GLOUCESTER RESOURCES LTD

ABN: 46 114 162 597

ROCKY HILL
COAL PROJECT

Groundwater Assessment

Prepared by

Australasian Groundwater & Environmental Consultants Pty Ltd

April 2013

Specialist Consultant Studies Compendium
Volume 2, Part 4

This page has intentionally been left blank

GLOUCESTER RESOURCES LTD

ABN: 46 114 162 597

Groundwater Assessment

Prepared for: R.W. Corkery & Co. Pty Limited
1st Floor, 12 Dangar Road
PO Box 239
BROOKLYN NSW 2083

Tel: (02) 9985 8511
Fax: (02) 9985 8208
Email: brooklyn@rwcorkery.com

On behalf of: Gloucester Resources Limited
Level 37, Riverside Centre
123 Eagle Street
BRISBANE QLD 4000

Tel: (07) 3006 1830
Fax: (07) 3006 1840
Email: gpolwarth@amci.com.au

Prepared by: Australasian Groundwater & Environmental Consultants Pty Ltd
36 Jeays Street
BOWEN HILLS QLD 4006

Tel: (07) 3257 2055
Fax: (07) 3257 2088
Email: daniel.barclay@ageconsultants.com.au

April 2013

Please Note:

On the following figures, the red line identified as the Mine Area Boundary is in fact the Site Boundary as displayed on **Figure 1.2** or the *Environmental Impact Statement*.

Figures 1, 2, 3, 5, 7, 10, 11, 38, 40, 41, 42, 44, 48 and **61**.

CONTENTS

Page

CONTENTS

Page

CONTENTS

Page

CONTENTS

Page

FIGURES

CONTENTS

CONTENTS

Page

TABLES

EXECUTIVE SUMMARY

The proposed Rocky Hill Coal Project (the Proposal) is owned by Gloucester Resources Limited (GRL). Exploration in the area commenced in the 1970s and in 2006 GRL commenced exploration within EL 6523. Detailed exploration by GRL within the south-eastern corner of EL 6523 has defined a mineable coal resource, which is now proposed as the Rocky Hill Coal Project.

The Proposal would allow the development of open cut mining operations within the Rocky Hill Coal Mine Area and the development of infrastructure for the mine operations.

The Proposal is located approximately 3.5km to 7km south-east of the Gloucester urban area and approximately 120km north of Newcastle. Based on the planned production schedule, the Proposal would have an operational life of approximately 14 years with an approval sought for an overall life of 21 years including construction and rehabilitation.

This groundwater impact assessment was prepared for the Environmental Impact Statement to support the application for development consent under Part 4 (Division 4.1) of the Environmental Planning and Assessment Act 1979 (EP&A Act).

The groundwater impact assessment includes a review of studies undertaken in the Gloucester Basin for surrounding mines and coal seam gas (CSG) development, conceptualisation of the groundwater regime, development of a finite difference (MODHMS) groundwater flow model with a coupled surface water model, and simulation of the impact of the Proposal on the groundwater regime.

Previous Studies

A number of studies have been undertaken in the Gloucester Basin for surrounding mines and proposed CSG developments. The Stratford Coal Mine commenced operation in 1995 and has undergone a number of extensions to its mining operations. Stratford Coal Pty Limited, a subsidiary of Yancoal Australia Limited, formerly Gloucester Coal Limited, has submitted an Environmental Impact Assessment for further extensions to the Stratford Coal Mine with the completion of a numerical impact assessment model for the Stratford Coal Mine extension. The background, details and results of this modelling were not made available to GRL during the development of the impact assessment for the Proposal, however the results of the Stratford Coal Mine extension groundwater impact assessment were made public during the finalisation of this report.

AGL intends to develop a 110 well CSG operation in the Gloucester Basin. AGL received conditional approval for their project in February 2011, although since February 2011, AGL has since carried out additional groundwater work to satisfy government and landholder concerns relating to groundwater. An impact assessment model has not yet been developed by AGL.

Groundwater Systems

A review of existing data and reports indicates that the hydrogeological regime of the Mine Area and surrounds consists of:

- A Quaternary Alluvial groundwater system associated with the Avon River, Waukivory Creek and minor tributaries;

- Areas of colluvial fill at the base of steep slopes and the margins with the Quaternary Alluvium;
- A veneer of weathered bedrock material (regolith);
- The coal seams of the Permian Dewrang Group and Gloucester Coal Measures; and
- The interburden and overburden of the Permian Dewrang Group and Gloucester Coal Measures.

The Quaternary Alluvium is up to 12m thick and contains clays, silts, sands and gravels. The alluvial groundwater is typically not exploited for irrigation or stock supplies as the surface water flow in the Avon River and Waukivory Creek is sufficient to support local use. Groundwater in the alluvium is variable in quality ranging from fresh water close to the stream bed to brackish towards the margins of the alluvium. The upper section of the alluvium is predominantly clay with minor sand and silt. The groundwater quality of the alluvial sediments is also variable with depth, with the poorest quality water present in the basal sections of the monitoring bores, likely due to discharge from the underlying Permian formations.

Colluvial sediments are up to 7m thick and are distinguished from alluvial material by the angular and poorly sorted nature of the sediments indicating deposition close to the source rocks. Groundwater in the colluvium is fresh in quality indicating relatively high rates of recharge during periods when surface runoff occurs. The colluvial sediments interfinger with the alluvial sediments particularly along the upper reaches of Waukivory Creek.

The regolith material comprises a thin soil cover and weathered bedrock up to 37m thick. The weathered material is only partially saturated.

The Permian formations and coal seams outcrop in the elevated terrain of the Mine Area and subcrop beneath the alluvium. They are generally low yielding and contain poor quality brackish water. The water table / potentiometric surface of the Permian formations and coal seams form a subdued reflection of the topography with groundwater flow and discharge to the alluvial areas of Waukivory Creek and the Avon River.

Hydraulic Properties

Hydraulic testing within the Mine Area is limited to falling and rising head tests undertaken on GRL groundwater monitoring bores. However, this data has been supplemented by hydraulic data conducted by AGL with packer tests, falling head tests, and core permeability tests undertaken to the south and north of the Mine Area. This hydraulic data is available for the Quaternary Alluvium, colluvium, regolith and Permian interburden/overburden and individual coal seams. This data has indicated a representative hydraulic conductivity for the Quaternary alluvium of about 50m/day to 150m/day. The hydraulic conductivity values for the coal seams range from about 0.15m/day to 2×10^{-3}m/day near the surface to 6×10^{-3}m/day to 5×10^{-4}m/day at a depth of approximately 300m to 500m below surface. The hydraulic conductivity values for the interburden range from about $0.^{2}$m/day and 4×10^{-2}m/day in the GRL monitoring bores to 0.9m/day to 2×10^{-6}m/day in the AGL monitoring bores.

Numerical Model

A finite difference numerical model was developed from the conceptualisation of the groundwater flow regime using the MODHMS software package. The model consisted of 10 layers, the upper layer representing the alluvium, colluvium and weathered bedrock (regolith) and the bottom (base of model layer), representing the underlying Alum Mountain Volcanics. The intermediate layers represent the Permian coal measures, these being the major coal seams separated by interburden. The hydraulic conductivity of the coal seams was reduced continuously with depth to account for the effect of increasing confining stress and the model was calibrated by adjusting the hydraulic conductivity.

The modelling software allowed for a coupled groundwater and surface water model to be developed and calibrated. The transient calibration provides a reliable match between observed and modelled data which provides confidence in the predictive capacity of the model.

The predictive numerical model includes the proposed AGL CSG development, the historical Stratford Coal Mine operations and the proposed Stratford Coal Mine Extension. These developments were included in the predictive simulations to assess the potential cumulative impacts in the Gloucester Basin.

Predictive Simulations

Results of the predictive simulations are summarised below:

- During the 14 year mining period, the modelling indicates the cumulative seepage rate to the four open cut voids will be on average 640ML/year inflow. This will vary throughout the mining period with a predicted peak of 1250ML/year in Year 4. However, the model is likely to overestimate the predicted inflows to the mine. A proportion of groundwater that seeps into the mine will be either evaporated from the coal face and interburden / overburden (likely to be up to 10% of total inflow), or removed as moisture with the coal and interburden / overburden during mining (reported to be 5-7% moisture content for ROM coal or 15% of total inflow). Where the coal seams within the Mine Area dip steeply, there will be a larger surface area of coal in the floor of the pit exposed to more direct sunlight compared with mines in the Hunter Valley. This larger surface area is likely to result in greater evaporation of water not only from the exposed coal faces but also from the interburden and overburden material in the open pits. It is considered that the predicted inflows to the mine, and water to be managed within the pit is likely to reduce by up to 25% after taking these factors into account.
- Typically the individual pit inflows vary from:
  - Bowens Road 2 Pit 0.5 – 1.0ML/day;
  - Weismantel Pit 0.5 – 1.5ML/day;
  - Avon Pit 0.5 – 1.0ML/day;
  - Main Pit Sub-pit 1 0.5 – 2.0ML/day;
  - Main Pit Sub-pit 2 0.5 – 1.0ML/day; and
  - Main Pit 0.5 – 2.0ML/day.

- The modelling indicates the zone of depressurisation in the coal seams attributable to the Proposal would expand to the south, north and west of the open cut pits, but will be restricted to the east by outcropping coal measures.
- The model predicts there is a net upward flow entering the alluvium from the Permian strata. This is predicted to be between 0.4ML/day to 0.6ML/day from the Permian strata to the Quaternary Alluvium. The model predicts that once mining commences the Permian strata depressurises and upward flow from the Permian to the alluvium reduces. This is due to changes in vertical gradients between the alluvium and Permian that reduces upward flow, and flow reversal to downward flow in areas adjacent to the mining areas. The modelling predicts that there would be a reduction of groundwater flow from the Permian to the alluvium of a maximum of 0.3ML/day. However, this reduction of flow is typically 0.1 - 0.2ML/day. The majority of this water does not flow to the proposed open cut mining area, but it simply remains in the underlying Permian bedrock and is therefore not lost from the larger system. When mining is complete the Permian strata start to re-pressurise and the predicted flow rate from the Permian basement to the overlying alluvium increases and returns to pre-mining rates over time. Approximately one third of this flow reduction (up to 0.12ML/day) will be groundwater that seeps directly to the pits from the Quaternary Alluvium.
- The impact of the Proposal on flows within the Avon River and Waukivory Creek is not expected to be measurable as groundwater base flow to surface water systems in the Gloucester Basin is a very small percentage of contribution to the regional water balance.
- River Oaks have been identified along the riparian zone of Waukivory Creek and the Avon River. The modelling indicates that there will unlikely be drawdown in groundwater levels in the Quaternary Alluvium. As a result, there will not be any reduced availability to the shallow groundwater system and no impact to any Groundwater Dependent Ecosystems (GDEs).
- There are no private groundwater users that are predicted to be impacted by the Proposal.

Post Closure Conditions

At the completion of coal mining operations at the Rocky Hill Coal Mine, the open cut pits will have been progressively backfilled with overburden and rejects from the Coal Handling and Preparation Plant (CHPP).

The model predicts that the groundwater levels recover to within 76% of the final groundwater levels within 5 years of closure. The remaining recovery is predicted to take approximately 10 years to stabilise. The predicted groundwater levels at recovery are higher than the original pre-mining groundwater level that is observed today. This higher post closure water table is a result of the higher recharge rate applied to the overburden emplacement areas. This higher recharge rate results in an overall increase in water level. The process of mining and progressively backfilling the pits with spoil and/or reject material is likely to result in the re-establishment of groundwater flow conditions similar to those observed pre-mining.

There is likely to be liberation of solute from the recently backfilled overburden and reject material in the pits. This solute will be mobilised by the infiltration of enhanced recharge in the backfilled overburden resulting in leachate from the backfilled overburden. This leachate is likely to comprise a mix of relatively fresh groundwater (<300µS/cm from the overburden / interburden samples) and brackish groundwater (<4,900µS/cm from the coal rejects). However, given the ratio of materials emplaced in the pits, it is likely that the electrical conductivity (EC) of this leachate will be more representative of the kinetic test results of the overburden / interburden samples (i.e. 300µS/cm) and is likely to have a lower EC compared against the baseline groundwater in the Permian strata.

The increased recharge component will yield better quality water (leachate) due to the increased component of fresh (low EC) rainfall mixing with the predicted solute concentrations from the kinetic leach testing. As a result of these processes, the post-mining groundwater quality that discharges from the Permian strata to the Quaternary Alluvium is likely to be slightly improved.

Mitigation Options

The Proposal is planned to encroach within 150m of the Waukivory Creek alluvium. Whilst a series of cut-off grout curtains or similar can feasibly be constructed in these areas, these structures are likely to result in a small reduction of flow in the order of 0.1ML/day (1L/s) and are not recommended. The structures are likely to involve considerable cost and these pit inflows represent peak flows and are predicted to occur over a 1 – 2 year period rather than a longer term sustained seepage. Therefore any grout curtain would have a short term effect and would be superfluous in the long term. The saving of 0.1ML/day flow reduction from the alluvium is considered insignificant when compared with the long term baseflow component of the Avon River (20ML/day) and represents 0.5% of baseflow in the downstream surface water system.

GRL currently holds water licences (267ML/yr) under the Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources. This entitlement is well in excess of the predicted 55ML/year (long term average) required to offset the loss of recharge to the alluvium under the Water Management Act 2000. Mitigative measures for any identified negative impacts beyond those predicted, may include relinquishment of surface water allocations as an offset to monitored leakage from the alluvium in excess of predictions.

On-going management should include a monitoring program to ensure that key water quality parameters within the groundwater monitoring network remain within appropriate criteria.

Groundwater Monitoring Program

A groundwater monitoring network has previously been established by GRL within the Mine Area, comprising paired and discrete bores located at 15 sites. All of these sites are regularly monitored for water levels and water quality.

The data collected to date is considered by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) to be adequate and suitable for the assessment and description of the existing environment. The data has enabled a numerical model to be calibrated to a transient dataset that is representative of baseline conditions. This transient calibration takes into account the various recharge conditions that occur to the groundwater and surface water systems and allows for surface and groundwater interactions to be simulated. This model has then been used to predict impact to the groundwater systems from the Proposal.

The existing monitoring network is considered suitable for the on-going monitoring of baseline conditions in the Mine Area and for future validation of the predictive model. This baseline data will provide a sufficient dataset with which to develop a series of trigger values for both groundwater levels and quality. This monitoring program will be continued and expanded with several additional groundwater monitoring bores installed as some of the current network of bores are progressively removed by mining.

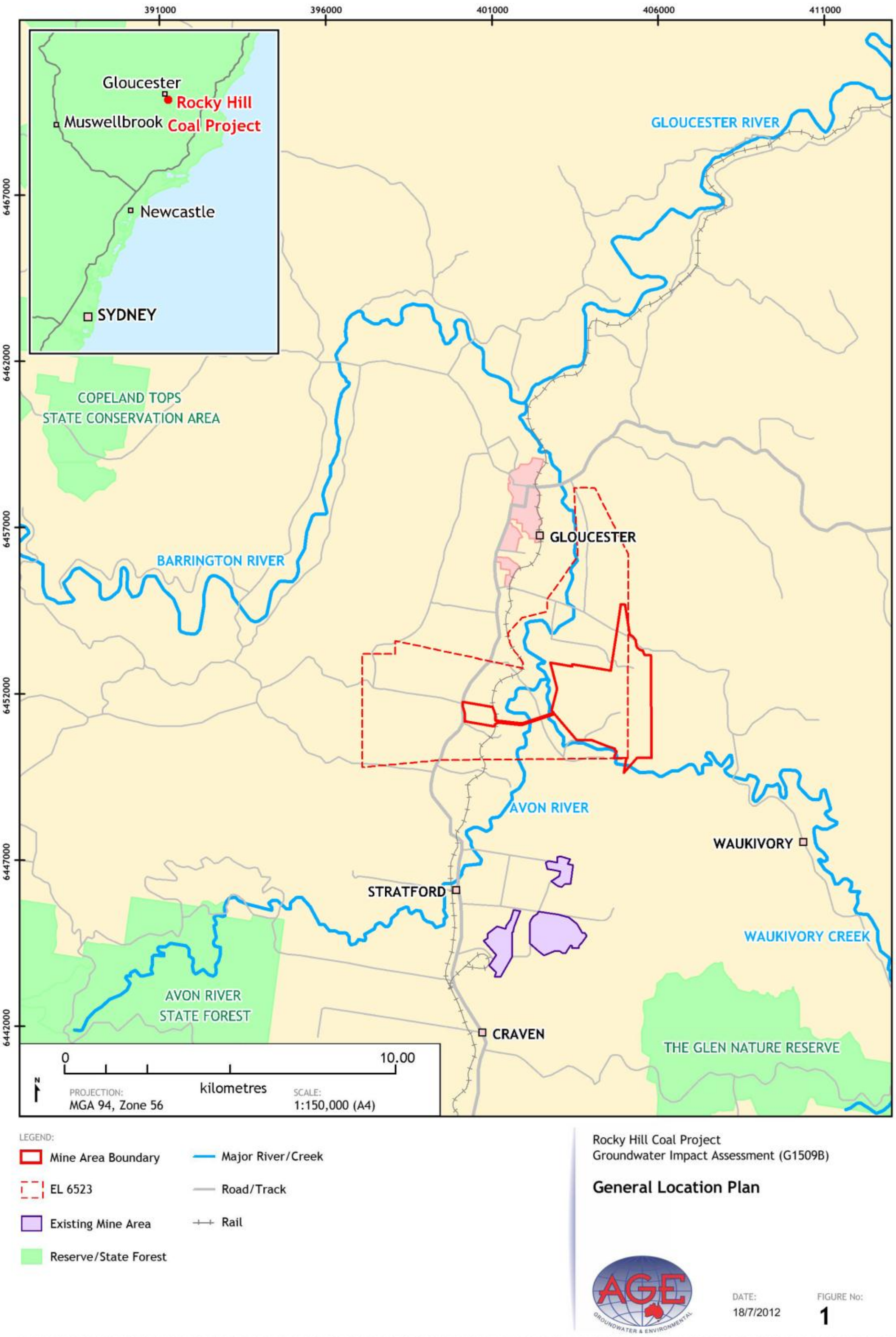
1. INTRODUCTION

The proposed Rocky Hill Coal Project (the Proposal) is located approximately 3.5km to 7km to the south-east of the township of Gloucester urban area in the Upper Hunter region of NSW, within the Gloucester Local Government Area (LGA) as shown on **Figure 1**. The proposed Mine Area is located largely within Exploration Licence 6523 (EL 6523). The Project is owned by Gloucester Resources Limited (GRL), a wholly owned subsidiary of GRL Holdings Pty Limited both of which are Australian companies.

Exploration licences across the Gloucester Basin were originally granted in the 1970s. Following this, exploration activities were undertaken with the aim of defining the local geology and a viable mine plan for the coal resources. In 2006, GRL was granted three exploration licences (EL 6523, EL 6524 and EL 6563). Detailed exploration by GRL within the south-eastern corner of EL 6523 has defined a minable coal resource, the Proposal.

GRL intends to apply for development consent under Part 4 (Division 4.1) of the *Environmental Planning & Assessment Act 1979* (EP&A Act) to facilitate the development of surface infrastructure and open cut mining activities for the Proposal for a period of 21 years. The boundary of the proposed Mine Area is shown on **Figure 1**.

GRL commissioned R.W. Corkery & Co Pty Ltd (R.W. Corkery) to prepare an Environmental Impact Statement (EIS) in support of the proposed application for development consent. This groundwater impact assessment has been completed by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) at the request of R.W. Corkery, on behalf of its client GRL, and forms part of the supporting documentation for the EIS.


391000
396000
401000
406000
411000
6467000
6462000
6457000
6452000
6447000
6442000
Gloucester
Rocky Hill Coal Project
Muswellbrook
Newcastle
SYDNEY
GLOUCESTER RIVER
COPELAND TOPS STATE CONSERVATION AREA
BARRINGTON RIVER
GLOUCESTER
AVON RIVER
WAUKIVORY
STRATFORD
WAUKIVORY CREEK
AVON RIVER STATE FOREST
CRAVEN
THE GLEN NATURE RESERVE
0
10.00
kilometres
N
PROJECTION:
MGA 94, Zone 56
SCALE:
1:150,000 (A4)
LEGEND:
Mine Area Boundary
EL 6523
Existing Mine Area
Reserve/State Forest
Major River/Creek
Road/Track
Rail
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
General Location Plan
AGE
DATE:
18/7/2012
FIGURE No:
1

2. OVERVIEW OF THE PROPOSAL

GRL is seeking development consent to allow the development of surface infrastructure and open cut mining activities within a proposed mining tenement for a period of 21 years. Approval is being sought for open cut extraction of up to 2.5 Million tonnes per annum (Mtpa) Run-of-Mine (ROM) coal.

The proposed Rocky Hill Coal Project comprises four principal components namely:

1. four separate and/or contiguous open cut pits and a coal handling and preparation plant (CHPP) within the Mine Area;
2. an overland conveyor for transporting product coal to the Rail Load-out Facility. The overland conveyor is located within a 50m wide Overland Conveyor Corridor;
3. a Rail Load-out Facility (incorporating a rail loop and two coal storage bins); and
4. two Power Line Corridors incorporating a re-located 132kV power line and a new 11kV power line external to the Mine Area.

The area covered by the entire Proposal is referred to as “the Site” and includes the Mine Area, overland conveyor and Rail Load-out Facility.

3. SCOPE OF WORK

The Director-General's Requirements (DGRs) for water-related assessments for the Proposal provided by the NSW Department of Planning and Infrastructure (DP&I) on 24 April 2012 are as follows:

- detailed modelling of the potential groundwater impacts of the Proposal, including any potential impacts on the alluvial aquifers of the Avon River and Waukivory Creek and confirmation of the physical extent of the rivers/creek's alluvium;
- impacts on affected licensed water users and basic landholder rights;
- impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including environmental flows;
- a detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures;
- an assessment of proposed water discharge quantities and quality/ies against receiving water quality and flow objectives, including water diverted by the construction and operation of the proposed mine;
- assessment of impacts of salinity from mining operations, including disposal and management of coal rejects and modified hydrogeology, a salinity budget and the evaluation of salt migration to surface and groundwater sources;
- identification of any licensing requirement or other approvals under the Water Act 1912 and/or Water Management Act 2000;
- demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP);
- a description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo;
- a detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts; and,
- a detailed flood impact assessment, which identifies impacts on local flood regimes, including:
  - an assessment of the potential for flooding to occur in the open-cut pits; and
  - any measures proposed to mitigate potential flood impacts.

Table 1 summarises the DGRs and additional matters provided by other government agencies and the section(s) of the report where they are addressed. The objective of the groundwater impact assessment was to assess the impact of the Proposal on the hydrogeological regime and to meet the applicable DGRs. To achieve this objective, a scope of work was developed that included:

- identification of groundwater resources in the vicinity of the Site which could be impacted by the Proposal;
- assessment of the potential for any groundwater impacts resulting from the Proposal, including modelling the cumulative groundwater impacts of the Proposal with existing and proposed mining and CSG projects (including groundwater impacts on each identified privately owned bore);
- assessment of post-mine groundwater impacts and recovery of groundwater levels;
- the development of groundwater management strategies;
- identification of any groundwater impact mitigation measures necessary for the Proposal; and
- a recommended groundwater monitoring program.

The area investigated as part of the groundwater study extends a distance of 15km surrounding the Mine Area and encompassed the alluvial groundwater systems adjacent to the Site.

Table 1
Coverage of DGRs and Additional Matters

Page 1 of 4

COVERAGE OF DGRs AND ADDITIONAL MATTERS		
Government Agency	**Paraphrased Requirement**	**Relevant Section(s)**
DP&I (24 April 2012)	The EIS must address the potential impacts on the quality and quantity of existing groundwater resources, including: • detailed modelling of potential groundwater impacts, including any potential impacts on the alluvial aquifers of the Avon River and Waukivory Creek and confirmation of the physical extent of the river/creek's alluvium;	11
	• impacts on affected licensed water users and basic landholder rights;	11.3
	• assessment of impacts of salinity from mining operations, including disposal and management of coal rejects and modified hydrogeology. A salinity budget and the evaluation of salt migration to surface and groundwater sources;	13
	• identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000;	4 & 14
	• demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP);	14
	• a description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo;	14
	• a detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate groundwater impacts; and	12 & 15

Table 1 (Cont'd)
Coverage of DGRs and Additional Matters

Government Agency	Paraphrased Requirement	Relevant Section(s)
	ADDITIONAL MATTERS	
EPA (02/04/12)	• describe existing groundwater quality. An assessment needs to be undertaken for any water resource likely to be affected by the proposal;	7
	• where groundwater may be impacted the assessment should identify appropriate groundwater environmental values;	7.1.6
	• assess impacts against the relevant ambient water quality outcomes;	13
	• the EIS needs to show an assessment of impacts on groundwater and groundwater dependent ecosystems;	11 &11.6
	• the EIS will need to carefully assess any impacts on groundwater or potential draw-down of Waukivory Creek. The EIS also needs to closely consider the possibility of breakthrough of Waukivory Creek to the open cut in times of flood and any ameliorative measures necessary to prevent this occurring;	11.5 & 12
	• all remedial measures proposed must be described and assessed in detail within the EIS.	12
Barrington-Gloucester-Stroud Preservation Alliance Inc. (26/03/12)	The EIS needs to incorporate a comprehensive groundwater model and describe the quality and quantity impacts that their activities would have on local groundwater used by landholders for stock and domestic bores;	10 & 11.3
	These impacts should include activities such as: • direct extraction of groundwater; • use of water in coal mining and processing; • collection and disposal of water from mine pits; • redirection of existing surface· flows during mine operation and in rehabilitation; and • use of water for dust suppression and mine spoil rehabilitation.	11 & refer surface water assessment
	Cumulative impacts of such water management be assessed in relationship to: existing coal mining by Gloucester Coal Limited at Stratford; • proposed extensions at Stratford coal mine (currently at the EIS development stage); • Concept Plan approval for AGL to extract coal seam gas in Stages 1,2 and 3; • the vertical interaction of proposed coal mining at 0-150m depth and coal seam gas(CSG) extraction at 150-900m at the same geographic location; • the water extraction by these operations; • future water usage by agriculture and urban development over the proposed 21 year life of the mine and 25 year potential operation of CSG extraction.	11
Gloucester Shire Council (02/04/12)	The EIS needs to outline potential cumulative impacts on the hydrology in this locality from the approved AGL coal seam gas project on the same land and other land in the immediate proximity is of fundamental importance. It is critical that the interrelationships between the two projects can be fully assessed.	11
	There have been concerns expressed about the simplicity of the modelling done for that project, given the complexity of the geology of the Gloucester Basin in this locality. It is understood that the Federal Government, through the newly created Interim Scientific Committee On Coal Seam Gas and Open Cut Coal mining to carry out an independent assessment in the Gloucester Basin in the immediate future. The EIS should clearly state how this process will relate to this mining project.	11

Table 1 (Cont'd)
Coverage of DGRs and Additional Matters

Page 3 of 4

ADDITIONAL MATTERS (Cont'd)		
Gloucester Shire Council (02/04/12)	Specific issues in regard to the potential hydrological impact should include analysis of the impacts on groundwater and surface water in an overall Water Balance Study.	11
(Cont'd)	The groundwater analysis should examine any potential impacts on aquifers and take into account the Department's recent Aquifer Disturbance Policy.	4.3.4 & 11
	The Water Balance Study should examine how the required annual supply of water will be drawn. It should examine water used for mining activities such as coal washing, dust suppression, landscaping maintenance etc. It should also examine the potential loss of base flow into Waukivory Creek as a consequence of water losses into mine pits from groundwater supply. It should also study any potential disposal of waters from the site and any contamination that it may incorporate from activities on the site. The Water Balance Study will need to address the variability of seasons in this landscape of droughts and floods.	11.4, 11.5 & 11.8
Government Agency	**Paraphrased Requirement**	**Relevant Section(s)**
NSW Catchment Management Authority (11/03/12)	The EIS should address groundwater monitoring of salinity at the site and downstream of this project throughout project operations.	15
	It is noted this proposal is in addition to two current operating coal mines and also approved and proposed coal seam gas operations. The EIS should not only address the impact of this project but also the cumulative impact of all these mining operations.	11
NSW Health – Hunter New England Local Health District (29/03/12)	The EIS should address all operational factors that may impact water quality downstream and demonstrate how downstream water quality will not be adversely impacted and demonstrate the proponent's consultation with the community with mitigation proposed and management plans for dealing with complaints regarding impacts on the quality of drinking water.	11 & refer surface water assessment
NSW Office of Water (30/03/12)	Detail baseline monitoring (minimum of fortnightly data sampling for at least 2 years prior to mine operations) of all groundwater sources and dependent ecosystems within and adjacent to the mining operation area for calibration of models and development of trigger criteria.	6.2.2 & 7
	Outline predictive assessments of potential impacts to groundwater sources, basic landholder's rights to water, adjacent licensed water users and dependent ecosystems and ongoing monitoring to enable comparison with predictions.	11 & 15
	Provide mitigation strategies to address impacts on groundwater sources and dependent ecosystems for the operational and post mining phases of the proposal and final landform.	12
	The EIS needs to : take into account the objectives, water management principles and regulatory requirements of the Water Act 1912 and Water Management Act 2000 (WMA 2000), as applicable.	4
	Demonstrate how the proposal is consistent with the relevant rules in the Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources 2009 plan including environmental water provisions, rules for access licences, distance restrictions for water supply works and rules for the management of local impacts in respect of surface water and groundwater sources, ecosystem protection, water quality and surface-groundwater connectivity.	4 & 14
	Provide a description of the site water use amount of water from groundwater sources.	11
	The EIS needs to provide details of all proposed surface water and groundwater extraction, and the potential for displacement of water between water sources, and all water supply works to take water. Information is required on the purpose, location, construction and expected annual extraction volumes including details on all existing and proposed water supply works and details on all bores and excavations for the purpose of investigation, extraction, dewatering, testing and monitoring.	14 &15

Table 1 (Cont'd)
Coverage of DGRs and Additional Matters

Page 4 of 4

ADDITIONAL MATTERS (Cont'd)		
NSW Office of Water (30/03/12) (Cont'd)	Water allocation account management rules, total daily extraction limits and rules governing environmental protection and access licence dealings also need to be considered, together with the capacity to obtain any additional entitlement required for the proposal either through application and/or trade.	14 & refer surface water assessment
	A groundwater assessment within and adjacent to the Mine Area must include details of all groundwater sources, potential groundwater dependent ecosystems (GDEs) and existing groundwater users within the area (including the environment) and details of any potential impacts;	5, 7 & 11
DP&I (02/04/12)	The EIS needs to provide in depth assessment and proposed mitigation measures has to be particularly comprehensive to address the risk to the alluvial aquifer associated with the Waukivory Creek.	12
	The EIS needs to outline impacts on surface and groundwater from the proposed mine have to be assessed with full regard to the total impacts of all existing and proposed coal mining and coal seam gas extraction operations in the Gloucester Basin.	11.1

In its correspondence to the DP&I, the New South Wales Office of Water (NOW) identified that the EIS for the proposal addresses the following:

1. Adequate, secure and appropriately authorised water supply is available for all activities for the life of the mine (Sections 4 and 14).
2. Compliance with the rules in the Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources and relevant legislation, water management policies and guidelines (Sections 4 and 14).
3. Baseline monitoring (minimum of fortnightly data sampling for at least 2 years prior to mine operations) of all surface water and groundwater sources and dependent ecosystems within and adjacent to the mining operation area for calibration of models and development of trigger criteria (Sections 6 and 7).
4. Predictive assessments of potential impacts to surface water and groundwater sources, basic landholder rights to water, adjacent licensed water users and dependent ecosystems and ongoing monitoring to enable comparison with predictions (Section 11).
5. Mitigation strategies to address impacts on surface water and groundwater sources and dependent ecosystems, for the operational and post mining phases of the proposal and final landform (Section 12).

The following information was considered by NOW to be essential to include in the EIS to demonstrate the above:

1. Details of all groundwater sources, potential Groundwater Dependent Ecosystems (GDEs) and existing groundwater users within the area (including the environment) and details of any potential impacts (Sections 5.7 and 7);
2. Baseline monitoring (minimum of fortnightly data sampling for at least 2 years prior to mine operations) for groundwater quantity and quality for all aquifers and GDEs (Sections 6 and 7);

3. Description of aquifer hydraulic properties, chemical characteristics and connectivity, including connectivity to surface water sources and assessment of the potential for enhance connectivity through the activation of geological structures such as faults and joints (Section 5 and 7);
4. Assessment of GDEs for condition and water quantity and quality requirements for both terrestrial and aquatic systems (macroinvertebrate, macrophyte and stygofauna), including diversity and abundance assessments (Section 7);
5. Details of the results of any models or predictive tools used to predict groundwater drawdown, inflows into the site and impacts on affected water sources and adjacent water users and GDEs (Section 10);
6. Assessment of the potential effects of mining operations on the quality of groundwater and connected surface water sources both in the short and long term including any pollutants potentially infiltrating into the groundwater sources and proposed waste water disposal methods and approval from the relevant authority (Section 11);
7. Demonstration of how the groundwater extraction will be managed within defined limits, so that groundwater levels and quality which are critical for GDEs will not be disrupted and there is sufficient flow to sustain ecological processes and maintain biodiversity (Section 11);
8. Protective measures that will minimise any impacts on groundwater sources, connected surface water sources, users and GDEs, including detailed description of measures to isolate the mining operation from Waukivory Creek and its connected alluvium and engineering works necessary to prevent drainage into the mining operation from surface water sources and/or alluvial groundwater sources (Section 12);
9. Determination of critical thresholds for negligible impacts to groundwater sources and GDEs (Section 15).

4. LEGISLATION, POLICY AND GUIDELINES

The following section outlines New South Wales State Government legislation, policy and guidelines with respect to groundwater that must be addressed in assessing a mining proposal.

4.1 WATER ACT 1912

The *Water Act 1912* (Water Act) governs the issue of water licences from water sources including rivers, lakes and groundwater systems in NSW. It also manages the trade of water licences and allocations.

The Water Act is progressively being replaced by the *Water Management Act 2000* (WM Act), but some provisions of the Water Act are still in force where water sharing plans are not in place. The Water Sharing Plan for this area known as the *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources* was released in August 2009 and includes provision for the management of the alluvial groundwater within and surrounding the Site. The *Water Act 1912* is still relevant for Permian groundwater in the Mine Area.

Licences under the Water Act will be required to account for the groundwater seepage from the Permian groundwater source within the Mine Area.

There is currently an embargo order under section 113 of the Water Act that applies to all coastal floodplain alluvial groundwater sources and highly connected alluvial groundwater sources of coastal catchments in NSW, including the Manning River Basin in which the Site is located. The embargo declares that no further applications for a licence under Part 5 of the Water Act may be made, unless the activity fits within one of the exemptions specified in the order. However, due to the commencement of the Water Sharing Plan over the Site, this embargo does not apply to alluvial groundwater that is impacted by the Project.

There is currently no embargo that applies to fractured or porous Permian rock aquifers in the vicinity of the Proposal under section 113 of the Water Act.

4.2 WATER MANAGEMENT ACT 2000

An objective of the *Water Management Act 2000* (WM Act) is the sustainable and integrated management of the State's water for the benefit of both present and future generations. The WM Act provides clear arrangements for controlling land-based activities that affect the quality and quantity of the State's water resources. It provides for four types of approval:

- water use approval – which authorises the use of water at a specified location for a particular purpose, for up to 10 years;
- water management work approval;
- controlled activity approval; and
- aquifer interference activity approval.

An aquifer interference activity approval authorises the holder to conduct activities that affect an aquifer such as approval for activities that intersect groundwater, other than water supply bores and may be issued for up to 10 years.

For controlled activities and aquifer interference activities, the WM Act requires that the activities avoid or minimise their impact on the water resource and land degradation, and where possible the land must be rehabilitated.

The WM Act requires that all extraction of surface water or groundwater must be properly accounted for under the rules of the relevant water sharing plan(s) (see Section 4.2.1.).

4.2.1 Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources

The *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources* commenced in August 2009. The water sharing plan sets the framework for managing groundwater in the Lower North Coast alluvial groundwater systems until 2019.

The *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water* Sources includes all water from the Avon River Water Source contained in the alluvial sediments below the surface of the land.

The objectives of the Water Sharing Plan are to:

a) "protect the important water dependent environmental, Aboriginal, cultural and heritage values;

b) protect basic landholder rights;

c) manage the river and alluvial groundwater to ensure equitable sharing between users;

d) provide opportunities for market-based trading of licences and water allocations;

e) provide flexibility for licence users in how they can use their water; and

f) allow for adaptive management, that is, to allow changes to be made when more information is available."

The report card for the Avon River water source (DWE, 2009) summarises the following licensed water use:

- 43 surface water licences − Peak Daily Demand = 26.3ML/day.
- Total surface water entitlement: 1,997ML/year (95% used for irrigation purposes, 0% used for industrial purposes).
- One groundwater licence.
- Total groundwater entitlement: 20ML/year (100% used for irrigation purposes).

A summary of the water access licences presented in the Water Sharing Plan that apply to the Avon River water sources are shown in **Table 2.**

Table 2
Summary of Water Access Licences – Avon River Water Sources

Category	Volumetric Licence (ML/yr)
Domestic and Stock	12
Native Title	0
Local Water Utility	0
Share Components	1985
Aquifer Access	20
Recharge	0

GRL currently holds the following five water access licences for the Avon River water source (WALs):

- WAL 19524 for 27 unit shares which can be extracted from Works Approval Number 20CA204351;
- WAL 19543 for 8 unit shares which can be extracted from Works Approval Number 20CA204371;
- WAL 19538 for 26 unit shares which can be extracted from Works Approval Number 20CA204357;
- WAL 19513 for 90 unit shares which can be extracted from Works Approval Number 20CA204403; and
- WAL 19512 for 116 unit shares which can be extracted from Works Approval Number 20CA204385.

The *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources* states that unit shares are equivalent to “1ML per unit share of access licence share component, or such lower amount resulting from clause 47”. With the five licences held by GRL, this amounts to a total of 267 unit shares or 267ML/year.

4.3 STATE GROUNDWATER POLICY

The NSW State Groundwater Policy (Framework Document) was adopted in 1997 and aims to manage the State’s groundwater resources to sustain their environmental, social and economic uses. The policy has three components parts, namely:

- the NSW Groundwater Quality Protection Policy, adopted in December 1998;
- the NSW State Groundwater Dependent Ecosystems Policy adopted in 2002; and
- the NSW Groundwater Quantity Management Policy (1998).

4.3.1 Groundwater Quality Protection Policy

The NSW Groundwater Quality Protection Policy (1998), states that the objectives of the policy will be achieved by applying the management principles listed below.

1. "All groundwater systems should be managed such that their most sensitive identified beneficial use (or environmental value) is maintained.
2. Town water supplies should be afforded special protection against contamination.
3. Groundwater pollution should be prevented so that future remediation is not required.
4. For new developments, the scale and scope of work required to demonstrate adequate groundwater protection shall be commensurate with the risk the development poses to a groundwater system and the value of the groundwater resource.
5. A groundwater pumper shall bear the responsibility for environmental damage or degradation caused by using groundwaters that are incompatible with soil, vegetation and receiving waters.
6. Groundwater dependent ecosystems will be afforded protection.
7. Groundwater quality protection should be integrated with the management of groundwater quality.
8. The cumulative impacts of developments on groundwater quality should be recognised by all those who manage, use, or impact on the resource.
9. Where possible and practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored."

The manner in which the Proposal satisfies the above objectives is presented in Section 11 and Section 13.

4.3.2 Groundwater Dependent Ecosystems

The NSW Groundwater Dependent Ecosystems Policy is specifically designed to protect valuable ecosystems which rely on groundwater for survival so that, wherever possible, the ecological processes and biodiversity of these dependent ecosystems are maintained or restored for the benefit of present and future generations. The policy defines Groundwater Dependent Ecosystems as *"communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater".*

Five management principles establish a framework by which groundwater is managed in ways that ensure, whenever possible, that ecological processes in dependent ecosystems are maintained or restored. A summary of the principles follows:

- groundwater dependent ecosystems (GDEs) can have important values. Threats should be identified and action taken to protect them;
- groundwater extractions should be managed within the sustainable yield of groundwater systems;

- priority should be given to GDEs, such that sufficient groundwater is available at all times to meet their needs;
- where scientific knowledge is lacking, the precautionary principle should be applied to protect GDEs; and
- planning, approval and management of developments should aim to minimise adverse effects on groundwater by maintaining natural patterns, not polluting or causing changes to groundwater quality and rehabilitating degraded groundwater ecosystems where necessary.

The *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources* states that the Gloucester Caves are the only identified GDE within the water plan area. The plan refers to a full list of potential GDEs on a Department of Water and Energy GDE register.

The manner in which the Proposal satisfies the above principles is discussed in Section 7.1.7 and Section 11.6.

4.3.3 Groundwater Quantity Management Policy

The objectives of managing groundwater quantity in NSW are:

- "to achieve the efficient, equitable and sustainable use of the State's groundwater;
- to prevent, halt and reverse degradation of the State's groundwater and their (sic) dependent ecosystems;
- to provide opportunities for development which generate the most cultural, social and economic benefits to the community, region, state and nation, within the context of environmental sustainability; and
- to involve the community in the management of groundwater resources."

This policy has effectively been superseded by the Aquifer Interference Policy.

4.3.4 Aquifer Interference Policy

The WM Act defines an aquifer interference activity as that which involves any of the following:

- penetration of an aquifer;
- interference with water in an aquifer;
- obstruction of the flow of water in an aquifer;
- taking of water from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations; and
- disposal of water taken from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations.

Examples of aquifer interference activities include mining, coal seam gas extraction, injection of water, and commercial, industrial, agricultural and residential activities that intercept the water table or interfere with aquifers.

According to the WM Act, an aquifer is defined as a geological structure or formation, or an artificial landfill, that is permeated with water or is capable of being permeated with water. This is at odds with the commonly used definition, which refers to an aquifer as a groundwater system that is sufficiently permeable to yield productive volumes of groundwater. The definition of aquifer provided by the WM Act is more consistent with the term groundwater system, which refers to any type of saturated geological formation that can yield low to high volumes of water.

The Policy states that "*all water taken by aquifer interference activities, regardless of quality, needs to be accounted for within the extraction limits defined by the water sharing plans. A water licence is required under the WM Act (unless an exemption applies or water is being taken under a basic landholder right) where any act by a person carrying out an aquifer interference activity causes:*

- the removal of water from a water source; or
- the movement of water from one part of an aquifer to another part of an aquifer; or
- the movement of water from one water source to another water source, such as:
  - from an aquifer to an adjacent aquifer; or
  - from an aquifer to a river/lake; or
  - from a river/lake to an aquifer. "

Predictions need to be carried out to assess the likely volume of water taken from a water source(s) as a result of an aquifer interference activity. These predictions need to occur prior to the issue of development consent. After project approval, and during operations, these volumes need to be measured and reported in annual environmental management reports (AEMRs) or similar documents. The water access licence must hold sufficient share component and water allocation to account for the take of water from the relevant water source at all times.

The Policy states that a water licence is required for the aquifer interference activity regardless of whether water is taken directly for consumptive use or incidentally. Activities may induce flow from adjacent groundwater sources or connected surface water. Flows induced from other water sources also constitute take of water. In all cases, separate access licences are required to account for the take from all individual water sources.

In water sources where water sharing plans do not yet apply, an aquifer interference activity that takes groundwater is required to hold a water licence under the *Water Act 1912*. It is possible for the *Water Act 1912* to apply in a groundwater source and the WM Act to apply in a connected surface water source or vice versa. Where this occurs and the aquifer interference activity is taking water from both water sources, then licences will be required under each Act.

In addition to the volumetric water licensing considerations, the following information needs to be considered to enable assessment and approval of the activity:

- establishment of baseline groundwater conditions including groundwater depth, quality and flow based on sampling of all existing bores in the area;
- a strategy for complying with any water access rules applying to relevant categories of water access licences, as specified in relevant water sharing plans;
- details of potential water level, quality or pressure drawdown impacts on nearby water users who are exercising their right to take water under a basic landholder right;
- details of potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources;
- details of potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems;
- details of potential for increased saline or contaminated water inflows to aquifers and highly connected river systems;
- details of the potential to cause or enhance hydraulic connection between aquifers;
- details of the potential for river bank instability, or high wall instability or failure to occur.

In particular, the Policy describes minimal impact considerations for aquifer interference activities based upon whether the water source is highly productive or less productive and whether the water source is alluvial or porous / fractured rock in nature. In general, the policy applies a predicted 2 m drawdown maximum limit at existing groundwater users.

The NOW's assessment of impacts and subsequent advice and proposed conditions of approval for a project is based on an "*account for, mitigate, avoid/ prevent, and remediate*" approach. NOW's methodology is based on "*a risk management approach to assessing the potential impacts of aquifer interference activities, where the level of detail required to be provided by the proponent is proportional to a combination of the likelihood of impacts occurring on water sources, users and dependent ecosystems and the potential consequences of these impacts*."

The Aquifer Inference Policy establishes and objectively defines minimal impact considerations as they relate to water dependent assets. Under the Policy an assessment of the potential impacts of an aquifer interference activity against the minimal impact considerations is required.

The Aquifer Interference Policy divides groundwater sources into "highly productive" and "less productive". Highly productive groundwater is defined by the Policy as a groundwater source that is declared in the Regulations and will be based on the following criteria:

a) has total dissolved solids of less than 1,500 mg/L, and

b) contains water supply works that can yield water at a rate greater than 5 L/s.

Highly productive groundwater sources are further grouped by geology into alluvial, coastal sands, porous rock, and fractured rock. "Less productive" groundwater includes aquifers that cannot be defined as "highly productive" according the yield and water quality criteria.

The Aquifer Interference Policy defines separate minimal impact considerations for “highly productive” and “less productive” groundwater sources. **Table 3** assesses the Proposal against the minimal impact considerations for “highly productive – alluvial groundwater sources” and the “less productive” groundwater sources.

If these minimal impact considerations are not met, the Proposal needs to demonstrate to the Minister’s satisfaction that the impact will be sustainable, or that “make good agreements” are in place. The Waukivory Creek and Avon River alluvium in some instances may be classified as “highly productive” however based on groundwater quality data adjacent to the Site they are generally assessed to be “less productive”. The Permian coal measures have been assessed and determined to satisfy the “less productive” criteria.

The minimal impact considerations have been addressed (in bold) within **Table 3**. It is demonstrated that the Proposal complies with the majority of the Policy requirements for both “highly productive” and “less productive” groundwater sources.

The Proposal involves the excavation of an open cut pit within 200 m of the high bank of Waukivory Creek (south-west corner of the Main Pit) and in this regard it does not comply with the minimal impact considerations. However, AGE is of the view that this groundwater impact assessment demonstrates that regardless of this activity the groundwaters within and adjacent to the Site are not impacted as a result of this activity. Numerical modelling is able to predict:

- drawdown and depressurisation as a result of the mine (Section 11.2);
- inflows to the mined voids (Section 11.4);
- loss of flow to the alluvium (Section 11.5); and
- the impact of mining on groundwaters to be assessed (Section 11.5).

In summary, AGE concludes that the Proposal adequately satisfies the minimal impact considerations outlined in the Policy and provides sufficient hydrogeological information for the Proposal to be assessed against these criteria.

The groundwater assessment for the Rocky Hill Coal Project complies with the objectives of the Aquifer Interference Policy. The objectives and requirements of the Policy, defined above, are addressed further in the following sections of this report:

- establishment of baseline groundwater conditions – Sections 6.1 and 6.2;
- licencing under the WM Act including compliance with the relevant water sharing plans – Sections 4.2.1 and 14;
- potential water level, quality or pressure drawdown impacts on nearby water users, including a nominal 2 m drawdown maximum limit at existing groundwater users – Sections 5.7, 11.3.1 and 11.3.2;
- details of potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems – Sections 7.1.7 and 11.6;
- details of potential for increased saline or contaminated water inflows to aquifers and highly connected river systems – Sections 7.1.6, 7.2.6, 7.3.6 and 13; and
- predictions assessing the volumetric take of water – Sections 11.4 and 11.5.

Table 3
Summary Minimal Impact Considerations – Aquifer Interference Policy

Category	1. Water Table	Water Pressure	Water Quality
Highly productive groundwater sources – alluvial water sources	1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan; or **No high priority groundwater dependant ecosystems or high priority culturally significant sites have been identified within the Project area or zone of influence (see Sections 7.1.7 and 11.6).** A maximum of a 2 m decline cumulatively at any water supply work. **Model predictions show that the maximum predicted drawdown at any water supply bore is less than 2 m (see Section 11.3.1). The predicted water level drawdown at the nearest alluvial water supply bore (GW054940) is 0 m.**	1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2 m decline, at any water supply work. **Model predictions show that the maximum predicted drawdown at any water supply bore is less than 2 m (see Section 11.3.1). The predicted water level drawdown at the nearest alluvial water supply bore (GW054940) is 0 m.**	1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity; and **Flow of groundwater from the Permian strata to the Quaternary Alluvium will re-establish under post closure conditions, and given the higher component of rainfall recharge in the local groundwater budget and the likely lower EC of this post-mining groundwater compared with the pre-mining Permian groundwater, the quality of groundwater ultimately discharging to the Quaternary Alluvium is expected to improve slightly (see Section 13).** (b) No increase of more than 1% per activity in long-term average salinity in a highly connected surface water source at the nearest point to the activity. **As above (see Section 13).** Redesign of a highly connected (3) surface water source that is defined as a "reliable water supply"(4) is not an appropriate mitigation measure to meet considerations 1.(a) and 1.(b) above. (c) No mining activity to be below the natural ground surface within 200 m laterally from the top of high bank or 100 m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". **The mine plan incorporates an open cut pit that is within 200 m of the high bank of Waukivory Creek (south-west corner of the Main Pit). The relevance of this activity to groundwater impact is summarised in the text above (Section 4.3.4) and detailed further within Section 11 of this report.** (d) Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200 m laterally from the top of high bank and 100 m vertically beneath a highly connected surface water source that is defined as a "reliable water supply" **The mine plan is assessed to comply with the above consideration.**

Table 3 (Cont'd)
Summary Minimal Impact Considerations – Aquifer Interference Policy

Page 2 of 2

Category	1. Water Table	Water Pressure	Water Quality
Less productive groundwater sources	1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan; or **No high priority groundwater dependant ecosystems or high priority culturally significant sites have been identified within the Project area or zone of influence (see Sections 7.1.7 and 11.6).** A maximum of a 2 m decline cumulatively at any water supply work. **Model predictions show that the maximum predicted drawdown at any water supply bore is less than 2 m (see Section 11.3.1). The predicted water level drawdown at the nearest Permian water supply bore (GW200330 and GW080487) is 0 m.**	A cumulative pressure head decline of not more than a 2m decline, at any water supply work. **Model predictions show that the maximum predicted drawdown at any water supply bore is less than 2 m (see Section 11.3.1). The predicted water level drawdown at the nearest Permian water supply bore (GW200330 and GW080487) is 0 m.**	Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. **Flow of groundwater from the Permian strata to the Quaternary Alluvium will re-establish under post closure conditions, and given the higher component of rainfall recharge in the local groundwater budget and the likely lower EC of this post-mining groundwater compared with the pre-mining Permian groundwater, the quality of groundwater ultimately discharging to the Quaternary Alluvium is expected to improve slightly (see Section 13).**

5. REGIONAL SETTING

5.1 LOCATION

The Mine Area is centred approximately 3.5km to 7km south-east of the Gloucester urban area, which is situated about 120km north of Newcastle. The Mine Area is located within the upper catchment of the Manning River and within Exploration Licence EL 6523, which covers an area of approximately 36km^2 (**Figure 1**).

