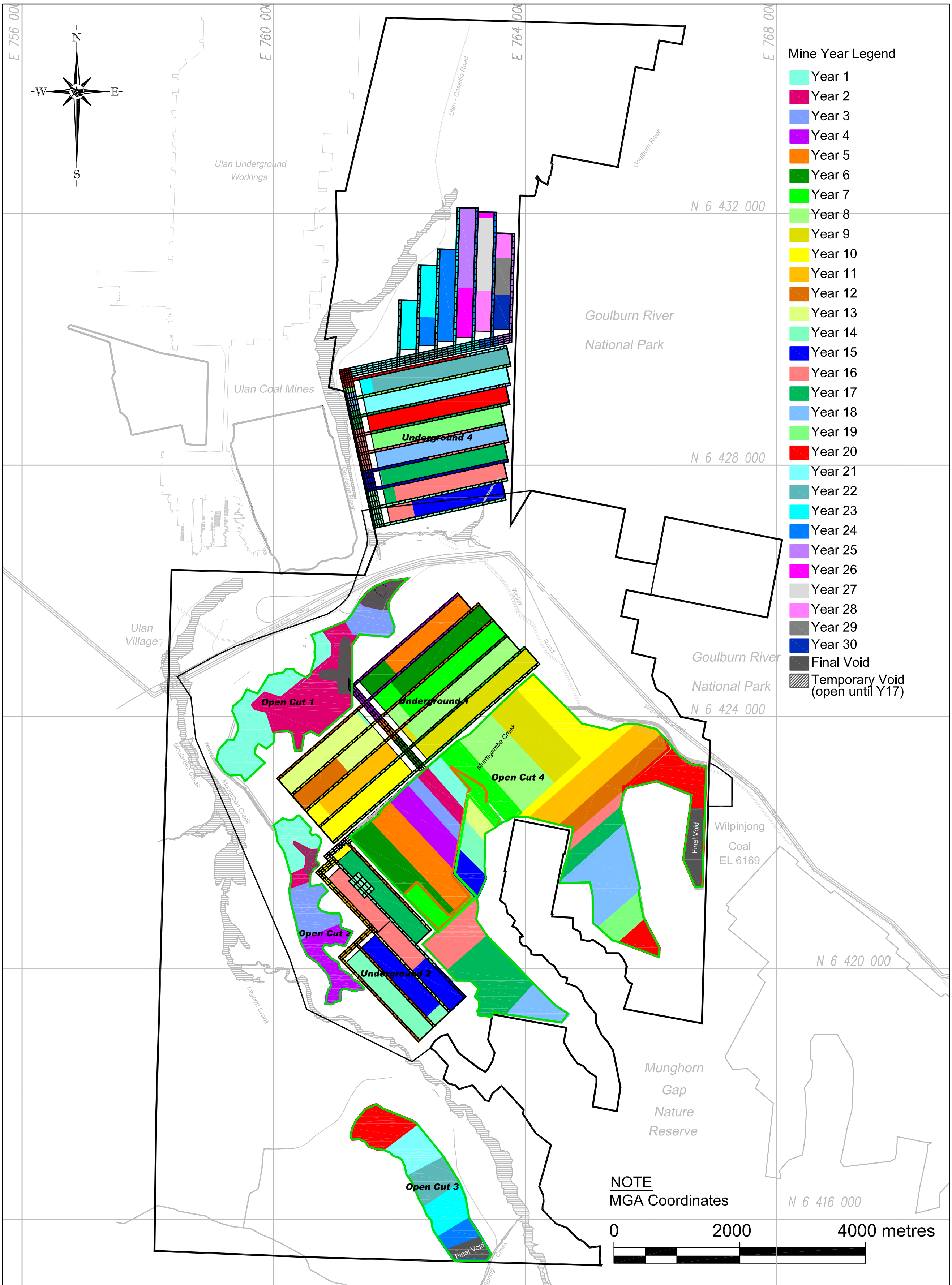


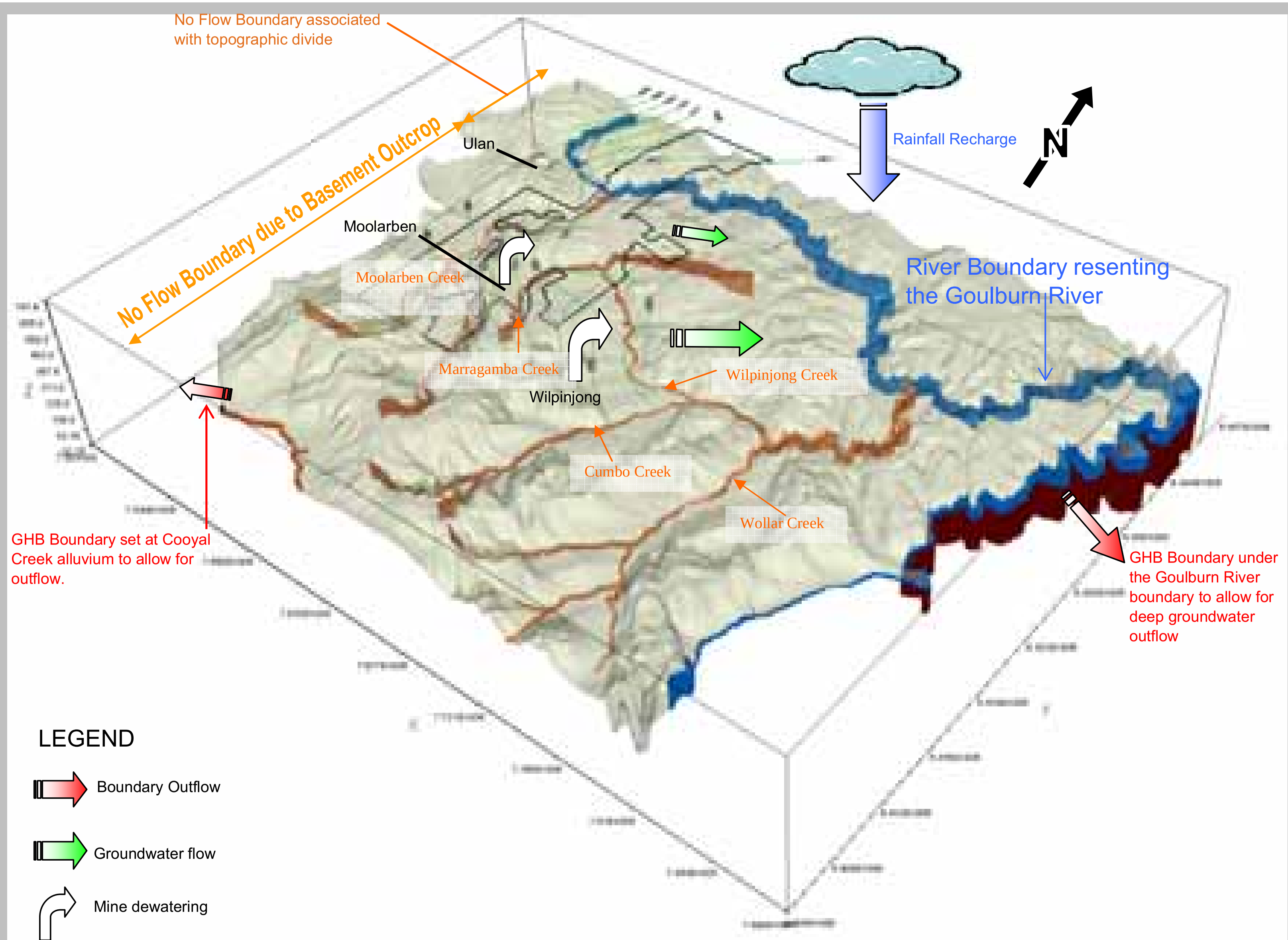


RPS Aquaterra

SURFACE WATER QUALITY FIGURE 3.10

