

WATERMARK

COAL PROJECT

ENVIRONMENTAL IMPACT STATEMENT

February 2013

T Groundwater Impact Assessment



Australasian
Groundwater & Environmental
Consultants Pty Ltd

REPORT on

***WATERMARK COAL PROJECT
GROUNDWATER ASSESSMENT***

***prepared for
HANSEN BAILEY PTY LTD***

***Project No. G1501
January 2013***



ABN:64 080 238 642



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EXECUTIVE SUMMARY

BASELINE WATER STUDIES

This report describes the hydrogeological regime within EL 7223 and the surrounding region, and assesses the impact of the Project on this regime. There were no detailed hydrogeological investigations of the aquifer systems in the Project area prior to the granting of EL 7223. The hydrogeological study commenced in tandem with the exploration program for EL 7223 in 2009 and has included four phases of drilling and field investigations. An extensive monitoring network has been installed over this three-year period which includes 87 monitoring bores, 9 large diameter bores for test pumping and 32 vibrating wire piezometers. Monitoring of groundwater levels and quality in the network commenced in 2009 and over three years of baseline data has been collected from the early bores. This network is significantly more extensive than for any other mining project in the region and comparable with more developed mines with longer history in the Hunter Valley.

Groundwater occurs within two main geological units that contain a number of local and regional aquifers. These are the:

- unconsolidated Quaternary / Tertiary age alluvial sediments of the Gunnedah and Narrabri Formations that host a regionally extensive aquifer system; and
- consolidated older and deeper bedrock that contains localised aquifers within weathered rock, porous sandstones, fractured zones, volcanics and coal seams.

Field testing indicated that the permeability of the coal in the Project Boundary is relatively low, and significantly lower than has been measured at other proposed mining areas within the Gunnedah Basin. The coal seams would be unable to supply usable volumes of groundwater to a well, and are therefore not considered aquifers. The main aquifer unit identified within the Project Boundary is the Clare Sandstone, a relatively coarse and porous unit, particularly where subjected to weathering. The finer grained interburden units are not considered aquifers with hydraulic conductivity similar to aquitards.

A significant aquifer adjacent to the Project Boundary is the Gunnedah Formation aquifer that has been heavily developed for agriculture and domestic water supplies and is in a stressed condition due to over allocation. As a result, groundwater allocations have been reduced significantly, in some cases by over 50%. Although significant cutbacks have been made, the aquifer has been slow to recover and in some areas has been partly dewatered, a condition that is not sustainable.

A significant component of the study was focused on understanding the hydraulic connection between the bedrock areas where mining is proposed, and the unconsolidated sediments that form the productive aquifers utilised by the agricultural sector.

Water quality data suggests there is a limited hydraulic connection between these systems. Groundwater quality is different, predominantly fresh for the Gunnedah Formation and saline for the Permian sequences. Groundwater quality in the Narrabri Formation is variable from fresh to saline. The age of the groundwater within the systems is also different, relatively young for the Gunnedah Formation (less than 5,000 years) and typically much older for the Permian (10,000 – 30,000 years).

Local recharge to the consolidated bedrock rock system is predominantly from elevated regions of the study area, including elevated areas within the ridge country of the Project. Regional recharge to the alluvial aquifer systems is predominantly from basalts of the Liverpool Ranges, some 50km south of the mining area, and from leakage from river systems within the catchment, particularly the Mooki River and Quirindi Creek.

No groundwater dependent ecosystems were identified within the Project Boundary.



PROPOSED MINING DEVELOPMENT

A conceptual model of the hydrogeological regime was gradually built-up over the exploration phase using data from the field investigations and information gathered by other investigators in the Liverpool Plains. This conceptual understanding of the structure and behaviour of the aquifer systems in the area was used as the basis for a numerical groundwater model. The purpose of the model was to simulate the historical groundwater trends and to predict the effect of mining on the surrounding groundwater regimes.

Prior to development of the model, it was recognised that leaving open voids in the open cut mining areas after mining was completed would have the potential to result in a long term flow of groundwater into the voids. There was also concern of a continuing leakage from adjacent Gunnedah Formation aquifers into the voids post mining. These were considered adverse environmental outcomes and the mine was planned to ensure the eastern and southern mining voids were backfilled to ground level and above, ensuring no long term drainage of groundwater into the mining area voids. An open void is proposed to remain at the western mining area, but this is distant from the surrounding alluvial aquifers.

The open cut mining areas were also planned to include a 150 m buffer between the proposed Southern and Eastern Mining Areas and the adjacent alluvial black soil plains. The presence of alluvial black soils does not necessarily indicate the occurrence of an underlying aquifer. To the south of the proposed mining areas, the black soils are underlain by the clay dominated Narrabri Formation, and the Gunnedah Formation aquifer is not present. The closest occurrence of this Gunnedah Formation aquifer is 0.9 km from the north-eastern corner of the Eastern Mining Area. To the south, the centre of the main palaeo-channel within the Gunnedah Formation, where the aquifer is thickest and most productive is between 3.8 km and 5.7 km from the proposed mining areas.

IMPACT OF MINING

The assessment utilised a regional numerical flow model to simulate the behaviour of the groundwater systems. The model was calibrated to historical water level fluctuations in government monitoring bores between 1980 and 2011. The model then simulated the impact of the Project on the groundwater regime over a 30-year period. This model predicted changes to the groundwater levels and pressures as the Project develops in the “ridge country” adjacent to the Liverpool plains. The model was constructed in accordance with the approach recommended in the Australian Groundwater Modelling Guidelines 2012, as required by the Aquifer Interference Policy. A Third Party Reviewer also assessed the model against the criteria in the Australian Groundwater Modelling Guidelines 2012 and the Murray Darling Basin Commission Groundwater Flow Modelling Guideline 2000.

The model predicted the groundwater seepage from the Permian Formations into the proposed open cut mining areas will average 0.5 ML/day (183 ML/yr) over the life of the Project, with a maximum annual seepage of 2.1 ML/day (756 ML/yr) in Year 23. The currently gazetted extraction limits for the Gunnedah–Oxley Basin Murray Darling Basin Groundwater Source (the groundwater source for the Permian Formations) is 199,893 ML/year. The groundwater seepage into the open cut mining areas therefore represents less than 0.1% of the extraction limit for this groundwater source.

The Project will reduce the water pressure (depressurise) in the bedrock around the proposed open cut mining areas. The depressurisation is greatest adjacent to the proposed open cut mining areas, and gradually reduces with distance. The model predicts the depressurisation of the aquifers extends a maximum distance of 3.7 km from the Southern Mining Area in Year 25 of the Project at which point there is a one-metre reduction in aquifer pressure from pre mining



conditions. A number of private bores are present within predicted the zone of depressurisation. The model predicts the depressurisation will reduce water levels by less than 2 m, which is below the minimal harm criteria in the Aquifer Interference Policy. The limited depressurisation is not considered likely to reduce the yield of bores within the zone, and is below the minimal harm criteria in the Aquifer Interference Policy.

The model predicts the reduced pressure in the bedrock will reduce the rate of flow of groundwater from the bedrock, into the overlying alluvium. This effectively reduces the rate of recharge to the alluvium. The model predicts the rate of groundwater flow from the bedrock into the overlying Alluvial Formations will reduce by an average of 0.09 ML/day over the life of the Project with a peak of 0.3 ML/day (~ 4 L/s). In accordance with the Aquifer Interference Policy, the modelling has determined the take of water from each of the alluvial water management zones. Shenhua Watermark is in the process of acquiring the licences to offset this take of water. In terms of volume, it is considered an inconsequential take from the alluvial aquifer, as it represents less than 0.5% of the extraction from the registered bores within 10km of the Project Boundary.

The depressurisation and associated take of water from the alluvial aquifer is considered to be insignificant and represents a negligible change in groundwater availability to adjacent groundwater users.

Negligible change to groundwater quality within the bedrock and alluvial groundwater systems is anticipated during mining as the sequence has a very limited potential to generate acid. Due to the low volumes and poor quality of the fractured rock aquifer beneath and surrounding the Project Boundary, no change to beneficial groundwater use is predicted.

POST MINING

The proposed mine plan has the Eastern and Southern Mining Areas backfilled and a void remaining in the Western Mining Area. Post mining, the backfilled mining areas will fill with rainfall seepage and groundwater. When mining is complete in the Southern Mining Area and Eastern Mining Area, the bedrock starts to repressurise and the predicted flow rate from the Permian to the overlying alluvium increases and returns to pre-mining rates over time. Groundwater within the rehabilitated Eastern and Southern Mining Areas will also return to pre-mining levels or above within 20 years. This will also mean there is no long-term zone of depressurisation generated around the Eastern and Southern Mining Areas. Groundwater levels in the open Western Mining Area are predicted to slowly recover, but remain a localised sink for groundwater flow. A localised zone of depressurisation will develop around the Western Mining Area post mining.

Due to the higher permeability of backfilled material placed in the mining areas compared to pre-mining conditions, rainfall recharge water through the overburden may locally freshen the predominantly saline fractured rock aquifers.

GROUNDWATER MONITORING AND MANAGEMENT

Predictions from the modelling work indicate negligible effect on alluvial aquifer systems outside of the Project Boundary. Ongoing monitoring of the two-aquifer systems is critical to confirm the predictions of the numerical modelling. In particular, regular monitoring of selected key private and government bores within 10km of the Project Boundary would provide the groundwater behaviour information essential for early warning of deviation from the predicted trends and regular validation of modelling predictions. In addition to this monitoring, it is recommended groundwater management for the Project includes:



- annual reports on groundwater level and quality trends within and adjacent to the Project Boundary which assess performance of the groundwater system against predictions. This should include investigations to quantify movement of groundwater between the bedrock and alluvial aquifer systems, where they co-exist,
- Three yearly review and recalibration of the groundwater model,
- Development of groundwater management plans that include appropriate backup mitigation measures, in the event they are required for the Project to ensure the groundwater quality and volumetric resource remain within acceptable levels.



Watermark Coal Project
Project No. G1501.V1.10
23 October 2012

REPORT ON

WATERMARK COAL PROJECT

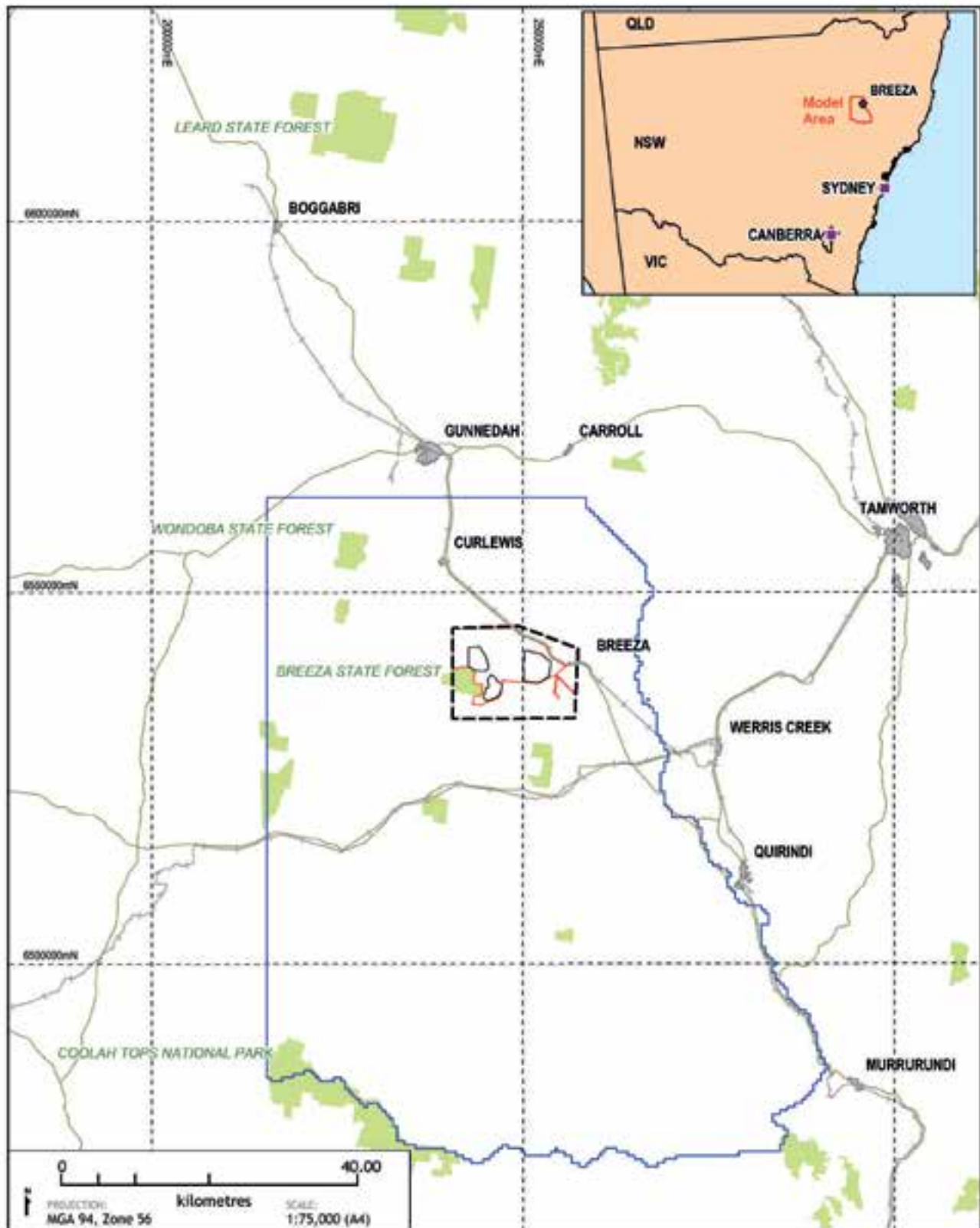
GROUNDWATER IMPACT ASSESSMENT

1.0 INTRODUCTION

The Watermark Coal Project (the Project) is located approximately 25 km south south-east of the township of Gunnedah and to the immediate west of the village of Breeza, within the Gunnedah Local Government Area (LGA). The Project is approximately 282 km by rail from the export Port of Newcastle. Figure 1.1 illustrates the regional locality of the Project in relation to the nearest centres of Breeza and Gunnedah.

Shenhua Watermark Coal Pty Limited (Shenhua Watermark) is a subsidiary of the Shenhua Group. In October 2008, Shenhua Watermark was granted Exploration Licence (EL) 7223. Shenhua Watermark is seeking State Significant Development Consent under Division 4.1 of the *Environmental Planning & Assessment Act 1979* (EP&A Act) to facilitate the development of surface infrastructure and open cut mining activities for the Project generally within its exploration lease for a period of 30 years. The Project Application Boundary (Project Boundary) is shown on Figure 1.2.

Shenhua Watermark commissioned Hansen Bailey Pty Ltd (Hansen Bailey) to prepare an Environmental Impact Statement (EIS) in support of the Division 4.1 Project Application. Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) have completed this groundwater assessment at the request of Hansen Bailey, on behalf of their client Shenhua Watermark, and forms part of the EIS.



LEGEND:

- | | |
|----------------------|---------------|
| Project Boundary | Railway |
| EL 7223 | Line |
| Proposed Mining Area | Road |
| Model Boundary | State Reserve |

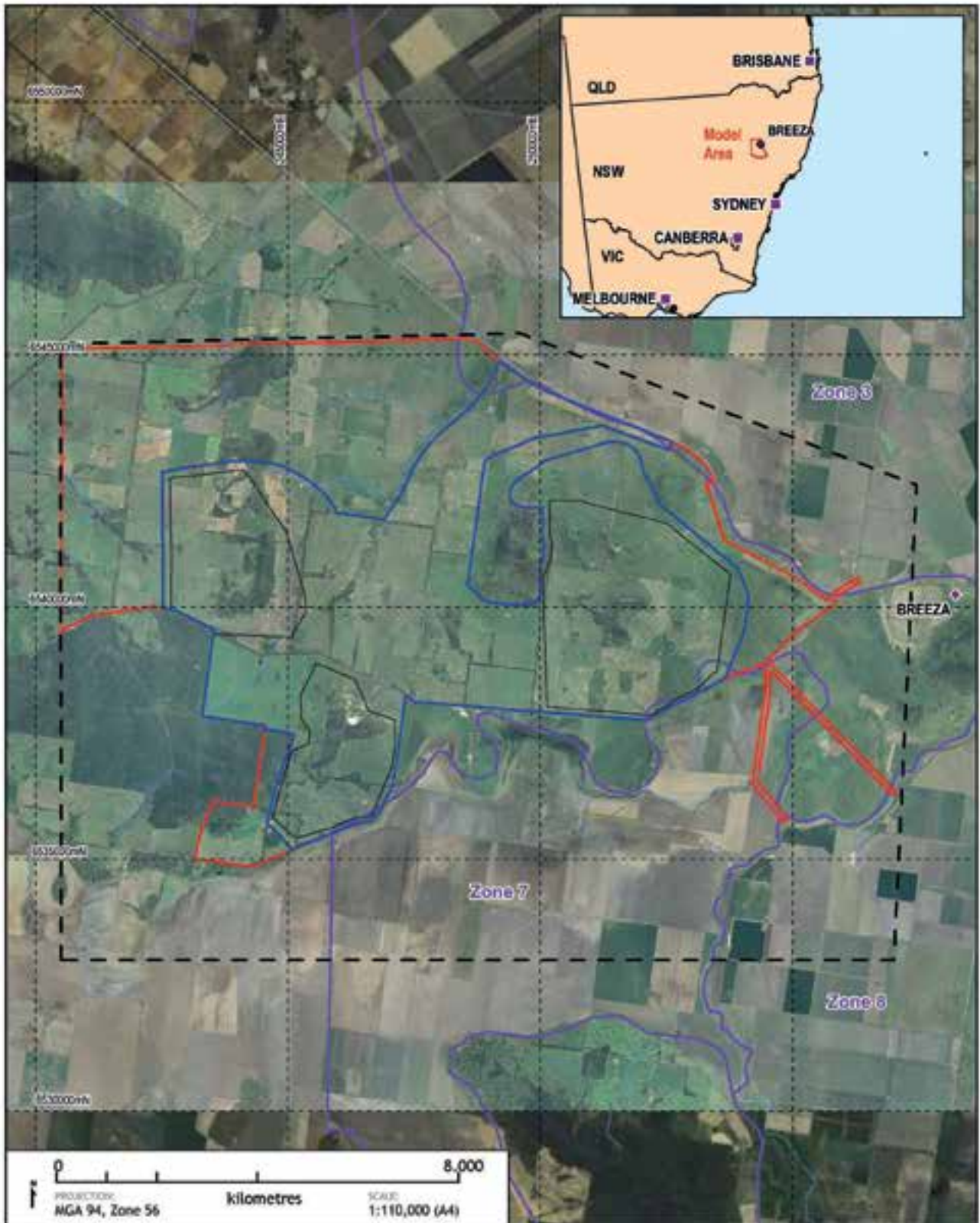
Watermark Coal Project (G1501)
Groundwater Assessment

Project Region



DATE:
10/10/2012

FIGURE No:
1.1



LEGEND:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Disturbance Boundary

Watermark Coal Project (G1501)
Groundwater Assessment

Project Location



DATE:
10/10/2012

FIGURE NO:
1.2



2.0 PROJECT DESCRIPTION

2.1 Overview

The Project generally comprises:

- the construction and operation of an open cut mining operation extracting up to 10 Million tonnes per annum (Mtpa) of Run of Mine (ROM) coal for a 30-year period;
- an open cut mining fleet of excavators and shovels, supported by haul trucks, dozers, graders, drill rigs and water carts;
- progressive rehabilitation of all disturbed areas;
- the construction and operation of a Coal Handling and Preparation Plant (CHPP) with a throughput of 10 Mtpa ROM coal;
- the co-disposal of tailings and coarse reject within the Overburden Emplacement Areas (OEA);
- the construction and operation of a rail spur, rail loop, Kamilaroi Highway rail overpass, associated load out facility and connection to the Werris Creek - Moree Railway Line;
- the construction and operation of a Mine Access Road;
- the construction and operation of administration, workshop and related facilities;
- the construction and operation of ground and surface water management and reticulation infrastructure including pipelines, pumping stations and associated infrastructure for access to water from groundwater aquifers, the Mooki River and private dams to the north-east of the Project Boundary;
- the installation of communications and electricity reticulation infrastructure; and
- a workforce of up to approximately 600 full-time equivalent employees during construction and up to 600 full-time equivalent employees during the operation of the Project.

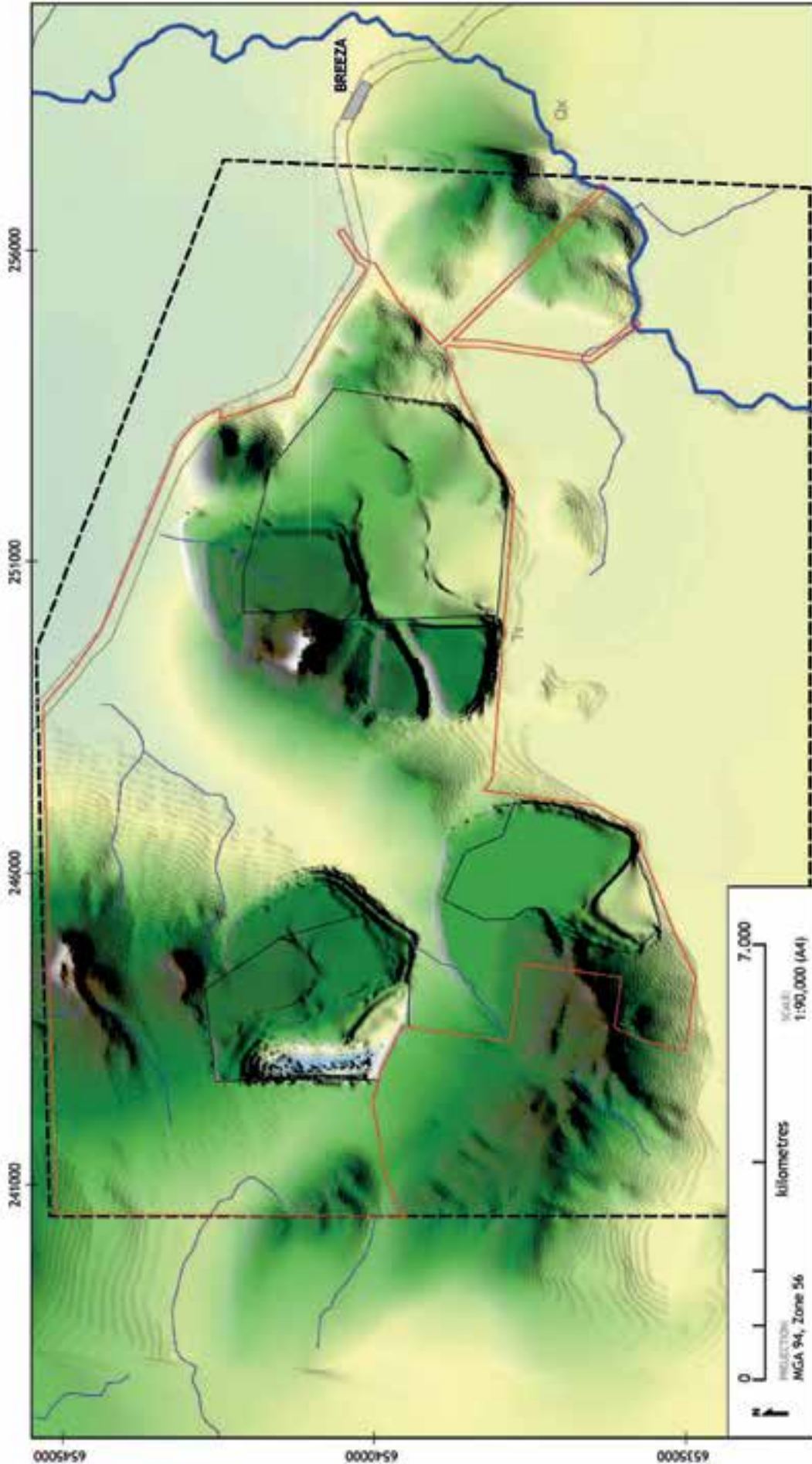
2.2 Mining Method

The Eastern and Southern Mining Areas are designed to be completely backfilled to ensure that no open voids remained adjacent to the Liverpool Plains after mining. Open voids that remain post mining have the potential to induce a continuous drainage of groundwater from surrounding aquifers. Backfilling of the Eastern and Southern Mining Areas is planned for early in the Project to ensure the aquifers of the Liverpool Plains were protected during and after mining. The modelling undertaken for the Project demonstrates this as is presented in Section 10.0.

A buffer zone has also been included between the Eastern and Southern Mining Areas and the Liverpool Plains in the mine design. The buffer zone is a minimum of 150 m from the edge of the Mining Areas to the edge of the Alluvial Black Soils on the Liverpool Plains. It is important to note that within the Project Boundary, the edge of the Alluvial Black Soils on the Liverpool Plains does not align with the edge of the Gunnedah Formation, the main aquifer. The Gunnedah Formation is generally located at a distance of greater than 0.9 km from the Eastern and Southern Mining Areas. This is discussed in more detail in Section 7.1.3. An open void will remain in the Western Mining Area, as this area is remote from the alluvial aquifers and backfilling has not significant environmental benefit, and significant operational costs. Figure 2.1 shows the final landform post mining.



DATE: 10/10/2012
FIGURE No: 2.1





Mining operations commence with an initial box cut in the north-west of the Eastern Mining Area. Electric rope shovels, hydraulic excavators and haul trucks are proposed to remove the overburden. Front-end loaders and rear dump trucks will then uncover and selectively mine the coal seams. Mining will continue to progress down-dip towards the eastern extent of the Project Boundary until Year 12. The mining will then shift to the southern side of the Eastern Mining Area and commence mining in reverse direction, up-dip back towards the initial box cut. Overburden will then be progressively placed and rehabilitated behind the active mining area up to 380 mAHD. By Year 17, active mining will be completed and the Eastern Mining Area and backfilling of the remaining void will commence.

In Year 17, mining operations will commence in the northern end of Southern Mining Area, progressing to the south-west. Overburden from the Southern Mining Area will initially be utilised to backfill the Eastern Mining Area void. By Year 21, the Eastern Mining Area will be completely backfilled and rehabilitated up to 340 mAHD. Overburden from the Southern Mining Area will then be placed behind active mining. By Year 24, active mining will be completed in the Southern Mining Area.

In Year 24, mining operations will commence in the eastern edge of the Western Mining Area, progressing to the west. All overburden from this Area will be initially utilised to backfill the Southern Mining Area void. By Year 26, the Southern Mining Area will be completely backfilled and rehabilitated up to 380 mAHD. Overburden from the Western Mining Area will then be placed behind active mining and by Year 30 active mining in this Area will be completed, leaving a final void distant from the Liverpool Plains.

2.3 Groundwater Management and Project Water Supply

All the of the proposed open cut mining areas will remain in the ridge country outside the Liverpool Plains agricultural areas. The mining will not directly intersect either the Narrabri or Gunnedah Formation aquifers. The mining will remain in areas of relatively low permeability competent rock and the rate of seepage of groundwater from these Permian rocks into the proposed excavations will be relatively low (on average 0.5 ML/d). In mining areas, pumps will remove groundwater seepage from drainage sumps. Modelling predicts there will be no need for any advance drainage of groundwater via bores ahead of mining.

Groundwater seepage to the Mining Areas is not expected to provide a reliable source of water for the Project. Supplementary water supply will be required for mining purposes, and will be sourced from licensed extractions from groundwater and surface water. Section 4.2.2 outlines the water licences available to support the Project.

3.0 SCOPE OF WORK

The following sections outline the requirements of both the New South Wales and Federal Governments for the water studies presented in this assessment.

3.1 New South Wales Government Requirements

The Director-General's Environmental Assessment Requirements (DGRs) for the water assessments for the Project provided by NSW Department of Planning and Infrastructure (DP&I) under Section 78A(8A) of the Environmental Planning and Assessment Act 1979 are as follows:

**Table 3.1: DIRECTOR-GENERAL'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS (DGRS)**

DGRs	Addressed in Section
• detailed assessment of potential impacts on the quality and quantity of existing surface and groundwater resources, including: ○ detailed modelling of potential groundwater impacts; ○ impacts on affected licensed water users and basic landholder rights; ○ impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including environmental flows; and ○ a consideration of the proposal against the draft Aquifer Interference Policy;	 8.0 - 9.3 10.7 10.9, 10.10 10.6, 10.7, 10.9, 10.12
• a detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures;	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
• an assessment of proposed water discharge quantities and quality/ies against receiving water quality and flow objectives;	11.0 and Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
• assessment of impacts of salinity from mining operations on groundwater and surface water resources, including disposal and management of coal rejects and modified hydrogeology, a salinity budget and the evaluation of salt migration to surface, near surface and groundwater sources;	10.0 and Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
• identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000;	4.2 and 10.8
• 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)	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
• a description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo;	10.8, 13.0
• a detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts; and	13.0
• a detailed flood impact assessment, which identifies impacts on local and regional flood regimes, including:	Surface Water Impact


Table 3.1: DIRECTOR-GENERAL'S ENVIRONMENTAL ASSESSMENT REQUIREMENTS (DGRS)

DGRs	Addressed in Section
	Assessment (WRM, 2012) (Appendix R of the EIS)
an assessment of the potential for flooding to occur in the open cut mining areas; and	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
any measures proposed to mitigate potential flood impacts.	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)

The New South Wales Office of Water (NOW) requires that the EIS demonstrate the following:

Table 3.2: NEW SOUTH WALES OFFICE OF WATER (NOW) REQUIREMENTS

Requirement	Addressed in Section
1. Adequate and secure water supply is available for the life of the project. This includes confirmation that water supplies for construction and operation of the mine and associated activities are sourced from an appropriately authorised and reliable supply in accordance with the operating rules of relevant water sharing plans, including the:	
<i>Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources 2003;</i>	4.2.6
<i>Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003;</i>	4.2.2
<i>Water Sharing Plan for the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources;</i>	4.2.7
<i>Draft Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011 (to commence early 2012); and</i>	4.2.3
<i>Draft Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources (to commence in 2012).</i>	4.2.5
2. Compliance with the rules in relevant WSPs, in particular the distance restrictions for water supply works and the process of assessment with respect to water source protection criteria.	Surface Water Impact Assessment (WRM, 2012) (Appendix R

**Table 3.2: NEW SOUTH WALES OFFICE OF WATER (NOW) REQUIREMENTS**

Requirement	Addressed in Section of the EIS)
3. Baseline monitoring/data over a minimum two year period of all surface and groundwater sources and dependent ecosystems within and adjacent to the mining operation area for calibration of models.	6.0 & 7.0
4. Predictive assessments of the impact of the project on surface and groundwater sources, basic landholder rights to water, adjacent licensed water users and groundwater dependent ecosystems.	8.0, 11.0
5. Definition of the boundary limit to the Upper Namoi alluvium, and assessment and justification for the nominated boundary limit. Full geomorphic, hydrologic and salinity assessment of the surface and alluvial groundwater systems associated with the Upper Namoi alluvium.	7.1
6. Development of a salinity budget, evaluation of salt migration to any surface water sources and justification for any salt migration changes pre to post mining.	10.12 and Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
7. Identification of and design and implementation of a monitoring program for all surface and groundwater sources and dependent ecosystems, within and adjacent to the mining operation area to provide confidence in predictions made on surface and ground water impacts by the proposal. This generally requires a baseline of at least two years surface and ground water data to form an adequate baseline.	11.1
8. Mitigation strategies to address unavoidable impacts on surface and groundwater sources and dependent ecosystems, for the operational and post mining phases of the Project, and final landform hydrogeological regime.	14.8
9. Measures to maintain any identified groundwater-dependent ecosystems, including stygofauna assemblages within the groundwater drawdown area of the Namoi alluvium.	10.10
10. Detailed examination of options to remediate and rehabilitate any excavated and/or disturbed areas of watercourses draining to Native Dog and/or Watermark Creeks and any connected alluvium, and justification for criteria to completion of the Project rehabilitation program.	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)

NOW considered the following information, which was provided with the DGRs, as essential to include in the EIS to demonstrate the above:



Table 3.3: NOW ESSENTIAL REQUIREMENTS

Requirement	Addressed in Section
Identification of site water demands in terms of both volume and timing for the life of the Project. This is to include details of any water reticulation infrastructure and alternate mechanisms (e.g. vehicles) that supply water to the site.	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
A description and assessment of any requirements (including potential requirements) to intercept groundwater, including predicted dewatering volumes, zone of drawdown and associated impact, and water quality and disposal methods.	10.5, 10.6 and 10.12
Definition of the boundary limits to the Upper Namoi alluvium; and assessment and justification for the nominated alluvial boundary limits. Full geomorphic, hydrologic and salinity assessment of the surface and alluvial groundwater systems associated with the Upper Namoi alluvium should be provided.	7.1 and Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS) and Geomorphology Impact Assessment (GHD, 2012) (Appendix W of the EIS)
Justification to nominated setback distance from the Upper Namoi alluvium in terms of existing and predicted changes in contribution, flux and migration of groundwater, and maintenance of existing groundwater quality ranges and zonations.	10.5, 10.8,
Salinity budgets for pre and post mining scenarios should be assessed in the EIS, including an evaluation of salt migration to any surface water sources and justification for any salinity discharge changes (i.e. pre to post mining).	10.12 and Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
Analysis of the water sources affected by the project and identification of which water sources are the subject of a water-sharing plan.	4.2 and 10.8
Detailed assessment of the impact of the Project on surface and groundwater sources, basic landholder rights to water, adjacent licensed	11.0

**Table 3.3: NOW ESSENTIAL REQUIREMENTS**

Requirement	Addressed in Section
water users and groundwater dependent ecosystems; and analysis of the effect of any predicted impacts on water sharing arrangements prescribed in any relevant water sharing plan which is in force. This must address the hierarchy of water source value and dependence, including but not limited to impacts on the following: yield or flow classes; quality; connectivity between porous/fractured rock, alluvial and surface water sources; environmental dependence and dependence for basic landholder rights; and environmental water established and maintained by the plan rules.	
Analysis of options for the project in terms of achieving avoidance of impacts to surface and groundwater sources, basic landholder rights to water, adjacent licensed water users and groundwater dependent ecosystems. If the options analysis cannot demonstrate avoidance, then sufficient mitigation, remediation and rehabilitation options must be examined.	13.0
Detailed examination of options to remediate and rehabilitate any excavated and/or disturbed watercourses including Watermark Creek and any connected alluvium, and justification for criteria regarding completion of the project rehabilitation program.	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)

3.2 Federal Government Requirements

Department of the Sustainability, Environment, Water, Population and Communities (SEWPaC) – requirements for the water study under Section 75F(3) of the NSW Environmental Planning and Assessment Act 1979 are:

Table 3.4: FEDERAL GOVERNMENT REQUIREMENTS

Requirement	Addressed in Section
1. How the proponent will comply with all relevant Commonwealth, state and local government environment laws and policies pertaining (either directly or indirectly) to water quality management.	4.0, 13.0
2. A description and maps of all surface water and groundwater sources relevant to the Project, and a delineation of their associated National Water Quality Management Strategy environmental values.	5.3, 7.0
3. The results of surface water and groundwater hydrological assessments, including an assessment of hydrological interactions where water sources are connected.	7.0, 11.0
4. Hydrogeological reports.	All sections


Table 3.4: FEDERAL GOVERNMENT REQUIREMENTS

5. A geological map showing fault lines.	Figure 5.4 & Figure 8.22
6. A topographical map.	Figure 5.1
7. Hydrological modelling information.	8.0, 9.0, 11.0, 11.0, 11.1, 13.0
8. Baseline data and information on current water quality, including reference and test site data. Where this information does not exist, there should be an undertaking to carry out the necessary investigations in order to provide the required baseline data, including a description of how these investigations will be carried out (methodology and timeframe).	6.0, 7.0
9. Data and information on proposed discharge water quality, including timing of discharges, concentrations, and loads of toxicants and stressors.	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
10. Water quality issues, including planning, monitoring and management informed by the National Water Quality Management Strategy (http://www.environment.gov.au/water/policy-programs/nwqms/index.html):	4.0, 10.12, 11.1
a. Sewage treatment; and,	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
b. Water way crossings.	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
11. Modelling showing the cumulative environmental impacts of the action.	11.1
12. A comprehensive water quality risk management and monitoring plan for the Project, including management triggers to detect potential issues in a timely manner and to avoid, minimise or ameliorate adverse impacts. This should include:	14.3.2
a. identification and description of all potential water quality hazards;	10.10, 10.12
b. water quality risks should be considered and, where possible, quantified;	10.10, 10.12
c. cumulative effects, including environmental impacts, should be considered;	11.1
d. threshold trigger and/or guideline values that protect Matter of National Environmental Significance (MNES) should be	14.3.2

**Table 3.4: FEDERAL GOVERNMENT REQUIREMENTS**

considered;	
e. biological as well as chemical monitoring and assessment;	Ecological Impact Assessment (Cumberland Ecology, 2012)(Appendix K of the EIS)
f. statistical analysis such as data averages, standard deviation and number of samples;	6.0, 8.0, refer GHD report (GHD, 2012)
g. test and reference site locations;	6.0
h. sampling and analytical methods; and,	6.0
i. quality control and quality assurance data.	GHD report (GHD, 2012)
13. Some of the main water quality issues the proponent should consider include:	
a. salinity;	10.10, 10.12
b. sedimentation;	Surface Water Impact Assessment (WRM, 2012) (Appendix R of the EIS)
c. nutrients;	6.0, 8.0, GHD report (GHD, 2012)
d. stressors such as pH, EC, turbidity;	6.0, 8.0, GHD report (GHD, 2012)
e. heavy metals and metalloids;	6.0, 8.0, GHD report (GHD, 2012)
f. macro-invertebrate species assemblages, compositions and assessment results;	Ecological Impact Assessment (Cumberland Ecology, 2012) (Appendix K of the EIS)
g. disturbed/exposed acid sulfate soils; and	Soil Survey and Land Capability Impact Assessment (GSSE, 2012) (Appendix X of the EIS)
h. hydrocarbons, hydrocarbon derivatives and Polycyclic Aromatic Hydrocarbons.	6.0, 8.0, GHD report (GHD, 2012)



3.3 Project Scope

The objective of the groundwater study was to assess the impact of the Project on the hydrogeological regime and to meet the applicable Director General Requirements to achieve this objective the scope of work included:

- identification of groundwater resources in the vicinity of the site;
- assessment of groundwater behaviour resulting from the Project, including;
 - modelling the changes in groundwater conditions due to the Project, with comparisons made with cumulative impact predictions of existing and proposed mining projects in the regional project area;
 - modelling behaviour of groundwater at each identified privately owned licensed pumping bore within 10 km of the proposed mining areas; and
 - assessing post-mine groundwater conditions;
- development of groundwater management strategies;
- identification of any groundwater impact mitigation measures necessary for the Project; and
- a recommended groundwater management program.

4.0 LEGISLATION, POLICY AND GUIDELINES

The following section summarises State and Federal government legislation, policy and guidelines for groundwater to which the Project will need to comply.

4.1 Water Act 1912

The New South Wales *Water Act 1912* regulates water sources including rivers, lakes and groundwater aquifers in NSW. It also manages the trade of water licences and allocations. However, relevant Parts of the *Water Act 1912* do not apply to any part of the State to which the equivalent parts of the *Water Management Act 2000* applies (see sections 27A and 129A).

The *Water Management Act 2000* is progressively replacing the *Water Act 1912* in NSW. The *Water Management Act 2000* has replaced the *Water Act 1912* for all water sources, which are relevant to the Project, and therefore the *Water Act 1912* is not applicable to the Project.

4.2 Water Management Act 2000

The New South Wales *Water Management Act 2000* is an Act to provide for the “*protection, conservation and ecologically sustainable development of the water sources of the State*”. The *Water Management Act 2000* provides clear arrangements for controlling land based activities that affect the quality and quantity of the State’s water resources. It provides for three primary types of approval in Part 3:

- water use approval – which authorise the use of water at a specified location for a particular purpose, for up to 10 years;
- water management work approval;



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

Section 9 of the *Water Management Act 2000* provides that the Act must be administered so as to “*promote the water management principles*” of the Act. The Water Management Principles (set out in Section 5 of the Act) incorporate that in relation to controlled activities:

- (a) the carrying out of controlled activities must avoid or minimise land degradation, including soil erosion, compaction, geomorphic instability, contamination, acidity, waterlogging, decline of native vegetation or, where appropriate, salinity and, where possible, land must be rehabilitated; and
- (b) the impacts of the carrying out of controlled activities on other water users must be avoided or minimised.

4.2.1 Water Sharing Plans

New South Wales Water Sharing Plans (WSPs) establish rules for sharing water between the environmental needs of the river or aquifer and water users, and between different types of water use such as town supply, rural domestic supply, stock watering, industry and irrigation.

NOW are progressively developing WSPs for rivers and groundwater systems across NSW following the introduction of the *Water Management Act 2000*. These purposes of the plans are to protect the health of rivers and groundwater, while also providing water users with perpetual access licences, equitable conditions, and increased opportunities to trade water through separation of land and water.

Two WSPs apply to the area of aquifers affected by the Project as follows:

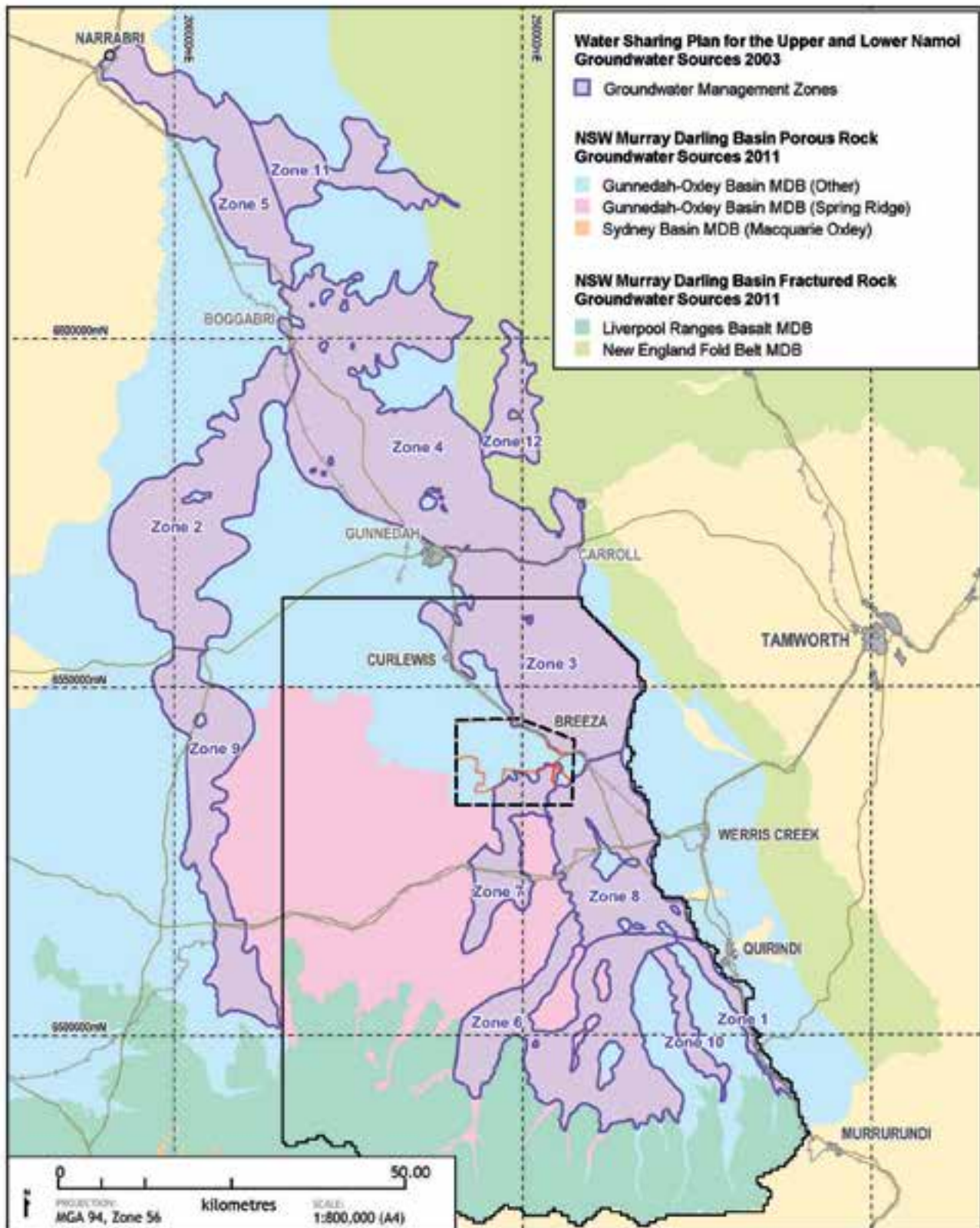
- Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003; and
- Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011

Within the model domain, the Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources is also active. The Project will not affect water availability in the fractured rock zones defined in this Water Sharing Plan.

Figure 4.1 shows the locations where WSP are active around the Project area.

4.2.2 Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003

The Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources commenced in November 2006. The Water Sharing Plan sets the framework for managing groundwater in the Upper and Lower Namoi alluvial aquifers until the end of the 2015/16 water year (at which time there will be a new water sharing plan over this area created). The Water sharing plan applies to the “Upper and Lower Namoi Groundwater Sources” which include all water contained in the unconsolidated alluvial aquifers associated with the Namoi River and its tributaries and is subdivided into 13 zones (refer to Figure 4.1). The Project is located in an area of outcropping bedrock surrounded by Zone 3 to the north, Zone 7 to the south, and Zone 8 to the east.



Watermark Coal Project (G1501)
Groundwater Assessment

Groundwater Management Zones



DATE:
10/10/2012

FIGURE No:
4.1



The objectives of the Water Sharing Plan are to:

- “(a) protect, maintain and, where practicable, enhance ecosystems dependent on groundwater, and the cultural and spiritual values of groundwater, by minimising the impacts on these of groundwater extraction,*
- (b) protect the structural integrity of the aquifers and groundwater quality, by ensuring groundwater extraction does not result in any aquifer compaction, aquitard compaction, land subsidence or change in the beneficial use of the aquifer,*
- (c) manage access to the extraction limits to ensure there are no long-term declines in water levels,*
- (d) preserve basic landholder rights access to these groundwater sources and ensure the fair, equitable and reliable access to groundwater through the management of local impacts or interference effects,*
- (e) contribute to the protection, maintenance and enhancement of the economic viability of groundwater users and their communities in the Namoi Valley,*
- (f) ensure opportunities for market based trading of groundwater access licence rights within sustainability and interference constraints, and*
- (g) ensure sufficient flexibility in account management to encourage efficient use of these groundwater sources and to manage these groundwater sources to account for climatic variations.”*

Table 4.1 summaries the aquifer access licences for Zones 3, 7 and 8 that surround the Project.

Table 4.1: SUMMARY OF AQUIFER ACCESS LICENCES				
Category	Aquifer Volumetric Licence (ML/yr)			
	Zone 3	Zone 7	Zone 8	TOTAL
Domestic and Stock	0	0	0	0
Native Title	0	0	0	0
Local Water Utility	199 (Curlewis)	0	56 (Caroona)	255
Share Components	17,101	3,700	15,944	36,745
Share Components - Supplementary	8,070	7	4,977	13,054
Recharge	0	0	0	0
TOTALS	25,370	3,707	20,977	50,054

Aquifer access licences for Zones 3, 7 and 8 that surround the Project total 50,054 ML/year. Shenhua Watermark currently holds the following Water Access Licences:

- Licence WAL12892 in the Upper Namoi Zone 7 Yarraman Creek (east of Lake Goran to Mooki River) for 42 unit shares, which can be extracted via works approval number 90CA807397.
- Licence WAL12878 in the Upper Namoi Zone 7 Yarraman Creek (east of Lake Goran to Mooki River) for 827 unit shares, which can be extracted via works approval number 90CA807368. Licence WAL12878 is held by three parties as tenants in common Birrawa Pastoral Co. Pty Ltd (997/1000 share), George Clift (1/1000 share) and Shenhua Watermark Coal Pty Ltd (2/1000 share).



- Licence WAL12896 in the Upper Namoi Zone 8 Mooki Valley (Quirindi – Pine Ridge to Breeza) for 164 unit shares, which can be extracted via works approval number 90CA807401.

4.2.3 *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011*

The *Water Sharing Plan for the Murray-Darling Basin Porous Rock Groundwater Sources* commenced in 16 January 2012. The area is subdivided in zones, with the Project being located in the Gunnedah-Oxley Basin Murray Darling Basin Zone (Other). A very small portion of the southwest corner of EL 7223 is within the Gunnedah-Oxley Basin Murray Darling Basin Zone (Spring Ridge). Figure 4.1 shows the water management zones.

Under the Water Sharing Plan, the Minister may prohibit or restrict the taking of water from a water source in order to manage local impacts in groundwater sources, where required to:

- maintain or protect water levels in an aquifer;
- maintain, protect or improve the quality of water in an aquifer;
- prevent land subsidence or compaction in an aquifer;
- protect groundwater-dependent ecosystems; and
- maintain pressure or to ensure pressure recovery, in an aquifer.

At the time of commencement of the plan, the share components of aquifer access licences authorised to take water from the Gunnedah–Oxley Basin MDB Groundwater Source was 16,197 unit shares. The plan reports the long-term average annual extraction limit of 199,893 ML/year for access licences, not including supplementary water and water taken pursuant to basic landholder rights.

Any seepage of groundwater to the proposed mining areas would require an aquifer access licence under this plan.

4.2.4 *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources 2011*

The *Water Sharing Plan for the NSW Murray Darling Basin Fractured Rock Groundwater Sources* commenced on 16 January 2012. The plan covers a large portion of New South Wales including the aquifers associated with the basement rocks of the New England and Lachlan Fold Belts. The closest water management zones to the Project are the Liverpool Ranges Basalt MDB Zone to the south and the New England Fold Belt MDB Zone to the east. The Project will not interact with these water management areas, as both zones are more than 30 km away.

4.2.5 *Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012*

The *Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012* was introduced in late 2012. The plan area comprises 23 unregulated water sources in the Namoi catchment and four alluvial water sources. The Mooki River and Quirindi Creek are excluded from the Water sharing plan. Shenhua Watermark has a licence to extract 1,223 ML from the Lake Goran Water Source via Joint Water Supply Scheme Licence (90SAO11701).



The plan covers four small alluvial aquifers (Manilla, Curabubula, Quipolly, Quirindi) that are relatively distant from the Project area. The Project will not interact with these water management areas, as they are all at least 20 km away.

4.2.6 *Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River Water Sources 2003*

The *Water Sharing Plan for the Upper Namoi and Lower Namoi Regulated River* commenced on 1 July 2004. The provisions in the plan provide water for the environmental needs of the river and its ecological processes and direct how water available for extraction is shared. The Plan also sets rules for the management of access licences, water allocation accounts, the trading of or dealings in licences and water allocations, the extraction of water, the operation of dams and the management of water flows.

The plan applies to the sections of the Namoi River that has flows regulated by the presence of Split Rock Dam on the Manilla River and Keepit Dam on the Namoi River. The regulated area of the Namoi River occurs to the north of the Project from the township of Gunnedah. The Project will not interact with the regulated river as it is at least 35 km away.

4.2.7 *Water Sharing Plan for the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources*

The *Water Sharing Plan for the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources* commenced in July 2004. The plan covers the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources upstream of the junction of the Mooki River with the Namoi River at Gunnedah.

The objectives of this Plan are to:

- a) implement the River Flow Objectives to protect, preserve, maintain or enhance the important river flow dependent environmental features, and cultural and Aboriginal heritage values of the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources, and to provide water for downstream subcatchments,
- b) manage in-river water resources of the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources to ensure equitable sharing of water between all uses and users, including basic rights, and to minimise any adverse socio-economic impacts in regard to communities and individuals in these water sources,
- c) protect the water resources of the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources by ensuring that extraction minimises any adverse environmental impacts,
- d) ensure water extraction from the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creeks Water Sources is managed within Murray Darling Basin Cap for the Namoi Water Management Area,
- e) provide rules for market based trading of access licence share components and individual daily extraction limits in the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources, and
- f) contribute to the achievement of water quality to support the environmental values of the Phillips Creek, Mooki River, Quirindi Creek and Warrah Creek Water Sources.

**Table 4.2: SUMMARY OF WATER ACCESS LICENCES**

Category	Water Source (ML/yr)			
	Phillips Creek	Mooki River	Quirindi Creek	Warrah Creek
Domestic and Stock	1	1.1	0.7	1.9
Native Title	0	0	0	0
Water Licences	426	27,449	2,458	264
TOTALS	427	27,450.1	2,458.7	265.9

The Project does not have any licences to extract from the Water Sources under this plan. The Project requires a water licence to offset any losses from the Mooki River baseflow (refer Section 10.9).

4.3 State Groundwater Policy

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

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

4.3.1 Groundwater Quality Protection

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

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



9. *Where possible and practical, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.*"

4.3.2 Groundwater Dependent Ecosystems

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

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

- GDEs can have important values. Threats should be identified and action taken to protect them;
- groundwater extractions should be managed within the sustainable yield of aquifers;
- priority should be given to GDEs, such that sufficient groundwater is available at all times to meet their needs;
- where scientific knowledge is lacking, the precautionary principle should be applied to protect GDEs; and
- planning, approval and management of developments should aim to minimise adverse effects on groundwater by maintaining natural patterns, not polluting or causing changes to groundwater quality and rehabilitating degraded groundwater ecosystems where necessary.

4.3.3 Groundwater Quantity Protection

The objectives of managing groundwater quantity in NSW are to (NOW 2012a):

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

4.3.4 Aquifer Interference Policy

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

- penetration of an aquifer;
- interference with water in an aquifer;
- obstruction of the flow of water in an aquifer;



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

Examples of aquifer interference activities (NOW 2012b) include mining, coal seam gas extraction, injection of water, and commercial, industrial, agricultural and residential activities that intercept the water table or interfere with aquifers.

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

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

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

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

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

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



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

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

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

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

4.3.5 Aquifer Risk

DLWC (2000) assessed the risks to various significant groundwater resources across the State. It classified the Upper Namoi Valley Alluvium as a “highest risk aquifer” according to the following:

- Licensed entitlements compared to sustainable yield;
- Local interference effects;
- System flows;
- Vulnerability to pollution;
- Land use threats;
- Poor quality water adjacent to aquifer;
- High water levels and salinity; and
- Groundwater dependent ecosystems.

Figure 4.2 shows the risk scores for the highest risk inland aquifers assessed by DLWC (2000).

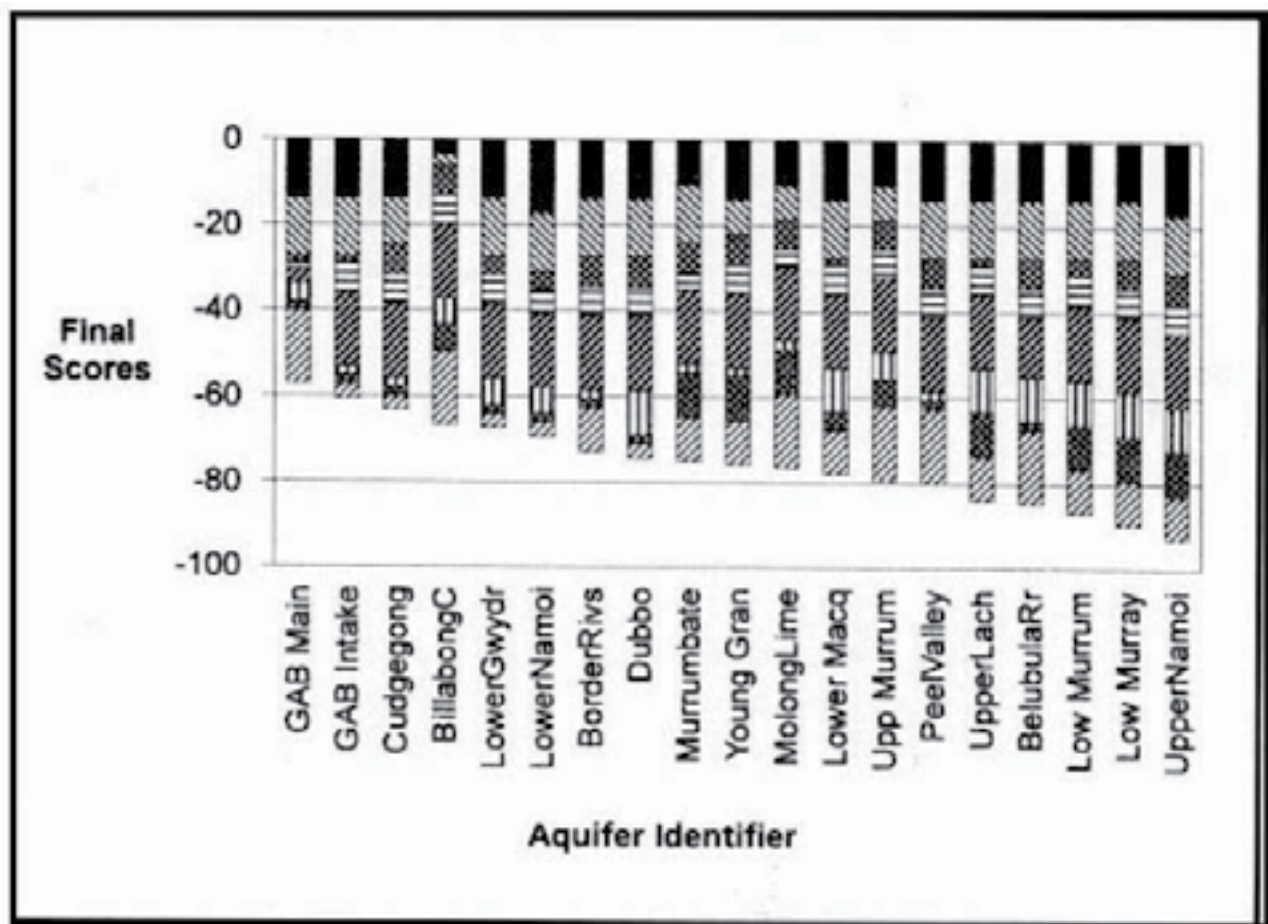


Figure 4.2: Highest Risk Inland Aquifers (from DLWC 2000)

It is clear from DLWC (2000) that the Upper Namoi aquifer system is under stress, and it will be important that the Project does not exacerbate these existing issues. The criteria used by DLWC (2000) to rank the aquifer risk reflect the DGRs for the Project and have generally been assessed within this report.

4.4 Federal Groundwater Legislation

4.4.1 Water Act 2007

The Federal *Water Act 2007* applies to the Murray Darling Basin in which the Project is located. There is no direct requirement for the licensing of water under this Act, however Basin Plans and Water Resource Plans for this area are currently being prepared. These plans may influence how water is extracted, stored, used and the rules for trading or transferring water rights.

4.4.2 Great Artesian Basin

The Federal Government does not have any requirements for licensing or regulation of the Great Artesian Basin (GAB). The legislation and policy relating to the GAB is governed by the state agencies; however, the Federal Government does provide funding and research in the form of the *GAB Sustainability Initiative*. The Project is not located within the NSW GAB management areas according to both the *Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources*



2008 and the *Water Sharing Plan for the NSW Great Artesian Basin Shallow Groundwater Sources*.

4.4.3 National Water Quality Management Strategy

The National Water Quality Management Strategy (NWQMS) is a joint national approach to improving water quality in Australian and New Zealand waterways. Since 1992 the NWQMS has been developed by the Australian and New Zealand Governments in cooperation with state and territory governments. The NWQMS aims to protect the nation's water resources, by improving water quality while supporting the businesses, industry, environment and communities that depend on water for their continued development. The NWQMS consists of three major elements:

- Policy;
- Process; and
- Guidelines.

The main policy objective of the NWQMS is to achieve sustainable use of water resources, by protecting and enhancing their quality, while maintaining economic and social development. The NWQMS process involves development and implementation of a management plan for each catchment, aquifer, estuary, coastal water or other water body, by community and government. These plans focus on the reduction of pollution released into coastal pollution hotspots and other aquatic ecosystems around the country. Local government, community organisations and other agencies carry out these plans using the NWQMS to protect agreed Environmental Values.

5.0 REGIONAL SETTING

5.1 Location

The Project is located approximately 25 km south-east of the township of Gunnedah and to the immediate west of the village of Breeza (Figure 1.1). Tamworth is located approximately 50 km to the north-east. The Kamilaroi Highway and Werris Creek - Moree Railway Line run adjacent to the Project Boundary in the east and form part of an important road and rail network that provides access throughout the region. The Project is approximately 282 km by rail from the export Port of Newcastle. The majority of the land required for the Project is owned by Shenhua Watermark.

The Breeza State Forest is located to the immediate south-west of the Project Boundary, falling within EL 7223. No mining is to occur within the Breeza State Forest. Other State Forests such as Doona and Spring Ridge State Forests are located to the south, whilst Goran and Black Jack State Forests are located to the north-west of the Project Boundary. Trinkey and Wondoba State Conservation Areas are located to the north-west and west respectively, whilst the closest National Parks are Somerton National Park to the north (25 km) and Coolah Tops National Park to the south (50 km).

5.2 Surrounding Mining and Coal Seam Gas Operations

There are other exploration leases in the region including the BHP Billiton Pty Ltd (BHPB) Caroona Coal Project (EL 6505) which is located immediately adjacent to the south of the Project Boundary. BHPB is currently undertaking exploration activities at Caroona to potentially develop an underground coal mine.



Whitehaven Coal operates the Sunnyside Mine is located 47 km north-west, and the Werris Creek mine is located 23 km south-east of the Project. The Sunnyside open cut produces around 1Mtpa of raw thermal coal for the export market. The coal is trucked by road to Whitehaven's Gunnedah CHPP for washing and loading for transport by rail to the Port of Newcastle. Werris Creek Mine produces up to 1.5 Mtpa as raw coal for the export market. The coal is transported directly by rail from Werris Creek to the Port of Newcastle. The truck and excavator mining method is used at both the Sunnyside and Werris Creek coal mines.

Santos Ltd (Santos) holds Petroleum Exploration Licence (PEL) No. 1 over the Project Boundary and adjacent lands. Santos commenced coal seam gas (CSG) exploration in 2008 and currently has interests in nine PELs in the Gunnedah Basin, and operates six. Santos has commenced the Gunnedah Basin Gas Exploration Project at Caroona, adjacent to the Project Boundary. Santos currently only has approval to explore for CSG within the Gunnedah Basin and has not yet sought approval to extract CSG on a commercial scale.

5.3 Topography and Drainage

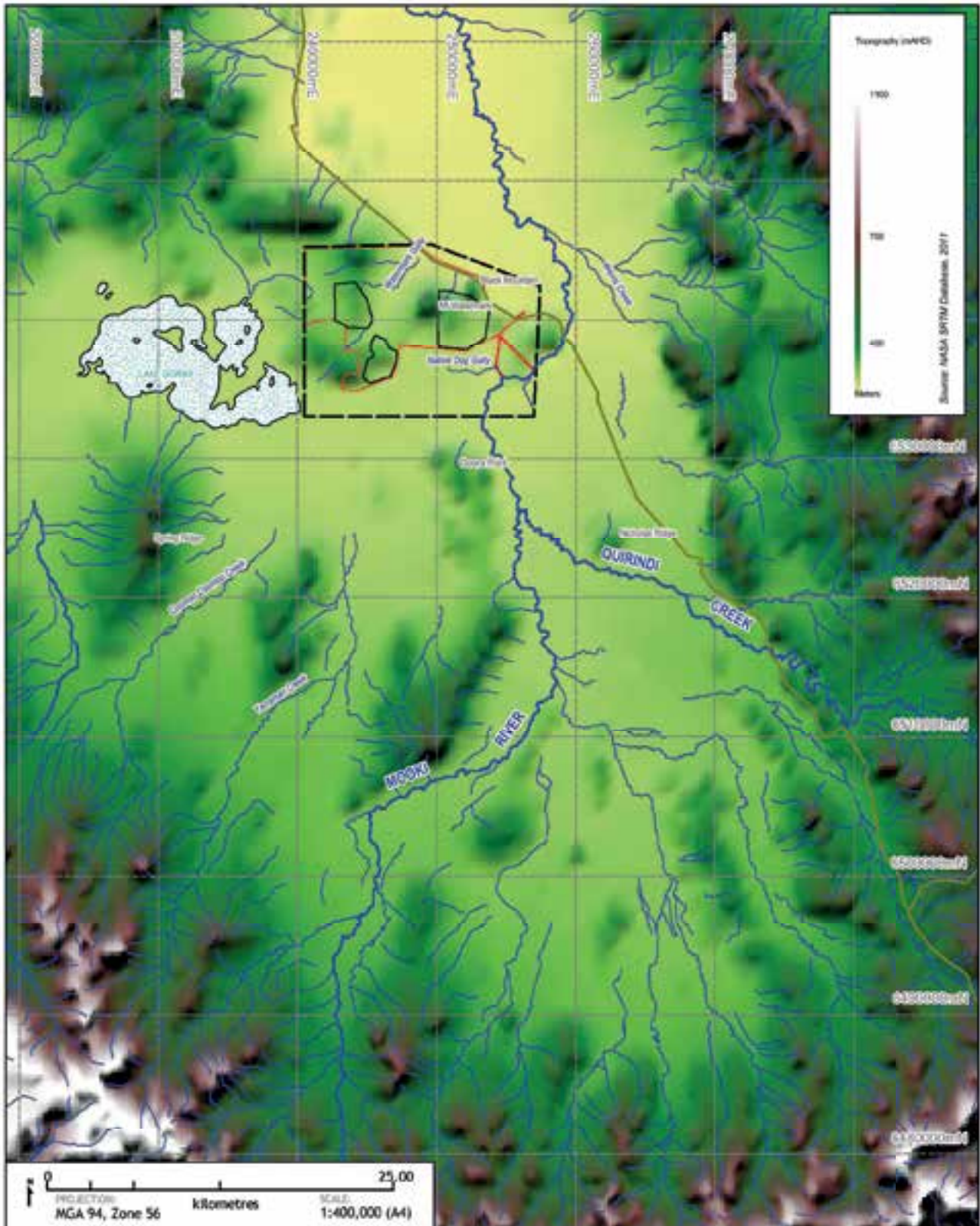
The Gunnedah LGA is located approximately 320 m above sea level (mAHD) on the Liverpool Plains of the Namoi River Valley. The region is generally flat with only 1% of the Gunnedah LGA recording land slopes greater than 15 degrees. Topography is variable across the Project Boundary, ranging from topographic highs associated with Mt Watermark (512 mAHD) and Smokey Point (447 mAHD) through to the black soil plains to the south and south-east of the Project Boundary. Gently undulating cleared grasslands (approximately 310 mAHD) dominate the central and western portions of the Project Boundary.

Within the Project Boundary, there are a range of watercourses including numerous first and second order streams; Watermark Gully, Native Dog Gully and the Mooki River (refer to Figure 5.1). The water bodies within the Project Boundary are primarily farm dam-type structures; however, Lake Goran, which is a naturally occurring ephemeral lake, is located to the west.

Flooding is primarily limited to the southern portion of the Project Boundary and is a result of flows from Coomoo and Yarraman Creeks as well as Lake Goran. Overflows from Coomoo Creek and Lake Goran occur in moderate to high flow events while flows from Yarraman Creek flood out into the low-lying floodplain in all flow events.

Historical flooding extents proximal to the Project for the 1998 and 2000 flood events are presented in the WRM (2012) surface water report. These extents were based on gauging station data and anecdotal evidence on flood depths and extents provided by landholders in Flood Study Landholder Interviews.

The WRM (2012) report presents a simulated extent of flooding and the flood depths for the 100-year average recurrence interval design flood. The predicted 100-year flooding extent is generally only slightly larger than the 1998 flood event. Native Dog Gully is projected to be heavily affected by breakout flows and backwater for the Mooki River. A small area of the south-east corner of the disturbance boundary is predicted to be inundated to a depth of 1.7m during a 100 year flood event (WRM, 2012).



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Groundwater Assessment

Topography and Drainage



DATE:
18/10/2012

FIGURE No:
5.1



5.4 Land Use

Land use within EL 7223 includes pastoral activities that are typically associated with elevated terrain and dryland and irrigated cropping activities associated with the black soil plains.

Within the Project Boundary, land use consists of grazing with limited cropping. This type of land use is different from the intensive cropping agriculture that is carried out on the black soil plains. The original landscape within the Project Boundary has been altered by disturbances such as tree clearing, pasture improvement, weed invasion and the alteration of natural drainage systems. These disturbances are commonly associated with livestock grazing operations, and have resulted in limited areas of native vegetation.

Shenhua Watermark owns all of the land directly proposed for mining disturbance and the majority of land within the Project Boundary. The land to the north, north-east and south of the Project Boundary is privately owned freehold land.

5.5 Climate

The climate within the region is mostly temperate, and is characterised by hot, wet summers and mild, dry winters. Climate data has been obtained for Gunnedah. The Bureau of Meteorology (BoM) has collected 136 years of rainfall records at the Gunnedah Pool recording station (55023) dating from 1876 to present. Evaporation is measured by BoM at the Gunnedah Resource Centre station (55024). Table 5.1 summarises the average temperatures, rainfall and evaporation.

Table 5.1: CLIMATE AVERAGES - GUNNEDAH POOL (55023)

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Mean max temp (°C)*	34.0	32.9	30.7	26.4	21.3	17.6	16.9	18.9	22.8	26.7	30.3	32.9	26.0
Mean min temp (°C)*	18.4	18.1	15.8	11.4	7.1	4.3	3.0	4.2	7.0	10.8	14.2	16.8	10.9
Mean rainfall (mm)*	71.3	67.3	47.9	37.6	42.5	43.6	42.4	41.5	40.3	55.5	62.6	70.1	623.0
Mean evaporation (mm)**	238.7	187.6	186	129	83.7	57	58.9	83.7	120	164.3	198	238.7	1752
Evaporation minus rainfall	167.6	121.1	138.1	91.4	41.2	13.4	16.2	42.2	80.1	108.9	136.5	168.9	1131.6

* Gunnedah Pool data ** Gunnedah Resource Centre data

The average annual rainfall is 623 mm, with January being the wettest month (71 mm). The mean annual evaporation rate is 1,752 mm/year, and the mean monthly evaporation exceeds mean annual rainfall all year round.

Rainfall records can be put into historical context using the Cumulative Rainfall Departure (CRD) method (also referred to as Rainfall Residual Mass). This method is a summation of the monthly departure of rainfall from the long-term average monthly rainfall. A rising trend in the CRD plot indicates periods of above average rainfall, whilst a falling slope indicates periods when rainfall is below average.

Figure 5.2 displays the CRD graph for the period 1876 to present. The CRD indicates that the area experienced a period of generally below average rainfall from the late 1800s through to the 1950s. Since the 1950s, the area has experienced above average rainfall through to the present day.

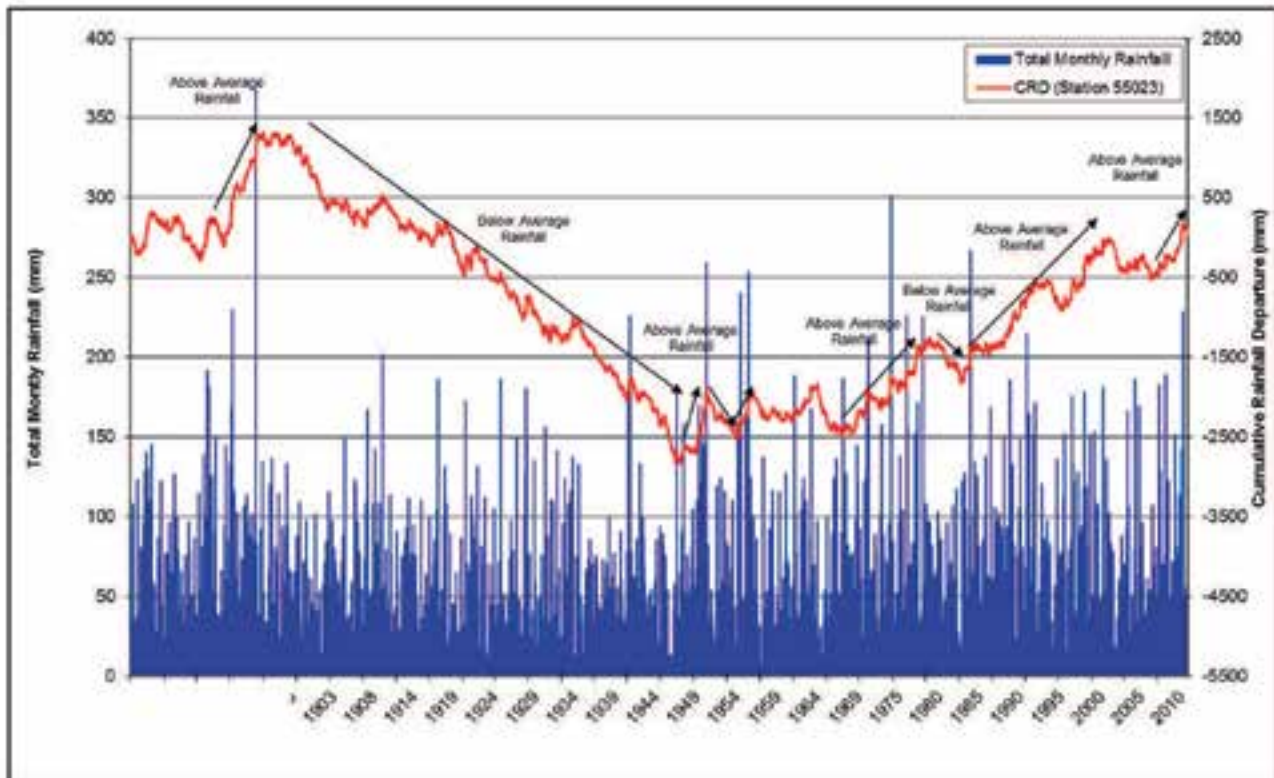


Figure 5.2: Cumulative Rainfall Departure Graph – Gunnedah Pool Station (55023)

5.6 Geology

5.6.1 Summary

The geology of the area is comprised of:

- Early Permian Watermark and Porcupine Formations and underlying Maules Creek Formation.
- Consolidated Gunnedah Basin sediments comprising:
 - Late Permian Black Jack Group sediments containing the Breeza Coal Member, Hoskissons Coal Seam and underlying Pamboola Formations containing the Melvilles coal seam;
 - Early Triassic Digby Formation lithic and quartz conglomerates alluvial fan deposits found to the west of the Project Boundary;
- Consolidated Surat Basin sediments comprising:
 - Jurassic Purlawaugh Formation sediments.
 - Jurassic to Cretaceous Pilliga Sandstone.
- Tertiary basalt and dolerite of the Liverpool Range Volcanics; and
- Unconsolidated Recent to Quaternary alluvium associated with the Liverpool Plains.



Figure 5.3 shows a generalised stratigraphic section for the Project Boundary. Figure 5.4 presents the surface geology of the area.

The New England Fold Belt (Devonian to Carboniferous) outcrops to the east of the Gunnedah Basin and is structurally separated from the Permian sediments by the Hunter-Mooki Thrust Fault which extends north-south.

The Great Artesian Basin (GAB), in particular the Surat Basin (Jurassic to Cretaceous) sediments outcrop to the south-west of the Project Boundary and unconformably overlie the Gunnedah Basin sediments. The Surat Basin sequence, namely the Jurassic Purlawaugh and Pilliga Sandstone consist of mudstones, sandstones and subordinate coal.

The Liverpool Ranges are comprised of Tertiary basalts and dolerite which unconformably overlie the Surat Basin/Gunnedah Basin sediments.

The Quaternary Alluvium is broadly spilt into two major formations, the Narrabri Formation (Pleistocene to recent) and the Gunnedah Formation (Pliocene to early Pleistocene). The Narrabri Formation is typically clay dominant with minor sands and gravels whereas the Gunnedah Formation is typically sand and gravel dominant with minor clay bands.

5.6.2 Gunnedah Basin

The Gunnedah Basin comprises approximately 1,200 m of marine and non-marine sediments of Late Permian and Triassic age (Tadros 1993). The basin sediments are spilt into two major geological groups, the Black Jack Group and the Millie Group and there are several major coal seams. Many areas of the Gunnedah Basin are intruded by Garrawilla Volcanics (Tadros 1993).

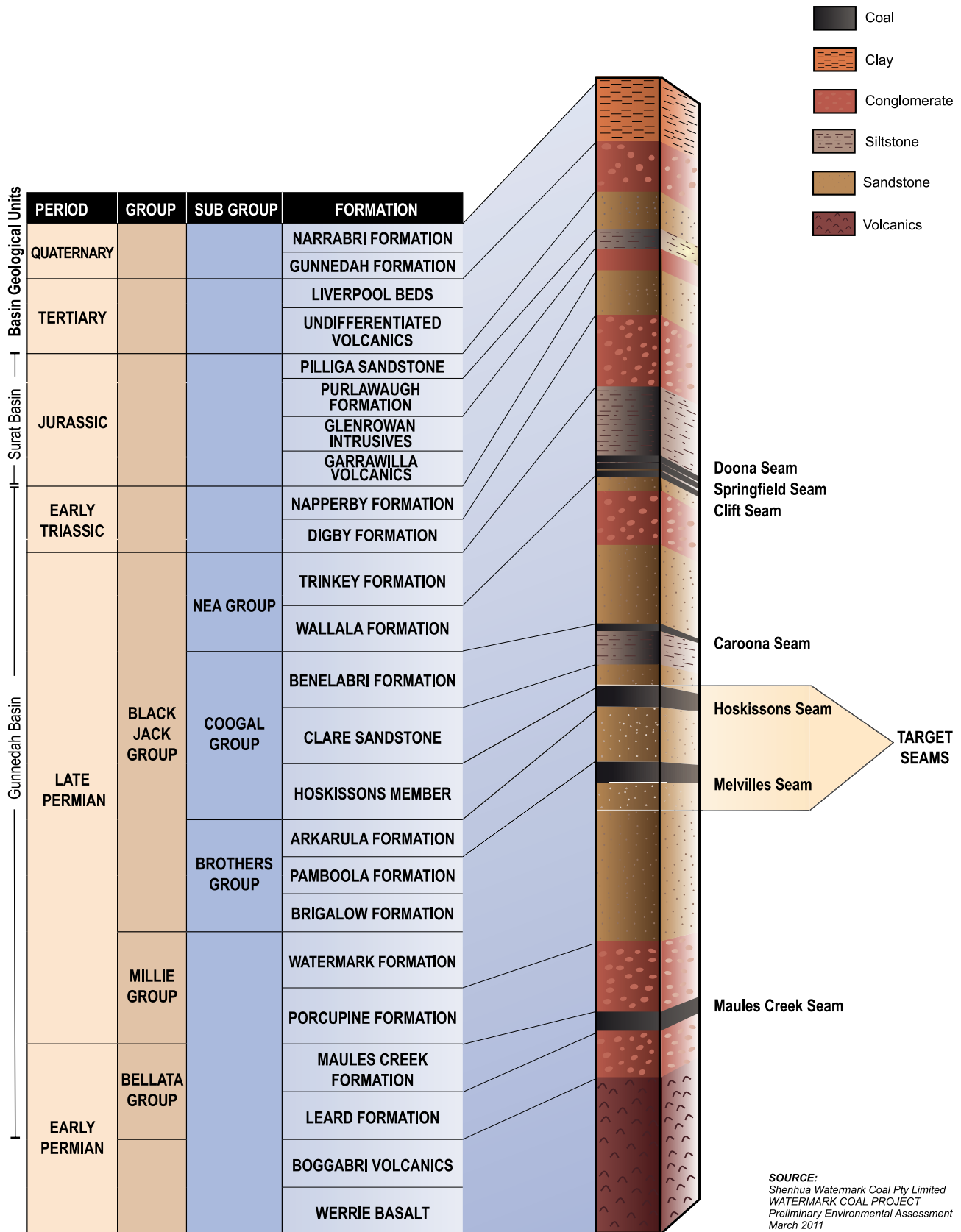
Black Jack Group

Tadros (1993) describes the Black Jack Group as a Late Permian sequence (up to 450 m thick) of deltaic and fluvial sediments. The Black Jack Group consists of conglomerate, sandstone, siltstone, claystone, tuff and a number of individual coal seams. The Black Jack Group coal measures outcrop in a narrow north-northwest trending line of hills that extend from Breeza in the south-east, north to Boggabri.

The Black Jack Group is spilt into three sub-groups, the Nea Sub-group, the Coogal Sub-group and the Brothers Sub-group. Each sub-group contains a number of individual formations as shown in Figure 5.3.

The Black Jack Group, in particular the Coogal Sub-group and Brothers Sub-group contains the minable coal seams in the Project area. These coal seams, the Hoskissons coal seam and the Melvilles coal seam form part of the Hoskissons Formation and Pamboola Formation respectively.

The Black Jack Group is unconformably overlain by the Triassic Digby Formation, which primarily consists of lithic/quartzose sandstones and conglomerates. This in turn is overlain by the Deriah and Napperby Formations, which consist of a series of claystone, siltstone and sandstone sequences (Tadros, 1993).

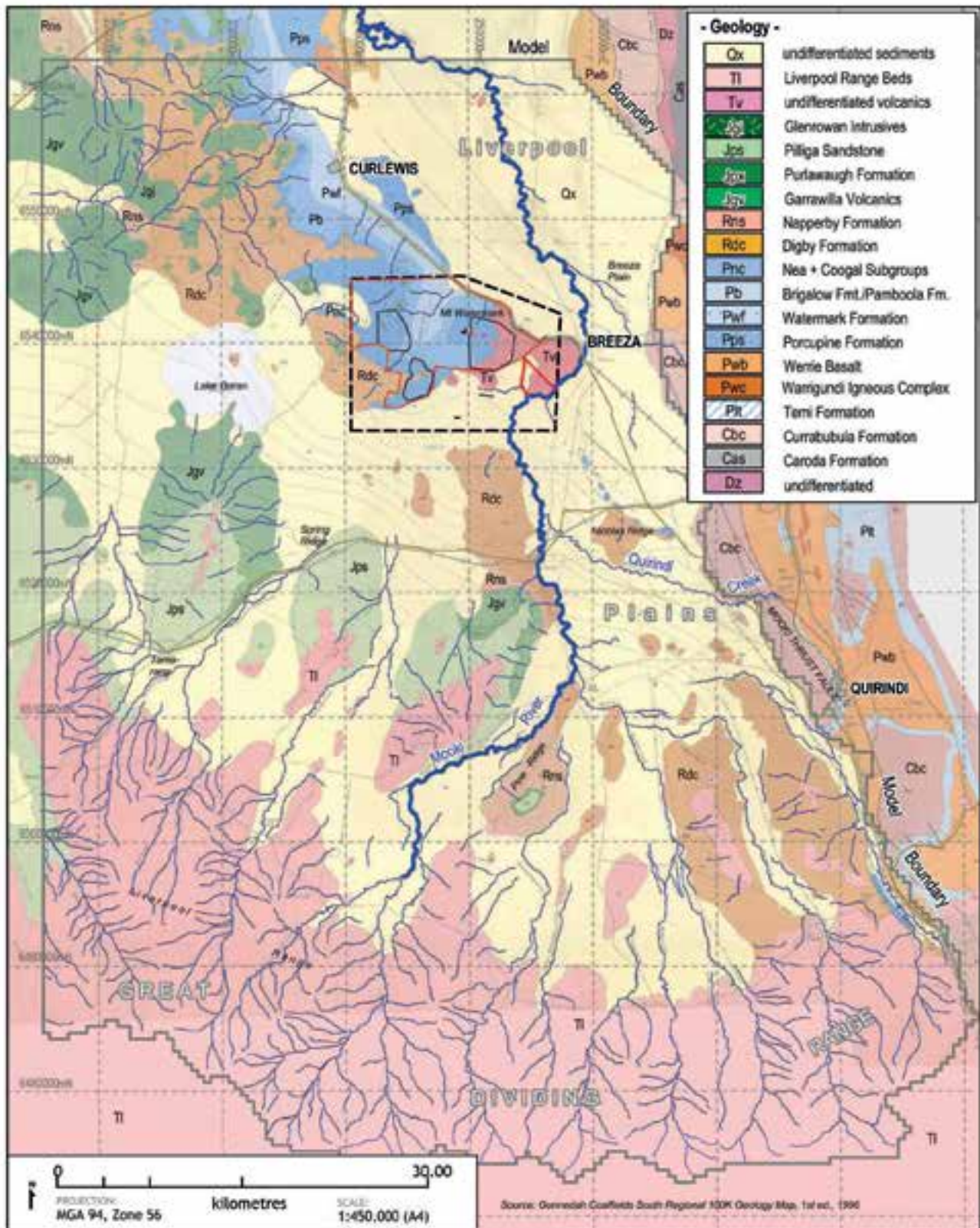


Indicative Stratigraphic Column

Figure 5.3

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)





Watermark Coal Project (G1501)
Groundwater Assessment

Geology



DATE:
10/10/2012

FIGURE No:
5.4



Millie Group

The Millie Group is split into two formations, the Watermark Formation and the Porcupine Formation. Tadros (1993) describes the Watermark Formation as prodelta and delta front sediments on which the Black Jack Group rests. The Porcupine Formation sits conformably on the Maules Creek Formation that is the lowermost coal seam in the Gunnedah Basin. The Maules Creek Formation includes claystone, siltstone, sandstone, conglomerate and coal layers, including the Maules Creek Seam (Tadros, 1993). The Maules Creek coal seam is not being mined as part of the Project.

5.6.3 Surat Basin

The Surat Basin is an extensive sub-basin of the GAB and is present in to the south-west of the Project area. The Surat Basin unconformably overlies the Gunnedah Basin. Within the Project region, the Surat Basin is part of the stranded Oxley Basin which is disconnected from the larger GAB to the west, meaning there is no hydraulic connection to the greater GAB. Oxley Basin Tadros (1993) locally splits the Surat Basin sediments into the Purlawaugh Formation and the Pilliga Sandstone. The Purlawaugh Formation consists of less than 75 m of mudstone, sandstone and minor coal. The Pilliga Sandstone (Middle to Late Jurassic) conformably overlies the Purlawaugh Formation and consists of medium to coarse-grained fluvial quartzose sandstone.

6.0 FIELD INVESTIGATION PROGRAM

6.1 Exploration / Pre-feasibility Phase

Shenhua Watermark engaged Gutteridge Haskings and Davey (GHD) to undertake groundwater studies to support the pre-feasibility and exploration phase work for the Project. Field investigations into the hydrogeology at EL 7223 commenced in 2009 and have included:

- installing a network of monitoring bores and vibrating wire piezometers (vwps);
- measurement of hydraulic properties using slug tests, packer tests and pumping tests;
- routine monitoring of groundwater levels and quality;
- geophysical studies to assess the limit of the Quaternary alluvium; and
- undertaking a census of private farm bores.

GHD prepared a series of reports documenting these studies as follows:

- GHD (2009) *Quaternary Alluvial Boundary Definition*.
- GHD (2010a) *Watermark Project Mine Feasibility Study Volume J Water Resources*.
- GHD (2010b) *Geophysical Investigations*.
- GHD (2010c) *Shenhua Watermark Coal Pty Ltd, Watermark Project, Hydrogeological Investigations, Stage 1 Bore Completion Report, January 2010*.
- GHD (2010d) *Shenhua Watermark Coal Pty Ltd, Watermark Project, Geophysical Investigations, August 2010*.
- GHD (2010e) *Shenhua Watermark Coal Pty Ltd, Hydrogeological Investigations, Stage 2 Drilling Program Completion Report, October 2010*.
- GHD (2011a) *Shenhua Watermark Coal Pty Ltd, Hydrogeological Investigations Stage 3 Bore Completion Report, March 2011*.



- GHD (2011b) *Shenhua Watermark Coal, Stage 3 A Drilling Program, AGE Groundwater Monitoring Bore Installations, July 2011.*
- GHD (2012) *Hydrogeological Investigations Stages, 1 – 4, July 2012* (this report is included as Appendix 1).
- Various quarterly environmental monitoring reports.

The above reports present the results of the field investigations and the reader should refer to these reports for detail about individual bores. This report reproduces the details particularly relevant to the groundwater assessment and modelling in Section 7.0.

6.1.1 Monitoring Bore Network

GHD have supervised four separate phases of drilling for the resource exploration program. As part of the hydrogeology studies, each borehole was evaluated for use as a groundwater monitoring bore. GHD (2012) installed bores or vibrating wire piezometers at a total of 103 groundwater monitoring sites during the hydrogeological investigations including:

- 87 groundwater monitoring bores cased with 50 mm diameter Class 18 uPVC;
- 9 bores cased with 150 mm diameter Class 18 uPVC (primarily for aquifer testing); and
- 32 vwps installed at 16 monitoring sites across the EL.

The monitoring bores were constructed using threaded Class 18, 50 mm nominal internal diameter unplasticised polyvinyl chloride (uPVC) pipe. The bore screens were constructed with machine slotted (0.45 mm aperture) Class 18 uPVC pipe. The drillers provided the casing and screen sections pre-washed, in sealed plastic wrap.

The gravel pack was comprised of 2 mm to 3 mm washed quartz sand and typically extended approximately 0.5 m to 1.0 m above the screen section. A bentonite seal was placed immediately above the filter pack to prevent the migration of water along the bore annulus and to prevent grout materials contaminating the filter pack. Once the seal was hydrated, the annulus was sealed with a cement bentonite grout mix, which filled the annulus to the ground surface.

A lockable protective cover was placed over the PVC standpipe and was concreted securely into place, protruding approximately 0.6 m above the ground surface and coloured to facilitate visibility. A 1 m cement pad was constructed at the surface around the bore to prevent ponding of surface water.

GHD (2012) describe in detail the methodology used for:

- bore licencing;
- drilling and installing the monitoring bores and vwps;
- bore surveying;
- water level and groundwater quality monitoring; and
- hydraulic conductivity testing.

GHD (2012) also includes all the details for each bore including geological and construction logs.

6.1.2 Aquifer Testing

GHD measured hydraulic conductivity using a variety of methods in the field. The testing included:



- 79 slug tests,
- 29 rising head tests,
- 8 short term pumping tests,
- 60 straddle packer tests in 12 exploration holes,

Sections 7.1.5 and 7.3.3 summarise the results of the hydraulic conductivity testing.

6.1.3 Water Level and Quality Monitoring

GHD undertook routine groundwater monitoring as part of the Shenhua Watermark Coal exploration program, to characterise the groundwater quality, groundwater levels and aquifer properties in the various geological formations. GHD collected samples for water quality analysis on a quarterly basis and monitored groundwater levels fortnightly or monthly when accessible, or more frequently following significant rainfalls. Nine groundwater bores were equipped with down-hole data loggers recording groundwater levels on a daily basis.

Routine monitoring commenced after the first monitoring bores were installed in August 2009 and is currently ongoing. The oldest bores have a data set that spans almost three years, with the majority of the bores having between 1½ and 3 years data.

6.1.1 Definition of the Edge of the Alluvium and Geophysics

GHD (2009) assessed and mapped the extent of the black soil plains within EL 7223 area using a variety of data including:

- geology and soils mapping;
- digital terrain data;
- airborne radiometrics;
- borehole logs; and
- follow up site inspections.

Section 7.1.3 presents the results of the investigation.

6.2 EIS Phase

Shenhua Watermark engaged AGE in late 2010 to undertake the groundwater modelling for the Project EIS. The first task for the EIS was to assess the available groundwater data collected as part of the pre-feasibility/exploration phase, and determine where gaps existed and more data was necessary. A program of further field investigation and laboratory testing was developed and included:

- installing additional monitoring bores in the buffer zone between the proposed Mining Areas and the aquifers underlying the black soil plains;
- installing additional monitoring bores in the weathered Permian including the Clare Sandstone;
- laboratory measurement of vertical/horizontal hydraulic conductivity and porosity in rocks core samples;



- radiocarbon dating the age of groundwater samples from selected bores to further understand groundwater recharge processes; and
- undertaking a geophysical survey within the buffer zone to locate geological structures that may link the proposed mining areas and the alluvial aquifers.

The sections below describe the general methodology used for these investigations. Section 7.0 presents the results of the investigations.

6.2.1 *Additional Bores*

GHD installed additional monitoring bores to characterise the hydrogeological properties of the buffer zone between the proposed Mining Areas and the aquifers underlying the black soil plains.

Boart Longyear installed the 16 additional monitoring bores using a sonic drill rig. The sonic drilling technique works by sending high frequency resonant vibrations down the drill string to the drill bit. Resonance magnifies the amplitude of the drill bit, which fluidises the soil particles at the bit face, allowing for fast penetration through most geological formations.

6.2.2 *Laboratory Core Testing*

AGE selected 32 HQ (96 mm diameter) core samples. These were analysed by the Weatherford Laboratory for permeability and porosity. Weatherford measured porosity and horizontal/vertical permeability for each sample. Table 7.7 summarises the results of the laboratory testing with the full laboratory report included as Appendix 2.

6.2.3 *Radiocarbon and Tritium Dating*

GHD collected samples from 28 monitoring bores for radiocarbon and tritium age dating. The aim of the testing was to enhance the understanding of recharge mechanisms occurring within the region of the groundwater model. The samples were collected from bores located in the ridge areas, at the break of slope, from the Liverpool Range basalts, and from the Narrabri and Gunnedah Formations. The number of samples collected from each aquifer was as:

- Narrabri Formation 7
- Gunnedah Formation 3
- Alluvium 5
- Regolith 2
- Basalt 1
- Pilliga Sandstone 1
- Clare Sandstone 3
- Interburden 0
- Coal Seams 8

Sections 7.1.8 and 7.3.6 discuss the age dating with the full laboratory report included in Appendix 3.

6.2.4 *Definition of the Edge of the Alluvium and Buffer Zone Properties*

GHD (2009) undertook a preliminary investigation to map the boundary of the black soils associated with the Liverpool Plains. This was followed up with further work to assess the aquifer properties of the bedrock that forms the buffer zone between the proposed mining areas and the



Narrabri/Gunnedah Formations. This included the 16 additional monitoring bores installed using a sonic drill rig, and a geophysical survey to locate geological structures that may link the proposed mining areas and the alluvial aquifers. The purpose of this investigation was to address the DGR requirements that included:

- *Definition of the boundary limits to the Upper Namoi alluvium; and assessment and justification for the nominated alluvial boundary limits. Full geomorphic, hydrologic and salinity assessment of the surface and alluvial groundwater systems associated with the Upper Namoi alluvium should be provided.*
- *Justification to nominated setback distance from the Upper Namoi alluvium in terms of existing and predicted changes in contribution, flux and migration of groundwater, and maintenance of existing groundwater quality ranges and zonations.*

A geophysical survey was undertaken by GHD/AGE within the buffer zone area (Groundwater Imaging, 2012). Section 7.1.2 summaries the alluvial boundary and the buffer zone investigations.

7.0 HYDROGEOLOGICAL REGIME

The following sections present the data for the groundwater regime in the Project Boundary and surrounds. The following hydro-stratigraphic units are discussed under the following headings:

- Alluvial groundwater systems;
- Tertiary units; and
- Gunnedah and Surat Basins.

7.1 Alluvial Groundwater Systems

7.1.1 Stratigraphy and Lithology

The upper section of the alluvial groundwater system is characterised by clays, silts and discontinuous lenses of sand. The lower zones are comprised of coarser grained alluvial sands and gravels, semi confined by the overlying clays. Previous investigators have split the Upper Namoi alluvium into two major formations, the Narrabri Formation and the Gunnedah Formation. The Narrabri Formation is typically a brown clay dominated aquitard, which becomes darker near the surface with minor sands and gravels, whereas the Gunnedah Formation is typically a sand and gravel aquifer with minor clay lenses.

The sand and gravel channel deposits range in thickness from 5 m to 30 m and were deposited by a northwards flowing braided river system. The Narrabri Formation conformably overlies the Gunnedah Formation and is tentatively assigned Pleistocene in age. The Gunnedah Formation is assigned Pliocene age (Gates, 1980). The alluvial sequence has been divided in this way to allow the geological complexity that exists to be simplified and represented in models of groundwater flow.

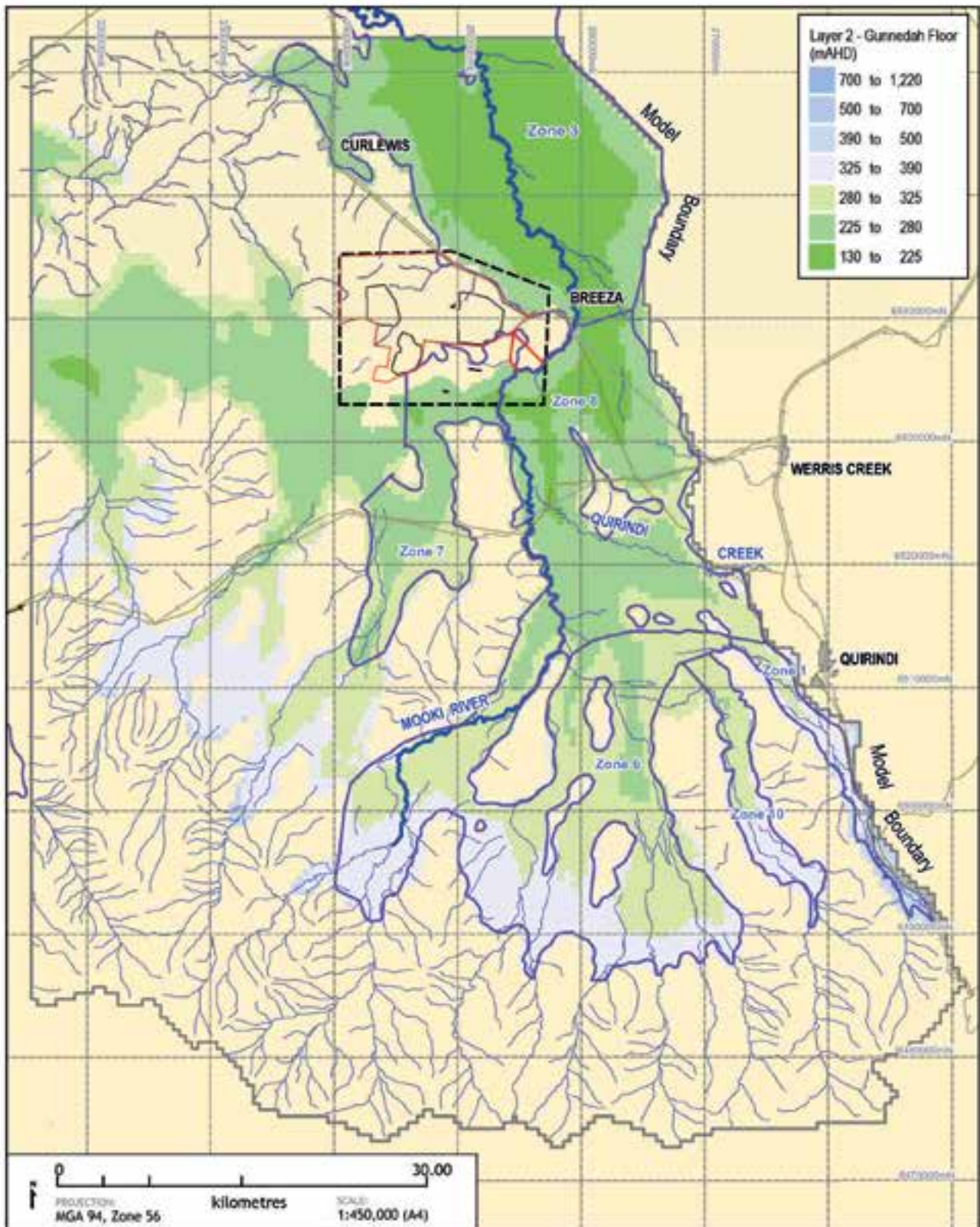
7.1.2 Regional Distribution and Thickness

The total area of alluvium in the Upper Namoi Catchment is in the order of 3,781 km² and is reported to be up to 145 m thick (DWE, 2005, Lavitt, 1999). Figure 7.1 shows the distribution of alluvium within the Project region.

The Upper Namoi groundwater system is associated with the Namoi River, Mooki River and Cocks Creek (SWS, 2012b). The thickness of the alluvial sediments is largely controlled by the bedrock topography (SWS, 2012b) and a palaeochannel that extends through the central portion of the Namoi Catchment forms the deepest part of the aquifer. Figure 7.2 presents the geological floor of the Gunnedah formation and illustrates the extent of the palaeochannels over the Project region.



Figure 7.1: Alluvial Sequence Looking North (Basemap Google Earth)



LEGEND:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

Watermark Coal Project (G1501)
Groundwater Assessment

**Gunnedah Alluvium Floor
Model Layer 2**



DATE:
10/10/2012

FIGURE No:
7.2



7.1.3 Local Distribution and Thickness

GHD (2009) undertook a multidisciplinary study to define the boundary limits to the Upper Namoi alluvium and mapped the extent of the black soil plain using:

- 1:100,000 Coalfields South Geology Map;
- 1:250,000 Geological Map;
- 1:100,000 Curlewis Soil Map;
- 2009 AAMHatch Digital Terrain Model (DTM);
- 2006 UTS Airborne Radiometrics Dataset;
- logs of the DPI and DWE exploration and registered groundwater bores; and
- initial field investigations.

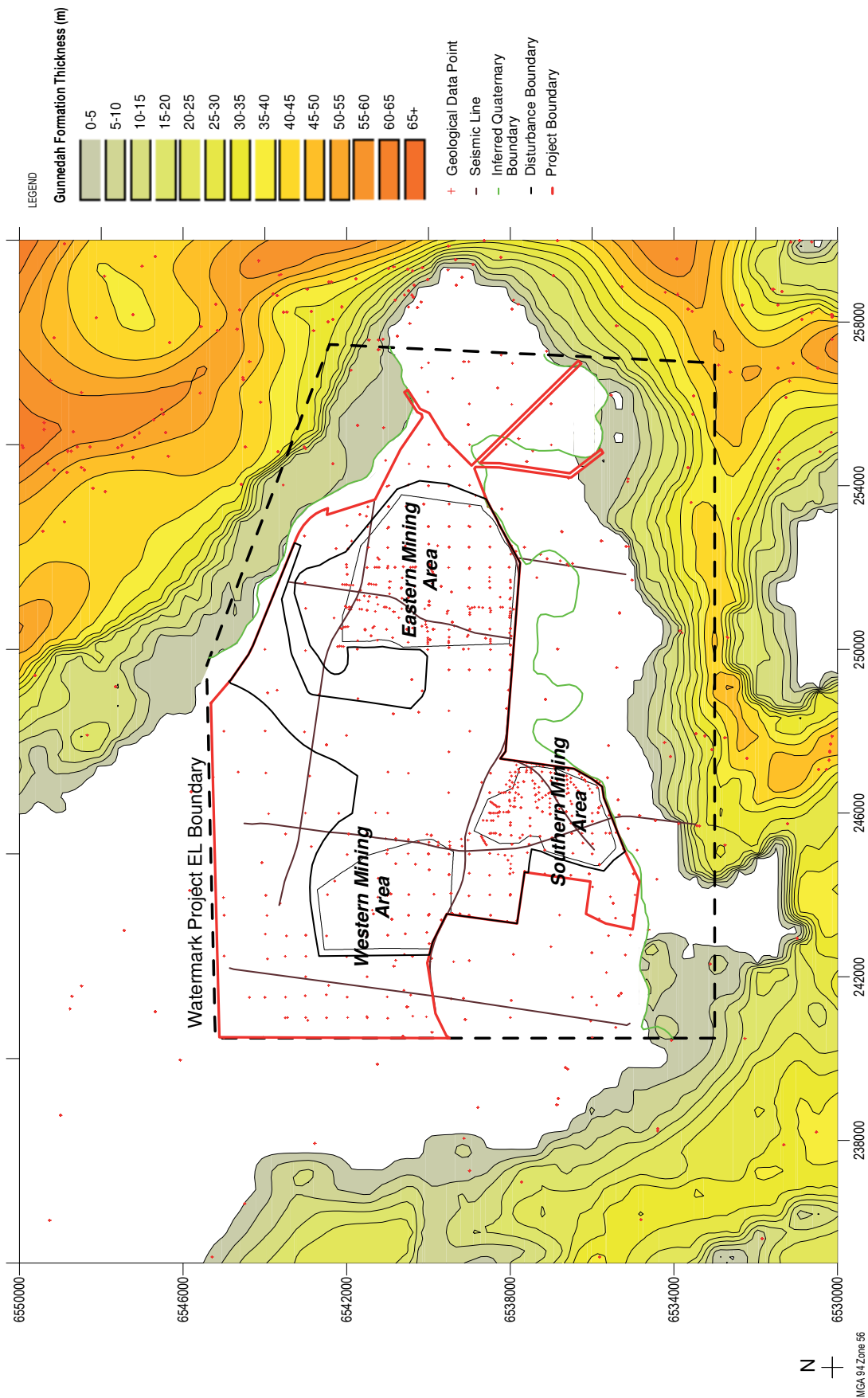
GHD (2009) correlated existing soil and geological maps and field observations, and concluded that the 1:100,000 Curlewis soil map defines the extent of the black soil plains for a substantial portion of the boundary. GHD modified the boundary in four locations based on the DTM and radiometrics data and confirmed this with field observations.

GSS Environmental (2012) built on the work undertaken by GHD and undertook a series of soil test pits to further define the black soil boundary.

In the Project Boundary, the Narrabri Formation has been described by GHD (2010b) as predominantly brown clay with small channel sands and gravel deposits usually less than 2 m. The Narrabri Formation is locally demonstrated to be clay dominant, consistent with the regional assessment of this formation. Figure 7.3 presents the extent of the black soil boundary overlying the inferred Quaternary boundary as defined by the Narrabri Formation.

The Gunnedah Formation is reported to consist of interbedded clays with sand and gravel layers (20 to 50% sand and gravel), where the sand and gravel can range in thickness from 2 m to 50 m (GHD, 2010a). The Gunnedah Formation is absent from the area fringing the Permian outcrop and has only been intersected along the southern EL 7223 boundary and the south-east corner of EL 7223. GHD (2010a) report that the Permian sediments are intersected at depths of between 20 m to 30 m below ground level in the area fringing the Permian outcrop.

The occurrence and thickness of the Gunnedah Formation was mapped using data collected from the Watermark exploration drilling program, and public domain on the government PINEENA database. Figure 7.3 presents the extent and thickness of the Gunnedah Formation aquifer, and demonstrates the significant distance between the proposed Mining Areas and the high yielding Gunnedah Formation.



Gunnedah Formation Thickness - Proximal to Watermark Project

Figure 7.3

Figure 7.3 demonstrates that the proposed Eastern and Southern Mining Areas are set back a minimum of approximately 1.0 km and 1.3 km respectively from the Gunnedah Formation. Figure 7.3 also shows that the proposed Eastern and Southern Mining Areas are set back a minimum of approximately 150 m from the inferred Quaternary Boundary and black soil plains.

7.1.4 Mining Area Buffer Zone Properties

The proposed Eastern and Southern Mining Areas are set back from the Upper Namoi alluvium by a minimum distance of approximately 150 m, and at least approximately 0.9 km from the Gunnedah Formation aquifer. This means a significant zone of bedrock, with a minimum width of 150 m will remain between the proposed Eastern and Southern Mining Areas and the black soil plains. If the mining area face in the Eastern and Southern Mining Areas adjacent to the buffer zone is sloped back for geotechnical reasons at an angle of about 45°, this will increase the buffer distance to approximately 260 m at the toe of the Southern Mining Area and approximately 230 m at the toe of the Eastern Mining Area. Figure 7.4 shows the concept of the buffer zone for the Southern Mining Area.

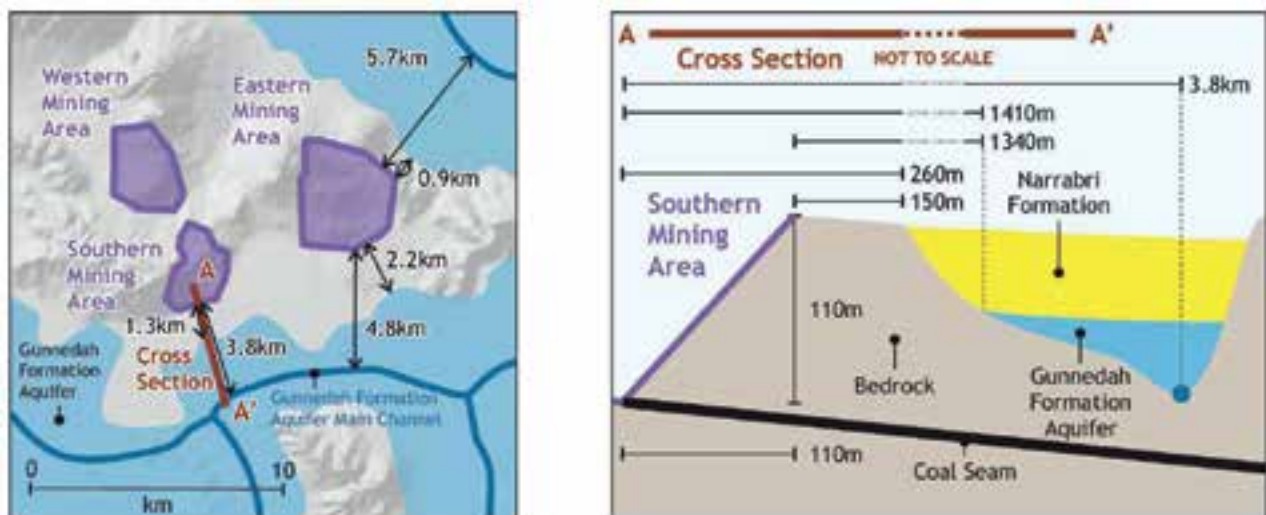


Figure 7.4: Southern Mining Area Setback Distances Schematic (not to scale)

A series of investigations that included drilling and geophysics were undertaken to assess the properties of the bedrock units within the buffer zone between the Eastern and Southern Mining Areas and the Upper Namoi alluvium.