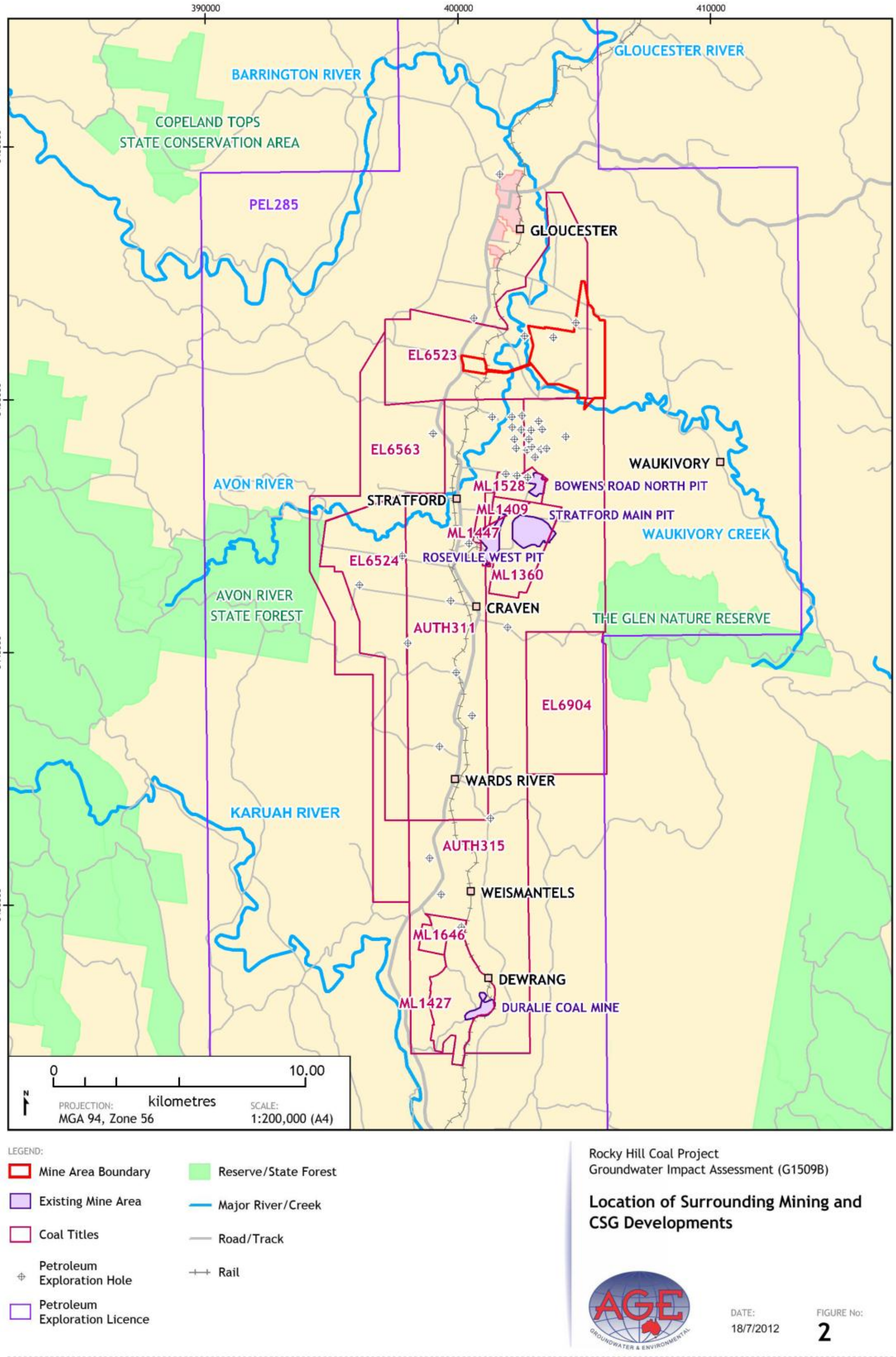
5.2 SURROUNDING MINING OPERATIONS

The Stratford Coal Mine (SCM) is an open cut mine owned and operated by Stratford Coal Pty Limited, a subsidiary of Yancoal Australia Limited, formerly Gloucester Coal Limited (GCL). SCM is located approximately 4km to the south of the southern boundary of EL 6523 and commenced production in 1995. SCM has several open cut pits including the Stratford Main Pit, Bowen Road North Pit which are located immediately to the north of Stratford Main Pit, and the Roseville West Pit located to the north-west of the Stratford Main Pit (**Figure 2**). The current method of open cut mining at the SCM allows coal extraction to occur in the upper and middle seams in the Gloucester Coal Measures including the Avon Coal Seam at the Stratford Main Pit and the Bowen Road Coal Seams at the Bowens Road North Pit. The Stratford Main Pit was mined for 8 years but is now used for the disposal of coal rejects and water storage, whereas the Bowens Road North Pit and the Roseville West Pit, which commenced operation in 2003 and 2007 respectively, are still in operation as active mines.

The Stratford Extension Project, as described in the EIS for the Project, will consist of the following activities:

- a proposed continuation and extension of open cut mining operations at the SCM for an additional operational life of approximately 11 years;
- continuation of open cut mining, including the extension of current open cut workings and emplacements, and the construction of two additional open cut pits, i.e.;
  - extension of the existing approved open pit (i.e. Roseville West Extension open pit) in the western and southern directions;
  - two additional open pits (i.e. Avon North and Stratford East); and
  - extension of the Stratford Waste Emplacement and Northern Waste Emplacement.

Duralie Coal Mine (DCM) is located some 20km to the south of Stratford Coal Mine and is owned and operated by Duralie Coal Pty Ltd, also a subsidiary of Yancoal Australia Limited, formerly Gloucester Coal Limited. DCM commenced coal production in 2003 and extracts coal from the Clareval and Weismantel Seams (**Figure 2**). Coal from this mine is transported by rail to the Stratford Coal Mine for washing prior to despatch of the product coal to Port of Newcastle.



Location of Surrounding Mining and CSG Developments

AGL Upstream Gas Pty Limited (AGL) holds Petroleum Exploration Licence (PEL) 285 which extends over the entire Gloucester Basin. AGL is proposing to develop the Gloucester Gas Project (GGP) and initial works for the GGP Stage 1 Gas Field Development Area (GFDA) and includes the drilling, completion and development of 110 coal seam gas (CSG) wells throughout the basin. The GGP will involve pumping groundwater from the CSG wells, depressurisation of the formation and extraction of CSG from the coal seams. The GGP is targeting the Gloucester Coal Measures, with depths varying from 200m and 1000m below ground level (mbGL).

Project approval was granted to AGL for the GGP Stage 1 GFDA by the NSW Government on 22 January 2011, although the project is also awaiting approval under the EPBC Act. **Table 4** summarises the petroleum exploration wells and CSG well within PEL285. **Figure 2** shows the locations of the petroleum exploration wells and surrounding coal mining projects.

Table 4
Summary of Petroleum Wells (PEL285)

Page 1 of 2

Site ID	Program	Hole Name	Hole Status	Licencee	Report No.	Year Drilled	Total Depth
APW-01	APW	1	Plugged & Abandoned	Lucas Energy Pty Ltd	GS2009/0987	2007	818.79
CRAVE-1	Craven	1	Plugged & Abandoned	Lucas Coal Seam Gas Pty Ltd	GS2009/0130	2007	959.3
CRAVE-3A	Craven	3A	Plugged & Abandoned	Lucas Energy Pty Ltd	GS2009/0129	2008	882.73
CRAVE-6	Craven	6	Unknown	AGL Energy Ltd		2009	-
CRAVE-7	Craven	7	Unknown	AGL Energy Ltd		2010	-
FAULK-1	Faulkland	1	Plugged & Abandoned	Lucas Energy Pty Ltd	GS2009/0986	2007	930
FAULK-1A	Faulkland	1A	Plugged & Abandoned	Lucas Energy Pty Ltd	GS2009/0986	2008	1374.27
FAULK-3	Faulkland	3	Plugged & Abandoned	Lucas Energy Pty Ltd	GS2009/0983	2008	1004.09
GLOU-1	Gloucester	1	Unknown	AGL Energy Ltd		2010	-
GLOU-2	Gloucester	2	Unknown	AGL Energy Ltd		2009	-
GLOUC-1	Gloucester Stratford	1	Unknown	Pacific Power	WCR253	1993	895
GLOUC-1A	Gloucester Stratford	1A	Unknown	Pacific Power	WCR253	1993	76.01
GLOUC-2	Gloucester Stratford	2	Unknown	Pacific Power	GS2000/070	1997	520.55
GLOUC-2D	Gloucester Stratford	2D	Unknown	Pacific Power	GS2002/477	1999	781.35
GLOUC-3	Gloucester Stratford	3	Unknown	Pacific Power	GS2000/070	1997	442.05
GLOUC-3D	Gloucester Stratford	3D	Unknown	Pacific Power	GS2002/483	1999	561.75
GLOUC-4	Gloucester Stratford	4	Unknown	Pacific Power	GS2000/070	1997	454.6
GLOUC-5	Gloucester Stratford	5	Unknown	Pacific Power	GS2000/070	1997	367
GLOUC-5D	Gloucester Stratford	5D	Unknown	Pacific Power	GS2002/482	1999	603.9
GLOUC-6	Gloucester Stratford	6	Unknown	Pacific Power	GS2002/484	1999	723.7

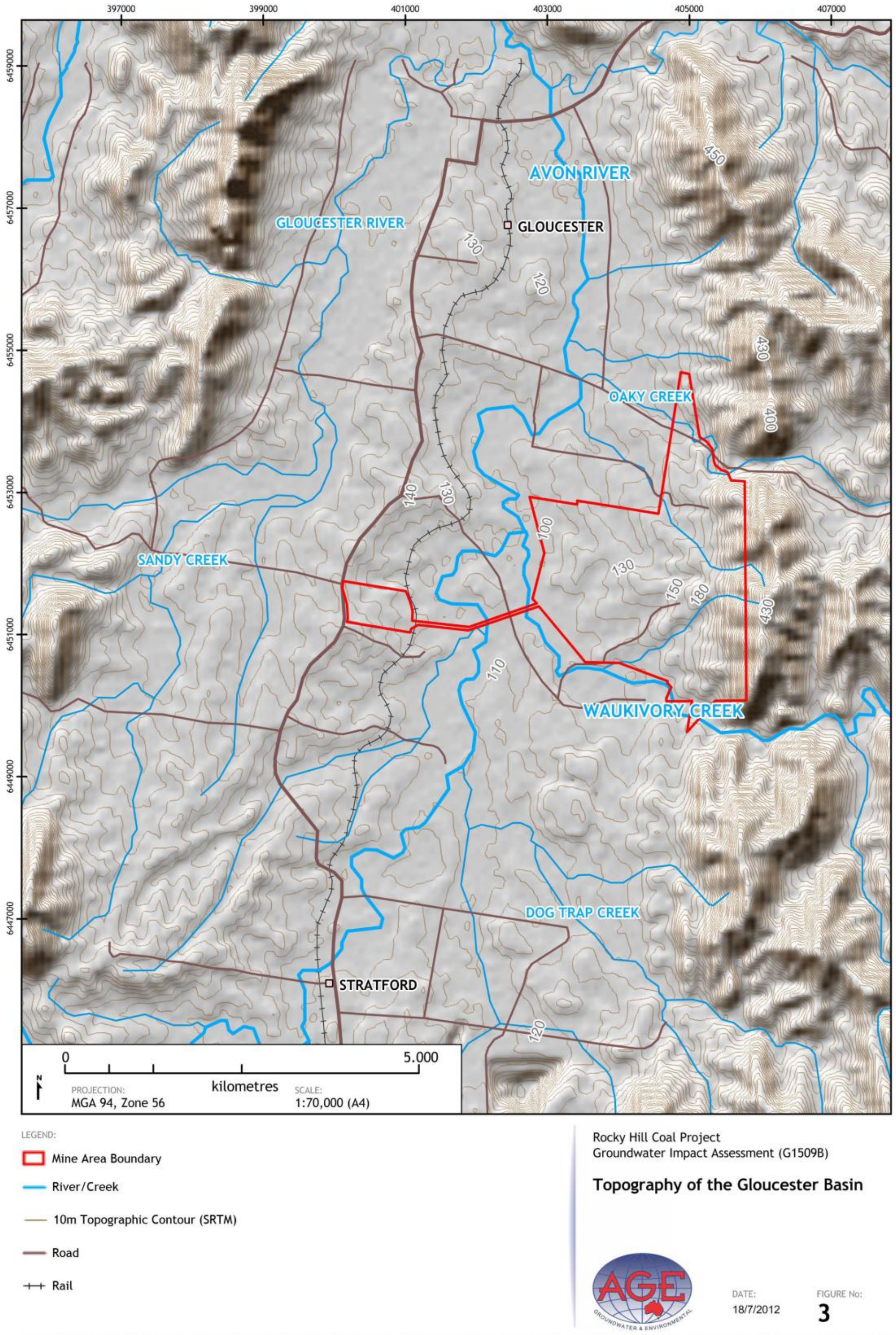
Table 4 (Cont'd)
Summary of Petroleum Wells (PEL285)

Page 2 of 2

Site ID	Program	Hole Name	Hole Status	Licencee	Report No.	Year Drilled	Total Depth
GLOUC-7	Gloucester Stratford	7	Unknown	Pacific Power	GS2002/485	1999	450.64
GLOUC-8	Gloucester Stratford	8	Unknown	Pacific Power	GS2002/486	1999	673.35
GLOUC-9	Gloucester Stratford	9	Unknown	Pacific Power	GS2002/487	1999	444.35
LMGC01	LMGC	1	Unknown	Molopo Australia Ltd	GS2009/0131	2006	-
LMGW01	LMGW	1	Unknown	Lucas Energy Pty Ltd	GS2008/0488	2006	-
STRAT-1	Stratford (LMG)	1	Cased and suspended	Lucas Energy Pty Ltd	GS2008/0279	2004	-
STRAT-10	Stratford	10	Unknown	AGL Energy Ltd		2008	-
STRAT-2	Stratford (LMG)	2	Unknown	Lucas Energy Pty Ltd	GS2008/0484	2004	-
STRAT-3	Stratford (LMG)	3	Capped etc. for gas prod	Lucas Energy Pty Ltd	GS2008/0278	2004	-
STRAT-4	Stratford	4	Unknown	Lucas Energy Pty Ltd	GS2009/0992	2007	846.3
STRAT-5	Stratford	5	Plugged & Abandoned	Lucas Energy Pty Ltd	GS2009/0991	2007	239.2
STRAT-5A	Stratford	5A	Unknown	Lucas Energy Pty Ltd	GS2009/0991	2007	667.72
STRAT-6	Stratford	6	Unknown	Lucas Energy Pty Ltd	GS2009/0989	2007	-
STRAT-6A	Stratford	6A	Unknown	Lucas Energy Pty Ltd	GS2009/0989	2007	-
STRAT-6B	Stratford	6B	Unknown	Lucas Energy Pty Ltd	GS2009/0989	2007	-
STRAT-7	Stratford	7	Unknown	AGL Energy Ltd		2008	-
STRAT-8	Stratford	8	Plugged & Abandoned	Lucas Energy Pty Ltd	GS2009/0981	2007	780.2
STRAT-9	Stratford	9	Plugged & Abandoned	Lucas Energy Pty Ltd		2008	993
WARD-1	Wards River	1	Unknown	AGL Energy Ltd		2010	-
WARD-5	Wards River	5	Unknown	AGL Energy Ltd		2010	-
WAUKI-1	Waukivory	1	Plugged & Abandoned	Lucas Energy Pty Ltd	GS2009/0128	2007	797.7
WAUKI-3	Waukivory	3	Unknown	AGL Energy Ltd		2009	-
WAUKI-4	Waukivory	4	Unknown	AGL Energy Ltd		2009	-

5.3 TOPOGRAPHY AND DRAINAGE

The topography of the Gloucester area is controlled by the underlying geology that is comprised of Carboniferous New England Fold Belt units overlain by Permian sedimentary coal measures, which are in turn overlain by alluvial sediments adjacent to the principal watercourses. The alluvial lands form a relatively flat floodplain with very gently undulating plains adjacent to the Avon River, Waukivory Creek and Gloucester River. Waukivory Creek extends north-south along the western edge of the Site and joins the Avon River to the north-west of the Mine Area boundary (**Figure 3**). Waukivory Creek has alluvial plains associated with it, however, these plains are naturally constricted where the creek discharges through an incised gap in the neighbouring elevated terrain. To the eastern side of this elevated terrain, Waukivory Creek drains a catchment of 75km^2 (refer **Figure 3**).


397000
399000
401000
403000
405000
407000
6459000
6457000
6455000
6453000
6451000
6449000
6447000
AVON RIVER
GLOUCESTER RIVER
GLOUCESTER
OAKY CREEK
SANDY CREEK
WAUKIVORY CREEK
DOG TRAP CREEK
STRATFORD
450
430
400
130
120
140
100
150
180
110
0
5.000
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:70,000 (A4)
LEGEND:
Mine Area Boundary
River/Creek
10m Topographic Contour (SRTM)
Road
Rail
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Topography of the Gloucester Basin
DATE:
18/7/2012
FIGURE No:
3

The outcrop of the New England Fold Belt basement geology is evident as upland slopes and hills that rise up to between 300mAHD and 450mAHD adjacent to the Site. Away from the ridgelines, the topography is undulating and ground slopes are principally less than 10%. The hills and slopes are drained by a series of generally westerly flowing ephemeral creeks and drainage features that extend across the Site and discharge into Waukivory Creek and the Avon River. The alluvial land falls gently from about 110mAHD in the south and west, to 100mAHD at the Avon River near the Site.

Photographs of the rivers and creek are included in **Appendix 1**.

5.4 LAND USE

The predominant land use in the Gloucester area is cattle grazing on native and improved pastures. Land use in the wider region includes national parks, forestry, mining and agriculture. Forestry activities occur predominantly on the steeper slopes and poorer soils.

5.5 CLIMATE

The climate in the vicinity of the Site is mostly temperate, and is characterised by warm, wetter summers and mild, drier winters. Rainfall data collected by the Bureau of Meteorology (BoM) was obtained for Gloucester Post Office, which is located about 2km to the north of the Site. The Gloucester Station (60015) has 123 years of rainfall data dating from 1888 to present. Evaporation data, collected by the BoM, was obtained for Chichester Dam (061151), which is located about 38km from the Site. A summary of average temperature, rainfall and evaporation is shown in **Table 5**.

Table 5
Climate Averages – Gloucester Station 60015

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Mean max temp (ºC)	26.2	24.9	23.3	20.2	17.4	14.2	13.7	15.5	19.1	21.4	24.1	26.6	20.6
Mean min temp (ºC)	16.7	16.7	16.2	12.7	9.7	7	6.2	6.9	9.8	12.1	14.9	17.2	12.2
Mean rainfall (mm)*	114.71	121.73	127.91	77.34	68.59	68.44	51.39	46.64	51.24	69.23	84.44	104.29	986.0
Mean evaporation (mm) **	139.5	110.2	93.0	69.0	46.5	33.0	40.3	58.9	87.0	108.5	123.0	148.8	1059.2
Evaporation minus rainfall	24.8	-11.6	-34.9	-8.3	-22.1	-35.4	-11.1	12.3	35.8	39.3	38.6	44.5	73.2

* Gloucester Post Office data ** Chichester Dam data

The average annual rainfall is 986mm, with March being the wettest month (127mm). The mean annual evaporation rate is 1059mm/year, and the mean monthly evaporation exceeds mean annual rainfall from August to January.

Recent rainfall years have been put into historical context using the Cumulative Rainfall Departure (CRD) method. This method is a summation of the monthly departure of rainfall from the long-term average monthly rainfall. A rising trend in the CRD plot indicates periods of above average rainfall, whilst a falling slope indicates periods when rainfall is below average.

The CRD graph for the period 1888 to 2012 is shown in **Figure 4**. The CRD indicates that the area experienced a period of generally below average rainfall since 2000, with rainfall at or above historic average rainfall since 2007.

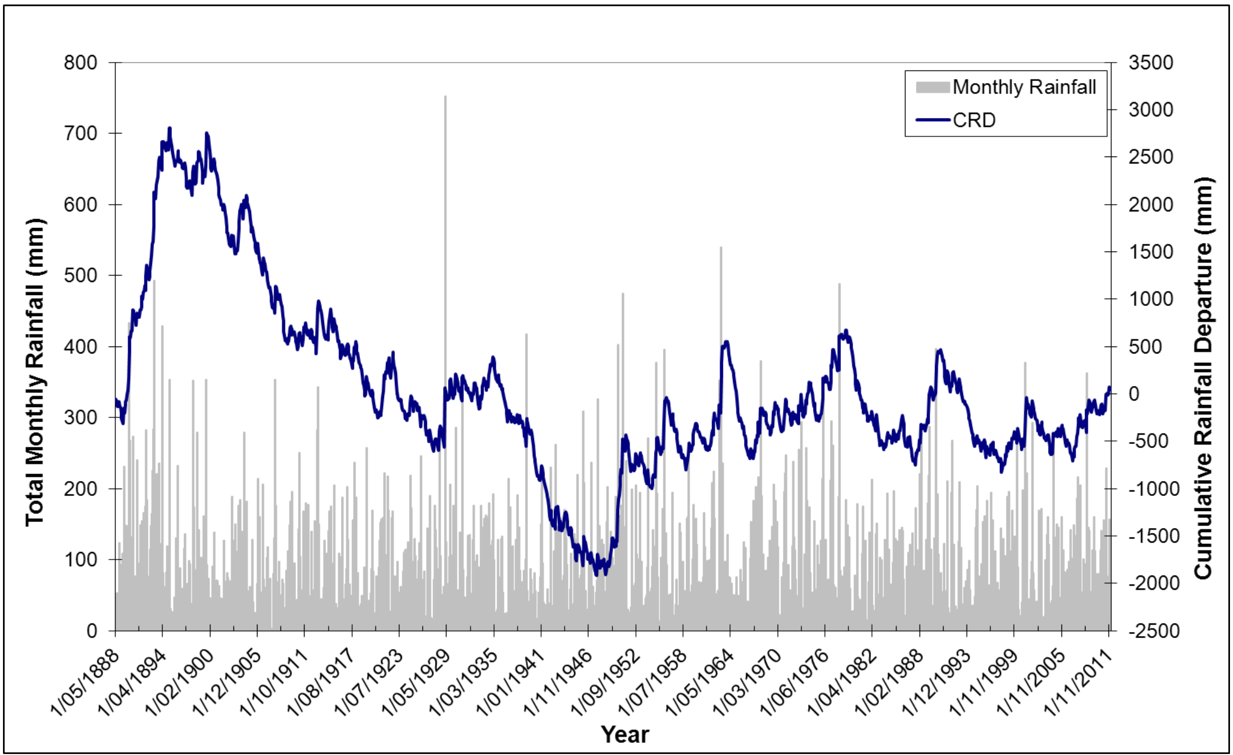


Figure 4 Cumulative Rainfall Departure Graph – Gloucester Post Office (Station 60015)

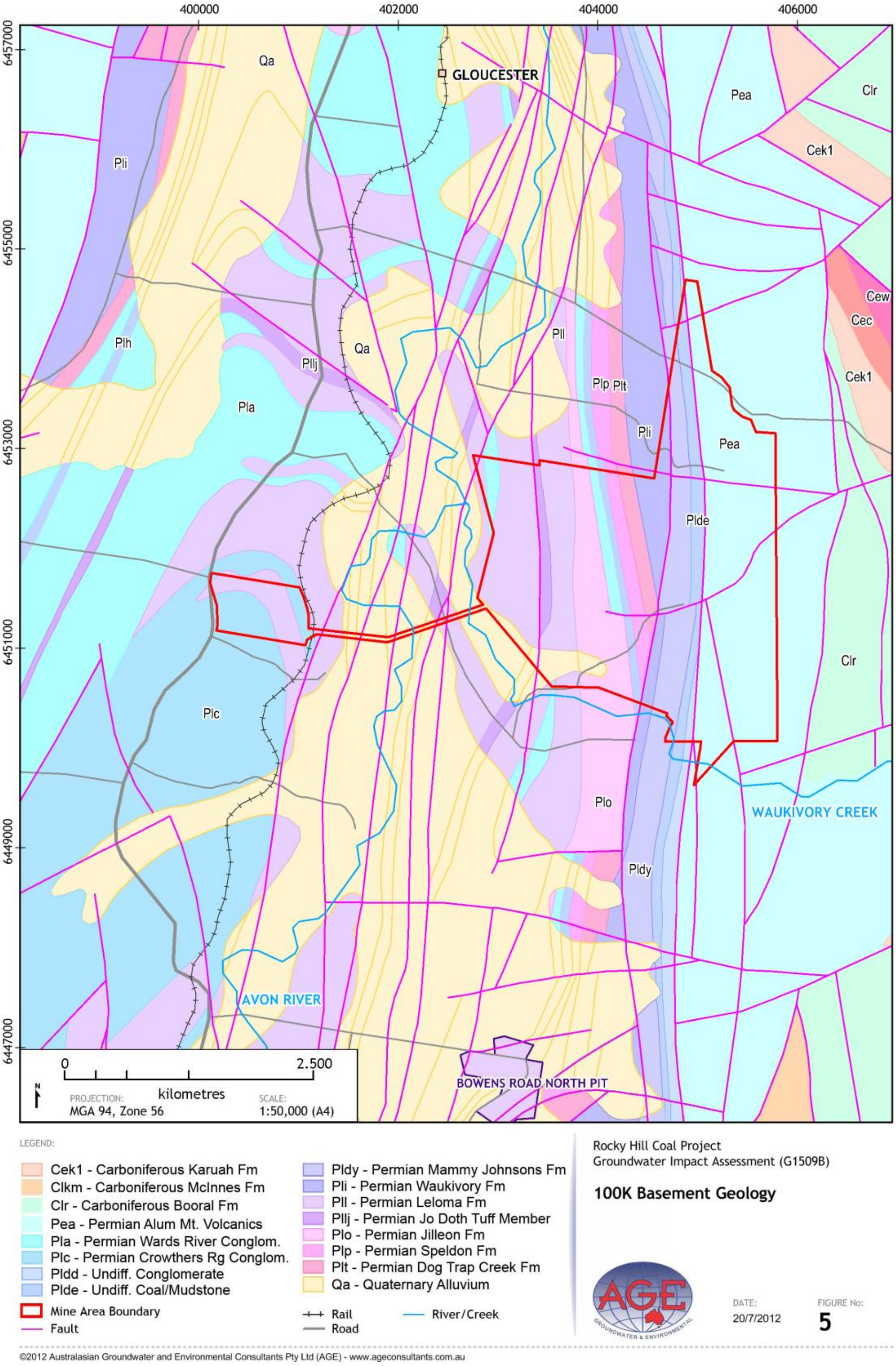
5.6 GEOLOGY

5.6.1 Basin Geology

EL 6523 is located in the northern part of the Permian age Gloucester Basin, a structural trough within the New England Fold Belt (**Figure 5**). The Gloucester Basin overlies the crystalline basement of the mid Palaeozoic age (Carboniferous) New England Fold Belt which outcrops immediately to the east of EL 6523.

The Permian sequences have been tightly folded into a generally north-south trending syncline. The Site is located on the steeply dipping eastern limb (**Figure 6**) of the syncline structure, with coal seams dipping between 40° to 70° (SRK, 2010). Several north-south and east-west trending faults cross the Site, and a large parasitic fold (reverse fault) has been recorded in the Avon Coal Seam, at the southern end of the Site (**Figure 6**).

The Gloucester Basin has undergone two major periods of deformation, resulting in faulting and minor (parasitic) folding. During the Early – Middle Permian, transcurrent (dextral) tectonic movement resulted in the formation of north-east and east-west, striking normal faults and reactivation of north-northwest striking faults. While in the Late Permian, subduction of tectonic plates (shortening) resulted in reverse and thrust faulting on north-northwest faults and some north-northeast faults (SRK, 2010).


400000
402000
404000
406000
6457000
6455000
6453000
6451000
6449000
6447000
GLOUCESTER
Qa
Pli
Plh
Pla
Pllj
Pll
Plp Plt
Pea
Clr
Cek1
Cew
Cec
Plde
Plc
Plo
Pldy
WAUKIVORY CREEK
AVON RIVER
BOWENS ROAD NORTH PIT
0
2.500
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:50,000 (A4)
LEGEND:
Cek1 - Carboniferous Karuah Fm
Clkm - Carboniferous McInnes Fm
Clr - Carboniferous Booral Fm
Pea - Permian Alum Mt. Volcanics
Pla - Permian Wards River Conglom.
Plc - Permian Crowthers Rg Conglom.
Pldd - Undiff. Conglomerate
Plde - Undiff. Coal/Mudstone
Pldy - Permian Mammy Johnsons Fm
Pli - Permian Waukivory Fm
Pll - Permian Leloma Fm
Pllj - Permian Jo Doth Tuff Member
Plo - Permian Jilleon Fm
Plp - Permian Speldon Fm
Plt - Permian Dog Trap Creek Fm
Qa - Quaternary Alluvium
Mine Area Boundary
Fault
Rail
Road
River/Creek
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
100K Basement Geology
AGE
DATE:
20/7/2012
FIGURE No:
5

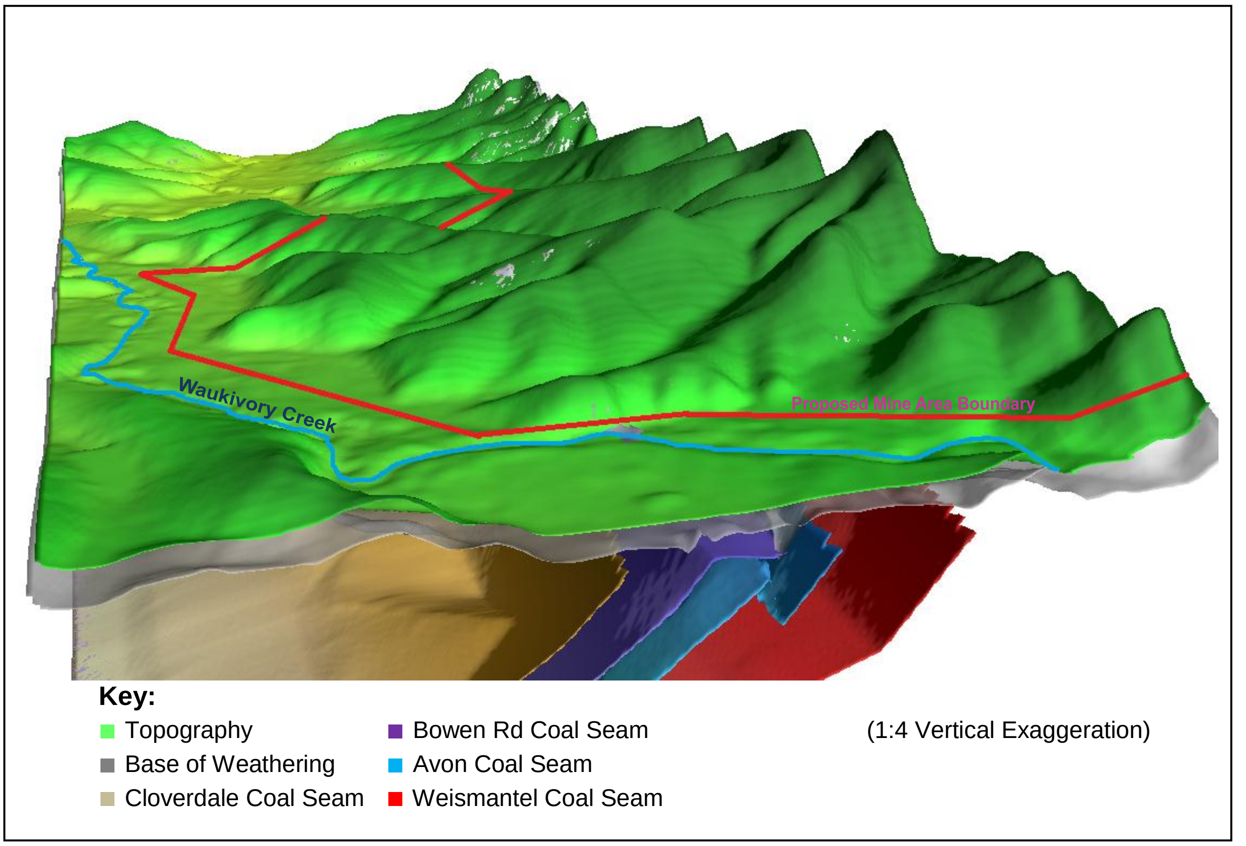


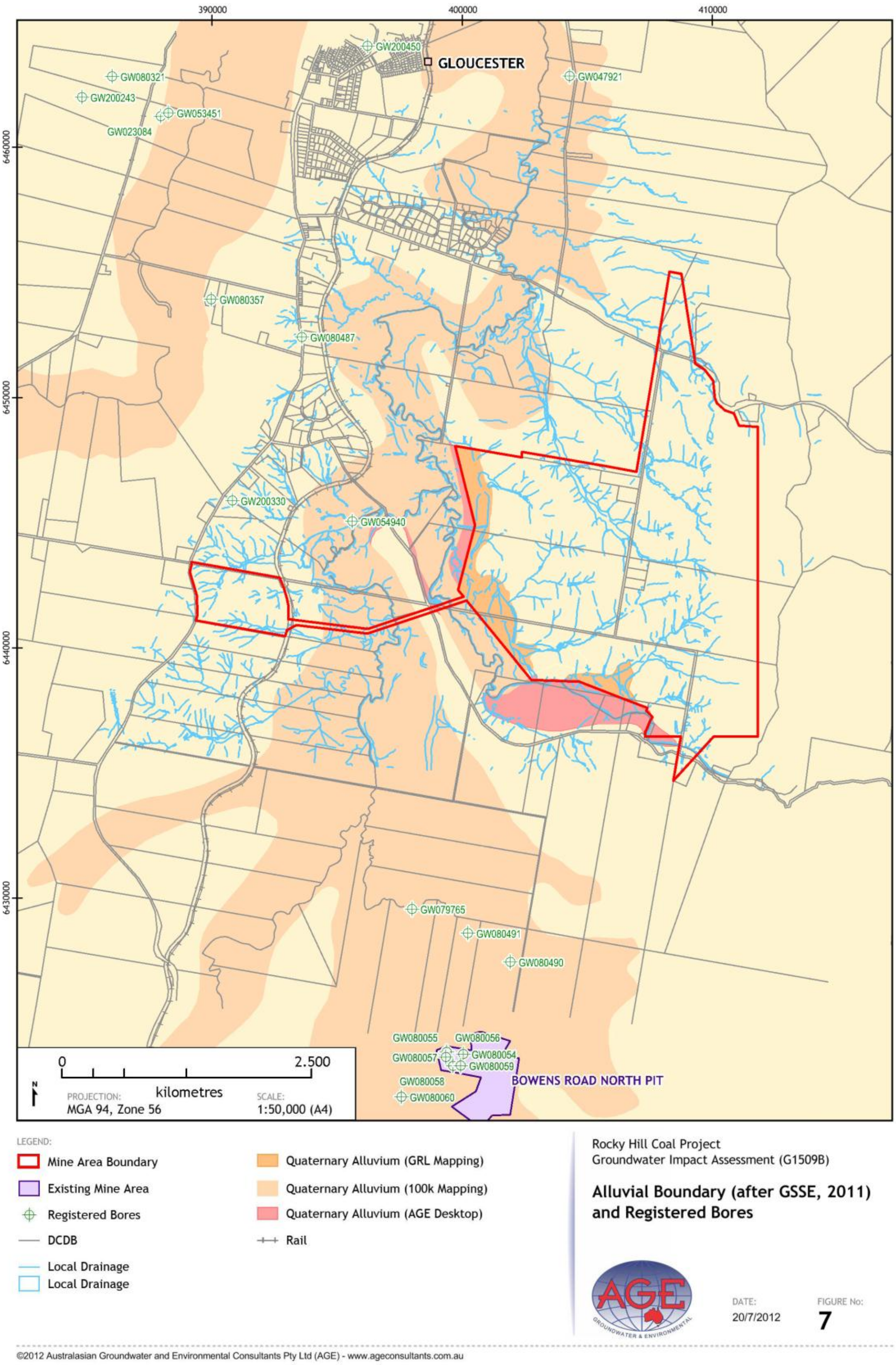
Figure 6 3D Schematic showing Topography and Partial Geology

5.6.2 Stratigraphy

The surface geology of the Mine Area and its surrounds comprises Quaternary aged alluvial sediments and the Permian Gloucester Coal Measures. The extent of the Quaternary sediments is restricted to the modern day drainage lines and surface water systems and the sediments unconformably overlie the Permian Coal Measures. The Gloucester Coal Measures overlie the Carboniferous New England Fold Belt sediments and volcanics.

The Quaternary alluvial sediments deposited by the Avon River and Waukivory Creek are comprised of an upper clay layer overlying coarse grained sands and gravels. There are also colluvial and regolith sediments comprising an upper clay layer overlying fine grained sands and sandy clays. The colluvial and regolith materials extend approximately 15m below surface level (PB, 2011). Within the proposed Mine Area, the boundary of the alluvial sediments have been defined by an independent geomorphology field study (GSSE, 2011). The boundary (**Figure 7**) was mapped through the excavation and logging of numerous test pits.

The alluvial boundary was further defined by AGE in a desktop assessment which mapped the extent of the Waukivory Creek alluvium using topography made available by GRL. **Figure 7** shows the inferred extent of alluvium.


390000
400000
410000
6460000
6450000
6440000
6430000
GLOUCESTER
GW200450
GW080321
GW200243
GW053451
GW023084
GW047921
GW080357
GW080487
GW200330
GW054940
GW079765
GW080491
GW080490
GW080055
GW080056
GW080057
GW080054
GW080059
GW080058
GW080060
BOWENS ROAD NORTH PIT
0
2.500
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:50,000 (A4)
LEGEND:
Mine Area Boundary
Existing Mine Area
Registered Bores
DCDB
Local Drainage
Local Drainage
Quaternary Alluvium (GRL Mapping)
Quaternary Alluvium (100k Mapping)
Quaternary Alluvium (AGE Desktop)
Rail
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Alluvial Boundary (after GSSE, 2011)
and Registered Bores
DATE:
20/7/2012
FIGURE No:
7

The Permian stratigraphy comprises early Permian aged Alum Mountain Volcanics overlain by late Permian aged fluvial and lacustrine sediments, which include the Dewrang Group and Gloucester Coal Measures (GCM). The main coal seam of the Dewrang Group is the Weismantel Seam. Within the GCM the proposed mine will target the Avon Coal Seam of the Avon Sub-group, as well as the Craven Sub-group, which includes the Cloverdale Coal Seam, Roseville Coal Seam and Bowen Road Coal Seam. **Figure 8** highlights the five main target coal seams, in descending stratigraphic order.

Group	Sub-group	Formation	Approx. thickness (m)	Coal seams
Gloucester Coal Measures (GCM)	Craven Sub-group	Crowthers Road Conglomerate	350	
		Leloma Formation or Woods Road	585	Linden Marker M6, M7 ("JD Coals") Bindaboo Deards
		Jilleon Formation or Bucketts Way	175	Cloverdale Roseville Marker M3, M8, M1 ("Tereel Coals"-Fairbairns Lane)
		Wards River Conglomerate	Varying thickness	
		Wenham Formation	23.9	Bowens Road (BR0-BR5) Bowens Road Lower (BR6)
	Speldon Formation		76.8	
	Avon Sub-group	Dog Trap Creek Formation	126	Glenview Marker 2
		Waukivory Creek Formation	326	Avon Triple Rombo Glen Road Valley View Parkers Road
Dewrang Group	Mammy Johnsons Formation		300	Mammy Johnsons
	Weismantel Formation		20	Weismantel
	Duralie Road Formation		250	
Unconformity				
Alum Mountain Volcanics				Clareval Basal Coal Seam

Figure 8 Summary of Local Stratigraphy

5.6.3 Cloverdale Coal Seam

The Cloverdale Coal Seam is a banded seam with an overall thickness of between 5m and 10m. Within the Mine Area it contains four main coal plies (1, 2, 2B and 2C) with a combined coal thickness of 7.8m. It is traceable over almost the entire eastern margin of the basin, although there is considerable variation in the relative amounts of coal and stone bands present. The coal seam is interbedded with upward coarsening sandstones and minor siltstone.

5.6.4 Roseville Coal Seam

The Roseville Coal Seam is a banded seam with an overall thickness of up to 16m and within the Mine Area, an average thickness of 3.7m. It is traceable over a significant part of the eastern margin of the basin, although there is a considerable variation in the amount of coal and stone bands present. Similar to the Cloverdale Seam, the Roseville Seam is interbedded with upward coarsening sandstones and minor siltstone.

5.6.5 Bowen Road Coal Seam

The Bowen Road Coal Seam is recognisable throughout a substantial portion of the basin. The seam varies considerably in thickness from 1m to 14m and is interbedded with fine-grained sandstones. Within the Mine Area this seam comprises six main plies (1A, 1B, 2, 3, 4 and lower) with a combined average true coal thickness of 9.2m.

5.6.6 Avon Coal Seam

The Avon Coal Seam is the most consistently recognisable seam in the basin. The Avon Coal Seam predominantly has one clean coal ply at the top. Within the Mine Area, it contains five main plies (1, 2, 3, 4A and 4B) with a combined average true coal thickness of 6.9m. The coal seams are interbedded with lithic sandstones and laminated mudstones.

5.6.7 Weismantel Coal Seam

The Weismantel Formation comprises coal and laminated mudstone and to the south of Site is the thickest uniform seam in the basin, up to 22m thick (Resource Strategies, 2001). In the Mine Area, the Weismantel Coal Seam contains five main plies (1, 2, 3, 4 and 5) with a combined average true coal thickness of 4.4m. The seam can be traced along the majority of the eastern margin of the basin and has been traced for approximately 10km along the western margin (from the southern closure of the basin into the southern part of EL 6523).

Figure 9 shows an east-west cross section through the basin and the proposed open cut pits in relation to the steeply dipping coal seams. The coal seams dip at 44^{o} in the west to 67^{o} in the eastern margin of the Gloucester Basin.

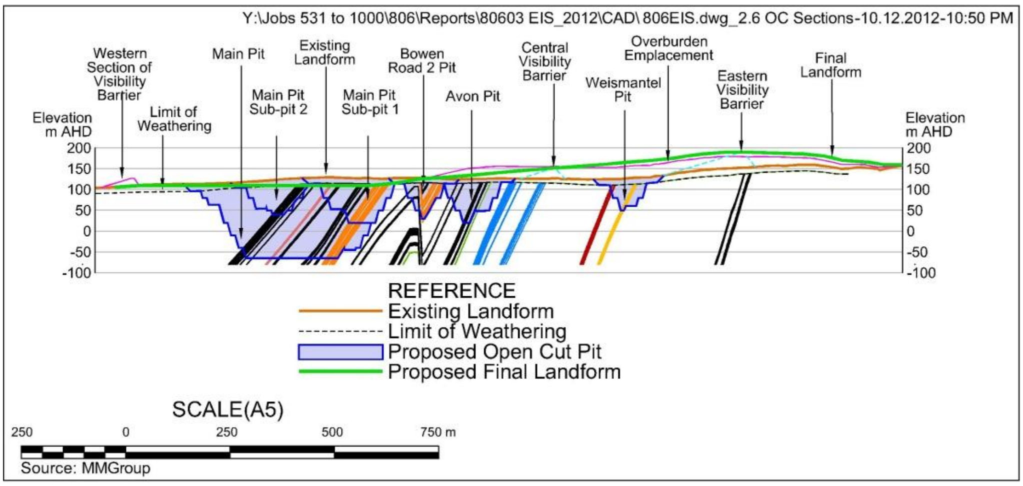


Figure 9 **East-west Cross Section**

5.7 GROUNDWATER USE

In excess of 20 registered bores are located within the local region with eight registered bores within 3km of the Mine Area boundary (**Figure 7**). Of these bores, the closest private bore is located some 1km to the west of the Mine Area boundary and on the western side of the Avon River. To the south of the Mine Area boundary, the nearest private bores are located some 2.5km away, immediately to the south of the AGL (Tiedman) pilot plant. To the north of the Mine Area boundary, the nearest private bore is located some 3.9km away and constructed within the Quaternary Alluvium of the Avon River.

Specific information relating to local groundwater facilities is limited however use appears restricted to shallow wells and bores extracting from the Quaternary Alluvium and deeper bores (up to 100m) drilled into the Permian strata. The number of groundwater facilities within 3km of the Mine Area boundary is restricted to eight (**Table 6**), however, three to the south of the Mine Area are closer to the Stratford Coal Mine. The bores within 3km of the Mine Area are generally less than 60m deep with standing water levels (SWL) within 14m to 17m of ground surface. Salinity within GW047921 and GW080357 is reported between 500 to 1000mg/L with the yield of GW080357 and GW080487 measured at 0.25L/s and 0.1L/s respectively. GW80357 is located within the Gloucester River catchment whereas the other seven bores are located within the Avon River catchment.

Table 6
Summary of Registered Bores Within 3km of Mine Area Boundary

Work No.	Easting (m)	Northing (m)	Type	Status	Date Drilled	Total Depth (mbGL)	SWL (mbGL)	Salinity (ppm)	Yield (L/s)
GW047921	403861	6456639	Bore	Collapsed Bore	Dec 1980	65	-	501-1000	-
GW054940	401727	6452184	Excavation	Abandoned & Destroyed	Feb 1981	4	-	-	-
GW079765	402361	6448334	Well	Unknown	June 1905	-	-	-	-
GW080357	400296	6454380	Bore	Unknown	June 1905	40.5	14	820	0.25
GW080487	401204	6454014	Bore	Existing	June 1905	60	17	-	0.1
GW080490	403349	6447816	Bore	Unknown	June 1905	-	-	-	-
GW080491	402924	6448098	Bore	Unknown	June 1905	-	-	-	-
GW200330	400528	6452381	Bore	Abandoned & Destroyed	June 1905	50	-	-	-

Note: Coordinates are in MGA94, Zone 56
mbGL – metres below ground level
SWL – standing water level
Units for salinity and yield are assumed
*excludes monitoring bores in Mine Area boundary.

6. FIELD INVESTIGATION PROGRAM

A field investigation in the proposed Mine Area was undertaken on behalf of GRL by Parsons Brinkerhoff (PB) in February and June 2011 (GR-P7A). The hydrogeological investigation program included:

- Drilling and construction of 13 groundwater monitoring bores within the Mine Area (**Figure 10**);
- Hydraulic conductivity testing (falling and rising head tests) and analysis of permeability for the stratigraphy targeted in each bore; and
- Compiling a drilling completion report (**Appendix 2**).

PB prepared groundwater monitoring reports commencing in April 2011. The quarterly reviews document the manual groundwater levels and 6-hourly logger data. The reports also assess the groundwater quality sampling and analyses that has been undertaken typically on a monthly sampling frequency. These monthly sampling events have been carried out by Carbon Based Environmental in accordance with the water quality sampling guidelines released by Geoscience Australia (Sundaram *et al.,* 2009). An annual monitoring review report was also completed by PB (2012b) in April 2012, which summarises the groundwater monitoring data collected from February 2011 to April 2012. The annual monitoring report which is included in **Appendix 3** also discusses long term water quality trend analysis using the Mann Kendall statistical analysis method. In early June 2012, two additional monitoring bores (GR-P10 and 11) were drilled (supervised by PB) to the immediate north of Waukivory Creek but outside the Mine Area.

6.1 GROUNDWATER MONITORING NETWORK

Construction of thirteen groundwater monitoring bores (GR-P1 to 9A) across the Mine Area commenced on 8 February 2011 and was completed on 24 February 2011. Two additional monitoring bores (GR-P10 and 11) were drilled immediately south of the Mine Area between 5 and 8 June 2012. The installation of the monitoring bores was undertaken by Highland Drilling in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (ARMCANZ, 2003). The details of monitoring bores constructed (GR-P1 through to GR-P9A) were provided to NOW in the PB (2011) drilling completion report. Details for the two additional monitoring bores (GR-P10 and GR-P11) were provided to NOW as construction borelogs and a short letter report (PB, 2012c).

Three bores were constructed within the Quaternary Alluvium, three within colluvium, five within the Permian interburden (siltstone/sandstone), and four within the Permian coal seams (Weismantel, Avon and Cloverdale Coal Seams). The locations of the bores are shown in **Figure 10**, with bore construction details summarised in **Table 7** and lithological logs shown in **Appendix 2**.

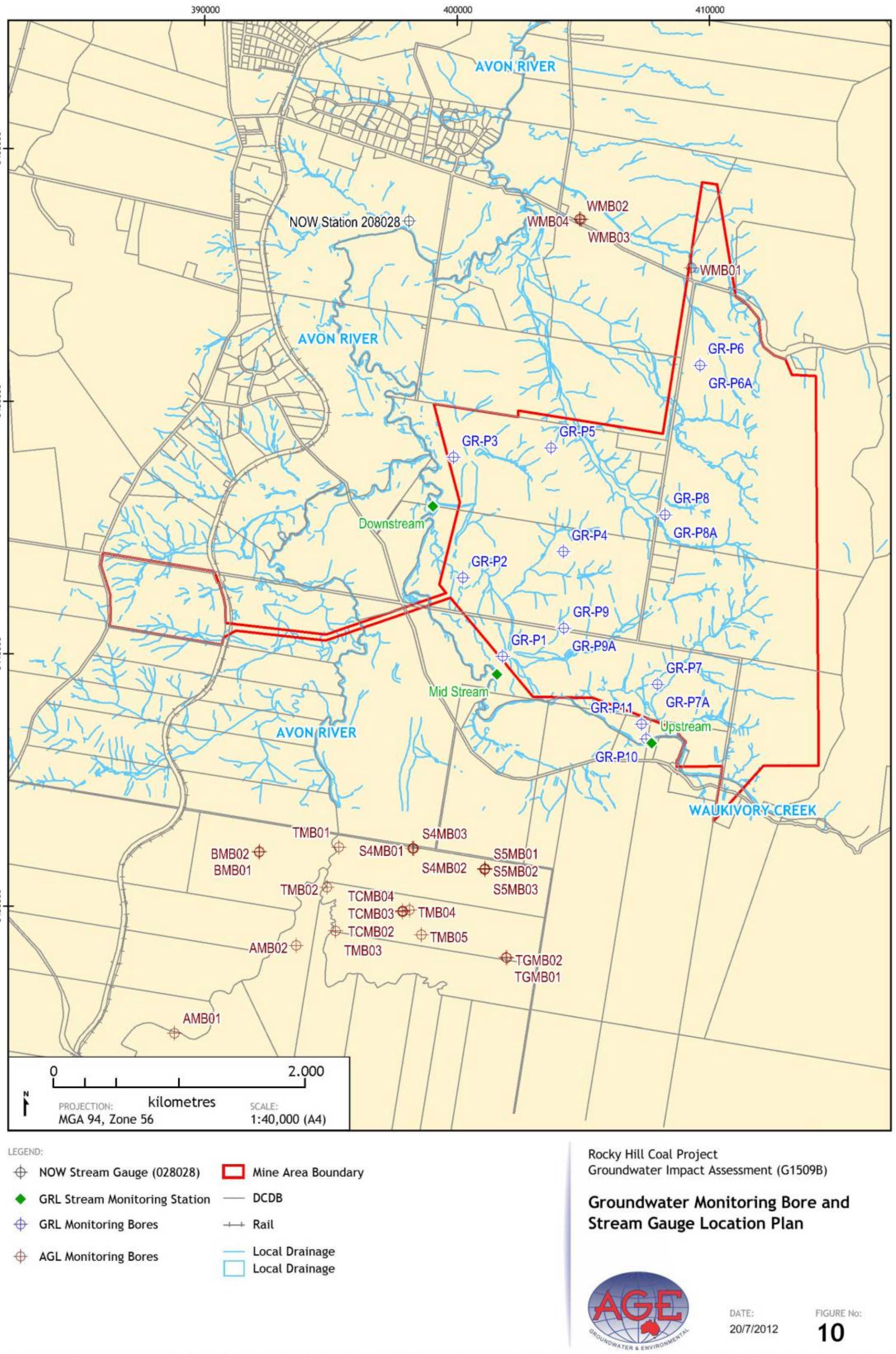

390000
400000
410000
6460000
6450000
6440000
6430000
AVON RIVER
AVON RIVER
AVON RIVER
WAUKIVORY CREEK
NOW Station 208028
WMB02
WMB04
WMB03
WMB01
GR-P6
GR-P6A
GR-P5
GR-P3
GR-P8
GR-P8A
GR-P4
GR-P2
GR-P9
GR-P9A
GR-P1
GR-P7
GR-P7A
GR-P11
GR-P10
Downstream
Mid Stream
Upstream
TMB01
S4MB03
S4MB01
S5MB01
S4MB02
S5MB02
S5MB03
BMB02
BMB01
TMB02
TCMB04
TCMB03
TMB04
TCMB02
TMB05
TMB03
AMB02
TGMB02
TGMB01
AMB01
0
2,000
kilometres
N
PROJECTION:
MGA 94, Zone 56
SCALE:
1:40,000 (A4)
LEGEND:
NOW Stream Gauge (028028)
GRL Stream Monitoring Station
GRL Monitoring Bores
AGL Monitoring Bores
Mine Area Boundary
DCDB
Rail
Local Drainage
Local Drainage
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Groundwater Monitoring Bore and Stream Gauge Location Plan
DATE:
20/7/2012
FIGURE No:
10

Table 7
GRL Monitoring Bores – Construction Details

Bore ID	Easting (m)	Northing (m)	Elevation (mAHD)	Casing Height (maGL)	Hole Depth (mbGL)	Screen Interval (mbGL)	Screened Geology	Screened Lithology
GR-P1	403,295	6,450,941	104.37	0.69	10.2	5.5-8.5	mixed gravels	Quaternary Alluvium
GR-P2	402,981	6,451,564	101.86	0.77	10	4-9	mixed gravels	Quaternary Alluvium
GR-P3	402,906	6,452,518	99.57	0.7	11.2	5-9	mixed gravels	Quaternary Alluvium
GR-P4	403,776	6,451,772	118.37	0.66	37	32.5-35.5	siltstone/shale	Interburden
GR-P5	403,679	6,452,595	126.39	0.7	30	24-30	siltstone	Interburden
GR-P6	404,856	6,453,250	145.3	0.7	24	17-23	siltstone	Interburden above Weismantel Seam
GR-P6A	404,860	6,453,248	145.33	0.67	97	89-95	coal (Weismantel Seam), siltstone	Weismantel Seam
GR-P7	404,525	6,450,723	115.69	0.64	7.6	4-7	mixed gravels and clay	Colluvium
GR-P7A	404,519	6,450,722	115.52	0.6	72	59-71	coal (Avon Seam)	Avon Seam
GR-P8	404,583	6,452,066	133.5	0.64	42	29-41	siltstone	Interburden above Avon Seam
GR-P8A	404,582	6,452,062	133.36	0.69	72	62-70	coal (Avon Seam), siltstone	Avon Seam
GR-P9	403,785	6,451,167	117.19	0.68	34	24-33	siltstone, sandstone	Interburden above Cloverdale Seam
GR-P9A	403,780	6,451,167	116.97	0.7	66	59-65	coal (Cloverdale Seam)	Cloverdale Seam
GR-P10	404,434	6,4502,90	109.88	0.55	10.2	5.5-8.5	mixed gravels and clay	Quaternary Alluvium
GR-P11	404,394	6,450,408	109.97	0.57	10.3	6.3-9.3	mixed gravels and clay	Quaternary Alluvium

Notes: mbGL – metres below ground level
maGL – metres above ground level
Coordinate Projection - MGA94, Zone 56

The boreholes were cased with Class 18, 50mm diameter, lead free, uPVC casing. Each bore was constructed with a minimum 1m blank PVC sump, with machine slotted uPVC screens (0.5mm aperture machine slots) placed at the target depth, and blank PVC casing completing the hole to the surface. A clean, 3 - 5mm gravel filter was placed by gravity around the screens and a bentonite seal (minimum 2m thick) was placed above the gravel pack. A cement/bentonite grout plug was used to seal the hole to the surface. Lockable steel covers protruding about 0.75m at the surface were placed at each site.

6.2 GROUNDWATER MONITORING

The fifteen monitoring bores were equipped with Solinst levelogger data loggers, programmed to record at six-hourly intervals. In addition, manual groundwater levels and water quality samples are collected on a monthly basis.

