Mt Arthur Coal

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Appendix B – Groundwater Impact Assessment

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REPORT ON

MT ARTHUR COAL OPEN CUT MODIFICATION GROUNDWATER IMPACT ASSESSMENT

1.0 INTRODUCTION

Hunter Valley Energy Coal Pty Ltd (HVEC), a wholly owned subsidiary of BHP Billiton Ltd, is proposing to extend the currently approved open cut mine footprint at the Mt Arthur Coal Mine. As such, it is seeking approval for a modification to its approved Mt Arthur Consolidation Project from the Minister of Planning and Infrastructure, under section 75W of the New South Wales (NSW) *Environmental Planning and Assessment Act 1979*.

HVEC has two current approvals for the Mt Arthur Coal Mine, these being:

- PA09_0062 granted on 24 September 2010 for the Mt Arthur Coal Consolidation Project. This approval is for open cut mining and infrastructure and allows a mining rate of up to 32 million tonnes per annum (Mtpa); and
- PA06_0091 granted on the 2 December 2008 for underground mining at the rate of 8 Mtpa.

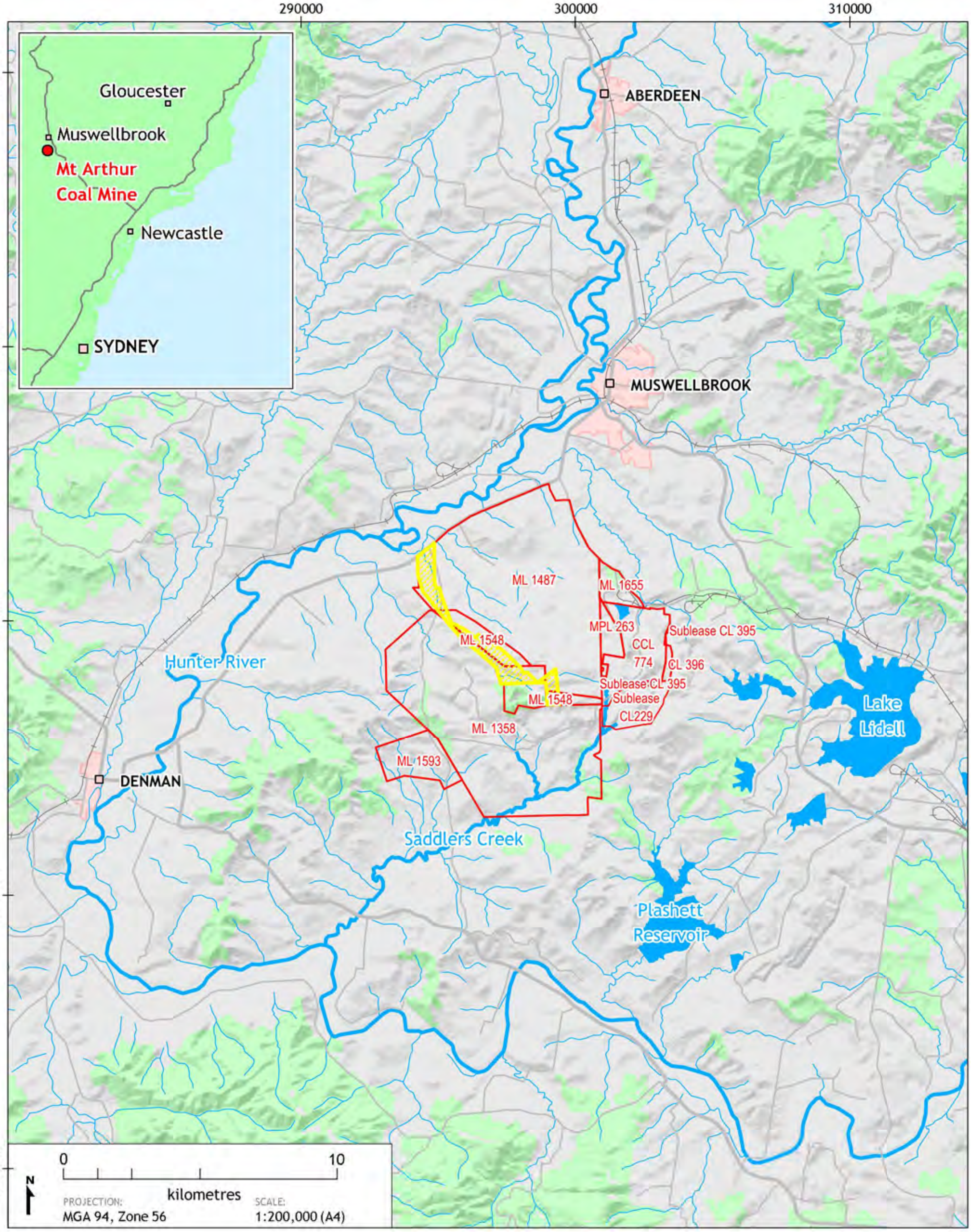
The Mt Arthur Coal Open Cut Modification (the Modification) includes the continuation of open cut mining operations at the Mt Arthur Coal Mine for an additional operational life of approximately four years (i.e. from Year 2022 to Year 2026).

The Modification involves an expansion of the open cut disturbance area to the south-west, as shown on Figures 1 and 2. The Modification Area lies between the approved open cut mine and the approved underground mine (Figure 2).

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) were commissioned by HVEC to undertake a groundwater impact assessment of the proposed Modification. This report, which describes the groundwater impact assessment, forms part of the Environmental Assessment (EA) being prepared by Resource Strategies Pty Ltd, in support of the application for approval of the Modification.

The report describes the hydrogeological regime of the Site area and identifies potential risks and constraints. The assessment is based on a refined three-dimensional transient, groundwater flow model of the Mt Arthur Coal Mine that was originally developed in 2009 for the Mt Arthur Coal Consolidation Project EA and has been updated to include the Modification.

In the context of this report, the term Site refers to the Mt Arthur Coal Mine Site and the term MAU is used to describe the Mt Arthur Underground Mine. The Model Area/Boundary refers to the extent of the numerical model footprint.



LEGEND:

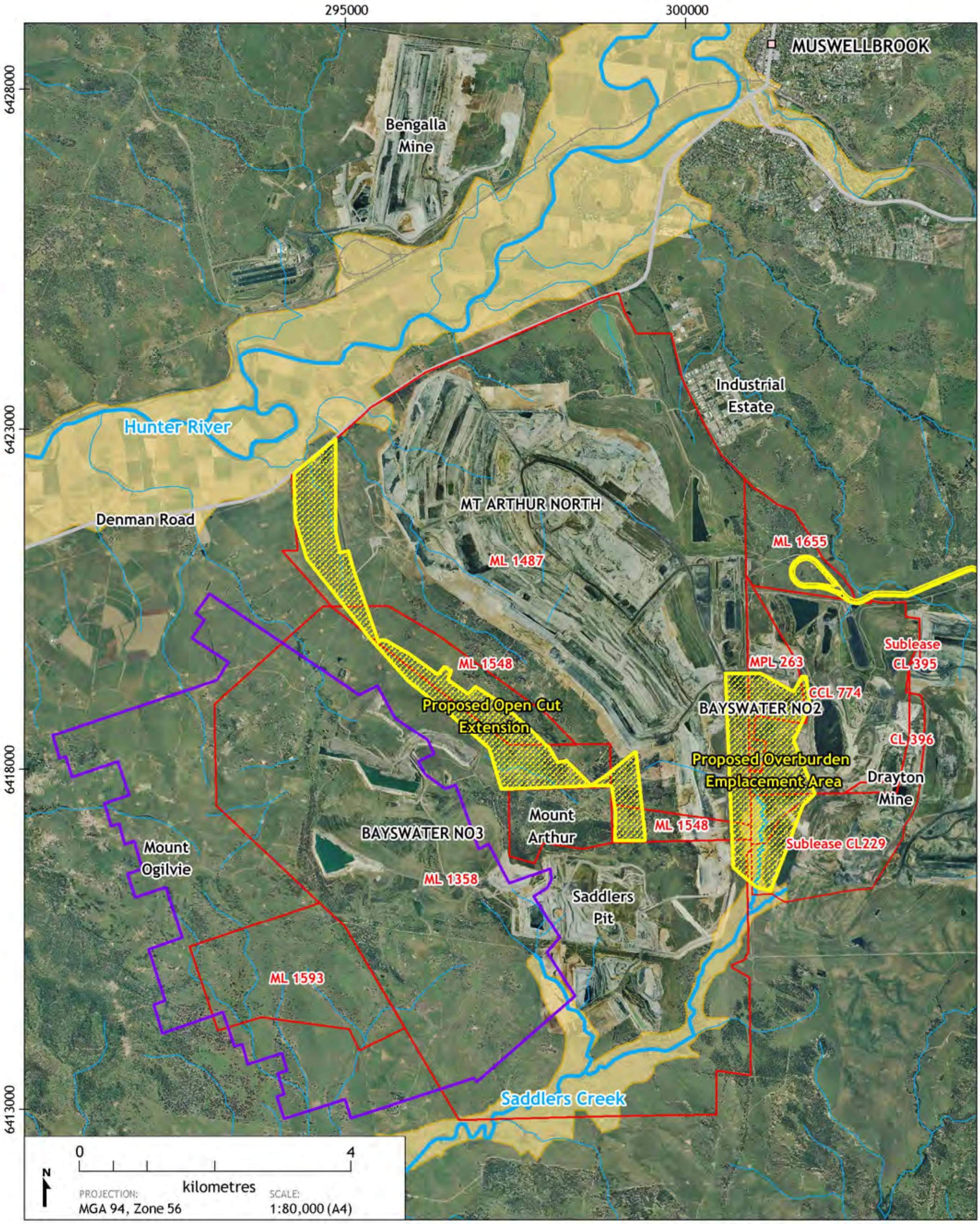
- Mt Arthur Coal Mining & Coal Lease Boundary
- Mine Modification Area
- Native Vegetation
- Road/Track
- Rail
- Town
- Reservoir/Lake
- River
- Creek

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

General Location Plan

DATE: 23/1/2013

FIGURE No: 1



LEGEND:

- Mt Arthur Coal Mining & Coal Lease Boundary
- Modification Area
- Proposed Rail Loop
- Mt Arthur Underground
- Alluvium
- River
- Creek
- Town
- Road
- Rail

Air Photo courtesy of Mt Arthur Coal Mine - photo date 15/11/2011

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Mt Arthur Mine Modification Study Area

DATE: 23/1/2013

FIGURE No: 2

2.0 PROJECT OVERVIEW

HVEC is seeking a modification to the Mt Arthur Coal Consolidation Project to facilitate the extension of open cut mining activities for a further four years. Open cut extraction of an additional 128 million tonnes is proposed. The Modification generally comprises:

- a four year continuation of the open cut mine life from 2022 to 2026 at the currently approved maximum rate of 32 Mtpa;
- an increase in open cut disturbance areas;
- use of the conveyor corridor for overburden emplacement;
- duplication of the existing rail loop;
- an increase in the maximum number of train movements per day from 24 to 38;
- the relocation of the load point for the overland conveyor which delivers coal to Macquarie Generation's Bayswater Power Station;
- the relocation and upgrade of the explosives storage, magazine and associated facilities; and
- the construction of additional offices and a control room and a small extension to the run-of-mine coal stockpile footprint.

3.0 SCOPE OF WORK

3.1 Legislation

The Director-General's Requirements (DGRs) for the Modification provided by the NSW Department of Planning and Infrastructure (DP&I) on 30 April 2012 included the following in regard to the soil and water assessments:

- *detailed assessment of potential impacts on the quality and quantity of existing surface and groundwater resources, including:*
    - *detailed modelling of potential groundwater impacts, including and potential impacts on the alluvial aquifers of the Hunter River;*
    - *impacts on affected licensed water users and basic landholder rights; and*
    - *impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including environmental flows and potential flooding impacts;*
- *a detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume, salinity 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;*
- *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 requirements 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 modified project 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*
- *compliance with the Hunter River Salinity Trading Scheme (HRSTS).*

The Site area investigated as part of the groundwater study had an approximate radius of 15 kilometres (km) surrounding the Modification Area and existing mine, and encompassed the alluvium surrounding the mine.

The NSW Office of Water (NOW) also provided relevant agency comments, as follows:

- *Adequate, secure and appropriately authorised water supply is available for all activities for the life of the mine.*
- *Compliance with the rules in the <u>Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources</u> and relevant legislation, water management policies and guidelines.*

- *Assessment of risks to the Hunter Regulated Alluvium which may be posed by the mining extension, including extended and cumulative depressurisation of the alluvial groundwater source, and impacts to groundwater quality which may result from extension of the mining operation.*
- *Development of adequate baseline monitoring (minimum of fortnightly data sampling for at least 2 years prior to mine operations, and appropriate scaled real time monitoring) 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.*
- *Predictive assessments of potential impacts to surface water and groundwater sources, basic landholder's rights to water, adjacent licensed water users and dependent ecosystems and ongoing monitoring to enable comparison with predictions.*
- *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*.

In their agency comments the following information was requested to demonstrate the above:

- *Details of all groundwater sources and existing groundwater users within the area (including the environment) and details of any potential impacts on these users;*
- *Identification of potential Groundwater Dependent Ecosystems (GDEs);*
- *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;*
- *Description of aquifer hydraulic properties, chemical characteristics and connectivity (including to surface water sources);*
- *Assessment of GDEs for condition and water quantity and quality requirements for both terrestrial and aquatic systems (macroinvertebrate, macrophyte and stygofauna) and is to include diversity and abundance assessments;*
- *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;*
- *Assessment of the potential effects of mining operations on the quality of groundwater 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;*
- *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;*
- *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; and*
- *Determination of critical thresholds for negligible impacts to groundwater sources and GDEs.*

Of the information specified by NOW to be included in the Modification EA, dot point 9 above refers to Waukivory Creek which is understood to be related to the Rocky Hill Coal Project near Gloucester. As Waukivory Creek is not related to the Mt Arthur Coal Mine, this dot point has been taken to refer to the Hunter River.

3.2 Methodology

The objective of the groundwater study was to assess the impact of the Modification on the hydrogeological regime and to meet the applicable DGRs. A scope of work was developed to achieve the objectives that included:

- identification of groundwater resources in the vicinity of the Site which could be impacted by the Modification – namely the Hunter River and Saddlers Creek alluvium; and
- assessment of the potential for any groundwater impacts resulting from the Modification, including modelling the cumulative groundwater impacts of the Modification with existing and proposed mining (including groundwater impacts on each identified privately owned bore).

The hydrogeological conceptual model, calibration and predictive model strategy used in this study has been developed to meet the study objectives and is consistent with that adopted by AGE (2009) for the Mt Arthur Coal Consolidation Project EA, including:

- the inclusion of the Hunter River and Saddlers Creek alluvial sediments and associated river boundary conditions within the model;
- simulation of flux to and from these alluvial bodies during mining predictive model runs;
- the simulation of water table drawdown for assessment of effects on groundwater abstraction and/or groundwater dependent ecosystems (GDEs); and
- prediction of pit inflows resulting from the Modification.

This assessment has been prepared in consideration of the Australian Modelling Guidelines (Barnett *et al*., 2012). A comparison of the model and report against these guidelines is presented in Section 17.

4.0 LEGISLATION, POLICY AND GUIDELINES

The following section outlines NSW State Government legislation, policy and guidelines with respect to groundwater that must be addressed in the assessment and operation of mining proposals.

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 aquifers 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 (WSPs) are not in place. This is the case in the bedrock outcrop area where the Modification is located.

Two WSPs have commenced for the Hunter River and groundwater sources that surround the Modification. Water access licences and approvals to take and use water are granted according to the WM Act.

4.2 Water Management Act 2000

The objectives of the WM Act include 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 relevantly for three types of approvals:

- Management works approvals:
  - water supply work approval;
  - drainable work approval; and
  - flood work approval (section 90 of the WM Act).
- Water use approvals which authorise the use of water at a specified location for a particular purpose, for up to 10 years (section 89 of the WM Act).
- Activity approvals comprising:
  - controlled activity approval; and
  - aquifer interference activity approval.

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 (see the Water Management Principles set out in section 5 of the WM Act).

4.3 Water Sharing Plans

4.3.1 Hunter Regulated River Water Sharing Plan

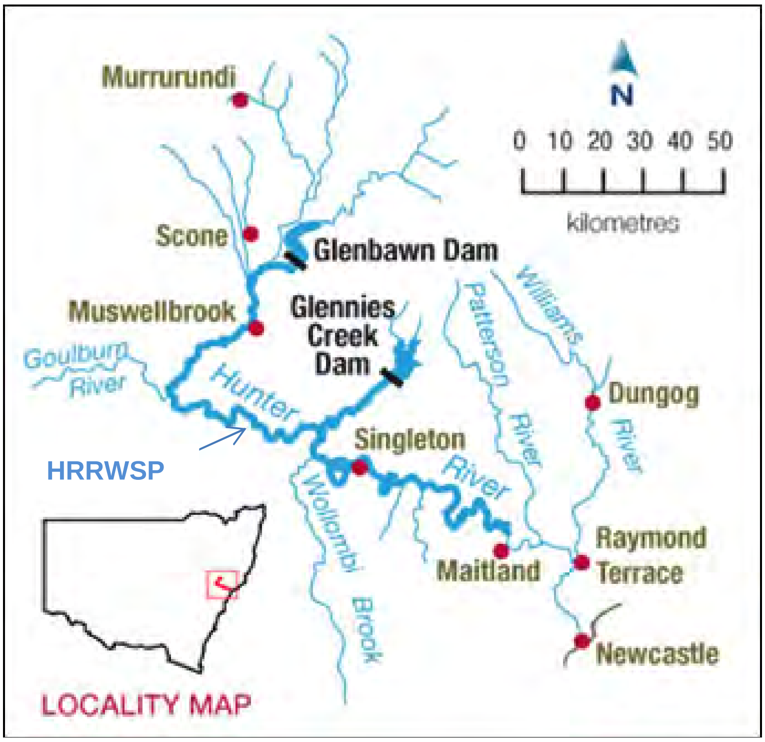
The Hunter Regulated River Water Sharing Plan 2003 (HRRWSP) commenced on 1st July 2004 and applies for a period of 10 years to 30 June 2014. It is a legal document made under the WM Act.

The HRRWSP contains rules for how water is shared between the environment and water users and different categories of licences.

The Hunter River is located in the central eastern area of NSW and drains an area of some 22,000 square kilometres (km^2). The Hunter River originates in the Mount Royal Range north-east of Scone and travels approximately 450 km to the sea at Newcastle. The river is regulated from Glenbawn Dam to Maitland, a distance of about 250 km. Glennies Creek is regulated by Glennies Creek Dam, which also provides water to the lower reaches of the Hunter River. The area to which the WSP applies is shown on Figure 3.

The HRRWSP applies to rivers (and associated alluvial sediments) regulated by Glenbawn and Glennies Creek Dams. The water source is divided into three management zones. These are:

- the Hunter River from Glenbawn Dam to its junction with Glennies Creek;
- the Hunter River downstream of its junction with Glennies Creek; and
- Glennies Creek downstream of Glennies Creek Dam.



Source: NOW (2011).

Figure 3: Locality Map for the Hunter Regulated River Water Sharing Plan

The Project is located within the first Hunter River management zone listed above; this being the Hunter River from Glenbawn Dam to its junction with Glennies Creek.

The vision for the HRRWSP is to achieve a healthy diverse and productive water source and sustainable management for the community, environment, towns, agriculture and industry. The HRRWSP also recognises the significance of water to the Aboriginal community.

The WM Act requires that the sharing of water must protect the water source and its dependent ecosystems and that WSPs establish specific environmental water rules. The environmental water rules are designed to:

- reserve all water volume above a specified limit for the environment;
- ensure that flows in the river do not drop below a prescribed minimum flow rate;
- provide water in Glenbawn and Glennies Creek Dams that can be used for water quality and other environmental management purposes; and
- preserve a portion of natural flows during periods when supplementary water access licences are permitted to extract water.

The HRRWSP provides for domestic and stock rights and native title rights – both forms of basic landholder rights which allow some extraction of water from the river without an access licence. All water extraction, other than basic landholder rights extractions, must be authorised by an access licence.

4.3.2 Hunter Unregulated and Alluvial Water Sources Water Sharing Plan

The Hunter Unregulated and Alluvial Water Sources Water Sharing Plan (HURAWSP) commenced on 1 August 2009 and applies for a period of 10 years to 31 July 2019. It is also a legal document made under the WM Act. Figure 4 displays the area to which the HURAWSP applies.

Source: NOW (2011).

Figure 4: Water Sharing Plan Area for the Hunter Unregulated and Alluvial Water Sources

WSPs for unregulated rivers and groundwater systems (such as the HURAWSP) have been completed using a “macro” or broader scale river catchment or aquifer system approach. Unregulated rivers are those which rely only on natural flow and are not regulated by releases from upstream dams.

The closest unregulated stream to the Modification is Sandy Creek, located about 7 km west of the current Site area.

The HURAWSP set rules for sharing water between the environment and water users and clearly defines shares in available water for licence holders, enabling better water trading opportunities. WSPs support the long-term health of rivers and aquifers by making water available specifically for the environment.

With respect to groundwater, macro WSPs for unregulated rivers may include rules that recognise that some alluvial aquifers are highly connected to their parent streams and in these circumstances, the goal of water sharing rules is to manage the surface water and highly connected groundwater as one resource.

A long-term average annual extraction limit referred to as the Extraction Management Unit applies across an entire catchment area. The limit is a longer term management tool against which total extraction will be monitored and managed over the 10-year life of the plan. The rules in the plan that determine when licence holders can and cannot pump on a daily basis are more specific. Basic landholder rights (i.e. extraction of a “reasonable use” volume of surface or groundwater for stock or domestic supply) do not require a water access licence, however, water access licences are required for mining activities where these activities intercept an unregulated river or connected aquifer water.

The HURAWSP includes alluvial sediments not covered by the HRRWSP.

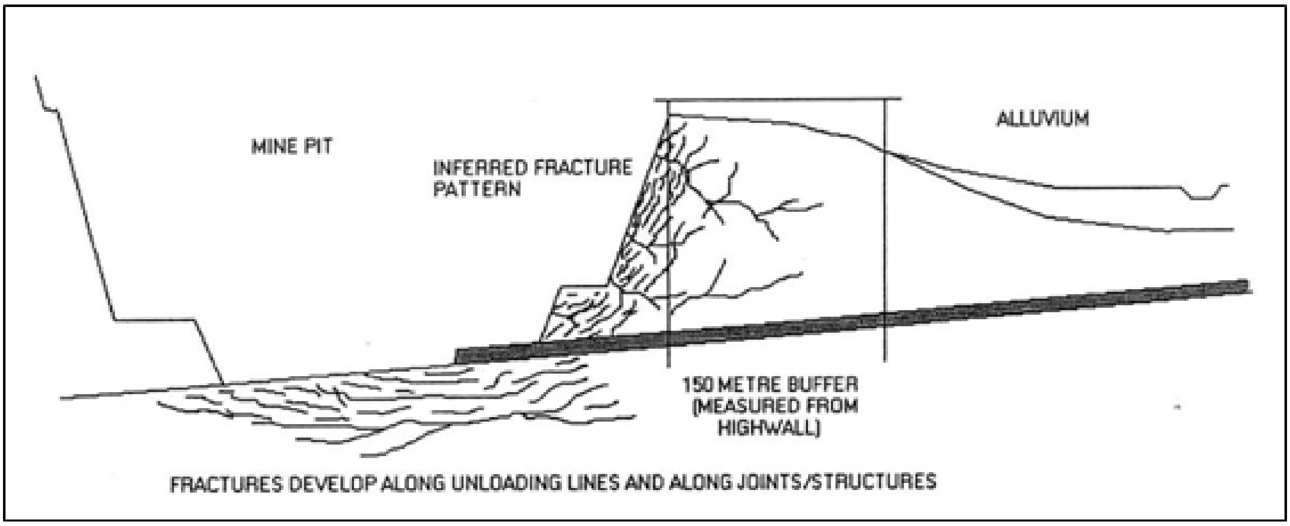
4.4 Buffer Zone Guidelines

Guidelines were prepared for the Hunter Region in April 2005, by the NSW Department of Infrastructure, Planning and Natural Resources (DIPNR, 2005) (now the DP&I) to assist the coal mining industry in managing risks when mining close to streams using either longwall or open cut mining methods. The guidelines relate to the classification of the stream that may be impacted by mining.

The guidelines provide a range of assessment and management criteria for each stream classification. This range is developed on the basis of:

- A checklist for minor stream systems (Schedule 1) with monitoring and remediation procedures to minimise the extent of damage which occurs to them.
- A notification system for significant stream systems (Schedule 2) to the department, so that an agreed monitoring and management regime can be developed for the stream system involved.
- A precautionary stance for primary rivers (Schedule 3), subject to environmental assessment which can demonstrate that the impact on those rivers and associated alluvial groundwaters can be minimised.

Based on the management guidelines, the Hunter River system is classified as a Schedule 3 stream/river. The guideline document indicates that the NOW is adopting a precautionary approach to mining in the vicinity of Schedule 3 streams and associated alluvial groundwater, involving a buffer between the mining area and the stream. The guideline requires a buffer of 150 metres (m) between an open cut mining area and the stream and its related alluvium, as shown on Figure 5.



Source: DIPNR (2005).

Figure 5: Buffer Zone Requirement for Open Cut Mining Operations Next to Rivers/Alluvium

In accordance with the Project Approval for the Mt Arthur Coal Mine – Open Cut Consolidation Project Statement of Commitments:

> *Mining (other than that already approved in the MAN EIS) will not extend beyond a nominal 150 m buffer zone from the Hunter River Alluvials until agreement is reached with NOW regarding the installation of a lower permeability barrier along the point of connections of mining and the alluvium or other appropriate safeguards.*

5.0 PREVIOUS STUDIES

5.1 Summary of Recent Studies

A number of previous studies have been undertaken within the Mt Arthur Coal Mine and surrounds dating back to 1979. The two most recent studies, both of which are highly relevant to the modification application, were undertaken in support of the MAU Project and the Mt Arthur Coal Consolidation Project approvals. The reports were prepared by Mackie Environmental Research Pty Ltd (MER) (2007) and AGE (2009) for the Underground and Consolidation Projects respectively.

MER (2007) conducted a groundwater impact assessment of multi-seam, longwall extraction, to obtain approval for the proposed MAU Project. A regional finite element groundwater model comprising 13 layers was developed incorporating each target seam and including the Hunter River and Saddlers Creek alluvium. Total groundwater seepage to the underground operations is predicted to steadily increase over the period of mining from 0.5 megalitres per day (ML/day) during entry and development of the Woodlands Hill Seam, to a maximum 6 ML/day at completion of mining in the deeper Piercefield Seam. Vertical leakage from the Hunter River alluvium due to depressurisation of the coal seam was predicted to remain unchanged whereas vertical leakage from the Saddlers Creek alluvium may be affected with a reduction in upward leakage from the coal seams of 0.08 ML/day. Recovery of groundwater levels post mining was predicted to take 50 years.

AGE (2009) conducted a study for the groundwater impact assessment as part of the Mt Arthur Coal Consolidation Project EA. A regional finite element groundwater model comprising eight model layers was developed which included the Hunter River and Saddlers Creek alluvium. Simulated groundwater inflow to the Northern Open Cut is predicted to rise from 0.85 ML/day to 2.45 ML/day between 2009 and 2016 and stabilise in the latter part of mining at about 2.4 ML/day. Simulated groundwater inflow to Saddlers Pit is predicted to stabilise after 2011 at a relatively constant rate of 0.15ML/day and leakage of groundwater from the Hunter River alluvial aquifer is predicted to be about 0.74 ML/day at the end of mining in 2022, with the alluvial aquifer affected over a length of approximately 6 km.

Both of these documents provide a summary of the historical studies undertaken at the Site in prior years and both rely to some extent on the data obtained from the earlier investigations. Section 9 provides a summary of the groundwater regime of the Site based on these reports, and a summary of the findings and conclusions of each report. Where newly available data (e.g. groundwater levels) are available, data sets have been updated.

5.2 Summary of Relevant Historical Studies

The earliest study cited was undertaken by Australian Groundwater Consultants Pty Ltd (AGC) in 1979 for the Electricity Commission of NSW. The investigation included:

- “packer” permeability tests at 10.54 m intervals to 216 m depth on a deep borehole;
- three falling head tests to obtain comparative permeability data; and
- two airlift/recovery type hydraulic tests.

The overall objective was to obtain data on the hydraulic characteristics of the stratigraphic profile in order to provide an assessment of groundwater inflow to a 2 km shallow strip mining operation at the Northern Open Cut. The seams of interest were the Vaux, Bayswater, Edinglassie and Ramrod Creek.

In August 1980 AGC revised and extended the prediction of groundwater inflow to take into consideration changes to the proposed mining areas, including a shallow pit north of Whites Creek and a deep pit north of Mt Arthur. An assessment was also undertaken of dewatering using deep boreholes and the potential impact of dewatering on the Hunter River alluvium. The Hunter River alluvium was also broadly considered as a water supply source.

AGC also undertook a groundwater investigation for the Mt Arthur South Coal Project in 1981 and the data obtained from this report is summarised by Sinclair Knight and Partners (SKP) in 1981. The AGC (1981) report assessed inflow to the pits and the potential to obtain a groundwater supply for coal processing.

Laurie Montgomerie and Petit Pty Ltd undertook a groundwater investigation for the Mt Arthur North Coal Project in 1982. The report summarises the results of a long-term pumping test and describes numerical modelling of the coal seam aquifer in Whites Creek and Ramrod Creek Pits using assumed borefield dewatering networks.

A groundwater study for the Mt Arthur North Coal Project and surrounding areas was undertaken by MER in March 2000 as part of an Environmental Impact Statement (EIS) prepared by Coal Operations Australia Limited (2000). The study included review of existing information, field investigations, groundwater monitoring, sampling and analysis. Additional monitoring piezometers were constructed as part of the studies and a composite piezometric surface was developed for the region. Historical and more recent hydraulic properties and hydrochemistry of groundwaters were summarised and a mathematical groundwater model of the aquifer systems was developed to assess the impact of open cut mining on the groundwater regime.

AGE (2003) completed a preliminary assessment of potential risks and constraints associated with groundwater for a proposed multi-seam underground mining operations within the Site. Inflow assessments were based on hydraulic properties reported from previous investigations and the proposed mine plan. It was assessed that inflow could range from 1.5 ML/day (17 litres per second [L/s]) from the shallow Glen Munro Seam to 0.14 ML/day (1.7 L/s) for the deep Edinglassie Seam, with cumulative inflow to the Edinglassie Seam from all overlying seams, assuming a top-down mining sequence of the seams, and goaf interconnections of the mined seams, of 3.6 ML/day (42 L/s). The maximum radius of influence of seam depressurisation was predicted to be 3.25 km from the perimeter of the mined area.

In March 2006 AGE completed an internal groundwater impact assessment for Mt Arthur Coal on the Northern Open Cut's impact on the groundwater regime (AGE, 2006a), particularly the Hunter River and Saddlers Creek alluvium, and to assess future inflows to the pits. A three-dimensional, transient, finite element model was developed with predictive modelling indicating a peak inflow rate of 2.9 ML/day at year 7, declining and stabilising at 1.5 ML/day at year 10. The model indicated an area of impact of about 3.2 km^2 of Hunter River alluvium after 21 years with flow rates from the alluvium to the pits of 0.47 ML/day (5.4 L/s), comparable to the annual rainfall recharge rate on that area of alluvium. Similarly the model indicated a reduced recharge to Saddlers Creek of 0.04 ML/day to 0.07 ML/day.

In July 2006, AGE undertook a groundwater impact assessment of the proposed South Pit Extension using a regional finite element model (AGE, 2006b). The study which was undertaken to obtain project approval found that the impact of the South Pit Extension will be overprinted during most of the mine life by dewatering of the adjacent Northern Open Cut Pit. Simulated groundwater inflow to the pit was of the order of 0.3 ML/day after 21 years of mining and the radius of depressurisation from the pit crest was predicted to be 1 km to 1.5 km.

All of the studies discussed in Section 5 have been considered in undertaking the current assessment.

6.0 METHODOLOGY

The methodology adopted for assessing the groundwater impact of the Modification is outlined below:

- Data review:
  - Updated mine plans were supplied by HVEC for the Years 2016, 2018 and 2022. The updated pit shells for Years 2016, 2018 and 2022 reflect the current mine development schedule to a finer detail than those available during the AGE (2009) study. In addition to these updated mine plans, HVEC provided a new mine plan covering the Modification (Year 2026).
  - Updated groundwater monitoring data and climate data available since the AGE (2009) groundwater impact assessment was reviewed. The updated groundwater monitoring bore level data and climate data was used for model verification purposes.

- Conceptual groundwater model development:
  - The conceptual hydrogeological model developed during the Mt Arthur Coal Consolidation Project (AGE, 2009) was reviewed. It was assessed that no further work was required to revise or re-conceptualise the groundwater regime and that the AGE (2009) conceptual hydrogeological model is still current and relevant to this study (Section 9).

- Verification of the AGE (2009) model:
  - The AGE (2009) model was verified against the latest available transient groundwater level data. The verification was carried out to determine if the model required recalibration prior to any numerical model refinement and predictions for the Modification. The verification determined that the 2009 model parameterisation was adequate for prediction of the Modification and that recalibration was not necessary (Section 12.7).

- Numerical modelling:
  - The three-dimensional numerical model developed and calibrated during the AGE (2009) study was used as a basis for the Modification assessment. This approach was adopted as the verification identified that the model calibration completed in 2009 was valid for the pre-mining steady state and that the model was fit for purpose for the Modification.
  - Model mesh refinement was carried out within the Modification Area and the newly available mine plan data (i.e. mine plans for years 2016, 2018, 2022 and 2026) was incorporated into the predictive scenarios.
  - Assessment and reporting criteria for the predictive scenarios were maintained as close as possible to those of the 2009 study for comparison purposes, these being:
    - changes in groundwater fluxes to the Hunter River and Saddlers Creek alluvial groundwater systems;
    - monitoring of drawdowns with relation to alluvial groundwater systems and surrounding groundwater users; and
    - prediction of pit inflows and inflows to the underground.

7.0 REGIONAL SETTING

7.1 Location

The Mt Arthur Coal Mine is located in the Upper Hunter Valley of NSW approximately 5 km south-west of Muswellbrook (Figure 1). The Mining Leases, Coal Lease, Consolidated Coal Lease, Mining Purposes Lease and sub-leases are located south of the Hunter River (Figures 1 and 2). The Site is bounded by Denman Road to the north-west and Thomas Mitchell Drive to the north-east.

7.2 Surrounding Mining Operations

The existing Bengalla Mine is located to the north of the Mt Arthur Coal Mine (Figures 6 and 7). The existing Drayton Mine is located to the south-east of the Mt Arthur Coal Mine (Figure 7). These mines occupy undulating hillslopes, similar in agricultural land use to the Site. Further to the south-west lies the Mount Ogilvie exploration area. Coal mining activities associated with the Bengalla Mine are located approximately 3 km to the north of the Site (Figure 7). The approved Mt Pleasant Mine is located on the northern side of the Bengalla Mine, approximately 4 km north of the Northern Open Cut northern Site boundary. Currently approval is being sought for the Drayton South mine located to the south of Saddlers Creek and for an extension to the Bengalla Mine.