(GHD, 2010b) carried out an electrical resistivity survey to further define the alluvial boundary and sub-surface geological features. The survey determined that the alluvial sediments gradually thicken to the south toward the southern Project Boundary, at which point the alluvium thickens rapidly. The thicker sections of the Quaternary Alluvium (Narrabri and Gunnedah Formations) are restricted to the southern Project Boundary and in the north-east corner of EL 7223 (GHD, 2010a).

The electrical resistivity survey identified potential faults located beneath the black soil plains, although the ability of these to transmit water could not be determined from the geophysics. The electrical survey was also used to assess the extent and nature of a palaeochannel that was identified during exploration drilling (bore hole WM0035). Resistivity profiles were carried out along The Dip Road and Watermark Gully. The palaeochannel sediments were assessed to have

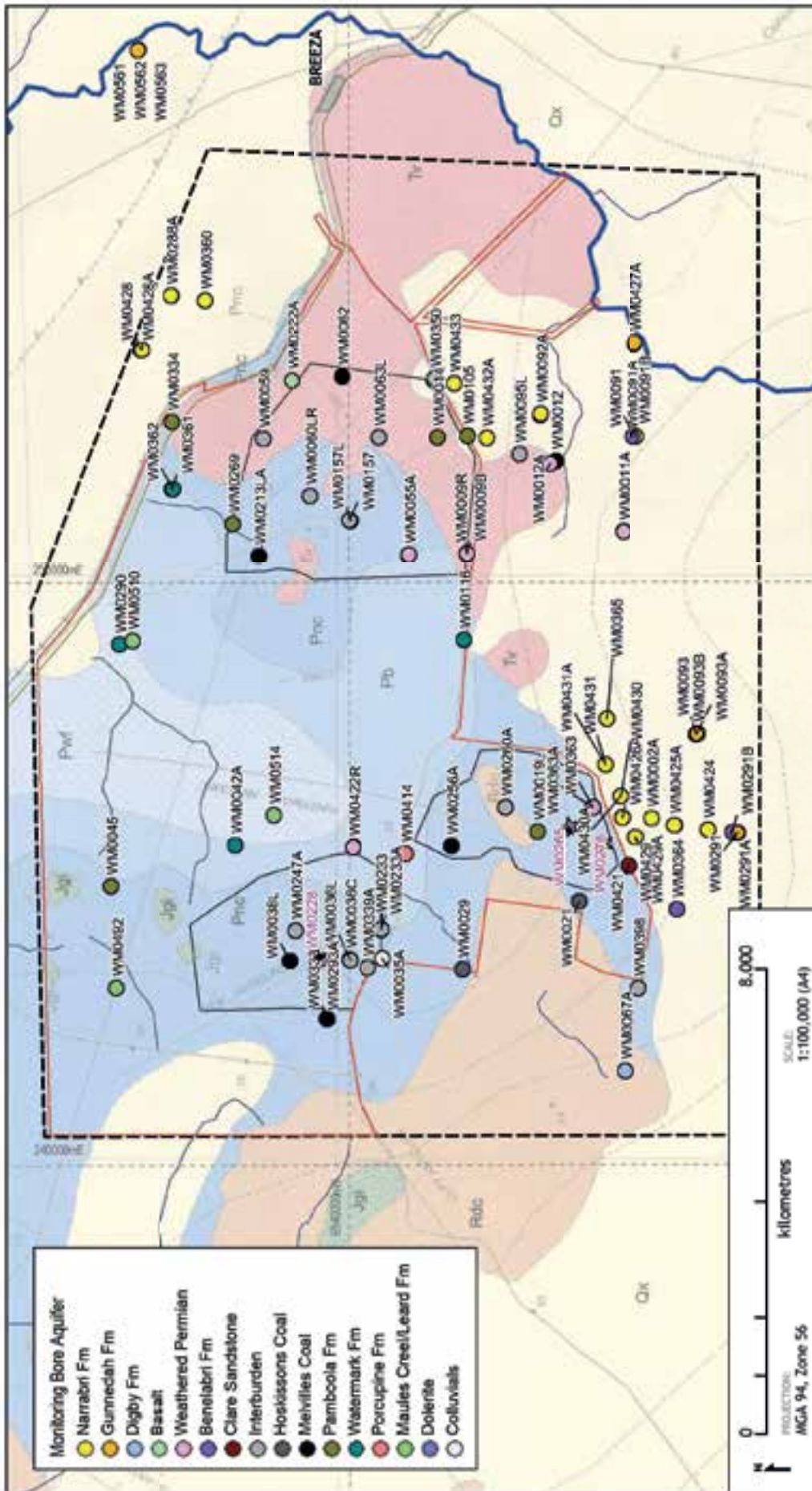


variable lithologies ranging from clays/silts to silty gravels. A number of structures were interpreted in the vicinity of the palaeochannel sediments from the geophysical survey (GHD, 2010b).

GHD (2010b) determined that the absence of the more permeable Gunnedah Formation adjacent to the Permian outcrop is likely to restrict the lateral connection between the Gunnedah Formation and the shallow Permian groundwater system. Groundwater discharging from any shallow colluvial and fractured rock aquifer system would encounter the low permeability Narrabri Formation clays restricting lateral flow and most likely discharge to surface. Areas where the Narrabri Formation is sandier have the potential to provide localised connections (GHD, 2010a).

GHD (2011b) installed an additional 16 monitoring bores using a sonic drill rig to define the properties of the bedrock within the land immediately to the south of the Southern and Eastern Mining Areas that will act as a buffer between the mining area and the alluvial aquifers. The bores targeted the shallow alluvium and weathered Permian zone. GHD collected water samples for analysis from each bore and conducted falling/rising head tests.

Table 7.1 summaries the geology of the screened zones, the water quality and hydraulic conductivity. Figure 7.5 shows the locations of the monitoring bores on EL 7223.



Watermark Coal Project (G1501)
Groundwater Assessment

Project Groundwater Monitoring Bore



DATE: 10/10/2012
FIGURE NO: 7.5

**Table 7.1: BUFFER ZONE BOREHOLES**

Bore	Screen Zone (mbgl)	Screen Formation and Lithology	Field TDS (mg/L)	Hydraulic Conductivity (m/day)
WM0426A	11 – 14	Narrabri Fm - clay with some sand and gravel	14,350	0.07
WM0424	31 - 37	Narrabri Fm - clayey sand with thin gravel bed	8,899	0.54
WM0430A	4 – 7	Narrabri Fm - plastic brown clay	15,470	0.48
WM0431A	3.5 – 6.5	Narrabri Fm - plastic brown clay	24,700	0.01
WM0429A	7 – 10	Narrabri Fm - sandy clay	7,599	0.03
WM0432A	10 – 13	Narrabri Fm - sandy gravelly clay	14,105	0.02
WM0002A	15.7 – 18.7	Narrabri Fm - silty sandy clay	-	-
WM0425A	24 – 30	Narrabri Fm - thin fine to medium grained sand beds	10,690	0.49
WM0433	11 – 14	Narrabri Fm-silty clay/gravelly clay	11,590	0.07
WM0002	45 – 48	Benelabri - sandstone/sand	-	-
WM0421	50 – 59	Benelabri Fm/Clare sandstone-	-	0.5
WM0291	75.7 – 81.7	Gunnedah Fm - conglomerate/clay	-	0.02
WM0350	18.8 – 27.8	Dolerite intrusive-	-	-
WM0105	21 – 30	Interburden inc D & E seams - conglomerate/carb clay/coal	-	0.02
WM0431	18.5 – 21.5	Weathered Benelabri Fm - silty clay/clayey gravel	21,970	0.02
WM0429	39 – 42	Weathered Clare sandstone - clayey sand	8,333	0.12
WM0425	34 – 37	Weathered Clare sandstone - extremely weathered, fine to medium grained sandstone	10,796	0.09
WM0426	21.5 – 27.5	Weathered Clare Sandstone - medium to coarse grained fractured sandstone	11,310	0.18
WM0430	20 – 23	Weathered Clare sandstone - silt and clayey sand	22,490	0.02
WM0432	21 – 24	Weathered Pamboola Fm-clayey gravel/clayey sand	22,360	0.12

Notes – hydraulic conductivity measured with either rising or falling head tests

When drilling was undertaken at a site where both the Narrabri and/or Gunnedah Formation was present, separate monitoring bores were constructed in the alluvium and underlying weathered rock. At these sites, the shallower paired bore was denoted with the suffix “A”.

The data from the bores indicated a low to moderate hydraulic conductivity in the buffer zone and saline to highly saline water quality. At sites with paired bores there appeared to be no significant difference between the salinity of water samples collected from the Narrabri Formation and the underlying weathered rock, suggesting hydraulic interconnection. The TDS of water from the bores was on average around 14,000 mg/L, which is classified as saline. The salinity means that much of the water has no beneficial use in agriculture or for maintenance of ecosystems. Sheep will tolerate water with a TDS from 10,000 mg/L to 13,000 mg/L, and beef cattle 5,000 mg/L to 10,000 mg/L (ANZECC 2000).

The slug testing recorded a hydraulic conductivity of between 0.01 m/day and 0.5 m/day for the Narrabri Formation, and 0.02 m/day and 0.2 m/day for the weathered bedrock. This indicates a low to moderate permeability, and demonstrates that the Narrabri Formation may behave as an aquitard, or a localised low permeability aquifer depending on the nature of the sediments. The similar water quality and hydraulic conductivity range suggests the Narrabri Formation and underlying zone of weathered rock are likely to behave as a single interconnected low yielding groundwater system in proximity to the proposed mining areas.

It is important to note that the slug tests measure the hydraulic conductivity in a small zone immediately around the screened section in a borehole. The slug tests do not account for geological boundaries and poor interconnection between fracture networks that serve to reduce the hydraulic conductivity on a wider scale. As such, the actual mine scale hydraulic conductivities are expected to be significantly less. This will need to be confirmed with continued monitoring during mining.

Groundwater Imaging (2012) further investigated the nature of the geology within the buffer zone with a Transient Electromagnetic Survey (TEM). The survey utilised a 6.5 x 5 m transmitter loop and receiver coils towed by a 4WD on a trailer.

Groundwater Imaging (2012) concluded that the TEM survey was not entirely successful as it “was difficult to distinguish weathered rock from alluvium in the acquired data. Unweathered basement rock was generally represented as resistive features, however, not all the basement rock is resistive.”

Comparison of the TEM dataset with the topography indicated the alluvial plains sediments, sediment is intercalated with colluvium, hide buried bedrock spurs. Figure 7.6 shows the modelled embayments and basement spurs near the proposed Eastern and Southern Mining Areas. Groundwater Imaging (2012) considered embayments were less than 10 m thick.

A potential zone of perched groundwater was also identified along The Dip Road between the proposed Mining Areas (refer Figure 7.6). A number of apparent steeply dipping features thought to be faults or steeply dipping low resistivity lithologies, such as hydrothermally weathered dykes were also identified from the survey. Figure 7.7 and Figure 7.8 show the structures.

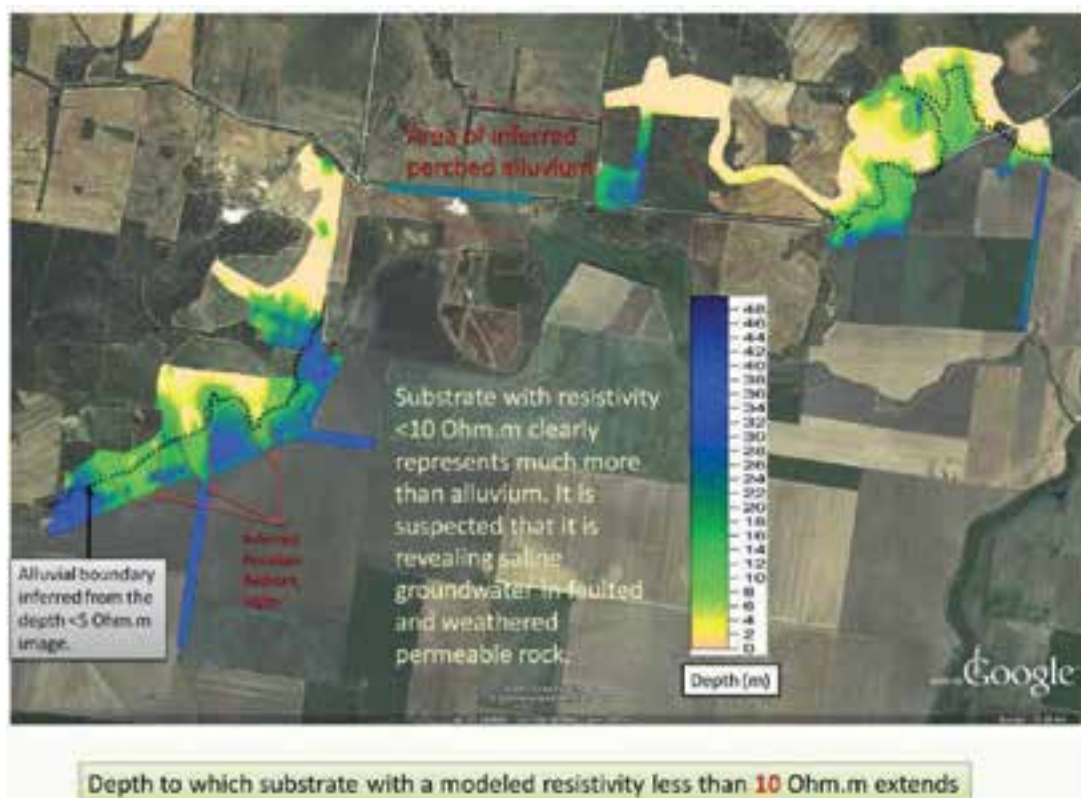


Figure 7.6: Resistivity Data Showing Buried Basement Spurs

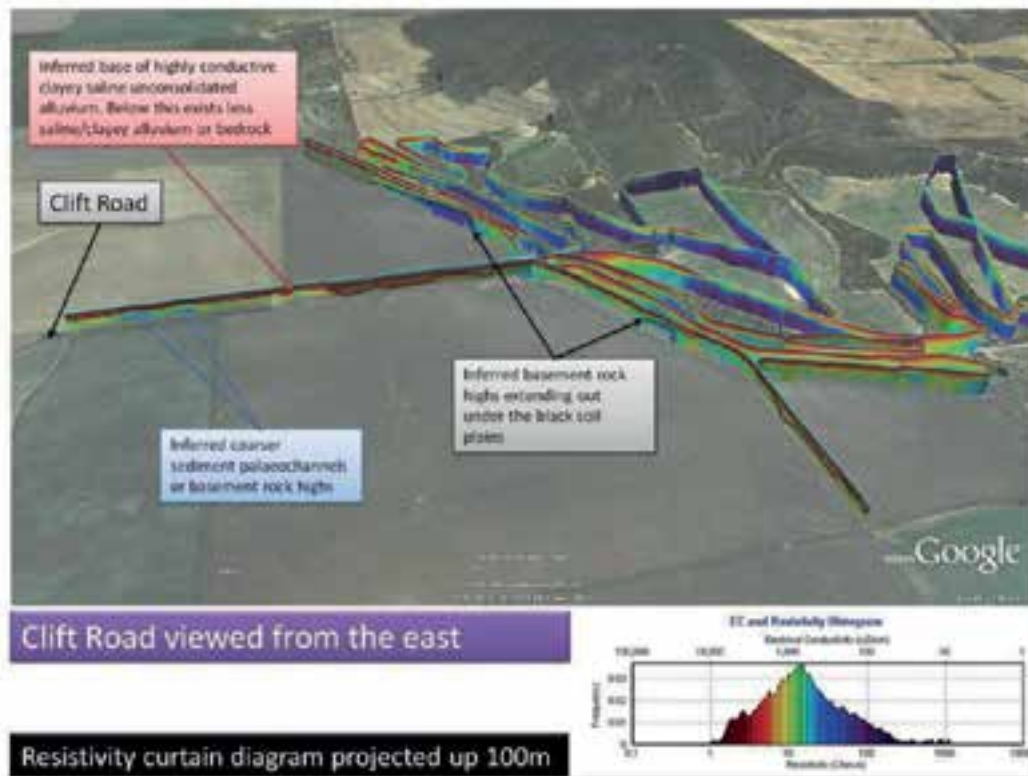


Figure 7.7: Resistivity Data Showing Structures

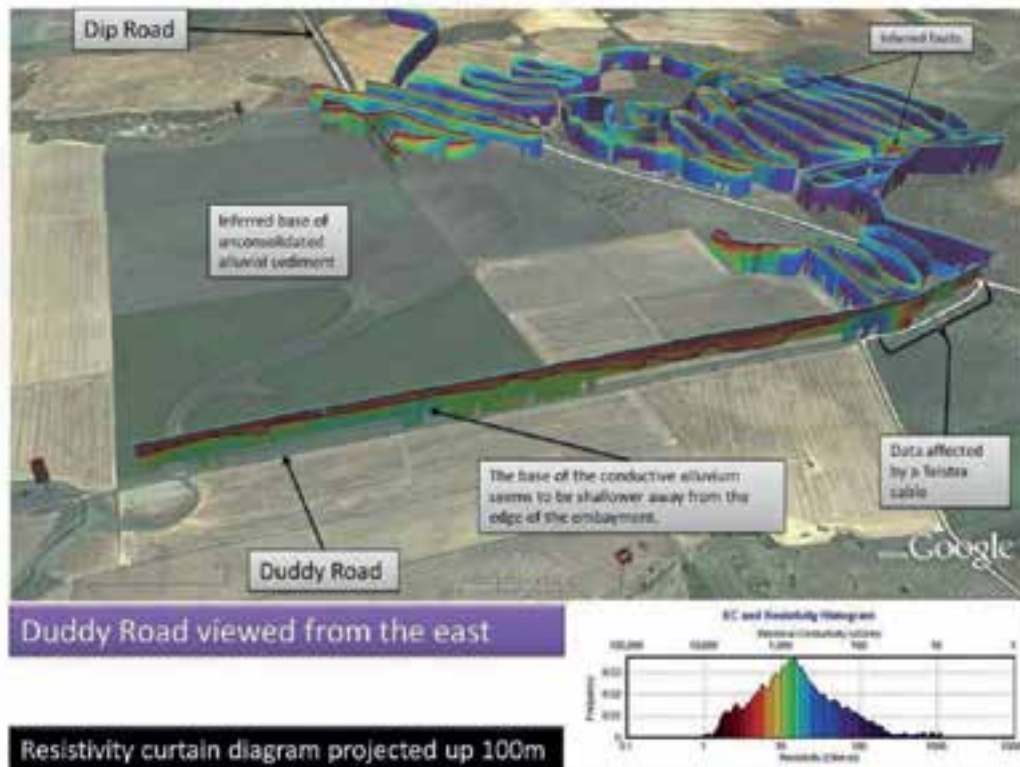


Figure 7.8: Resistivity Data Showing Potential Faults in Eastern Mining Area



The geophysical survey indicates that there may be some contrast in hydraulic properties of the alluvium in the embayment zones and the dividing bedrock spurs, however the proposed mining will not intersect the alluvial material, and therefore these structures are not likely to have a significant influence on the groundwater seepage within the Project. The survey did not suggest the presence of any large-scale bedrock structures that could connect the proposed mining areas with the Gunnedah Formation. To confirm the geophysical survey work, Section 14.0 recommends a monitoring network of bores to monitor for changes in groundwater conditions prior, during and after mining.

7.1.5 Hydraulic Parameters

The hydraulic properties of the Narrabri and Gunnedah Formations are highly dependent on the location and nature of the aquifer/aquitard material. Slug testing from the Project Boundary has recorded hydraulic conductivity values of the Narrabri Formation between 0.01 and 0.5 m/day.

Where clean sands and gravels are present in the Gunnedah Formation, the hydraulic conductivity is significantly higher. Dawes (2000) summarised hydraulic conductivity data from various sources as shown in Figure 7.9 and found most data is in the 10 m/day to 100 m/day range.

Further presentation of the hydraulic parameters of the alluvial units ascertained from GHD field and laboratory testing in the Project area is presented in Section 9.2.3 and in the GHD Stage 4 Report (GHD, 2012).

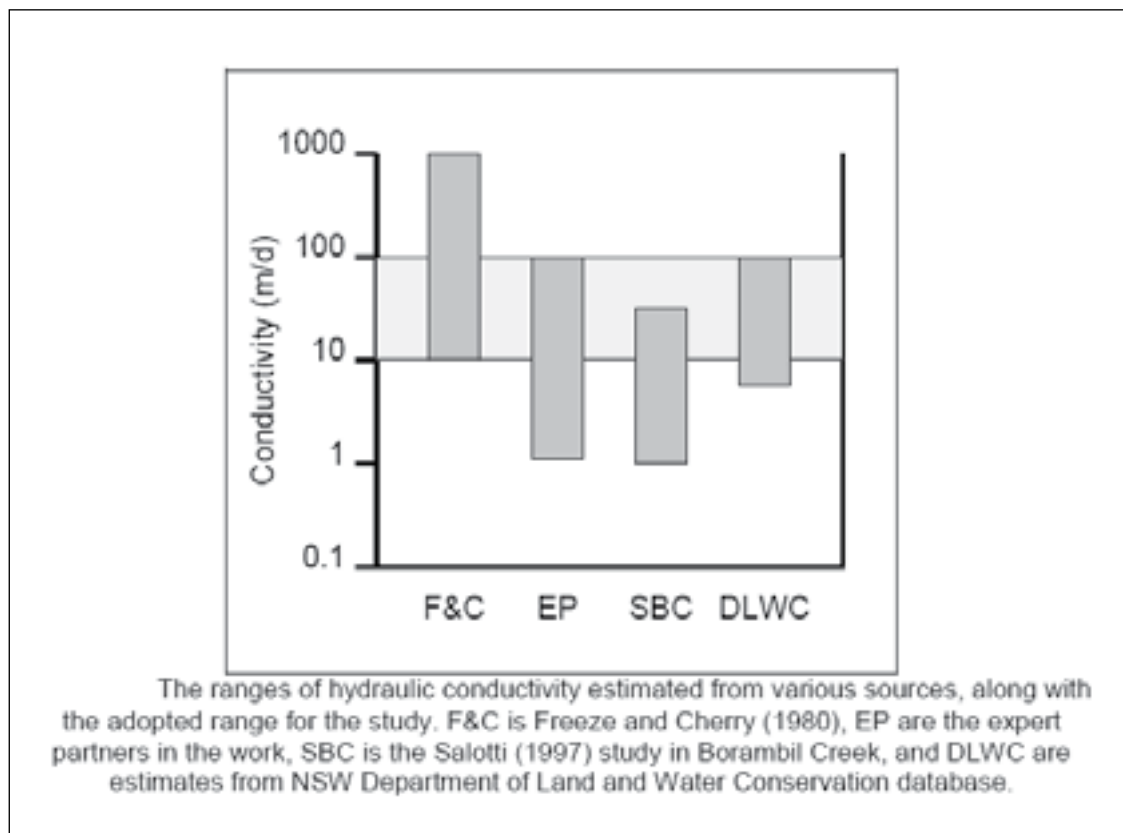


Figure 7.9: Gunnedah Formation Hydraulic Conductivity – from Dawes (2000)



Berhane (2001) noted that no aquifer test data was available for Zone 7, but estimated horizontal conductivities for coarse-grained sediments from drillers logs are in the range from 1 m/day to 10 m/day.

Shenhua Watermark has installed four monitoring bores within the Gunnedah Formation and tested the hydraulic conductivity with slug tests. Monitoring Bore WM0427, located adjacent to the Mooki River close to the southern boundary of EL 7223 recorded a hydraulic conductivity of 28 m/day.

The overlying Narrabri Formation, which is widely recognised as having a more clay dominant nature, has recorded a hydraulic conductivity of between 0.01 and 0.5 m/day within the Project Boundary.

7.1.6 Yields and Usage

The Gunnedah Formation typically has high permeability and yield and is commonly accepted as the primary aquifer system in the region (GHD, 2009). Groundwater from the Gunnedah Formation is used extensively for irrigation, stock and domestic use and for the town water supply at Gunnedah, Breeza, Curlewis and Quirindi.

A review of the NOW groundwater data (GHD, 2011a) indicates a substantial variation in yield, and hence hydraulic conductivity for the Gunnedah Formation around EL 7223. The highest yielding bores are located in the thick gravel sediments located to the east of the Mooki River, which is consistent with historical mapping. Broughton (1994) identified a high yield (greater than 50 L/s) zone that is located to the east of EL 7223. The yields decrease down to between 5 – 50 L/s in the south-east corner of EL 7223 and further reduce to 0.5 L/s – 5 L/s in the southern and north-eastern portions of the lease.

SWS (2010) have reported that historical, over-abstraction of groundwater within the alluvium has resulted in falling groundwater levels in several areas of the Namoi River catchment. In particular, the aquifer at the basin margins are being dewatered (e.g. near Wee Waa) and abstraction has resulted in the aquifer becoming unconfined.

There are 508 groundwater monitoring and pumping bores within a 10 km radius of the proposed Mining Areas. Seventy-one of these bores are licenced and metered by NOW for water allocation purposes. Table 7.2 presents the details for the 71 licenced bores with the locations shown in Figure 7.10.

Table 7.2: LICENCED PUMPING BORES WITHIN 10 KM OF WATERMARK MINING AREAS

Work Number	Easting (m)	Northing (m)	Licence	Work Type	Owner Type	Completed Depth (mbgl)	Parish	Salinity Description ppm	Average Annual Recorded Extraction (ML)
GW014665	257822	6544668	90BL119002	Bore	Private	44.2	TEXAS	0-500	30.5
GW015505	247716	6534230	90BL010506	Bore	Private	35.1	CLIFT	501-1000	131.3
GW022348	256450	6529598	90BL014947	Bore	Private	45.7	FERRIER	Good	25.1
GW022620	247682	6530161	90BL015145	Bore	Private	48.8	DOONA	(Unknown)	1.4
GW022621	247496	6530187	90BL015146	Bore	Private	40.8	DOONA	(Unknown)	66.4
GW022622	247284	6530213	90BL015147	Bore	Private	45.1	DOONA	(Unknown)	5.9
GW022826	258131	6530130	90BL015237	Bore	Private	45.1	WALLALA	0-500	11.1
GW022827	258061	6530868	90BL015238	Bore	Private	43	FERRIER	Good	5.2
GW022847	256751	6529173	90BL015084	Bore	Private	49.4	WALLALA	Good	5.2
GW022977	247867	6530134	90BL022082	Bore	Private	148.4	DOONA	501-1000	1.6

**Table 7.2: LICENCED PUMPING BORES WITHIN 10 KM OF WATERMARK MINING AREAS**

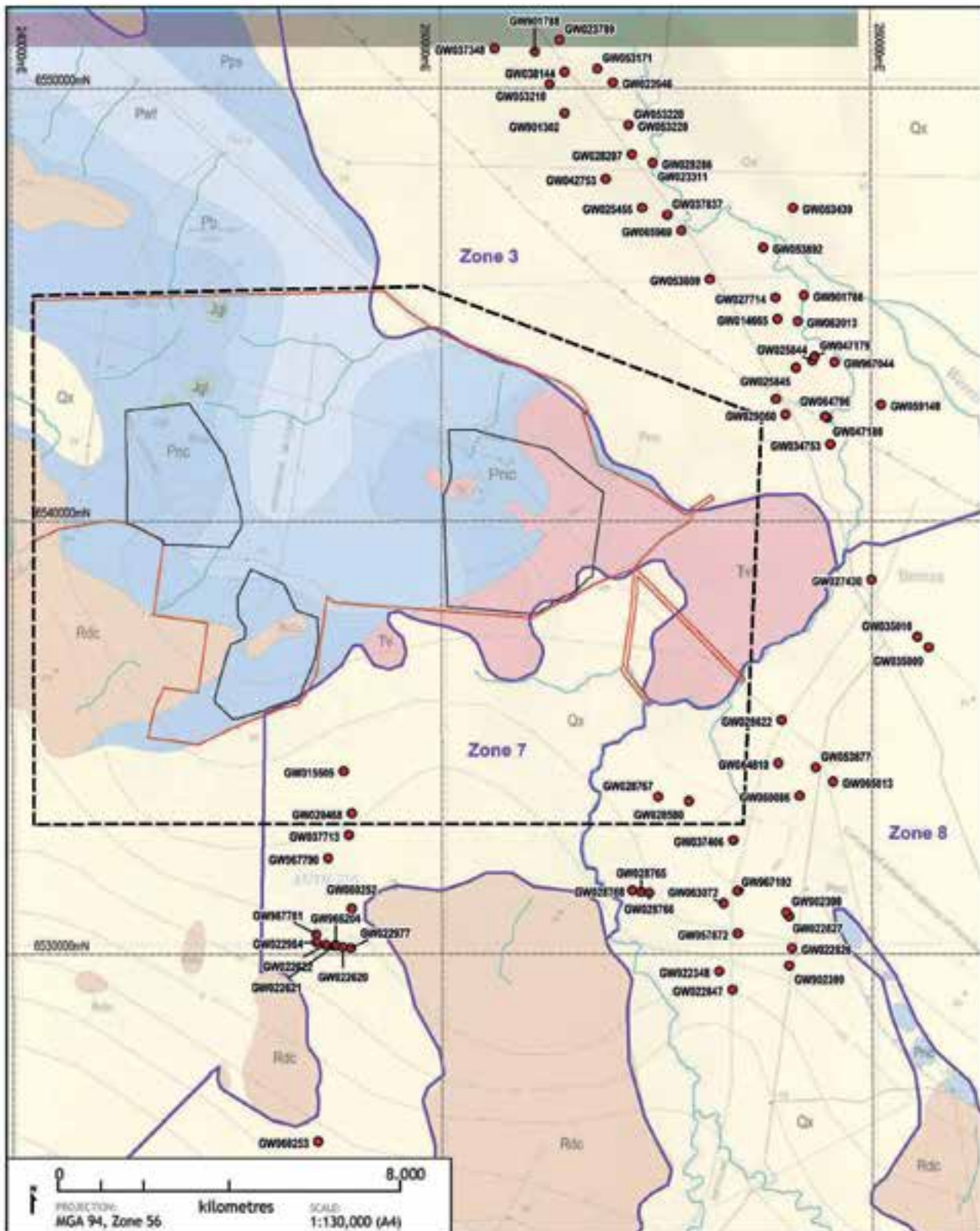
Work Number	Easting (m)	Northing (m)	Licence	Work Type	Owner Type	Completed Depth (mbgl)	Parish	Salinity Description ppm	Average Annual Recorded Extraction (ML)
GW022984	247071	6530269	90BL015148	Bore	Private	45.1	DOONA	(Unknown)	94.8
GW023311	254934	6548274	90BL021133	Bore	Private	79.6	CURLEWIS	(Unknown)	24.3
GW023789	252771	6551115	90BL017022	Bore	Private	53.3	CURLEWIS	(Unknown)	26.9
GW023946	254013	6550127	90BL017305	Bore	Private	56.7	CURLEWIS	(Unknown)	221.5
GW025455	254690	6547234	90BL030305	Bore	Private	79.9	CURLEWIS	0-500	175.3
GW025844	258639	6543701	90BL017657	Bore	Private	53.9	BREEZA	0-500	82.8
GW025845	258245	6543538	90BL017655	Bore	Private	51.2	BREEZA	0-500	0.8
GW027430	259999	6538647	90BL019872	Bore	Private	64.3	MOOKI	(Unknown)	384.9
GW027714	257784	6545160	90BL019874	Bore	Private	81.4	TEXAS	0-500	102.9
GW028286	254934	6548274	90BL016203	Bore	Private	59.4	CURLEWIS	0-500	416.7
GW028287	254449	6548473	90BL015627	Bore	Private	53.9	CURLEWIS	0-500	150.1
GW028580	255750	6533526	90BL023743	Bore	Private	52	FERRIER	Good	195.5
GW028622	257903	6535394	90BL020452	Bore	Private	64.6	FERRIER	Good	159.5
GW028765	254635	6531435	90BL022463	Well & Bore	Private	48.8	FERRIER	Good	437.4
GW028766	254821	6531409	90BL022466	Well & Bore	Private	45.7	FERRIER	(Unknown)	437.4
GW028767	255033	6533633	90BL022464	Bore	Private	42.7	FERRIER	Good	236.3
GW028768	254423	6531461	90BL022465	Well & Bore	Private	48.8	FERRIER	Good	318.9
GW029060	258005	6542454	90BL020223	Bore	Private	58.2	BREEZA	(Unknown)	134.0
GW029062	257785	6542818	90BL020222	Bore	Private	50	BREEZA	(Unknown)	103.2
GW029062	257785	6542818	90BL020222	Bore	Private	50	BREEZA	(Unknown)	408.6
GW029468	247898	6533248	90BL018607	Bore	Private	64.6	CLIFT	(Unknown)	349.5
GW034753	259054	6541769	90BL031475	Bore	Private	59.4	BREEZA	0-500	29.9
GW035009	261332	6537075	90BL030243	Bore	Private	63.7	FERRIER	-	10.9
GW035010	261061	6537316	90BL030244	Bore	Private	67	FERRIER	-	0.3
GW037348	251264	6550925	90BL030455	Bore	Private	74.9	CURLEWIS	-	269.8
GW037406	256777	6532625	90BL030897	Bore	Private	66.1	FERRIER	Good	141.0
GW037713	247831	6532753	90BL030403	Bore	Private	64	DOONA	Good	248.9
GW037837	255276	6547075	90BL031115	Bore	Private	59.1	TEXAS	-	135.4
GW038144	252894	6550378	90BL100316	Bore	Private	76.2	CURLEWIS	(Unknown)	205.4
GW042753	253840	6547899	90BL031566	Bore	Private	56.7	CURLEWIS	0-500 ppm	393.3
GW047179	258695	6543803	90BL108124	Bore	Private	71.6	BREEZA	(Unknown)	68.3
GW047180	258987	6542384	90BL108125	Bore	Private	65.5	BREEZA	(Unknown)	188.5
GW053171	253652	6550449	90BL118404	Bore	Private	79.2	CURLEWIS	(Unknown)	108.3
GW053218	252539	6550087	90BL118917	Bore	Private	64	CURLEWIS	(Unknown)	88.2
GW053220	254380	6549149	90BL105666	Bore	Private	87.2	CURLEWIS	(Unknown)	70.7
GW053220	254380	6549149	90BL105666	Bore	Private	87.2	CURLEWIS	(Unknown)	27.4
GW053439	258187	6547234	90BL118230	Bore	Private	59	TEXAS	(Unknown)	327.0
GW053609	256262	6545582	90BL118424	Bore	Private	65	BREEZA	(Unknown)	57.5
GW053877	258696	6534303	90BL122877	Bore	Private	38.7	FERRIER	Good	3.9
GW053892	257490	6546318	90BL103305	Bore	Private	56.5	TEXAS	(Unknown)	6.1
GW057872	256880	6530471	90BL122995	Bore	Private	74	FERRIER	Good	30.5
GW059148	260224	6542689	90BL120673	Bore	Private	81.5	MOOKI	0-500	131.3
GW060086	258314	6533647	90BL130804	Bore	Private	44.2	FERRIER	Good	25.1
GW060252	247898	6531060	90BL132581	Bore	Private	148.4	DOONA	(Unknown)	1.4
GW060253	247102	6525678	90BL132587	Bore	Private	26.8	DOONA	(Unknown)	66.4
GW062013	258298	6544610	90BL132073	Bore	Private	64	TEXAS	(Unknown)	5.9
GW063072	256546	6531172	90BL130841	Bore	Private	55.7	FERRIER	(Unknown)	11.1
GW064796	258933	6542413	90BL137572	Bore	Private	73	BREEZA		5.2
GW064810	257820	6534406	90BL138227	Bore	Private	54.3	FERRIER		5.2
GW065013	259100	6533973	90BL130616	Bore	Private	90	FERRIER		1.6

**Table 7.2: LICENCED PUMPING BORES WITHIN 10 KM OF WATERMARK MINING AREAS**

Work Number	Easting (m)	Northing (m)	Licence	Work Type	Owner Type	Completed Depth (mbgl)	Parish	Salinity Description ppm	Average Annual Recorded Extraction (ML)
GW065969	255606	6546710	90BL142816	Bore		83	TEXAS		94.8
GW901302	252890	6549423	90BL152440	Bore		63.4	CURLEWIS		24.3
GW901786	258438	6545209	90BL143828	Bore		70.1	TEXAS		26.9
GW901788	252200	6550844	90BL150191	Bore		67	CURLEWIS		221.5
GW902398	258006	6530959	90BL247181	Bore		67	WALLALA		175.3
GW902399	258061	6529728	90BL247182	Bore		67	WALLALA		82.8
GW965204	247520	6530201	90BL249671	Bore	Private	48.5	DOONA	Good	0.8
GW967044	259147	6543674	90BL112440	Bore		63	BREEZA		384.9
GW967192	256884	6531456	90BL249012	Bore		75	FERRIER		102.9
GW967781	247063	6530457	90BL252103	Bore	Private	50	DOONA		416.7
GW967790	247346	6532215	90BL252465	Bore	Private	70	DOONA		150.1

Note: Co-ordinates are in GDA94
mbgl – metres below ground level

Figure 7.11 displays the average rate of groundwater extraction for each bore from the period 1980 to mid-2011. Figure 7.12 illustrates average pumping rates during periods of recorded pumping, and illustrates average operational rates to account for bores which have only recently been installed, or bores which are operated infrequently. Records show that the highest rates occur from the Mooki River and Quirindi Creek palaeochannel where the alluvial aquifer is thickest.



LEGEND:

- Groundwater Management Zone
- Proposed Mining Area
- EL 7223
- Licenced Pumping Bore
- Drainage Line / Creek
- Project Boundary

- Geology -

- Qx undifferentiated sediments
- Tv undifferentiated volcanics
- Glenrowan Intrusives
- Rdc Digby Formation
- Pnc Nea + Coogal Subgroups
- Pb Brigalow Fm./Pamboula Fm.
- Pwf Watermark Formation
- Pps Percupine Formation

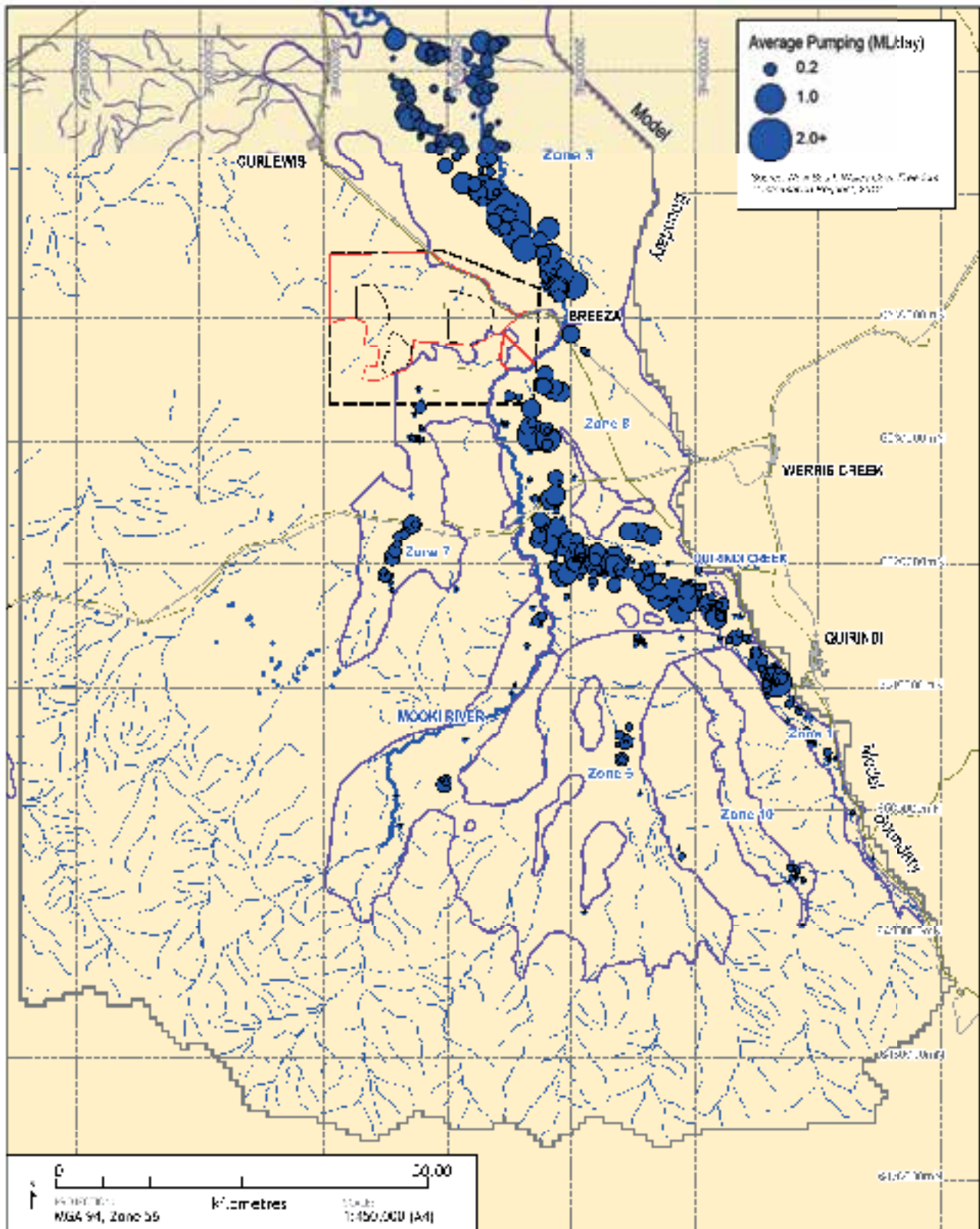
Watermark Coal Project (G1501)
Groundwater Assessment

Groundwater Pumping Bores Within 10km Radius of Open Cut Mining Areas



DATE:
10/10/2012

FIGURE No:
7.10



Legend

- L. 122
- Project Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

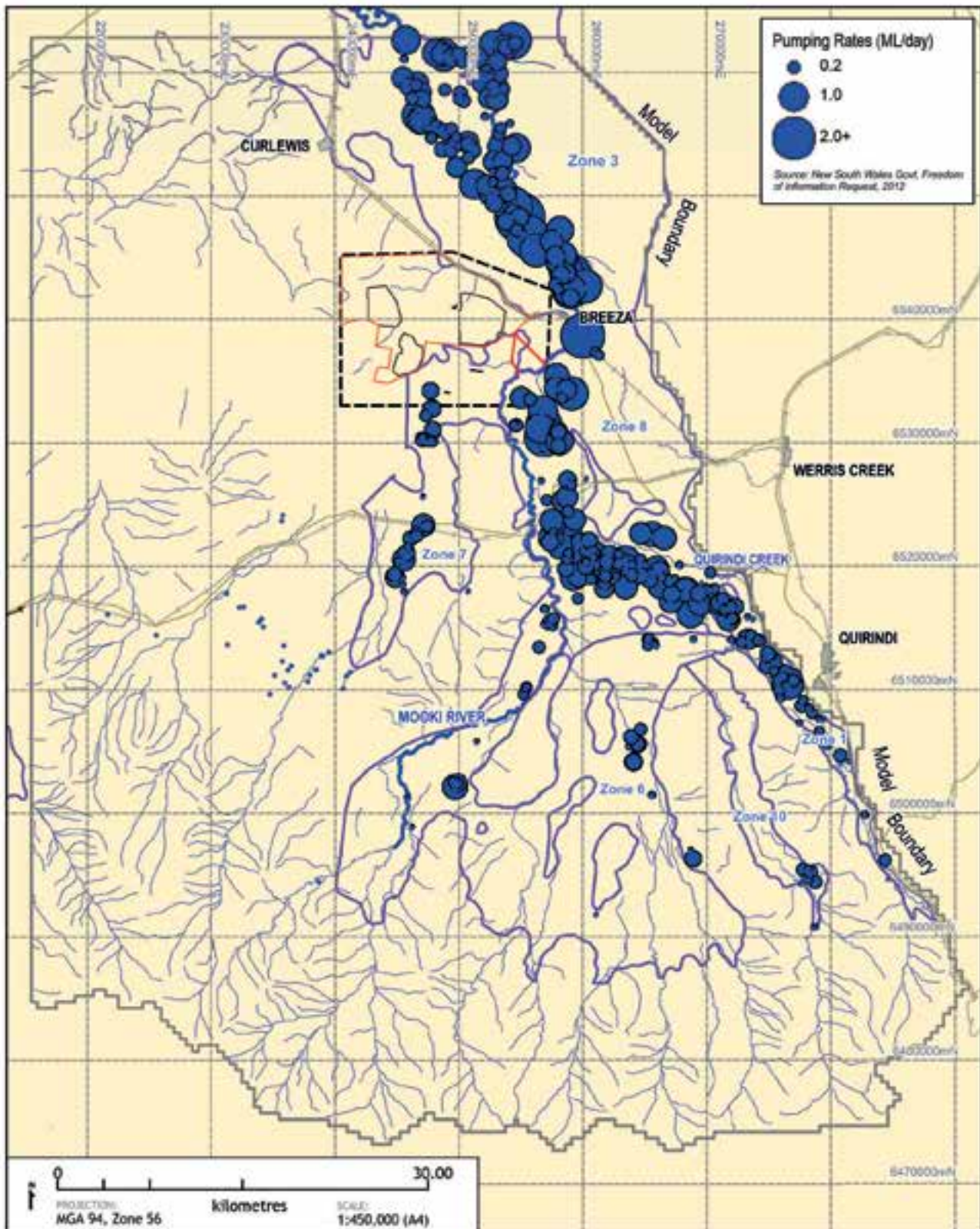
Watermark Coal Project (G1517)
Groundwater Assessment

Project Groundwater Pumping -
Average (1980 - mid 2011)



DATE:
18/10/2012

TIME:
7.11



LEGEND:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

Watermark Coal Project (G1501)
Groundwater Assessment

Project Groundwater Pumping - Recorded Averages



DATE:
10/10/2012

FIGURE No:
7.12



Figure 7.13 and Figure 7.14 (Barrett, 2010) provide a summary of annual groundwater usage for the Upper Namoi groundwater zones up to and including the 2009/2010 financial year. Extraction in all three zones proximal to the Project (Zones 3, 7 & 8) has been below the Government prescribed limits since 2007/2008.

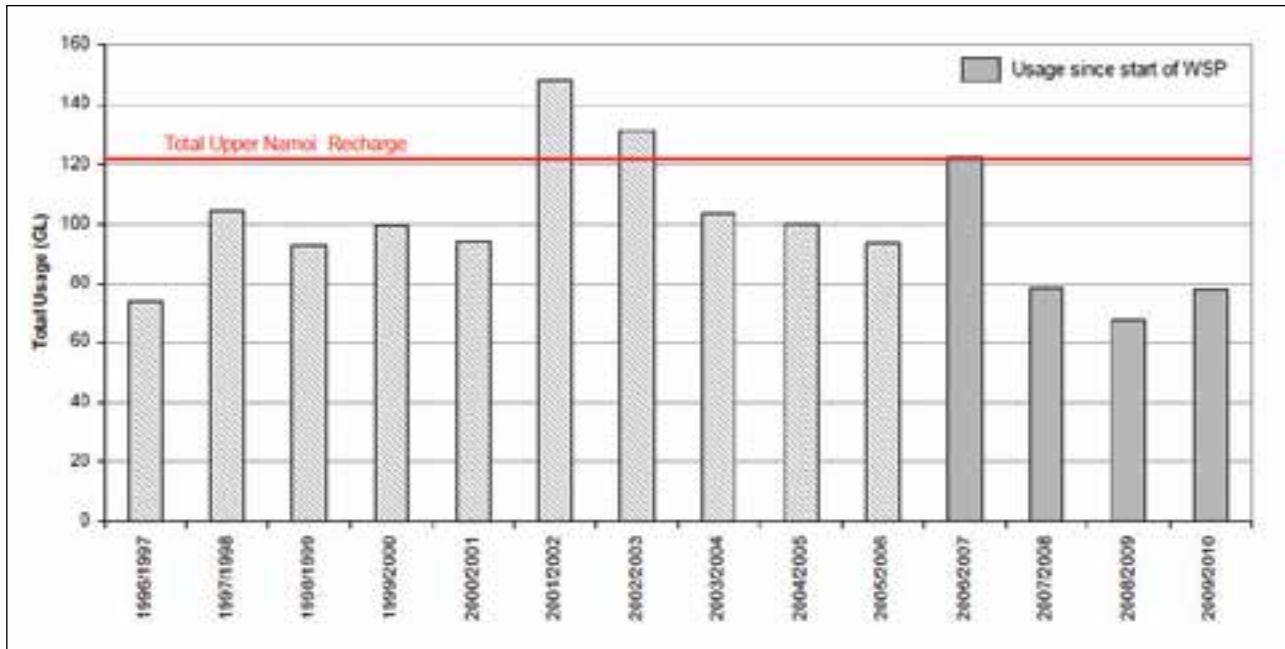


Figure 7.13: Total Upper Namoi Usage 1996/97 to 2009/10 – from Barrett (2010)

Water Source	Extraction Limit AAL, plus SWAL Access	2006-2007			2007-2008			2008-2009			2009-2010		
		Extraction Limit AAL, plus SWAL Access plus 5%	Usage	% of Usage per WSP Extraction Limit	Extraction Limit AAL, plus SWAL Access plus 5%	Usage	% of Usage per WSP Extraction Limit	Extraction Limit AAL, plus SWAL Access plus 5%	Usage	% of Usage per WSP Extraction Limit	Extraction Limit AAL, plus SWAL Access plus 5%	Usage	% of Usage per WSP Extraction Limit
Zone 1	2,900	4,009	2,236	56 %	4,009	1,530	38 %	3,792	1,260	33 %	3,570	1,425	40 %
Zone 2	7,200	13,189	12,219	93 %	12,861	10,626	83 %	11,926	10,214	86 %	11,310	6,860	61 %
Zone 3	17,300	26,787	28,068	105 %	24,840	18,008	73 %	24,094	9,591	40 %	23,347	17,800	77 %
Zone 4	25,700	39,874	30,654	77 %	38,440	23,455	61 %	37,018	20,294	55 %	35,578	18,023	51 %
Zone 5	16,000	19,648	19,697	100 %	19,640	16,456	84 %	19,648	12,426	63 %	19,648	16,542	84 %
Zone 6	14,000	14,700	1,952	13 %	14,700	1,023	7 %	14,700	676	5 %	14,700	1,132	8 %
Zone 7	3,700	3,892	2,876	74 %	3,892	946	24 %	3,892	941	24 %	3,892	696	18 %
Zone 8	10,000	21,899	19,028	87 %	20,877	11,495	55 %	20,455	9,643	47 %	19,933	11,020	55 %
Zone 9	11,400	11,979	3,256	27 %	11,570	1,911	16 %	11,978	2,141	18 %	11,970	1,449	12 %
Zone 10	4,500	4,725	0	0 %	4,725	0	0 %	4,725	17	0 %	4,725	0	0 %
Zone 11	3,200	3,326	988	30 %	3,326	467	14 %	3,326	641	19 %	3,326	691	21 %
Zone 12	2,000	2,914	1,206	41 %	2,914	573	20 %	2,914	432	15 %	2,914	626	22 %

SWAL – Supplementary Water Access Licences
AAL – Aquifer Access Licences
WSP – Water Sharing Plan

Figure 7.14: Groundwater Usage by Zones (2006 to 2010) – from Barrett (2010)



7.1.7 Hydraulic Gradients and Water Levels

The regional direction of flow typically follows topography, with groundwater flowing from the highlands of the Liverpool Range in the south of the catchment down into the Upper Namoi alluvial floodplain and continuing to flow to the north along the alignment of the Quirindi Creek and Mooki River. Groundwater levels within the Tertiary basalts of the Liverpool Ranges can reach around 1000 mAHD down to about 250 mAHD in the lower lying Mooki River plain towards the south of the Project. Bedrock outcropping through the alluvial plains can support elevated groundwater levels with gradients following topography down to the alluvial plains. This is the case within the Project Boundary; however, some outcrops are understood to show limited mounding of groundwater including the Doona Point and Spring Ridge areas. Figure 7.15 shows the observed alluvial and Tertiary unit groundwater levels within the Project Boundary and surrounding region from June 2010. Figure 9.20 to Figure 9.23 included in Section 9.2.8 show the modelled groundwater levels in the alluvium and Permian formations, and highlight the differences between the shallow and deeper units. In the shallow geological units the potentiometric surface and hydraulic gradients are influenced by the presence of topographic features, however with increasing depth the surface becomes more subdued with a more even gradual hydraulic gradient from south to north. Generally under the Liverpool Plains there is an upward gradient, with groundwater flow from the bedrock into the overlying alluvium.

Groundwater flow rates in the alluvium east of Caroonah are estimated to be 2 m/yr to 10 m/yr. Groundwater flow in the alluvium is constricted at the Breeza Gap, and over abstraction between Breeza and Carroll/Gunnedah has resulted in a reversal of groundwater flow in this area, such that locally groundwater flows south (SWS, 2010).

Barrett (2010) examined the hydrographs for monitoring bores across all 12 zones in the Upper Namoi. It was concluded, *“since 2000 the overall water level trend in the Upper Namoi alluvium has been declining, however the drawdowns in the last two years have not been as significant compared to previous years. This is due to a decline in usage resulting from reduced access to entitlement and the wetter conditions since 2008.”*

A review of groundwater levels in the NOW monitoring bore network indicated a general correlation between water level and the CRD (cumulative rainfall departure) in the area up until the 1990s. From approximately 1990 onwards, groundwater levels tend to decline, even when rainfall has been above average. From the start of the *Water Sharing Plan (Upper and Lower Namoi Groundwater Sources 2003)* in 2006/2007, the extraction of groundwater has been reducing, but groundwater levels have still continued to decline despite this. At some sites, the aquifer has become unconfined as groundwater levels have continued to decline.

Since the 1960s, NOW have been gradually installing a network of monitoring bores in Narrabri and Gunnedah Formations. A large number monitoring bores and records now exist. The figures below are examples of water level trends that have been observed in the monitoring network:

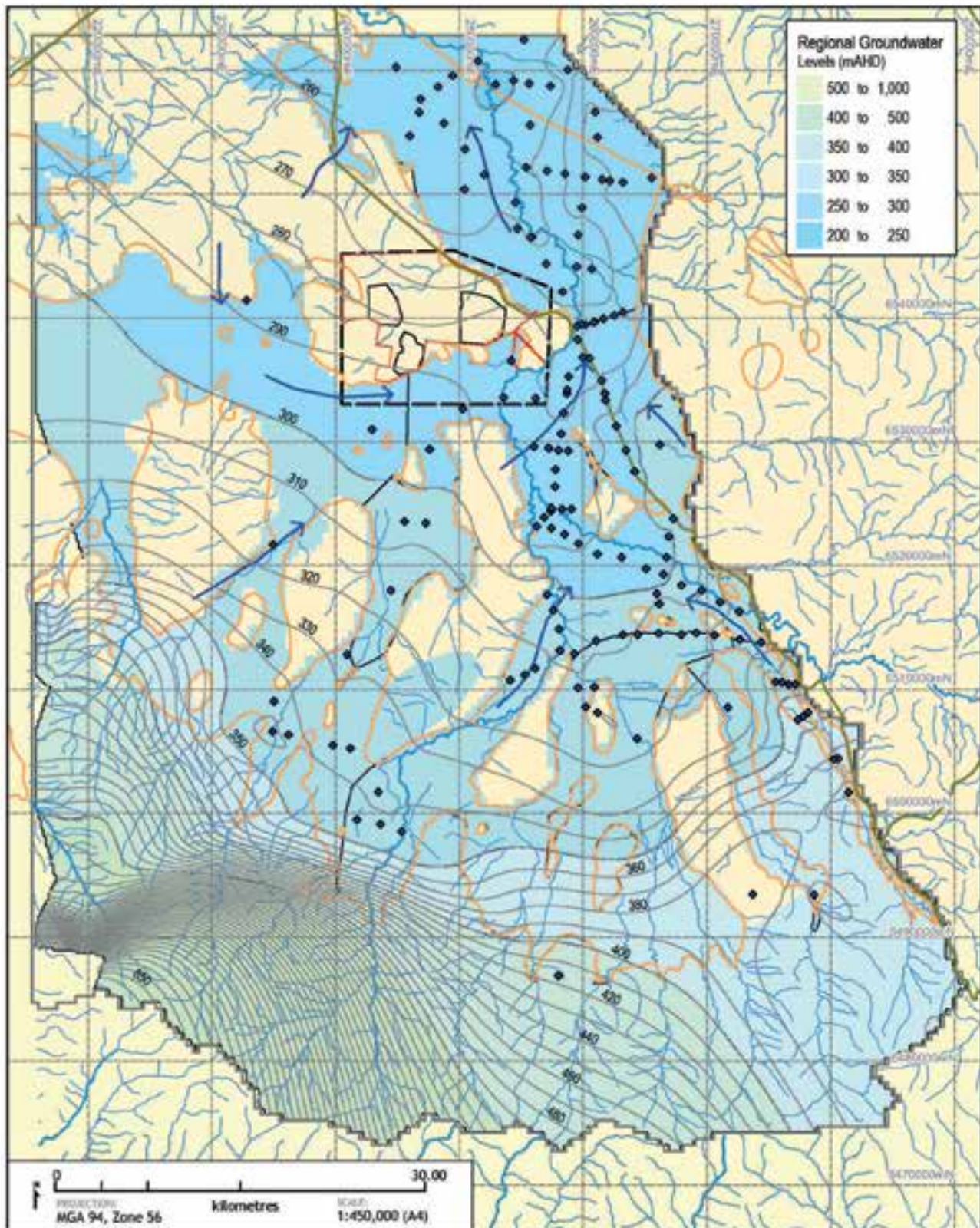
- Figure 7.16 – shows declining trend in groundwater levels, despite being located close to the Mooki River;
- Figure 7.17 – shows declining trend at Mooki River/Quirindi Creek Confluence;
- Figure 7.18 – shows significant water level fluctuations due to high extraction rates;
- Figure 7.19 – shows declining water levels and change from confined to unconfined conditions;
- Figure 7.20 – shows the influence of high extraction rates at Quirindi Creek area; and



- Figure 7.21 – the less significant decline in groundwater levels in bores closer to the Liverpool Ranges.

Figure 7.16 shows the hydrograph for monitoring bore GW030000, located 2 km east of the Project Boundary, which demonstrates the declining water level trend. This bore is located proximal to the Mooki River and shows minimal response to the Gunnedah Formation aquifer following major flooding events.

Fluctuations in groundwater levels in monitoring bores correlate with cropping practices. Irrigation of cotton is undertaken during the 'growing season' (November to February), resulting in increased extraction from Gunnedah Formation. Recharge from diffuse rainfall and irrigation during these months appears to be limited as the more transmissive Gunnedah Formation aquifer is capped by the clay dominant Narrabri Formation. As a result, recharge through the Narrabri Formation is less than the pumping rate from the Gunnedah aquifer during the growing season and water levels decline at this time of year. Water levels then rise again during the winter when irrigation is limited.



LEGEND:

- | | |
|---------------------------------------|-------------------------------|
| — Proposed Mining Area | — Groundwater Contour (mAHID) |
| — EL 7223 | □ Alluvium (1:250k) |
| — Drainage Line / Creek | □ Model Boundary |
| → Inferred Groundwater Flow Direction | □ Project Boundary |
| + Regional Observation Bore | |

Watermark Coal Project (G1501)
Groundwater Assessment**Regional Groundwater Levels -
June 2010 (Alluvial & Tertiary Aquifers)**DATE:
10/10/2012FIGURE No:
7.15

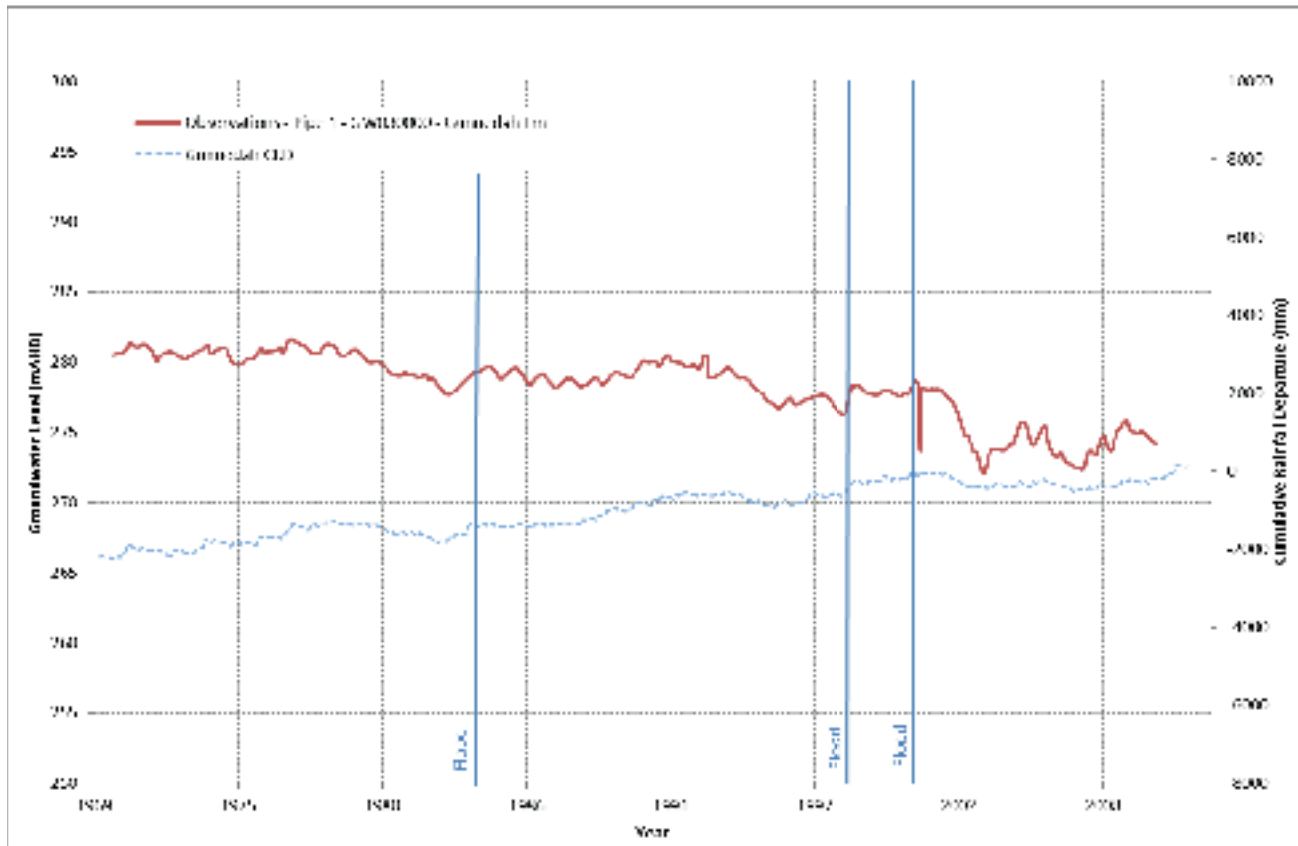


Figure 7.16: Hydrograph - Bore GW030000 – Village of Breeza / Mooki River

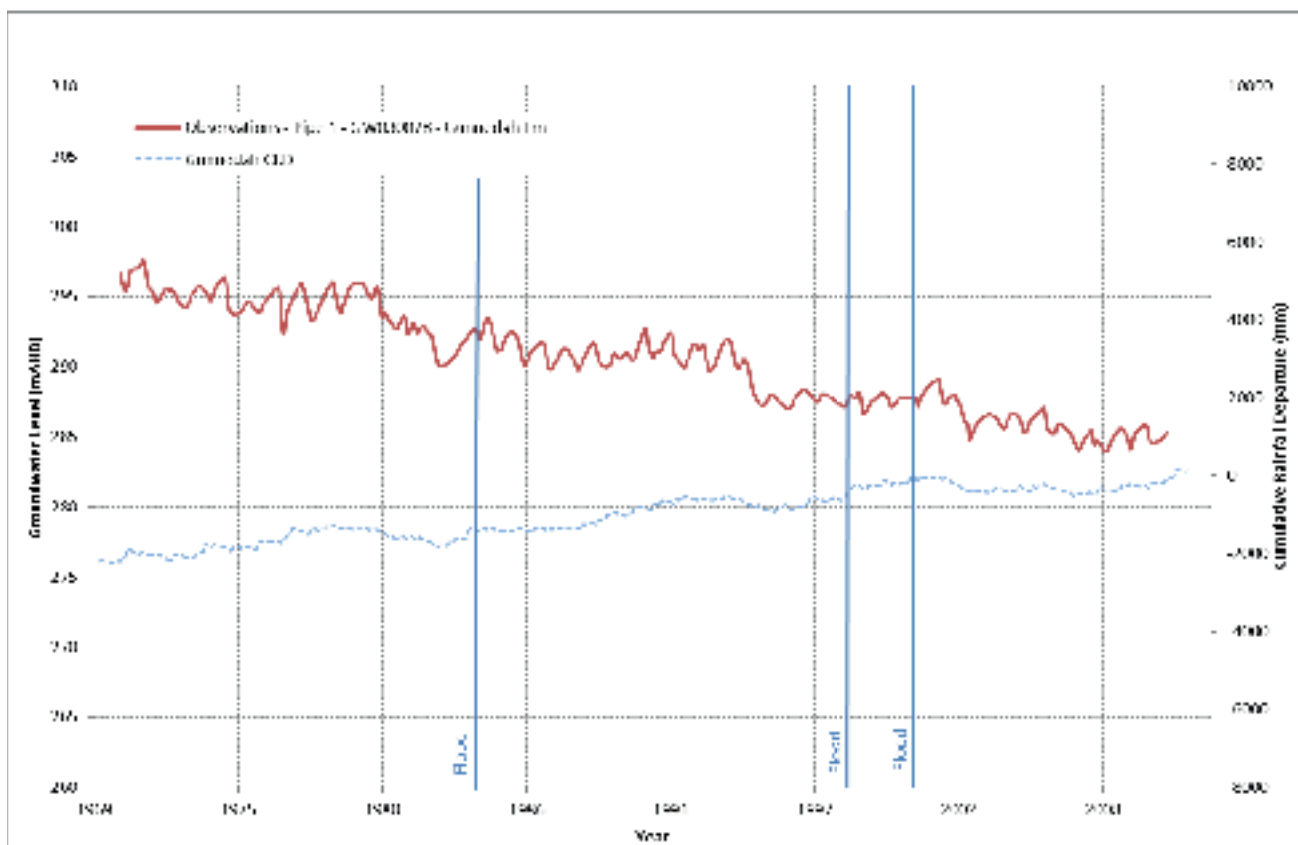


Figure 7.17: Hydrograph - Bore GW030078 – Mooki River/Quirindi Creek Confluence

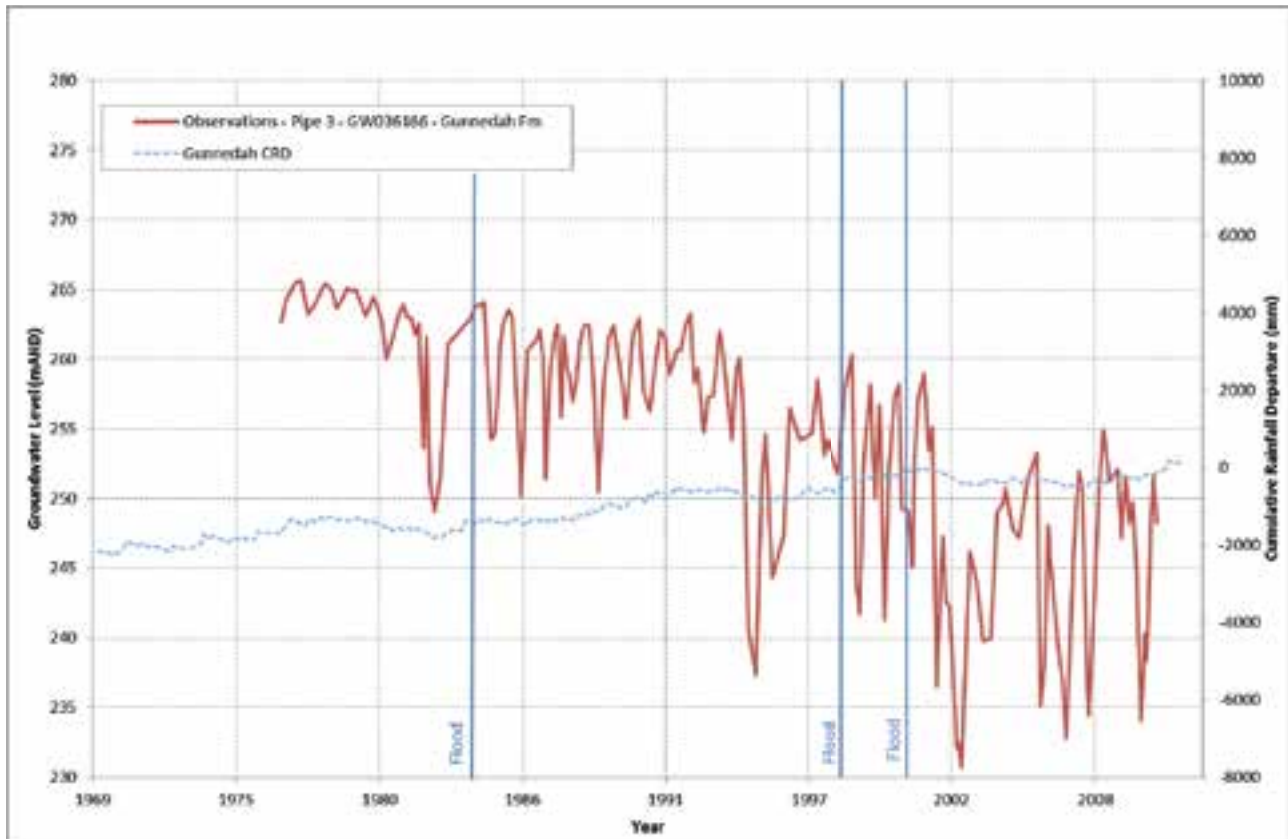


Figure 7.18: Hydrograph - Bore GW036166 – High pumping – Northern Boundary

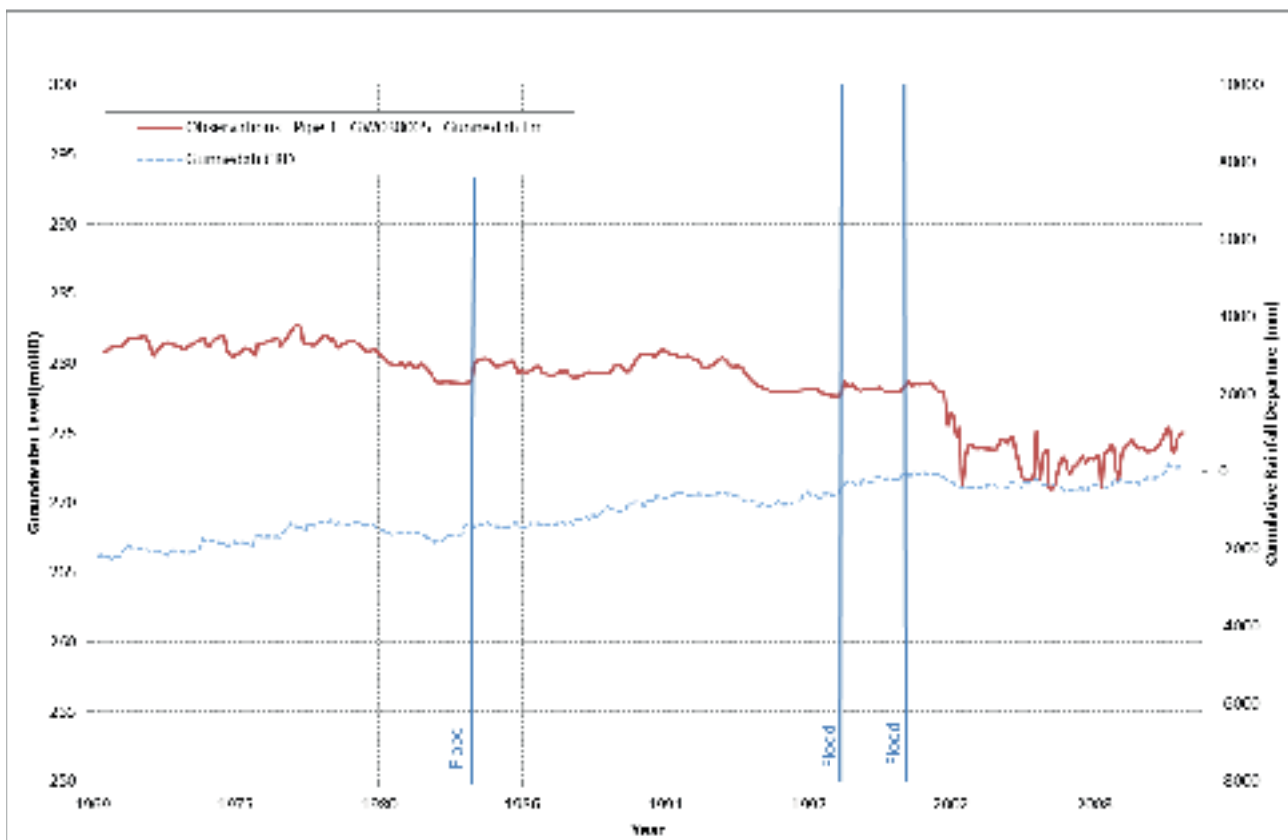


Figure 7.19: Hydrograph - Bore GW030005 – Mooki River

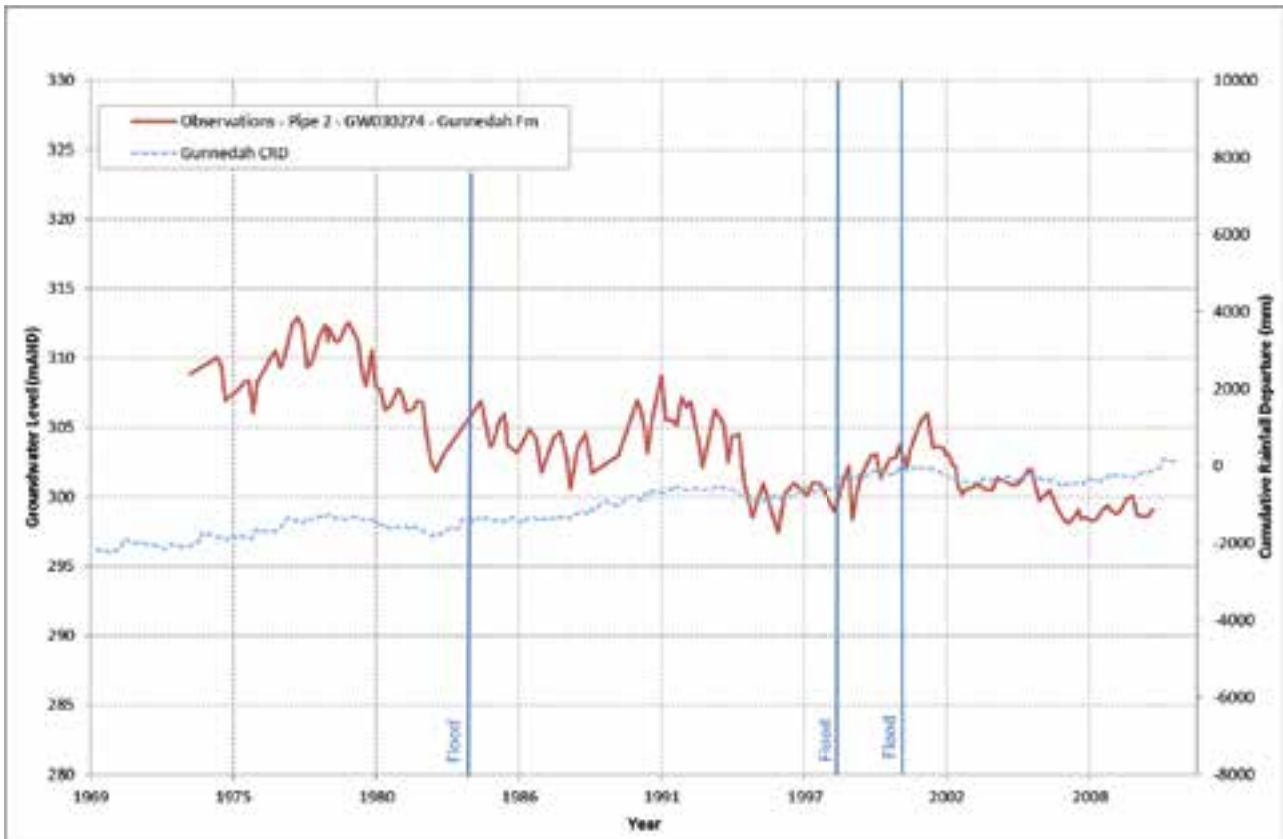


Figure 7.20: Hydrograph - Bore GW030274 – High Pumping - Quirindi Creek

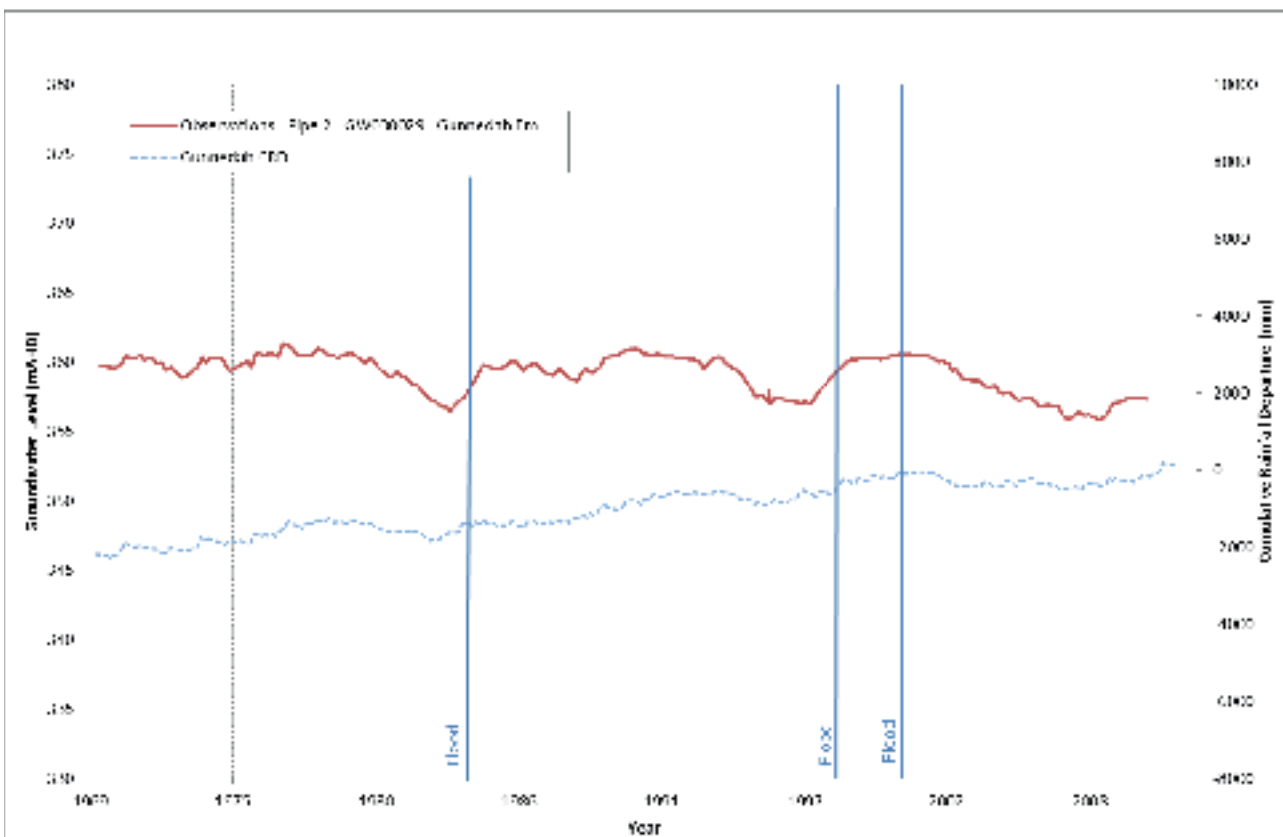


Figure 7.21: Hydrograph - Bore GW030029 – Irrigation - Zone 1

7.1.8 Regional and Local Recharge, Discharge and Groundwater Flow

Research studies in the district, including Lavitt (1999), Dawes et al (2000) and Merrick (2001) have indicated that recharge to the alluvial aquifers occurs via a number of mechanisms including:

- Surface Water - seepage through the bed of the major watercourses;
- Streamflow - streamflow gauging stations in the regional Project area;
- Hillslope/Floodplain Break of Slope - seepage at the toe of the ridge areas where rainfall runoff is concentrated and areas of permeable sediments are present;
- Diffuse Rainfall Infiltration - diffuse infiltration of rainfall through the black soil plains;
- Irrigation - irrigation returns;
- Flooding; and
- Bedrock Up-flow - up-flow from underlying bedrock.

Figure 7.22 illustrates the recharge mechanisms graphically.

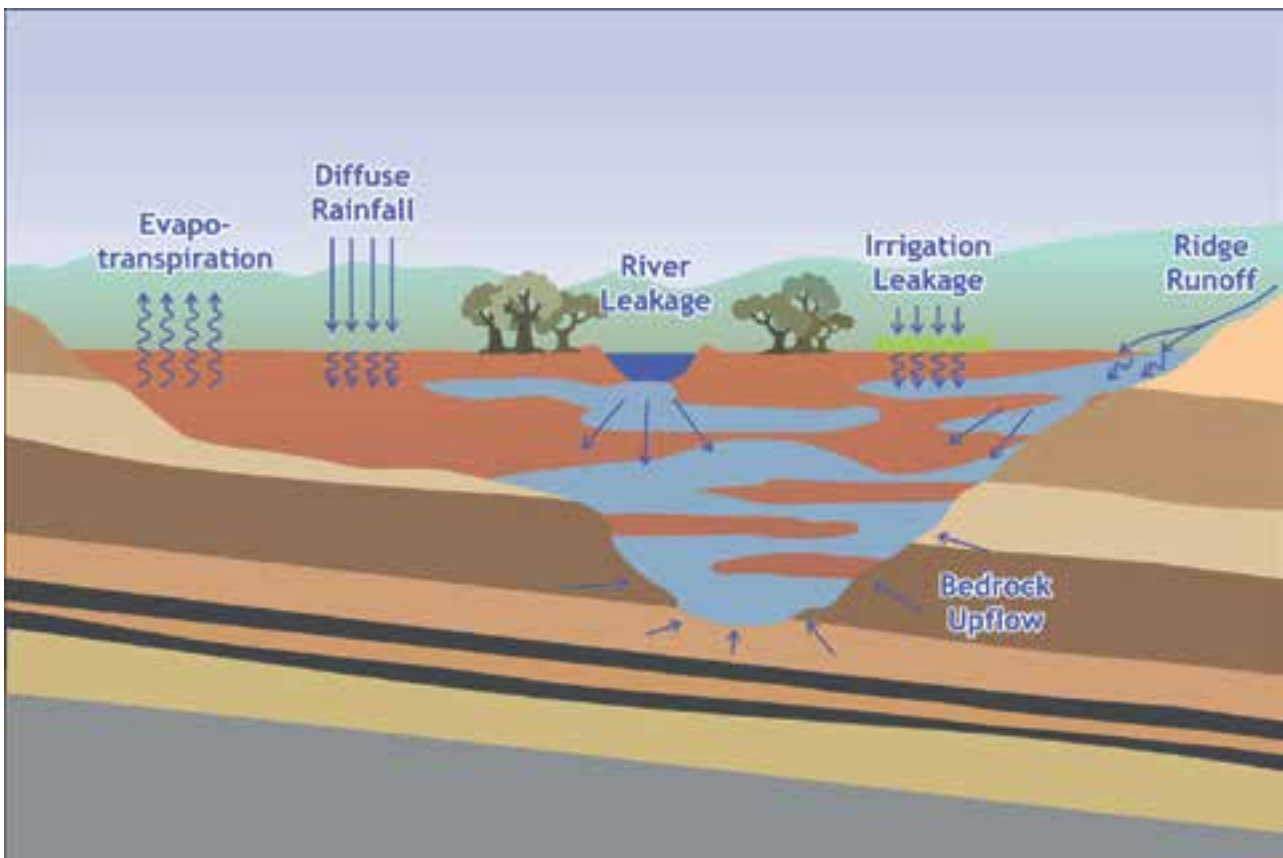


Figure 7.22: Groundwater Recharge Mechanisms – (adapted from Timms, 2012)

Surface Water

Seepage of water through the streambed of major watercourses into the underlying aquifers is considered a significant recharge mechanism. CSIRO (2008) documented that the Upper Namoi has a 23% (of total water balance) river recharge component.



Large stretches of the Quirindi Creek, Mooki River and Namoi River and associated tributaries are known to be losing systems, meaning that during events of high intensity rainfall where runoff occurs, the surface water flow can seep into the underlying alluvial aquifers. This seepage or groundwater recharge is obviously more consistent in sections of rivers whereby streamflow is perennial, or maintained by releases from upstream dams. Figure 7.23 shows a largely dry section of Quirindi Creek that is expected to act as a recharge zone during periods of surface water flow.



**Figure 7.23: Quirindi Creek on 10 May 2012 at Slack Smith Lane Road Crossing
(269,671 mE, 6,5184,28 mN)**

Figure 7.24 shows an aerial view of an unnamed creek that flows from the eastern ridge areas of the regional project domain and dissipates across the Liverpool Plains. Figure 7.25 shows the soil profile of the drainage lines in this area, which consists of black soils overlying sands and gravels which allow recharge to occur through the drainage lines. There are numerous similar locations to this where water from the ridges is dispersed over the plains, and is not directly connected with the major drainage lines of Quirindi Creek, Mooki River and Namoi River.



Figure 7.24: Recharge Area on 10 May 2012 at Perfremment Road Crossing (265,849 mE, 6,549,162 mN) – source Google Earth Imagery



Figure 7.25: Soil Profile at Perfremment Road Crossing Showing Black Soils Overlying Sands and Gravels (265856 mE, 6549162 mN)



GHD (2012) report relatively young groundwater ages from selected water samples collected from bores in the Gunnedah Formation adjacent to the Mooki River and Quirindi Creek indicating seepage from the river is recharging the underlying aquifers.

Streamflow

There are five streamflow gauging stations in the regional project area, including two stations on the Mooki River (419027 and 419034). Mooki River at Breeza (419027) is located downstream of the Project and upstream of the Kamilaroi Highway Bridge, and Mooki River at Caroonna (419034) is located upstream of the Project. Figure 7.26 presents stream gauging data at station 419027. Peak flows and heads in the river at this location are related to high rainfall events, including the largest flood on record during the July 1998 event.

Figure 7.27 presents streamflow data in relation to the Cumulative Streamflow Residuals (CSD). This method is a summation of the daily departure of streamflow from the long-term average daily streamflow. The data indicates that trends in flow are dominated by high rainfall events, and suggest that the flow in the Mooki River is lower than the monthly longtime averages following high rainfall events.

Further analysis on streamflow data in the regional project area is presented in the WRM Surface Water Report (WRM, 2012).

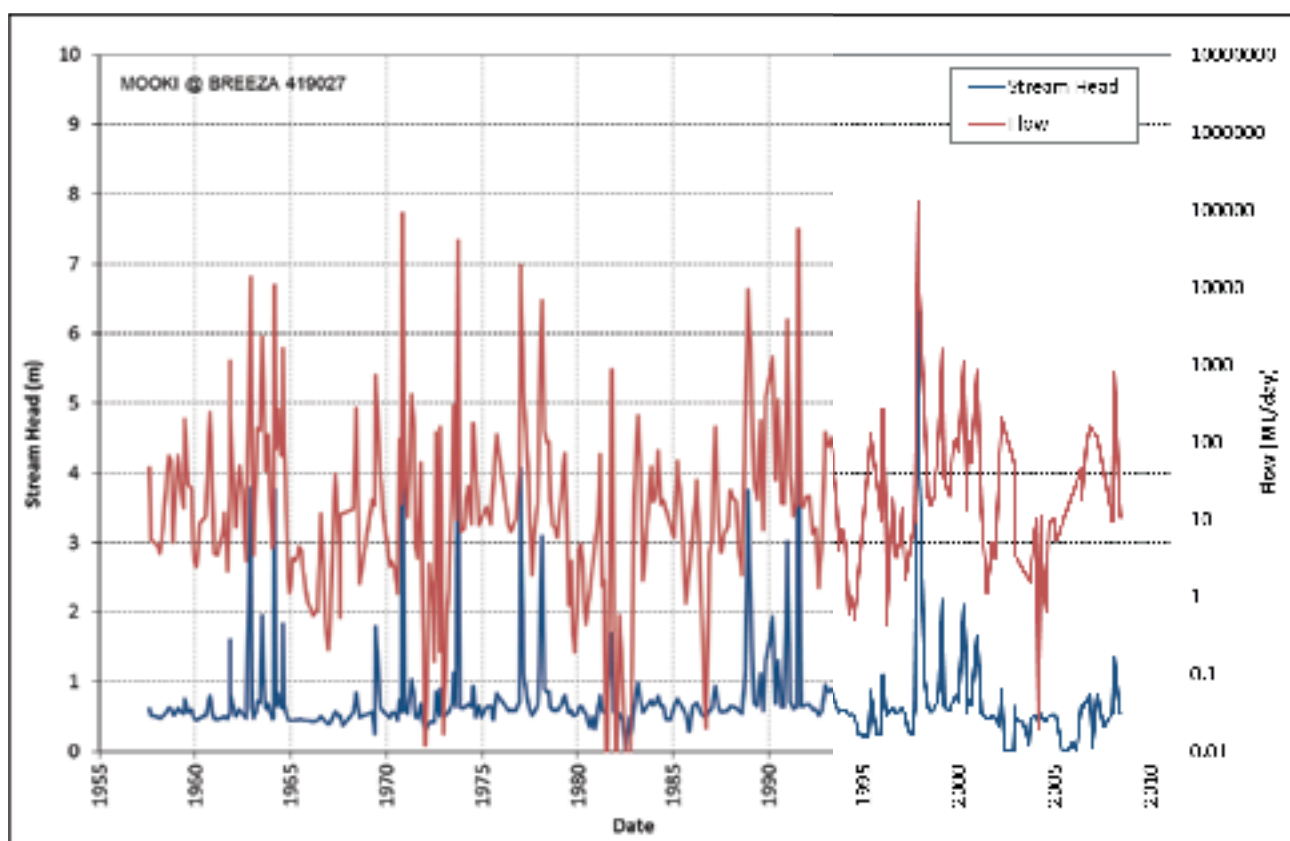


Figure 7.26: Stream Gauging Data - Mooki River at Breeza (419027)

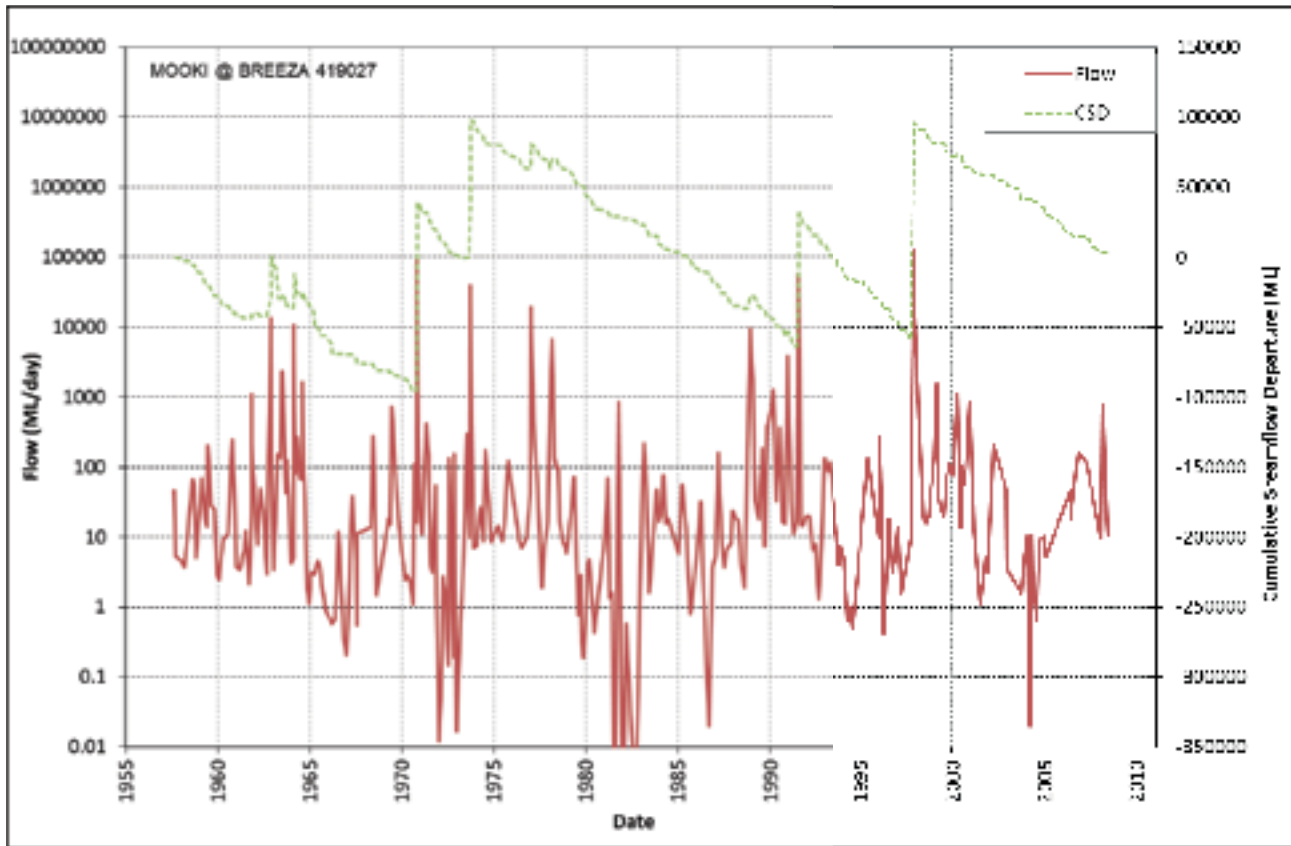


Figure 7.27: Streamflow Gauging Data - Mooki River at Breeza (419027) CSD

WRM conducted a historical calibration exercise using a RAFTS model (XP Software, 2009) to give confidence in surface water predicts and to assist in the validity of groundwater modelling simulations. The RAFTS model was then used to calculate baseflow predictions at various locations across the regional project area. Figure 7.28 presents baseflow predictions at Mooki River at Caroon (419034). The simulation results suggest that this portion of the Mooki River (i.e. headwaters of the Mooki River to station 419034) contributes an average baseflow recharge rate of 27.4 ML/day to the groundwater system (1980 – 2012).

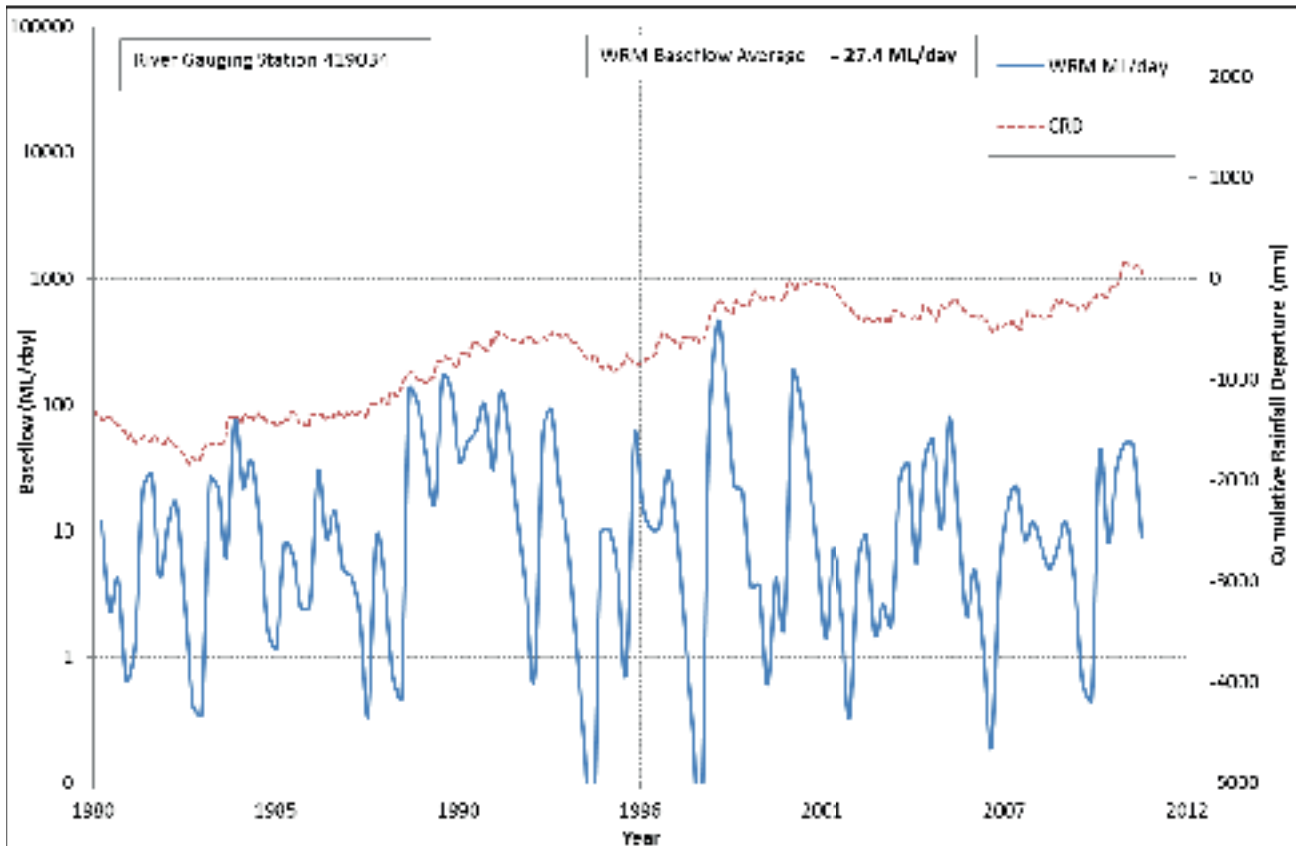


Figure 7.28: Predicted Baseflow - Mooki River at Caroona (419034)

Further analysis on the RAFTS model and baseflow predictions across the regional project area is presented in the WRM Surface Water Report (WRM, 2012).

Hillslope / Flood Plain Break of Slope

Enhanced areas of recharge occur in areas where rainfall runoff from the ridge areas is channelled into localised tributaries and drainage features onto the edge of the alluvium. These recharge areas occur at the break of slope between the hills and the floodplain. The ephemeral surface water systems in these areas direct the runoff onto the edge of the alluvial sediments whereby under favourable local conditions (i.e. permeable sediments) the runoff infiltrates the alluvium.

A large number of variables control the volume of recharge that enters the alluvial aquifers at the break of slope between the hills and floodplains. These include the upstream catchment area, geology, soils, elevation and aspect. A significant volume of recharge occurs to the Gunnedah Formation on the weathered basalt slopes and drainage channels near the Liverpool Ranges 50 km to the south of EL 7223. This is due to permeable geology and large catchment areas delivering significant volumes of water.

In contrast, Lavitt (1999) noted water levels at the eastern boundary of Groundwater Management Zone 3 adjacent to the Mooki Thrust fault had recorded a water level rise in areas of clay facies, indicating enhanced recharge in this area.

Some of the smaller ridge areas outcropping through the floodplain alluvium are likely to contribute less to groundwater recharge due to the dominance of clays and smaller catchments. This is certainly the case for the southern part of the Project Boundary, where clays and silts of the



Narrabri Formation dominate the break of slope zone between the hills and the floodplain, and the more permeable Gunnedah Formation does not occur.

Diffuse Rainfall Infiltration

Diffuse rainfall across the black soil plains infiltrating the soil profile and draining beyond the root zone is another recharge mechanism. Most investigators consider the rate of rainfall recharge through the black soil plains to be very low (Lavitt, 1999, UNSW, 2012). Groundwater in the Narrabri Formation is generally more saline than the underlying Gunnedah Formation, indicating evapo-concentration of salts in rainfall and a low recharge rate. In contrast, the underlying Gunnedah Formation generally yields fresh to slightly brackish groundwater, indicating the overlying Narrabri Formation is not a large contributor to recharge to the Gunnedah Formation. SWS (2010) noted that the rate of recharge from the Narrabri Formation to the underlying Gunnedah Formation was dependent on differences in hydraulic pressures and that *“in the eastern parts of the plain, there is a downward movement of groundwater from the Narrabri to the Gunnedah Formation, whilst at the western margin the direction is reversed”*.

Researchers from the University of New South Wales have estimated the rate of deep drainage through the black soils in a number of studies at Breeza Research Station. Studies involving geophysical and hydro-chemical techniques have concluded that only a small portion of rainfall infiltration makes its way through the black soils and the unsaturated zone due to the black soils natural ability to soak up water. Studies suggest that as little as 0.2% of annual rainfall replenishes the underlying alluvial aquifer systems (Breeza Research Field day, pers comms, Wendy Timms, 2011).

Crawford and Timms (2004) assessed leakage through clay-rich soils and found that swelling clay may leak through a relatively open pore structure and through fractures. Electrical resistivity records also indicated leakage through fractures in clays.

Berhane (2001) estimated groundwater recharge to Groundwater Management Zone 7. The researchers installed five monitoring bores and estimated recharge using the chloride mass balance and water table level fluctuation methods. They estimated a significantly higher groundwater recharge rate of 6% of average rainfall (35 mm per year).

A number of numerical models have used inverse modelling to estimate the rate of diffuse rainfall recharge to the Narrabri Formation. Salotti (1997) modelled rainfall infiltration near Borambil Creek (Quirindi) at a rate between 6% of rainfall (for light rainfall events) and 13% of rainfall (for high intensity events). These recharge rates are considered to be very high and other studies carried out in the region support the application of lower rates to represent diffuse rainfall recharge. Dawes et al., (2000) report values of 0.05 to 0.07 mm/day (18.25 – 25.55 mm/yr) or 2.8 to 3.9% of annual rainfall (assuming 645 mm/year at Breeza).

Merrick (2001) applied recharge values equal to 0.5% of rainfall and 0.1% of rainfall in the Lower Namoi groundwater model. Recent modelling undertaken by SWS (2010 and 2011) adopted a 3% of annual rainfall recharge rate for the Upper Namoi aquifers. McNeilage (2006) also applied enhanced recharge to simulate irrigation at 30 and 72 mm/year, but applied these rates to localised areas only.

The available data highlights that previous investigators have estimated a wide range in the diffuse recharge rate through the black soil plains to the underling aquifers. The estimates derived from modelling are considered the most uncertain as the models can still achieve calibration by increasing recharge from other sources or varying the hydraulic properties of the aquifers.



Section 9.2.4 outlines the recharge rates determined through calibration of the model used to assess the impact of the Project.

Irrigation

Deep drainage of irrigated waters is a potential source of recharge to the underlying aquifers in areas particularly where cotton is grown.

Flooding

Floodwater is a known source of rainfall recharge to the Narrabri and Gunnedah Formations. Figure 7.29 highlights water levels following flood events in 1984, 1998 and 2000. The role floods play in recharge is evident in Figure 7.29, with water level responses of several metres. However, it is important to note that the flood events generally result in reduced irrigation, which may also have a role in the rising groundwater levels observed after floods. SWS (2010) considered that recharge to the alluvium would occur from the leakage of water from streams and rivers under normal flow conditions; however, during flood events this recharge would be enhanced in areas close to surface water systems.

During flood events, the presence of ponded water on the land surface is likely to enhance recharge to the Narrabri Formation. This recharge would be of a short duration when compared with diffuse rainfall recharge; however, recharge from flood events has the potential to provide larger rates over a shorter duration. CSIRO (2008) documented that flood recharge supplied 4.5% of the total water balance to the Upper Namoi aquifer.

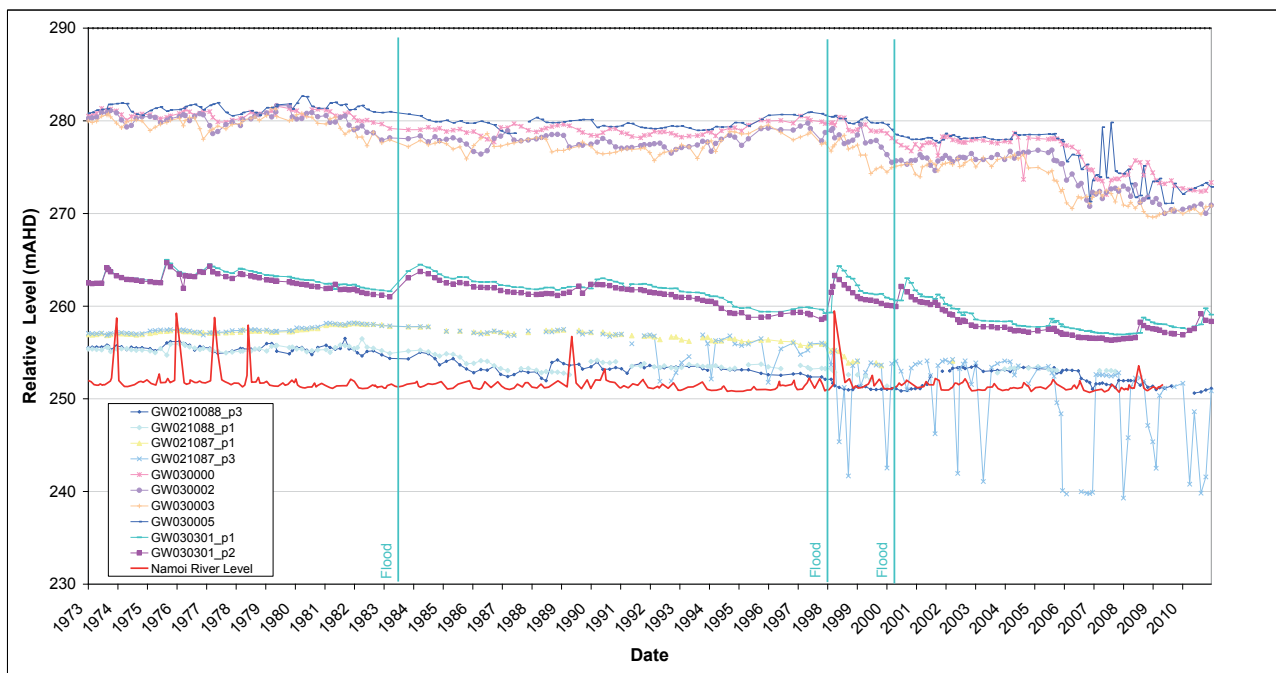


Figure 7.29: Groundwater Level Response vs. Namoi River Height (Station No. 049001)

Bedrock Upflow

Most investigators (Merrick, 2001, McNeillage, 2006) have considered the flow of groundwater from the bedrock formations into the overlying alluvial aquifers to be only a very small contributor to recharge and the water budget. Most previous numerical models have not included the underlying bedrock and therefore sourced all recharge from break of slope, rivers, floods and diffuse rainfall. SWS (2012b) developed the first regional scale model of the alluvial aquifers that



also included underlying bedrock. Merrick (2001) also had GAB up-flow in Lower Namoi, represented as a General Head Boundary.

Summary

Table 7.3 summarises the recharge values applied to models in the region.