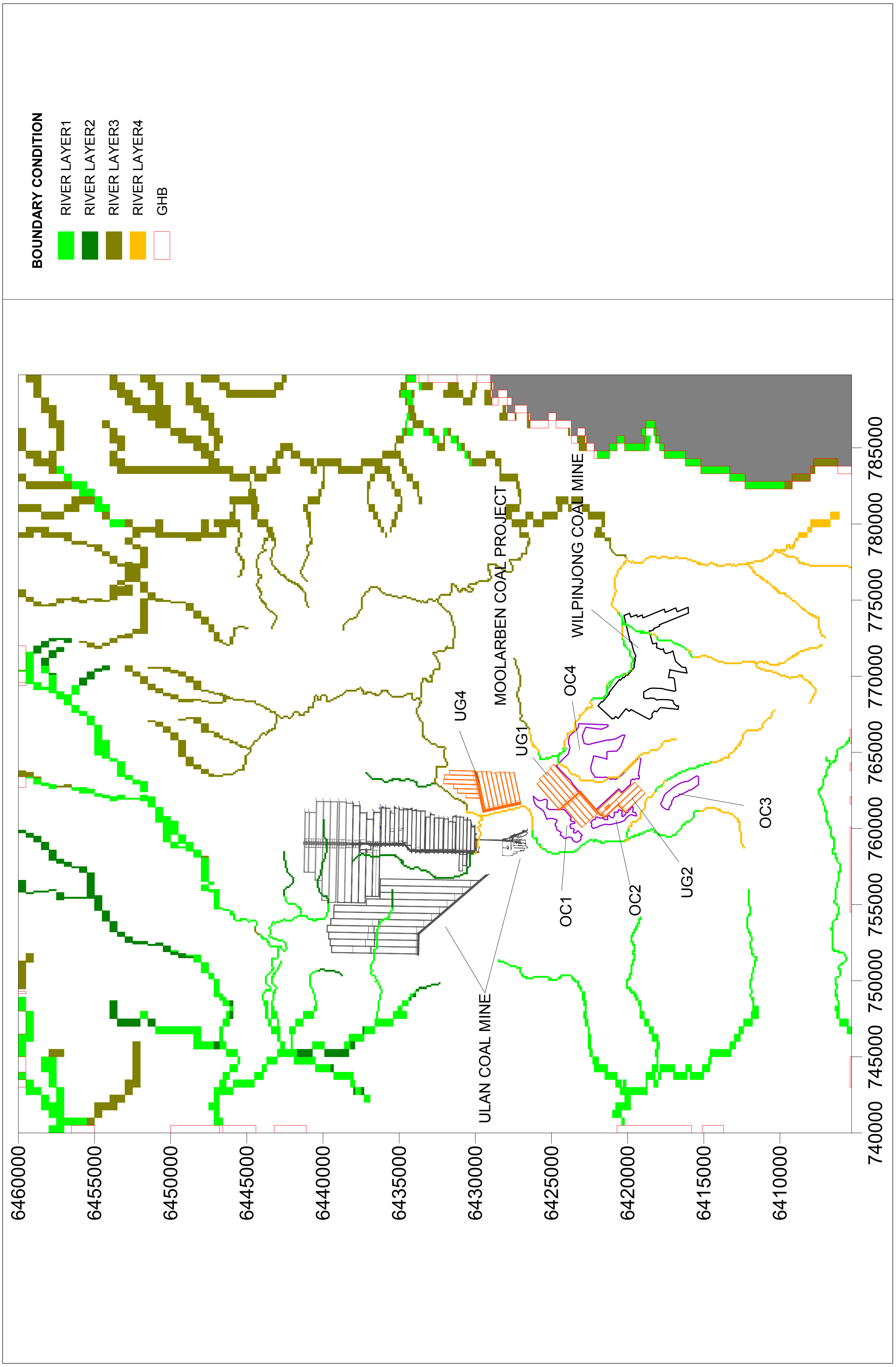


DATE: 11 May 2011	SCALE: as indicated	**Moolarben Coal Mines Pty Ltd**
AUTHOR: TL CHECKED: PJD	PROJECT NO: S6L	**Proposed Mining Schedule for EA2**
DRAWING NO: S6L-003	REVISION: C	
RPS Aquaterra		**Figure 4.1**