6.2.1 Groundwater Levels and Yield

Groundwater level measurements were recorded at each bore following construction, as detailed in **Table 8** below. Water levels within the alluvium and regolith are relatively shallow across the Mine Area. The results for the paired bores indicate that the Permian stratigraphy, including the interburden and the coal seams, are confined. This is based on recorded water levels being well above the screened intervals and upper extent of the stratigraphic unit.

Table 8 also shows the hydraulic conductivity values, which were determined from falling and rising head tests conducted at each bore by PB (2011). The results indicate a relatively high hydraulic conductivity for the gravels within the Quaternary Alluvium, for bores located along Waukivory Creek (GR-P1 to GR-P3) while the Permian stratigraphy generally recorded moderate to low hydraulic conductivities, except for bore GR-P9A.

Table 8
GRL Monitoring Bores – Groundwater Levels

Bore ID	Elevation (mAHD)	Total Depth (mbGL)	Screen Interval (mbGL)	SWL (mbGL)	SWL (mAHD)	Hydraulic Conductivity (m/day)	Screened Lithology
GR-P1	104.37	10.2	5.5-8.5	4.40	100.55	50-150	Quaternary Alluvium
GR-P2	101.86	10	4-9	2.24	100.39	50-150	Quaternary Alluvium
GR-P3	99.57	11.2	5-9	2.95	97.32	50-150	Quaternary Alluvium
GR-P4	118.37	37	32.5-35.5	6.68	112.32	0.2	Interburden
GR-P5	126.39	30	24-30	14.44	112.64	0.05	Interburden
GR-P6	145.30	24	17-23	3.81	142.22	0.04	Interburden above Weismantel Seam
GR-P6A	145.33	97	89-95	10.43	135.58	0.06	Weismantel Seam
GR-P7	115.69	7.6	4-7	2.47	113.83	0.08	Colluvium
GR-P7A	115.52	72	59-71	1.41	114.72	0.002	Avon Seam
GR-P8	133.50	42	29-41	8.66	125.48	0.015	Interburden above Avon Seam
GR-P8A	133.36	72	62-70	6.73	127.31	0.01	Avon Seam
GR-P9	117.19	34	24-33	10.44	107.42	0.2	Interburden above Cloverdale Seam
GR-P9A	116.97	66	59-65	9.71	107.98	0.15	Cloverdale Seam
GR-P10	109.88	10.2	5.5-8.5	4.8	105.73	126-392	Quaternary Alluvium
GR-P11	109.97	10.3	6.3-9.3	4.58	105.96	27-108	Quaternary Alluvium

Notes: mbGL – metres below ground level

6.2.2 Groundwater Quality

Table 9 summarises the groundwater quality recorded from twenty-one groundwater quality sampling events carried out on the GRL monitoring bores between March 2011 and August 2012 by Carbon Based Environmental Pty Ltd. GR-P10 and GR-P11 were added to the monitoring round after construction. Samples were collected in appropriately preserved bottles and sent to a NATA registered laboratory (ALS Laboratory Group) in chilled eskies under appropriate chain-of-custody documentation.

Table 9
GRL Monitoring Bores – Groundwater Quality

Bore ID	Elevation (mAHD)	Total Depth (mbGL)	EC (µS/cm)	pH	Redox (mV)	DO (mg/L)	Screened Lithology
GR-P1	104.37	10.2	5000 – 6450	5.81 – 7.07	-92 - +57	0.46 – 3.4	Quaternary Alluvium
GR-P2	101.86	10	1003 – 1885	6.03 – 6.95	-56 - +193	0.4 – 3.4	Quaternary Alluvium
GR-P3	99.57	11.2	3110 – 3880	6.26 – 7.14	-112 - +37	0.37 – 3	Quaternary Alluvium
GR-P4	118.37	37	5740 – 7480	5.26 – 6.42	-93 - -9	0.22 – 3.5	Interburden
GR-P5	126.39	30	2880 – 4400	5.86 – 6.97	-155 - +17	0.56 – 3.8	Interburden
GR-P6	145.3	24	2470 – 2810	6.36 – 7.79	-95 - +59	0.52 – 3.5	Interburden above Weismantel Seam
GR-P6A	145.33	97	2800 – 5230	6.79 – 9.05	-207 - -19	0.49 – 2.9	Weismantel Seam
GR-P7	115.69	7.6	1162 – 1357	6.05 – 7.43	-91 - +54	0.37 – 4.3	Colluvium
GR-P7A	115.52	72	3150 – 3900	6.2 – 7.31	-211 - +64	0.47 – 4.8	Avon Seam
GR-P8	133.5	42	3610 – 5700	6.59 – 7.47	-87 - +6	0.38 – 3.1	Interburden above Avon Seam
GR-P8A	133.36	72	5020 – 6550	6.78 – 7.63	-151 - +20	0.43 – 2.86	Avon Seam
GR-P9	117.19	34	4170 – 6840	6.33 – 7.22	-66 - +117	0.35 – 3.3	Interburden above Cloverdale Seam
GR-P9A	116.97	66	3580 – 6400	6.25 – 6.90	-173 - +38	0.41 – 2.8	Cloverdale Seam
GR-P10*	109.88	10.2	589 – 594	6.45 – 6.74	1 - +12	2.5	Quaternary Alluvium
GR-P11*	109.97	10.3	1629 - 1642	6.55 – 6.79	-6 - +1	1.8 – 3.5	Quaternary Alluvium

Notes: EC, pH, redox and DO are field based measurements
mbGL – metres below ground level
DO – Dissolved Oxygen

The data shows that groundwater beneath and immediately adjacent to the Mine Area is typically slightly acidic to slightly alkaline with electrical conductivity (EC) values in the range of 589µS/cm to 6,840µS/cm, indicating fresh to brackish groundwaters. Groundwater quality is discussed further in Section 7.

The groundwater monitoring network and the data used in this assessment is considered by AGE to be adequate and suitable to enable a description of the existing groundwater environment (refer Section 7). In addition to the data presented in this impact assessment report, GRL has carried out subsequent monitoring of the groundwater network resulting in up to 26 individual sampling events from March 2011. The results of monitoring carried out subsequent to August 2012 are consistent with the earlier results.

7. HYDROGEOLOGICAL REGIME

Three distinct groundwater systems are present within and surrounding the Site, namely:

- Permian coal seams and interburden;
- shallow weathered bedrock (regolith) with associated colluvial deposits; and
- shallow alluvium associated with the floodplains of Waukivory Creek and the Avon River.

7.1 ALLUVIUM

7.1.1 Distribution and Structure

The unconfined shallow alluvium comprises floodplain deposits from the Avon River and Waukivory Creek which are of limited areal extent. The alluvial boundary (**Figure 7**) is delineated by changes in the slope, with the boundary most evident adjacent to convex slopes and less evident adjacent to concave slopes (GSSE, 2011). The alluvial deposits are reported to comprise a sequence of silty sands, gravelly sands and clays. In areas of sufficient thickness and permeability, the alluvium is known to yield sufficient quantities and quality of water for farm water supplies. In the proposed Mine Area, the alluvial sediments typically comprise 4.0m to 6.5m of mixed, rounded gravels deposited on a siltstone basement. The gravels are overlain by 2m to 5m of clay and up to 1m of topsoil. GR-P2 is located on the eastern side of Waukivory Creek, and the monitoring bore completion log (**Appendix 2**) provides an excellent example of the alluvial sediments and profile.

Monitoring bores GR-P10 and GR-P11 were drilled in the upper reaches of the Waukivory Creek alluvium. These bores intersected more angular gravels than the material observed in GR-P1, GR-P2 or GR-P3. At these locations this angular material is likely to be related to the close distance of the sediments from their parent rocks.

7.1.2 Hydraulic Parameters

The hydraulic conductivity of the alluvium varies according to the proportions of clay, silt, sand and gravel present. Falling head tests were carried out on the monitoring bores within the alluvium. Alluvial hydraulic conductivity values between 50m/day to 150m/day (PB, 2011) were measured. Monitoring bores GR-P10 and GR-P11 recorded hydraulic conductivity values in the order of 27m/day to 392m/day. PB (2012a) also carried out falling head tests on the AGL alluvial monitoring bores with a similar range of values measured (0.32m/day to 150m/day), as detailed in **Table 10**.

Hydraulic testing has been carried out for the Stratford Coal Mine (SCM), south of the Site. Values presented by AGE (2000) for the Avon River alluvium in the vicinity of the SCM were 0.01m/day to 2.9m/day. These values are lower than those measured closer to the Site by GRL and AGL, and suggest a finer grained (clay and silt dominant) alluvium further upstream from the Proposal.

For the purpose of this impact assessment, falling head tests on monitoring bores are considered a suitable approach to determining hydraulic conductivity within the alluvium. Pumping tests within the alluvium were not considered necessary and these would be complicated by barrier and recharge boundary effects from the narrow alluvial channel and surface water systems, short circuiting of discharge water back to the groundwater system, and the quality of the discharge water.

Table 10
Hydraulic Properties of AGL Monitoring Bores

Bore ID	Elevation (mAHD)	Total Depth (mbGL)	Screen Interval (mbGL)	SWL (mbTOC)	SWL (mAHD)	Hydraulic Conductivity (m/day)	Screened Lithology
S4MB01	118.38	66	58 – 64	6.28	112.91	4×10^{-5}	Leloma Formation
S4MB02	118.44	97	89 – 95	5.51	113.58	5×10^{-3}	Leloma Formation
S4MB03	118.37	170	162 – 168	4.27	114.73	0.01	Jilleon Formation - Cloverdale Coal Seam
S5MB01	129.98	60	52 – 58	39.61	90.9	2×10^{-6}	Jilleon Formation
S5MB02	129.87	114	100 – 112	17.91	112.49	7.9×10^{-4}	Jilleon Formation
S5MB03	129.79	166	158 – 164	17.74	112.58	0.01	Jilleon Formation - Roseville Coal Seam
TCMB02	123.16	183	175 – 181	9.85	114.01	1.1×10^{-4}	Leloma Formation
TCMB03	123.18	268	260 – 266	11.43	112.38	1.6×10^{-3}	Jilleon Formation - Cloverdale Coal Seam
TCMB04	123.31	335	327 – 333	12.66	111.84	2.3×10^{-3}	Jilleon Formation - Roseville Coal Seam
BMB01	108.95	30	15 – 29	5.7	103.78	0.12	Leloma Formation
BMB02	108.83	138	124 – 136	5.63	103.74	1.5×10^{-3}	Leloma Formation
TMB01	106.82	12	7 – 10	4.05	103.55	0.32	Avon River Alluvium
TMB02	106.81	15.5	9 – 12	4.43	103.07	50 – 100	Avon River Alluvium
TMB03	106.48	12.5	5 – 11	3.06	104.04	20 – 50	Avon River Alluvium
AMB01	111.48	12.6	8 – 10	4.64	103.93	100 – 500	Avon River Alluvium
AMB02	107.88	11.5	6.5 – 11	6.03	106.14	50 – 100	Avon River Alluvium
WMB01	111.06	8.5	5 – 8	4.11	107.81	50 - 150	Alluvium
WMB02	106.13	23	15 – 21	4.91	101.95	0.9	Wenhams Formation
WMB03	106.39	36	32 – 34	5.15	101.93	0.03	Wenhams Formation - Bowens Road Coal
WMB04	106.12	80.5	67 – 79	4.82	101.98	2 – 20	Wenhams Formation
RMB01	128.68	51	42 – 48	4.34	125.04	0.01	Leloma Formation (upper)
RMB02	128.49	93	85 – 91	3.89	125.34	0.01	Leloma Formation (upper)

7.1.3 Yields and Usage

Airlift yield was not reported during drilling of the alluvial monitoring bores at GRL (GR-P1, GR-P2 and GR-P3), nor during the drilling of monitoring bores at AGL. Airlift yields were recorded during the drilling of monitoring bores GR-P10 and GR-P11. These bores yielded 2-3L/s and 4L/s respectively, consistent with the high hydraulic conductivity measured at these sites (126-392m/day and 27-108m/day respectively).

A search of the NOW registered bores in the region indicates yield data is limited. There are only six bores that have yield information, however, these bores all appear to be completed within the Permian sediments with water intersected in consolidated siltstone and sandstones, at depths greater than 10m.

7.1.4 Groundwater Levels and Hydraulic Gradients

The depth to the water table in the alluvial plain within and adjacent the Mine Area (**Table 8**) typically ranges between about 0.5m and 4mbGL (97 – 102mAHD). Locally, groundwater in the alluvium discharges into Waukivory Creek and the Avon River. However, following dry periods, stream flow is likely to form a source of recharge to the shallow alluvial groundwater system. Stream level monitoring has been carried out at three locations along Waukivory Creek. This monitoring data is discussed in Section 8.

Hydraulic gradients in the alluvium are very flat (0.0002 between GR-P1 and GR-P2) which is indicative of the high measured hydraulic conductivity values (50m/day to 150m/day) of the alluvial sediments. The hydraulic gradient from GR-P10 (105.73mAHD) to GR-P1 (100.55mAHD) is slightly steeper at 0.0035.

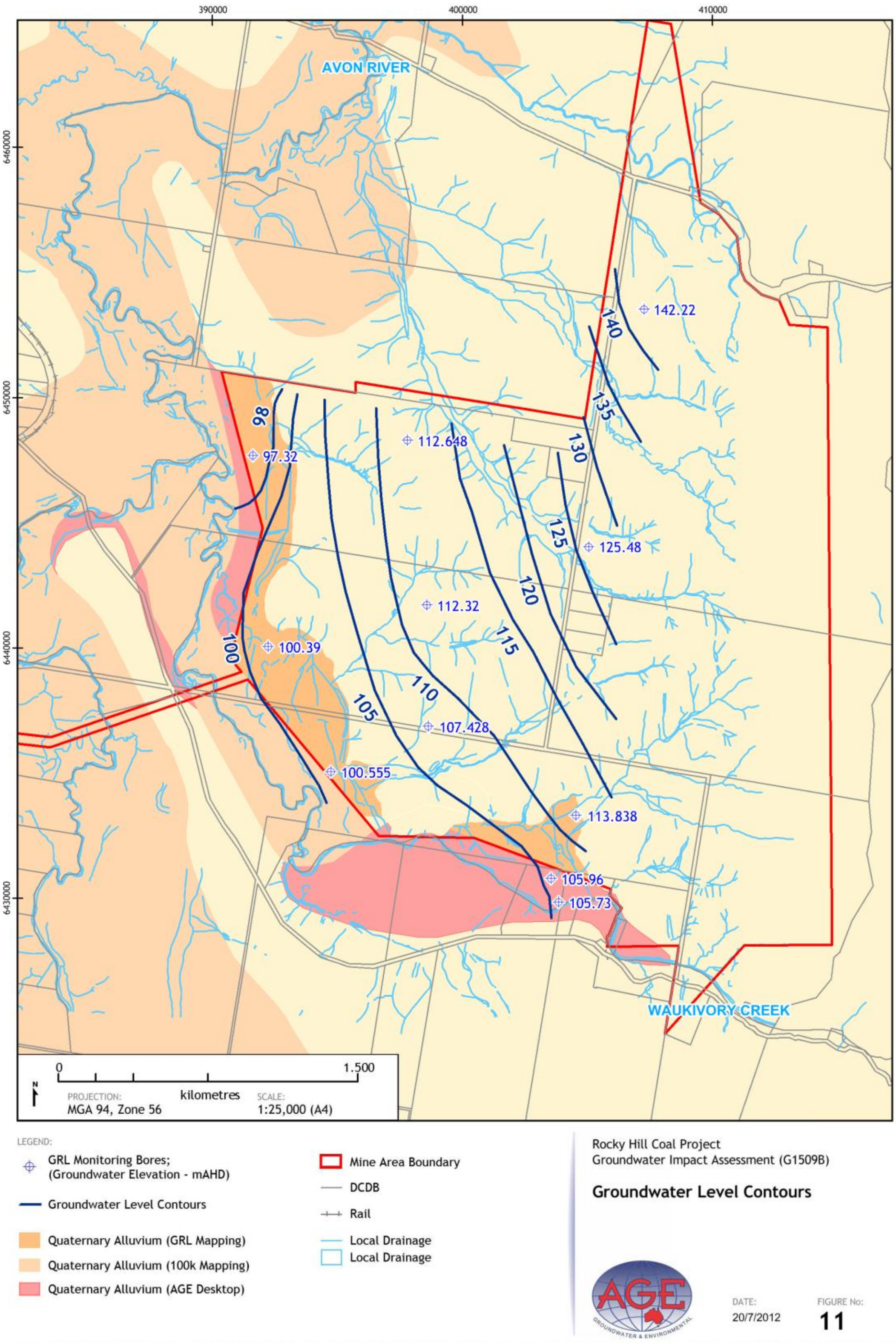
7.1.5 Regional and Local Recharge, Discharge and Groundwater Flow

The groundwater table is a subdued reflection of the topography, with groundwater in the alluvium flowing from the south to the north following the natural gradient of the Avon River and from the south-east to the north-west along Waukivory Creek (**Figure 11**).

Direct rainfall infiltration into the alluvium is expected to be the main recharge mechanism to the alluvial plains. The alluvial groundwater also discharges into the creek and river, however, following high river levels or floods, stream flow may also form a source of recharge to the shallow alluvium when groundwater elevations may be lower than the water level in either Waukivory Creek or the Avon River.

Given the relatively poor brackish water quality and the groundwater levels, it is evident that the alluvium also receives a component of subsurface recharge or flow from the Permian sediments.

Figure 12 to **Figure 14** show the groundwater level hydrographs for the GRL alluvial monitoring bores (**Figure 10**). The alluvium shows a relatively rapid response to rainfall events indicating a significant component of direct recharge and also the potential to receive significant volumes of recharge from the infiltration of stream flow. The gradual decline in groundwater level following the rainfall event indicates the discharge of groundwater, to the nearby surface water systems of the Avon River and Waukivory Creek.


390000
400000
410000
6460000
6450000
6440000
6430000
AVON RIVER
WAUKIVORY CREEK
142.22
140
135
130
125
125.48
120
115
112.648
112.32
110
105
107.428
98
97.32
100
100.39
100.555
113.838
105.96
105.73
0
1.500
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:25,000 (A4)
N
LEGEND:
GRL Monitoring Bores; (Groundwater Elevation - mAHD)
Groundwater Level Contours
Quaternary Alluvium (GRL Mapping)
Quaternary Alluvium (100k Mapping)
Quaternary Alluvium (AGE Desktop)
Mine Area Boundary
DCDB
Rail
Local Drainage
Local Drainage
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Groundwater Level Contours
DATE:
20/7/2012
FIGURE No:
11

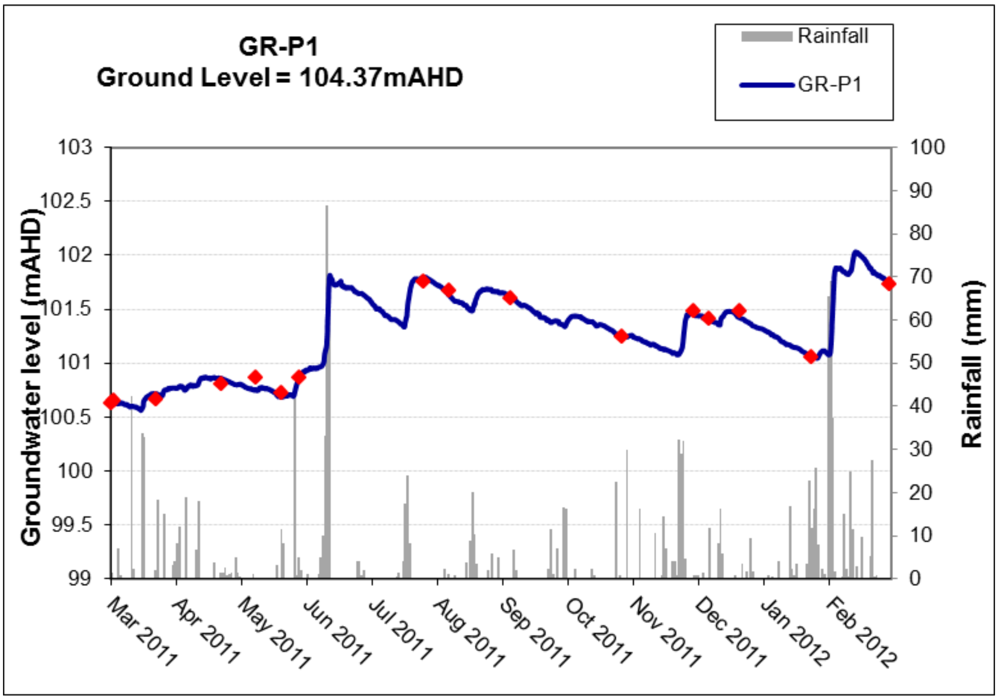


Figure 12 Groundwater Level Hydrograph for GR-P1 (Alluvium)

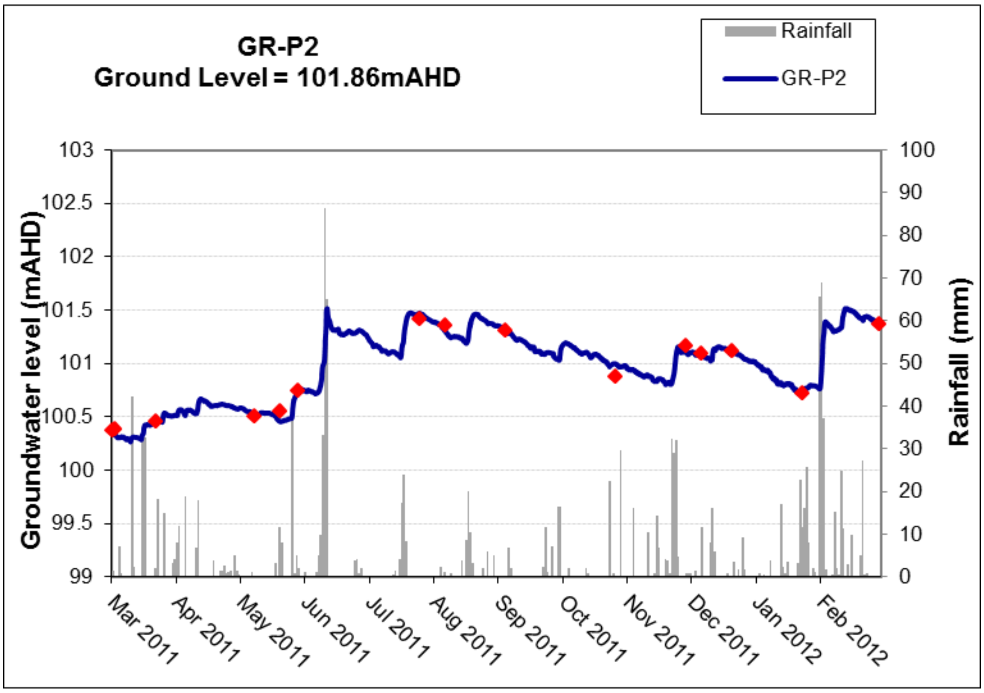


Figure 13 Groundwater Level Hydrograph for GR-P2 (Alluvium)

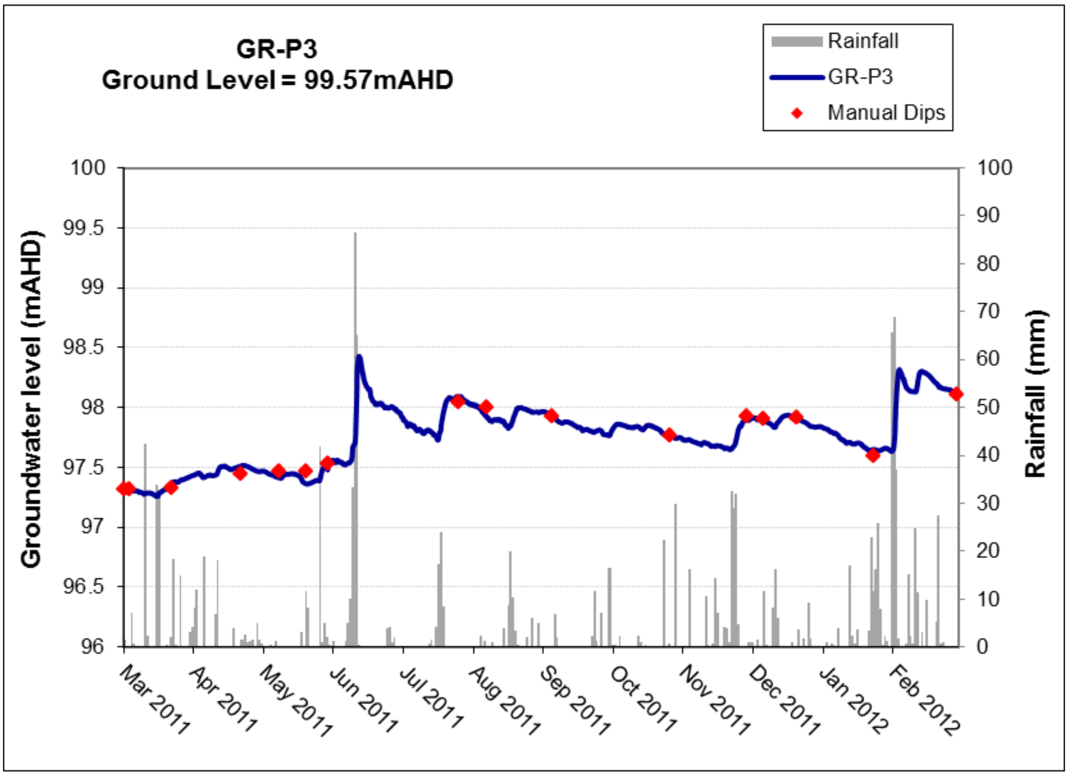


Figure 14 Groundwater Level Hydrograph for GR-P3 (Alluvium)

7.1.6 Water Quality

PB (2012b) described the alluvial groundwater as typically moderately fresh to brackish amongst the alluvial monitoring bores with GR-P1 described as moderately saline. The groundwater quality of the alluvium varies within the Mine Area (GR-P1, 5,000 – 6,450µS/cm; GR-P2, 1,003 - 1,885µS/cm and GR-P3, 3,110 – 3,880µS/cm). The range of electrical conductivity (EC) indicates that the alluvium receives recharge not only from direct rainfall recharge but also via a sub-surface groundwater flow component from the Permian sediments.

The pH in the alluvial monitoring bores was moderately acidic to neutral and ranged from 5.81 to 7.14 pH units (PB, 2012b). The groundwater in the Quaternary Alluvium is classified as a Sodium Chloride water type.

Figure 15 to **Figure 17** show the results of down-hole EC and temperature profiling that was carried out on monitoring bores GR-P1, GR-P2 and GR-P3 respectively. The profiles show that in GR-P1 there is a gradual increase in EC (from 5,800µS/cm to 6,200µS/cm) with depth through the screened interval (5.5mbGL to 8.5mbGL). A similar yet sharper increase is observed in GR-P2 (**Figure 16**) with EC increasing from 1,200µS/cm at the top of the screen (4mbGL) to 2,100µS/cm at the base of the screen (9mbGL). GR-P3 (**Figure 17**) shows a gradual increase in EC with depth with values of 3,350µS/cm at the top of the screen (5mbGL) to 3,500µS/cm at the base of the screen (9mbGL). This increase in EC with depth in the alluvial sediments suggests that there is likely to be some inflow into the alluvial sediments from the base or margins of the alluvium. Given the brackish EC of the Permian groundwater, this inflow is likely to be from the Permian sediments (see Section 7.3). The range of EC observed within the down-hole profiling for the alluvial monitoring bores is consistent with the range of EC reported from water sampling and analysis.

The groundwater temperature measured during the downhole profiling indicates a general increase of temperature with waters closest to the surface. However, the range of temperature values is likely to be influenced by seasonal changes and also daily temperature variations particularly for the shallow bores.

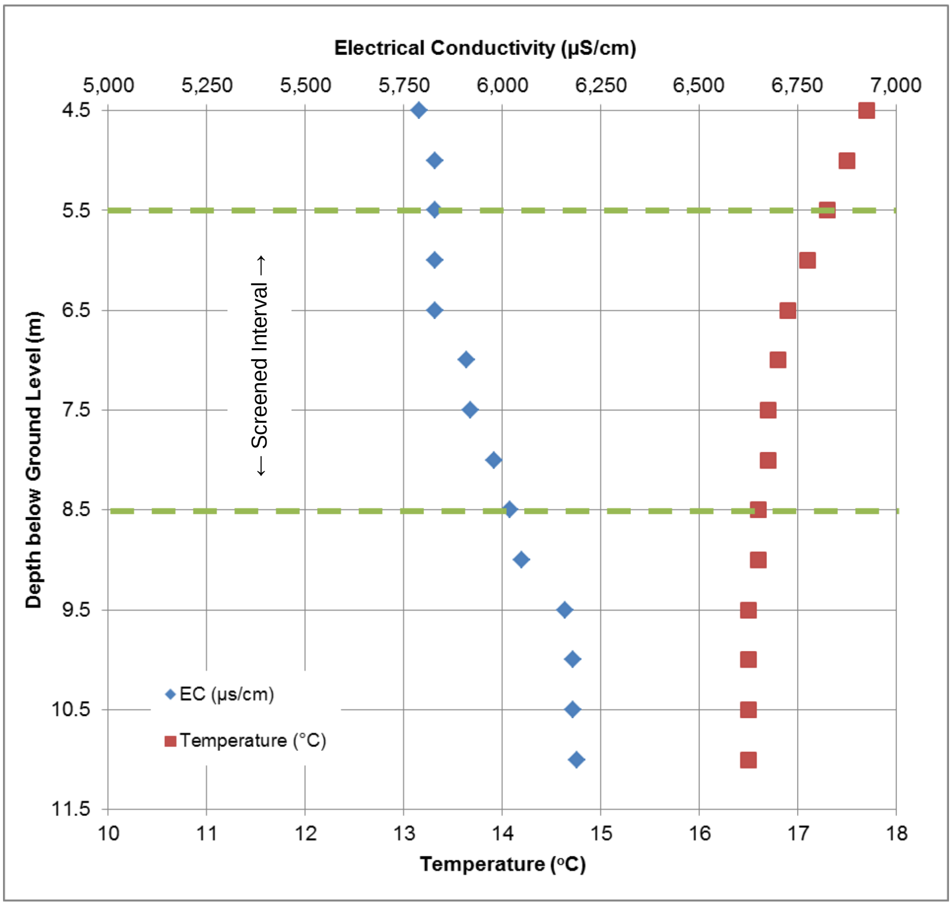


Figure 15 Down-hole EC and Temperature Profile for GR-P1

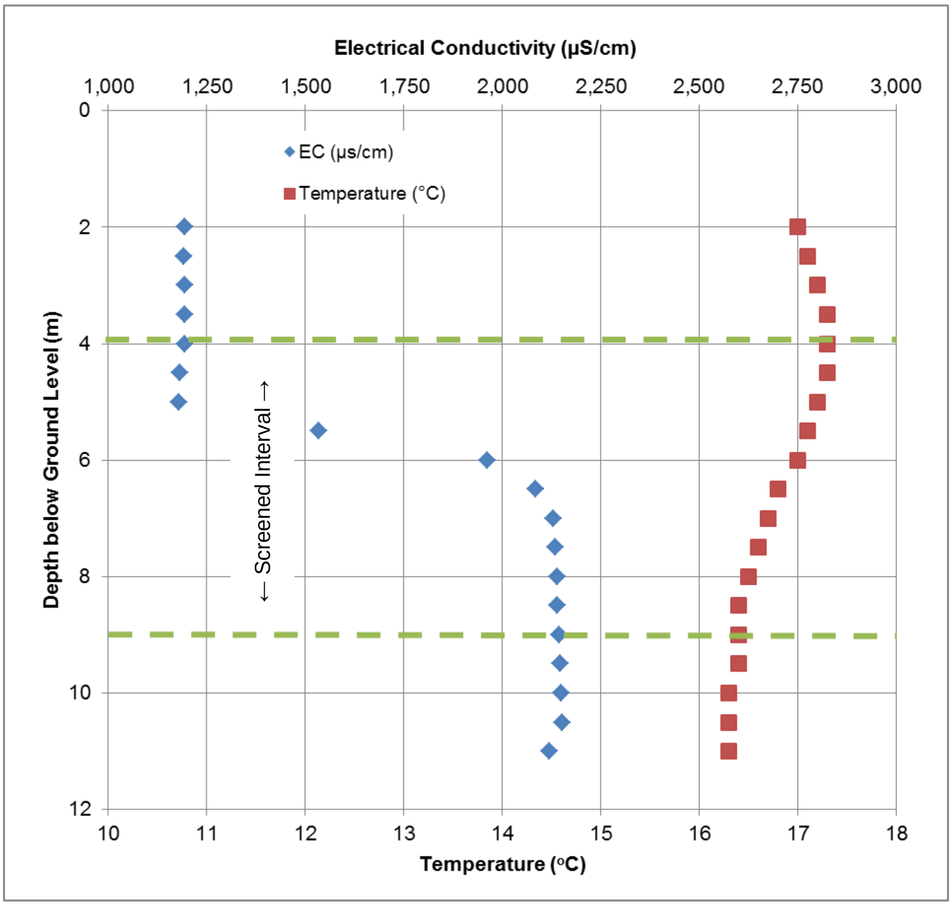


Figure 16 **Down-hole EC and Temperature Profile for GR-P2**

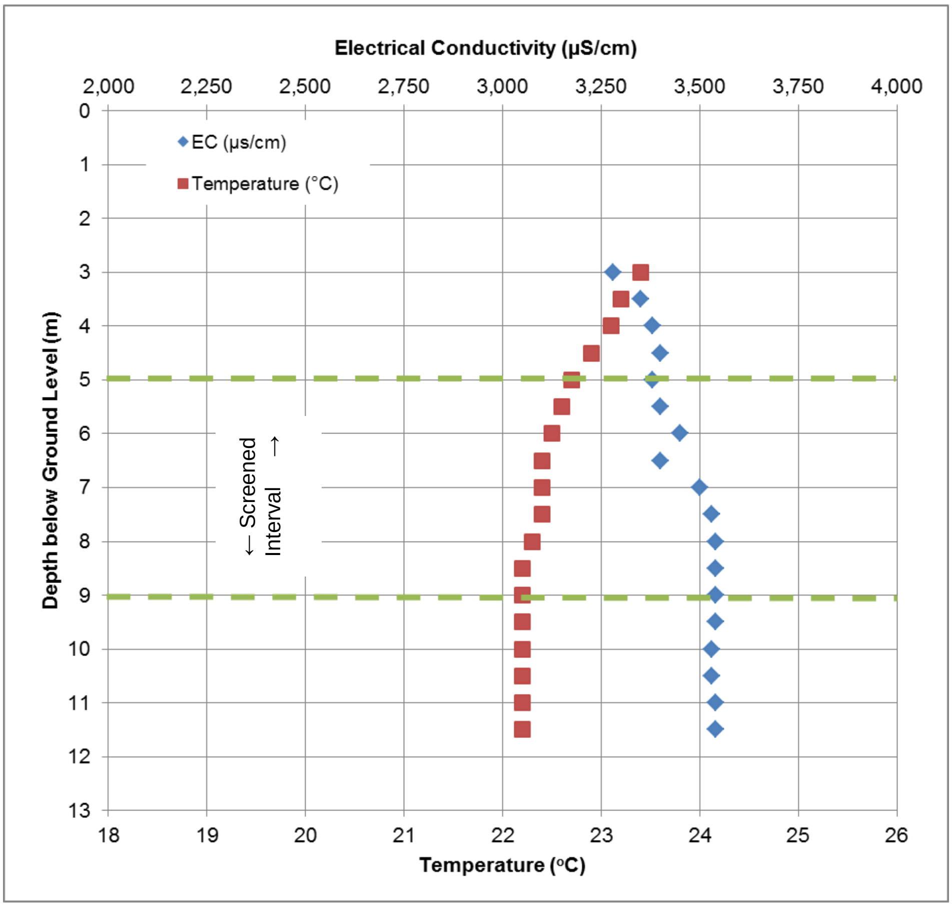


Figure 17 Down-hole EC and Temperature Profile for GR-P3

7.1.7 Groundwater Dependent Ecosystems

Threatened Species, Populations and Ecological Communities

A field survey was undertaken by Ecotone Ecological Consultants (2012) to identify known or likely threatened species, populations, ecological communities or other matters relating to local biodiversity that may need to be addressed or considered in a further and more detailed impact assessment. As part of this study EEC (2012) identified that the riparian zone along Waukivory Creek and the Avon River is predominantly River Oak, Cabbage Gum and Broad-leaved Apple. River Oaks are understood to be similar to River Red Gums and these species are likely to rely on groundwater from underlying formations.

No threatened flora species or endangered populations were recorded within the Site and no Threatened Ecological Communities listed within the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) are considered to occur in the Study Area (R.W. Corkery, 2012).

Stygofauna

Stygofauna are highly specialised aquatic macro-invertebrates and some fish that are adapted to living in groundwater habitats. They may exhibit high levels of endemism (i.e. species restricted to particular localities) and may function in the breakdown of organic material and assist in the transfer of water by burrowing. Previous studies have indicated stygofauna tend to be present in greater diversity and abundance in alluvium than in coal seam groundwater systems. The frequently high EC of groundwaters and lower levels of dissolved oxygen in the latter has been suggested as a cause of the lower proportion of stygofauna, while groundwaters with EC values exceeding 3,000µS/cm are thought to be unsuitable for stygofauna.

Stygofauna samples were collected by Cardno Ecology Laboratory Pty Ltd within GRL groundwater monitoring bores drilled in the Mine Area. In total, 37 samples were collected from the three types of groundwater systems (coal seam, interburden and alluvial) on three separate sampling occasions. Stygofauna were sampled by pumping water from bores through a fine mesh and examining the material retained on the mesh under a microscope.

During sampling, groundwater from all units had medium to high ECs, ranging from 1,240µS/cm to 7,047µS/cm. There was a large variability among boreholes and within the three types of groundwater, but variability through time was generally small. With the exception of one sample, all the coal seam samples had ECs in excess of 3,000µS/cm and in some samples ECs exceeded 6,000µS/cm. In total, 432 invertebrates from nine taxa were collected in the three types of groundwater. Only four individuals were collected from the coal seam groundwater, representing less than 1% of total abundance. All of the taxa collected were either terrestrial or soil/water dwelling that are not obligate stygofauna. This result is expected given the salinity of the groundwater.

7.2 REGOLITH/COLLUVIUM

7.2.1 Distribution and Structure

The material intersected in monitoring bores GR-P7 and GR-P8 are examples of colluvium and regolith or weathered material within the Site. GR-P7 is located in the southern extent of the proposed Mine Area within a proposed open cut pit. The bore is also located at the base of a steep incised drainage gully and at the northern limit of the mapped alluvial sediments (GSSE, 2011). Given the angular and sub-angular nature of the sediments intersected at this site, and the location of the bore at the base of a steep drainage gully, it is assessed that these sediments are more likely to be colluvial, deposited by gravity rather than alluvium deposited by streams (alluvium). Colluvial deposits occur at the base of the steep slopes on the eastern and southern side of the Site and interfinger with alluvial sediments at the edge of the floodplains.

GR-P8 is located in the middle of the Site on steep terrain. The monitoring bore completion log provides an example of the weathered profile that has developed on the Permian sequence. In this case, the weathered zone extends some 36mbGL and the standing water level at this monitoring bore is approximately 7mbGL (126mAHD) indicating that the weathered zone is partially saturated.

At other locations in the Site, the weathered zone extends to depths of 32m (GR-P4), 22m (GR-P5), 12m (GR-P6), 26m (GR-P6A), 18m (GR-P8A), 6m (GR-P9) and 19m (GR-P9A). There is significant variability observed in the nested piezometer locations with regards to the depth of the weathered zone or regolith.

7.2.2 Hydraulic Parameters

The colluvial deposits are typically of similar or greater permeability than the underlying coal seams or interburden. A hydraulic conductivity value of 0.08m/day was measured in the colluvium at GR-P7. Colluvial monitoring bores have not been completed for the nearby AGL project and hence no comparison can be made to the site further to the south.

A hydraulic conductivity value of 0.015m/day was measured in the regolith or weathered zone at GR-P8.

7.2.3 Yields and Usage

Airlift yield was not reported during drilling of the colluvial or regolith monitoring bores at GRL (GR-P7 and GR-P8). It is understood that GR-P8 did not yield enough groundwater on completion to provide an initial quality sample.

7.2.4 Groundwater Levels and Hydraulic Gradients

The groundwater level for GR-P7 is approximately 115mAHD which is slightly lower than the ground level at the monitoring bore. The hydrograph for the bore (**Figure 18**) shows a significant rise from March 2011 and since then, the SWL has been at or near surface. The nearby nested monitoring bore (GR-P7A) which is completed in a coal seam, exhibits a very similar hydrograph trend and has regularly displayed artesian (free flowing) conditions. The water levels at this location indicate a consistent upward vertical hydraulic gradient from the deeper coal seam to the colluvium.

There is also a steep hydraulic gradient from the colluvial monitoring bore GR-P7 (115mAHD) to Waukivory Creek (106mAHD). This is due to the higher permeability alluvial sediments butting up against and interfingering with the lower permeability colluvial sediments. Monitoring bores GR-P10 and GR-P11 both recently recorded (June 2012) groundwater levels in the order of 105.7mAHD and 106mAHD within the alluvium. Whilst recorded at different times, the elevation in the two recently drilled monitoring bores is generally consistent with the surface water level in Waukivory Creek.

The groundwater level for GR-P8 is approximately 126mAHD and has shown a gradual increase in level since March 2011 (**Figure 19**). The nearby nested monitoring bore (GR-P8A) which is completed in a coal seam, exhibits a similar increasing trend; however, the hydrograph for GR-P8A is not as subdued as GR-P8 and shows greater fluctuations to rainfall events. The water level in the deeper coal seam completion is consistently at a higher elevation than the weathered material, indicating an upward vertical hydraulic gradient from the coal seam to the weathered material, or regolith.

7.2.5 Regional and Local Recharge, Discharge and Groundwater Flow

The colluvial deposits are likely to be recharged by direct rainfall infiltration and by runoff from the steep slopes. Regolith material is likely to be recharged by rainfall infiltration and upward leakage from the higher permeability units such as coal seams.

Groundwater flow within the regolith and colluvium is toward Waukivory Creek and the Avon River.

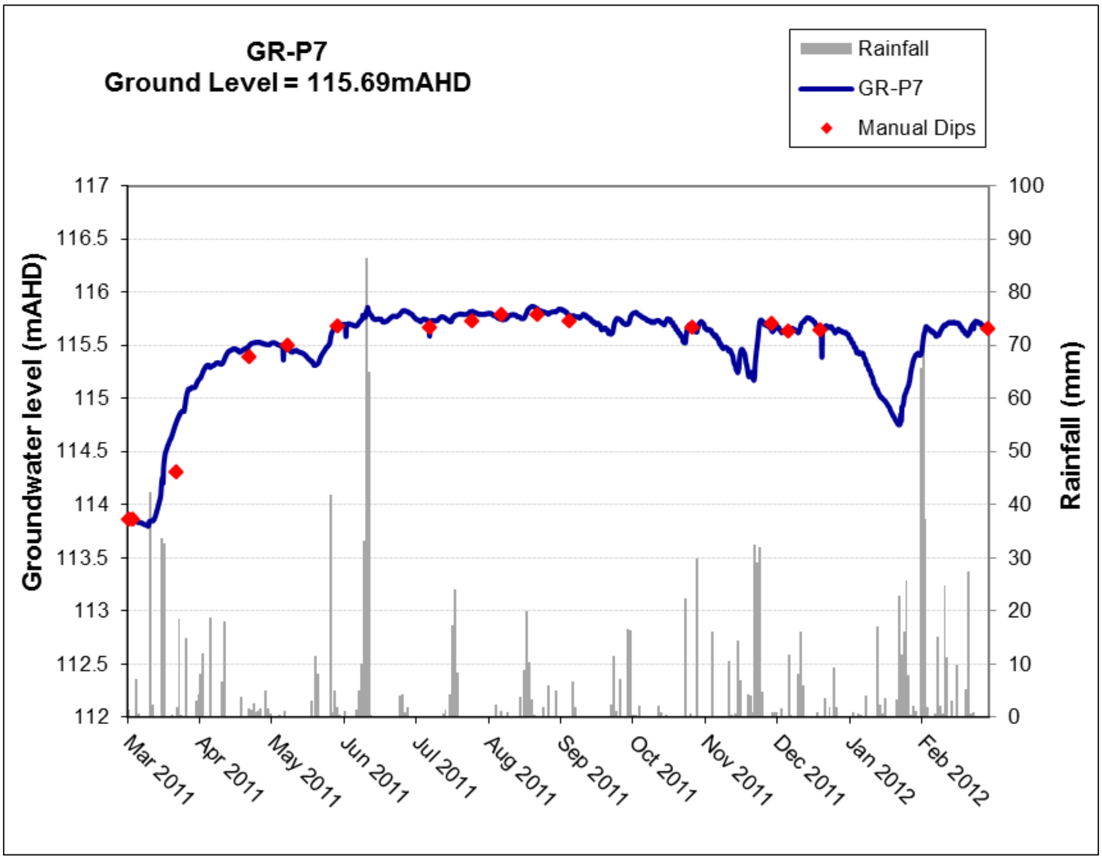


Figure 18 Groundwater Level Hydrograph for GR-P7 (Colluvium)

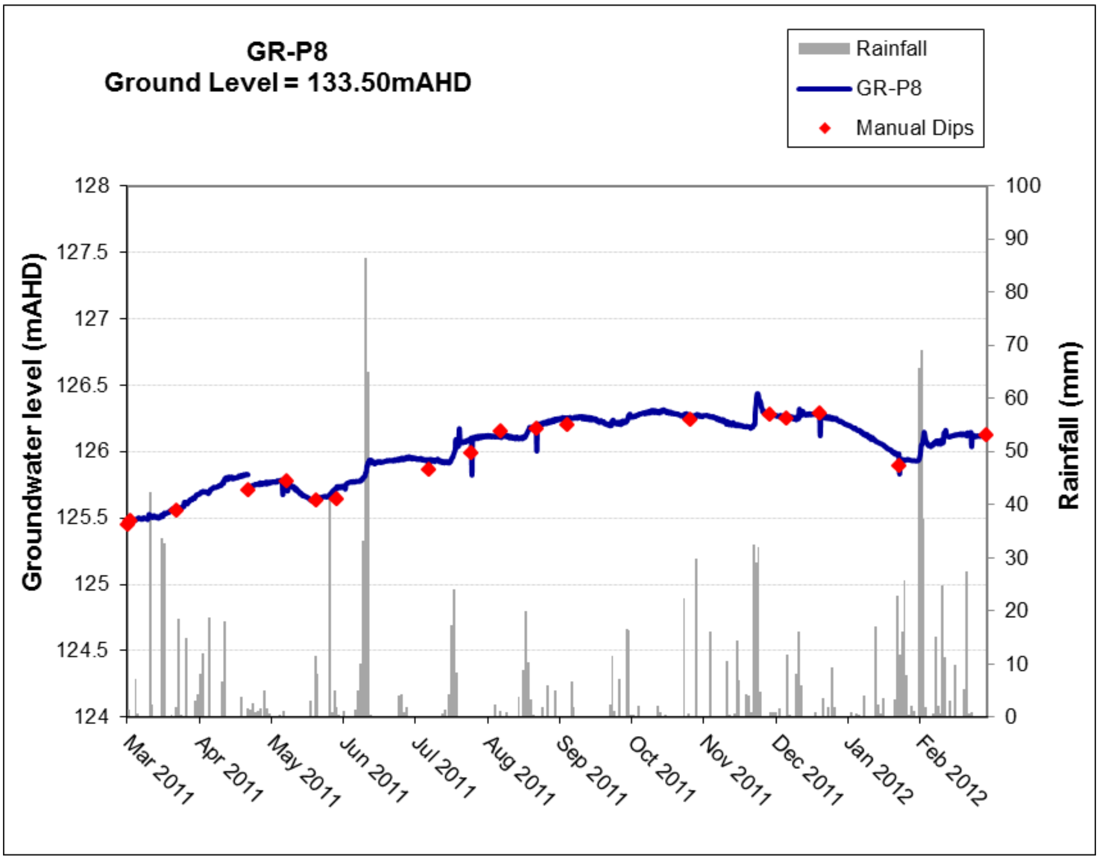


Figure 19 Groundwater Level Hydrograph for GR-P8 (Regolith)

7.2.6 Water Quality

The groundwater quality in the colluvium at bore GR-P7 is in the range 1,162 to 1,357µS/cm with pH between 6.05 and 7.43. The groundwater in the colluvium is classified as a sodium chloride water type.

Groundwater within the regolith is brackish with EC at GR-P8 reported between 3,610 to 5,700µS/cm. The pH at GR-P8 was measured between 6.59 and 7.47 indicating near neutral groundwater. GR-P8 is a sodium / chloride - bicarbonate water type.

Figure 20 and **Figure 21** show the down-hole EC and temperature profiling that was carried out on monitoring bores GR-P7 and GR-P8. The profile for GR-P7 shows a relatively flat trend in EC (1,200µS/cm) with no appreciable increase or decrease with depth. The down-hole profile for GR-P8 shows a similar trend within the screened section of the monitoring bore (29 – 41mbGL) with EC constant around 3,500µS/cm.

The EC observed during the down-hole profiling for GR-P7 is consistent with the range of EC measured during water quality sampling and analysis. For monitoring bore GR-P8, the range of EC measured during water analysis (3,610 – 5,700µS/cm) exceeds the small range of EC measured during the profiling (~3,500µS/cm). GR-P8 does not make much water during sampling and it is understood the bore runs dry during sampling events. It is likely that the higher EC values reported for this bore were sampled early in the life of the bore and are not strictly representative of equilibrated formation quality.

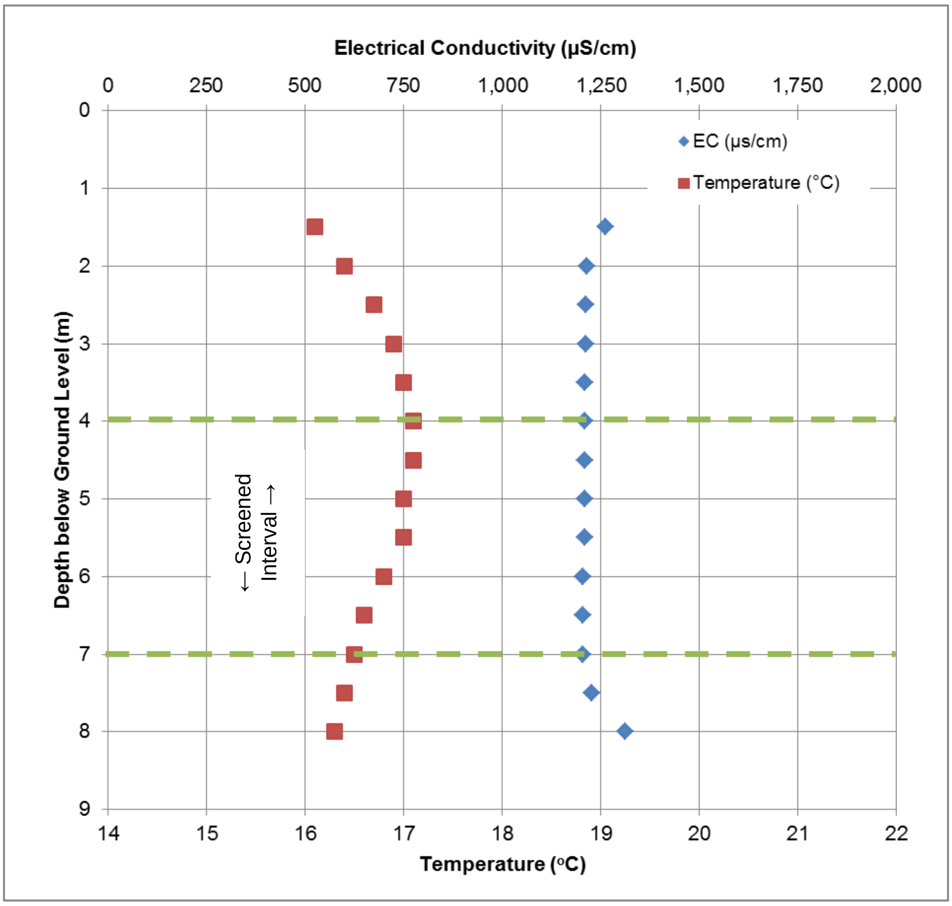


Figure 20 **Down-hole EC and Temperature Profile for GR-P7**

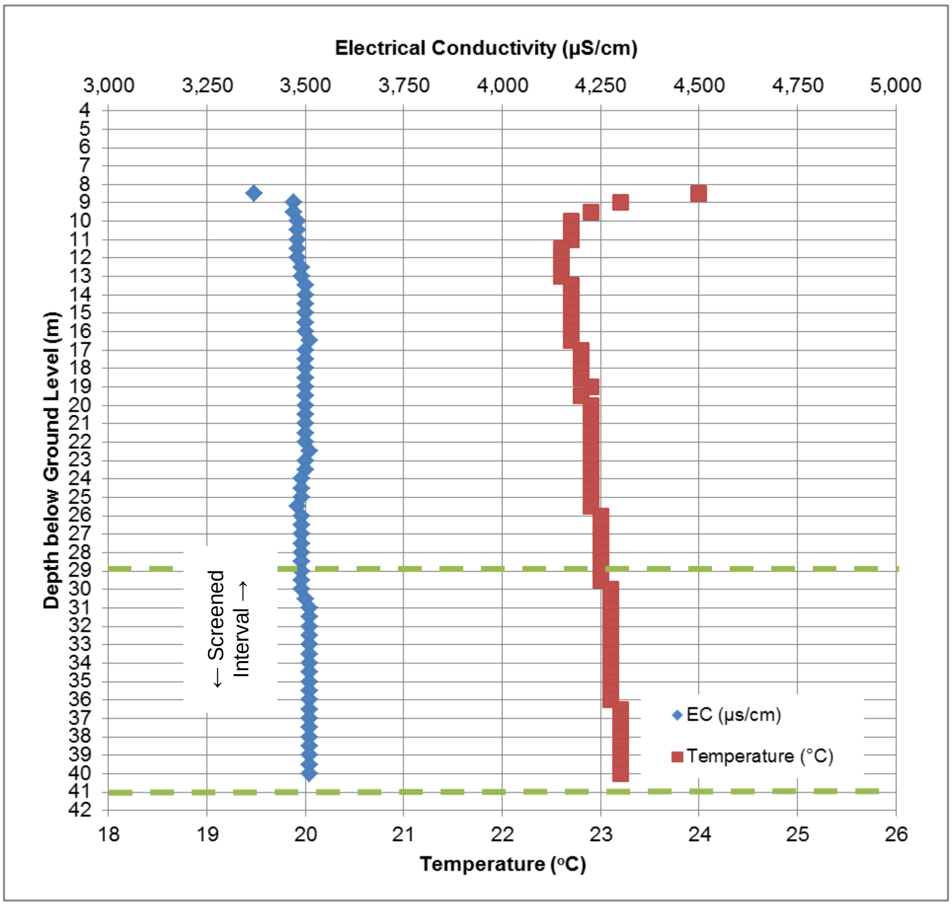


Figure 21 **Down-hole EC and Temperature Profile for GR-P8**

The groundwater temperature measured during the downhole profiling indicates temperatures in the range of 16°C to 17°C for the shallower GR-P7 and 22°C to 24°C for the deeper GR-P8. The range of temperature values is likely to be influenced by seasonal changes and also daily temperature variations particularly for the shallow bores.