Table 7.3: RECHARGE SUMMARY TABLE (after SWS, 2012b)		
Area of Study	Findings	Reference
Upper Namoi Groundwater Model	Rainfall recharge (includes recharge from ridge runoff and flooding) - spatially variable but an average of 3% (20 mm/yr). Irrigation - 30 and 72 mm/yr over localised areas.	McNeillage, 2006
Lower Namoi Groundwater Model	Recharge equivalent to 0.5% of rainfall in the southern half of the model and 0.1% in the northern half. Previously used a value of 0.6% (4 mm/yr).	Merrick, 2001
Liverpool Plains	Diffuse recharge of 20 mm/yr. Estimates from other models evaluated range from 157 mm/yr in the Liverpool Ranges to 70 mm/yr on the sedimentary hills, and from <20 to 32 mm/yr on the alluvial plains.	Zhang et al., 1997
Liverpool Plains	Groundwater recharge estimated as between 0 – 75 mm/yr, with recharge only occurring in wet years. Over 50% of the predicted recharge occurred in two particular years. Average recharge is estimated at approximately 5.3 mm/yr.	Sun and Cornish, 2005
Lake Goran	When wet, the lake is estimated to provide 6 mm/yr recharge.	Zhang et al., 1997
GAB Intake Beds	Recharge rates of 0.5 to 10 mm/yr estimated using chloride mass balance techniques.	GAB sustainability initiative, 2010
GAB Southern Recharge Zone	Long-term average annual recharge to the Southern Recharge Zone is 42,400 ML/yr. Average of 1.3 mm/yr recharge.	DWE, 2009
Boggabri Coal Mine	Calibrated model values: - Alluvial aquifer – 18 mm/yr - Slope wash zone – 90 mm/yr - Ephemeral creeks – 90 mm/yr - Bollol Creek headwaters – 150 mm/yr - Outcrop hill zones – 1 mm/yr	AGE, 2010
Maules Creek Coal Mine	Calibrated model values: - Alluvial aquifer – 7.2 mm/yr - Permian outcrop – 0.66 mm/yr - Volcanics outcrop – 2.7 mm/yr - Slope wash zone – 116.3 mm/yr	AGE, 2011
Narrabri North Coal Mine	Calibrated model values: Variable from 0.5% (~3 mm/yr) to 5% (~30 mm/yr) of rainfall	Aquaterra, 2009
Breeza	~1 mm/yr through the black soils as diffuse rainfall recharge	UNSW Breeza Field day

Although there is significant variability in the recharge rate adopted by previous studies for the alluvial aquifers, it is considered that on a regional scale recharge through the black soils and into the underlying Narrabri Formation is very limited. The rate of recharge is significantly enhanced at break of slope where the ridge lines meet the plains and runoff has the opportunity for seepage through more permeable zones in the bed of drainage lines. The major drainage lines of Quirindi



Creek, Mooki River and Namoi River also have significant reaches where surface water flows can recharge through zones of clean sands and gravels to the underlying aquifers.

Further testing of groundwater samples was undertaken to better understand the recharge mechanisms within the Project Boundary and in the surrounding areas. GHD collected water samples from 17 monitoring bores constructed in the alluvium and submitted the samples to GNS Sciences in New Zealand to determine groundwater age using the tritium and radiocarbon methods. The aim of the testing was to enhance the understanding of the groundwater recharge zones and flow between hydrogeological units proximal to the Project and in the surrounding region. Water samples were collected from monitoring bores within the Project Boundary, and from NOW monitoring bores in the surrounding area. The age dating does not reveal the actual recharge rate, but was used to indicate zones where recharge is enhanced including the break of slope and areas close to the major watercourses.

Table 7.4 summarises the results of radiocarbon and tritium analyses on water samples from selected alluvial groundwater bores.



Table 7.4: SUMMARY OF RADIOCARBON AGE DETERMINATION IN ALLUVIUM

Site ID	Sampling Date	¹³ C (%)	¹⁴ C (‰mC)	TDIC (mmol/kg)	¹⁴ C age (years)	¹⁴ C age range (years)	Geology
GW030060(D)	5/12/2011	-12	24	5.8	5899	4667 - 7013	Gunnedah Fm
GW030060(S)	5/12/2011	-13	36	7.3	3052	1820 - 4166	Gunnedah Fm
GW030176(D)	11/12/2011	-3.9	0.1	43	45675	40515 - 60529	Narrabri Fm
GW036203(D)	6/12/2011	-7.7	9.4	8.7	9822	8589 - 10938	Gunnedah Fm
GW036203(S)	6/12/2011	11	1819	5.4	7078	5845 - 8193	Gunnedah Fm
GW036305(D)	11/12/2011	-14	34	5.3	3816	2584 - 4931	Gunnedah Fm
GW040832(D)	5/12/2011	12	104	13	<100	-	Narrabri Fm
GW040832(S)	5/12/2011	-11	107	14	<100	-	Narrabri Fm
WM0011	7/11/2011	-12	52	2.3	<100	-	Narrabri Fm
WM0091A	2/11/2011	-9.8	13	9.3	9320	8087 - 10436	Narrabri Fm
WM0093A	31/10/2011	-9.9	23	7.9	4342	3109 - 5457	Gunnedah Fm
WM0291	21/09/2011	-7.6	0.8	24	30596	29248 - 31855	Gunnedah Fm
WM0424	19/11/2011	-10	0.5	10	36033	34571 - 37447	Narrabri Fm
WM0426A	5/10/2011	-8.7	20	11	4465	3233 - 5580	Narrabri Fm
WM0427A	22/09/2011	-9.4	8.3	10	12530	11297 - 13646	Gunnedah Fm
WM0428A	23/10/2011	-9.6	65	7.1	<100	-	Narrabri Fm
WM0432A	22/09/2011	-8.2	41	3.8	<100	-	Narrabri Fm

Source - GNS Science (2012).

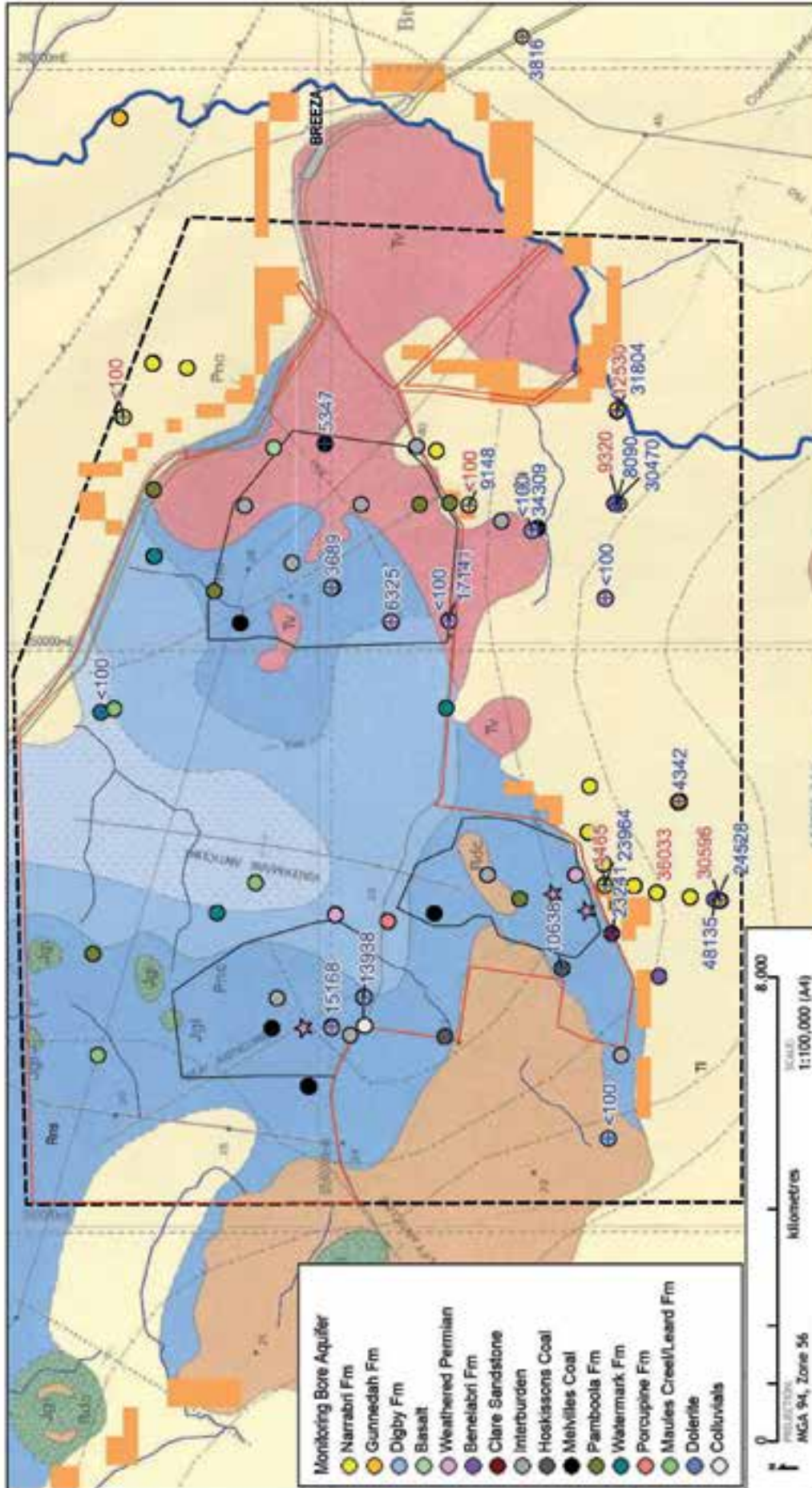
‰mC = percent modern carbon (sample post-dates atmospheric testing of nuclear weapons)

TDIC = total dissolved inorganic carbon expressed in mmol.kg⁻¹

Figure 7.30 presents the interpreted ages in the Project Boundary.

The age determination indicates that there is a large range in groundwater ages within EL 7223. The results suggest that there is no consistent distinction between the Narrabri and Gunnedah Formations in term of groundwater age. Groundwater age is dependent on geographic location and distance from the recharge source, i.e. break of slope zones. Very recent groundwater less than 100 years old is located close to the alluvial boundaries surrounding the Eastern Mining Area and to the west of the Southern Mining Area. In contrast, old groundwater is observed south of the Southern Mining Area in both the Narrabri and Gunnedah Formations and suggests that recharge and groundwater flow in this area is limited. This is most likely due to the high percentage of clay materials in the soil profile, low alluvial/bedrock transfer flow rates, evaporative concentration of recharge, and compartmentalisation/poor interconnection between sand and gravel lenses that mean water remains trapped within these zones.

Section 7.3.6 further discusses groundwater ages in the ridge areas of the Project Boundary.





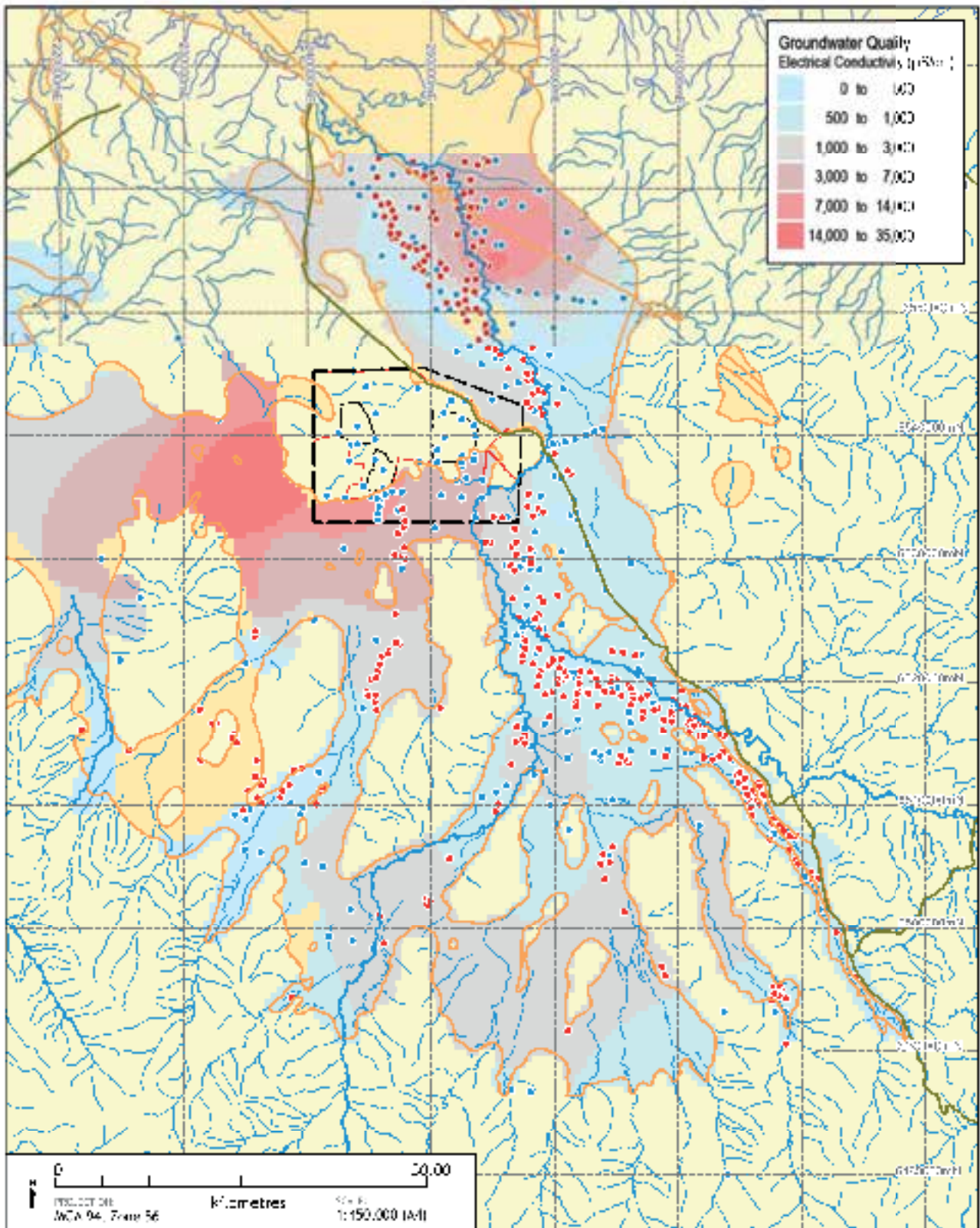
7.1.9 Water Quality and Environmental Values / Beneficial Use

Groundwater in the Narrabri Formation is typically brackish to saline with electrical conductivity (EC) values reported up to 35,000 $\mu\text{S}/\text{cm}$ (Ringrose et. al., 2003). Water quality in the underlying Gunnedah Formation is significantly better and typically fresh to slightly brackish. Water quality records from the NOW monitoring bores indicate groundwater within the Gunnedah Formation to the west of the Mooki River is typically slightly brackish at between 1,200 mg/L to 3,000 mg/L total dissolved solids (TDS). East of the Mooki River groundwater is much fresher with TDS less than 500 mg/L. GHD (2011) explain this as being related to the hydraulic conductivity distribution within the alluvium.

Figure 7.31 presents the salinity distribution from the NOW groundwater monitoring bore network sourced from the PINEENA database. The database does not identify which aquifer each bore is constructed within, however as the monitoring bores generally target the more permeable sands and gravel zones the data is considered to largely represent the Gunnedah Formation. Figure 7.31 shows that the fresh groundwater is generally present along the alignment of the Gunnedah Formation palaeochannel where the most significant thickness of sands and gravels are present.

Groundwater is more saline within Zone 7 and within the Project area and is likely a by-product of groundwater salinization due to the evaporation of groundwater at the break of slope and around Lake Goran.

Figure 7.32 presents average total dissolved solids concentrations for the Shenhua monitoring bores in the Quaternary alluvium and Permian. The results show that groundwater salinity is lower close to recharge sources, i.e. break of slope zones and the Mooki River. Salinity in the alluvial units to the south of the Southern Mining Area are high, suggesting evaporative concentration of salt in this area.



Legend

- Construction Dam
- Proposed Mining Area
- EL 7223
- Drainage Line / Creek
- Usage Zone
- Alluvium < 253K
- Project Boundary

Watermark Coal Project (G157)
Groundwater Assessment

**Regional Groundwater Quality
(Alluvial Aquifers)**



DATE:
18/10/2012

7.31

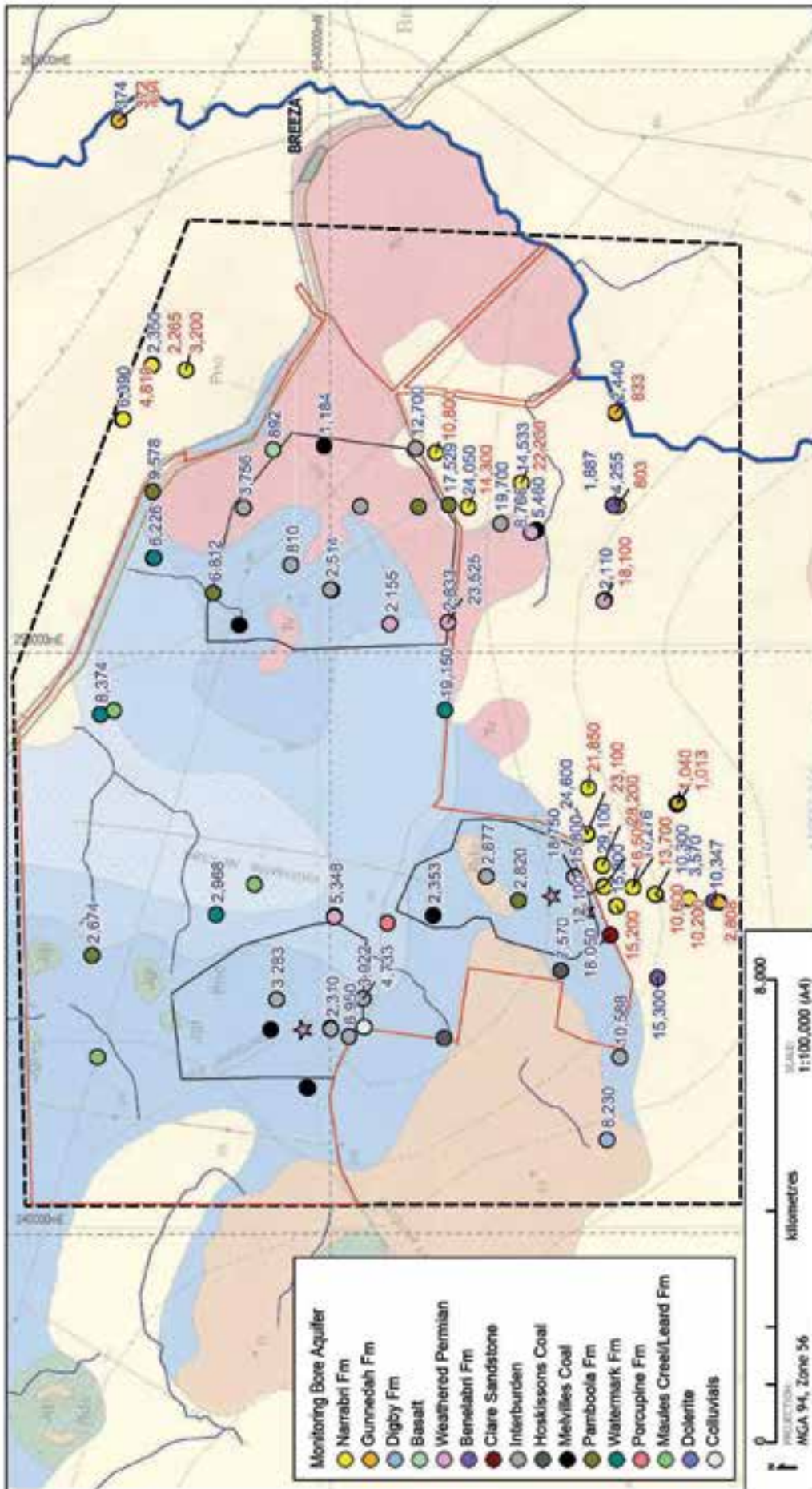




Figure 7.33 shows a histogram grouping the water samples from the alluvial aquifers within EL 7223 according to salinity class.

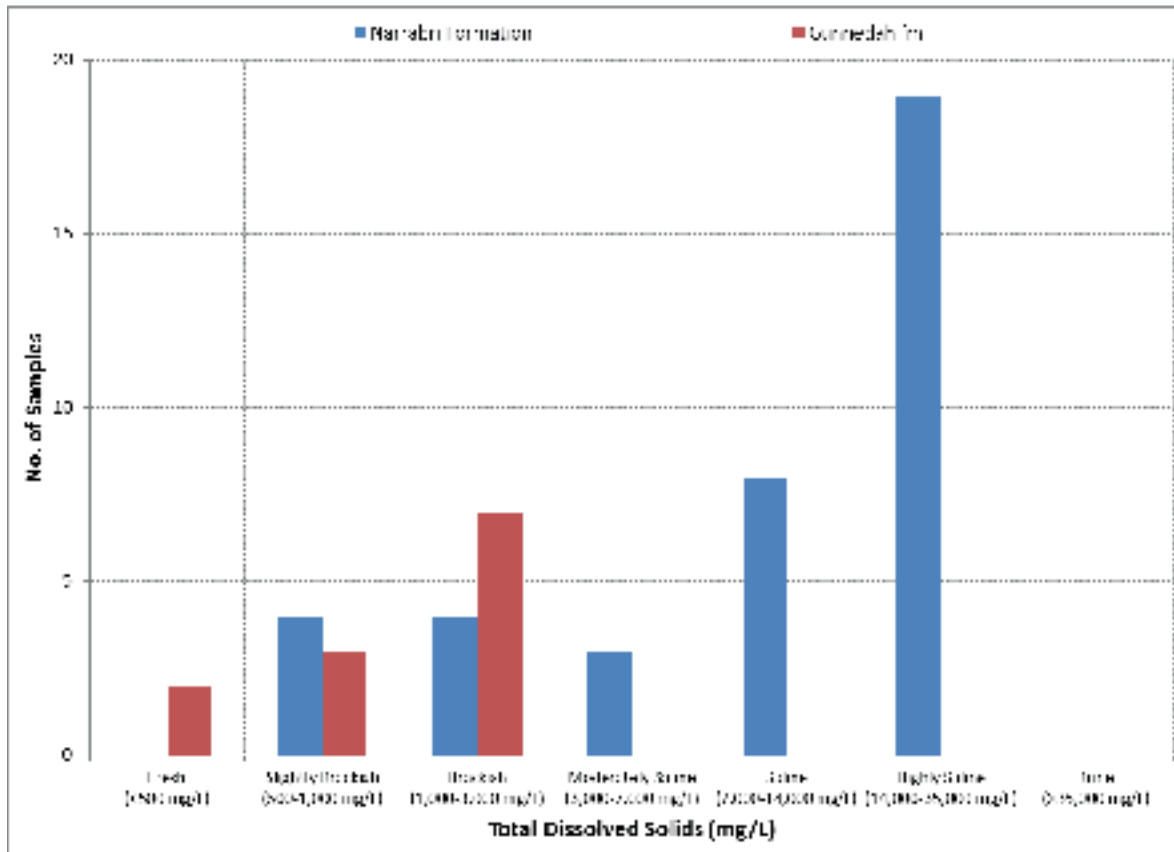


Figure 7.33: Total Dissolved Solids Histogram – Water Classification

Figure 7.33 highlights groundwater in the alluvial Gunnedah Formation is typically fresh to brackish. The samples from the Narrabri Formation are more variable in salinity ranging between slightly brackish to highly saline, with most samples in the highly saline range within EL 7223.

The potential use and environmental value of groundwater is dependent upon the water quality, with the overriding constituent controlling use being the salinity. Table 7.5 summarises the salinity limits that control the potential beneficial use of groundwater. Figure 7.34 again groups the alluvial water samples according to suitability for beef cattle. It shows that most of the groundwater samples from the Narrabri Formation have TDS concentrations greater than 10,000 mg/L and are not suitable for beef cattle. Table 7.5 indicates sheep can tolerate salinity up to 13,000 mg/L indicating a small proportion of groundwater from the Narrabri Formation would be suitable for this purpose.

All samples from the Gunnedah Formation are suitable for stock. Figure 7.34 demonstrates that the environmental value, or beneficial use of the groundwater within the Narrabri and Gunnedah Formations is spatially variable depending on location. The more saline zones of groundwater in the Narrabri Formation cannot be used for stock and irrigation.

The brackish to saline water in the Narrabri Formation likely slowly discharges to the underlying Gunnedah formation, or into rivers and creeks and is diluted by the fresher surface water and groundwater in these zones. The groundwater in the Narrabri Formation is not expected to form a



high proportion of the baseflow in the rivers, creeks and therefore the environmental value is considered limited.

In contrast, the beneficial use and environmental value of the groundwater from the Gunnedah Formation is high, typically being fresh enough for a wide range of uses including agriculture, town water and as baseflow to rivers, creeks and ecosystems.

Table 7.5: WATER QUALITY AND BENEFICIAL USE LIMITS

Beneficial Use	Salinity Limits		Limits of Suitability and Range
	Electrical Conductivity (µS/cm)	TDS (mg/L)	
Human consumption	120-750	80-500	Good drinking water quality
	750-1200	500-800	Fair drinking water quality
	1200-1490	800-1000	Poor drinking water quality
	>1490	1000	Unacceptable drinking water
Irrigation	5500	3685	Unsuitable for Sunflower irrigation
	6000	4020	Unsuitable for Wheat irrigation
	7700	5160	Unsuitable for Cotton irrigation
	8000	5360	Unsuitable for Barley irrigation
Stock water	5970	4000	Loss of production and a decline in poultry condition and health
	10450	7000	dairy cattle and horses
	11940	8000	Pigs
	14920	10000	Beef cattle
	19400	13000	Sheep

Sources: NHMRC (2004), ANZECC (2000)

Figure 7.35 presents groundwater quality in the alluvial aquifers over time. Groundwater quality is fairly stable thorough the sampling period and displays a slight general rise in total dissolved solids from the period July 2011 to November 2011.

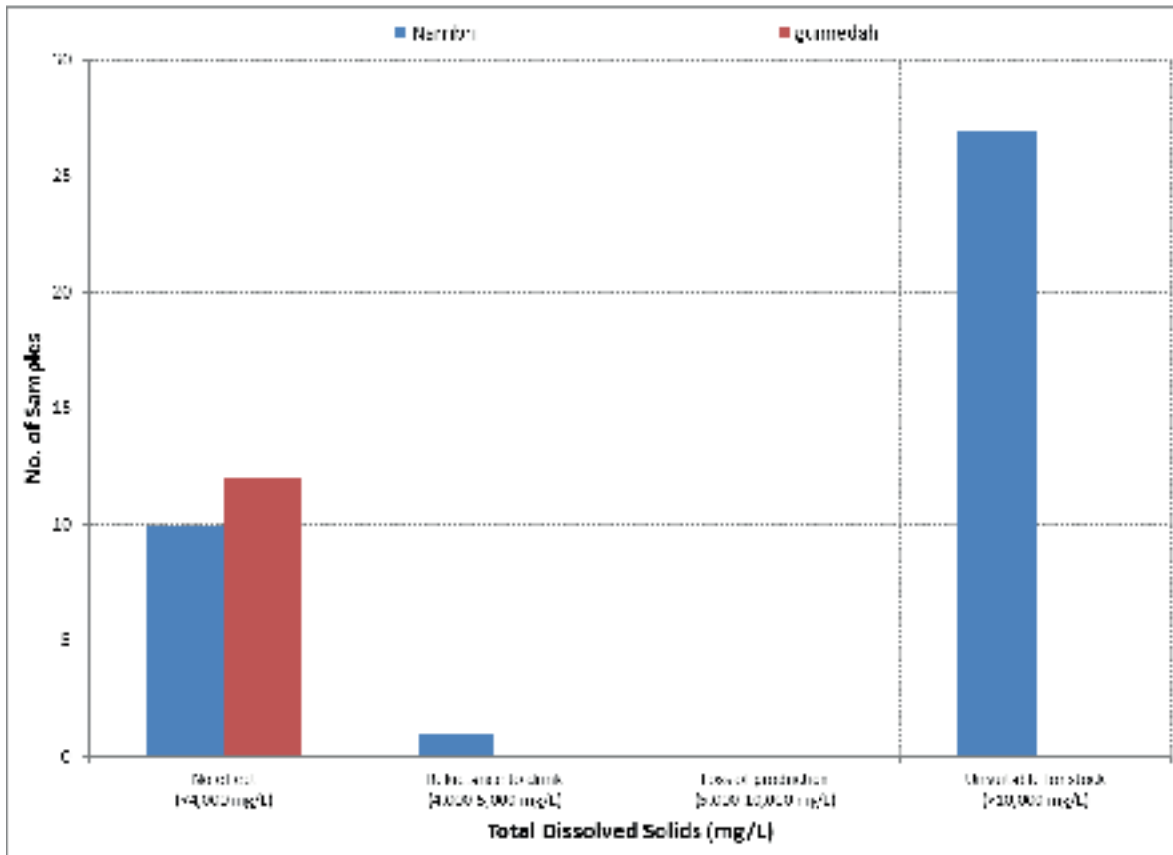


Figure 7.34: Total Dissolved Solids Histogram – Beef Cattle Suitability

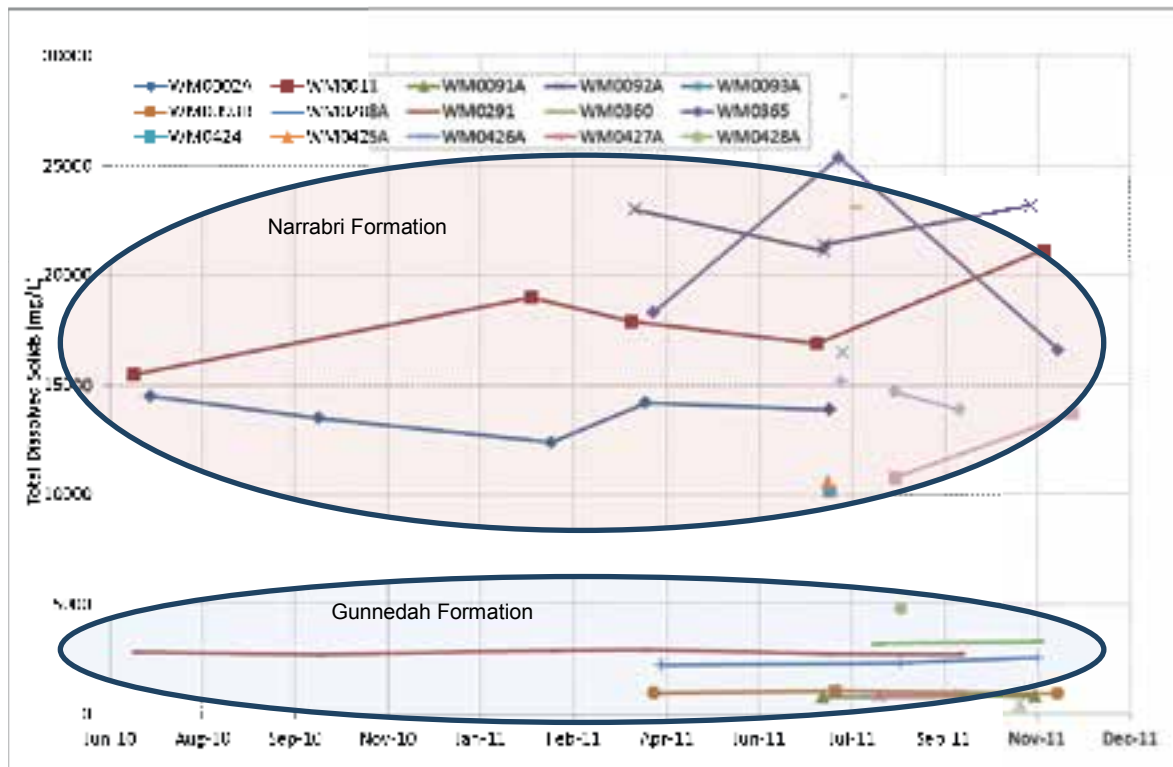


Figure 7.35: Project Area Total Dissolved Solids Records – Alluvial Aquifers



7.1.10 Groundwater Dependent Ecosystems

Eco Logical Australia (2012) collected samples from the monitoring bores within EL 7223 and inspected the samples for the presence of stygofauna. Eco Logical Australia (2012) summarised the study as follows:

“Samples were collected from bores screened within a range of strata present in the Watermark Coal Project area, focusing on aquifers in the Narrabri and Gunnedah Formations and the weathered part of the Permian aquifers, as these were identified as the aquifers most suitable for stygofauna. No animals were collected from the Permian aquifers. This absence is likely due to the high electrical conductivity, the depth of the screened section of the bore, and the low aquifer porosity. A single Oligochaete worm from the family Enchitraeidae was collected from bore WM429A (see Figure 7.5) in the Narrabri Formation. Although this family includes species that live in aquifers, Enchitraeids are more common in soil and surface-aquatic environments. As only one animal was identified in the Narrabri Formation, it is likely to have fallen into the bore from the soil horizons. Further sampling may clarify the status of this worm as stygofaunal if it is collected again from the aquifer. If the identified worm is truly stygofaunal, then resampling of this bore may also collect additional taxa such as Copepoda and Bathynellacea, which often co-occur in aquifers with Oligochaetes. These taxa are not known to occur in the region of the Project Boundary. After one round of sampling, there appear to be no significant stygofauna in aquifers within the Project Boundary. The alluvial aquifers would be the most suitable habitat for stygofauna, with densities and species diversity increasing with proximity to the Mooki River and to recharge areas.”

Using data obtained from Eco Logical (2011, 2012) and various previous studies in the Project region, Cumberland Ecology (2012) concluded, *“although there is some potential for vegetation in the Project Boundary to comprise a groundwater dependant ecosystem, none are obviously groundwater dependant. One vegetation community recorded from the Project Boundary is considered by Eco Logical to comprise a GDE; this is Fuzzy Box woodland on colluvium and alluvial flats in the Brigalow Belt South (including Pilliga) and Nandewar Bioregions.”*

It is likely that no river baseflow groundwater dependant ecosystems occur within the Namoi Catchment, as there are no permanently flowing rivers in the Project Boundary (Cumberland Ecology, 2012).

7.1.11 Compaction and Subsidence

Compaction and land subsidence is the process of settling or sinking of the natural ground surface due to subsurface movement of earth materials. Gradual compaction of aquifer systems can be caused by the depressurisation of the groundwater system in response to landholder or mining extraction. Land subsidence may result in loss of aquifer storage, increased flooding, cracks at land surface, and damage to man-made structures (Ali et al, 2004).

Currently, benchmark surveys of land subsidence in the Upper Namoi Valley do not exist; however, there are some areas, such as the Lower Namoi, where subsidence has been investigated. Measurable subsidence has occurred in the Lower Namoi Valley, a host to over 30 years of irrigated agriculture. Similar to the Upper Namoi Valley, large quantities of water are extracted to irrigate predominantly cotton crops.

In 1974, a series of benchmarks was established from which land subsidence could be monitored. A more intensive network installed in 1981 supplemented these. Survey levelling of these sites was carried out in 1982, 1987, 1988 and 1990. Subsidence of between 0.08 m and 0.21 m was recorded for the 10-year period 1981 to 1990 (Ross and Jeffery, 1991).



Since that time, the volume of groundwater pumping has continued to increase and water levels have continued to fall.

Ali et al (2004) constructed a 3-layer regional MODFLOW groundwater flow model of the Lower Namoi Valley to assess subsidence. The model was calibrated to the period 1980 to 1998, verified, subjected to post audit and externally reviewed. The model was used to simulate subsidence, to see if MODFLOW is sufficient for this purpose, and to see if satisfactory calibration is possible with plausible storage and compressibility parameters. Reasonable calibration was achieved as the model was able to reproduce the observed levels of subsidence. The model implemented the Interbed Storage Package (IBS), which models compaction in response to groundwater depressurisation using the following parameters:

- Elastic storage coefficient;
- Inelastic storage coefficient;
- Initial pre-consolidation head; and
- Initial compaction.

Ali's (2004) model was calibrated using the following best combination of parameters:

- Elastic skeletal specific storage $2.1 \times 10^{-6} \text{ m}^{-1}$;
- Inelastic multiplier 75 (specific storage $1.6 \times 10^{-4} \text{ m}^{-1}$).

Figure 7.36 shows the simulated distribution of land subsidence at 1998 derived from Ali's MODFLOW based modelling. Maximum predicted simulated subsidence is less than 0.5 m. Section 10.13 summarises the results of a subsidence study undertaken for the Project.

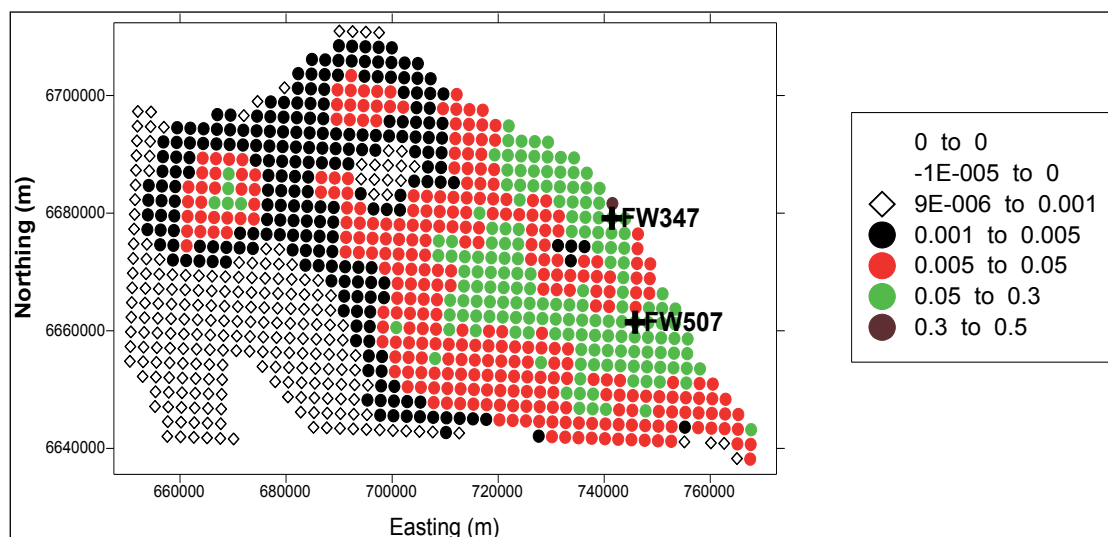


Figure 7.36: Predicted Subsidence (m) - Lower Namoi – Ali et al (2004)

7.2 Tertiary Units

A large region of Tertiary volcanics known as the Liverpool Ranges occur some 45 km to the south of EL 7223 and cover an area of 5,600 km². In a regional context, these Tertiary aquifers are important to groundwater flow and constitute a significant recharge source for the alluvium. The Tertiary volcanics, namely basalt, dolerite and conglomerate deposits, are generally highly heterogeneous in hydrogeological characteristics. Groundwater flow through these units is dominantly secondary through fracture networks, as well as primary flow through weathered and



porous vesicular zones within the unit. Fresh groundwater can be associated with the shallow Tertiary basalts.

A capping of Tertiary basalts occurs in the eastern area of EL 7223 between the Eastern Mining Area and the township of Breeza. Pratt (1992) noted the basalts are potentially outliers of the Liverpool Range Beds that occur on the Liverpool Ranges to the south.

Exploration drilling undertaken for the Project delineated the extent of the Tertiary basalts, which were significantly less extensive than shown on earlier geological maps (GHD 2011b). GHD concluded Tertiary basalts form localised flow systems developed in fractures and fissure networks

GHD (2011b) concluded the Tertiary basalt is of limited extent and in locations where it forms a capping in the elevated areas to the east of the lease is unsaturated, but is saturated where it is found at lower elevations.

7.3 Gunnedah and Surat Basin Units

7.3.1 Stratigraphy and Lithology

The Gunnedah Basin contains up to 1200 m of marine and non-marine Permian and Triassic sediments resting unconformably upon Early Permian volcanics (Werrie Basalt and Boggabri Volcanics). The Gunnedah Basin sediments which underlie the Quaternary / Tertiary alluvium, form low-yielding localised fractured rock groundwater systems. The Permian aged sediments generally contain saline groundwater, however fresher groundwater can be found in the weathered veneer of the Permian strata and in the Tertiary Basalts that are found some 45 km to the south of the Project Boundary. The Gunnedah Basin fractured rock aquifer is currently used for stock and domestic supply in EL 7223 (GHD, 2011a).

Surat Basin Jurassic sediments unconformably overly the Gunnedah Basin sediments to the south-west of the Project. The Surat Basin, in particular the Pilliga Sandstone, forms an aquifer used locally for stock and domestic purposes and limited irrigation. There is limited information on the hydrogeological characteristics of the Pilliga Sandstone relevant to the Project Boundary. The unit has been regionally characterised as a fluvial derived, medium to coarse-grained quartzose and plagioclase sandstone. There are a number of bores that likely screen productive horizons within the aquifer unit, producing average bore yields of approximately 1.5 L/s.

7.3.2 Distribution and Structure

The Permian aged Gunnedah Basin sediments contain and transmit water within fractures; joints and bedding planes and form a fractured rock aquifer in the region (GHD, 2010a). Locally within EL 7223, groundwater is available within the Permian sediments; however, the Quaternary Alluvium and in particular the Gunnedah Formation typically yields better quality groundwater and higher yields. The Gunnedah Basin is present throughout EL 7223.

7.3.3 Hydraulic Parameters

GHD (2011a,b) undertook an extensive program of hydraulic conductivity testing in the key geologic units within EL 7223. The program included falling/rising head tests, short term pumping tests, packer tests and airlift tests. Figure 7.37 and Figure 7.38 present the field-measured values for each geological unit. Table 7.6 summaries the ranges in values.

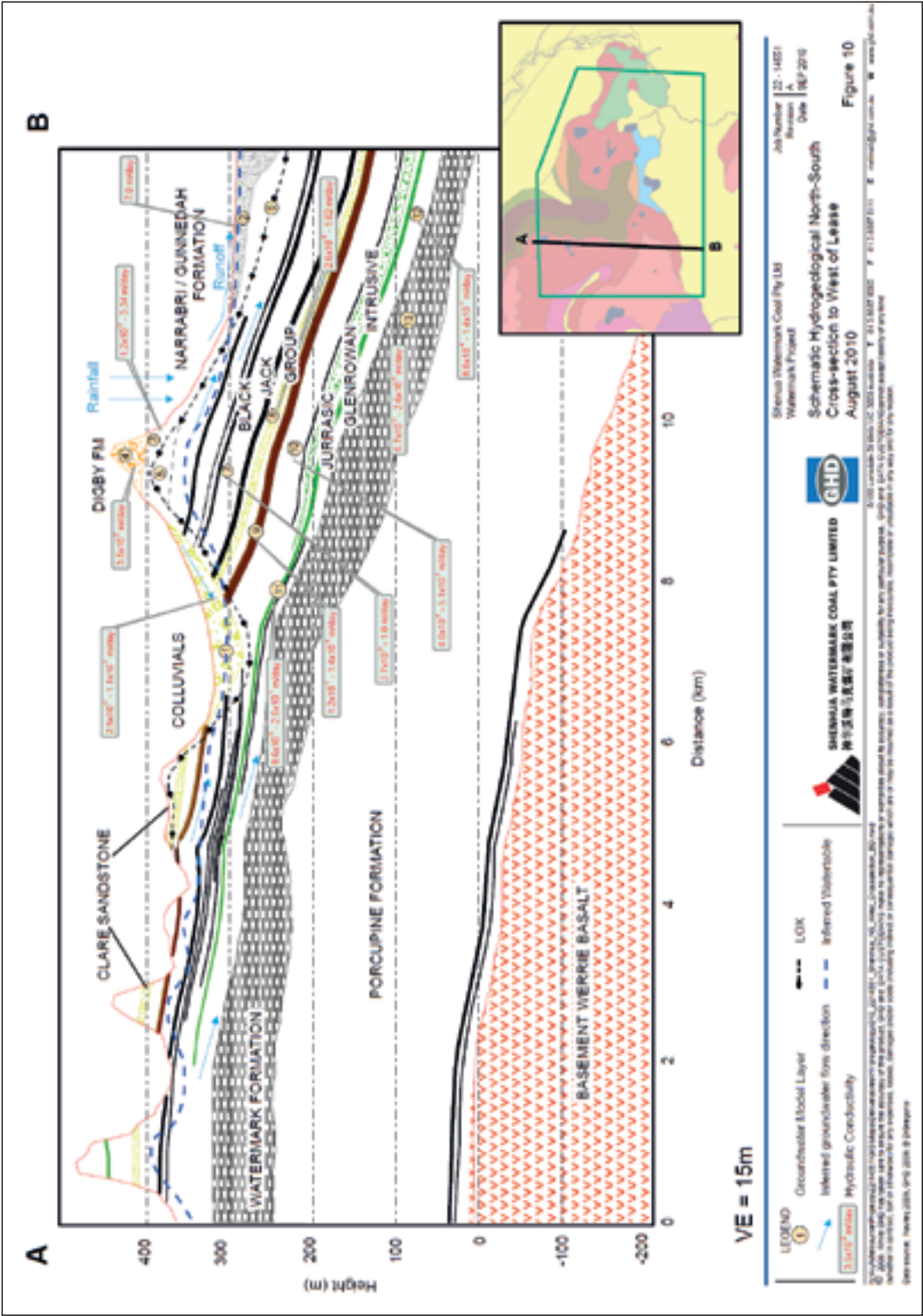


Figure 7.37: Cross Section with Hydraulic Conductivity Data – GHD 2011

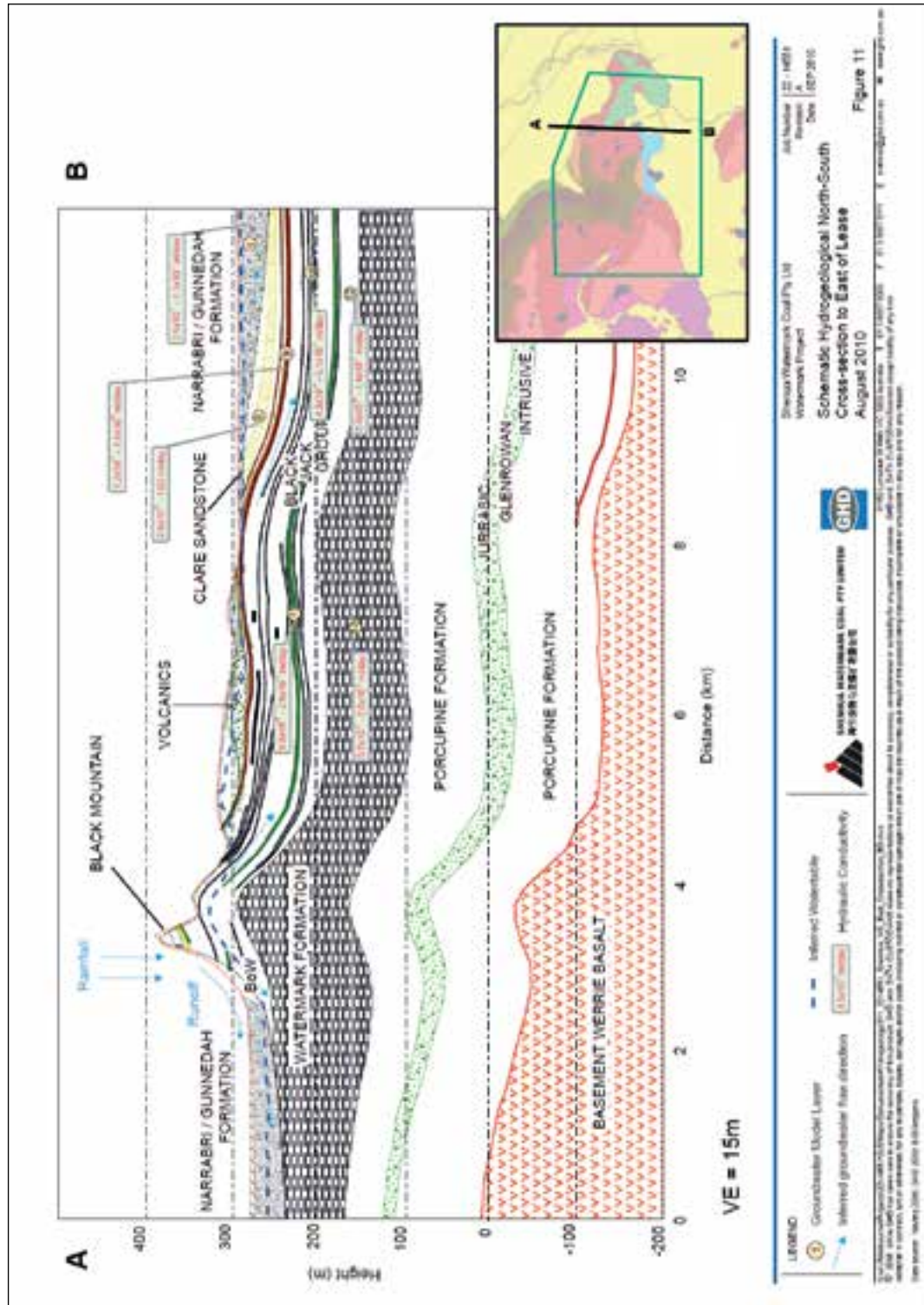


Figure 7.38: Cross Section with Hydraulic Conductivity Data – GHD 2011

**Table 7.6: HYDRAULIC PROPERTIES OF GEOLOGICAL UNITS**

Formation	Hydraulic Conductivity (m/day)
Tertiary Volcanics	1.7×10^{-3} - 5.2×10^{-3}
Pilliga Sandstone	-
Purlawaugh Formation	-
Weathered Permian	5.6×10^{-5} - 1.8
Interburden	2.6×10^{-3} - >1
Clare Sandstone	2.6×10^{-5} - 3.3
Interburden	2.6×10^{-3} - 1.02
Hoskissons Seam	1.7×10^{-4} - 1.2×10^{-1}
Interburden	8.6×10^{-5} - 5.1×10^{-1}
Melvilles Seam	8.6×10^{-5} - 2.4×10^{-1}
Interburden	8.6×10^{-4} - 1.4×10^{-1}
Watermark	2.2×10^{-4} - 5.7×10^{-3}

The field testing data indicates the hydraulic conductivity of the Black Jack Group ranges over several orders of magnitude, which is typical for fractured rock. The hydraulic testing identified that the Tertiary basalt and shallow dolerite, weathered Permian and the Benelabri Formation typically have higher hydraulic conductivity values than the remainder of the Permian sediments. The Watermark Formation shows the lowest range of hydraulic conductivity values for all of the Permian sediments. GHD (2010b) concluded it has the properties of an aquitard.

The nature of the parent geological material influences the hydraulic conductivity of the weathered zone, with higher permeability values associated with the shallow Clare Sandstone (GHD, 2010a). The Clare Sandstone is typically a fine to medium quartzose sandstone with intermittent cobble sized horizons and can measure up to approximately 40 m in thickness regionally. The Clare Sandstone is only present within the Southern and Eastern Mining Areas and does not extend into the Western Mining Areas. The testing indicates the Clare Sandstone and to a lesser degree the weathered zone are the only geological units that can be considered as aquifers in the Permian sequence. The interburden units and coal seams within EL 7223 are not sufficiently permeable to be considered aquifers, with the testing data indicating the hydraulic conductivity is more representative of an aquitard.

In addition to the field testing a program of laboratory testing was undertaken to measure both the vertical and hydraulic conductivity in core samples of interburden units. Table 7.7 summarises the results of the core testing.

Table 7.7: SUMMARY OF LABORATORY PERMEABILITY TESTS

Bore	Unit	from (mbGL)	to (mbGL)	length (m)	Kh (m/day)	Kv (m/day)	Kv:Kh
WM0291	Alluvium	67.4	67.6	0.2	6.05×10^{-3}	3.12×10^{-3}	0.52
	Alluvium	72.9	73.1	0.2	2.15×10^{-2}	failed	
	Sandstone	96.14	96.34	0.2	1.30×10^{-4}	1.12×10^{-4}	0.87
	Sandstone	99.2	99.4	0.2	3.80×10^{-3}	2.51×10^{-3}	0.66
	Conglomerate	101.33	101.44	0.11	2.07×10^{-2}	2.03×10^{-2}	0.98
	Sandstone	102.8	103	0.2	5.44×10^{-5}	2.59×10^{-5}	0.48


Table 7.7: SUMMARY OF LABORATORY PERMEABILITY TESTS

Bore	Unit	from (mbGL)	to (mbGL)	length (m)	Kh (m/day)	Kv (m/day)	Kv:Kh
	Carb Mudstone	105.15	105.3	0.15	8.29×10^{-3}	5.10×10^{-3}	0.61
	Conglomerate	131.7	131.9	0.2	2.56×10^{-4}	3.20×10^{-4}	1.25
	Mudstone/Siltstone	141.18	141.32	0.14	1.72×10^{-3}	8.00×10^{-7}	4.7×10^{-4}
	Sandstone	143.06	143.26	0.2	7.60×10^{-4}	9.68×10^{-4}	1.27
WM0012	Interburden	52	52.2	0.2	failed	$<8.64 \times 10^{-7}$	
WM0042	Siltstone	32.8	32.92	0.12	8.64×10^{-7}	8.64×10^{-7}	1.00
	Conglomerate	216.2	216.33	0.13	9.85×10^{-4}	7.43×10^{-4}	0.75
	Sandstone	292.24	292.5	0.26	2.76×10^{-5}	failed	
	Maules Creek	318.46	318.66	0.2	8.99×10^{-3}	6.74×10^{-3}	0.75
WM0255	Siltstone	69	69.15	0.15	2.49×10^{-3}	2.14×10^{-3}	0.86
	Sandstone	153.03	153.2	0.17	1.04×10^{-4}	8.64×10^{-5}	0.83
WM0074R	Sandstone	42.3	42.4	0.1	1.30×10^{-4}	2.51×10^{-5}	0.19
	Sandstone	103.63	103.83	0.2	8.41×10^{-1}	9.85×10^{-2}	0.12
	Hoskissons U roof	105.4	105.55	0.15	3.34×10^{-3}	9.07×10^{-4}	0.27
	Sandstone	140	140.3	0.3	2.07×10^{-5}	1.38×10^{-5}	0.67
	Dolerite	164.4	164.55	0.15	1.73×10^{-6}	8.64×10^{-7}	0.50
WM0066	Conglomerate	45.67	45.87	0.2	5.49×10^{-1}	4.33×10^{-1}	0.79
	Siltstone	116.71	116.91	0.2	1.56×10^{-4}	4.58×10^{-5}	0.29
	Carb Mudstone	151.49	151.69	0.2	1.02×10^{-3}	4.41×10^{-4}	0.43
	Sandstone	158.81	159.01	0.2	5.18×10^{-5}	3.11×10^{-5}	0.60
	Sandstone	185.9	186.05	0.15	8.21×10^{-3}	4.75×10^{-3}	0.58
	Sandstone	225.64	225.8	0.16	3.97×10^{-5}	3.28×10^{-5}	0.83
	Mudstone	240.76	240.96	0.2	1.73×10^{-6}	8.64×10^{-7}	0.50
	Hosk-Mel Interburden	243.24	243.36	0.12	2.71×10^{-2}	7.52×10^{-4}	0.03
WM0239	Sandstone	14	14.2	0.2	4.67×10^{-5}	2.25×10^{-5}	0.48
WM0258	Hosk-Mel Interburden	40.84	40.99	0.15	6.74×10^{-3}	4.84×10^{-3}	0.72

The laboratory measurements test the hydraulic conductivity of the core matrix, not the secondary fracture based conductivity. The core tests are therefore a lower bound on the hydraulic conductivity for the purposes of groundwater modelling. As expected the core testing typically indicates relatively low horizontal hydraulic conductivity for the interburden material between 10^{-3} m/day and 10^{-6} m/day. The contrast between horizontal and vertical hydraulic conductivity is not large, vertical hydraulic conductivity typically being between 1.2 and 2 times lower than horizontal hydraulic conductivity.

Coal Seams

There is a large body of work that has been undertaken in the Hunter Valley that shows that the hydraulic conductivity of the coal seams declines with depth (AGC, 1984; MER, 2009). This work quantifying the hydraulic properties of coal seams refers to fracture condition, depth and coal quality (Mackie, 2009). The decline can be described by an exponential function and is based on measurements from drill stem/packer test data (Figure 7.39). Drill stem testing from various CSG exploration wells and well testing results within the project area were obtained online from the DIGS® database. Figure 7.39 shows the hydraulic conductivity values from packer and slug tests undertaken in coal seams on EL 7223 and in regional coal seam gas wells, overlain on the relationship developed by Mackie (2009) for the Hunter Valley. The data generally shows a relationship with depth, but the relationship cannot be considered strong, likely due to the limited number of data points and the variability in the data.



A measured hydraulic conductivity of the coal seams within EL 7223 is relatively low and between 1.7×10^{-4} to 1.2×10^{-1} m/day for the Hoskissons coal seam and 8.6×10^{-5} to 2.4×10^{-1} m/day for the Melvilles coal seam. This relatively low hydraulic conductivity values for the coal indicate there is no notable increase in the coal compared with the interburden material. This is not always the case in the Gunnedah Basin with testing work at the Maules Creek complex indicating a median hydraulic conductivity for the coal seams of between 10^{-2} and 10^{-1} m/day (AGE 2011). SWS (2010) reported hydraulic conductivity values of 2×10^{-3} to 3×10^{-2} m/day for the Black Jack Group, comprising the Hoskissons coal seam, Arkaroola Formation/Brigalow Formation and the Pamboola Formation.

Coal seams generally display vertical hydraulic conductivity values similar or equal to horizontal hydraulic conductivity rates, due to the alignment of the conductive cleats within the unit (refer to Figure 7.40). In this case, vertical hydraulic parameters of the coal seams are assumed to 10% of the vertical conductivity, but are conceptually allowed to increase to 100% of the horizontal hydraulic conductivity rates.

Further presentation of the hydraulic parameters of the Gunnedah units ascertained from GHD field and laboratory testing in the Project area is presented in Section 9.2.3 and in the GHD Stage 4 Report (GHD, 2012).

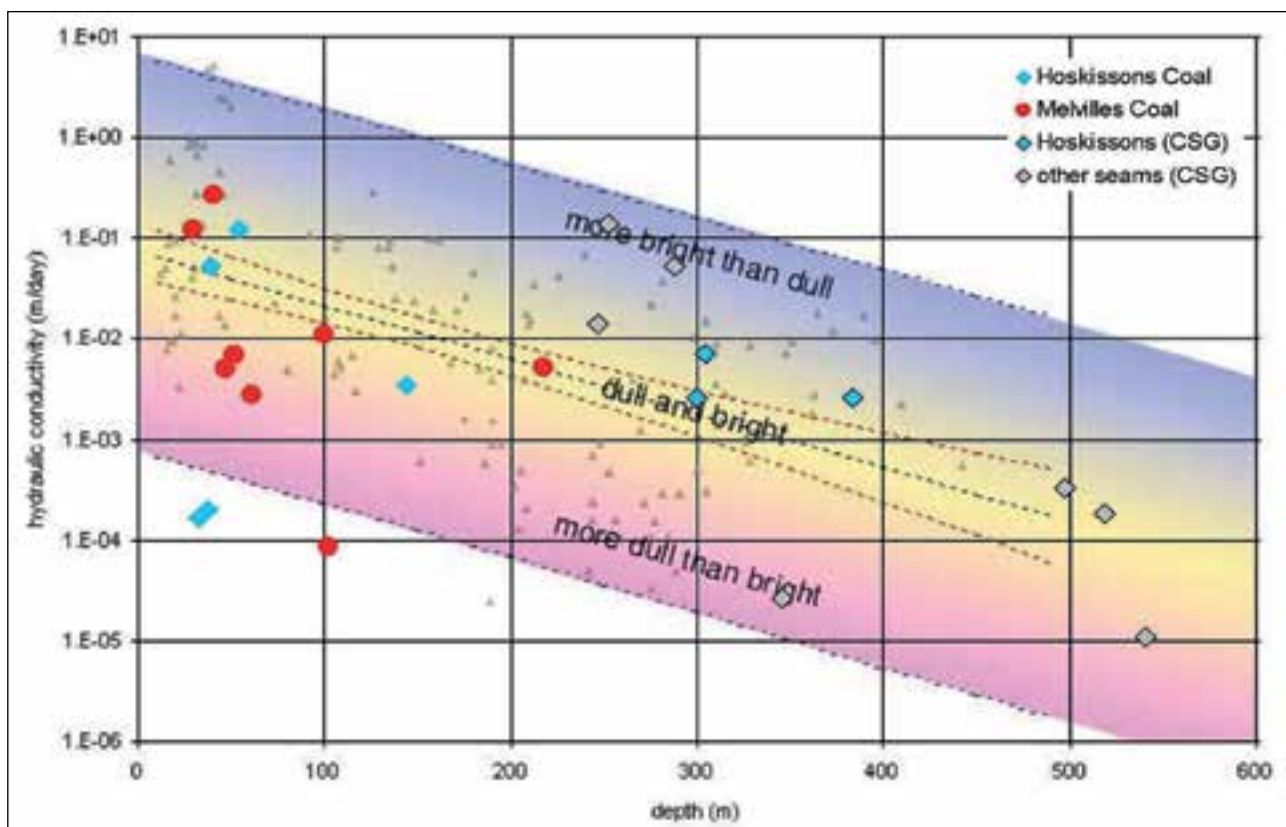


Figure 7.39: Representation of the Influence of Depth and Brightness on Coal Seam Hydraulic Conductivity (source: modified from Mackie 2009)

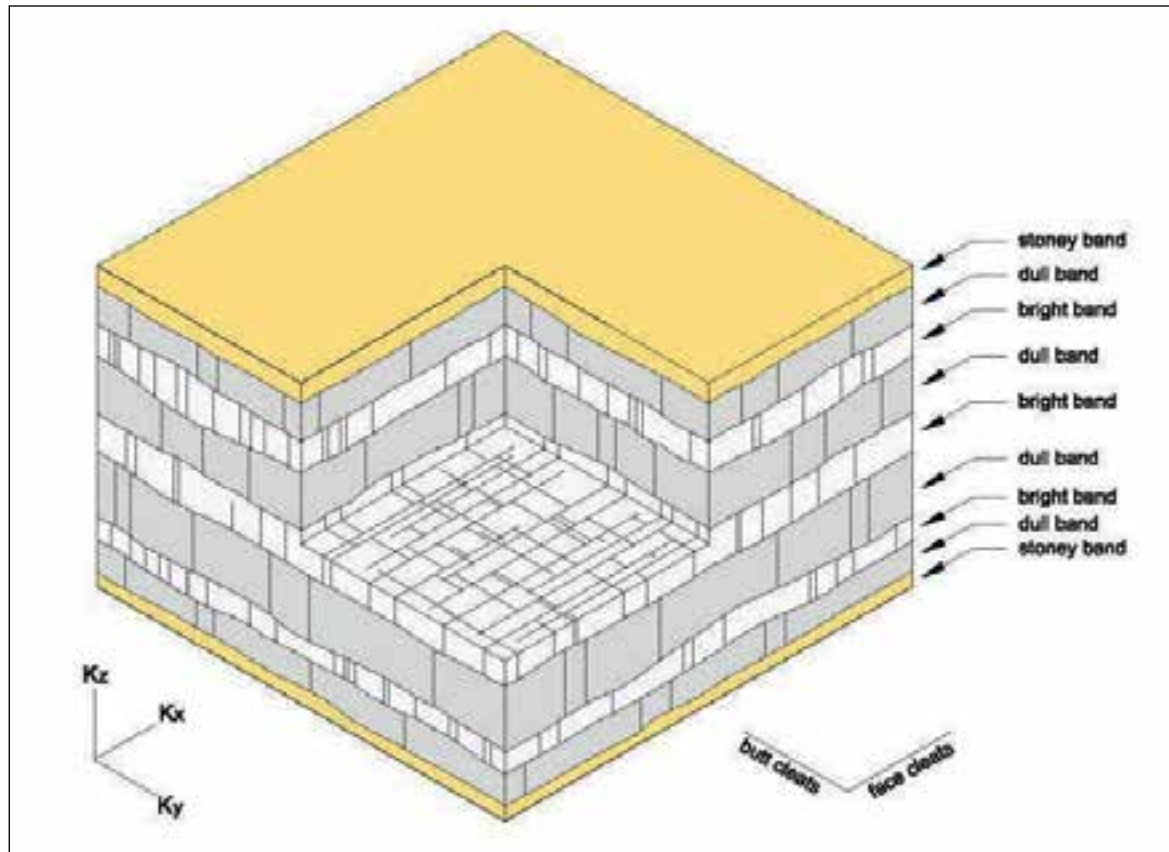


Figure 7.40: Geometry of Cleating in Banded Coals (source: Mackie 2009)

7.3.4 Yield and Usage

GHD (2010b) undertook a bore census within EL 7223 that indicated there are numerous registered stock and domestic bores. General observations from the census show that many of the older bores in the western and central Permian basement areas are no longer in use due to poor water quality and declining yields. Twenty-one of the registered bores in EL 7223 were abandoned. The census showed that better groundwater quality and more consistent yields were found on the eastern side of EL 7223. Two bores were identified on the eastern side of EL 7223 that intersect and extract groundwater from old underground mine workings (GHD, 2010a). Groundwater yields from bores in the Permian sediments are typically low at less than 1 L/s (GHD, 2010a).

7.3.5 Groundwater Levels and Hydraulic Gradients

A total of 103 monitoring sites have been established throughout the Project Boundary to monitor groundwater levels within the different aquifers. The monitoring sites are comprised of single standpipe bores and vibrating wire piezometers (vwps).

Groundwater levels are measured at approximately fortnightly intervals: levels within standpipe bores are measured manually with a water level dipper that is lowered down the bore; levels within vwps are manually downloaded using an electronic readout box. In addition to manual readings, some standpipe bores have been equipped with “Levellogger” pressure transducers to automatically record groundwater levels at daily intervals.



Groundwater level hydrographs are shown in Appendix 4. A moving 30-day average daily rainfall is shown on each hydrograph to assess trends against rainfall. Daily rainfall data is derived from the Bureau of Meteorology (BoM) rainfall station at Gunnedah Airport (station no. 055202).

Most monitoring bores located within the shallow Narrabri Formation (Figure A4-1, A4-2) and Gunnedah Formation (Figure A4-7, A4-8) show a good correlation to rainfall with clear increasing trends following rainfall events.

Overall, most monitoring bores within the geologically older Permian formations show stable to slightly declining levels over the monitoring period. A clear response to rainfall is seen in some monitoring bores e.g. WM0157 - Hoskissons Seam (Figure A4-4) and WM0012A – Benelabri Formation (Figure A4-5); however, the response is generally more delayed than those observed within shallower aquifers. Some bores e.g. WM0362 – Watermark Formation (Figure A4-11) show slow recovery following purging and sampling resulting in a saw-tooth like pattern. This slow recovery response is most likely due to low permeability within the screened aquifer.

Locally, downward vertical gradients have been measured, indicating a decrease in hydraulic heads from the weathered and more permeable sediments to the deeper, fresher sediments (GHD, 2011a,b). There is some evidence of shallow groundwater levels increasing in response to rainfall whilst the deeper monitoring bore completions show a stable to steady decline in groundwater level. This trend indicates a limited vertical hydraulic connection between the shallow and deeper groundwater systems within EL 7223 (GHD, 2011a,b). In some areas, this vertical hydraulic connection appears to be good and is explained by local structural features.

Groundwater flow within the Permian Formations across EL 7223 typically occurs to the north to north-east along Watermark Gully and to the south to south-east and westerly towards Lake Goran on the central western boundary. Groundwater quality and water level data indicates that recharge to the fractured rock groundwater system occurs within the elevated terrain. Groundwater then flows from the elevated terrain (ridgelines and peaks) to the central drainage lines and plains.

Figure 7.41 presents interpolated groundwater levels measured in the monitoring bores within EL 7223 at January 2011 (GHD 2011b). The figure indicates that elevation strongly controls groundwater levels in the Permian, with flow from the many topographic highs in EL 7223, down to the floodplain. Figure 7.42 presents the modelled average Gunnedah Basin groundwater levels in the Project Area.

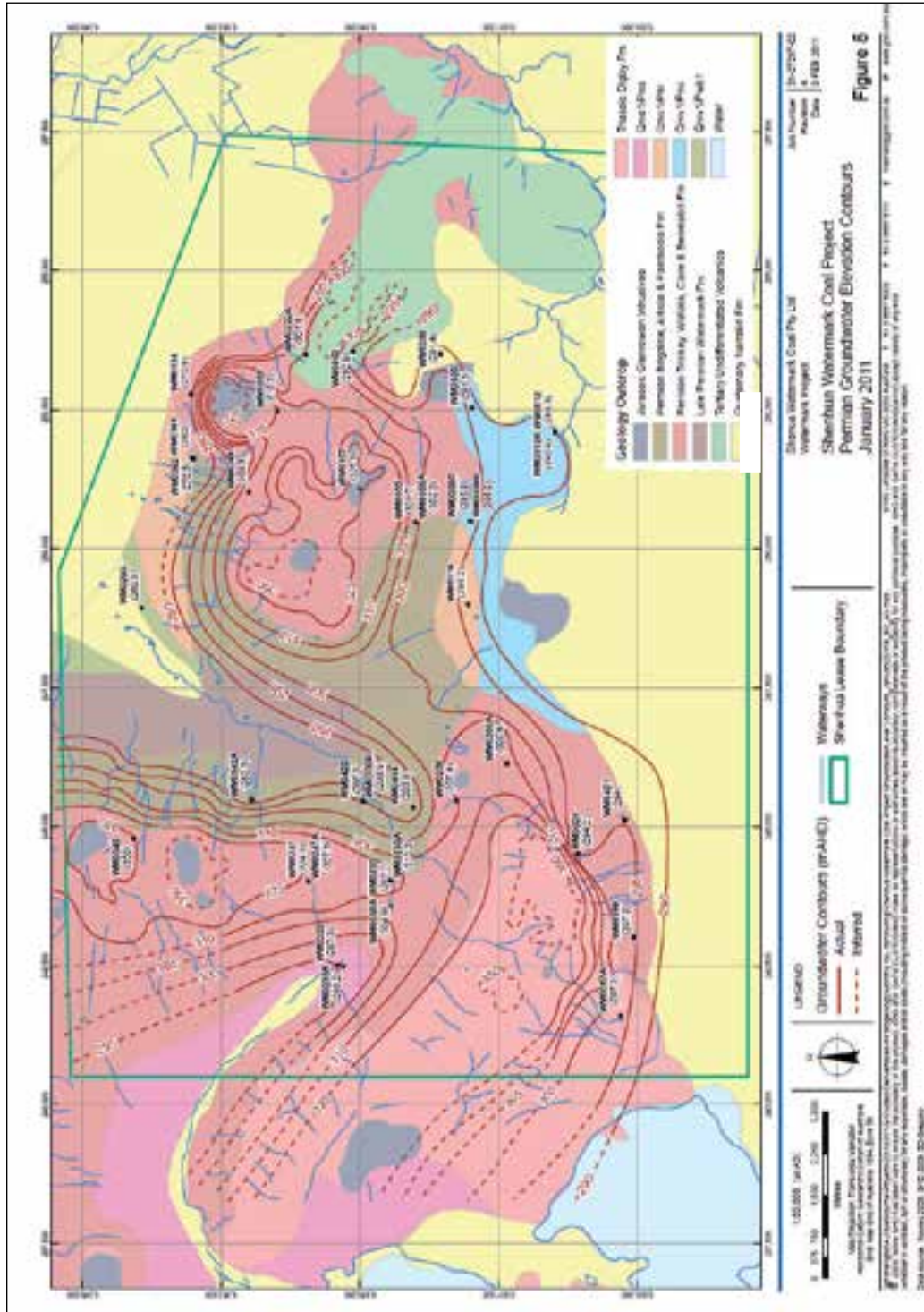
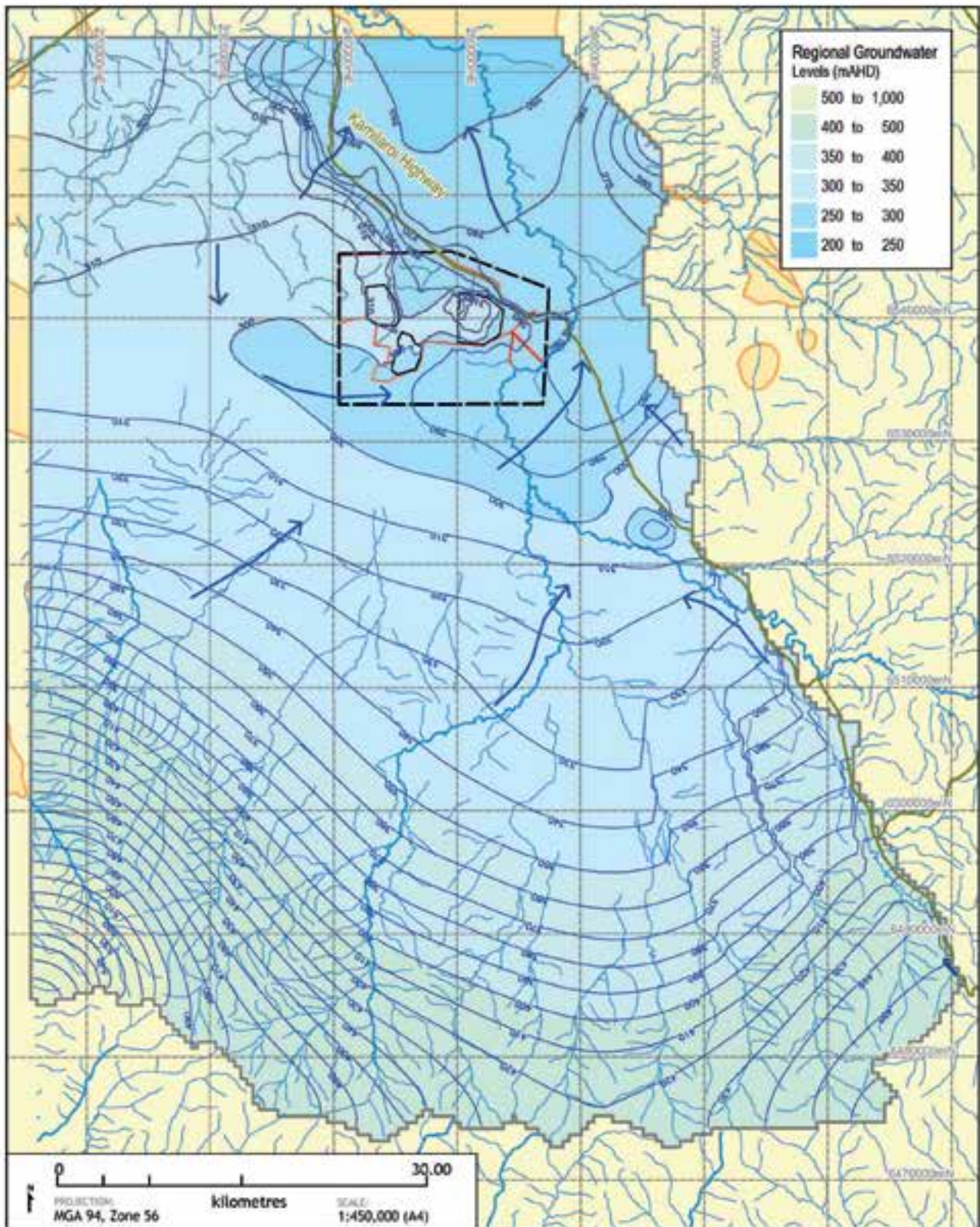


Figure 7.41: Project Area Observed Groundwater Levels – from GHD (2011b)



LEGEND:

- Inferred Groundwater Flow Direction
- Proposed Mining Area
- EL 7223
- Drainage Line / Creek
- Project Boundary

Watermark Coal Project (G1501)
Groundwater Assessment

Regional Groundwater Levels (Gunnedah Basin Aquifers)



DATE:
10/10/2012

FIGURE NO.:
7.42



7.3.6 Recharge and Discharge

Recharge to the ridge areas that outcrop through the alluvial floodplain is primarily via of diffuse rainfall infiltration. The rate of recharge is controlled by a combination of slope, aspect, geology, weathering, soils, vegetation and elevation. The highest recharge rates occur through the weathered basalt slopes and drainage channels at the Liverpool Ranges which feed recharge to the alluvial aquifers. The recharge rates through the Jurassic and Permian ridge areas is expected to be much lower. Timms and Ackworth (2006) noted that “sandstone hill slopes found at Pine Ridge, Spring Ridge, and near Caroon are not as important to recharge. For example, at one sandstone hill slope, monitoring and investigation found that groundwater levels were lower under the ridge than on the plains and that almost no recharge occurred. Rainfall on the sandstone ridges appears to be lost mainly to evaporation with minor runoff. However, further investigation is needed to confirm this.”

The high groundwater salinity within many of the Permian bores indicates the recharge rates are generally relatively low, but can be enhanced where zones with locally enhanced permeability are close to the surface.

Table 7.8 summaries the results of radiocarbon and tritium analyses on water samples from selected Permian bores.

Table 7.8: SUMMARY OF RADIOCARBON AGE DETERMINATION IN PERMIAN SEDIMENTS							
Site ID	Sampling Date	¹³ C (%)	¹⁴ C (‰mC)	TDIC (mmol/kg)	¹⁴ C age (years)	¹⁴ C age range (years)	Geology
DUPE01	23/11/2011	-12	23	9	6084	4852 - 7199	-
WM0009B	18/09/2011	-12	77	17.3	<100	-	Weathered Interburden
WM0009R	18/09/2011	-13	6.7	6.1	17141	15906 – 18259	Melville's Coal
WM0012	22/09/2011	-11	0.7	8.2	34309	32937 – 35600	Hoskissons Coal
WM0012A	22/09/2011	-11	76	15	<100	-	Weathered Sst Benelabri Fm
WM0021	11/12/2011	-13	15	12	10638	9406 - 11753	Howes Hill Coal Lower/Clare Sst
WM0036C	31/10/2011	-16	10	7	15168	13935 - 16284	Fractured Interburden
WM0055	22/10/2011	-12	23	19	6325	5092 - 7440	Melville's Coal
WM0062	23/11/2011	-14	29	9	5347	4115 - 6462	Interburden – F Coal seam
WM0067A	2/10/2011	-9.5	49	5.9	<100	-	Digby Fm
WM0091	1/11/2011	-9.8	15	13	8090	6857 - 9205	Hoskissons Coal
WM0091B	1/11/2011	-9.8	1.0	8.5	30470	29169 - 31669	Benelabri Fm
WM0157	30/10/2011	-13	33	11	3689	2457 - 4804	Hoskissons Coal
WM0233	3/10/2011	-12	8.7	13	13938	12705 – 15055	Melville's Coal
WM0290	4/10/2011	-0.1	0.5	83	<100	-	Watermark Fm
WM0291A	21/09/2011	-7.3	1.5	23	24528	23265 - 25679	Hoskissons Coal
WM0291B	21/09/2011	-6.1	0.1	30	48135	43512 - 58551	Benelabri Fm
WM0421	21/09/2011	-9.5	2.3	11	23241	21996 - 24371	Clare Sst
WM0426	5/10/2011	-8.8	1.9	6.8	23964	22714 - 25100	Weathered Clare Sandstone
WM0427	22/09/2011	-9.6	0.8	14.3	31804	30474 - 33039	Weathered Pamboola Fm
WM0432	22/09/2011	-11	15	7.5	9148	7916 - 10263	Weathered Pamboola Fm

Source – GNS Science (2012)

‰mC = percent modern carbon (sample post-dates atmospheric testing of nuclear weapons)

TDIC = total dissolved inorganic carbon expressed in mmol.kg⁻¹



The radiocarbon analyses indicate that the Permian groundwater ranges in age from very recent at less than 100 years to many millennia at 48,135 years. Four bores WM009B, WM0012A, WM0067A and WM0290 recorded the presence of tritium indicating very young groundwater of less than 100 years old. The presence of recent groundwater in these bores suggests localised connection to surface waters.

The remaining 17 bores recorded much older groundwater ranging in age from 3,689 to 48,135 years, with an average age of 18,354 years suggesting very low rates of recharge to the ridge areas. The age data does not show a clear distinction between geological formations, indicating groundwater within the different Permian Formations (including coal seams) is of a similar age range. However compared to Table 7.4, it appears that groundwater in the Permian Formations is generally older than groundwater within the alluvial aquifers that has an average age of about 10,500 years and median of 4,500 years.

The age dating data suggests a low rate of diffuse recharge to the ridge areas, with isolated structurally controlled areas that experience rapid recharge.

7.3.1 Water Quality and Environmental Values

Groundwater quality in the fractured rock groundwater system is variable with generally saline groundwater found in the deeper Permian Formations (GHD, 2010a). Data from NOW and from site groundwater monitoring bores shows that near elevated ridges within the Project Boundary, groundwater salinity in the Permian sediments is less than 3,000 mg/L TDS, whereas data down gradient from the ridgelines suggests that the Permian sediments are more saline (5,000 to 10,000 mg/L TDS). Away from the elevated terrain and toward the alluvial plains, Permian bores with shallow groundwater levels (less than 3 m below ground surface) typically yield highly saline groundwater (10,000 to 20,000 mg/L TDS) (GHD, 2011a,b).

Figure 7.43 presents a histogram grouping the water samples from the Permian aquifers within EL 7223 according to salinity class.

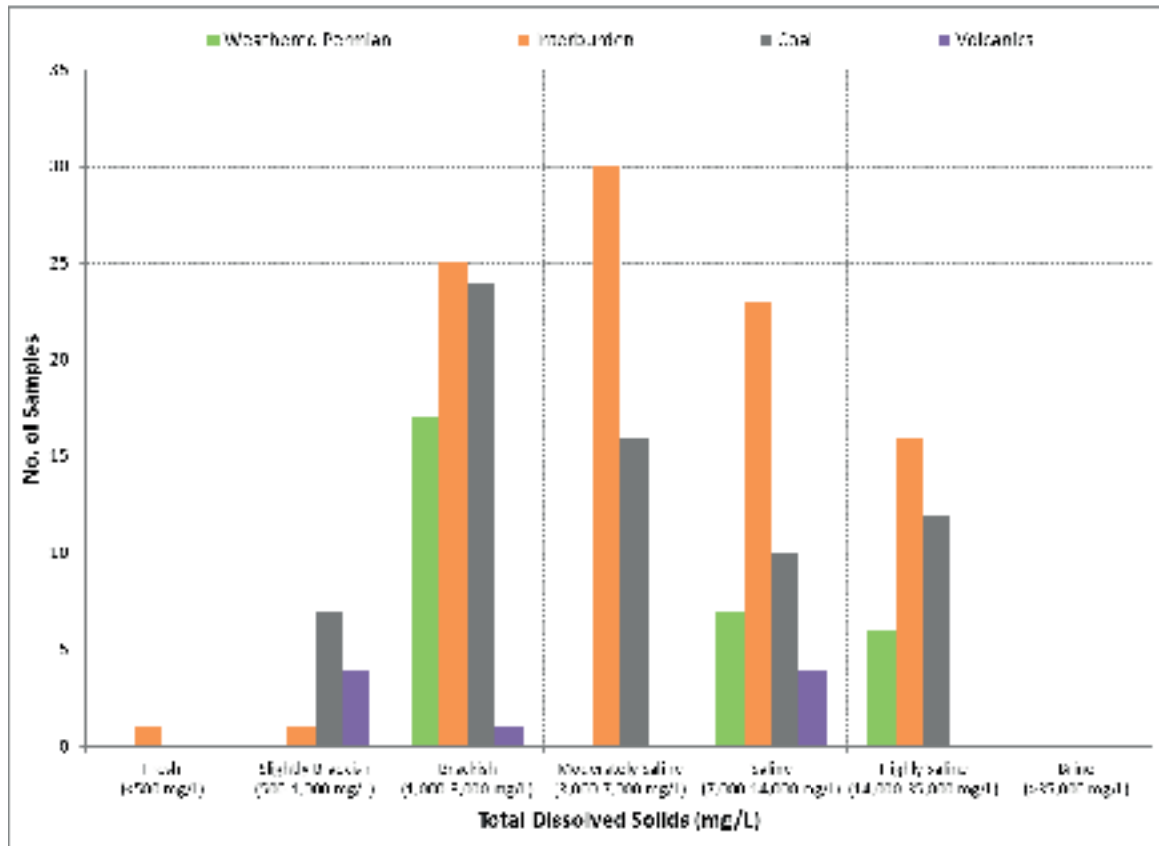


Figure 7.43: Total Dissolved Solids Histogram – Water Classification

Figure 7.43 shows the variability in salinity within EL 7223 with samples from fresh to highly saline. The majority of the samples are in the brackish to moderately saline range. Coal seam and interburden samples were generally brackish to highly saline. The variability in the Permian water quality is attributed to variable recharge rates caused by local variations in geology, weathering and evapotranspiration.

Figure 7.44 again groups the Permian water samples according to suitability for beef cattle. It shows the suitability of groundwater from the Permian aquifers for beef cattle is highly variable. All aquifers range from being suitable to unsuitable for stock. This highlights that the environmental value and beneficial use of the Permian groundwater also varies depending on local factors.

Figure 7.45 shows the trends in TDS over time in the monitoring bore network.

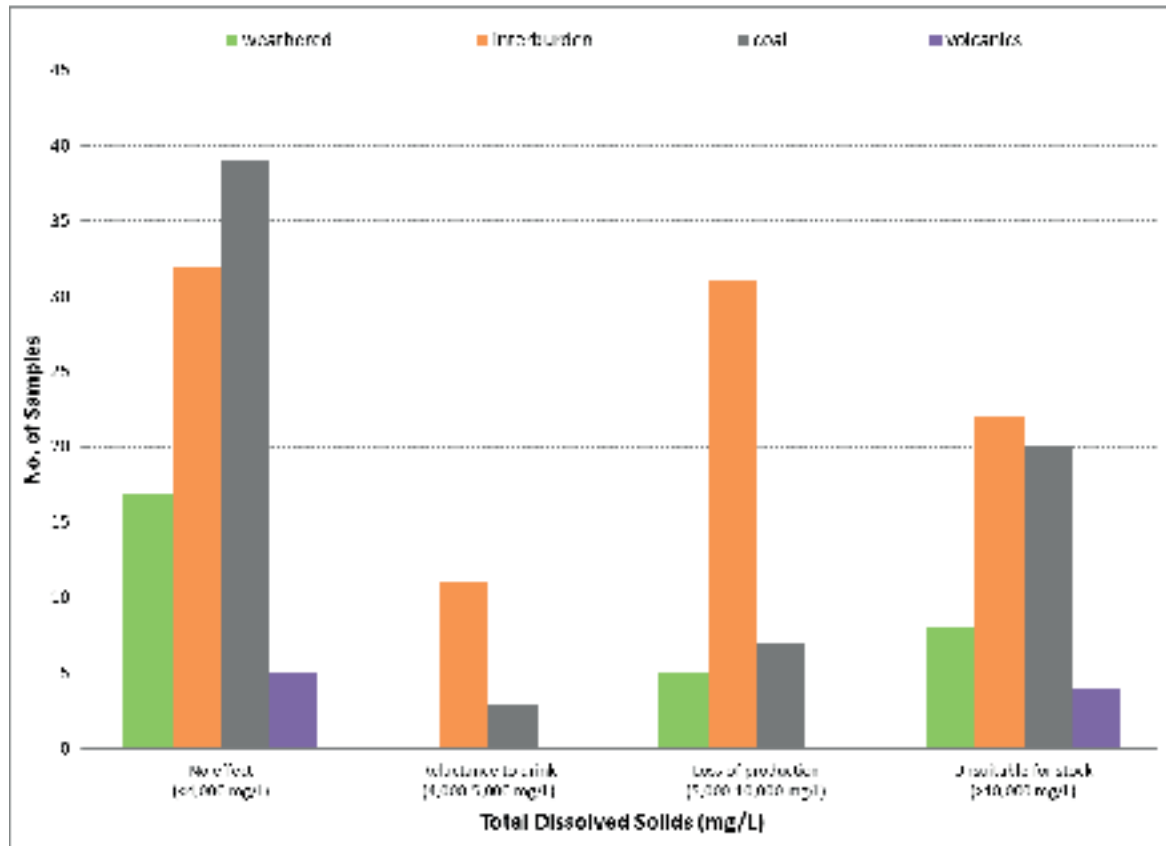


Figure 7.44: Total Dissolved Solids Histogram – Beef Cattle Suitability

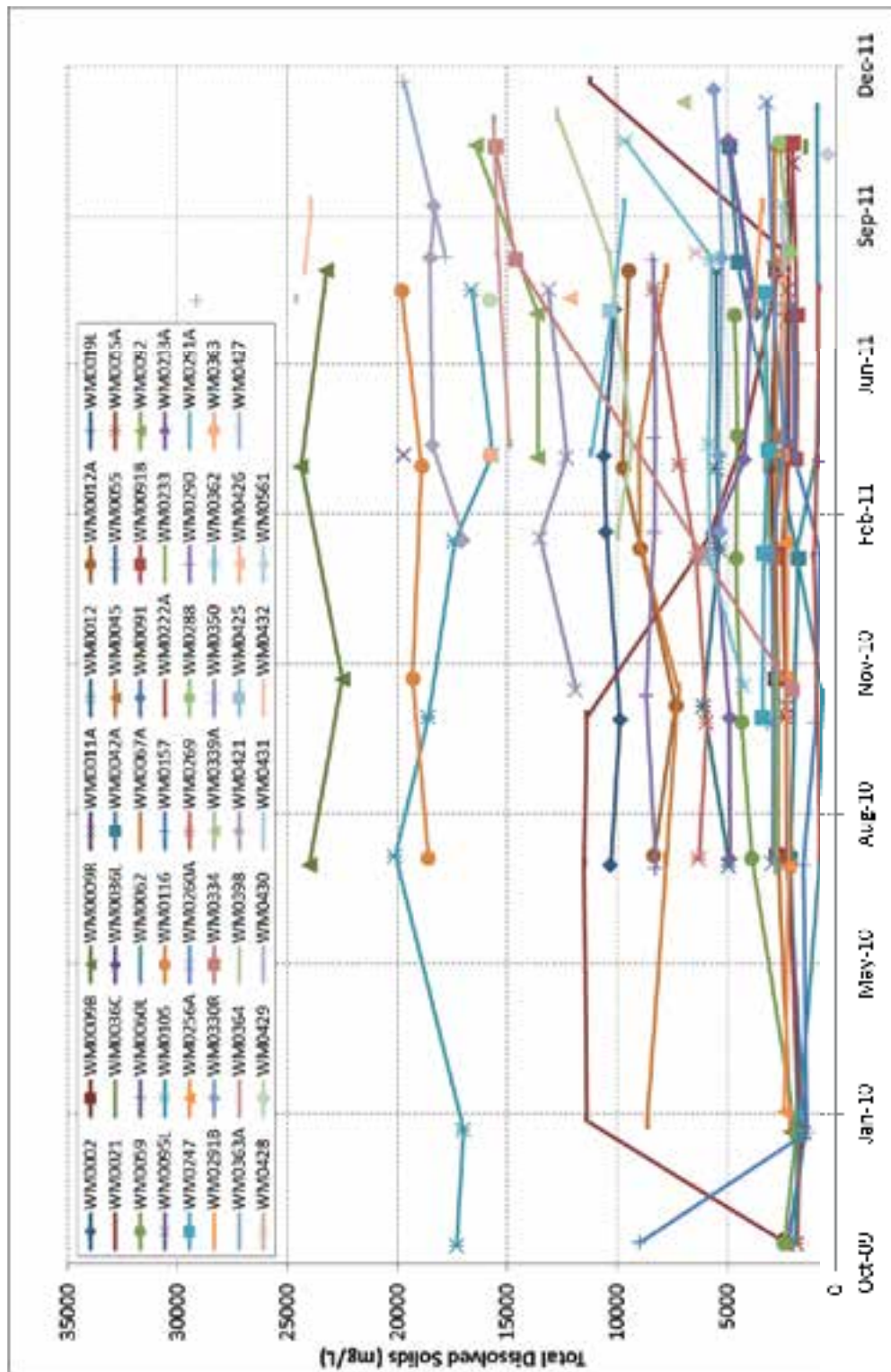


Figure 7.45: Project Area Total Dissolved Solids Records - Permian



7.3.2 Groundwater Dependent Ecosystems and Springs

A hydrogeologist from SRK Consulting and ecologist from Cumberland Ecology and the previous landowner inspected EL 7223 on the 4th April 2012 for known groundwater fed springs and soaks. For the purposes of this report, a soak is an area where groundwater is visible at the ground surface, but there is no obvious flow from the soak area. A spring is also an area where the water table is above the ground surface, but has a visible flow away from the spring area.

EPNRMB (2010) define springs, soaks and waterholes as wetlands that occur naturally where underground water (groundwater) discharges to the surface, or where the natural or modified topography of a watercourse, wetland or lake intersects the underground water table. They are commonly found in watercourses, upper gullies and on hillsides. The team identified four groundwater soaks towards the south-west corner of EL 7223 as shown in Figure 7.46.

SWS (2012b) as part of the Namoi Catchment Water Study did not identify any GDEs within or in close proximity to EL 7223.

Cumberland Ecology (2012) concluded that the maximum depth of the roots in the Project Boundary is likely to be approximately 20 m and therefore areas where the groundwater table is less than 20 m below the surface level have the potential to support GDEs. Based on this assumption, the presence of the woodlands and the results of SKM approximations of GDE presence (SKM, 2011), *“approximately 50 ha of vegetation in the Project Boundary to considered to have High potential to comprise a GDE, and 308 ha is considered to have Moderate potential.”*

The Project is contained almost wholly on weathered Gunnedah Basin hydrostratigraphic units, and is therefore likely that tree roots grow to their full potential across the majority of the Project area.



LEGEND:

- EL 7223
- Proposed Mining Area
- Soak Location
- Surface Interpreted Seismic Fault
- Black Soil Boundary
- Drainage Line / Creek
- Project Boundary

Watermark Coal Project (G1501)
Groundwater Assessment

Observed Seepage Locations



DATE:
10/10/2012

FIGURE No:
7.46



The team inspected each soak to determine if it was fed by groundwater and supported a groundwater dependent ecosystem.

Soak 1 – “Pigs Wallow Soak”

Figure 7.47 shows Soak 1, the “Pigs Wallow”.



Figure 7.47: Soak 1 “Pigs Willow Soak”

This soak covers an area of approximately 25 m² and consists of minor standing fresh water, which was less than 5 mm deep at the time of inspection. It is possible that the soak is located within a colluvial channel. The water source for this soak is likely derived from Breeza State Forest ridges to the south-west of the site. However, the soak may also be influenced by a north-west/south-east trending fault which is located immediately to the south of this location (refer to Figure 7.46). Local landholders indicate that this soak generally stays wet throughout the year and is a source of water for wild pigs in the area.

Soak 2 – “Wallaby Soak”

Figure 7.48 shows Soak 2, the Wallaby Soak. This soak is located within an area of lush grass covering an area of approximately 25 m² immediately to the south of the same north-west/south-east trending fault identified near Soak 1. At the time of inspection, no free standing water was visible. As for Soak 1, the water source is likely derived from Breeza State Forest ridges to the south-west of the site. The influence from the nearby fault is unknown.



Figure 7.48: Soak 2 “Wallaby Soak”

Soak 3 – “Property 36”

Figure 7.49 and Figure 7.50 show Soak 3. This soak covers an area of approximately 100 m² and consists of standing fresh water measured at less than 5 mm deep. The ground surface at this location is comprised of gravels and pebbles which may represent colluvium or weathered sandstones/conglomerates. Hard rock is reported by local landholders to be encountered nearby at shallow depths less than 5 m from the surface. The likely water source for this soak is from ridges located in Breeza State Forest to the north of this location.



Figure 7.49: Soak 3 “Property 36”



Figure 7.50: Soak 3 “Property 36” Surface Gravels/Pebbles

Soak 4 – “Spring-Fed Dam”

Figure 7.51 and Figure 7.52 show Soak 4, “Spring-Fed Dam”. This soak feeds a nearby dam which is approximately 200 m² in surface area. At the time of inspection, the water level in the dam was about 2 m below ground level and local landholders indicate that the dam has never gone dry since its construction in the early 1980s. Similar to Soak 3, the ground surface is comprised of gravels and pebbles which may represent colluvium or weathered sandstones/conglomerates.



Figure 7.51: Dam Fed by Soak 4 “Property 19 Spring-Fed Dam”



Figure 7.52: Soak 4 “Property 19 Spring-Fed Dam” Surface Gravels/Pebbles

The site walkover indicated that no significant groundwater dependent ecosystems were present in the areas of the springs and soaks.

7.4 Conceptualisation of Hydrogeology

7.4.1 Introduction

Every numerical groundwater model has as its foundation a conceptual model. The conceptual model is an understanding of how the groundwater system operates and is an idealised and simplified representation of the natural system. MDBC (2000) define a conceptual model as an *“idealised summary of the current understanding of catchment conditions, and the key aspects of how the flow system works...subject to some simplifying assumptions.”*

Extensive information on the natural system is typically required to develop an equivalent and simplified conceptual groundwater model representative of the system. A great deal of hydrogeological data has been collected proximal to the Project. Regional data has been incorporated into this study to ensure the level of detail across the Project Boundary is also of high quality and representative of measured conditions.

Development of the conceptual groundwater model is a crucial step in groundwater modelling. Care has to be taken during the development of such models since errors in the conceptual model cannot be corrected during the model calibration, or at any later stage of the modelling study, without major revisions. Formulation of the conceptual model often highlights gaps in data or deficiencies in the understanding of the groundwater system.

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



7.4.2 Hydrostratigraphic Units

The following section presents a simplified conceptual understanding of the hydrogeological regime. This conceptual model forms the basis of the assumptions used when developing the more detailed numerical model. The data presented in previous sections indicate the Regional Project area supports a number of geological units that have similar properties and can be considered as hydrostratigraphic units. Table 7.9 summarises the hydro-stratigraphic units.

Table 7.9: HYDROSTRATIGRAPHIC UNITS		
Formation	Dominant Lithology	Typical Properties
Narrabri Formation	clays with sand lenses	aquitard to poor aquifer
Gunnedah Formation	sands and gravels	high yield aquifer
Weathered bedrock (regolith)	weathered sedimentary rocks	poor yield aquifer
Liverpool Range and Tertiary Volcanics	basalt	low to moderate yield aquifer
Jurassic Pilliga Sandstone	sandstone	low to moderate yield aquifer
Permian Clare Sandstone	sandstone	low to moderate yield aquifer
Permian coal groundwater measures	coal	aquitard
Permian interburden groundwater measures	coal, mudstone and sandstones	aquitard

Section 8.4.3 outlines how the hydrostratigraphic units have been represented in the groundwater model.

7.4.3 Recharge and Discharge

Recharge to the key hydrostratigraphic units is discussed in the paragraphs below.

Recharge to the alluvial aquifers occurs via watercourses at the break of slope and via leakage from the major watercourses including the Mooki River and Quirindi Creek running through the floodplains. The breakoff slope area around the edge of the black soil plains slows rainfall runoff and enhances recharge to the underlying alluvium. The rate of recharge in the break of slope areas is controlled by the permeability of the underlying sediments, and the presence of surface water drainages with permeable sandy beds. Some areas exist such as within the southern Project Boundary where the break of slope is dominated by clayey sediments and the recharge rate is not considered to be significant.

The rate of diffuse recharge through the black soil profile in areas distant from the break of slope or rivers is expected to be very low. The high clay content in the black soils encourages evaporation of rainfall and concentrations of salts that slowly drain to the Narrabri Formation.

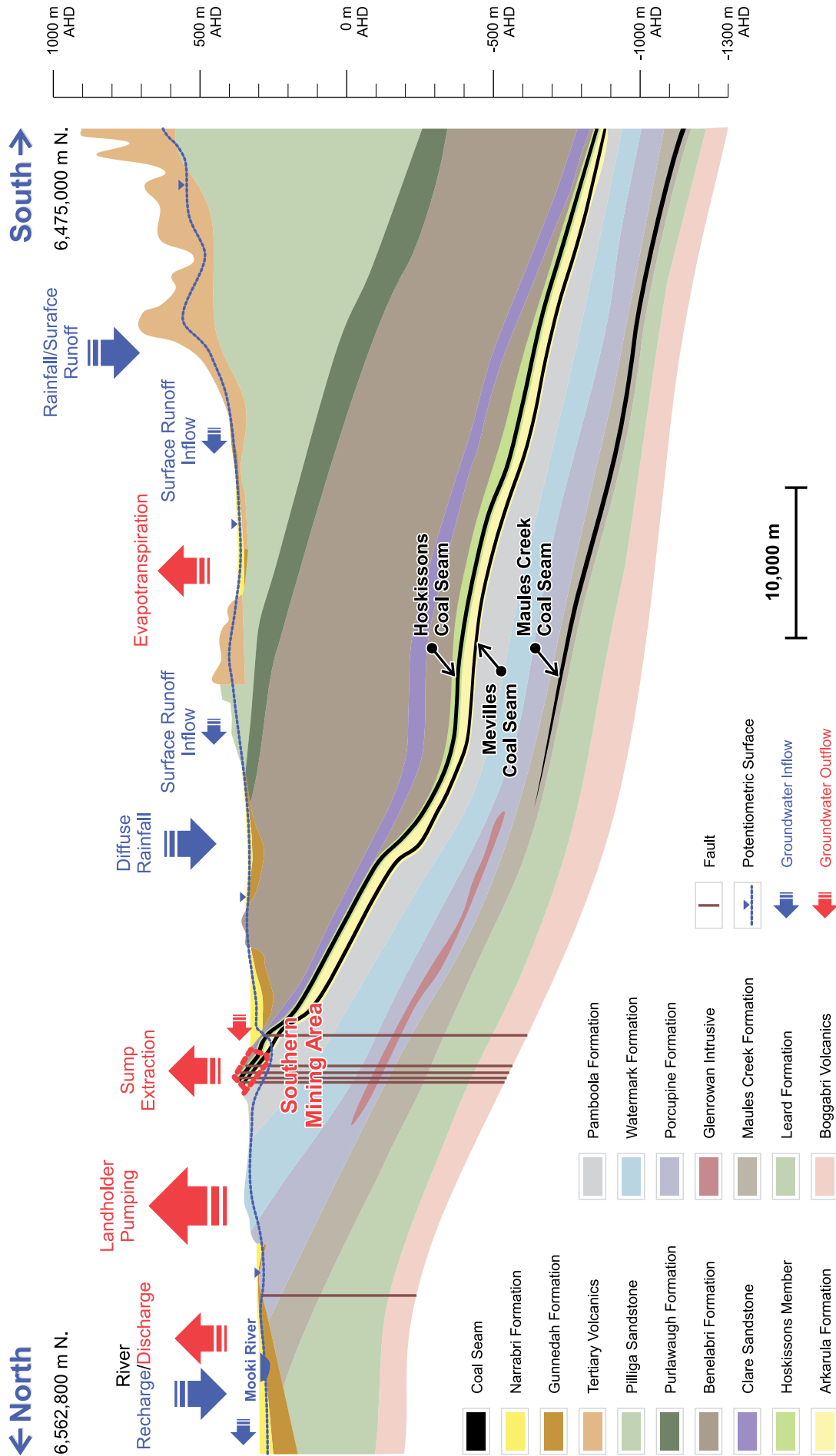
Recharge to the alluvial aquifers through upward seepage is also expected to occur but it is considered to be only a small component of the water that recharges the alluvial systems. Previous government studies (McNeillage, 2006, Merrick, 2001) have excluded the bedrock aquifers from the groundwater models, and have still been able to achieve calibration of the models indicating bedrock seepage is not a significant contributor to the alluvial water budget.



The Permian coal measures form an aquifer system with both primary and secondary fracture porosity. The weathered Permian zones collect and store diffuse rainfall recharge, and allows slow drainage to the underlying fresh rock sequence. The recharge is highly heterogeneous and is enhanced by near surface structures.

Groundwater discharges from the alluvial aquifers is via pumping, from creek/river baseflow, evapotranspiration via vegetation and down-gradient flow. The volumes of water discharging via pumping from the alluvial aquifers has gradually increased over time due to agricultural pumping. This is expected to have reduced the baseflow to rivers, vegetative evapotranspiration and down-gradient flow.

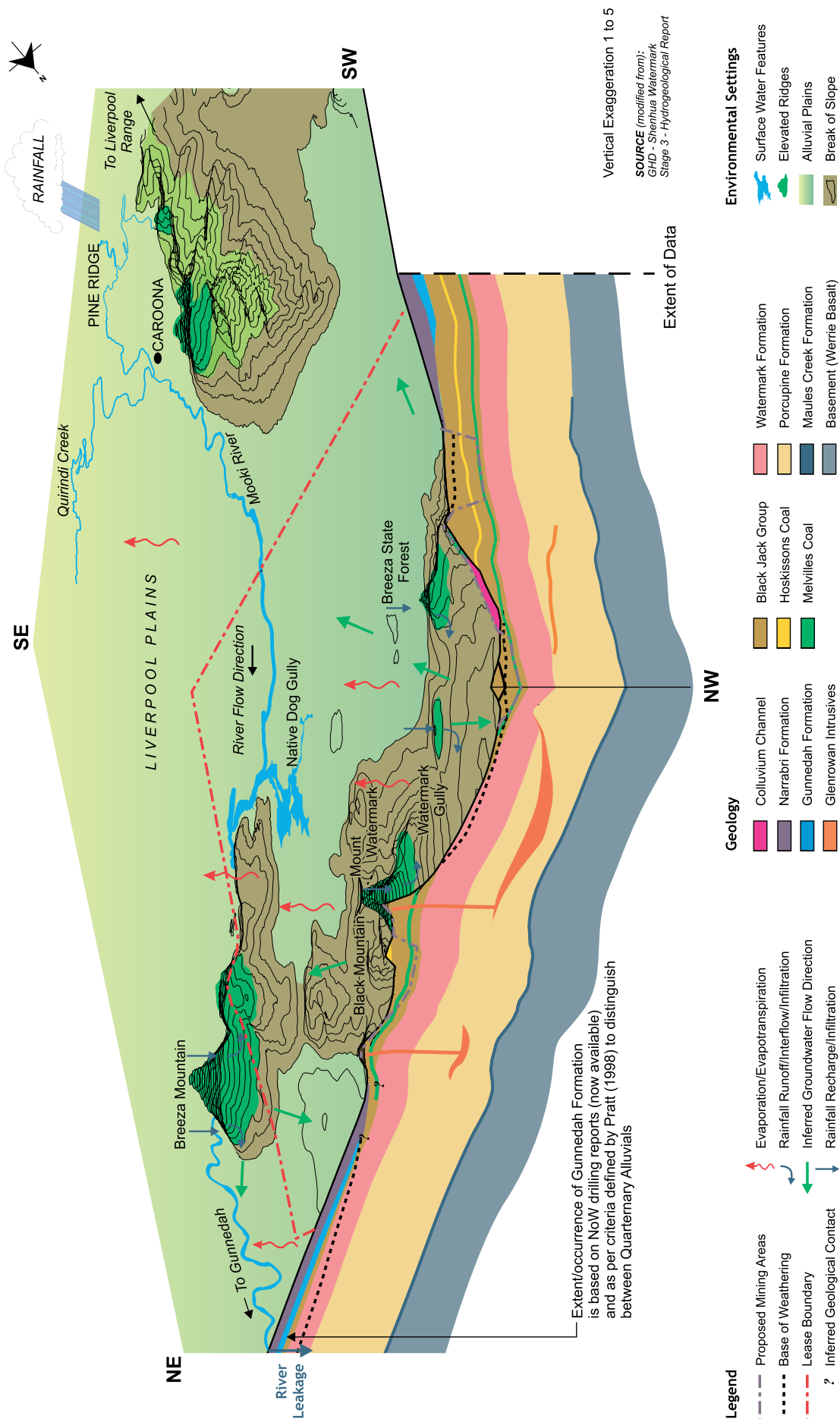
Figure 7.53 and Figure 7.54 present graphically the conceptual model. The illustration outlines the regional geological structure, hydrogeological stresses and their relationship to the hydrogeological units.



Schematic Section Showing Conceptualised Water Balance

Figure 7.53

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



3D Block Diagram of Groundwater Flow

Figure 7.54

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



8.0 NUMERICAL MODEL DESIGN

8.1 Previous Numerical Models

Previous investigators have undertaken a number of groundwater modelling simulations within the region. These include:

- Noel Merrick Zone 8 Model (2001);
- Craig McNeillage Zone 3, 5, 8 and 7 Model (2006);
- David Salotti Zone 1 Model (1997);
- Schlumberger Namoi Catchment Model (2012); and
- Maules Creek Groundwater Model (AGE) (2011).

These models were closely studied and have been used as guides to the modelling approach. Therefore comparisons with the models, in terms of modelling approaches and output water budgets/impacts, have been documented.