RPS Aquaterra

MOOLARBEN COAL MC2.2 CONCEPTUAL MODEL AND BOUNDARY CONDITIONS FIGURE 5.1



MC2.2 MODEL DOMAIN FIGURE 5.2a
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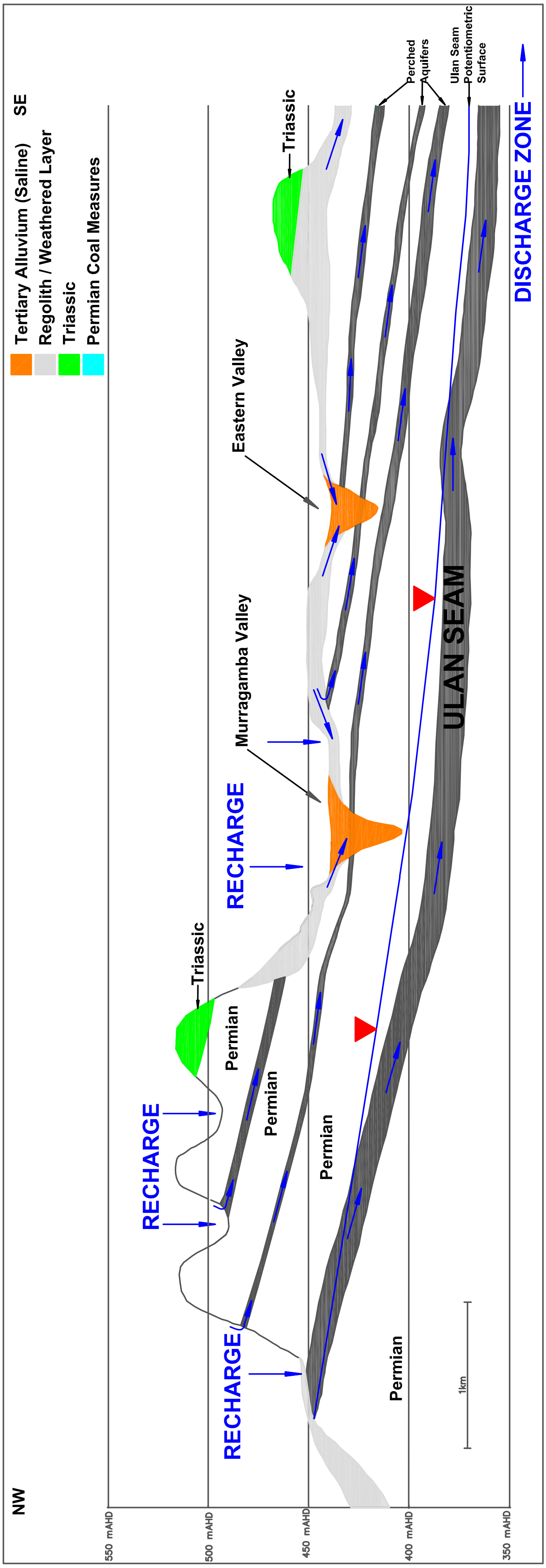
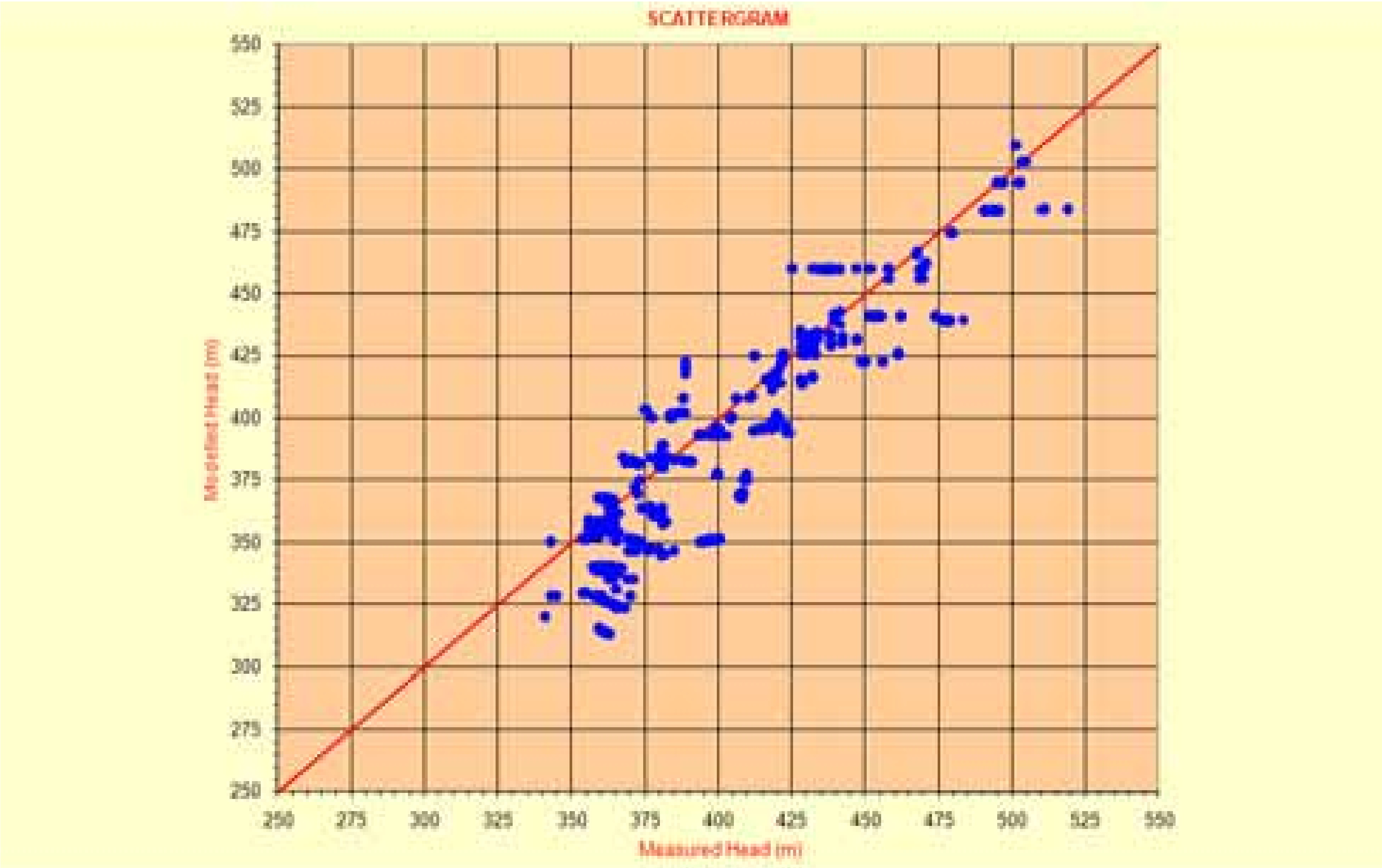