7.3 PERMIAN COAL SEAMS AND INTERBURDEN

7.3.1 Distribution and Structure

The coal seams are the main continuous water-bearing formations throughout the Gloucester Basin. The Permian strata can be categorised into the following hydrogeological units:

- Hydrogeologically "tight" and hence very low yielding sandstone, siltstones and mudstones that comprise the Permian overburden / interburden; and
- Low to moderately permeable coal seams which are the prime water-bearing strata within the Permian Coal Measures.

Groundwater monitoring bores GR-P4, GR-P5, GR-P6 and GR-P9 are constructed within the Permian interburden or overburden, whereas bores GR-P6A, GR-P7A, GR-P8A and GR-P9A are representative of coal seam conditions.

7.3.2 Hydraulic Parameters

The hydraulic conductivity of the coal seam is variable with hydraulic testing at GR-P6A, GR-P7A, GR-P8A and GR-P9A recording permeability values of 0.06m/day, 0.002m/day, 0.01m/day and 0.15m/day respectively. These represent several orders of magnitude difference and it is expected that these values are influenced by the depth of burial of the seam and degree of jointing and cleat density locally. According to Mackie (2009) coal seams in the Hunter Valley generally display vertical hydraulic conductivity values equal to horizontal hydraulic conductivity values, due to the alignment of the conductive cleats within the unit (refer to **Figure 22**).

There is little public data available to suggest whether the vertical hydraulic conductivity values are equal to horizontal hydraulic conductivity values in the Gloucester Basin. The Gloucester Basin coal seams are more steeply dipping compared with those in the Hunter Valley and the assumption that vertical hydraulic conductivity is equal to horizontal hydraulic conductivity would be conservative in terms of regional impact assessment.

The hydraulic testing of the interburden / overburden material measured in hydraulic conductivity values of 0.2m/day, 0.05m/day, 0.04m/day and 0.2m/day for sites GR-P4, GR-P5, GR-P6 and GR-P9 respectively. There is also a considerable range and variation in these hydraulic conductivity values for the interburden and overburden.

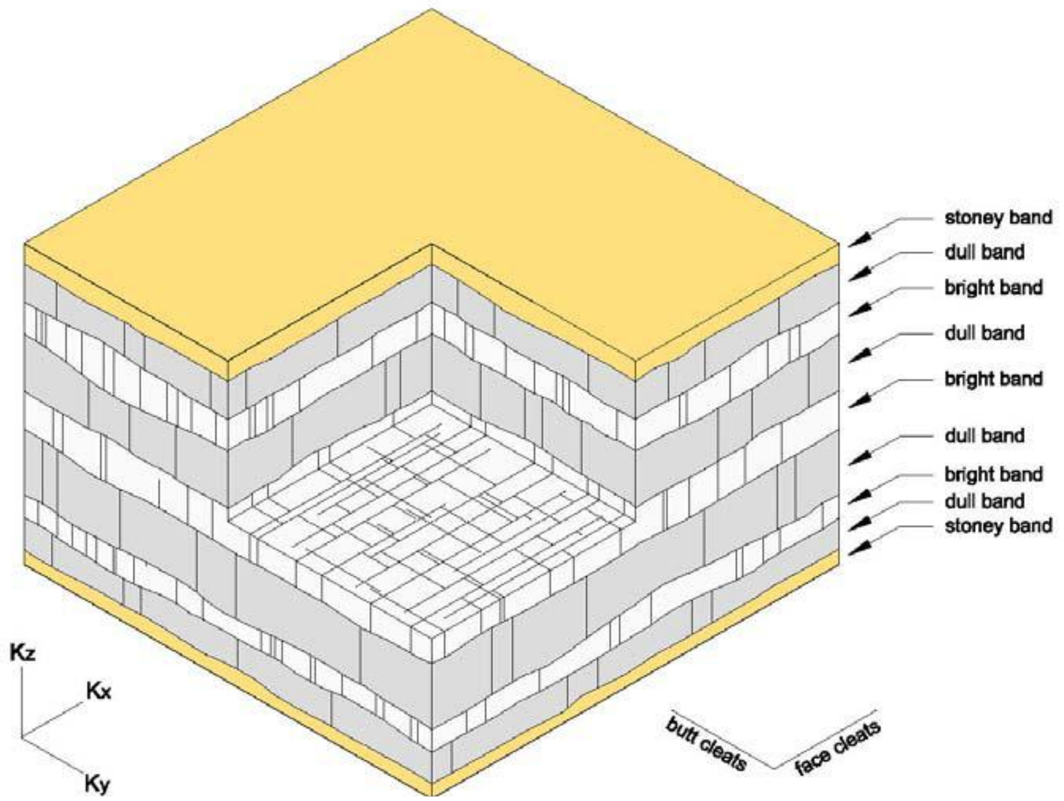


Figure 22 Geometry of Cleating in Banded Coals (source: Mackie 2009)

PB (2012a) reported permeability values measured from falling head or rising head tests from the AGL monitoring bores for the various coal seams at 0.03m/day to 2.3×10^{-3}m/day (**Table 10**). AGL also carried out down-hole packer testing at monitoring bore (TCMB04). A hydraulic conductivity value for the Cloverdale Coal Seam was derived from this testing with a value of 8 x 10^{-3}m/day to 9 x 10^{-3}m/day from a depth of 270 – 273mbGL. Laboratory derived values for hydraulic conductivity were also measured from core sampled at AGL monitoring bore TCMB04. The values reported are 1.82m/day for the Cloverdale Coal Seam (270mbGL) and 0.067m/day for the Roseville Coal Seam (333mbGL), however, PB (2012a) suggest that the value of 1.82m/day for the Cloverdale Coal Seam is abnormally high, likely to be due to drying and expanding of the core. Laboratory hydraulic conductivity values for the interburden material were measured at 1 x 10^{-3}m/day to 2 x 10^{-3}m/day, much lower than at the proposed Mine Area.

PB (2012a) also refers to a change in hydraulic conductivity of the coal seam with depth (after SRK, 2010). **Table 11** summarises this data which indicates a general reduction in hydraulic conductivity with increasing depth below surface.

Table 11
Coal Seam Hydraulic Conductivity with Depth

Formation Name	Hydraulic Conductivity (m/day)	Depth (mbGL)
Coal seams of the Gloucester Coal Measures and Dewrang Group	8.6 x 10^{-2}	100
	6.1 x 10^{-3} – 2.3 x 10^{-2}	300
	4.8 x 10^{-4}	500
PB, 2012a after SRK, 2010		

7.3.3 Yields and Usage

Airlift yield was not reported during drilling of the Permian monitoring bores at GRL, nor during the drilling of monitoring bores at AGL.

A search of the NOW registered bores in the region indicates yield data is limited. There are only six Permian bores that have yield information associated with them. These bores all appear to have intersected groundwater within consolidated siltstones and sandstones representative of the Gloucester Basin. Yields were generally intersected at depths greater than 10mbGL, with yields of between 0.1L/s to 1.9L/s and typically less than 0.6L/s.

7.3.4 Groundwater Levels and Hydraulic Gradients

The pristine water table surface is a subdued reflection of the topography. Groundwater levels in higher elevated areas vary from between 5m and 10m below the surface. GR-P4 and GR-P5 are located in the central portion of the Site and show a relatively flat yet slightly increasing groundwater level trend since March 2011 (**Figure 23** and **Figure 24**). Little response is seen in relation to rainfall events, in particular the high intensity rainfall event captured in June 2011.

GR-P6 and GR-P6A are a nested piezometer completion located in the far north of the Site on elevated and steep terrain. There is a significant downward vertical gradient at this site indicating that the interburden material monitored in GR-P6 (K = 0.04m/day) is draining into the coal seam monitored at GR-P6A (K = 0.06m/day). This hydraulic gradient is likely to be driven by localised rainfall recharge (**Figure 25** and **Figure 26**).

As discussed in Section 7.2.4, the groundwater levels at GR-P7A indicate a consistent upward vertical hydraulic gradient from the deeper coal seam to the colluvium. The coal seam bore exhibits a very similar hydrograph trend to the shallower colluvium monitoring bore and has regularly displayed artesian (free flowing) conditions (**Figure 27**).

Upward gradients are also observed at GR-P8A. The water level in the deeper coal seam completion is consistently at a higher elevation than the weathered material indicating an upward vertical hydraulic gradient. The nested monitoring bores show a similar increasing trend; however, the hydrograph for GR-P8A is not as subdued as GR-P8 and shows greater fluctuations to rainfall events (**Figure 28**).

GR-P9 and GR-P9A are located in the central southern portion of the Mine Area. Both hydrographs show elevated spikes in the dataset during May 2011. These spikes are not likely to be due to rainfall infiltration as this coincides with a period of low rainfall and a delayed effect of rainfall recharge would result in a subdued and gradual increase as is observed at other monitoring bores across the Mine Area. The groundwater level response is likely to be associated with nearby exploration drilling (**Figure 29** and **Figure 30**). There is a gradual upward vertical hydraulic gradient at the site from the coal seam (109mAHD) to the overburden (107.5mAHD). Little response is seen at this monitoring site in relation to high intensity rainfall events.

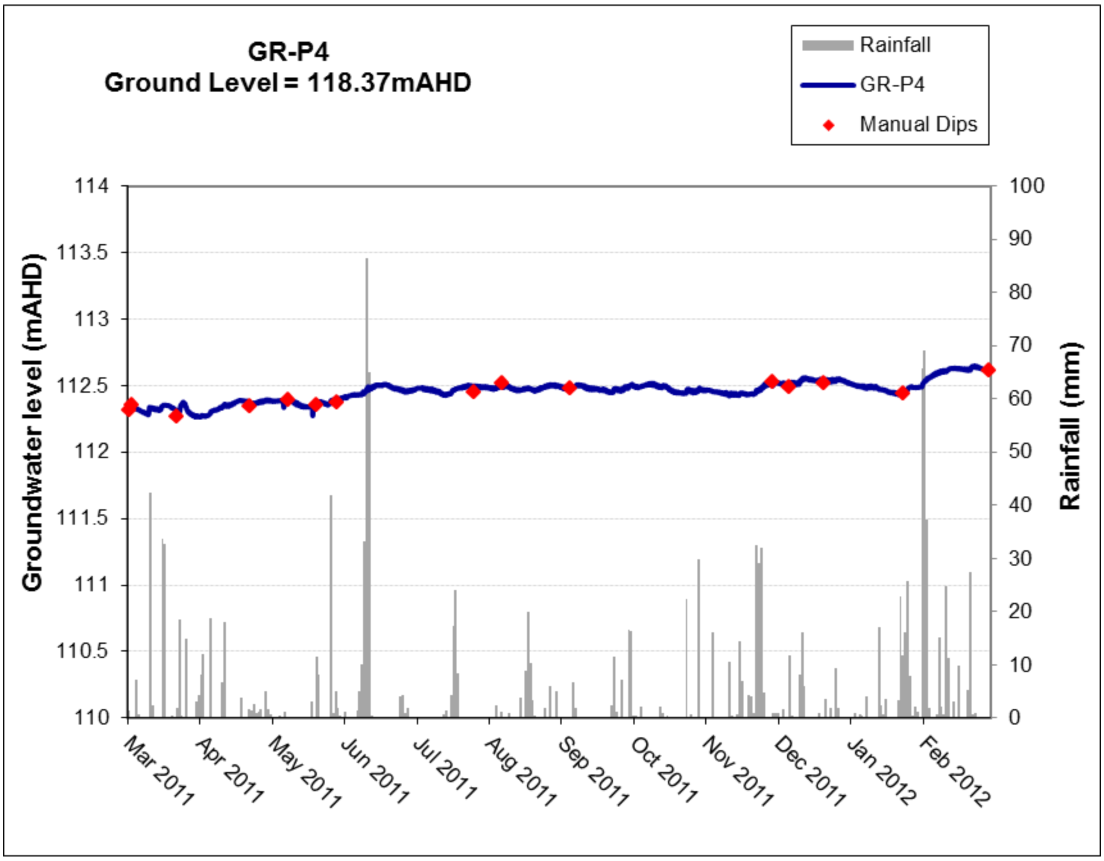


Figure 23 **Groundwater Level Hydrograph for GR-P4 (Interburden)**

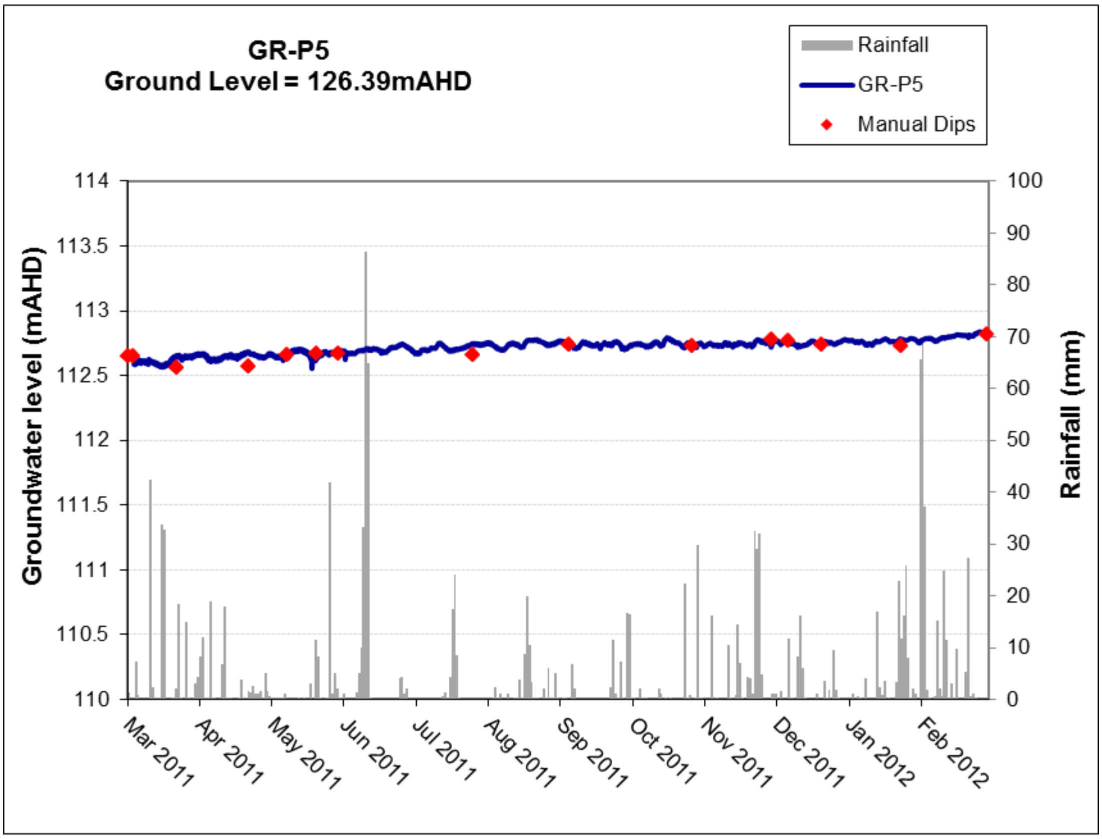


Figure 24 **Groundwater Level Hydrograph for GR-P5 (Interburden)**

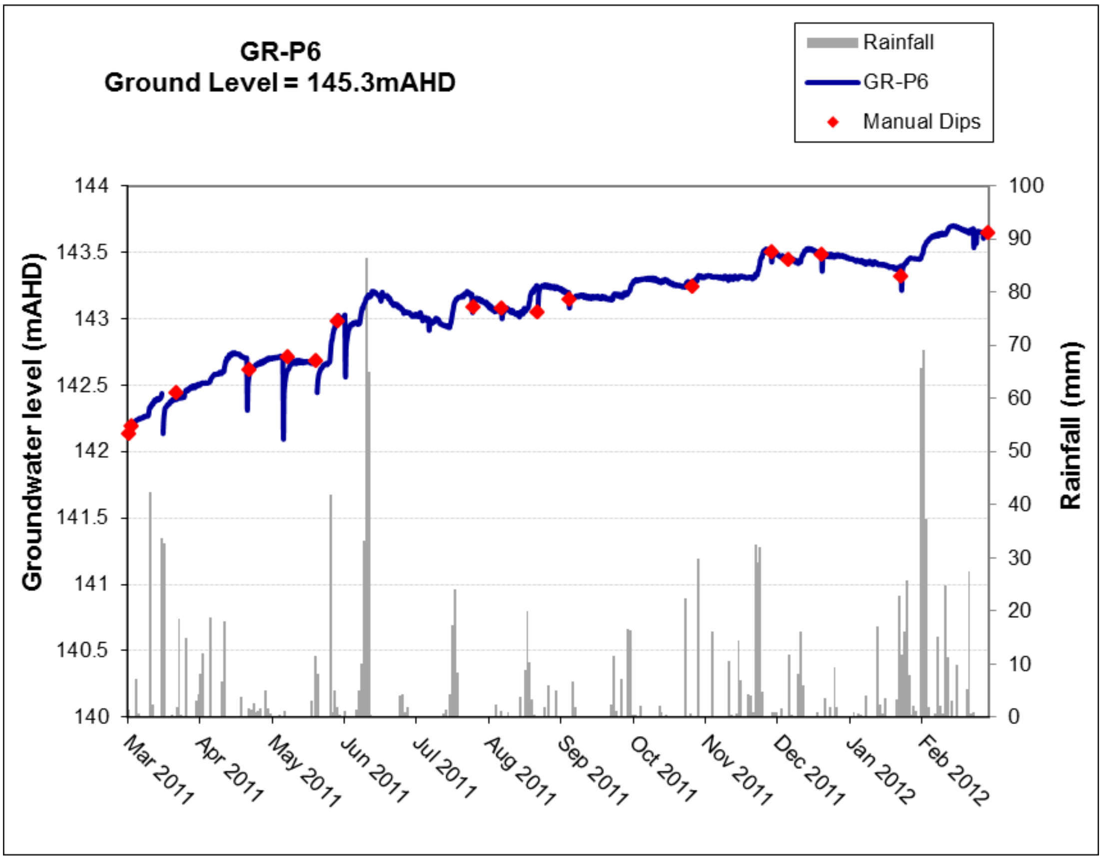


Figure 25 **Groundwater Level Hydrograph for GR-P6 (Interburden)**

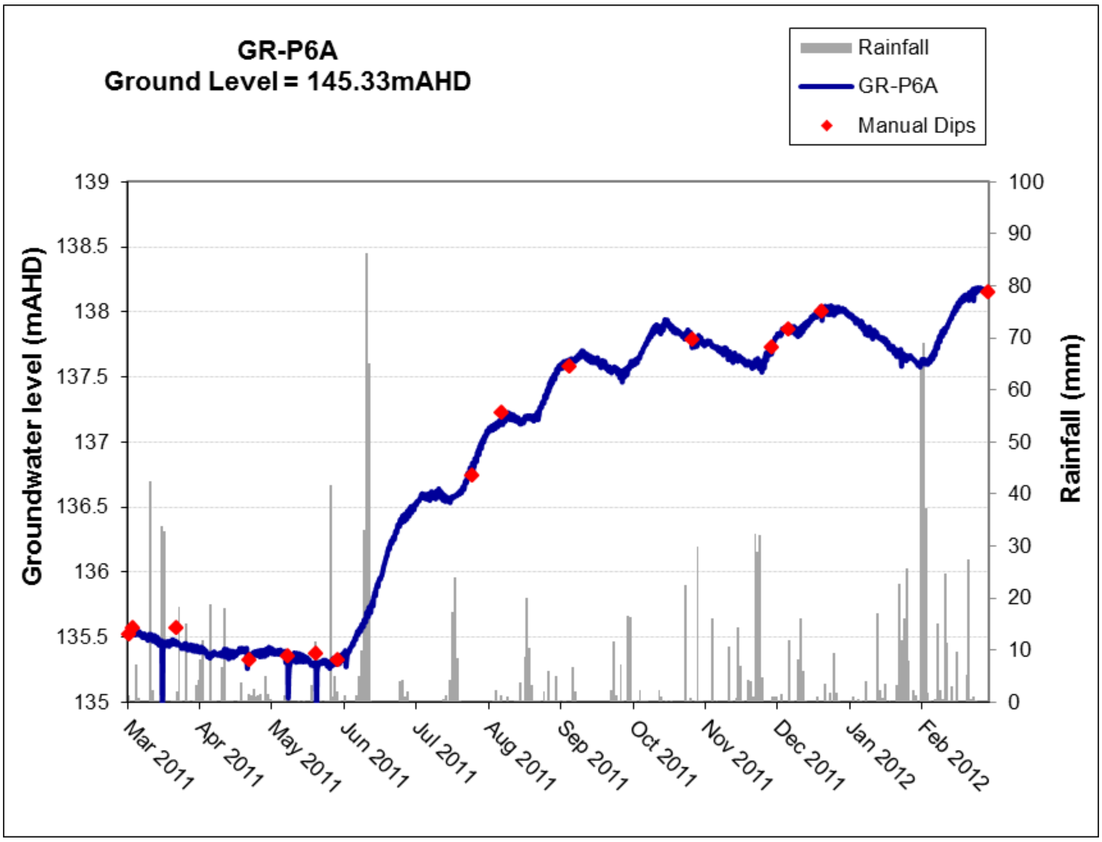


Figure 26 Groundwater Level Hydrograph for GR-P6A (Coal Seam)

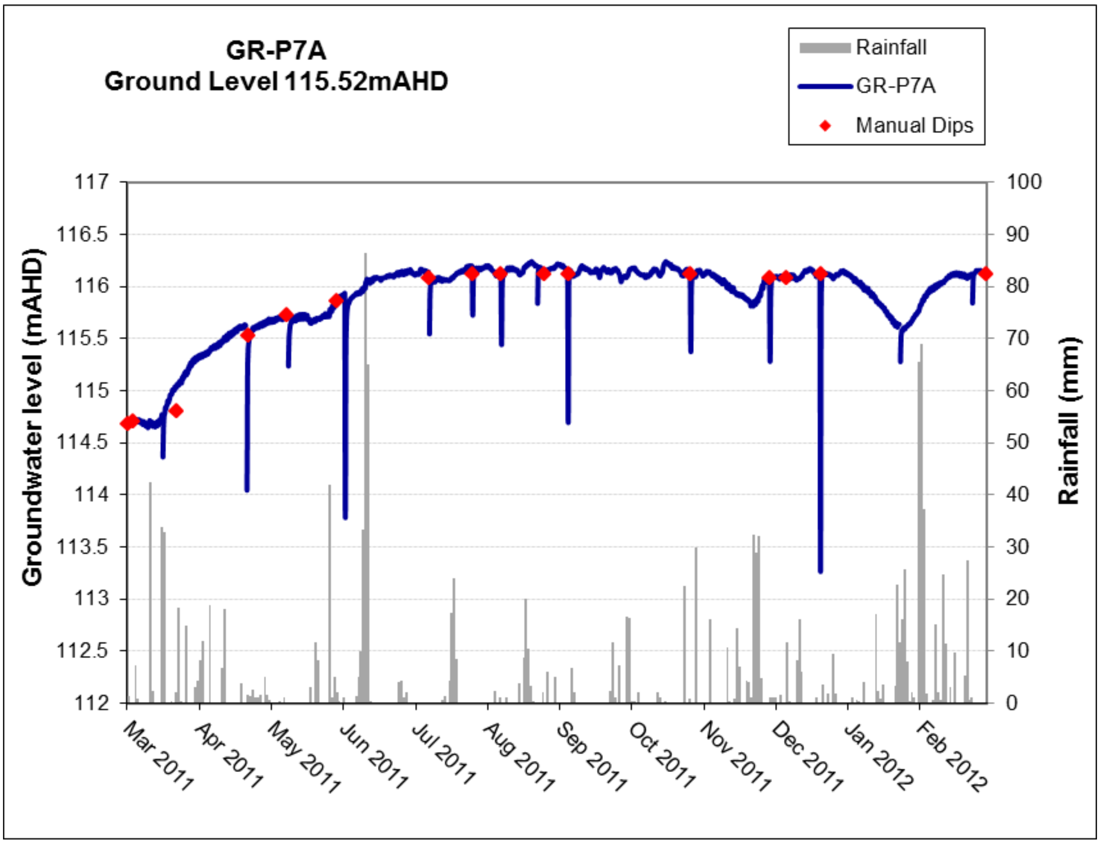


Figure 27 Groundwater Level Hydrograph for GR-P7A (Coal Seam)

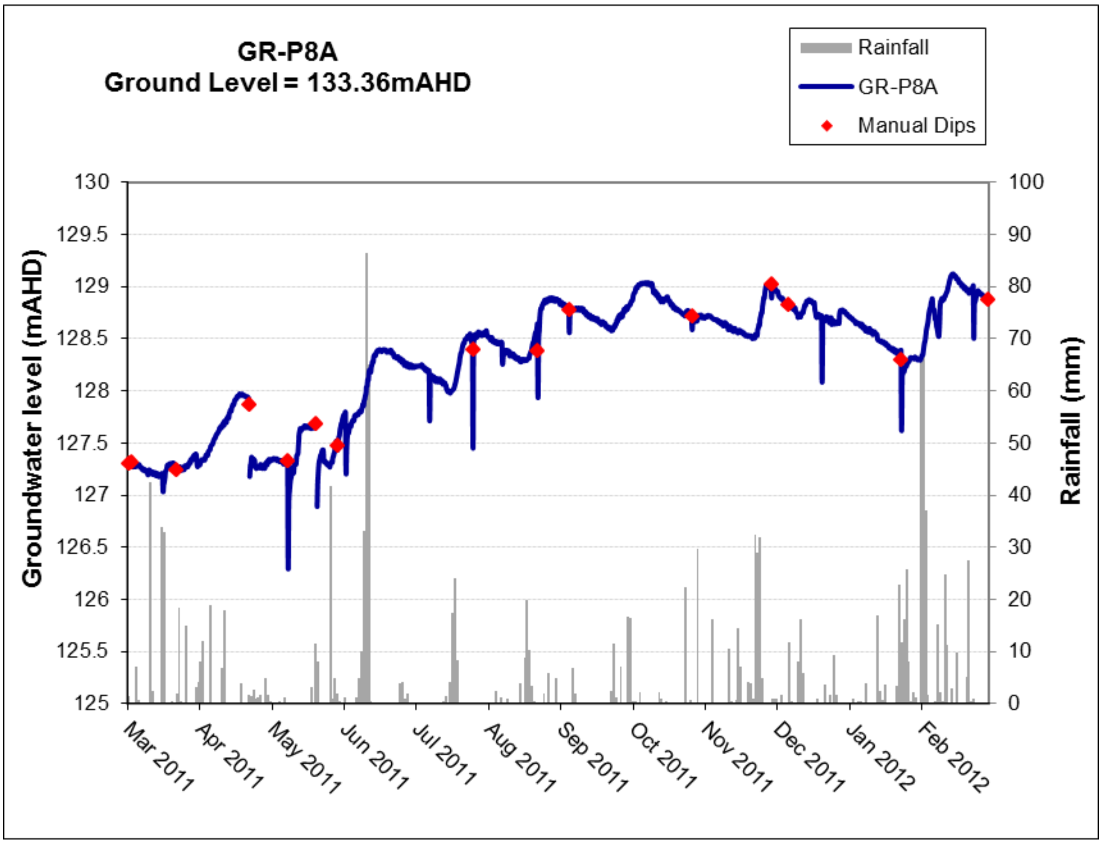


Figure 28 **Groundwater Level Hydrograph for GR-P8A (Coal Seam)**

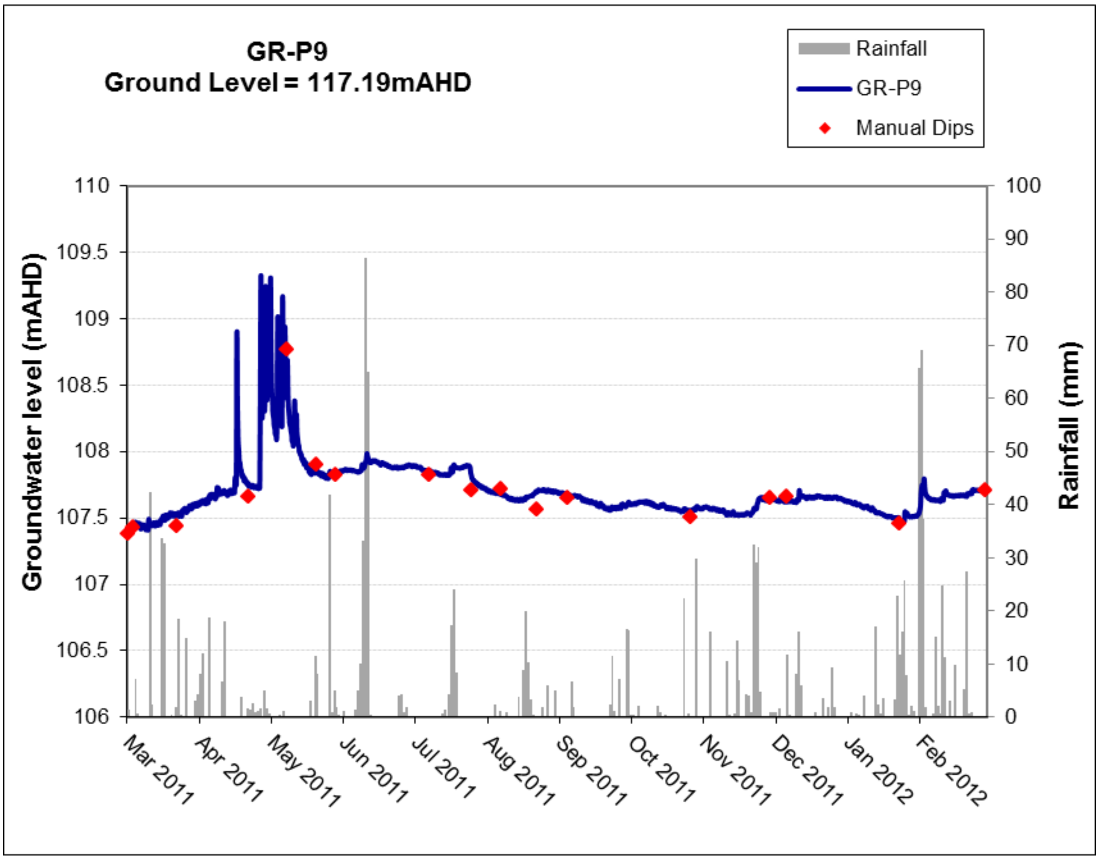


Figure 29 **Groundwater Level Hydrograph for GR-P9 (Interburden)**

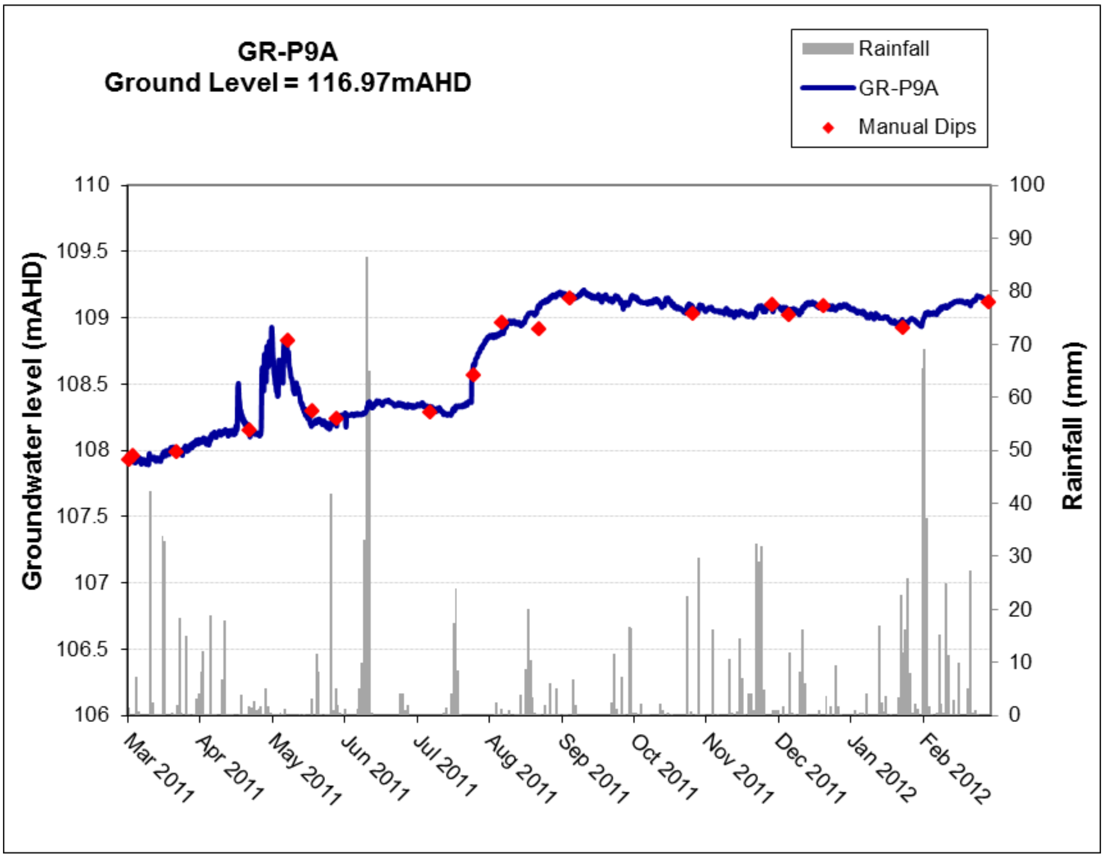


Figure 30 **Groundwater Level Hydrograph for GR-P9A (Coal Seam)**

7.3.5 Regional and Local Recharge, Discharge and Groundwater Flow

Groundwater flow in the coal seams and interburden / overburden is primarily from the east to the west-northwest. There is also expected to be a component of groundwater flow that occurs laterally along strike of the Permian strata to the north and to the south with potential for discharge to the alluvium along the creek/river system.

The coal seams are recharged by direct rainfall in subcrop areas or via leakage from the regolith or overlying alluvial and colluvial deposits.

7.3.6 Water Quality

Groundwater quality of the interburden material (GR-P4, 5,740 – 7,480µS/cm; GR-P5, 2,880 – 4,400µS/cm; GR-P6, 2,470 – 2,810µS/cm and GR-P9, 4,170 – 6,840µS/cm) indicates brackish groundwater that is consistent with the hydraulic conductivity and the residence time in the interburden. These groundwater chemistries are considered to be representative of the interburden groundwater within the Gloucester Basin.

Groundwater quality of the coal seams (GR-P6A, 2,800 – 5,230µS/cm; GR-P7A, 3,150 – 3,900µS/cm; GR-P8A, 5,020 – 6,550µS/cm and GR-P9A, 3,580 – 6,400µS/cm) indicates a relatively consistent chemistry that is also typical of coal seam groundwater within the Gloucester Basin.

Down-hole EC and temperature profiling was carried out on the groundwater monitoring bores to assess any change in water quality with depth. The down-hole profiling was carried out using a water quality meter and the results are only representative in the screened interval of the monitoring bore. The down-hole profiling had a depth limitation of 40m and so any bores with screened intervals deeper than 40mbGL (GR-P6A, GR-P7A, GR-P8A and GR-P9A) show groundwater quality in the blank section of casing which is subject to stratification over time. The water quality profiles in the monitoring bore above the screened intervals are not considered to be representative of the formation water quality.

Figure 31 to **Figure 34** show the down-hole profiles for interburden monitoring bores GR-P4, GR-P5, GR-P6 and GR-P9. The profile for GR-P4 shows a flat trend of EC (6,150µS/cm) with depth through the screened interval (32.5mbGL to 35.5mbGL). The same can be said for GR-P5 and GR-P9 which show consistent ECs of ~2,800µS/cm and ~6,300µS/cm through their screened intervals (24 - 30mbGL and 24 - 33mbGL respectively). GR-P6 shows a gradual decreasing trend of EC with depth. EC decreases from ~2,700µS/cm and ~2,550µS/cm through the screened interval (17mbGL - 23mbGL).

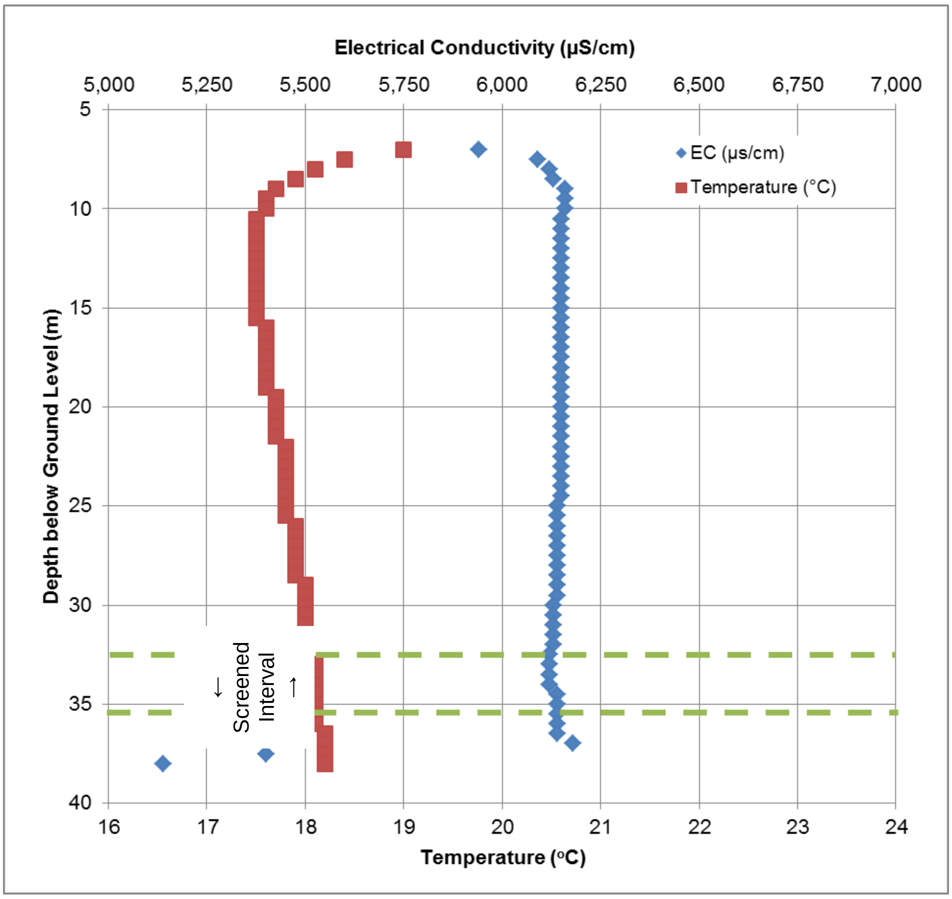


Figure 31 Down-hole EC and Temperature Profile for GR-P4

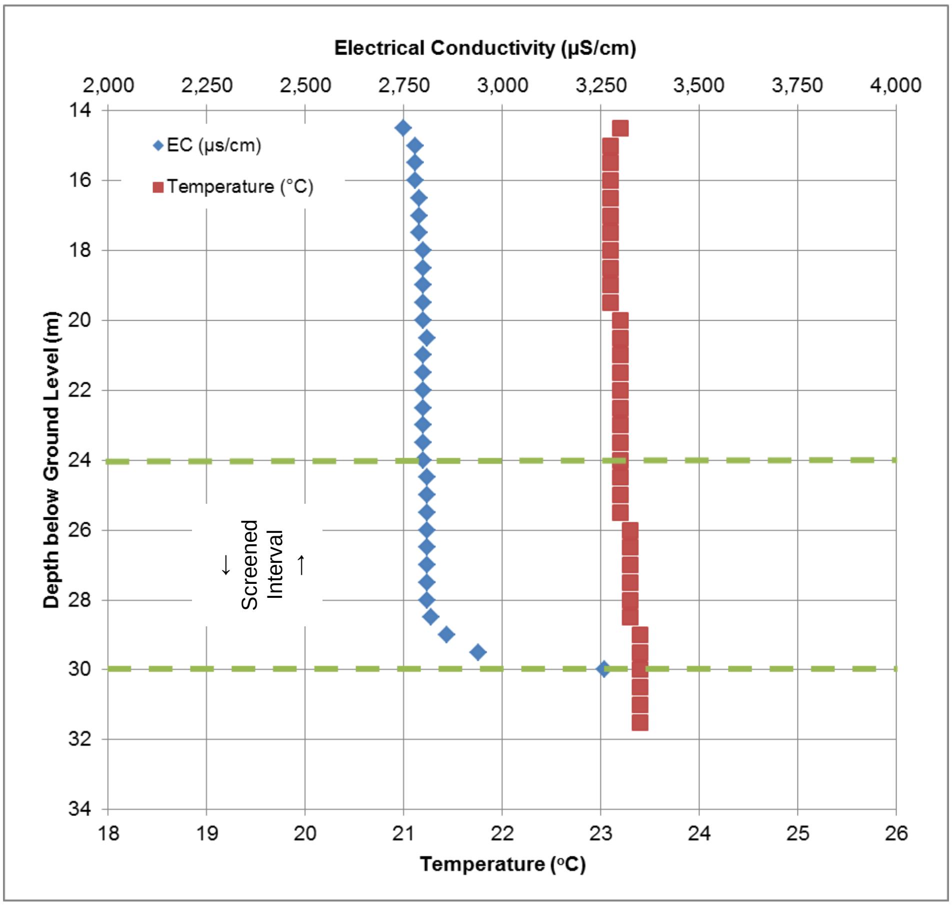


Figure 32 Down-hole EC and Temperature Profile for GR-P5

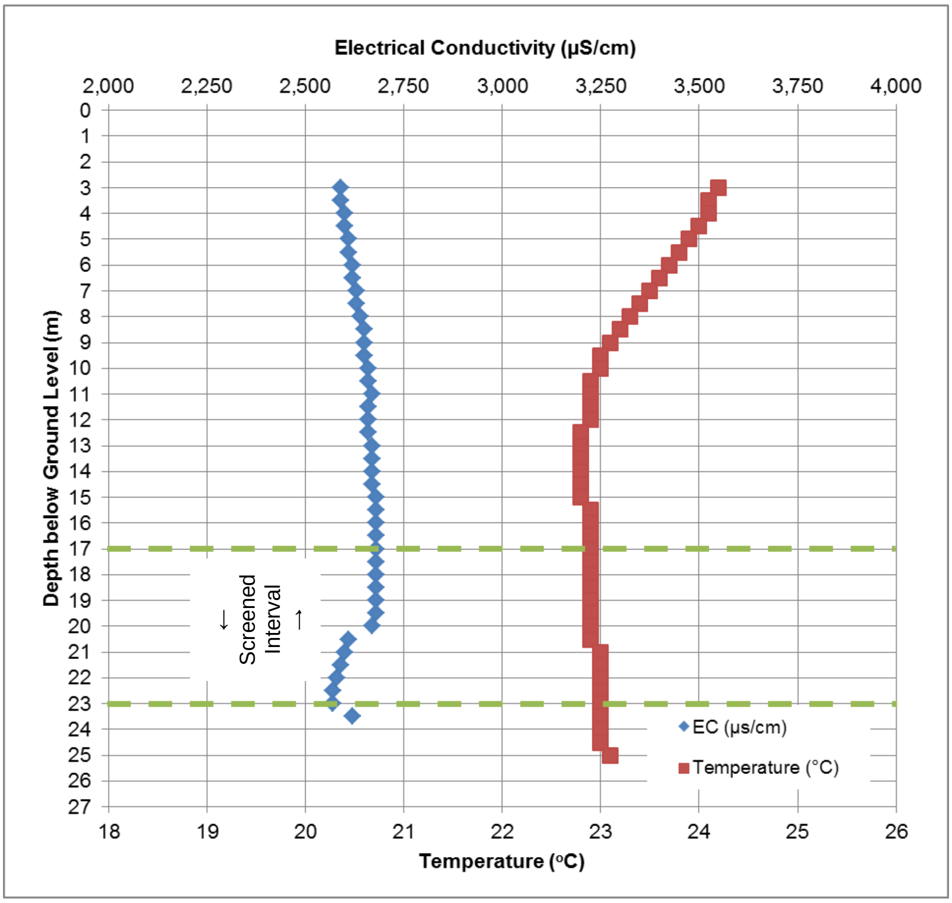


Figure 33 **Down-hole EC and Temperature Profile for GR-P6**

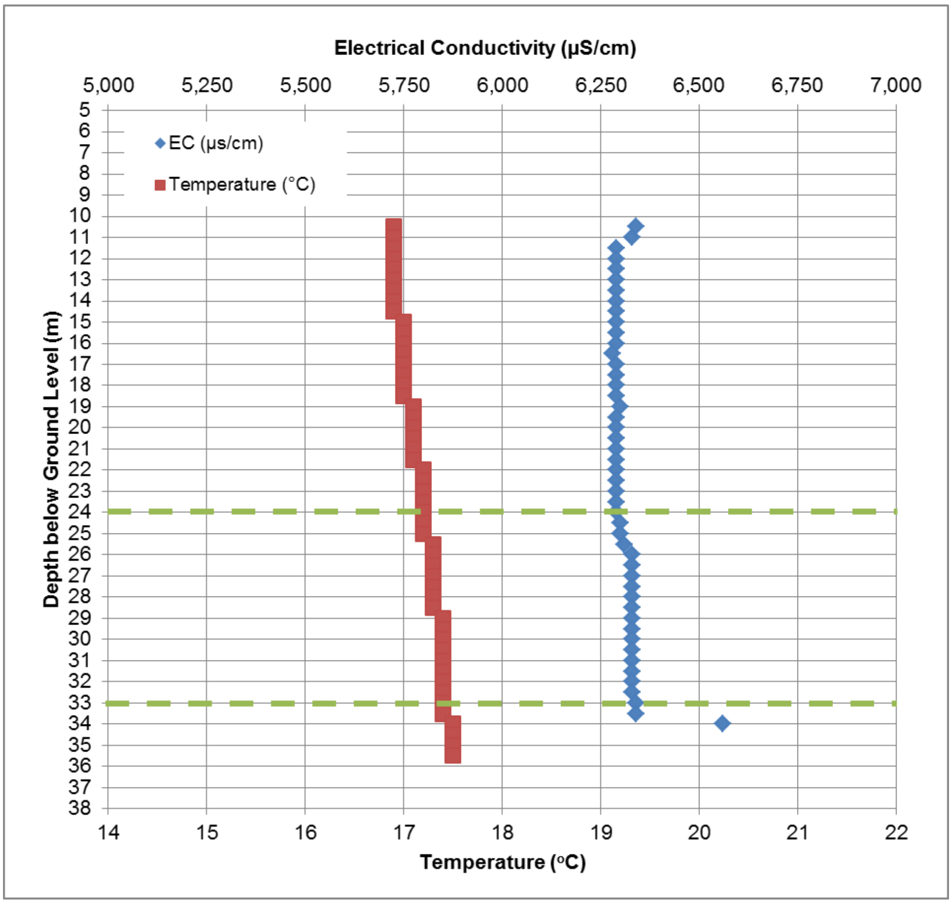


Figure 34 Down-hole EC and Temperature Profile for GR-P9

8. SURFACE WATER

The Quaternary alluvium is hydraulically connected to the surface water systems of Waukivory Creek and the Avon River adjacent to the Mine Area. The nearest streamflow gauge is located on the Avon River (GS208028) adjacent to the Mine Area, downstream of the Waukivory Creek confluence (**Figure 10**). This gauge has been operated by NOW since September 2004 and has a catchment area of 225km^2. The flow records at this gauge indicate that baseflow tends to persist over long periods (**Figure 35**). With the exception of prolonged dry periods, flows generally exceed 20ML/day. This is considered to be groundwater baseflow from the alluvium adjacent to the Avon River and its tributaries.

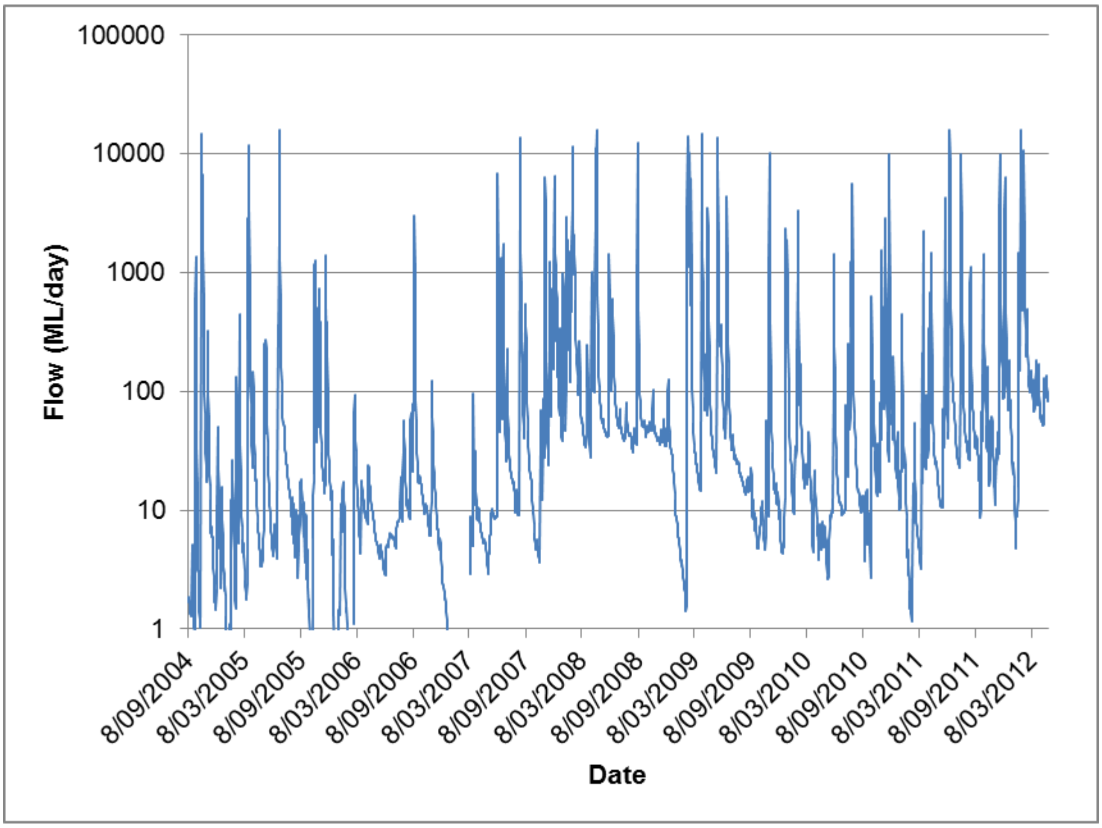


Figure 35 NOW Stream Gauging – Avon River D/S Waukivory Creek GS208028

Additional routine surface water level logging commenced in August 2011 at three locations on Waukivory Creek (Waukivory Upstream, Midstream and Downstream) (**Figure 10**). The purpose of these streamflow logging stations was to provide additional surface water data to characterise the hydrological regime of the region and to assess the baseflow contribution in Waukivory Creek. The streamflow sections were surveyed, and whilst these locations do not constitute stream flow gauging (ratings curves, etc.) they are useful in assessing the behaviour of stream flow in Waukivory Creek in response to rainfall events and under baseflow conditions. The streamflow levels in Waukivory Creek are shown in **Figure 36**. All three streamflow hydrographs show very similar trends, that is, sharp increases in response to rainfall and flood events with a corresponding recession and decrease in level during drier periods.