8.2 Modelling Objectives

The objective of the groundwater modelling is to produce an output that represents the current understanding of the interactions between the aquifers at the Project Boundary and the regional groundwater system. Following calibration, it could be used to provide an indication of changes in groundwater conditions due to future activities within the model domain including but not limited to the development of the Project. The design, construction and calibration of the model were all tailored to meet these objectives as well as providing a framework for future iterations of the model following the addition of new data. The objectives of the modelling were to:

- replicate measured groundwater levels at each observation bore within 10 m and the trends over time, with an overall scaled root square mean error of less than 5% for all observation points;
- replicate known water budget components, with a numerical error of less than 1% at each time step and on a cumulative basis;
- estimate groundwater seepages to the open cut Mining Areas over the 30-year Project life;
- predict the zone of depressurisation in alluvial and other aquifers from mining activities and the level and rate of drawdown at specific locations;
- predict the magnitude of any drainage from the alluvial aquifer into the underlying Permian strata;
- predict the changes in groundwater drawdown to surface flows and other groundwater users due to Project operations; and
- identify areas of potential risk where groundwater impact mitigation/control measures may be necessary.



8.3 Model Confidence Level Classification

The degree of confidence with which a model's predictions can be used is a critical consideration. Several factors are considered in order to determine a model confidence-level classification, and typically depend on the following factors:

- available data;
- calibration procedures;
- consistency between calibration and predictive analysis; and
- level of stresses.

Barnett et al (2012) developed a system to classify the confidence-level for groundwater models. Models are classified as either Class 1, Class 2 or Class 3 in order of increasing confidence. The Project model complies with most of the Class 3 criteria, according to the system presented by Barnett et al, (2012). This conclusion was reached based upon:

Data

- numerous studies have been undertaken to define the proximal/regional aquifer systems and hydraulic parameters;
- the majority of all groundwater monitoring data points over the calibration period has been used in the calibration process;
- quarterly measured extraction, rainfall, is used in the calibration simulation;
- estimated quarterly areal potential Evapotranspiration used in the calibration;
- streamflow and baseflow estimates at several locations have been undertaken to ensure consistency; and
- high resolution digital elevation data used across the entire model domain.

Calibration

- validation demonstrated;
- Scaled Root Mean Squared error (SRMS) is below prescribed limits;
- long-term trends in seasonal fluctuations and response to groundwater extraction replicated in majority of monitoring bores;
- recent transient calibration data used; and
- fluxes of regional flow calibrated from surface water exercises.

Prediction

- length of prediction model is equal to the calibration model;
- temporal discretisation and stresses are within the range of those used in the calibration model; and
- model verification suggests calibration is appropriate post calibration period.

Key indicators

- calibration statistics meet agreed targets;
- mass balance error is close to zero;
- model parameters are consistent with conceptualisation; and
- appropriate computational methods and spatial discretisation used.



This confidence level classification is suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions and the evaluation and management of potentially high-risk impacts.

8.4 Model Design

8.4.1 Model Code

Numerical simulation of groundwater flow in the aquifers was undertaken using the MODFLOW SURFACT code (referred to as SURFACT for the remainder of the report). A commercial derivative of the standard MODFLOW code, SURFACT is distributed by Hydrogeologic Inc and has some distinct advantages over the standard MODFLOW, that are critical for the simulation of groundwater flow in the vicinity of the Project Boundary.

The MODFLOW code (on which SURFACT is based), is the most widely used code for groundwater modelling and is presently considered an industry standard. Use of the SURFACT modelling package is becoming increasingly widespread, particularly in mining applications where mine water seepage and groundwater level recovery are simulated.

SURFACT is capable of simulating variably saturated conditions. This is critical for the requirements of the Project where coal seams will be progressively mined with time resulting in desaturated model cells within the Mining Area dimensions. Then active mining will cease, and groundwater recovery will rewet the spoil within the Mining Area and adjoining depressurised strata.

SURFACT is also supplied with robust numerical solution schemes to handle the more complex numerical problem resulting from the unsaturated flow formulation. Added to the robust numerical solution schemes is an adaptive time-stepping function that aids the progression of the solution past difficult and complex numerical situations such as oscillations.

The MODFLOW pre and post processor PMWIN (Chaing and Kinzelbach, 1996) was used to generate some of the input files for the SURFACT model; such is the similarity between it and the standard MODFLOW. Where files differ to allow for the additional capabilities of SURFACT, these files were manually edited without using a graphical user interface.

The Pre-conditioned conjugate gradient solver (PCG5) was used for all transient modelling.

8.4.2 Model Extent and Boundary Conditions

Figure 8.1 and Figure 8.2 show the regional and predictive model grids. The model boundaries are as follows:

- Eastern Boundary – The Mooki Thrust Fault forms a boundary between the Quaternary/Permian aquifers and the outcropping crystalline basement of the New England Fold Belt which has a relatively poor ability to transmit water when compared to the alluvial system. The Mooki Thrust Fault forms the eastern boundary to the active model domain.
- Northern Boundary – This boundary is an east-west line from Curlewis in the west to the Mooki Thrust Fault in the east. A general head boundary across this zone represents down valley flow. The groundwater levels assigned to the general head boundary were based on historic groundwater levels recorded in the nearby bores and varied with each quarter.



- Western Boundary – The western boundary roughly follows a north-south alignment through Milroy that coincides with a groundwater divide in the Quaternary Narrabri and Gunnedah Formations. This boundary ensures the model encompasses Lake Goran within the model domain.
- Southern Boundary – The Namoi River catchment divide in the Liverpool Ranges forms the topographic boundary. This boundary ensures that any surface and groundwater interactions between the Liverpool Range volcanics and the overlying Quaternary Alluvium are simulated accurately.

The model grid is about 75 km wide (E-W) and 91 km long (N-S). This domain was developed to minimise any modelling boundary effects within the area of interest of the immediate surrounds of the Project.

The orthogonal axes of the model grid were aligned to (and normal to) the principal groundwater flow direction which is from south to north in the alluvial aquifer.

8.4.3 Model Layers

Section 7.4.2 identified seven key hydrostratigraphic units that control groundwater flow in the Project Boundary and on a regional scale. The hydrostratigraphic units were represented in the groundwater model by 11 layers as follows:

- Layer 1 - Narrabri Formation + Regolith + Tertiary Volcanics,
- Layer 2 - Gunnedah Formation + Regolith + Tertiary Volcanics,
- Layer 3 - Tertiary Volcanics,
- Layer 4 - Jurassic Pilliga Sandstone,
- Layer 5 - Interburden Units,
- Layer 6 - Clare Sandstone,
- Layer 7 - Interburden Units,
- Layer 8 - Hoskissons Coal Seam,
- Layer 9 - Interburden Units,
- Layer 10 - Melville Coal Seam,
- Layer 11 - Watermark - Maules Creek Formations

The thicknesses of the alluvial formations and layer elevations for all layers have been presented as Figure 8.5 to Figure 8.17. The weathering profile was simulated using enhanced zones of vertical and horizontal permeability assigned to base of weathering depths according to site and regional geological data. The Tertiary volcanics and intrusives in the Project Boundary were represented as zones within the model layers, but not as individual layers. The basement in the system was considered to be the Boggabri Volcanics, the top of which formed the base of the model. All units between the base of the Melville coal seam and the top volcanics were grouped as Layer 11.

The aim of the layer discretisation was to find a balance between having sufficient layers to represent the key detail in the system, while still limiting the number of cells to retain computational efficiency. To achieve this, the model layers grouped geological units with similar aquifer properties into single 'interburden' aquitard layers.



8.4.4 Grid and Cell Size

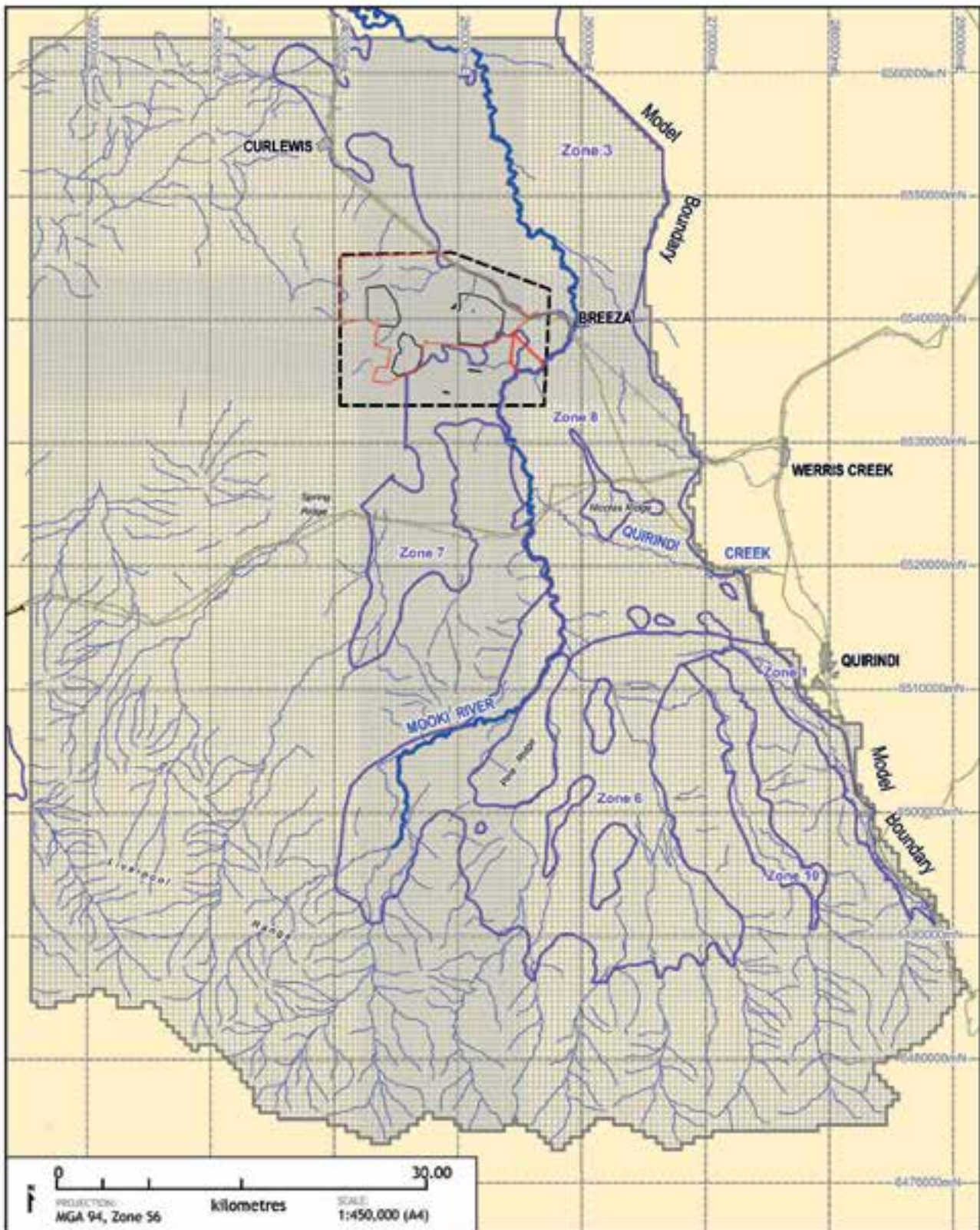
Two separate models were constructed for the Project. The first model, referred to as the 'calibration model' had a larger cell size, which reduces the total number of cells and therefore the time required to run the model. A relatively rapid run time was required to ensure the calibration model could be calibrated within a practical time-frame. Once a satisfactory calibration was achieved the grid size in the model was refined around the Project Boundary to allow a more detail in the geology and mining to be simulated, referred to as the "predictive model".

A cell size of 500 m x 500 m for the calibration model was refined within the Project Boundary to 250 m x 250 m. The total number of cells in the 'calibration' model is 305,921, comprising 27,811 cells per layer (11 layers).

For the second 'predictive model' the cell size was further refined in the Project Boundary to 50 m x 50 m. This refinement ensured the steeper hydraulic gradients in the groundwater phreatic and potentiometric heads that occur adjacent to the open cut Mining Areas were accurate. The 50 m x 50 m cells also ensured the groundwater heads within a 150 m zone between the Mining Areas and the boundary of the black soil plains were simulated. Figure 8.2 displays the model grid for the refined predictive model.

Figure 8.3 and Figure 8.4 present cross-sections through the model grid in relation to the geological layers and the grid refinement for the predictive refined model.

The upper cell size limit remained at 500 m by 500 m to ensure the aspect ratio of any one cell was a maximum of 10. Neighbouring cells were increased by a factor of 1.5 outside the Project Boundary to ensure numerical stability. The total number of active cells in the 'predictive model' was 1,225,873, comprising 111,443 cells per layer.



LEGEND:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Drainage Line / Creek
- Project Boundary

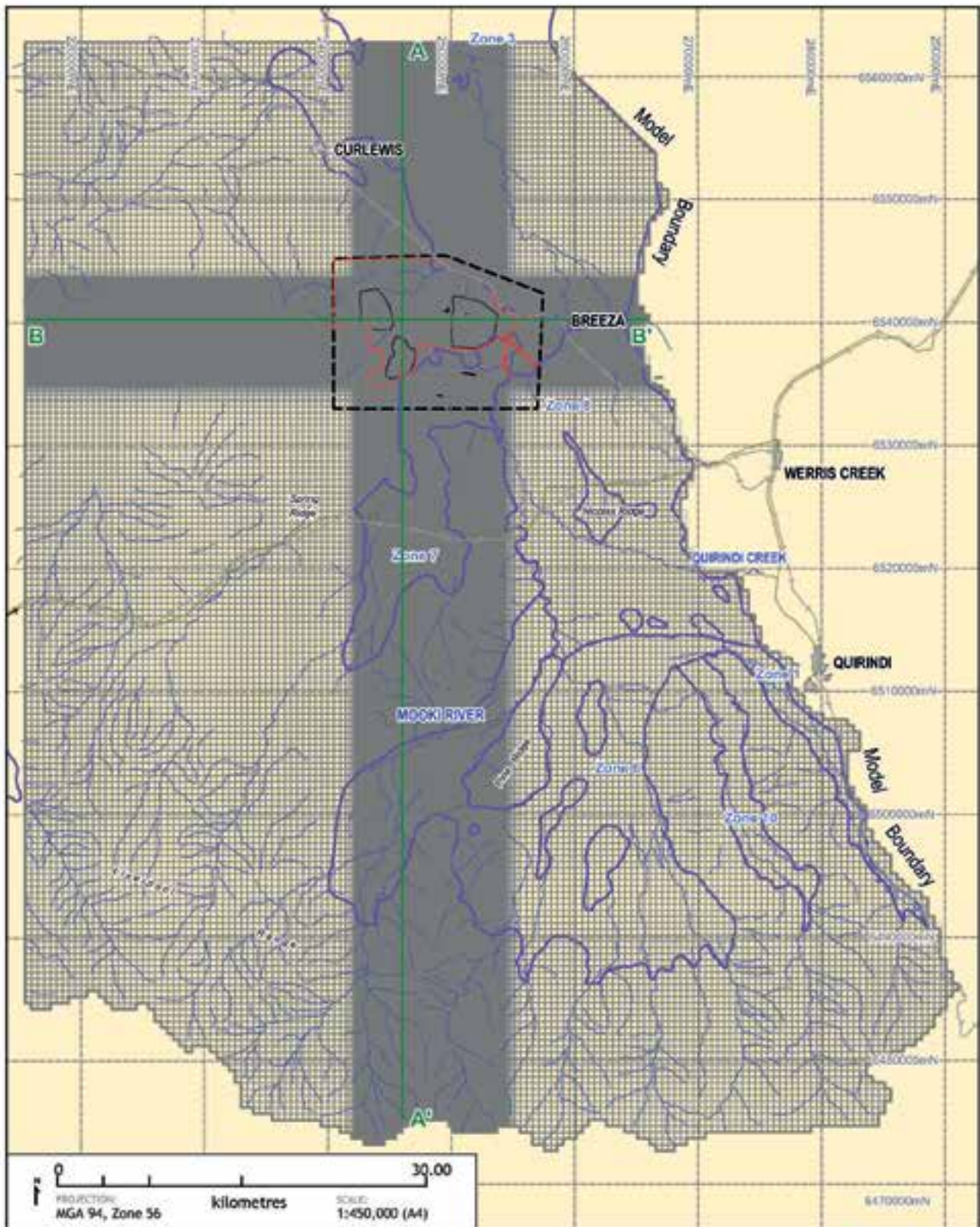
Watermark Coal Project (G1501)
Groundwater Assessment

Model Extent - Calibration Model



DATE:
10/10/2012

FIGURE No:
8.1



LEGEND:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek
- Cross Section Lines

Watermark Coal Project (G1501)
Groundwater Assessment

Model Extent - Predictive Model

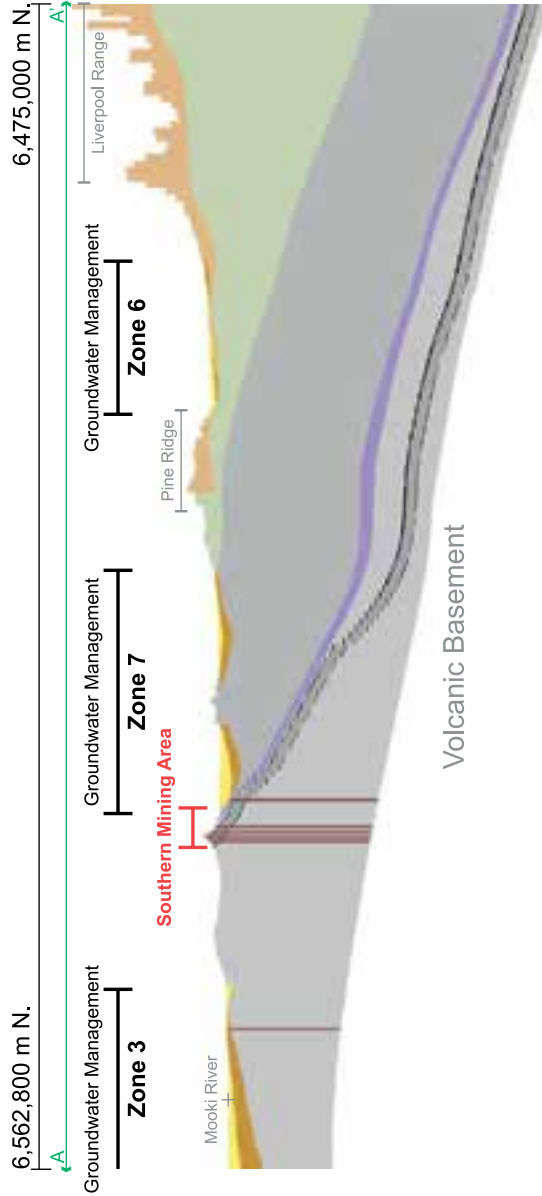
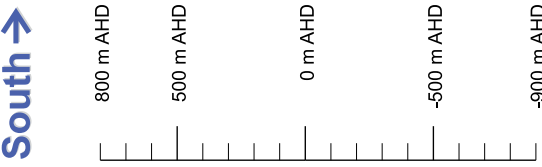


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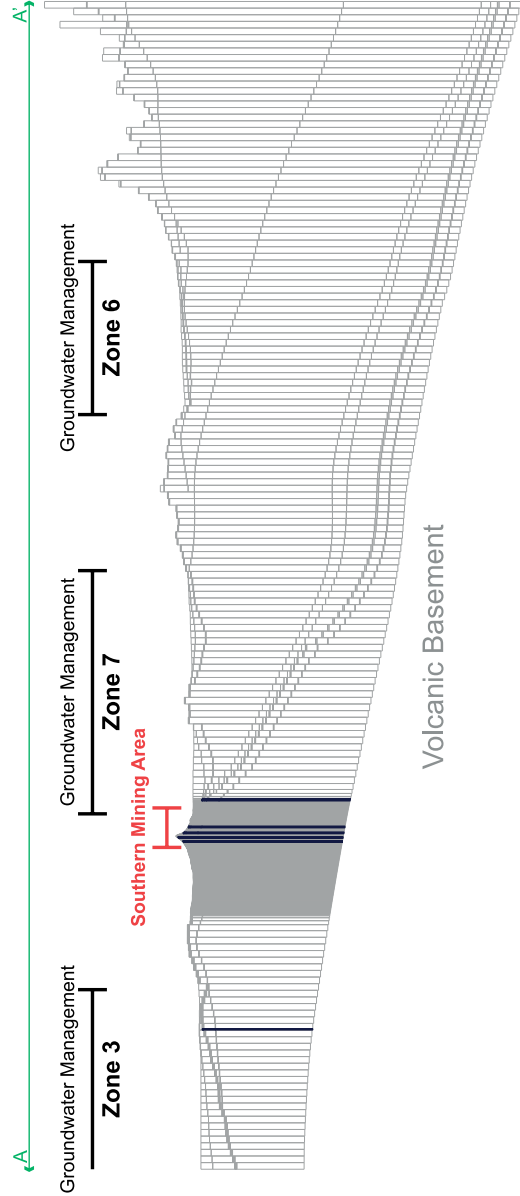
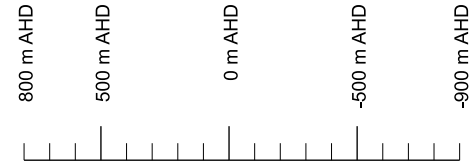
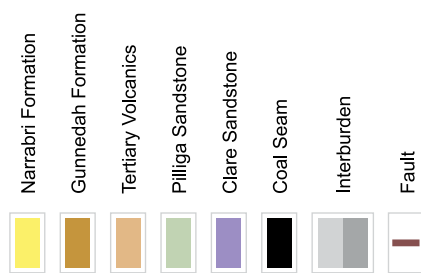
FIGURE No:
8.2



South →



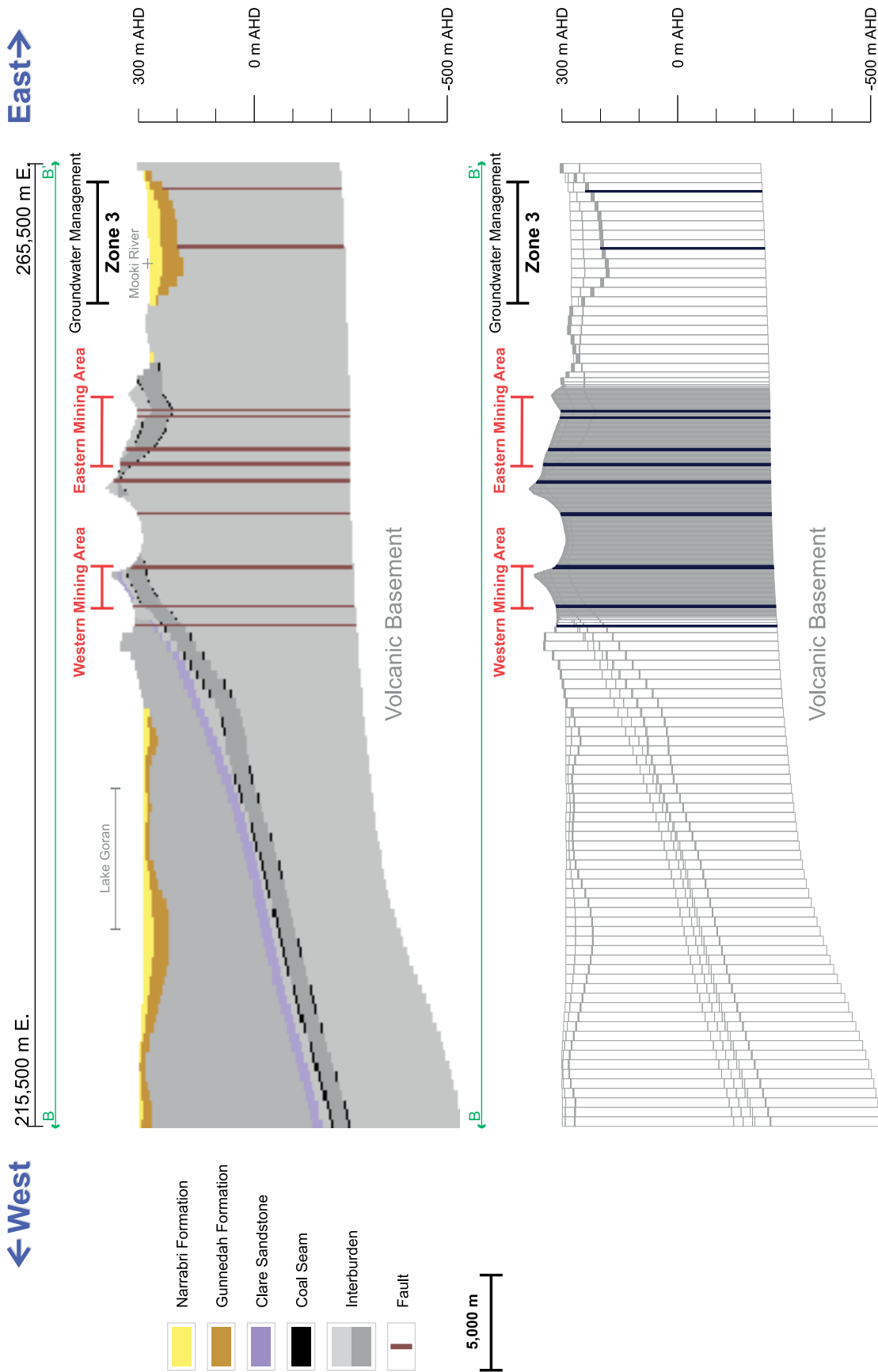
← North



Model Grid - Cross Section - North - South

Figure 8.3

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Model Grid - Cross Section - West - East

Figure 8.4

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Figure 8.5 to Figure 8.17 present the floor elevations and layer thicknesses of the key layers in the 'calibration model'.

8.4.5 Aquifer Properties

Starting hydraulic parameters were determined from extensive hydraulic testing at the Project Boundary, in combination with calibrated parameters from previous modelling in the Upper Namoi catchment. Where data was unavailable, textbook and extra-regional data was incorporated into the model.

8.4.6 Recharge

Average annual rainfall recorded in the BoM stations across the catchment was interpolated to create a rainfall distribution map (refer Figure 8.18). The rainfall variability across the model domain was normalised with the average annual rainfall at the Breeza 'The Park' Station (No. 055065) represented by a factor of 1, with the factor increasing up to about 1.5 where the rainfall is higher on the Liverpool Ranges. Quarterly rainfall totals recorded at the Breeza Station between 1980 and 2010 were then multiplied by the normalised rainfall factor to determine the rainfall at each model cell, which was in turn multiplied by the estimated percentage of recharge for the corresponding recharge zone.

The proportion of annual rainfall that recharged the aquifers was constant within the following defined zones:

- Alluvium,
- Regolith/Permian outcrop,
- Liverpool range basalt,
- Break of slope.

The break of slope recharge cells were determined by analysing the slope (in degrees) across the model area. A slope measuring between 0.5 to 1 degrees generally coincided with the black soil/ridge interface, and was set as a recharge zone in the model. These zones were further subdivided into nine subzones according to location, underlying geology and findings of previous modelling (Merrick 2001).

The break of slope subzones used in the model and calibrated with Parameter Estimation software (PEST) were as follows (refer Figure 8.19):

- Zone 1 – South Western Liverpool range interface,
- Zone 2 – Doona Point,
- Zone 3 – Watermark East,
- Zone 4 – GMZ 8 (Central),
- Zone 5 – North eastern boundary,
- Zone 6 – GMZ 1,
- Zone 7 – North western boundary,
- Zone 8 – Watermark West,
- Zone 9 – Central West.



Subdividing the break of slope zones allowed the differing geology and associated recharge potential to be represented. This was considered particularly important for the Project Boundary where the break of slope of recharge is considered far less significant than at the Liverpool ranges and areas along the eastern boundary of the alluvial aquifers.

Figure 8.19 shows the recharge zones applied to layer 1 of the model.

Initial recharge zones and rates were based on previous modelling studies by Merrick (2001) and McNeillage (2006) as follows:

- Alluvium - 1.2% of rainfall
- Break of slope (alluvium) - 5.0% of rainfall

Previous modelling in the area has focussed on the Quaternary Alluvial aquifer system and therefore starting values for the Permian and Tertiary recharge rates were based on previous modelling in the region.

- Regolith/Permian outcrop - 0.5% of rainfall
- Liverpool range basalt - 5.0% of rainfall

The break of slope recharge value given as a starting value is considered high, but is realistic due to the nature of the break of slope colluvium/alluvial interface.

Gridded monthly areal potential evapotranspiration rates for the period 1961 to 1990 was the basis of the evapotranspiration rates applied to the model (BoM). *“Areal Potential ET is the ET that would take place, under the condition of unlimited water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average”*. This data was used to calculate the quarterly average evapotranspiration rate across a 10 km x 10 km grid. Figure 8.20 shows the average annual areal potential evapotranspiration rates applied to layer 1 of the model. These rates used in the model simulation were scaled back to 10% of areal potential evapotranspiration (1270-1390 mm/year) rates, for numerical stability.

The mean annual pan evaporation rate is 1,752 mm/year, and the mean monthly evaporation exceeds mean annual rainfall all year round. The adopted EVT rate for the model therefore represents about 8% the pan evaporation rate.

An extinction depth of 3 m from the ground surface was applied in the SURFACT Evapotranspiration (EVT) package to simulate root system capillary action and the natural decline of evaporation with depth.

Rivers and surface drainage were simulated using the SURFACT river package and were segregated into zones according to stream order. Simulation of river recharge to the alluvial aquifers was set up for the Mooki River and Quirindi Creek. In these areas, the bed of the river was set at 5 m below ground level, with a 3 m of permanent water set in the river. Other surface drainage systems (as shown in Figure 8.21) were given the function to allow baseflow out of the aquifer, but no flow into the aquifer.

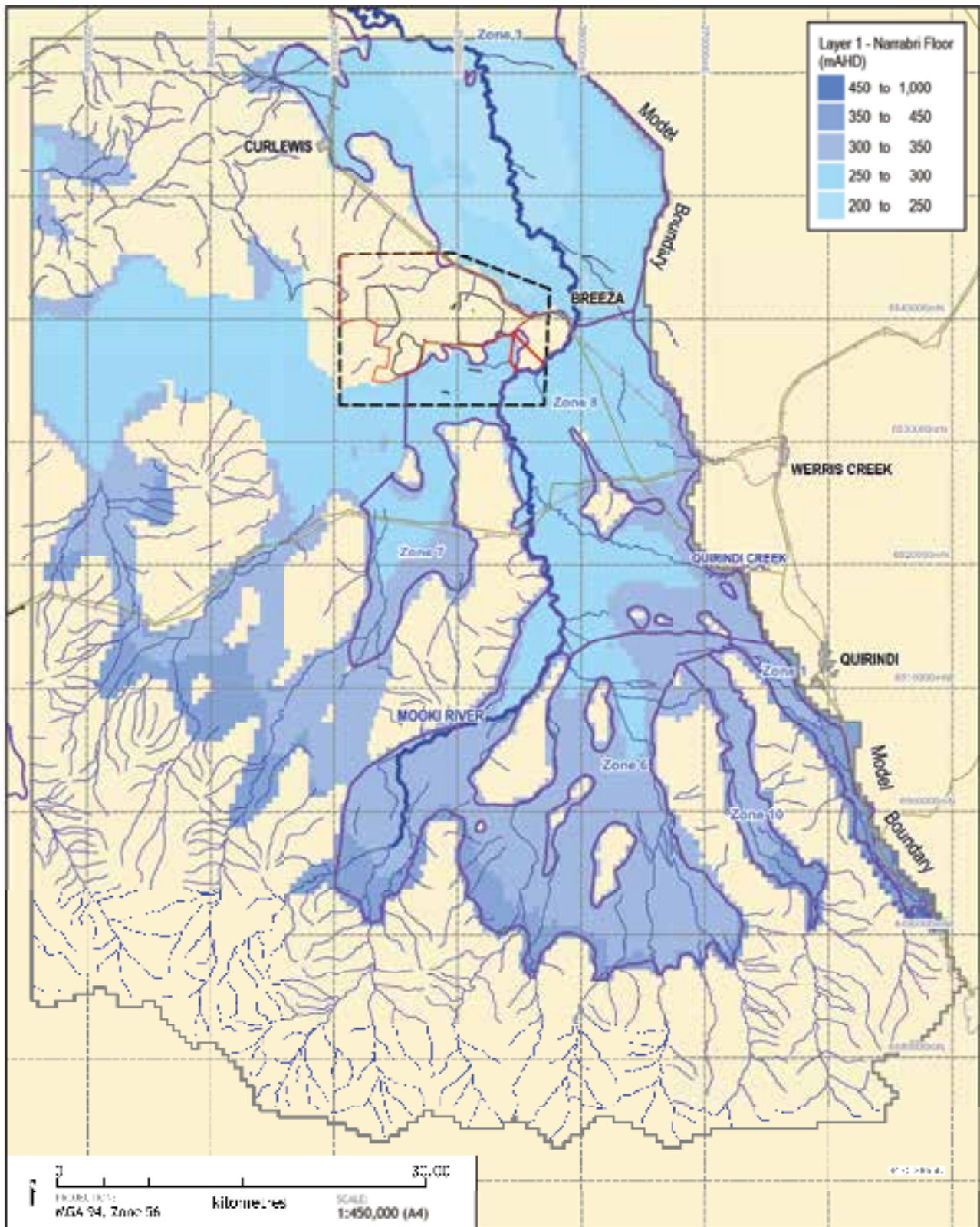
8.4.7 Faults

There are a number of identified fault structures which compartmentalise groundwater flow across the Watermark Boundary and are simulated in the model. These typically trend to North West -



North East orientations and are likely a response of regional folding and faulting. A series of North West trending regional faults are also apparent in geological maps of the area and are typically aligned with the major Mooki Thrust fault, which forms the eastern boundary of the model.

Faults were simulated using SURFACTs Horizontal Flow Barrier Package (HFB) and applied to model layers 1 to 11. The conductance of these fault barriers was initially assigned to a value similar to the background hydraulic conductivity rates and was allowed to calibrate higher or lower during calibration simulations. The distribution of the faults used in the simulation has been presented in Figure 8.22.



- Legend:
- EL 7223
 - Proposed Mining Area
 - Groundwater Management Zone
 - Project Boundary
 - Drainage Line / Creek

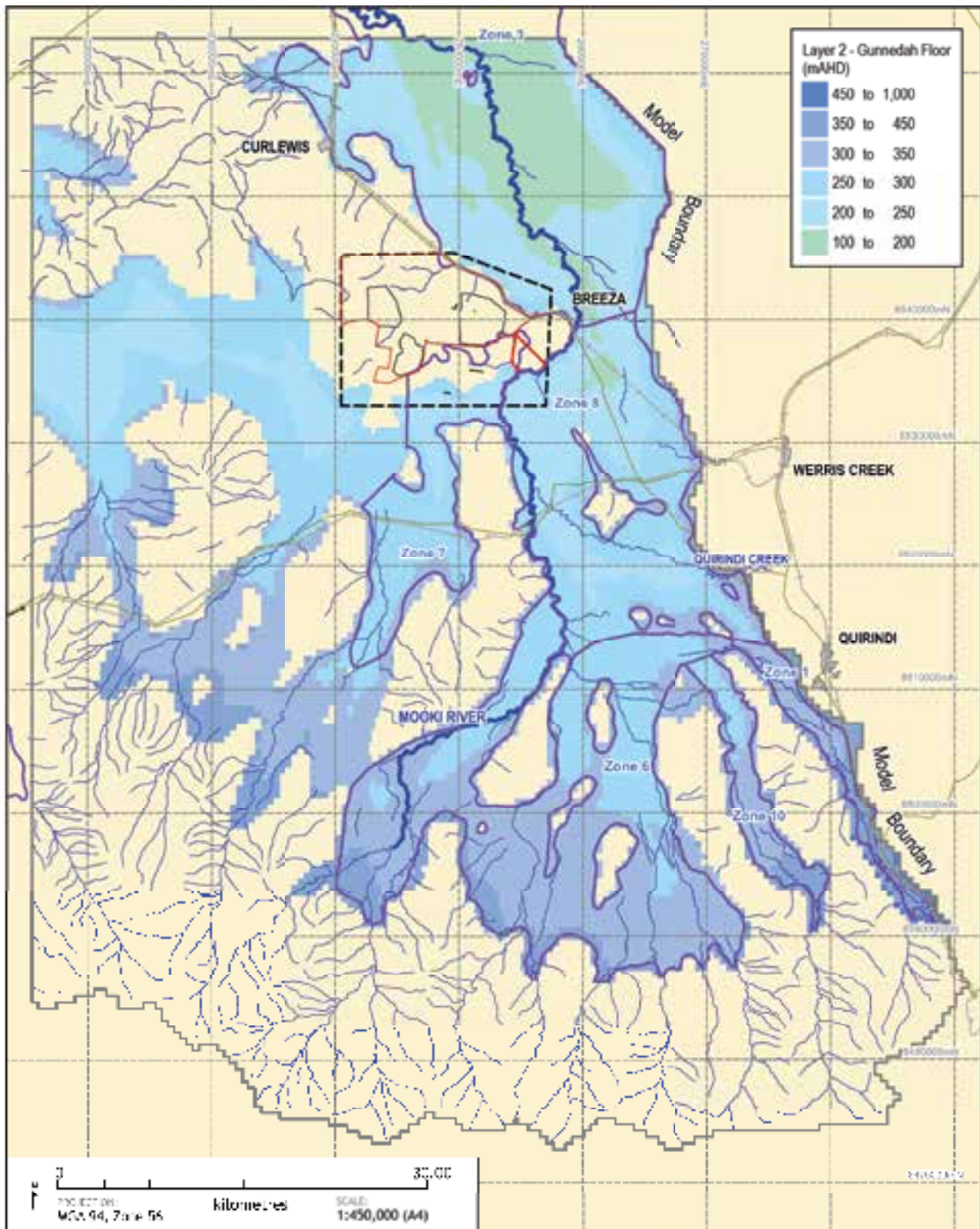
Watermark Coal Project (G1501)
Groundwater Assessment

**Narrabri Alluvium Floor
Model Layer 1**



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FIGURE No:
8.5



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

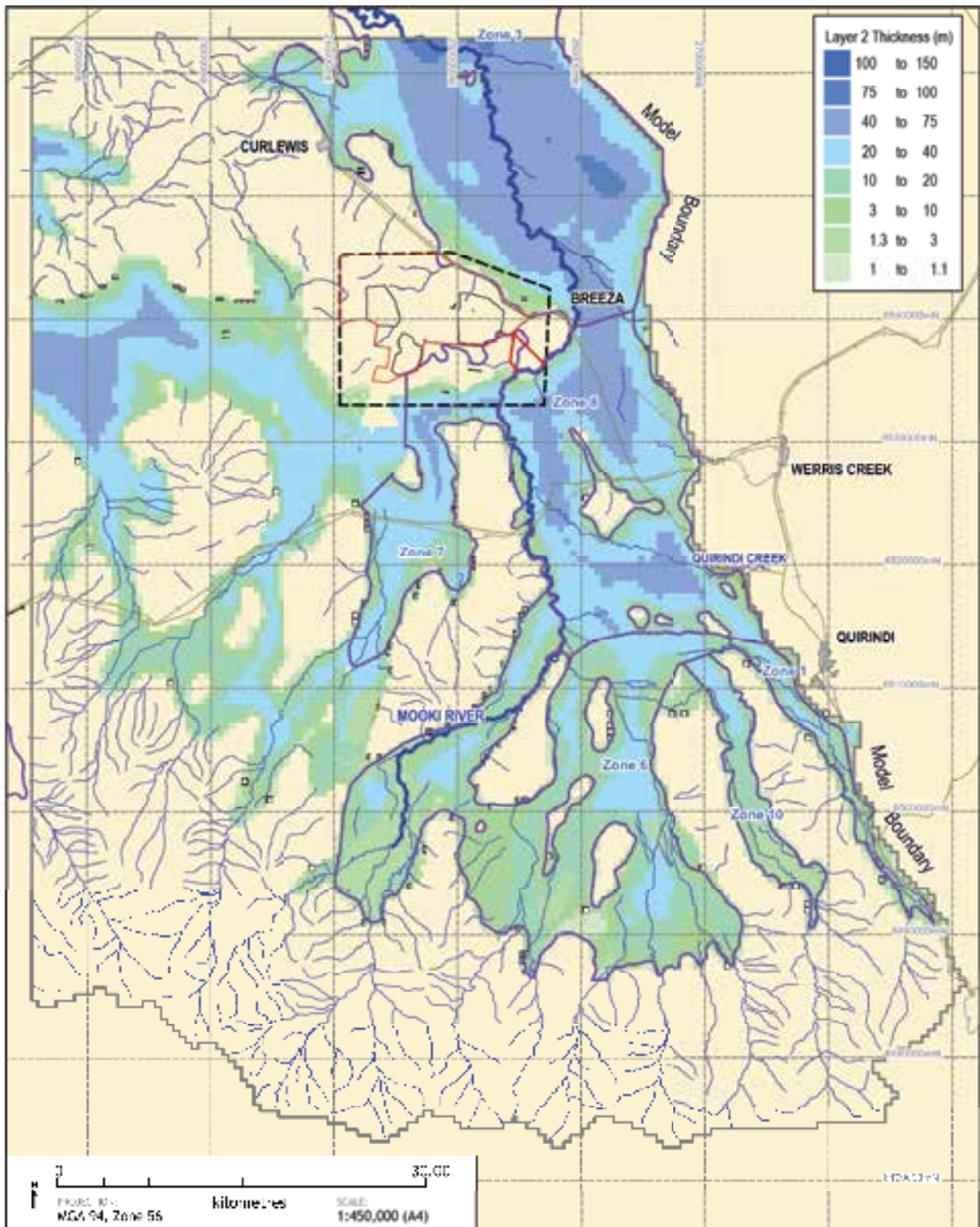
Watermark Coal Project (G1501)
Groundwater Assessment

**Gunnedah Alluvium Floor
Model Layer 2**



DATE:
10/10/2012

FIGURE No:
8.6



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

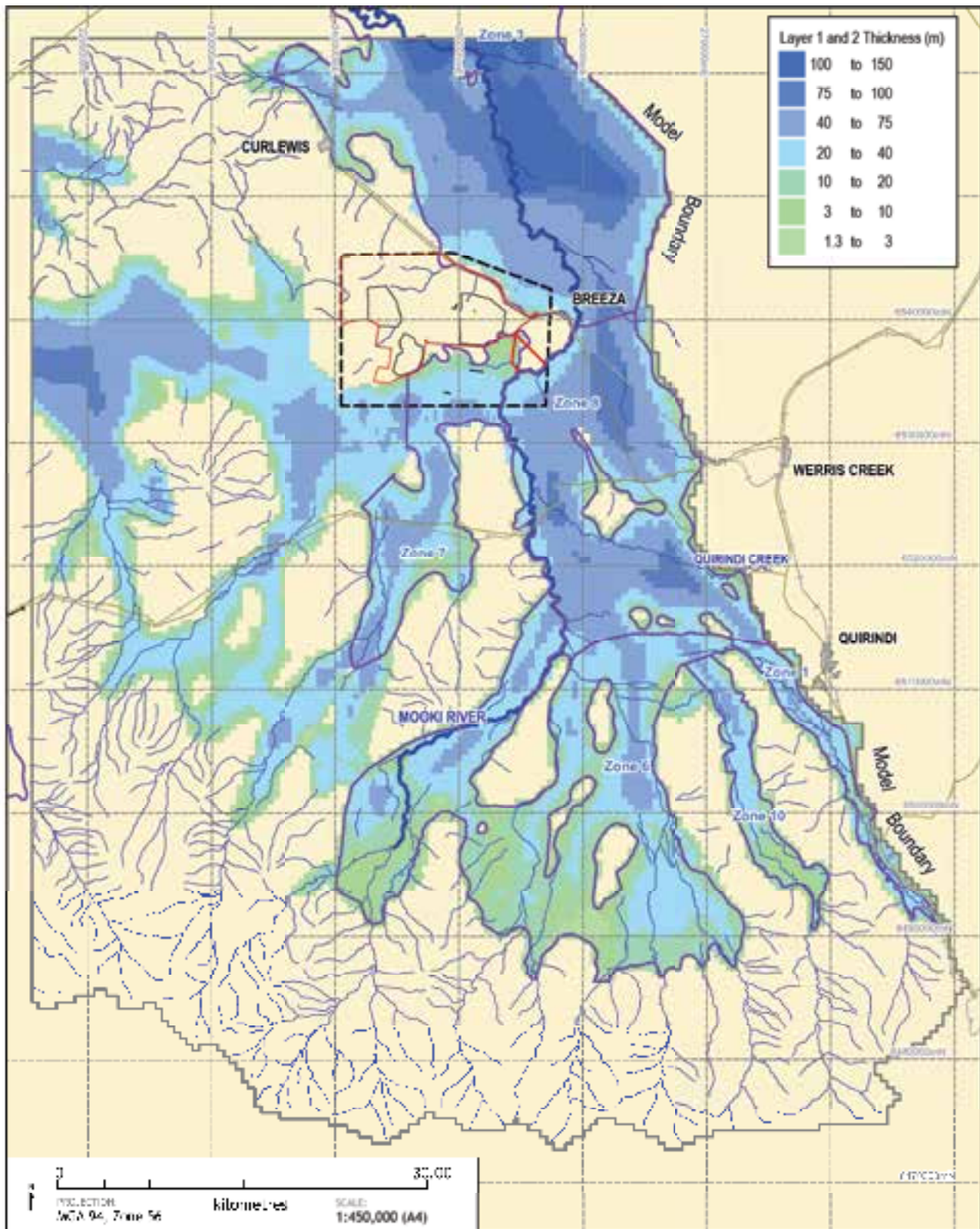
Watermark Coal Project (G1501)
 Groundwater Assessment

**Gunnedah Formation Thickness
 Model Layer 2**



DATE:
 10/10/2012

FIGURE No:
8.7



LEGEND:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

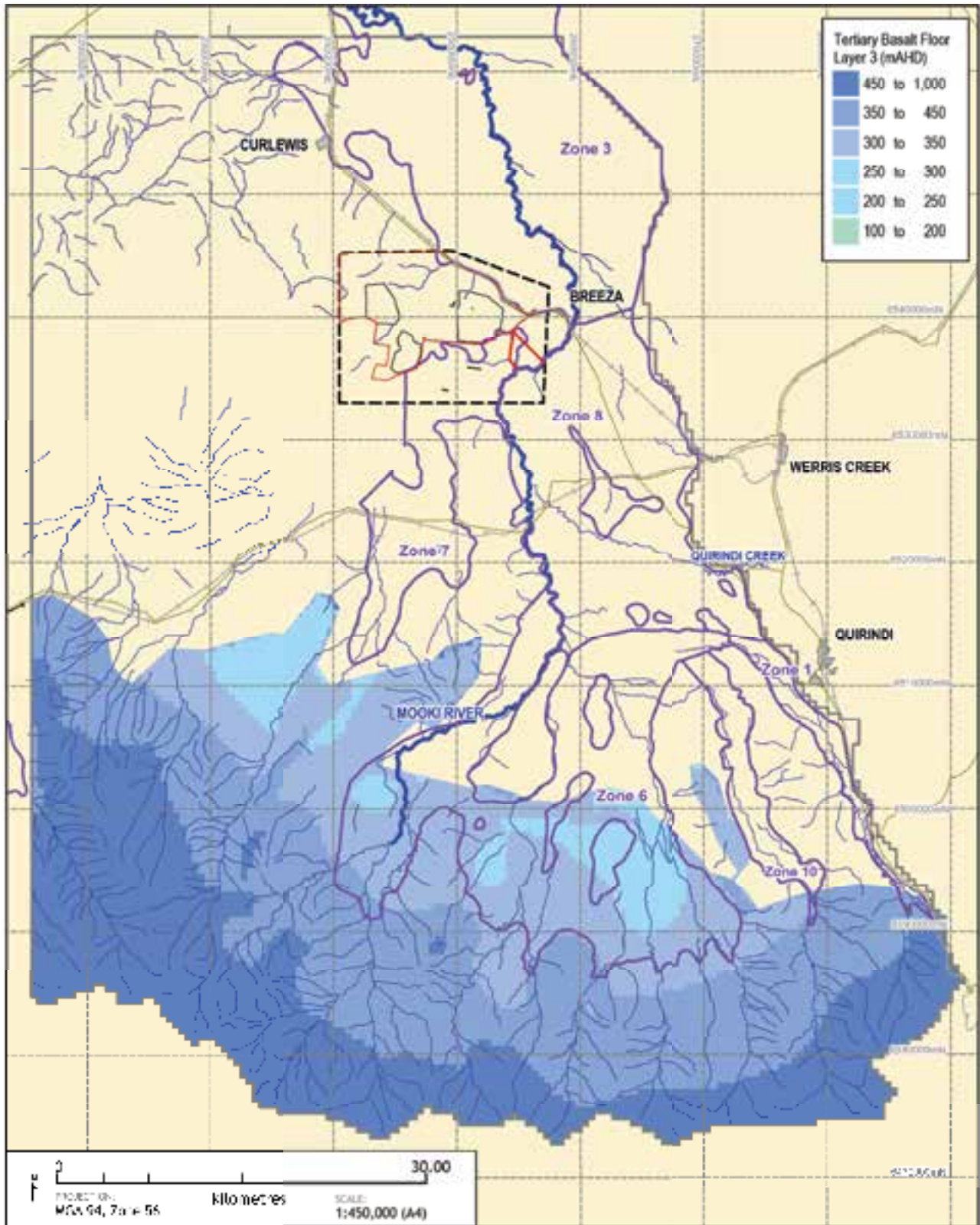
Watermark Coal Project (G1501)
Groundwater Assessment

**Total Alluvium Thickness
Model Layer 1 & 2**



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10/10/2012

FIGURE No:
8.8



- Legend:
- EL 7223
 - Proposed Mining Area
 - Groundwater Management Zone
 - Project Boundary
 - Drainage Line / Creek

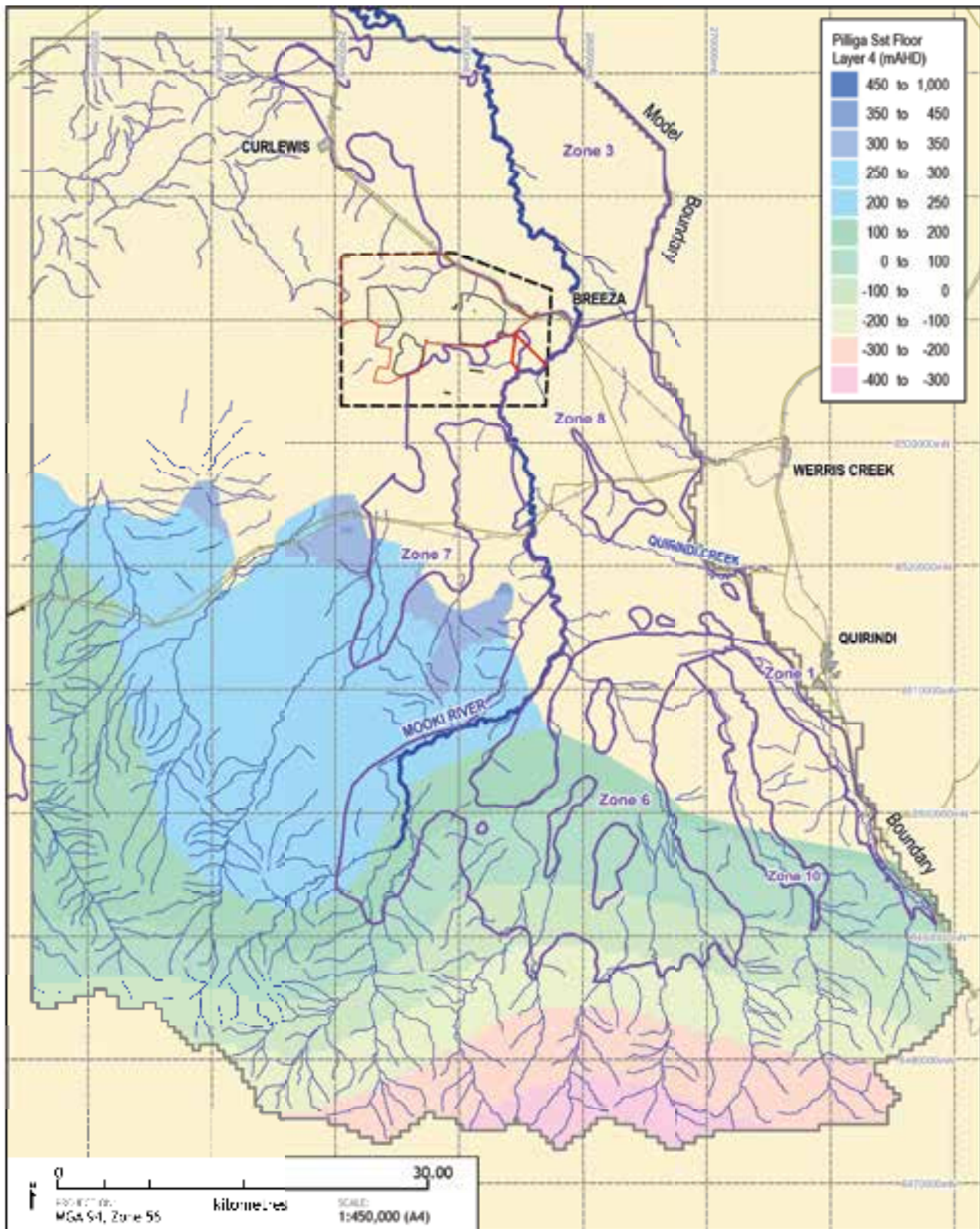
Watermark Coal Project (G1501)
Groundwater Assessment

Tertiary Basalt Floor Model Layer 3



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10/10/2012

FIGURE No:
8.9



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

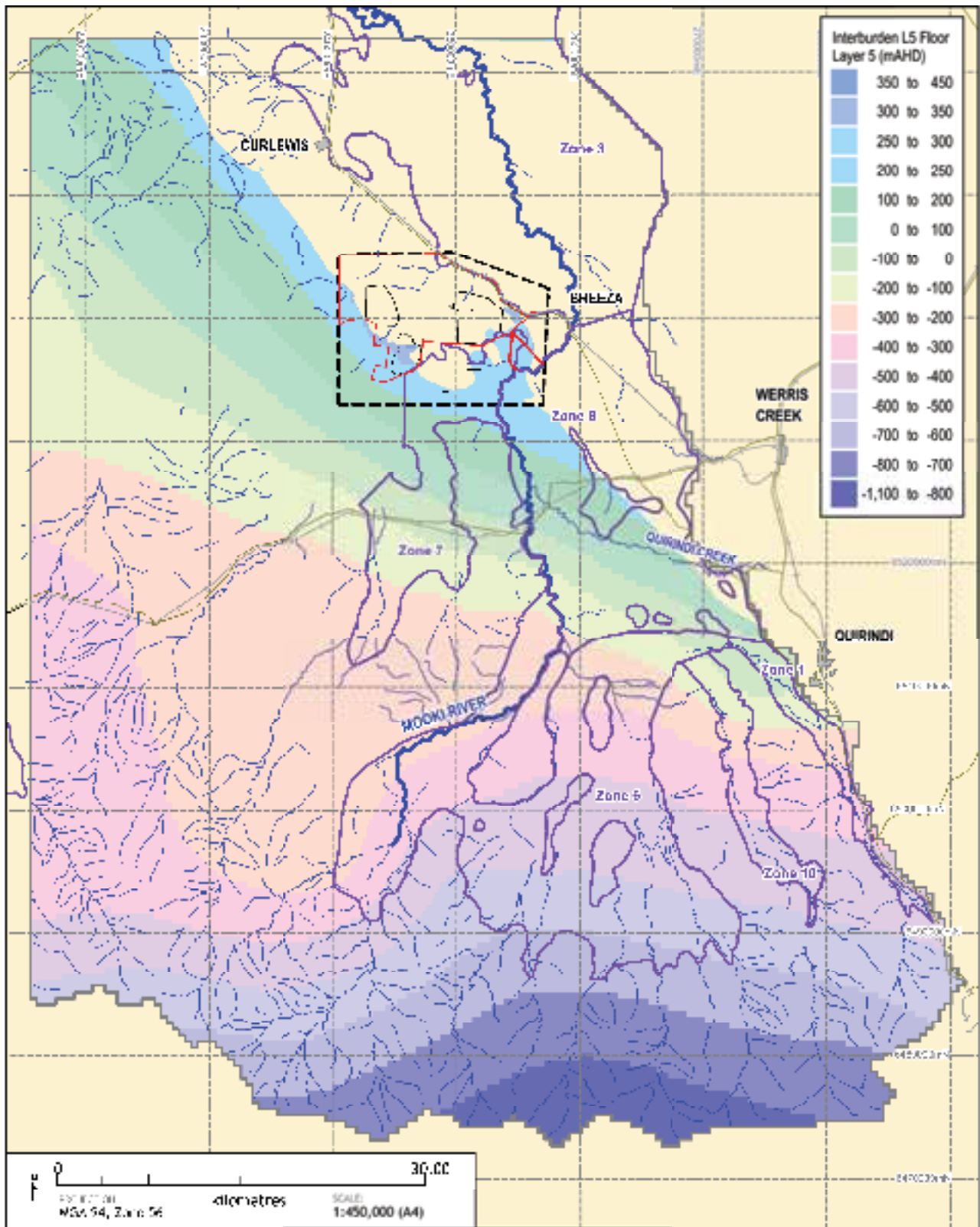
Watermark Coal Project (G1501)
Groundwater Assessment

**Pilliga Sandstone Floor
Model Layer 4**



DATE:
10/10/2012

FIGURE No:
8.10



Legend:

- H. 1991
- Proposed Min. Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

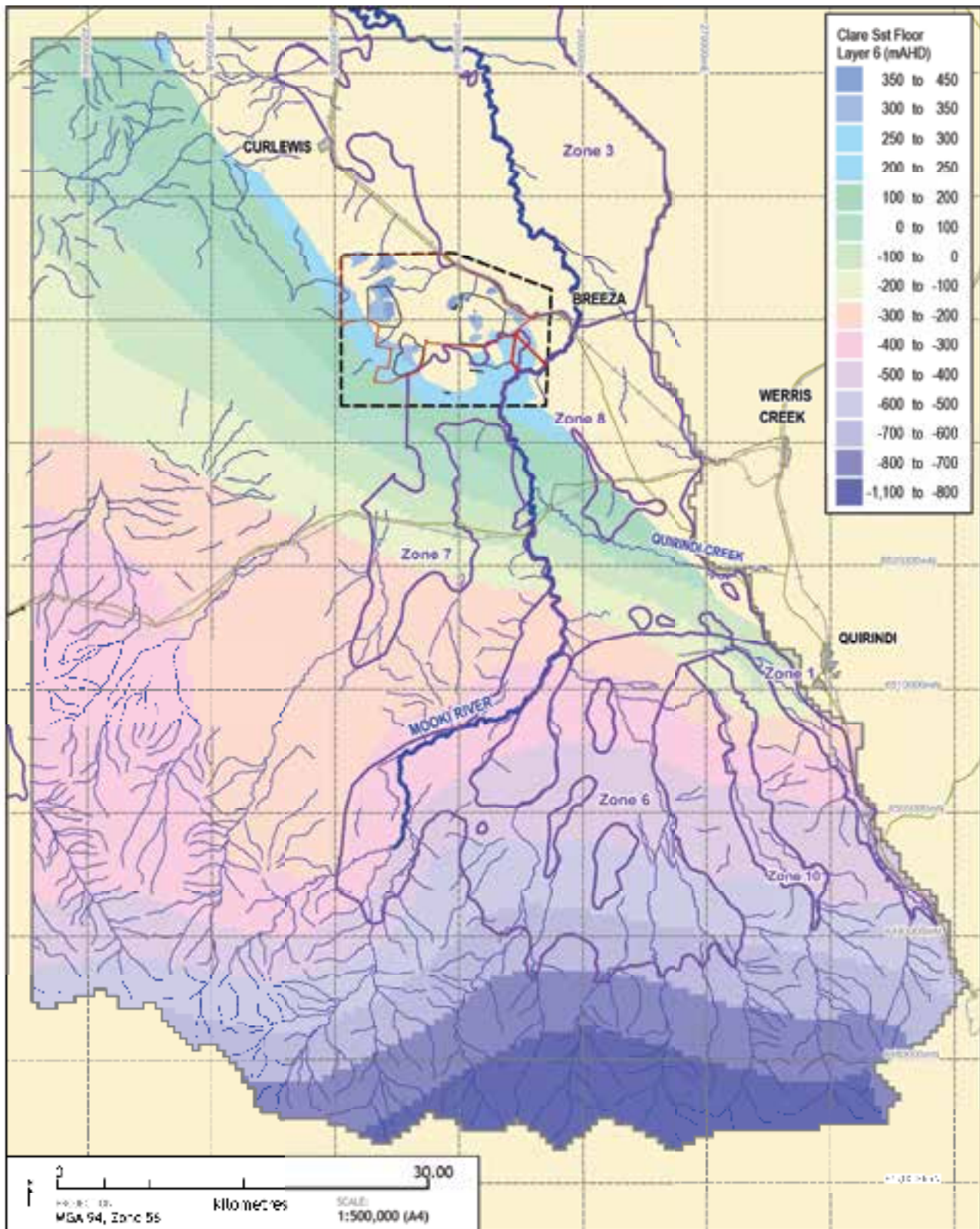
Watermark Coal Project (G110)
Groundwater Assessment

Interburden Floor
Model Layer 5



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10/10/2012

FIGURE NO:
8.11



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

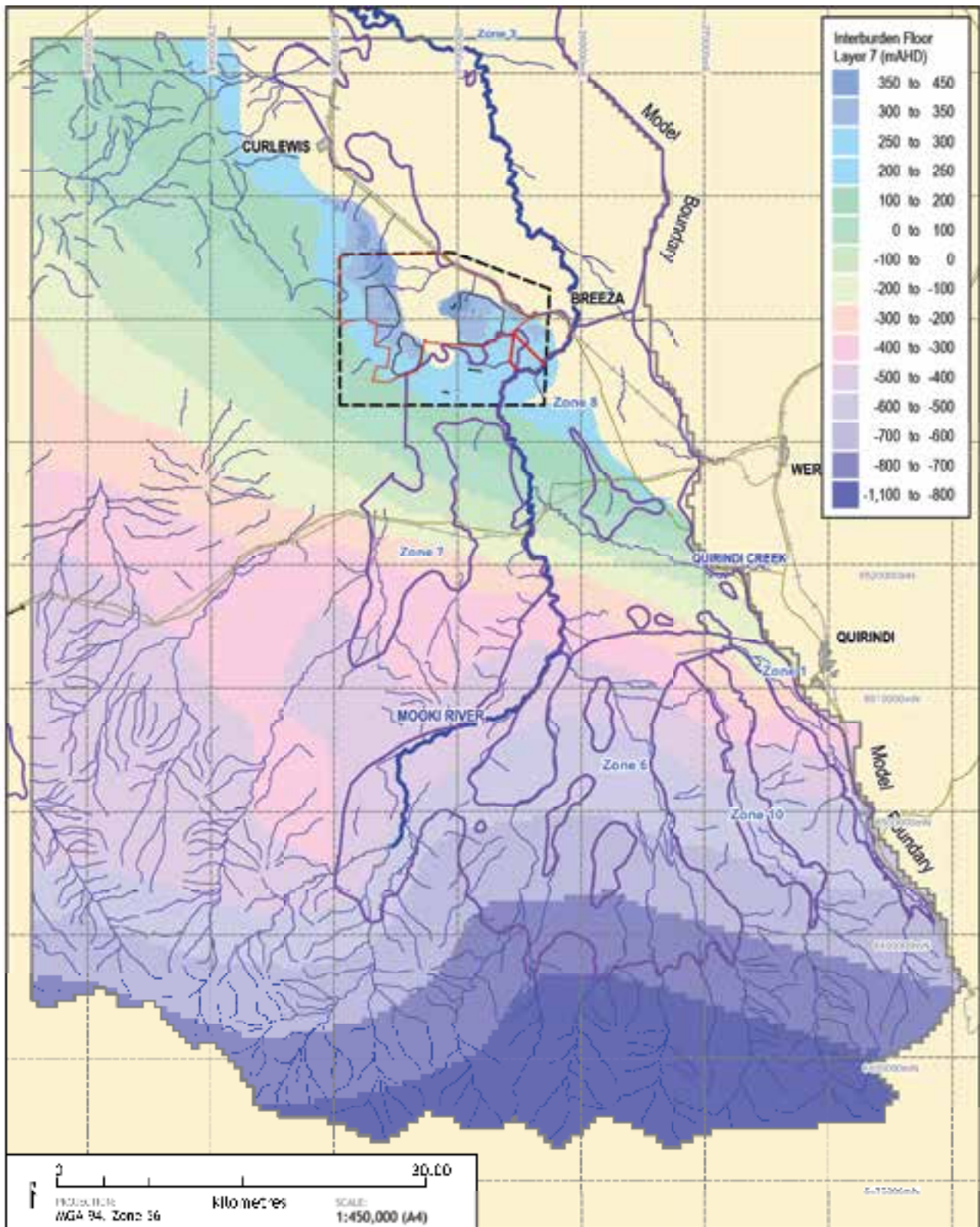
Watermark Coal Project (G1501)
Groundwater Assessment

**Clare Sandstone Floor
Model Layer 6**



DATE:
10/10/2012

FIGURE No:
8.12



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

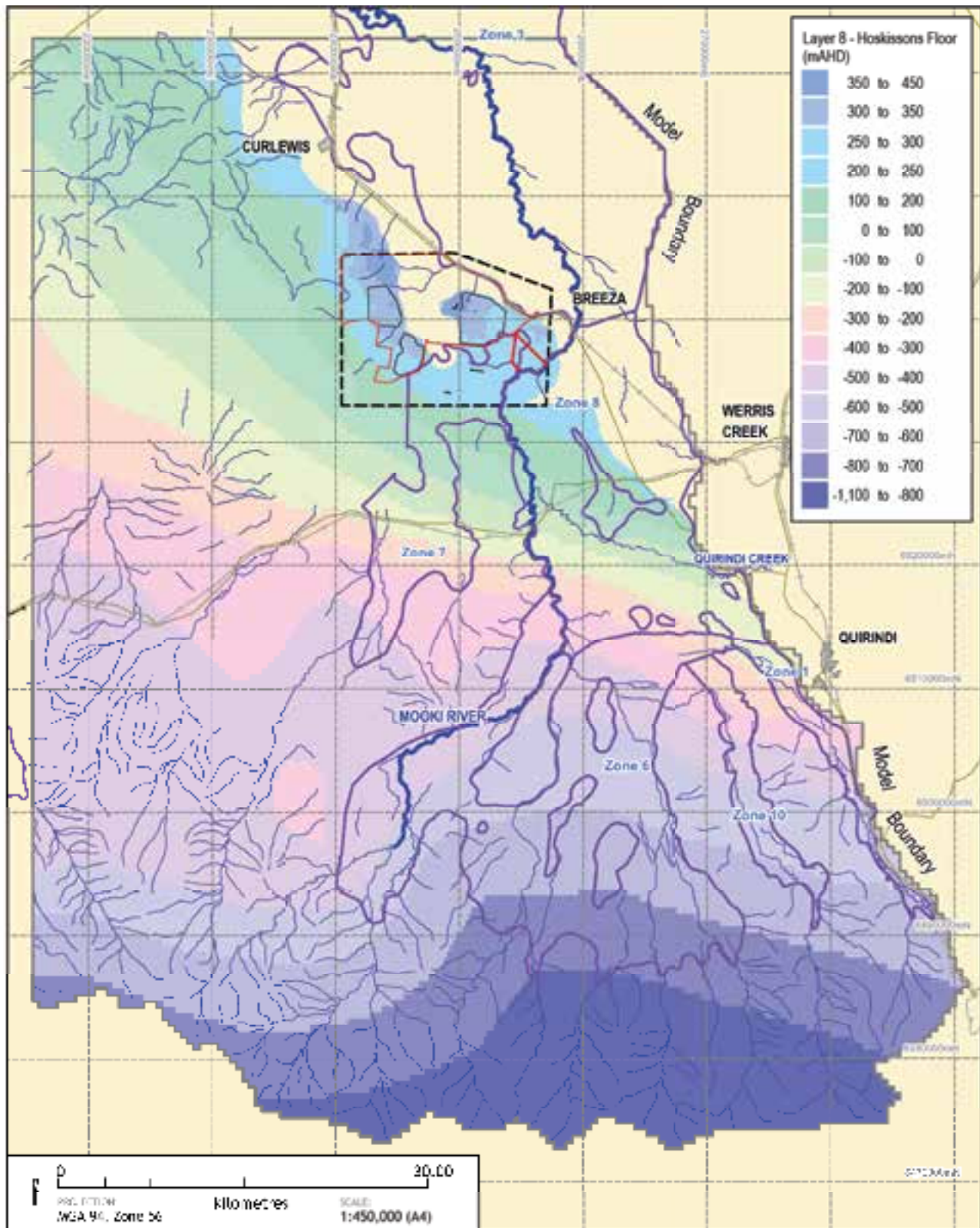
Watermark Coal Project (G1501)
Groundwater Assessment

Interburden Floor
Model Layer 7



DATE:
10/10/2012

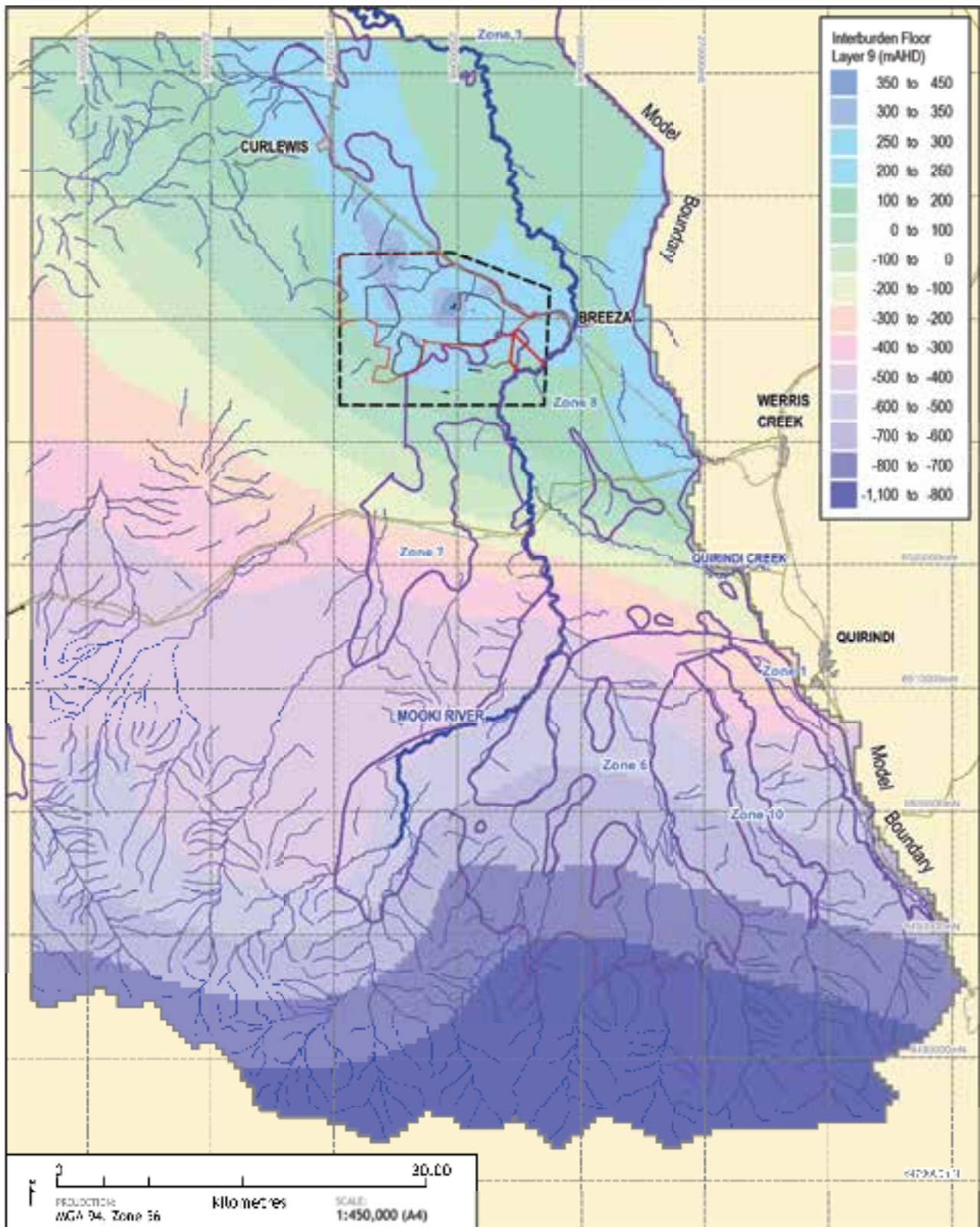
FIGURE No:
8.13



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

Watermark Coal Project (G1501)
Groundwater AssessmentHoskissons Coal Seam Floor
Model Layer 8DATE:
10/10/2012FIGURE No:
8.14



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

Watermark Coal Project (G1501)
Groundwater Assessment

Interburden Floor
Model Layer 9



DATE:
10/10/2012

FIGURE No.
8.15

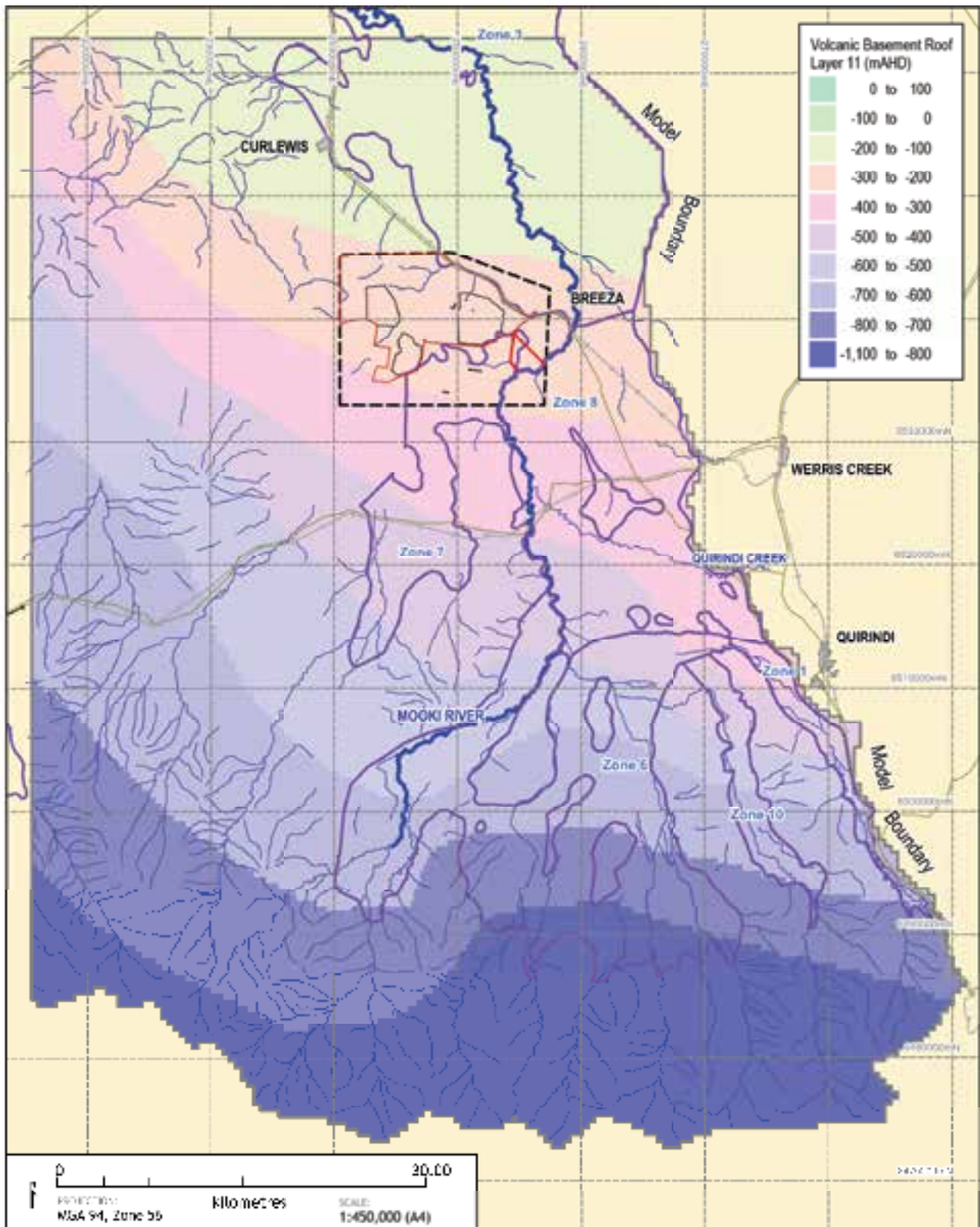


- Watermark Coal Project (G1501)
-
- Groundwater Assessment

Merrills Coal Seam Floor
Model Layer 10

DATE: 10/16/2012

FIGURE 8.16



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

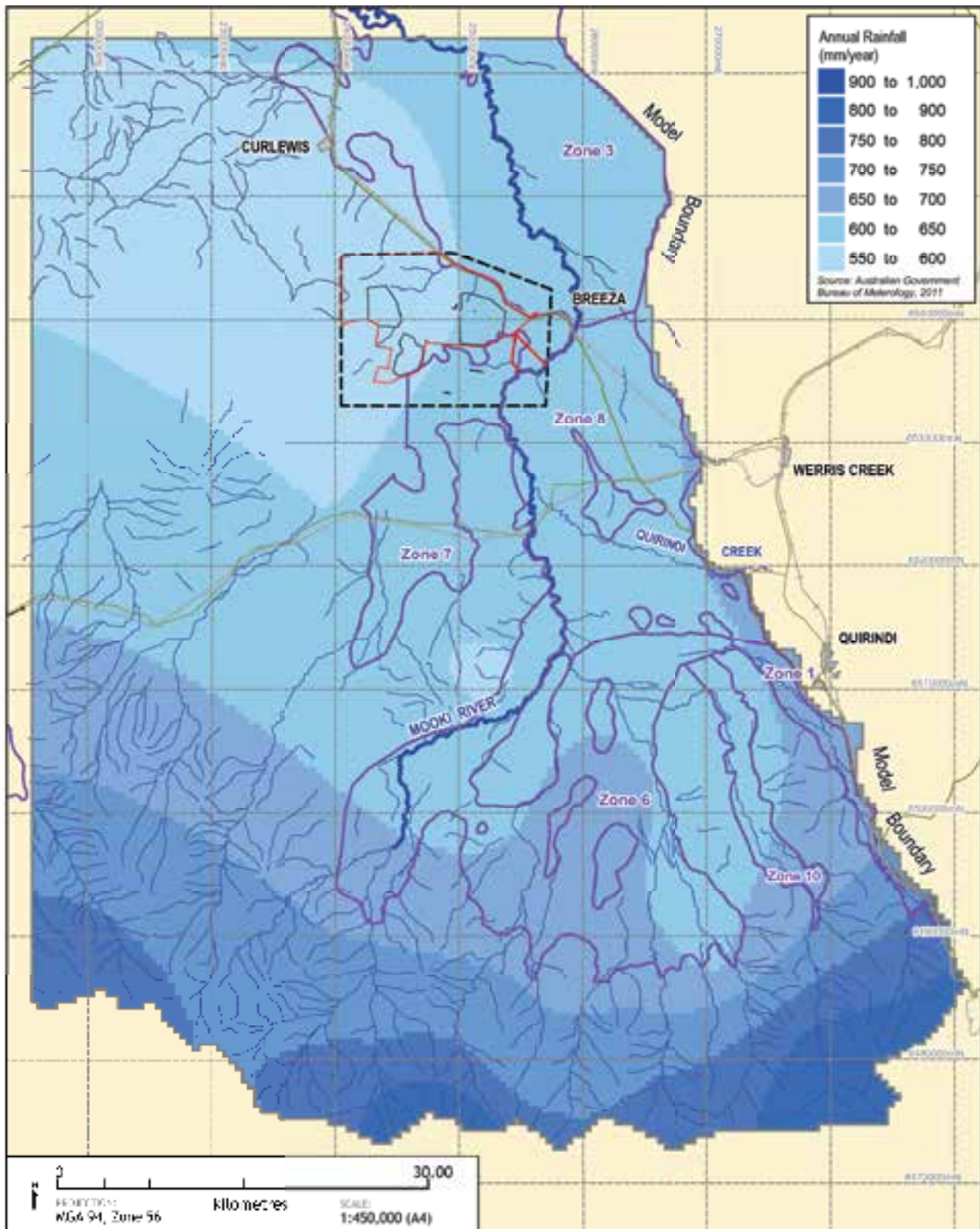
Watermark Coal Project (G1501)
Groundwater Assessment

**Volcanic Basement Roof
Model Layer 11**



DATE:
10/10/2012

FIGURE No:
8.17



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Drainage Line / Creek
- Project Boundary

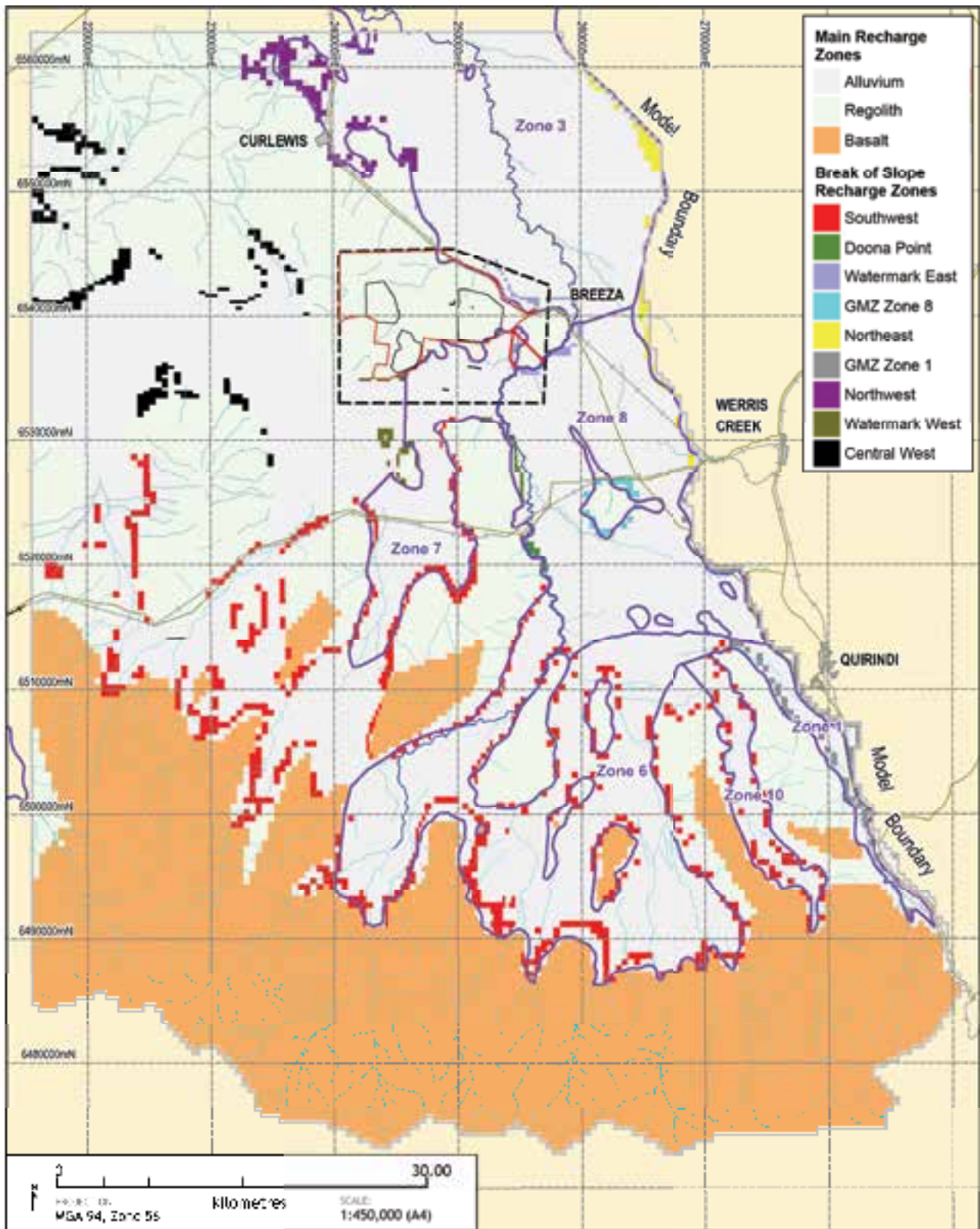
Watermark Coal Project (G1501)
Groundwater Assessment

Annual Rainfall Distribution



DATE:
10/10/2012

FIGURE No:
8.18



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary

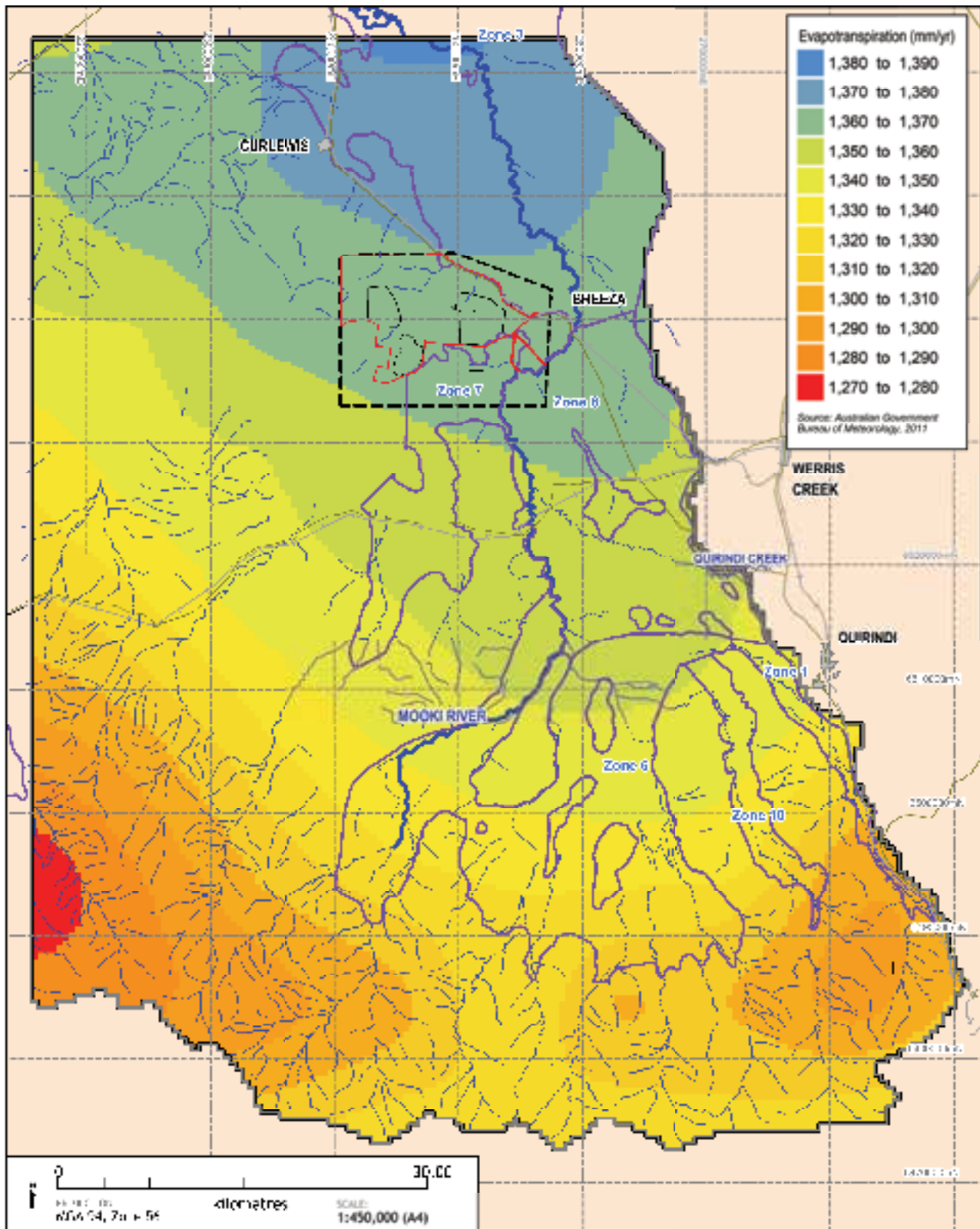
Watermark Coal Project (G1501)
Groundwater Assessment

Model Recharge Zones



DATE:
10/10/2012

FIGURE No:
8.19



LEGEND:

- EL 723
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

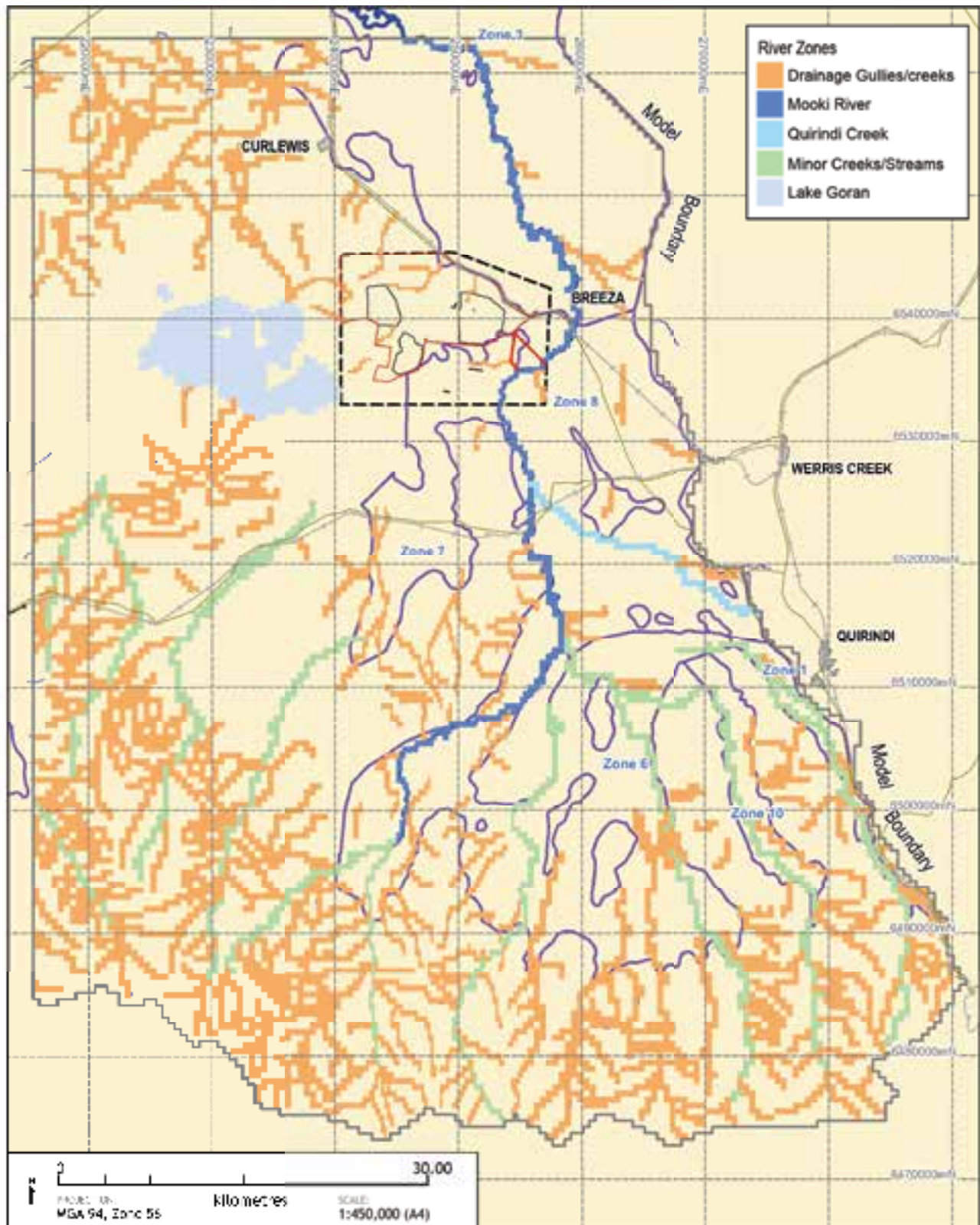
Watermark Coal Project (G130)
Groundwater Assessment

**Areal Potential
Evapotranspiration Rates**



DATE:
10/10/2012

FIGURE No:
8.20



Legend:

- EL 7223
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Watercourse Lines

Watermark Coal Project (G1501)
Groundwater Assessment

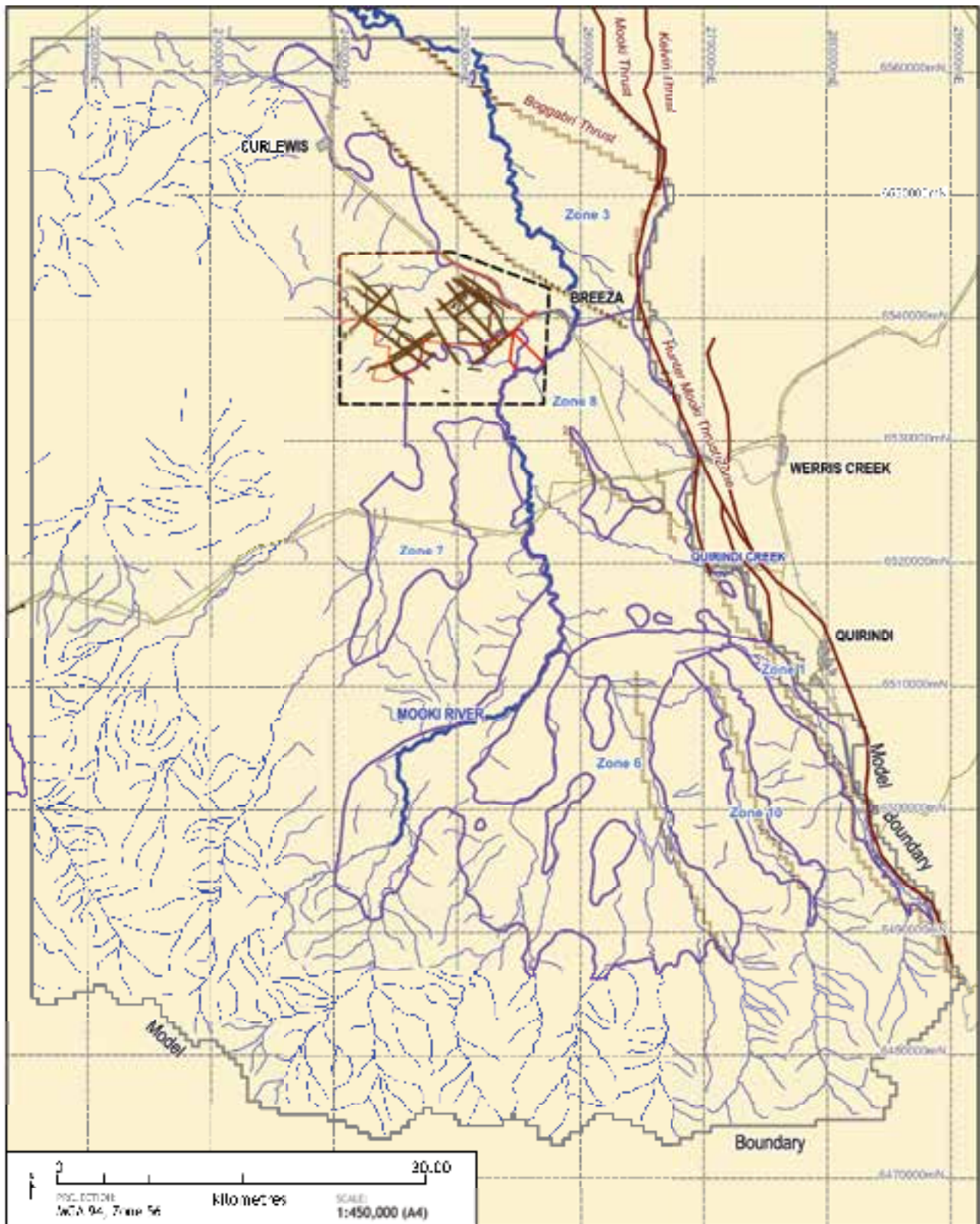
Model Rivers - River (RIV) Package Layer 1

Source: 250k Topographic Map - Tarnworth



DATE:
10/10/2012

FIGURE No:
8.21



Legend:

- EL 7225
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

Fault

Source:
Inside EL 7225 - GHD Geological Model Database
Outside EL 7225 - Geomedia Coalfields South Regional
100k Geological Map 1st ed 1998

Watermark Coal Project (G1501)
Groundwater Assessment

**Model Faults - Horizontal Flow Barrier
(HFB) Package - Layers 3 to 11**



DATE:
10/10/2012

FIGURE No:
8.22



9.0 MODEL CALIBRATION AND VERIFICATION

9.1 Calibration

9.1.1 Calibration Objectives

The objective of the steady state and transient model calibration was to simulate pre-mining groundwater levels from 1980 to mid-2011.

The groundwater model was calibrated by adjusting aquifer parameters and stresses to produce the best match between the observed and simulated water levels and fluxes. The calibration of the model followed the objectives set out by Barnett et al, (2012) and the objectives presented in Section 8.2.

A well-calibrated regional model indicates that the model closely replicates real world hydrogeological conditions, the first modelling objective, and therefore provides confidence in the predicted changes to the groundwater regime due to mining.

9.1.2 Calibration Data Points

The model simulated water levels in all available monitoring bores within the bedrock and alluvial aquifers. There are a total of 6502 bores in the PINEENA database which have varying levels of water level and construction data. A total of 445 monitoring bores with time variant data readings were used to calibrate the model and were comprised of:

- 351 bores from the NOW PINNENA database, which are predominantly screened in the Narrabri and Gunnedah Formations and located within management Zones 1, 3, 6, 7, 8 and 10; and
- 94 bores from the Watermark Project Boundary which provided data on the bedrock water levels.

The model weighted each bore according to the level of confidence in the data. Geological borehole logs were examined to ensure each bore was represented within the correct layer in the model.

The groundwater model covers a large area including high and low relief areas with highly variable hydraulic parameters. Due to the size of the model grid and spatial discretisation (250 x 250 m to 500 x 500 m cell size), some groundwater calibration points cannot practically be met, particularly in the compartmentalised Permian hydrogeological system, e.g. perched aquifer systems.

The model was calibrated to data over a 31½ year period from the first quarter 1980 to the second quarter 2011. Groundwater level records from the monitoring bores were linearly interpolated to create a water level target for each quarterly stress periods in the model. Figure 9.1 shows the locations of the NOW and Shenhua Watermark bores used in the calibration process. Where there are multiple bores at a single site, Figure 9.1 shows only the lowest screened aquifer unit the bores are constructed within.

Water budgets obtained from previous modelling in the area guided the calibration process to ensure the model was in general agreement with the estimated flows.



9.1.3 Steady State Calibration

The objective of the calibration of the model was to reproduce groundwater levels at the individual monitoring bores and hence replicate the general pattern of the groundwater potentiometric surface and the direction of groundwater flow. The model was calibrated in two stages. Firstly, the steady state model was manually calibrated as part of an initial testing phase to check model budgets and stability. This was achieved using uniform parameters across the entire model domain. The uniform model parameters were adjusted sequentially to determine sensitivity and correlation of the parameters. The steady state model was calibrated to June 1980 water level records.

The automated parameter estimation software PEST was then used to calibrate the steady state groundwater model. The software makes small adjustments to the parameter set within bounds determined by the user in order to provide the best possible match between the observed and simulated data. PEST adjusted the following properties in the model to achieve the calibration:

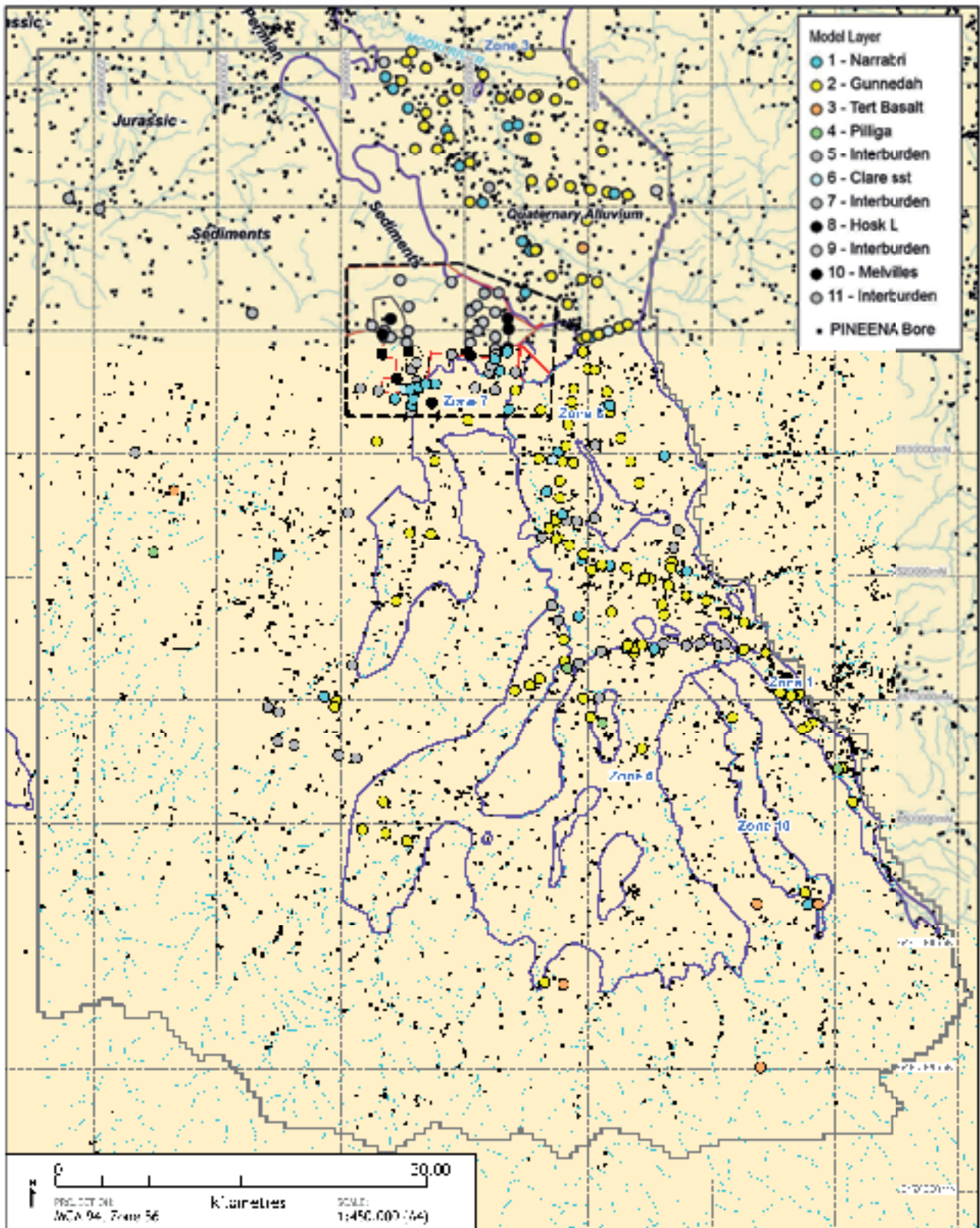
- horizontal and vertical hydraulic conductivity;
- recharge rate to each recharge zone;
- conductance of the river bed in each river zone;
- conductance of the horizontal flow barriers used to represent faults; and
- general head boundary conductance at the model outflow boundary.

9.1.4 Transient Calibration

Approach

The hydraulic heads and aquifer properties from the manual steady state calibration provided the starting values for the transient calibration of the model. To begin each transient model calibration run, a steady state simulation was undertaken and the parameters were calibrated. A weighting factor of 10% was applied to the steady state observation points from June 1980 to ensure that the transient calibration not only calibrated to changes in transient head data, but also absolute steady state groundwater levels. The solved steady state heads for each calibration scenario were transferred into the transient calibration model as starting groundwater levels.

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



- Legend
- Groundwater Management Area
 - Transport Mining Area
 - EL 7223
 - Project Boundary
 - PINEENA Bore

Source: NSW PINEENA Groundwater Database, 2011
GHD Groundwater Monitoring Database, 2011

Watermark Coal Project (G157)
Groundwater Assessment

Groundwater Monitoring Bores;
Shenhua and Pineena



DATE:
18/10/2012

Version:
9.1



Time

Following steady state calibration to June 1980 conditions, the transient version of the model commences from the first quarter of 1980, progressing at quarterly stages to the 2nd quarter of 2011. This represents 126 stress periods at 91.3125 (quarterly lengths). SURFACT's Adaptive time stepping package (ATO) was used to promote model stability with minimal run time.

Parameters

PEST calibrated 380 parameters during the transient simulation as follows:

- storage properties - specific yield and specific storage;
- horizontal and vertical hydraulic conductivity;
- recharge rate to each recharge zone;
- conductance of the river bed in each river zone;
- conductance of the horizontal flow barriers used to represent faults; and
- general head boundary conductance at the model outflow boundary

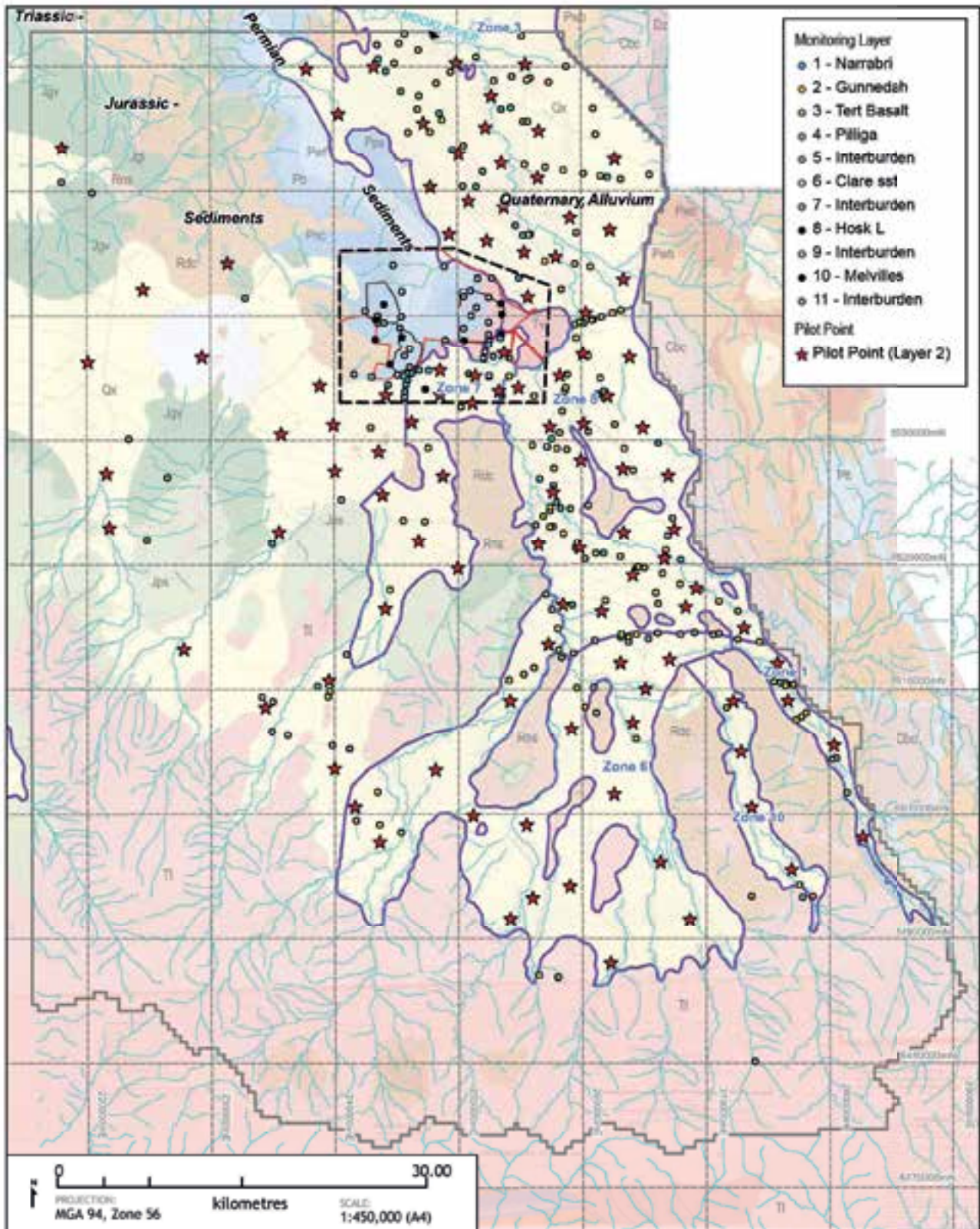
PEST varied the hydraulic conductivity of the alluvium (Layers 1 & 2 only) spatially to assist the model in matching the different water level fluctuations in the monitoring bore data. This allowed the spatial variability in the aquifer properties of the alluvium, that is evident in the channelised nature of the alluvial sediments and the production bore distribution to be represented.