7.3 Topography and Drainage

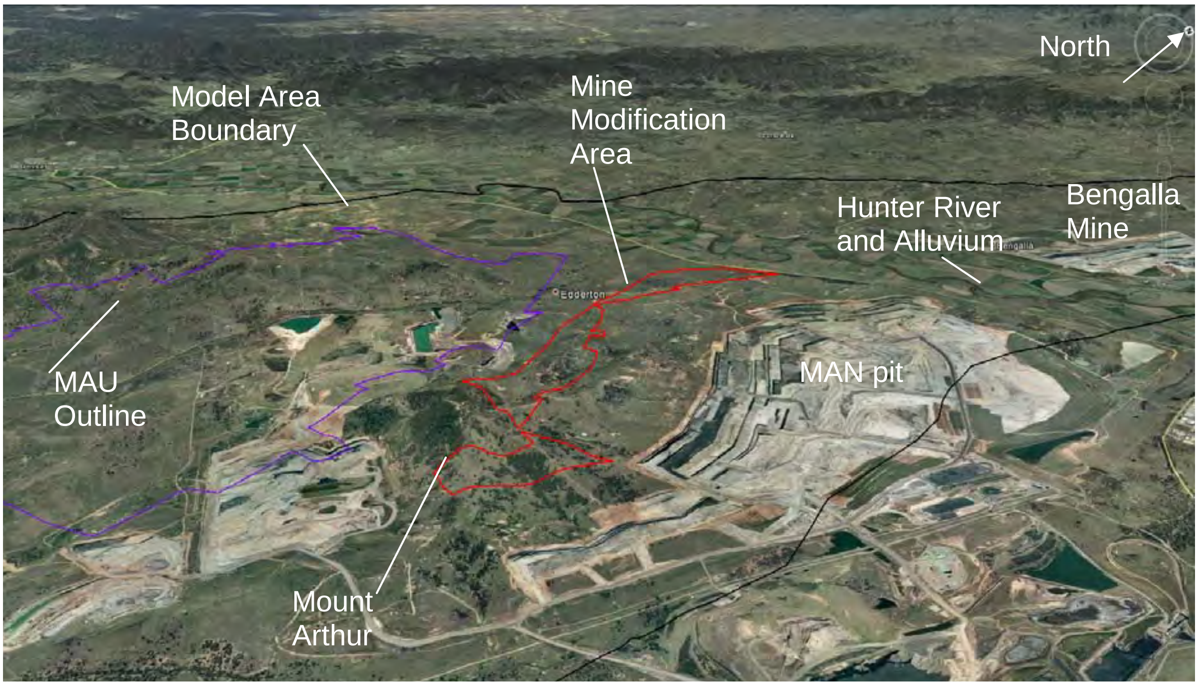
The topography of the Site is gently undulating, steepening in the south-eastern corner near the base of Mount Arthur. Surface elevations vary from approximately 140 m Australian Height Datum (AHD) along Denman Rd to the north of the Modification Area and up to 482 m AHD at Mount Arthur.

Surface drainage generally comprises ephemeral creeks with headwaters within the Modification Area flowing north and south-westwards, ultimately draining into the Hunter River. Quarry Creek, Ramrod Creek, Fairford Creek, Whites Creek and several small unnamed creeks flow northwards into the Hunter River on the northern side of the existing mining operations. Saddlers Creek has its headwaters in the south of the Modification Area. Saddlers Creek flows generally to the south-west (Figure 1) and joins the Hunter River downstream of Denman. The extension of the Northern Open Cut associated with the Modification is above the recorded 1955 flood level, which is estimated to be equivalent to a 100 year average recurrence interval event (Gilbert & Associates, 2012).

The Hunter River flows all year round and discharges into the Port of Newcastle approximately 170 km downstream of the Site. The Hunter River flows at Muswellbrook are regulated by discharges from the Glenbawn Dam.

7.4 Land Use

Land use other than coal mining in the local area includes residential and rural residential dwellings and industrial operations, while alluvial lands near the Hunter River are utilised for crop production including vineyards and orchards, thoroughbred breeding and cattle grazing. Much of the surrounding lands have been cleared of original vegetation cover and are predominantly grassland. Areas of original and remnant vegetation are scattered throughout the Modification Area especially on Mount Arthur, within the upper portion of Saddlers Creek Catchment and in the western portions of the Modification Area.



Source: Google Earth.

Figure 6: Three-Dimensional View of Mt Arthur Coal Mine

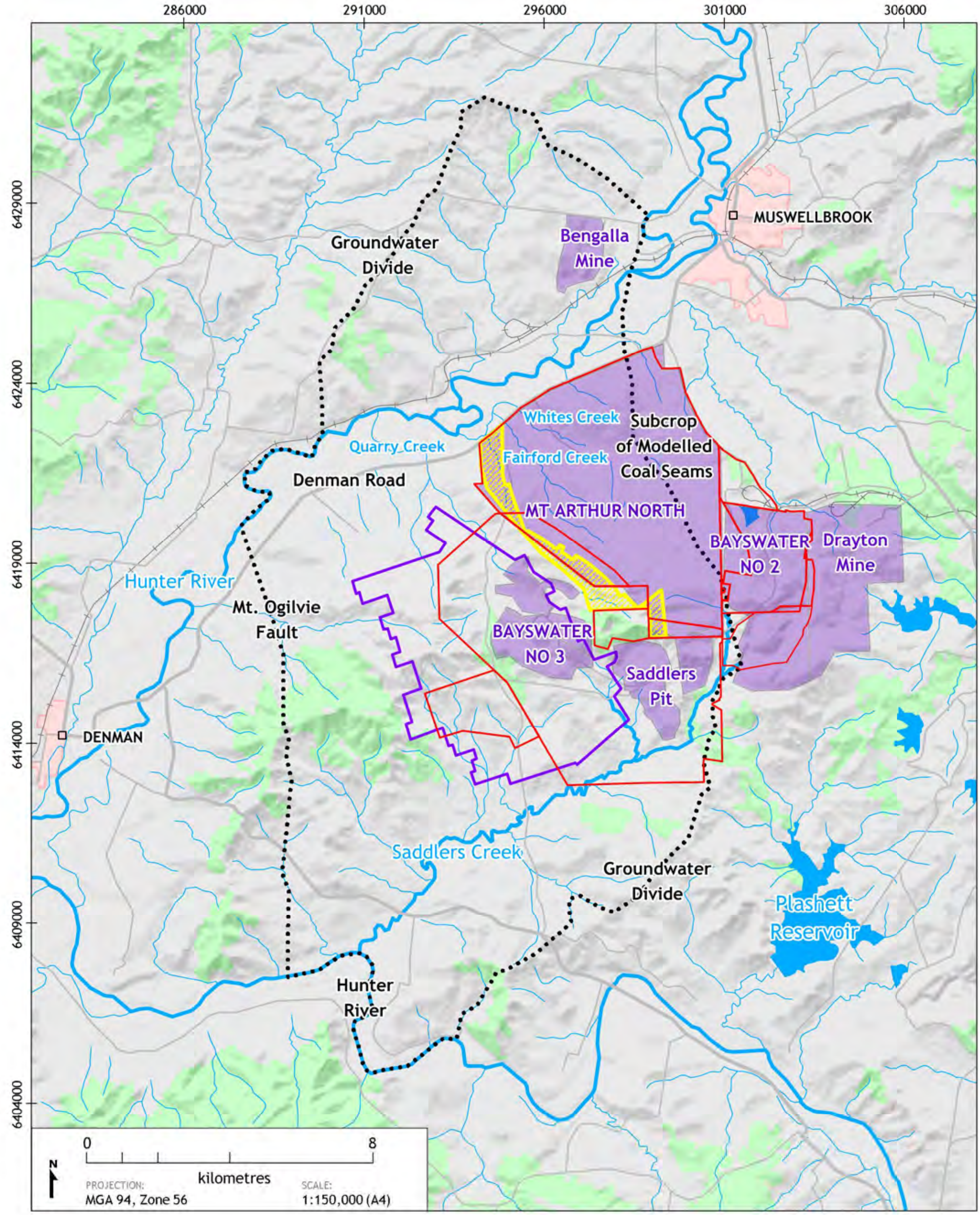
7.5 Climate

The climate in the Mt Arthur Coal Mine is typical of temperate areas and is characterised by hot summers featuring thunderstorms and mild dry winters. Statistical data of mean monthly temperatures are available from Jerrys Plains Station. The mean maximum temperature during winter varies in the range of 17.4 to 19.4 degrees Celsius (°C) and in summer, the mean maximum daily temperature reaches 31.7°C (January). The average annual rainfall is 645 millimetres (mm), with January being the wettest month (76.8 mm). Evaporation of 1,642 millimetres per year (mm/year) exceeds mean rainfall throughout the year, the highest moisture deficit occurring during summer. Average monthly rainfall for Jerry Plains Post Office meteorological station shows summer dominated rainfall (Table 1).

Table 1: AVERAGE MONTHLY PRECIPITATION JERRYS PLAINS POST OFFICE (061086) (1884 to 2012)

Month	Rainfall (mm)
January	77
February	73
March	59
April	44
May	41
June	48
July	44
August	37
September	42
October	52
November	61
December	68

Source: Bureau of Meteorology (BoM) (2012).



LEGEND:

- Mt Arthur Coal Mining & Coal Lease Boundary
- Mine Modification Area
- Existing Mine Area
- Model Boundary
- Mt Arthur Underground
- Road/Track
- Rail
- Town
- Reservoir/Lake
- River
- Creek
- Native Vegetation

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Existing Mine Leases and Conceptual Model Area

AGE GROUNDWATER & ENVIRONMENTAL

DATE: 23/1/2013

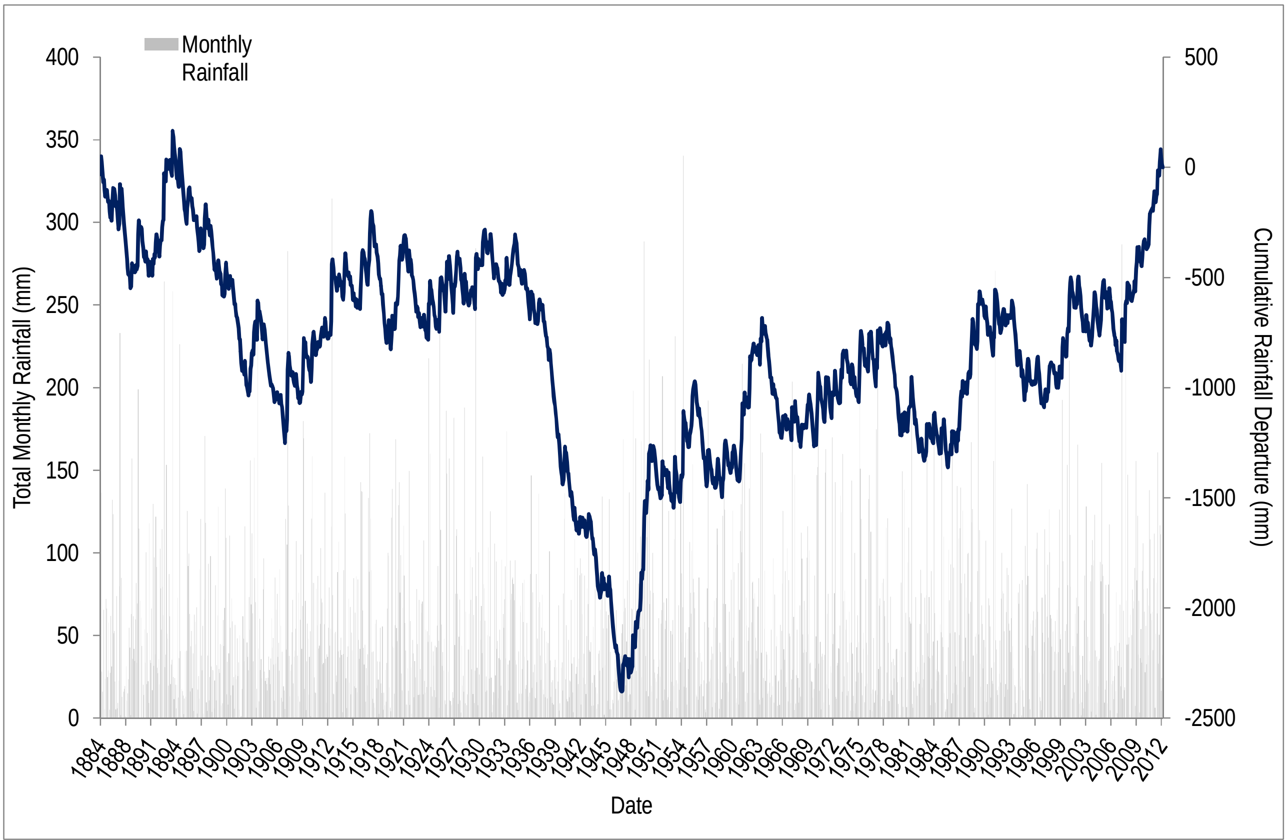
FIGURE No: 7

In order to place recent rainfall years into an historical context the Cumulative Rainfall Departure (CRD), which is a summation of the monthly departures of rainfall from the long-term average monthly rainfall, was calculated as follows:

$$CRD_n = CRD_{n-1} + (R_n - R_{av})$$

Where:	CRD_n	=	CRD for a given month
	CRD_{n-1}	=	CRD for a preceding month
	R_{av}	=	long-term average rainfall
	R_n	=	actual rainfall for given month

The average monthly rainfall used to produce the CRD graph was obtained from the BoM, Jerrys Plains Post Office (061086), which has a continuous record for the period 1884-2012. A positive slope in the CRD plot indicates periods of above average rainfall, whilst a negative slope indicates periods when rainfall is below average. The CRD from 1884-2012 shown on Figure 8 indicates that the Site area experienced a long period of generally above average rainfall from January 2007 until the present.



Source: BoM (2012)

Figure 8: Jerrys Plains Post Office (061086) Monthly Rainfall Data and CRD

8.0 Geology

8.1 Stratigraphy

The stratigraphic sequence across the Mt Arthur Coal Mine comprises two distinct units, namely a Permian coal seam sequence with an overburden and interburden consisting of lithic sandstone, interbedded with siltstone, tuffaceous claystone and mudstone. The Permian sediments are unconformably overlain by thin Quaternary alluvial deposits. The Quaternary alluvial deposits consist of sand and gravel along the creek valleys within the Mt Arthur Coal Mine, and in the alluvial floodplain of the Hunter River to the north.

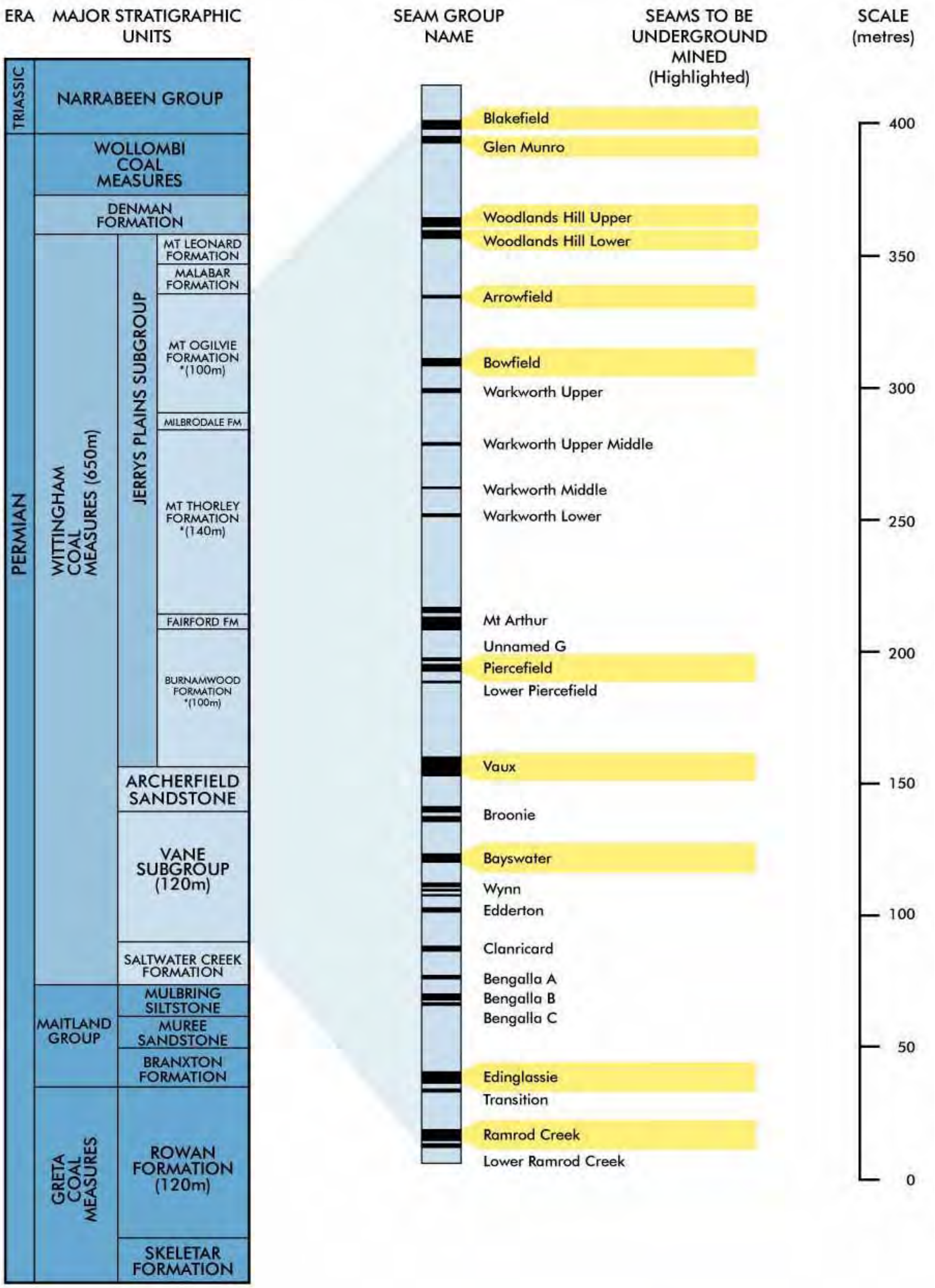
The Permian rocks form a regular layered sedimentary sequence dipping to the west-south-west consisting of the following two main units:

- The Wollombi Coal Measures that, within the Mt Arthur Coal Mine, contain uneconomic coal seams and are confined to isolated portions of elevated sections of the Mount Ogilvie area. These measures are typically above the groundwater table.
- The Wittingham Coal Measures that contain economic coal seams and underlie the whole of the Mt Arthur Coal Mine to a maximum depth of about 500 m.

The Wittingham Coal Measures which include the basal Saltwater Creek Formation are underlain by a thick, non-coal bearing sequence of siltstone, sandstone and mudstone known as the Maitland Group which in turn overlies the Greta Coal Measures. Both the Wittingham Coal Measures and the Maitland Group outcrop in the eastern part of the Site. The Greta Coal Measures outcrop at the closed Bayswater No. 2 Mine and at Drayton Mine where they are currently being mined. A general stratigraphic section for the Site area is given on Figure 9.

The coal seams within the Jerrys Plains and Vane Subgroups of the Wittingham Coal Measures are to be mined as part of the Modification. A summary of the seams and interburden and their average thicknesses are presented in Table 2. The data referring to the thickness of the seams and interburden are based on information received from HVEC. The total thickness of the coal measures is 200 to 220 m.

Igneous intrusions within the Site occur mainly as dolerite dykes generally 0.5 to 1 m in width. These intrusions selectively intrude the coal seams in localised areas. Occurrences of igneous sills, recorded at Mt Arthur South and in the upper seams of the MAU, are not expected to be significant in the Site (URS, 2000).



Source: HVEC.

Figure 9: Stratigraphic Column

Table 2: DETAILS OF SEAMS BEING MINED BY HVEC			
Seam Name	**Thickness (m)**		**Interburden to Underlying Seam (m)**
	Range	*Average*	*Average*
Blakefield	0.2-5.6	3.8	54
Glen Munro	0.2-5.6	2.7	34
Woodlands Hill	0.2-7.5	3.6	33
Arrowfield	0.1-3.7	2.3	20
Bowfield	0.4-4.7	2.5	14
Mt Arthur		4.5	5
Unnamed 1		< 1	10
Piercefield	0.4-5.4	2.3	26
Vaux	0.5-4.5	4	20
Broonie	1-1.5	1.3	13
Bayswater	0.5-4.8	2.8	10
Wynn		<1	5
Unnamed 2		1	5
Edderton		2	10
Clanricard	1.5-2.0	1.8	10
Bengalla	<3.5	2.5	10
Edinglassie	3.0-4.8	3.9[1]	30
Ramrod Creek	<8.5	6.5	-

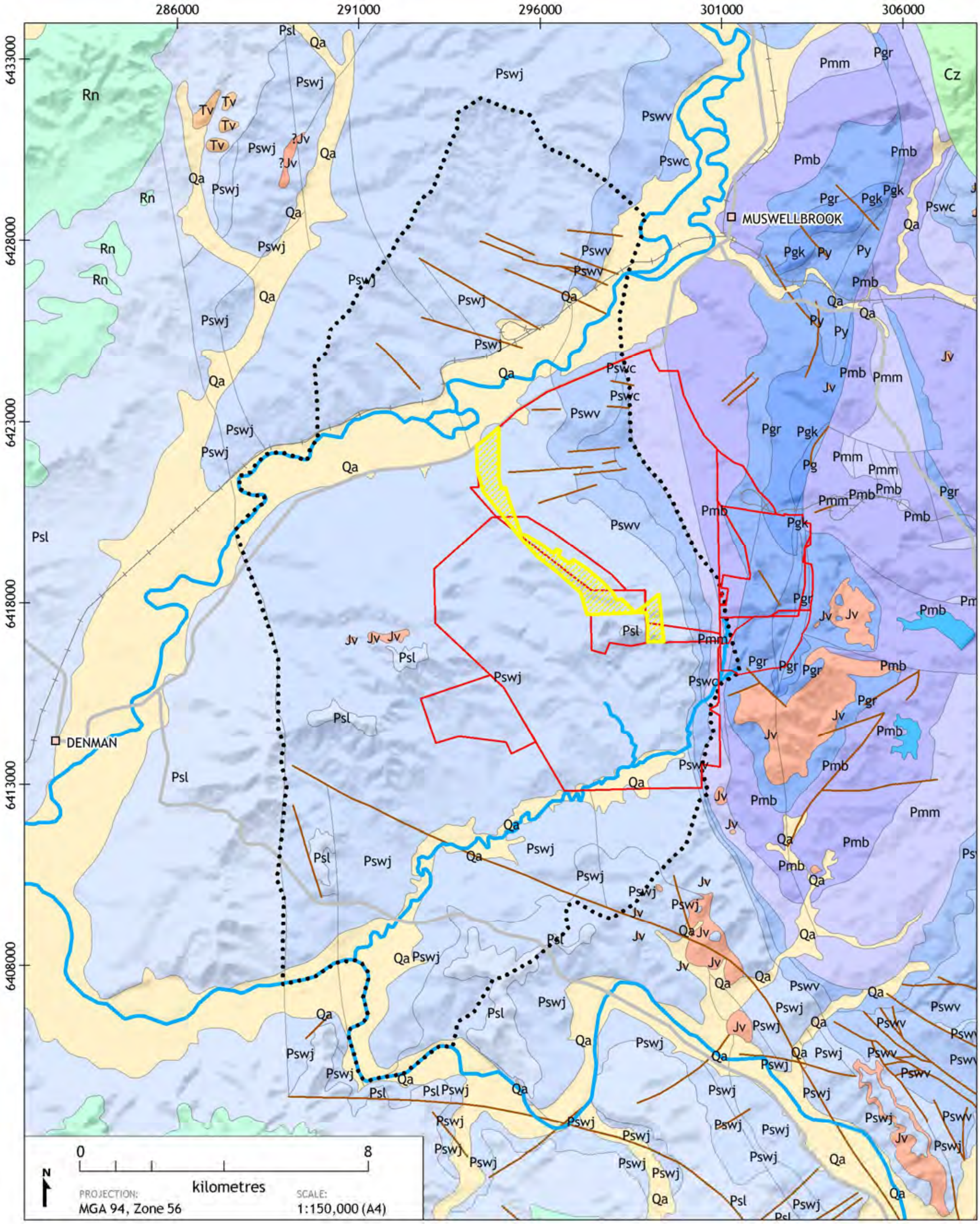
[1] Information received from HVEC.

The mapped 100,000 scale geology of the Site is shown in Figure 10. The geology map shows the distribution of the Quaternary Alluvium which is confined in 1 to 2 km strips associated with the Hunter River and its associated tributaries. The remainder of the area comprises Permian lithologies with minor outcrop of Jurassic aged volcanic rocks.

8.2 Structure

The Modification is located to the west of the Muswellbrook Anticline where the seams sub-crop (Figure 11). The coal seam sub-crop continues to the north of the Modification beneath the Quaternary Alluvium of the Hunter River. The Wittingham Coal Measures dip to the west-southwest towards the Calool Syncline.

The regional geological structure is dominated by a north-south trending monocline and open cut mining has generally been located to the north-east and east of the monocline but will extend to the west as part of the Modification.



LEGEND:

- Mine Modification Area
- Model Boundary
- Mt Arthur Coal Mining & Coal Lease Boundary

100K Geology

- Qa - Quaternary Alluvium
- TV - Tertiary Basalt
- Rn - Hawkesbury Sandstone, Narrabeen G.
- Psl - Wollombi Coal Measures
- Pswj - Denman F., Jerrys Plains Subgroup
- Pswv - Archerfield Ss., Vane Subgroup
- Pswc - Saltwater Creek Formation
- Pmm - Mulbring Siltstone
- Pms - Muree Sandstone
- Pmb - Braxton Formation
- Pgr - Greta Coal Measures
- Pgk - Greta Coal Measures
- Cz - Tuff and Ignimbrite
- Water
- Fault
- Town
- Road
- Rail
- River

Geology based on 1:100,000 Hunter Coalfield Regional Geology

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Geology Map and Major Structures

DATE: 23/1/2013

FIGURE No: 10

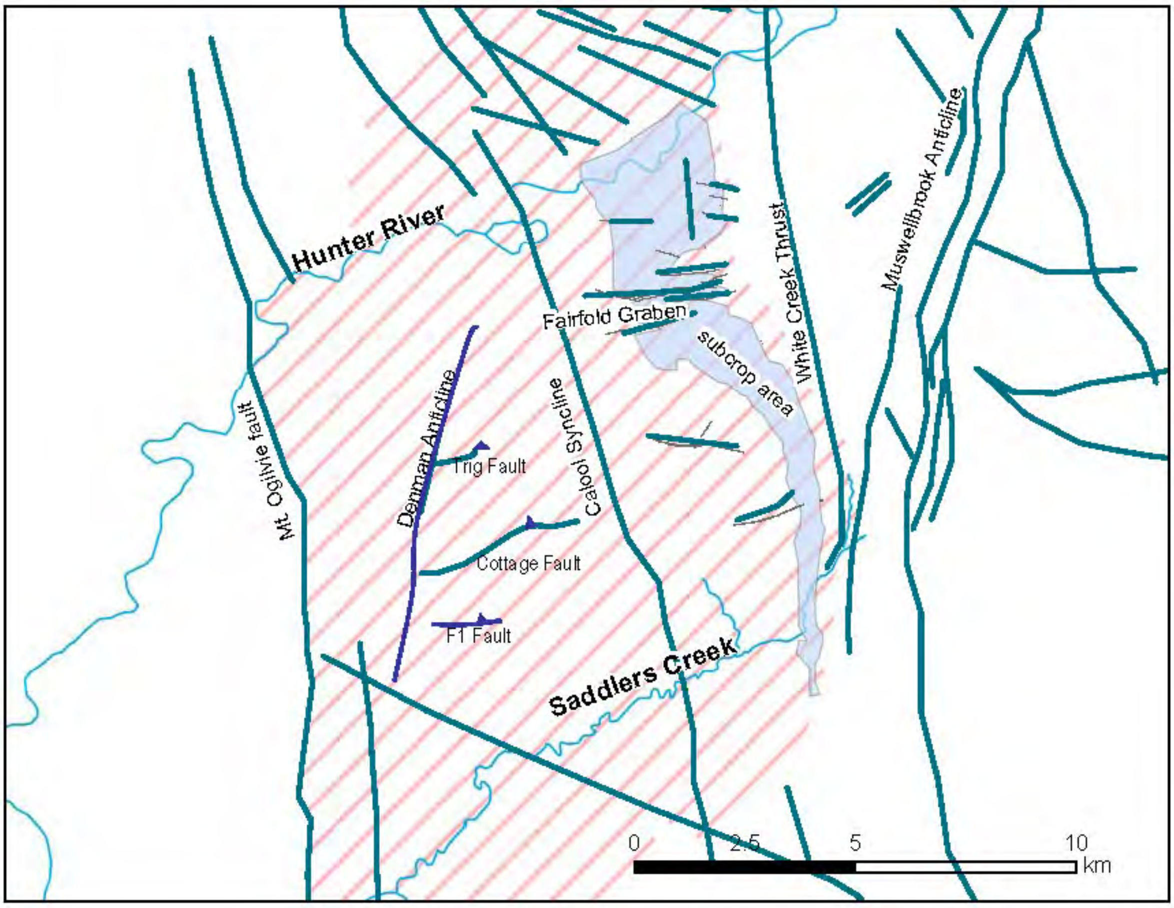


Figure 11: Overview of Main Faults and Structures within Mt Arthur Coal Mine and Surrounds

Major faulting within the Site area is infrequent, however several faults have been identified from the studies undertaken (Figure 11), including:

- An east-west trending graben structure: the Fairford Graben located in the central part of Mt Arthur Coal Mine Pit which varies in width from 750 to 1,000 m and which displaces coal seams by up to 110 m. North of the Fairford Graben, the dip of the seams varies between 2 and 10 degrees (º) with an average dip of about 8º. To the south, the dip varies between 2 to 20º.
- The northerly trending Mount Ogilvie Fault Zone in the west of the Modification, which is significant in that it exhibits a regional displacement (down-throw to the west) of 200 m. The Mount Ogilvie Fault forms a structural boundary to the west of the Mt Arthur Coal Mine.
- North-easterly trending faults including:
  - Trigg Fault which has a displacement varying from 0 m to about 40 m, east to west;
  - Cottage Fault which has a displacement varying from 0 m at the eastern (MacDonald's Pit) end up to 120 m at the western end; and
  - F1 Fault which has a displacement of 20 m to 45 m, east to west.
- The F4 Fault which strikes east-west from the current highwall beneath the Hunter River alluvium east-west.

8.3 Leakage from Faults

There is potential for leakage from the Hunter River alluvium from faults that may occur beneath the alluvium. The identified F4 fault strikes east-west from the current highwall beneath the Hunter River alluvium. In consideration of this, AGE was commissioned by HVEC to undertake a hydrogeological investigation of the F4 Fault to confirm or otherwise the risks to mining imposed by the fault. An interim report was prepared by AGE (2011) which provides a preliminary assessment of the fault based on the work undertaken. A summary of the work undertaken and conclusion reached is given below:

Available details from drill holes and other observations made within the current highwall alignment indicate that the F4 Fault:

- *is visible within the upper northern end section of the current highwall configuration with minor displacement observed;*
- *dips between 63° and 73° the south;*
- *exhibits multiple areas of displacement suggesting splay faulting and potentially a relatively complex structure;*
- *exhibits a vertical displacement which increases from less than 1m where exposed in the current highwall, up to 30m adjacent to Denman Road;*
- *contains areas of fault gouge and possible zones of brecciation, with sympathetic minor faulting interpreted in conjunction with the major fault alignment; and*
- *may contribute to the groundwater flows measured whilst drilling which ranged from 0.3L/sec to 3L/sec (measured over a V–notch weir).*

…

In May 2011, Mt Arthur Coal in conjunction with AGE commenced a drilling program to characterise the properties of the F4 Fault structure and the overlying Hunter River Alluvium. The objectives of this field investigation program were to:

- *define the structure and hydraulic conductivity of the fault zone within the field area;*
- *define the nature of the alluvial sediments; and*
- *establish a Vibrating Wire Piezometer (VWP) network for long-term monitoring of prominent coal seam aquifers and fault zones.*

…

To achieve these objectives, the scope of work for the field investigations included:

- *drilling three fault exploration holes to confirm the location and depth of the F4 Fault;*
- *packer testing at selected intervals within each drill hole; and*
- *installation of nested (multiple) VWPs in each exploration hole.*

A series of packer tests were conducted on the fault zones, interburden and coal seams. Analysis of this permeability testing indicates the interburden, F4 Fault Zone and Splay Fault Zone sequences to be of low to very low permeability, with the coal seam permeability at least one order of magnitude higher.

Based on these preliminary results, it would appear that the F4 Fault is highly unlikely to act as a conduit for groundwater flow from the alluvium.

9.0 HYDROGEOLOGICAL REGIME

9.1 Groundwater Use

A search of the NOW database of registered bores and wells within a radius of approximately 5 km from the Mr Arthur Coal Mine was undertaken. The data indicates that there are 50 registered bores within this radius as shown on Figure 12 and tabulated in Appendix 1. This compares to 32 bores found for a similar radius search in the AGE (2009) study. The registered bores include one bore licensed for domestic, two for stock and irrigation supply, 13 for stock and domestic only, 22 for stock supplies only, six for domestic, irrigation and stock, two for monitoring and four unknown.

Fifteen of the bores are thought to be in the Hunter River alluvium based on their location and depth. The remaining 35 bores are located in sandstone, conglomerate, siltstone or coal of the Permian strata. Sixteen of the bores are located on HVEC owned land (three in alluvium), five located on Bengalla Mine owned land (three in alluvium) and the remainder on privately-owned land of which nine are in alluvium.

The database gives an indication of groundwater usage in the vicinity of the Site. The data suggests that groundwater from the Permian groundwater systems is used primarily for stock use whereas those bores in the alluvial flats are used for a combination of irrigation, stock and domestic supply.

There are no registered bores in the alluvium of Saddlers Creek.

9.2 Conceptualisation Summary

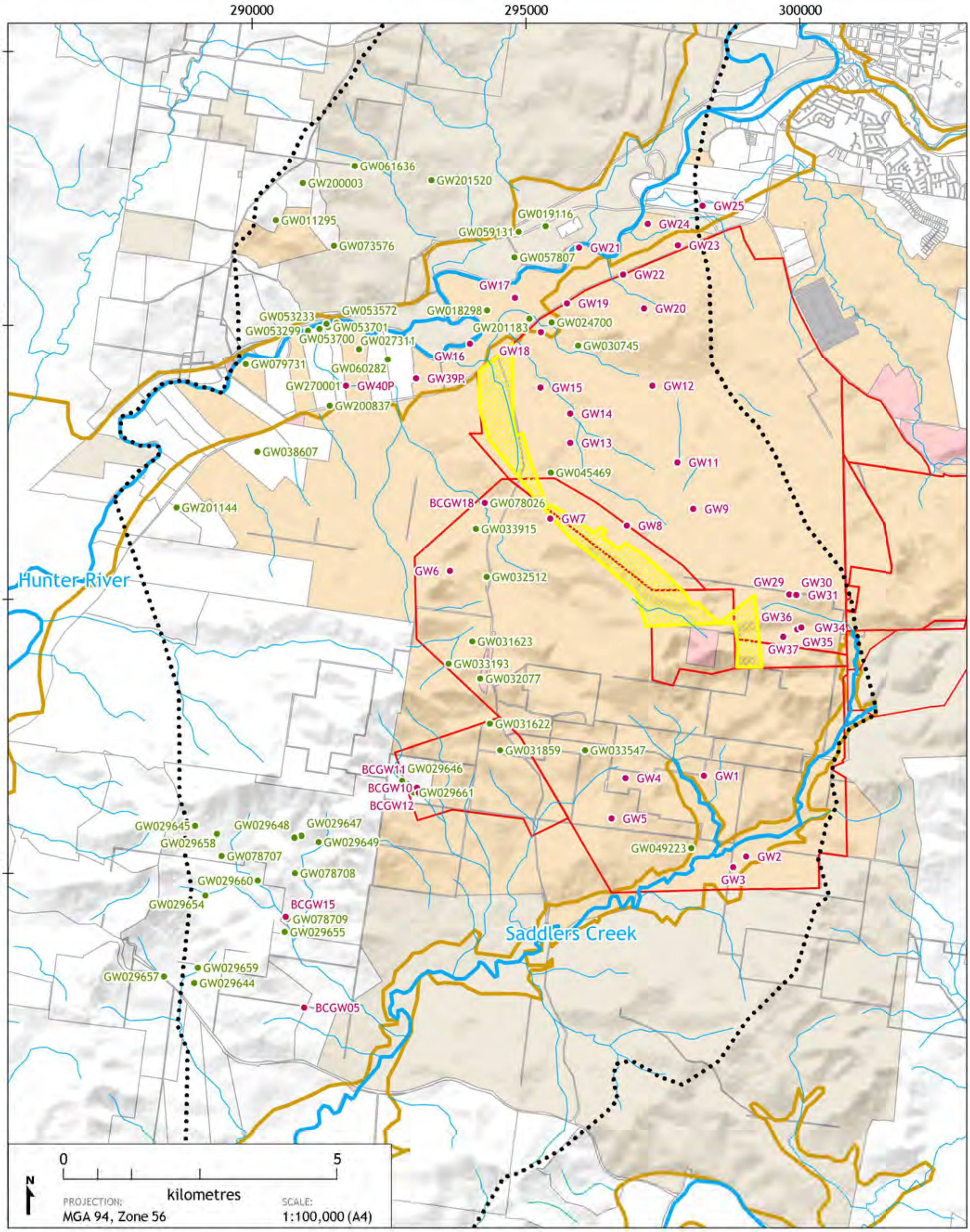
The conceptual groundwater model of the Modification was developed based on geological and topographical maps of the Site area, geological information provided by HVEC, hydraulic information and on the results of previous studies, namely MER (2007) and AGE (2009).