Conceptual Hydrogeological Cross-section Figure 5.2b



SCATTER DIAGRAM FOR MC2.2 MODEL TRANSIENT CALIBRATION (JUNE 1987 TO JUNE 2008) FIGURE 5.3

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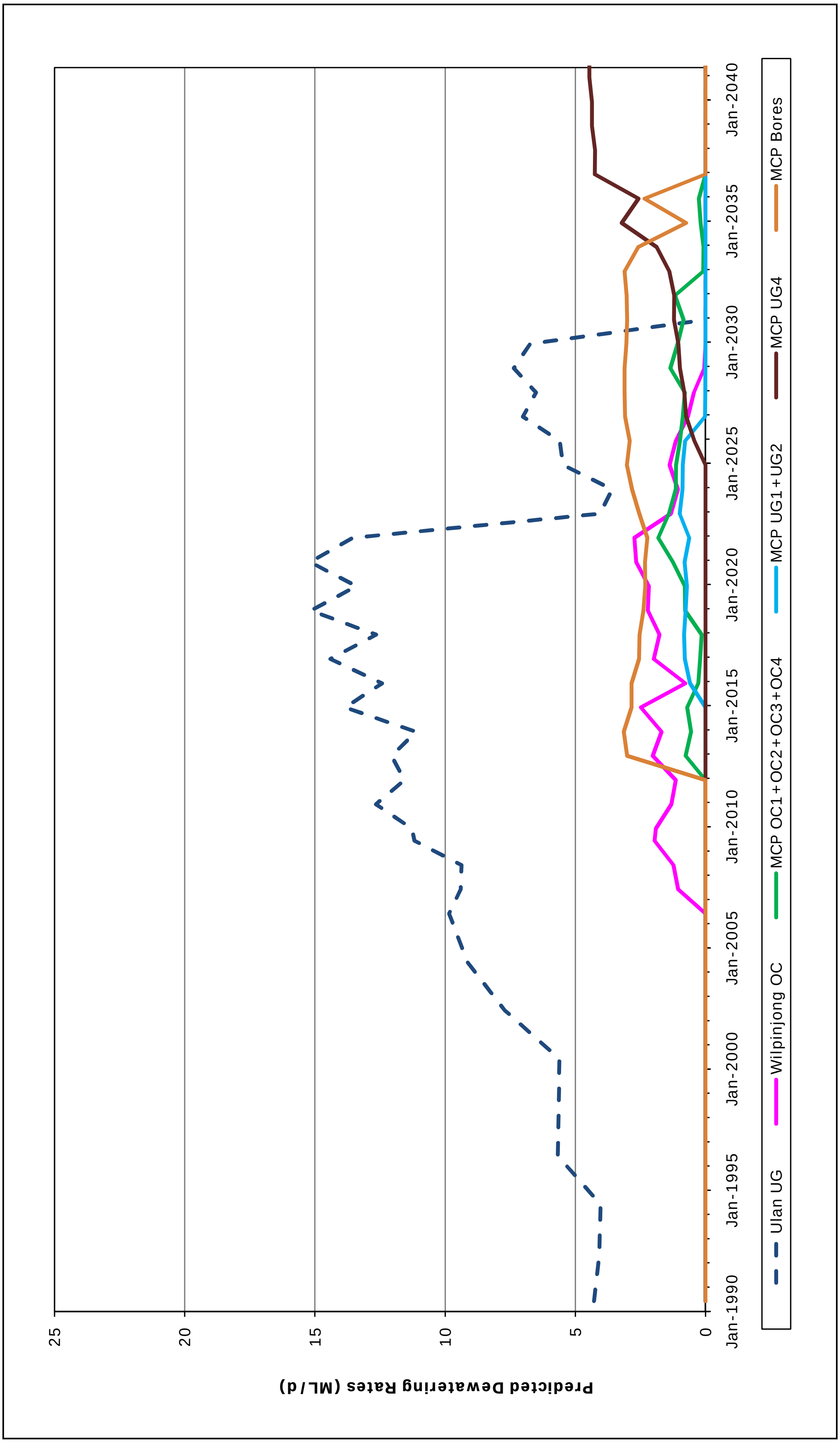
RPS Aquaterra