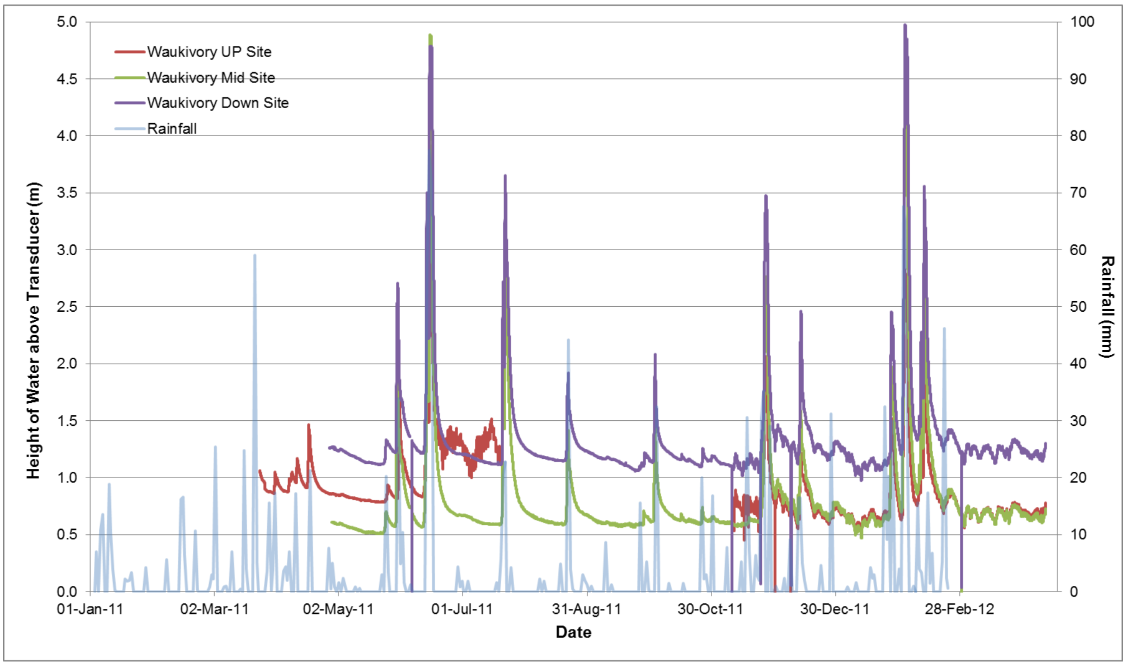


Figure 36 **Waukivory Creek Streamflow Monitoring**

9. MINE PLAN

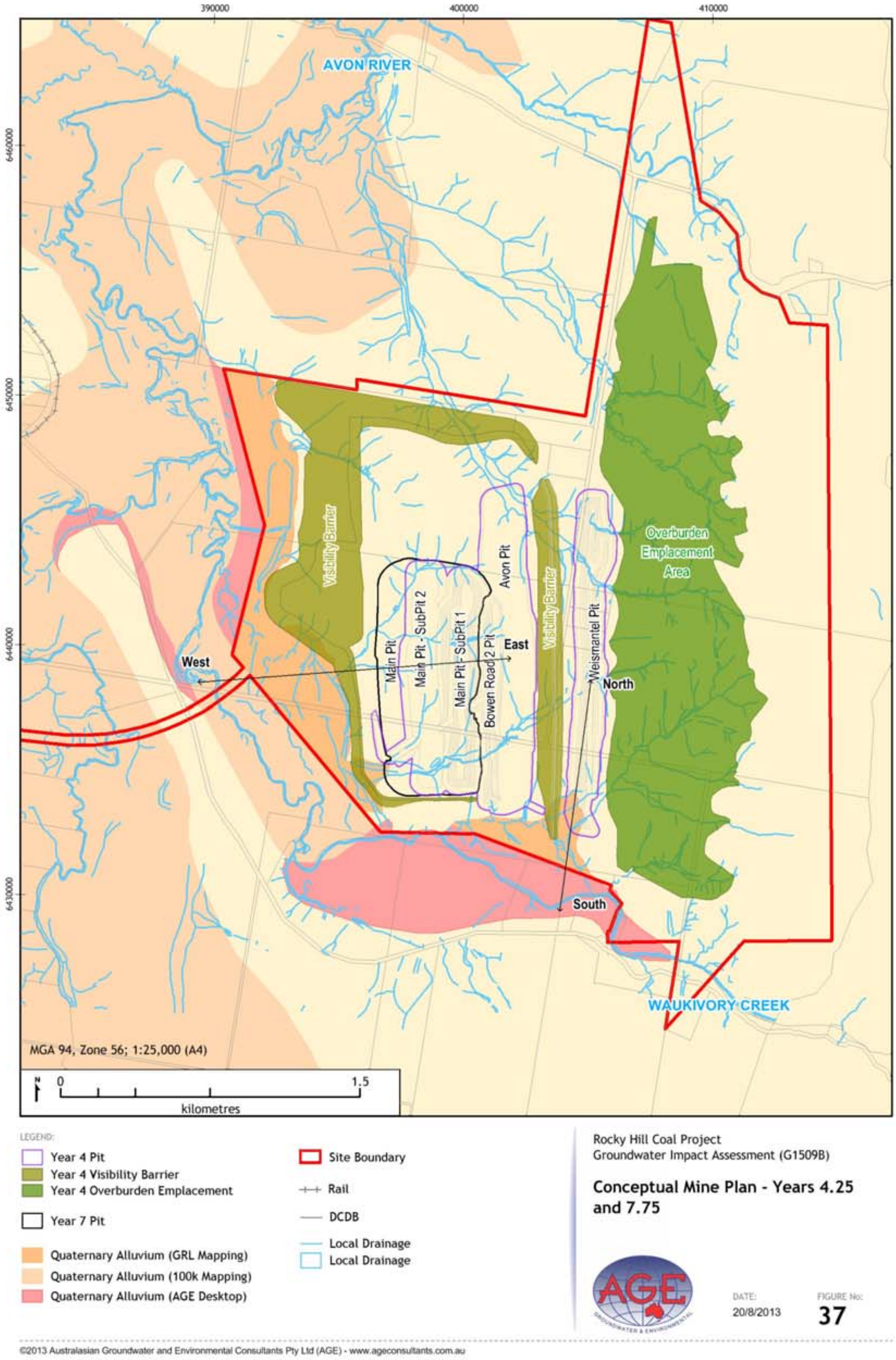
The proposed mining operations will consist of the development of four open cut pits; the Weismantel Pit, Avon Pit, Bowen Road 2 Pit and Main Pit. The Main Pit will initially involve the development of two smaller, shallower sub-pits (Main Pit Sub-pit 1 and Main Pit Sub-pit 2) to enable some high quality coal production during the initial years of mining. The proposed mining depths are in the order of 70m to 190m below the ground level with the ultimate depths of development dependent upon mine planning and the optimisation of coal quality.

Three generally north-south trending short term or long term visibility barriers are proposed as stand-alone structures on the western margins of the out-of-pit emplacement as it is progressively developed.

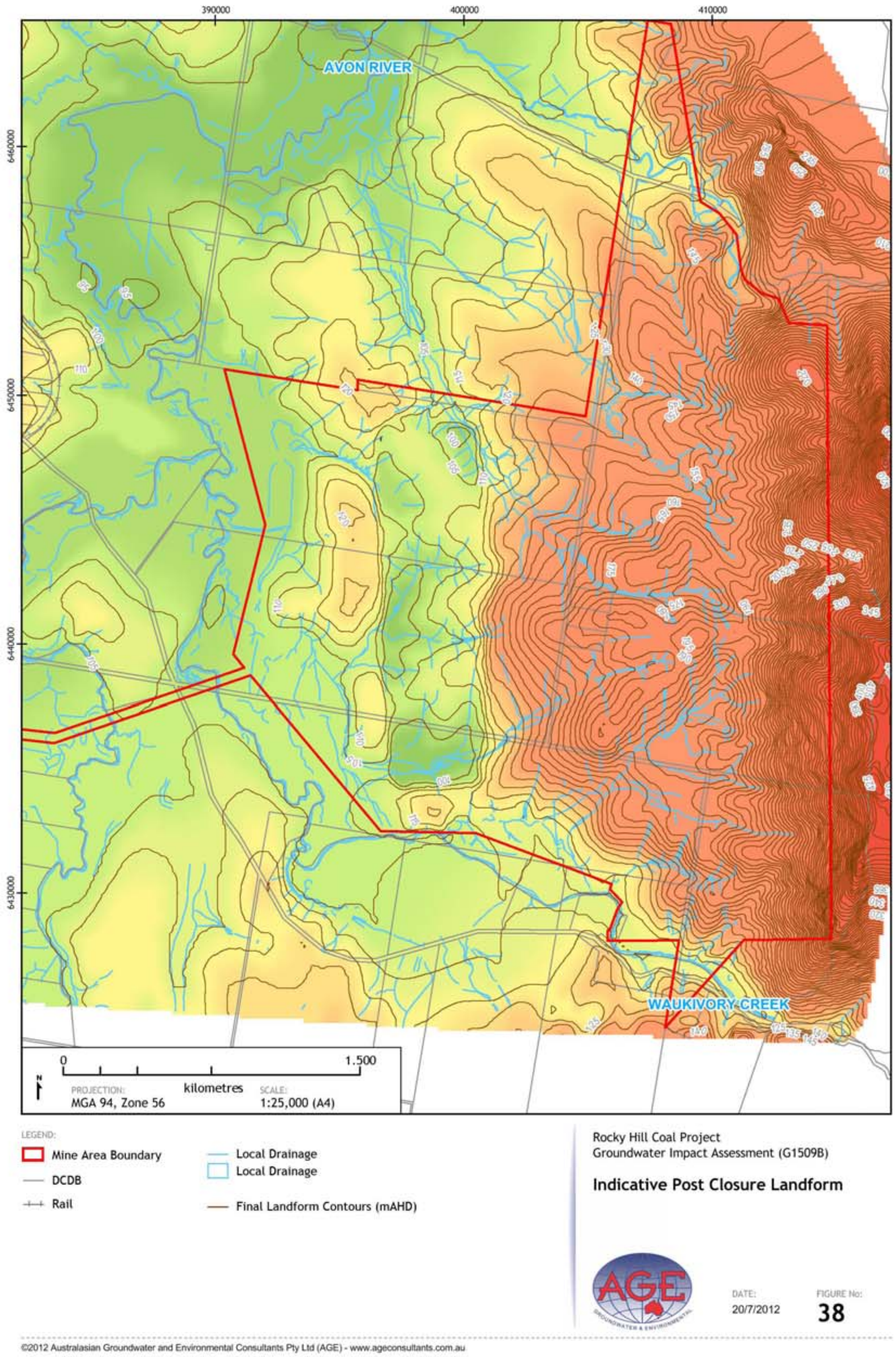
Mining is proposed to commence on the southern end of two of the four open cut pits during the first 12 months of mining and the third in the second year of mining, progressing along the strike of the coal seams. Beyond Year 7, mining will be confined to the Main Pit which will also be progressively mined from south to north. The conceptual mine plan for Years 4 and 7 is shown in **Figure 37**.

The post closure landform will not include a final void and has been designed so as blend the final landform with that of the surrounding topography, provide a low maintenance, stable and safe landform with minimal erosion and to re-instate the pre-disturbance land capability and agricultural suitability (**Figure 38**).

The Proposal also includes provision for the construction of a rail loop and load-out facility to be constructed on the western side of the North Coast railway line and to the east of The Bucketts Way. The rail loop would be approximately 2.5km long, and would require a program of cut and fill to achieve the required grade. Whilst this load-out facility is located outside the numerical model domain (Section 10.3) the impact of this facility is addressed in Section 11.3.



390000
400000
410000
6460000
6450000
6440000
6430000
AVON RIVER
WAUKIVORY CREEK
Visibility Barrier
Visibility Barrier
Overburden Emplacement Area
Avon Pit
Main Pit
Main Pit - SubPit 2
Main Pit - SubPit 1
Bowen Road 2 Pit
Weismantel Pit
West
East
North
South
MGA 94, Zone 56; 1:25,000 (A4)
0
1.5
kilometres
LEGEND:
Year 4 Pit
Year 4 Visibility Barrier
Year 4 Overburden Emplacement
Year 7 Pit
Quaternary Alluvium (GRL Mapping)
Quaternary Alluvium (100k Mapping)
Quaternary Alluvium (AGE Desktop)
Site Boundary
Rail
DCDB
Local Drainage
Local Drainage
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Conceptual Mine Plan - Years 4.25 and 7.75
DATE:
20/8/2013
FIGURE No:
37
©2013 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au


390000
400000
410000
6460000
6450000
6440000
6430000
AVON RIVER
WAUKIVORY CREEK
0
1,500
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:25,000 (A4)
LEGEND:
Mine Area Boundary
DCDB
Rail
Local Drainage
Local Drainage
Final Landform Contours (mAHD)
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Indicative Post Closure Landform
DATE:
20/7/2012
FIGURE No:
38
©2012 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

10. NUMERICAL GROUNDWATER MODEL

10.1 MODELLING OBJECTIVES

The key objective of the numerical modelling exercise was to predict impacts on the groundwater regime from the Proposal. The key issues associated with the proposed open cut mining that were assessed were:

- the requirement for a buffer zone between the alluvial aquifer and the open cut pits which will potentially reduce the mineable resource;
- the rate for groundwater seepage to the open cut pits from the coal seams, overburden units and alluvial sediments;
- dewatering and depressurisation of the coal seams and overburden in the open cut pits and the potential to impact on the alluvial groundwater systems; and
- the impact on farm bores used for irrigation, stock and domestic supplies.

The modelling also identified the 'worst case' drawdown influence in the region, at the end of mining and during recovery.

The Murray Darling Basin Commission (MDBC) groundwater modelling guidelines (2000) discuss model design in detail and summarise impact assessment type models as follows:

> *"the term Impact Assessment model ….reflects the fundamental purpose of the modelling study – to design groundwater management features and assess their impact as part of the project approvals process.*
>
> *More detailed assessments are possible with an Impact Assessment approach, which usually requires more data, better understanding, and greater resources for the study. With this approach, where understanding or data are lacking, it is possible to design the associated model aspects to be conservative with respect to their intended use (e.g. assuming an unknown aquifer parameter or stress is at the upper or lower limit of a realistic range)."*

The groundwater flow model was developed in accordance with the MDBC groundwater modelling guidelines (2000). The 2012 Australian Groundwater Modelling Guidelines (Barnett *et al.,* 2012) were released in June 2012, a number of weeks after completion of the model development, calibration and predictive analysis. Whilst construction of the model occurred without these new guidelines in place, a review indicates that the Rocky Hill Coal Project Groundwater Model conforms with these new guidelines. Based upon the model confidence level classification, AGE assesses that the model attains a Class 2 to Class 3 confidence level classification. Class 2 and 3 models are deemed suitable for assessing higher risk developments in higher-value groundwater systems.

10.2 CONCEPTUAL MODEL

Every numerical groundwater model has as its foundation, a conceptual model. The conceptual model is an understanding of how the groundwater system operates and is an idealised and simplified representation of the natural system but containing the essential and key elements of the flow system.

Extensive information on the natural system is typically required to develop an equivalent and simplified conceptual groundwater model representative of the system. Development of the conceptual groundwater model is a crucial step in groundwater modelling. Care has to be taken during the development of such models since errors in the conceptual model cannot be corrected during the model calibration, or at any later stage of the modelling study, without major revisions. Formulation of the conceptual model often highlights gaps in data or deficiencies in the understanding of the groundwater system.

Zheng and Bennett (1995) note that 'a conceptual model contains numerous qualitative and subjective interpretations. The appropriateness of the conceptual model cannot be tested until a numerical model is built and comparisons between field observations and model simulation results are made'.

The conceptual model forms the basis of the assumptions used when developing the more detailed numerical model. MDBC (2000) define a conceptual model as an "idealised summary of the current understanding of catchment conditions, and the key aspects of how the flow system works…subject to some simplifying assumptions."

The data indicate the Mine Area supports three distinct groundwater systems:

- Permian coal seams and interburden;
- shallow weathered bedrock (regolith) with associated colluvial deposits; and,
- shallow alluvium associated with the floodplains of Waukivory Creek and the Avon River.

Recharge to the groundwater system is from rainfall, lateral groundwater flow at the boundaries of the Study Area, and leakage from the major rivers and tributaries. Groundwater inflow to the alluvial groundwater system from the surrounding bedrock is considered to be low. During events of high water flows in the ephemeral creeks, water can discharge or leak into the alluvial groundwater system.

Although groundwater levels are sustained by recharge, they are controlled by surface topography, surface water levels and the hydraulic conductivity of the geological strata. Groundwater mounds tend to be present beneath the hill areas, with a hydraulic gradient towards the lower lying alluvial topography. Groundwater flows from these elevated areas with discharge to the Avon River and Waukivory Creek, and removal by evaporation and/or evapotranspiration through vegetation where the water table is within a few metres of ground surface (**Figure 39**).

The MDBC groundwater modelling guidelines (2000) discuss the concept or principle of simplicity or parsimony, viz:

> *"While the conceptual model is an idealised summary of the current understanding of catchment conditions, and the key aspects of how the flow system works, it is subject to some simplifying assumptions. The assumptions are required partly because a complete reconstruction of the field system is not feasible, and partly because there is rarely sufficient data to completely describe the system in comprehensive detail. However, the conceptual model should be developed using the principle of simplicity (or parsimony), such that the model is as simple as possible, while retaining sufficient complexity to adequately represent the physical elements of the system, and to reproduce system behaviour."*

This modelling approach has been adopted in the modelling methodology for the Proposal. An example of parsimony relates to faults and geological structure. Whilst it is recognised that there are geological faults and structures within the Gloucester Basin, it is not the intention to include any structures or faults within the numerical model. Aside from 1:100,000 scale surface mapping and the local geological model, there is limited information to suggest with any confidence the location, orientation, magnitude or hydraulic characteristics of any fault or structure.

While there is a common perception that fault zones are conduits for increased groundwater flow this is not necessarily the case. Faults can not only exhibit increased hydraulic conductivity but often show reduced hydraulic conductivity particularly in a synclinal region such as the Gloucester Basin. Where there is localised increased permeability along faults, the void space is usually discontinuous and therefore not a suitable conduit for the increased transmission of groundwater over significant distances. In isolated cases faults may act as partial barriers to groundwater flow. It is our understanding that in the current region where mining has occurred, there has been no reported incidence of increased groundwater inflow or influence on potentiometric levels associated with mapped fault zones. The main sources of groundwater flow are from Quaternary alluvial sediments and Permian coal seams. Contact made with Mr John Ross (Senior Hydrogeologist at AGL) has indicated that although AGL is to further investigate the hydraulic nature of the Thrust Fault referred to by NOW (NOW letter 30 July 2012 to R Corkery Ref:ER21816), he is of the opinion that because it occurs in a synclinal structure it is very likely a closed structure. When contacted by our reviewer Dr Kalf on the 6 August 2012, Mr Ross stated that a bore was drilled through the fault zone for piezometer placement and no appreciable flow was encountered.

To account for any uncertainty relating to geological complexity (derived from faulting), the modelling methodology includes sensitivity and uncertainty analysis (see Sections 10.4.2 and 11.8) and discusses these in relation to model calibration and predicted inflows.

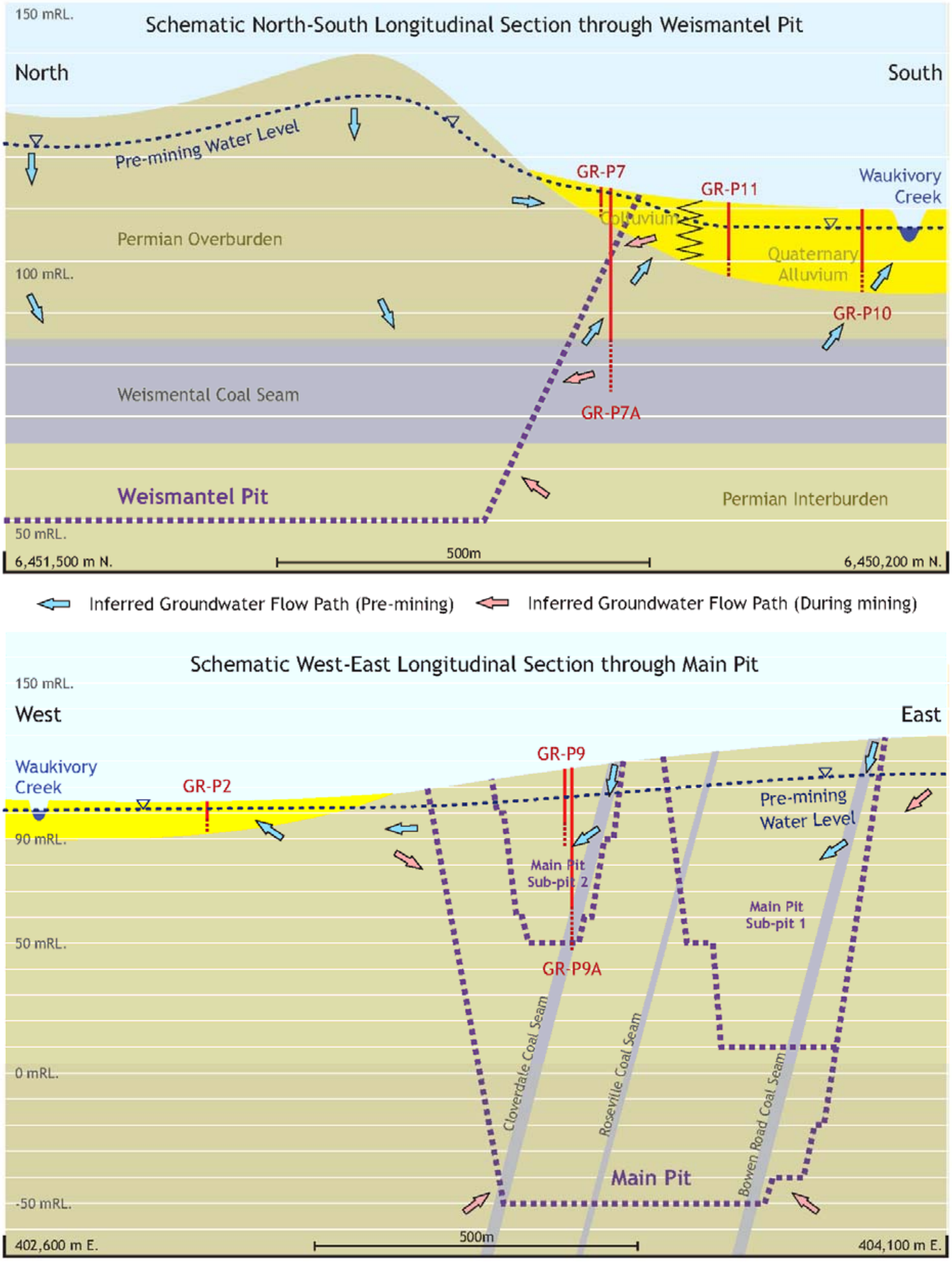
The conceptual model is illustrated in **Figure 39**. It should be noted this figure displays the key concepts in the hydrogeological regime but does not represent localised detail in the geological surfaces.

10.3 MODEL DEVELOPMENT

10.3.1 Model Code

The Rocky Hill groundwater flow model was constructed in MODHMS (HGL, 2001). MODHMS is a physically based, spatially distributed, finite difference, integrated surface water and groundwater model. It comprises a 3-D MODFLOW compatible groundwater simulator and includes additional modules to simulate 2-D overland flow, 1-D channel flow and solute transport. The main features of MODHMS are as follows:

- it contains all the features of MODFLOW-SURFACT, a robust simulator for sub-surface flow and transport under unsaturated and saturated conditions;
- for simulating systems with strong groundwater and surface water interactions, MODHMS solves the surface and sub-surface equations in a fully implicit manner which preserves mass balance independent of time step size;



Conceptual Model

Figure 39

ROCKY HILL COAL PROJECT (G1509B)

- MODHMS can simulate structures (dams, weirs, culverts, and gates) with dynamic operational rules. Overland flow is simulated using the diffusive wave approximation and special provisions are available for flow between the overland flow plane and channels that depend on channel bank geometry;
- it can simulate flow and transport simultaneously for an integrated surface and subsurface hydrologic system; and
- owing to its adherence to MODFLOW file standards, MODHMS is compatible with all graphical user interfaces developed for MODFLOW.

10.3.2 Model Geometry and Boundary Conditions

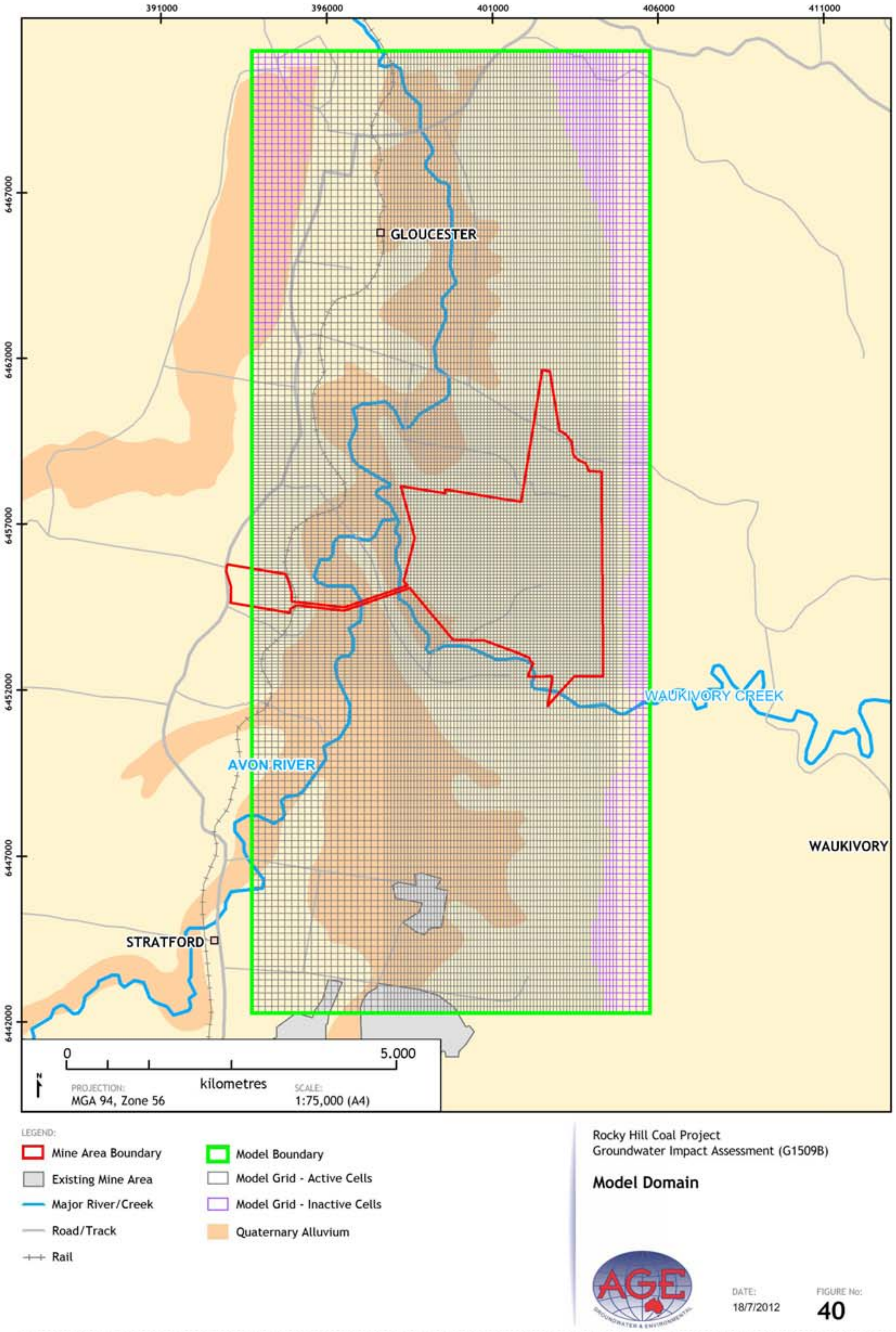
The selection of the regional model boundaries was based on the following considerations:

- Eastern Boundary - The geological contact between the Permian and Carboniferous lithologies was an appropriate eastern boundary to the active model domain as it forms a boundary between the Permian units and the outcropping crystalline basement of the New England Fold Belt, which would be expected to have a poor ability to transmit water.
- Northern Boundary - This boundary was defined as the northern extent of the Permian sediments. The northern extent of the Gloucester Basin occurs where the syncline feature shallows to the north. The northern boundary is located some 7km from the northern boundary of the GRL Mine Area.
- Western Boundary - The western boundary was set within the centre of the Gloucester Basin. Little geological and hydrogeological data exists beyond the proposed western model boundary and the extrapolation of data beyond this would be required. Within the centre of the basin, the coal seams reach depths of greater than 1000mbGL. At this depth, the hydraulic conductivity of the coal seams will have decreased substantially, thus forming a relatively natural no flow boundary.
- Southern Boundary - The limit to the southern boundary was set to coincide with the location of the Stratford Coal Mine and an area of Quaternary Alluvium. The southern boundary is located some 6km from the southern boundary of the GRL Mine Area.

The model boundaries also approximately correlate with the Avon River catchment boundaries. This model extent allows for the inclusion of the alluvial aquifer and the surface water flow regime. Using these boundaries, the model grid was 6km wide (E-W) and 14.5km long (N-S).

10.3.3 Grid and Cell Size

Figure 40 shows the model grid. The initial model domain for the steady state and transient calibration was discretised into 10 layers with 178,600 rectilinear cells comprising 188 rows and 95 columns. The dimensions of the model cell size vary from 50m by 50m within the Mine Area, up to 100m by 100m outside the Mine Area boundary.


391000
396000
401000
406000
411000
6467000
6462000
6457000
6452000
6447000
6442000
GLOUCESTER
WAUKIVORY CREEK
AVON RIVER
WAUKIVORY
STRATFORD
0
5,000
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:75,000 (A4)
LEGEND:
Mine Area Boundary
Existing Mine Area
Major River/Creek
Road/Track
Rail
Model Boundary
Model Grid - Active Cells
Model Grid - Inactive Cells
Quaternary Alluvium
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Model Domain
DATE:
18/7/2012
FIGURE No:
40

The north-west corner of the grid is located at 400,500mE and 6,459,500mN (MGA94, Z56), with the grid oriented directly north-south to align the principal axis direction with the regional observed groundwater flow directions.

The same grid was also used for the 2D overland flow model domain. The major rivers and tributaries within the model domain were discretised as 1D channel flow segments as shown in **Figure 41**.

10.3.4 Layers

The ten layers in the model (**Table 12**) represent the geological strata as follows:

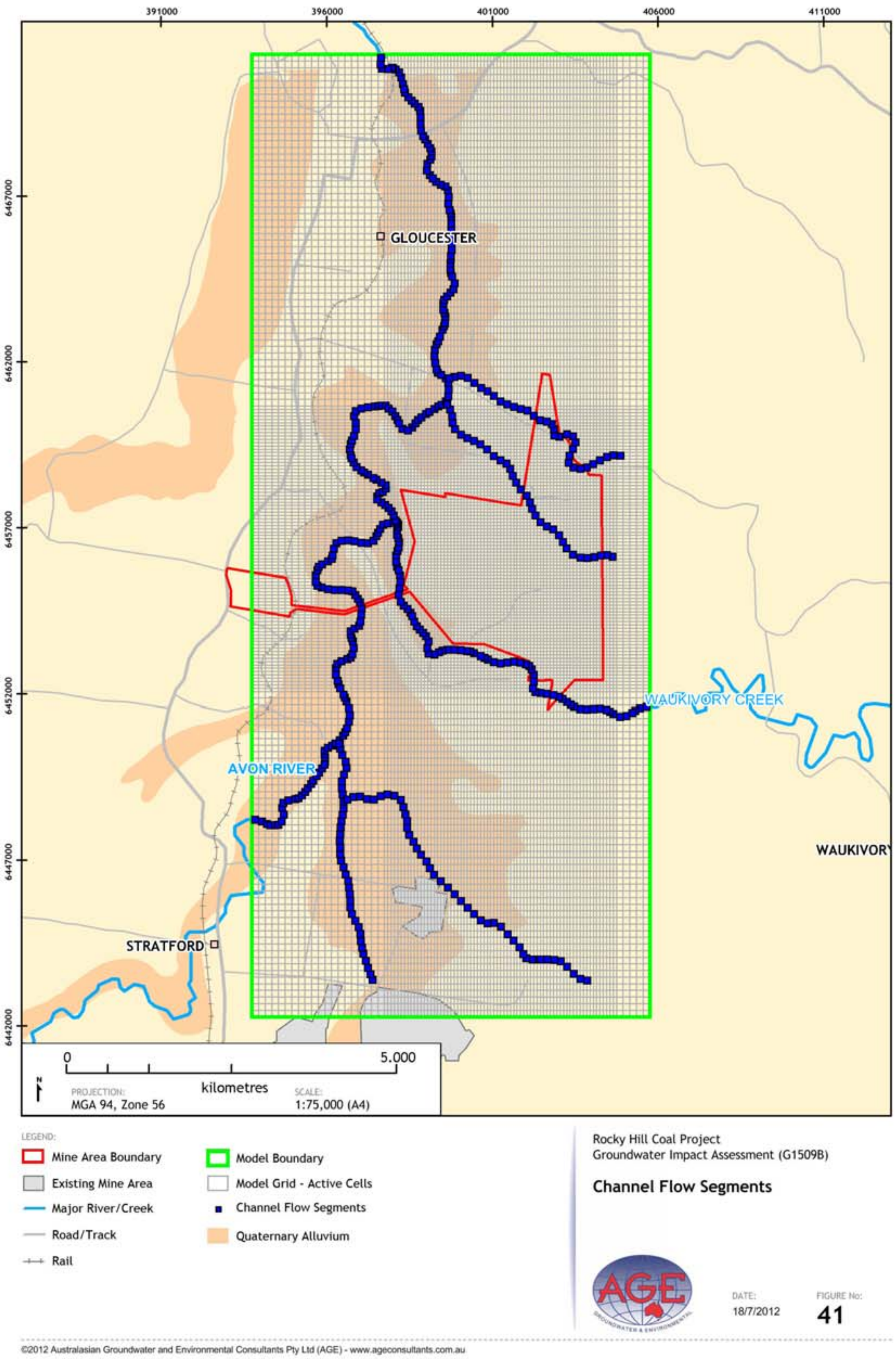
- Quaternary Alluvium in the alluvial parts of Layer 1;
- Colluvium / Weathered Permian (Regolith) in Layer 1 where there is no alluvium;
- Permian interburden and minor coal seams in Layers 2, 4, 6 and 8;
- Major coal seams and minor interburden in Layers 3, 5, 7, and 9; and the
- Alum Mountain Volcanics form the base of the model (Layer 10).

Table 12
Summary of Model Layers

Layer	Description	Layer Type
1	Alluvial Sediments / Colluvium / Weathered Material	43
2	Overburden above Cloverdale Coal Seam	43
3	Cloverdale Coal Seam to top of Roseville Coal Seam	43
4	Interburden	43
5	Bowen Road Coal Seam	43
6	Interburden	43
7	Avon Coal Seam	43
8	Interburden	43
9	Parkers Road and Weismantel Coal Seams	43
10	Alum Mountain Volcanics (Basement)	43

Layer type 43 represents a model layer which may switch between confined and unconfined conditions with varying transmissivity plus saturated / unsaturated properties.

Publicly available digital elevation data (SRTM) with 90m x 90m grid spacing (1 second) was used to represent the ground surface (top of Layer 1) in the model. Within the Mine Area boundary, this data was replaced with more detailed topographic mapping data collected for the Proposal.


391000
396000
401000
406000
411000
6467000
6462000
6457000
6452000
6447000
6442000
GLOUCESTER
WAUKIVORY CREEK
AVON RIVER
WAUKIVORY
STRATFORD
0
5.000
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:75,000 (A4)
LEGEND:
Mine Area Boundary
Existing Mine Area
Major River/Creek
Road/Track
Rail
Model Boundary
Model Grid - Active Cells
Channel Flow Segments
Quaternary Alluvium
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Channel Flow Segments
DATE:
18/7/2012
FIGURE No:
41
©2012 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

The following boundary conditions were applied to the model:

- the majority of the model boundaries were set as no-flow boundaries for all layers;
- limited cells in Layer 1 were set as constant head boundaries to represent inflow (upstream) and outflow (downstream) from the Quaternary Alluvium;
- recharge and evapotranspiration (ET) to/from the model domain were used for the steady-state model;
- ephemeral creeks were represented as drains in the steady-state model;
- rainfall was applied to the overland surface for the integrated transient model rather than using the standard application of recharge. ET was applied on the overland surface and from model Layer 1 in the integrated transient model;
- surface runoff from upper catchment areas were estimated based on catchment size and runoff coefficients and applied to the starting segments of the river and tributaries; and
- critical depth boundary conditions were applied to the outlets of channel flow and overland flow.

10.3.5 Hydraulic Parameters

The hydraulic conductivity of the key geologic units was measured in the GRL Mine Area by PB (2011). The field measured values are presented in **Table 13**.

Table 13
Hydraulic Properties of GRL Monitoring Bores

Bore ID	Elevation (mAHD)	Total Depth (mbGL)	Screen Interval (mbGL)	SWL (mbGL)	SWL (mAHD)	Hydraulic Conductivity (m/day)	Screened Lithology
GR-P1	104.37	10.2	5.5-8.5	4.40	100.55	50-150	Quaternary Alluvium
GR-P2	101.86	10	4-9	2.24	100.39	50-150	Quaternary Alluvium
GR-P3	99.57	11.2	5-9	2.95	97.32	50-150	Quaternary Alluvium
GR-P4	118.37	37	32.5-35.5	6.68	112.32	0.2	Interburden
GR-P5	126.39	30	24-30	14.44	112.64	0.05	Interburden
GR-P6	145.30	24	17-23	3.81	142.22	0.04	Interburden
GR-P6A	145.33	97	89-95	10.43	135.58	0.06	Weismantel Seam
GR-P7	115.69	7.6	4-7	2.47	113.83	0.08	Alluvium / Colluvium
GR-P7A	115.52	72	59-71	1.41	114.72	0.002	Avon Seam
GR-P8	133.50	42	29-41	8.66	125.48	0.015	Interburden
GR-P8A	133.36	72	62-70	6.73	127.31	0.01	Avon Seam
GR-P9	117.19	34	24-33	10.44	107.42	0.2	Interburden
GR-P9A	116.97	66	59-65	9.71	107.98	0.15	Cloverdale Seam

The hydraulic conductivity testing for the neighbouring AGL groundwater monitoring bores were also available to use in the numerical model development (PB, 2012a). The field measured values are presented in **Table 14**.

Table 14
Hydraulic Properties of AGL Monitoring Bores

Bore ID	Elevation (mAHD)	Total Depth (mbGL)	Screen Interval (mbGL)	SWL (mbTOC)	SWL (mAHD)	Hydraulic Conductivity (m/day)	Screened Lithology
S4MB01	118.38	66	58 – 64	6.28	112.91	4×10^{-5}	Leloma Formation
S4MB02	118.44	97	89 – 95	5.51	113.58	5×10^{-3}	Leloma Formation
S4MB03	118.37	170	162 – 168	4.27	114.73	0.01	Jilleon Formation - Cloverdale Coal Seam
S5MB01	129.98	60	52 – 58	39.61	90.9	2×10^{-6}	Jilleon Formation
S5MB02	129.87	114	100 – 112	17.91	112.49	7.9×10^{-4}	Jilleon Formation
S5MB03	129.79	166	158 – 164	17.74	112.58	0.01	Jilleon Formation - Roseville Coal Seam
TCMB02	123.16	183	175 – 181	9.85	114.01	1.1×10^{-4}	Leloma Formation
TCMB03	123.18	268	260 – 266	11.43	112.38	1.6×10^{-3}	Jilleon Formation - Cloverdale Coal Seam
TCMB04	123.31	335	327 – 333	12.66	111.84	2.3×10^{-3}	Jilleon Formation - Roseville Coal Seam
BMB01	108.95	30	15 – 29	5.7	103.78	0.12	Leloma Formation
BMB02	108.83	138	124 – 136	5.63	103.74	1.5×10^{-3}	Leloma Formation
TMB01	106.82	12	7 – 10	4.05	103.55	0.32	Avon River Alluvium
TMB02	106.81	15.5	9 – 12	4.43	103.07	50 – 100	Avon River Alluvium
TMB03	106.48	12.5	5 – 11	3.06	104.04	20 – 50	Avon River Alluvium
AMB01	111.48	12.6	8 – 10	4.64	103.93	100 – 500	Avon River Alluvium
AMB02	107.88	11.5	6.5 – 11	6.03	106.14	50 – 100	Avon River Alluvium
WMB01	111.06	8.5	5 – 8	4.11	107.81	50 - 150	Alluvium
WMB02	106.13	23	15 – 21	4.91	101.95	0.9	Wenhams Formation
WMB03	106.39	36	32 – 34	5.15	101.93	0.03	Wenhams Formation - Bowens Road Coal
WMB04	106.12	80.5	67 – 79	4.82	101.98	2 – 20	Wenhams Formation
RMB01	128.68	51	42 – 48	4.34	125.04	0.01	Leloma Formation (upper)
RMB02	128.49	93	85 - 91	3.89	125.34	0.01	Leloma Formation (upper)

Following the principle of parsimony, model parameterization was kept as simple as possible while accounting for the system processes and characteristics that are evident in observations and important to predictions. In this study, hydraulic conductivity (K) and storativity (S) values were assigned as homogeneous values within the hydrogeologic units.

Six uniform zones of horizontal and vertical hydraulic conductivity (Kx and Kz) were assigned to the model layers. An additional eight storativity parameters (storage coefficient (Sc) and specific yield (Sy)), were assigned to the transient model. The model parameterisation is summarised in **Table 15**.

Table 15
Parameterisation of the Model Domain

Model Layer	Representative Formation	Kh	Kz	Sc	Sy
1	Alluvium / Colluvium	Kh1	Kz1	Sc1	Sy1
	Regolith	Kh2	Kz2	Sc1	Sy1
2	Overburden above Cloverdale Coal Seam	Kh3	Kz3	Sc3	Sy3
3	Cloverdale Coal Seam and minor interburden	Kseam*	Kseam**	Sc4	Sy4
4	Roseville Coal Seam and interburden	Kh5	Kz5	Sc3	Sy3
5	Bowen Road Coal Seam and minor interburden	Kseam*	Kseam**	Sc4	Sy4
6	Minor Coal Seams and interburden	Kh5	Kz5	Sc3	Sy3
7	Avon Coal Seam and minor interburden	Kseam*	Kseam**	Sc4	Sy4
8	Minor Coal Seams and interburden	Kh5	Kz5	Sc3	Sy3
9	Parkers Road & Weismantel Coal Seams & minor interburden	Kseam*	Kseam**	Sc4	Sy4
10	Duralie Road Formation and Alum Mountain Volcanics	Kh6	Kz6	Sc5	Sy5

Note: Kseam* and Kseam** are horizontal and vertical K parameters varying with depth.

The hydraulic conductivity zones in Layer 1 are shown in **Figure 42**. The anisotropic factor of Kh to Kz is assumed to be 10, except for the parameter Kseam.

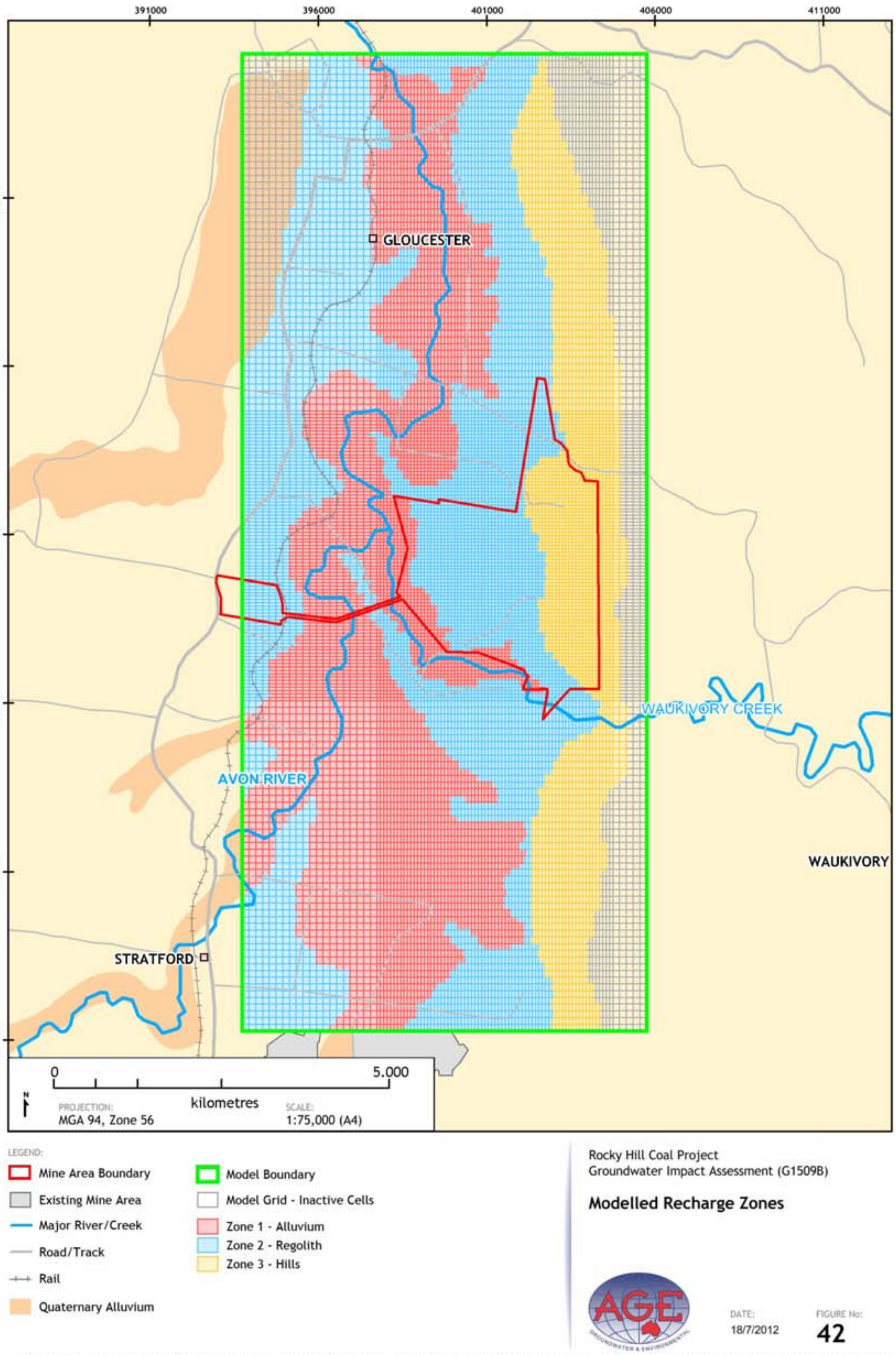
PB (2012a) and SRK (2010) have reported a reduction in coal seam hydraulic conductivity in the Gloucester Basin with depth below ground level. According to Mackie (2009), the horizontal hydraulic conductivity of coal seams in the Hunter Valley generally declines by an order of magnitude per 180m depth of cover. For deeper coal seams, the coal seam hydraulic conductivity can decline by an order of magnitude per 55m. In order to represent the declining hydraulic conductivity of the coal seam (Kseam* and Kseam**), three parameters were formulated to support the conceptualisation (i.e. initial K value (K_0) at the surface, depth of cover, cut off depth where K values start declining and the anisotropic factor between Kh and Kz). These parameters along with other Kh and Kz were determined in the steady-state calibration process whilst parameters of Sc and Sy were determined through the transient calibration process.

10.3.6 Recharge and Discharge

Recharge zones and rates were based on previous modelling studies by AGE (2000), and Heritage Computing, (2009). These previous recharge zonations and values were derived from calibrated numerical models and provided an ideal dataset on which to base recharge for the Rocky Hill model. The previous models considered both alluvial sediments and Permian strata within the Gloucester Basin which is considered applicable to this assessment. The recharge zones in the steady state model are shown in **Figure 42** and are as follows:

- Zone 1 - Quaternary Alluvium - 1% of annual rainfall
- Zone 2 - Weathered Permian regolith - 0.1% of annual rainfall
- Zone 3 - Hills or Slope wash zone - 5% of annual rainfall

The recharge was applied to the uppermost layer in the model that represented the topographic surface.


391000
396000
401000
406000
411000
6467000
6462000
6457000
6452000
6447000
6442000
GLOUCESTER
WAUKIVORY CREEK
AVON RIVER
WAUKIVORY
STRATFORD
0
5,000
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:75,000 (A4)
LEGEND:
Mine Area Boundary
Existing Mine Area
Major River/Creek
Road/Track
Rail
Quaternary Alluvium
Model Boundary
Model Grid - Inactive Cells
Zone 1 - Alluvium
Zone 2 - Regolith
Zone 3 - Hills
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Modelled Recharge Zones
DATE:
18/7/2012
FIGURE No:
42

For transient calibration and predictive models, the coupled surface/subsurface capability of MODHMS was used. Rainfall, rather than recharge, was applied to the models. Daily rainfall was used for the transient calibration model; while mean quarterly rainfall was used for the predictive simulation to represent normal weather conditions and maintain wet/dry cycles within a year.

Discharge from the steady state model was via drain cells assigned along drainage features and the major ephemeral creeks. The bed elevations of the drain cells were set to 4m below the topographic surface elevation.

The Avon River, Waukivory Creek and other major creeks and tributaries within the model domain were simulated in the transient model using the channel flow package in MODHMS, rather than using the drain package as was carried out in the steady state model. Dynamic interactions of surface water-groundwater and stream-overland flow can be simulated more appropriately through this approach.

For the steady state model, evapotranspiration (ET) was applied to the entire model domain at the mean annual rate of 1059mm/year with an extinction depth of 2m below ground surface using the evapotranspiration package.

For the transient models, ET was simulated through a comprehensive ET package (IPT) in MODHMS to simulate the process occurring in overland surface and subsurface.

Extraction of water from irrigation bores in the alluvium was not included in the model as the volume of abstraction is low, and not considered a significant component of the regional water balance. According to the water sharing plan for the area (*Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources*), there is only one licenced groundwater facility in the Avon River management area with an annual entitlement of 20ML/yr (55m^3/day or 0.6L/s) from the alluvium.

Excluding groundwater and surface water abstraction means it becomes accounted for in the balance of inputs and outputs adopted during the steady state model calibration.

10.4 MODEL CALIBRATION

Anderson and Woessner (1992) note that 'calibration of a groundwater flow model refers to a demonstration that the model is capable of producing field measured heads and flows which are the calibration values. Calibration is accomplished by finding a set of parameters, boundary conditions and stresses that produce simulated heads and fluxes that match field measured values within an acceptable range of error'. The calibration of the model is described below.

10.4.1 Steady State Calibration

The objective of the steady state modelling was to simulate pre-mining conditions. A total of 39 bores with water level records were used to calibrate the model in steady state conditions. Groundwater levels were collated for monitoring bores within the GRL Mine Area boundary, AGL monitoring bores and public domain data for the SCM. A groundwater level was adopted from these monitoring sites as the steady state calibration target.

The prime objective of steady state model calibration was to reproduce groundwater levels at the individual monitoring bores and hence the general pattern of the groundwater contours and the direction of the groundwater flow.

Comparison of observed groundwater levels against model simulated groundwater levels are presented in **Table 16** and as scattergram in **Figure 43**. Ideally in the scattergram of observed versus simulated groundwater levels the data points should fall along a straight line with a slope of 1. In the case of the calibration data for the Rocky Hill Coal Mine, the R^2 of the data is 0.95 which represents an excellent comparison. The simulated steady state water levels in Layer 1 are presented in **Figure 44**.

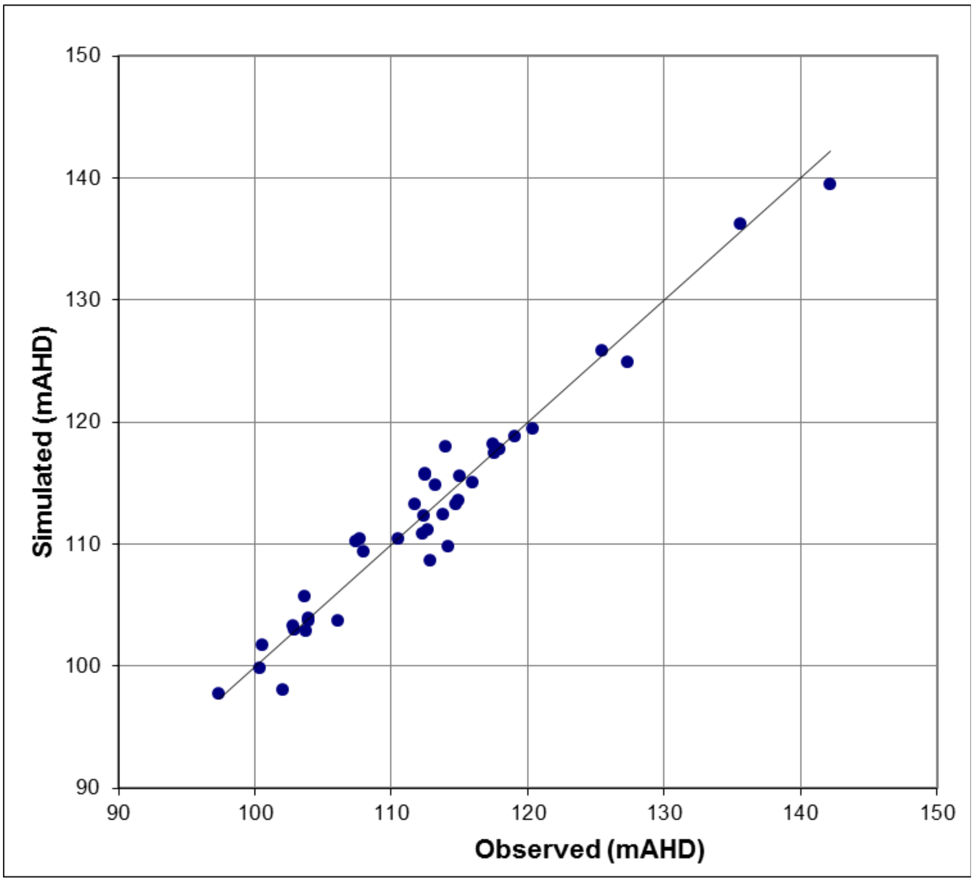


Figure 43 **Observed vs Simulated Groundwater Levels – Steady State Model**

Table 16 shows the residual error for each groundwater monitoring location used in the model calibration. This residual is a measure of the difference between the observed or measured groundwater level and the model simulated or predicted groundwater level in the steady state model and represent the "match" of the model to replicate the natural system.

The calibrated model provides a good match between the observed and simulated heads. The average residual between the observed and simulated groundwater levels is 0.11m. The GRL, AGL and SCM observation bore subsets produced 0.36m, 0.23m and -0.41m as average absolute residuals respectively from the calibration. These statistics indicate that the greatest residuals in the steady state calibration are associated with the area furthest to the south, and are likely to be influenced by the mining at SCM, which have been operational since 1995 to the present day.