Alluvial deposits in the region are present along the Hunter River and also along Saddlers Creek. The Permian Wittingham Coal Measures are typically not considered an aquifer. While some coal seams have elevated hydraulic conductivities, the dominant interburden sections are of very low hydraulic conductivity. Only the weathered bedrock (regolith) directly below the ground surface may have a somewhat higher hydraulic conductivity due to weathering. Therefore, from a conceptual groundwater model perspective, the groundwater system in the Mt Arthur Coal Mine model area is considered to consist of three groundwater systems, including:

- alluvium along the Hunter River and Saddlers Creek;
- weathered bedrock (regolith); and
- the coal seams of the Permian Wittingham Coal Measures.

Recharge to the groundwater systems is assumed to occur over the entire model area. The rate of recharge over the alluvial deposits and areas of coal seam sub-crops is considered to be higher than over the areas covered by the overburden and interburden.

The following sections characterise the different groundwater systems and discuss the underlying data.



LEGEND:

- Mt Arthur Coal Mining & Coal Lease Boundary
- Mine Modification Area
- Model Boundary
- NOW Registered Bore
- Groundwater Monitoring Bore
- Alluvium
- River
- Creek
- Crown Land / The State of NSW
- HVEC Owned Land
- Industrial Zone
- Mine Owned Land
- Private Owned Land

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Monitoring Bore and NOW Registered Bore Location

DATE: 23/1/2013

FIGURE No: 12

9.3 Alluvium

9.3.1 Distribution

Deposits of unconsolidated silts, sand and minor fine gravels of mixed colluvial-alluvial origin occur in the valleys of the creeks and gullies within the model area. These deposits are thin and of limited extent, and hence do not have significant groundwater storage capacity. They may contain groundwater which has infiltrated from surface runoff following periods of heavy rainfall and discharge of this groundwater from the alluvium maintains baseflow in the creeks and gullies following rainfall. The alluvium however drains quickly and discharge/baseflow to the creeks is of short duration.

To better understand the nature of the alluvial sediments along Whites Creek and Fairford Creek, a series of test pits and boreholes were completed in 2009 (AGE, 2009). This investigation identified a narrow band of alluvium extending between 200 and 350 m to the south-east along Whites and Fairford Creeks respectively, and that in the down-gradient end of the creeks, the alluvium is saturated and in hydraulic connection with the Hunter River alluvium. The sediments in the upper part of the creeks however consist predominantly of silty to sandy clays which typically form an aquitard and hence do not readily transmit groundwater. The extent of these alluvial sediments along the Whites Creek and Fairford Creek drainage alignments is similar to that shown by MER (2007).

Farm dams have been constructed on many of the creeks within the model area indicating that the alluvium is both of very low permeability and is thin, otherwise the dams would leak and not retain water. Field investigations have shown that the upper part of the Saddlers Creek valley is in-filled with the less permeable unconsolidated silts.

In contrast, the alluvial deposits of the Hunter River to the immediate north of the Site are a significant source of groundwater. The distribution of the alluvium is shown on Figures 10 and 12. MER (2000) reviewed available data from existing stock and irrigation bores in the Hunter River alluvium and constructed five monitoring bores (MGW1-5). These were subsequently renamed by Mt Arthur Coal as GW16, GW17, GW21, GW24 and GW25. The data indicated that groundwater within the alluvial lands of the Hunter River occurs within the basal gravel sequence and overlying sands.

The Hunter River alluvium is up to 13 m thick and contains basal gravel varying between about 2.5 and 4 m in thickness. The material overlying the basal gravel consists predominantly of silt with minor clay. Water bearing sand lenses occur within the silt. The saturated thickness of the alluvium in bores GW16, 17, GW21, GW24 and GW25 ranged from 2 to 6 m (MER, 2000).

9.3.2 Hydraulic Parameters

Pumping tests on bores GW16, GW17, GW21, GW24 and GW25 by MER (2000) indicate that the basal gravel of the Hunter River alluvium has a moderate to high hydraulic conductivity in the range 5 metres per day (m/day) to 40 m/day, with a median value of 8.2 m/day. Values determined at other locations in the model area range from 2 m/day to more than 60 m/day. The data suggests a highly variable and anisotropic hydraulic conductivity distribution in the alluvium.

9.3.3 Yield

Due to the relatively thin saturated thickness of the alluvium, bore yields are generally quite low; the higher yielding bores being those with the greatest saturated thickness. MER (2000) undertook pumping tests on the five monitoring bores (GW16, GW17, GW21, GW24 and GW25) at rates of around 0.25 L/s, with the drawdown in individual bores varying between 0.01 and 0.97 m. Yields from larger diameter production bores within the alluvium are likely to be greater.

9.3.4 Groundwater Levels and Hydraulic Gradients

Groundwater levels in the Saddlers Creek and Hunter River alluvium have been recorded bi-monthly from February 2008 to present. The position of all monitoring bores is shown in Figure 12 with bores GW16, GW17, GW18, GW21, GW24 and GW25 monitoring the Hunter River alluvium and bores GW2 and GW3 monitoring the Saddlers Creek alluvium.

Generally water levels in the Hunter River and Saddlers Creek alluvium are approximately 8 to 10 m below ground level. Levels remained fairly static for the period 2008 to present. Groundwater levels are discussed in relation to post and current mining activities in Section 10.

There are no nested piezometers measuring both alluvial groundwater levels and those in the underlying Permian formations. Therefore no information is available on pre-mining vertical hydraulic gradients.

9.3.5 Regional and Local Recharge, Discharge and Groundwater Flow

Recharge to the alluvium is likely to occur from direct infiltration of rainfall, and runoff from elevated bedrock sub-crop areas. Apart from infiltration of rainfall and runoff from elevated areas, the alluvium along the Hunter River is potentially recharged during very dry periods from flow in the Hunter River. Release of water from Glenbawn Dam upstream of the Site maintains flow in the river.

Interflow may occur from thin, limited alluvial deposits associated with minor ephemeral streams, and this flow may lead to short lived perched groundwater bodies that drain rapidly to downstream alluvium, creeks and gullies.

Upward leakage of poorer quality water from the underlying coal measures also adds to recharge of the Hunter River alluvium, and to the Saddlers Creek baseflow.

MER (2000) states that groundwater within the alluvium indicates a shallow hydraulic gradient towards the Hunter River, and this is consistent with the regional hydraulic gradient. That is the hydraulic gradient from the edge of the alluvium appears to be consistent with that of the coal seams and with the overall gradient in the Northern Open Cut area. The alluvial water table also has a general downstream hydraulic gradient coinciding with the topographic gradient of the alluvium and flow of the Hunter River.

9.3.6 Water Quality

HVEC monitors groundwater quality of the Hunter River alluvium in monitoring bores GW16, GW17, GW21, GW24 and GW25. This has occurred since their installation in January 1999.

The data indicates that the groundwater quality, as reflected by the Electrical Conductivity (EC), is quite variable, in the range 1,500 to 9,370 microSiemens per centimetre (µS/cm). The EC range within individual bores is similarly quite large and probably reflects the dominant recharge source at the time, that is, recharge from the underlying coal measures resulting in poorer quality water, or recharge from rainfall or the river itself, resulting in slightly improved quality water.

The pH ranges from 6.7 to about 7.6, that is, from slightly acid to slightly alkaline.

Monitoring data indicates the surface water in Saddlers Creek is brackish and this is supported by observations made during a Site visit by AGE in December 2005. The brackish surface water indicates a potential discharge source from the underlying Permian coal measures.

A summary of laboratory analysis of samples collected from alluvial bores is presented in Table 3 below. The table shows indicative values prior to commencement of mining at the Northern Open Cut and more recent 2012 EC results.

Table 3 : GROUNDWATER QUALITY-ALLUVIUM

Location	Hunter River					
	Bore GW16		Bore GW21		Bore GW25	
	Mar. 1999	Jun. 2012	Mar. 1999	Jun. 2012	Mar. 1999	Jun. 2012
Electrical Conductivity (µS/cm)	3,810	3,480	3,111	1040	5,780	5,260
Sodium	440	-	390	-	840	-
Magnesium	140	-	86	-	160	-
Potassium	1.8	-	3.7	-	2.5	-
Calcium	145	-	110	-	145	-
Chloride	690	-	470	-	1,130	-
Bicarbonate	400	-	680	-	560	-
Iron	0.02	<0.05	0.05	0.14	0.03	0.4
Manganese	-	-	0.11	-	-	-
Phosphorus	0.2	-	0.1	-	0.2	-

Note: all results other than EC expressed in milligrams per litre mg/L.

The data are compared to Australian and New Zealand Environment Conservation Council (2000) guidelines for “livestock” and for “potable” (human consumption) use. Given that groundwater in the alluvium is unsuitable for human consumption in most locations due to salinity in that it exceeds 500 mg/L total dissolved solids (TDS) and has localised, relatively high iron concentrations, the environmental value has been classified as “primary industry”, with the main use being for irrigation and stock watering. The environmental value of localised areas, such as swamps or more deeply incised channels (if any) across the floodplain with permanent water holes, could be classified as “aquatic ecosystems”.

9.3.7 Groundwater Dependent Ecosystems

No groundwater dependent vegetation comprising GDEs occurs within the Modification Area or immediate surrounds (Hunter Eco, 2012).

9.4 Shallow Bedrock (Regolith)

The regolith or shallow bedrock groundwater systems comprises surficial soils and weathered bedrock. The depth of the profile is variable and depends on such factors as:

- depth of weathering; and
- extent and frequency of fracturing.

Interpretation of available data indicates that there is perched groundwater at the interface between the soil and bedrock, and zones of locally increased permeability caused by weathering of the bedrock. MER (2000) states that the transition of the surficial mixed colluvial-alluvial type deposits to underlying weathered coal measures is often difficult to define in areas where coarse clastics occur and the depth of weathering is significant.

MER (2007) states that the rainfall recharge to other shallow groundwater systems situated in elevated areas including the weathered rock zone or regolith, is often variable. The coal measures in these areas tend to weather to a relatively thin regolith (5 to 10 m thick), comprising mixed sandy, silty-clayey sediments. These silty-clay zones have poor transmission characteristics but the sandy areas offer increased potential for groundwater recharge.

The regolith acts as a potential temporary water store during sustained wet periods and provides a potential source for recharge to the underlying coal measures. However, the very low hydraulic conductivities of deeper strata and observed minimal change in water levels in deep monitoring bores throughout the region infers recharge to the underlying coal measures is limited (discussed further in Section 9.5). This differentiation in properties between the regolith and underlying coal measures can sometimes result in the presence of shallow springs, although few are noted within the Mt Arthur Coal Mine Site.

The conceptual groundwater model represents the shallow bedrock groundwater system as a zone of enhanced hydraulic conductivity compared to the Permian coal measures.

9.5 Permian

The Permian strata may be categorised into the following hydrogeological units:

- hydrogeologically “tight” and hence very low yielding to essentially dry sandstone and lesser siltstone that comprise the majority of the Permian interburden/overburden; and
- low to moderately permeable coal seams which are the prime water bearing strata within the Permian sequence.

9.5.1 Distribution

As discussed, the Permian deposits occur across the whole of the Site as a regular layered sedimentary sequence.

9.5.2 Hydraulic Parameters

Various tests including pump-out, variable head and packer tests have been undertaken in the past. Packer tests indicate that the hydraulic conductivity of the interburden varies between 5.2×10^{-3} m/day to 8.6×10^{-5} m/day, and that the coal seam hydraulic conductivity varies between 0.01 to 0.69 m/day. In contrast, pumping tests gave unusually high hydraulic conductivity values for the coal seams in the range of 2 to 20 m/day, which is more characteristic of a fine to coarse sand.

A reduction in the hydraulic conductivity of the coal seams with depth is observed in many coal mines. AGC (1984) developed an equation based on the interpretation of depth-dependent hydraulic conductivities of 17 seams in the Upper Hunter Valley as shown below:

$$k = k_o * e^{(-cz)}$$

where:

k	=	hydraulic conductivity [m/day]
k_o	=	reference hydraulic conductivity = 5 [m/day]
c	=	slope of trendline (0.046 for Hunter Valley coal seams)
z	=	depth [m]
e	=	base of the natural logarithm (approximately 2.71828182846)

Therefore even if very high hydraulic conductivities are indicated by the pumping tests within the sub-crop area, much lower values can be expected at greater depths.

Coal Operations Australia Limited (2000) states that laboratory permeability tests on core samples yielded a vertical hydraulic conductivity range of the interburden between 1.8×10^{-4} m/day and 1×10^{-7} m/day.

Applying the above equation allows prediction of the value of hydraulic conductivity of the interburden for different depths.

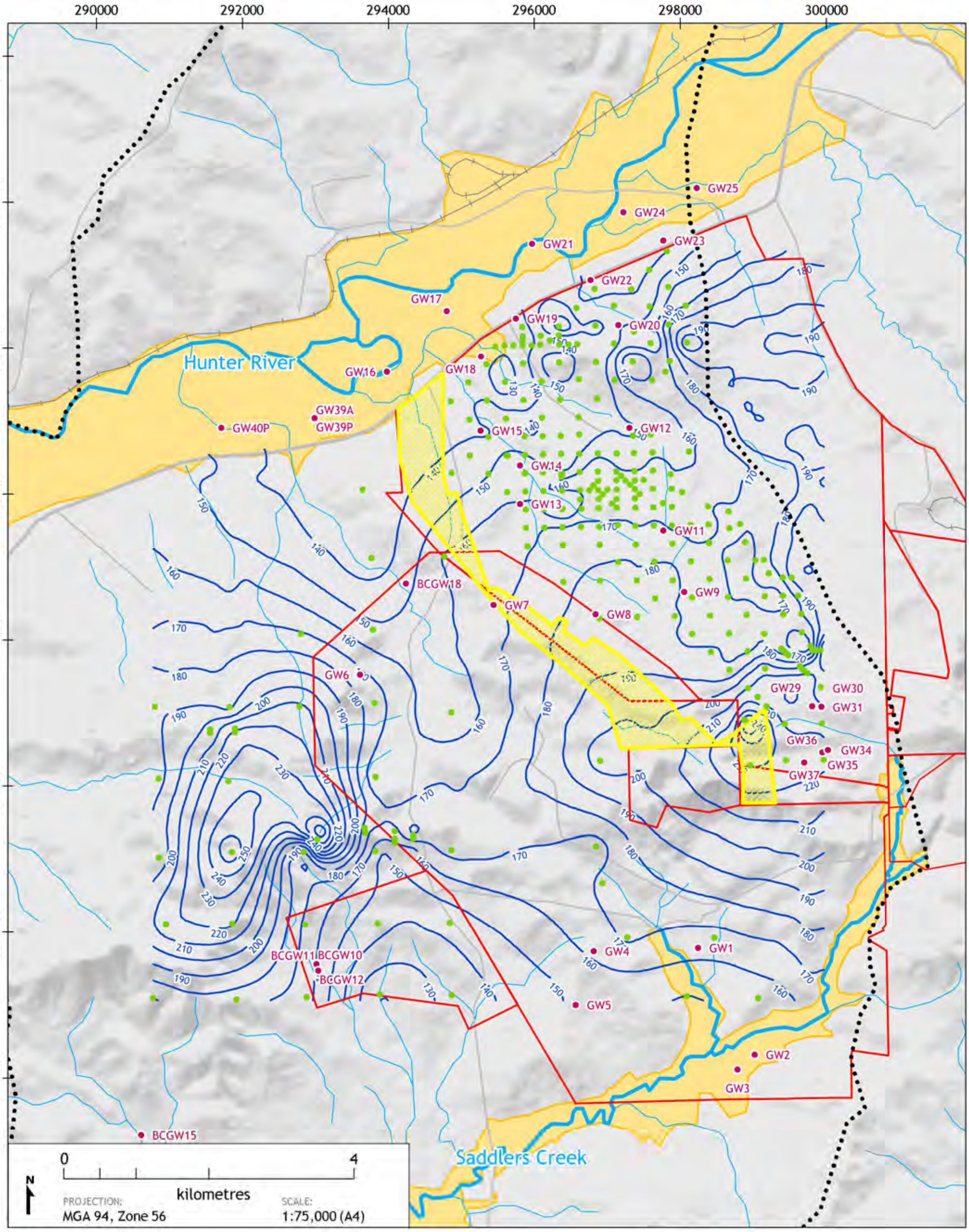
9.5.3 Yields

A number of hydraulic tests have been undertaken on various coal seams within the Mt Arthur Coal Mine study area in the past. The tests indicate that yields from individual bores within the coal seams are in the range of 1 to 3.3 L/s, which is considered to be high given the depth of the tested sections of the seam.

9.5.4 Groundwater Levels and Hydraulic Gradients

A groundwater level (potentiometric) surface contour map was developed by AGE (2009) from water levels measured by HVEC in open exploration holes, as well as in dedicated monitoring bores (Figure 13). The map indicates that the potentiometric surface is a subdued reflection of the topography, with a groundwater mound beneath the topographically elevated areas of the ridgeline between Mount Arthur and Mount Ogilvie, and a hydraulic gradient towards the Hunter River valley to the north, and Saddlers Creek to the south.

Groundwater levels and hydraulic gradients are discussed in Section 10, using available water level data for the current mine development.



LEGEND:

- Mt Arthur Coal Mining & Coal Lease Boundary
- Mine Modification Area
- Model Boundary
- Groundwater Level Contour Premining (mAHD)
- Groundwater Level Measurement
- Groundwater Monitoring Bore
- River
- Creek
- Alluvium
- Road/Track
- Rail

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Interpreted Groundwater Table

DATE: 23/1/2013

FIGURE No: **13**

9.5.5 Regional and Local Recharge, Discharge and Groundwater Flow

Groundwater recharge is considered likely to occur by rainfall infiltration via the regolith. Groundwater flow occurs toward the lower lying areas where discharge occurs into the alluvial valleys and creeks/rivers.

9.5.6 Water Quality

Table 4 provides pre-mining water quality data from boreholes intersecting coal seams and from samples collected from a sump within a box cut. The table indicates that the TDS content ranges from about 1,750 to 7,760 mg/L and that the pH is generally alkaline at about 8. The data shows that groundwater in the Permian is of poor quality and is typical of coal seam water quality.

The general low yield and poor quality of the groundwater in the coal seams indicates that the environmental value can be classified as "primary industry" with the main potential use being for stock watering.

Table 4: PRE-MINING GROUNDWATER QUALITY-PERMIAN GROUNDWATER SYSTEMS

Location	Bore K15	Bore WB1	ID1014A (GW8)	ID1049 (GW12)	ID1030 (GW19)	Box Cut West
	Dec. 1980	Jan. 1981	Feb. 1999	Feb. 1999	Feb. 1999	Feb. 1999
pH (unit)	8.6	8.1	-	-	-	-
Electrical Conductivity (µS/cm)	8,950	7,005	-	-	-	-
Total Dissolved Solids	6,560	5,370	3,340	6,500	1,750	7,760
Hardness as $CaCO_3$	235	1,000	-	-	-	180
Sodium	2,440	1,640	860	1,500	350	2,100
Potassium	9	15	20	13.5	13	18.5
Calcium	39	95	72	155	36	17.5
Magnesium	32	190	245	380	38	460
Chloride	3,174	2,045	1,100	2,500	450	3,460
Bicarbonate	826	1,390	1,250	730	650	620
Sulfate	250	590	-	-	-	-
Iron	<0.01	<0.01	-	-	1.04	-
Manganese	<0.01	0.63	0.02	0.28	0.28	-
Nitrate	0.4	0.53	-	-	-	-
Phosphorus	-	-	0.2	0.3	0.2	0.2

Source: SKP (1981); MER (2000).

Notes: Bore name in brackets e.g. (GW8) is new monitoring bore name adopted by HVEC.
All concentration in mg/L unless otherwise stated.
$CaCO_3$ = calcium carbonate.

10.0 IMPACT OF MINING TO DATE

This section provides an assessment of the current impact of open cut mining at the Mt Arthur Coal Mine on the groundwater resources of the Hunter River alluvium and the Permian coal measures. The assessment is based on an analysis of the groundwater monitoring data obtained from monitoring bores located around the Site. The depressurisation effects observed in Permian coal measures may also be used to infer hydraulic conditions for the groundwater system, a surrogate for nested piezometers within the three main hydro-stratigraphic units (alluvium, regolith, Permian). The monitoring bore locations are shown on Figures 12 and 13.

10.1 Impact of Mining on Hunter River Alluvium

10.1.1 Hydrographs

Monitoring of groundwater levels in the Hunter River alluvium to the immediate area north of the Northern Open Cut has been undertaken since January 1999. Monitoring has also been undertaken in the Permian coal measures from two bores located in the zone between the edge of the alluvium and the limit of current and proposed future mining. The bores monitored that are of relevance to this report are summarised in Table 5, their locations are shown on Figure 12, and the hydrographs are shown on Figure 14.

Table 5: MONITORING BORES ALONG THE HUNTER RIVER

Bore	Location		Elevation	Depth	Formation
	(mE)	(mN)	(mRL)	(mbGL)	
GW16	294,082.9	6,422,888.3	131.77	13	Alluvium
GW21	296,069.6	6,424,639.2	136.06	16	Alluvium
GW25	298,323.8	6,425,403.7	140.05	13	Alluvium
GW22	296,870.7	6,424,147.7	154.05	96.3	Permian
GW23	297,870.3	6,424,683.8	181.40	51.4	Permian

Note: mE = metres Easting
mN = metres Northing
mRL = metres relative level
mbGL = metres below ground level

The hydrographs of bores GW16, GW21 and GW25 indicate that alluvial groundwater levels have remained relatively constant since monitoring commenced in 1999. The fluctuations do not correspond to the CRD which would be expected of a predominantly rainfall recharged alluvial groundwater system. This indicates some buffering of the alluvial groundwater levels by the potentially interconnected Hunter River.

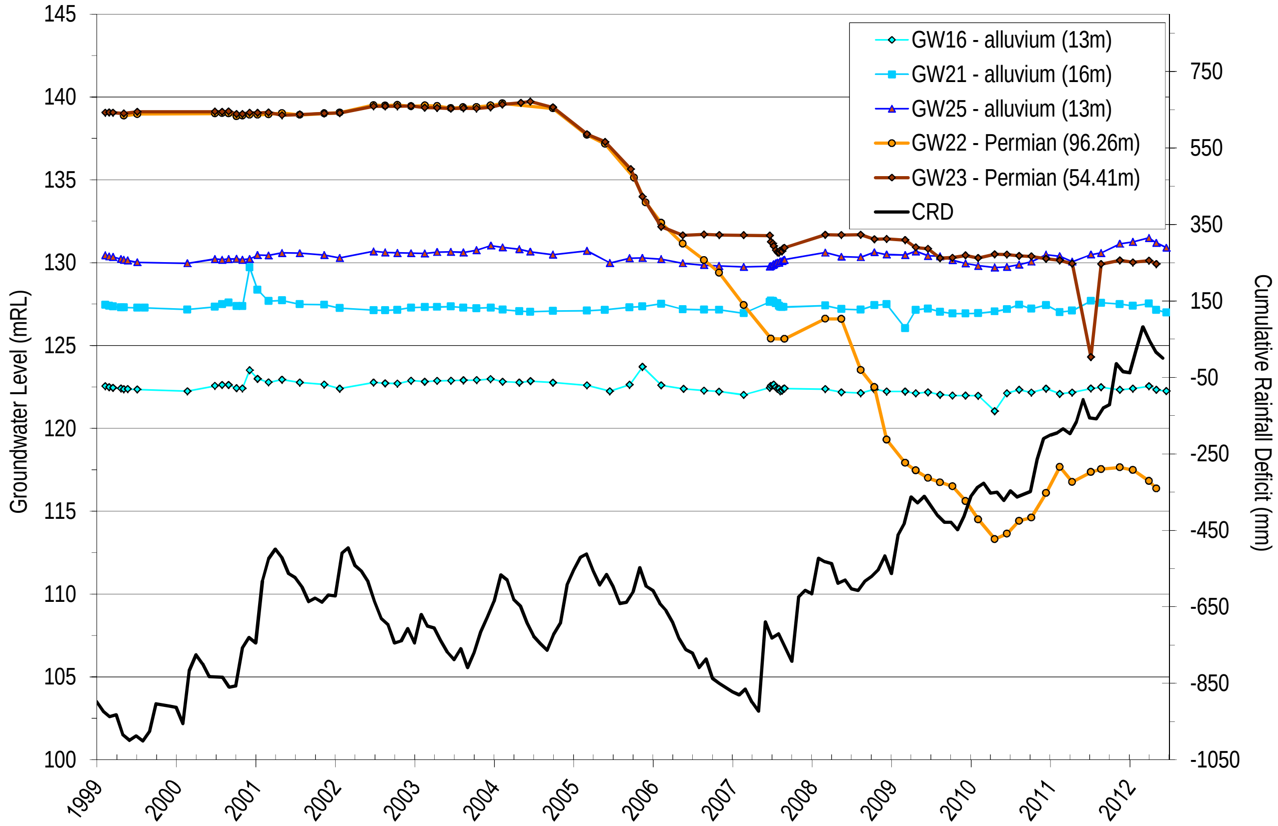


Figure 14: Hydrographs of Selected Monitoring Bores along the Hunter River

In contrast, the Permian coal measures show significant depressurisation with the piezometric surface declining by about 26 m in the deepest bore GW22 (96.3 m deep), until April 2010, with a recovery of about 4 m from that time until the present. There is also a decline of about 15 m in the shallower bore GW23 (54.4 m deep), commencing in mid-2004, with the most rapid decline of 5.7 m occurring since April 2011, although this has subsequently recovered during early 2012. Between 1999 and mid-2004, the potentiometric surface of the coal measures was at about 139 mRL, indicating groundwater discharge from the brackish Permian groundwater systems to the alluvium where the water table varies between 131 mRL (upstream at GW25) to 125 mRL (downstream at GW16). However, due to depressurisation, the potentiometric surface in GW22 and GW23 is currently at 117.3 mRL and 130 mRL respectively, which is lower than the alluvial water table surface, and the potential is for a reversal of groundwater flow from the alluvium to the Northern Open Cut.

The decline in the piezometric surface at the Permian monitoring bores commenced in 2004, and it was at this time that HVEC commenced box cutting in the northern area of the lease in preparation for mining the adjoining Macleans Hill. It is reported that the box cut was reasonably wet at the time of development. As discussed, the water table in the alluvium has remained static and the data suggests that there has been no impact on the alluvium as a consequence of depressurising the Permian coal measures.

10.1.2 Electrical Conductivity

Monitoring of EC of the alluvium and Permian coal measure groundwaters also occurs and is presented graphically in Figure 15. The EC indicates that the groundwater in the alluvial bores and in the Permian coal measure bores is of poor quality ranging from about 3,000 to 9,000 µS/cm (EC in GW21 ranges from about 1,000 to 5,000 µS/cm).

The base of the alluvium generally contains poor quality water potentially due to discharge from the coal seams, however if this were to be reversed, that is flow is from the alluvium to the pits as a result of depressurisation, it would be expected that the water quality at the base of the alluvium and in the Permian coal measure monitoring bores would improve, that is the EC would decrease. Figure 15 indicates that this may be occurring in the alluvial bores as shown by the trendlines of GW16, GW21 and GW25.

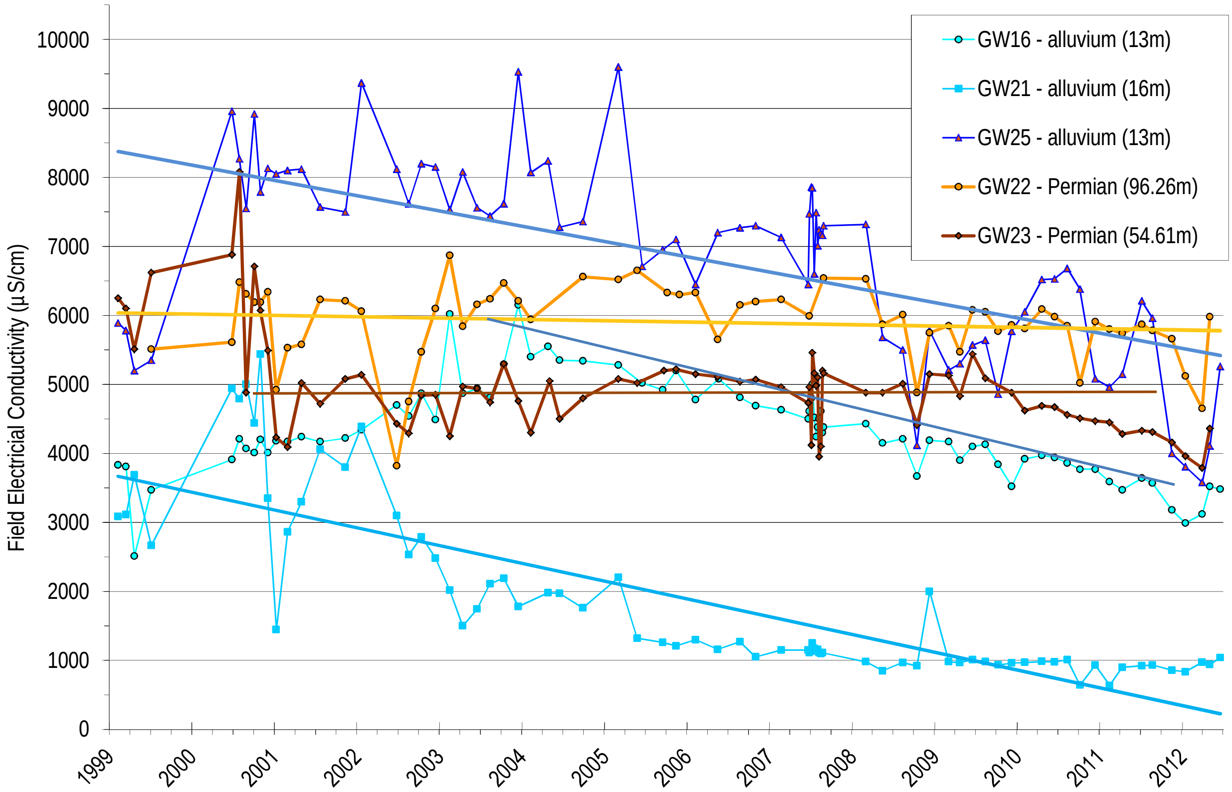


Figure 15: Electrical Conductivity Trends of Monitoring Bores

10.2 Impact of Mining on Saddlers Creek Alluvium

Two bores monitoring the Permian sequence below Saddlers Creek indicates that there is minor long term depressurisation to mid-2011 (approximately 3 m) of the Permian coal measures underlying the Saddlers Creek alluvium (Figure 16). The depressurisation is associated with mining at Saddlers Pit and provides broad confirmation of the modelling undertaken by AGE (2009) which indicates no drawdown in the alluvium of the creek, but states that there will be minor leakage from the alluvium due to depressurisation of the underlying Permian. Recovery is noted in water levels since mid-2011.

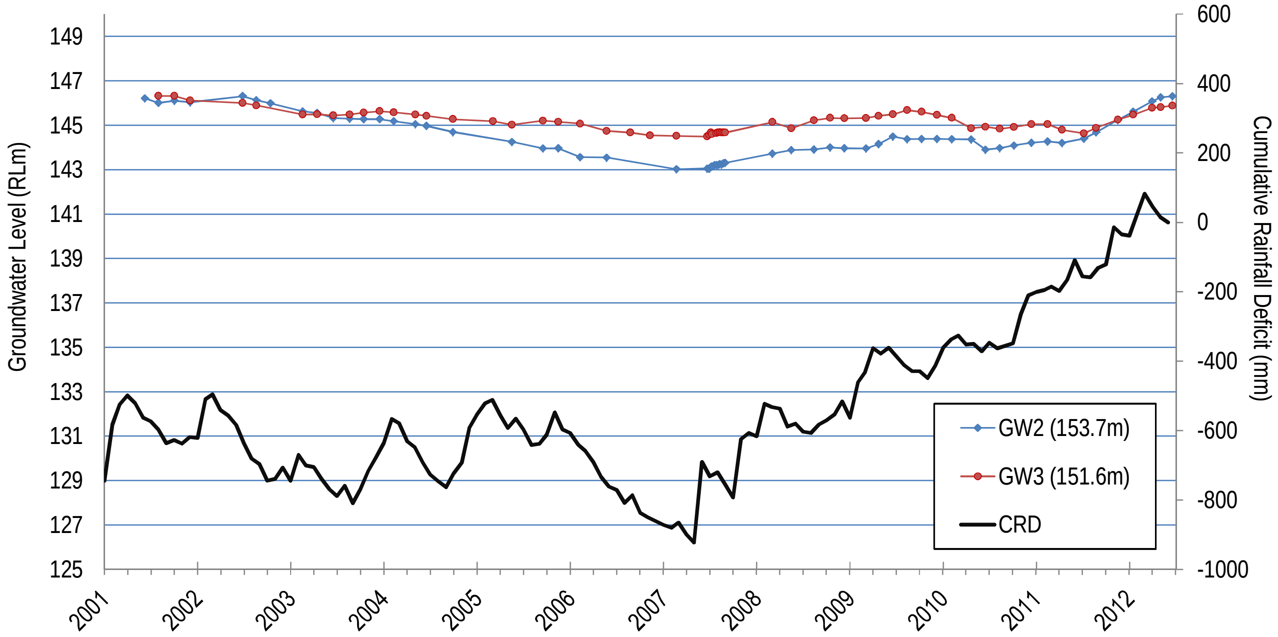


Figure 16: Hydrographs of Permian Coal Measures Monitoring Bores-Saddlers Creek

10.3 Impact of Mining on Permian Coal Measures

Depressurisation of the coal seams in the areas to the north-west and south-south-east of the current open cut mining operation is evident from the hydrographs of monitoring bores established in the Permian coal measures (Figures 17 and 18). Figure 17 indicates significant depressurisation in bores monitored ahead of the highwall advancement with groundwater levels/pressure declining by up to 70 m in bore GW8 and to a slightly lesser extent in bores GW13 and GW15[1]. It should be noted that Figure 17 indicates that there has been no decline of groundwater levels/pressure in bore GW7 (depth of which is unknown). It is suspected that this bore may have collapsed or is blocked.

Figure 18 indicates a similar decline in groundwater level/pressure in the south-south-east of up to 50 m. The hydrographs show some recovery before declining again and levelling out, suggesting that the pit has probably reached its maximum depth at this location. Bores GW35 and GW36 were destroyed by mining in June 2009 while no access was possible to GW37 from November 2011.