MC2.2 PREDICTED MINE DEWATERING RATES FIGURE 5.4

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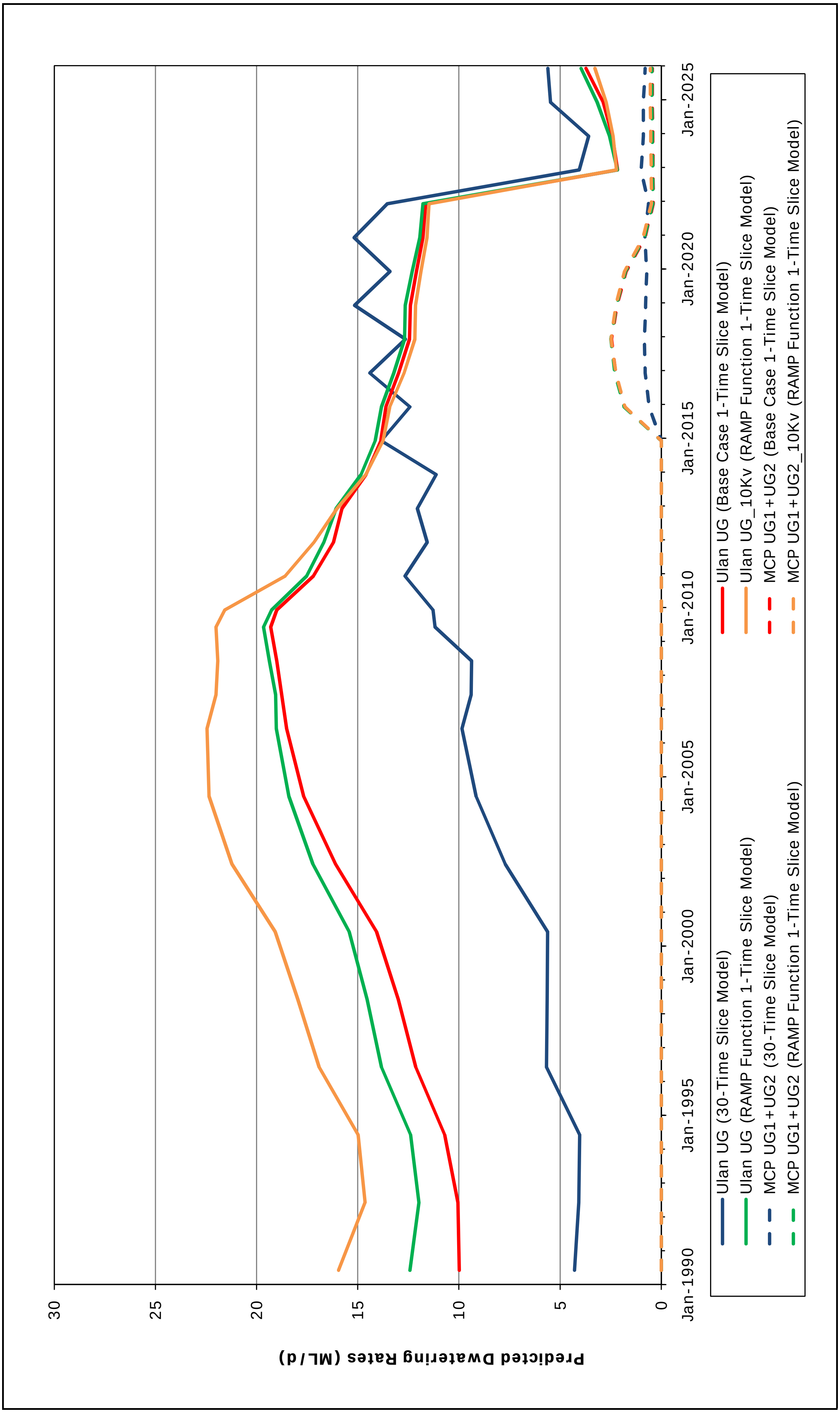