To achieve the spatial parameter distribution, the enhanced spatial parameterisation features of PEST were used. The parameter values of each model cell in the Gunnedah Formation were defined by interpolation between 105 defined 'pilot points' (as shown in Figure 9.2). The parameter values at the pilot points were controlled through the 'regularisation' function of PEST (where variation between neighbouring points is reduced as part of the calibration objective). This provides a reduction in parameter non-uniqueness.

Singular value decomposition assist (SVDA assist) was implemented to minimise the computation time for the calibration. SVDA assist groups modelled parameters into 'super' parameters by determining the major sensitivities and their relationships between one another. The 380 modelled parameters were grouped into 30 super parameters, which cut optimisation run times down to 10% of the ungrouped calibration run times.

The hydraulic conductivity of the Narrabri Formation was determined as a fraction of the underlying Gunnedah formation during the calibration. The hydraulic conductivity of the Narrabri Formation calibrated to a maximum of 70% of the Gunnedah Formation in areas of high pumping within the Narrabri Formation, decreasing to a minimum of 3% to 10% in areas where pumping is low and clay dominates the unit.

The vertical hydraulic conductivity of the Quaternary aquifers was calibrated as a consistent fraction of the horizontal hydraulic conductivity of the Gunnedah Formation. A vertical hydraulic conductivity of 50% of the horizontal hydraulic conductivity achieved the best calibration for the Narrabri Formation and 9% for the Gunnedah Formation.



The reducing hydraulic conductivity of the Hoskissons and Melvilles coal seams with depth below surface was represented using an exponential decline equation determined from local and regional packer/pumping test data (refer Section 7.3.3). To calibrate this value, the K_0 (zero depth) was allowed to calibrate and therefore adjust the exponential decline.

The weathered zone was represented by applying a multiplication factor to the cells above the base of weathering, to reflect the observed increase in hydraulic conductivity.

The vertical hydraulic conductivity of the riverbed varied between 0.002 m/day and 1 m/day for each of the river zones during calibration.

Minor creeks, drainage lines and Lake Goran were set as 'river drains' and act as discharge zones for groundwater only. Quirindi Creek and Mooki River were set with 1 m and 2 m of water in the river respectively and therefore allowed the transfer of water from the river to the aquifer and represented both losing and gaining stream conditions. Table 9.1 presents the calibrated vertical hydraulic conductivity of each stream. Figure 9.3 illustrates the method used to allow rivers to act as groundwater sinks and groundwater sources from the groundwater model.

Table 9.1: CALIBRATED STREAM BED HYDRAULIC CONDUCTIVITY	
River Package Unit	Vertical Hydraulic Conductivity (m/day)
Minor Creeks (Sink)	1.00
Mooki River (Source)	0.002
Quirindi Creek (Source)	0.005
Drainage Lines (Sink)	1.00
Lake Goran (Sink)	0.007

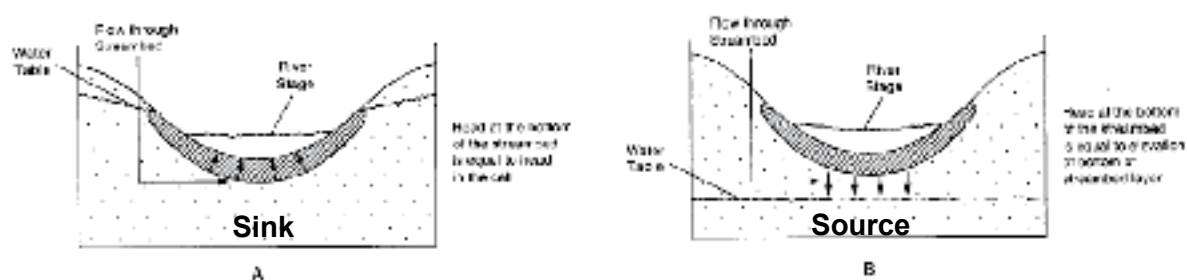


Figure 9.3: River Package Schematic – From MODFLOW Online Manual

Figure 9.4 shows an east-west section through the Liverpool Ranges demonstrating the setup of the river cells, particularly where topography is highly variable.

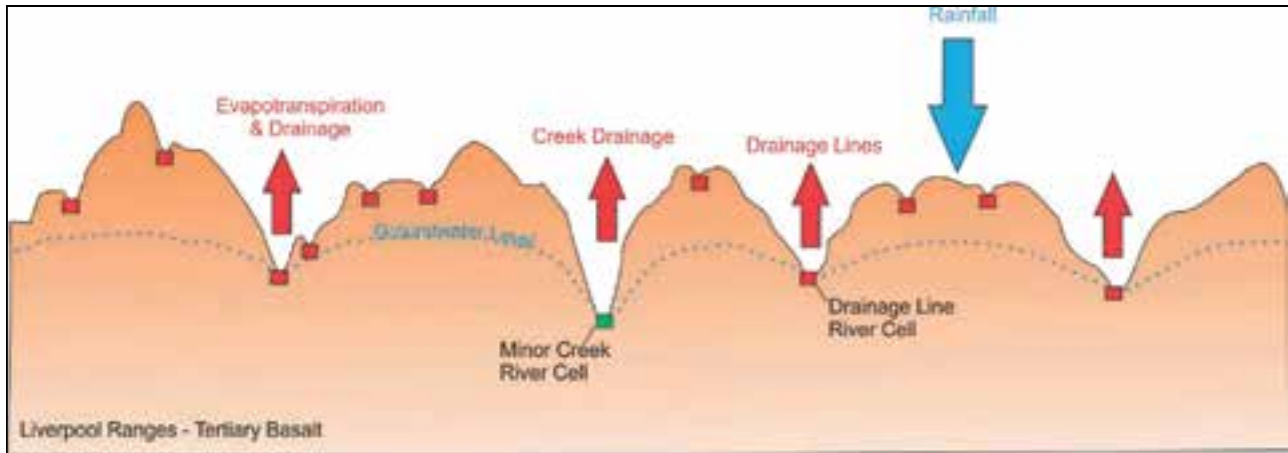


Figure 9.4: East-west Cross Section through Liverpool Ranges showing River Cells

The regional transient model was set up with 126 quarterly (91.3 days) stress periods, representing the period from the first quarter of 1980 to the second quarter of 2011.

Hydrographs from the NOW groundwater monitoring network were examined to determine the transient calibration period. The hydrographs show that groundwater levels in the alluvium have generally fallen in a step-like manner over the past 40 years; around 1981, 1995, and 2003 (refer to Figure 9.5 – Bore GW030005, located proximal to Breeza). This downward trend has been steadily decreased in spite of increases in rainfall recharge (CRD) and flood events over the observed period. The calibration therefore commenced prior to the first major step down in 1981. Prior to 1981, the groundwater levels appear to be relatively stable and agricultural extraction from the aquifers was significantly lower than the present day. The water levels from 1980 were therefore assumed more representative of steady state. Although this is not strictly correct, given the lack of any data from prior to the development of agriculture on the Liverpool Plains, this is considered an acceptable assumption.

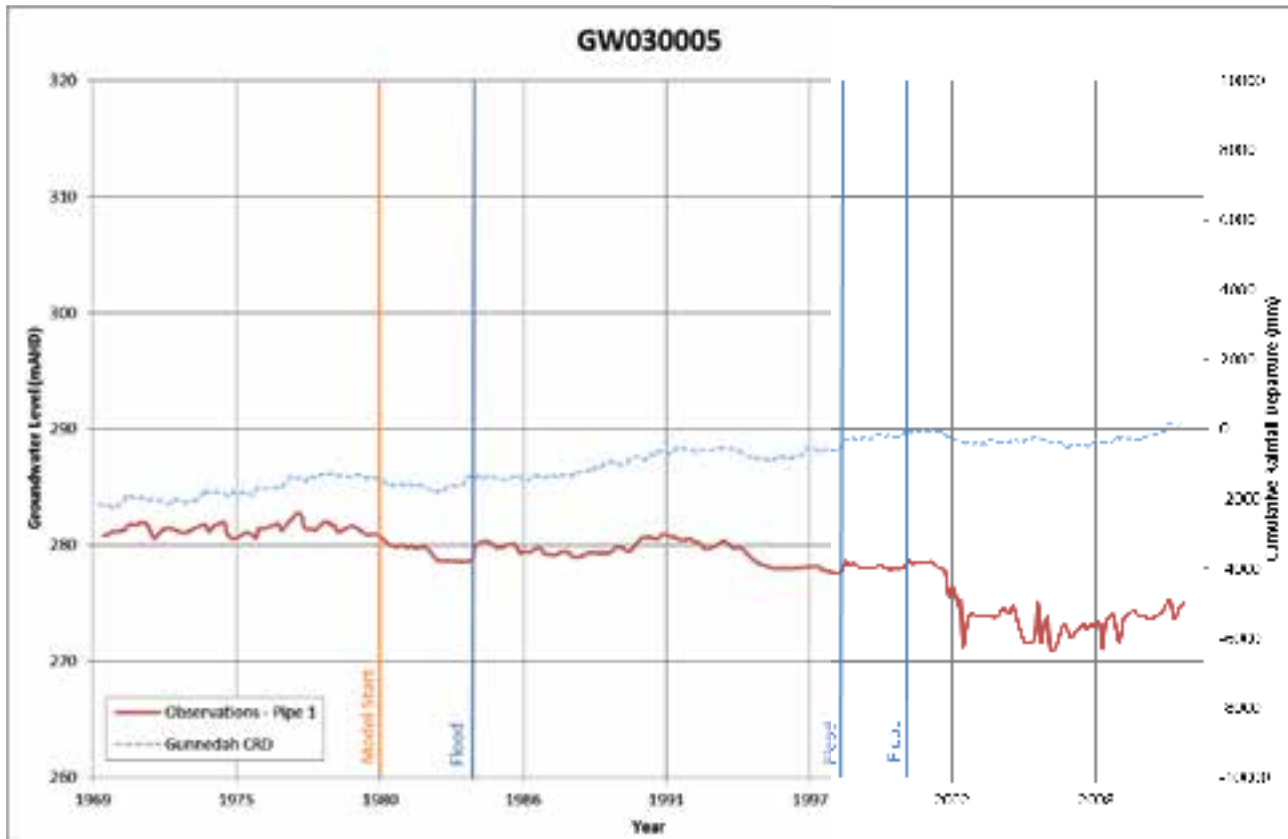


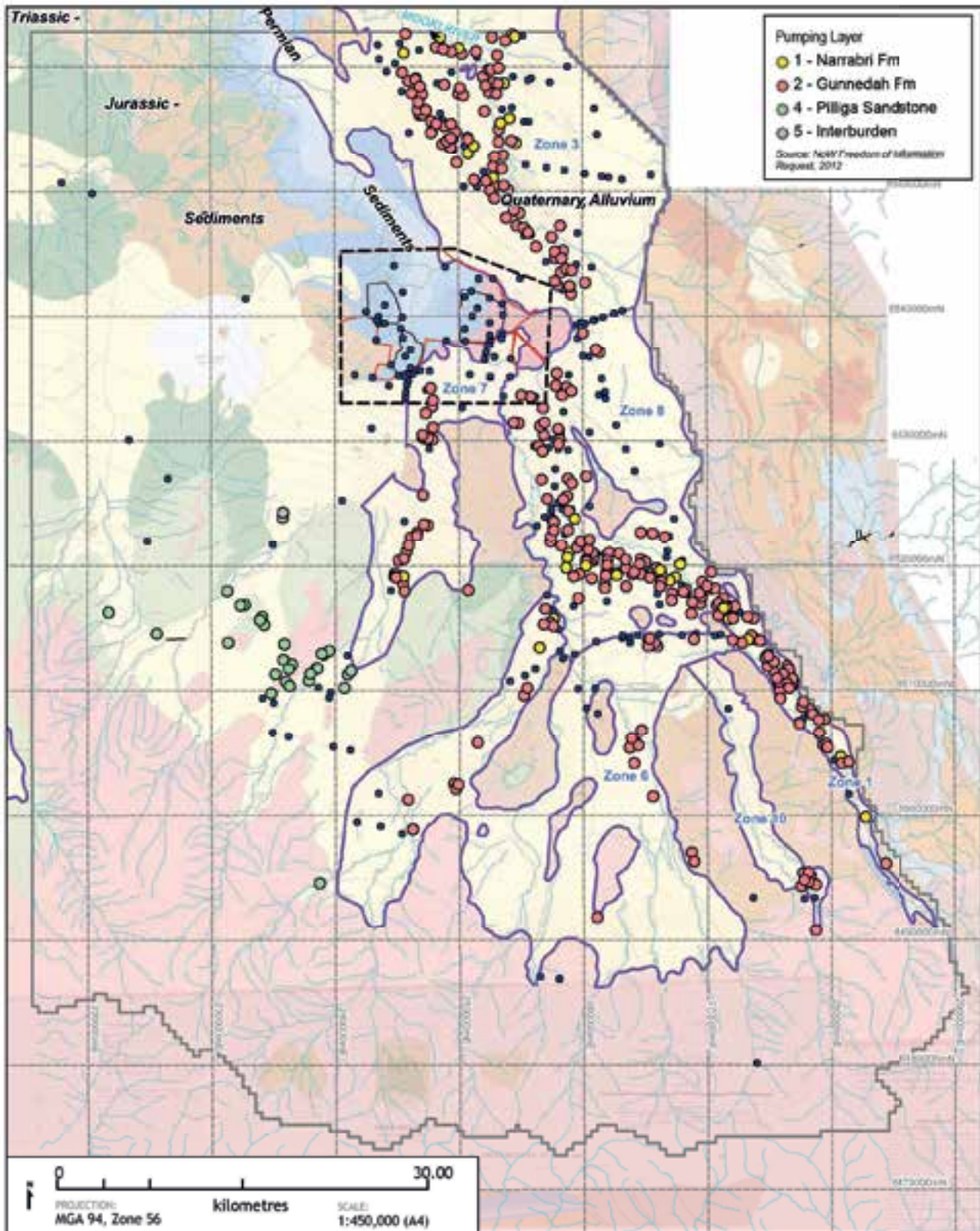
Figure 9.5: Hydrograph of GW030005 vs. Gunnedah Cumulative Rainfall Departure

Groundwater Abstraction

The steady state model represents pre-mining and irrigation conditions and therefore groundwater abstraction was not included in the simulation.

Groundwater pumping records from individual bores were obtained from a Freedom of Information Request (FOI). NOW provided monthly groundwater pumping data from corporate databases from June 1990 to November 2011. These monthly readings were reduced to an average daily rate per 3-month quarter to capture seasonal changes in pumping at each individual bore. Pumping data prior to 1990 was approximated using yearly averages and weighting applied for seasonal use as reported in the Merrick (2001) Zone 8 model. The SURFACT Well (WEL) package assigned the quarterly seasonal pumping rates to a modelled cell and layer according to the coordinates and screen depth of each individual bore. The pumping rates varied at each bore on a quarterly basis over the period from 1980 to 2011 according to the data obtained from the FOI Request.

Figure 9.6 presents the model cells where pumping was implemented.



LEGEND:

- Groundwater Management Zone
- Proposed Mining Area
- EL 7223
- Monitoring Bore
- Project Boundary

Watermark Coal Project (G1501)
Groundwater Assessment

Groundwater Pumping and Monitoring Bores



DATE:
18/10/2012

FIGURE No:
9.6



9.2 Calibration Results

9.2.1 Calibration Performance Measures

The performance of the calibration was assessed by calculating the sum of squared residuals as follows:

$$\text{Sum of squared residuals} = \sum_{i=1}^n W_i |h_i - H_i|^2$$

where:

W_i = weighting = (1 / number of water level observations per bore)
 h_i = observed head
 H_i = predicted head

An initial run of the un-calibrated model with the adopted starting values reported a sum of squared residuals error of 14,000 m. A series of manual calibration runs were then performed to reduce the difference between the observed and predicted water levels and the sum of squared residuals. PEST was then used to automate the calibration process reduced the sum of squared residuals error to 615 m.

9.2.2 Sensitivity of Calibrated Parameters

PEST was used to automatically calculate the sensitivities at the end of each optimisation iteration. Figure 9.7 presents the initial composite parameter sensitivities within respect to the first stage of automated transient calibration and model output. At the initial stages of calibration runs, the distributions of the parameters were slightly refined, using a single break of slope recharge zone (par_rch_4), and 72 pilot points (Hc, Sy and Ss) in the Gunnedah Formation.

The sensitivity results (Figure 9.7) show that the calibration simulation is most sensitive to changes in the recharge rate over the three geological zones (alluvium (par_rch_1), regolith (par_rch_2) and Tertiary basalt (par_rch_3)). The calibration simulation is also sensitive to horizontal conductivity rates, including the weathering factors. The sensitivities of each of the pilot points are generally uniform and have moderate implications to the calibration residuals.

The calibration model was refined following several optimisation iterations. The final calibration optimisation incorporated all 105 pilot points in the Gunnedah Formation and the segregation of the nine (9) break of slope recharge zones. Figure 9.8 presents the final composite parameter sensitivities for the first stage of automated transient calibration and model output.

The final sensitivity results (Figure 9.8) show that the calibration simulation is most sensitive to changes in the recharge rate over the three geological zones, and the horizontal hydraulic conductivity rates. The most sensitive break of slope zone is sub-zone 6 – GMZ 1 (bos_par_6), an area where recharge and pumping is high. The most sensitive hydraulic parameter is the weathering factor of the interburden geological layers. The sensitivity of the pilot points were greatly reduced in the latter stages of the calibration optimisations and generally have low composite sensitivities to the calibration residuals.

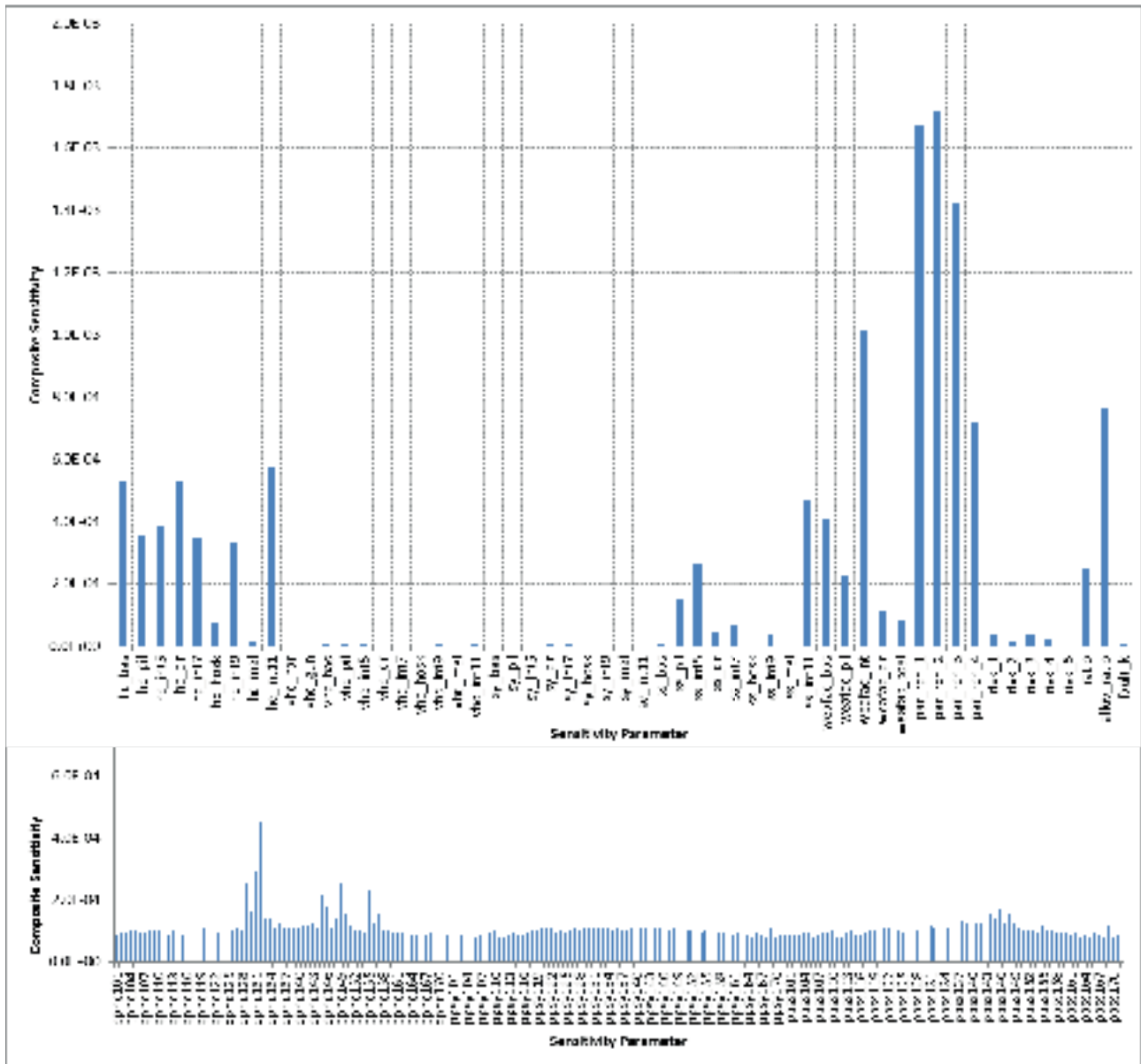


Figure 9.7: Initial Composite Parameter Sensitivities

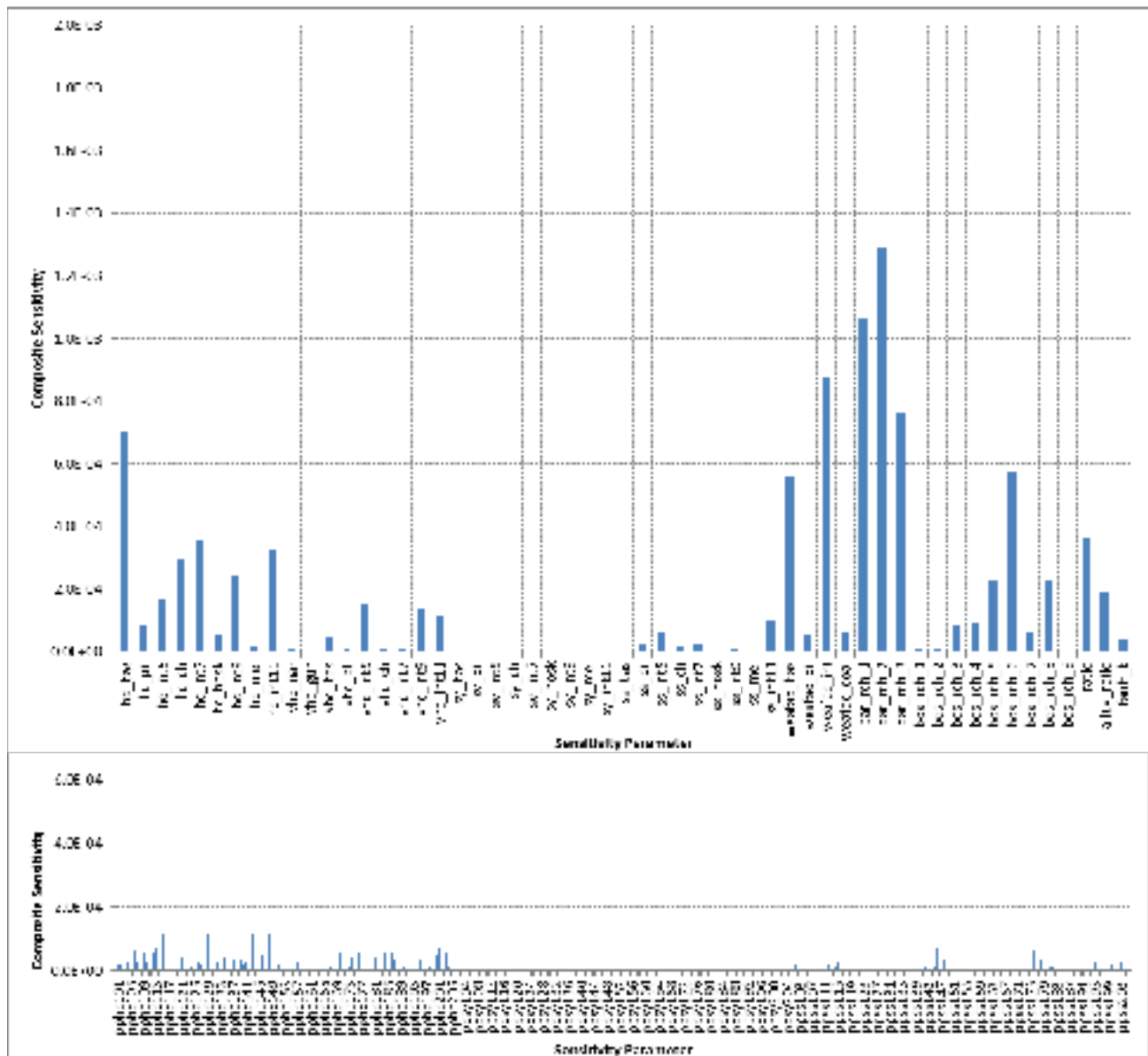


Figure 9.8: Final Composite Parameter Sensitivities

9.2.3 Aquifer Properties

Table 9.2 presents a summary of the calibrated hydraulic properties for the regional model. Figure 9.9 to Figure 9.14 present the spatially varying aquifer properties (hydraulic conductivity, specific yield and specific storage).

The regional model calibrated to a hydraulic conductivity for the Narrabri Formation of 0.05 m/day to 24.9 m/day and 0.1 m/day to 48.5 m/day for the Gunnedah Formation. The distribution of the alluvial parameters derived from pilot point PEST calibration supports the conceptualisation of a channelized flow system, with the highest hydraulic conductivity values proximal to the centre and deepest part of the alluvial formation. The model also represents the clayey nature of the Narrabri Formation in the Project Boundary well with calibrated values close to site tested parameters that average 0.2 m/day. Figure 9.15 and Figure 9.16 presents horizontal and vertical hydraulic conductivity rates derived from field and laboratory testing, compared with average modelled parameter values. The Standard deviation (σ) of the full suite of data in each formation is



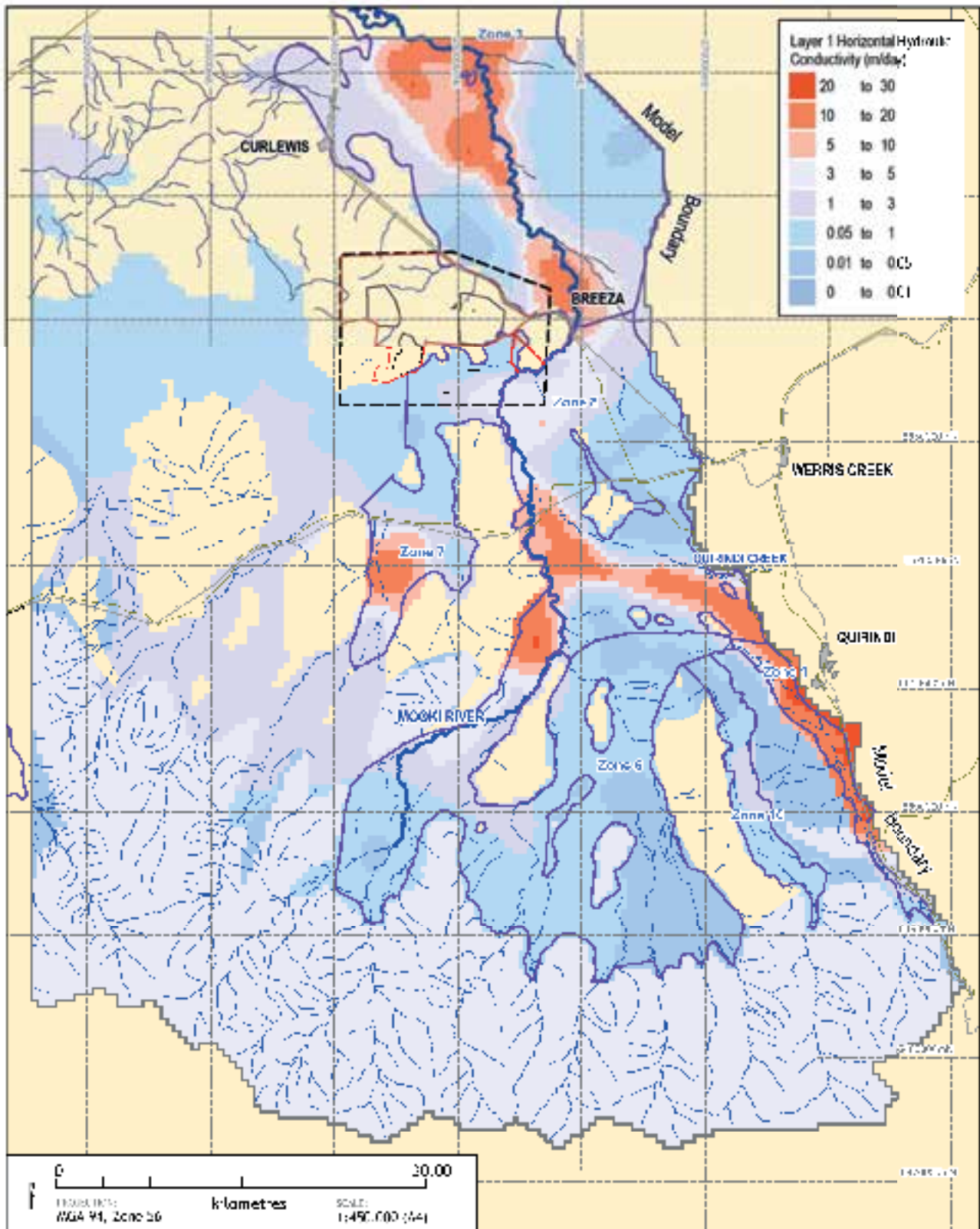
presented on Figure 9.15 and Figure 9.16. Horizontal hydraulic conductivity data for the Gunnedah Formation and Melvilles coal seam has the highest standard deviation values.

It should be noted that while in general the Narrabri Formation is consistent in clay content, a review of the drilling logs indicates that the division of the Narrabri and Gunnedah Formations is not easy to pick, meaning that the high hydraulic conductivity values assigned to the Narrabri Formation are considered possible in some areas across the model domain.


Table 9.2: CALIBRATED HYDRAULIC PARAMETERS

Geology	Parameter	Calibrated Value	
		Fresh	Weathered
Narrabri Formation (Alluvial)	Horizontal Hydraulic Conductivity	0.01 to 25.1 (refer Drawing No. 10.17)	
	Vertical Hydraulic Conductivity	50% of Kh	
	Specific Yield Sy	3.2×10^{-2} to 2×10^{-1} (refer Drawing No. 10.21)	
	Specific Storage Ss	1×10^{-5} - 1×10^{-3}	
Gunnedah Formation (Alluvial)	Horizontal Hydraulic Conductivity	0.1 to 46.7 (refer Drawing No. 10.18)	
	Vertical Hydraulic Conductivity	9% of Kh	
	Specific Yield Sy	3.2×10^{-2} to 2×10^{-1}	
	Specific Storage Ss	1×10^{-5} to 1×10^{-3} (refer Drawing No. 10.22)	
Tertiary Basalts	Horizontal Hydraulic Conductivity	6.5×10^{-1}	3.23
	Vertical Hydraulic Conductivity	1.9×10^{-1}	0.96
	Specific Yield Sy	1.4×10^{-2}	
	Specific Storage Ss	$5.6 \times 10^{-5} \text{ m}^{-1}$	
Jurassic /Triassic Interburden	Horizontal Hydraulic Conductivity	1.0×10^{-3}	1.0×10^{-2}
	Vertical Hydraulic Conductivity	1.0×10^{-4}	1.0×10^{-3}
	Specific Yield Sy	2.6×10^{-3}	
	Specific Storage Ss	$5 \times 10^{-5} \text{ m}^{-1}$	
Pilliga Sandstone	Horizontal Hydraulic Conductivity	1.2×10^{-3}	1.2×10^{-2}
	Vertical Hydraulic Conductivity	1×10^{-1}	1.0
	Specific Yield Sy	1.5×10^{-2}	
	Specific Storage Ss	5.0×10^{-4}	
Clare Sandstone	Horizontal Hydraulic Conductivity	2.0×10^{-1}	3.0×10^{-1}
	Vertical Hydraulic Conductivity	1.0×10^{-2}	1.5×10^{-2}
	Specific Yield Sy	1.2×10^{-3}	
	Specific Storage Ss	$5 \times 10^{-5} \text{ m}^{-1}$	
Permian Interburden	Horizontal Hydraulic Conductivity	1×10^{-3} to 1×10^{-4}	1×10^{-2} to 1×10^{-3}
	Vertical Hydraulic Conductivity	1×10^{-4} to 1×10^{-5}	1×10^{-3} to 1×10^{-4}
	Specific Yield Sy	1×10^{-3}	
	Specific Storage Ss	$1 \times 10^{-5} \text{ m}^{-1}$	
Hoskissons Coal Seam	Horizontal Hydraulic Conductivity	5×10^{-3} to 8.6×10^{-6}	5×10^{-2} to 8.6×10^{-6}
	Vertical Hydraulic Conductivity	5×10^{-4} to 8.6×10^{-7}	5×10^{-3} to 8.6×10^{-7}
	Specific Yield Sy	2.2×10^{-3}	
	Specific Storage Ss	$1.7 \times 10^{-5} \text{ m}^{-1}$	
Melvilles Coal Seam	Horizontal Hydraulic Conductivity	5×10^{-3} to 8.6×10^{-6}	5×10^{-2} to 8.6×10^{-6}
	Vertical Hydraulic Conductivity	5×10^{-4} to 8.6×10^{-7}	5×10^{-3} to 8.6×10^{-7}
	Specific Yield Sy	3×10^{-3}	
	Specific Storage Ss	$1.5 \times 10^{-5} \text{ m}^{-1}$	

Note: Horizontal Hydraulic Conductivity (Kh) is in m/day
Vertical Hydraulic Conductivity (Kv) is in m/day
Specific Yield is a percentage (unconfined storage) (%)
Specific Storage (Ss) is in m^{-1}



Legend

- H-24
- Trezona Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

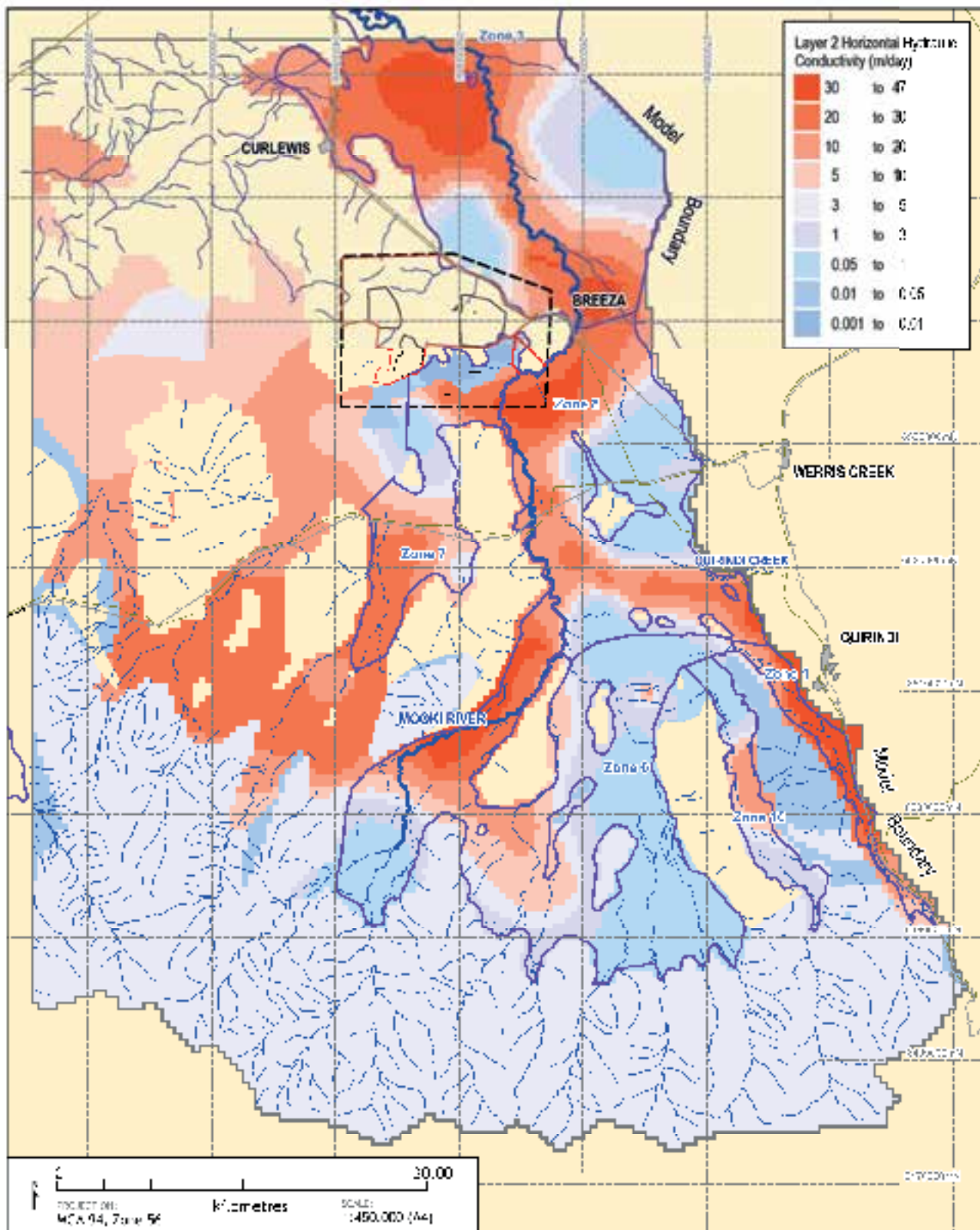
Watermark Coal Project (G157)
Groundwater Assessment

Horizontal Hydraulic Conductivity
Layer 1



DATE:
18/10/2012

Version:
9.9



Legend

- 1:2.5
- 1:2.5
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

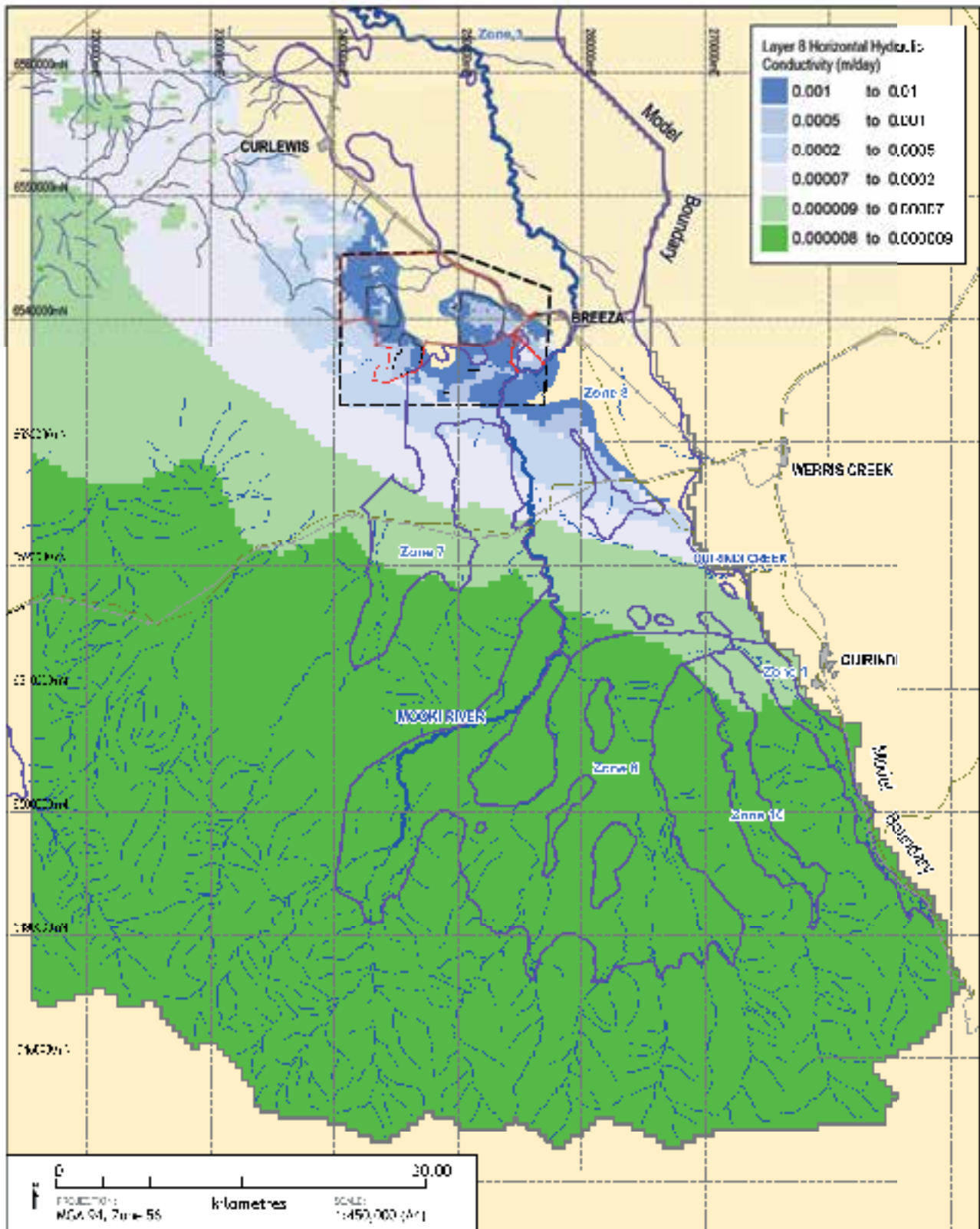
Watermark Coal Project (G157)
Groundwater Assessment

**Horizontal Hydraulic Conductivity
Layer 2**



DATE:
18/10/2012

VERSION:
9.10



- Legend:**
- H-100
 - - - - - H-1000
 - Groundwater Management Zone
 - Project Boundary
 - Drainage Line / Creek

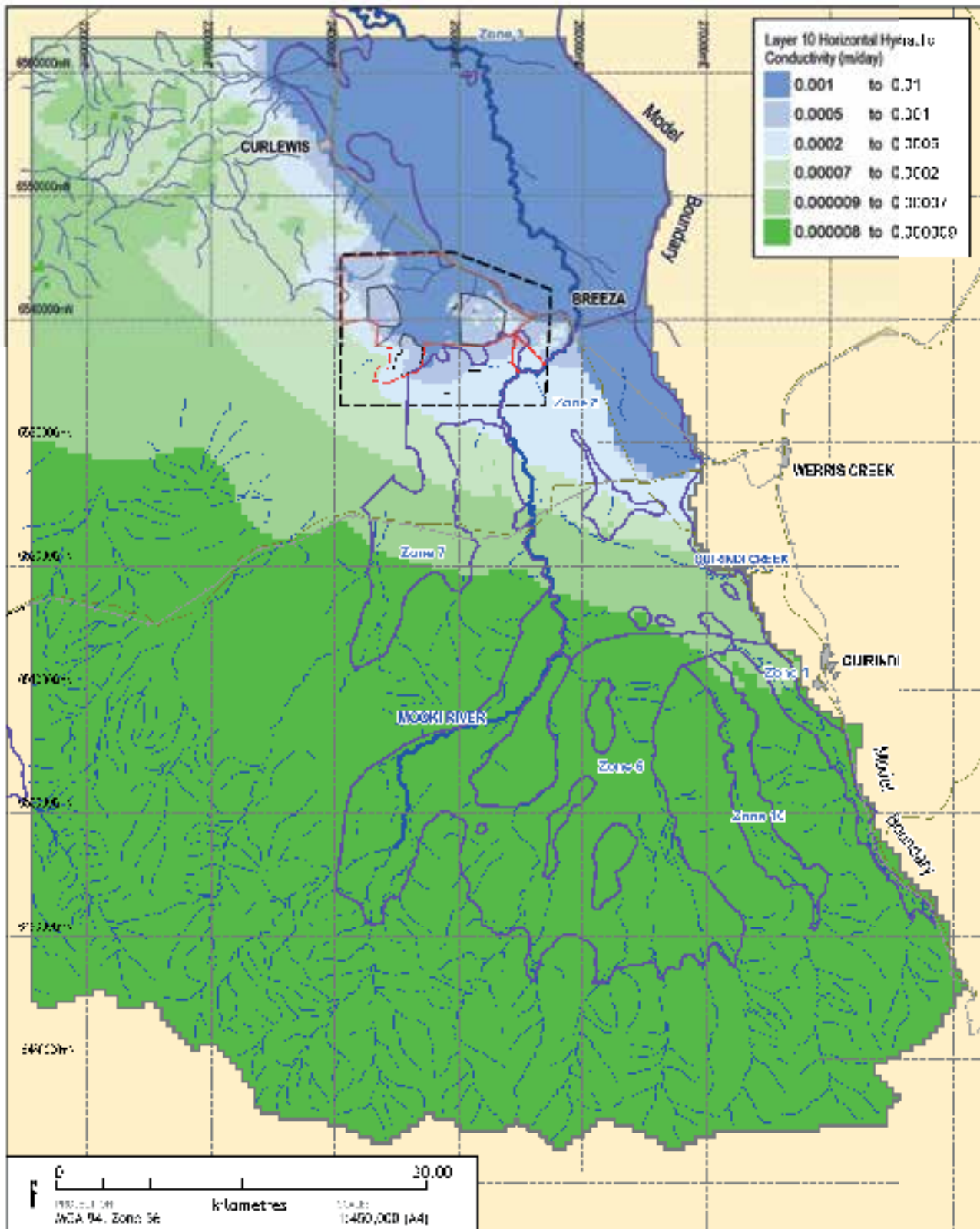
Watermark Coal Project (G157)
 Groundwater Assessment

Horizontal Hydraulic Conductivity Layer 8



DATE:
 18/10/2012

TIME:
 9.11



Legend

- H-10
- Tropicana Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

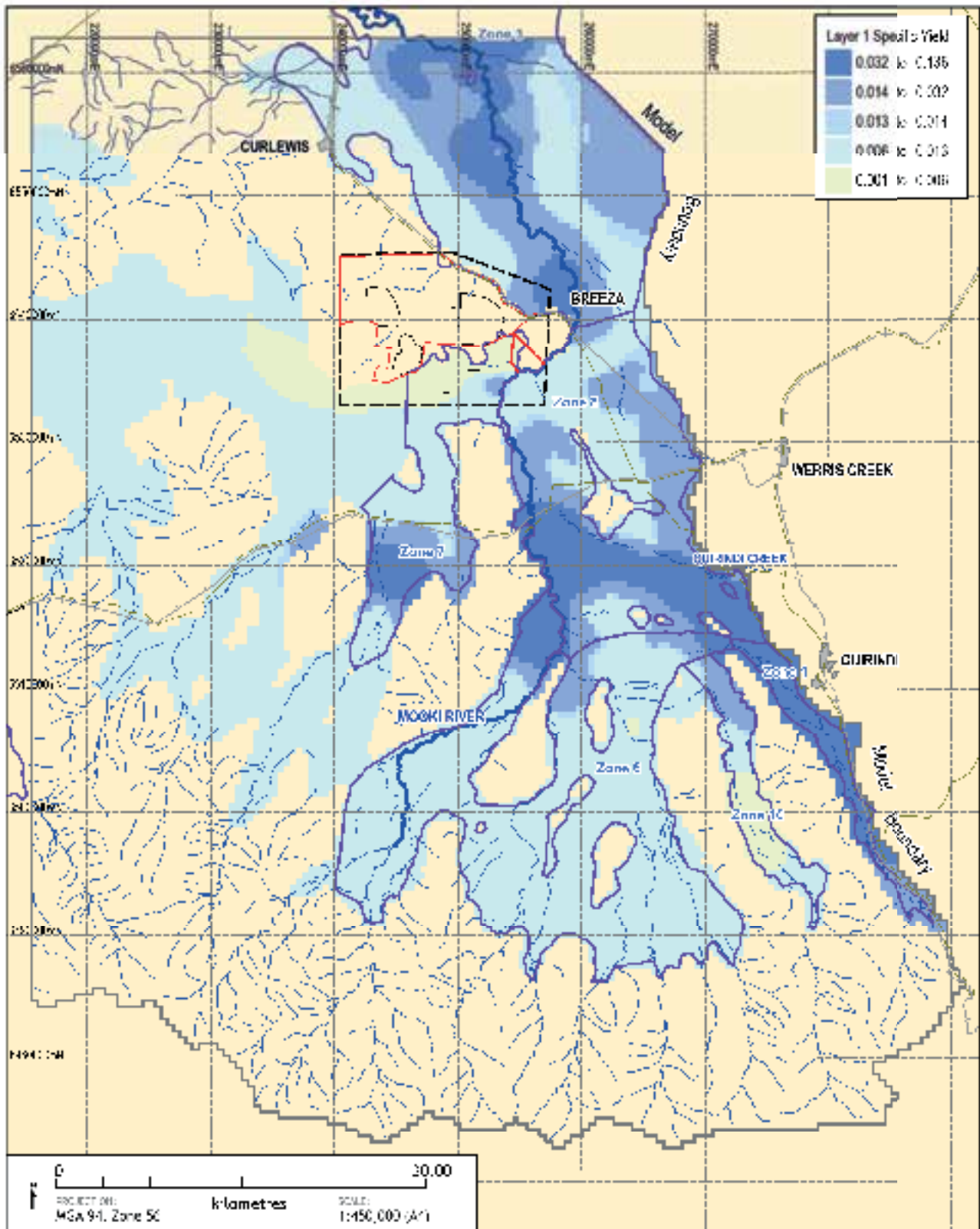
Watermark Coal Project (G157)
Groundwater Assessment

**Horizontal Hydraulic Conductivity
Layer 10**



DATE:
18/10/2012

FIGURE
9.12



Legend

- L-122
- Project Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

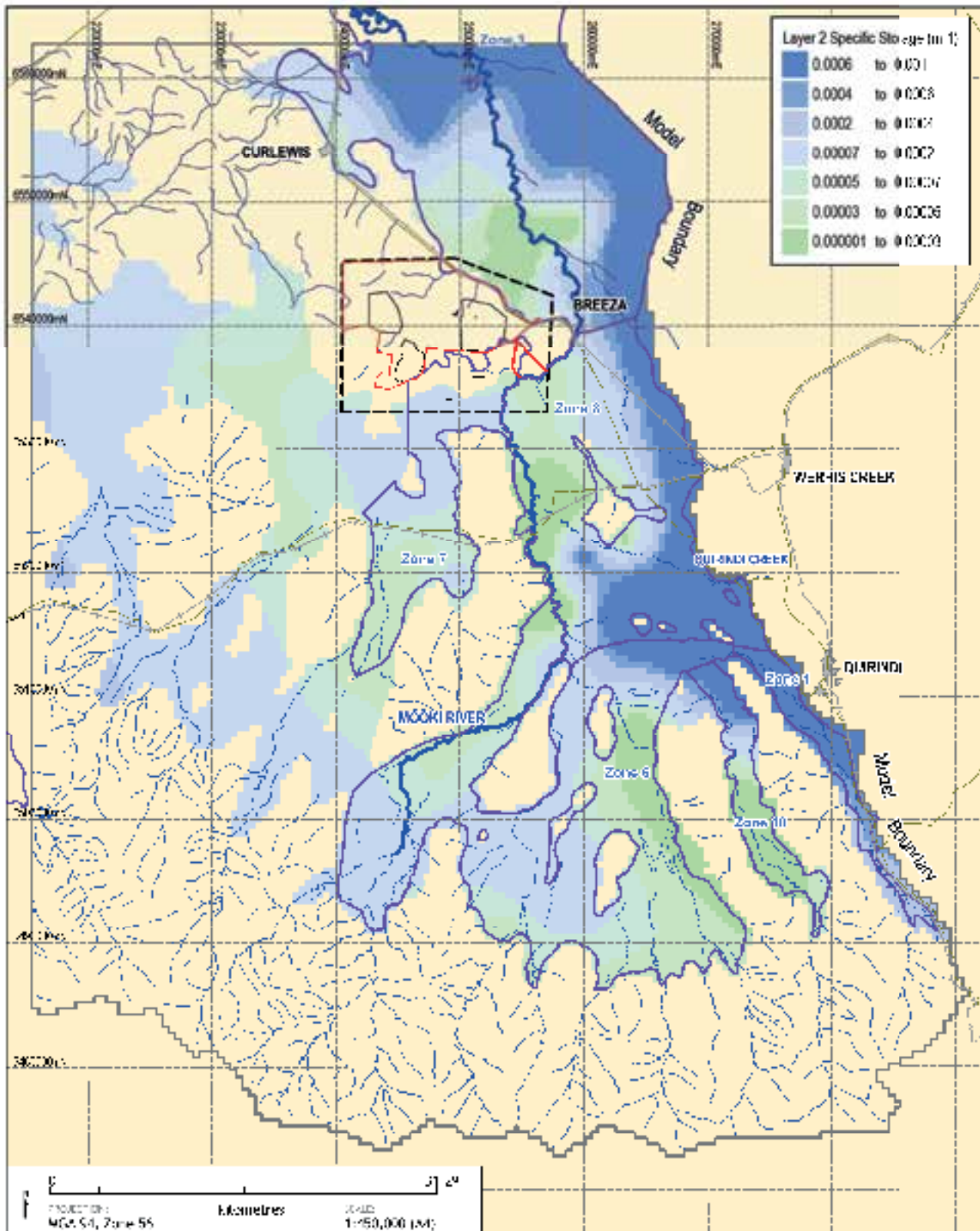
Watermark Coal Project (G157)
Groundwater Assessment

Specific Yield
Narrabri Formation (Layer 1)



DATE:
18/10/2012

TIME:
9.13



Legend

- F 722
- Proposed Mining Area
- Groundwater Management Zone
- Project Boundary
- Drainage Line / Creek

Watermark Coal Project (G157)
Groundwater Assessment

Specific Storage
Gunnedah Formation (Layer 2)



DATE:
18/10/2012

VERSION:
9.14

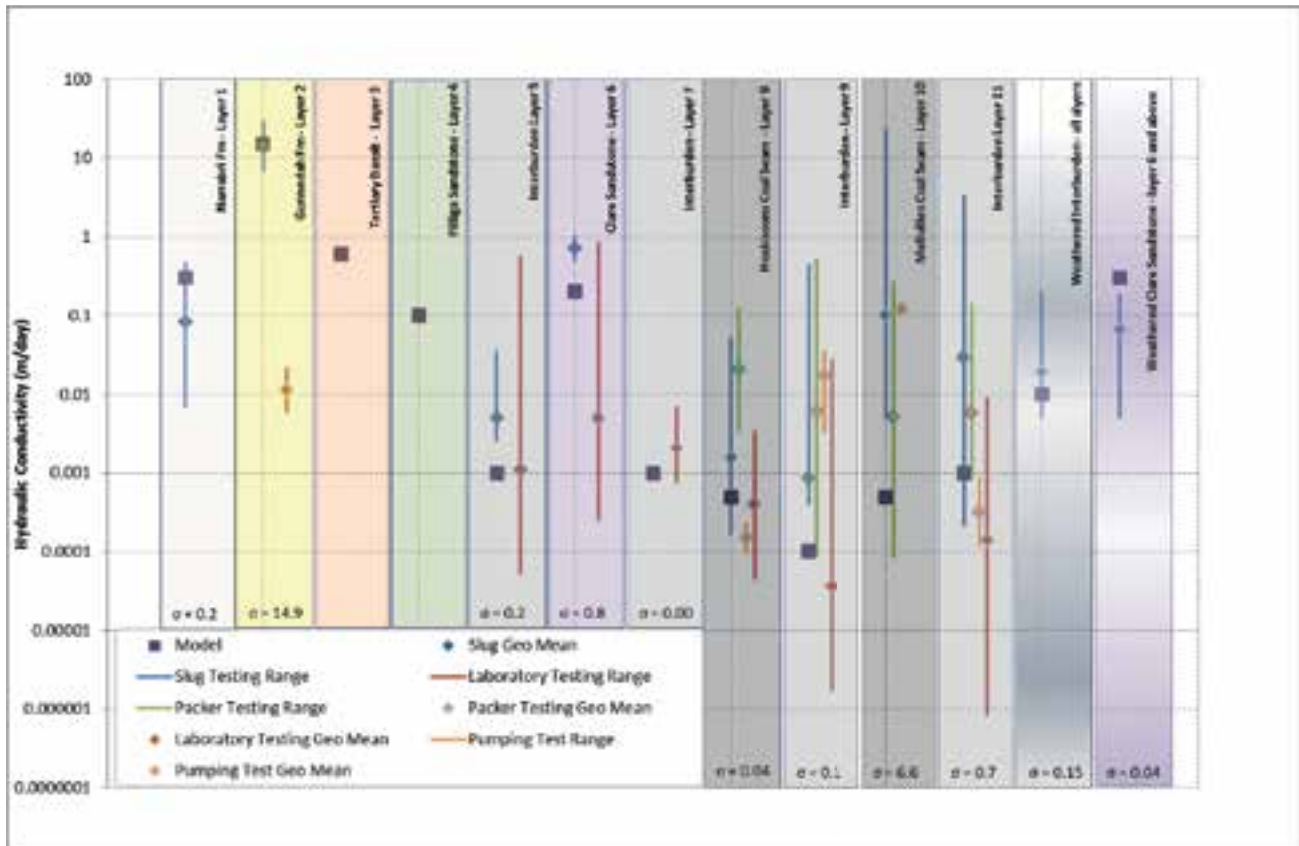


Figure 9.15: Geometric Mean Horizontal Hydraulic Conductivity Values

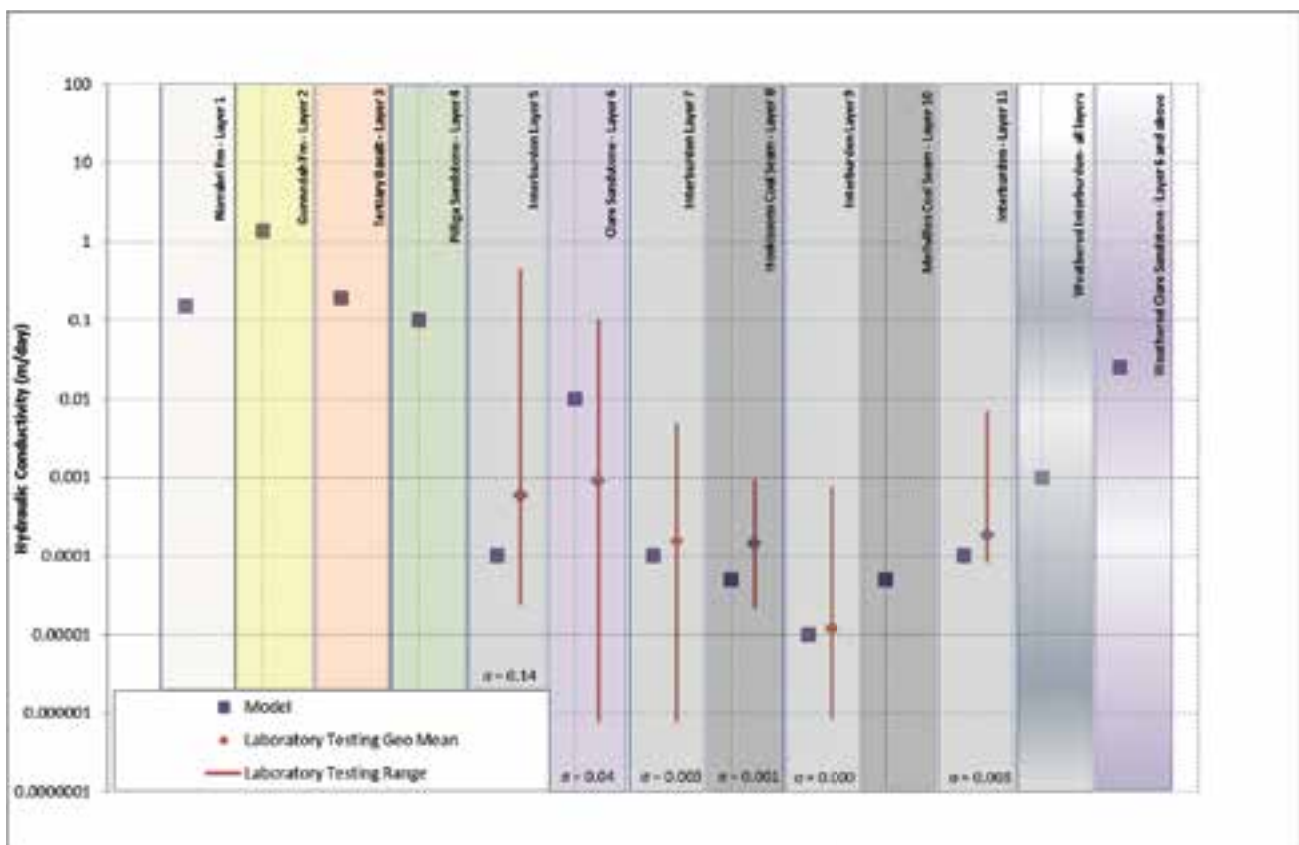


Figure 9.16: Geometric Mean Vertical Hydraulic Conductivity Values



The specific yield distribution reflects areas where the Gunnedah Formation is thickest and most transmissive and extraction via bores is high. This specific yield determined during the calibration was then reflected in the Narrabri Formation. The specific storage values calibrated for the Gunnedah Formation were highest along the eastern edge of the Liverpool plains, and show less relationship to the main palaeochannel, particularly in Zone 3. This was because in the model the Gunnedah Formation is unconfined in these areas and the specific storage has approached specific yield values.

Faulting in the Permian coal measures represented by the Horizontal Flow Barrier (HFB) package, as described in Section 8.4.7, calibrated to a very low value of 1×10^{-8} m/day. This suggested that the faults within the model domain more commonly act as groundwater barriers to flow and supports the interpretation of a compartmentalised aquifer system in the Permian bedrock.

9.2.4 Recharge

The recharge zones determined during the transient calibration were as follows:

- | | | |
|-----------------------------|---------------|-----------------------|
| • Alluvial aquifer | 9.7 mm/yr | - 1.5% of rainfall |
| • Regolith/Permian outcrop | 0.3 mm/yr | - 0.05% of rainfall |
| • Liverpool range basalt | 32.2 mm/yr | - 5.0% of rainfall |
| • Break of slope (alluvium) | 6 – 161 mm/yr | - 1 - 25% of rainfall |

Figure 9.17 presents the spatial distribution of the recharge for each zone.

The calibrated recharge rates for the break of slope subzones as a proportion of annual rainfall were:

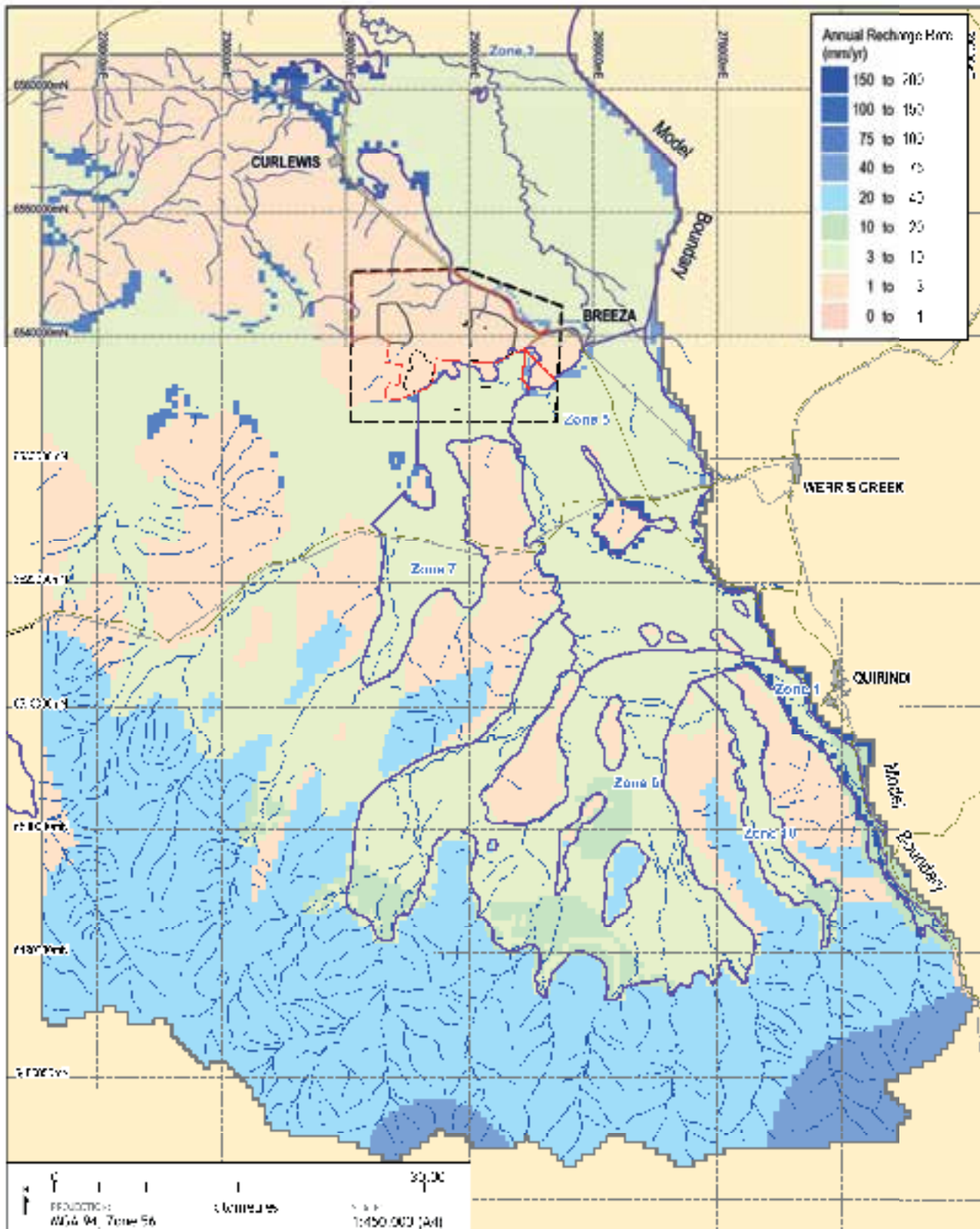
- | | |
|--|------|
| • sub-zone 1 – South western Liverpool range interface | 1 % |
| • sub-zone 2 – Doona Point | 1 % |
| • sub-zone 3 – Watermark East | 8 % |
| • sub-zone 4 – GMZ 8 (Central) | 25 % |
| • sub-zone 5 – North eastern boundary | 10 % |
| • sub-zone 6 – GMZ 1 (Zone 1) | 25 % |
| • sub-zone 7 – North western boundary | 25 % |
| • sub-zone 8 – Watermark West | 15 % |
| • sub-zone 9 – Central West | 19 % |

The highest recharge rates of 25% of annual rainfall were calibrated at the break of slope in Water Management Zone 1 (GMZ Zone 1), in the Curlewis area (northwest zone) and around Nicholas Ridge (GMZ Zone 8). The high recharge rate in Zone 1 is likely due to the model compensating for the extensive irrigation and associated irrigations returns to the aquifer in this area that are not simulated in the model. In the Curlewis area, there is extensive agricultural pumping and the high recharge rate may be due to the model injecting water to sustain groundwater levels in this area. It should be noted that although these recharge rates are high, the area of which these rates occur is relatively small, and therefore is not the dominant driver for groundwater recharge into the alluvial formations.



In the Project Boundary, the model calibrated recharge rates of 8% for the eastern break of slope zones and 15% for the southern and westerns zones. The rate of 15% for subzone 8 at the southern part of the Project Boundary is relatively high considering clays and silts of the Narrabri Formation dominate the break of slope zone between the hills and the floodplain, and the more permeable Gunnedah Formation does not occur in this area. However, there is a limited number of cells in this area meaning that total volume of recharge contributed from this area is still relatively low.

The recharge rate from the break of slope zones in the Liverpool Ranges was relatively low at 1% because the alluvium receives high volumes of recharge from the large expanse of basalts on the ranges up-gradient.



Legend

- Hatched Area
- Drainage Line / Creek
- Project Boundary
- Groundwater Management Zone

Watermark Coal Project (G157)
Groundwater Assessment

Calibrated Model Recharge



DATE:
18/10/2012

FIGURE
9.17



9.2.5 Surface Water Interactions

Section 7.1.8 presents and discusses the method whereby baseflow along the Mooki River at Caroon (419034) was simulated by WRM. Figure 9.18 presents the simulated new baseflow for the section of the Mooki River from the head waters to gauging station 419034. The regional calibration model simulation predicts an average of 2.4 ML/day entering the groundwater system, which is an order of magnitude lower than the baseflow estimates as simulated by the WRM RAFTS Model (WRM, 2012).

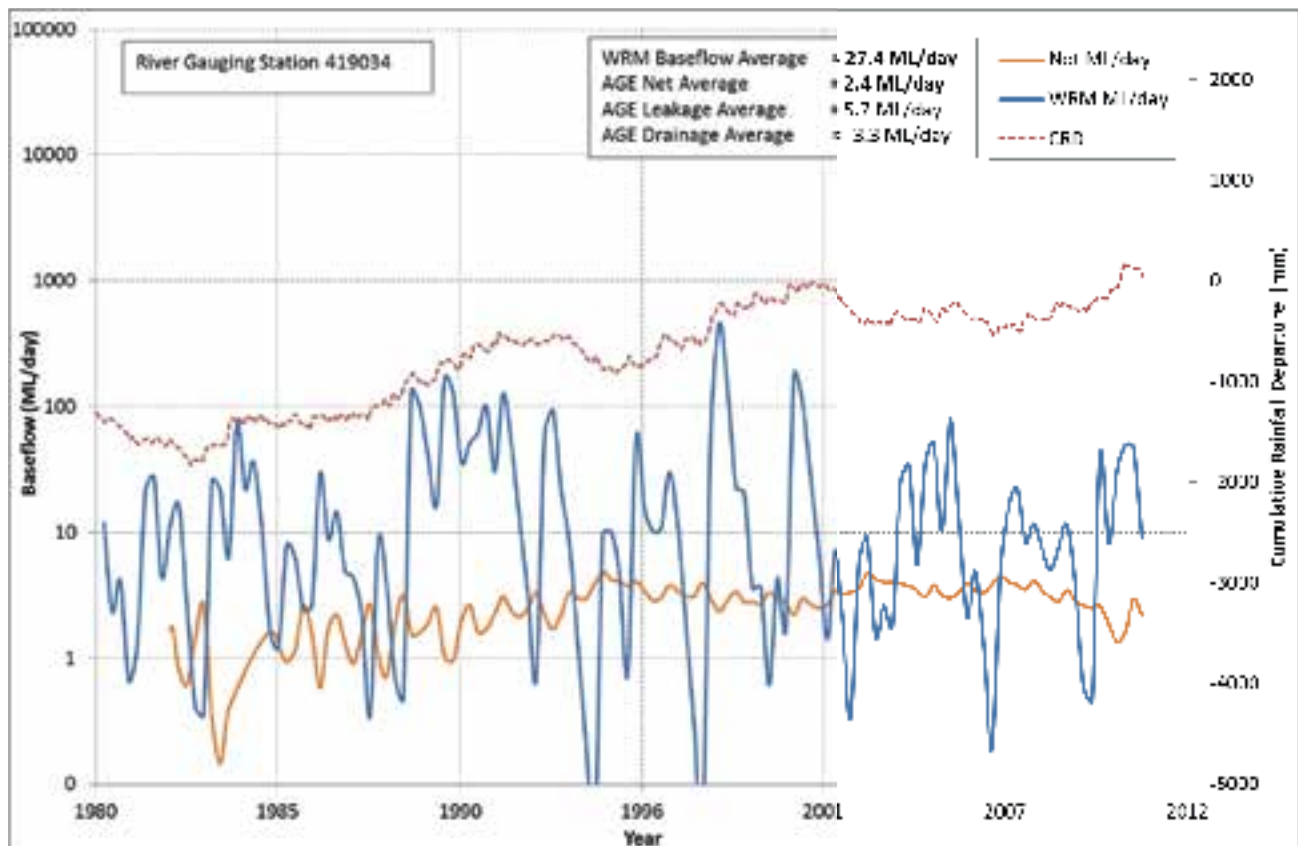


Figure 9.18: Calibrated Baseflow Comparison

9.2.6 Steady State Hydraulic Heads

Figure 9.19 compares the simulated and observed steady state groundwater levels for the Alluvial and Permian aquifer systems (layers 1 and 2, and 3 – 11).

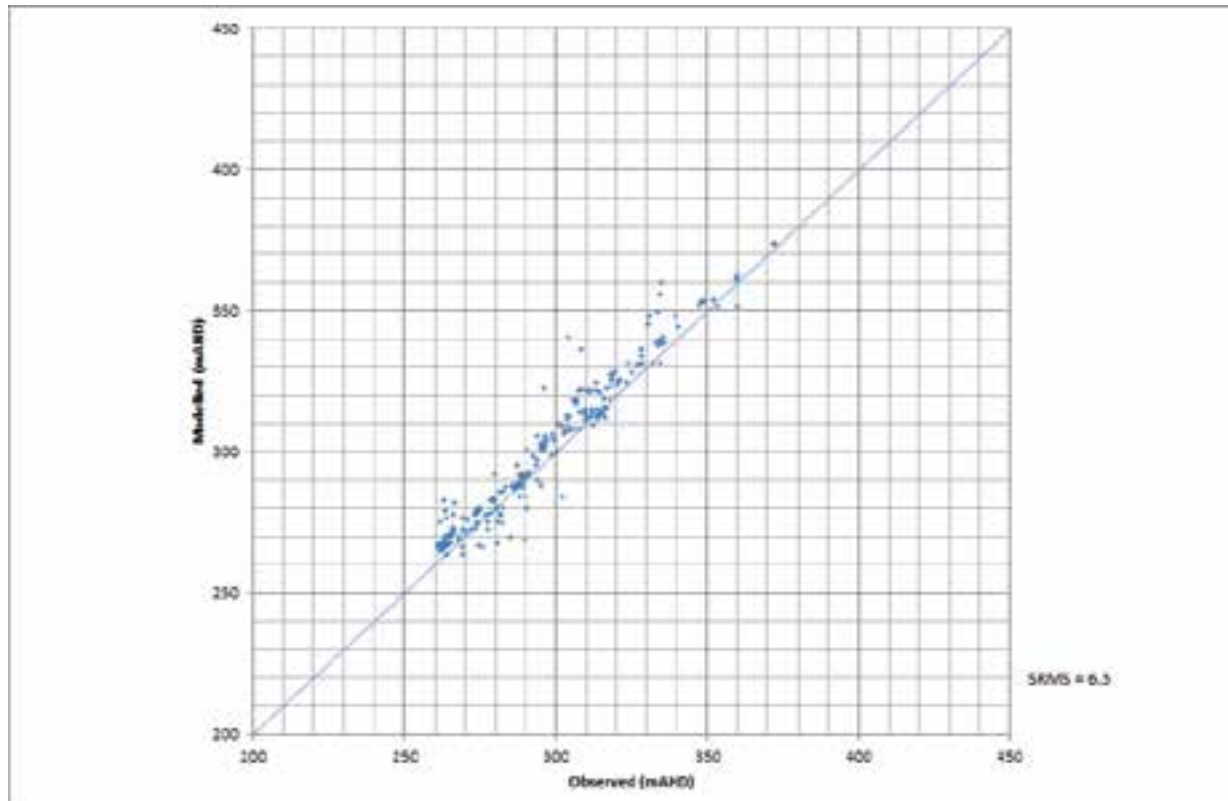


Figure 9.19: Scattergram showing Observed and Modelled Heads – Steady State

Figure 9.19 generally shows a good correlation between observed and simulated water levels. There is a slight bias to over-predict water levels, which occurs because the calibration is preferentially weighted towards the transient simulation.

Figure 9.20 to Figure 9.23 display the simulated steady state heads. The simulated heads agree with previous studies (Merrick 2001, Schlumberger 2012) that identified regional northerly groundwater flow directions through the quaternary alluvial aquifers.

Groundwater pumping was not simulated in the steady state simulation. In reality, June 1980 groundwater levels were likely to have been already impacted by the onset of previous groundwater abstraction. This explains the over prediction of steady state groundwater levels.

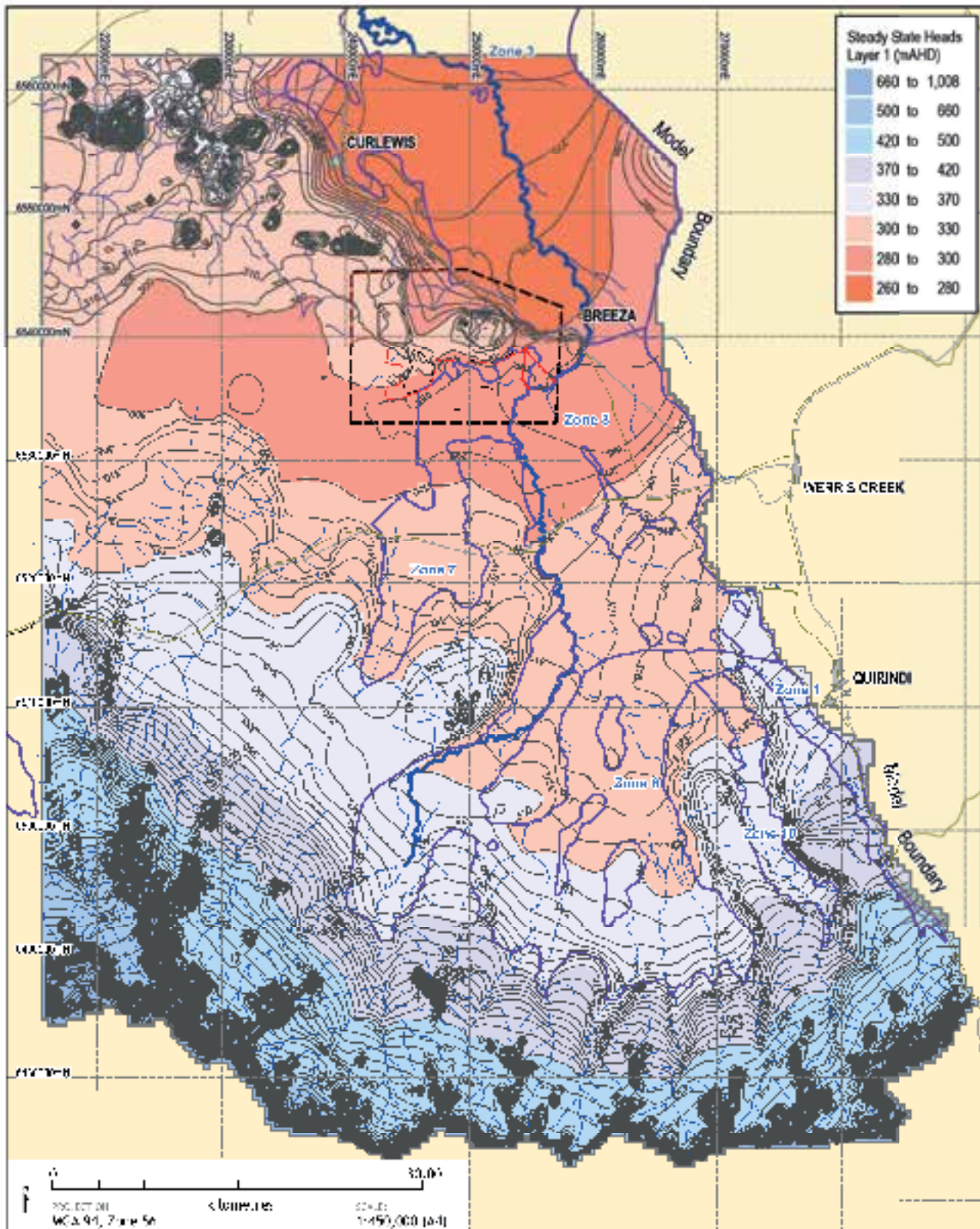
Table 9.3 presents a summary of the transient model calibration statistics for all data, as outlined by MDBC (2000).

Table 9.3: STATISTICAL ANALYSIS – ALL – STEADY STATE	
Calibration Performance Measure	Unweighted Value
Sum of Residuals (SR) (m)	-1069.35
Mean Sum of Residuals (MSR) (m)	-3.95
Scaled Mean Sum of Residuals (SMSR) (%)	-3.54
Sum of Squares (SSQ) (m ²)	14248.53
Mean Sum of Squares (MSSQ) (m ²)	52.58
Root Mean Square (RMS) (m)	7.25
Root Mean Fraction Square (RMFS) (%)	0.06
Scaled RMFS (SRMFS) (%)	0.16
Scaled RMS (SRMS) (%)	6.5



The RMS error, which is a statistic similar to standard deviation, is a measure of the variability in the observed versus simulated water level records. The RMS error calculated for the unweighted calibrated transient model results was 7.25 m. The unweighted RMS assumes each bore contributes equally to the RMS error, whereas a weighted RMS error reduces the influence of bores that are not considered to supply reliable water level records.

The ratio of RMS to the total head change across the calibration points (111.42) indicated a SRMS of 6.5%. This indicates a moderate calibration and close to the MDBC (2000) and project target of 5% or less.



Legend

- H-1-2-3
- Tropic Mining Area
- Groundwater Management Zone
- Groundwater Level (mAH)
- Project Boundary

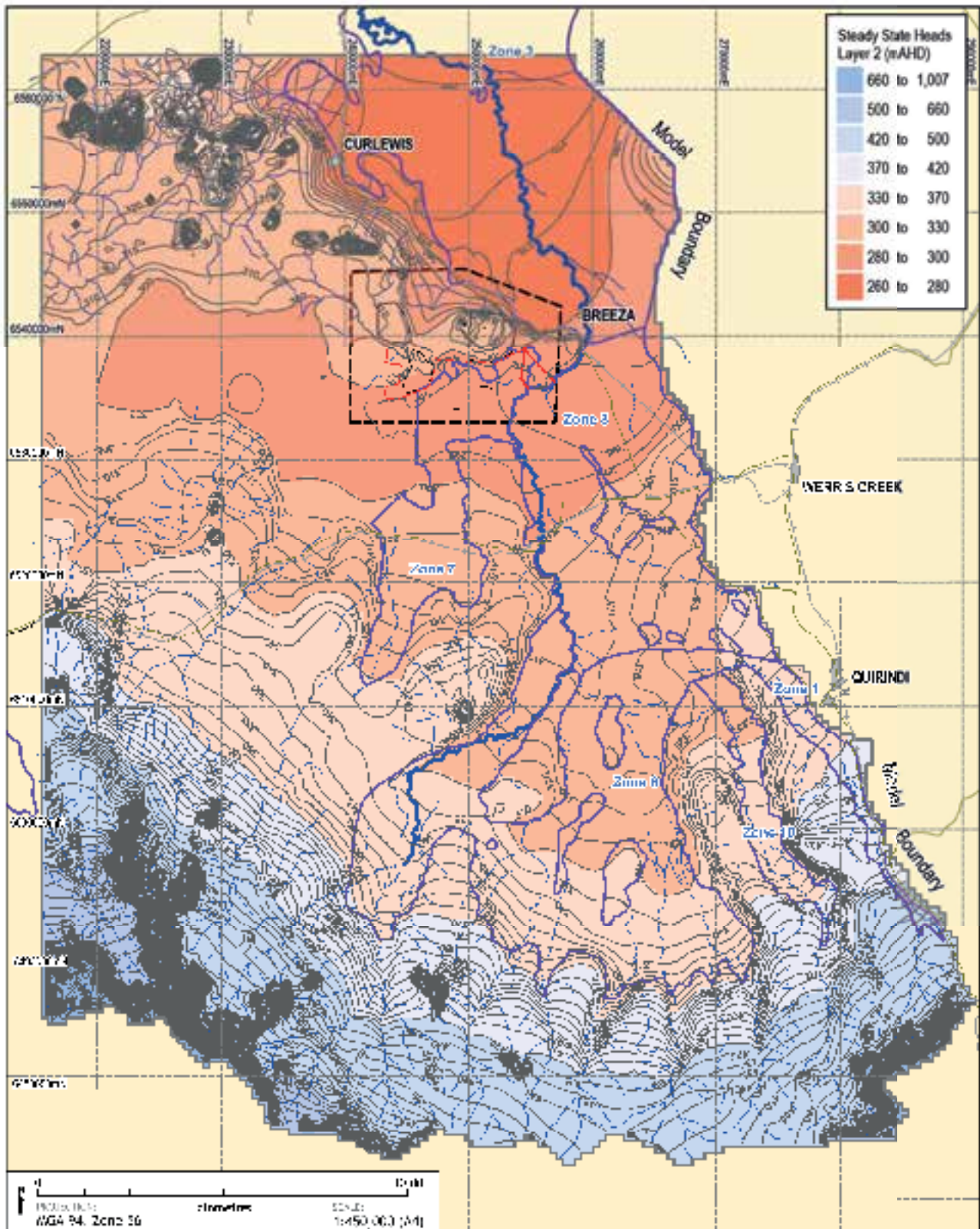
Watermark Coal Project (G157)
Groundwater Assessment

Steady State Heads Model Layer 1



DATE:
18/10/2012

CONFIDENCE:
9.20



Legend

- H-123
- Thoussou Mining Area
- Groundwater Management Zone
- Groundwater Level (mAH)
- Project Boundary
- Neer's Creek
- Drainage Line / Creek

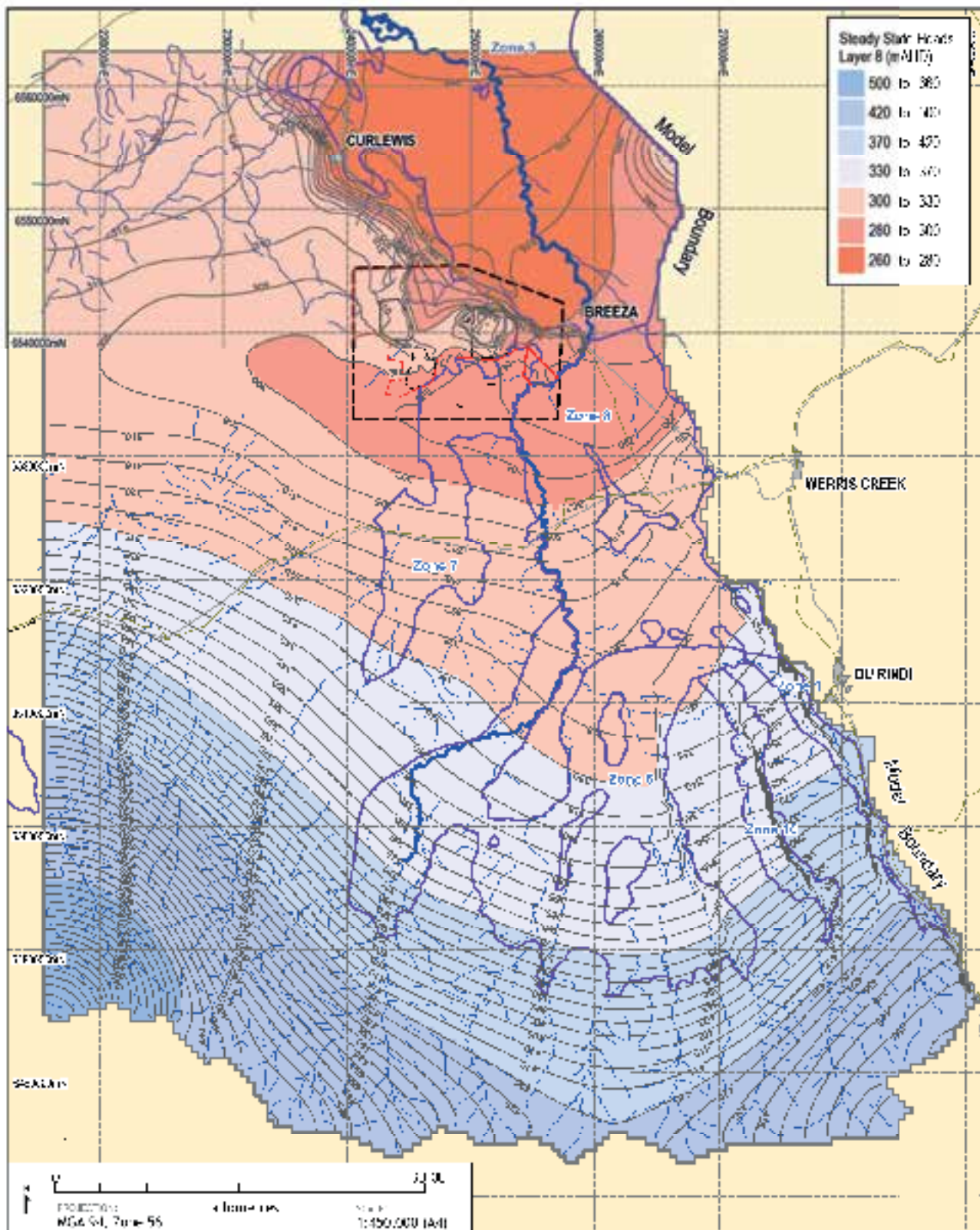
Watermark Coal Project (G157)
Groundwater Assessment

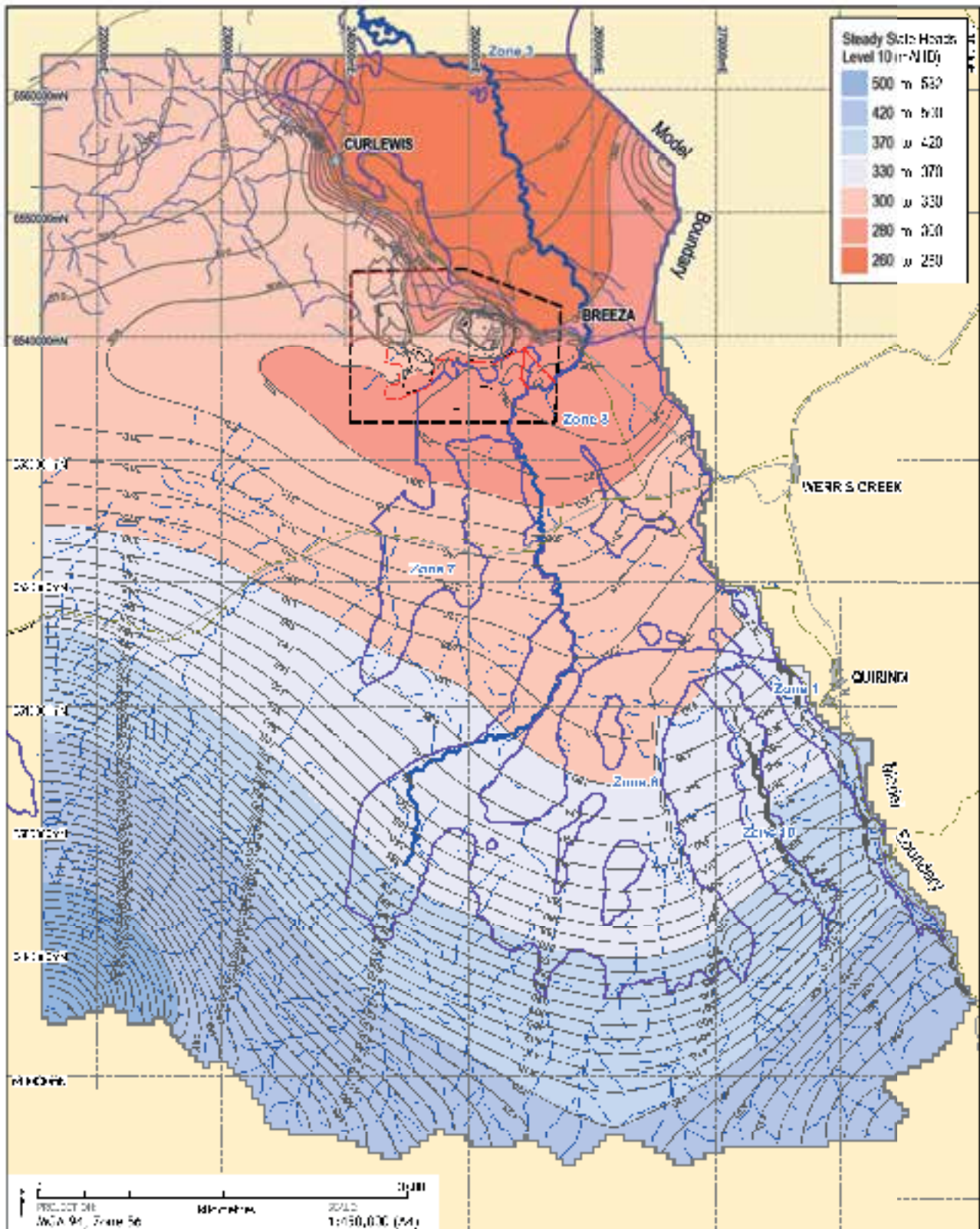
Steady State Heads Model Layer 2



DATE:
18/10/2012

TIME:
9.21





Legend

- H-10/11
- Township Boundary
- Groundwater Management Zone
- Groundwater Level (mNHD)
- Project Boundary
- Model Grid
- Drainage Line / Creek

Watermark Coal Project (G1517)
Groundwater Assessment

Steady State Heads Model Layer 10



DATE:
18/10/2012

TIME:
9.23



9.2.7 Transient Hydraulic Heads

Regional Calibration

Appendix 5 presents observed and simulated hydrographs from bores used in the transient calibration. The hydrographs show a good match between the observed and simulated water levels in both the NOW and Shenhua Watermark monitoring bores. The majority of the bores screened in the quaternary alluvium accurately replicate the water levels induced by seasonal pumping, as well as the long-term downward trend in groundwater levels. Several bores are screened in the weathered Permian, immediately below the Gunnedah Formation and display a localised pressure response caused by nearby or adjacent pumping.

The calibration results are discussed for each Water Management Zone below (refer to Figure 4.1).

- **Zone 1** – The observed and simulated water levels typically show a good correlation across Zone 1, in spite of the variable topography and narrow alluvial aquifer system in this area, particularly in the southern area. Towards the northern limit of the groundwater management zone the model under predicts groundwater levels by up to 5 m from the mid-1990s to mid-2011. This under-prediction of groundwater levels may be caused by a number of factors, such as an under-representative hydraulic conductivity value for the Gunnedah Formation in this area, or insufficient localised recharge to the aquifer system. Another explanation for the under prediction of groundwater levels could be assumptions made in the groundwater pumping data.
- **Zone 3** – The observed and simulated water levels generally show an excellent correlation across Zone 3, and the model accurately reproduces the observed decline in groundwater levels. The presence of the General Head Boundary package in the very northern area of Zone 3 locally affects simulated water levels in this area. There is a slight under prediction of heads in the north-western region of Zone 3, where observed water levels have not declined at the rate observed in other areas of the alluvial system. It is likely that both the influence of the general head boundary, and high conductivity rates assigned to the Gunnedah Formation causes the under prediction of the simulated heads in this area. Groundwater levels attributed with the general head boundary were assigned to observed groundwater head measurements from observation bores towards the central east area of the northern boundary. Groundwater levels are higher in the west of the GHB cells, and therefore groundwater levels in the north-western alluvial formation are underpredicted. Groundwater level rise in this area has been attributed to the dominance of clays in the area and high break of slope recharge. Pilot points in this area approached low conductivity value bounds of 0.1 m/day and break of slope recharge rates approached upper bounds of 25%. The calibration results suggests that hydraulic conductivity values may be lower than represented in the model, and break of slope recharge rates may be higher in isolated areas where significant under prediction of groundwater levels occur.
- **Zone 6** – The decline in observed groundwater levels is less evident in the Zone 6, particularly in the south-western area. The observed and simulated water levels generally show an acceptable correlation in the southern area of Zone 6. The model generally under predicts groundwater levels in the central area of Zone 6 in response to pumping. The cause of the under prediction in these areas of the central Zone 6 is likely due to isolated zones of high break of slope recharge, which have not been segregated in this region of the groundwater model.
- **Zone 7** – The magnitude of the decline in observed water levels is less evident in Zone 7 compared to surrounding zones. This is likely due to the lower transmissivity of the alluvial



aquifer and resultant low number of bores extracting groundwater. The simulated water levels typically reproduce the variation in water levels induced by seasonal pumping. The commencement of pumping towards the northern area of Zone 6 from 2000 onwards is well represented by the model, as presented in Figure 9.39 (GW093103) and in Appendix 5 as GW093101-1 calibration hydrograph.

- **Zone 8** – The observed and simulated water levels generally show an excellent correlation across Zone 8 and accurately simulate the gradual decline in groundwater levels, as well as the short-term season fluctuations in water levels induced by pumping and recharge. The model slightly over predicts groundwater levels around the junction of the Mooki River and Quirindi Creek from 2007 to mid-2011, suggesting that there may be some localised recharge or pumping that has not been represented in the model simulation. There is also a general over prediction of groundwater levels in the south-eastern area of Zone 8. This may be due to insufficient recharge into the model, too low hydraulic conductivity or an underrepresentation of historical pumping in this area. It should also be noted that previous modelling in this area, including Merricks Zone 8 model (Merrick, 2001), suggesting that there may be data issues in this area.

Simulated steady state groundwater levels (i.e. mid 1980) are approximately 10 m higher than measured in June 1980. Groundwater levels may have already been impacted prior to 1980 in these areas.

The south-western region of Zone 8 along Quirindi Creek displays significant under prediction of simulated levels. Groundwater level response to pumping is over represented, suggesting that net groundwater inputs to the aquifer are too low in this region. Quirindi Creek may supply more water as river leakage than represented by the river package over this area. A varying river conductance, river depth and height along the length of the Quirindi Creek may have reduced this under prediction.

- **Zone 10** – The observed and simulated water levels generally show a good correlation with a slightly muted response, suggesting the recharge has been sufficiently represented along this thin alluvial valley system.
- **Watermark EL 7223** – The observed and simulated water levels generally show a good correlation, in spite of the compartmentalised nature of the Permian aquifer system (refer Section 8.1.7). Groundwater levels in Permian interburden and coal seams display a muted response, depending of the level of weathering of the formation and depth of screened aquifer. The model tends to over predict groundwater levels to the south west of the Watermark Project Boundary, whereas levels are under predicted to the north. 60% of groundwater level observations in the bores within the EL 7223 display over prediction, suggesting there is a reasonable balance between over prediction and under prediction of groundwater levels across the EL 7223 area. Groundwater bores in the alluvial aquifers display excellent calibration, in spite of the lack of long-term data.

A gradual decline in groundwater levels has occurred in some of the alluvial monitoring bores, which is due to a combination of climatic conditions and pumping. As noted previously this occurs as a series of steps around 1981, 1995, and 2003. This is generally evident in hydrographs for bores around EL 7223, as shown in Figure 9.25 and Figure 9.45 below and more regional bores included in Appendix 5. It is clear the model replicates the gradual decline and where evident the steps in water levels as well. Many of the NOW monitoring bores are located in proximity to operating bores, and a seasonal cycle related to irrigation of crops is evident in these bores. In most cases across the domain, the model reproduces the observed pumping cycles as observed by the monitoring bores.

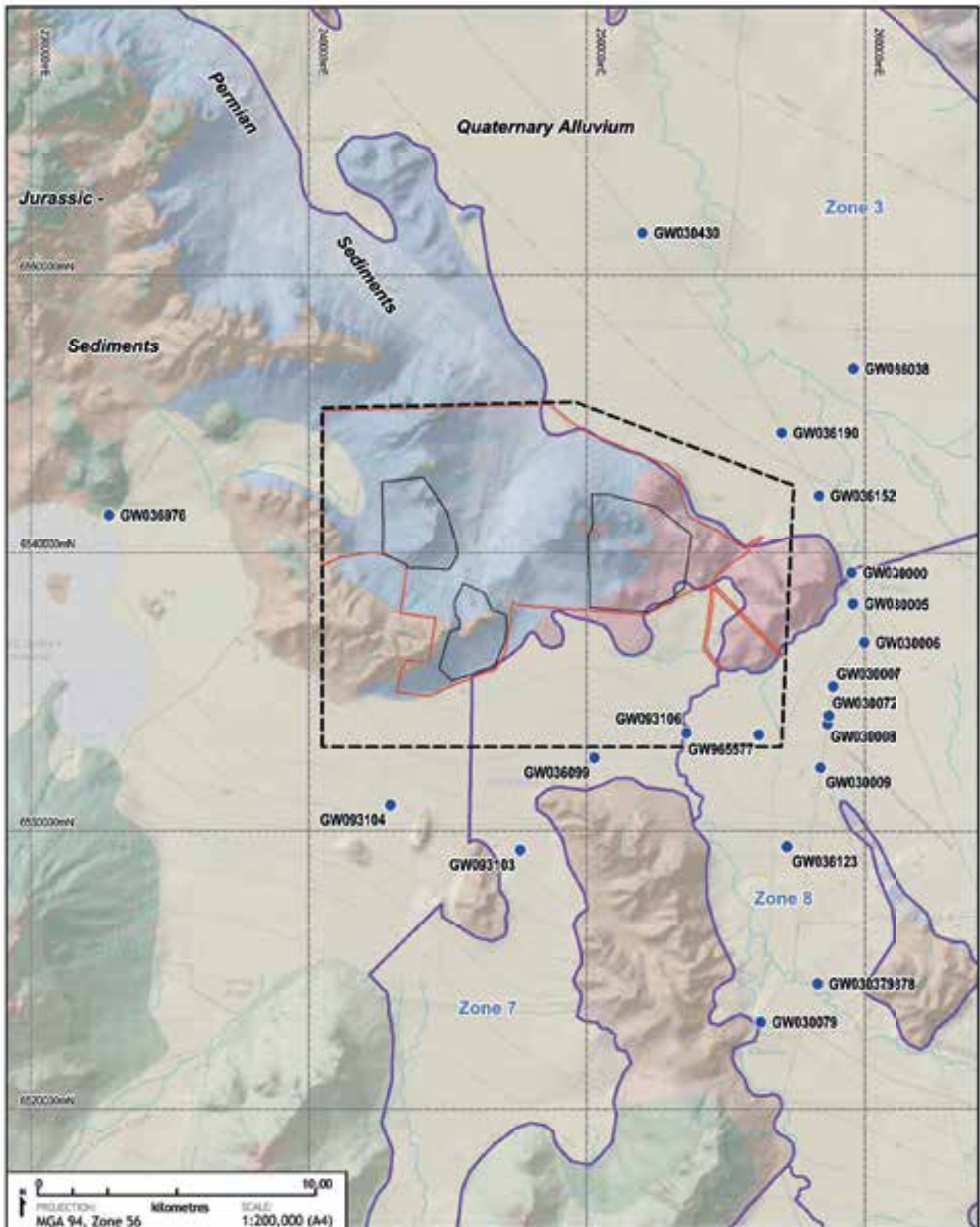


Watermark Project Calibration

The majority of the NOW bores across the model domain are screened within the Narrabri and Gunnedah Formations, which generally produce very good calibration results. The monitoring bores screened within the Permian strata also displayed adequate calibration results, although at some locations the model does not closely match observed and simulated water levels. This may be the result of coarse grid discretisation in these areas.

Figure 9.24 presents key groundwater calibration bores surrounding EL 7223. Figure 9.25 to Figure 9.45 present the calibration hydrographs for each pipe within each bore presented on Figure 9.24. Several of the pipes are screened across different sections of the Gunnedah Formation and therefore the same layer in the model. As a result, the simulated hydrographs overlay each other in these instances.

The calibration hydrographs proximal to the Project Boundary display very good calibration results in the alluvial aquifer units. The simulated and observed water levels for NOW bores that are screened across the Permian units have a poorer match. This is because NOW has installed several bores at a single site, the deepest bore is often screened within weathered Permian strata. At these locations in the model, the cell centroids are below the base of weathering and the bores have therefore been assigned fresh Permian interburden properties, instead of weathered. As a result, the heads in these bores are approximately 10 m higher, due to the vertical gradient between the fresh bedrock and the alluvium, than heads in the overlying alluvial aquifer. This mismatch is seen clearly in bores GW030079, GW030378, and GW030379 (refer to Figure 9.32 to Figure 9.34).