1 No recent data is available for bore GW13 and GW15.

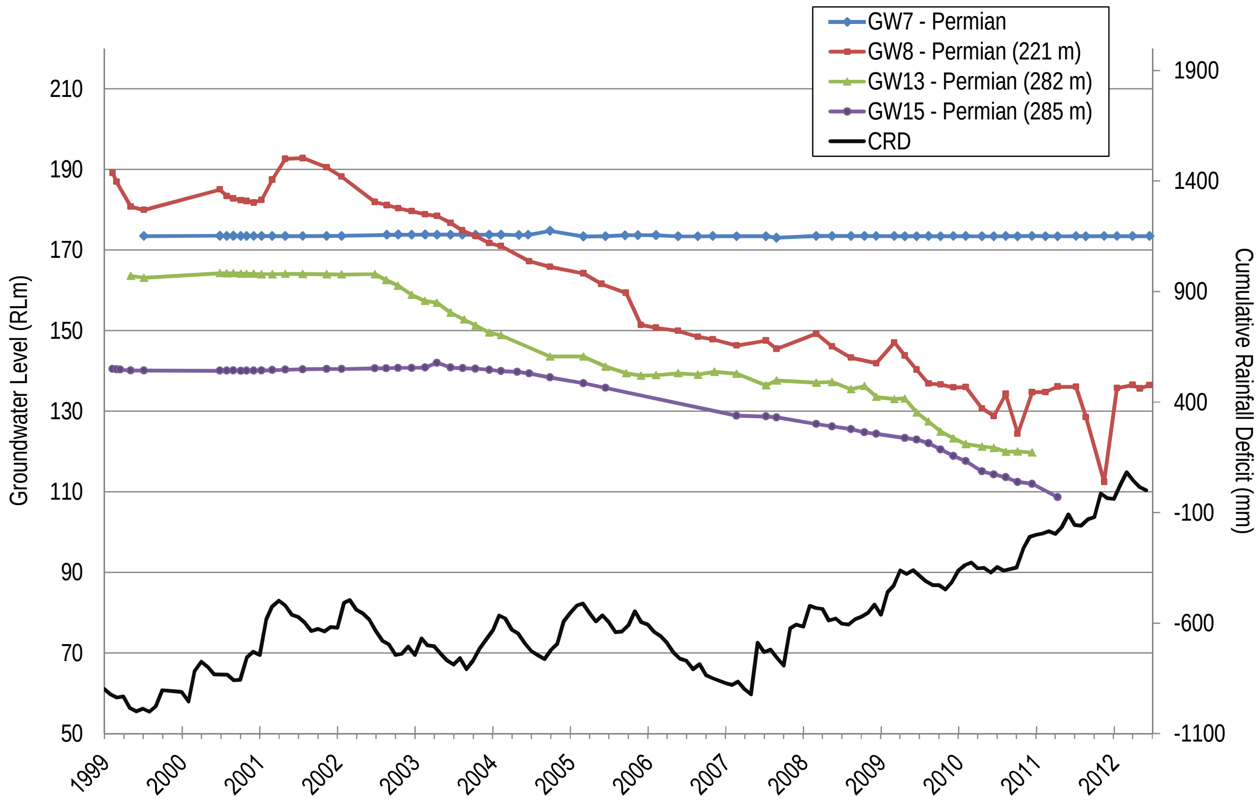


Figure 17: Hydrographs of Permian Coal Measures Monitoring Bores – North-West

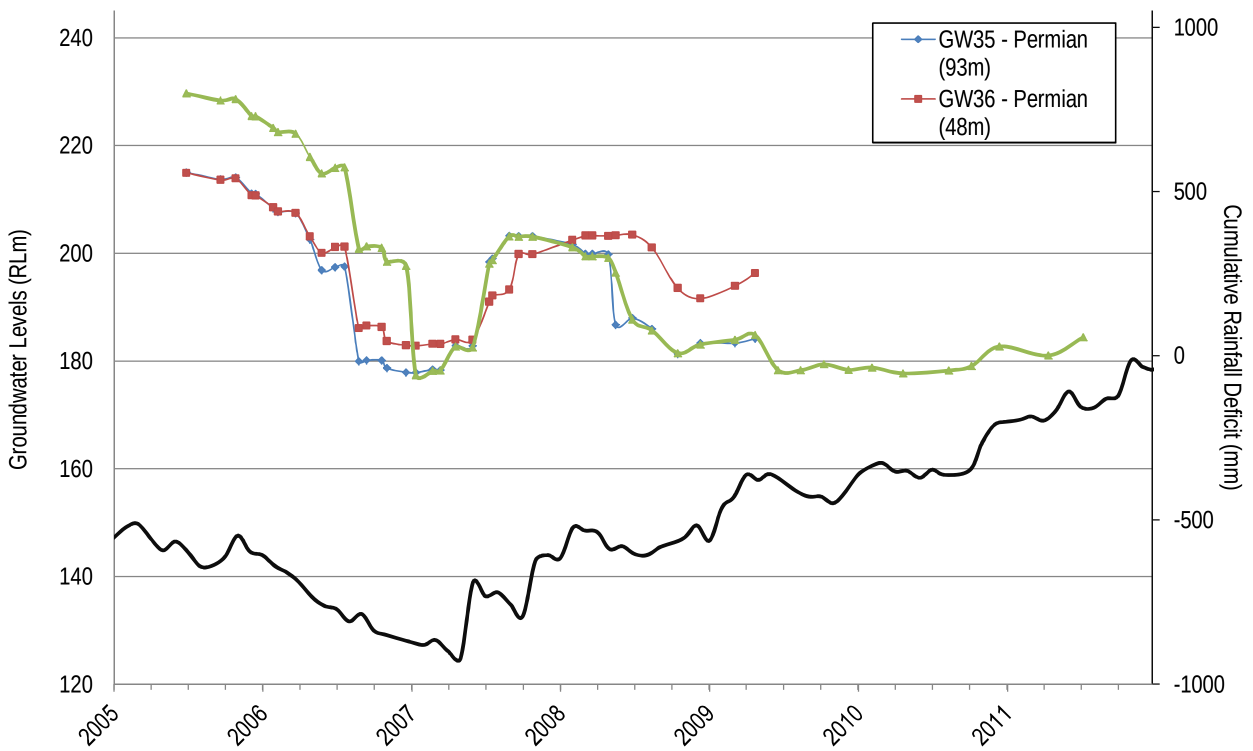


Figure 18: Hydrographs of Permian Coal Measures Monitoring Bores – South-East

10.4 Summary and Conclusions

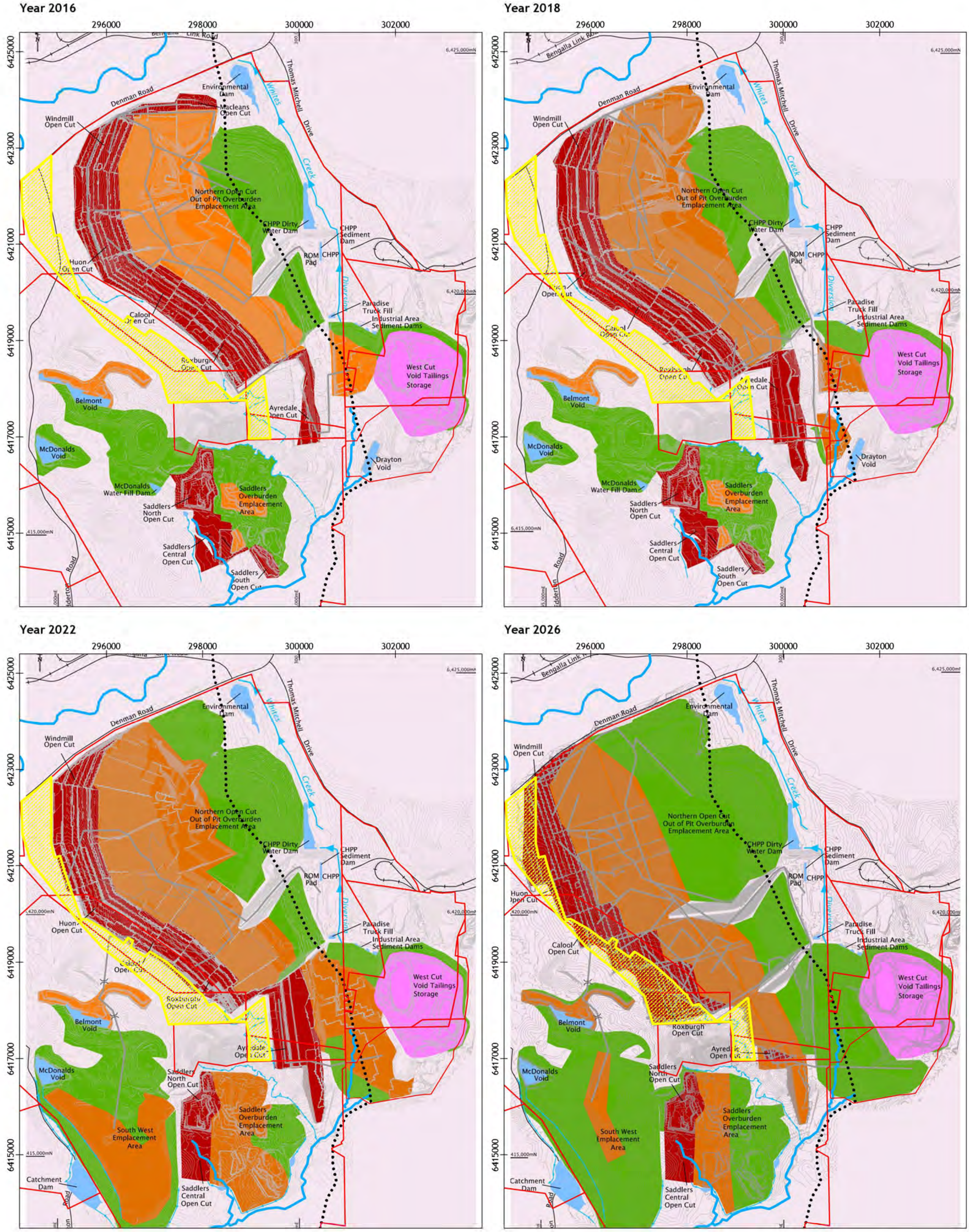
Monitoring of groundwater levels and groundwater quality at the Mt Arthur Coal Mine since 1999 has shown changes on the groundwater regime of the Permian coal measures sequence of which the coal seams are the prime water bearing strata. Negligible change has been noted in groundwater levels within alluvium.

Monitoring has also confirmed the validity of the predictions of the numerical models, primarily the AGE (2009) model, which simulates the impact of open cut mining.

Monitoring has shown that the Permian coal measures are depressurised by open cut mining and the extent to which this is occurring, and as stated, confirms the model predictions. Monitoring has also shown that there is no impact on groundwater levels in the alluvium; however, the groundwater gradient beneath the alluvium has reversed as indicated by a slowly improving water quality at the base of the alluvium. That is there is no longer discharge from the coal seams to the alluvium in the vicinity of open cut mining, but leakage from the alluvium to the pit as a result of depressurisation. Again this confirms the model predictions of AGE (2009) which indicate that in 2012, the leakage rate from the alluvium is about 0.1ML/day (1.2L/s).

11.0 MINE PLAN

The previous mine consolidation study (AGE, 2009) included mine plans for the open cut operations up to Year 2022, including pit shells for Years 2011, 2016 and 2022. Updated mine plans were available for this study from HVEC for the mine Years 2016, 2018, 2022 and for the mine Modification period to Year 2026. This study included integrating the four new mine plans (2016 to 2026) into the existing model. The updated mine plan sequence is shown in Figure 19 with approximate active mining areas.



LEGEND:

- Mine Modification Area
- Mt Arthur Coal Mining & Coal Lease Boundary
- Model Boundary
- River
- Haul Road
- Water Storage
- Active Mining
- Spoil
- Tailings Storage
- Rehabilitated
- Diversion/Drain
- Railway
- Road
- Culvert

N

PROJECTION:
MGA 94, Zone 56

SCALE:
1:75,000 (A3)

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Updated Mine Plan 2016 to 2026

DATE:
23/1/2013

FIGURE No:
19

Base maps sourced from "Gilbert and Associates" (2012)

12.0 NUMERICAL GROUNDWATER MODEL

12.1 Modelling Objectives

The numerical model for the Modification has been designed to answer the key study objectives, including:

- change in groundwater flux to and from the Hunter River alluvium due to the Modification;
- drawdowns in the piezometric surface due to the Modification;
- effects on local registered bores due to this drawdown; and
- prediction of pit inflows resulting from the Modification.

The objectives of the numerical model remain the same as those of the previous 2009 study (AGE, 2009) while including updated geometry for the Year 2016, 2018 and 2022 pits and inclusion of the mine Modification period to Year 2026.

The developed groundwater model is based on the calibrated model presented in AGE (2009) study. The calibrated parameter set of the previous 2009 model is consistent with this study. Current piezometric data post 2009 has been used to verify the predictive capability of the previous calibrated model.

12.2 Conceptual Model

During the AGE (2009) study, based on suggestions made by HVEC personnel, the Wittingham Coal Measures have been divided into three groups, which are treated as different groundwater systems in the model. From a conceptual groundwater model perspective, the Mt Arthur Coal Mine Site area is considered to consist of the following groundwater systems:

- alluvium along Hunter River and Saddlers Creek and an upper weathered bedrock zone;
- an upper Permian section of the Jerrys Plain Subgroup;
- a mid Permian section of the Jerrys Plain Subgroup (Burnamwood Formation); and
- a lower Permian section of the Vane Subgroup including the Archerfield Sandstone.

12.3 Model Development

The finite-element simulation package FEFLOW (Diersch, 2008) was used to simulate the impact of the mining operations on the groundwater regime. FEFLOW is a high-end groundwater flow package, capable of simulating two and three-dimensional density-coupled groundwater flow, mass and heat transport in saturated and unsaturated media. Since its creation in 1979, FEFLOW has been continuously improved. The FEFLOW source code is written in ANSI C/C++ and contains more than 1,300,000 lines. It is applied worldwide for groundwater related tasks within the mining sector.

FEFLOW was also used by AGE (2006a) for the simulation of the Northern Open Cut, simulation of the South Pit Extension (AGE, 2006b), by MER (2007) for simulation of the MAU Project, and by AGE (2009) for the Mt Arthur Coal Consolidation Project. The current model has been developed from these models.

12.3.1 Model Settings

The model was developed in FEFLOW using flow mode using both steady state and transient modes and also using the free and movable model setting. In this mode, the top slice is adjusted automatically to the elevation of the groundwater table. All other slices are distributed along the top and bottom of the saturated model layers, preserving the original material distribution. This so-called Best-Adaptation-to-Stratigraphic-Data (BASD) technique is also useful if applying drainage boundary conditions for the mine dewatering. The node, on which such a boundary condition is set, automatically moves to the corresponding elevation in the model. Running FEFLOW in this mode negates modelling instabilities associated with the simulation on the unsaturated zone.

The model was run using the SAMG solver with automated time stepping (for transient runs) with a convergence criteria set at 1×10^{-3}.

12.3.2 Model Geometry and Model Extents

The lateral extent of the groundwater flow model conforms to the hydrological boundaries described for the conceptual model (Figure 20). In agreement with the conceptual model, the numerical groundwater model is surrounded by “no flow” boundaries. While the northern and southern borders run along topographic watersheds which correspond to groundwater divides, which by definition are “no flow” boundaries, the western border was set along the Mount Ogilvie Fault, which with a displacement of 200 m is assumed to be a barrier to groundwater flow. The eastern boundary is formed by the outcrop of the low permeability Saltwater Creek Formation.

The mesh density varies laterally with the highest discretisation at the different mine sites (approximately 30 m cell size). The model mesh for this study was based on the mesh developed by AGE (2009). The mesh was subsequently refined in the Modification Area. The model contains 391,480 elements, up from 292,592 elements in the 2009 study.

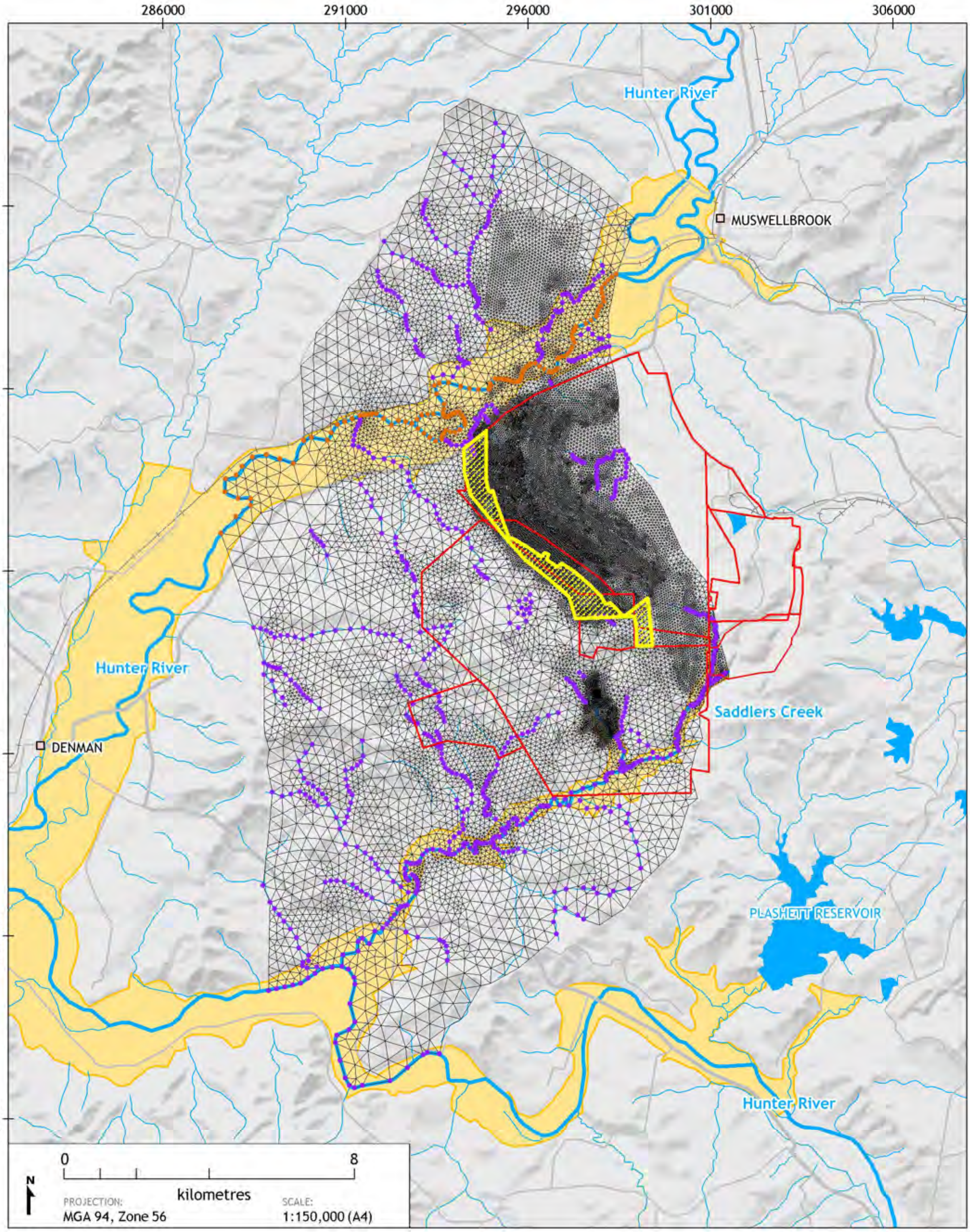
12.3.3 Boundary Conditions

The Hunter River to the north of the Modification is simulated as a fixed hydraulic head boundary (1^{st} kind Dirichlet boundary condition). This boundary condition allows for the infiltration of surface water into the groundwater systems or drainage of the groundwater system, depending on the hydraulic gradient between the river and the surrounding model layers. The location of 1^{st} kind boundaries representing the Hunter River are shown in Figure 20.

The creeks within the model domain are assumed to drain the thin alluvial deposits associated with the creeks. Recharge from these creeks is conceptually not thought of as major recharge source. Therefore drainage boundary conditions have been assigned in the model along the creek beds which do not allow infiltration of surface water into the alluvial deposits. These have been implemented using constrained fixed hydraulic head boundaries (1^{st} kind Dirichlet boundary condition) with a constraint only letting water discharge from the boundary condition. The location of 1^{st} kind boundaries representing the creeks (including Saddlers Creek) are shown in Figure 20.

12.3.4 Layers

The groundwater model represents the conceptual model of the mine Modification and consists of eight model layers representing six layers with different geo-hydraulic properties. The top or base of the layers has been defined from structure contours provided by HVEC with extrapolation to the model perimeter where the structure contours did not extend to the model boundaries.



LEGEND:
- Mt Arthur Coal Mining & Coal Lease Boundary
- Mine Modification Area
- Finite Element Mesh (FEM)
- 1st Kind Boundary Conditions Hunter River
- 1st Kind Boundary Conditions Creeks
- River
- Creek
- Reservoir/Lake
- Alluvium
- Town
- Road/Track
- Rail

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Model Area and Finite Element Mesh (FEM) and Boundary Conditions

AGE GROUNDWATER & ENVIRONMENTAL

DATE: 23/1/2013

FIGURE No: **20**

Due to model restrictions, each layer has to extend over the whole model domain even where the represented groundwater systems have sub-cropped or outcropped. However, due to the use of the free and movable function in FEFLOW to simulate units below the water table, much of these sub-crop zones are not simulated.

<u>Layer 1</u>

The top layer represents the alluvium along the Hunter River and Saddlers Creek as well as the weathered regolith zone outside these alluvial areas. The layer has a saturated thickness of 5 to 10 m. Its top is defined by the topographic surface.

<u>Layers 2, 3 and 4</u>

Three layers are included in the overburden between the base of alluvium (Layer 1) and the upper Wittingham Coal Measures (Layer 5). Multiple layers were used to represent a better vertical discretisation of the model. The base of Layer 4 represents the top of the Mt Arthur Coal Seam. Structure contours for this model slice are shown in Figure 21.

<u>Layers 5 and 6</u>

These layers represent the upper section of the Wittingham Coal Measures between the top of the Mt Arthur Coal Seam and the floor of the Bayswater Coal Seam. Its thickness is derived from contour maps of the seam geometry of the Mt Arthur and Bayswater Coal Seams as provided by HVEC. The thickness of these layers is up to 100 m within the Site area. The unit sub-crops in the eastern part of the Site area. Structure contours for the base of Layer 6 are shown in Figure 22.

<u>Layer 7</u>

This layer represents the lower unit of the mined section of the Wittingham Coal Measures. Its bottom is defined by the base of the Ramrod Creek Coal Seam (the top of the Saltwater Creek Formation). This layer has a thickness of up to 120 m within the model domain. Structure contours for this model slice are shown in Figure 23.

<u>Layer 8</u>

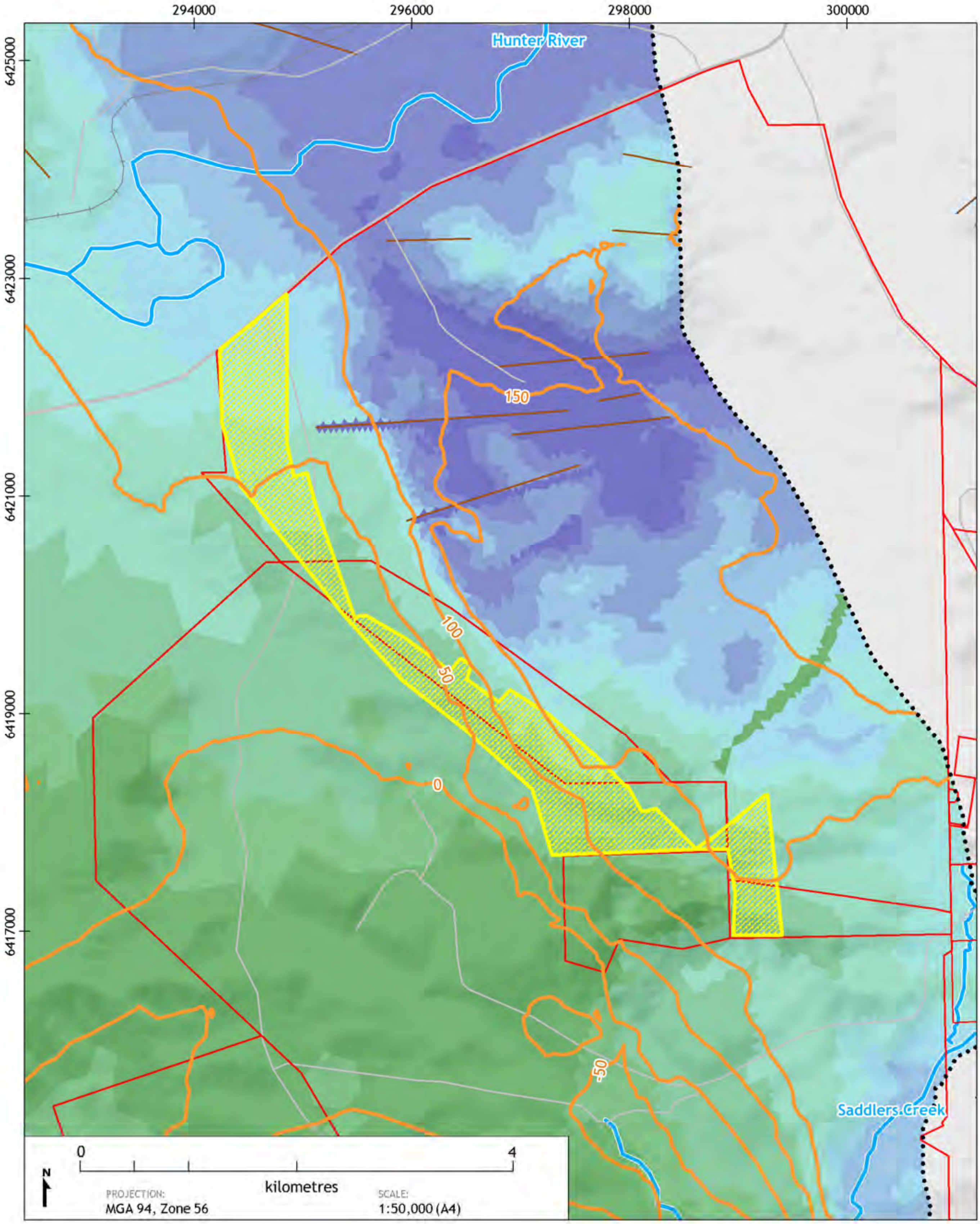
This layer, the base of the model, has been added representing the relatively impermeable Saltwater Creek Formation in order to prevent dry-out of finite elements during the dewatering of the Ramrod Creek Seam.

Figure 24 shows the three-dimensional model mesh with the initial hydraulic head distribution.

12.3.5 Hydraulic Parameters

The top model layer (Layer 1) represents the alluvium along the Hunter River, the creeks and the zone of weathered bedrock. A horizontal hydraulic conductivity of 8 m/day was assigned to the alluvium associated with the Hunter River, consistent with data presented in MER (2000). MER (2007) states that for the MAU model:

> *The alluvium is assumed to exhibit homogeneity and isotropy, even though data suggests stratification of unconsolidated sands, silts and clays. … adoption of a uniform conductivity is considered to represent a conservative approach in determining potential leakage from the alluvium*.



LEGEND:

Horizontal Hydraulic Conductivity m/d

- 0.189 to 0.864
- 0.152 to 0.189
- 0.101 to 0.152
- 0.078 to 0.101
- 0.057 to 0.078
- 0.031 to 0.057
- 0.01 to 0.031
- 0.002 to 0.01
- 0.001 to 0.002
- 0 to 0.001

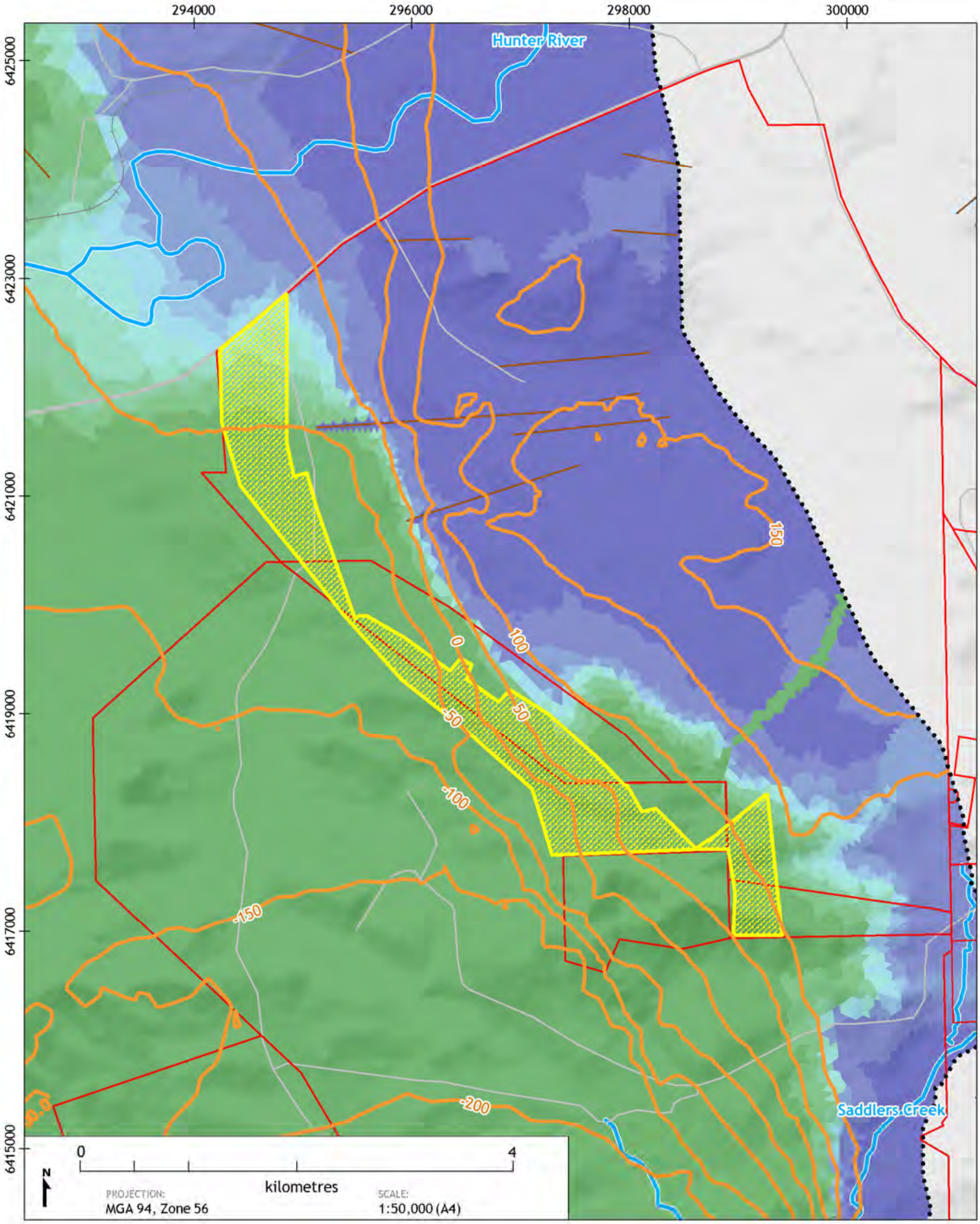
- Mine Modification Area
- Mt Arthur Coal Mining & Coal Lease Boundary
- Model Boundary
- Slice 5 Elevation (mAHD)
- Fault
- Road/Track
- Rail
- River

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Structure Contours of base of Layer 4 (top Mt Arthur Seam) and Hydraulic Conductivity Distribution

DATE: 23/1/2013

FIGURE No: **21**



LEGEND:

Horizontal Hydraulic Conductivity m/d

- 0.043 to 0.864
- 0.011 to 0.043
- 0.007 to 0.011
- 0.006 to 0.007
- 0.005 to 0.006
- 0.004 to 0.005
- 0.003 to 0.004
- 0.002 to 0.003
- 0.001 to 0.002
- 0 to 0.001

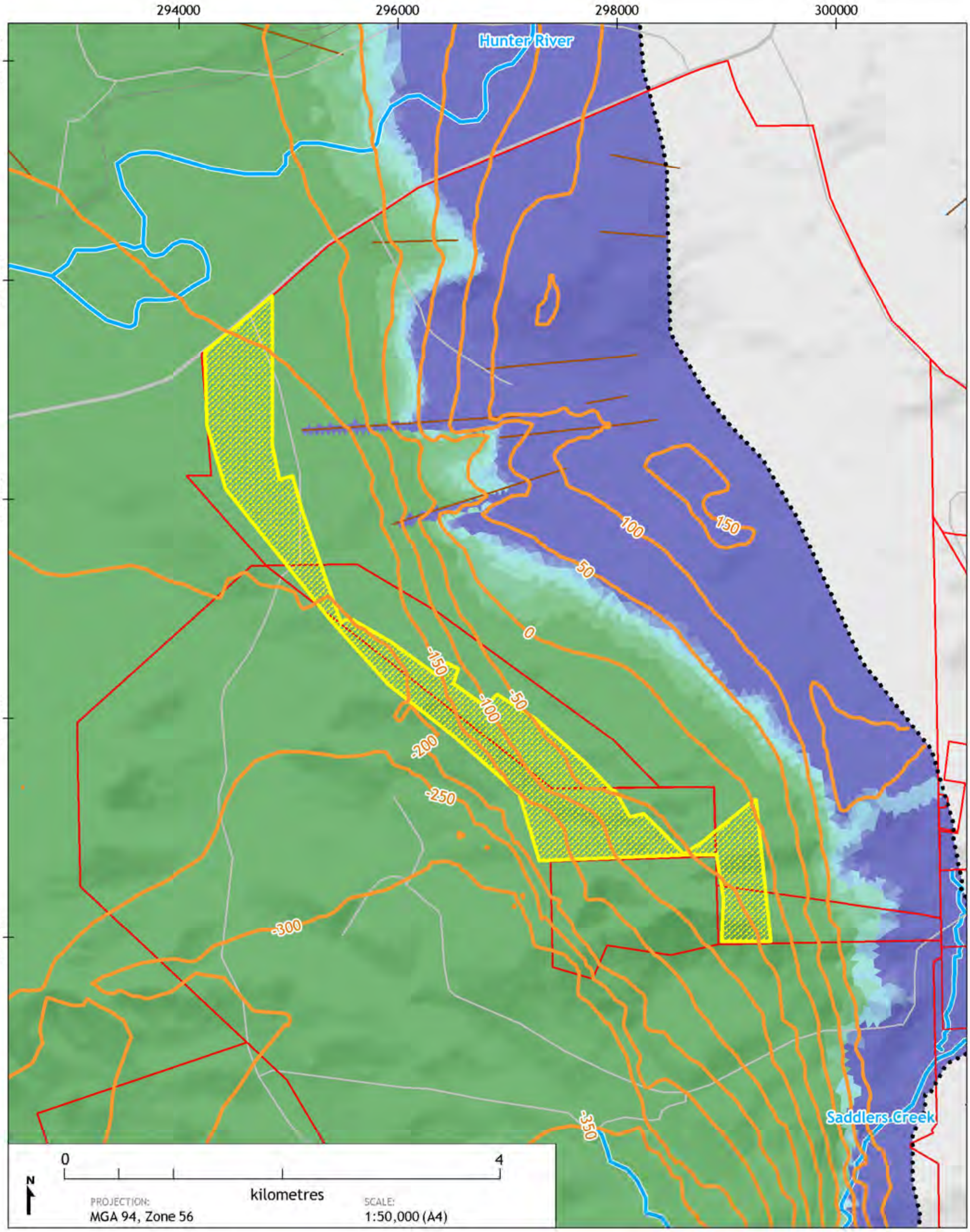
- Mine Modification Area
- Mt Arthur Coal Mining & Coal Lease Boundary
- Model Boundary
- Slice 7 Elevation (mAHD)
- Fault
- Road/Track
- Rail
- River

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Structure Contours of base of Layer 6 (Bayswater Seam) and Hydraulic Conductivity Distribution

DATE: 23/1/2013

FIGURE No: **22**



LEGEND:

Horizontal Hydraulic Conductivity m/d

- 0.009 to 0.864
- 0.008 to 0.009
- 0.007 to 0.008
- 0.006 to 0.007
- 0.005 to 0.006
- 0.004 to 0.005
- 0.003 to 0.004
- 0.002 to 0.003
- 0.001 to 0.002
- 0 to 0.001

- Mine Modification Area
- Mt Arthur Coal Mining & Coal Lease Boundary
- Model Boundary
- Slice 8 Elevation (mAHD)
- Fault
- Road/Track
- Rail
- River

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Structure Contours of base of Layer 7 (Base Ramrod Seam) and Hydraulic Conductivity Distribution

DATE: 23/1/2013

FIGURE No: **23**

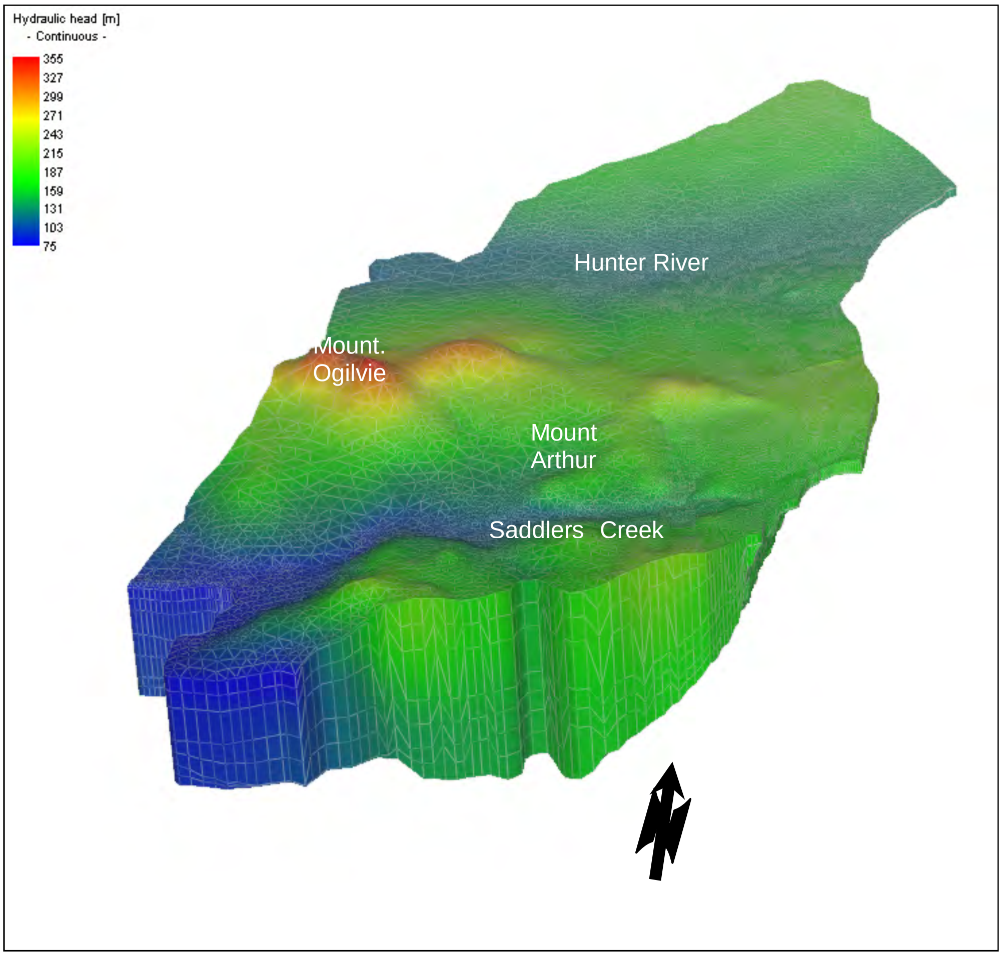


Figure 24: Three-Dimensional Model Mesh

However, in the current model, the vertical hydraulic conductivity within the alluvium has been reduced from 8 m/day to 0.2 m/day to take into account the silt and clay layers. This vertical hydraulic conductivity is still significantly higher than the hydraulic conductivity of the underlying bedrock groundwater systems, and is considered conservative in that the model does not account for the likely occurrence of a weathered, clay rich transition zone at the base of alluvium that may inhibit leakage.