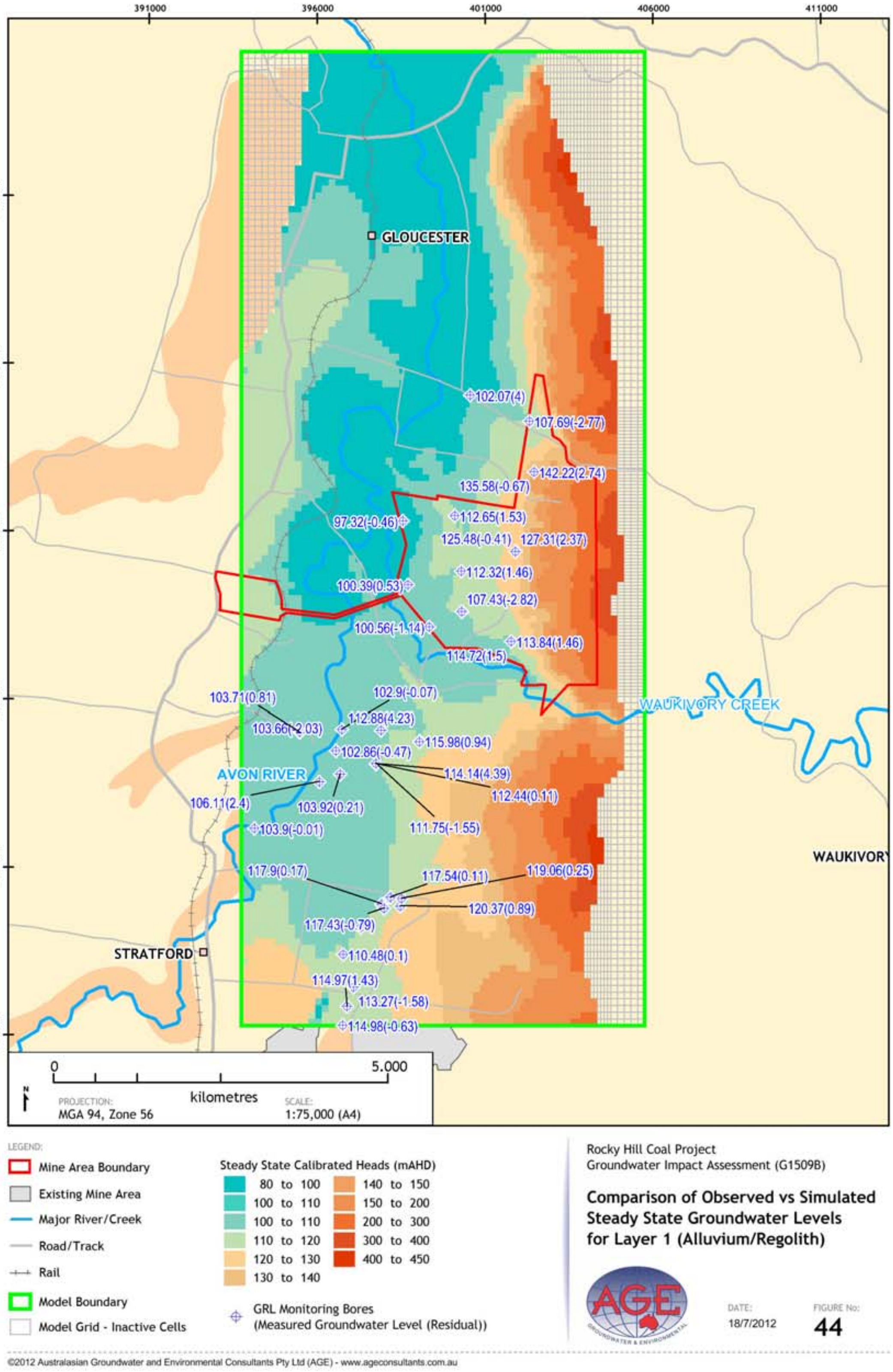

391000
396000
401000
406000
411000
6467000
6462000
6457000
6452000
6447000
6442000
GLOUCESTER
STRATFORD
AVON RIVER
WAUKIVORY CREEK
WAUKIVORY
102.07(4)
107.69(-2.77)
142.22(2.74)
135.58(-0.67)
112.65(1.53)
97.32(-0.46)
125.48(-0.41)
127.31(2.37)
112.32(1.46)
100.39(0.53)
107.43(-2.82)
100.56(-1.14)
113.84(1.46)
114.72(1.5)
103.71(0.81)
102.9(-0.07)
103.66(-2.03)
112.88(4.23)
115.98(0.94)
102.86(-0.47)
114.14(4.39)
112.44(0.11)
106.11(2.4)
103.92(0.21)
111.75(-1.55)
103.9(-0.01)
117.9(0.17)
117.54(0.11)
119.06(0.25)
120.37(0.89)
117.43(-0.79)
110.48(0.1)
114.97(1.43)
113.27(-1.58)
114.98(-0.63)
0
5.000
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:75,000 (A4)
LEGEND:
Mine Area Boundary
Existing Mine Area
Major River/Creek
Road/Track
Rail
Model Boundary
Model Grid - Inactive Cells
Steady State Calibrated Heads (mAHD)
80 to 100
100 to 110
100 to 110
110 to 120
120 to 130
130 to 140
140 to 150
150 to 200
200 to 300
300 to 400
400 to 450
GRL Monitoring Bores
(Measured Groundwater Level (Residual))
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Comparison of Observed vs Simulated
Steady State Groundwater Levels
for Layer 1 (Alluvium/Regolith)
DATE:
18/7/2012
FIGURE No:
44
©2012 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

Table 16
Calibration Targets and Simulated Water Levels – Steady State Model

BORE_ID	Easting (m)	Northing (m)	Observed Water Level (mAHD)	Simulated Water Level (mAHD)	Residual (m)	Monitoring Bore Location
GR-P1	403295	6450941	100.56	101.69	-1.14	GRL
GR-P2	402981	6451564	100.39	99.86	0.53	GRL
GR-P3	402906	6452518	97.32	97.78	-0.46	GRL
GR-P4	403776	6451772	112.32	110.86	1.46	GRL
GR-P5	403679	6452595	112.65	111.12	1.53	GRL
GR-P6	404856	6453250	142.22	139.48	2.74	GRL
GR-P6A	404860	6453248	135.58	136.25	-0.67	GRL
GR-P7	404525	6450723	113.84	112.38	1.46	GRL
GR-P7A	404519	6450722	114.72	113.22	1.50	GRL
GR-P8	404583	6452066	125.48	125.89	-0.41	GRL
GR-P8A	404582	6452062	127.31	124.93	2.37	GRL
GR-P9	403785	6451167	107.43	110.25	-2.82	GRL
GR-P9A	403780	6451167	107.98	109.37	-1.39	GRL
RB1	402008	6445014	114.98	115.61	-0.63	SCM
RB2	402075	6445297	114.97	113.54	1.43	SCM
RB3	402166	6445581	113.27	114.85	-1.58	SCM
RB4	402016	6446069	110.48	110.38	0.10	SCM
R8097	402274	6446469	113.99	118.02	-4.03	SCM
R8098	402623	6446758	117.43	118.22	-0.79	SCM
R8099	402588	6446821	117.90	117.73	0.17	SCM
R8101	402866	6446786	120.37	119.48	0.89	SCM
C8102	402888	6446898	119.06	118.81	0.25	SCM
R8103	402722	6446918	117.54	117.43	0.11	SCM
S4MB01	402582	6449410	112.88	108.65	4.23	AGL
S5MB01	403156	6449250	115.98	115.04	0.94	AGL
S5MB02	403153	6449245	112.45	115.68	-3.23	AGL
S5MB03	403151	6449240	112.53	115.80	-3.27	AGL
TCMB02	402502	6448904	114.14	109.75	4.39	AGL
TCMB03	402503	6448910	112.44	112.33	0.11	AGL
TCMB04	402504	6448915	111.75	113.30	-1.55	AGL
TMB01	401997	6449420	102.90	102.97	-0.07	AGL
TMB02	401905	6449101	102.86	103.33	-0.47	AGL
TMB03	401970	6448755	103.92	103.72	0.21	AGL
AMB01	400694	6447946	103.90	103.91	-0.01	AGL
AMB02	401659	6448640	106.11	103.71	2.40	AGL
BMB01	401366	6449379	103.71	102.90	0.81	AGL
BMB02	401368	6449384	103.66	105.69	-2.03	AGL
WMB01	404791	6454007	107.69	110.46	-2.77	AGL
WMB02	403908	6454391	102.07	98.07	4.00	AGL

Note: Coordinates are in GDA94, Zone 56

An objective method to evaluate the calibration of the model is to examine the statistical parameters associated with the calibration. One such method is by measurement of the root mean square (RMS) between the modelled and observed (measured) water levels. The RMS is expressed as follows:

$$RMS = \left[1/n \sum (h_o - h_m)_i^2 \right]^{0.5}$$

where: n = number of measurements
h_o = observed water level
h_m = simulated water level

The RMS calculated for the calibrated model was 1.98m. The maximum acceptable value for the calibration criterion depends on the magnitude of the change in heads over the model domain. If the ratio of the RMS error to the total head change is small, known as the Scaled RMS (SRMS), the errors are only a small part of the overall model response (Anderson and Woessner, 1992). The ratio of RMS (1.98m) to the total head change across the calibration points (44.90m) indicated a SRMS of 4.4%. The acceptable target for SRMS varies between models but is typically below 5% (MDBC 2000), which has been achieved.

Table 17 shows the hydraulic parameters adopted through the calibration process for the various geological units simulated in the model.

Table 17
Steady State Calibrated Hydraulic Parameters

Geology Type	Parameter	Value (m/day)
Quaternary Alluvium	Horizontal Hydraulic Conductivity (Kh)	5
	Vertical Hydraulic Conductivity (Kv)	0.5
Weathered Permian (regolith)	Horizontal Hydraulic Conductivity (Kh)	5×10^{-3}
	Vertical Hydraulic Conductivity (Kv)	5×10^{-4}
Coal Seams and minor interburden	Horizontal Hydraulic Conductivity (Kh)	2.64×10^{-2}
	Vertical Hydraulic Conductivity (Kv)	2.64×10^{-2}
Permian Interburden	Horizontal Hydraulic Conductivity (Kh)	4×10^{-3}
	Vertical Hydraulic Conductivity (Kv)	4×10^{-4}
Alum Mountain Volcanics	Horizontal Hydraulic Conductivity (Kh)	1×10^{-5}
	Vertical Hydraulic Conductivity (Kv)	1×10^{-6}

The calibrated hydraulic conductivity parameter values were within the ranges determined in the field investigations and by previous testing and modelling studies. Measured hydraulic conductivity of the coal seams at GRL is variable with hydraulic testing at GR-P6A, GR-P7A, GR-P8A and GR-P9A resulting in permeability values of 0.06m/day, 0.002m/day, 0.01m/day and 0.15m/day respectively (an average of 0.055m/day). These represent several orders of magnitude difference and can be expected in a natural system. These hydraulic conductivity values are typically influenced by the depth of burial of the seam, the degree of jointing and cleat density and in some cases drilling techniques.

The calibrated hydraulic conductivity value of the model layers representing the major coal seams is 0.0264m/day. This value is considered conservative as the measured hydraulic conductivity values discussed above are specifically for the coal seams, whereas the model layers representing the coal seams also include interburden material which will be of lower hydraulic conductivity.

Measured hydraulic conductivity of the interburden / overburden material recorded 0.2m/day, 0.05m/day, 0.04m/day and 0.2m/day for sites GR-P4, GR-P5, GR-P6 and GR-P9 respectively (average of 0.12m/day). The steady state model calibration resulted in a lower hydraulic conductivity value of 4 x 10^{-3}m/day for the model layers representing Permian interburden / overburden. Whilst this calibrated value is lower than the observed GRL hydraulic conductivity values, this value is comparable to the observed hydraulic conductivity values collected by AGL. The dataset available at GRL is relatively small and considered to represent the upper end of the hydraulic conductivity range.

According to Mackie (2009), the horizontal hydraulic conductivity of coal seams in the Hunter Valley generally declines by an order of magnitude per 180m (depth of cover). For deeper coal seams, it is reported that the coal seam hydraulic conductivity can decline by an order of magnitude per 55m (depth cut-off).

These parameters for depth of cover and depth cut-off were included in the calibration of the steady-state model to represent a reduction of coal seam hydraulic conductivity with depth. The calibrated value for the depth of cover for the Rocky Hill Coal Project is 170m, and the cut-off value calibrated at 100m, viz:

- 0m to 170mbGL K = 2.64 x 10^{-2}m/day;
- 170mbGL to 270mbGL K = 2.64 x 10^{-3}m/day; and
- 270mbGL to 370mbGL K = 2.64 x 10^{-4}m/day.

10.4.2 Sensitivity Analysis

Sensitivity analysis involves evaluating the effects of changes in individual model parameters on model results and indicates the uncertainty in the estimates of model parameters. The sensitivity of simulated heads to parameters was used to aid model calibration and was assessed through relative composite sensitivity (RCS). The RCS is defined as follows (PEST, 2008):

$$s_i = (J^tQJ)^{0.5}b_i/m$$

where: J = Jacobian matrix, derivatives of simulated heads at observations with respect to the i^{th} parameter in vector b

Q = cofactor matrix, a diagonal matrix with the elements being the squared observation weights

b_i = i^{th} parameter value in vector b

m number of observations that have non-zero weights

The composite sensitivity values were calculated during the PEST calibration process for the steady-state model and were converted to RCS as shown in **Figure 45**. The reason for scaling the sensitivity data is that sensitivities are typically presented in the units of the simulated value divided by the units of the parameter (Hill and Tiedeman, 2007). For example, the parameter units may consequently be in m^3/day, m/day or mm/yr and the method of scaling (composite sensitivity) provides sensitivity measures with the same units and a method for comparison.

RCS is therefore a dimensionless statistic and is a measure of the composite changes in model outputs that are incurred by a change in the value of the parameter. That is, whether the model calibration is sensitive to an input parameter such as hydraulic conductivity or recharge. This statistic can be used to assess the relative sensitivity of model parameters given the set of observations used in the model.

RCS can reflect the total amount of information provided by the observations for the estimation of each parameter (Hill and Tiedeman, 2007). Generally, if the RCS of a parameter is greater than 1, the model is sensitive to this parameter and the model observations have provided enough information to estimate the parameter with greater certainty. In this case, two parameters (Kh3 and Kh4) have RCS greater than 1 (**Figure 45**), indicating that these are the most sensitive with regards to model calibration yet were estimated with sufficient information. Kh3 and Kh4 relate the hydraulic conductivity of the overburden above the Cloverdale Coal Seam and the hydraulic conductivity of the interburden layers (Layer 2 and Layers 4, 6 and 8) respectively.

Where parameters have a low RCS, the model calibration is less sensitive to these yet there is greater uncertainty associated with them and they are likely to contribute more to the uncertainty of the model predictions. In this case, the predictive uncertainty has been guided by this sensitivity analysis within the constraints of the model calibration statistics (Section 11.8).

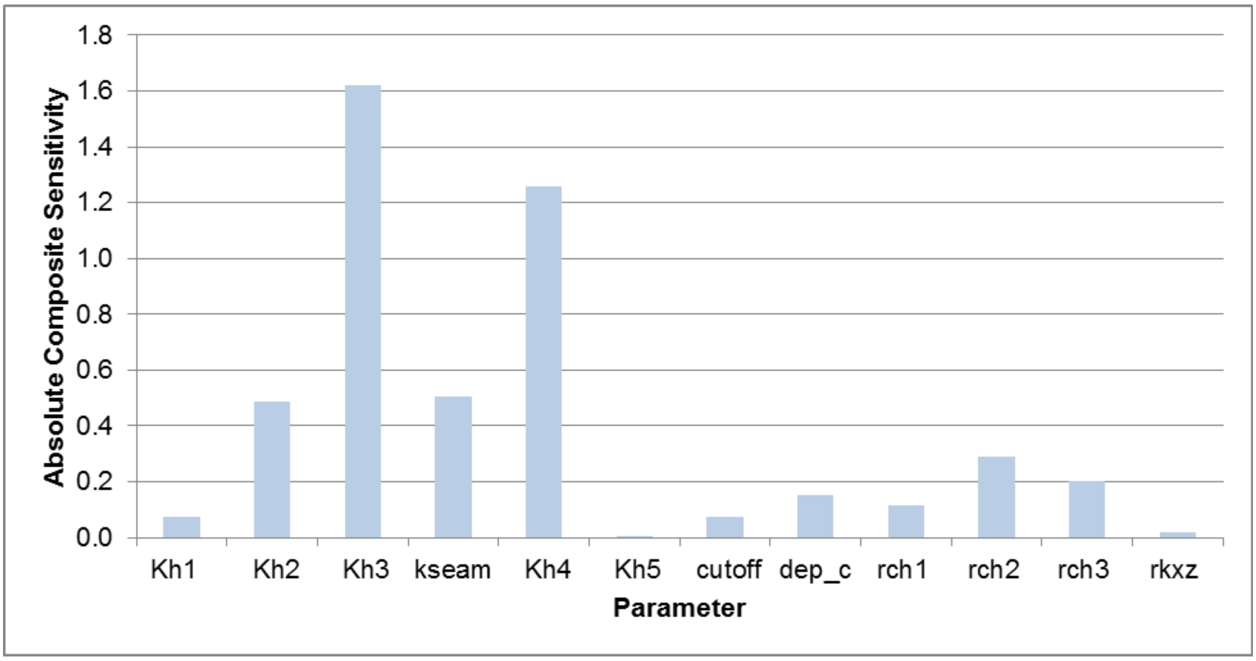


Figure 45 Relative Composite Sensitivity for Parameters in Steady-State Calibration

The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration (expressed as a percentage of discrepancy) was 0.0%. This value indicates that the model is highly stable and has good accuracy in the numerical solution. The model water budget is summarised in **Table 18**.

Table 18
Water Budget – Steady State Model

Parameter	Input (m^3/d)	Output (m^3/d)
Rainfall recharge	2974 (99.4%)	0.0
Evapotranspiration	0.0	2911 (97.3%)
Drains	0.0	68 (2.3%)
Fixed head	18 (0.6%)	13 (0.4%)
TOTALS	2992	2992

The water budget indicates a net discharge of approximately 68m^3/day to surface drainages (drains) across the model area. Of the long term average of 2974m^3/day of recharge entering the groundwater system, approximately 68m^3/day is discharged to surface drainage, 2911m^3/day is lost to evapotranspiration, and the remainder (13m^3/day) is removed as down valley flow in the alluvial groundwater system. With regards to evapotranspiration, the modelled evapotranspiration fraction is approximately 1% of the potential evaporation (1,059mm/yr) across the Site.

The fixed or constant heads represented in the model show 18m^3/day inflow upstream of the model domain and 13m^3/day outflow downstream of the model domain north of Gloucester. These constant heads represent a very small component of the steady state water balance (0.6% and 0.4% respectively).

10.4.3 Transient Calibration

Approach

The hydraulic heads and model parameters from the steady state calibration provided the starting values for the transient calibration of the model. At the start of each transient model calibration run, a steady state simulation was undertaken with the modified parameters. The solved steady state heads for each calibration run were then transferred into the transient model as starting groundwater levels.

This approach ensured that initial conditions (steady state groundwater levels) for the transient run were derived from the corresponding parameter set being applied in the transient simulation. Otherwise discrepancies between these two parameter sets would impact on groundwater flow budgets as the transient version of the model settles to pseudo steady state conditions throughout the simulation.

Time

The transient version of the model ran from March 2011 to February 2012, which is the period where transient water level records have been collected at the Site. Daily rainfall and monthly average ET rate were used during the simulation period. MODHMS Adaptive time stepping package (ATO) was used to ensure model stability and efficiency with minimal run time.

Parameters

Parameters calibrated during the transient simulation include storage properties specific yield / storage coefficient and overland flow leakance / stream bed leakance, and are summarised in **Table 19**.

Table 19
Transient Calibrated Model Parameters

Geology Type	Parameter	Value*
Quaternary Alluvium	Specific Yield (Sy)	0.05
	Storage Coefficient (Sc)	2×10^{-4}
Weathered Permian (regolith)	Specific Yield (Sy)	0.05
	Storage Coefficient (Sc)	2×10^{-4}
Coal Seams and Minor Interburden	Specific Yield (Sy)	5×10^{-3}
	Storage Coefficient (Sc)	1×10^{-5}
Permian Interburden	Specific Yield (Sy)	0.02
	Storage Coefficient (Sc)	1×10^{-5}
Alum Mountain Volcanics	Specific Yield (Sy)	5×10^{-3}
	Storage Coefficient (Sc)	1×10^{-5}
OLF Leakance (Alluvial Zone)		1×10^{-3}/d
OLF Leakance (Hill Zone)		2×10^{-3}/d
Streambed Leakance		0.5/d

Note: * Specific yield and storage coefficient are dimensionless

The calibrated value for streambed leakance of 0.5/d is based upon the vertical hydraulic conductivity and thickness of the underlying unsaturated geology (0.5m/d x 1m for the alluvial sediments and 0.0005m/d and 0.001m for the regolith / colluvial sediments). Conversely, the OLF leakance is based upon the vertical hydraulic conductivity and thickness of the underlying geology. In this regard, the OLF leakance for the alluvial zone (0.001/d) assumes a vertical hydraulic conductivity of 0.001m/d and 1m thickness. This assumes the alluvial sediments in the upper unsaturated profile are more clayey than the gravelly water bearing sediments at depth. The OLF leakance for the hill zone (0.002/d) is based upon a vertical hydraulic conductivity of 0.0005m/d and thickness of 0.25m for the unsaturated regolith / colluvial sediments.

Results

Appendix 4 presents the 13 hydrographs used to calibrate the model. The hydrographs show what is considered a good match, and whilst the absolute values of the predicted model do not match, they are all less than 3m different to the observed values, and more often less than 1m different.

The trends (increasing and stable) observed at all the GRL monitoring bores are well simulated as part of the predictive model. Furthermore, where nested monitoring bores have been constructed (GR-P6, 7, 8 and 9) the model replicates well the vertical hydraulic gradients that are observed at all sites, indicating a robust model.

Surface flow conditions were simulated using MODHMS. In the transient calibration, the surface flow conditions were matched against the NOW streamflow gauging station (028028) on the Avon River (downstream of the Waukivory Creek confluence). The model shows a good calibration to the observed dataset (**Figure 46**). The modelled data also simulates several lower flow events occurring during April 2011 and November 2011 which have not been measured at the gauging station. This is explained through the use of rainfall data from the

Gloucester (Hiawatha) Station (060112). The surface water model that is coupled to the groundwater model simulates surface runoff over a large catchment area (approximately 10,000ha) and it is likely that rainfall over this area will be highly variable especially considering the variable topography in the region which would have a significant influence over rainfall distribution and intensity and the volumes of water that reach the gauging station.

In addition, the lower simulated high-flow events are partly attributed to incomplete catchment boundaries, coarser resolution of the overland surface and channel flow grid, and more importantly the high likelihood of spatially varied rainfall intensity.

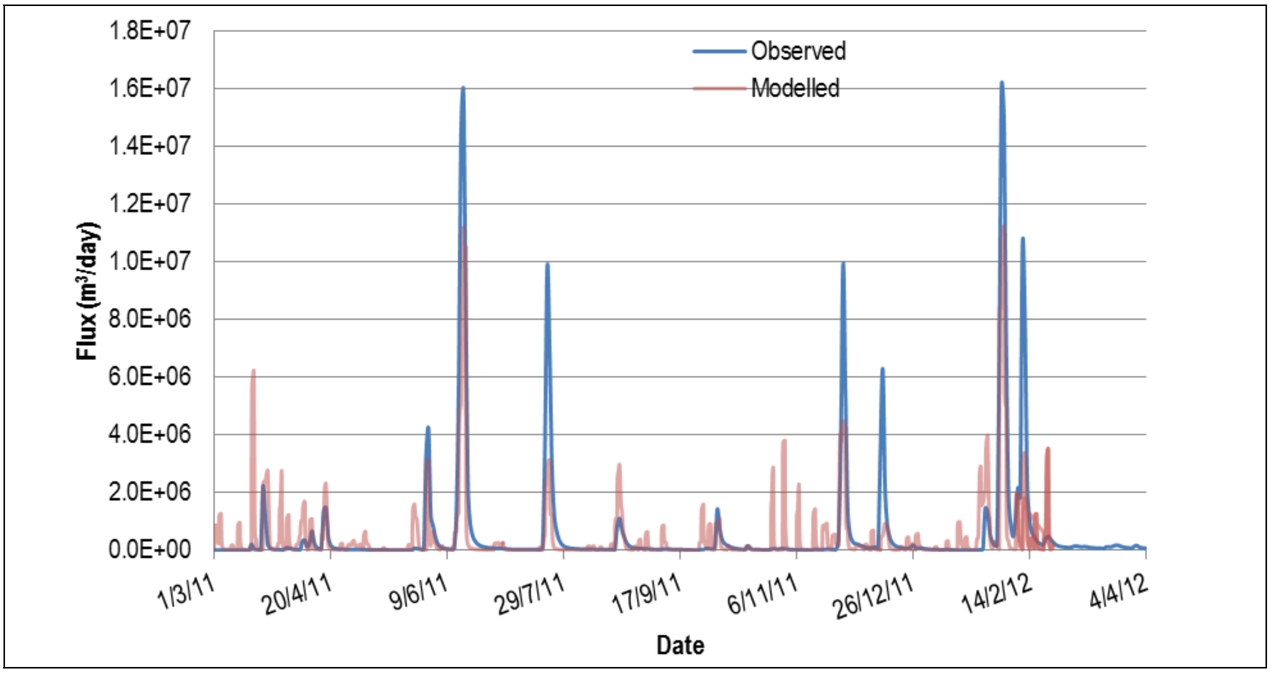


Figure 46 Observed vs Modelled Stream Flow Data for the Avon River Gauging Station (028028)

10.5 MODEL VERIFICATION

The transient calibration model was then verified using the transient dataset measured at 12 AGL monitoring bores (**Appendix 5**). The hydrographs were deliberately excluded from the transient calibration to ensure that there was a reserved dataset to match the simulation against. The model shows an acceptable match to the observed dataset. Some hydrographs show an excellent correlation between observed and simulated values (e.g. BMB01, TMB01, TMB02 and TMB03), whereas other sites (such as S5MB02, S5MB03, TCMB03 and WMB02) show a rising water level compared with a stable, flat observed water levels. Overall however, the comparison of the transient calibration against the AGL observed transient dataset is considered acceptable and verifies the model is well calibrated.

11. PREDICTIVE SIMULATIONS

After the transient model was calibrated to the available data, the model was then modified to predict the impact of the Proposal. The heads at the end of 2011 in the transient calibration were used as the starting heads in the predictive model. To achieve the transient simulation of mine progression, a number of assumptions were made as outlined below.

11.1 SET-UP AND ASSUMPTIONS

The transient model was set up with 64 quarterly (91.3125 days) stress periods, representing the period from mining Year 2 to Year 14. Specific yield, specific storage and hydraulic conductivity values were set at values determined during the calibration process.

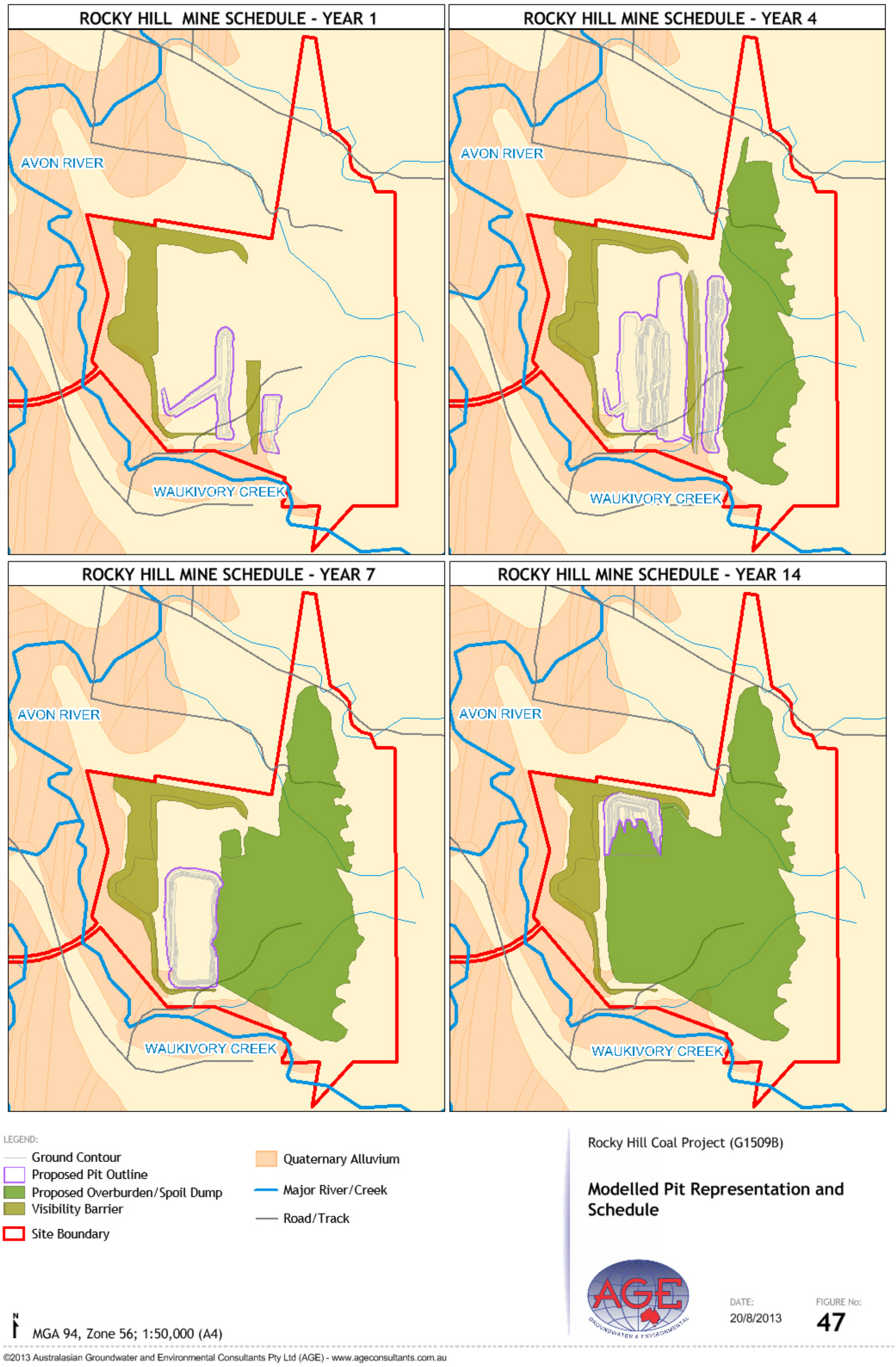
Dewatering of the open cut pits was represented by the introduction of drain cells to the designated elevation of the seam being mined. Mine progression and the placement of overburden and coal rejects (from processing) within the pit were simulated through a yearly base by assuming that backfill occurred immediately after drain cells were switched off. The TMP (time varying material property) package in MODHMS was used to undertake the change of model properties (K and S) during the simulation.

The number of drain cells defined as active mining increased with each quarterly stress period. Drains were applied with a conductance value of 1,000m^2/day. Once a drain boundary condition was applied, it was assumed to be active for the entire year. At the completion of each yearly stage, the drain cells were removed from the area where mining had been completed for that year and were then reapplied to the cells representing the first stress period in the next year. At this point, the model parameters for the previously mined areas were reset to parameters representing spoil, as shown in **Table 20**. These parameters were based on a Hunter Valley study undertaken by Mackie (2009). This allowed for the simulation of groundwater level recovery within the backfilled pits as mining progresses, beyond mined out areas, as well as the simulation of potentially increased pit seepage rates through the backfilled pits.

Table 20
Hydraulic Parameters of Spoil

Geology Type	Parameter	Value
Spoil	Horizontal Hydraulic Conductivity (Kh)	1 m/day
	Vertical Hydraulic Conductivity (Kv)	1 m/day
	Specific Yield (S_y)	0.1
	Specific Storage (S_s)	1 x $10^{-3}m^{-1}$

The locations of the proposed open cut pits and the rate of advancement used in the transient simulations are shown in **Figure 47**.


ROCKY HILL MINE SCHEDULE - YEAR 1
ROCKY HILL MINE SCHEDULE - YEAR 4
ROCKY HILL MINE SCHEDULE - YEAR 7
ROCKY HILL MINE SCHEDULE - YEAR 14
AVON RIVER
WAUKIVORY CREEK
LEGEND:
Ground Contour
Proposed Pit Outline
Proposed Overburden/Spoil Dump
Visibility Barrier
Site Boundary
Quaternary Alluvium
Major River/Creek
Road/Track
MGA 94, Zone 56; 1:50,000 (A4)
Rocky Hill Coal Project (G1509B)
Modelled Pit Representation and Schedule
DATE: 20/8/2013
FIGURE No: 47
©2013 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

Cumulative Impacts

To simulate the AGL GGP Stage 1 development, a staged well development was incorporated into the model using the fracture well (FWL) package. The pumping schedule was based upon information provided by AGL (John Ross pers. comm.) and is summarised in **Table 21**. The CSG wells were assumed to be completed in the major coal seams and extracting groundwater from the model Layers 3, 5, 7 and 9. **Figure 48** shows the distribution of the pumping bores as per the Rocky Hill Coal Project description. The cumulative impact model included the operation of a number of CSG wells within the Mine Area during active mining by GRL. The effect of simulating both CSG and mining in close proximity is considered to have negligible effect on the predictive impacts as two models have been developed, one showing the impacts of CSG operations and the other showing impact of CSG and mining at GRL. The model results can be subtracted from one another to show the true impact of mining at GRL.

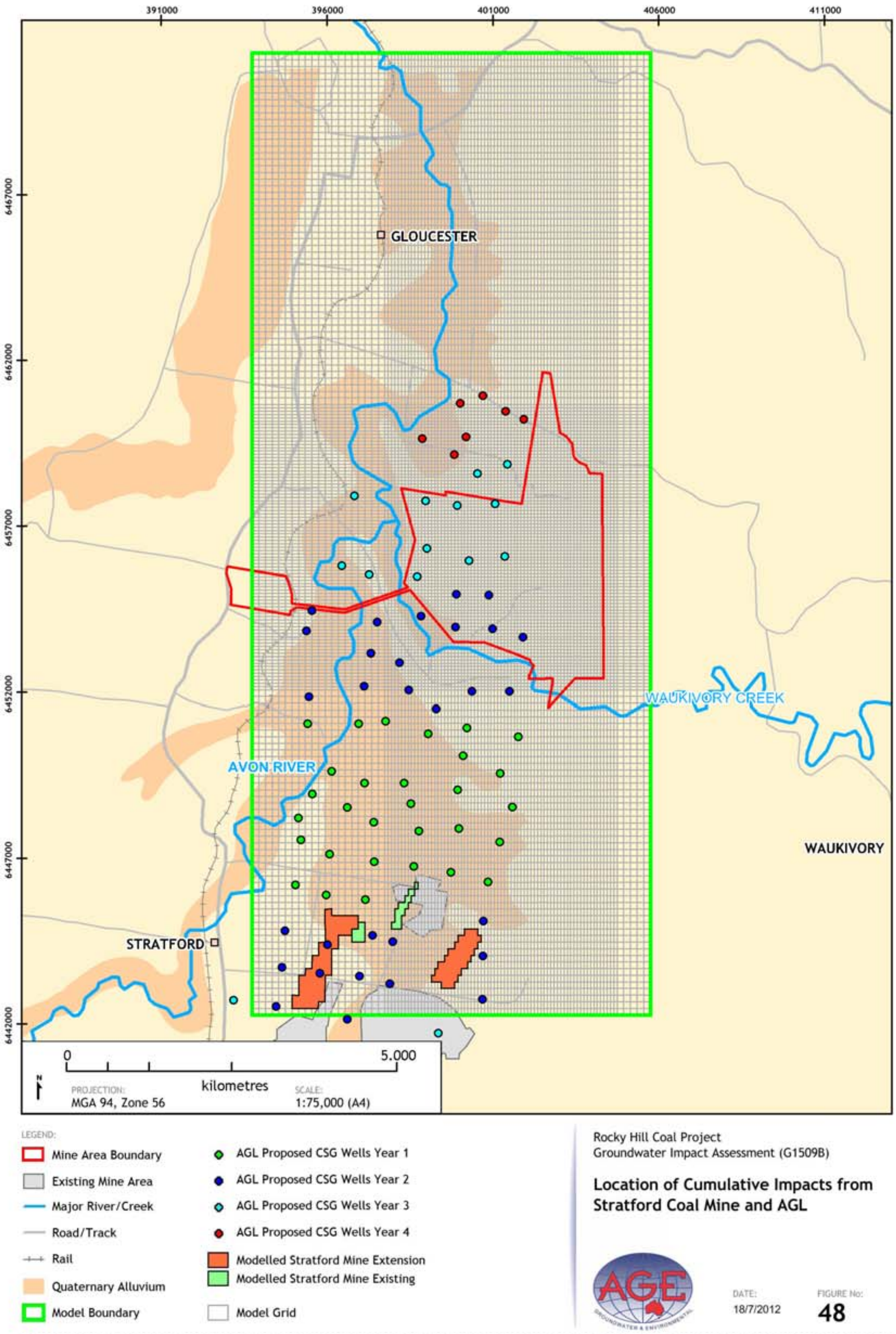
Table 21
AGL Gloucester Gas Project Pumping Schedule

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9-15**	**15-25**
No. of Wells	30	60	90	110	110	110	110	110	110	110
Rate (L/s)	0.4	0.35	0.25	0.21	0.21	0.21	0.21	0.21	0.1	0.05
Total Volume (ML/yr)	1.04	1.81	1.94	2	2	2	2	2	0.95	0.48

As part of the assessment of the cumulative impacts, the Stratford Coal Mine (SCM) extension was included in the predictive model. At the time of model development, little information existed regarding the mine plan and progression for this mine development and therefore a number of assumptions were made with regards to this.

The only information available with regards to mining and schedule for the SCM extension was a map showing the general extent of the proposed pits. No information was available for pit depth or mine progression so therefore the following assumptions were made:

- The existing mining conditions at SCM were implemented in the transient calibration prior to introducing to the predictive simulation.
- The Stratford Main Pit was active from 1995 through to mid-2003 and is now not actively mined. It is understood that the pit is now used for water storage for the SCM. The southern model boundary extends through the middle of the Stratford Main Pit.
- The existing Roseville West and Bowens Road North open cut pits were assumed to be active from mid-2006 and mid 2003 respectively.
- Mining of these pits was conservatively assumed to be continuous until 2017.
- Drain cells were applied to the model at depths of 20mAHD to represent groundwater drainage to the Roseville West and Bowens Road North open cut pits.
- The proposed Avon North open cut and Roseville West Extension were assumed to be active from 2014 to 2024.


391000
396000
401000
406000
411000
6467000
6462000
6457000
6452000
6447000
6442000
GLOUCESTER
WAUKIVORY CREEK
AVON RIVER
WAUKIVORY
STRATFORD
0
5,000
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:75,000 (A4)
LEGEND:
Mine Area Boundary
Existing Mine Area
Major River/Creek
Road/Track
Rail
Quaternary Alluvium
Model Boundary
AGL Proposed CSG Wells Year 1
AGL Proposed CSG Wells Year 2
AGL Proposed CSG Wells Year 3
AGL Proposed CSG Wells Year 4
Modelled Stratford Mine Extension
Modelled Stratford Mine Existing
Model Grid
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Location of Cumulative Impacts from
Stratford Coal Mine and AGL
DATE:
18/7/2012
FIGURE No:
48

- Drain cells were applied to the model at depths of -40mAHD to represent groundwater drainage to the proposed Avon North and Roseville West Extension open cut pits.
- Drain cells in the area of mine development down to model Layers 3, 5 or 7 depending upon the pit location.
- Mining in these proposed pits was assumed to occur in a similar manner to the mining method proposed by GRL. The simulation of the SCM extension (mine drainage and application of spoil) was applied in a similar manner to the GRL mine development, that is with progressive backfill of the pits with overburden.

Subsequent to the development, calibration and scenario modelling, the EIS for the SCM extension was released to the public in November 2012. From the information that has been provided by SCM in their groundwater impact assessment, it would appear that the assumptions detailed above for the mine progression are valid and are sufficiently detailed to accurately simulate the cumulative impact of this neighbouring mining operation on the regional groundwater regime.

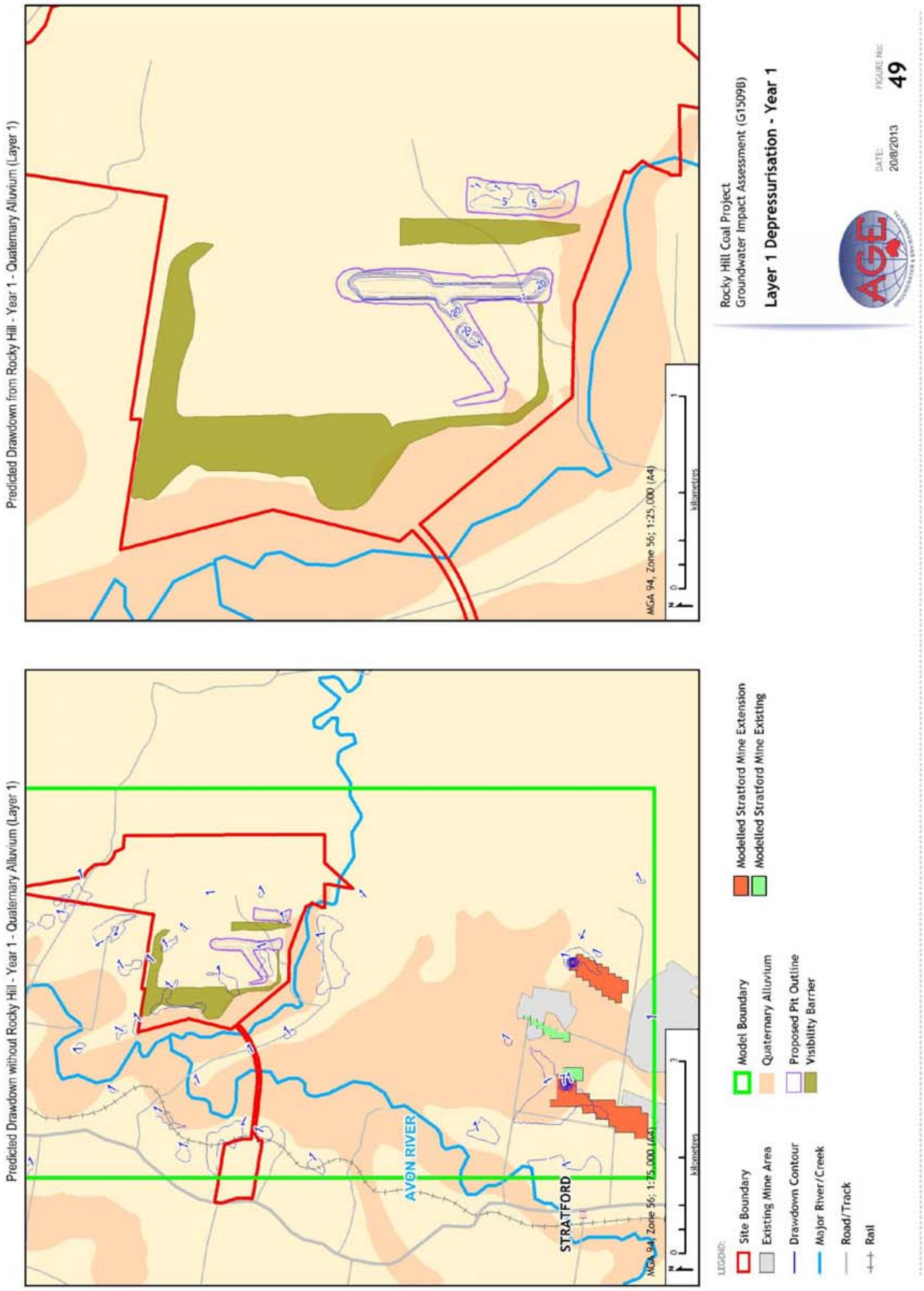
11.2 PIEZOMETRIC SURFACE/WATER TABLE LEVELS

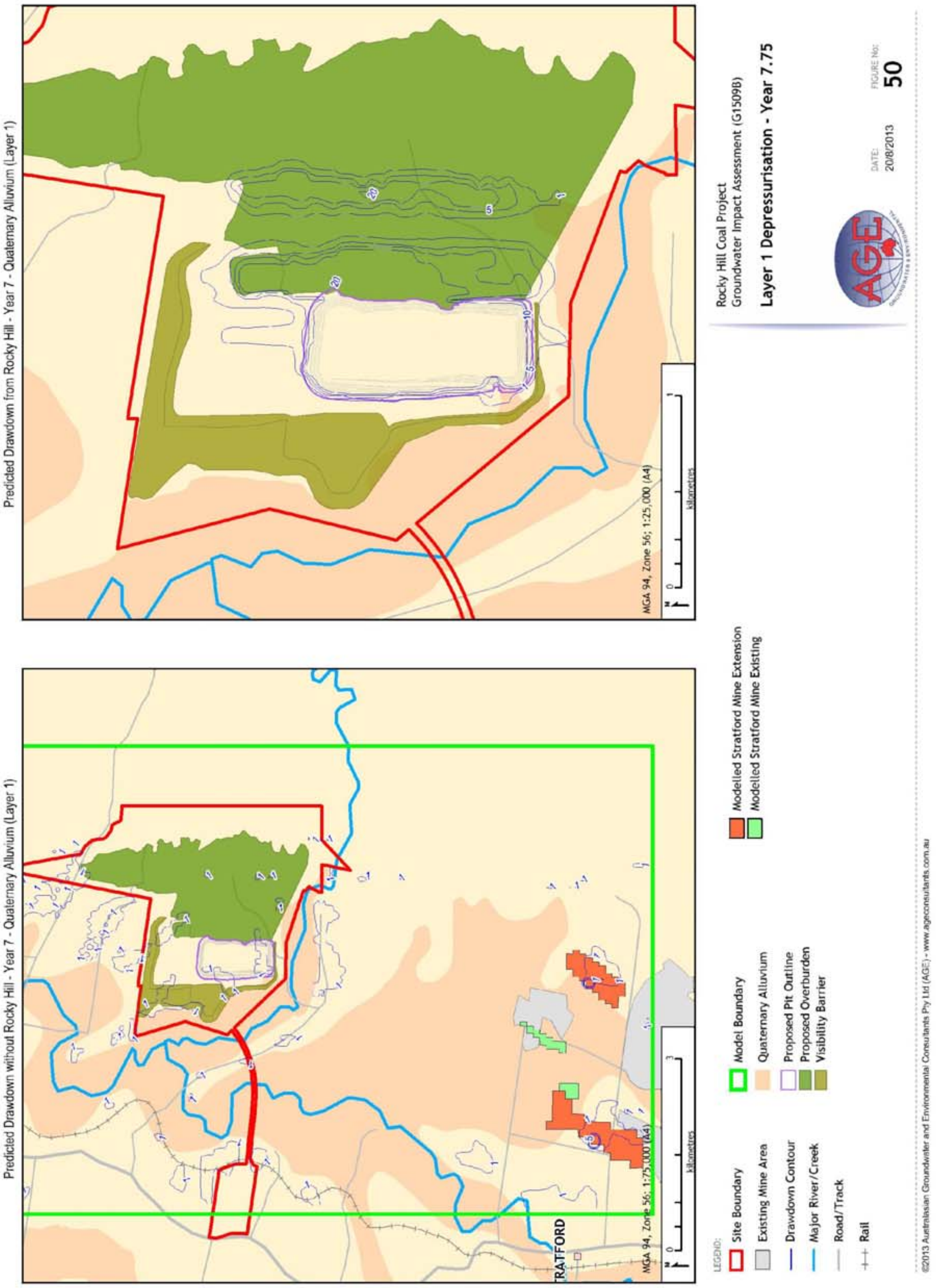
Figure 49 to **Figure 54** show the depressurisation in response to the mine progression for Years 1, 7 and 13 in Layer 1 (alluvium/regolith) and Layer 5 (Bowen Road Coal Seam and minor interburden).

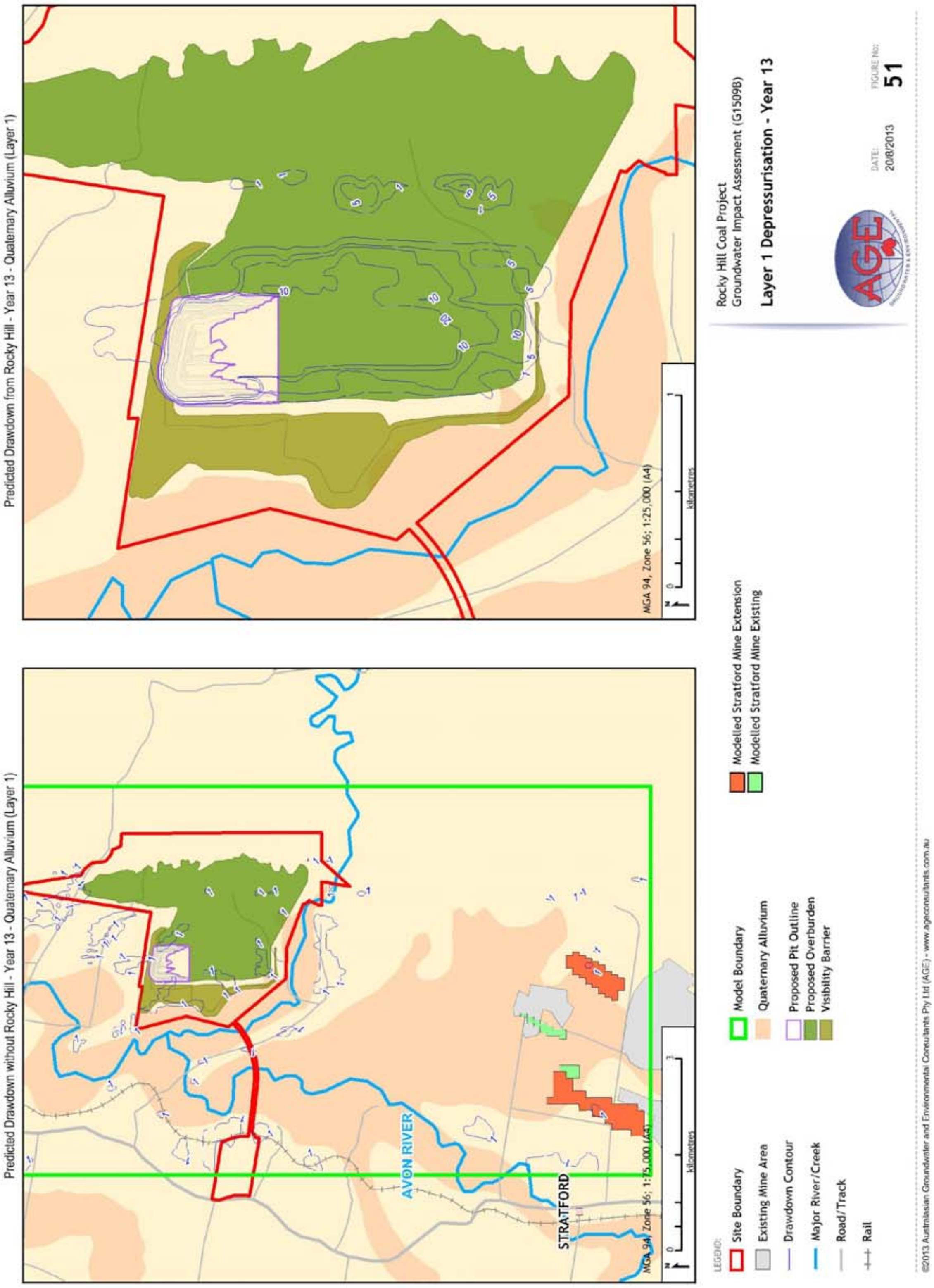
The modelling indicates the depressurised zone in Layer 1 of the model (alluvium/regolith), as indicated by the 1m drawdown contour toward the end of mining in Year 13 (**Figure 51**), extends a maximum of 500m from the northern extent of the Main Pit. The depressurisation within model Layer 5 (Bowen Road Coal Seam and minor interburden) for Year 13 shows depressurisation (1m contour) extending up to 300m to the east of the Main Pit and up to 2km to the north. This depressurisation in Layer 5 also extends up to 1.5km to the south-west of the Mine Area boundary. To the west, the depressurisation extends to the western model boundary.