- LEGEND
- Groundwater Management Zone
 - Proposed Mining Area
 - EL 723
 - Project Boundary
 - Model Calibration Bore

Source: NSW PREENA Groundwater Database, 2011

Watermark Coal Project (G1501)
Groundwater Assessment

Local Model Calibration Bore Locations



DATE:
18/10/2012

FIGURE No:
9.24

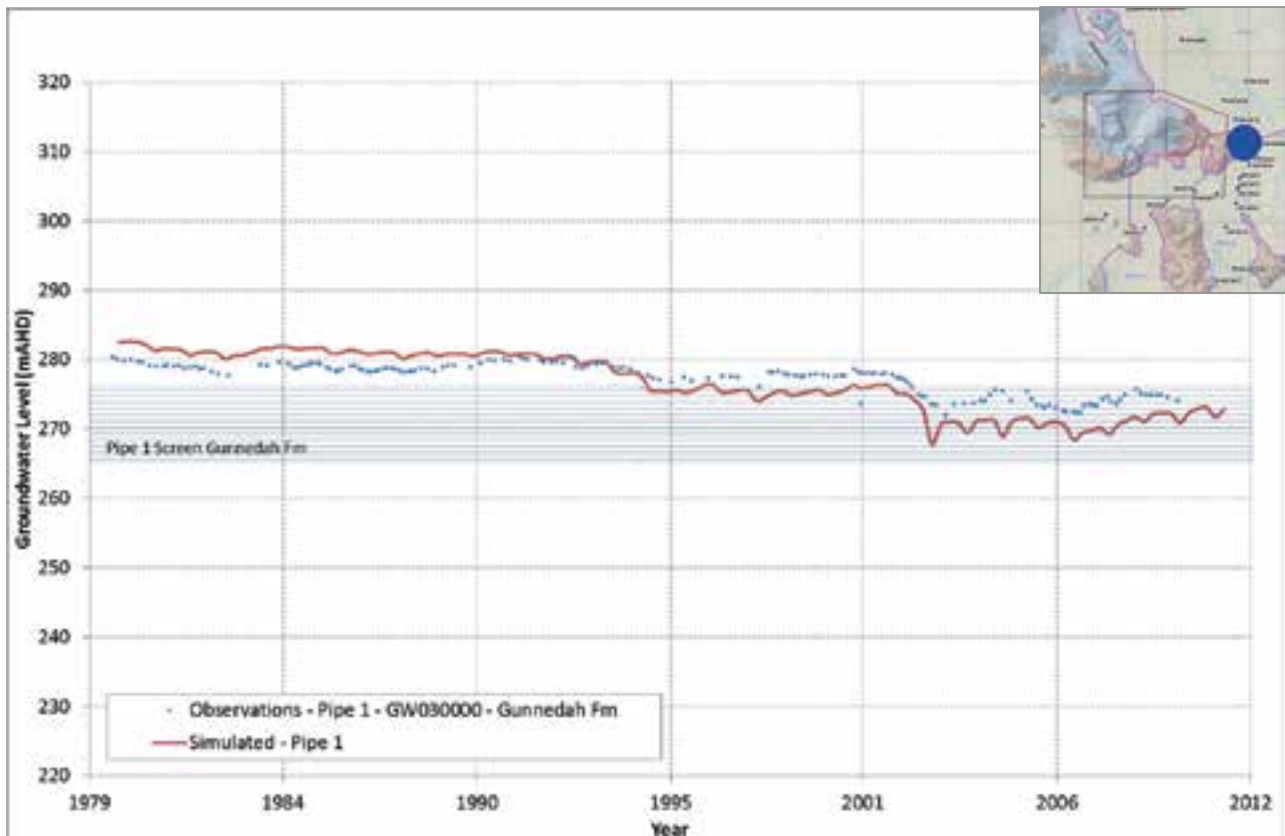


Figure 9.25: Calibration Hydrograph – GW030000

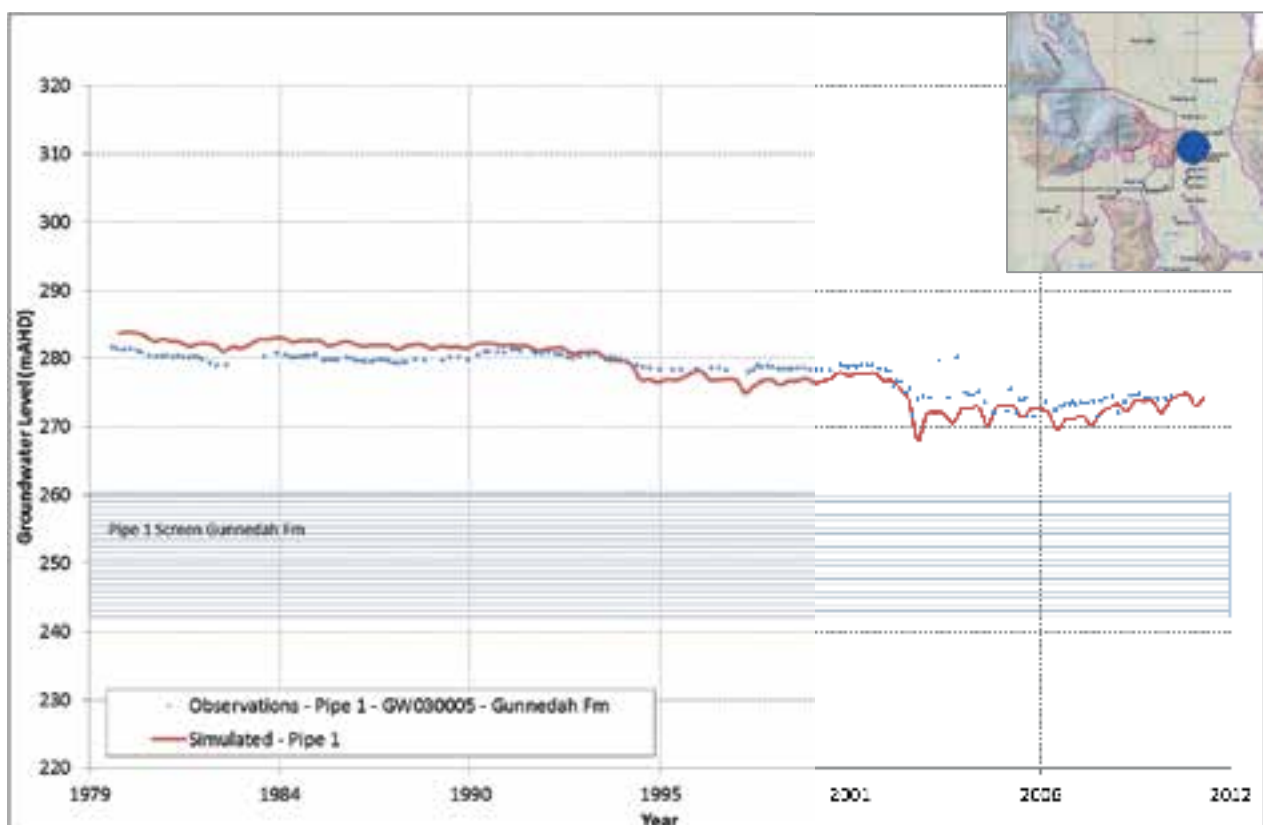


Figure 9.26: Calibration Hydrograph – GW030005

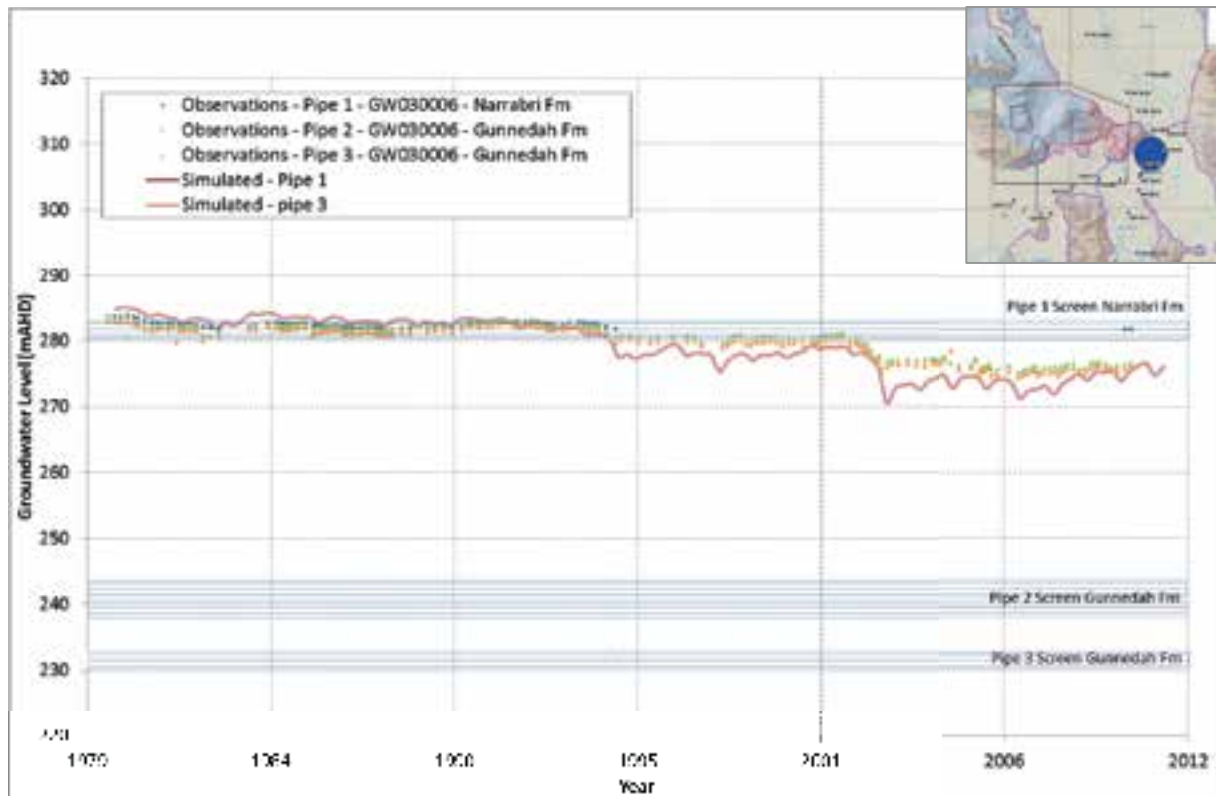


Figure 9.27: Calibration Hydrograph – GW030006

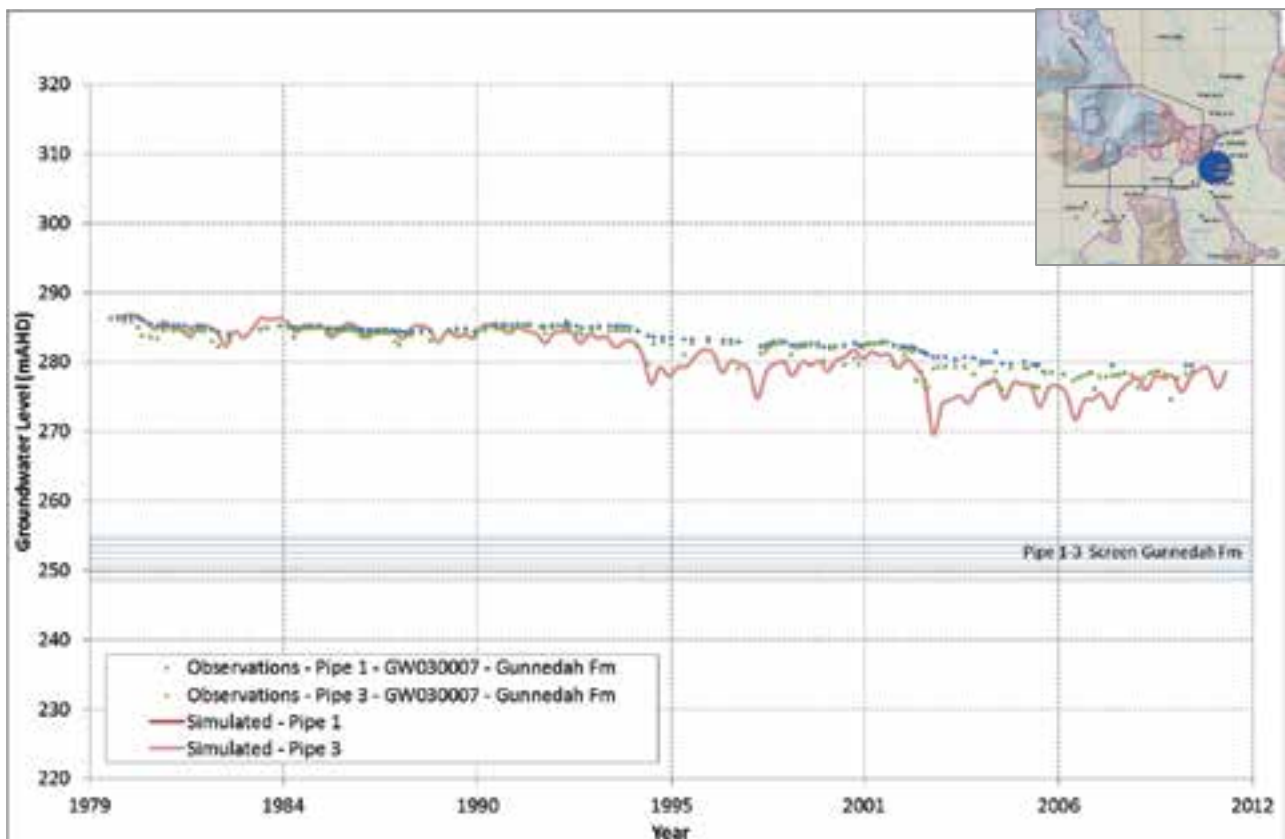


Figure 9.28: Calibration Hydrograph – GW030007

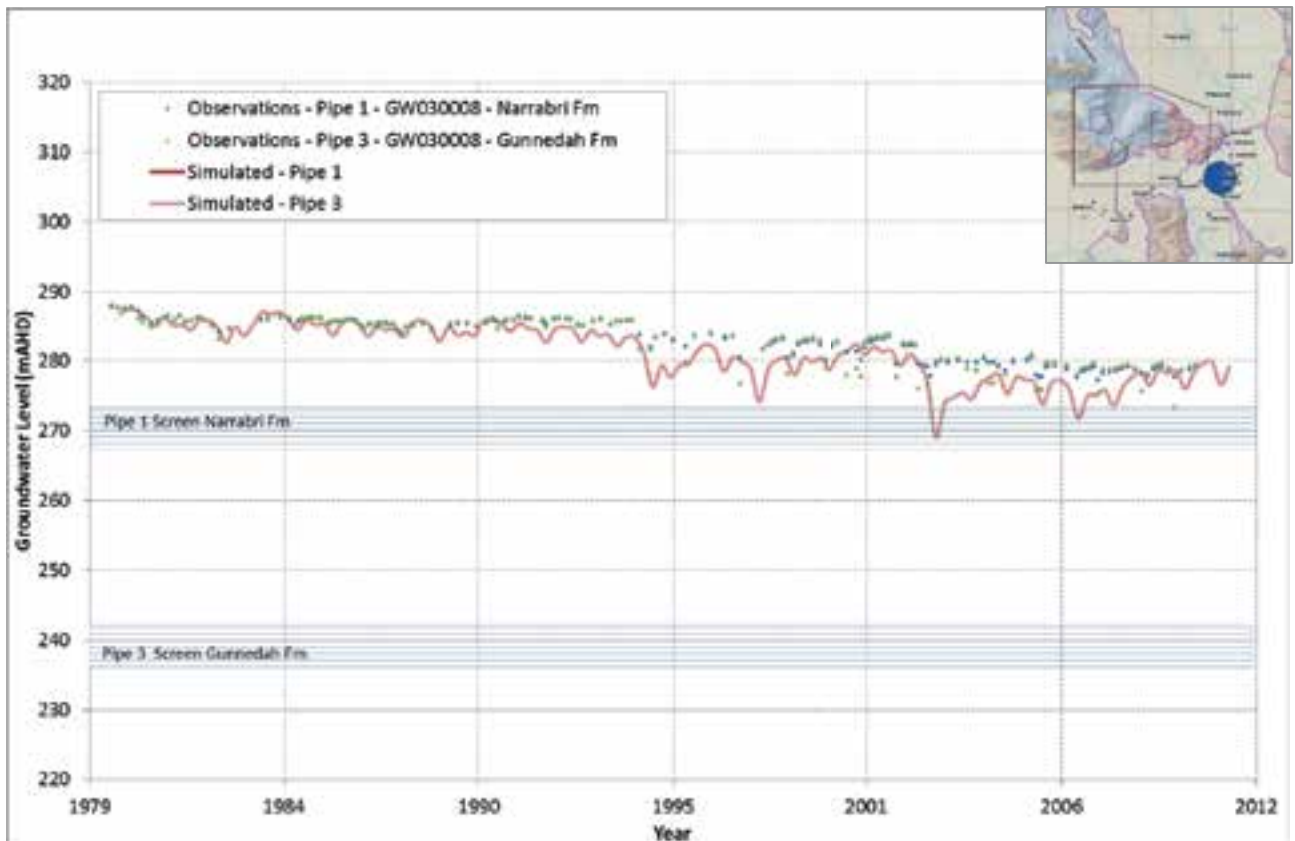


Figure 9.29: Calibration Hydrograph – GW030008

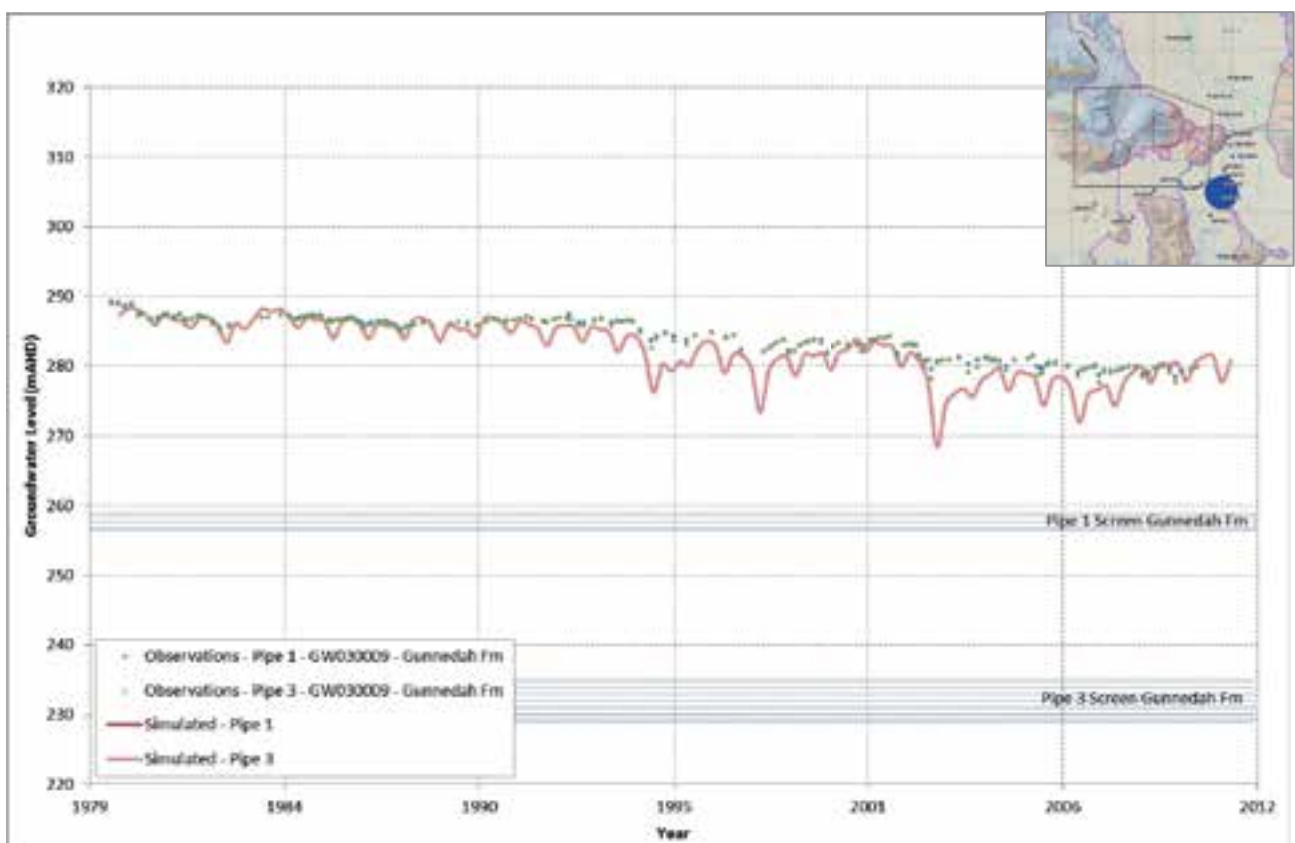


Figure 9.30: Calibration Hydrograph – GW030009

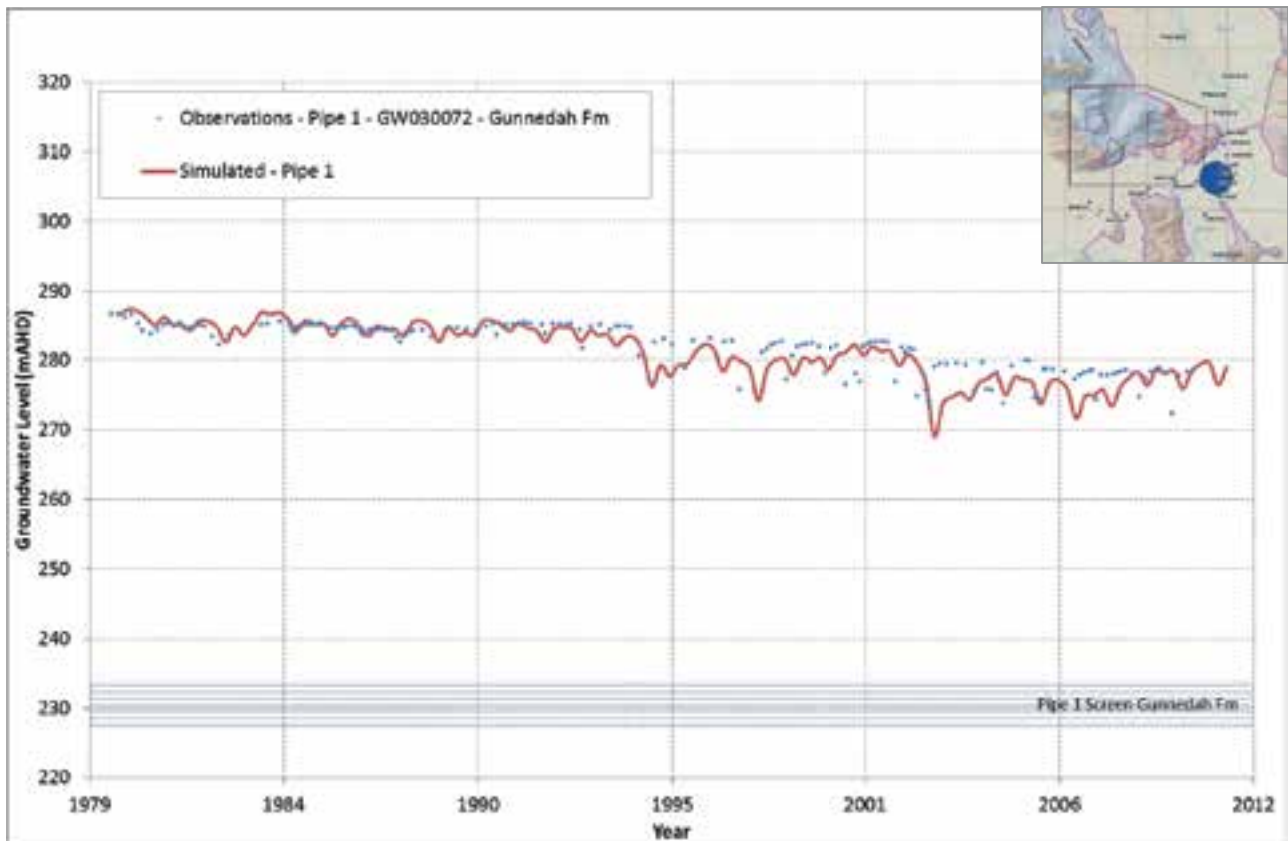


Figure 9.31: Calibration Hydrograph – GW030072

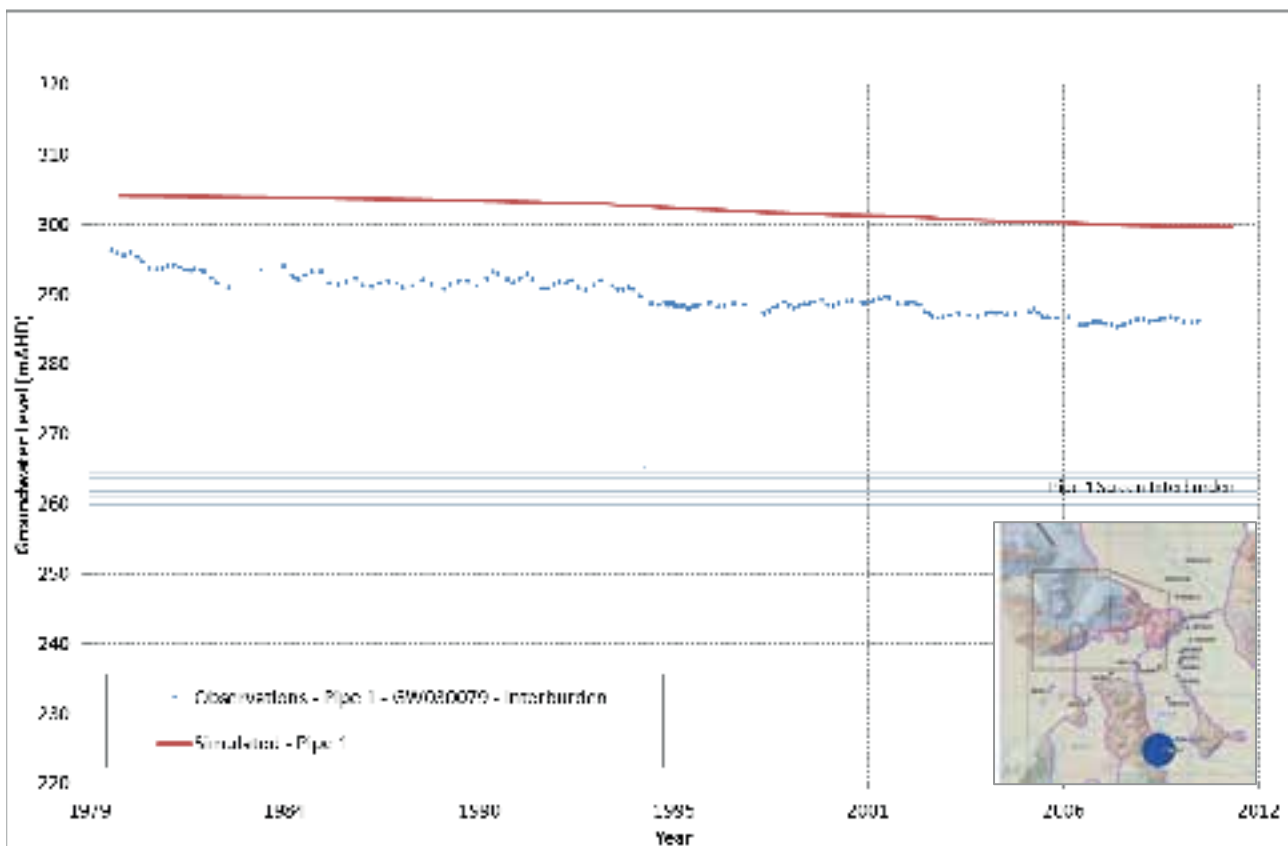


Figure 9.32: Calibration Hydrograph – GW030079

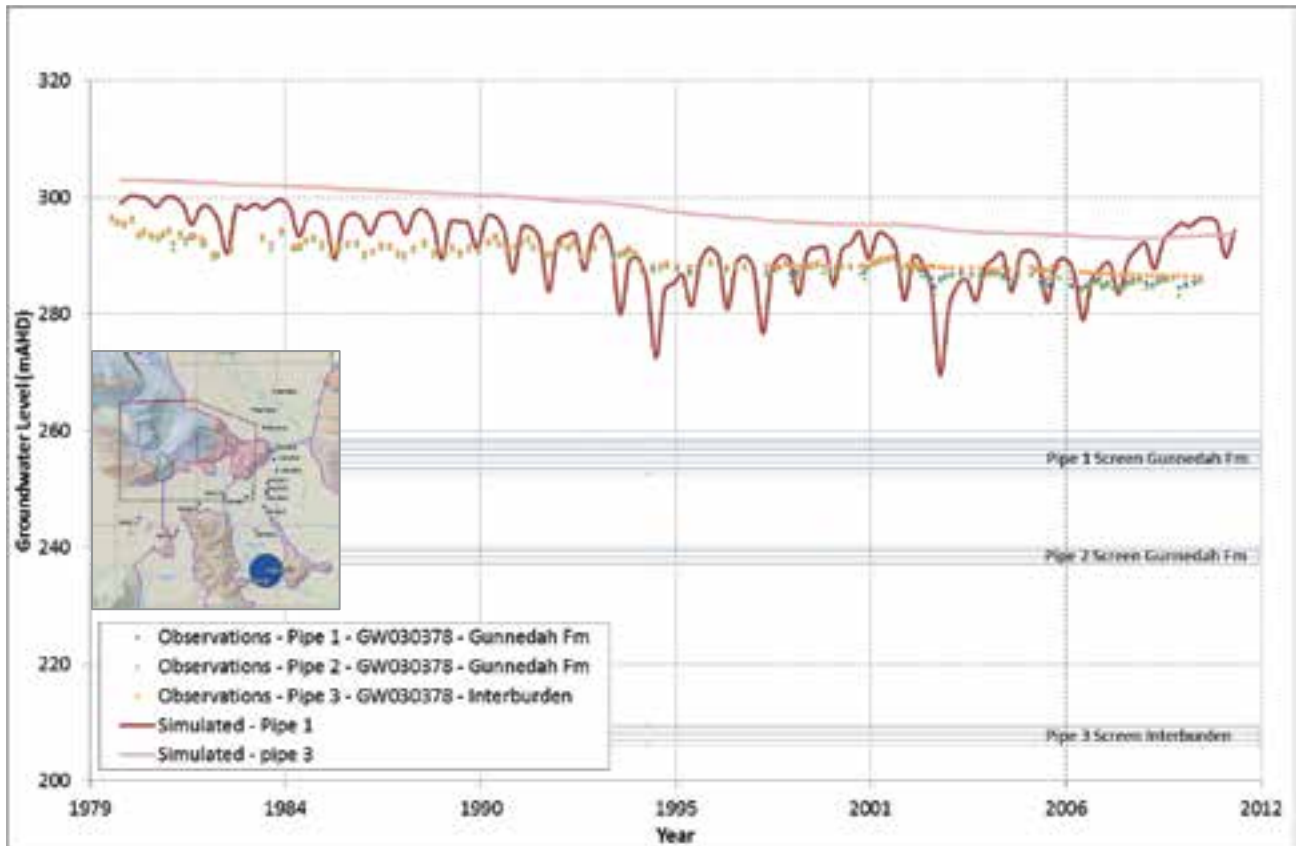


Figure 9.33: Calibration Hydrograph – GW030378

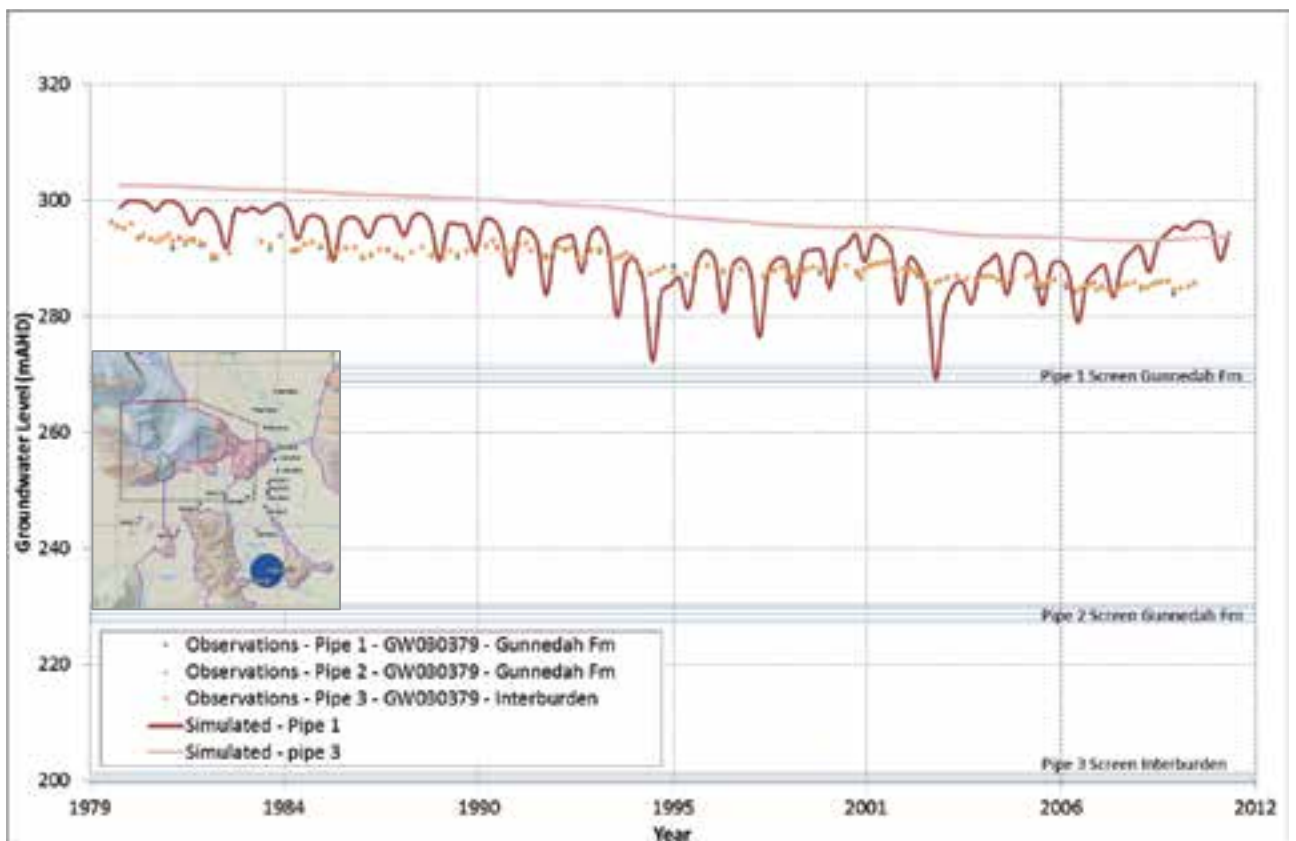


Figure 9.34: Calibration Hydrograph – GW030379

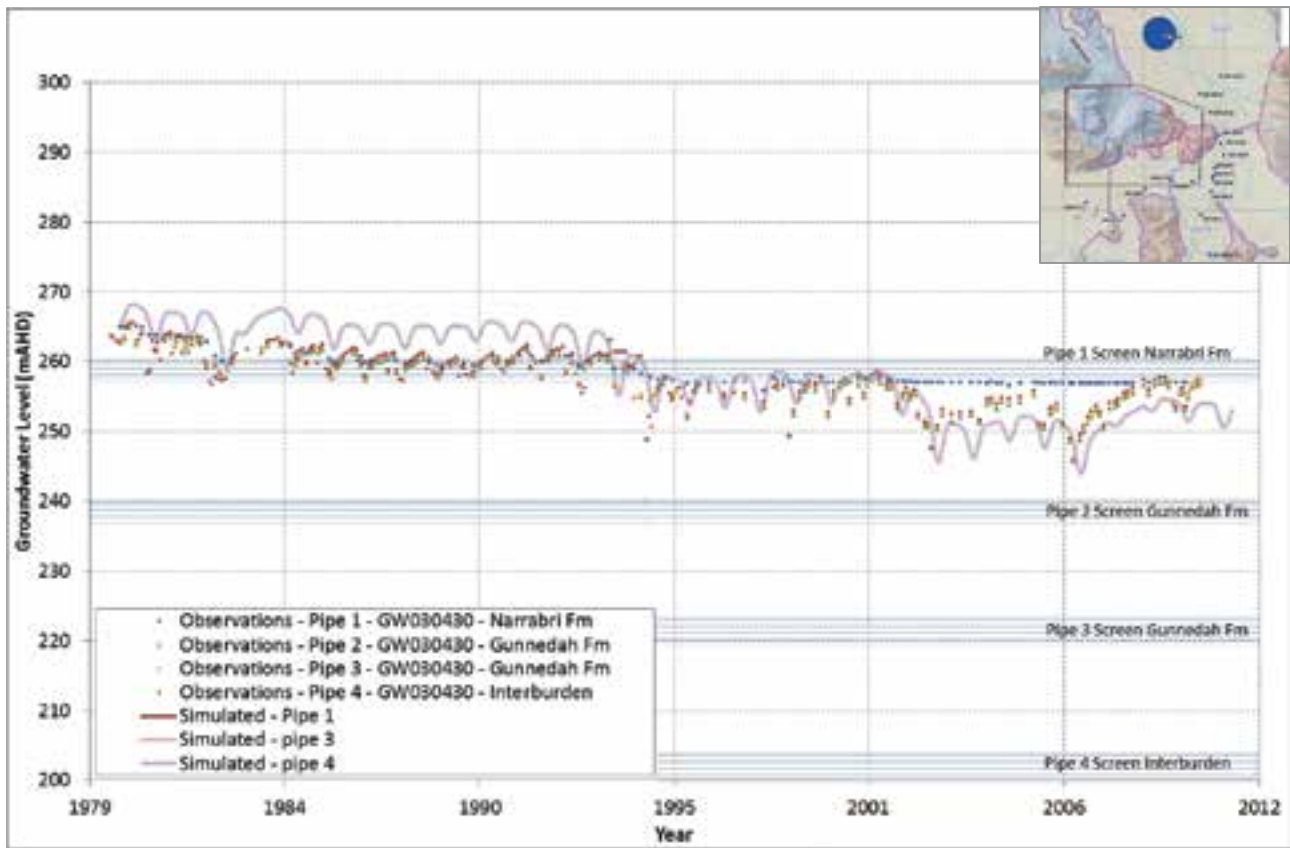


Figure 9.35: Calibration Hydrograph – GW030430

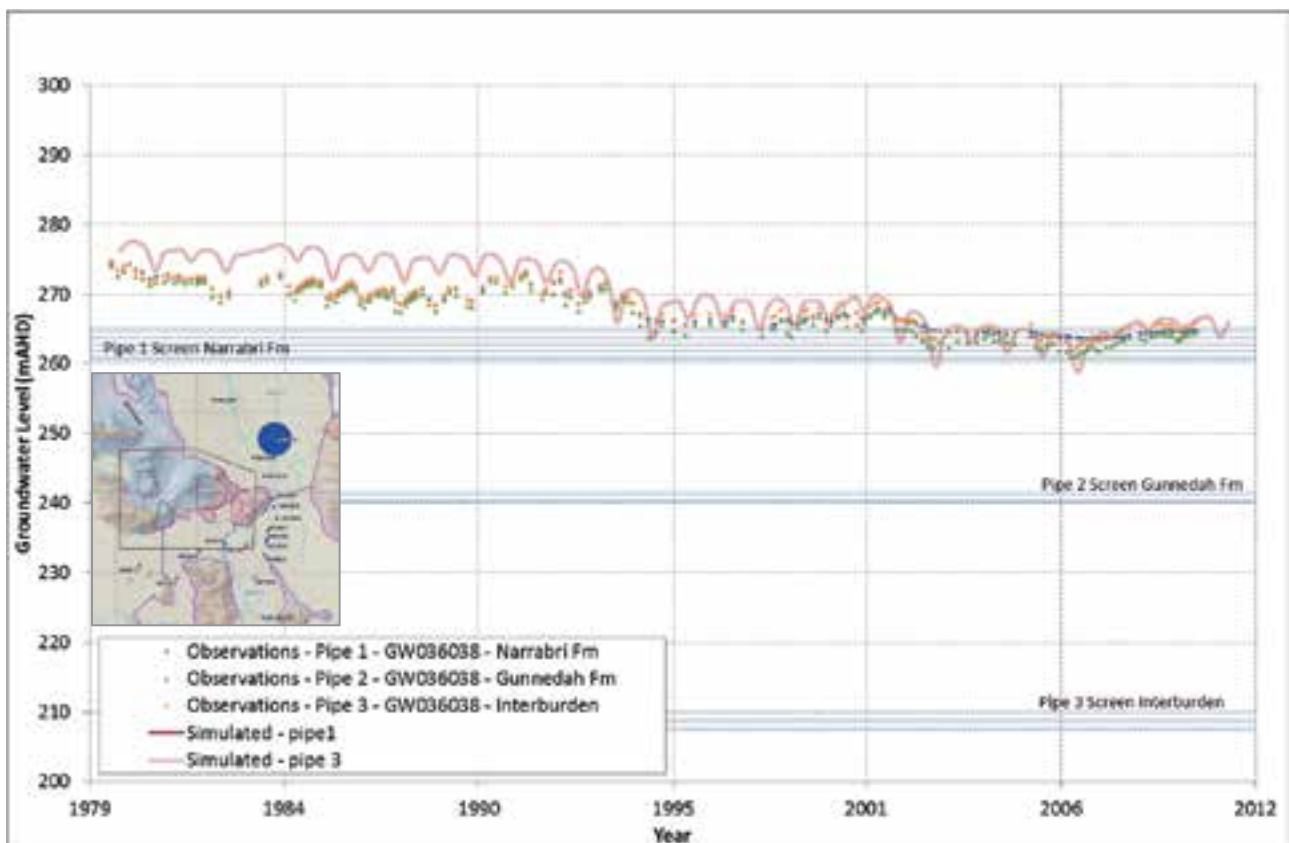


Figure 9.36: Calibration Hydrograph – GW036038

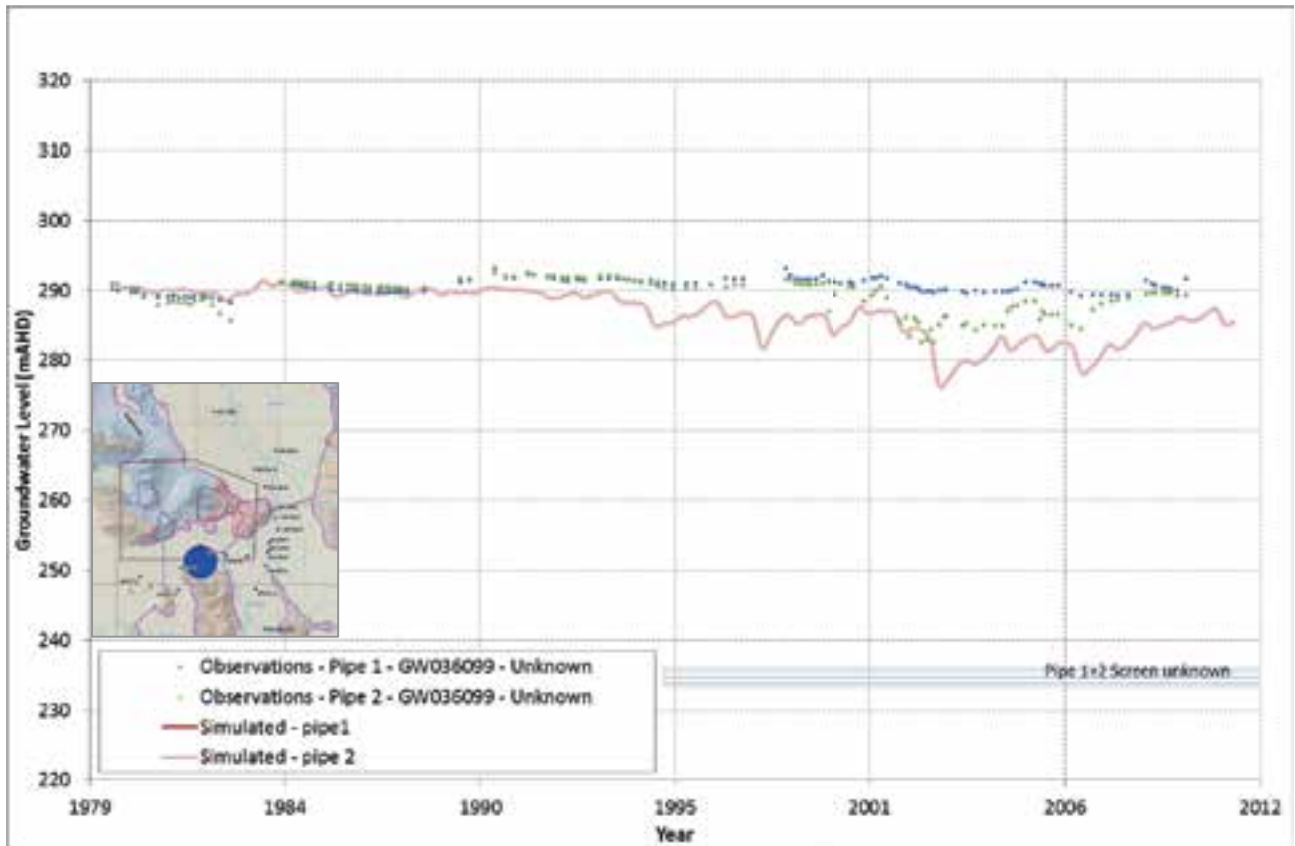


Figure 9.37: Calibration Hydrograph – GW036099

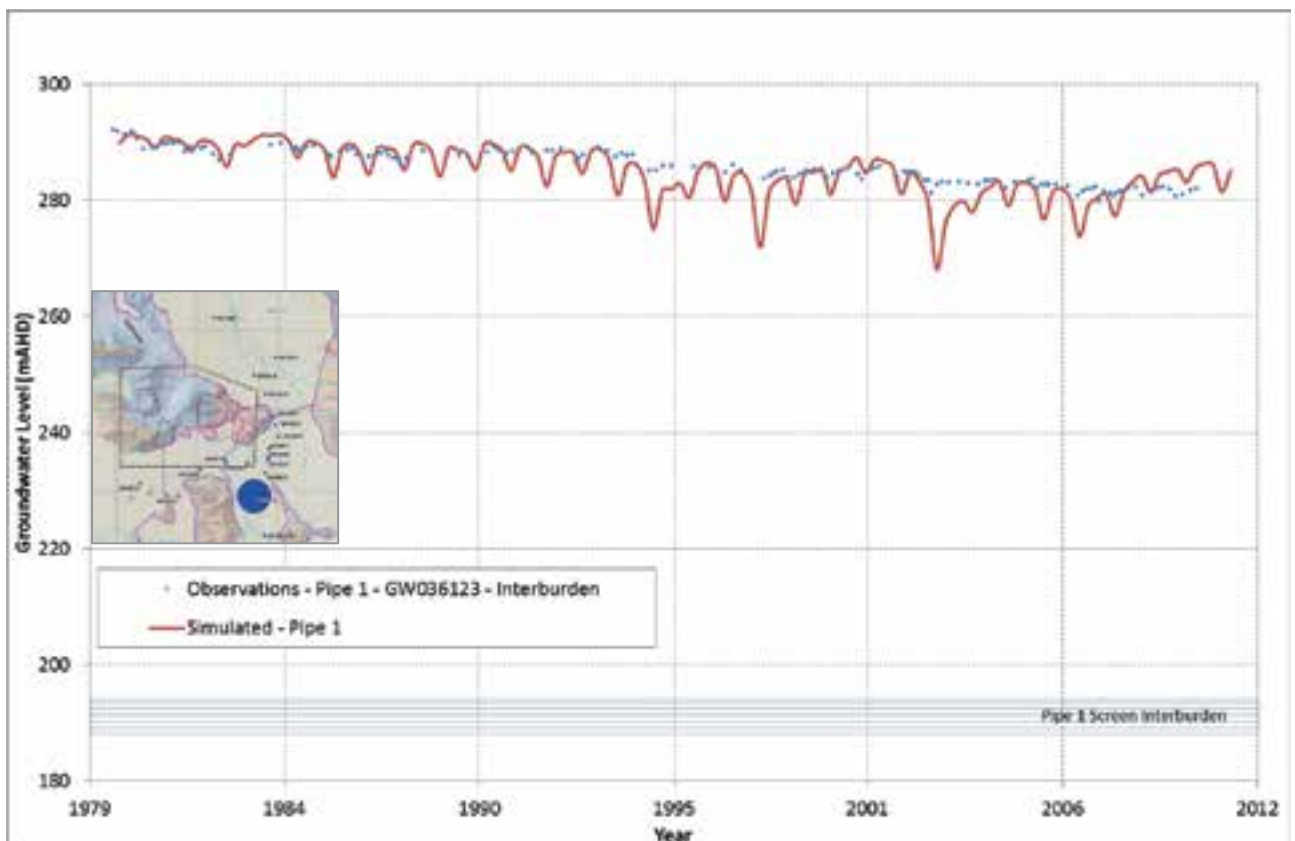


Figure 9.38: Calibration Hydrograph – GW036123

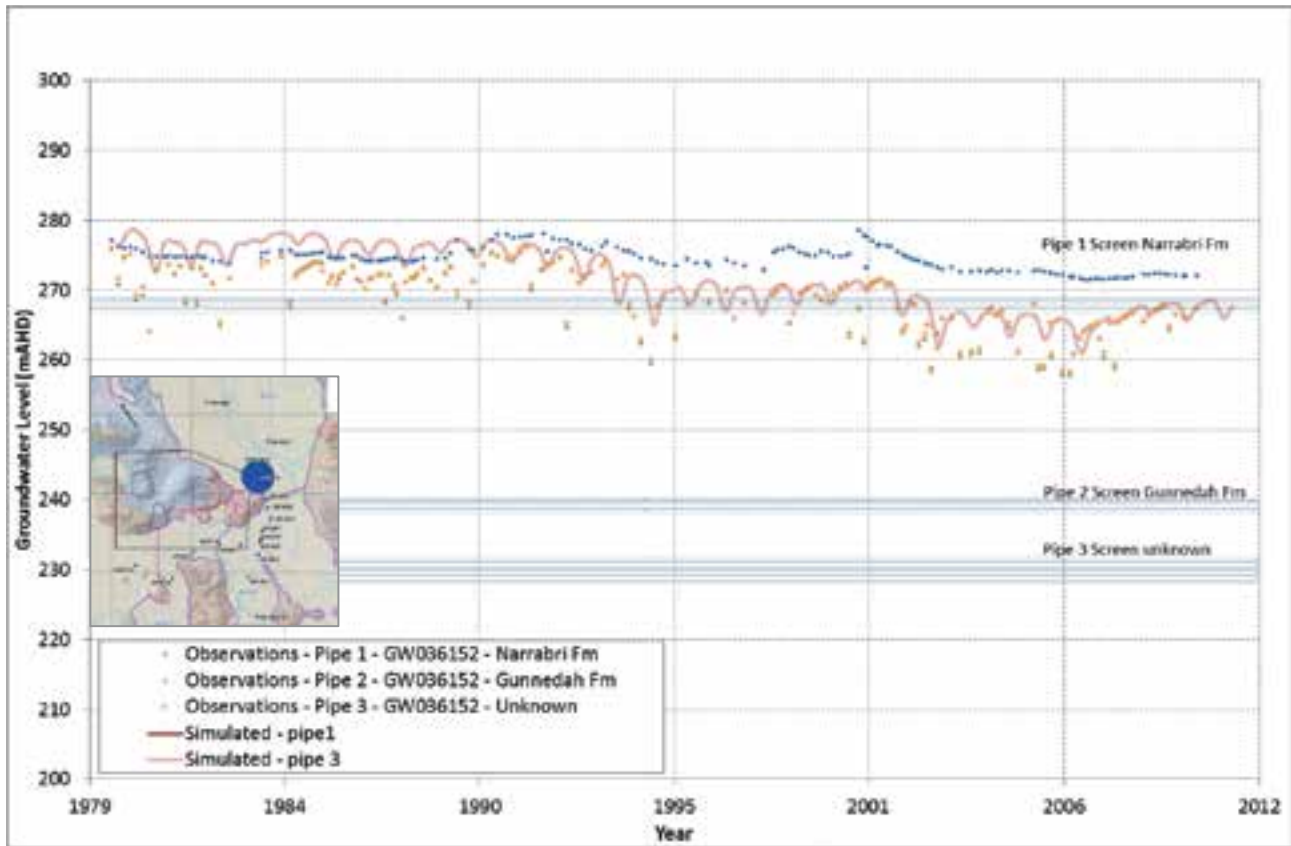


Figure 9.39: Calibration Hydrograph – GW036152

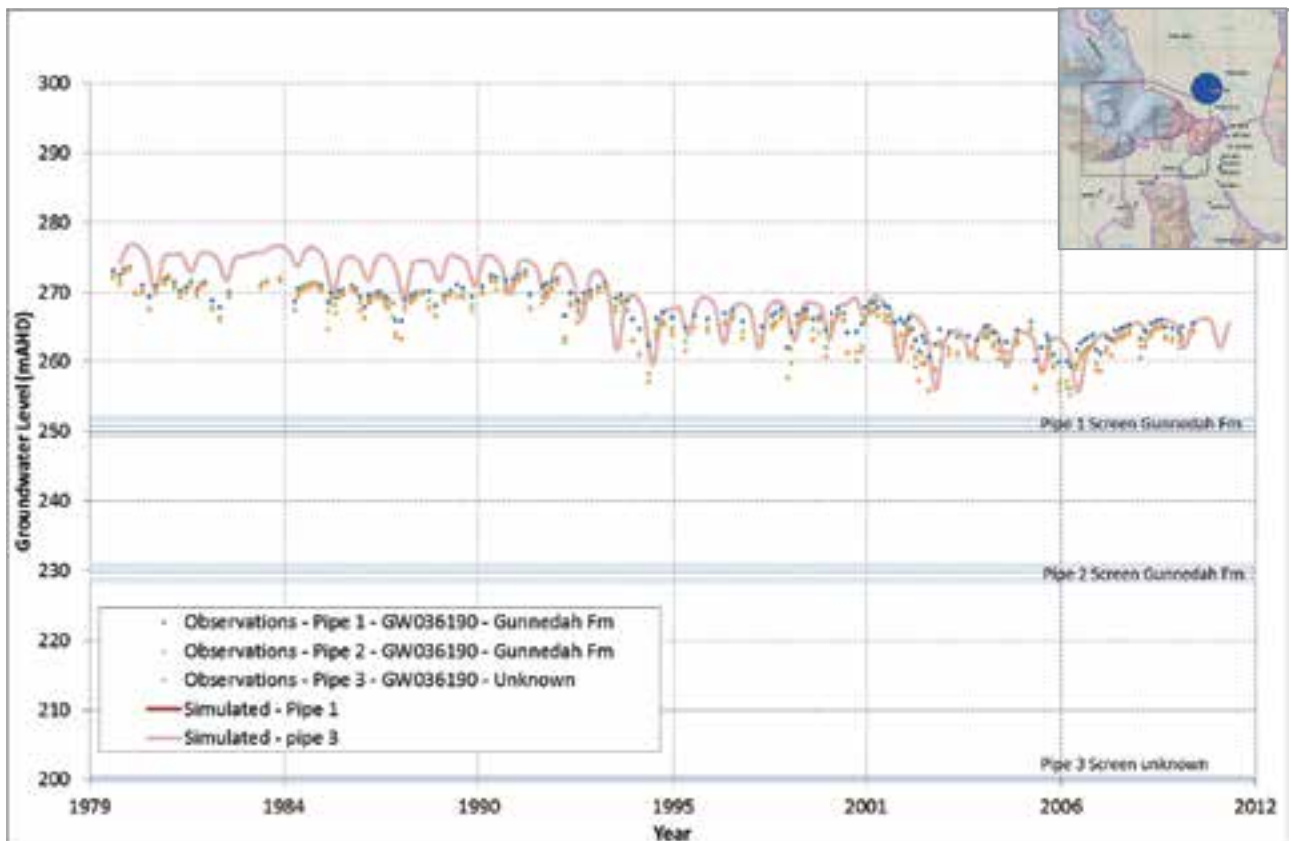


Figure 9.40: Calibration Hydrograph – GW036190

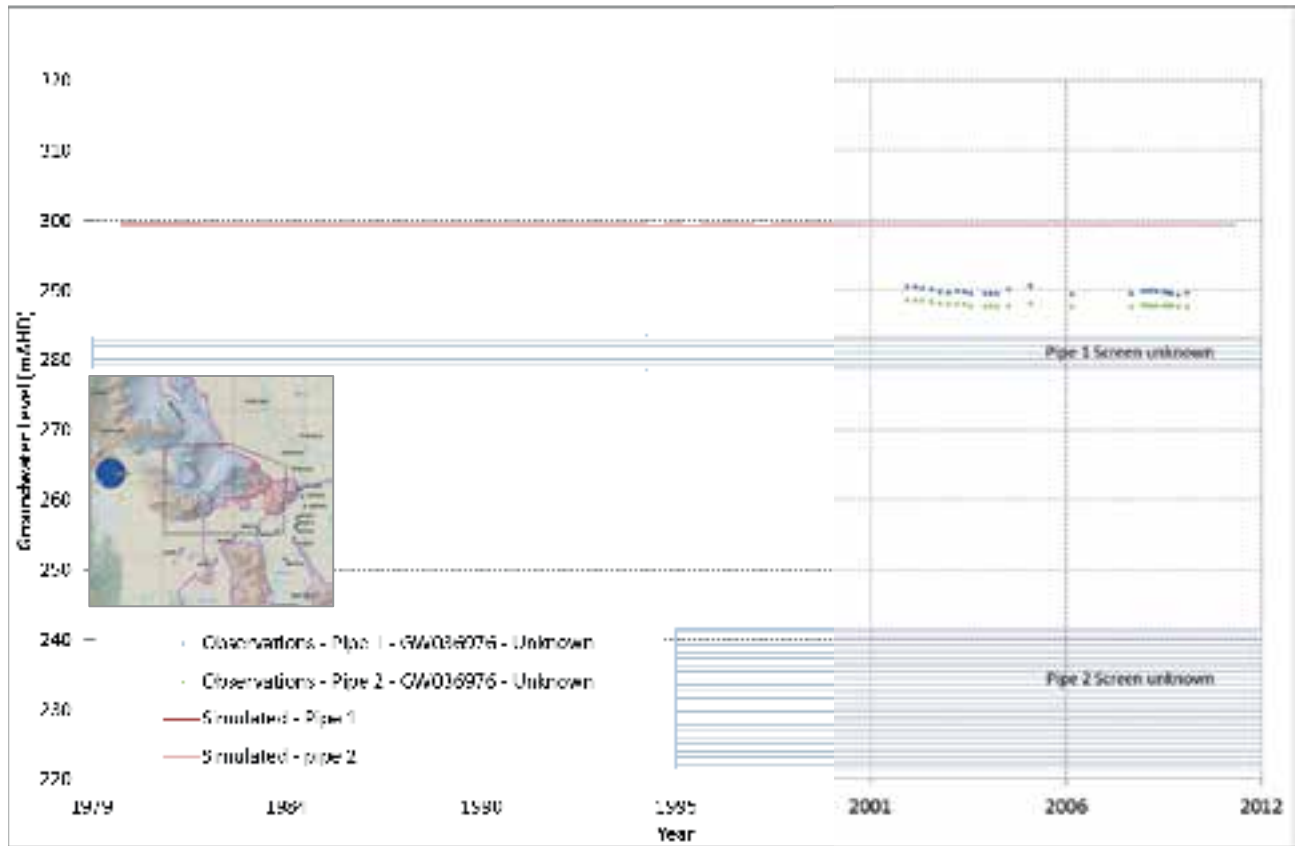


Figure 9.41: Calibration Hydrograph – GW036976

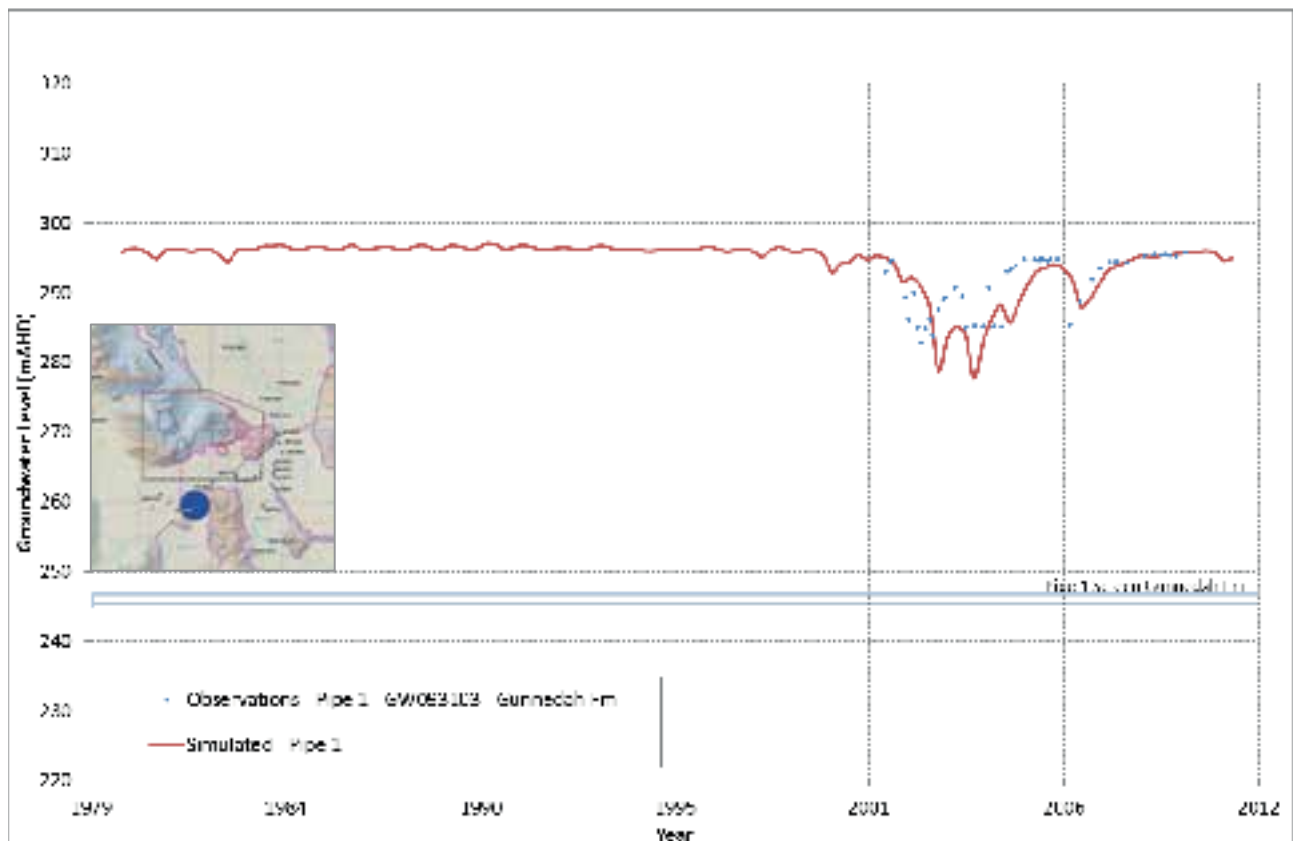


Figure 9.42: Calibration Hydrograph – GW093103

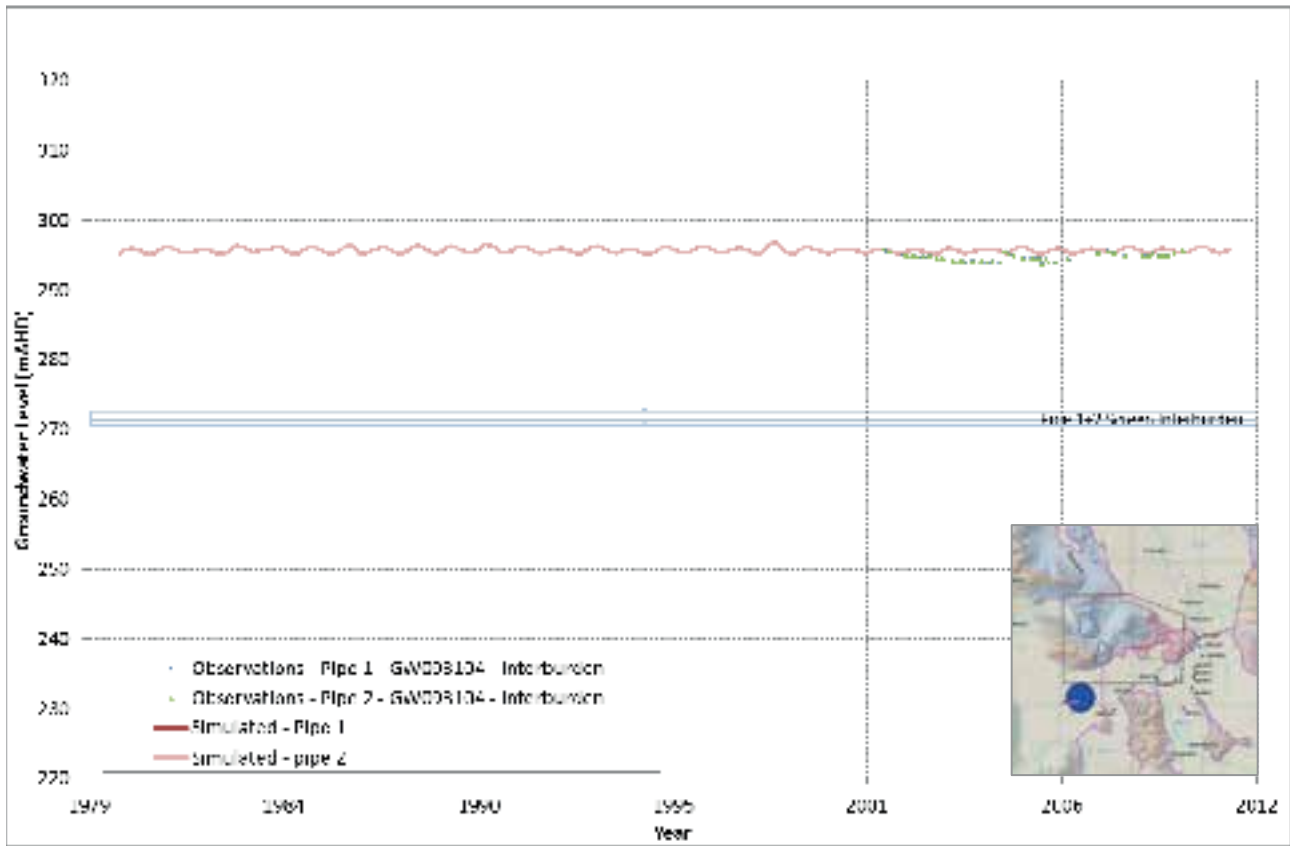


Figure 9.43: Calibration Hydrograph – GW093104

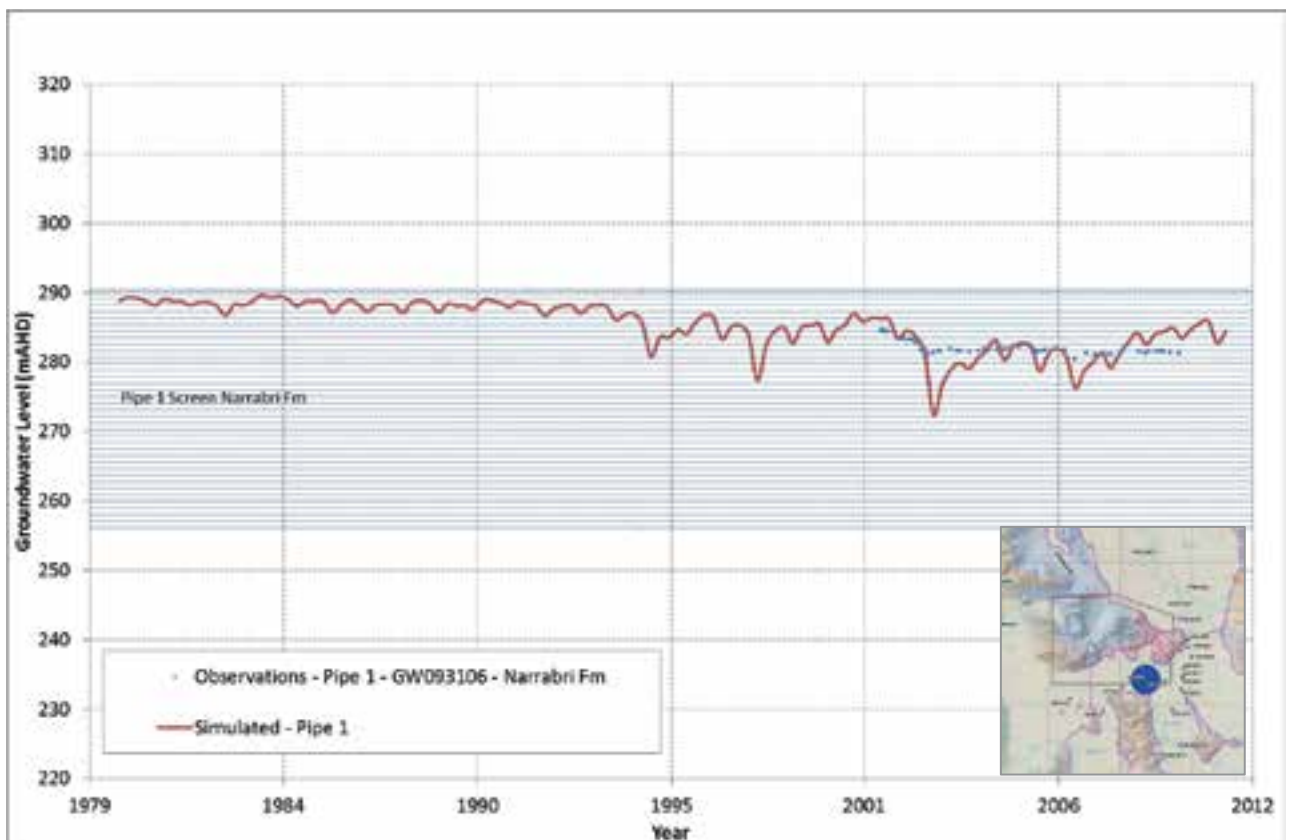


Figure 9.44: Calibration Hydrograph – GW093106

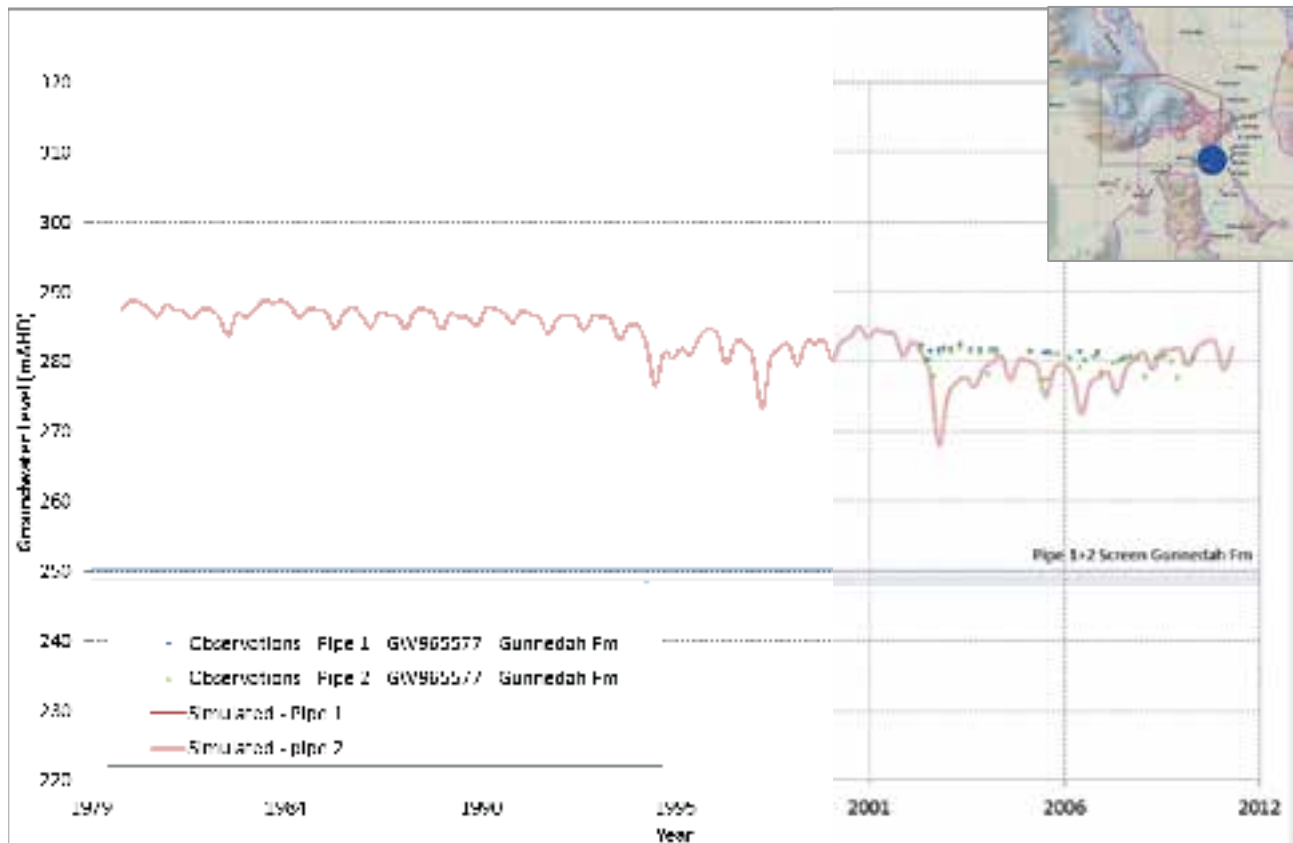
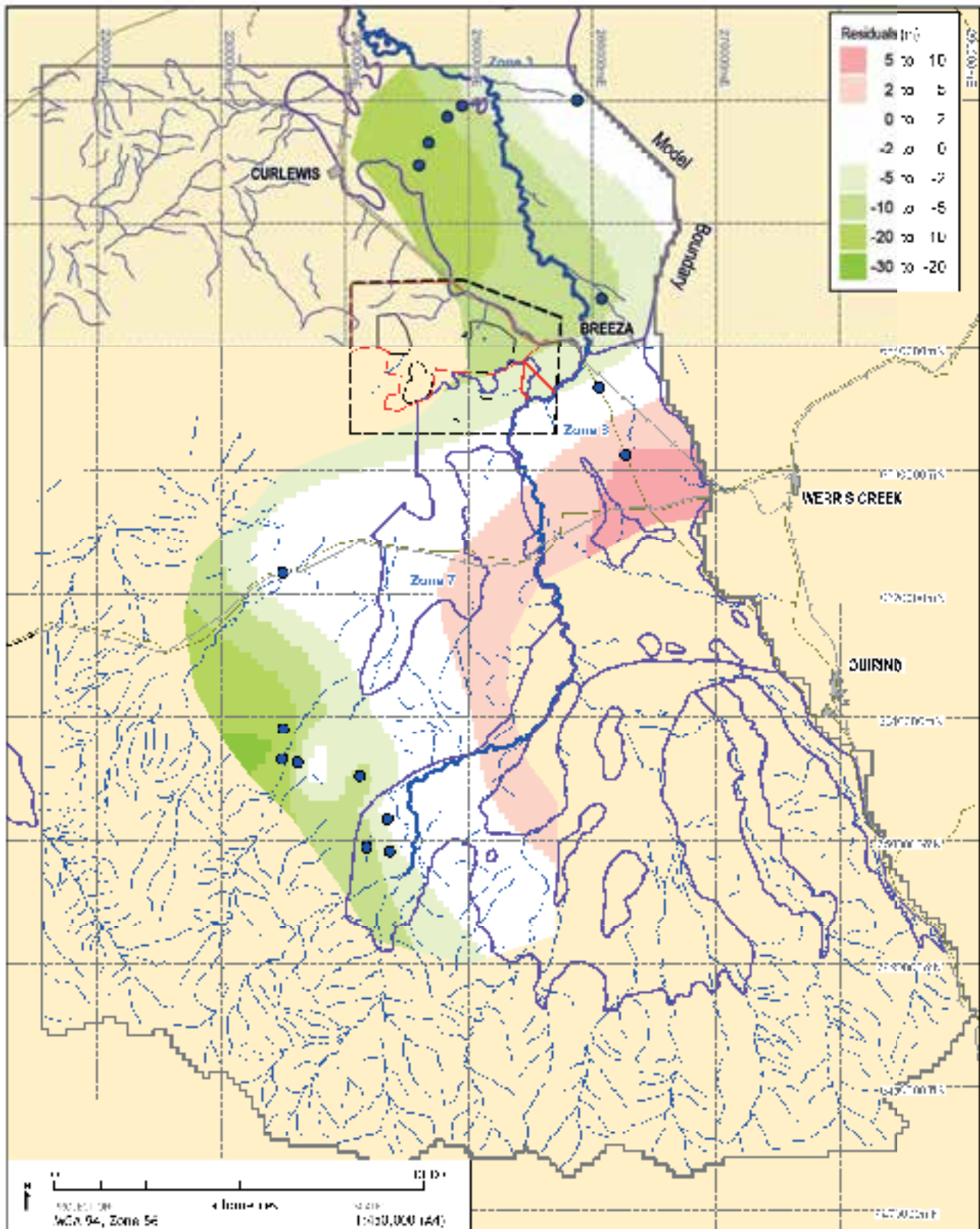


Figure 9.45: Calibration Hydrograph – GW0965577

Spatial Residuals Distribution

Figure 9.46 to Figure 9.48 presents the residuals (observed water levels minus simulated water levels) for the transient simulation at 10-year intervals. Areas of red represent regions where the model under-predicted groundwater levels, and green areas shows over-predictions.

Figure 9.46 to Figure 9.48 suggests that groundwater calibration is best at approximately halfway through the calibration period (~ Year 2000). Residuals increase towards the end of the calibration period (~2011) in clear areas that are directly related to the contribution to error, as discussed earlier in this Section. Areas of over-prediction occur at the Mooki River/Quirindi Creek confluence, suggesting that too much water is entering the groundwater system at this location, or that pumping records under represent the extraction from bores. Areas of under-prediction, such as the eastern margin of Quirindi Creek, could be due to too little groundwater entering the system, combined with the inadequacy of the hydraulic properties of the Gunnedah Formation to provide the extracted volumes to the well locations in the area.



Legend

- H-1234
- Township Mining Area
- Groundwater Management Zone
- Observation Bore
- Project Boundary
- Model River
- Drainage Line / Creek

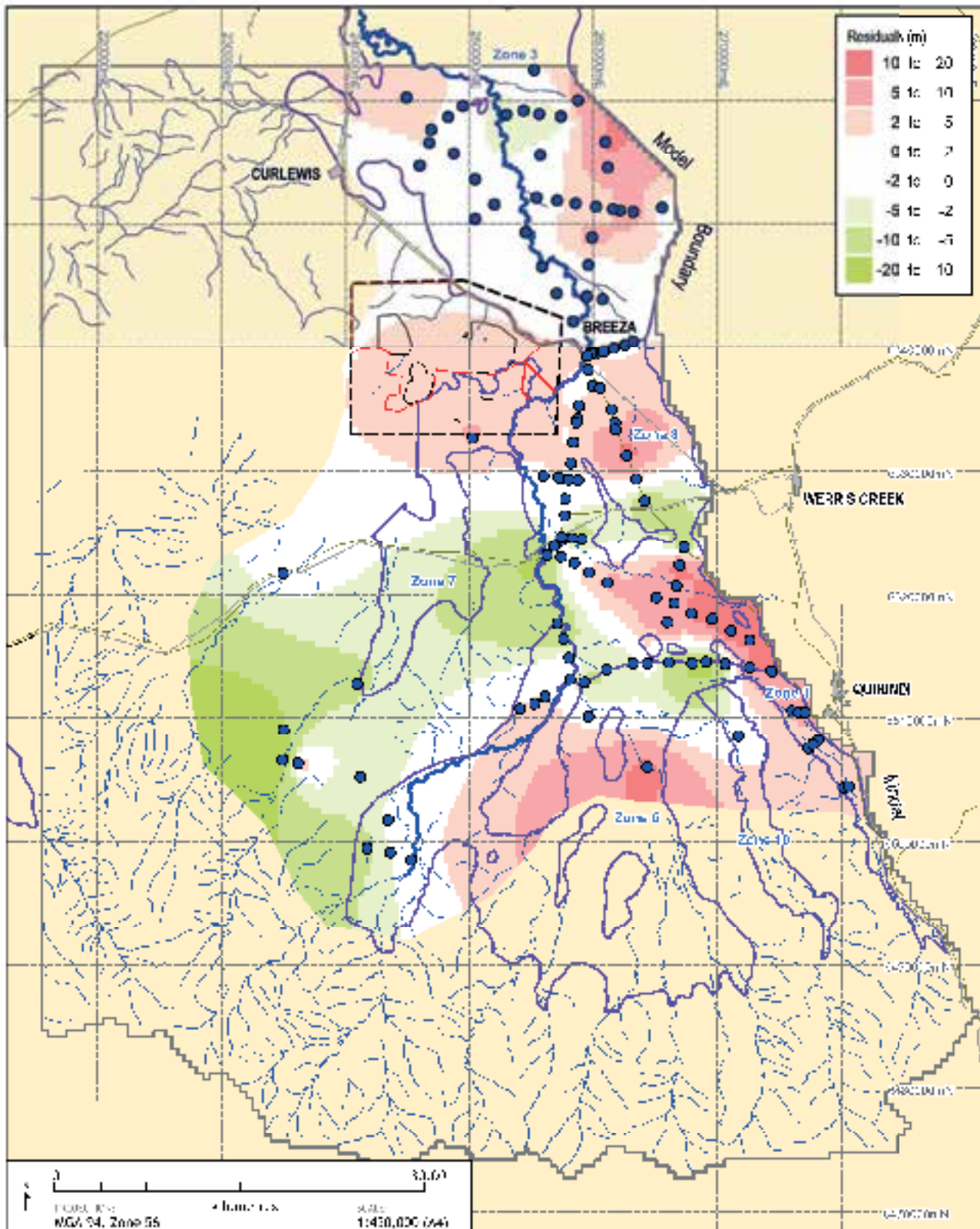
Watermark Coal Project (G157)
Groundwater Assessment

Mid-1990 Observation Residuals



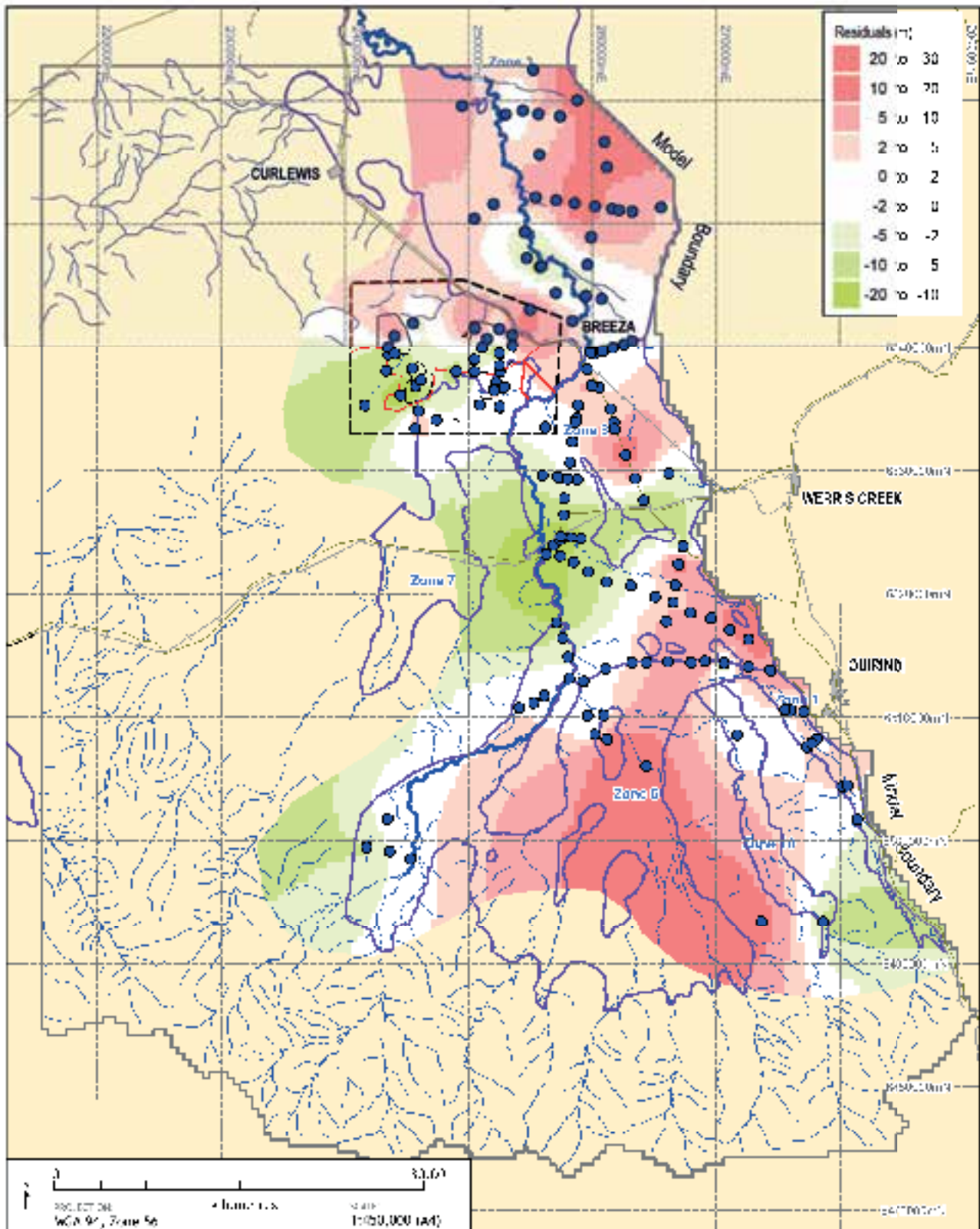
DATE:
18/10/2012

TIME:
9.46



Legend

- 1:1000
- 1:2500
- 1:5000
- 1:10000
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- 1:40000
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- 1:2560000
- 1:5120000
- 1:10240000
- 1:20480000
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Legend

Watermark Coal Project (G1517)
 Groundwater Assessment

Mid-2010 Observation Residuals



DATE:
 18/10/2012

TIME:
 9.48

9.2.8 Hydraulic Head Statistics

Regional Calibration

Figure 9.49 compares the observed and simulated groundwater levels from the regional transient calibration (January 1980 to June 2011).

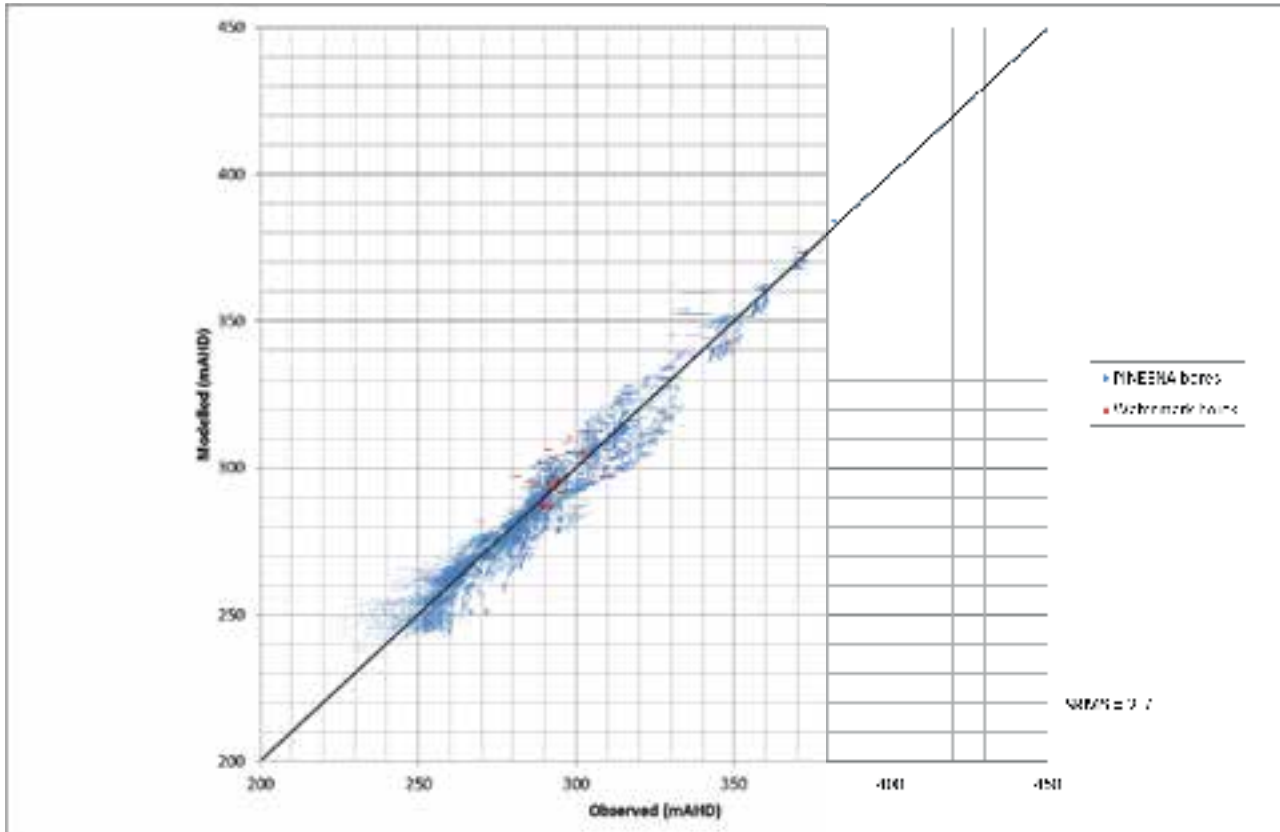


Figure 9.49: Scattergram showing Observed and Modelled Heads – Regional Transient Data

Based on the regional nature of the model and the irregular spacing of the data points, it is considered that the model results represent a very good calibration match for both the PINEENA and Shenhua Watermark bores, which are primarily located in the Permian strata.

Table 9.4 presents a summary of the transient model calibration statistics for all data, as outlined by MDBC (2000).

**Table 9.4: TRANSIENT MODEL STATISTICS - ALL**

Calibration Performance Measure	Value
Sum of Residuals (SR) (m)	18258.01
Mean Sum of Residuals (MSR) (m)	0.41
Scaled Mean Sum of Residuals (SMSR) (%)	0.19
Sum of Squares (SSQ) (m ²)	1574830
Mean Sum of Squares (MSSQ) (m ²)	35.6
Root Mean Square (RMS) (m)	5.97
Root Mean Fraction Square (RMFS) (%)	0.04
Scaled RMFS (SRMFS) (%)	0.06
Scaled RMS (SRMS) (%)	2.7

The RMS error, which is a statistic similar to standard deviation, is a measure of the variability in the observed versus simulated water level records. The RMS error calculated for the unweighted calibrated transient model results was 5.97 m. The unweighted RMS assumes each bore contributes equally to the RMS error, whereas a weighted RMS error reduces the influence of bores that are not considered to supply reliable water level records.

The ratio of RMS to the total head change across the calibration points (219.34 m) indicated a SRMS of 2.7%. This indicates a very good calibration and is within the MDBC (2000) and project target of 5% or less.

It is important to note that the calibration is not unique and a similar level of fit between the observed and predicted groundwater levels could be achieved with a combination of other model parameters. The issue of non-uniqueness is explored in the sensitivity and uncertainty analysis (refer to Section 11.0).

Project Calibration

Figure 9.50 presents the observed and simulated groundwater levels for the Shenhua Watermark area for the period June 2009 to June 2011.

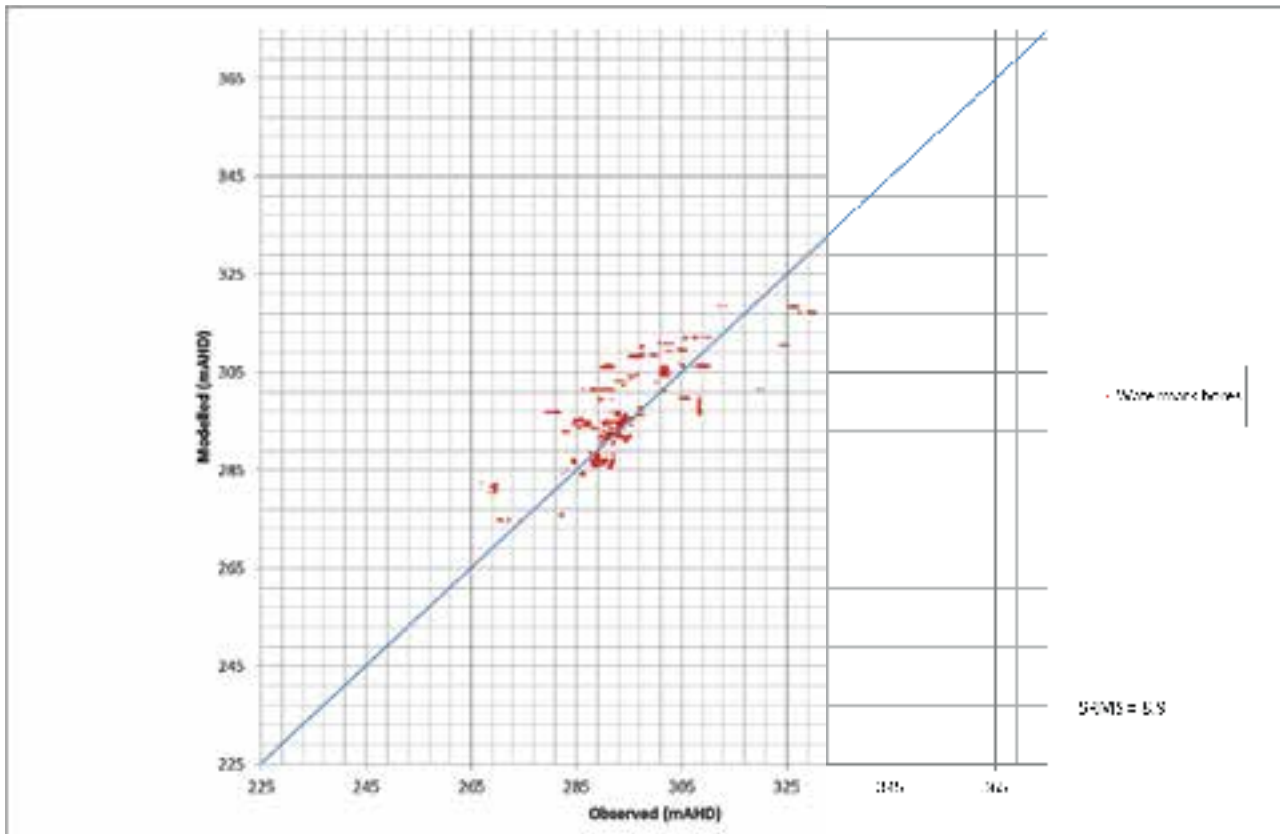


Figure 9.50: Scattergram - Observed and Modelled Heads – Watermark Transient Data

Generally the model reproduces the observed water groundwater levels well; however, there are a number of bores where the model over-predicts the groundwater levels with muted or flat water levels responses. In general, the predicted water levels for the fractured dominated bedrock system do not match as closely as the regional bores, which are primarily screened in the porous Quaternary alluvium. This is a common outcome, and it is never possible to obtain the same level of match for a heterogeneous fractured rock system than can be obtained for more porous and homogenous alluvium.

Table 9.5 presents a summary of the transient model calibration statistics for the Project observation data, as outlined by MDBC (2000).

**Table 9.5: TRANSIENT MODEL STATISTICS - PROJECT**

Calibration Performance Measure	Value
Sum of Residuals (SR) (m)	-2337.4
Mean Sum of Residuals (MSR) (m)	-0.9
Scaled Mean Sum of Residuals (SMSR) (%)	-1.4
Sum of Squares (SSQ) (m ²)	84094.8
Mean Sum of Squares (MSSQ) (m ²)	32.2
Root Mean Square (RMS) (m)	5.68
Root Mean Fraction Square (RMFS) (%)	0.04
Scaled RMFS (SRMFS) (%)	0.18
Scaled RMS (SRMS) (%)	8.9

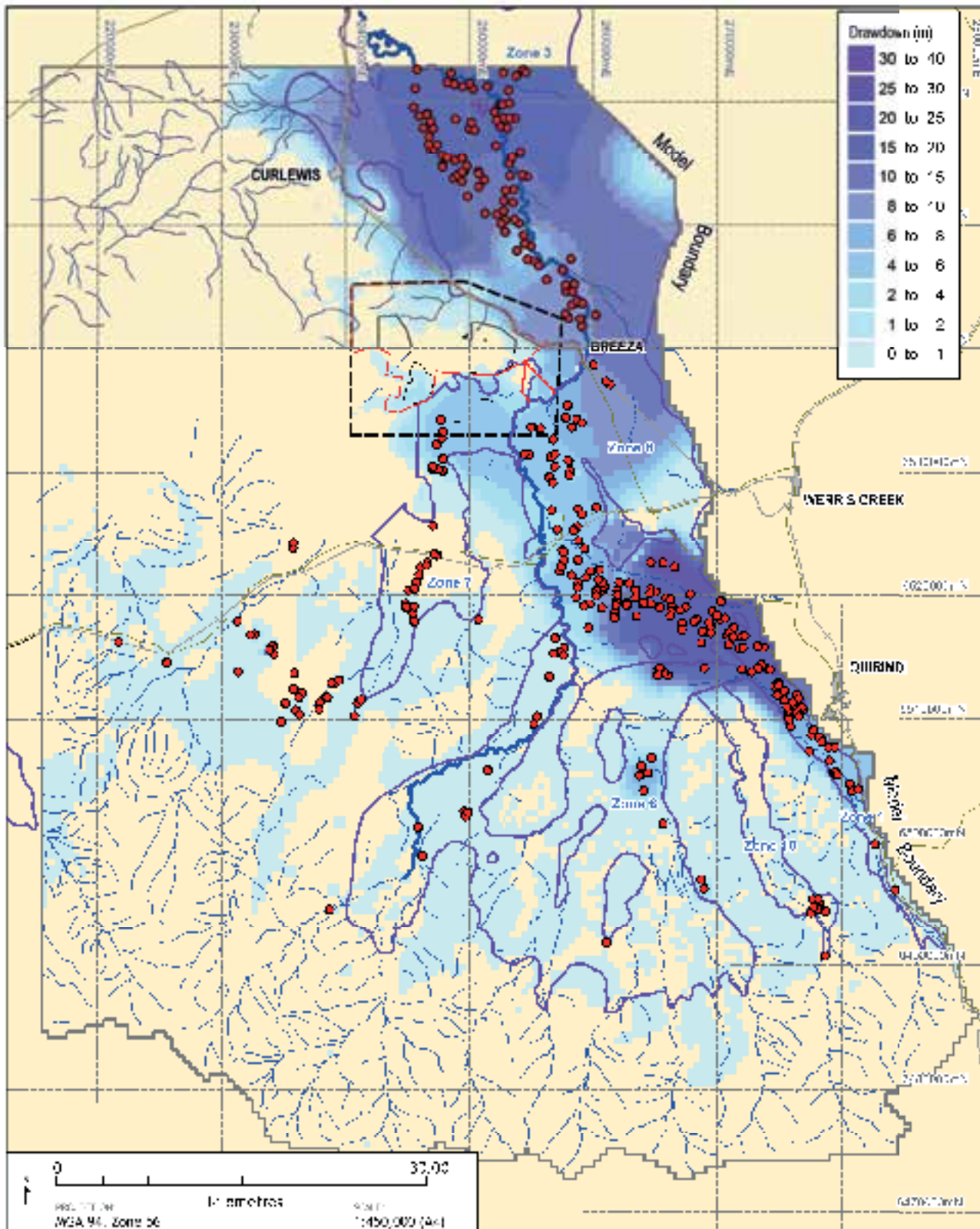
The RMS error calculated for the unweighted calibrated transient model results was 5.68 m. The ratio of RMS to the total head change across the calibration points (63.57 m) indicated a SRMS of 8.9%. This indicates a moderate calibration and is above the MDBC (2000) suggested target of 5% or less. However, for fractured rock systems a SRMS target of less than 10% is generally considered acceptable which was achieved.

9.2.9 Groundwater Drawdown

The groundwater model reproduces the observed decline in groundwater levels due to the historic extraction of groundwater from the Gunnedah and Narrabri Formations. Figure 9.51 illustrates the model simulated decline in water levels between January 1980 to mid-2011. The simulated decline in water levels is accurate to approximately 1 m to 2 m in areas where residuals are low, and up to 10 m where residuals were high and calibration accuracy was low (refer to Section 9.2.7 and Figure 9.46 to Figure 9.48).

The residuals are relatively low, between 0 m and 5 m in the proposed Eastern Mining Area, where the first activity is proposed.

Regional groundwater drawdown correlates well with groundwater extraction rates and pumping bore density (refer to Figure 7.11 and Figure 9.6). Drawdown is highest along Quirindi Creek (up to 20 m) and to the north of the Project, close to Gunnedah.



Legend

- 1:100,000
- Project Boundary
- Project Boundary
- Model
- Groundwater Management Zone
- Drainage Line / Creek
- Pumping Bore

Watermark Coal Project (G157)
Groundwater Assessment

Simulated Drawdown Prior to the
Project 1980-2011



DATE:
18/10/2012

7.51



9.2.10 Surface Water Connectivity

The simulated water levels provide an opportunity to examine zones where the river systems are 'losing' or 'gaining' water. A 'losing' river or creek loses water as it flows downstream. The water infiltrates into the ground recharging the local groundwater, because the water table is below the bottom of the river-bed. A gaining stream increases in water volume farther downstream as it gains water from the underlying aquifers.

The 'losing' or 'gaining' segments of the Mooki River and Quirindi Creek were determined by comparing the simulated water levels with the water levels set for the river systems using the river package.

Figure 9.52 demonstrates losing conditions in the Quirindi Creek showing a photograph of an area with flow going dry in a downstream area.



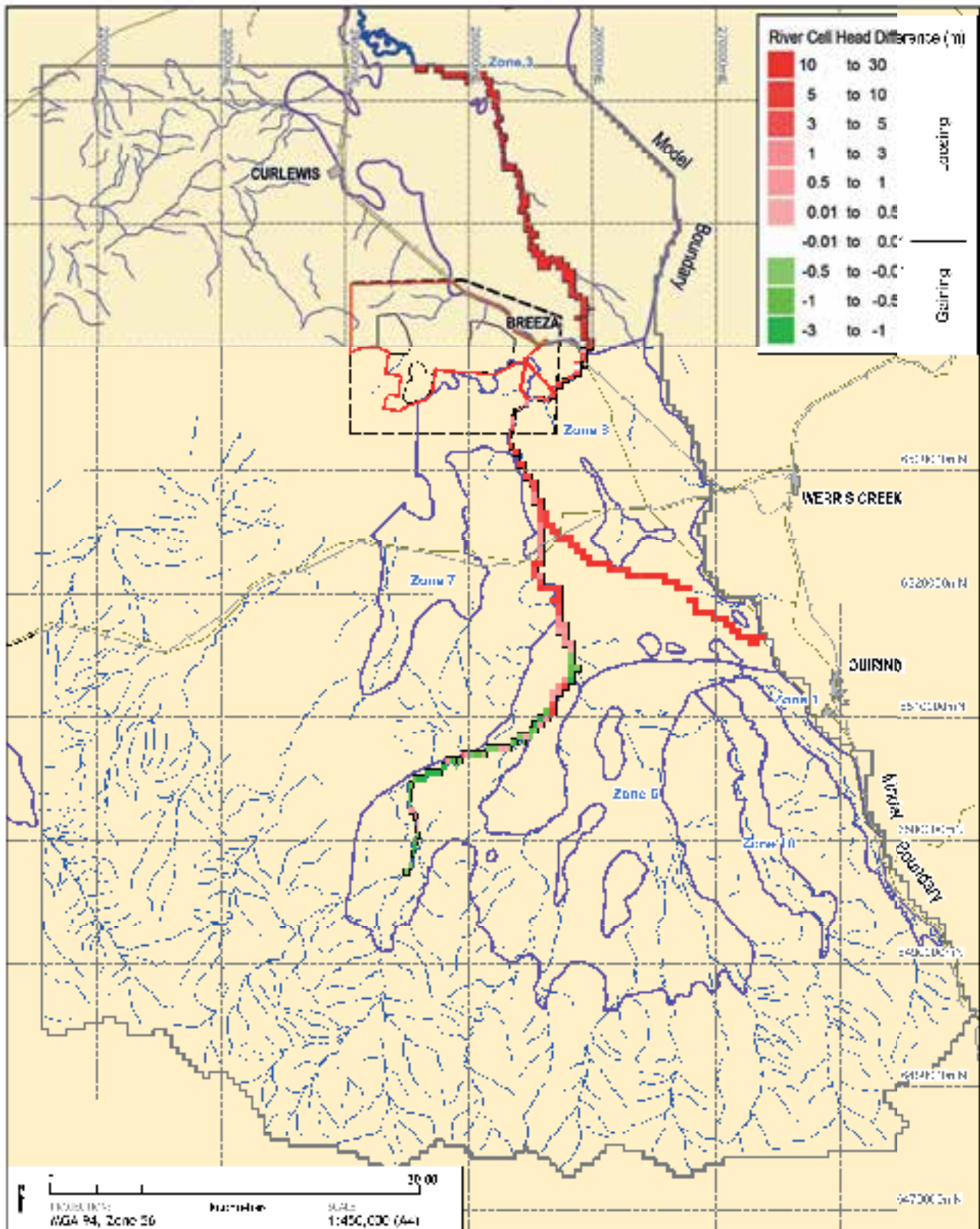
Figure 9.52: Quirindi Creek – showing Up-Stream Flowing Area and Downstream Dry Area



Figure 9.53 shows segments of the Mooki River and Quirindi Creek where water is either flowing from the watercourse to the aquifer (losing stream), or from the aquifer to the watercourse (gaining stream). Figure 9.3 illustrates the concept of losing and gaining streams. The majority of the Mooki River is losing surface water to the underlying aquifer, with some small segments in the upper part of the catchment gaining, i.e. groundwater-feeding river. The Quirindi Creek is dominated by losing conditions as well.

Figure 9.54 shows the transfer of water between the Mooki River/Quirindi Creek, and the underlying aquifers. Figure 9.54 shows that during the 1980s, seasonal cycles resulted in fluctuations between losing and gaining conditions. From the 1990s, this cycle is less evident as losing conditions become more dominant due to drawdown induced from pumping. Figure 9.54 also presents the losing, gaining and net flows for each drainage line. On a net basis, both the Mooki River and Quirindi Creeks are losing streams, i.e. water flows from the stream through the bed to recharge the underlying aquifer. The Mooki River is the most significant component of the model water budget contributing between 10 ML/day and 30 ML/day of leakage from the river to the underlying aquifer. The rate of loss from the Mooki River also increases over time as the pumping from the aquifers increases.

The minor creeks and smaller drainage systems including Lake Goran are set in the model to allow only gaining conditions. The smaller drainage lines are removing about 81 ML/day from the aquifers. Lake Goran removes 2 ML/day over an area of approximately 52 km².



Legend

- CL 7023
- Proxied Vintipase
- Groundwater Management Zone
- Model Boundary
- On-farm Lateral Flow
- Mooki River

Watermark Coal Project (G1507)
Groundwater Assessment

Simulated River Cell Head Difference
(Gaining/Losing) - 2011



DATE:
18/10/2012

TIME:
9.53

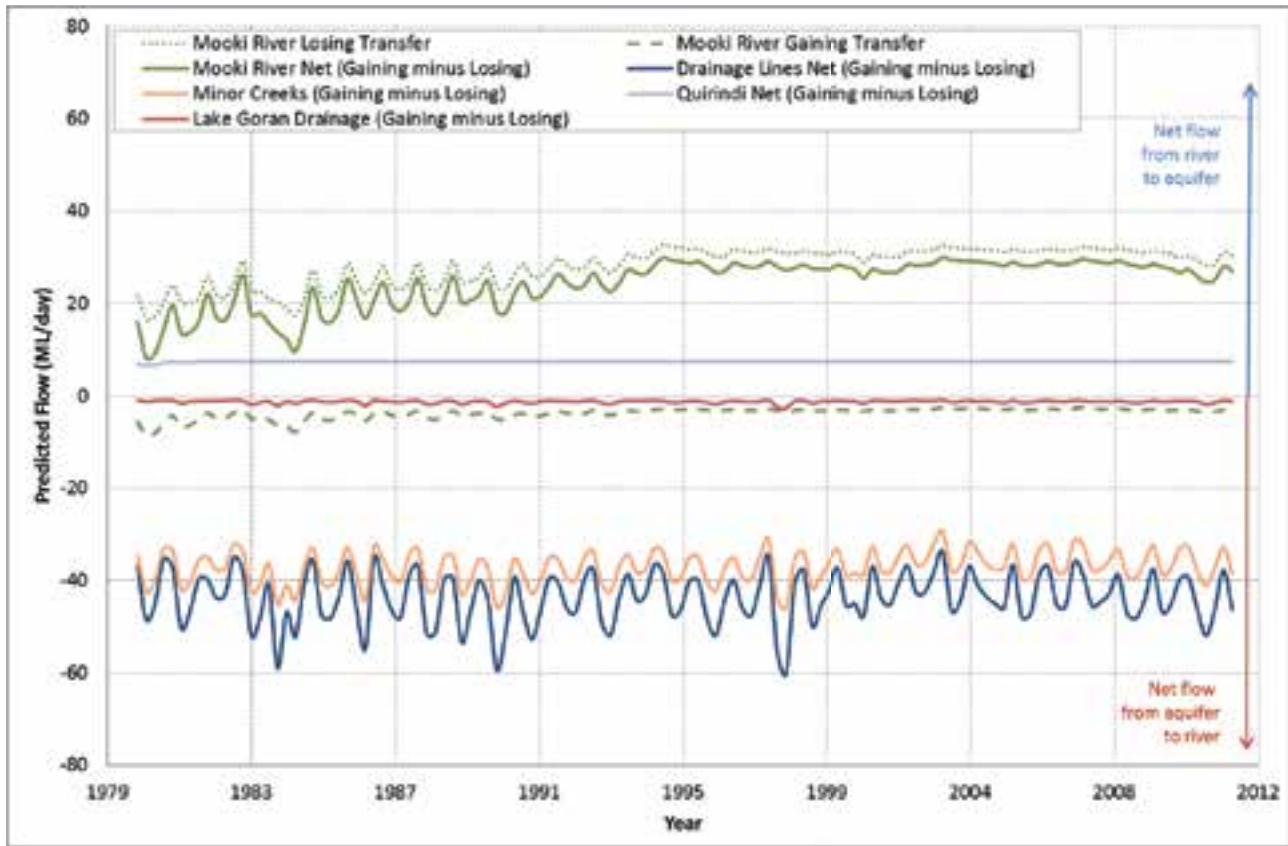


Figure 9.54: Stream Water Budgets

9.2.11 Water Budgets

Table 9.6 summarises the transient model water budget.

Table 9.6: WATER BUDGET – TRANSIENT MODEL WATER BUDGETS (ML/DAY)						
Parameter	Input			Output		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Rainfall recharge	39.4	245.1	764.4	-	-	-
River leakage	15.8	35.5	40.1	66.5	86.0	113.1
Evapotranspiration	-	-	-	50.5	111.2	211.4
General head	0.0	15.7	270.2	0.0	32.2	403.8
Wells	-	-	-	6.9	95.3	412.3
TOTALS	236.2	423.1	884.7	236.2	423.1	884.7

The budget indicates that on average, water enters the model domain as follows:

- 245.1 ML/day from rainfall recharge;
- 35.5 ML/day from leakage from rivers; and
- 15.7 ML/day from inflow across the northern boundary of the model domain when there is high pumping from the alluvium adjacent to the boundary.



The model predicts average discharge that consists of:

- 86.0 ML/day discharging into rivers and creeks;
- 111.2 ML/day from evapotranspiration;
- 32.2 ML/day via flow through the northern boundary of the alluvium; and
- 95.3 L/day is removed from the aquifer via pumping bores.

Figure 9.55 presents the transient water budget over the calibration period. Negative values indicate water leaving the model domain, and positive values represent water entering the model. Note GHB stands for general head boundary.