The weathered bedrock (regolith) is assumed to have a hydraulic conductivity at least one order of magnitude higher than the underlying Permian coal measures. The alluvium of Saddlers Creek, which consists of the fine grained material, was assigned hydraulic properties similar to those of the weathered bedrock.

Layers 2, 3 and 4 represent the overburden of the Mt Arthur Coal Seam, that is, from the base of the alluvium or regolith to the top of the Mt Arthur Coal Seam. This group consists of very low conductivity siltstones and sandstones and thin Warkworth Coal Seams of the Mt Thorley Formation. Horizontal hydraulic distribution for Layer 4 is shown in Figure 21.

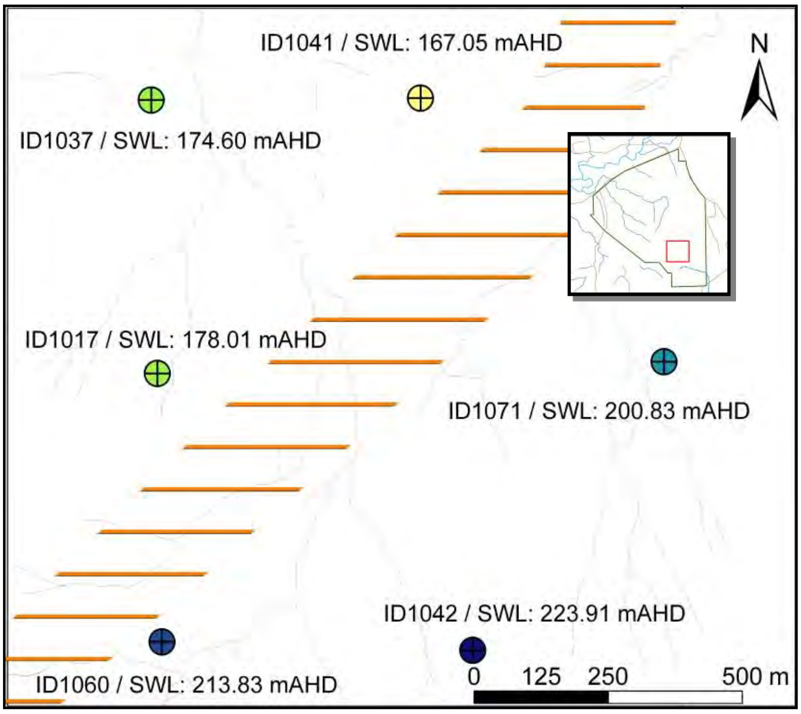
Model Layers 5 and 6 represent the coal seams and interburden between and including the Mt Arthur and Bayswater Coal Seams. Horizontal hydraulic distribution for Layer 6 is shown in Figure 22.

Model Layer 7 represents the section of the Wittingham Coal Measures from the base of the Bayswater Coal Seam to the floor of the basal Ramrod Creek Coal Seam. Horizontal hydraulic distribution for this layer is shown in Figure 23.

The underlying Saltwater Creek Formation represents the base of the groundwater flow model since this formation is considered to be impermeable. Nevertheless, this formation has been added to the model as a 100 m thick "dummy layer" of very low hydraulic conductivity. This allowed for the simulation of dewatering of the Ramrod Creek Coal Seam due to mining to the base of this seam. This also provided numerical stability to the model.

The hydraulic conductivity of each model layer was calculated as the weighted sum of the interburden and coal seam permeabilities. The applied weighting factor was the thickness of the interburden and the coal seams within each model layer. The hydraulic conductivity was reduced continuously with depth by applying the formulas for the change of hydraulic conductivity with depth as discussed in Section 9.5.2. Only model Layer 8, representing the Saltwater Creek Formation, was assigned a uniform hydraulic conductivity of 8.64×10^{-7} m/day. This is a very low hydraulic conductivity value representative of unfractured metamorphic and igneous rocks, shales or unweathered marine clays.

The area in the vicinity of the Fairford Graben was represented in the model by assigning high conductivity zones of 0.6 m/day along the fault lines. Another structure was identified during data review and model calibration in the southern part of the Northern Open Cut where two groups of adjacent groundwater monitoring bores show differences in groundwater elevation of up to 57 m (Figure 25). In order to simulate such a steep hydraulic gradient, a north-east/south-west striking fracture with a reduced hydraulic conductivity of 8.6×10^{-4} m/day was assigned in the groundwater model. This fracture feature has no impact on the groundwater inflow into the pits as it is excavated during the first years of operation of the currently approved Northern Open Cut.



Note: low conductivity area is hatched.

Figure 25: Assumed Low Conductivity Zone with Nearby Monitoring Bores

A long section showing the hydraulic conductivity distribution with depth and along the Fairford Graben is shown on Figure 26.

As discussed, the model does not account for a potentially weathered, clay rich, low permeability transition zone between the base of alluvium and unweathered bedrock that would reduce leakage from the alluvium to the depressurised bedrock groundwater systems.

Storativity has been calculated based on the thickness of the coal seams and the interburden within each model layer and assuming a storativity of the coal seams and the interburden of 0.5 percent (%) and 0.005 % respectively. A uniform storage compressibility value of 5 x 10^{-6} per metre was applied in the model.

12.3.6 Recharge and Discharge

Only rainfall sourced recharge was used as an external input to the model domain. The dense natural drainage network at the Site suggests most of the rainfall discharges as surface run-off. There is only a relatively low rate of recharge to the groundwater system on the relatively high to moderate hill slopes of the model area due to this high percentage of surface run-off, whereas on the floodplains, the rate of recharge is significantly higher.

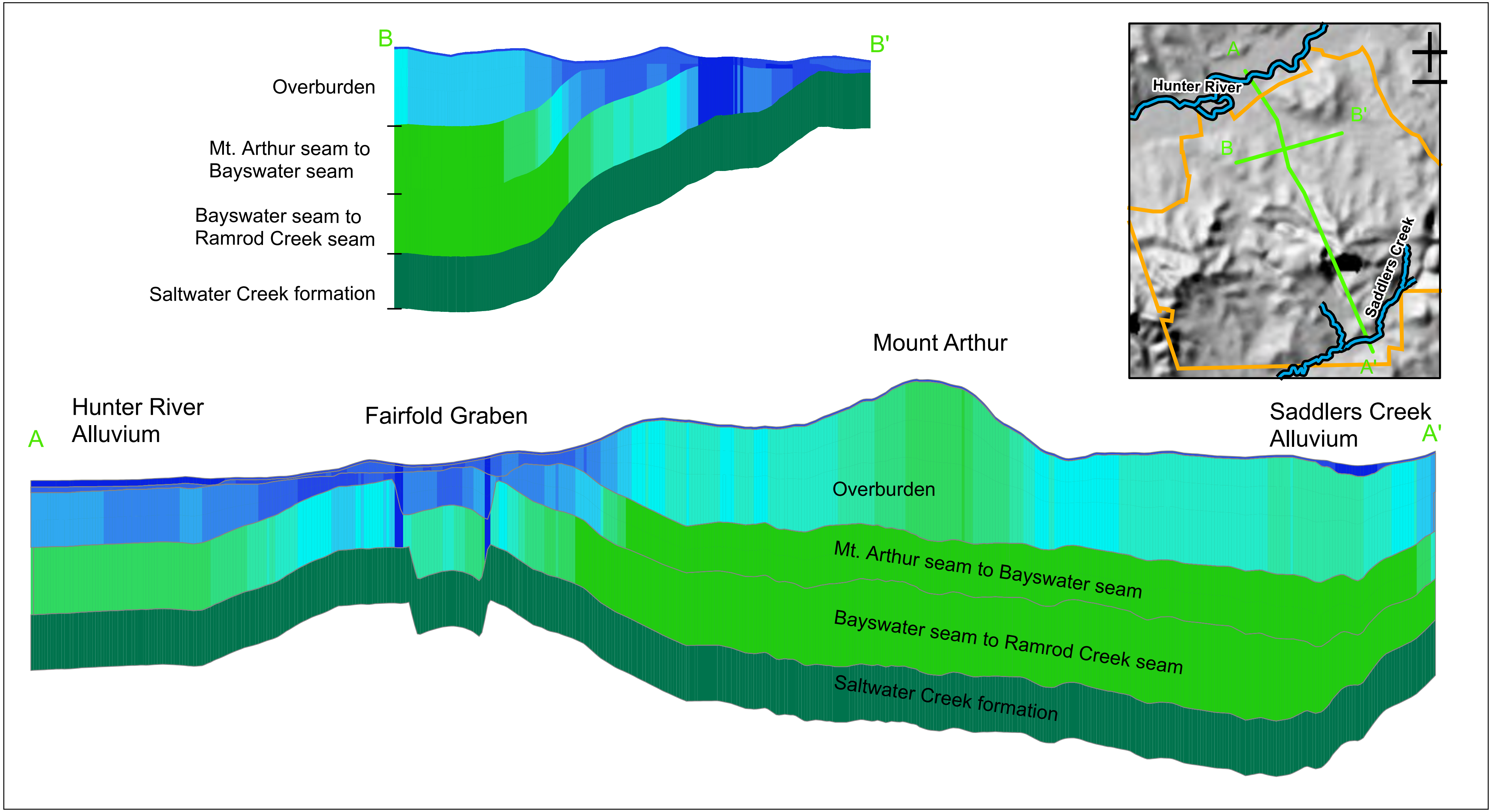
Areas of known coal seam sub-crop are believed to receive more recharge than remaining areas and it became apparent during calibration of the model that coal seam sub-crop areas are likely to receive as much as 2.4% or 15 mm/year of the average annual rainfall as recharge, even in the areas of steeper slopes.

The highest recharge is expected over the permeable alluvium of the Hunter River. It was assumed in the model that the recharge over these alluvial areas is 10% of the average annual rainfall, that is, a recharge rate of 60 mm/year. The rate of recharge in the model to the remaining areas was assumed to be:

- areas with gradient < 5%, recharge is 1% or 6mm/year of the annual average rainfall; and
- hilly regions with gradient >5%, recharge is 0.4% or 2.4 mm/year of the annual average rainfall.

The distribution of recharge used in development of the model is shown on Figure 27.

A summary of the hydraulic parameters specified in the model is presented in Table 6.



LEGEND: **Hydraulic Conductivity (m/day)**

<1e-6	- 1e-2
- 1e-4	- 2e-2
- 2e-4	- 5e-2
- 5e-4	- 0.1
- 1e-3	- 0.2
- 2e-3	- 0.5
- 5e-3	>0.5

0m
100m
200m
vertical exaggeration 5x

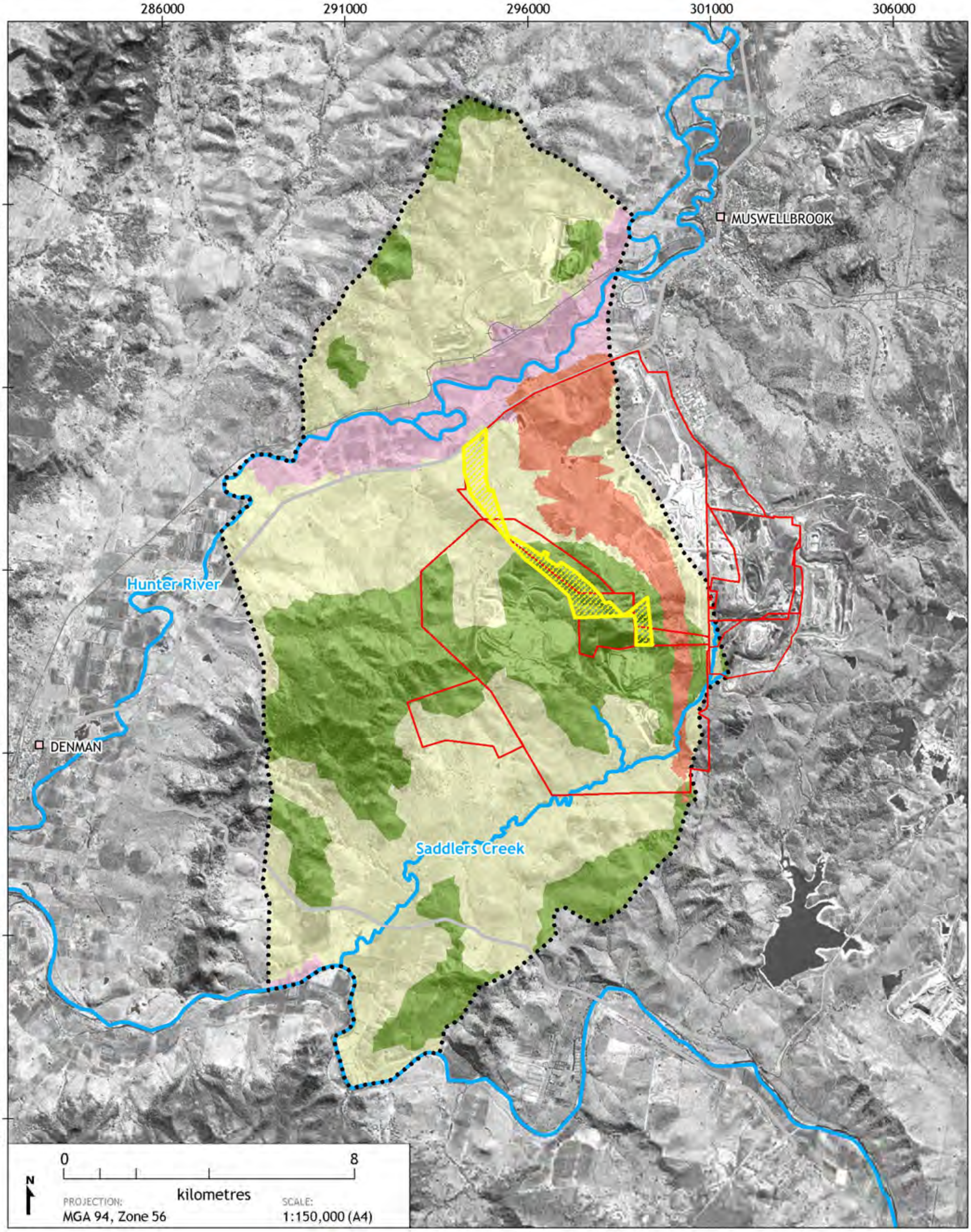
0 500 1,000 2,000 3,000m

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assessment (G1602)

Long Sections - Hydraulic Conductivity

DATE: 23/1/2013

FIGURE No: **26**



LEGEND:

Groundwater Recharge Zones

- Hunter River alluvium, 60mm/year
- Subcrop areas =< 15mm/year
- Gently sloping areas, 6mm/year
- Steep Mountain slopes, 2.4mm/year
- Mine Modification Area
- Mt Arthur Coal Mining & Coal Lease Boundary
- Model Boundary
- Town
- Road
- Rail
- River

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Recharge Distribution

DATE: 23/1/2013

FIGURE No: **27**

Table 6: SUMMARY OF GROUNDWATER MODEL PARAMETERS			
Model Layer	**Layer Name**	**Feature/Parameter**	**Value**
1	Alluvium and Weathered zone	distribution	Alluvium along Hunter River and Saddlers Creek, weathered zone over the entire model area
		top	Interpolated from topographic data
		base	Weathered zone 5 m thick, Hunter River alluvium 6 m saturated thickness, Saddlers Creek deducted from topographic map
		horizontal hydraulic conductivity	8.2 m/day Hunter River Alluvium, 0.4 m/day Upper Saddlers Creek and weathered zone
		vertical hydraulic conductivity	0.2 m/day
		storativity	0.2 Hunter River alluvium, 0.01 elsewhere
		storage coefficient	$5 \times 10^{-6} m^{-1}$
		recharge	Hunter River alluvium 60 mm/year (10% of average annual rainfall), remaining area 2.4 mm/year to 15mm/year (0.4% to 2.4% of average annual rainfall), depending on slope of topography
2, 3 & 4	Overburden Weathered zone to Mt Arthur Seam	distribution	Entire model area
		top	Base of Layer 1
		base	Top of Mt Arthur Coal Seam
		horizontal hydraulic conductivity	0.01 m/day to 0.6 m/day (along Fairford Faults) in the area of the Northern Open Cut, 5.6×10^{-5} m/day to 0.2 m/day elsewhere
		vertical hydraulic conductivity	20% of horizontal hydraulic conductivity
		storativity	10^{-4}
		storage coefficient	$5 \times 10^{-6} m^{-1}$
		thickness	Up to 180 m at western border of lease area
5 & 6	Mt Arthur Seam to Bayswater Seam	distribution	Entire model area
		top	Top of Mt Arthur Coal Seam
		base	Floor of Bayswater Coal Seam
		horizontal hydraulic conductivity	1.6×10^{-4} m/day to 0.6 m/day (along Fairford Faults)
		vertical hydraulic conductivity	20% of horizontal hydraulic conductivity
		storativity	10^{-4}
		storage coefficient	$5 \times 10^{-6} m^{-1}$
		thickness	Up to 100 m at western border of lease area
7	Bayswater Seam to Ramrod Creek Seam	distribution	Entire model area
		top	Floor of Bayswater Coal Seam
		base	Base of Ramrod Creek Coal Seam
		horizontal hydraulic conductivity	1.8×10^{-4} m/day to 0.6m/day (along Fairford Faults)
		vertical hydraulic conductivity	20% of horizontal hydraulic conductivity
		storativity	10^{-4}
		storage coefficient	$5 \times 10^{-6} m^{-1}$
		thickness	Around 120m at western border of lease area
8	Saltwater Creek Formation	distribution	Entire model area
		top	Base of Ramrod Creek Coal Seam
		base	100 m below top
		horizontal hydraulic conductivity	8.6×10^{-7}m/day
		vertical hydraulic conductivity	10% of horizontal hydraulic conductivity
		storativity	10^{-4}
		storage coefficient	$5 \times 10^{-6} m^{-1}$
		thickness	100 m (uniform)

12.4 Model Calibration

As stated in Anderson & Woessner (1992), “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 objective of model calibration was to reproduce the estimated steady state groundwater levels in the Site area and allow simulation of the impact of the Modification on the groundwater regime. The calibration presented in this report was carried out for the AGE (2009) study, no further calibration was carried for this Modification study. Section 12.7 discusses the predictive model verification used to justify using the existing AGE (2009) calibration.

The accuracy of the model calibration depends on the quality of calibration parameters and the data defining the model domain such as geometry, boundaries, hydraulic properties and stresses imposed on the groundwater systems. It is considered that the horizontal and vertical extent of the model and model boundaries are sufficiently well defined to calibrate the groundwater model. Calibration was achieved from the rainfall recharge rate distribution shown on Figure 27 and adjusting hydraulic conductivity values.

For the steady state model calibration, groundwater measurements from the years 1999 to 2003 were available from groundwater monitoring bores within the Site area. The most recent data prior to commencement of mining activities within the Northern Open Cut were selected as calibration targets. It was assumed that the water levels in the selected monitoring bores were representative of the long-term average (steady state) groundwater levels, as no impact from the mining operation was assumed to have occurred at that time.

The steady-state calibration is shown in Table 7 and as a scatter plot in Figure 28. Figure 29 shows the resulting calibrated groundwater table for steady state conditions.

Table 7: STEADY STATE MODEL CALIBRATION RESULTS

Bore ID	Simulated Water Level Elevation (mRL)	Observed Water Level Elevation (mRL, pre-mining)	Difference (m)
GW1	161.59	166.47	4.88
GW2	145.85	146.13	0.28
GW3	145.61	143.96	-1.65
GW4	175.48	170.63	-4.85
GW5	171.62	175.27	3.65
GW6	206.77	196.40	-10.37
GW7	173.68	173.43	-0.24
GW8	182.22	177.26	-4.96
GW9	182.67	179.66	-3.01
GW10	218.58	210.67	-7.91
GW12	147.80	146.79	-1.01
GW13	161.60	155.40	-6.20
GW15	140.61	141.94	1.33
GW16	122.69	122.67	-0.02
GW17	124.49	126.83	2.34
GW19	137.29	131.51	-5.78
GW20	143.21	144.32	1.11
GW21	127.18	127.59	0.40

Table 7: STEADY STATE MODEL CALIBRATION RESULTS			
Bore ID	**Simulated Water Level Elevation (mRL)**	**Observed Water Level Elevation (mRL, pre-mining)**	**Difference (m)**
GW22	139.39	133.53	-5.86
GW23	139.45	133.37	-6.08
GW24	129.59	130.37	0.78

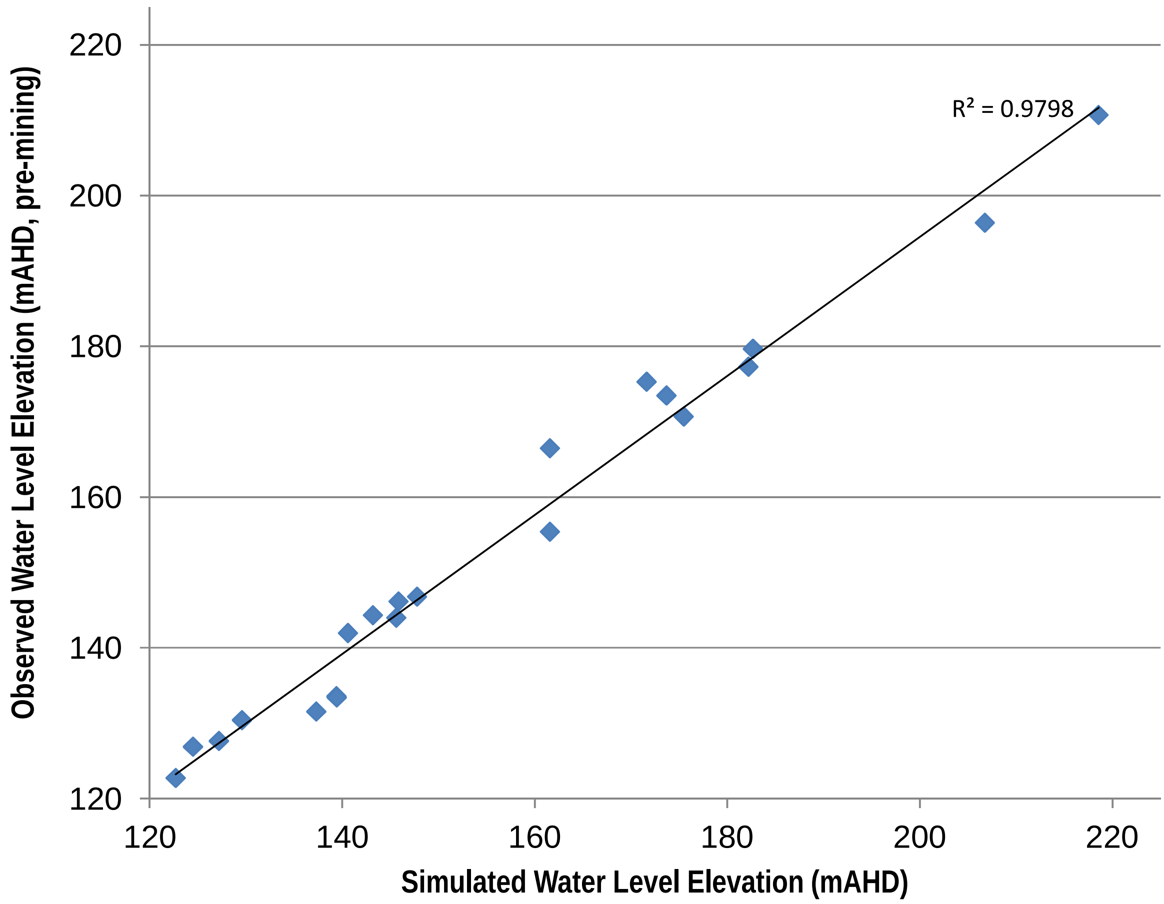
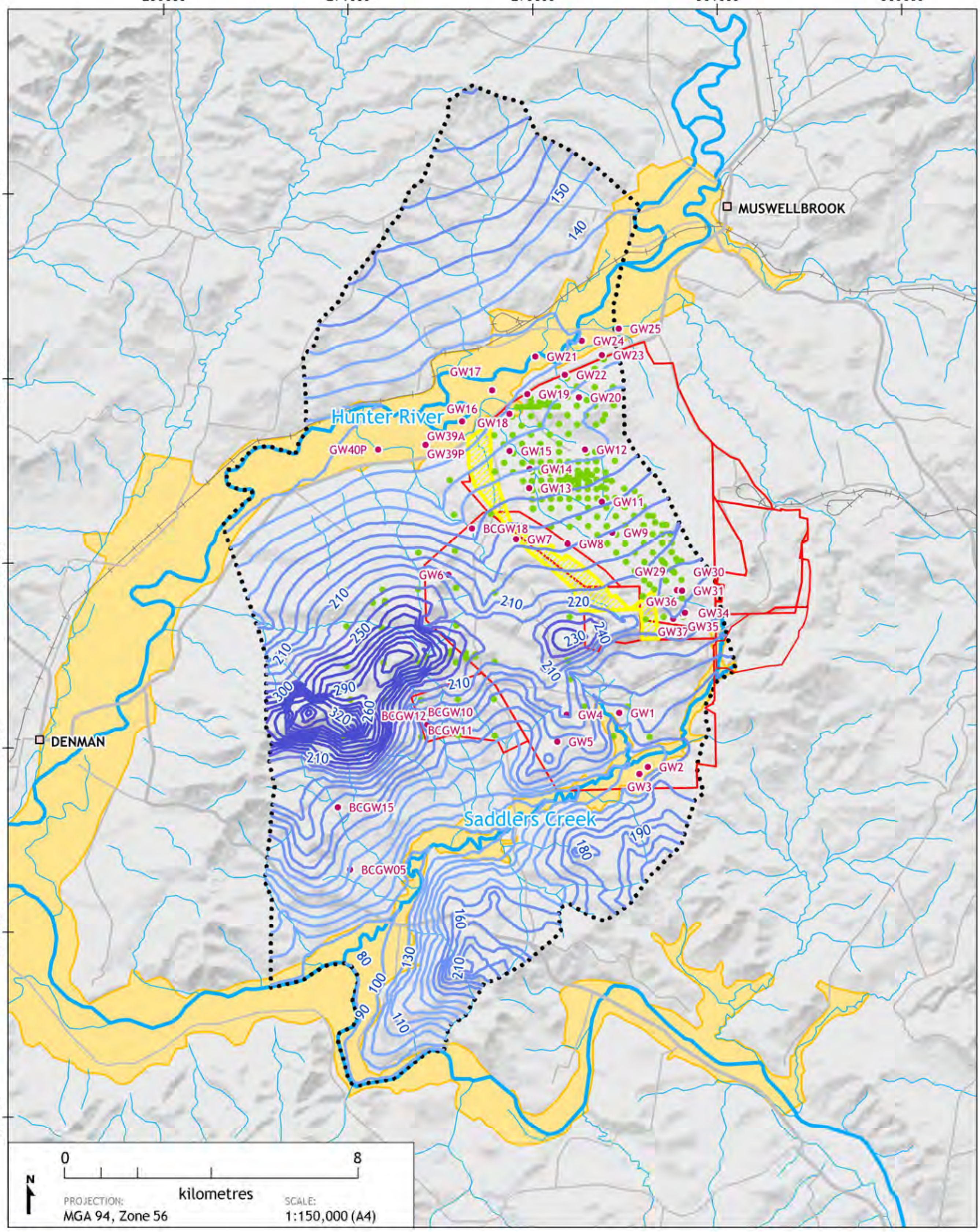


Figure 28: Calibrated Steady State Observed vs. Modelled Heads Scatter Plot



LEGEND:

Mine Modification Area

Mt Arthur Coal Mining & Coal Lease Boundary

Model Boundary

Simulated Pre-Mining Steady-State Groundwater Level Contours (mAHD)

- 240 to 350
- 230 to 240
- 220 to 230
- 160 to 220
- to 160

Groundwater Level Measurement

Groundwater Monitoring Bore

River

Creek

Alluvium

Road/Track

Rail

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Calibrated Steady State Water Table Contours

DATE: 23/1/2013

FIGURE No: 29

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 error between the modelled and observed (measured) water levels. A root mean square (RMS) expressed as:

$$RMS = \left[\frac{1}{n} \sum_{i=1}^{n} \Sigma (h_o - h_m)^{\ 2} \right]^{0.5}$$

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

is considered to be the best measure of error, if errors are normally distributed.

The RMS error calculated for the calibrated model is 4.5 m. 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 loss in the system is small, the errors are only a small part of the overall model response (Anderson and Woessner, 1992). The total head loss within the model area where the observation targets are distributed is 130 m, so therefore the ratio of RMS to the total head loss is 3.5% referred to as scaled RMS (SRMS).

This error is considered to be acceptable and it is thought that calibration of the model is accomplished in that the simulated heads match field measured values within an acceptable range of error. Barnett *et al.* (2012) suggests a target of <5% SRMS as a target for model calibration. The calibrated steady state model meets this criteria.

This is supported by a mass balance error of 1.5%, that is, the difference between calculated inflows and outflows to the model at the completion of the calibration run expressed as a percentage of discrepancy, as discussed in Section 12.6. This is slightly higher but close to a target of 1% suggested by Barnett *et al*. (2012).

12.5 Calibrated Model Validation

Calibration of the model was validated by using a second set of groundwater level measurements. The purpose of the validation is to confirm that the steady state calibrated model is representative of the real-world groundwater regime.

Groundwater measurements were provided for a larger number of bores for the years 1998 and 1999. This data set was used to create the contour plan of the interpreted groundwater table shown on Figure 13, and as reference data for the validation of the model calibration.

For validation, only those water level measurements collected in years 1998 and 1999 across the whole of the area within the wider mine area were considered where the final depth of the monitoring bore was known. An additional condition was that at least one week must have passed between the completion of drilling of the bore and the water level measurement in order to allow a reasonable accuracy of the measurement. Appendix 2 presents a summary of the validation results and the bore locations are shown on Figure 29.

Similar to model calibration, the selected performance measure for testing the validity of the model is the RMS error. The error was 7.2 m or SRMS of 5.5% in respect to the total head loss of 130 m for the observed model domain. The validation shows that the model responds sufficiently well to different sets of observed groundwater levels. The higher RMS value can be explained by the greater number of observations, the different year of observation, and generally lower accuracy of water level measurements.

12.6 Pre-Mining Groundwater Balance

The steady state water balance of the calibrated model is shown in Table 8, and the breakdown of the simulated total losses to the different creeks and river is shown in Table 9.

Table 8: MODEL STEADY STATE WATER BUDGET

Model Component	Flow Rate (m^3/day)
River Leakage	-5,885
Recharge	5,974
Difference between Inflow and Outflow from the Model Domain	89
Percent Discrepancy (%)	1.5%

Note: m^3/day = cubic metres per day

Table 9: SIMULATED GROUNDWATER DISCHARGE TO THE CREEKS AND HUNTER RIVER

Creek/River	Discharge (m^3/day)
Hunter River	-3,580
Saddlers Creek	-1,080
Secondary Creeks	-1,225
Total	-5,885

Model simulation runs indicate steady state groundwater losses to the Hunter River of about 3,580 m^3/day (3.58 ML/day) and to Saddlers Creek of about 1,080 m^3/day (1.08 ML/day). The Hunter River is the main sink for groundwater within the region, followed by Saddlers Creek.