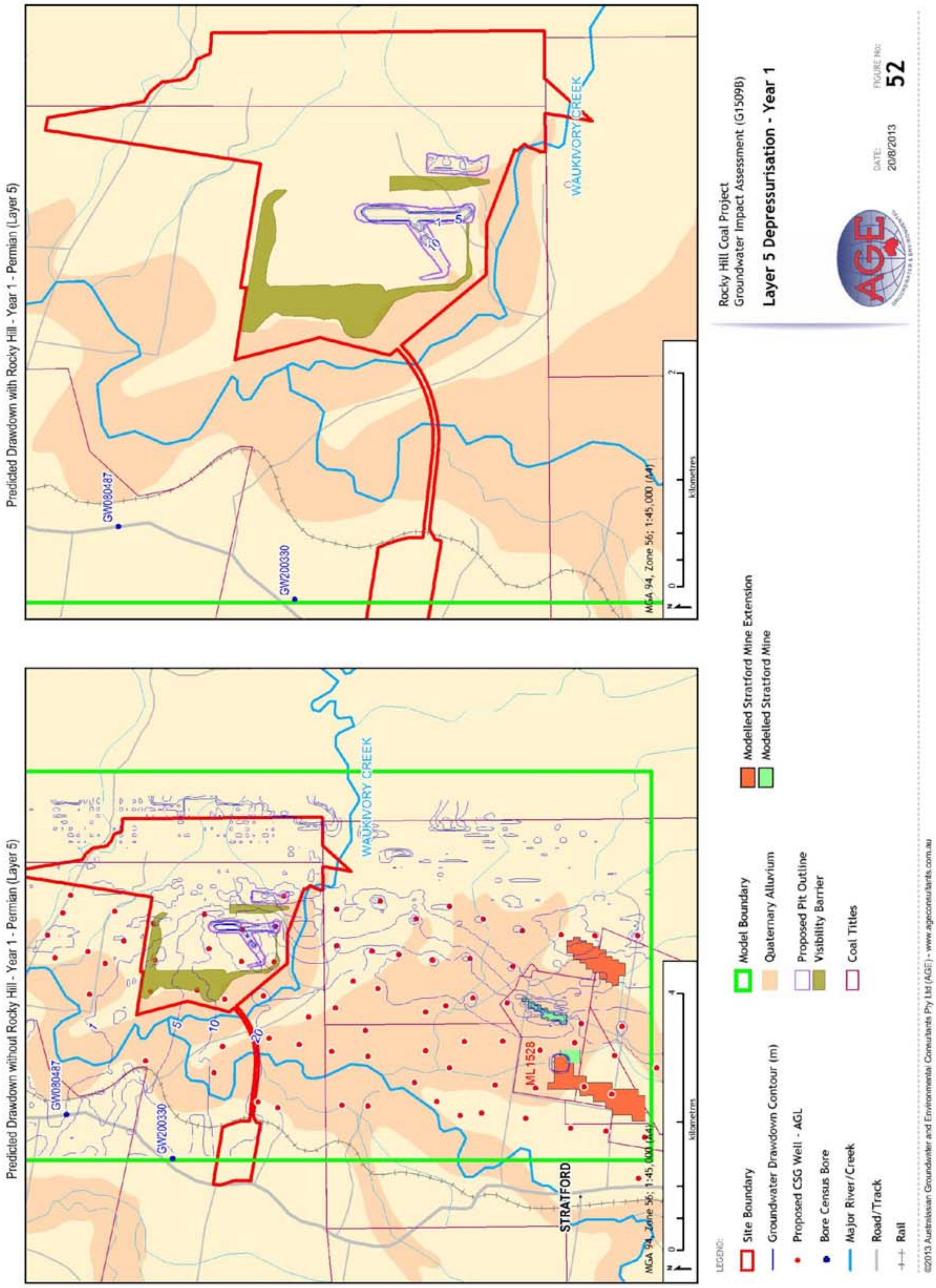
The extent of groundwater depressurisation around the proposed mine and on a regional scale is affected largely by the operation and development of the numerous AGL CSG wells in the region. The CSG wells have the effect of causing significant localised drawdown or depressurisation of the coal seams (greater than 100m depressurisation at the wellhead) which, when combined with a cumulative wellfield effect, causes greater drawdown over a more regional area. At the Site, these CSG wells have the effect of imparting an additional 10m of depressurisation west of the Mine Area boundary.

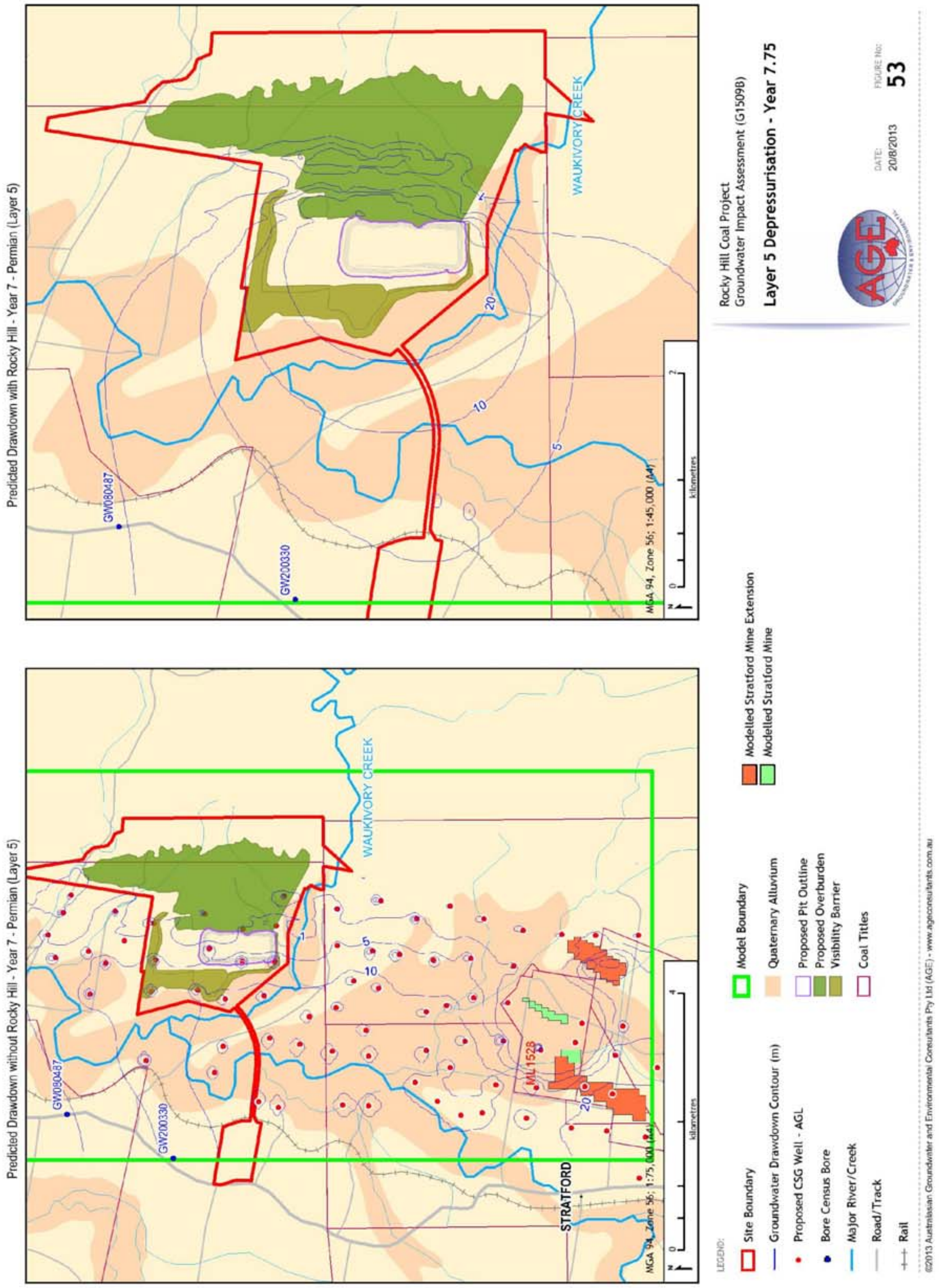
This depressurisation of the deeper coal seam layers due to gas well pumping is not evident in the shallower zones due to the presence of a thick overburden layer, representing all material above the Cloverdale Coal Seam (Layer 2 in the numerical model). Layer 2 represents the Crowthers Road Conglomerate (massive polymictic boulder to pebble conglomerate, interbedded medium to coarse-grained lithic sandstone and mudstone) and the Leloma Formation (lithic sandstone, mudstone, coal and mudstone and claystone).


Predicted Drawdown from Rocky Hill - Year 1 - Quaternary Alluvium (Layer 1)
MGA 94, Zone 56; 1:25,000 (A4)
kilometres
Predicted Drawdown without Rocky Hill - Year 1 - Quaternary Alluvium (Layer 1)
MGA 94, Zone 56; 1:75,000 (A4)
AVON RIVER
STRATFORD
LEGEND:
Site Boundary
Existing Mine Area
Drawdown Contour
Major River/Creek
Road/Track
Rail
Model Boundary
Quaternary Alluvium
Proposed Pit Outline
Visibility Barrier
Modelled Stratford Mine Extension
Modelled Stratford Mine Existing
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Layer 1 Depressurisation - Year 1
DATE:
20/8/2013
FIGURE No:
49
©2013 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au


Predicted Drawdown from Rocky Hill - Year 7 - Quaternary Alluvium (Layer 1)
MGA 94, Zone 56; 1:25,000 (A4)
kilometres
Predicted Drawdown without Rocky Hill - Year 7 - Quaternary Alluvium (Layer 1)
MGA 94, Zone 56; 1:75,000 (A4)
kilometres
LEGEND:
Site Boundary
Existing Mine Area
Drawdown Contour
Major River/Creek
Road/Track
Rail
Model Boundary
Quaternary Alluvium
Proposed Pit Outline
Proposed Overburden
Visibility Barrier
Modelled Stratford Mine Extension
Modelled Stratford Mine Existing
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Layer 1 Depressurisation - Year 7.75
DATE: 20/8/2013
FIGURE No: 50
©2013 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au


Predicted Drawdown from Rocky Hill - Year 13 - Quaternary Alluvium (Layer 1)
Predicted Drawdown without Rocky Hill - Year 13 - Quaternary Alluvium (Layer 1)
MGA 94, Zone 56; 1:25,000 (A4)
kilometres
AVON RIVER
STRATFORD
LEGEND:
Site Boundary
Existing Mine Area
Drawdown Contour
Major River/Creek
Road/Track
Rail
Model Boundary
Quaternary Alluvium
Proposed Pit Outline
Proposed Overburden
Visibility Barrier
Modelled Stratford Mine Extension
Modelled Stratford Mine Existing
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Layer 1 Depressurisation - Year 13
DATE:
20/8/2013
FIGURE No:
51
©2013 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au


Predicted Drawdown with Rocky Hill - Year 1 - Permian (Layer 5)
Predicted Drawdown without Rocky Hill - Year 1 - Permian (Layer 5)
WAUKIVORY CREEK
GW080487
GW200330
STRATFORD
ML 1528
MGA 94, Zone 56; 1:45,000 (A4)
kilometres
LEGEND:
Site Boundary
Groundwater Drawdown Contour (m)
Proposed CSG Well - AGL
Bore Census Bore
Major River/Creek
Road/Track
Rail
Model Boundary
Quaternary Alluvium
Proposed Pit Outline
Visibility Barrier
Coal Titles
Modelled Stratford Mine Extension
Modelled Stratford Mine
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Layer 5 Depressurisation - Year 1
DATE: 20/8/2013
FIGURE No: 52


Predicted Drawdown with Rocky Hill - Year 7 - Permian (Layer 5)
Predicted Drawdown without Rocky Hill - Year 7 - Permian (Layer 5)
WAUKIVORY CREEK
GW080487
GW200330
STRATFORD
ML1528
MGA 94, Zone 56; 1:45,000 (A4)
MGA 94, Zone 56; 1:75,000 (A4)
kilometres
LEGEND:
Site Boundary
Groundwater Drawdown Contour (m)
Proposed CSG Well - AGL
Bore Census Bore
Major River/Creek
Road/Track
Rail
Model Boundary
Quaternary Alluvium
Proposed Pit Outline
Proposed Overburden
Visibility Barrier
Coal Titles
Modelled Stratford Mine Extension
Modelled Stratford Mine
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Layer 5 Depressurisation - Year 7.75
DATE: 20/8/2013
FIGURE No: 53
©2013 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

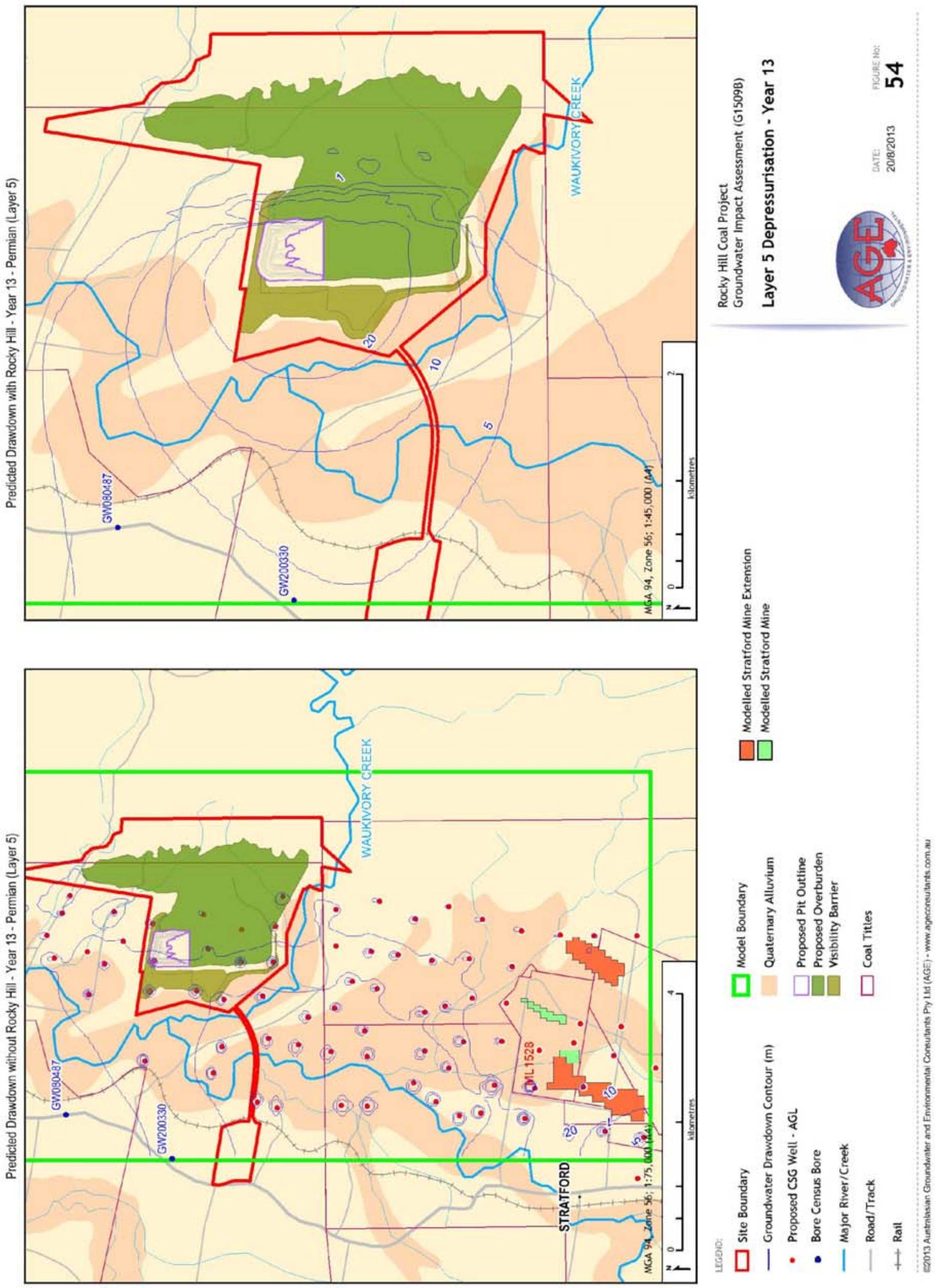

Predicted Drawdown with Rocky Hill - Year 13 - Permian (Layer 5)
Predicted Drawdown without Rocky Hill - Year 13 - Permian (Layer 5)
WAUKIVORY CREEK
GW080487
GW200330
STRATFORD
CL 1528
MGA 94, Zone 56; 1:45,000 (A4)
MGA 94, Zone 56; 1:75,000 (A4)
kilometres
LEGEND:
Site Boundary
Groundwater Drawdown Contour (m)
Proposed CSG Well - AGL
Bore Census Bore
Major River/Creek
Road/Track
Rail
Model Boundary
Quaternary Alluvium
Proposed Pit Outline
Proposed Overburden
Visibility Barrier
Coal Titles
Modelled Stratford Mine Extension
Modelled Stratford Mine
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Layer 5 Depressurisation - Year 13
DATE: 20/8/2013
FIGURE No: 54
©2013 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au

Figure 49 to **Figure 54** also present both the simulated depressurisation and drawdown in Layer 1 and Layer 5 that are attributable only to the Proposal, and the cumulative drawdown at the end of mining in Year 13. The cumulative impact is based on the Proposal, the Stratford Coal Mine extension and the AGL Stage 1 GGP operating as modelled.

After review of the SCM extension groundwater impact assessment (Heritage Computing, 2012), it is considered that the modelling approach used by AGE to simulate the SCM extension is valid and compares well with the mine progression and schedule presented by SCM.

It is concluded that the drawdown and model output that was completed in April 2012 by Stratford Coal Pty Limited (SCPL) for their project alone should be considered as the true impact of the SCM extension project, rather than the cumulative impacts presented by either SCPL or GRL. The impact from the SCM extension suggests limited drawdown in the Permian strata (1m) up to 1.5km from the open pits. Predicted drawdown within the immediate vicinity of the open cut pits is of similar magnitude (greater than 20m) to that predicted for the Proposal.

In this regard, it is assessed that there is no cumulative groundwater impact between the SCM extension and the Proposal.

11.3 IMPACT ON GROUNDWATER USERS

11.3.1 Mine Area

As discussed in Section 5.7, there are eight registered bores within 3km of the Mine Area boundary. Of these bores, the closest private bore is located some 1km to the west of the Mine Area boundary and on the western side of the Avon River. To the south of the Mine Area boundary, the nearest private bores are located some 2.5km away, immediately to the south of the AGL (Tiedman) pilot plant. A total of 17 registered bores are located within the model area. The locations of the registered bores are shown in relation to the zone of depressurisation in **Figure 49** to **Figure 54**.

GW054940 is an abandoned shallow well that was excavated into the Quaternary Alluvium of the Avon River and is the closest private bore to the Mine Area boundary. The Quaternary Alluvium is represented in Layer 1 of the numerical model, and **Figure 49** to **Figure 54** show no drawdown or impact in this area due to the Proposal.

Figure 52 to **Figure 54** show that GW200330 and GW080487 are located within the Layer 5 predicted zone of influence for the Proposal and it is understood that these bores were drilled and constructed in 1905 into Permian sediments. However, the bores are relatively shallow (50m and 60m depth respectively) and are more likely representative of the model Layer 2 which represents the thick overburden sequence above the Cloverdale Coal Seam. In Layer 2 the model predicts zero drawdown at these bores over the life of the Proposal and hence there is no impact. It is understood that GW200330 has been abandoned and GW080487 is still usable however it is not currently in use.

11.3.2 Rail Loop

A rail loop and load-out facility is to be constructed on the western side of the North Coast Railway Line and to the east of The Bucketts Way. The Bucketts Way typically follows the ridgeline in this area with elevations of 140mAHD. There are several small drainage features to the east of The Bucketts Way that have incised into the landscape and ultimately drain into the Avon River. The elevations of the drainage features are approximately 110mAHD to the north of the rail loop and 120mAHD to the south of the rail loop. It is understood that excavation of Permian strata will be required for the rail loop which at a maximum will be removing approximately 22m of material to bring the railway elevation to approximately 114mAHD to 116mAHD.

Given the heavily incised nature of the geology in this area it is unlikely that groundwater will be encountered during the excavation of the rail loop cutting. If in the unlikely scenario that groundwater is encountered, it is likely to be very deep in this location (~20mbGL). This may result in the localised drawdown of approximately 2m in the Permian strata.

There is only one registered private bore (GW200330) in the area and this is located some 1km to the north of the cutting. This bore was drilled in 1905 to a depth of 50m and it is understood to be abandoned and no longer used. Based on a simple Theis equation a discharge of 1.3m^3/day from a groundwater formation of 0.5m^2/day with storage coefficient of 1 x 10^{-4} is likely to result in a drawdown of less than 1m at a bore 1km away after 10 years. The impact of this rail loop cutting on groundwater users is assessed to be negligible.

11.4 INFLOW TO MINE VOIDS

Flows into drain cells representing dewatering were extracted for each stress period to assess the rate of groundwater seepage to the open cut pits. The model simulated inflow rates to the Proposal are shown in **Figure 55**.

As shown in **Figure 55**, the simulated pit seepage rates were predicted for a quarterly time step and vary throughout the mining period. This variability and these peaks in inflow are directly related to the proposed mine plan, the seasonal (quarterly) application of recharge, the depth/thickness of saturated coal being mined, the quarterly application of drains to represent new mine development and the hydraulic gradients induced by the depressurisation of the coal seams. In reality, the measured seepage rate would not be expected to peak at the values predicted by the model simulation. A gradual strip mining method which would occur in reality, as opposed to the quarterly model removal of large blocks of coal and overburden will result in a more consistent seepage to the open cut pits.

Figure 56 shows the percentage of inflow associated with each of the open cut pits. During the first few years of mining (Years 1 and 2.25) the Weismantel and Bowens Road 2 Pits yield between 40% and 60% of the total inflow. Seepage into the Weismantel Pit continues to be a substantial proportion of pit inflow until Year 5. The Bowens Road 2 Pit seepage steadily declines from Year 2.5. The Avon Pit (between Years 4 and 8) provides up to 50% of total pit inflows, whereas inflow to Sub-pit 1 increases steadily during the early years of mining and provides between 50% to 70% of total seepage during Years 7 to 10. The percentage of total inflow from the Main Pit (formed from merging the Main Pit Sub-pit 1 and Main Pit Sub-pit 2), steadily increases to comprise 100% of inflow during the later stages of mining. The peak seepage rates predicted during Years 3 and 4.25 (4ML/day) occur when the Weismantel Pit, Avon Pit, Bowens Road 2 Pit and Main Pit Sub-pit 1 are all being mined.

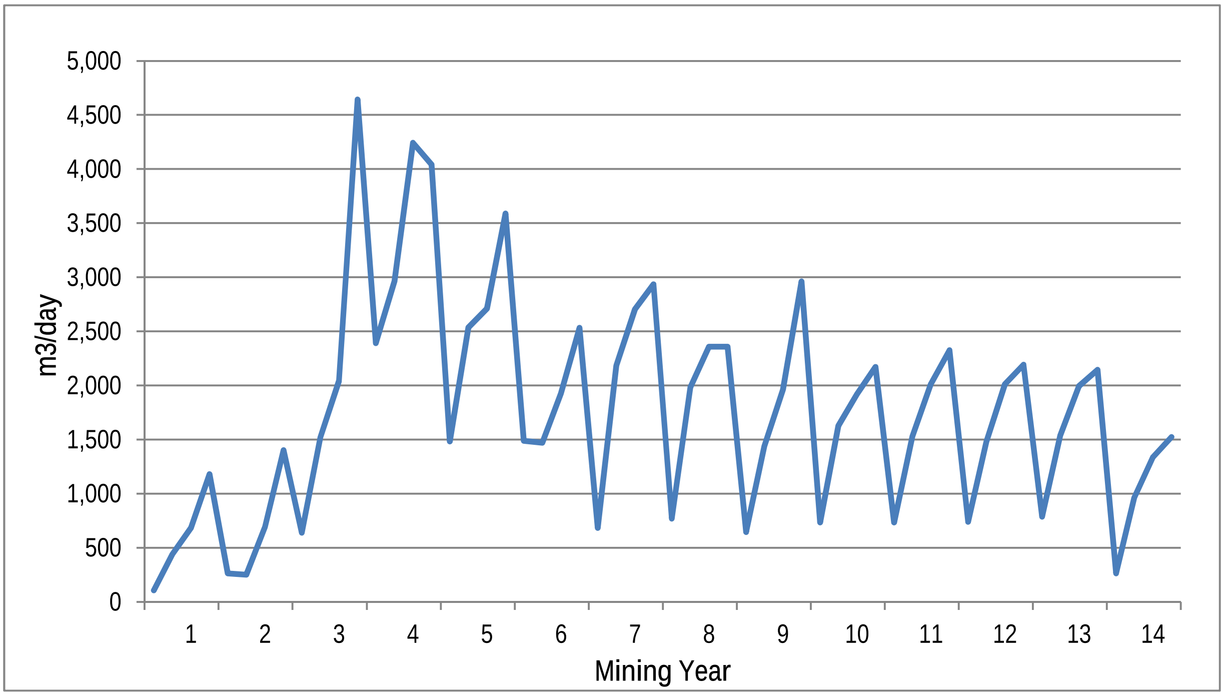


Figure 55 Simulated Seepage into the Rocky Hill Coal Mine – all Open Cut Pits

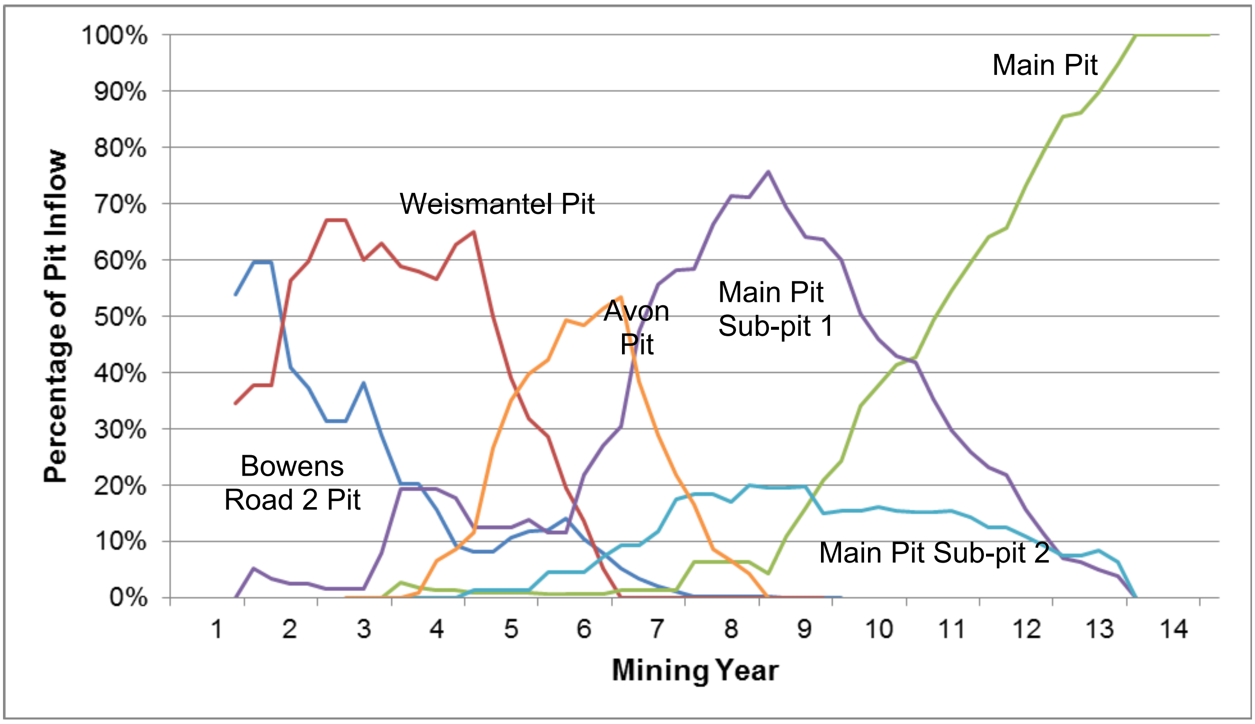


Figure 56 Proportion of Seepage into Individual Pits

From Year 7, groundwater inflow stabilises with an average rate of 1ML/day to 2ML/day. This stabilisation is due to the concentration of active mining within the Main Pit (Main Pit Sub-pit 1 and Main Pit Sub-pit 2). With the exception of the northern-most sections of the Avon Pit, the remainder of the other pits by Year 6 have been backfilled with overburden.

Typically the individual pit inflows vary from:

- Bowens Road 2 Pit 0.5 – 1.0ML/day;
- Weismantel Pit 0.5 – 1.5ML/day;
- Avon Pit 0.5 – 1.0ML/day;
- Main Pit Sub-pit 1 0.5 – 2.0ML/day;
- Main Pit Sub-pit 2 0.5 – 1.0ML/day; and
- Main Pit 0.5 – 2.0ML/day.

The annual simulated seepage volumes to the open cut pits are shown in **Figure 57** below. The predicted cumulative inflow of groundwater over the life of the mine is approximately 8,990ML, which is an average of 640ML/yr (20L/s) over an approximate 14-year mine life. The peak year is Year 4 when the seepage is predicted to be at 1,250ML/yr. Whilst **Figure 55** shows peak quarterly inflow occurring in Year 3, **Figure 57** represents an annual average which has the peak annual flow occurring in Year 4.

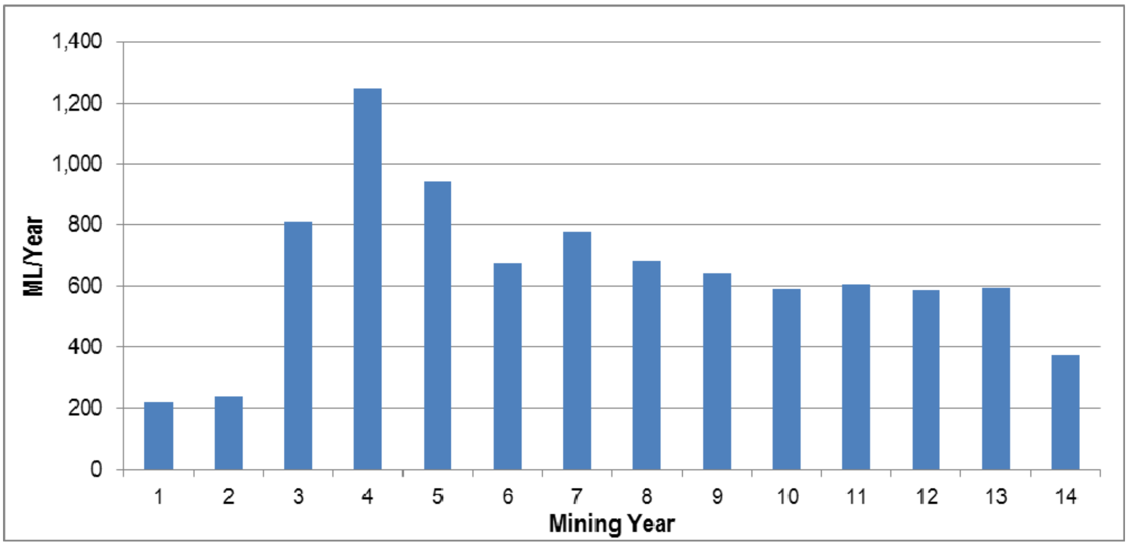


Figure 57 Simulated Annual Seepage

Based on experience, representing the pit dewatering with the drain package is likely to overestimate the predicted inflows to the mine. A portion of groundwater that seeps into the mine will be either evaporated from the coal face and interburden / overburden, or removed as moisture with the coal and overburden during mining. These mine water components (evaporation and moisture with the mined material) are typically small components of the overall water balance. However, as the coal seams within the Mine Area dip steeply, there will be a larger surface area of coal in the floor of the pit exposed to more direct sunlight compared with mines in the Hunter Valley. This larger surface area (estimated to be up to 60,000m^2) of steeply dipping strata is likely to result in greater evaporation of water not only from the exposed coal faces but also from the interburden and overburden material in the open pits. The potential evaporation over this area (1m/yr over 60,000m^2) could be up to 60ML/yr or 10% of the total predicted inflow volumes. The moisture content of the ROM coal is reported to be 5-7% of an average 2,000,000 tonnes/year (ROM coal), this is equivalent to 100ML/yr or 15% of the total predicted inflow volumes.

It is considered that the predicted inflows to the mine, and consequently the water required to be managed are likely to reduce by up to 25% after taking these factors into account.

11.5 IMPACT ON ALLUVIUM

Two model scenarios were generated to simulate the:

- cumulative impacts from the surrounding developments (AGL Gloucester Gas Project and the Stratford Coal Mine and Extension) only; and
- cumulative impacts from the surrounding developments and the Rocky Hill Coal Project.

These two scenarios were developed to determine the impact of the Proposal on the alluvial groundwater system.

The model representing the surrounding mine and CSG development (AGL Gloucester Gas Project and the Stratford Coal Mine and Extension) indicates that there is typically groundwater flow from the Permian strata to the Quaternary Alluvium (of Waukivory Creek and the Avon River). The model predicts there is a net upward flow entering the alluvium from the Permian strata. This volume of groundwater flow seasonally varies between 0.4ML/day to 0.6ML/day (**Figure 58**).

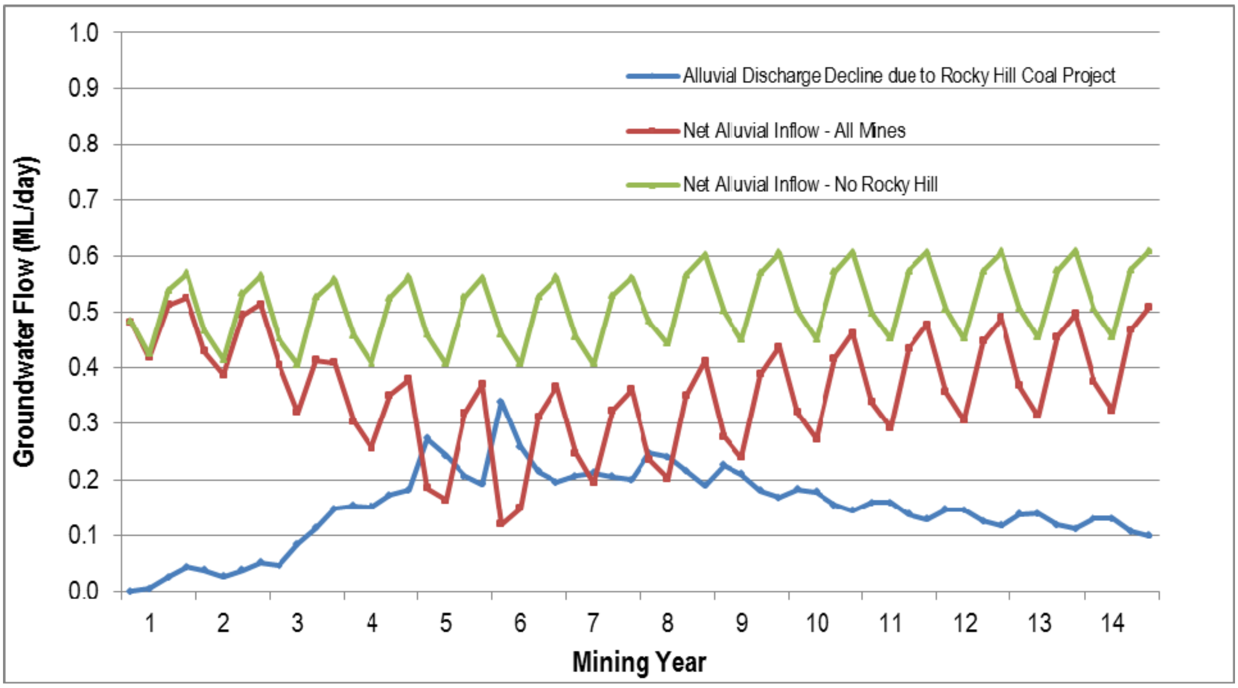


Figure 58 Simulated Net Flow to the Alluvium - Layer 1

For the scenario which includes the surrounding mine and CSG developments and the Rocky Hill Coal Mine, the volume of groundwater flow from the Permian strata to the Quaternary Alluvium decreases from an initial volume of 0.4ML/day to 0.6ML/day, to a volume of 0.1ML/day to 0.4ML/day. **Figure 58** shows that the volume of groundwater flow from the Permian strata to the Quaternary alluvium decreases as a result of the Rocky Hill Coal Project. The model implies that once mining commences the Permian strata depressurises and within the zone of influence, upward flow from the Permian to the alluvium reduces. This is due to changes in vertical gradients between the alluvium and Permian that reduces upward flow, and flow reversal to downward flow in areas adjacent to the mining areas.

The overall reduction in groundwater flow from the Permian strata to the Quaternary Alluvium due solely from the Proposal ranges between 0.05ML/day to 0.3ML/day. This reduction in flow occurs from Year 1 and reaches a maximum in Year 6. From Year 6, this flow reduction declines from the peak of 0.3ML/day to 0.1ML/day in Year 14. This trend in **Figure 58** indicates that the reduction in flow from the Permian to the alluvium is not solely due to mining of a single pit but relates to the mining of a number of pits, because:

- the Weismantel Pit and Bowen Road 2 Pit are developed early in the mine plan from Years 1 to 4 and mining in these pits progresses from the south to the north;
- the Main Pit Sub-pit 1 is mined from Years 2 to 6;
- the Avon Pit commences in Year 4 and continues through to Year 6;
- the Main Pit Sub-pit 2 is mined from Years 4 to 6;
- the Main Pit is developed from Year 7 and includes the development of the Main Pit Sub-pit 1 and Main Pit Sub-pit 2. The Main Pit is mined until Year 13/14.

From the above information, it is clear that Year 6 represents the period when the majority of the open cut pits are still active, resulting in the maximum reduction in groundwater flow from the Permian to the Quaternary Alluvium.

It is important to note that **Figure 58** presents the net predicted change in the groundwater flow rate from the Permian strata to the alluvium due to the Proposal. The majority of this water does not flow to the proposed open cut mining area, but it simply remains in the underlying Permian bedrock and is therefore not lost from the larger system. When mining is complete, the Permian strata start to repressurise and the predicted flow rate from the Permian basement to the overlying alluvium increases and returns to pre-mining rates over time. The alluvial flow reduction results as a combination of:

- reversal of groundwater flow at the margins of the pits resulting in inflow direct from the Quaternary Alluvium; and
- reduced hydraulic gradients from the Permian strata to the Quaternary Alluvium resulting in a reduction of flow.

The groundwater drawdown contours for Layer 1 do show some minor drawdown occurring in the Quaternary Alluvium adjacent to the open cut pits. This occurs in three areas:

- the southern portion of the Weismantel Pit where it intersects the alluvial sediments of Waukivory Creek. This drawdown in the alluvium occurs from Years 1 to 7, after which the groundwater levels in the Weismantel Pit and in the alluvium to the south of this pit recover after closure;
- the southern portion of the Avon Pit and the Bowens Road 2 Pit where it encroaches on the alluvial sediments of Waukivory Creek. The drawdown in the alluvium occurs from Years 5 to 7; and
- the south-western portion of the Main Pit where the access ramp encroaches on the Quaternary Alluvium. The drawdown in this area occurs from Years 5 to 13, however, the drawdown slowly diminishes over this mining period due to the progression of the Main Pit to the north and progressive backfill of the Main Pit with overburden.

The reversal of groundwater flow at the margins of the pits results in direct groundwater inflows from the Quaternary Alluvium in the order of 0.01ML/day to 0.12ML/day (**Figure 59**). This shows that the direct inflow from the alluvium comprises up to one third of the maximum net flow reduction to the alluvium.

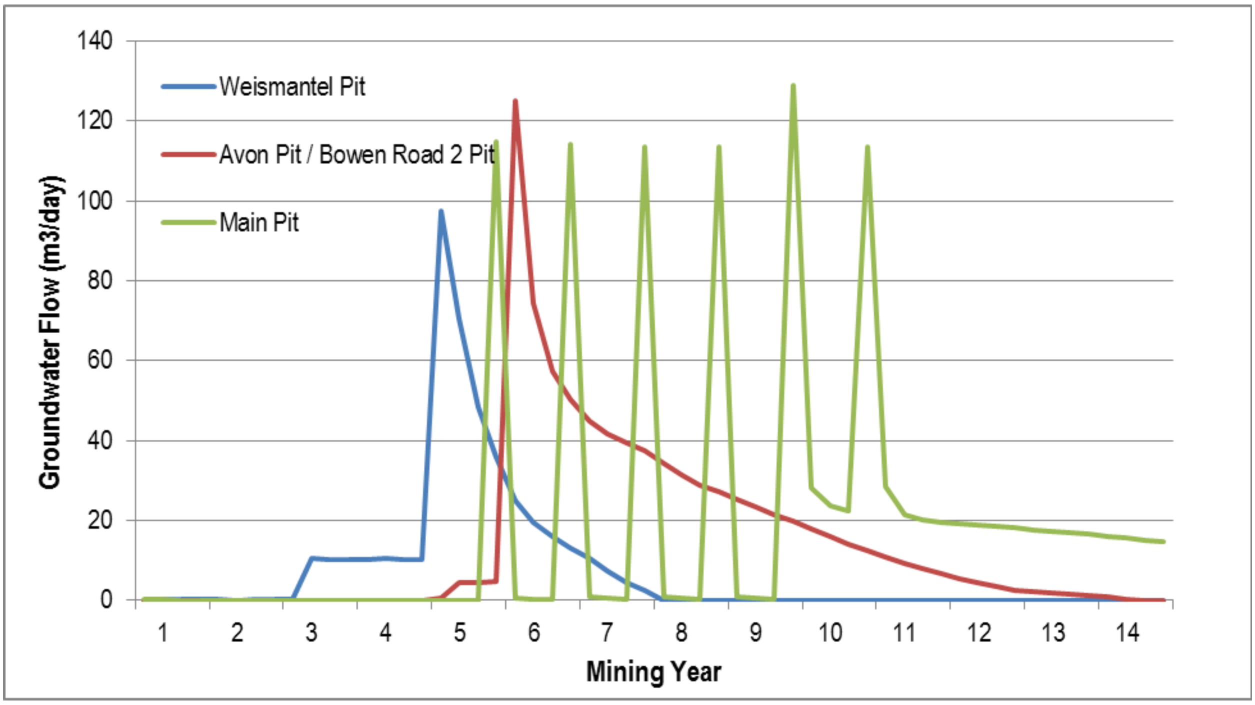


Figure 59 Modelled Inflow from the Quaternary Alluvium to Individual Pits

The cumulative predicted reduction of groundwater flow from the Permian strata to the Quaternary Alluvium directly attributable to the Proposal over the approximate 14-year mine life is 772ML. This is equivalent to an average annual volume of about 55ML/year or 0.15ML/day. This volume of water is equivalent to approximately 5% of the rainfall recharge simulated by the steady state model or less than 1% of the average baseflow component (20ML/day) of the Avon River measured at the NOW stream gauging station downstream of the Site. It is relevant that capture of groundwater from the Permian strata to the alluvium would prevent much higher salinity in the Permian strata from migrating into the lower salinity groundwater in the alluvium.

The numerical groundwater model included a coupled surface water model (MODHMS) and this software was chosen to provide a reliable calibration between groundwater and surface water systems. The calibrated model considered daily rainfall data whereas the predictive model reverted to averaged quarterly (three monthly) rainfall data. The climate boundary conditions used in the predictive model are considered coarse and whilst the groundwater flow reduction to the alluvium is presented as a model output, the groundwater model should not be used to assess the flow reduction to the surface water system. The surface water modelling carried out as part of the surface water impact assessment will include greater climatic data in the predictive model and will be fit for purpose to address any flow reduction in the surface water systems and any impact of this reduction on the downstream users of the resource.

11.6 GROUNDWATER DEPENDENT ECOSYSTEMS

Stygofauna

Stygofauna were sampled within the GRL groundwater monitoring bores. In total, 432 invertebrates from nine taxa were collected with only four individuals collected from the coal seam groundwater, representing less than 1% of total abundance. All of the taxa collected were either terrestrial or soil/water dwelling taxa that are not obligate stygofauna. Considering the very low populations of stygofauna sampled from the coal seam groundwaters, the depressurisation of the coal seam (**Figure 52** to **Figure 54**) is highly unlikely to cause impact to stygofauna.

Threatened Species Populations and Ecological Communities

The riparian zone along Waukivory Creek and the Avon River is predominantly River Oak, Cabbage Gum and Broad-leaved Apple. River Oaks are understood to be similar to River Red Gums and these species are likely to rely on groundwater from underlying formations. The predictive modelling indicates that the Proposal would not result in significant drawdown of groundwater levels in the Waukivory Creek and Avon River alluvium. For this reason, it is assessed that the potential groundwater dependent vegetation that has been identified along the riparian zone will not be impacted by the Proposal.

11.7 GROUNDWATER RECOVERY

After cessation of active mining operations in Year 14 and commencement of the backfilling and rehabilitation of the final void in the Main Pit, dewatering of the open void would no longer be required and a recovery in groundwater levels in the area will occur. The Main Pit is assumed to be backfilled to a level above the pre-mining groundwater levels.

Modelling of the backfilled overburden involved converting the final areas of mining into overburden and applying additional recharge to the overburden. An extended groundwater model run was carried out which allowed the groundwater levels within the pit footprint to recover to equilibrium.

The simulated water level recovery in the backfilled void is presented in **Figure 60**. The simulated groundwater level recovery is based on the monitoring bore GR-P5 which located within the final void area of the northern portion of the Main Pit.

The model shows that within the northern portion of the Main Pit, the groundwater levels would recover to an elevation of 117mAHD. As shown in **Figure 60,** the majority of the groundwater level recovery would occur in the initial 5 years post mining, with the backfilled void recovering to 76% of total predicted recovery after 5 years. The remaining recovery is predicted to take approximately 15 years (after mine closure) to stabilise.

Groundwater level recovery in the other pits (Weismantel and Avon Pits) is likely to occur quicker than that shown in **Figure 60**. Mining activities and backfilling in these pits will have occurred a number of years earlier than the closure and backfill of the Main Pit, allowing for groundwater level recovery to commence earlier.

The rate of groundwater recovery in the Mine Area is quicker than what is reported in the EIS for the SCM extension. From the information that has been provided by SCM in their groundwater impact assessment, groundwater level recovery post closure is predicted to take approximately 200 years to stabilise. This is a significantly longer timeframe than that predicted for the Proposal as SCM is proposing to leave final voids post closure whereas GRL is proposing to backfill the pits with spoil. An open void has significantly more volume to fill (100% porosity compared to 10%) and is also exposed to higher rates of evaporation. These factors will influence the rate of recovery post closure and explain the difference between the predictions of the two sites.

The predicted groundwater level at recovery (117mAHD) is higher than the original pre-mining groundwater level that is observed today (112mAHD to 113mAHD). This higher post closure water table compared to the pre-mining water table is a result of the higher recharge rate applied to the emplaced overburden. This higher recharge rate results in an overall increase in water level within the backfilled pit areas. The original surface elevation at monitoring bore site GR-P5 is 126.4mAHD indicating that the water table is still well below ground surface at this location.

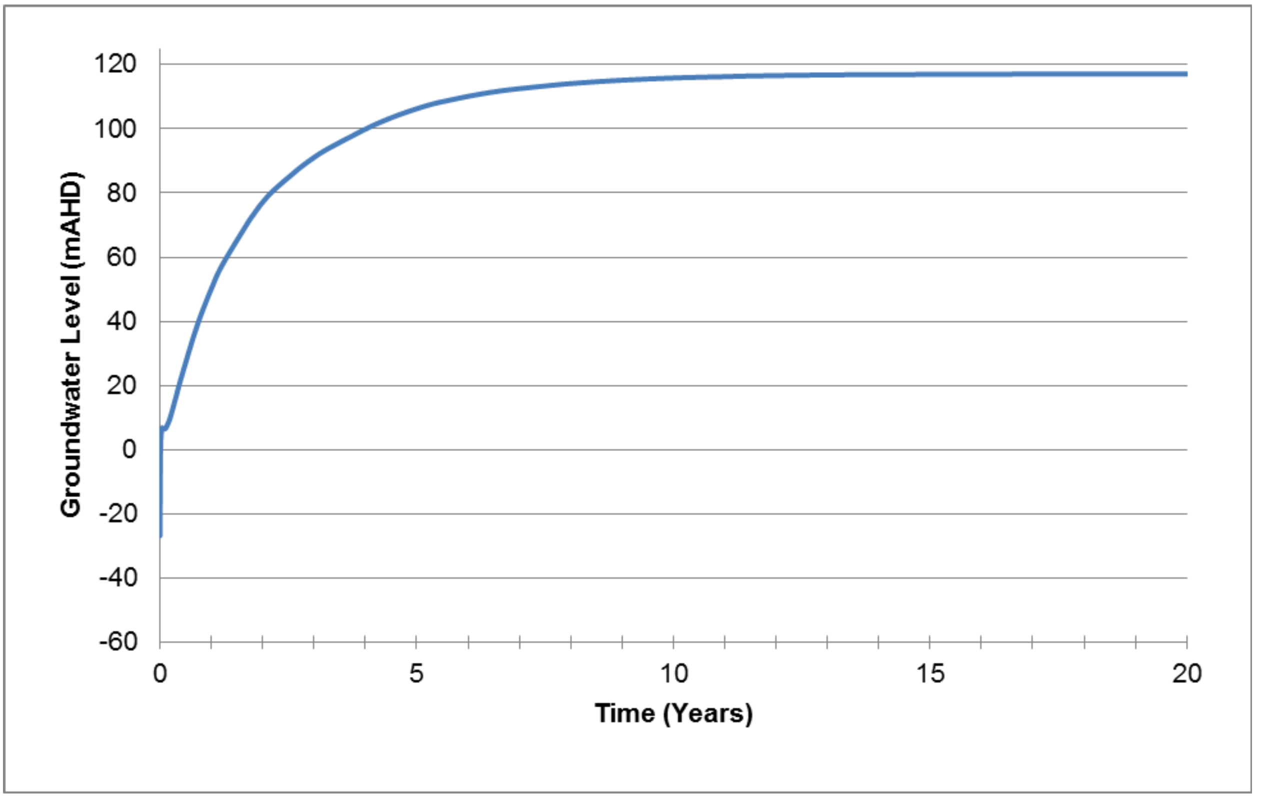


Figure 60 Simulated Water Level in Backfilled Main Pit

Figure 61 shows the post closure groundwater level contours in the Mine Area. The groundwater level contours show that within the area of the Main Pit, the groundwater levels are between 116mAHD and 118mAHD and tend to be relatively flat. This flat gradient is a result of the backfill of the pit with spoil which is assumed to have a higher hydraulic conductivity than in-situ material.

Groundwater level recovery is based upon long term recharge to the backfilled pits. If above average rainfall occurs, groundwater levels may rise above the final landform elevation. Sufficient drainage of the final landform will be required to allow for this.

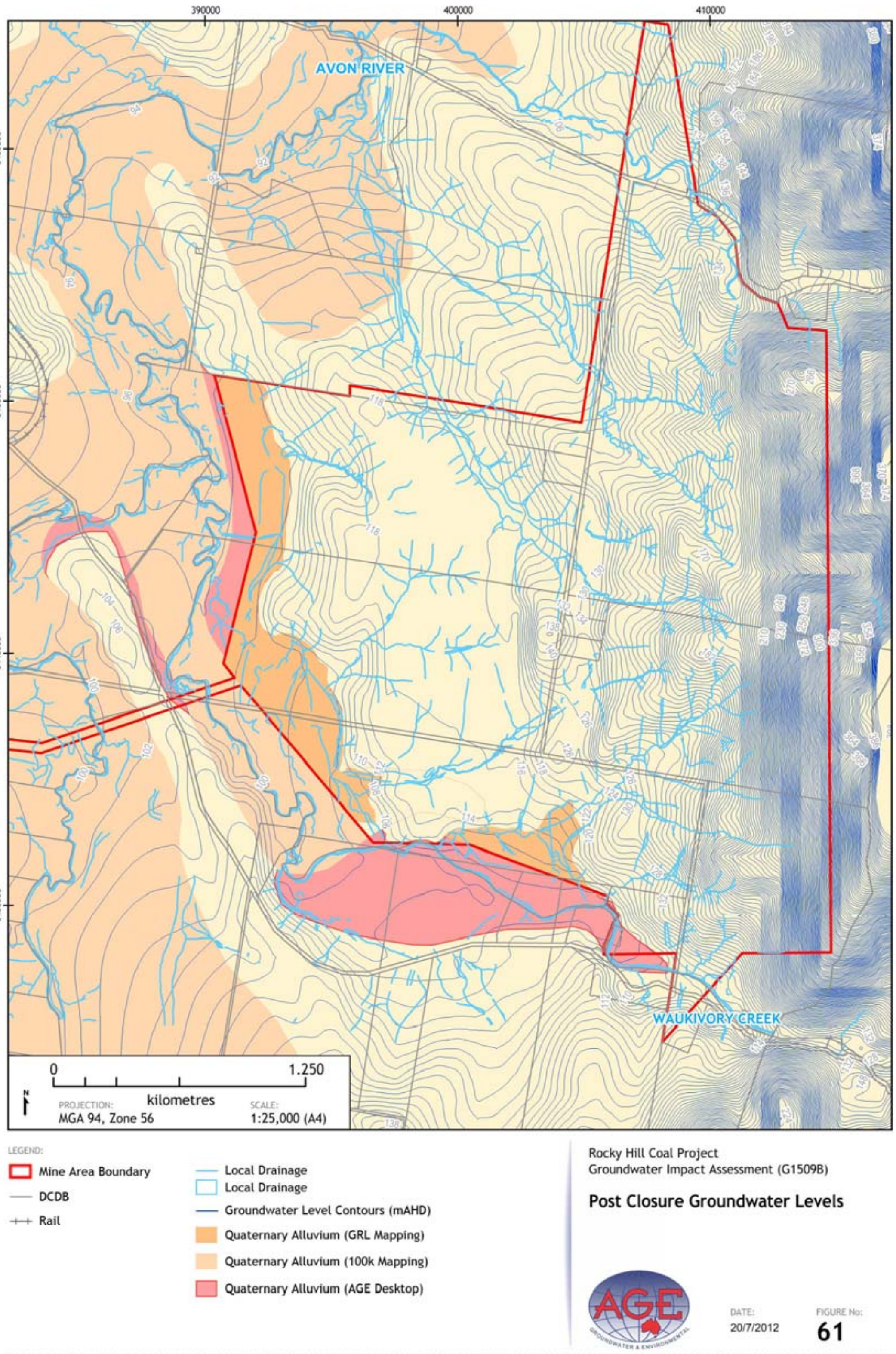
As a mine water management option, disused pits may be used for the short term storage of groundwater inflow and excess mine water. Whilst this has not been included in the predictive modelling this water management option is likely to result in the quicker recovery of groundwater levels within the disused and backfilled pits. This strategy has been considered further in the site water balance modelling.

11.8 UNCERTAINTY ANALYSIS

Parameter uncertainty was explored through additional model scenario runs using different parameters values. These parameters were considered potentially sensitive to the model calibration with impacts on predictive inflow values. The uncertainty analysis was conducted, along with calibration statistics, for both steady-state and transient models to examine whether the additional predictive runs were still within the calibration constraints (based on site specific data).