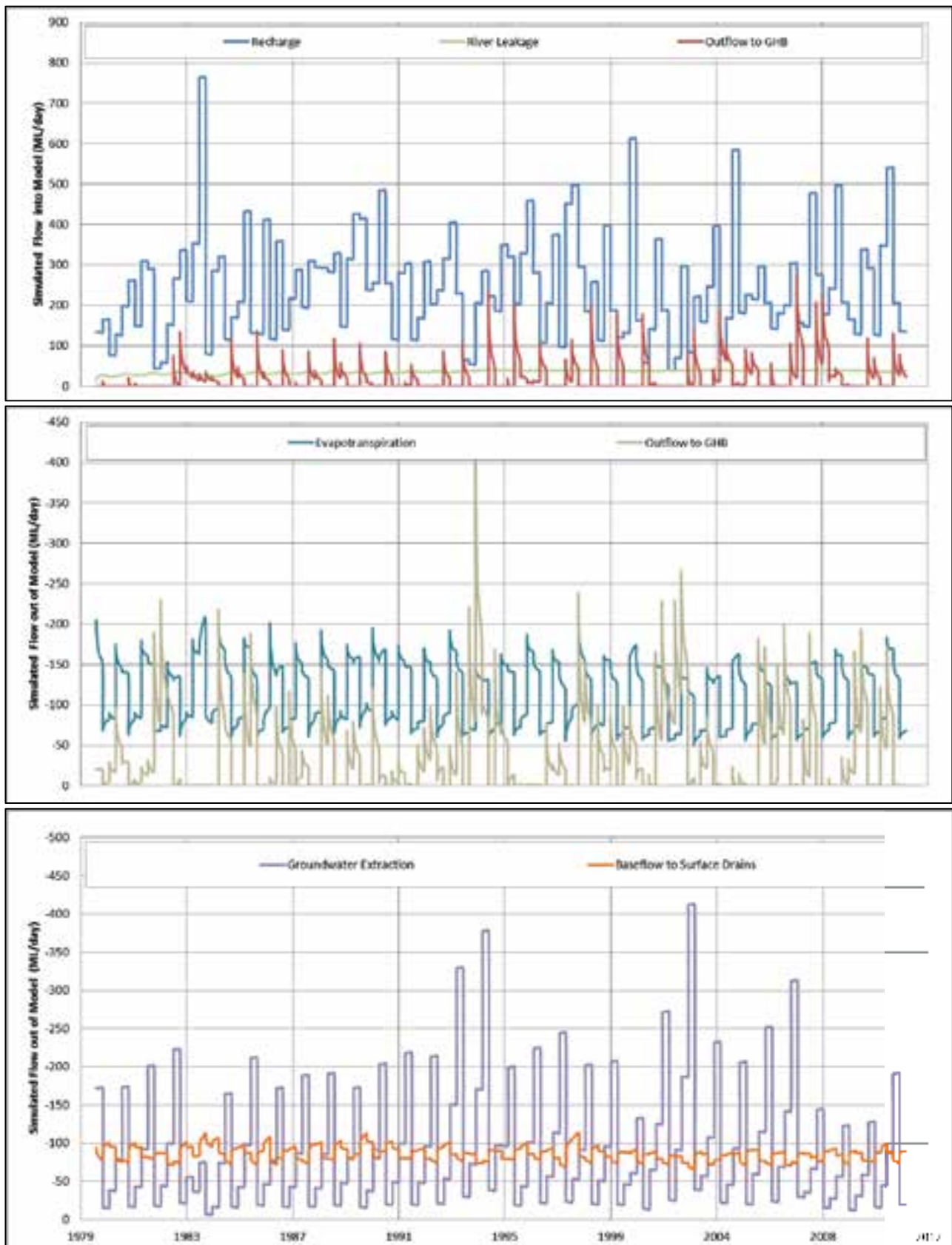


Figure 9.55: Transient Water Budget



Figure 9.55 shows that in some instances the seasonal peaks in pumping have exceeded recharge during the growing season when irrigation is intensive. This results in the signature of rising and falling water levels in observation bores induced by seasonal pumping. On an annual basis, the volume extracted by pumping across the entire model is slightly above the recharge rate, which is why the water levels have exhibited a decline over time.

During the irrigation season, groundwater extraction close to the northern boundary of the model locally reverses the regional hydraulic gradient from south to north to north to south. This allows water to enter the model domain, which has been observed at the Breeza Field Station (pers comm. W.Timms, 2012). This reversal of groundwater flow is represented on Figure 9.52 as inflow to and from the General Head Boundary (red line).

There is also a notable increase in the rate of river leakage over the calibration period shown in Figure 9.55 and Figure 9.54. This is due to the increasing pumping that induces a larger hydraulic gradient between the river and the underlying aquifers.

Figure 9.56 presents the transient water budget for the alluvial formations only. Figure 9.56 shows that outflow from the alluvium exceeds inflow, and this results in the overall decline in groundwater levels that has been observed in regional observation bores. Total recharge to the alluvium is 163 ML/day, versus a total outflow of 193 ML/day, indicating a deficit of 30 ML/day. This deficit is practically replaced by additional river leakage and backflow from down gradient aquifers.

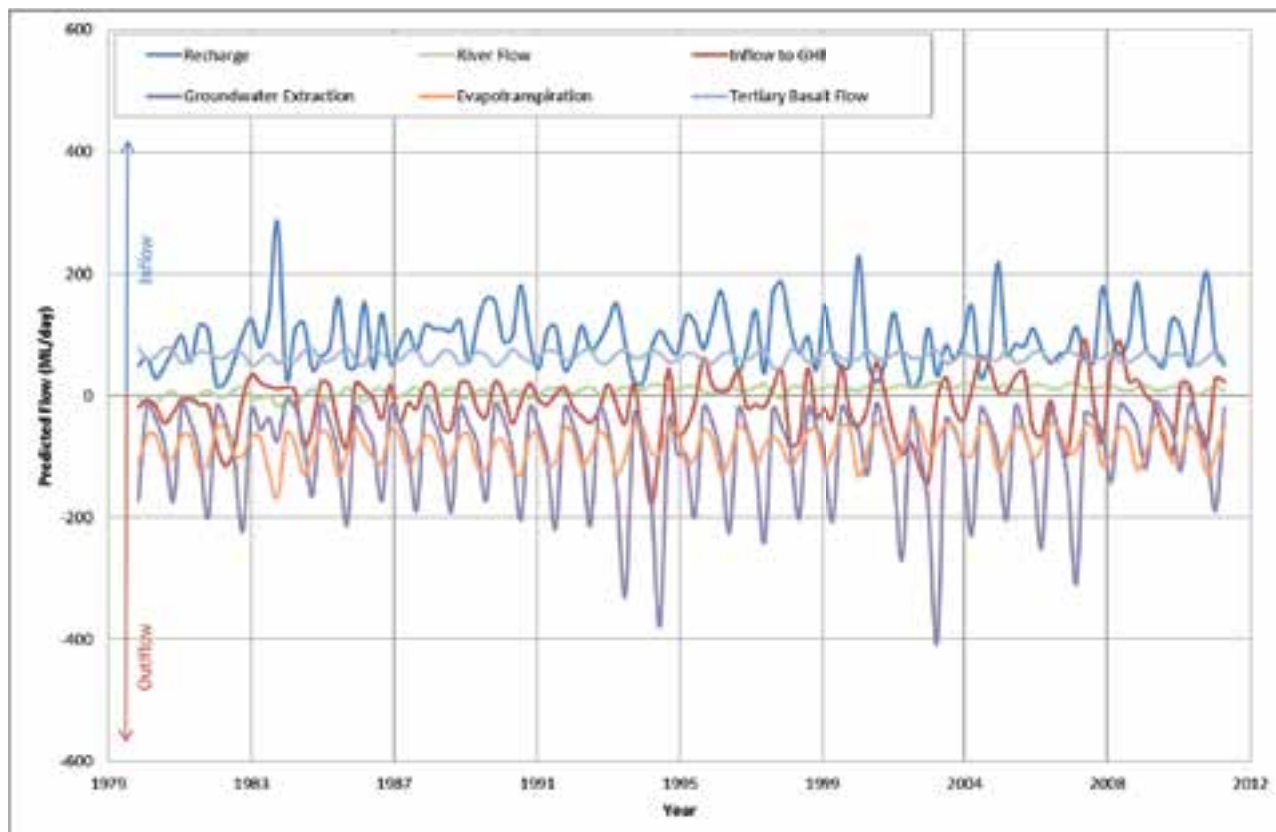


Figure 9.56: Transient Water Budget – Alluvium

**Comparison of Budgets to Previous Modelling**

As discussed in Section 9.1.3, a manual calibration process was undertaken to ensure that the model replicates both realistic groundwater flows in relation to expected field observations and previous groundwater modelling studies in the area. Table 9.7 compares water budgets from the models undertaken by Merrick (2001), McNeilage (2006) and Salotti (1997).

Table 9.7: WATER BUDGET COMPARISON (1980 – 2000) Rate (ML/day)		
Model	Previous Studies	Watermark Project
River Leakage - Zone 3	6.0 ¹	15.0
River Leakage - Zone 8	13.3 ²	13.2
Recharge - Zone 8	28.1 ²	11.1
Recharge - Zone 1	3.9 * (1979-1996) ³	7.5

1 - Zone 3 Upper Namoi Model - McNeilage (2006)

2 - Zone 8 Merrick (2001)

3 - Salotti (1997)

Table 9.7 indicates a reasonable to close agreement with previous models for recharge and river leakage rates. Previous models have had different underlying assumptions and have also not simulated the presence of the bedrock aquifers and therefore a very close agreement between the models would not be expected. However, the fact that the models are not fundamentally different suggests the parameters adopted for the Project model are realistic.

To cross check the model, the predicted volume of recharge entering the alluvial aquifers from the Liverpool Ranges area was compared with the groundwater flow rates from the Tertiary basalt to the alluvial aquifers. WRM (2012) assessed the transmission loss from river gauging stations in the area. WRM assessed rainfall records and data from stream gauging stations to estimate the potential magnitude of groundwater recharge in the Liverpool Ranges. Figure 9.57 compares the flow to the Quaternary alluvial aquifer from the Liverpool Range Basalt predicted by WRM (2012) and the groundwater model.

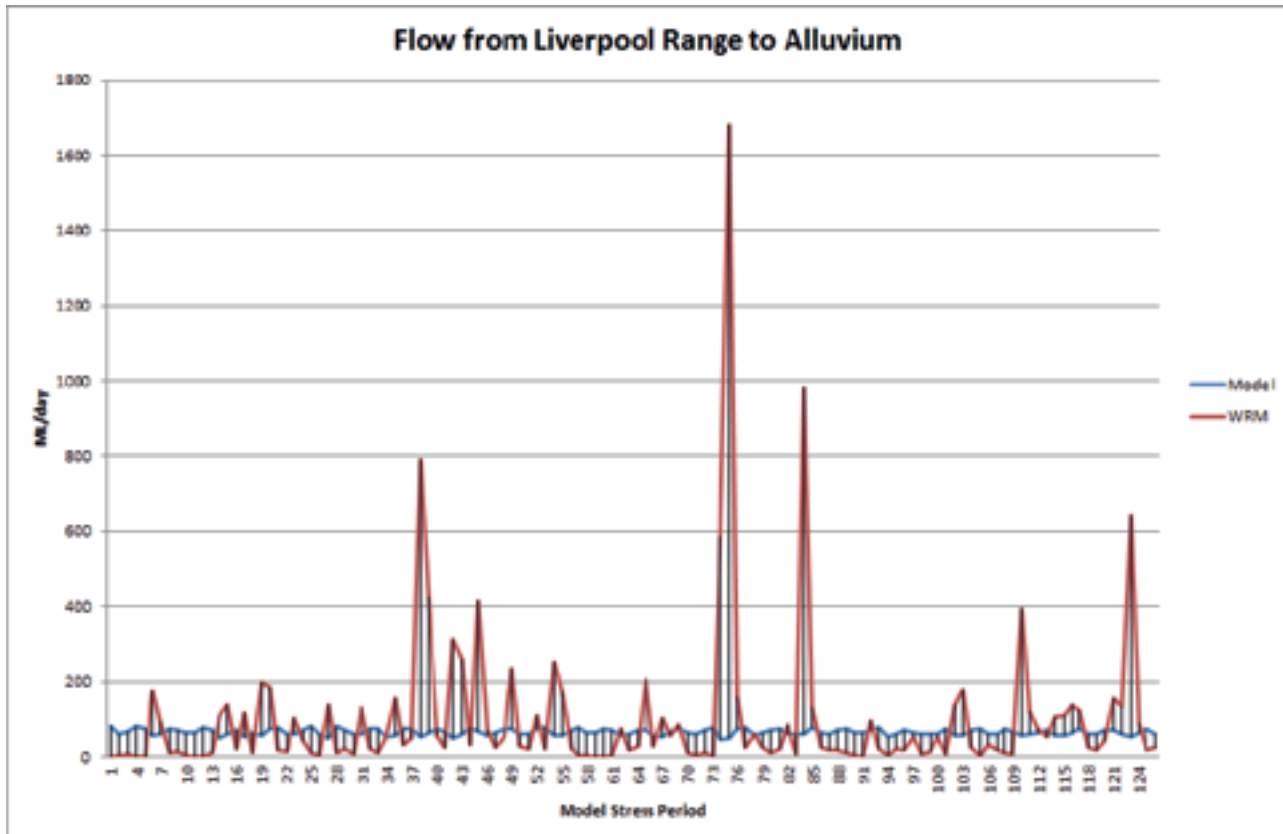


Figure 9.57: Groundwater Flow from Liverpool Range to Quaternary Alluvium

Groundwater flows from the groundwater model were on average (64 ML/day) similar to the transmission loss estimated by WRM (93 ML/day), suggesting that calibrated groundwater recharge rates and modelled parameters in this region were within realistic ranges. The spikes in the WRM estimate were due to the monthly flow calculations as compared to quarterly calculations in the groundwater flow model.

9.2.12 Numerical Error

The cumulative mass balance error reported by the model, that is, the difference between calculated model inflows and outflows, at the completion of the steady state and transient calibration run is 0.00% (effectively nil difference), indicating a numerically accurate and stable model. Figure 9.58 shows the maximum discrepancy for the cumulative and individual time step discrepancies. The maximum discrepancy for the individual time steps was within the model run was 0.08%, This maximum error is well within acceptable limits for adequate numerical convergence of <2% recommended by MDBC (2000).

For completeness, Figure 9.58 presents the numerical discrepancy error throughout the simulation. MDBC (2000) Guidelines suggest a value under 2% for any model time-step is acceptable, and as can be seen in Figure 9.58, this criterion is certainly met for all time-steps.

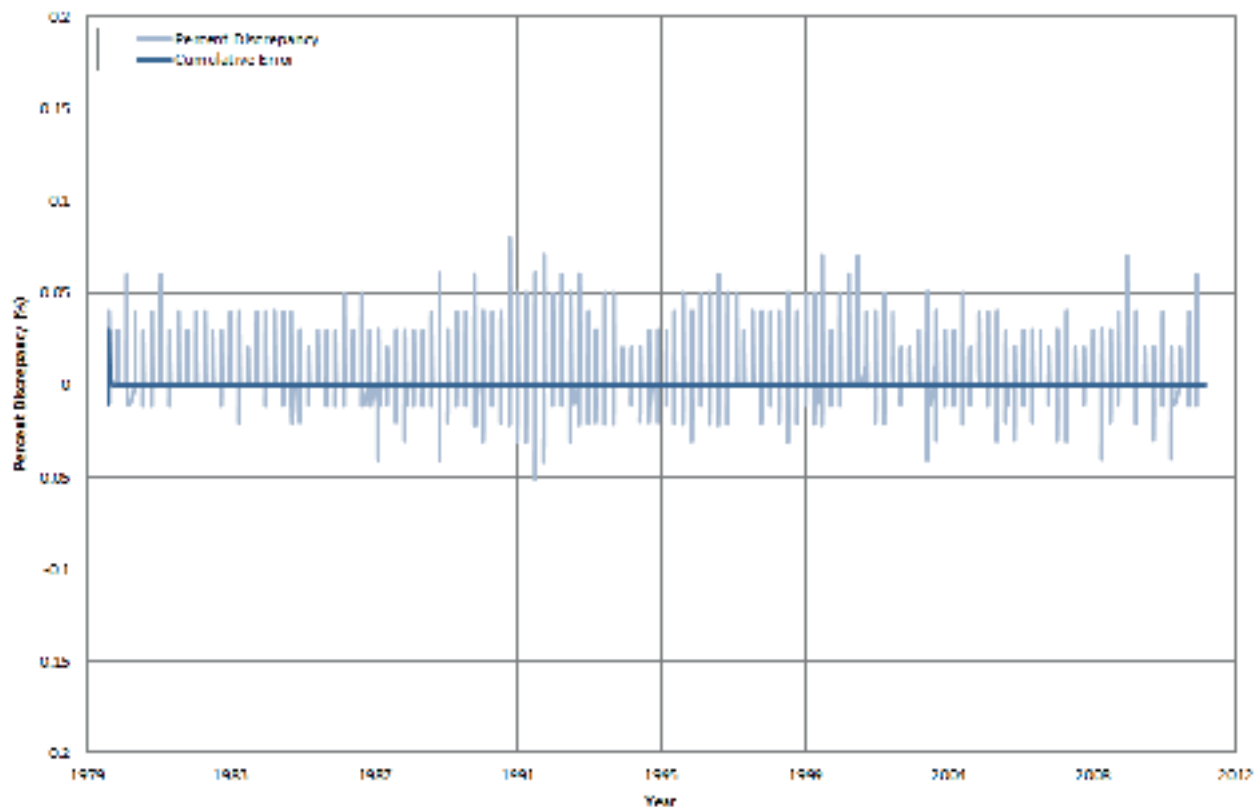
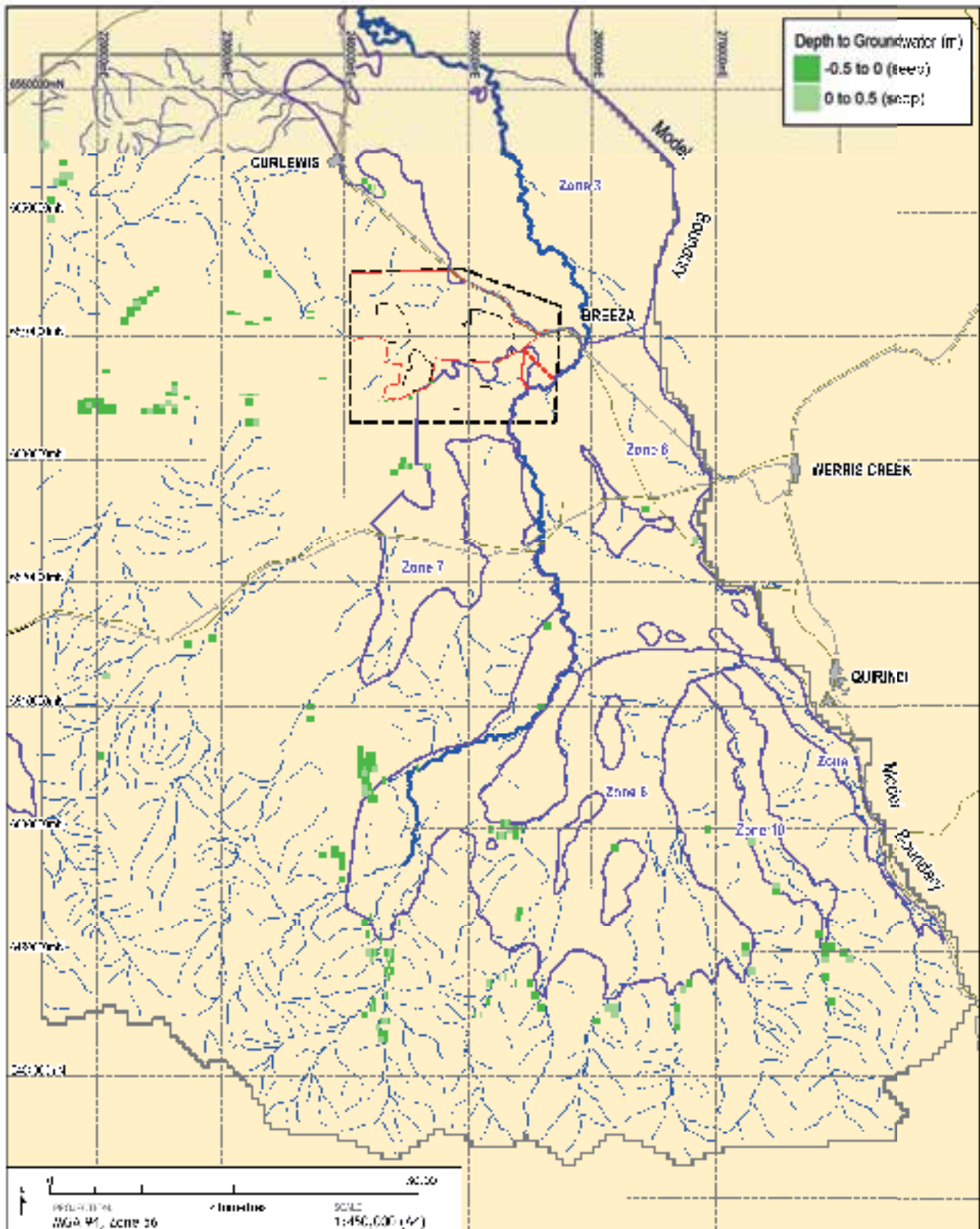


Figure 9.58: Numerical Error – Regional Calibration Simulation

9.2.13 Groundwater Seepage Zones

It was recognised that during the exploration program, and following discussions with landowners across the EL 7223, a number of groundwater seepage zones existed or had existed during high rainfall periods. Zones where the depth to groundwater is less than 2 m below the surface were extracted from the model to verify the representation of groundwater seepage zones in the groundwater model. The results indicated a good correlation between known and modelled seepage zones. The depth to groundwater within the Narrabri Formation has been presented in Figure 9.59.



Legend

- 1:1000
- 1:2000
- 1:4000
- 1:8000
- 1:16000
- 1:32000
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9.2.14 No Pumping Scenario

In order to assess the robustness and stability of the groundwater model, a scenario was run where all pumping from licenced bores was turned off. The expected result of such a scenario was flat and stable predicted groundwater levels.

The resulting modelled groundwater levels (Figure 9.60) displayed stability with some minor responses to recharge, river leakage and evapotranspiration, reflecting the natural equilibrium on the system before high-level extraction in the area triggered a regional groundwater decline in the Narrabri and Gunnedah Formations.

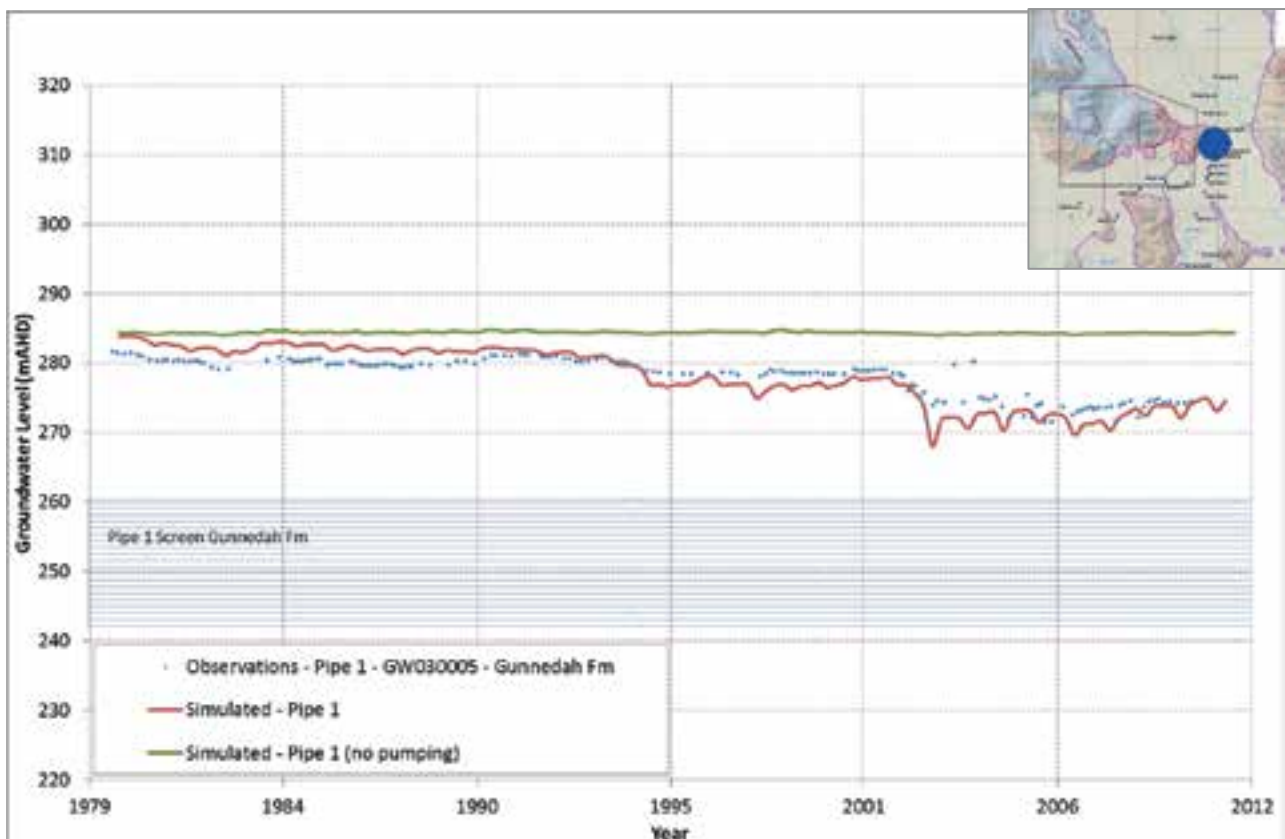


Figure 9.60: Calibration Hydrograph – No Pumping Scenario – GW030005

9.3 Verification

In order to verify the performance of the regional groundwater model, the transient groundwater model was extended by three quarters to replicate groundwater levels from mid-2011 to March 2012. Several readings from the Shenhua Watermark database were assessed against the simulated levels. Figure 9.61 to Figure 9.64 display the models performance against stresses outside the calibration period. The model replicates the general pattern of fluctuations.

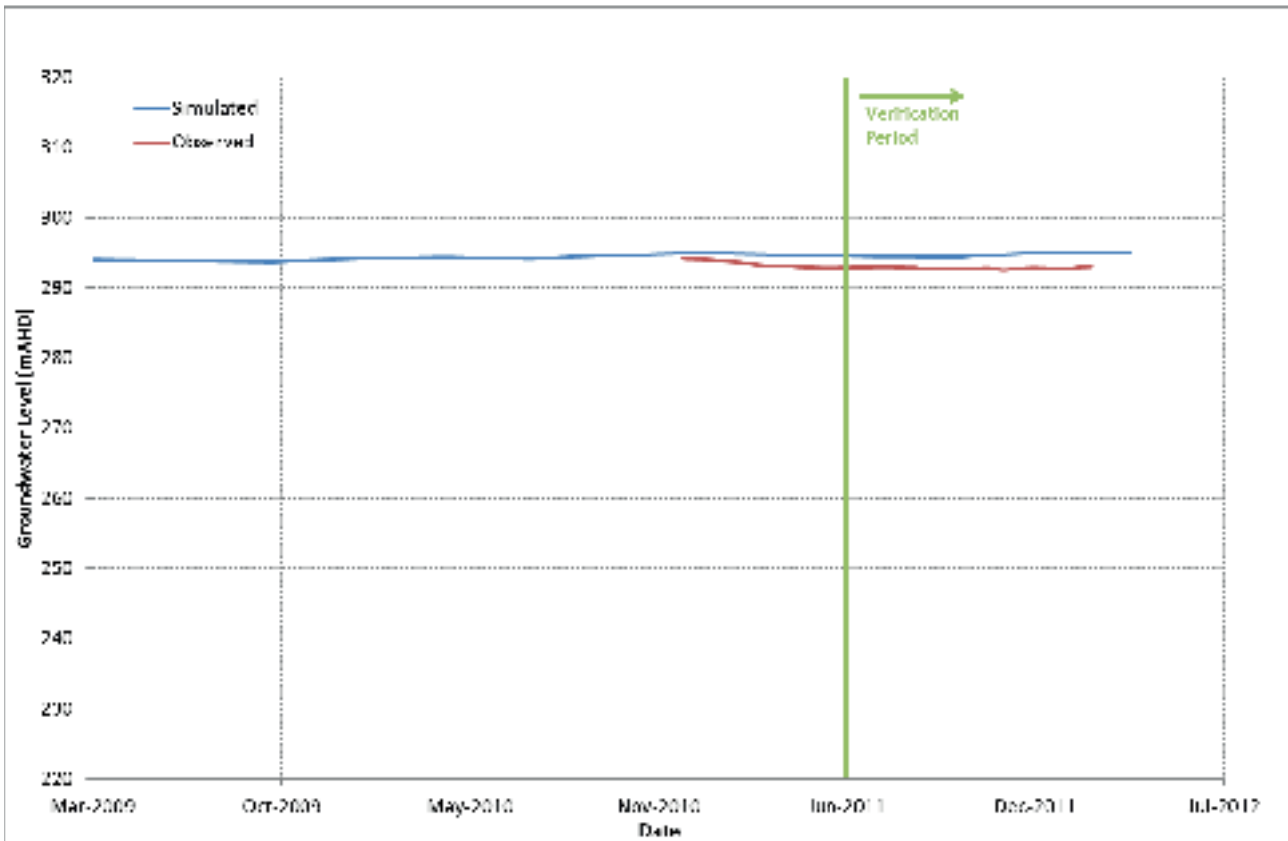


Figure 9.61: Verification Hydrographs – WM0421 (Clare Sandstone)

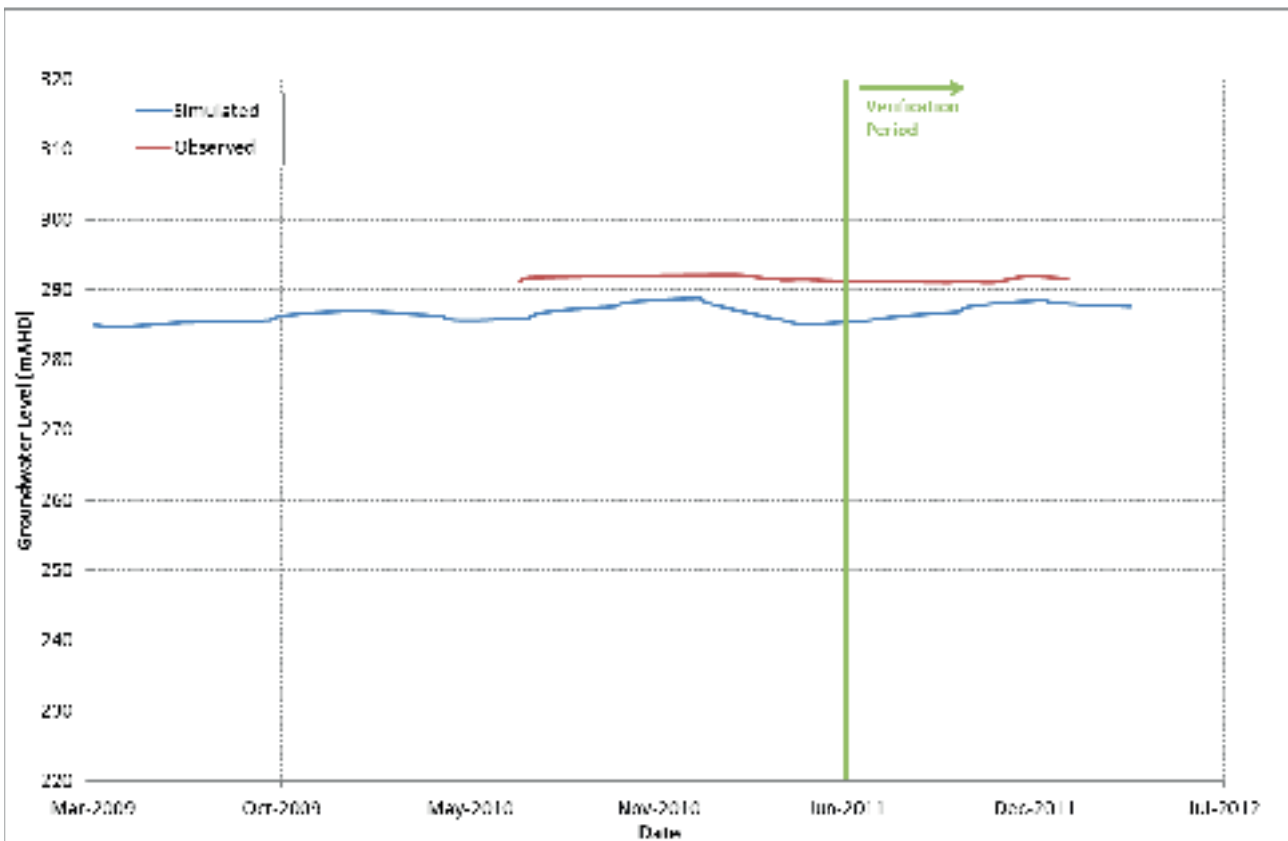


Figure 9.62: Verification Hydrographs – WM0011 (Narrabri Formation)

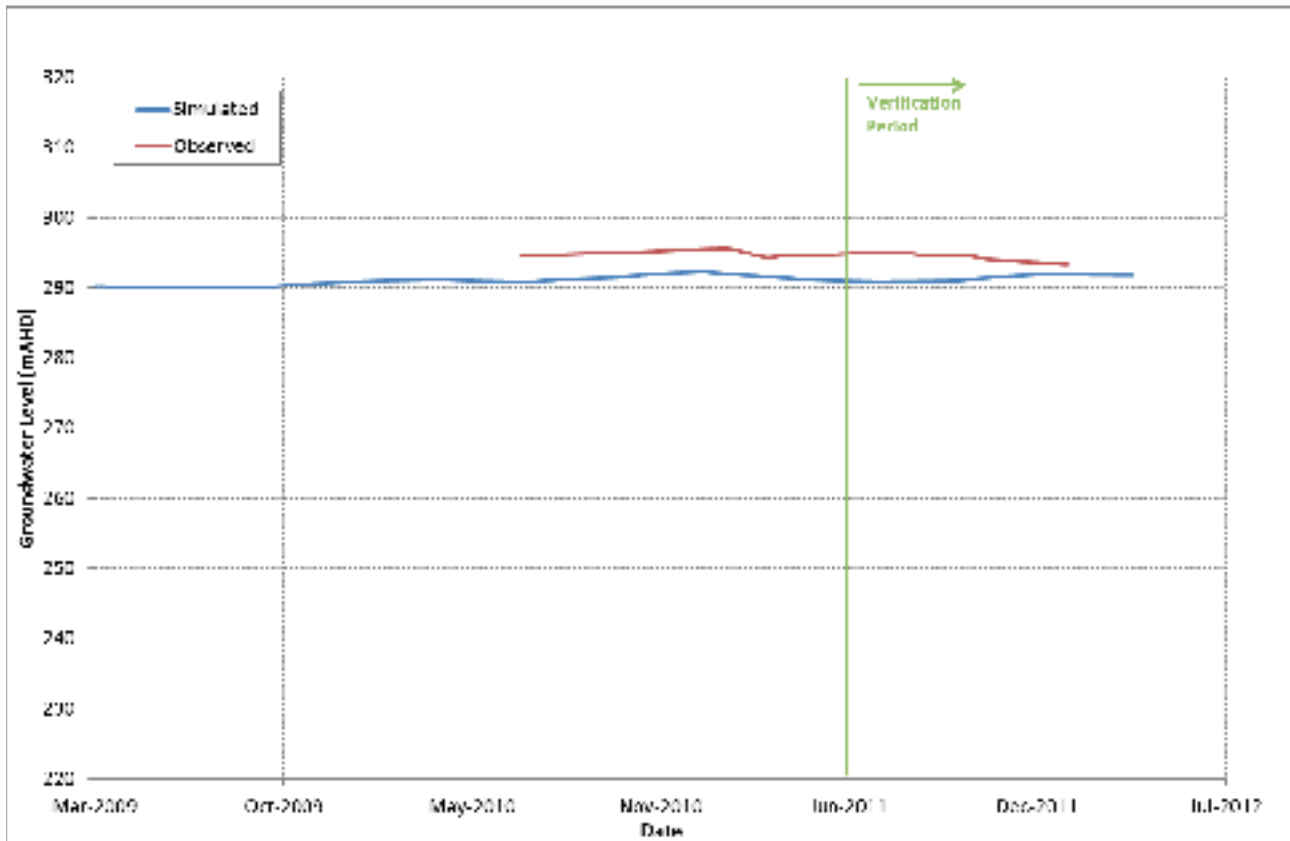


Figure 9.63: Verification Hydrographs – WM0291

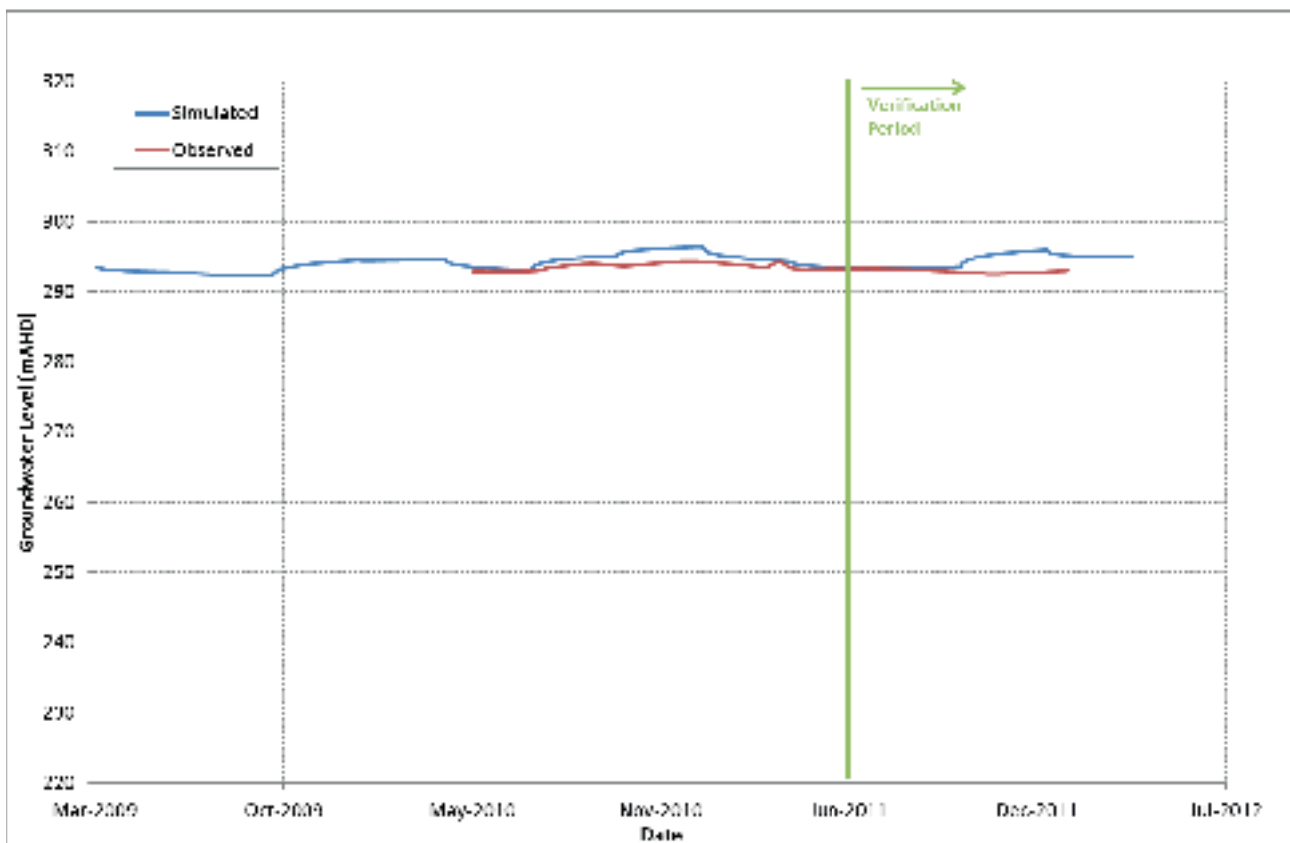


Figure 9.64: Verification Hydrographs – WM0002A



Figure 9.65 compares the observed and simulated groundwater levels of 21 randomly selected Shenhua Watermark bores from the regional transient verification simulation (July 2011 to March 2012).

Table 9.8 presents a summary of the transient model calibration statistics for the verification data, as outlined by MDBC (2000).

Based on the regional nature of the model and the irregular spacing of the data points, it is considered that the verification results represent a good calibration match for Shenhua Watermark bores, which are primarily located in the Permian strata.

The RMS error calculated for the unweighted calibrated transient model results was 3.03 m. The ratio of RMS to the total head change across the calibration points (45.6 m) indicated a SRMS of 6.6%. This indicates a good calibration and is close the MDBC (2000) and project target of 5% or less.

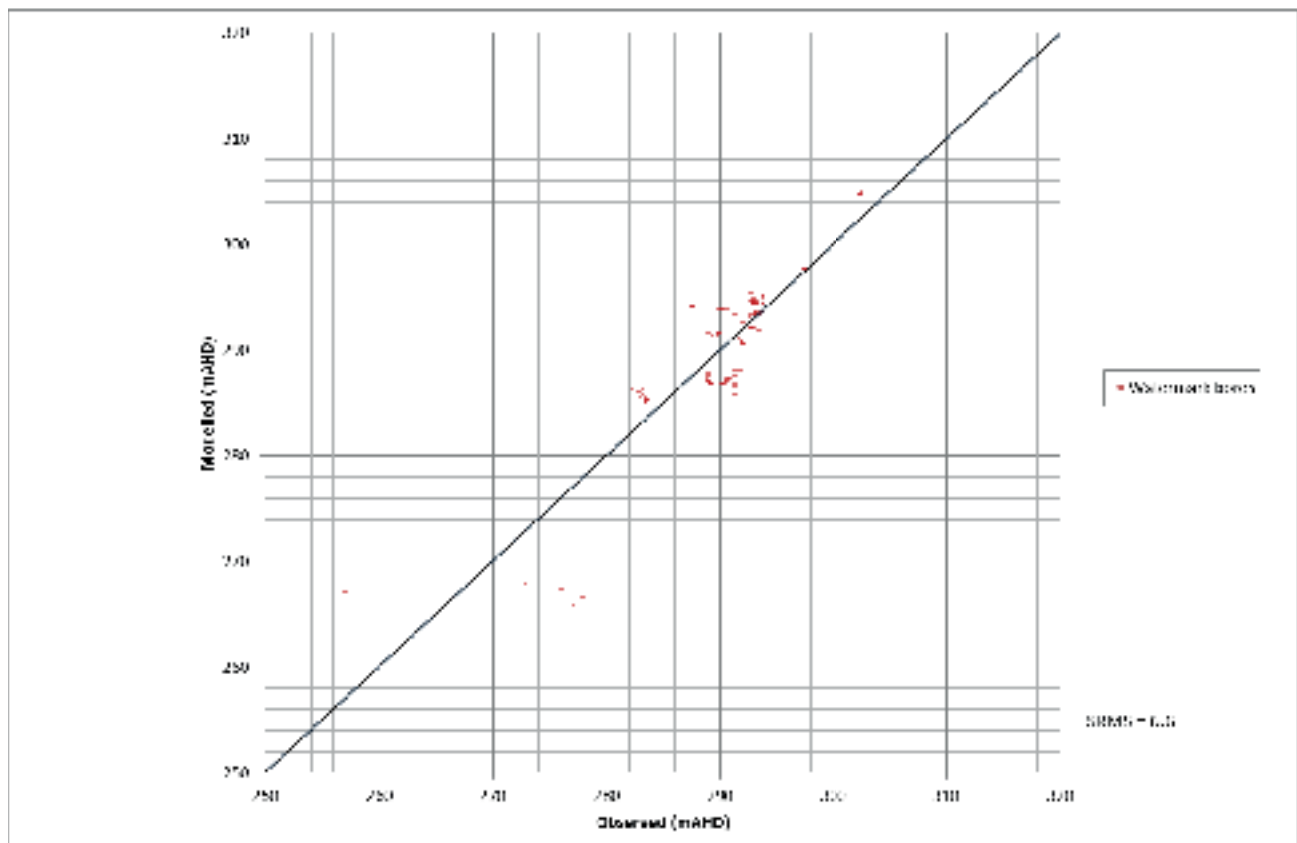
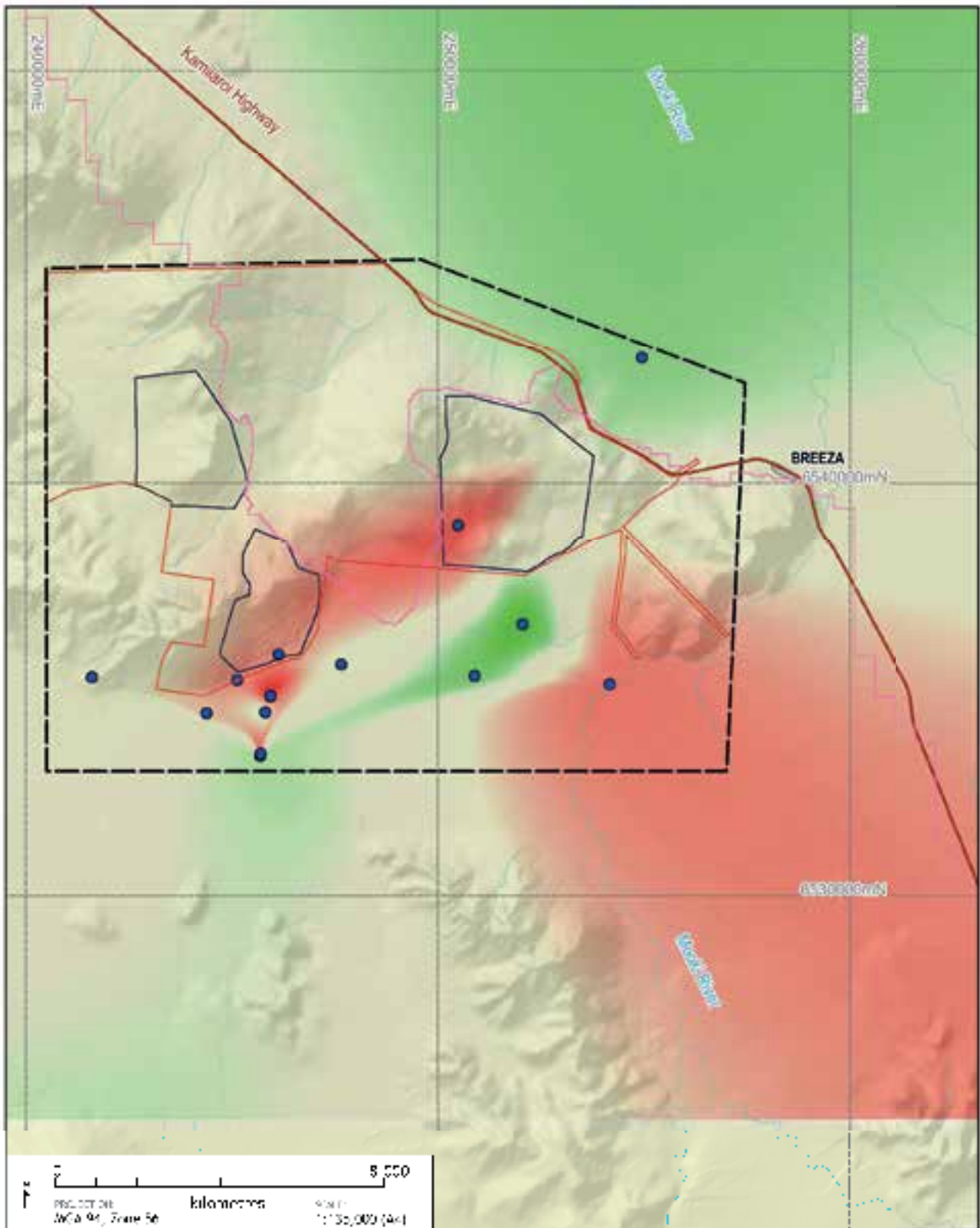


Figure 9.65: Scattergram showing Observed and Modelled Heads – Verification Bores

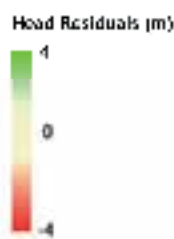
**Table 9.8: STATISTICAL ANALYSIS – VERIFICATION – WATERMARK BORES**

Calibration Performance Measure	Unweighted Value
Sum of Residuals (SR) (m)	-71.57
Mean Sum of Residuals (MSR) (m)	-0.33
Scaled Mean Sum of Residuals (SMSR) (%)	-0.72
Sum of Squares (SSQ) (m ²)	1987.53
Mean Sum of Squares (MSSQ) (m ²)	9.16
Root Mean Square (RMS) (m)	3.03
Root Mean Fraction Square (RMFS) (%)	0.01
Scaled RMFS (SRMFS) (%)	0.07
Scaled RMS (SRMS) (%)	6.64

Figure 9.66 presents groundwater residuals for the last stress period of the verification model run (March 2012). Generally, simulated groundwater levels are within 2 m of the observed groundwater levels, suggesting that the model is continuing to exhibit good calibration performance spatially past the calibration model simulation.



- Legend
- Borehole
 - Proposed Mining Area
 - CL7226
 - Watercourse Line
 - Highway
 - Melville's Coal Seam - Extent
 - Project Boundary



Watermark Coal Project (G157)
Groundwater Assessment
Verification Model Residuals
March 2012



DATE:
18/10/2012

FIGURE NO.
9.66



9.4 Conclusions

The calibration of the Project regional model across the model area in time and spatial dimensions is considered very good. The model also performed well during verification and mass balance tests, confirming the accuracy and robustness of the model. It can be concluded that:

- Groundwater levels in the Quaternary alluvium are accurately reproduced by the model. Both long term and short-term stresses are simulated accurately across the majority of the model area.
- Groundwater levels in the Permian are generally well reproduced or slightly over predicted. However, due to the coarse nature of the interburden cells, weathering features cannot always be represented in the model and therefore several calibration points within the Permian interburden will be over represented. As the cell centres in areas of thick interburden layers are often well below the base of weathering, these potentially weathered layers will be assigned to hydraulically tight fresh rock parameters, and therefore increasing the hydraulic head.
- Permian groundwater levels in the project area have an acceptable level of calibration, considering the homogenous representation of the Permian interburden in the model.



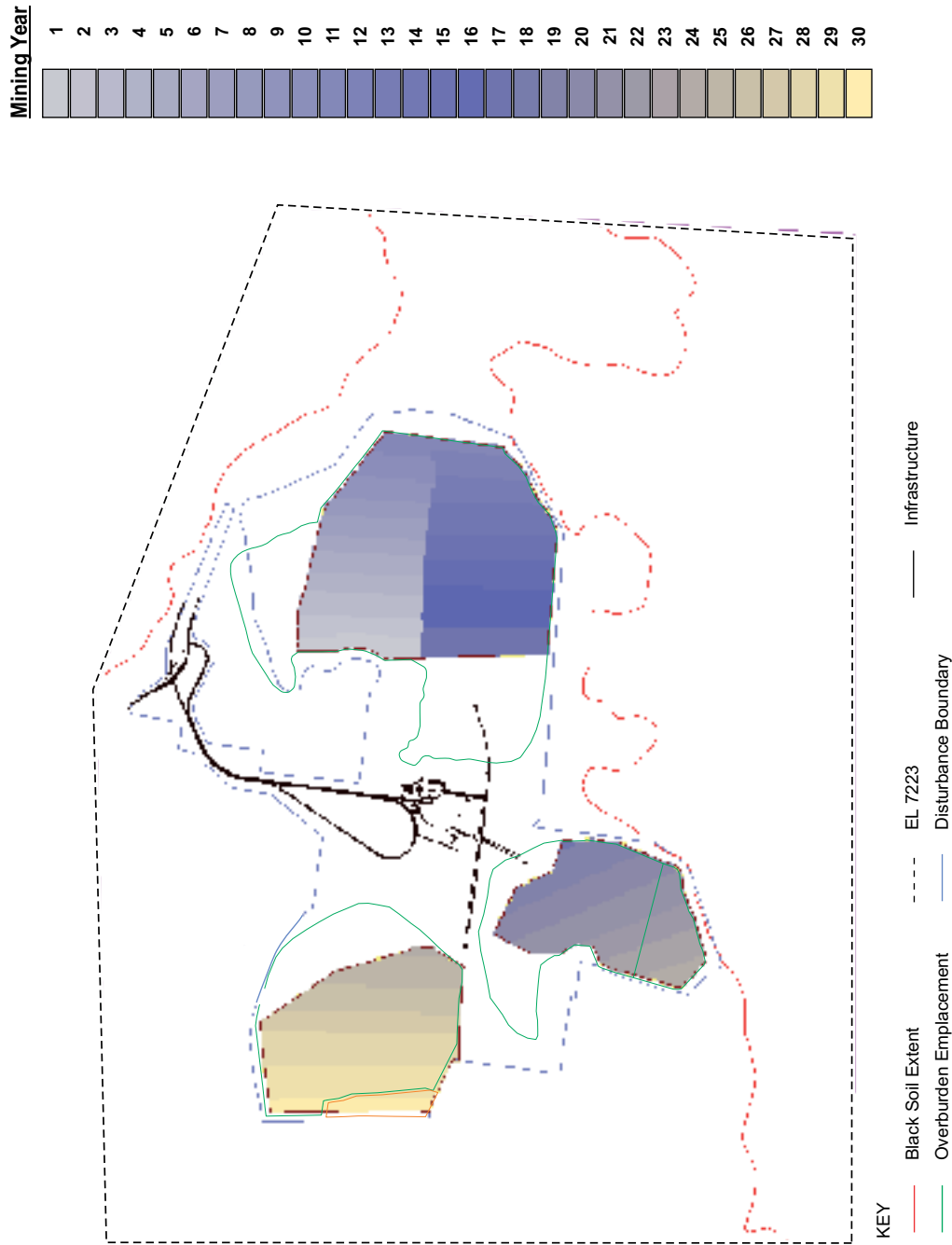
10.0 MODEL PREDICTIONS AND IMPACT ASSESSMENT

10.1 Introduction

Following the calibration of the regional model, the aquifer parameters were transferred from the “calibration model” into the refined grid of the “predictive model”. This predictive model was identical to the calibration model, with the exception of a refined cell size of 50 m around the proposed Mine Areas. This was considered appropriate to enable model predictions within a conservative 150 m Mining Area crest set back from the dominantly clay rich Narrabri Formation which, although containing limited and poor quality groundwater is considered part of the Namoi Alluvium. This grid detail also provided better-detailed representation of the mine design and progress.

10.2 Mine Plan

The Project comprises of three proposed open cut Mining Areas, namely the Eastern Mining Area (3.5 x 4 km), the Southern Mining Area (2 x 3 km), and the Western Mining Area (2.5 x 3 km). Figure 10.1 presents the locations and progression rates of the Project open cut Mining Areas.



Watermark Project Mine Plan Year 1 to Year 30

Figure 10.1

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



10.2.1 Buffer to Black Soil Plains

The extents of the Project Mining Areas have been designed to ensure they comply with the buffer zone recommended by DIPNR (2005). DIPNR (NOW) recommended *'the minimum defined notification area is 150 metres from the high bank of a Schedule 3 river or the defined edge of alluvium to an agreed point on the highwall of open cut mines'*.

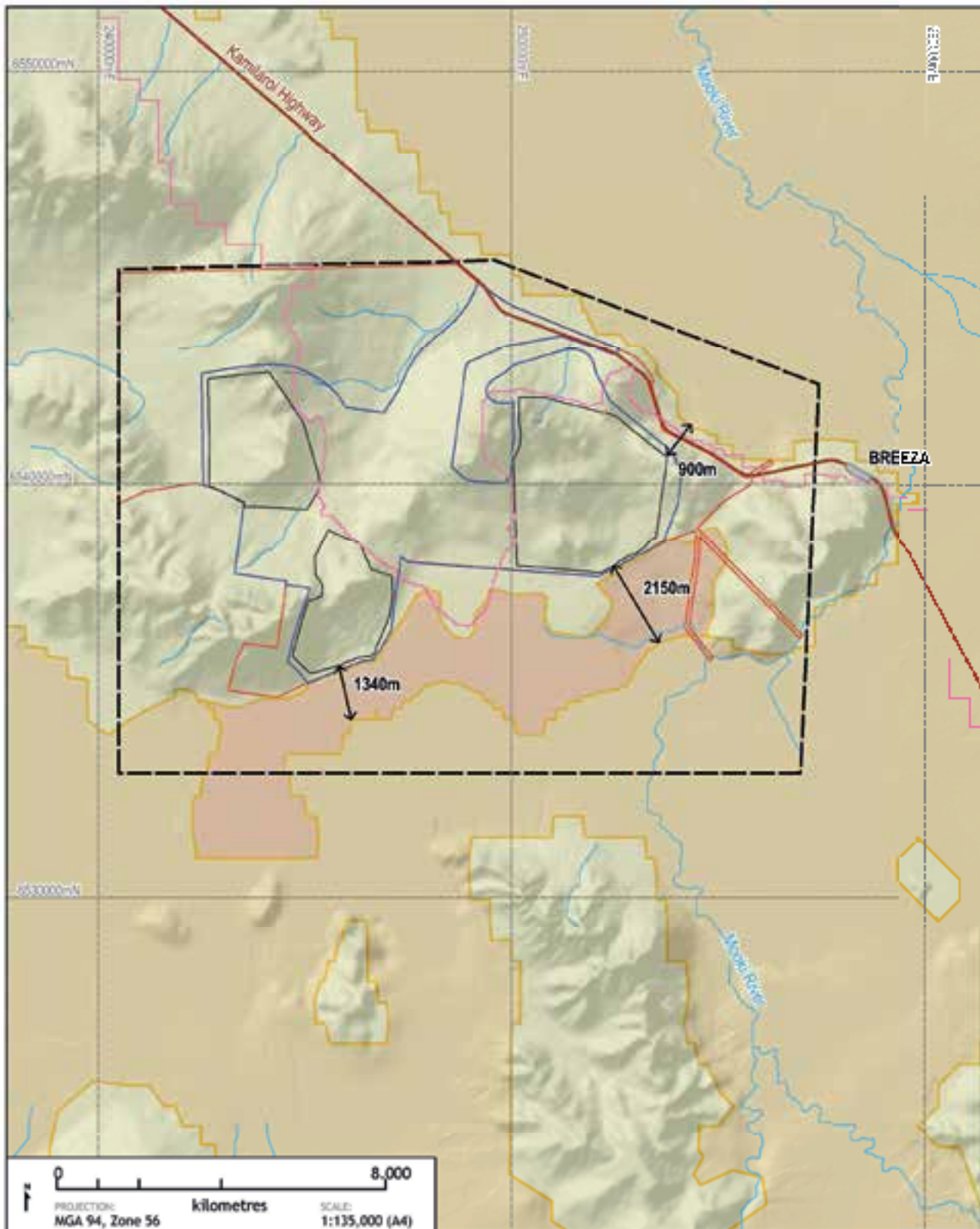
The Watermark open cut mining areas have been designed with a minimum buffer of 150 metres to the edge of the Upper Namoi Alluvium/Narrabri Formation/black soil plains.

10.2.2 Buffer to Gunnedah Formation

The extent of the Watermark open cut mining areas have been designed to ensure they comply with the buffer zone specified in Condition 50 of EL 7223 which states that *"All plans for mining within the Licence area must include a horizontal barrier of natural material with a minimum width of 150 metres, between proposed mining excavations and the Gunnedah Formation."*

Figure 10.2 illustrates the significant setback distance between the edge of the proposed Southern Mining Area and Eastern Mining Area from the Gunnedah Formation aquifer. The edge of the Southern Mining Area is approximately 1.3 km from the edge of the Gunnedah Formation. The Eastern Mining Area is approximately 1.0 km from the Gunnedah Formation at the northern edge and approximately 2.2 km from the southern edge. The buffer around the open cut mining areas significantly exceeds the 150 m buffer zone specified in EL 7223.

Figure 10.3 presents a 3D representation of the predictive groundwater model and the Project open cut Mining Areas in relation to the distribution of the alluvial formations. The elevation of the Mining Area floor in the Southern Mining Area at 195 mAHD extends below the base of the Gunnedah formation aquifer, which is at 230 mAHD. In contrast, the floor of the Eastern Mining Area at 225 mAHD remains slightly above the base of the Gunnedah Formation, at 190 mAHD.



LEGEND:

- | | |
|-------------------------------|-------------------------|
| — Proposed Mining Area | Narrabri Aquifer Extent |
| --- EL 7223 | Gunnedah Aquifer Extent |
| — Melville Coal Seam - Extent | Disturbance Boundary |
| Project Boundary | Highway |

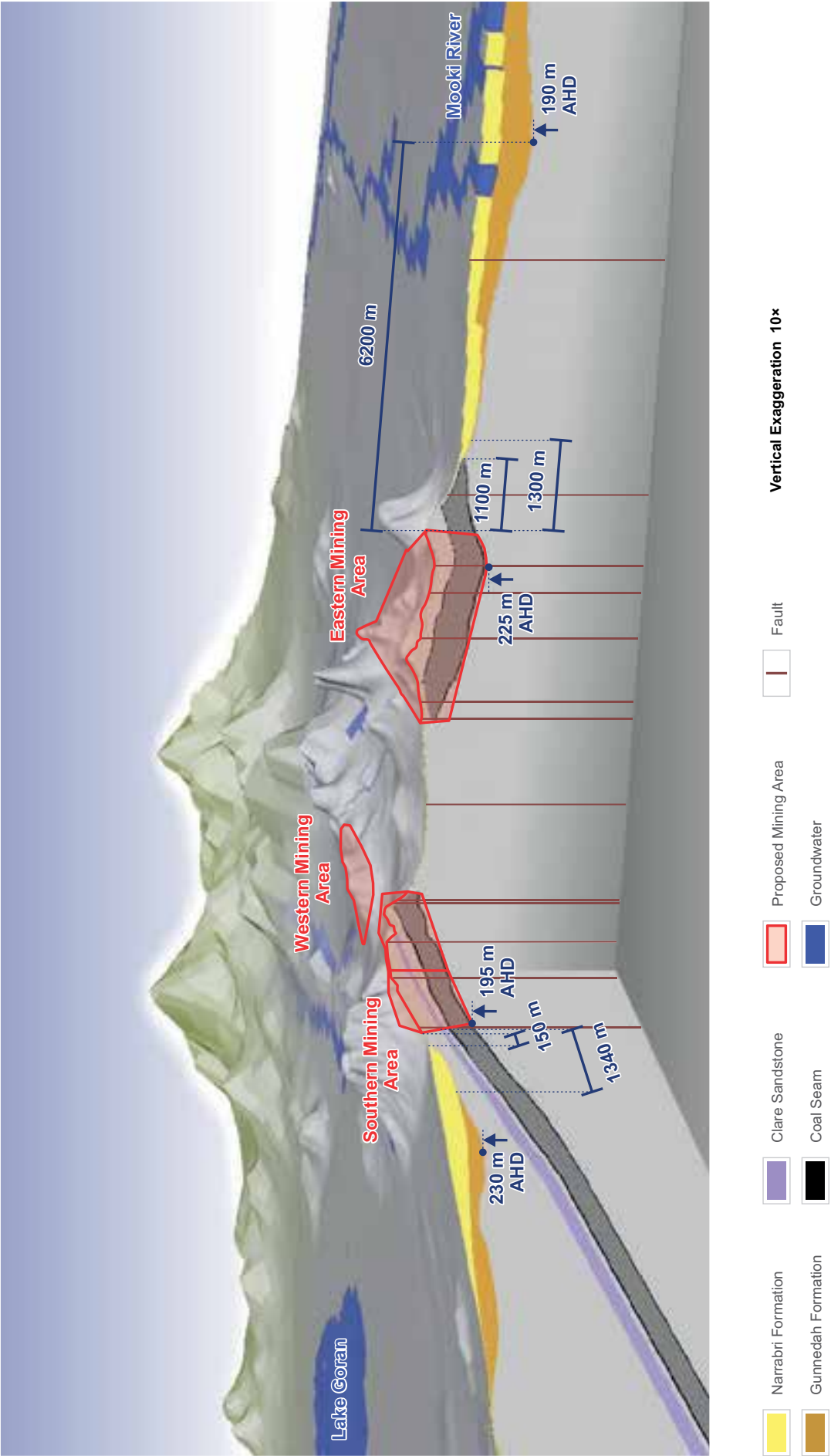
Watermark Coal Project (G1501)
Groundwater Assessment

**Open Cut Mining Areas Aquifer
Offset Distance**



DATE:
18/10/2012

FIGURE No:
10.2



3D Groundwater Block Model

Figure 10.3
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



10.3 Setup and Assumptions

10.3.1 Model Goals

The purpose of the predictive modelling was to:

- estimate groundwater seepages to the open cut void over the 30-year mine life;
- predict the zone of influence of aquifer depressurisation and the level and rate of drawdown at specific locations;
- predict the magnitude of any drainage from the alluvial aquifer into the underlying Permian strata;
- predict the change in groundwater discharges to surface flows and other groundwater users as a result of mine development and mine water seepage;
- indicate potential impact on GDEs (if present); and
- identify areas of potential risk where groundwater impact mitigation/control measures may be necessary.

10.3.2 Staged Timing and Stress Periods

The predictive model was set up with 126 quarterly (each 91.3 days) stress periods, commencing from the end of the calibration period (June 2011) with an initial pre-mining stage of 1.5 years before the onset of mining. The model simulated mining (dewatering of mine cells) on a quarterly basis until the end of mining after 30 years.

At the end of each quarter, the model stopped and aquifer parameters in the recently mined areas changed to represent the spoil. These changes were required to represent the resultant increase in the hydraulic conductivity, porosity and recharge rate to the spoil.

10.3.3 Starting Heads

Precise starting heads were required for the predictive simulations to ensure numerical stability and water budget accuracy. To generate the starting heads, the model ran in steady state, followed by a transient simulation from January 1980 to June 2011. The June 2011 heads from the transient simulation were then used as starting heads.

10.3.4 Recharge

The recharge zones used in the predictive model were the same as those used in the calibration model, and are described in Section 8.4.6. The calibration model calculated recharge to each zone as a fixed percentage of annual rainfall, and these fractions remained the same for the predictive model. The average annual rainfall was recalculated for the predictive model using the last five years of records in the calibration model from June 2006 to June 2011. The average annual rainfall over this period was 659 mm, similar to the long-term average of 644 mm at Breeza 'The Park' Station. The adopted rate was uniform and did not vary with seasons.

The recharge zones used for the predictive model were as follows:

- | | | |
|----------------------------|-----------|---------------------|
| • Alluvial aquifer | 9.9 mm/yr | - 1.5% of rainfall |
| • Regolith/Permian outcrop | 0.3 mm/yr | - 0.05% of rainfall |



- Liverpool range basalt 33.0 mm/yr - 5.0% of rainfall
- Break of slope (alluvium) 6.6 – 165 mm/yr - 1 - 25% of rainfall depending on subs-zone
- Spoil recharge 35.4 mm/yr -5.5% of rainfall

10.3.5 Evapotranspiration

The evapotranspiration applied to the predictive model was the same as the calibrated model, as described in Section 8.4.6.

10.3.6 Groundwater Pumping

The pumping rates applied to bores in the model were based on the metered average pumping rates from June 2006 and June 2010. These rates were uniform and did not vary seasonally. Figure 10.4 shows the quarterly pumping rates adopted for the calibration and predictive models. The long-term average groundwater extraction rates based on available records was estimated at 95.3 ML/day. The predictive model used a slightly lower rate of 85.9 ML/day. Figure 10.4 presents the groundwater extraction rates adopted in the calibration and predictive models.

The slightly lower extraction rate used in the predictive model accounts for the reduction in pumping required over the life of the Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources.

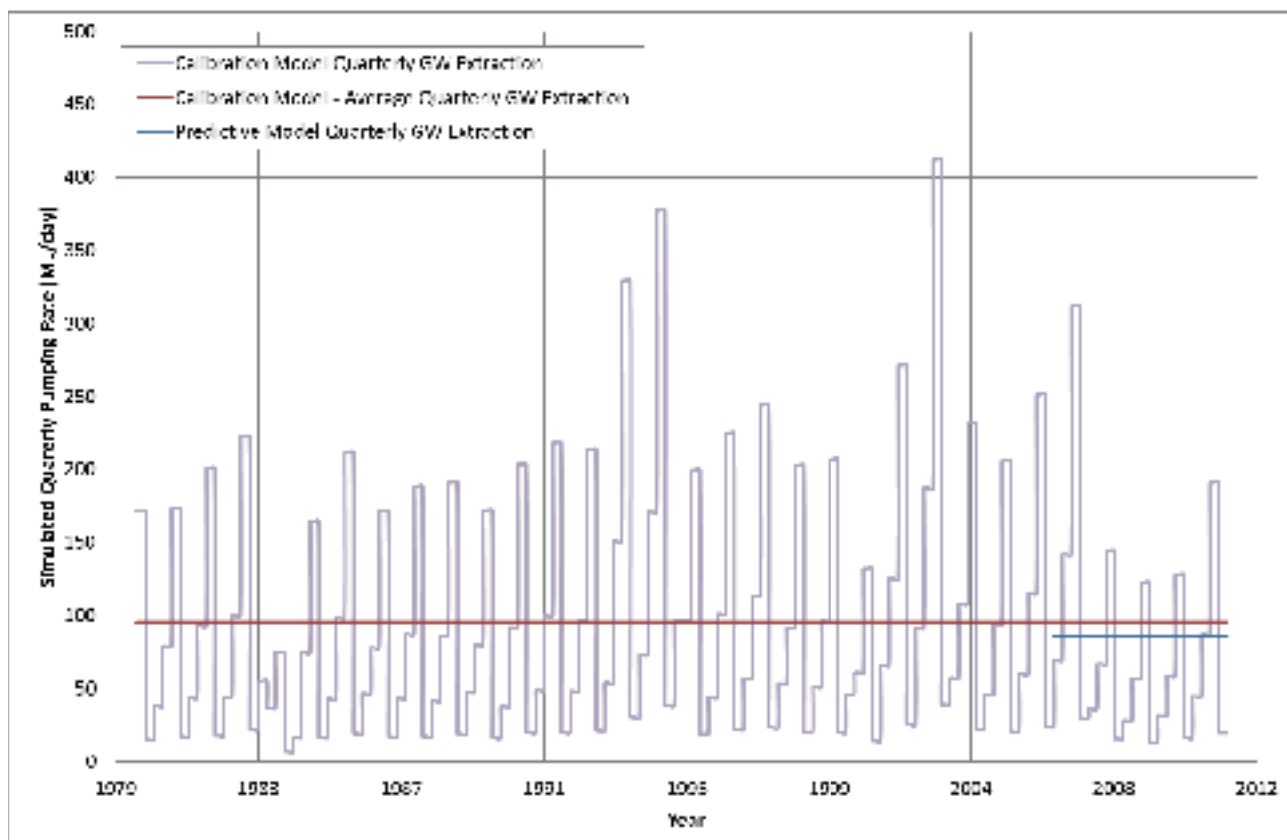


Figure 10.4: Quarterly Groundwater Extraction – Calibration and Predictive



10.3.7 Mine Water Seepage

The SURFACT Drain package (DRN) represented the drainage of groundwater into the open cut Mining Areas. Drain cells were set in the model down to Layer 10, which represents the base of the Melvilles coal seam, the deepest mined formation. Drain cells were assigned a conductance of $100 \text{ m}^2/\text{day}$ to ensure complete dewatering to the base of the mining area floor during each quarter.

Once a drain boundary condition was applied, it remained active for one year. The drain cells were removed from the area where mining had been completed after one year and were then reapplied to the cells representing new strips of mining.

Figure 10.1, presented and discussed in Section 10.2 shows the mines and the rate of advancement used in the transient simulations.

10.3.8 Overburden Backfilling

The mining involves blasting and excavation of overburden, which is deposited behind the working face. The blasted and redeposited overburden material has different aquifer properties to the in-situ material. Mackie (2009) reported that Hunter Valley overburden waste particle size typically ranges between 0.1 m and 2 m, indicating coarse gravel like material. The blasting process and associated change in the physical properties of the overburden increases the hydraulic conductivity, porosity and recharge rates of the overburden waste.

A quarterly 'stop/start' process simulated mining progress in the placement of overburden waste within the Mining Area. The model was stopped every quarter and the aquifer parameters updated to represent the zones where overburden waste had been deposited. shows the aquifer parameters for the spoil. These parameters were based on previous experience in the Hunter Valley documented by Mackie (2009).

Table 10.1: HYDRAULIC PARAMETERS OF SPOIL		
Geology Type	Parameter	Value
Spoil	Horizontal Hydraulic Conductivity k_h	1 m/day
	Vertical Hydraulic Conductivity k_v	0.1 m/day
	Specific Yield S_y	0.1
	Specific Storage S_s	$1 \times 10^{-3} \text{ m}^{-1}$

The stop start process allowed the model to simulate the recovery of water levels in the overburden waste areas as mining progressed and the heightened recharge rate to the overburden waste.

Mackie (2009) noted that deep recharge rates to overburden waste in the Hunter Valley ranges from 1% to 5.5% of long-term rainfall. Based on Mackie's work, when model cells were defined as spoil, the recharge applied to the overburden waste surface was modified for the next stage. A recharge rate of 35.44 mm/year (5.5% of annual rainfall) was adopted for overburden waste areas.

The evapotranspiration surface acting on the overburden waste was adjusted to reflect the final landform surface as the Mining Areas were progressively backfilled. The overburden waste surface was generally five to ten metres higher than the pre-mining land surface.



10.4 Water Budget

Figure 10.5 shows the changes in the model water budget over the 30-year mine life.

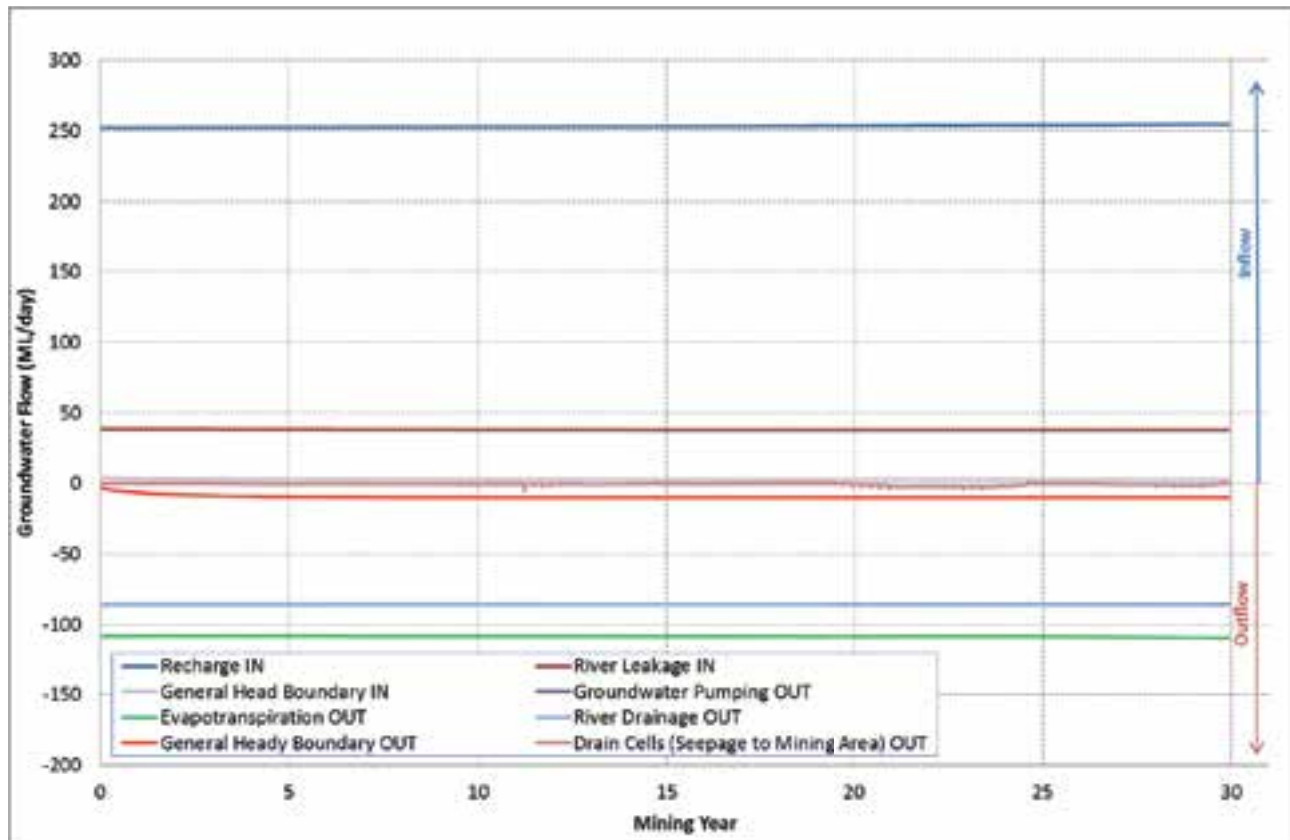


Figure 10.5: Mining Phase Water Budget

Figure 10.5 shows recharge to both the alluvial and fractured rock aquifers dominates inputs to the model water budget averaging about 252 ML/day. The recharge rate to the aquifers increases slightly over the 30-year mining period to 255 ML/day, due to the increased recharge through the overburden waste material in the backfilled mining areas. Seepage through the bed of the rivers into the underlying alluvial aquifers is also a significant contributor to recharge averaging 38 ML/day.

Evapotranspiration is the main mechanism removing water from the model at an average rate of 108 ML/day. Flow from the aquifers to the rivers also removes about 86 ML/day. Pumping from bores also removes an average of 86 ML/day (note this is hidden in Figure 10.5 under the River Drainage OUT). Section 10.3.6 provides more detail on how the pumping rate was determined. Flow out of the model due to mining, which is represented by drains is less than 2 ML/day. The general head boundary, which is located at the northern edge of the model, reports an average inflow to the model of 3 ML/day and outflow of 10 ML/day. There is no significant change in the general head boundary inflow or outflow through the transient predictive simulation, indicating that these boundaries are set at appropriate distances away from the proposed mining.

10.5 Groundwater Seepage to Mining Areas

Figure 10.6 shows the model predicted fluxes of water into proposed Mining Areas.

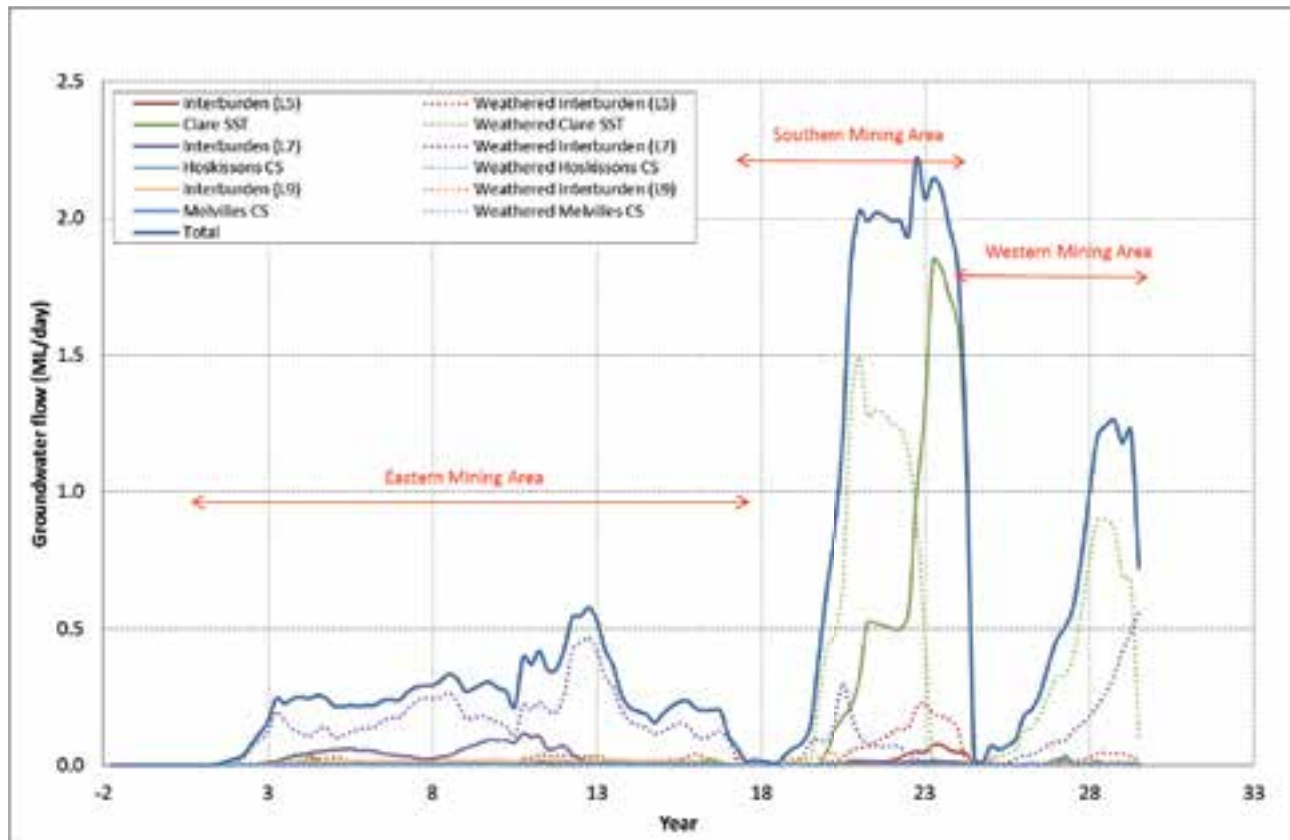


Figure 10.6: Simulated Seepage into the Watermark Mining Areas

The predicted mining seepage rates vary throughout the mining period. The variability is due to the proposed mine depth, strata being mined and hydraulic gradients induced by the depressurisation.

The model predicts seepage rates to the Eastern Mining Area are largely less than 0.5 ML/day, and derived from weathered interburden layers. As mining moves into the Southern Mining Area, seepage rates peak at about 2.2 ML/day (26 L/s) in Year 23. This is because mining intercepts saturated weathered to fresh Clare Sandstone, which is the most porous interburden unit.

The model predicts a maximum seepage rate of 1.25 ML/day in the Western Mining Area in Year 29. Similar to the Southern Mining Area, the majority of the seepage to the Western Mining Area is sourced from the Clare Sandstone (model Layer 6).

The contribution from the coal seams to predicted Mining Area seepage is relatively low. This is due to the low hydraulic conductivity determined from field testing and adopted in the model.

The total predicted groundwater seepage to the Mining Areas over the 30-year Project life is 5500 ML, averaging 180 ML/year (0.51 ML/day). The peak average annual seepage of 760 ML/year occurs during Year 23 from the Southern Mining Area. Groundwater seepage reduces as the mining area is backfilled following mining. Note based on the abstraction licence data obtained, an average irrigation bore within the entire model domain withdraws groundwater at



a rate of 730 ML/year. The average pumping rate from a single licensed agricultural bore within 10 km of the Project Boundary is lower at 142 ML/year.

Representing the groundwater seepage to the Mining Area with the drain package has a number of simplifying assumptions. The predicted drain flows include groundwater that would drain to the Mining Area sumps, and groundwater that would not reach the Mining Area sumps before being evaporated. In reality, evaporation from the coal face exposed in the highwall and endwall would remove a proportion of the seepage predicted by the modelling and not all of the simulated seepage would flow to sumps for removal by pumping.

Evaporative losses of groundwater from the Mining Areas were estimated simplistically by assuming an evaporation rate of 5 mm/day from the water bearing units in the active face. This indicates evaporative losses from the regolith and Clare Sandstone, which are the main water bearing units in the mining areas, may range between 0.1 ML/day and 0.4 ML/day. When the evaporative loss is accounted for, the seepage to the Eastern Mining Area requiring pumping will be relatively low. Figure 10.7 presents simulated seepage into the Mining Areas corrected for evaporative loss (red).

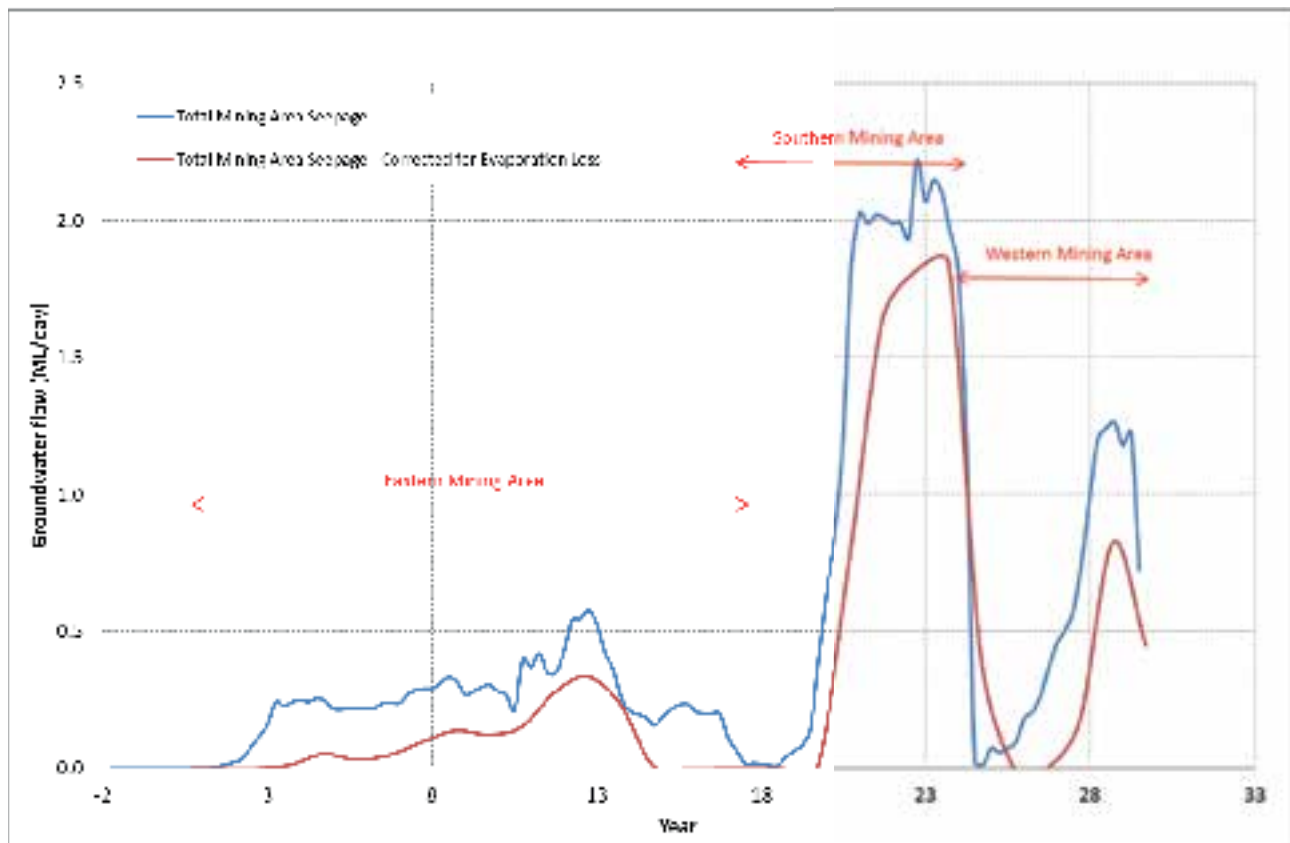


Figure 10.7: Simulated Seepage into the Mining Areas – Corrected for Evaporation Loss

Corrected evapotranspiration seepage rates were calculated as yearly averages, and therefore there is a slight overlap of data during year 24 and year 25.

NSW Office of Water (NOW) required the groundwater study justify the “*nominated setback distance from the Upper Namoi alluvium in terms of existing and predicted changes in contribution, flux and migration of groundwater, and maintenance of existing groundwater quality ranges and zonations.*” The modelled seepage rates are relatively low and in the typical range for coal mining



operations. The modelling indicates the setback distance is sufficient to control the flux of groundwater into the proposed Mining Areas.

10.6 Changes in Potentiometric Surface/Water Table Levels

The process of open cut mining reduces water pressures in surrounding aquifers. The extent of the zone affected is dependent on the properties of the coal seams and interburden units, and in this study is referred to as the zone of depressurisation. Depressurisation of the coal formations is greatest at the working coalface, and gradually reduces with distance from the mine.

The numerical model calculated the extent of the zone of depressurisation within the Permian and alluvial groundwater systems due to mining by comparing water levels with and without the proposed mine operating. Two scenarios were simulated, firstly with all proposed mining active, and secondly with no mining. The zone of depressurisation due to mining was determined as the difference in the potentiometric surface between these runs.

The modelling indicates that the groundwater seepage into the mine will result regionally in a generally radial zone of depressurisation in the potentiometric surface expanding away from the active Mining Area face.

10.6.1 Permian Drawdown

Figure 10.8 to Figure 10.11 present the predicted zone of depressurisation for the Melvilles coal seam for years 12.5, 21, 25.5 and 30 of the Project. These years represent periods where the active Mining Area faces are adjacent to the Quaternary alluvium and the zone of depressurisation is most extensive. The depressurisation in the other Permian units, including the Clare Sandstone is similar to that shown for the Melvilles Coal Seam.

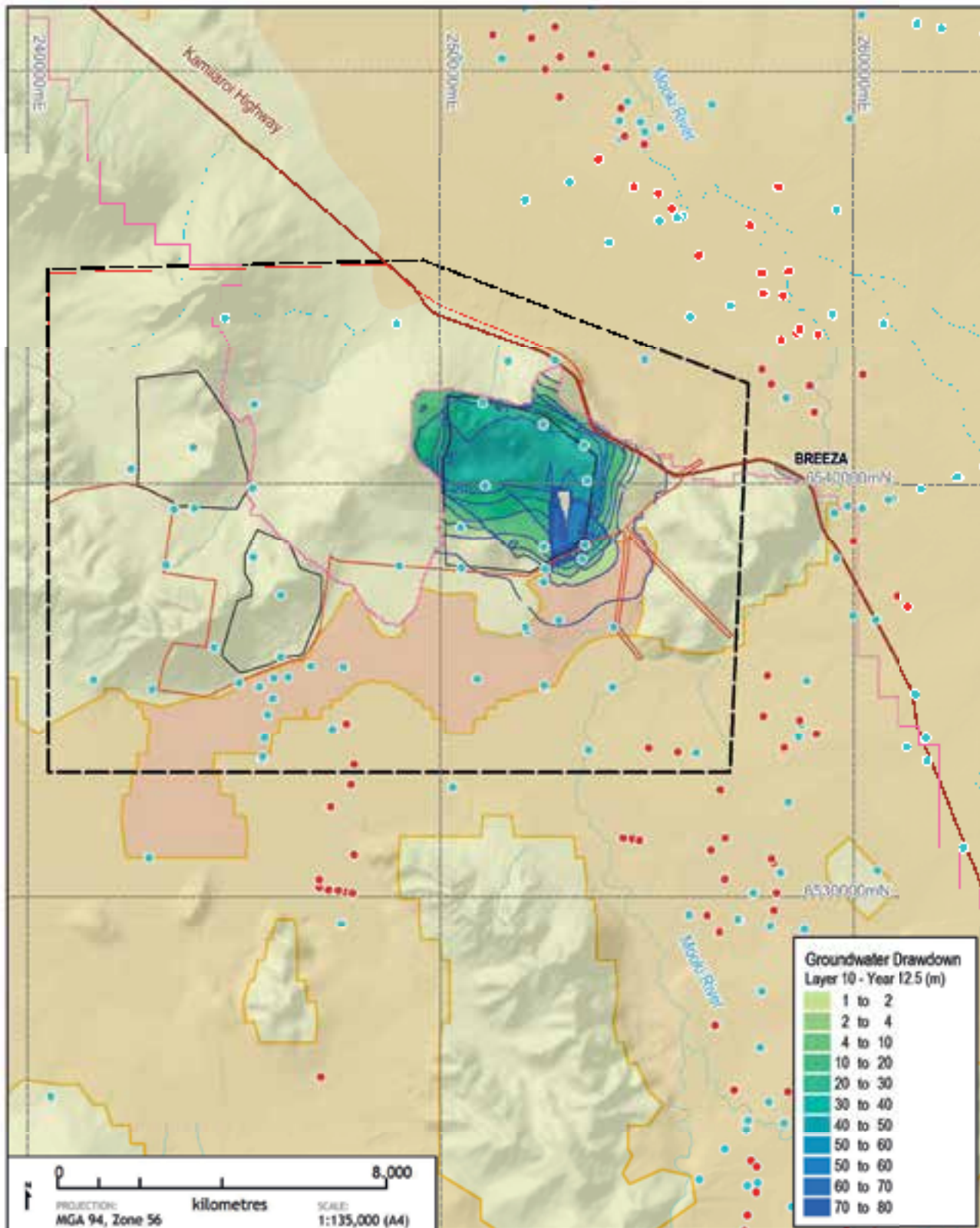
The depressurisation induced by mining in the Eastern Mining Area extends to a maximum of 1.8 km from the Mining Area in year 21 (based on 1 m drawdown contour). The model predicts significant depressurisation largely in the ridge area, but a reduction in groundwater levels of 3 m or less is predicted in the Permian underlying the Narrabri Formation, laterally extending up to 0.7 km. The model does not predict drawdown of greater than 1 m in the Permian underlying the Gunnedah Formation due to the Eastern Mining Area.

The depressurisation induced by mining in the Southern Mining Area, is more extensive and extends to a maximum of 3.2 km from the Mining Area in year 25.5 (based on 1 m drawdown contour). The model predicts a drawdown of 25 m or less in the Permian underlying the Narrabri Formation. The depressurisation in the Permian extends to the south where the overlying Gunnedah Formation is present. At this distance, drawdown in the Permian is predicted to be less than 2 m.

The depressurisation induced by the Western Mining Area is less significant than the Southern Mining Area and Eastern Mining Area because it is located in an elevated area where groundwater levels are deeper and the operating life is short at 6 years. The zone of depressurisation extends to a maximum of 1 km from the Mining Area in year 30 (based on 1 m drawdown contour). Depressurisation due to the Western Mining Area does not extend in the Permian under the alluvial aquifers, as they are relatively remote. The model does indicate that the zone of depressurisation merges with the zone developed around the Southern Mining Area, locally increasing the magnitude of the drawdown.



Radial drawdown in the Permian is slightly constrained by hydraulic fault barriers, particularly in the southern area of the Eastern Mining Area and south-west of the Western Mining Area. The model indicates groundwater levels begin to recover after the backfilling of the Eastern Mining Area and Southern Mining Area. This is due to seepage into the spoil from the Mining Area walls and from rainfall recharge. In the Southern Mining Area, this results in groundwater levels recovering higher than pre-mining levels. Section 10.11 presents further detail in the recovery.



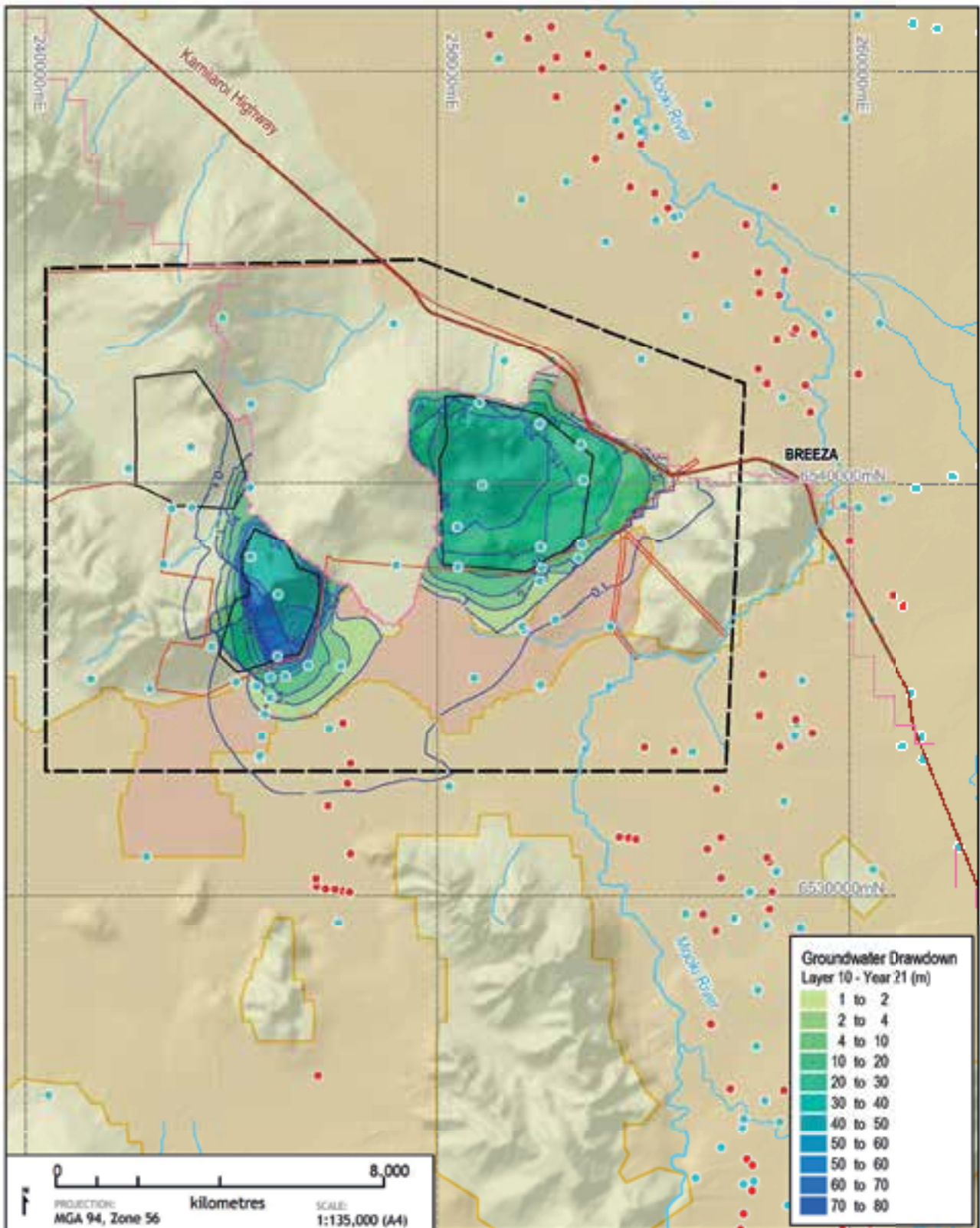
Watermark Coal Project (G1501)
Groundwater Assessment

Drawdown Contours Year 12.5 (Melville's Coal Seam)



DATE:
18/10/2012

FIGURE No:
10.8



- LEGEND:**
- Observation Bore
 - Proposed Mining Area
 - EL 7223
 - Watercourse Line
 - Usage Bore
 - Highway
 - Melville Coal Seam - Extent
 - Drawdown Contour (m)
 - Gunnedah Aquifer Extent
 - Narrabri Aquifer Extent
 - Project Boundary

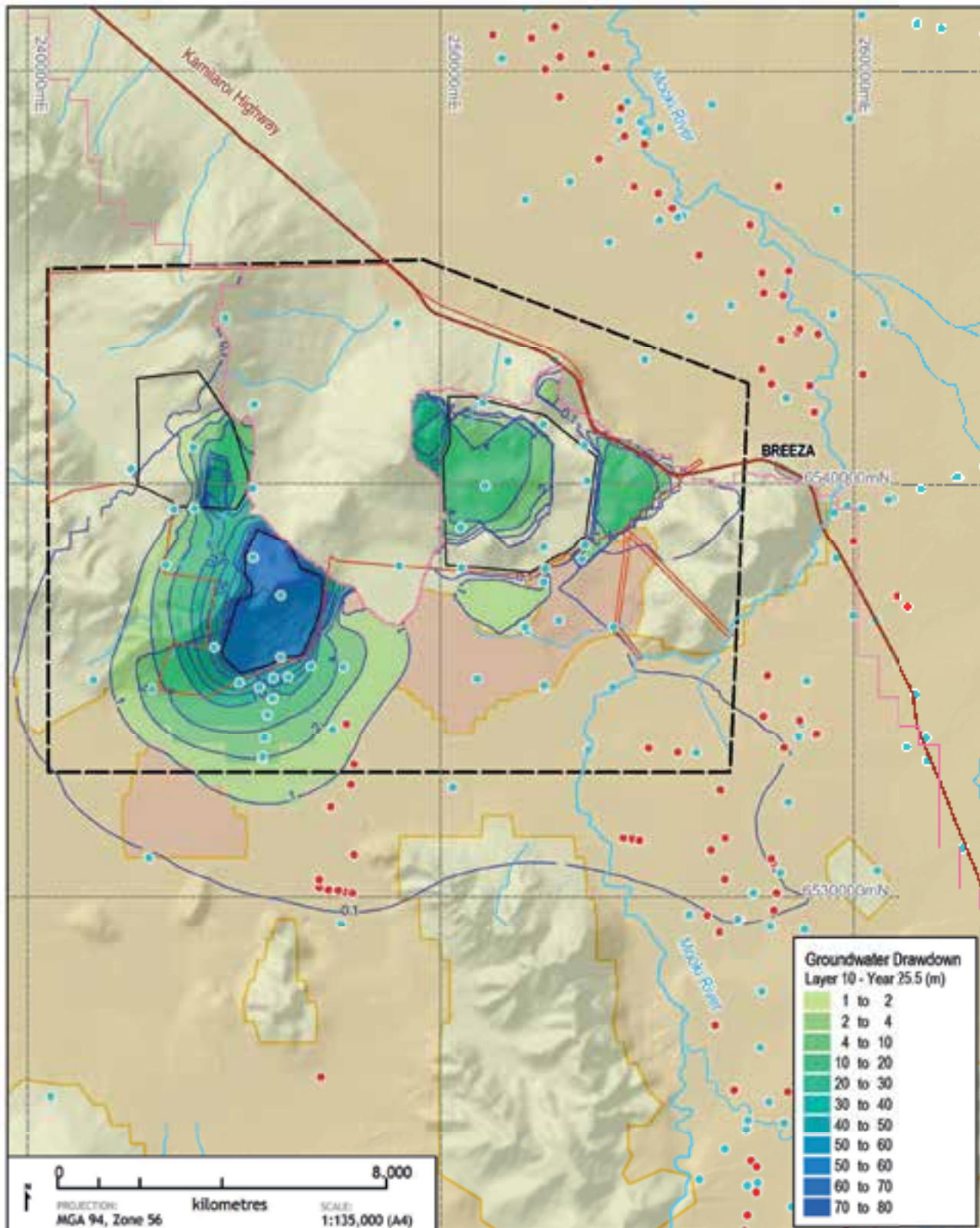
Watermark Coal Project (G1501)
Groundwater Assessment

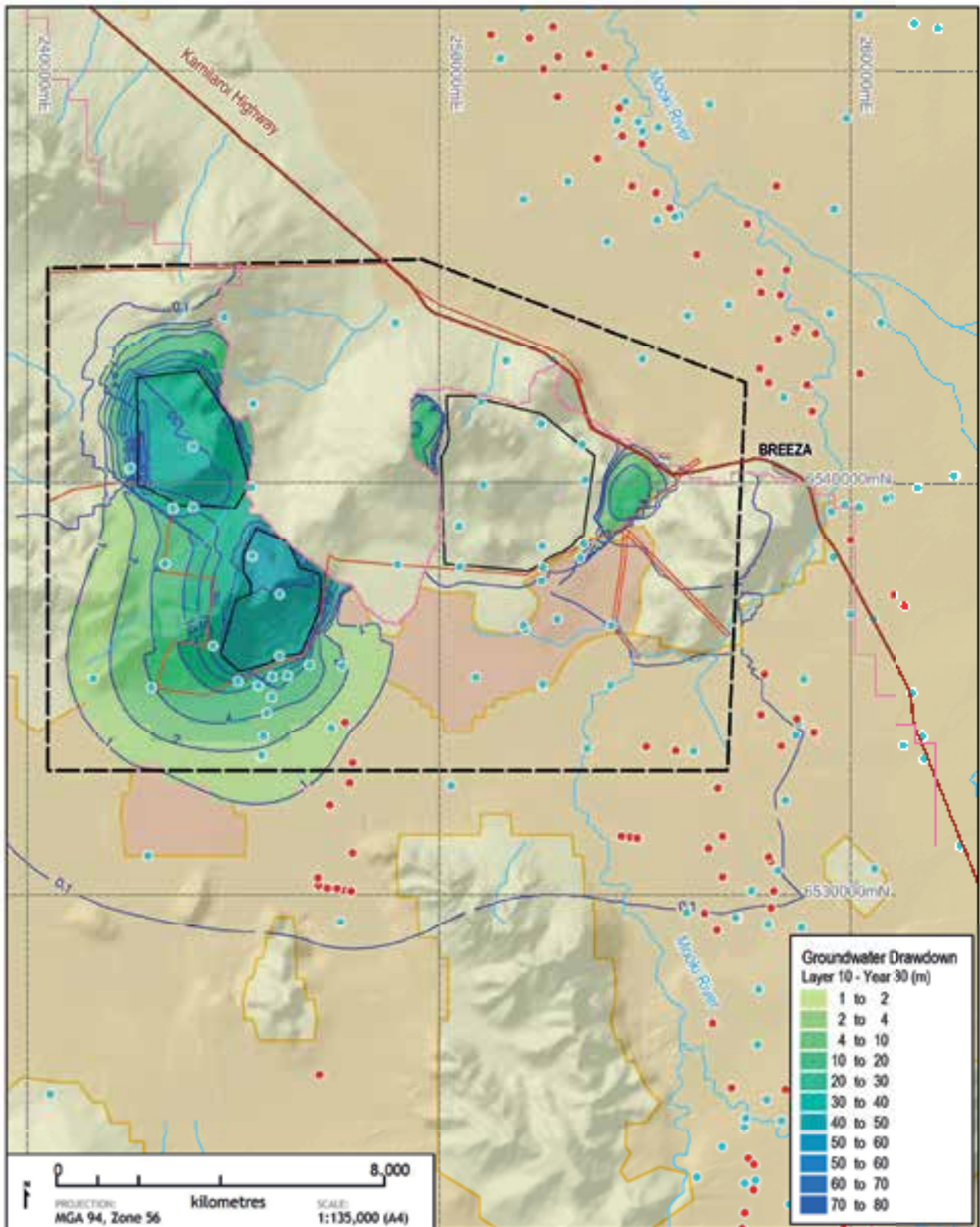
**Drawdown Contours
Year 21 (Melville Coal Seam)**



DATE:
18/10/2012

FIGURE NO:
10.9





- LEGEND:**
- Observation Bore
 - Proposed Mining Area
 - EL 7223
 - Watercourse Line
 - Usage Bore
 - Highway
 - Melville Coal Seam - Extent
 - Drawdown Contour (m)
 - Gunnedah Aquifer Extent
 - Namabri Aquifer Extent
 - Project Boundary

Watermark Coal Project (G1501)
Groundwater Assessment

**Drawdown Contours
Year 30 (Melville Coal Seam)**



DATE:
18/10/2012

FIGURE NO:
10.11



10.6.2 Clare Sandstone Formation Drawdown

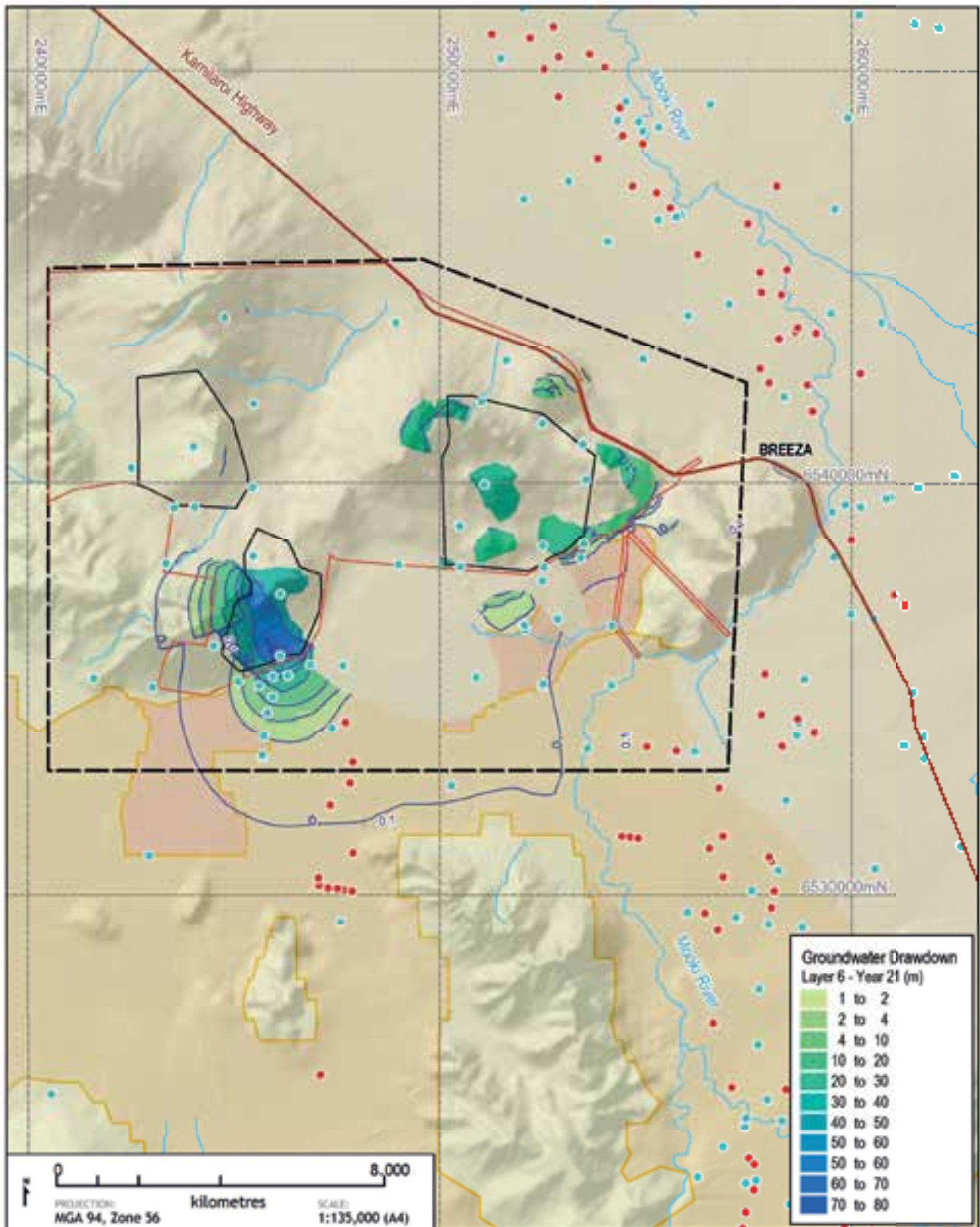
The proposed open cut mining areas intersects both the weathered and fresh units of the Clare Sandstone and suggests depressurisation extends slightly further than the Melvilles coal seam drawdown extents due to the higher hydraulic conductivity of this aquifer formation. Figure 10.12 to Figure 10.14 present the predicted zone of depressurisation in the Clare Sandstone Formation for years 21, 25.5 and 30 of the Project.