12.7 Predictive Model Verification

The calibrated model was verified against currently available transient groundwater level data sets, which are available to mid-2012. This was carried out to test the predictive capability of the model prior to simulating the Modification and also to test whether model recalibration would be required. Data available for the verification included 45 monitoring bores; of which 35 bores had coordinates within the model domain. Construction details are available for a number of bores, although it is generally known whether bores are monitoring alluvium or Permian coal measures. Appendix 3 shows the observed versus modelled hydrographs for 25 bores, with their location shown in Figure 12. Based on available data the model predicted heads for the most appropriate model slice are displayed.

Selected hydrographs were plotted against observed data for a series of bores associated with the Quaternary Alluvium (Figure 30). Bores within the Hunter River alluvium (GW16 and GW21) show a good comparison between simulated and observed data, that is remaining fairly static. GW23 is located in the Permian coal measures between the Northern Open Cut and the Hunter River alluvium and shows a slight under prediction in simulated drawdown (3 m). The simulation of water levels within the Permian coal measures below Saddlers Creek (GW02) is closely aligned with observed data.

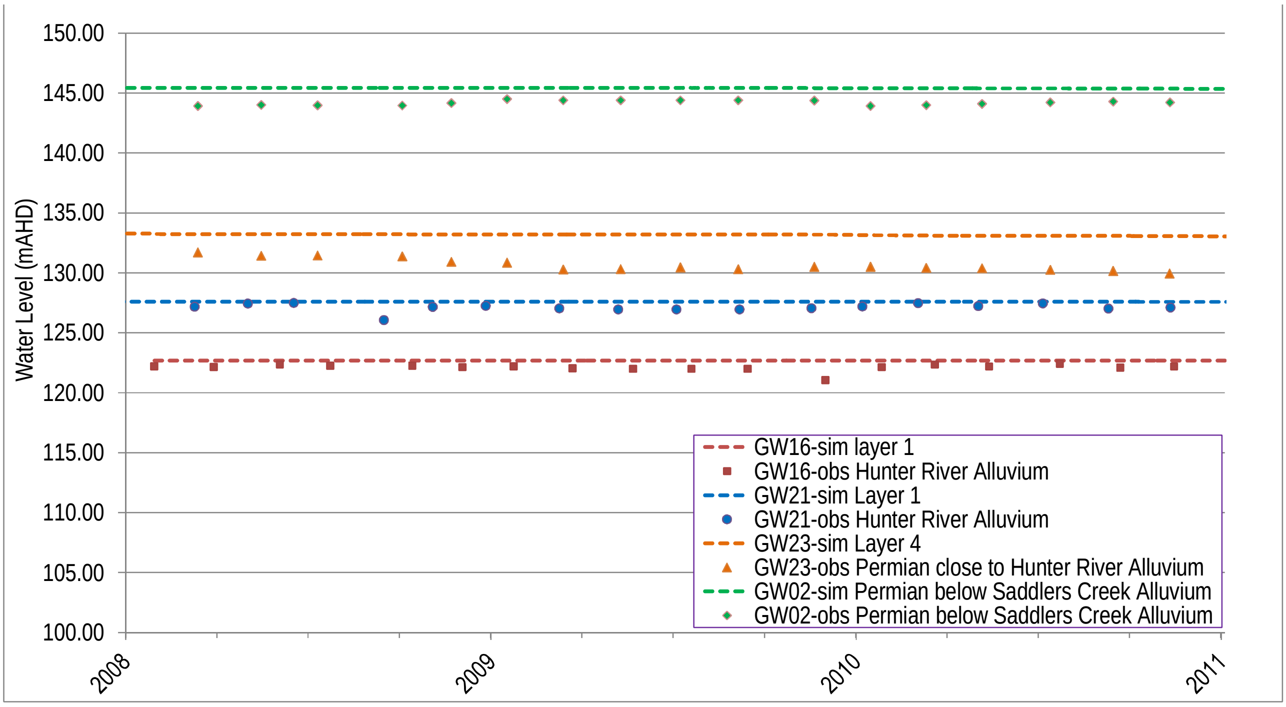


Figure 30: Transient Verification Hydrographs Associated with Alluvium

A selection of hydrographs from bores within the Permian strata to the west and south of the Northern Open Cut area is shown in Figure 31. The simulated hydrographs show that the model under predicts depressurisation in some bores west of the pit (GW07 and GW13), whilst over predicting depressurisation in GW37 to the south of the Northern Open Cut.

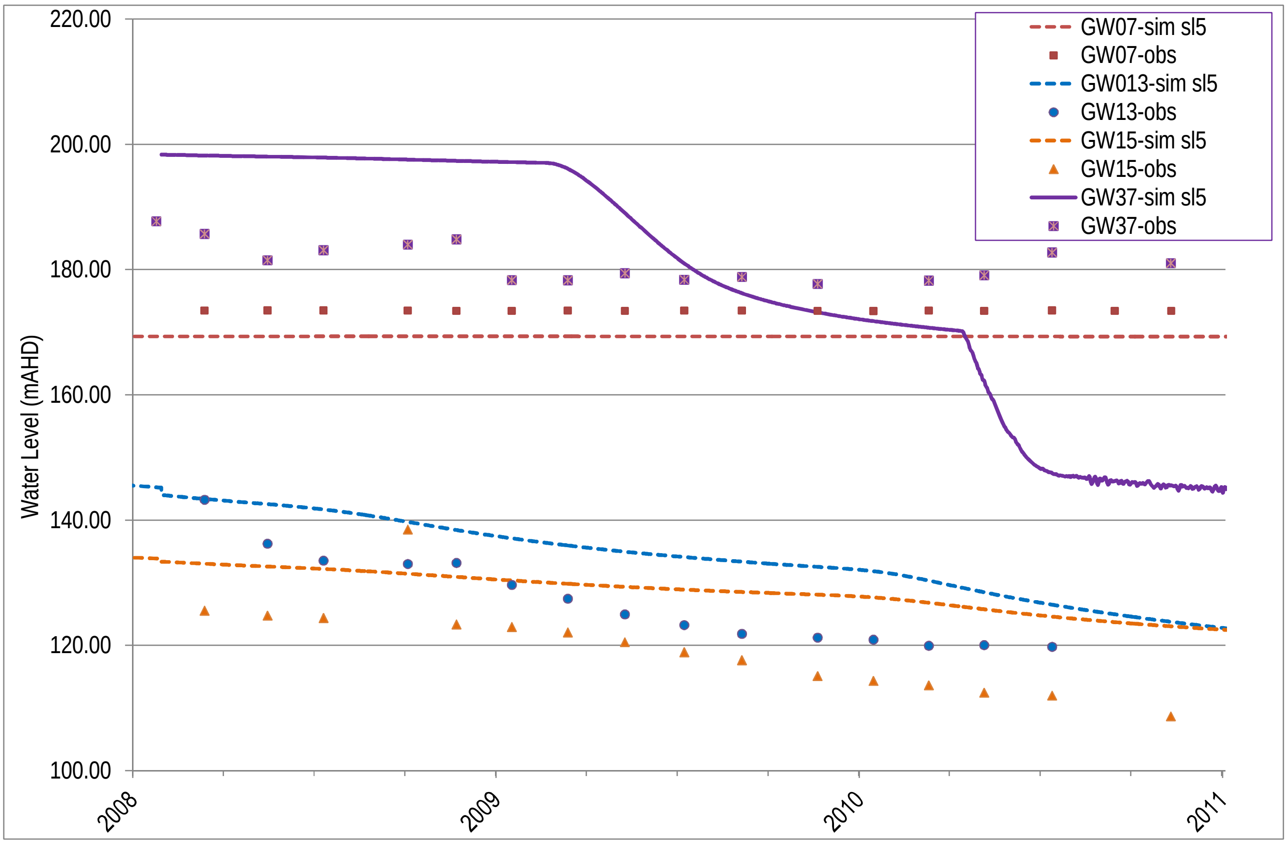


Figure 31: Transient Verification Hydrographs Associated Permian Coal Measures West and South of the Modification

The model results for the entire verification (Appendix 3) show reasonable predictions for bores both unaffected and affected by mine depressurisation. For example Appendix 3 GW13 shows an excellent drawdown trend compared to observed data. Where absolute values are not predicted by the model, major trends are simulated. These trends are considered more important than absolute levels when assessing changes in alluvium flux due to mining.

The BCGW series bores located in the MAU area have been included in Appendix 3. As can be seen in these hydrographs, the simulated effects of approved underground mining can be seen in model Slice 5 data. As the underground operations have not commenced, no drawdown is evident in observed data.

12.7.1 Verification Summary

Transient model verification was carried out to access the predictive capability of the model in the context of the Modification. Model verification suggests an adequate predictive capability of the previous study (AGE, 2009) for the Mt Arthur Coal Consolidation Project. The existing steady state calibration as documented in Section 12.4 is considered appropriate for use in the Modification study.

13.0 PREDICTIVE SIMULATIONS

The model developed for the Mt Arthur Coal Consolidation Project (AGE, 2009) was used as a basis for this study. Mine plans used in this previous study were accurate up to Year 2016, with new mine plans supplied by HVEC for the Northern Open Cut for Years 2016, 2018, 2022 and 2026 (Section 11).

The scope for the predictive simulation has been developed to meet the study objectives and align closely with results from the previous AGE (2009) modelling study. Results from the mine Modification period from Years 2022 to 2026 have been compared throughout this section to the previous model (which ran to 2022). This has been carried out so that additional effects from the Modification can be assessed against the impacts predicted for the current approvals. These results include:

- extension of the zone of depressurisation/drawdown to the west;
- minor changes in leakage rates from the alluvial lands of the Hunter River;
- minor loss of groundwater yield at existing bore locations; and
- change in groundwater quality.

The Mt Arthur Coal Mine and the Bengalla Mine to the north of the Hunter River were simulated in the model.

13.1 Predictive Model Strategy

The finite element model mesh was refined in the immediate vicinity of the Modification (Section 12.3.2). Heads were integrated from the previous modelling study for 2016 as an initial head for this study. Following the integration of new mine pit shells, the updated Modification model was run for the period 2016 to 2026. Predictive models were run in transient mode with adaptive time stepping with a 10-day time step maximum.

13.1.1 Mt Arthur North Pit Modification

Active open cut areas were simulated using transfer boundary conditions (3rd kind Cauchy boundary condition). In general, transfer boundary conditions represent a reference hydraulic head outside the model domain, for instance the water level of a lake. Water exchange with the model is controlled by the hydraulic gradient between the boundary condition and the groundwater elevation, and by a percolation layer between the groundwater body and the reference hydraulic head. The percolation layer is expressed as a constant factor and can be set so that it only allows water to be removed from the model domain, that is by drainage, if the hydraulic head at a node is above a nominated groundwater level.

In the case of the Northern Open Cut for Years 2016 to 2026, the elevations of the pit floors (the deepest seam mined being the Ramrod Creek Coal Seam) was the nominated elevation of the boundary condition. The drainage boundary conditions also covered areas of the mine, where only seams above the Ramrod Creek Coal Seam were mined. The elevation at each boundary condition node varied in accordance with progress of the mine as shown on the mine plans for the Modification (Section 11).

It should be noted that pit backfilling is not simulated in the predictive model. During predictive runs, groundwater is allowed to seep at the previously mined face (irrespective of backfilling). In reality as the Northern Open Cut extends west, previously mined areas are backfilled with spoil (Figure 19). This may overestimate the cone of depression (particularly to the east) from mining, as it is expected there will be some groundwater level recovery in the backfilled pit areas. However, this recovery is likely to be minor as the high permeability of the backfilled spoil will still channel seepage to the lower elevation pit areas.

13.1.2 Mt Arthur Coal Mines

The approved MAU mine was modelled using time-constant transfer boundary conditions. The boundary conditions describing the drainage elevations were exported from the existing MER (2007) groundwater model and assigned manually at different time stages with the simulated progress of mining (Years 2016-2018 and 2018-2022). Boundary conditions previously modelled for Year 2022 were applied to the Modification period to Year 2026. The MER (2007) model explicitly modelled the mined coal seams as five different layers, while the current model groups the coal seams and the interburden into three layers as described in Section 12.3.4. To take account of the different drainage levels, the drainage boundary conditions in the current model are distributed on numerical model slices. By applying the BASD technique (Section 12.3.1), the numerical slices are automatically mapped at the correct elevation during the simulation run.

In addition to the drainage elevations, the groundwater model takes into account the effects of subsidence and fracturing within the overburden. The overburden of the underground mined areas are simultaneously applied with a relatively high vertical hydraulic conductivity of 8.6×10^{-3} m/day at the time of mining. This is also in agreement with the MER (2007) model.

The approved Saddlers Pit to the south of the Modification has also been modelled using time-constant boundary conditions. These boundary conditions remain consistent with the AGE (2009) study. The Saddlers Pit is assumed to run to the end of the Modification period (2026).

13.1.3 Surrounding Mines

The currently approved Bengalla Mine and Bengalla Wantana Extension, located to the north of the Northern Open Cut and the Hunter River, were modelled using time variable transfer boundary conditions. The Bengalla Mine extracts coal to the Edderton Seam and boundary conditions have been generated using publically available data in environmental approval documents (AGE, 2007). These boundary conditions were set consistent with AGE (2009) with mine operations ending at the Bengalla Mine in 2017.

It is understood that DGRs have been issued for application SSD-5170 for the Bengalla Continuation Project for a 24 year period (Hansen Bailey, 2012). The Bengalla Continuation Project has not been simulated in this study as there is a lack of publicly available data. The Bengalla Continuation Project, if approved, is likely to have minimal effect on Mt Arthur Coal Mine operations due to the extension area moving away from both the Mt Arthur Coal Mine and Hunter River to the west, following the dip of the coal seams. Maximum impact from the Bengalla Mine is expected where the mine operations are closest to the Northern Open Cut and the Hunter River Alluvium and therefore the cumulative hydraulic impact on the Hunter River alluvium associated with the Bengalla Continuation Project would likely be less than that associated with the current Bengalla Mine operations.

The approved Mt Pleasant Mine (EMGA Mitchell McLennan, 2010) directly to the north of the Bengalla Mine has not been included in this model. Effects of the Mt Pleasant Mine, if modelled, are not expected to be material in comparison to those occurring due to the Bengalla Mine. Therefore, it is assessed that the simulation of the current Bengalla Mine is sufficient for this assessment to determine cumulative effects of Mt Arthur Coal Mine operations on the Hunter River alluvium.

The currently approved Drayton Mine (AGE, 2006c) has not been simulated in this model. This mining operation located to the east of the model boundary extracts coal from geological formations that are below the low permeability Saltwater Creek Formation (which is the lowermost layer in the Modification model). Drawdown and depressurisation from these mine developments are unlikely to transfer through to the coals measures mined at the Northern Open Cut. Consistent with AGE (2009) a no flow boundary is applied in the model to represent this conceptualisation.

Groundwater impacts of the proposed Drayton South Coal Project have been assessed by AGE (2012). In regard to impacts on the Hunter River Alluvium associated with Drayton South Coal Project, AGE (2012) states:

> *… it has been determined that the Project will not have any measurable impact on the Hunter River alluvial aquifer …*

Given the above, cumulative impacts to the Hunter River Alluvium predicted to result from the Modification are not expected to change in consideration of the Drayton South Coal Project.

In regard to impacts on Saddlers Creek Alluvium associated with Drayton South Coal Project, AGE (2012) states:

> *Seepage fluxes determined at the cessation of mining indicate the net upward flux would reduce to about 0.19 ML/day, and would continue to decline to about 0.1 ML/day, over a period of 150 years after the cessation of mining.*

Further, in regard to cumulative impacts to Saddlers Creek Alluvium associated with Drayton South Coal Project and the currently approved Mt Arthur Coal Mine, AGE (2012) states:

> *The remaining influx to the Saddlers Creek alluvium along the same 6 km section (~0.12 ML/day) may therefore be reduced to zero as a result of the Project.*

As discussed in Section 13.4, the Modification would not result in an increase in flux from Saddlers Creek Alluvium. On this basis, cumulative impacts to Saddlers Creek associated with the proposed Drayton South Coal Project resulting from the Modification are not expected to change.

13.2 Depressurisation/Drawdown – Regional Impact

Open cut mining together with modelled underground mining will result in a cumulative depressurisation of the coal seams and water bearing layers in the interburden within the immediate area of mining activities. Depressurisation, that is, the cone of depression (drawdown) in the piezometric surface/water table will migrate out from the highwall of the pit as mining progresses to the west and north and as the pit becomes deeper.

The cumulative drawdown in the water table at Year 2026 as a result of the Modification is shown in Figure 32. This figure shows the combined drawdown of all modelled pits (MAN, Bengalla and Saddlers Pits) and the MAU operations[2]. The cone of depression south of the Hunter River is, to a large part, the result of the dewatering in the northern and central parts of the Northern Open Cut and the MAU Project.

A variant of the predictive model was run to show the drawdown of the Modification only. The MAU, Bengalla Pit and Saddlers Pit were removed for this run. The model was run for the same period as the model used to assess cumulative impacts (2016 to 2026). A comparison was made between the drawdown at Year 2022 and Year 2026 to demonstrate the extent of water level change due to the Modification only. Figure 33 shows the additional drawdown resulting from the Modification.

The cone of depression extends partially into the Hunter River alluvium but does not extend under the Hunter River. The drawdown caused by the Mt Arthur Coal Mine impacts the whole south-eastern part of the model area to the south of Saddlers Creek.

In summary the extent of additional drawdown resulting from the Modification is shown in Figure 33, where the impact area from this activity can be seen to extend to the north and west of the mine leases but is completely within HVEC owned land, with the exception of a small portion of crown land.

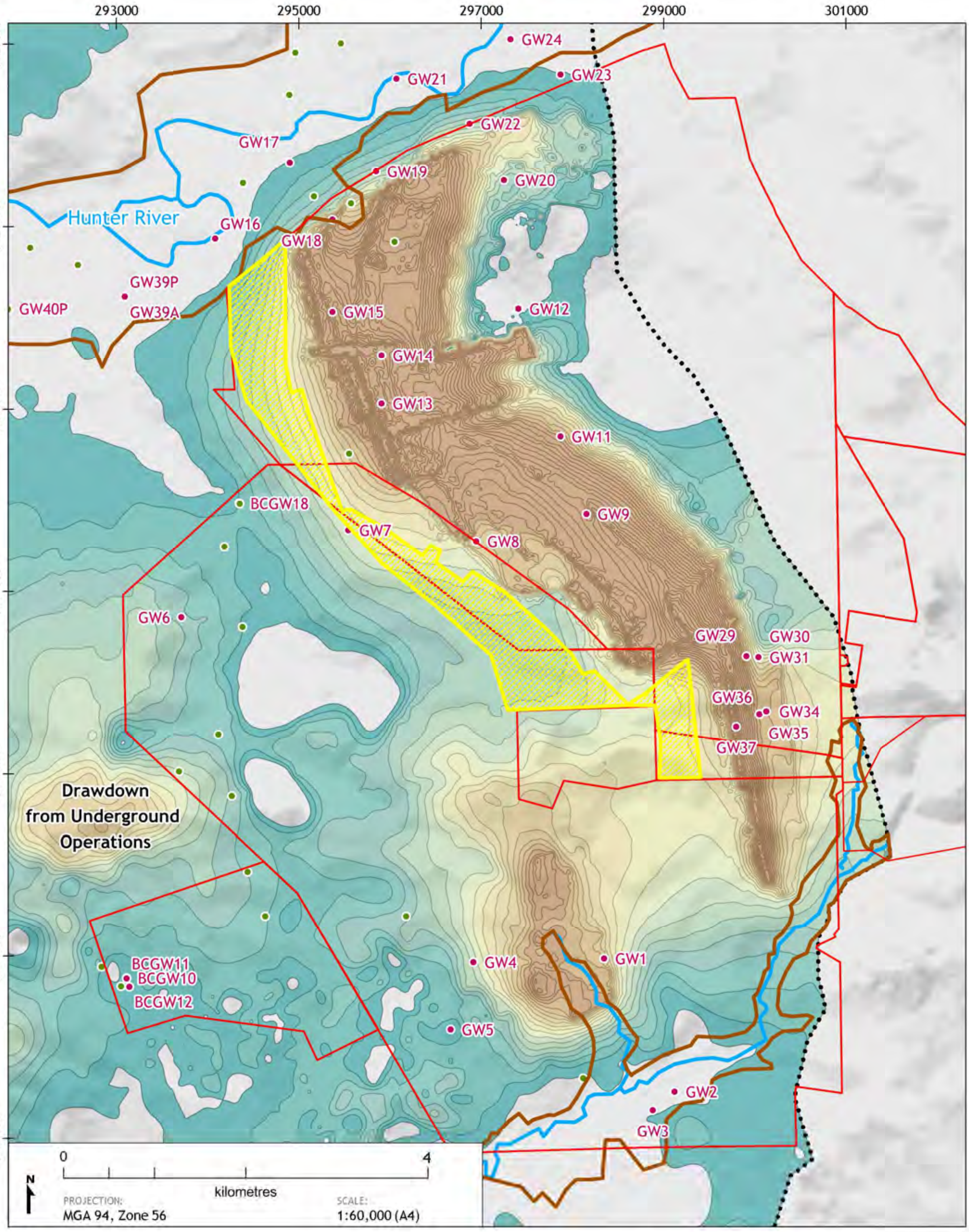
13.3 Pit Inflows

The majority of groundwater inflow occurs to the Northern Open Cut together with the South Pit Extension (Table 10). The results have been plotted against results from the 2009 study (AGE, 2009) for comparison (Figure 34). Inclusion of the updated mine plans and the associated model mesh refinement for Years 2016 to 2022 has had minimal impact on the predicted pit inflows and the results are comparable over this period. Northern Open Cut Pit inflows peak around Year 2016 and reduce after Year 2022. Inflows continue to reduce over the Modification period to Year 2026. Inflows to the open cut pit can be seen to increase at Year 2026 as a result of the Modification, although during mid-2026, they stabilise around 2.16 ML/day (25 L/s).

Table 10: PREDICTED AVERAGE INFLOW TO THE PITS (ML/day)

Project Years	MAN Pit	South Pit	Saddlers Pit	TOTAL
2016	2.33	0.15	0.13	2.61
2017	1.94	0.16	0.13	2.22
2018	2.04	0.16	0.13	2.33
2019	1.77	0.21	0.12	2.10
2020	1.96	0.18	0.16	2.30
2021	1.94	0.18	0.15	2.27
2022	1.90	0.19	0.15	2.24
2023	1.79	0.19	0.13	2.11
2024	1.81	0.20	0.12	2.13
2025	1.63	0.20	0.12	1.95
2026	2.16	0.21	0.12	2.50

2 It should be noted the drawdown noted around MAU operations differs from the figure present in AGE (2009), which only presents drawdowns associated with open pit mining operations.



LEGEND:

- Mine Modification Area
- Mt Arthur Coal Mining & Coal Lease Boundary
- Model Boundary
- NOW Registered Bore
- Groundwater Monitoring Bore
- Alluvium
- River

Water Table Drawdown at Year 2026 (m)

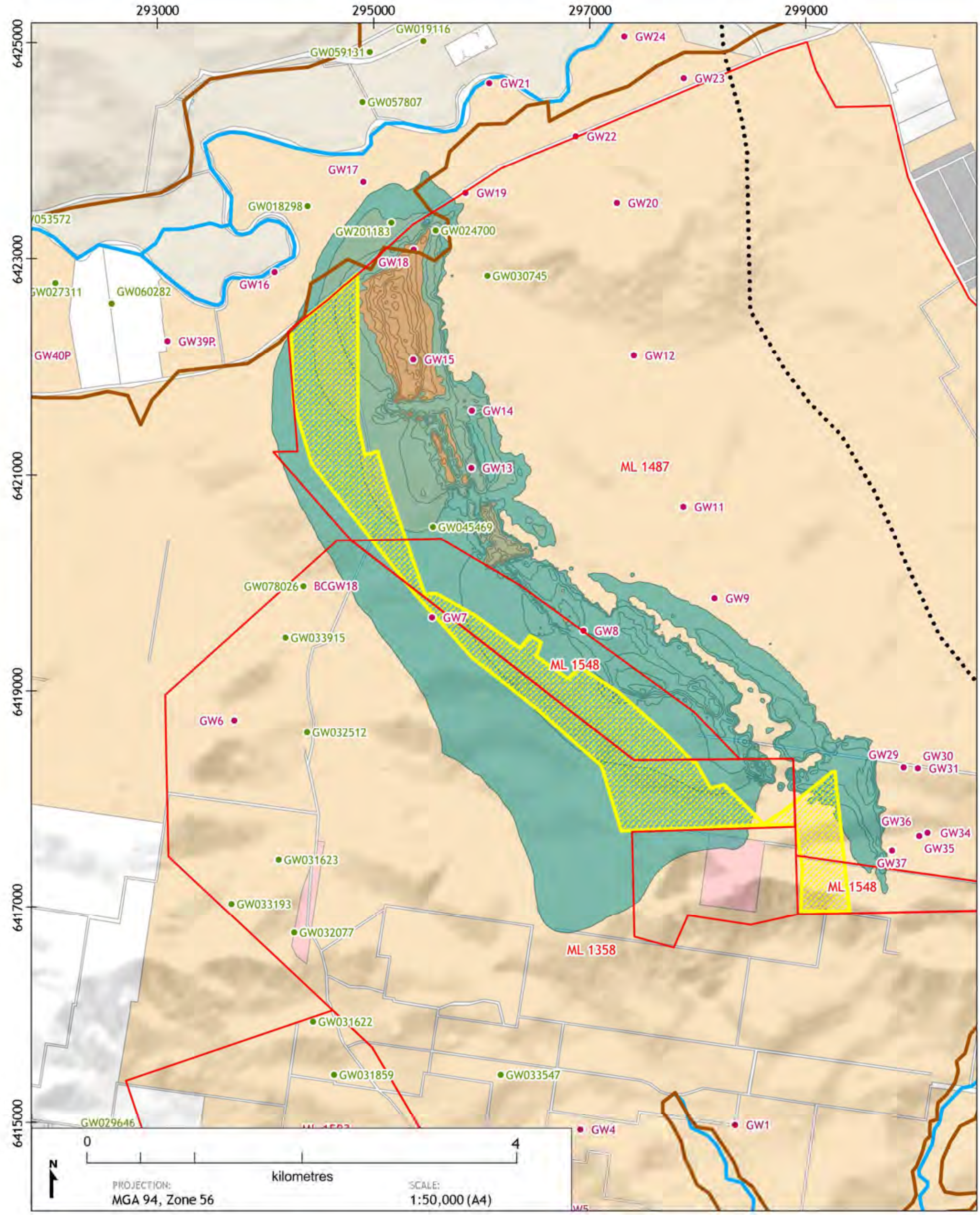
2	42
7	47
12	52
17	57
22	62
27	67
32	72
37	77 to 197

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Water Table Drawdown at Year 2026

DATE: 23/1/2013

FIGURE No: **32**



LEGEND:

- Mine Modification Area
- Mt Arthur Coal Mining & Coal Lease Boundary
- Model Boundary
- NOW Registered Bore
- Groundwater Monitoring Bore
- Alluvium
- River
- Crown Land / The State of NSW
- HVEC Owned Land
- Industrial Zone
- Mine Owned Land
- Private Owned Land

Water Table Drawdown (m)

- 2 to 5
- 5 to 10
- 10 to 20
- 20 to 30
- 30 to 90

Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Drawdown Associated with the Mine Modification

AGE GROUNDWATER & ENVIRONMENTAL

DATE: 23/1/2013

FIGURE No: 33

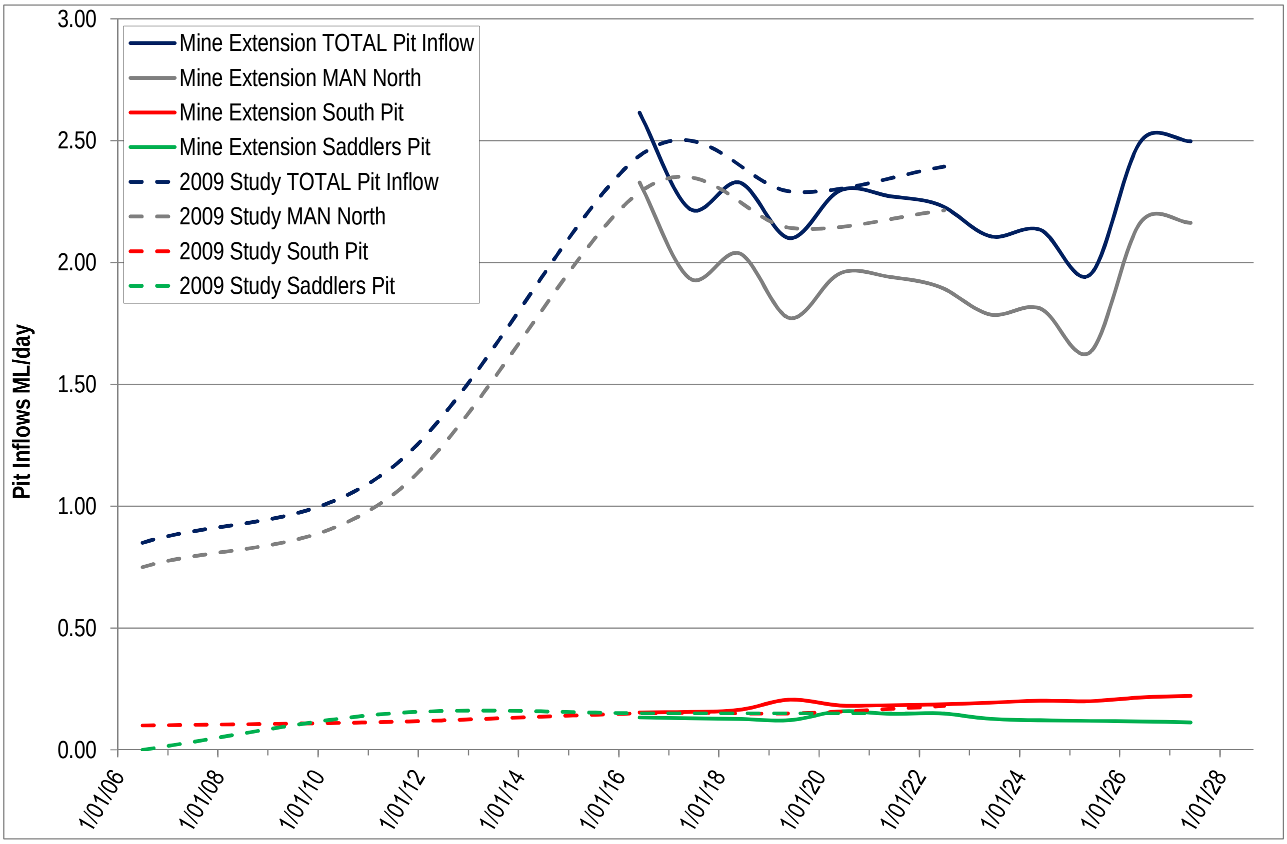


Figure 34: Prediction of Groundwater Inflow into the Pits

The sudden increase in pit inflows in Year 2026 are a result of the instantaneous pit modification at a single time step in the model. In reality pit modification will result in gradual increase in pit inflows, hence the increase in pit inflows are not expected to be as sudden as modelled, rather spread out over the 4-year Modification period.

From Table 10 it can be seen that the maximum total average pit inflow predicted for the Modification period (i.e. Years 2022 to 2026) is approximately 2.50 ML/day. Comparatively, the maximum total average inflow for the approved pit predicted by the updated model, (Year 2016) is approximately 2.6 ML/day (Table 10). Therefore, the Modification would not result in an increase of maximum total average pit inflow.

Not all of this predicted pit inflow will need to be managed or available for mine operations in the pit. The actual volume of water pumped from the mine is likely to be less than the volumes predicted as some water will be removed as moisture with the coal and some lost through evaporation. At least 3% to 5% of this water will be exported with the product coal. Further water loss can be expected by evaporation from the pit floor and coal face seepage with meteorological data indicating that the mean daily evaporation rate from the pit floor can be as high as 3 mm/day. This amounts to an average water loss of about 300 L/day from each 100 square metres of exposed pit floor and wall area.

The differences in pit inflows simulated by the AGE (2009) study and those simulated for this study, illustrated in Figure 34, are a result of both refinement of the model mesh within the Modification Area and incorporation of the newly available mine plan data (from 2016). The incorporation of the newly available mine plan data has resulted in minor differences between the timing of mine development simulated in the AGE (2009) study and this study. These differences are due to the inclusion of the updated mine plan data only and is not a material result of the Modification.

13.4 Leakage of Groundwater from Alluvium

As discussed previously, recharge of the alluvium occurs by rainfall infiltration and upward leakage from the Permian coal seams that sub-crop beneath the alluvium, the latter being responsible for the generally brackish to saline groundwaters at the base of the alluvium. Mining in the area will reduce the rate of the groundwater discharge from the Permian coal measures to the alluvium of the Hunter River and Saddlers Creek. The groundwater salinity measured within the alluvial monitoring bores suggests a reduction in Permian coal measure discharge is occurring, with a corresponding reduction in bore salinity (Section 10.1.2).

Under natural conditions, groundwater flows from the northern part of the Mt Arthur Coal Mine area towards the Hunter River (and south to Saddler Creek); however, with mining at the Northern Open Cut and depressurisation of the Permian coal measures, this groundwater flow will be reduced and with time, will be reversed on a local scale.

Flow path analysis (Figure 35) shows the direction of groundwater flow to a series of points (seeds) simulated along the Hunter River Alluvial/Permian boundaries. To the west, particle tracks flow from the MAU area to discharge to the alluvium (the pre-mining situation), while to the east in the vicinity of the Northern Open Cut, particle tracks move from the alluvium in the direction of the Northern Open Cut. An approximate 4 km length of the Hunter River alluvium and 2.5 km length of the Saddlers Creek alluvium is affected by Mt Arthur Coal Mine open pit operations. These affected alluvial reaches noted from particle tracking correspond with areas of drawdown and depressurisation in the alluvium. It should be noted that the particle tracking includes the cumulative effects of mining prior to Year 2022 as well as the Modification period from 2022 to 2026.

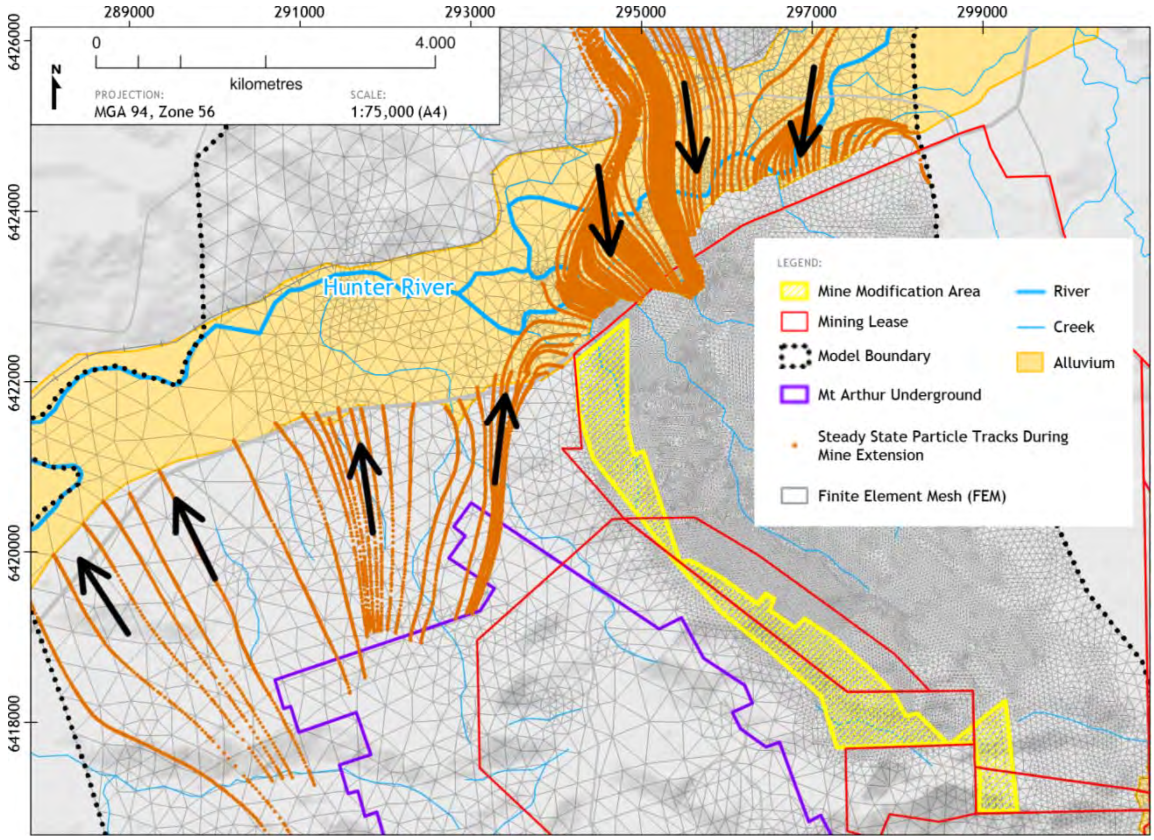


Figure 35: Flow Path Analysis from the Hunter River Alluvium

Flux between the Modification and the MAU to and from the Hunter River and Saddlers Creek alluvium are shown in Table 11 and, as with pit inflows, the fluxes are plotted against AGE (2009) data for comparison in Figure 36.