MC2.2 UNCERTAINTY ANALYSIS - MOOLARBEN MINE DEWATERING RATES FIGURE 5.5

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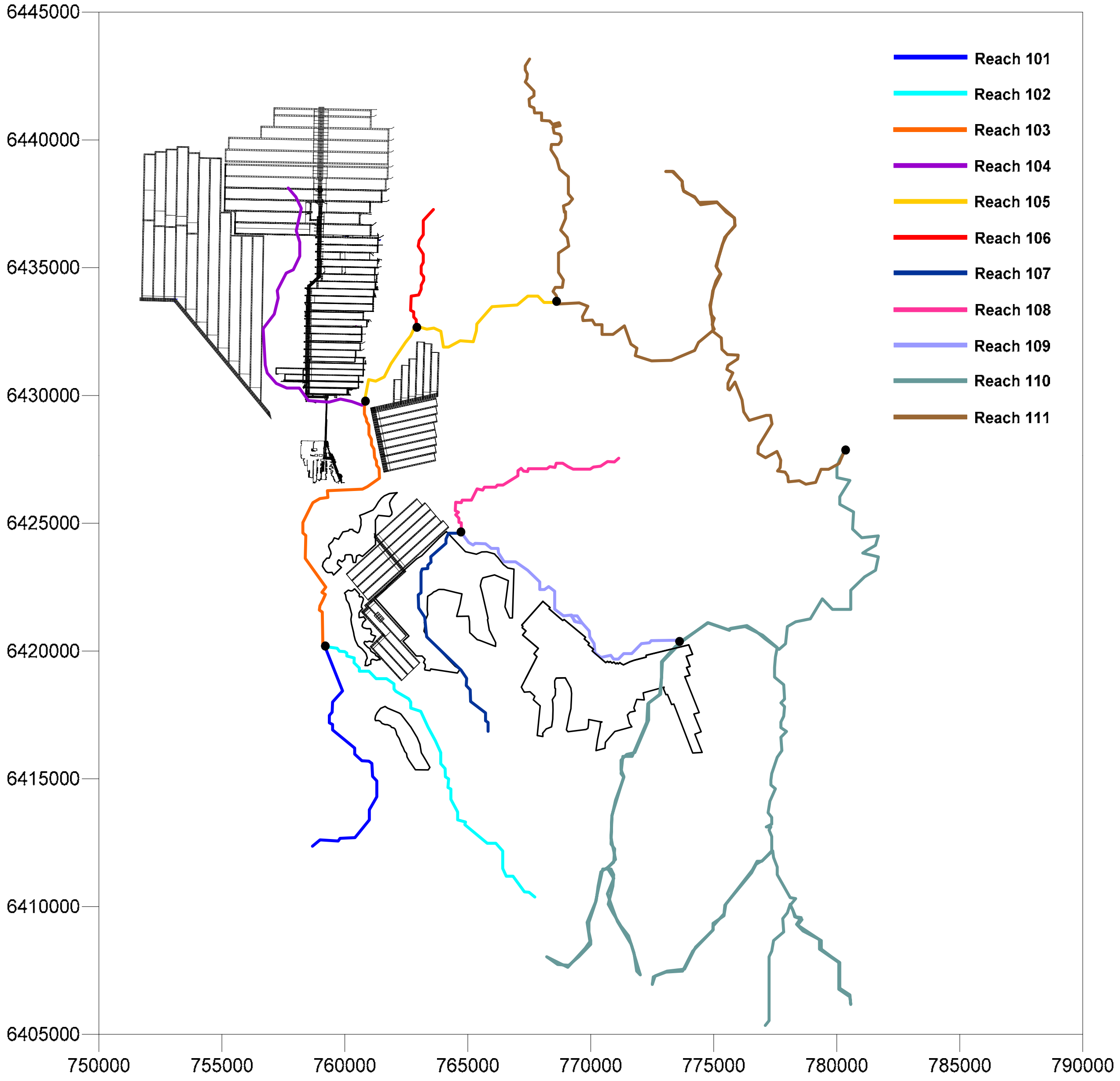
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