The following perturbations were assessed in the uncertainty analysis:

- a ±50% change in Kx1, the horizontal hydraulic conductivity of Layer 1 representing the alluvium and colluvium;
- a ±50% change in Kx3, the horizontal hydraulic conductivity of Layer 2 representing the overburden above the Cloverdale Coal Seam;
- a ±50% change in Kx4, the horizontal hydraulic conductivity of Layers 3, 5, 7 and 9 representing the major mined coal seams and minor interburden layers;
- a -50% change in Kx5, the horizontal hydraulic conductivity of Layers 4, 6, and 8 representing the major interburden layers and minor coal seams;
- a ±50% change in Sc1, the specific storage of Layer 1 representing the alluvium / colluvium and regolith;
- a +100% change in Sc3, the specific storage of Layers 2, 4, 6 and 8 representing the major interburden layers and minor coal seams;
- a +500% change in Sc4, the specific storage of Layers 3, 5, 7 and 9 representing the major mined coal seams and minor interburden layers;
- a ±50% change in Sy1, the specific yield of Layer 1 representing the alluvium / colluvium and regolith;
- a -50% change in Sy3, the specific yield of Layers 2, 4, 6 and 8 representing the major interburden layers and minor coal seams;


390000
400000
410000
6460000
6450000
6440000
6430000
AVON RIVER
WAUKIVORY CREEK
0
1,250
kilometres
PROJECTION:
MGA 94, Zone 56
SCALE:
1:25,000 (A4)
LEGEND:
Mine Area Boundary
DCDB
Rail
Local Drainage
Local Drainage
Groundwater Level Contours (mAHD)
Quaternary Alluvium (GRL Mapping)
Quaternary Alluvium (100k Mapping)
Quaternary Alluvium (AGE Desktop)
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Post Closure Groundwater Levels
DATE:
20/7/2012
FIGURE No:
61

- a +50% change in Sy4, the specific yield of Layers 3, 5, 7 and 9 representing the major mined coal seams and minor interburden layers;
- a +100% change in the Overland Flow (OLF) leakance for the alluvial zone, representing recharge rate to the alluvium;
- a -50% change in the OLF leakance for the hill zone, representing recharge rate to the elevated terrain to the east of the Mine Area;
- a ±50% change in channel bed leakage representing transfer of flow from the MODHMS channel package to the underlying groundwater model layer; and
- a ±10% change in the mean quarterly rainfall value applied across the model domain.

Table 22 summarises the variation of key model outputs with changes in the listed model parameters. These model outputs are shown in **Figure 62** and **Figure 63**. The uncertainty analysis shows limited change to the steady state model calibration as a result of amending the model hydraulic conductivities. The RMS and SRMS are within 0.5m and 1% of the base-case model results respectively. The base-case model results in a cumulative inflow to the pit of approximately 9,000ML. The 21 model sensitivities result in cumulative inflows ranging from 8,216ML to 9,207ML (9% reduction and a 2% increase) over the duration of the 14-year mine life. This uncertainty analysis indicates that the base-case numerical model predicts in the upper range of likely inflows and in this regard is considered conservative. Mean quarterly inflow for the uncertainty analysis is also present and shows a similar pattern in response to the parameter changes. The mean inflow in the base-case model is 1.759ML/day and this ranges between 1.607ML/day and 1.801ML/day in the uncertainty analysis. Once again the base-case inflow is in the upper range of inflows predicted during the uncertainty analysis.

The largest increase in the predictive model budget occurred when varying the specific yield of Layer 1 in the model by +50% (Case 12). The largest reduction in the predictive model budget occurred in Case 7 which involved reducing the horizontal hydraulic conductivity of Layers 4, 6, and 8 representing the major interburden layers and minor coal seams.

Cases 5 and 6 relate to a ±50% change in Kx4, which represents the horizontal hydraulic conductivity of Layers 3, 5, 7 and 9 (the major mined coal seams and minor interburden layers) in the model. The results of these sensitivities show mean and cumulative inflows of 92% and 102% of the base-case model.

Table 22
Summary of Model Uncertainty Analysis

Parameter			RMS	SRMS	Mean Inflow	Min Inflow	Max Inflow	Cumulative Inflow
Units			**m**	**%**	**ML/day**	**ML/day**	**ML/day**	**ML**
Baseline			**1.98**	**4.4%**	**1.759**	**0.104**	**4.677**	**8994**
1	Kx1	50%	2.00	4.5%	1.732	0.103	4.825	8857
2	Kx1	-50%	1.95	4.3%	1.724	0.105	4.206	8814
3	Kx3	50%	2.08	4.6%	1.789	0.103	4.920	9149
4	Kx3	-50%	2.40	5.4%	1.697	0.106	4.606	8676
5	Kx4	50%	2.03	4.5%	1.800	0.106	4.664	9207
6	Kx4	-50%	2.00	4.4%	1.620	0.105	4.497	8285
7	Kx5	-50%	2.05	4.6%	1.607	0.109	5.158	8216
8	Sc1	50%	-	-	1.740	0.104	4.131	8898
9	Sc1	-50%	-	-	1.737	0.104	4.213	8880
10	Sc3	100%	-	-	1.765	0.104	4.812	9026
11	Sc4	500%	-	-	1.767	0.105	5.216	9035
12	Sy1	50%	-	-	1.801	0.125	5.521	9209
13	Sy1	-50%	-	-	1.660	0.071	3.441	8488
14	Sy3	-50%	-	-	1.730	0.104	4.044	8845
15	Sy4	50%	-	-	1.783	0.104	5.365	9117
16	OLF Leak (alluvium)	100%	-	-	1.751	0.104	4.106	8957
17	OLF Leak (hills)	50%	-	-	1.738	0.104	4.431	8889
18	Channel Bed	50%	-	-	1.770	0.104	4.683	9053
19	Channel Bed	-50%	-	-	1.721	0.104	4.238	8801
20	Rainfall	10%	-	-	1.779	0.107	3.945	9097
21	Rainfall	-10%	-	-	1.673	0.099	4.374	8553

Note: Kx = hydraulic conductivity, Sc = Storage Coefficient, Sy = Specific Yield, OLF = Overland Flow
RMS = Root Mean Square residual – a measure of the difference between modelled and predicted values
SRMS = Scaled RMS - ratio of the RMS error to the total head change
Case 1 to Case 7: Kz was changed with the same factor due to the fixed ratio of 1:10
Case 5 and Case 6: only Kx4 changed; depth of cover, cut-off depth and Kx-Kz ratio assumed to be the same as the base case

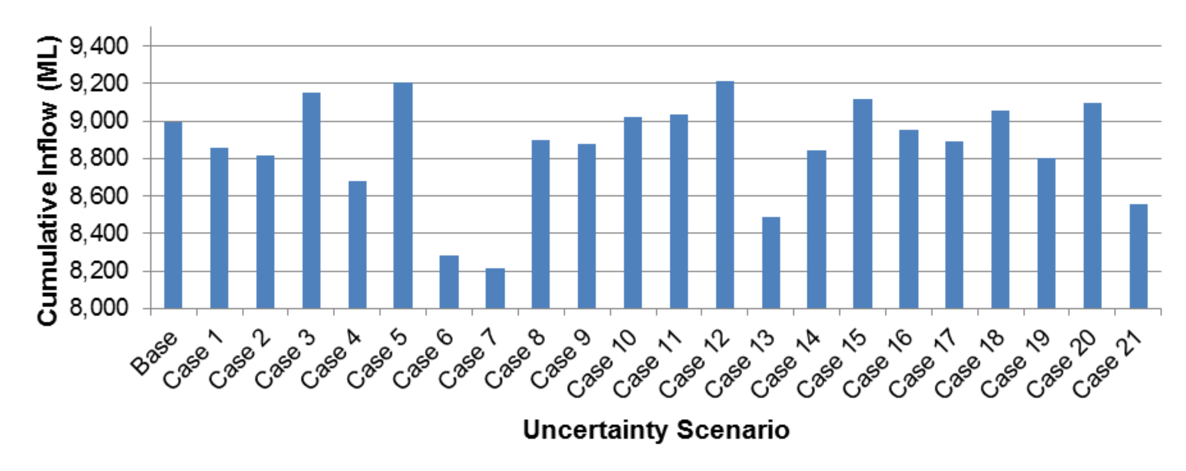


Figure 62 Uncertainty Analysis – Cumulative Inflow

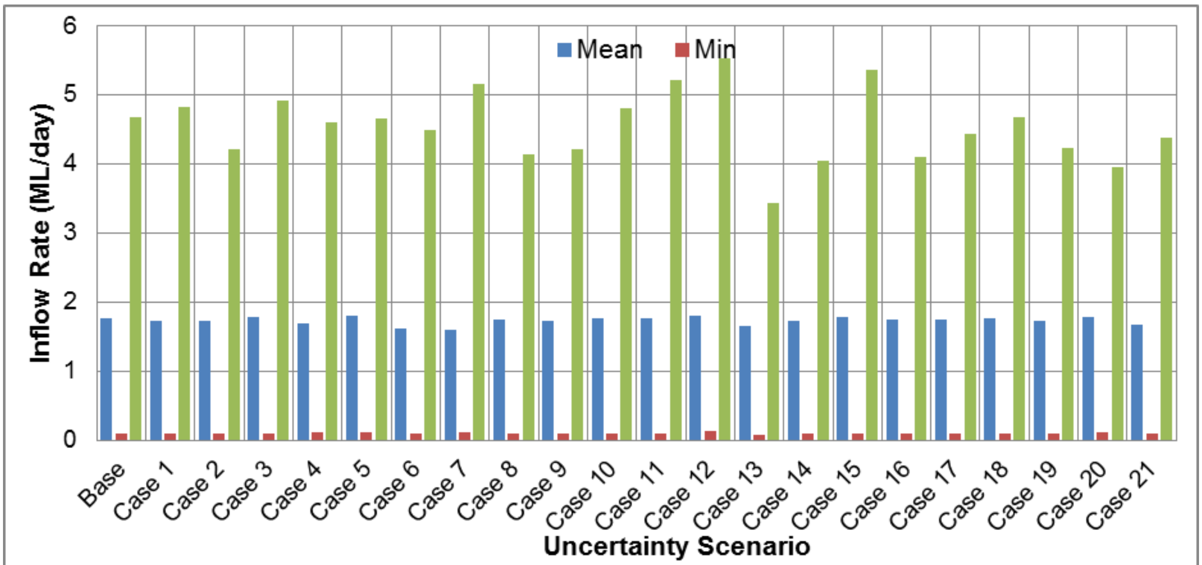


Figure 63 Uncertainty Analysis – Inflow Rate

11.9 MODEL UNCERTAINTY AND LIMITATIONS

Development, calibration and the results of predictive simulations from any groundwater model are based on available data characterising the groundwater system under investigation. It is not possible to collect all the data characterising the whole groundwater system in detail and therefore a number of various assumptions have been made during the development of the groundwater model. Where an assumption was necessary, a conservative approach was taken, such as adopting model parameters from plausible ranges, so that the model would likely over predict impacts or be representative of the worst case scenario. These assumptions and their impact on the simulation results are discussed in this report.

The model assumed that the hydraulic properties of the layers were uniform across the entire model domain. In reality, the permeability of the groundwater system is variable and this variability can result in a less uniform zone of depressurisation than that predicted by the numerical model. Faults and structures were not included in the model development as the inclusion of any structures would complicate the model. It is our understanding that in the current region where mining has occurred, there has been no reported incidence of increased groundwater inflow or influence on potentiometric levels associated with fault zones. The main sources of groundwater flow have been identified as the Quaternary alluvial sediments and Permian coal seams and these have been simulated using homogenous model layers.

The major coal seams at the Site were grouped into four model layers for the purposes of simplifying a complex geological system into a numerical groundwater model. In reality these coal seams have minor interburden layers which would have the result of reducing coal seam permeability.

The numerical model has been developed as a conservative impact assessment tool and is not required to include complex geological structure. The model adopts a conservative approach and has been based upon a sound conceptual model and a suitable steady state and transient calibration. The model has been verified / validated against a transient dataset and is considered to be more than suitable for predicting impacts of the Proposal.

The conceptual and numerical model were peer reviewed by Kalf and Associates Pty Ltd (KA). This peer review is included in **Appendix 6** which expresses KA's agreement with the key issues presented in this report.

11.10 MODEL CONCLUSIONS

The results of the modelling are summarised below:

- The predictive modelling indicates that seepage rates to the open cut pits are likely to peak at 4ML/day during Years 3 and 4 of the mining operations. However, as the model is conservative this maximum seepage rate is more likely to be in the order of 3ML/day. Seepage will stabilise to an average rate of 1ML/day to 2ML/day from Year 6 to Year 14.
- The predictive model indicates that the zone of depressurisation attributable to the Proposal is likely to expand to the north and south of the open cut pits with limited depressurisation occurring to the east and west. The depressurisation is limited to the Permian coal seams and typically follows the strike of the Permian strata.
- The model predicts that there will be a reduction in groundwater flow from the Permian strata to the Quaternary Alluvium. Without mining at Rocky Hill this groundwater flow is modelled to be approximately 0.4ML/day to 0.6ML/day. With mining at the Rocky Hill Coal Project this groundwater flow is predicted to reduce by up to 0.3ML/day (peak reduction in Year 6) with typical reductions in groundwater flow to the alluvium of 0.1ML/day to 0.2ML/day toward the latter half of mining operations.

- There are three private registered groundwater facilities that are located within the Layer 5 zone of influence, however, one of these bores is understood to be an abandoned and destroyed shallow well excavated into Quaternary Alluvium (Layer 1). Layer 1 shows no water level drawdown at this Site and hence no impact from the Proposal. The two remaining bores are drilled and constructed into Permian sediments and are relatively shallow (50m and 60m depth respectively). The depths of these bores suggest that they are likely to be represented by the model Layer 2 which shows no depressurisation or impact from the Proposal. Therefore the model predicts that no groundwater users will be impacted by the Proposal. It is understood that one of these registered bores (GW200330) has been abandoned and the other (GW080487) is still usable however it is not currently in use.

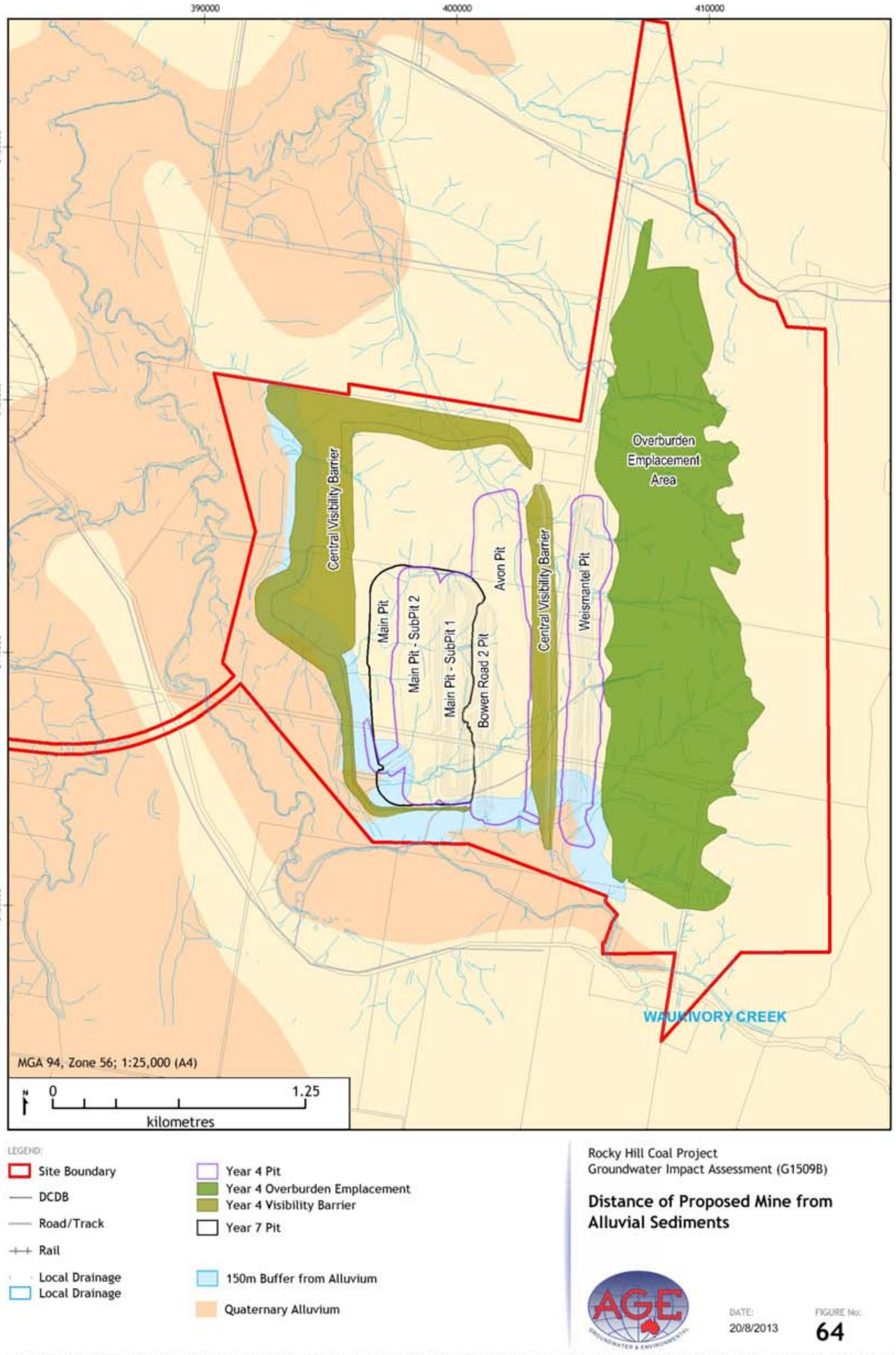
12. MITIGATION

Figure 64 shows a 150m buffer zone on the alluvial sediments of Waukivory Creek and the Avon River. The Rocky Hill mine development encroaches on this 150m buffer zone and in some instances encroaches on the alluvial sediments themselves. Section 11.5 discusses the impact of the Proposal on the Quaternary Alluvium. The model predicts a reduction in groundwater flow from the Permian strata to the Quaternary Alluvium of 0.1ML/day to 0.3ML/day and of this flow reduction, up to one third (0.12ML/day) of this is likely to flow directly from the alluvial sediments into the pits. This inflow is predicted to occur in the following locations:

- the southern portion of the Weismantel Pit where it intersects on the alluvial sediments of Waukivory Creek;
- the southern portion of the Avon Pit and the Bowens Road 2 Pit where it encroaches on the alluvial sediments of Waukivory Creek; and
- the south-western portion of the Main Pit where the access ramp encroaches on the Quaternary Alluvium.

Cut-off grout curtains have been successfully implemented in the Hunter Valley at the Coal and Allied operations Hunter Valley Operations North Complex (HVO North). At HVO North, there have been two types of artificial structures that have been constructed. The first structure involved excavating a substantial trench into alluvial sediments and this trench was then backfilled with grout slurry and topped with a compacted raised wall which serves as a flood levee. The second type of structure at HVO North involves clay capping and infill on a benched highwall. This clay capping covers alluvial sediments and also Permian strata beneath the alluvial sediments. Both styles of artificial structures have been/are successful in reducing the hydraulic conductivity of the alluvial sediments adjacent to an open cut pit operation.

Another type of cut-off grout curtain has been successfully implemented at the Ashton Coal Mine in the Hunter Valley. It is understood that the technique employed at Ashton involved the injection of grout within the coal seam which has resulted in a reduction of groundwater inflow and a resultant groundwater level and pressure recovery. This method is believed to involve the injection of grout under pressure into the target formation. This results in a reduction of hydraulic conductivity to form an effective barrier to groundwater flow.


390000
400000
410000
6460000
6450000
6440000
6430000
Central Visibility Barrier
Overburden Emplacement Area
Main Pit
Main Pit - SubPit 2
Main Pit - SubPit 1
Bowen Road 2 Pit
Avon Pit
Central Visibility Barrier
Weismantel Pit
WAUKIVORY CREEK
MGA 94, Zone 56; 1:25,000 (A4)
0
1.25
kilometres
LEGEND:
Site Boundary
DCDB
Road/Track
Rail
Local Drainage
Local Drainage
Year 4 Pit
Year 4 Overburden Emplacement
Year 4 Visibility Barrier
Year 7 Pit
150m Buffer from Alluvium
Quaternary Alluvium
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Distance of Proposed Mine from Alluvial Sediments
DATE:
20/8/2013
FIGURE No:
64

Whilst a series of cut-off grout curtains or similar can feasibly be constructed in the areas of the pits which encroach on the alluvial sediments of Waukivory Creek, these structures are likely to result in a small reduction of flow in the order of 0.1ML/day (1L/s) and are not recommended. The structures are likely to involve considerable cost associated with the engineering design and construction for the benefit of reducing inflows to the pit of 0.1ML/day. These pit inflows represent peak flows and are predicted to occur over a 1 – 2 year period rather than a longer term sustained seepage. Therefore any grout curtain would have a short term effect and would be superfluous in the long term. The saving of 0.1ML/day flow reduction from the alluvium is considered insignificant when compared with the long term baseflow component of the Avon River (20ML/day) and represents 0.5% of baseflow in the downstream surface water system. Also, GRL currently hold sufficient water licences under the Water Sharing Plan to offset any reduction in flow to the alluvium. The construction of a grout curtain is likely to require a significant volume of water for construction purposes (i.e. for compaction of clay material to the necessary engineered standards). This additional water requirement for the construction of the mitigation infrastructure would comprise a significant component of the groundwater inflow it would be designed to reduce, hence further reducing the effectiveness of such infrastructure in the overall site water balance.

A groundwater monitoring network designed to monitor groundwater levels and quality in all key groundwater systems has been provided in Section 15.

13. WATER QUALITY

The following discussion relates to a qualitative assessment on likely changes to groundwater quality over time as a result of the Proposal.

Baseline groundwater monitoring indicates that the EC of groundwater in the Permian coal seams and overburden / interburden material varies typically between 2,470µS/cm and 7,480µS/cm across the Site. This Permian groundwater ultimately discharges into the Quaternary Alluvium and this is observed along the margins of the alluvium in monitoring bores GR-P1, GR-P2 and GR-P3 where groundwater quality ranges between 5,000µS/cm and 6,450µS/cm for GR-P1, 1,003µS/cm and 1,885µS/cm at GR-P2 and 3,110µS/cm and 3,880µS/cm for GR-P3. Monitoring bores GR-P10 and GR-P11 are located close to Waukivory Creek and exhibit fresh quality groundwater in the range of 589 - 594µS/cm and 1,629 – 1,642µS/cm respectively. The water quality in the margin of the alluvium gradually decreases with depth in the saturated alluvial profile. This water quality data indicates that there is currently similar water quality in the margins of the alluvium as there is in the Permian groundwater systems. The water quality is highly likely to be influenced by flow from the Permian groundwater systems.

Kinetic leach column tests were carried out on five composite overburden/interburden samples and three composite coarse reject samples. These samples are considered to be representative of backfilled overburden material and reject material from the coal handling and preparation plant (CHPP). The kinetic leach testing indicates that the EC value of leachate from the overburden/ interburden samples ranged from 34.8µS/cm to 304µS/cm, and the EC of leachate from the coarse reject samples ranged from 568µS/cm to 4,900µS/cm (RGS Environmental, 2013). Whereas pH of leachate from the five overburden/interburden samples ranged from 6.17 to 8.85 and was significantly higher than pH of leachate from the three coarse reject samples (2.52 to 4.18).

The ratio of overburden versus reject material is likely to be 3:1 or 4:1 and hence the quality of leachate from the backfilled pits is likely to be skewed toward the kinetic leach test results presented for the overburden/interburden samples (i.e. 34.8μS/cm to 304μS/cm).

The process of mining the coal seams and progressively backfilling the pits with overburden and reject material is likely to have the following effects:

- A slight improvement in quality of the seepage water is likely to occur due to an increased component (up to 8% of total pit seepage) of alluvial inflow to the pits;
- The presence of backfilled overburden within the open cut pits will allow an increased percentage of rainfall to infiltrate to the groundwater system as recharge;
- There is likely to be limited liberation of solute from the recently backfilled overburden and reject material in the pits principally due to the method of placement and effective encapsulation of the reject material. This solute will be mobilised by the infiltration of enhanced recharge in the backfilled overburden resulting in leachate in the backfilled pits. This leachate is likely to comprise a mix of relatively fresh groundwater (<300μS/cm from the overburden / interburden material) and brackish groundwater (<4,900μS/cm from the coal rejects). However, it is likely that the EC will be more representative of the overburden /interburden material;
- The increased recharge component will yield better quality water (leachate) due to the increased component of fresh (low EC) rainfall infiltrated water mixing with the predicted solute concentrations from the kinetic leach testing. This leachate is highly likely to have a lower EC compared against the baseline groundwater in the Permian coal seams and interburden / overburden material; and
- The post closure groundwater levels are predicted to recover to levels similar to pre-mining conditions, and it is highly likely that pre-mining groundwater flow conditions will re-establish. Flow of groundwater from the Permian strata to the Quaternary Alluvium will re-establish under post closure conditions, and given the higher component of rainfall recharge in the local groundwater budget and the likely lower EC of this post-mining groundwater compared with the pre-mining Permian groundwater, the quality of groundwater ultimately discharging to the Quaternary Alluvium is expected to improve slightly.

Whilst specific kinetic or leachate testing of fine rejects has not been carried out, it is expected that water quality from the fine rejects generated in the CHPP would be comparable to that predicted for the coarse rejects. RGS (2013) states that "*the risk of potentially significant water quality impacts from overburden/interburden and potential coal reject materials is low. In contrast, there is some potential for water quality impacts form coarse (and potentially fine) reject, if appropriate management measures are not adopted for these materials*". The rejects from the CHPP would be a blend of both coarse and fine materials and contain a proportion of residual process water typically at approximately 20%. During the first 3 years of the mining operations, the blended fine and coarse rejects would be co-disposed with overburden within the permanent out-of-pit emplacement east of the Weismantel Pit and covered within 7 days, or sooner. All rejects within the out-of-pit overburden emplacement would ultimately be covered by at least 10m of overburden. From about Year 4 onwards, all rejects would be co-disposed with overburden in an exhausted section of an open cut pit, commencing in the Weismantel Pit.

This encapsulation of the rejects within the out-of-pit emplacement will serve two purposes.

1. To minimise and reduce the rate of infiltration or seepage into the fine rejects by providing a low permeability barrier.
2. To limit the availability of oxygen to the rejects material to reduce the potential for acid generation.

Providing the rejects are stored in this manner, the potential for groundwater impact associated with the proposed co-disposal of rejects in the permanent out-of-pit waste rock emplacement is considered very low. Allowing for the comparatively steep topography of the out-of-pit emplacement landform, the rate of rainfall infiltration through the out-of-pit emplacement is likely to be low with a greater proportion of runoff. A compacted layer within the landform will shed any infiltrated groundwater before it reaches the fine rejects.

All rejects material stored within the exhausted open cut pits are likely to result in water quality similar to those presented for the process of progressively backfilling the pits with overburden and reject material.

The post closure groundwater quality change in the Mine Area is different to that reported in the EIS for the SCM extension. From the information that has been provided by SCM in their groundwater impact assessment, groundwater quality (in particular salinity) post closure in the final voids is predicted to increase through evaporative concentration. This conclusion is different to that presented for the Rocky Hill Coal Project and is related to the final landforms that are proposed at the two sites. SCM proposes several final voids in which groundwater salinity will be concentrated over time due to evaporation whereas GRL propose backfilled voids which will not be subject to this evaporative process. Hence, post closure groundwater salinity for the Proposal is not predicted to increase over time.

There is potential for hydrocarbons spills at the mine workshop, waste disposal and fuel storage areas. However, adequate bunding and immediate clean-up of spills (which is a legislated requirement at mine sites) is likely to prevent contamination of the groundwater systems. Spills such as these are typically very small (less than 100L) and localised in extent. Occurrence of these spills usually triggers an internal environmental investigation, however, these are typically not regionally significant.

14. WATER LICENCING

The numerical modelling predicts an average groundwater seepage rate to the open cut pits of 640ML/year with a peak of up to 1,250ML/year. The groundwater seepage into the proposed mine will also result in a reduction in the volume of groundwater flow from the Permian bedrock into the Quaternary Alluvium. The model predicts an average reduction of flow to the alluvium of 55ML/year during the 14-year mining period with a maximum of 91ML/year in Year 6. On average, the reduction of flow to the alluvium represents approximately 8% of the total inflow to the open cut pits.

The groundwater seepage into the proposed mine is largely sourced (92% or a long term average of 585ML/yr) from storage in the Permian overburden / interburden and the coal seams and a water licence under the *Water Act 1912* will be required to offset these seepage losses.

Licensing under the *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources* will be required to account for the reduction of flow to the alluvium (55ML/yr). Currently GRL holds a total of 267 unit shares or 267ML/yr under the Water Sharing Plan. This entitlement is well in excess of the predicted 55ML/year (long term average) required to offset the loss of recharge to the alluvium under the *Water Management Act 2000*.

It must be noted that the short term (14 year) reduction of groundwater flow from the Permian strata into the Quaternary Alluvium is expected to result in an improvement of groundwater quality in the alluvial sediments. The Permian groundwater has EC measured in the range of 2,500µS/cm to 7,500µS/cm whereas the Quaternary Alluvium has measured EC in the range of 600µS/cm to 1,900µS/cm. At the margin of the alluvium, ECs of up to 6,000µS/cm have been measured, however it is assessed that these levels are maintained by the flow of groundwater from the Permian strata. A reduction in groundwater flow from the Permian to the alluvium will result in increases to the alluvial water balance components of rainfall recharge and streamflow recharge. This will provide an increased component of fresh quality groundwater which is likely to result in the short term improvement in alluvial groundwater quality.

This short term improvement in groundwater quality is likely to persist post-mining. Flow of groundwater from the Permian strata to the Quaternary Alluvium will re-establish under post closure conditions. Given the higher component of rainfall recharge to the backfilled pits and the likely lower EC of this post-mining groundwater compared with the pre-mining Permian groundwater (Section 13), the quality of groundwater ultimately discharging to the Quaternary Alluvium is expected to slightly improve.

15. GROUNDWATER MONITORING SYSTEM

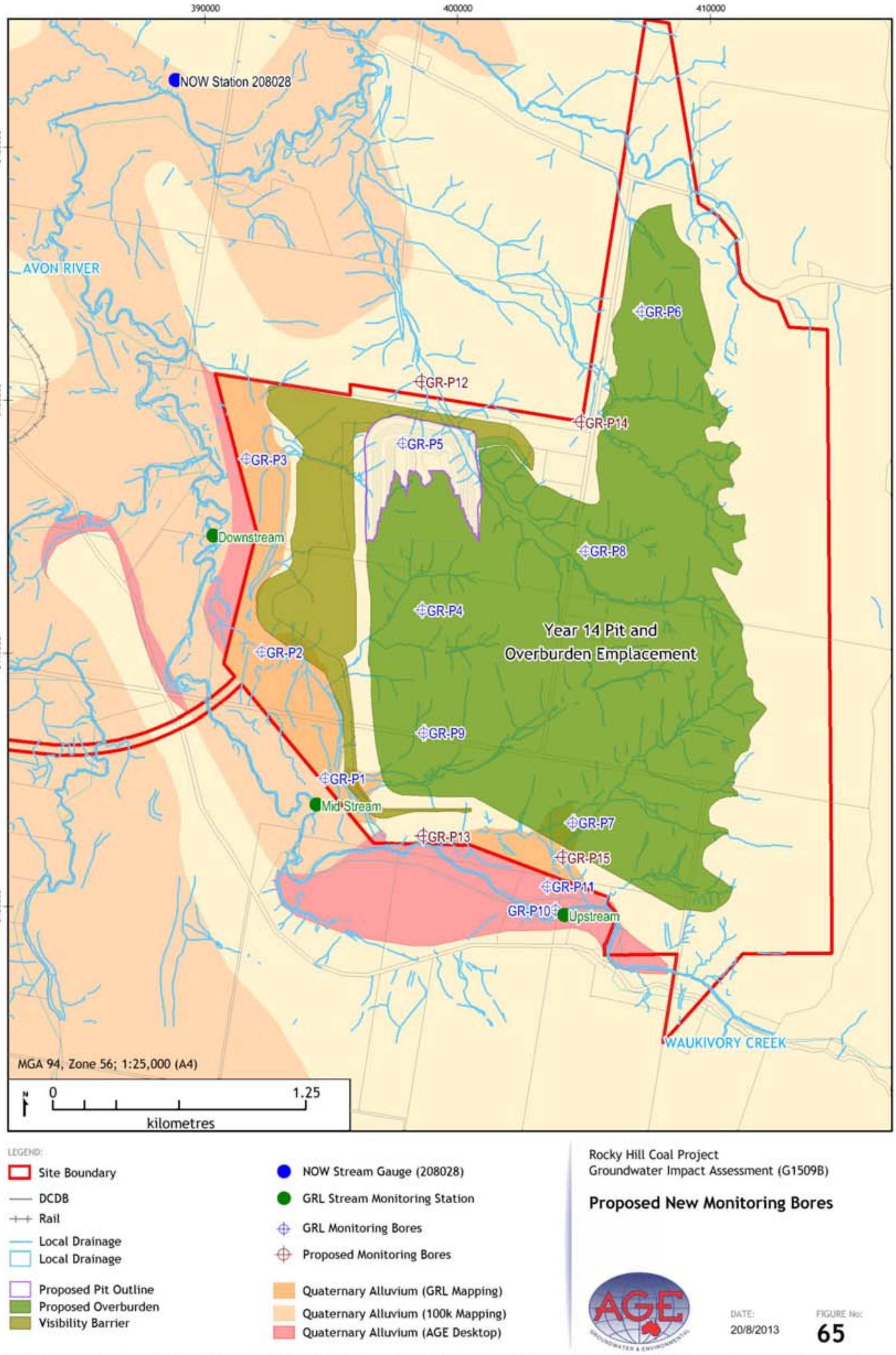
This section of the report provides a recommended groundwater monitoring program that will provide both an on-going assessment of the impact of the Proposal, a proactive indicator of any adverse impacts on the groundwater regime and a baseline dataset with which to validate the numerical groundwater model.

The existing monitoring network of bores and groundwater database has been established since February 2011 i.e. 13 bores were developed in February 2011 and 2 further bores developed in June 2012. Currently the groundwater levels are monitored every 6 hours using dedicated data-loggers in each of the monitoring bores. These data-loggers are downloaded every quarter with manual measurements taken every month for verification and calibration. Groundwater quality samples have been collected at least monthly, and fortnightly on some occasions, and analysed at a NATA approved laboratory. This groundwater data is compiled by an experienced hydrogeologist into a database for analysis and reporting. Every quarter the groundwater levels and quality parameters are assessed to discuss the results and any trends. An annual report is also prepared which synthesises all data collected during the year. This annual report includes trend analysis and discussion on quality control and assurance (**Appendix 3**).

The data collected to date is considered by AGE to be adequate and suitable for the assessment and description of the existing environment, this is addressed in Section 7. The data has enabled a numerical model to be calibrated to a transient dataset that is representative of baseline conditions. This transient calibration takes into account the various recharge conditions that occur to the groundwater and surface water systems (Section 10) and allows for surface and groundwater interactions to be simulated. This model has then been used to predict impact to the groundwater systems from the Proposal. The existing monitoring network is considered suitable for the on-going monitoring of baseline conditions in the Mine Area. This baseline data will provide a sufficient dataset with which to develop a series of trigger values for both groundwater levels and quality.

15.1 INSTALLATION OF ADDITIONAL MONITORING BORES

Ten of the existing 15 monitoring bores are within the footprint of the proposed open pits or overburden emplacements and will therefore be removed during the life of the Proposal. It is recommended that the remaining five sites be augmented with additional monitoring bores that will not be disturbed during the life of the mine. These additional monitoring bores can be progressively installed as the existing monitoring bores are removed by advancement of mining. The sites of the existing and proposed additional monitoring bores are shown in **Figure 65**. The proposed monitoring bores are located to the north and south of the existing monitoring bore sites which will be disturbed by mining. The purpose of the replacement observation bores is to monitor depressurisation in the coal seams and overburden material and where applicable water level drawdown in the alluvium. In the future, this observation data can be used to confirm and validate the model predictions.


390000
400000
410000
6460000
6450000
6440000
6430000
NOW Station 208028
AVON RIVER
GR-P6
GR-P12
GR-P14
GR-P5
GR-P3
Downstream
GR-P8
GR-P4
Year 14 Pit and
Overburden Emplacement
GR-P2
GR-P9
GR-P1
Mid Stream
GR-P7
GR-P13
GR-P15
GR-P11
GR-P10
Upstream
WAUKIVORY CREEK
MGA 94, Zone 56; 1:25,000 (A4)
0
1.25
kilometres
LEGEND:
Site Boundary
DCDB
Rail
Local Drainage
Local Drainage
Proposed Pit Outline
Proposed Overburden
Visibility Barrier
NOW Stream Gauge (208028)
GRL Stream Monitoring Station
GRL Monitoring Bores
Proposed Monitoring Bores
Quaternary Alluvium (GRL Mapping)
Quaternary Alluvium (100k Mapping)
Quaternary Alluvium (AGE Desktop)
Rocky Hill Coal Project
Groundwater Impact Assessment (G1509B)
Proposed New Monitoring Bores
DATE:
20/8/2013
FIGURE No:
65

A bore licence should be obtained from NOW before installation of any new monitoring bores. All monitoring bores should be constructed according to the Australian guidelines by an appropriately qualified water bore driller. The recommended sites for replacement monitoring bores are summarised in **Table 23**. As per the existing monitoring sites that they will replace, the monitoring bores should be of a nested construction with separate bores in coal seams and overburden material, or Quaternary Alluvium where this is present.

It should be noted the proposed locations are preliminary, accessibility issues and ground conditions have not yet been assessed.

Table 23
Summary of Recommended Replacement Monitoring Bores

Bore ID	Easting	Northing	Location	Nominal Depth (m)
GR-P12	403770	6452900	North of Main Pit	40
GR-P12A	403770	6452900	North of Main Pit	80
GR-P13	403780	6450655	South of Main Pit	10
GR-P13A	403780	6450655	South of Main Pit	80
GR-P14	404560	6452700	North of Weismantel Pit	40
GR-P14A	404560	6452700	North of Weismantel Pit	80
GR-P15	404470	6450550	South of Weismantel Pit	10
GR-P15A	404470	6450550	South of Weismantel Pit	80
Note: coordinates are in MGA94, Zone 56.				

15.2 TRIGGER LEVELS

Trigger levels will be derived for water quality parameters as part of the development of the Water Management Plan. Due to the natural variability in the salinity within the Mine Area, the triggers for major ions will be set on a bore by bore basis. The trigger levels may be recalculated after 12 observations, the mean and standard deviations re-calculated and the criteria adjusted.

The following relevant trigger values are recommended:

- Salinity – Individual trigger values to be calculated for each monitoring bore using the values for EC, TDS, and cations/anions.
- Metals – as the primary use of the water in the area is for irrigation and stock watering, the ANZECC (2000) trigger levels for Livestock Drinking Water are recommended.
- Pesticides and Hydrocarbons – no triggers are recommended.

It is important to recognise that trigger levels are not pass or fail compliance criteria but are simply a threshold value above which some further investigation should be carried out. Where a water quality result exceeds its threshold value on three or more consecutive occasions, this triggers further investigation to determine if the adopted value is too conservative, or if the concentrations of the element are increasing. Each trigger exceedance should be investigated and a formal report completed for the AEMR if results from three consecutive sampling events exceed a trigger level.

Water level trigger values should be determined for the bores monitoring the Waukivory Creek alluvium. The trigger levels should be set after a baseline data set of two years of water level data has been collected. The baseline monitoring period will allow the natural fluctuations in alluvial water levels due to variability in rainfall recharge and surface water flow to be assessed, and a method for separating mining induced water level fluctuations developed. As per the water quality trigger values, exceedance of these groundwater level trigger values would induce investigations to be carried out. Recommendations for additional monitoring or mitigation may result from these assessments. Trigger levels for the monitoring bores installed in the Permian water bearing formations are not considered appropriate as the Permian units within and immediately surrounding the proposed mining area will be depressurised.

Further discussions will be held with NOW to determine the appropriate trigger levels for groundwater level and quality.

15.3 WATER LEVEL MONITORING PLAN

Groundwater levels are currently measured in the existing monitoring network on a daily basis via automatic water level loggers. These loggers are verified on a monthly basis by manual monitoring. The water level loggers currently provide excellent data on short term events such rainfall recharge.

It is recommended that electronic water level loggers are continued to be used in all groundwater monitoring bore sites. The loggers are currently set to record every 6 hours and it is recommended that this methodology is continued. This will enable water level fluctuations due to rainfall recharge and natural decline in water level to be distinguished from potential water level declines due to depressurisation as a result of open cut mining.

15.4 WATER QUALITY MONITORING PLAN

An excellent baseline groundwater quality dataset exists for the proposed mine development. It is recommended that the monthly groundwater samples that are currently being collected from the monitoring bores continue until the completion of the first 12 months of mining operations. After this, it is recommended that on-going sampling occur on a six monthly basis. Collected samples should be analysed in the laboratory for:

- major cations and anions;
- nutrients - ammonia, nitrate, nitrite; and
- metals - iron, lead, chromium, cadmium, zinc, arsenic, copper and nickel.

15.5 MINE WATER SEEPAGE MONITORING

It is recommended that monitoring of mine water seepage be undertaken, particularly to identify seepage rates and quality. Laboratory analysis should be the same as for the groundwater monitoring bores. The seepage monitoring program should include:

- recording of the time, location and volume of any unexpected increased groundwater outflow;

- measurement of all water pumped from the pits particularly using flow meters or other suitable gauging apparatus;
- quarterly monitoring of water pumped from the pits for the same analytical suite outlined in Section 15.4;
- correlation of rainfall records with pit seepage records so groundwater and surface water can be separated; and
- monitoring of coal moisture content.

15.6 DATA MANAGEMENT AND REPORTING

It is recommended that data management and reporting include the following.

- An annual groundwater monitoring assessment and review has been carried out for 2011/2012 data (PB, 2012b). It is recommended that these annual assessments continue to be carried out. The assessments should identify monitoring data trends and departures. If consecutive monitoring data over a period of 6 months exhibit an increasing divergence in an adverse impact sense from the previous data or from the established or predicted trend, then such departures should initiate further actions. These may include a need to conduct more intensive monitoring or to invoke impact re-assessment and/or mitigative measures.
- Formal review of depressurisation of coal measures and alluvium should be undertaken annually by a suitably qualified hydrogeologist. Every five years the validity of the model predictions should be assessed and if the data indicates significant divergence from the model predictions, an updated or new groundwater model should be constructed for simulation of mining.
- Annual reporting (including all water level and water quality data).

AUSTRALASIAN GROUNDWATER AND ENVIRONMENTAL CONSULTANTS PTY LTD

MING-SHU TSOU
Groundwater Modeller
Sub-Consultant (MTNA Pty Ltd)

DANIEL BARCLAY
Principal Hydrogeologist

JAMES S. TOMLIN
Principal Hydrogeologist

ANDREW DURICK
Principal Modeller

16. REFERENCES

AECOM, (2009), *"Gloucester Gas Project Environmental Assessment",* Prepared for AGL Gloucester L E Pty Ltd, (November 2009), Volume 1.

Anderson and Woessner, (1992), *"Simulation of Flow and Advective Transport",* Academic Press, New York (1992).

Aquaterra Consulting Pty Ltd, (2000), *"Murray-Darling Basin Commission, Groundwater Flow Modelling Guideline",* November 2000, Project No. 125.

ARMCANZ (2003), *"Minimum Construction Requirements for Water Bores in Australia",* Edition 2.

Australasian Groundwater and Environmental Consultants Pty Ltd, (2000), *"Report on Bowen Road North Open Cut, Assessment of Dewatering and Regional Groundwater Impacts of the Proposed Open Cut",* December 2000, Project No. G1089.

Barnett et al, (2012), *"Australian groundwater modelling guidelines",* Waterlines report, National Water Commission, Canberra.

Cardno Ecology Lab Pty Ltd, (2012), *"Gloucester Exploration Project, Exploration Licence 6523: Aquatic Ecology Opportunities and Constraints",* Job Number: EL0261011 B, Prepared for R.W. Corkery & Co. Pty. Limited. March 2011.

Department of Water and Energy, (2009), "*Commenced Water Sharing Plan for the Lower North Coast unregulated and alluvial water sources, Avon River water source – Report Card 1 of 21*", August 2009. Downloaded on 30/7/2012 from www.water.nsw.gov.au/.../wsp_lnc_**report_card_avon_river**.pdf.aspx

GSS Environmental (2011), *"Final Alluvial Soil Assessment, Gloucester Resources Limited",* March 2011.

Heritage Computing, (2009), *"Duralie Extension Project Groundwater Assessment, A Hydrogeological Assessment of the Duralie Extension Project Environmental Assessment",* November 2009, Project Number GCL-06-07.

Hill and Tiedeman, (2007), *"Effective Groundwater Model Calibration: with analysis of data, sensitivities, predictions and uncertainty".* John Wiley and Sons (2007).

HydroGeologic Inc. (2001), MODFLOW-HMS User's Manual, Herndon, VA.

Mackie C.D. (2009), *"Hydrogeological Characterisation of Coal Measures and Overview of Impacts of Coal Mining on Groundwater Systems in the Upper Hunter Valley of NSW",* January 2009.

Heritage Computing Pty Ltd (2012), "*A Hydrogeological Assessment in Support of the Stratford Coal Project Environmental Impact Statement*", Report HC2012/2 April 2012.

NOW (2012), www.water.nsw.gov.au/.../policy_advice_8-gwquantitymanagement.pdf.aspx

PB, (2011), "*Gloucester Resources Limited, Drilling Completion Report Monitoring Bores",* March 2011.

PB, (2012a), "*Phase 2 Groundwater Investigations, Stage 1 Gas Field Development Area Gloucester Gas Project*", January 2012.

PB, (2012b), "*Gloucester Resources Limited, Groundwater Investigation Annual Monitoring Report",* April 2012.

PB, (2012c), "*GRL Groundwater monitoring bores (GR-P10 & GR-P11): Drilling completion report",* June 2012.

PEST, (2008), *"FORTRAN 90 Modules for Implementation of Parallelised, Model-Independent, Model-Based Processing".*

Resource Strategies, (2001), "*Bowens Road North Project – Environmental Impact Statement",* January 2001.

RGS Environmental, (2013), "*Rocky Hill Coal Project: Geochemical Assessment of Overburden/Interburden and Coal Reject Materials*", February 2013, Project No. 101117.

R.W. Corkery & Co Pty Limited, (2012), "*Documentation Supporting and Application for Director-General's Requirements for the Rocky Hill Coal Project",* February 2012.

SRK Consulting (2010), *"Gloucester Basin Stage 1 Gas Field Development Project, Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model"*, July 2010, Project No. AGL002.

Sundaram, B., Feitz, A., Caritat, P. de, Plazinska, A., Brodie, R., Coram, J. and Ransley, T., (2009), "*Groundwater Sampling and Analysis – A Field Guide*". Geoscience Australia, Record 2009/27 95 pp.

Zheng, C., and G. D., Bennett, (1995), *"Applied Contaminant Transport Modelling: Theory and Practice"*. Van Nostrand Reinhold (now Wiley), New York, 440 pp.

17. GLOSSARY

Alluvium - Sediment (gravel, sand, silt, clay) transported by water (i.e. deposits in a stream channel or floodplain).

Aquiclude - A low-permeability unit that forms either the upper or lower boundary of a ground-water flow system.

Aquifer - Rock or sediment in a formation, group of formations, or part of a formation which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.

Aquifer, Confined - An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer.

Aquifer, Perched - A region in the unsaturated zone where the soil may be locally saturated because it overlies a low-permeability unit.

Aquifer, Semi-confined - An aquifer confined by a low-permeability layer that permits water to slowly flow through it. During pumping of the aquifer, recharge to the aquifer can occur across the confining layer. Also known as a leaky artesian or leaky confined aquifer.

Aquifer, Unconfined - An aquifer in which there are no confining beds between the zone of saturation and the surface. There will be a water table in an unconfined aquifer. Water-table aquifer is a synonym.

Aquitard - A low-permeability unit than can store ground water and also transmit it slowly from one aquifer to another.

Barrier Boundary - An aquifer-system boundary represented by a rock mass that is not a source of water.

Baseflow - That part of stream flow that originates from ground water seeping into the stream.

Colluvium - Sediment (gravel, sand, silt, clay) transported by gravity (i.e. deposits at the base of a slope).

Cone of Depression - The depression in the water table around a well or excavation defining the area of influence of the well. Also known as cone of influence.

Discharge - The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.

Discharge Area - An area in which there are upward components of hydraulic head in the aquifer. Ground water is flowing toward the surface in a discharge area and may escape as a spring, seep, or baseflow or by evaporation and transpiration.

Drawdown - A lowering of the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping of ground water from wells or excavations.

Falling/Rising Head (Slug) Test - A test made by the instantaneous addition, or removal, of a known volume of water to or from a well. The subsequent well recovery is measured and analysed to provide a permeability value.

Groundwater - The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.

Groundwater Flow - The movement of water through openings in sediment and rock; occurs in the zone of saturation.

Groundwater, Perched - The water in an isolated, saturated zone located in the zone of aeration. It is the result of the presence of a layer of material of low hydraulic conductivity, called a perching bed. Perched ground water will have a perched water table.

Ground water, unconfined - The water in an aquifer where there is a water table.

Heterogeneous - Pertaining to a substance having different characteristics in different locations. A synonym is non-uniform.

Hydraulic Conductivity - A measure of the rate at which water moves through a soil/rock mass. It is the volume of water that moves within a unit of time under a unit hydraulic gradient through a unit cross-sectional area that is perpendicular to the direction of flow.

Hydraulic Gradient - The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

Hydrogeology - The study of the interrelationships of geologic materials and processes with water, especially ground water.

Infiltration - The flow of water downward from the land surface into and through the upper soil layers.

Leakance - Average vertical hydraulic conductivity of the confining unit divided by its thickness.

Model Calibration - The process by which the independent variables of a digital computer model are varied in order to calibrate a dependent variable such as a head against a known value such as a water-table map.

Monitoring Bore (Piezometer) - A non-pumping well (bore), generally of small diameter, that is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short well screen through which water can enter.

Packer Test - An aquifer test performed in an open borehole to determine rock permeability; the segment of the borehole to be tested is sealed off from the rest of the borehole by inflating seals, called packers, both above and below the segment.

Porosity - The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

Potentiometric Surface - A surface that represents the level to which water will rise in tightly cased wells. If the head varies significantly with depth in the aquifer, then there may be more than one potentiometric surface. The water table is a particular potentiometric surface for an unconfined aquifer.

Pumping Test - A test made by pumping a well for a period of time and observing the response/change in hydraulic head in the aquifer in order to determine aquifer hydraulic characteristics.

Recharge Area - An area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area.

Recharge Basin - A basin or pit excavated to provide a means of allowing water to soak into the ground at rates exceeding those that would occur naturally.

Recharge Boundary - An aquifer system boundary that adds water to the aquifer. Streams and lakes are typically recharge boundaries.

Recharge Well - A well specifically designed so that water can be pumped into an aquifer in order to recharge the ground-water reservoir.

Recovery - The rate at which the water level in a well rises after the pump has been shut off. It is the inverse of drawdown.

Rock, Volcanic - An igneous rock formed when molten rock called lava cools on the earth's surface.

Specific Yield - The ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take many months to occur.

Storativity - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to the specific yield. Also called storage coefficient.

Transmissivity - The rate at which water of a prevailing density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. It is a function of properties of the liquid, the porous media, and the thickness of the porous media.

Unsaturated Zone - The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched ground water, may exist in the unsaturated zone. Also called zone of aeration and vadose zone.

Water Budget - An evaluation of all the sources of supply and the corresponding discharges with respect to an aquifer or a drainage basin.

Watertable Map - A specific type of potentiometric-surface map for an unconfined aquifer; shows lines of equal elevation of the water table.

Well Development - The process whereby a well (bore) is pumped or surged to remove any fine material that may be blocking the well screen or the aquifer outside the well screen.

Well Screen - A tubular device with either slots, holes, gauze, or continuous-wire wrap; used at the end of a well casing to complete a well. The water enters the well through the well screen.

18. COMMONLY USED ACRONYMS

BoM – Bureau of Meteorology	CHPP – Coal Handling and Preparation Plant
CRD – Cumulative Rainfall Departure	CSG – Coal Seam Gas
DCM – Duralie Coal Mine	DGRs – Director-General's Requirements
EC – electrical conductivity	EL – Exploration licence
EIS – Environmental Impact Assessment	GCL – Gloucester Coal Limited
GFDA – Gas Field Development Area	GGP – Gloucester Gas Project
GRL – Gloucester Resources Limited	K – hydraulic conductivity
LGA – Local Government Area	L/s – litres per second
maGL – metres above ground level	mAHD – metres above Australian height datum
mbGL – metres below ground level	mbTOC – metres below top of casing
ML – megalitre	NOW – New South Wales Office of Water
PEL – Petroleum Exploration Licence	ppm – parts per million
PVC – poly vinyl chloride	RCS – Relative composite sensitivity
RMS – root mean square	ROM – Run of Mine
SCM – Stratford Coal Mine	SRMS – scaled RMS
SWL – standing water level	µS/cm – microseimens per centimetre

LIMITATIONS OF REPORT

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) has prepared this report for the use of Gloucester Resources Limited in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 22 February 2012.

The methodology adopted and sources of information used by AGE are outlined in this report. AGE has made no independent verification of this information beyond the agreed scope of works and AGE assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to AGE was false.

This study was undertaken between 22 February 2012 and 23 August 2012 and is based on the conditions encountered and the information available at the time of preparation of the report. AGE disclaims responsibility for any changes that may occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. It may not contain sufficient information for the purposes of other parties or other users. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

This report contains information obtained by inspection, sampling, testing and other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. Where borehole logs are provided they indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the frequency and method of sampling, and the uniformity of the site, as constrained by the project budget limitations. The behaviour of groundwater is complex. Our conclusions are based upon the analytical data presented in this report and our experience.

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, AGE must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge, information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time. Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

This page has intentionally been left blank