Table 11: PREDICTED FLUX TO AND FROM ALLUVIUM (ML/day)

Project Years	Hunter River to the Northern Open Cut	Hunter River to MAU	Saddlers Creek to Northern Open Cut	Saddlers Creek to MAU
2016	0.634	-0.247	0.007	-0.048
2017	0.634	-0.235	0.008	-0.032
2018	0.647	-0.233	0.008	-0.029
2019	0.675	-0.236	0.009	-0.034
2020	0.667	-0.234	0.009	-0.027
2021	0.675	-0.226	0.010	-0.026
2022	0.690	-0.220	0.010	-0.025
2023	0.707	-0.210	0.010	-0.027
2024	0.722	-0.196	0.010	-0.027
2025	0.713	-0.182	0.010	-0.027
2026	0.718	-0.171	0.010	-0.027

Note: negative flux in this table is from Permian coal measures to alluvium.

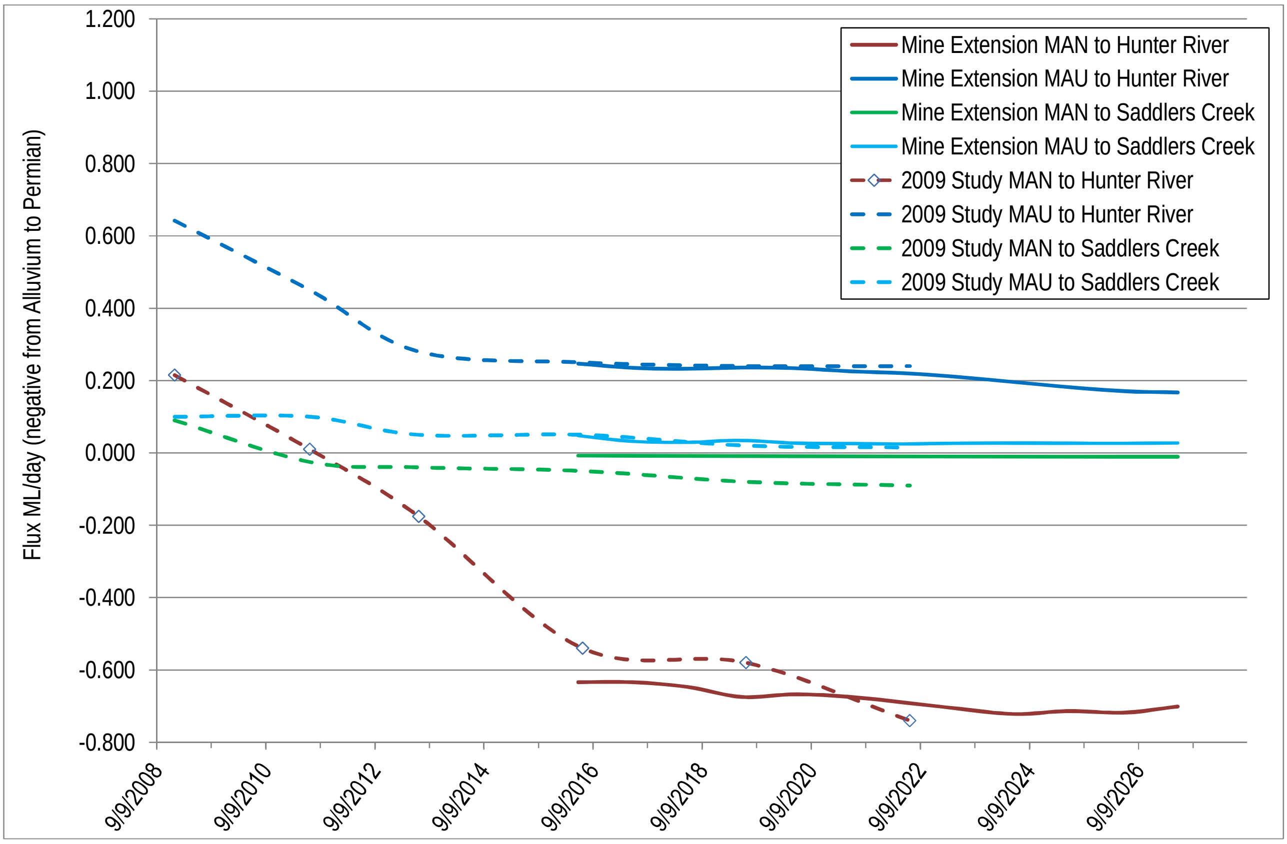


Figure 36: Groundwater Seepage Rates to/from Hunter River and Saddlers Creek Alluvium

Flux from the Hunter River alluvium to the Permian coal measures predicted by the updated model for the approved mining extent (Years 2016 to 2022) is comparable to that predicted by AGE (2009) and is between 0.63 ML/day (7.3 L/s) to 0.69 ML/day (7.9 L/s). Flux from the alluvium remains fairly stable for the Modification period (Years 2022 to 2026) between 0.69 ML/day (7.9 L/s) and 0.72 ML/day (8.3 L/s). Flux from the Hunter River alluvium appears to reach a "quasi-equilibrium" by Year 2022, with the major changes in flux occurring prior to Year 2016 as the Northern Open Cut passes at it closest point to the alluvium.

From Table 11, it can be seen that the maximum flux from the Hunter River alluvium for the Modification period (i.e. Years 2022 to 2026) is approximately 0.72 ML/day. Comparatively, the maximum flux from the Hunter River alluvium predicted by the updated model for the currently approved mining extent (2022) is approximately 0.69 ML/day. On this basis, the flux from the Hunter River is predicted to increase by approximately 0.03 ML/day due to the Modification.

It can also be seen from Table 11 that the maximum flux from Saddlers Creek alluvium to the open pit for the Modification period (i.e. Years 2022 to 2026) is approximately 0.01 ML/day. The maximum flux from Saddlers Creek alluvium to the open pit predicted by the updated model for the approved mining extent (Years 2016 to 2022) is also 0.01 ML/day. On this basis, the Modification would not result in an increase in flux from Saddlers Creek alluvium.

For consistency and comparison to the AGE (2009) study, fluxes between the MAU and alluvium have been included in Table 11 and Figure 36. These remain positive (from Permian coal measures to alluvium), although reduce through the simulation.

As shown in Figure 36, AGE (2009) predicted the maximum flux from the Hunter River alluvium to be approximately 0.74 ML/day for the approved mining extent. The differences in Permian and alluvial flux simulated by the AGE (2009) study and those simulated for this study, illustrated in Figure 36, are a result of both refinement of the model mesh within the Modification Area and incorporation of the newly available mine plan data. The incorporation of the newly available mine plan data has resulted in minor differences between the timing of mine development simulated in the AGE (2009) study and this study. These differences are due to the inclusion of the updated mine plan data only and is not a material result of the Modification.

The volume of leakage from the alluvium to the Permian strata reported in this section is considered a worst case scenario. The model assumes direct hydraulic connection between the base of alluvium and bedrock, that is, the model does not account for the likely occurrence of a weathered clay rich transition zone at the base of alluvium that inhibits leakage.

It should be noted that water quality at the base of the Hunter River alluvium is anticipated to improve in the area of predicted water level change as groundwater discharge from the Permian groundwater systems decline.

13.5 Leakage from Faults

Apart from general leakage due to depressurisation of the coal seam beneath the base of the alluvium, there is also potential for leakage from faults that may occur beneath the alluvium. Fairford Graben was simulated in the model by assigning high conductivity zones of 0.6 m/day along the fault lines. No other faults were simulated in the model. If other faults are identified in the Site area and strike beneath the alluvium and are likely to present a risk with respect to groundwater inflow from the alluvium or to pit wall stability, they will be investigated (consistent with the investigation undertaken for the F4 [Section 8.3]), and if considered to present a risk, mitigation options will be identified and implemented, as per the Project Approval for the Mt Arthur Coal Mine – Open Cut Consolidation Project Statement of Commitments:

> *Mt Arthur Coal will continue to monitor hydro-geomorphological conditions and scrutinise for evidence of any groundwater ingress or endwall instability indicators as it progresses the previously approved mining towards the Hunter River Alluvials. Mining (other than that already approved in the MAN EIS) will not extend beyond a nominal 150 m buffer zone from the Hunter River Alluvials until agreement is reached with NOW regarding the installation of a lower permeability barrier along the point of connections of mining and the alluvium or other appropriate safeguards.*

13.6 Impact on Groundwater Users

Drawdown of the piezometric surface of the coal seams and of the water table of the shallow alluvial and regolith has the potential to impact existing groundwater users. These potential impacts are discussed in the following sections.

13.6.1 Loss of Yield from Existing Bores

Depressurisation and leakage as a result of mining may result in a lowering of water table/piezometric levels in those existing bores that are used for irrigation, stock and domestic water supplies where these facilities lie within the radius of the cone of depression. As discussed in Section 9.1, existing bores were identified from a search of the NOW database, these are shown on Figure 32 against Year 2026 drawdowns and in Figure 33 against the drawdown impact zone associated with the mine Modification. The potential drawdown for all bores at Year 2026 (the maximum) is tabulated in Appendix 1 along with the drawdown associated with the mine Modification period.

Bores where additional drawdown can be attributed to mine Modification project have been highlighted orange in Appendix 1. These three bores (GW024700, GW045469 and GW201183) are all located on HVEC owned land with bore GW201183 located outside of the mine tenements, although this bore is only used for monitoring purposes.

As documented in Section 9.1 the updated bore search produced a number of bores not included in the AGE (2009) study, these are noted in Appendix 1. Eight of these additional bores show impact from mining activities, although according to the findings of this study, this impact is not directly attributable to the Modification. As documented in AGE (2009), impact is predicted to be greater for bores constructed within the Permian/regolith strata, rather than bores constructed within alluvium.

Notwithstanding the negligible effects due to the Modification noted in surrounding private bores, consistent with the Project Approval for the Mt Arthur Coal Mine – Open Cut Consolidation Project Statement of Commitments:

> *In the event of interruption to water supply resulting from the Project, an alternative water supply will be provided, until such interruption ceases.*

13.6.2 Impact of the Placement of Overburden on Saddlers Creek Alluvium

The Modification includes the placement of overburden in an upper section of Saddlers Creek Alluvium; the area is shown in Figure 2. The placement of this overburden has not been specifically modelled in this study. The soil profile in this area is moderately drained in the topsoil, becoming poorly drained thereafter (GSS Environmental, 2012). The mapping of soil within this area includes depositional sediments associated with the creek flow, however, due to limited size and poor texture and structural characteristics, these alluvial are not commonly associated with good agricultural land (GSS Environmental, 2012). Therefore, it is expected that any rainfall that is captured and may infiltrate into the overburden is likely to emerge at the base of the overburden as minor seep, rather than infiltrate to alluvium or weathered bedrock.

13.6.3 Groundwater Dependent Ecosystems

No groundwater dependent vegetation comprising GDEs occurs within the Modification Area or immediate surrounds (Hunter Eco, 2012). The regolith and Permian formations are topographically elevated and it is unlikely that the alluvial areas will be impacted from the mine.

13.7 Groundwater Recovery

Groundwater level recovery in the final void following cessation of mining has been simulated using a modified version of the FEFLOW groundwater model developed for the Modification.

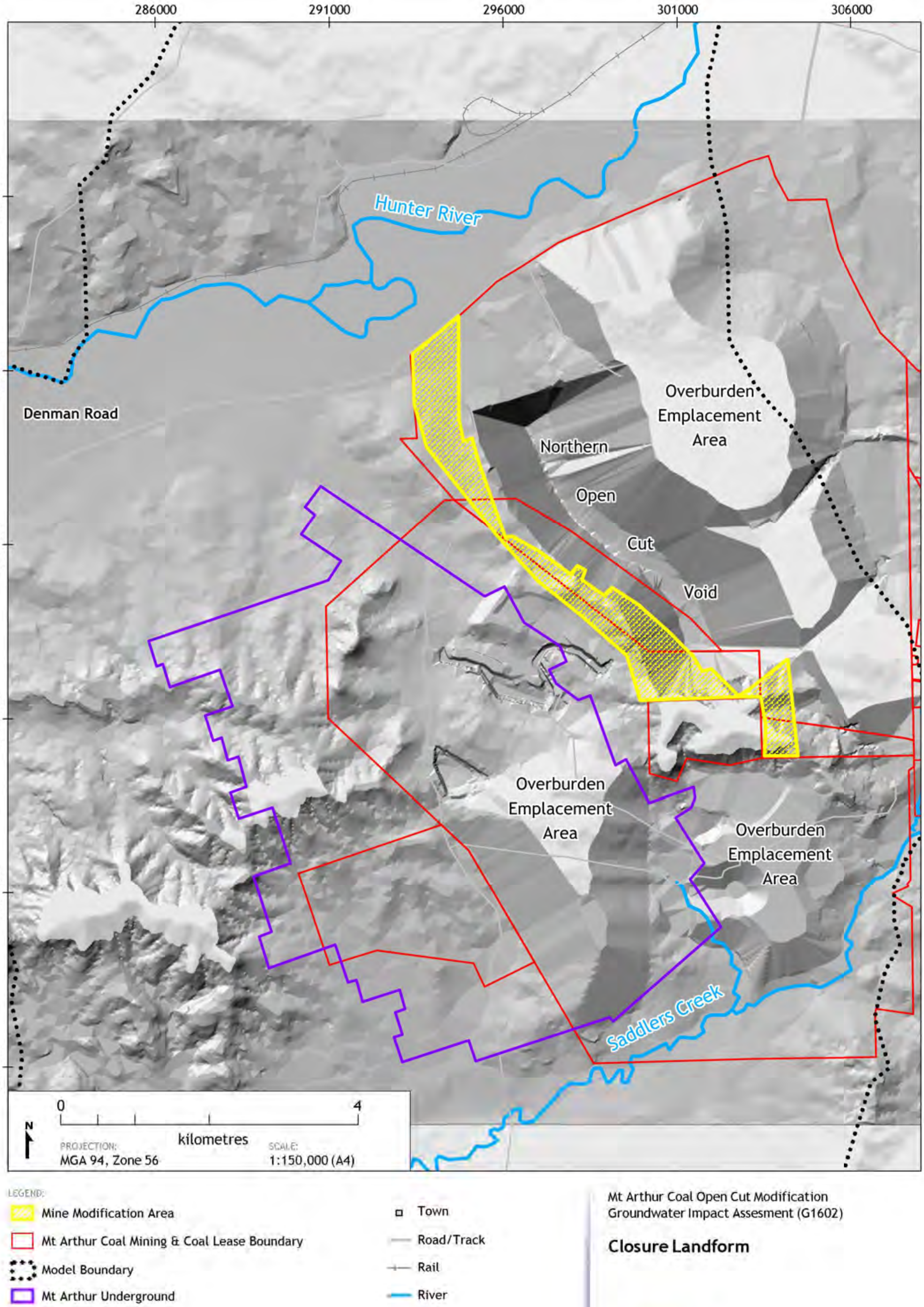
13.7.1 Surface Water Study Final Void Fill Calculations

The surface water study for the Modification also addressed final void recovery using water balance techniques and estimates of pit lake groundwater inflows supplied by AGE (Gilbert & Associates, 2012). The study by Gilbert and Associates (2012) presents an excellent comparison to the recovery modelling discussed here. The results of the surface water study show a period of rapid lake fill (Years 0 – 20) to a level of -20 mRL (170 m below the pit lake spill point), followed by a gradual filling period from Year 20 to Year 500. The surface water study presents a final void level of 15 mRL (135 m below the pit lake spill point).

13.7.2 Recovery Groundwater Modelling Build

The final backfilled pit and spoil landform (final landform) is shown as a shaded relief image in Figure 37. Using this final landform, the following process was used to develop the recovery model:

- The calibrated model and scenario model results presented in previous sections of this report were used as a starting point to recovery model development. All parameterisation and settings remain the same as previously discussed in this report, unless otherwise as stated in this section.
- Drawdown at year 2026 (cessation of mining) from scenario modelling was used as the starting heads (as shown in Figure 32 for one model layer) for the recovery model development.
- The complete final landform (including spoil) above the original land surface (as shown in Figure 37) was integrated to form a new ground surface within the model as Slice 1.
- Spoil:
    - Although spoil was not simulated during the dewatering simulation, it was deemed necessary to include spoil in this simulation which is to run up to 500 years post closure.
    - Increased horizontal and vertical hydraulic conductivity was applied to the spoil at 1 m/day to represent increased permeability over in-situ material. This also represents the general isotropic permeability of spoil over the relatively anisotropic (layered) permeability of coal seams, overburden and interburden.
    - Storage properties for spoil were set at 5%.
    - Increased recharge to the spoil was initially set at 5% of rainfall, believed to be an upper bound of increased recharge potential. In subsequent scenarios, this recharge to the spoil was reduced to 2.5% of rainfall to take into account increased evapotranspiration that is expected over the spoil pile. Both of these recharge values are a net increase in recharge compared with the predictive pit dewatering model.
    - In backfilled mined areas, spoil hydraulic conductivity and storage parameters were set in all model layers to the base of Layer 7 (base of the Ramrod Coal Seam), while in areas of spoil overlying previously unmined formations, spoil parameterisation was only set for Layer 1.



Mt Arthur Coal Open Cut Modification
Groundwater Impact Assesment (G1602)

Closure Landform

DATE: 23/1/2013

FIGURE No: 37

- Pit Lake:
  - The final void pit lake was simulated by applying a high permeability void within the model environment. The original ground surface was used as a top of this void, with the final void (as shown in Figure 37) used as a base to this zone. Hydraulic conductivity was set at 1,000 m/day and storage properties set at 99% to represent the open void. Using a high permeability/storage zone for a pit lake within FEFLOW maintains stability in the model and allows pit lake level to be monitored via an observation node measuring the water table (a surrogate for pit lake level).
  - The pit lake void was developed in the model in an area representative of the three-dimensional void shown in Figure 37. Hence the area of the void was smallest at the base (Layer 7) and increased in size toward the surface layers to represent the inverted cone shape of the final pit structure.
  - Recharge to the final void pit lake was modified to simulate a simple water budget of incident rainfall (645 mm/year) minus evaporation (1,642 mm/year) which equates to 997 mm/year water deficit from the pit lake. A second scenario was run to simulate increased run-off to the pit at essentially 75% of 997 mm/year, which equates to 747 mm/year of water taken from the pit lake. These evaporation rates were implemented in FEFLOW using the Inflow/Outflow on top setting.

- Model Settings
  - To increase numerical stability, the recovery model was run in Phreatic mode in FEFLOW (versus Free and Movable for the calibrated model). As a result of this, the top slice of the model is maintained as per the ground surface (and the elevated spoil piles).
  - The top slice of the model was set as a seepage face, hence any water that may seep from the spoil would be rejected from the model as seepage.
  - The modified model was then run using year 2026 starting heads, initially this was run to make sure the final landform was dewatered and formed a stable starting condition to the recovery modelling. Dewatering to the final landform was run using the same settings as scenario dewatering modelling (i.e. through implementation of 3rd kind boundary conditions at the pit face). The result of this short dewatering run “bridged the gap” between the final 2026 modelled pit and the final landform dewatered surface.

A schematic cross-section through the final pit lake model (in the vicinity of the pit) is shown in Figure 38. The final pit lake void is represented in red, the spoil pile above ground and in previously mined areas is represented in orange, the unmodified model layers representing overburden, interburden and coal seams are represented in yellow. The blue area in this schematic represents the low permeability Saltwater Creek Formation. It should be noted that during the long-term recovery runs (>100 years) an upward hydraulic gradient was observed from the Saltwater Creek Formation below the pit void area. Conceptually the Saltwater Creek Formation is described through this report as an aquitard. To mitigate any long-term effects in the recovery model from upward leakage from this aquitard, hydraulic conductivity was reduced further in this model layer compared to the previously calibrated model.

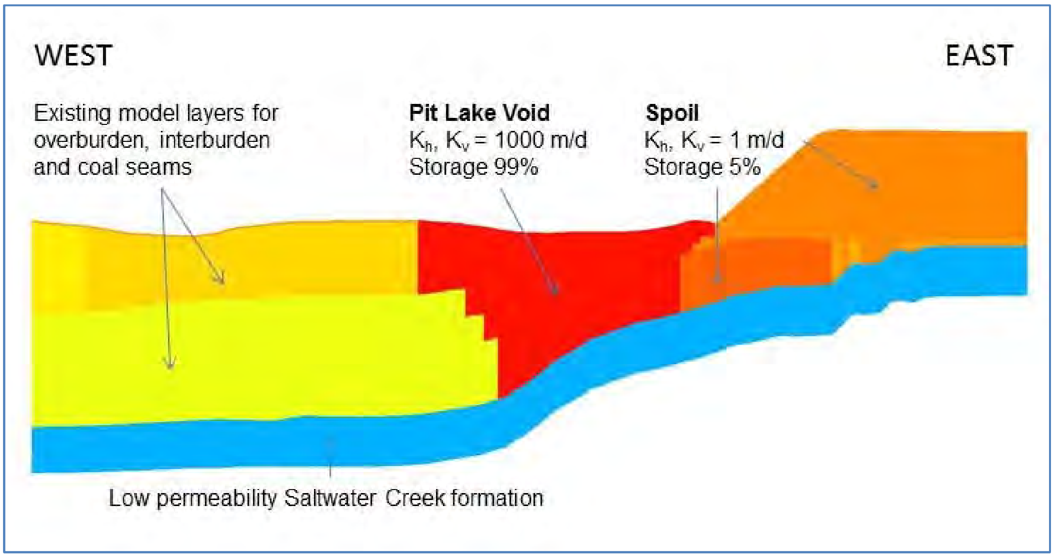


Figure 38: Schematic of the Final Void Recovery Model

13.7.3 Recovery Groundwater Modelling Scenarios

The modified final landform model was run for a period of 500 years to simulate pit lake level recovery. Four scenarios were carried out as described in Table 12. The range of scenarios is thought to include the possible range of combinations effecting evaporation from the pit lake and additional recharge to spoil, representing a base-level sensitivity analysis. The transient results are shown in Figure 39 compared against a final pit lake spill point of 150 mRL and also against the Hunter River boundary condition elevation which ranges between 120 mRL to 135 mRL (in the vicinity of the pit). Pit lake levels at year 200 and year 500 are also noted in Table 12. The simulation also showed that the groundwater system would recover over time with substantial recovery to levels similar, or above those within the pit lake.

Table 12: PIT LAKE RECOVERY MODEL SCENARIOS

Scenario	Pit Lake Evaporation (mm)	Spoil Recharge (% of rainfall)	Final Lake Level at 200 Years (mRL)	Final Lake Level at 500 Years (mRL)
1	-747	5	48 (102 m from spill)	59 (91 m from spill)
2	-997	5	45 (105 m from spill)	55 (95 m from spill)
3	-997	2.5	41 (109 m from spill)	45 (105 m from spill)
4	-747	2.5	48 (102 m from spill)	59 (91 m from spill)

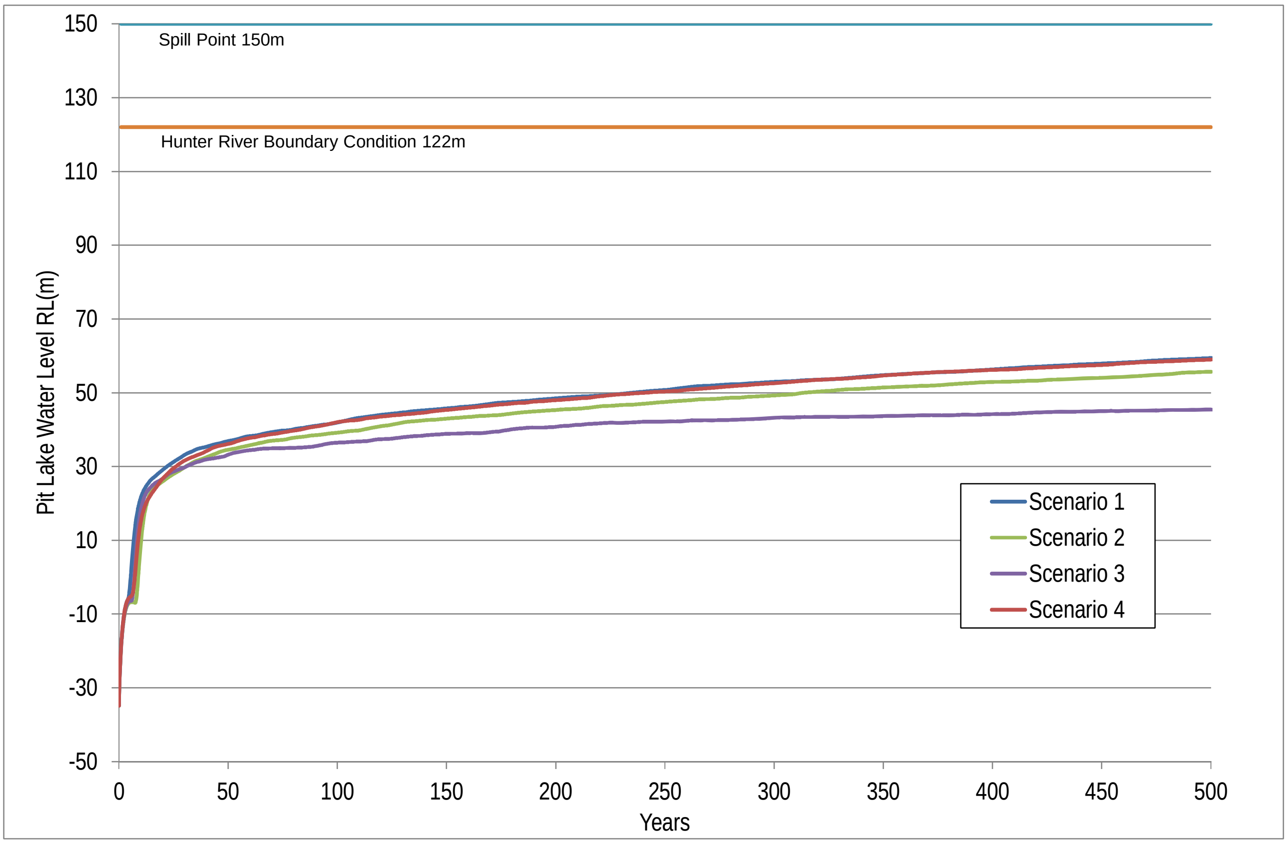


Figure 39: Pit Lake Recovery Levels

The shape of the lake level fill curves are comparable between Figure 39 and results from the surface water study (Gilbert & Associates, 2012). Both fill rapidly to year 20 with a reduction in the fill rate after this time - shown as a gradual recovery in Figure 39 from year 20 to year 500. Results from the simulation show final pit lakes in the range of 45 mRL to 59 mRL or between 105 m to 91 m from the final spill point. All scenario results show final lake level well below the Hunter River Boundary condition, outlining that groundwater discharge from the pit lake to this boundary is highly unlikely to occur.

While final lake levels from recovery groundwater modelling are higher (30 m - 44 m) than those presented by the surface water study, the results are generally consistent. It is noted that both approaches for predicting final lake water levels (i.e. development of a water balance versus numerical groundwater model predictions) conclude that the final lake water level is well below the groundwater discharge point (i.e. Hunter River elevation) and the potential pit spill level. The slightly higher final lake level predicted by the groundwater model can possibly be attributed to extra recharge introduced through spoil in this simulation, which was not included in the surface water study. The modelling results suggest that the final void pit lake will behave as a “sink” in the local groundwater environment, suggesting a very low probability of discharge from the final pit lake to the wider groundwater environment in the post closure situation.

14.0 WATER QUALITY

Groundwater monitoring data suggests, based on bore EC results, a lowering of salinity in alluvial monitoring bores directly to the north of the Northern Open Cut (Section 10.1.2). It is likely this change is due to a reduction in groundwater flux of more saline groundwater from the Permian Coal Measures to the alluvium, resulting from pit dewatering. The Modification modelling predicts a continued dewatering in the mine pit area, suggesting an ongoing “sink” in the local Permian coal measures. Due to this ongoing sink in the Permian coal measures, there is not expected to be significant migration or deterioration in groundwater quality resulting from the Modification.

15.0 WATER LICENSING

Licensing under the HURAWSP is required to account for any loss of flow to the alluvium resulting from the Modification. The HURAWSP is discussed in Section 4.3.2. Details of the current groundwater licences held by HVEC are summarised in Table 13.

Table 13: GROUNDWATER LICENCE SUMMARY

Licence Number	Licence Volume (ML/annum)	Issue Date	Expiry Date
Licence under the Water Management Act 2000			
WAL18175	13	16/11/2011	Perpetuity
WAL18141	104	25/07/2011	Perpetuity
WAL18247	247	25/07/2011	Perpetuity
Licences under the Water Act 1912			
20BL171995	750	5/11/2008	4/11/2013
20BL168155	750	28/05/2007	27/05/2017
20BL171156	150	13/03/2007	Perpetuity
20BL170620	250	5/12/2011	4/12/2016

Source: BHP Billiton Ltd (2011).
ML/annum = megalitres per annum.

The maximum predicted annual groundwater volumes required to be licensed for the approved operations and for the Modification are summarised in Table 14.

Table 14: LICENSING REQUIREMENT SUMMARY

Relevant Legislation	Groundwater Source	Predicted Maximum Annual Licensing Requirements (ML/annum)		
		Approved	Incremental Increase due to the Modification	Total Including the Modification
HURAWSP	Hunter River Alluvium	252[1]	12[2]	264
Water Act	Porous Rock	1,270[3]	No Increase[4]	1,270

1 Based on the maximum simulated average flux from the Hunter River Alluvium for the approved operations predicted by the current model.
2 Based on the maximum simulated average flux from the Hunter River Alluvium predicted for the Modification.
3 Based on the maximum simulated average pit inflow and corresponding underground mine inflow for the approved operations predicted by the current model.
4 Based on the maximum simulated average pit inflow and corresponding underground mine inflow predicted for the Modification.

Table 13 indicates that HVEC currently hold licence entitlements of 364 ML/annum for the HURAWSP and 1,900 ML/annum for water extracted from porous rock. Table 14 shows that the Modification will result in an additional 12 ML/annum from the Hunter River Alluvium and no increase in water extracted from porous rock. In addition the Modification would not result in an increase in water extracted from Saddlers Creek alluvium (Section 13.4). Therefore adequate licences are available to account for the potential incremental increase in take of water associated with the Modification. If required, HVEC would transfer water entitlements between water management zones in order to adequately licence groundwater extraction.

The post-closure annual licensing requirements are expected to be less than the licensing requirements during operation. Post-closure licensing requirements would be refined as mining progresses.

16.0 CLIMATE CHANGE

Current assessments for climate change in the region of the Modification range from (Commonwealth Scientific and Industrial Research Organisation, 2012):

- 10th percentile: -15% rainfall (-96 mm/year) and +3% evapotranspiration (+49 mm/year);
- 50th percentile: -3.5% rainfall (-22 mm/year) and +6% evapotranspiration (98 mm/year); and
- 90th percentile: +7.5% rainfall (+48 mm/year) and +10% evapotranspiration (164 mm/year).

This suggests a slight decrease in potential recharge to the system and therefore potential cumulative impacts to the groundwater system associated with the Modification and climate change. However, as the Modification is not predicted to result in significant impacts relative to impacts of the currently approved mining, and in the context of the four-year Modification period, the simulation of the effect of climate change is not considered to be warranted within the numerical model.

17.0 ASSESSMENT AGAINST GUIDELINES

The model and report has been assessed against the Australian Modelling Guidelines (Barnett et al., 2012). The guidelines discuss model confidence level classifications (Class 1, Class 2 or Class 3 in order of increasing confidence). These are summarised as follows:

- Class 1 – The model meets the lowest level of classification.
- Class 2 – The study meets the majority of Class 2 confidence levels other than mass balance closure <1% (1.5% in the steady state model) and a lack of baseflow estimates.
- Class 3 – The study meets a large number of the Class 3 confidence level confidence levels but lacks in the following areas:
  - Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. While these are adequate to meet the study objectives they may not meet Class 3 standards for aquifer geometry definition across the entire model domain.
  - Streamflow and stage measurements are not available with reliable baseflow estimates at a number of points.
  - Seasonal fluctuations are not adequately replicated, although with little seasonal fluctuations in Permian Coal Measures these may not be relevant.
  - The model is not calibrated to measured fluxes (only heads) although boundary fluxes were checked against plausible values.
  - The Length of predictive model is excessive compared to length of calibration period as only steady calibration was carried out. The same point is valid for models where predictive time frames are greater than three times the duration of the transient calibration and temporal discretisation in the predictive model is the same as that used in calibration.

The impact assessment model and report is assessed as having a Class 2 confidence level classification but also meets many of the Class 3 level criteria. The study generally meets the compliance checklist of the guidelines but does lack in the areas relating to sensitivity and uncertainty analysis. The lack of sensitivity and uncertainty does not detract from the model being used as a predicative tool. This conclusion is supported by verification of the 2009 calibrated model against available transient groundwater level data. In consideration of the above, the current study (model and report) is deemed fit for purpose to simulate the impact of the Modification.

18.0 LIMITATIONS AND ASSUMPTIONS

Development, calibration and the results of predictive simulations from any groundwater model is 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 various assumptions have to be made during development of the groundwater model. A number of assumptions were made during development of the groundwater model described in this report and these assumptions together with their impact on the simulation results are discussed below.

Since the simulated groundwater systems sub-crop along the eastern border of the groundwater model, it is assumed that they are hydraulically separated from the groundwater regime east of the Modification. The impact of such an assumption on the simulation results is such that the cone of depression caused by the Northern Open Cut cannot extend beyond the eastern boundary. It also implies that the Bayswater No. 2 and Drayton Mine have no impact within the mine Modification Area.

The conceptual model assumes that the hydraulic properties of the numerous Permian coal seams present within the mine Modification can be represented by three major layers. The hydraulic properties of a number of coal seams present within these layers were merged with the properties of the interburden. This simplification may lead to underestimation of the extent and the velocity of development of the cone of depression. This is because the cone of depression in coal seams that have relatively higher hydraulic conductivity is likely to develop somewhat quicker than in the less permeable interburden. However, the chosen approach is considered to be acceptable since the cone of depression is limited in extent and the period of the simulated mine development is sufficiently long enough to compensate for any major difference between the development of the cone of depression in the coal seams and in the interburden.

With respect to the Modification model, all information and data relating to the MAU used in the current model has been extracted from the corresponding numerical groundwater flow model of the underground mine (MER, 2007). Nonetheless, some discrepancies occur in the interpretation of the results regarding the hydraulic impact of the underground mine. This may be due to the different settings of the outer boundaries. Where the MER model extended the model domain beyond the Mount Ogilvie Fault, the current model uses this structural feature as model boundary, reducing the available volume for dewatering. This leads to a prediction of a somewhat higher impact on the Saddlers Creek and Hunter River alluvium, even though the general assessment remains similar. The MAU conditions used for Year 2022 have been extended to the mine Modification period (2026) for this study.

The model predicts transient mine impacts using time constant conditions representing recharge and river flow. This approach is common place for a model of this complexity with the need to model more complex transient recharge and climatic data beyond the scope and objectives of the model.

Progressive backfilling of the pits with spoil has not been simulated in the predictive simulations. This is likely to slightly over-predict the extent of depressurisation from mining, particularly in areas mined first to the east of the Northern Open Cut.

In the predictive scenarios, the Bengalla Mine is simulated to cease operation in 2017. It is understood there is a current application by Coal and Allied Pty Ltd to extend the Bengalla Mine operations beyond this date; however, this has not been simulated within the model. Previous modelling (AGE, 2009) of the Bengalla Mine Pit (pre 2017) at its closest position to the Hunter River, showed no connection of depressurisation or drawdown beneath the Hunter River from the Bengalla Mine Pit to the Northern Open Cut. Further mine expansion at Bengalla Mine is likely to occur down-dip and away from both the Northern Open Cut and Hunter River alluvium. The lack of previous interconnection and the likely progression of the mine from the alluvium are deemed adequate reasoning to not include the Bengalla Mine expansion in the current mine Modification model.

Further, the model does not simulate the approved Mt Pleasant and Drayton Mines or the proposed Drayton South Coal Project. Simulation of these mines was not considered necessary to quantify the cumulative impact of the Modification and justification for this is provided in Section 13.1.3.

19.0 CONCLUSIONS

This study has included an update of the conceptualisation and numerical groundwater model of the Mt Arthur Coal Mine to include current groundwater level and quality information, updated mine plans and a simulation of the proposed mine Modification period from Years 2022 to 2026. The earlier calibrated model proved accurate in its predictive capability when verified against a transient data set.

The scope of this study included an assessment of change in the alluvium groundwater level and quality, the impacts on groundwater users from the Modification, and prediction of inflows to the open pit operations.

Relatively small changes in leakage from and drawdown in the alluvium are noted from this study. Very little change was also noted in pit inflows compared to the previously approved mine operations. On-going drawdown is noted in Permian coal measures from both the mine Modification and simulated approved underground operations.

Results suggest that the largest impacts on groundwater users occur around the 2016 period, with operations till 2022 having already been approved for operation. It is thought that effects are the largest at this time to alluvial groundwater users (2016) due to mining activities being at their nearest to the Hunter River alluvium, with the ongoing mine Modification slightly further away from the alluvium, hence reduced impacts on the alluvial system after 2016. It is also assessed that following the initial dewatering, a quasi-steady state has developed in the groundwater environment for the period of the mine Modification.

Although the effects based on this study on the Hunter River Alluvium and private bore users of the Modification were assessed to be minor, in accordance with the Project Approval for the Mt Arthur Coal Mine – Open Cut Consolidation Project Statement of Commitments:

- *Mt Arthur Coal will undertake a census of privately owned groundwater bores to ascertain their current usage and provide a baseline against which to compare any future impacts. In the event of interruption to water supply resulting from the Project, an alternative water supply will be provided, until such interruption ceases.*

- *Mt Arthur Coal will continue to monitor hydro-geomorphological conditions and scrutinise for evidence of any groundwater ingress or endwall instability indicators as it progresses the previously approved mining towards the Hunter River Alluvials. Mining (other than that already approved in the MAN EIS) will not extend beyond a nominal 150m buffer zone from the Hunter River Alluvials until agreement is reached with NOW regarding the installation of a lower permeability barrier along the point of connections of mining and the alluvium or other appropriate safeguards.*

These safeguards are consistent with AGE (2009), the approved current mining operations and are appropriate to cover any inherent uncertainty in modelled predictions in this study.

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21.0 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 groundwater 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.

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.

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 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.

Head - sum of datum level, elevation head and pressure head which in unconfined aquifers is equal to the groundwater elevation.

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.

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

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.

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.

Piezometer - A non-pumping well, 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.

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.

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.

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.

Transmissivity - A measure of the rate at which water moves through an aquifer of unit width under a unit hydraulic gradient.

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.

AUSTRALASIAN GROUNDWATER AND ENVIRONMENTAL CONSULTANTS PTY LTD

Reviewed by:

DOUGLAS MCALISTER
Principal Hydrogeologist / Modeller

DANIEL BARCLAY
Principal Hydrogeologist

Appendix 1

REGISTERED BORE SUMMARY

Registration No.	License No.	Drilled	mE	mN	Depth (m)	SWL (m)	Yield (L/s)	Salinity (ppm)	Aquifer	Use/Comments	Owner	Cumulative Drawdown at year 2022	Drawdown greater than 2m due to Modification	Discussed in the 2009 study
GW011295	20WA212203	1955	290536	6425144	29	6.9			Permian	STOCK	Private Owned Land	4.5	-	Yes
GW018298	20CA208185	1960	294391	6423498	9.1	7.9			Alluvium	IRRIGATION STOCK	HVEC Owned Land	<1	-	Yes
GW019116	20CA212202	1951	295459	6425029	11.9				Alluvium	IRRIGATION STOCK	Mine Owned Land	1.1	-	Yes
GW024700	NA	1979	295573	6423275					Alluvium	UNKOWN	HVEC Owned Land	31.3	15.8	Yes
GW027311	20CA207877	1967	292056	6422787	11.6	9.4	1.5		Alluvium	DOMESTIC IRRIGATION STOCK	Private Owned Land	<1	-	Yes
GW029644	20BL023940	1920	289048	6411215	28.7				Permian	DOMESTIC STOCK	Private Owned Land	<1	-	No
GW029645	20BL023939	1969	289066	6414082	18.3				Permian	STOCK	Private Owned Land	3.6	-	No
GW029646	20BL023938	1914	292841	6414900	9.1				Permian	STOCK	Private Owned Land	9.0	-	Yes
GW029647	20BL023417	1914	291005	6413906	36.6				Permian	DOMESTIC STOCK	Private Owned Land	10.8	-	Yes
GW029648	20BL023418	1912	290875	6413873	31.1				Permian	DOMESTIC STOCK	Private Owned Land	10.5	-	Yes
GW029649	20BL023419	1912	291321	6413790	25.9				Permian	DOMESTIC STOCK	Private Owned Land	11.3	-	No
GW029654	20BL023411	1921	289250	6412822	95.1				Permian	STOCK	Private Owned Land	<1	-	No
GW029655	20BL023405	1936	290702	6412144	25.3				Permian	STOCK	Private Owned Land	1.5	-	No
GW029658	20BL023408	1957	289462	6413936	55.8				Permian	STOCK	Private Owned Land	2.6	-	No
GW029659	20BL023407	1936	289121	6411494	74.7				Permian	DOMESTIC STOCK	Private Owned Land	<1	-	No
GW029660	20BL023412	1938	290211	6413089	74.7	39.6	0.5		Permian	STOCK	Private Owned Land	1.7	-	Yes
GW029661	20BL023406	1914	293054	6414688	42.7				Permian	STOCK	Private Owned Land	2.8	-	Yes
GW030745	NA	1979	296052	6422854	220				Permian	UNKOWN	HVEC Owned Land	126.6	-	Yes
GW031622	20BL024276	1969	294440	6415949	91.4	28.7	0.4		Permian	STOCK	HVEC Owned Land	13.3	-	Yes
GW031623	20BL023652	1969	294122	6417453	38.1	18.3	2.3		Permian	STOCK	HVEC Owned Land	12.8	-	Yes
GW031859	20BL024674	1969	294633	6415460	61	22.9	0.68		Permian	STOCK	HVEC Owned Land	12.3	-	Yes
GW032077	20BL024716	1969	294266	6416778	53.3	28.7	1.5		Permian	STOCK	HVEC Owned Land	17.0	-	Yes
GW032512	20BL024338	1969	294386	6418629	33.5				Permian	STOCK	HVEC Owned Land	5.9	-	Yes
GW033193	20BL026154	1971	293686	6417043	46.9	12.8	0.9		Permian	STOCK	HVEC Owned Land	27.2	-	Yes
GW033547	40BL026898	1972	296176	6415461	12	4.3			Permian	STOCK	HVEC Owned Land	18.1	-	Yes
GW033915	20BL024261	1971	294185	6419509	39.6	21.0	0.3		Permian	STOCK	HVEC Owned Land	8.0	-	Yes
GW038607	20BL029567	1973	290205	6420916	13.4	11.5	0.4		Permian	STOCK	Private Owned Land	<1	-	No
GW045469	20BL103870	1976	295550	6420532	49.1	33.1	0.3		Permian	STOCK	HVEC Owned Land	60.0	4.0	Yes
GW049223	20BL106334	1979	298120	6413682	67.1		0.6		Permian	STOCK	HVEC Owned Land	1.2	-	Yes
GW053233	20CA208013	1981	291336	6423158	11.2				Alluvium	DOMESTIC IRRIGATION STOCK	Private Owned Land	<1	-	Yes
GW053299	20WA207634	1981	291127	6423123	10.1	2.5		3000	Alluvium	DOMESTIC STOCK	Private Owned Land	<1	-	Yes
GW053572	20CA207877	1981	291651	6423266	10.5	8.0		1000	Alluvium	DOMESTIC IRRIGATION STOCK	Private Owned Land	<1	-	Yes
GW053700	20BL120419	1981	291465	6423253	8	6.0			Alluvium	DOMESTIC STOCK	Private Owned Land	<1	-	Yes
GW053701	20WA207640	1981	291492	6423192	8.4			3000	Alluvium	DOMESTIC STOCK	Private Owned Land	<1	-	Yes
GW057807	20CA207901	1981	294895	6424463	10	7.0	15.2		Alluvium	DOMESTIC IRRIGATION STOCK	Mine Owned Land	<1	-	Yes
GW059131	20BL119201	1981	294964	6424927	11.6			3000	Alluvium	DOMESTIC IRRIGATION STOCK	Mine Owned Land	2.2	-	Yes
GW060282	20BL119795		292578	6422598	14.9				Alluvium	DOMESTIC IRRIGATION STOCK	Private Owned Land	<1	-	No
GW061636	20BL133914	1986	291981	6426129	42.7				Permian	DOMESTIC STOCK	Mine Owned Land	6.4	-	No
GW073576	20BL166372	1995	291596	6424675	20				Permian	DOMESTIC STOCK	Private Owned Land	3.5	-	Yes

Registration No.	License No.	Drilled	mE	mN	Depth (m)	SWL (m)	Yield (L/s)	Salinity (ppm)	Aquifer	Use/Comments	Owner	Cumulative Drawdown at year 2022	Drawdown greater than 2m due to Modification	Discussed in the 2009 study
GW078026	NA	2000	294351	6419981	0				Permian	UNKOWN	HVEC Owned Land	5.6	-	No
GW078707	20BL167441		289548	6413537	43		13		Permian	STOCK	Private Owned Land	3.4	-	Yes
GW078708	20BL167442		290888	6413226	43				Permian	STOCK	Private Owned Land	2.8	-	Yes
GW078709	20BL167443		290749	6412391	50				Permian	STOCK	Private Owned Land	1.3	-	Yes
GW079731	20WA207724		289989	6422513	10		1		Alluvium	DOMESTIC STOCK	HVEC Owned Land	<1	-	No
GW200003	20BL166521		291033	6425814	21				Permian	DOMESTIC STOCK	Private Owned Land	5.9	-	No
GW200837	20BL172265	2009	291518	6421752	15	9	0.5		Alluvium	DOMESTIC	Private Owned Land	<1	-	No
GW201144	20BL170860	2009	288730	6419900	70	32	0.6		Permian	DOMESTIC STOCK	Private Owned Land	1.1	-	No
GW201183	20BL172665	2011	295165	6423349	282	12		5938	Permian	MONITORING BORE	HVEC Owned Land	10.3	4.7	No
GW201520	20BL172816	2011	293375	6425866	48	35	0.08		Permian	MONITORING BORE	Mine Owned Land	5.2	-	No
GW270001	20WA212203	1955	291815	6422117	13.8				Alluvium	UNKOWN	Private Owned Land	<1	-	No

Note: Shaded bores represents bore potentially effect due the mine Modification only.

m = metre.
L/s = litres per second.
ppm = parts per million.
mE = metres easting.
mN = metres northing.

Appendix 2

VALIDATION RESULTS

MODEL VALIDATION RESULTS						
SITE ID	Location		End Depth (m)	Water Level (mRL)		Difference Observed-Simulated (m)
	(mE)	(mN)		Observed	Simulated	
ID1024	296997	6420498	28.34	174.39	167.48	6.91
ID1017	299021	6419032	32.31	178.01	194.26	-16.25
ID1023	298026	6419516	-1.8	182.32	182.87	-0.55
ID1025	297495	6420504	49.05	178.08	169.11	8.97
ID1028	298003	6420008	32.32	178.75	177.98	0.77
ID1011	296502	6419986	-62.13	177.53	171.02	6.51
ID1014A	296993	6419486	-33.54	185.9	179.15	6.75
ID1032	297005	6419997	2.91	182.91	172.61	10.30
ID1026	297715	6422748	151.57	167.86	151.20	16.66
ID1027	297898	6422863	159.36	166.75	152.69	14.06
ID1029	297919	6424515	126.84	139.25	136.24	3.01
ID1030	295938	6423477	-47.39	137.53	134.06	3.47
ID1035	295472	6421967	-136.35	139.65	143.32	-3.67
ID1031	296975	6421495	30.64	166.63	152.51	14.12
ID1037	299010	6419539	73.72	174.6	189.16	-14.56
ID1033	295957	6422477	-38.02	139.73	140.29	-0.56
ID1038	300040	6418053	148.06	219.31	210.98	8.33
ID1039	298994	6420533	160.13	167.27	178.61	-11.34
ID1041	299512	6419542	126.41	167.05	192.35	-25.30
ID1043	297871	6421069	105.65	167.54	163.09	4.45
ID1046	300065	6417546	135.64	221.17	208.87	12.30
ID1048	297696	6422008	116.25	151.56	148.09	3.47
ID1051A	298774	6420726	145.92	177.7	174.00	3.70
ID1040	296494	6420486	-28.13	174.87	165.63	9.24
ID1044	297994	6420514	70.29	175.08	171.36	3.72
ID1054	295948	6422977	-53.9	139	137.18	1.82
ID1056	296948	6422997	96.32	145.46	143.41	2.05
ID1058	296985	6420996	55.99	164.9	159.71	5.19
ID1042	299610	6418518	66.75	223.91	210.78	13.13
ID1052	297513	6419505	-10.67	184.51	182.12	2.39
ID1053	299552	6417539	11.48	224.5	208.66	15.84
ID1055	299065	6417471	-54.89	230.84	208.56	22.28
ID1040A	296494	6420486	127.86	175.02	165.63	9.39
ID1057	296457	6422485	27.2	143.11	141.75	1.36
ID1064	295457	6422468	-112.03	141.75	138.76	2.99
ID1056A	296945	6422997	134.84	143.31	143.28	0.03
ID1057A	296459	6422484	124.85	140.58	141.51	-0.93
ID1060	299030	6418534	-3.63	213.83	208.16	5.67
ID1065	298511	6419522	24.63	180.3	185.49	-5.19
ID1066	296939	6423496	75.68	153.52	140.63	12.89
ID1067	296439	6423484	9.78	178.63	137.68	40.95
ID1068	296007	6420473	-159.49	170.9	163.67	7.23
ID1069A	295976	6421475	30.78	156.56	151.09	5.47

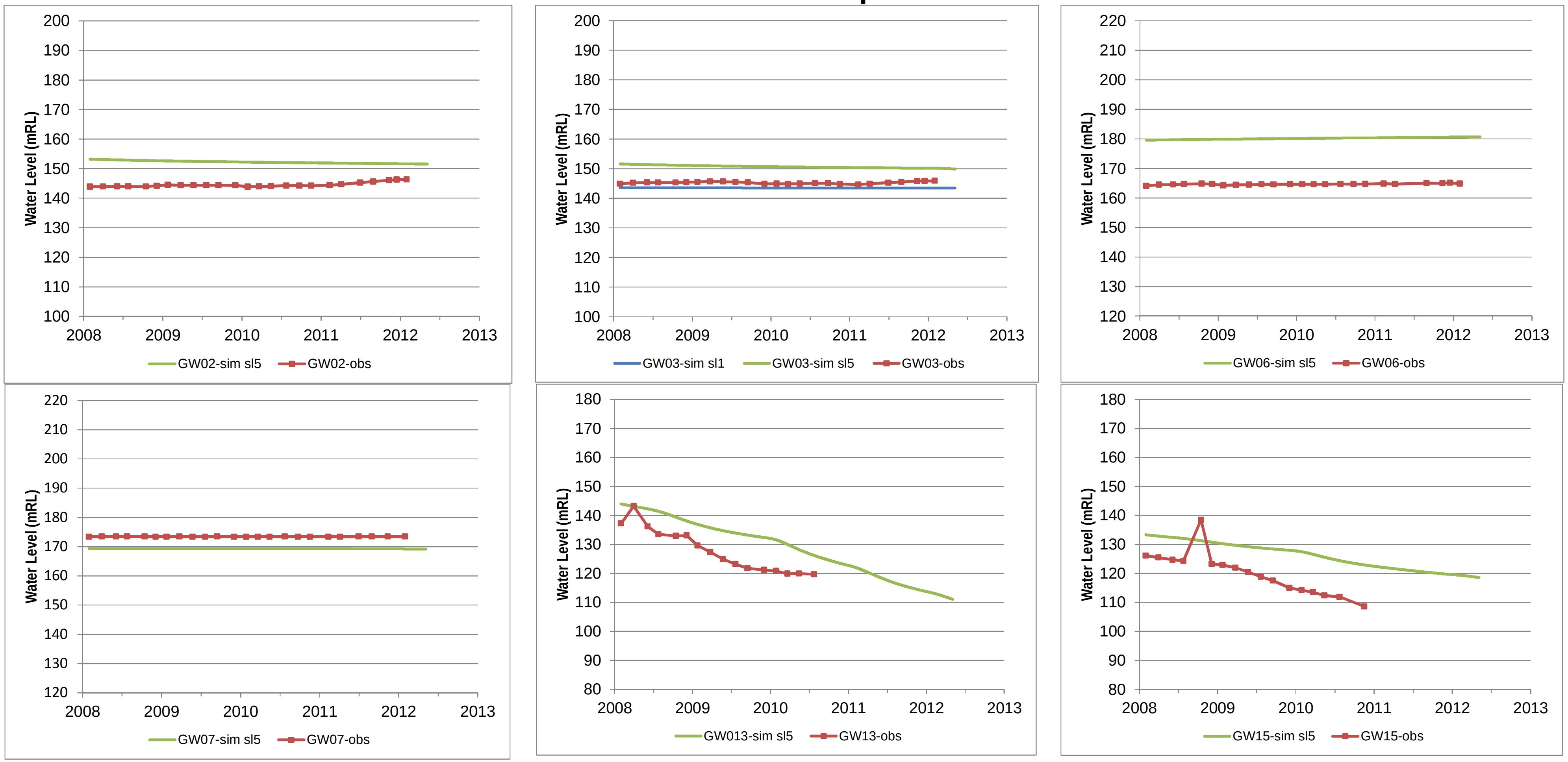
MODEL VALIDATION RESULTS						
SITE ID	Location		End Depth (m)	Water Level (mRL)		Difference Observed-Simulated (m)
	(mE)	(mN)		Observed	Simulated	
ID1068A	296011	6420472	-48.71	167.27	163.70	3.57
ID1070	297957	6423011	163.24	169.29	153.86	15.43
ID1071	299967	6419054	182.73	200.83	209.71	-8.88
IR2001	296480	6421236	-19.26	160.44	156.19	4.25
IR2002	296476	6421456	-32.65	161.55	153.52	8.03
IR2003	296477	6421427	-26.57	160.53	153.94	6.59
ID1072	297428	6423996	86.02	139	139.09	-0.09
IR2005	296226	6421482	-54.59	156.46	152.12	4.34
IR2006	297226	6421500	64.07	158.67	153.20	5.47
IR2008	297471	6421755	52.45	158.5	150.66	7.84
IR2007	297726	6421510	94.47	166.42	155.15	11.27
IR2009	296235	6420981	-67.97	157.53	157.43	0.10
ID1073	297739	6420759	76.59	171.72	166.16	5.56
ID1074	297729	6421260	113.4	166.61	159.46	7.15
ID1075	298242	6420768	105.98	166.96	169.15	-2.19
IR2004	295972	6421727	-42.83	152.72	148.65	4.07
ID1069	295976	6421477	-87.23	156.48	151.06	5.42
ID1102	296242	6420731	-47.24	171.76	160.72	11.04
IR2019	295991	6420727	-132.24	166.86	160.04	6.82
ID1101	296221	6421732	2.13	142.91	149.08	-6.17
IR2010	296469	6421737	44.18	141.56	149.60	-8.04
IR2012	296727	6421489	-10.2	161.45	153.38	8.07
IR2013	296981	6421244	34.96	163.53	157.62	5.91
ID1096	297747	6420260	41.24	178.32	173.93	4.39
IR2018	296493	6420736	2.16	170.81	161.87	8.94
ID1103	296741	6420741	32.95	173.68	162.50	11.18
IR2011	296974	6421747	78.93	158.82	150.11	8.71
IR2014	297481	6421254	91.43	165.91	158.71	7.20
IR2015	297736	6421007	88.79	167.44	163.00	4.44
IR2016	297233	6421002	59.08	168.03	160.59	7.44
IR2017	296717	6422007	68.05	142.9	146.66	-3.76
IR2021	297990	6420764	89.3	168.7	167.70	1.00
IR2023	297980	6421264	126.21	162.51	161.44	1.07
IR2024	297489	6420756	62.85	168.95	165.20	3.75
IR2025	296748	6420987	-19.67	161.48	159.22	2.26
ID1107	296712	6422242	73.99	144.22	144.60	-0.38
ID1111	296203	6422732	-17.68	139.75	139.70	0.05

mE = metres easting.
mN = metres northing.
mRL = metres relative level.
m = metre.

Appendix 3

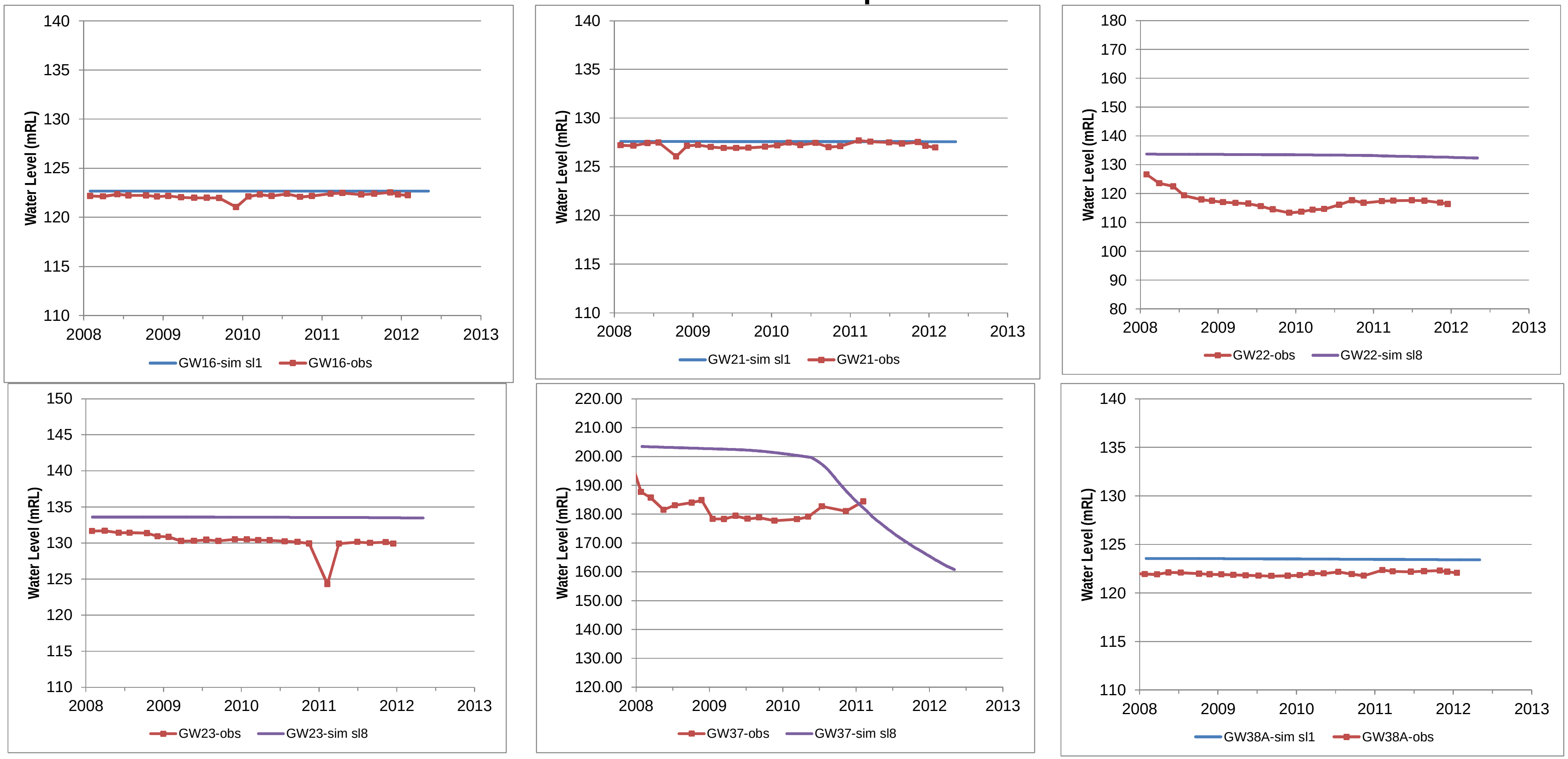
Model Verification Hydrographs

Bores in Mt Arthur Open Pit Area



Notes: sim –simulated piezometric head, obs –observed piezometric head, sl –model slice number

Bores in Mt Arthur Open Pit Area



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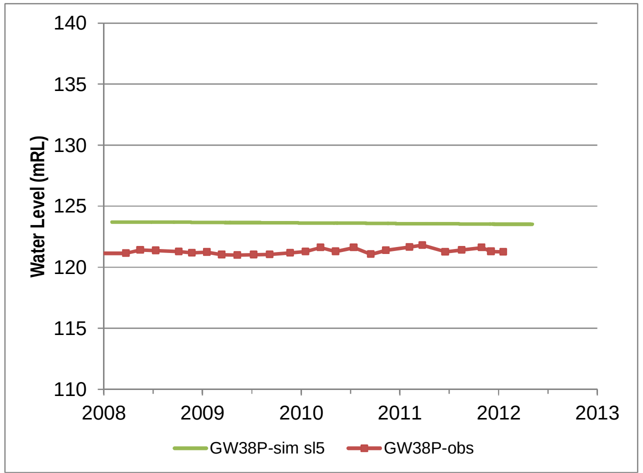
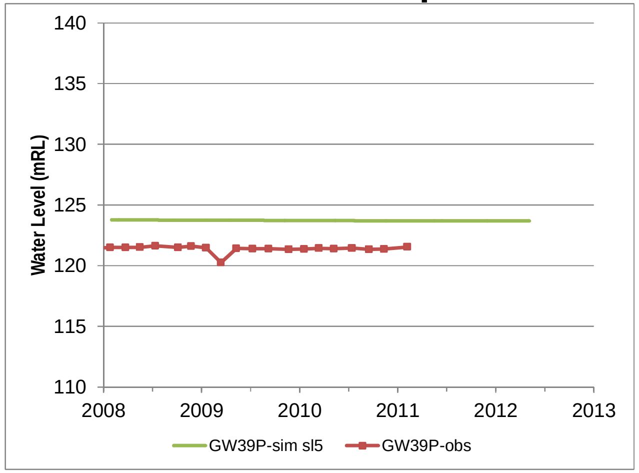
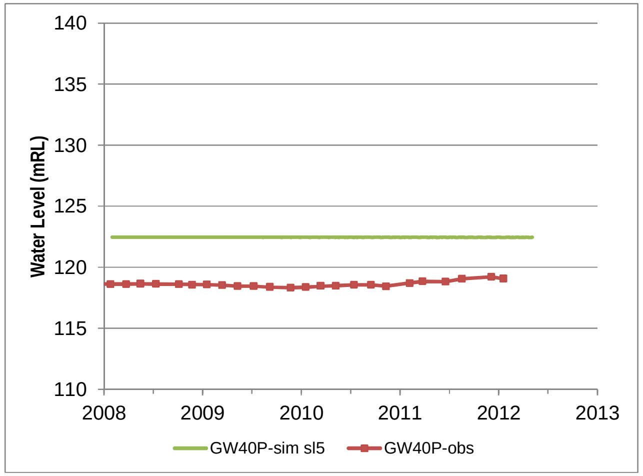
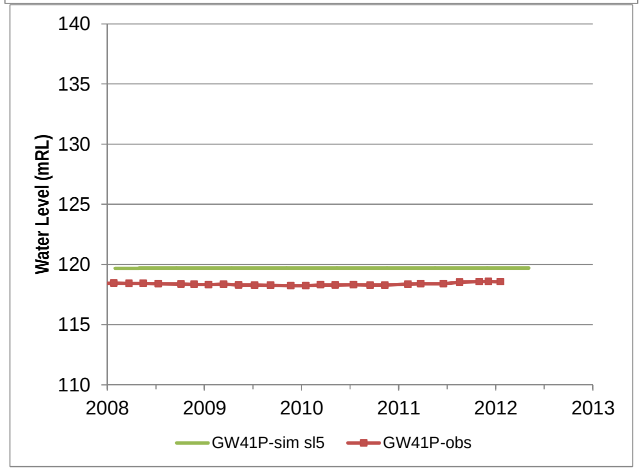
Bores in Mt Arthur Open Pit Area



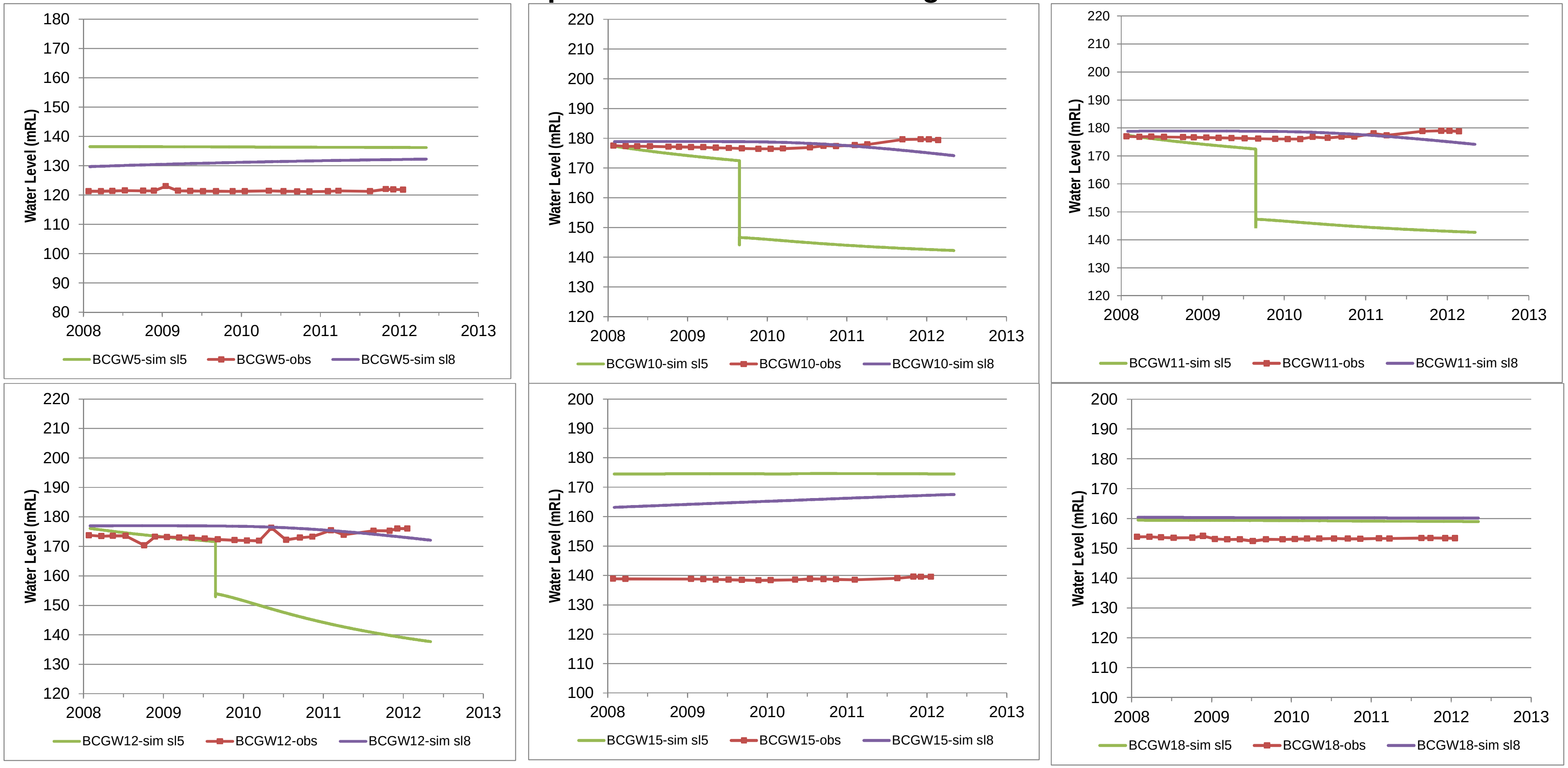






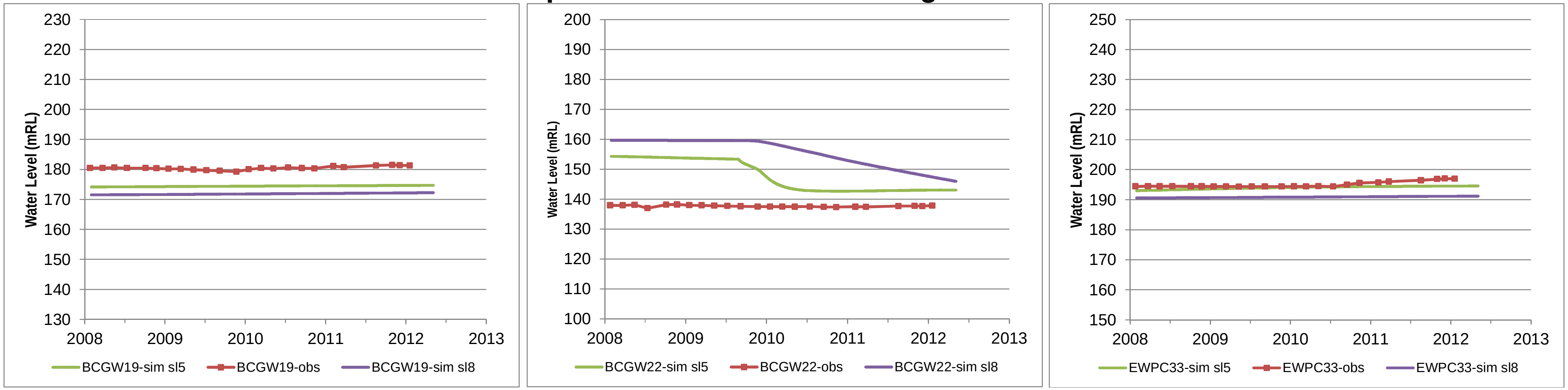
Notes: sim –simulated piezometric head, obs –observed piezometric head, sl –model slice number

Deep Bores in Mt Arthur Underground Area



Notes: sim –simulated piezometric head, obs –observed piezometric head, sl –model slice number

Deep Bores in Mt Arthur Underground Area



Notes: sim –simulated piezometric head, obs –observed piezometric head, sl –model slice number