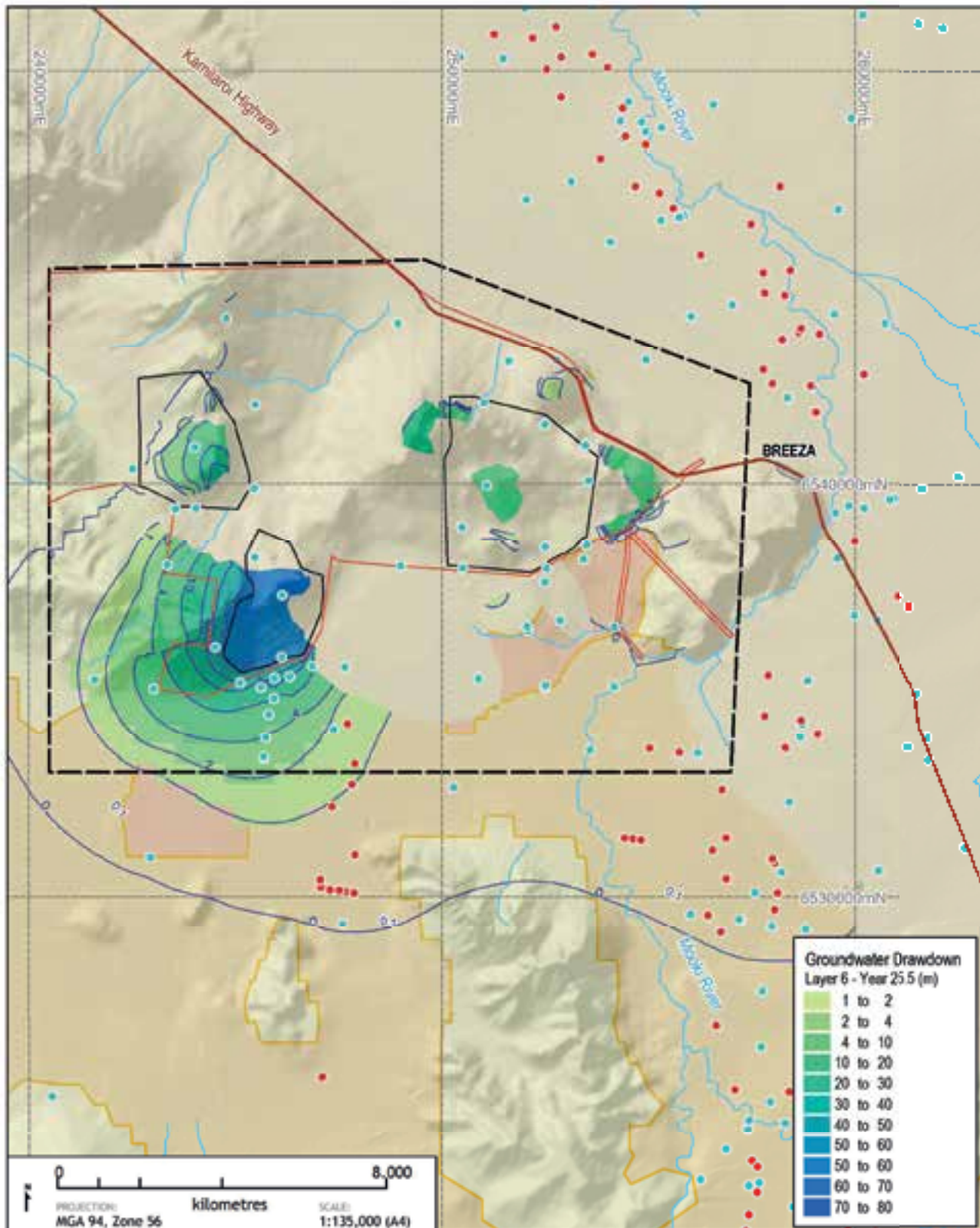
The depressurisation induced by mining in the Eastern Mining Area is negligible, due to the absence of saturated Clare Sandstone over this location.

Depressurisation induced by the Southern Mining Area is more extensive and extends to a maximum of 3.7 km from the southern wall in year 25.5 (based on 1 m drawdown contour).

Following this period, groundwater drawdown induced by mining in the Western Mining Area, combined with a slower recovery than in the lower Permian strata, extends to maximum radial drawdown extents of 4.0 km from the western wall of the Southern Mining Area at year 30. Radial drawdown west of the Western Mining Area is less extensive, due to the hydraulic disconnection of the unit where the Clare Sandstone has been eroded away (refer to Figure 10.14)

Radial drawdown in the Clare Sandstone is slightly constrained by hydraulic fault barriers, particularly in the southern area of the Eastern Mining Area and south-west of the Western Mining Area.





LEGEND:

- Observation Bore
- Proposed Mining Area
- EL 7223
- Watercourse Line
- Usage Bore
- Highway
- Groundwater Drawdown (m)
- Gunnedah Aquifer Extent
- Namabri Aquifer Extent
- Project Boundary

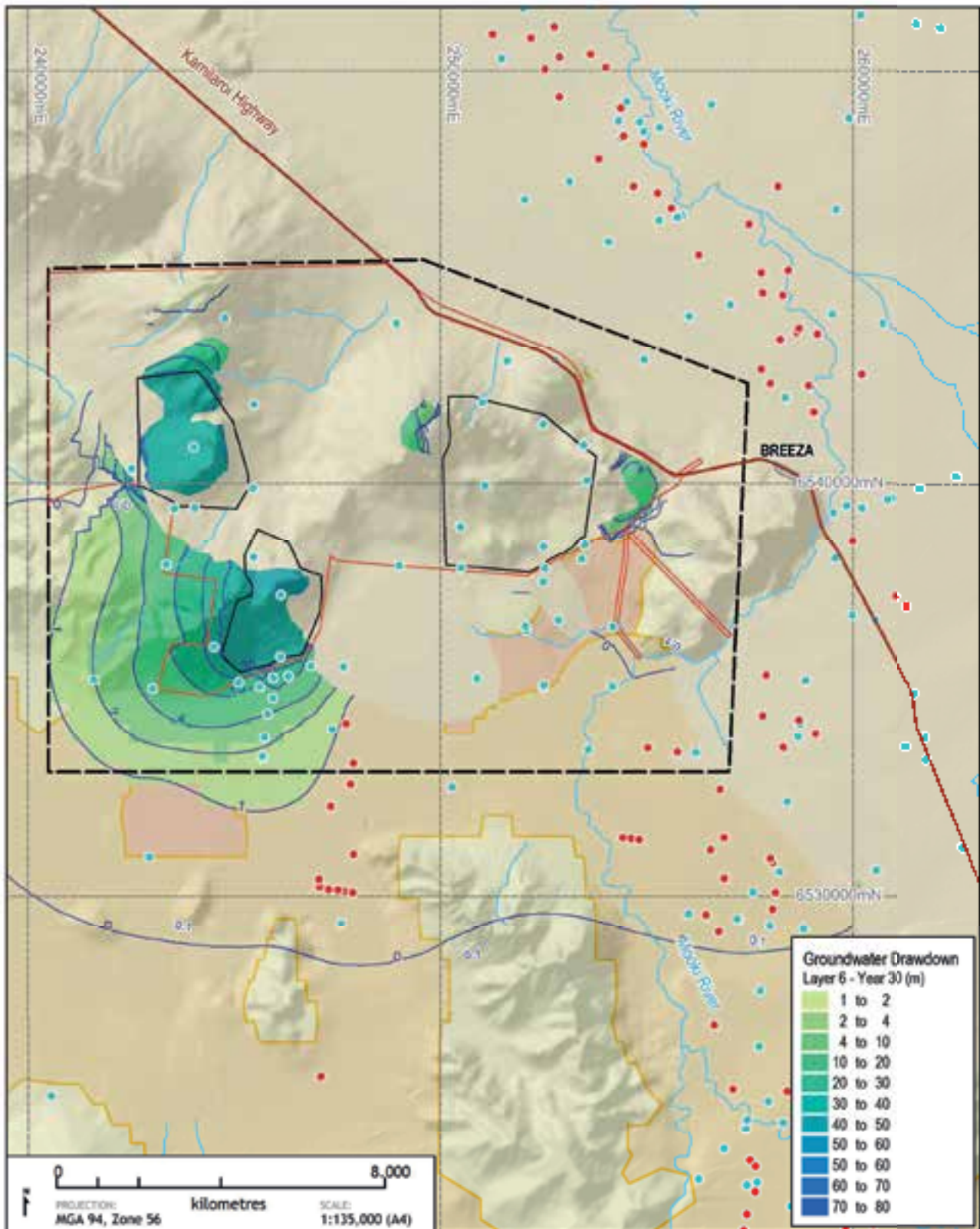
Watermark Coal Project (G1501)
Groundwater Assessment

**Drawdown Contours
Year 25.5 (Clare Sandstone)**



DATE:
18/10/2012

FIGURE No:
10.13



Watermark Coal Project (G1501)
Groundwater Assessment
**Drawdown Contours
Year 30 (Clare Sandstone)**



DATE:
18/10/2012

FIGURE No:
10.14



10.6.3 Alluvial Formation Drawdown

The proposed open cut mining areas do not directly intersect the alluvial aquifers in the Narrabri and Gunnedah Formations. The model suggests depressurisation in the underlying Permian strata may induce vertical flow from the overlying alluvial aquifers into the underlying Permian. This downward flow within the model induces drawdown in groundwater levels in the alluvial aquifers. Figure 10.15 to Figure 10.18 present the predicted zone of depressurisation in the Narrabri Formation for the years 12.5, 21, 25.5 and 30.

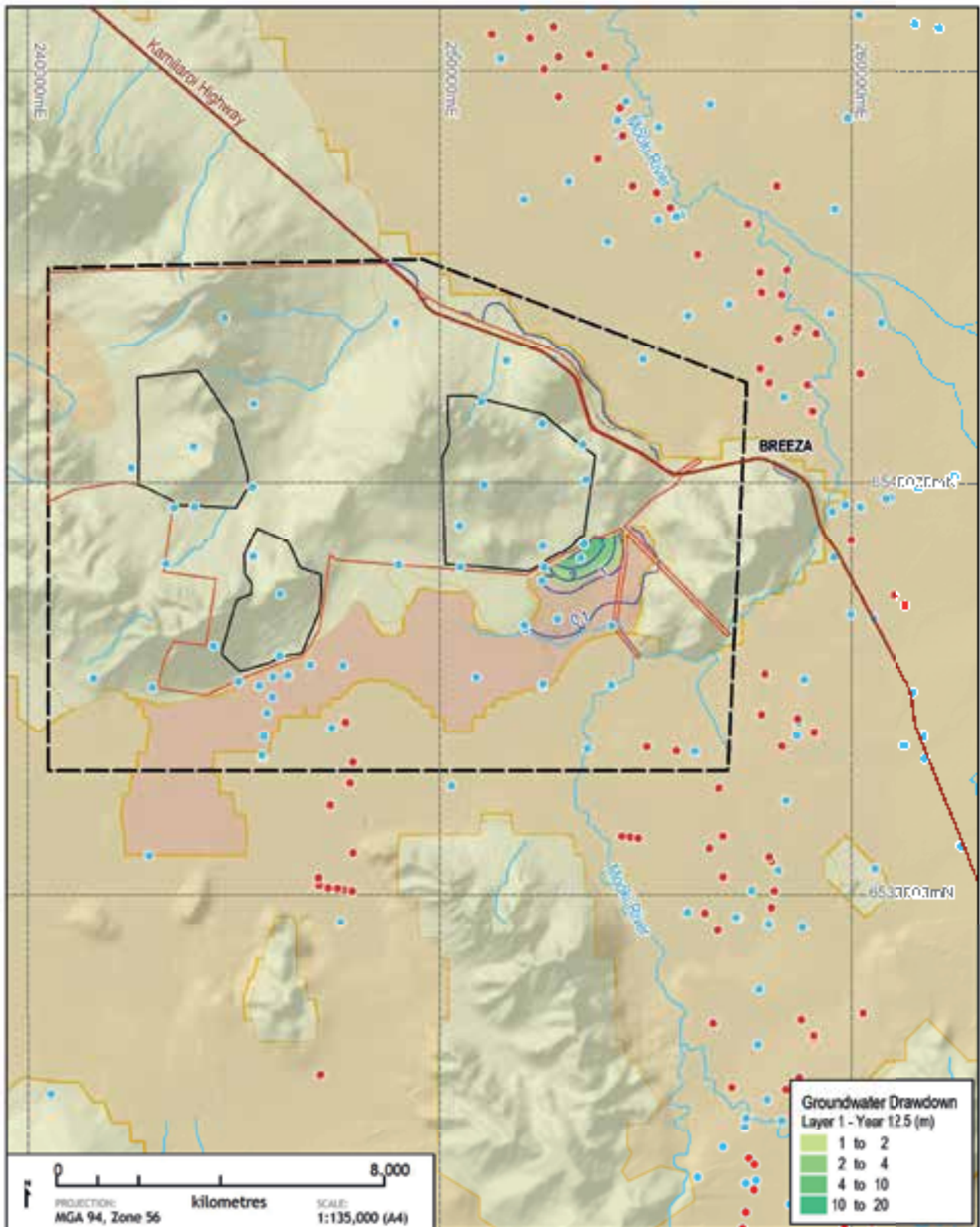
The model predicts a zone of drawdown that extends into the Narrabri Formation adjacent to the Eastern Mining Area and Southern Mining Area. The zone of drawdown is greatest adjacent to the high/end walls, and reduces in magnitude with distance. The zone of drawdown generated by the Eastern Mining Area extends about 1 km from the high wall and is within the Narrabri Formation only. The zone of drawdown around the Southern Mining Area is more extensive and extends towards the south and into the underlying Gunnedah Formation. Figure 10.19 to Figure 10.22 show the drawdown in the Gunnedah Formation. The model predicts drawdown in the Gunnedah Formation to be generally 1 m to 2 m at year 21. Depressurisation in the alluvium extends to a maximum of 3.9 km from the Southern Mining Area in year 25.5 (based on 1 m drawdown contour).

As seasonal variation is typically ± 1 m to 2 m, it is possible the groundwater drawdowns could be masked during periods of significant sustained recharge.

The proposed Mining Areas will not directly intersect the Narrabri and Gunnedah Formations, and the predicted change in water level is therefore induced by a reduction in pressure in the underlying Permian bedrock. The model allows water to transfer from the alluvium into the underlying Permian bedrock. It is possible in reality that the hydraulic connection between the Narrabri Formation and the underlying Permian adjacent to the proposed Southern and Eastern Mining Areas is not as direct and uniform as simulated by the model. In this case, the depressurisation in the alluvium would be expected to be significantly less extensive than the conservative groundwater model predicts.

10.6.4 Saturation Level Head

Figure 10.23 to Figure 10.28 present hydraulic heads and the potentiometric surface along north-south and west-east sections through the groundwater model at years 21, 25.5 and 30 of the Project.



LEGEND:

- | | |
|---|--|
| ● Observation Bore | — Highway |
| — Proposed Mining Area | — Drawdown Contour (m) |
| - - - EL 7223 | Gunnedah Aquifer Extent |
| — Watercourse Line | Narrabri Aquifer Extent |
| ● Usage Bore | Project Boundary |

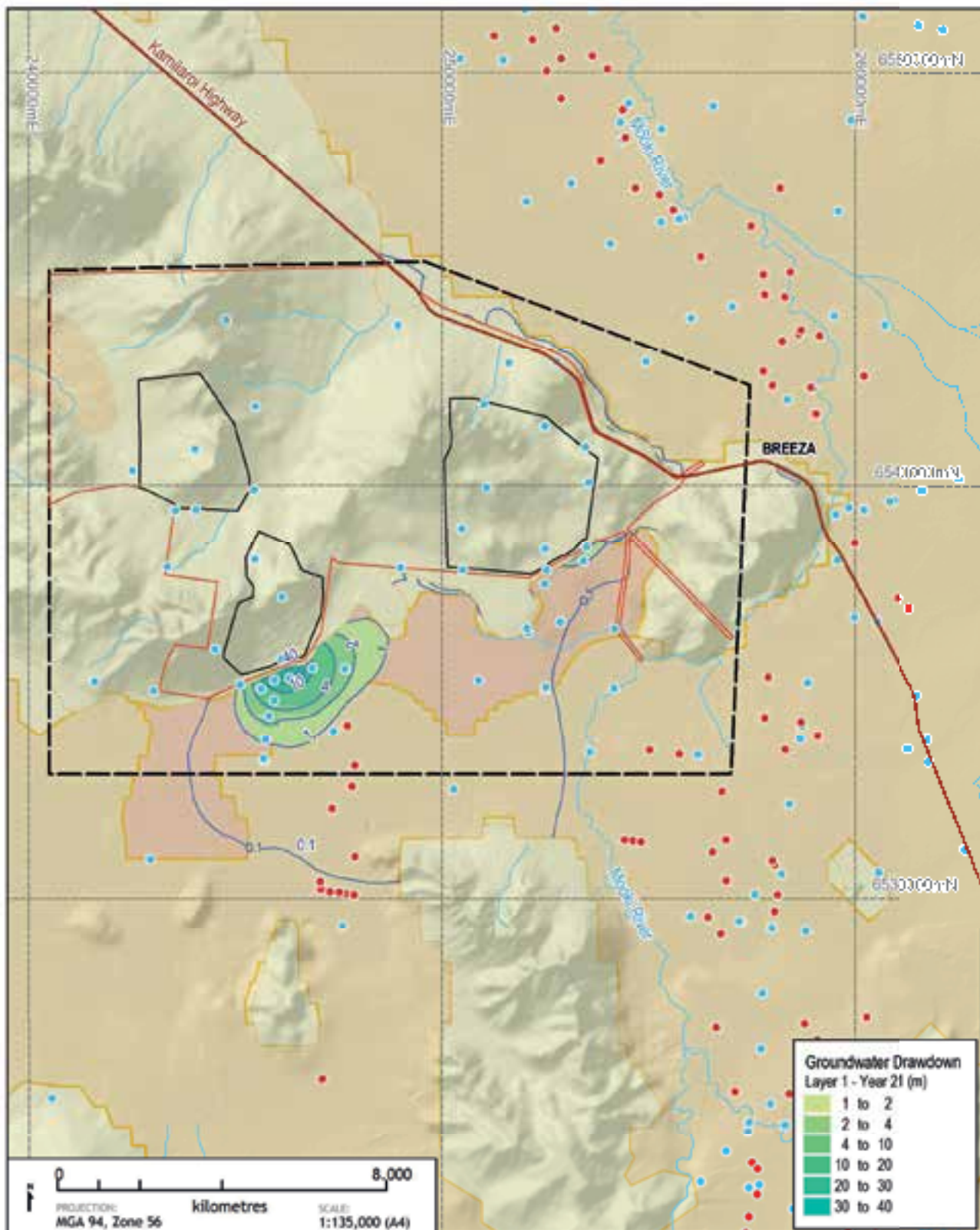
Watermark Coal Project (G1501)
Groundwater Assessment

**Drawdown Contours
Year 12.5 (Narrabri Formation)**



DATE:
18/10/2012

FIGURE No:
10.15



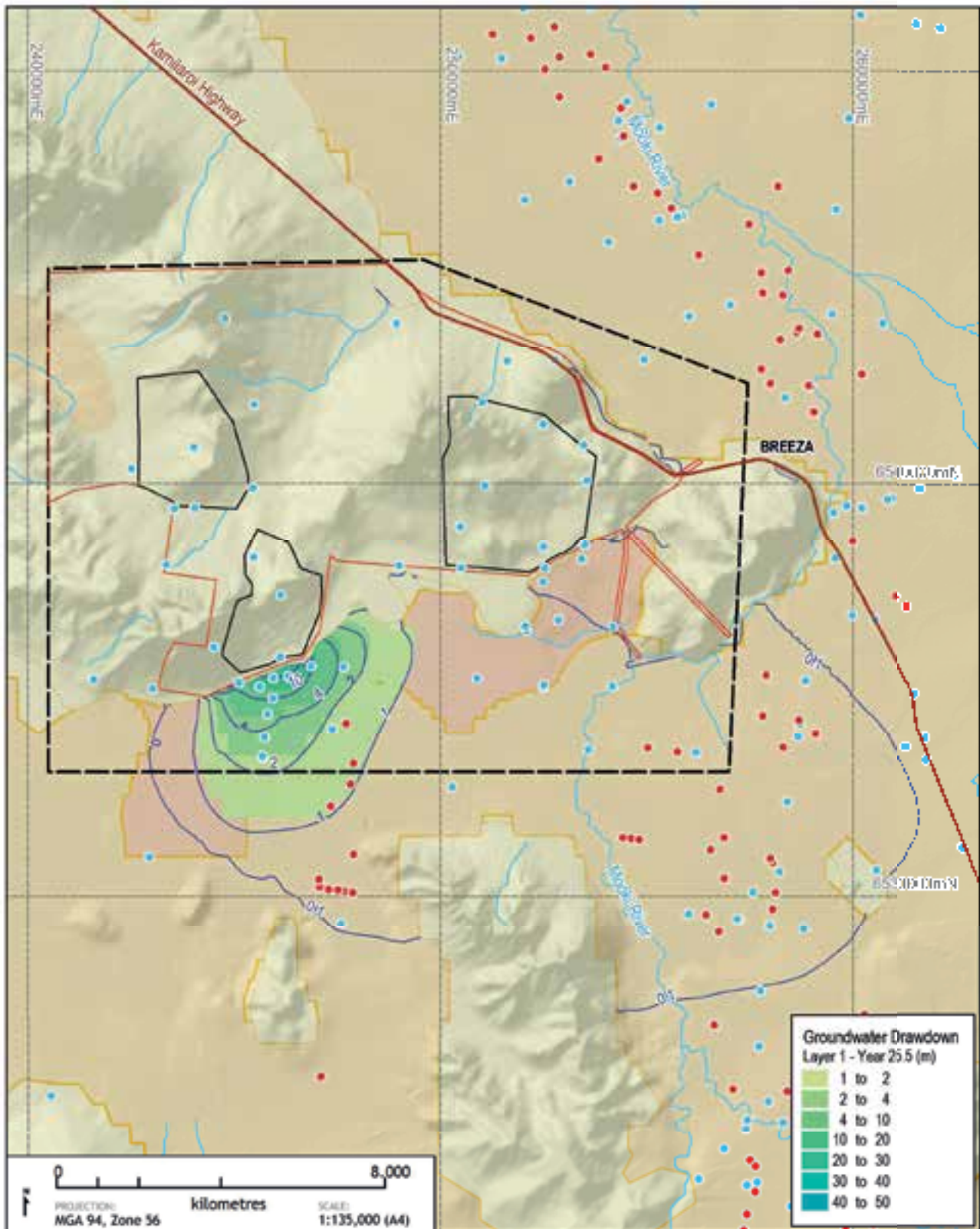
Watermark Coal Project (G1501)
Groundwater Assessment

**Drawdown Contours
Year 21 (Narrabri Formation)**



DATE:
18/10/2012

FIGURE No:
10.16



LEGEND:

- | | |
|------------------------|---------------------------|
| ● Observation Bore | — Highway |
| — Proposed Mining Area | — Drawdown Contour (m) |
| — EL 7223 | ■ Gunnedah Aquifer Extent |
| — Watercourse Line | ■ Narrabri Aquifer Extent |
| ● Usage Bore | □ Project Boundary |

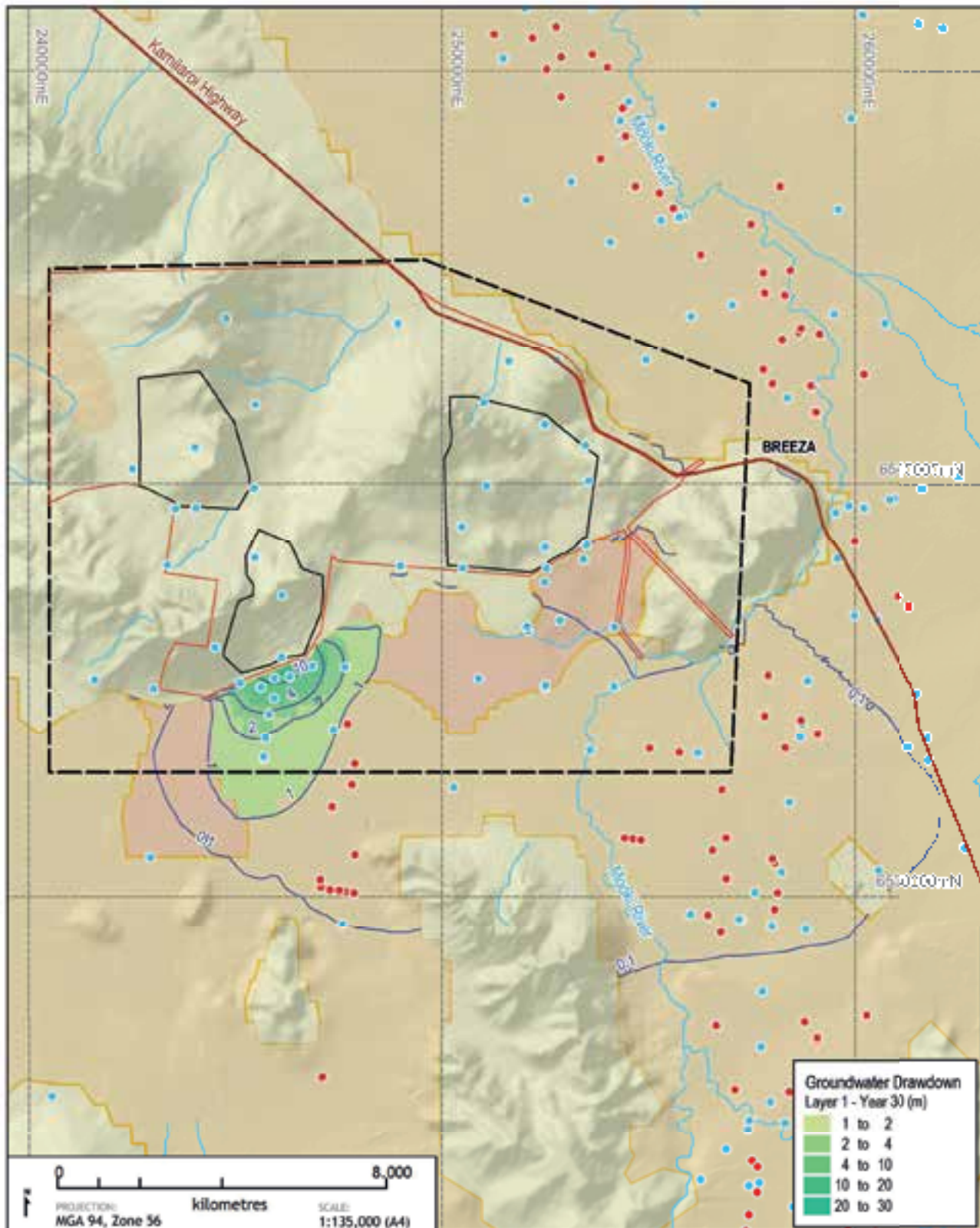
Watermark Coal Project (G1501)
Groundwater Assessment

**Drawdown Contours
Year 25.5 (Narrabri Formation)**



DATE:
18/10/2012

FIGURE NO:
10.17



LEGEND:

- Observation Bore
- Proposed Mining Area
- EL 7223
- Watercourse Line
- Usage Bore
- Highway
- Drawdown Contour (m)
- Gunndah Aquifer Extent
- Narabri Aquifer Extent
- Project Boundary

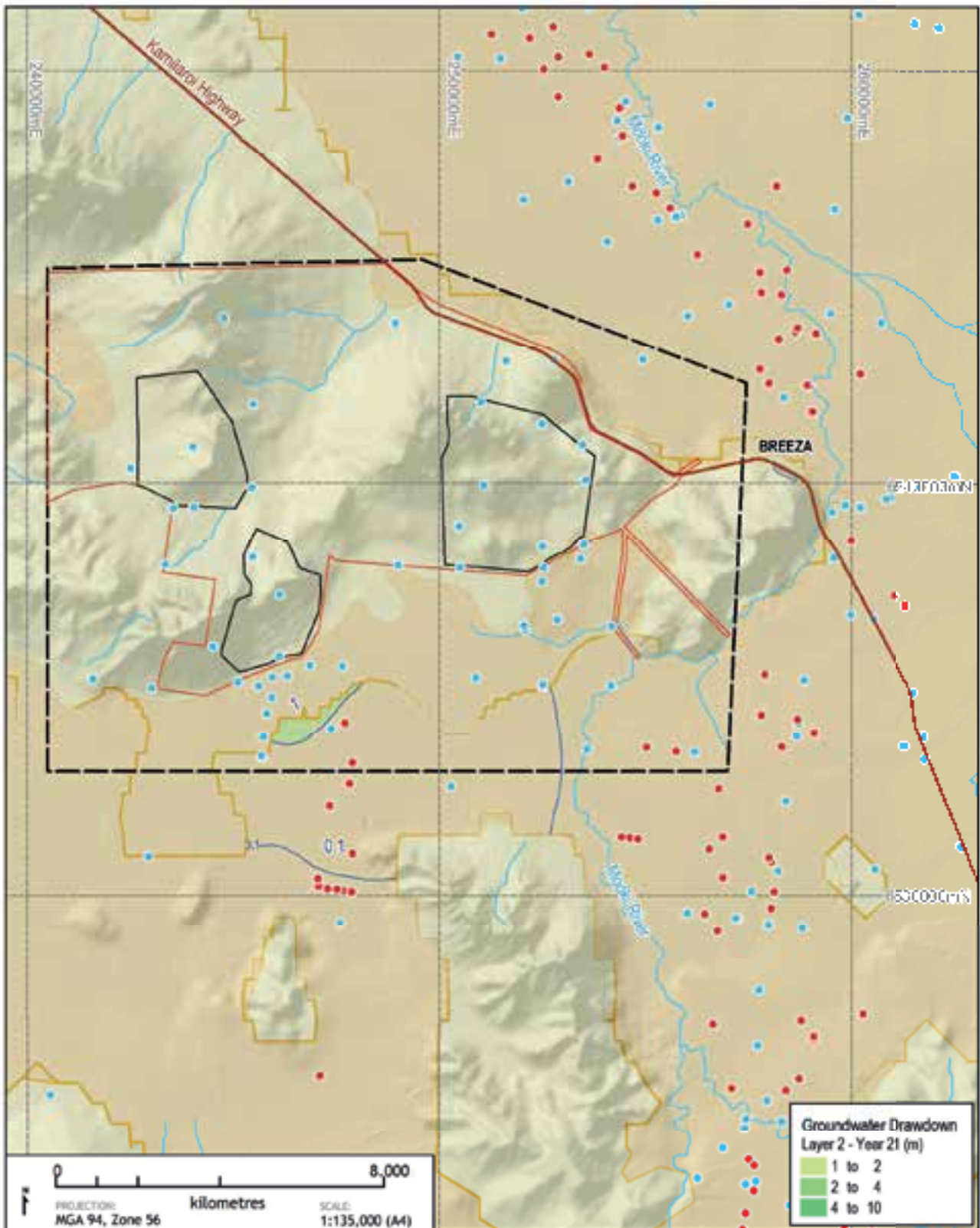
Watermark Coal Project (G1501)
Groundwater Assessment

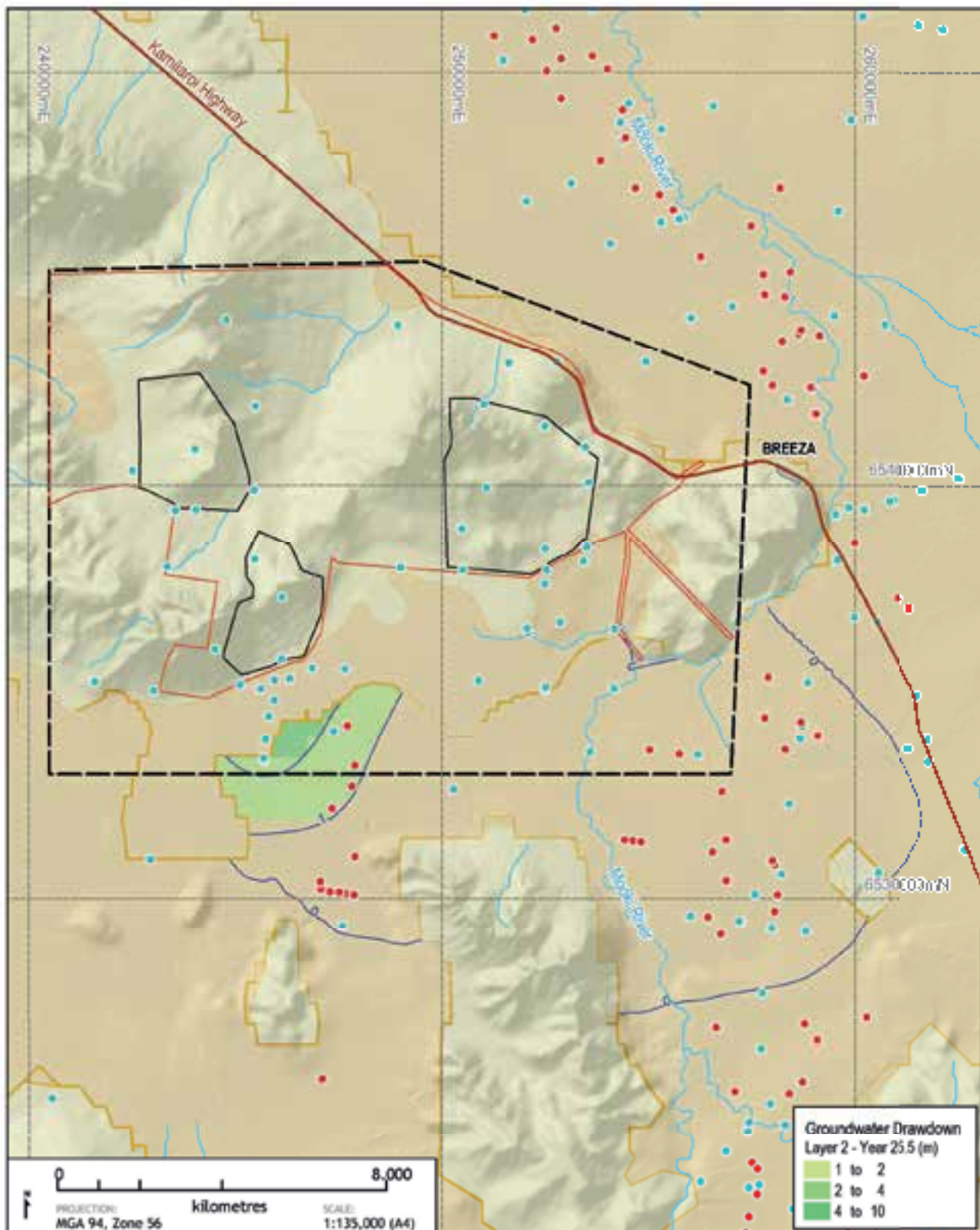
**Drawdown Contours
Year 30 (Narabri Formation)**



DATE:
18/10/2012

FIGURE No:
10.18





LEGEND:

- Observation Bore
- Proposed Mining Area
- EL 7223
- Watercourse Line
- Usage Bore
- Highway
- Drawdown Contour (m)
- Gunnedah Aquifer Extent
- Narrabri Aquifer Extent
- Project Boundary

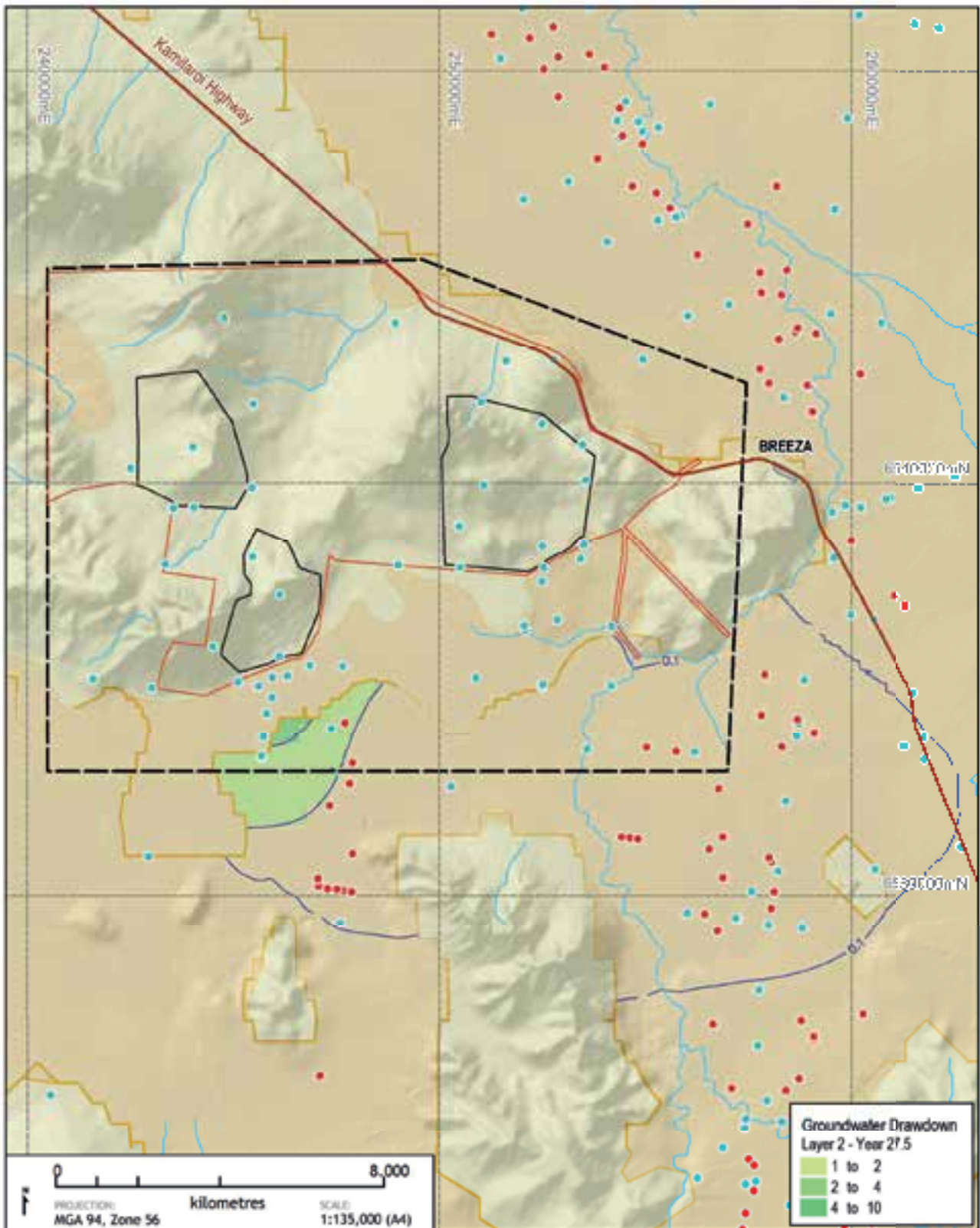
Watermark Coal Project (G1501)
Groundwater Assessment

**Drawdown Contours
Year 25.5 (Gunnedah Formation)**



DATE:
18/10/2012

FIGURE No:
10.20



LEGEND:

- | | |
|---|---|
| ● Observation Bore | — Highway |
| — Proposed Mining Area | — Drawdown Contour (m) |
| - - - EL 7223 | Gunndah Aquifer Extent |
| — Watercourse Line | Namabri Aquifer Extent |
| ● Usage Bore | Project Boundary |

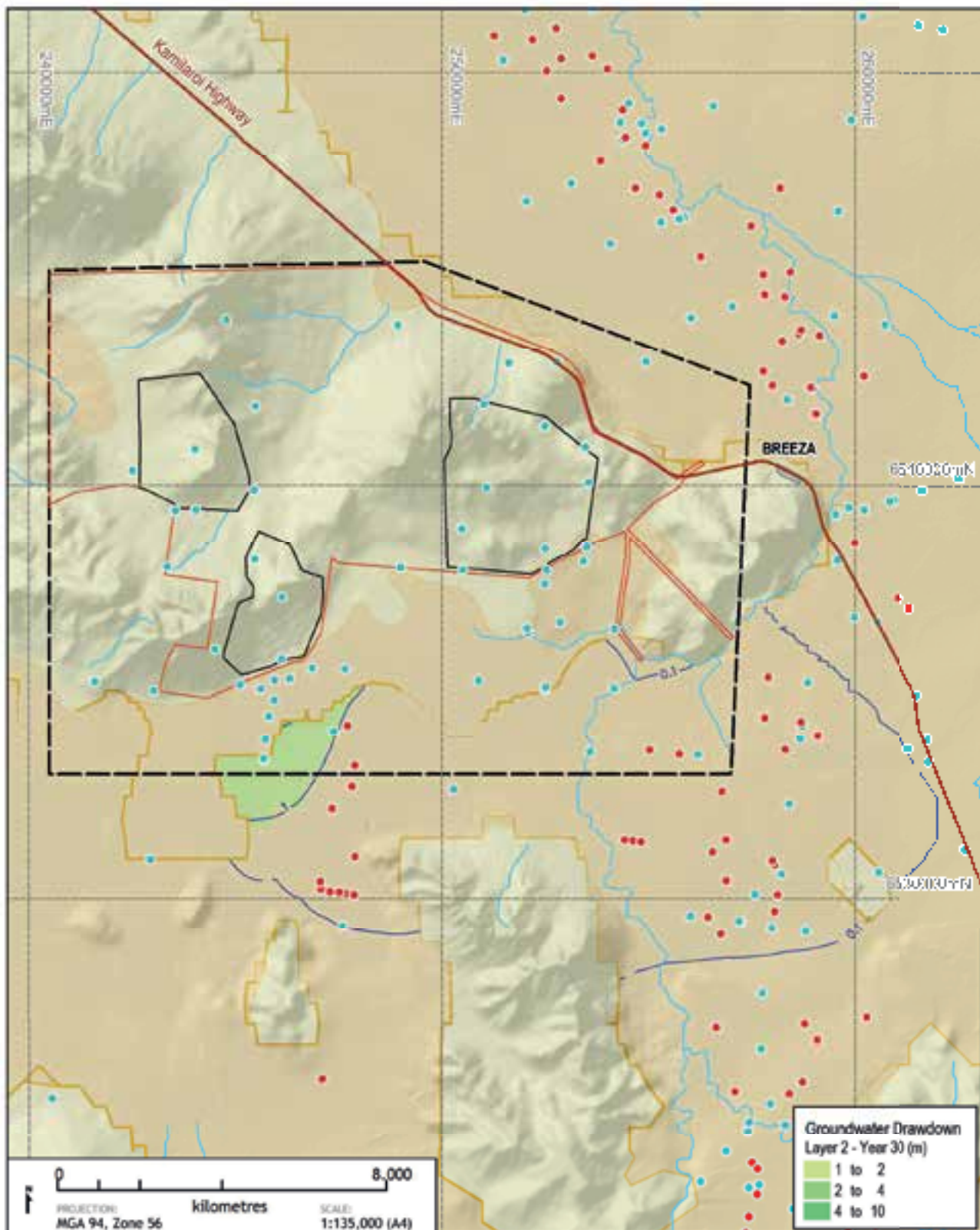
Watermark Coal Project (G1501)
Groundwater Assessment

**Drawdown Contours
Year 27.5 (Gunndah Formation)**



DATE:
18/10/2012

FIGURE NO:
10.21



LEGEND:

- | | |
|----------------------|-------------------------|
| Observation Bore | Highway |
| Proposed Mining Area | Drawdown Contour (m) |
| EL 7223 | Gunnedah Aquifer Extent |
| Watercourse Line | Narrabri Aquifer Extent |
| Usage Bore | Project Boundary |

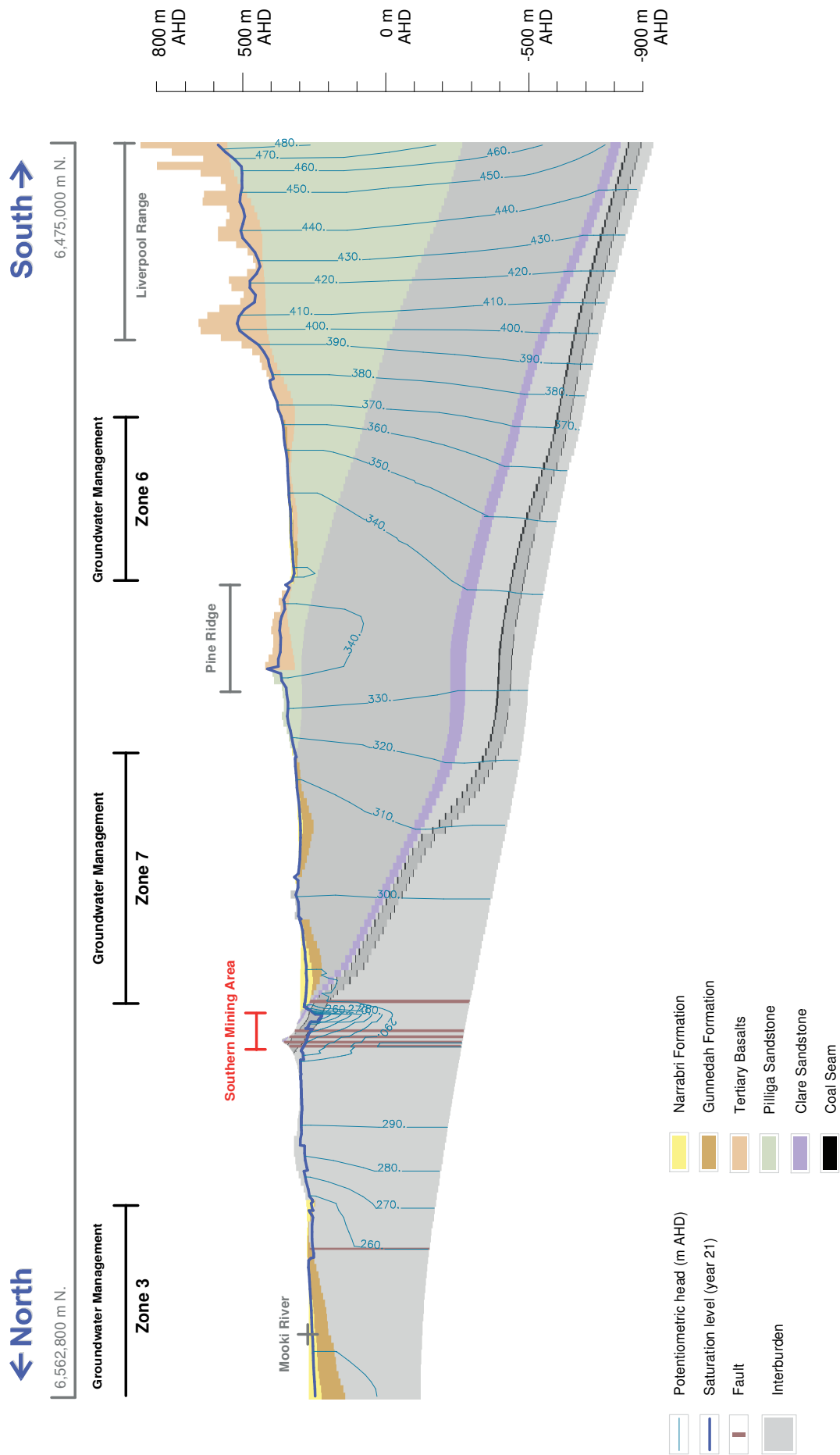
Watermark Coal Project (G1501)
Groundwater Assessment

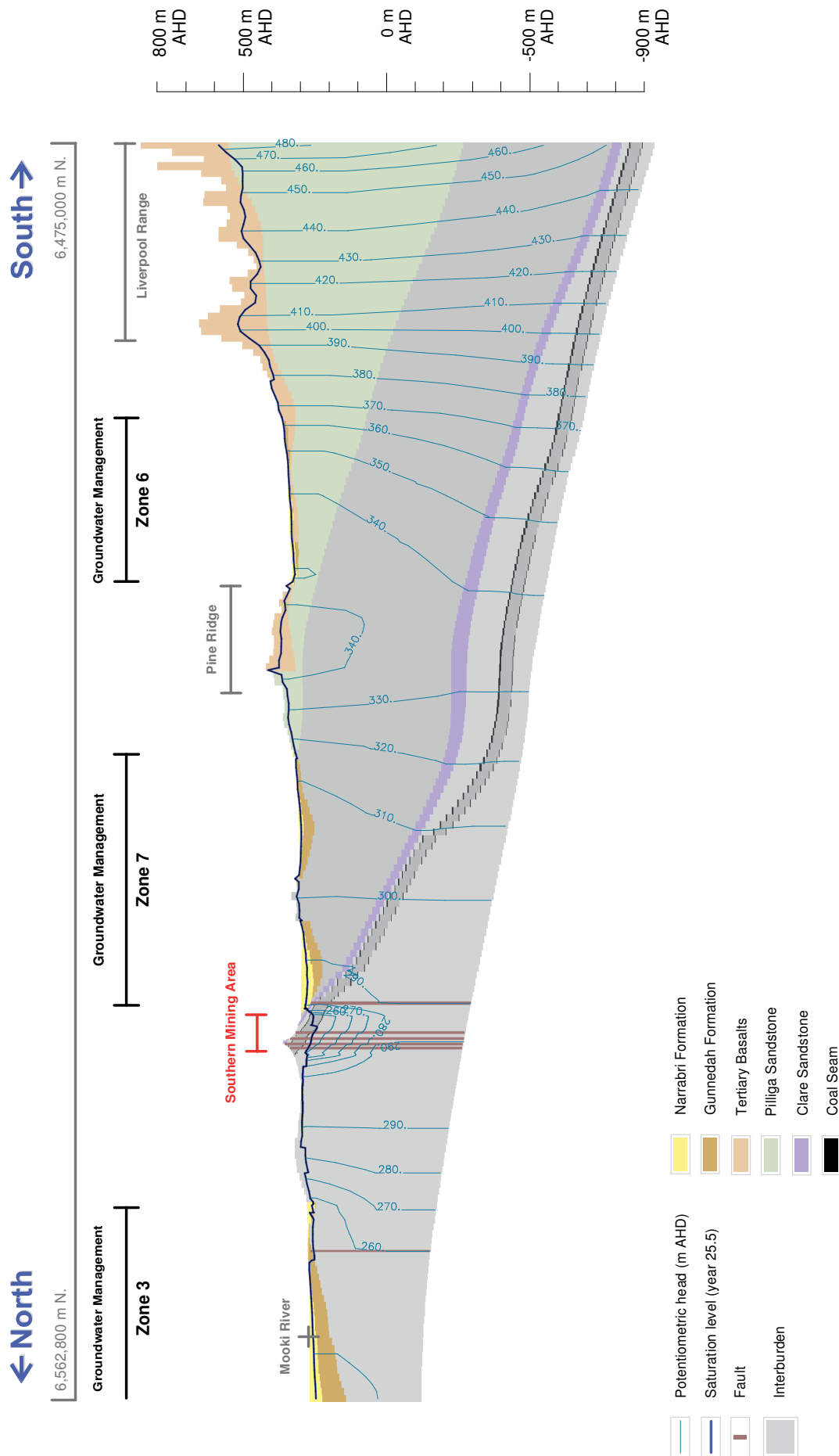
**Drawdown Contours
Year 30 (Gunnedah Formation)**



DATE:
18/10/2012

FIGURE No:
10.22

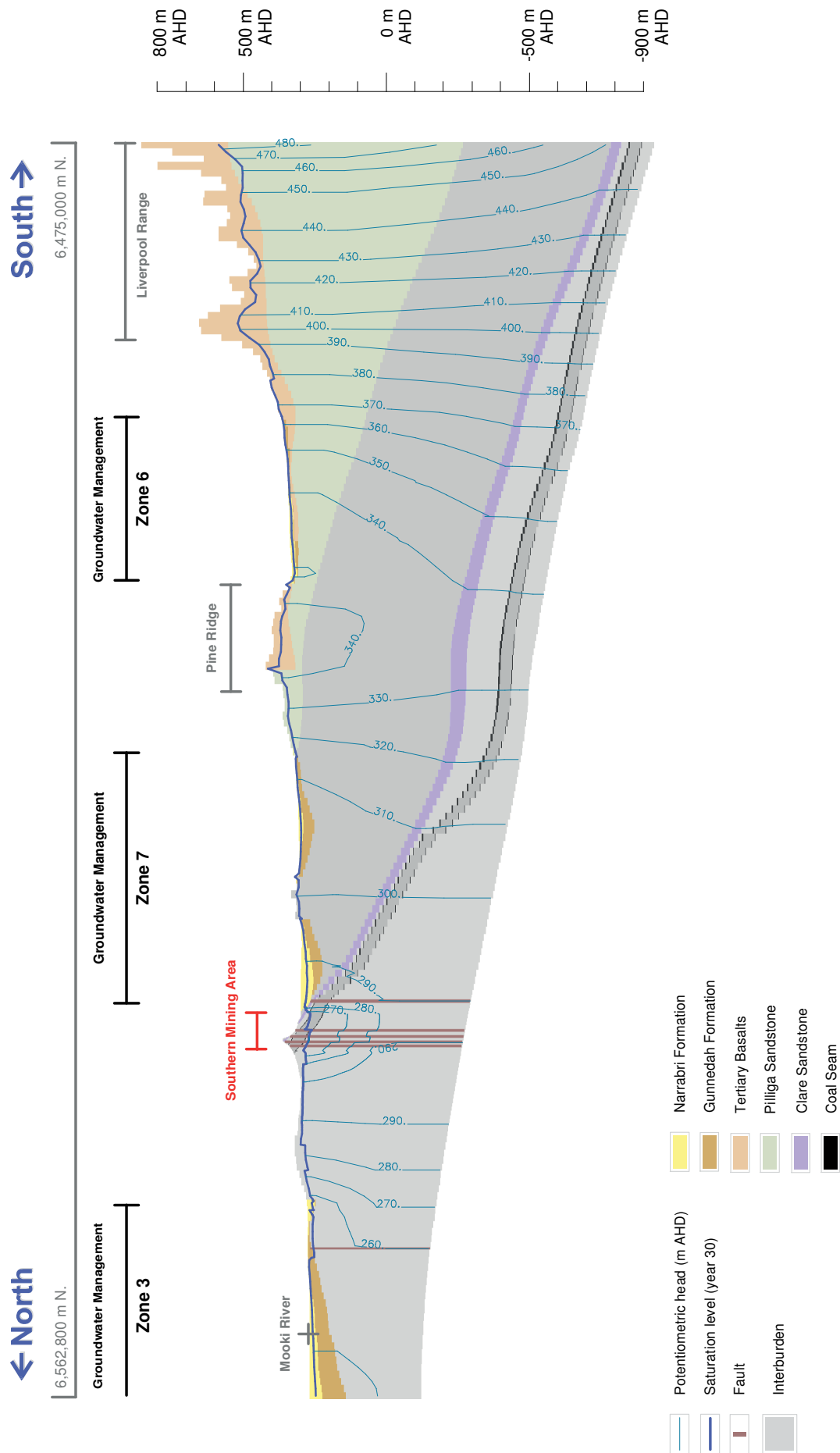




Groundwater Head - North-South - Year 25.5

Figure 10.24

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Groundwater Head - North-South - Year 30

Figure 10.25

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)

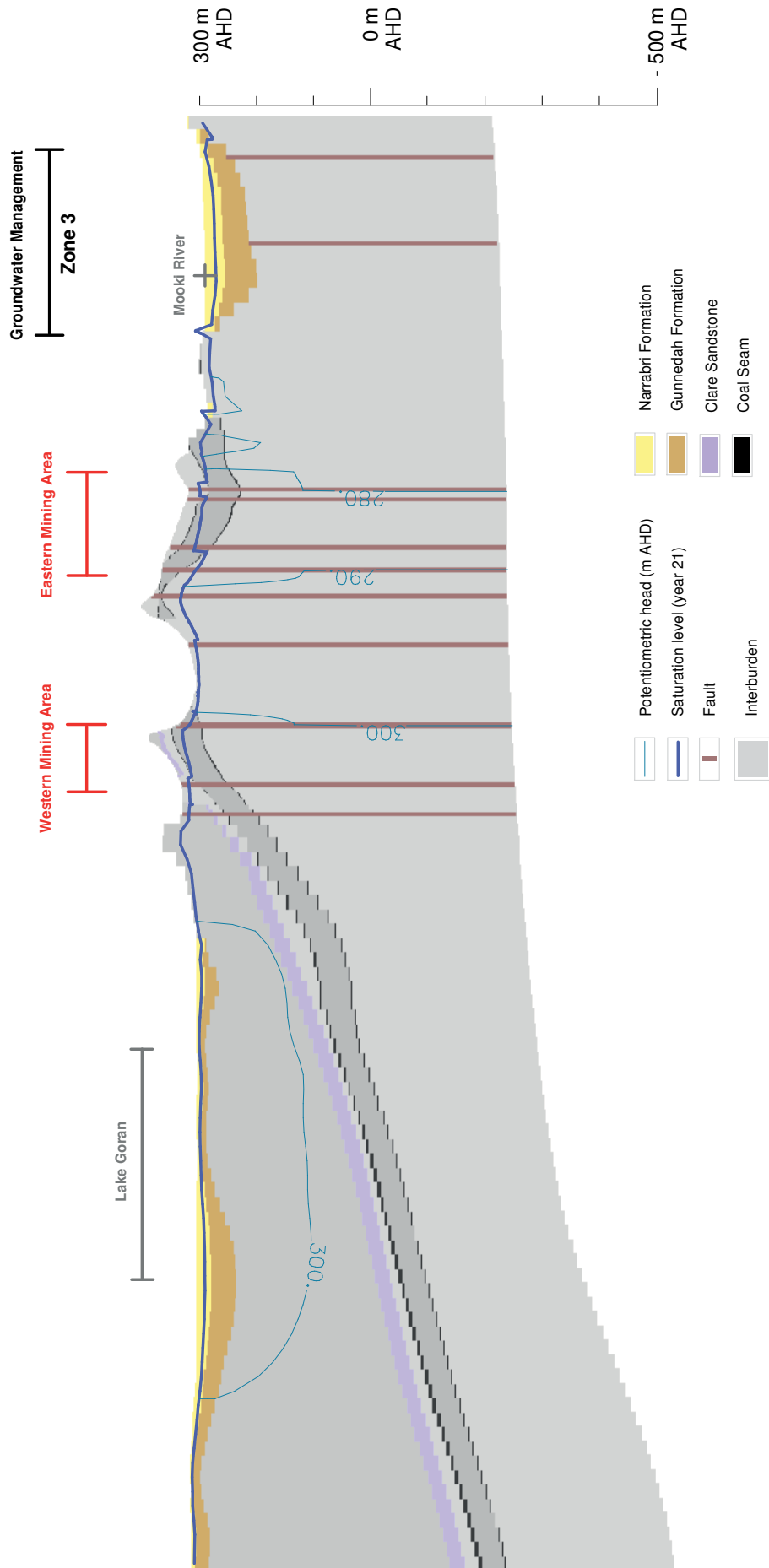


← West

215,500 m E.

East →

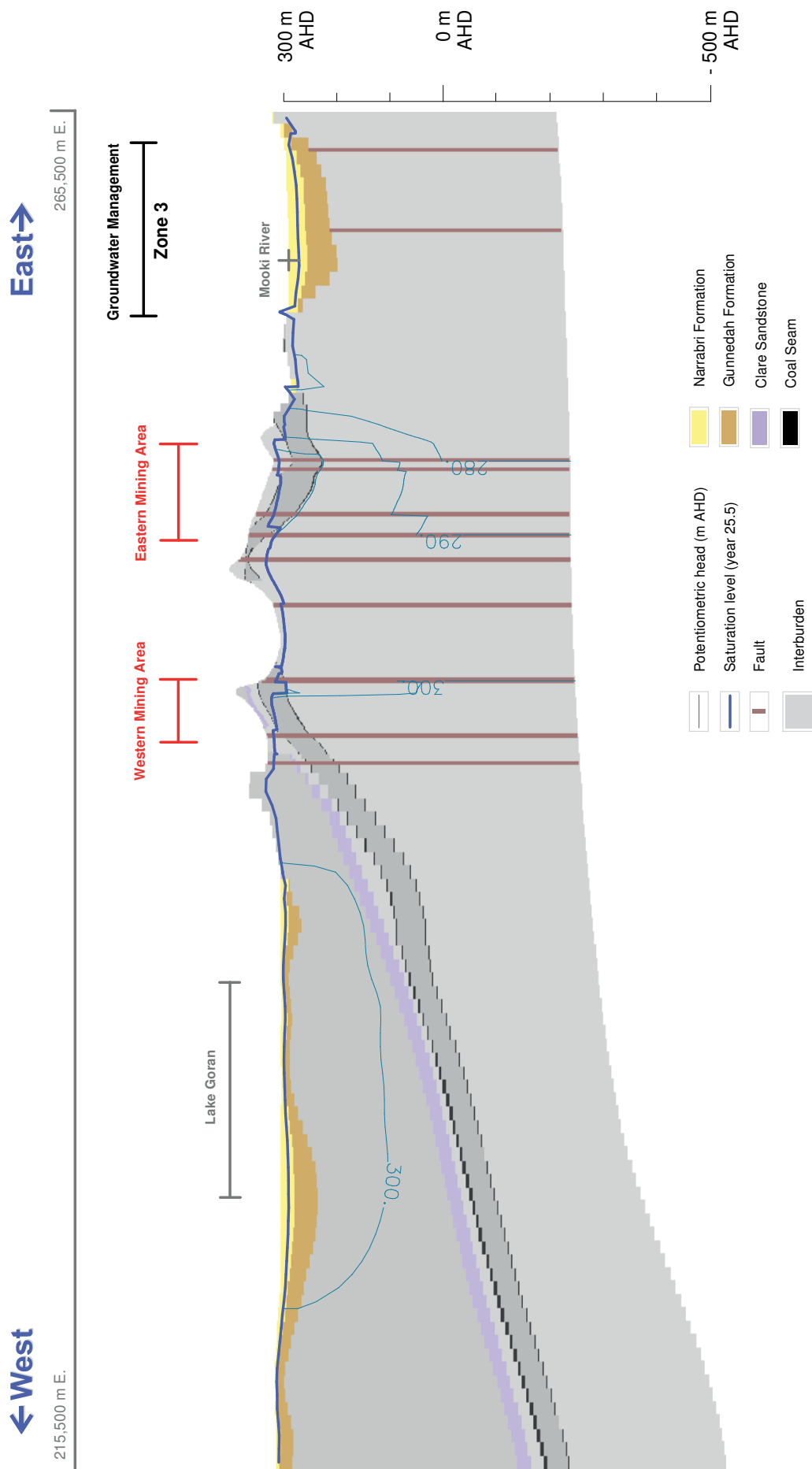
265,500 m E.



Groundwater Head - West-East - Year 21

Figure 10.26

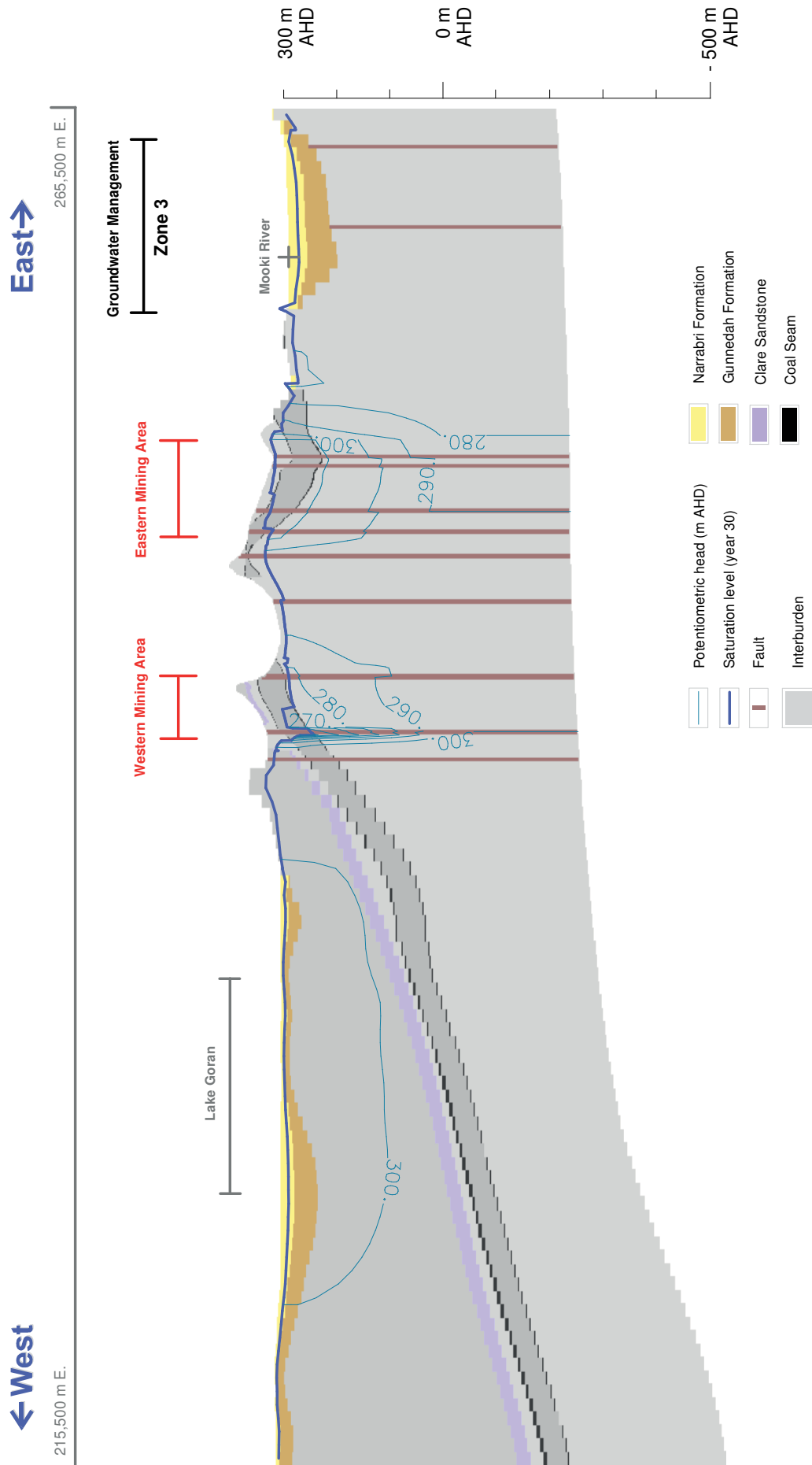
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Groundwater Head - West-East - Year 25.5

Figure 10.27

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Groundwater Head - West-East - Year 30

Figure 10.28

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



10.7 Impact on Groundwater Users

There are 508 groundwater monitoring and pumping bores in the PINEENA database within a 10 km radius of the proposed Mining Areas at the Project. Seventy-one of these bores are licenced and metered by NOW for water allocation. The majority of these bores abstract groundwater from the Gunnedah Formation.

Table 10.2 presents the modelled drawdown for each of the licenced and metered bore sites within a 10 km radius of the Project. Figure 10.29 shows the locations of the bores.

Table 10.2: DRAWDOWN IN LICENCED PUMPING BORES WITHIN 10 KM OF WATERMARK MINING AREAS AT YEAR 25

Work Number	Easting (m GDA94)	Northing (m GDA94)	Completed Depth (mbgl)	Drawdown (m)	Topo (mAHD)	Head (mAHD) (2037)	Head Available (m)	Percent Change (%)	Distance from Open Cut Mining Area (km)
GW015505	247716	6534230	35.1	1.4	298.8	286.8	19.2	7.41	1.96
GW029468	247898	6533248	64.6	1.1	298.5	286.5	48.6	2.25	2.9
GW037713	247831	6532753	64	1.0	298.8	286.5	47.7	2.20	3.33
GW967790	247346	6532215	70	1.1	297.2	287.0	55.9	1.94	3.71
GW029062	257785	6542818	50	0.0	284.6	268.1	29.5	0.07	4.55
GW029062	257785	6542818	50	0.0	284.6	268.1	29.5	0.07	4.55
GW029060	258005	6542454	58.2	0.0	285.0	268.5	37.8	0.06	4.6
GW060252	247898	6531060	148.4	0.6	297.2	289.3	136.5	0.45	4.98
GW028767	255033	6533633	42.7	0.2	292.4	283.8	30.1	0.67	5.09
GW025845	258245	6543538	51.2	0.0	281.6	267.9	33.5	0.06	5.3
GW967781	247063	6530457	50	0.4	297.2	288.6	37.4	0.95	5.31
GW034753	259054	6541769	59.4	0.0	283.8	270.1	41.6	0.06	5.38
GW064796	258933	6542413	73	0.0	282.4	269.2	55.8	0.04	5.44
GW053609	256262	6545582	65	0.0	280.0	264.7	45.7	0.03	5.44
GW047180	258987	6542384	65.5	0.0	282.2	269.3	48.5	0.05	5.48
GW022984	247071	6530269	45.1	0.3	297.7	290.0	33.4	0.90	5.5
GW028622	257903	6535394	64.6	0.1	290.9	279.9	49.6	0.24	5.5
GW028580	255750	6533526	52	0.2	292.8	283.1	38.3	0.47	5.56
GW022622	247284	6530213	45.1	0.3	298.5	290.2	32.8	0.93	5.59
GW965204	247520	6530201	48.5	0.3	299.8	290.5	35.2	0.90	5.68
GW022621	247496	6530187	40.8	0.3	299.8	290.6	27.6	1.13	5.69
GW014665	257822	6544668	44.2	0.0	280.0	266.8	27.0	0.07	5.7
GW025844	258639	6543701	53.9	0.0	280.7	267.9	37.2	0.05	5.73
GW022620	247682	6530161	48.8	0.3	300.0	291.4	36.3	0.86	5.75
GW047179	258695	6543803	71.6	0.0	280.4	267.9	55.1	0.04	5.84
GW022977	247867	6530134	148.4	0.3	300.0	292.2	136.6	0.23	5.85
GW065969	255606	6546710	83	0.0	279.8	262.8	62.0	0.02	5.91



Table 10.2: DRAWDOWN IN LICENCED PUMPING BORES WITHIN 10 KM OF WATERMARK MINING AREAS AT YEAR 25

Work Number	Easting (m GDA94)	Northing (m GDA94)	Completed Depth (mbgl)	Drawdown (m)	Topo (mAHD)	Head (mAHD) (2037)	Head Available (m)	Percent Change (%)	Distance from Open Cut Mining Area (km)
GW025455	254690	6547234	79.9	0.0	278.4	261.0	58.5	0.02	5.99
GW062013	258298	6544610	64	0.0	280.0	267.1	47.1	0.04	6
GW027714	257784	6545160	81.4	0.0	280.0	266.4	63.8	0.03	6.03
GW037837	255276	6547075	59.1	0.0	279.3	262.0	37.8	0.03	6.05
GW064810	257820	6534406	54.3	0.1	292.8	280.5	37.9	0.34	6.1
GW967044	259147	6543674	63	0.0	280.1	268.3	47.2	0.04	6.14
GW042753	253840	6547899	56.7	0.0	276.7	259.1	35.2	0.02	6.36
GW027430	259999	6538647	64.3	0.1	284.4	274.4	50.3	0.11	6.43
GW901786	258438	6545209	70.1	0.0	280.0	267.0	53.1	0.03	6.52
GW059148	260224	6542689	81.5	0.0	281.7	269.9	65.7	0.04	6.75
GW053892	257490	6546318	56.5	0.0	280.0	265.2	37.7	0.04	6.76
GW028768	254423	6531461	48.8	0.2	295.0	284.7	34.5	0.61	6.8
GW053877	258696	6534303	38.7	0.1	293.6	279.9	21.0	0.57	6.8
GW037406	256777	6532625	66.1	0.2	295.0	282.2	49.3	0.33	6.83
GW028765	254635	6531435	48.8	0.2	295.0	284.6	34.4	0.59	6.89
GW060086	258314	6533647	44.2	0.1	294.5	280.6	26.3	0.49	6.98
GW028766	254821	6531409	45.7	0.2	295.0	284.4	31.1	0.63	6.99
GW023311	254934	6548274	79.6	0.0	277.6	259.3	57.3	0.02	7.05
GW028286	254934	6548274	59.4	0.0	277.6	259.3	37.1	0.02	7.05
GW028287	254449	6548473	53.9	0.0	276.6	258.7	31.9	0.03	7.1
GW065013	259100	6533973	90	0.1	294.6	279.8	71.2	0.16	7.32
GW901302	252890	6549423	63.4	0.0	274.7	256.7	41.3	0.01	7.62
GW035010	261061	6537316	67	0.1	290.0	276.4	49.4	0.14	7.67
GW053220	254380	6549149	87.2	0.0	275.7	257.9	65.5	0.01	7.73
GW053220	254380	6549149	87.2	0.0	275.7	257.9	65.5	0.01	7.73
GW967192	256884	6531456	75	0.2	295.0	282.6	58.6	0.27	7.9
GW053439	258187	6547234	59	0.0	280.5	264.8	39.3	0.03	7.91
GW035009	261332	6537075	63.7	0.1	290.0	276.6	46.3	0.15	7.96
GW063072	256546	6531172	55.7	0.2	295.0	283.2	39.9	0.40	7.98
GW053218	252539	6550087	64	0.0	275.0	255.3	40.3	0.01	8.19
GW038144	252894	6550378	76.2	0.0	274.9	255.4	52.7	0.01	8.55
GW023946	254013	6550127	56.7	0.0	274.7	256.9	34.9	0.02	8.58
GW057872	256880	6530471	74	0.2	295.0	283.6	58.6	0.26	8.76
GW053171	253652	6550449	79.2	0.0	274.6	256.1	56.8	0.01	8.84
GW901788	252200	6550844	67	0.0	275.0	254.3	42.3	0.01	8.86



Table 10.2: DRAWDOWN IN LICENCED PUMPING BORES WITHIN 10 KM OF WATERMARK MINING AREAS AT YEAR 25

Work Number	Easting (m GDA94)	Northing (m GDA94)	Completed Depth (mbgl)	Drawdown (m)	Topo (mAHD)	Head (mAHD) (2037)	Head Available (m)	Percent Change (%)	Distance from Open Cut Mining Area (km)
GW037348	251264	6550925	74.9	0.0	275.0	253.3	49.2	0.01	8.87
GW902398	258006	6530959	67	0.1	296.7	282.7	49.0	0.30	8.95
GW022827	258061	6530868	43	0.1	296.9	282.8	24.9	0.59	9
GW023789	252771	6551115	53.3	0.0	275.0	254.7	29.0	0.01	9.25
GW022348	256450	6529598	45.7	0.1	295.0	285.6	32.3	0.45	9.31
GW022826	258131	6530130	45.1	0.1	296.7	283.6	28.0	0.51	9.66
GW022847	256751	6529173	49.4	0.1	294.6	286.4	37.2	0.36	9.83
GW060253	247102	6525678	26.8	0.0	304.3	302.5	21.1	0.02	9.96
GW902399	258061	6529728	67	0.1	296.3	284.6	51.4	0.27	9.98

Note: mAHD – metres above Australian Height Datum

mbgl – metres below ground level

available head is calculated assuming a pump is set at 4m above the base of each bore

Table 10.2 presents the drawdown at Year 25, which is when the predicted zone of depressurisation is most extensive due to mining the Southern Mining Area. The modelling predicts water levels at most of the bores will reduce by less than one metre due to the Project. The majority of the licenced pumping bores are screened in the mid to lower sections of the Gunnedah Formation, with the exception of bores GW060252 and GW022977, which are installed in the underlying Permian.

Of the 71 bores listed in Table 10.2, 35 bores are predicted to experience groundwater level reductions of greater than or equal to 0.1 m. Of these 35 bores, four bores have a drawdown greater than 1 m. The largest predicted reduction in water levels is still relatively limited at 1.4 m in bore GW15505 (Figure 10.30), which is the closest bore to the Southern Mining Area.

The predicted reduction in groundwater levels in nearby bores is relatively small (<1 m) compared with the available drawdown in each bore and is within the seasonal variation. Mining reduces water levels by less than 1% at the majority of the bores. The model predicts five bores will experience a water level change of between 1% and 7.4%, however this change is considered unlikely to noticeably reduce the pumping yield from any bore.

When mining of the Southern Mining Area and Eastern Mining Area is completed, the model predicts that groundwater levels in the depressurised zone will recover relatively rapidly.

Figure 10.30 to Figure 10.33 show the predicted groundwater levels and the screened section of the bore, and illustrate both the available drawdown and a relatively rapid recovery (~5 years) in groundwater levels within the zone of depressurisation. Figure 10.29 shows the locations of the bores.



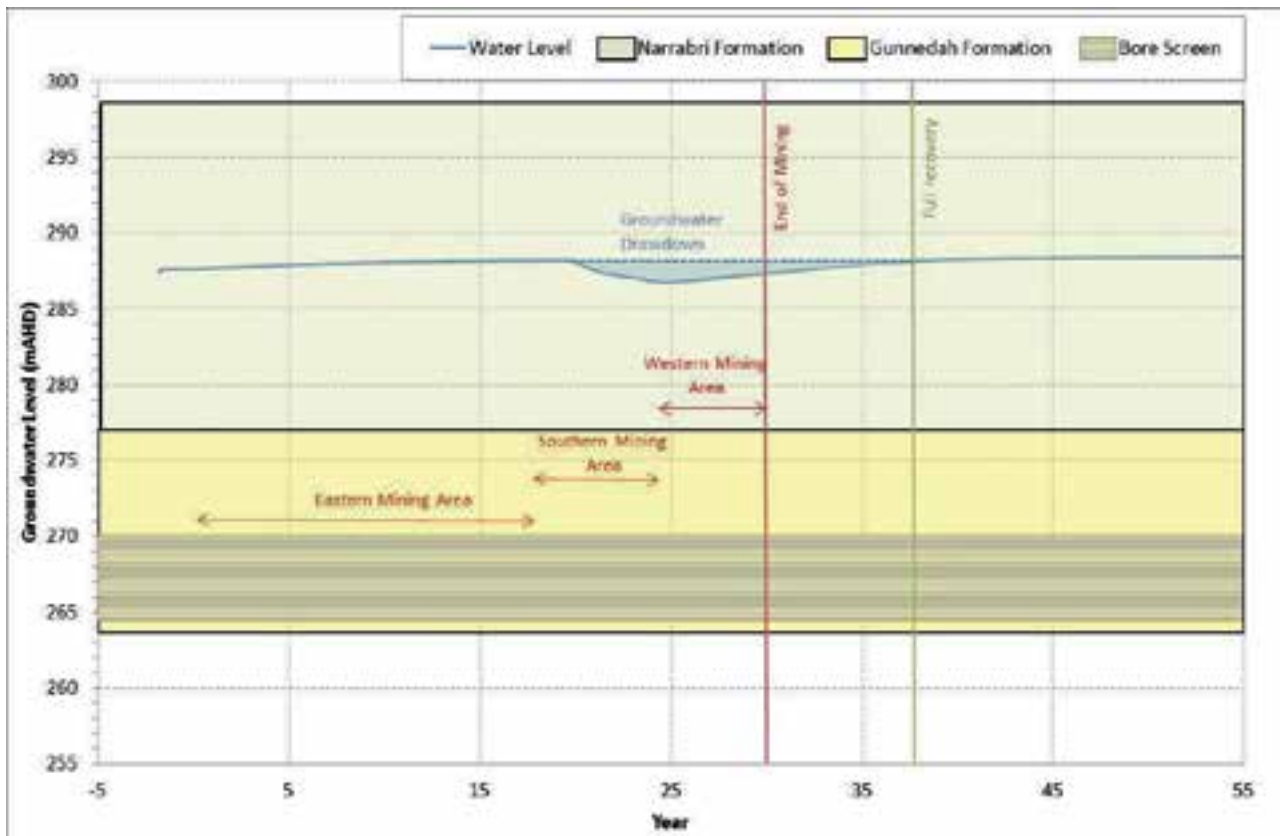


Figure 10.30: Predicted Hydrograph and Bore Construction – GW015505

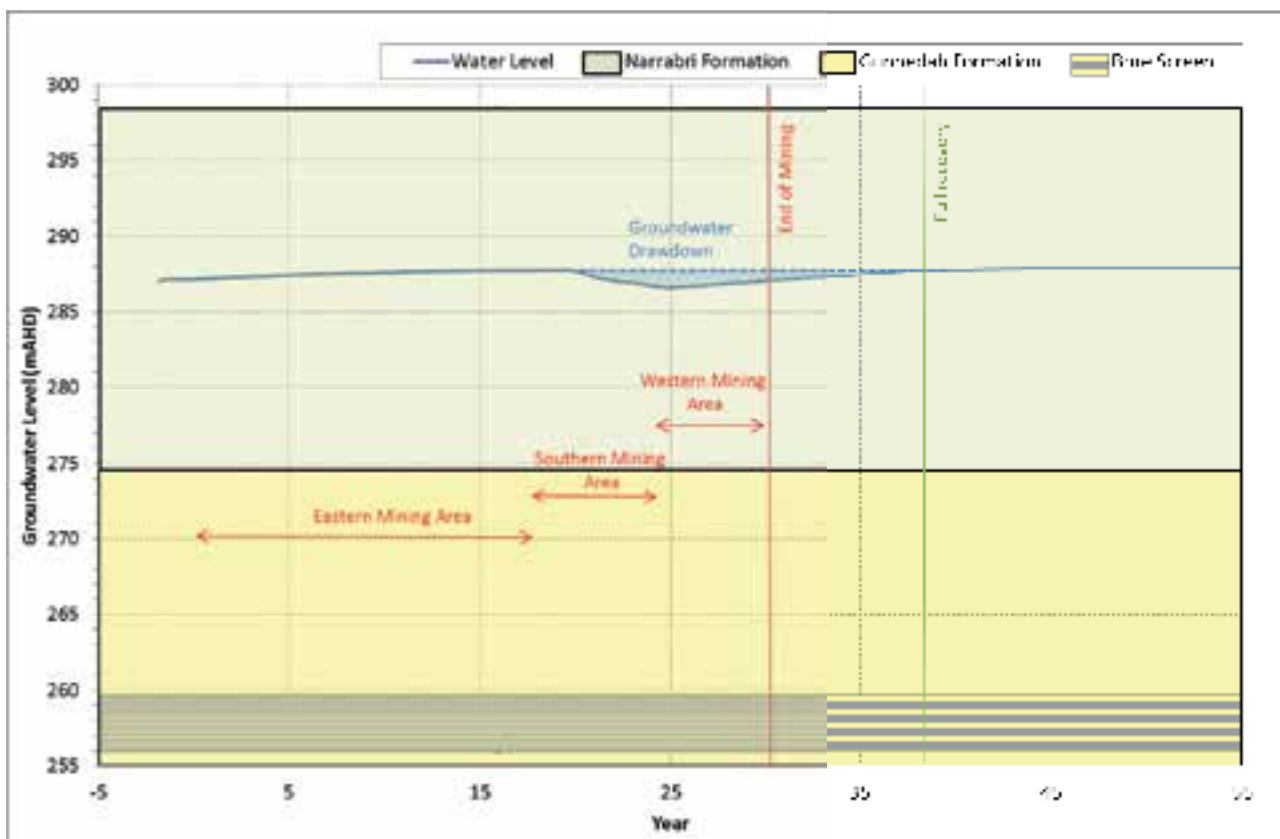


Figure 10.31: Predicted Hydrograph and Bore Construction – GW029468

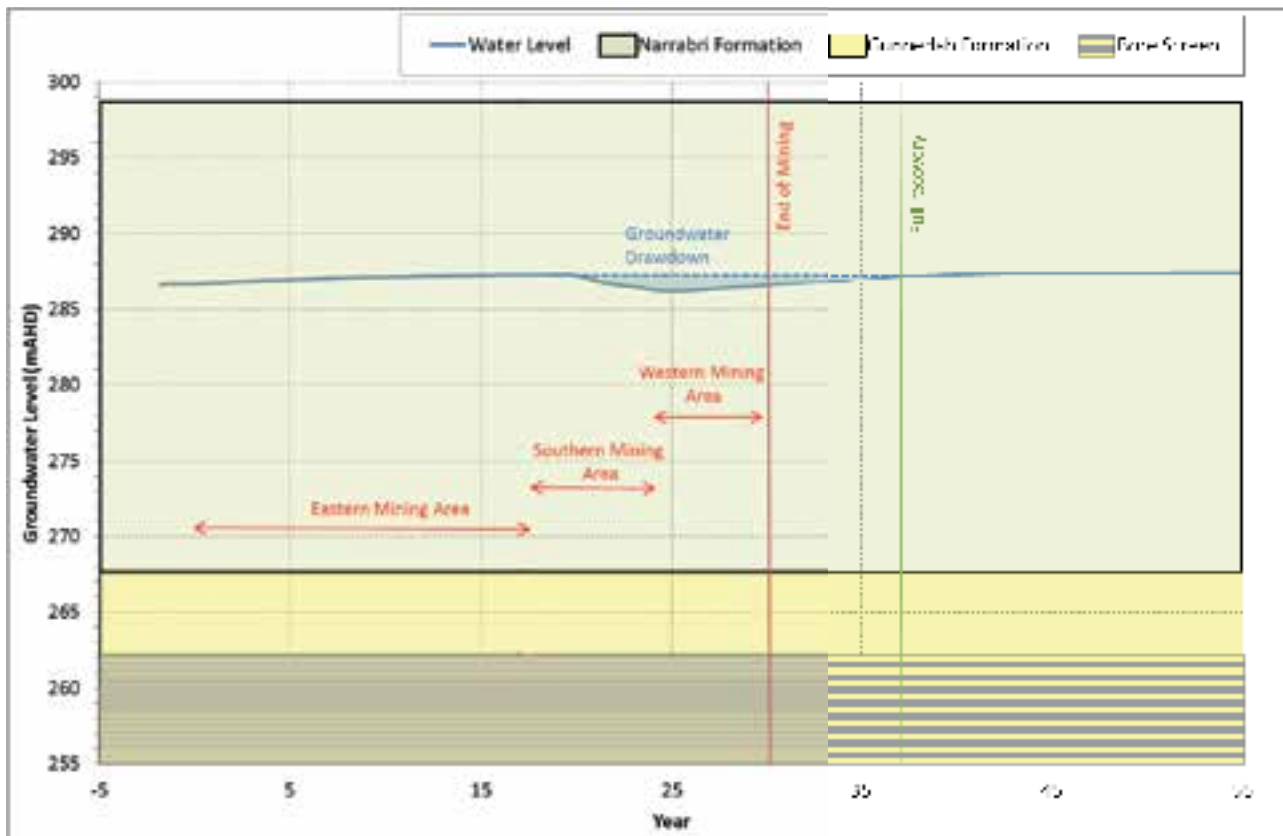


Figure 10.32: Predicted Hydrograph and Bore Construction – GW037713

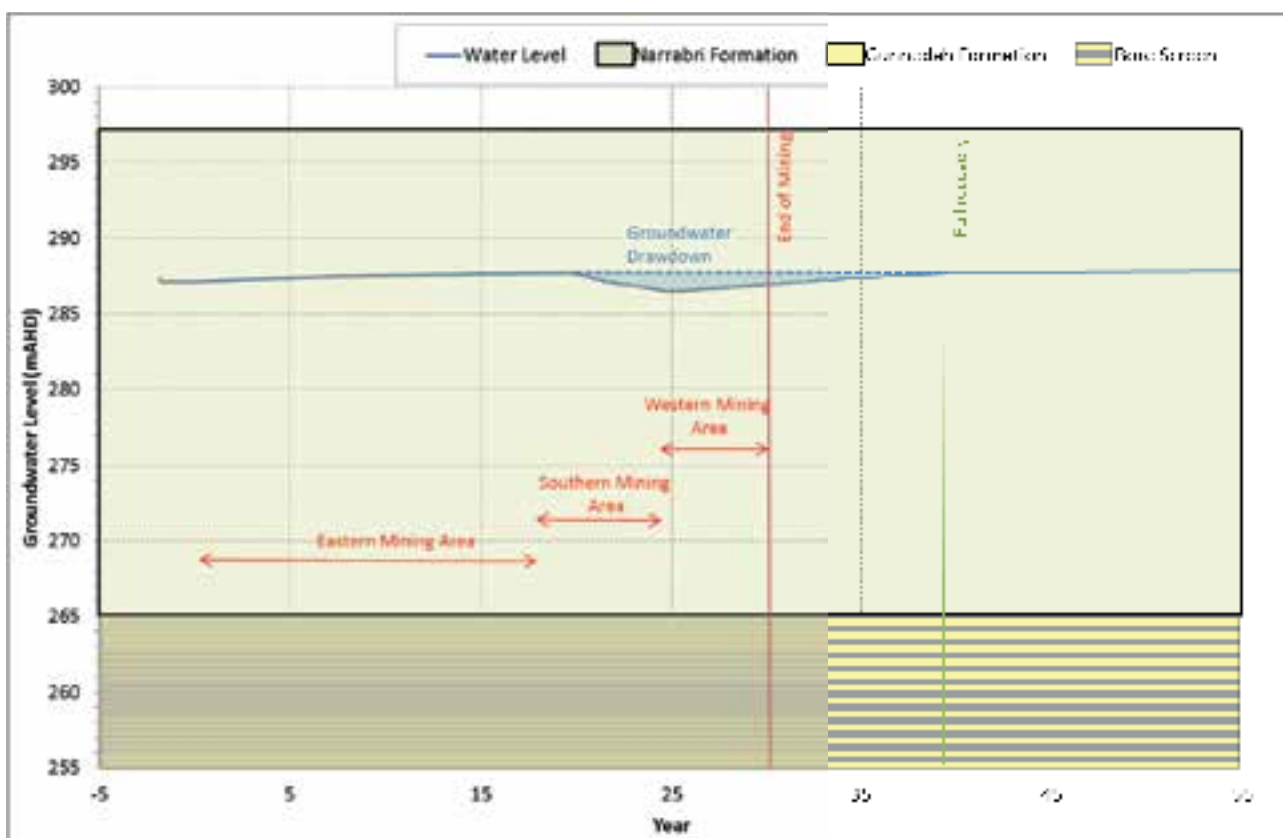


Figure 10.33: Predicted Hydrograph and Bore Construction – GW967790



NOW (2012a) define acceptable levels of drawdown in the *NSW Aquifer Interference Policy (AIP)*. The AIP classifies aquifers according to available yields and water quality. Highly productive groundwater has a TDS of less than 1500 mg/L, and contains water supply works that can yield water at greater than 5 L/sec.

The water quality and yields from the Narrabri Formation are highly variable, but most commonly fits the criteria of a less productive groundwater source. The Gunnedah Formation is a highly productive groundwater source when assessed against the AIP criteria. The AIP sets out “*minimal impact considerations*” and indicates, “*if the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable*”.

The AIP requires that aquifer interference activities do not induce a decline of more than 2 m in the water table or water pressure at any water supply work, i.e. a bore or a well in both highly and less productive groundwater sources. As described above the modelling predicted a maximum drawdown in a private bore of 1.4 m, which is less than the 2 m, indicating the Project complies with this requirement of the AIP.

10.8 Interaction with Alluvial Aquifers and Groundwater Management Zones

10.8.1 Alluvial Aquifers

Figure 10.34 shows the water budget for a model run without mining. It shows average volumes of water entering and leaving the alluvium, for the entire model domain, and for groundwater management Zone 7, over the 30-year proposed mining period.

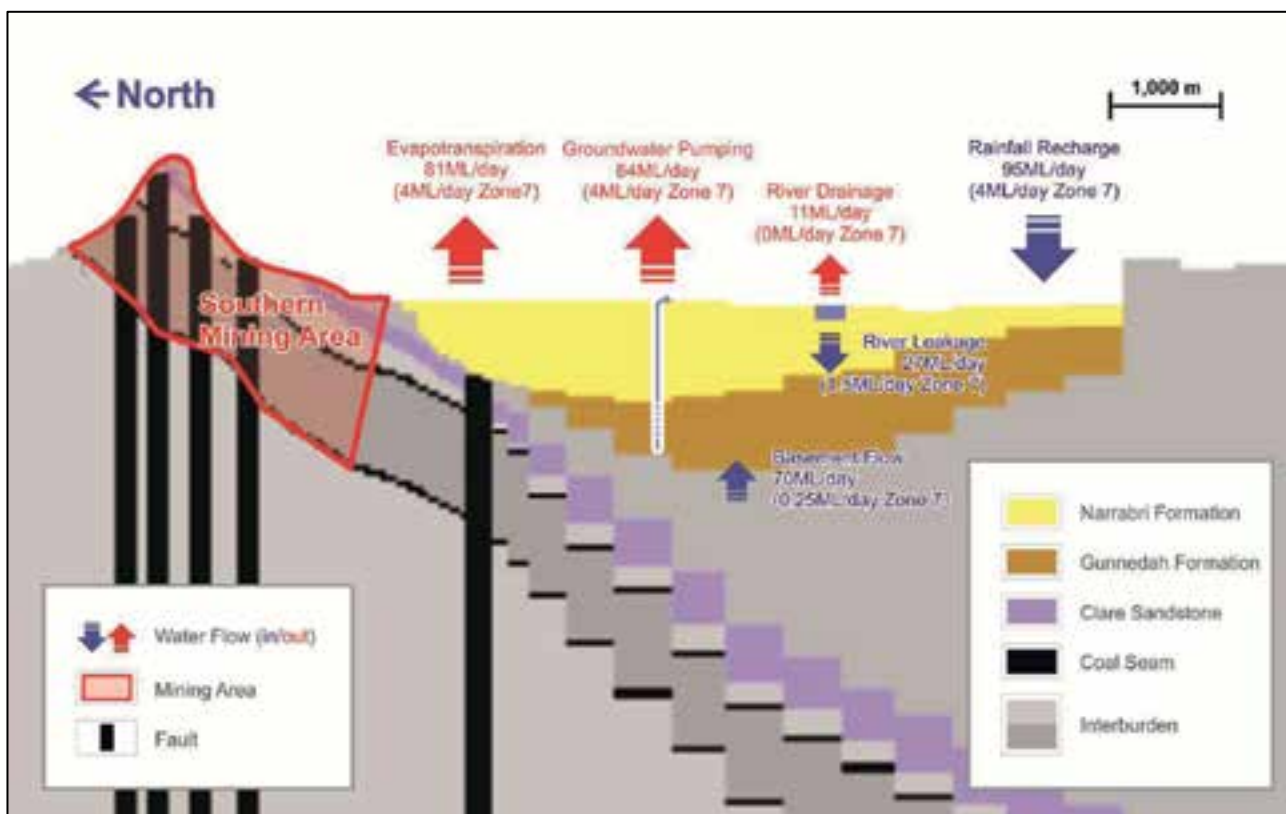


Figure 10.34: Alluvial Flow Transfer – Model Area and Zone 7



In the absence of mining, the model predicts there is a net upward flow entering the alluvium from the Triassic and Permian formations of 70 ML/day across the whole model domain. This is comprised of 173 ML/day upward flow and 102 ML/day downward flow. In Groundwater Management Zone 7, which is the closest zone to the proposed Mining Areas, the net upward flow is 0.25 ML/day (0.36 ML/day upward and 0.1 ML/day downward).

The model implies that once mining commences, the Permian strata depressurises and within the zone of influence, upward flow from the Permian to the alluvium reduces. This is due to changes in vertical gradients between the alluvium and Permian that reduces upward flow, and flow reversal to downward flow in areas adjacent to the Mining Areas.

Two model runs were used to estimate the change in groundwater flow from the Permian to the alluvial aquifers following the simulated depressurisation of the Permian strata due to mine development. The first run was a simulation without mining, the second included the Project. The change in flow contribution from the Permian to the alluvial aquifer was then calculated by extracting geologically zoned cell-by-cell flow data for each stress period from the “mine” and “no mine” scenarios.

For management purposes, the alluvium has been subdivided into Groundwater Management Zones under the *Water Sharing Plan for the Upper and Lower Groundwater Sources 2003*. Zones 1, 3, 6, 7, 8 and 10 are present within the groundwater model area.

Figure 10.35 presents the groundwater flow rates from the Permian to the Quaternary alluvium for each of Zones 3, 7, and 8. Zones 1, 6 and 10 are relatively distant from the Project and will not be impacted.

The upward flow from the Permian to the alluvium reduces most significantly in Zone 7, due to the depressurisation of the Permian bedrock during mining. Figure 10.36 shows the net reduced upward flow rate to each of the Groundwater Management Zones 3, 7, and 8. Figure 10.36 shows the difference in the net transfer (upward flow minus downward flow) between the Permian and Quaternary alluvium due to mining. Table 10.3 presents the net reduction in transfer for the each Water Management Zone on an annual basis.

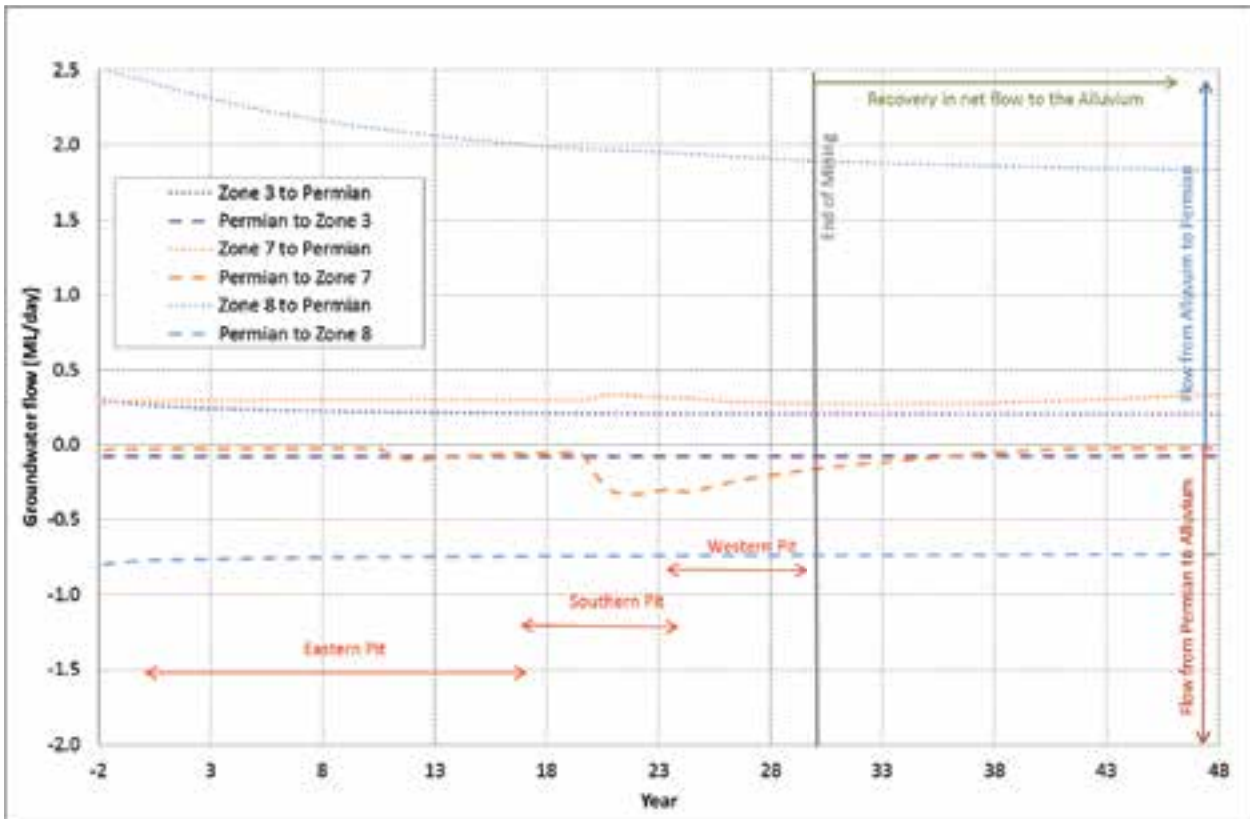


Figure 10.35: Simulated Change in Flow from Bedrock to Alluvium

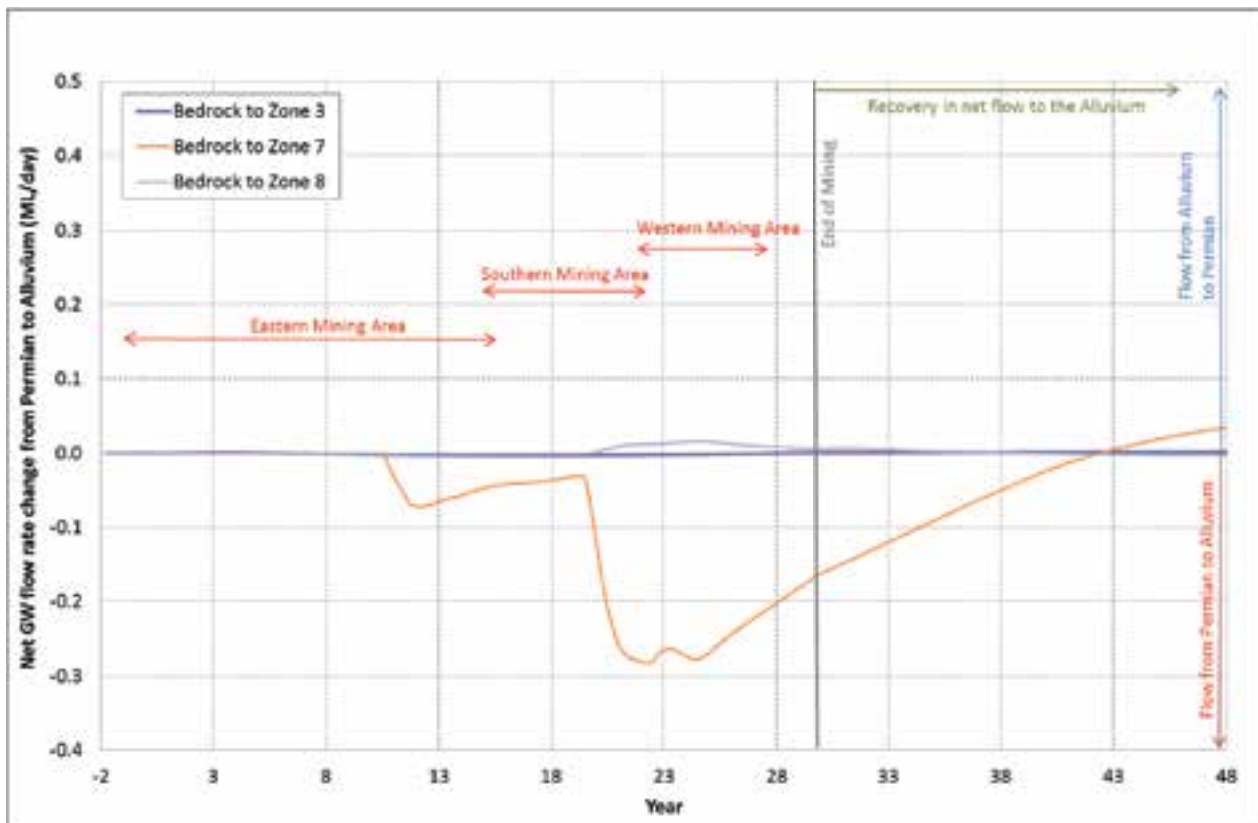


Figure 10.36: Simulated Net Change in Flow from Bedrock to Alluvium



Table 10.3: NET ANNUAL REDUCTION IN GROUNDWATER TRANSFER FROM PERMIAN TO ALLUVIAL WATER MANAGEMENT ZONES (ML/year)

Year	Zone 3	Zone 7	Zone 8
1	0.0	0.0	0.0
2	0.0	0.1	0.1
3	-0.1	0.0	0.1
4	-0.2	0.1	0.1
5	-0.2	0.0	0.1
6	0.0	0.0	0.0
7	0.1	0.1	0.1
8	0.2	0.1	0.1
9	0.3	0.1	0.1
10	0.4	0.1	0.1
11	0.5	1.6	0.3
12	0.6	18.4	0.4
13	0.7	25.8	0.3
14	0.8	22.6	0.3
15	0.9	19.4	0.3
16	1.0	16.4	0.3
17	1.1	14.9	0.3
18	1.1	14.1	0.2
19	1.1	12.7	0.2
20	1.1	15.4	0.2
21	0.9	67.3	-1.8
22	0.8	98.9	-3.9
23	0.8	101.8	-4.5
24	0.6	97.0	-5.0
25	0.6	100.7	-5.8
26	0.5	94.7	-5.2
27	0.3	86.0	-4.1
28	0.2	78.3	-3.4
29	0.0	70.9	-2.8
30	-0.1	63.5	-2.3

Note - negative numbers indicate an increase in transfer rate from Permian to alluvium above Pre-mining conditions

Figure 10.36 and Table 10.3 indicates the reduced upward flow of Permian groundwater largely affects flow to Groundwater Management Zone 7, which is located adjacent the Southern Mining Area and Eastern Mining Area.

The model indicates that groundwater flow from the underlying Permian formations to the alluvium reduces by a maximum rate of 0.3 ML/day in Zone 7, with the maximum annual loss at 101.8 ML/year. The rate of transfer of water from the Permian to the alluvium reduces as the zone of depressurisation increases and reaches a peak when mining in the Southern Mining Area is most extensive in Year 24.



The average pumping rate from a single licensed agricultural bore within 10 km of the Project Boundary is 142 ML/year. The groundwater model predicts that the volume of water removed from the Zones 3, 7 and 8 is a very small quantity of water being equivalent to no more than the usage from a single bore in the peak years of mining.

Post mining, the water levels in the Southern Mining Area and Eastern Mining Area recover and the surrounding Permian repressurises. The emplacement of spoil in the mining areas and the associated enhanced recharge rapidly reverses the effects of groundwater depressurisation on the alluvial aquifer system. The model indicates that 15 years after mining ceases (Year 45), upward flow from the Permian to the alluvium has returned to pre-mining rates. Beyond 15 years of recovery, the enhanced spoil recharge and mounding causes a net gain of 0.1 ML/day to the alluvial groundwater management areas.

The change in upward flow from the Permian to the alluvium due to mining is negligible beyond the immediately adjacent Zone 7. Zones 3 and Zone 8 report only a very small change (refer Figure 10.36 and Table 10.3). The model does not predict a change in flow rates for Zones 1, 6 and 10, which as discussed, are relatively distant from the Project.

It is important to note that Figure 10.36 and Table 10.3 present the predicted change in the groundwater transfer rate from the Permian bedrock to the alluvium due to the Project. The majority of this water does not flow to the proposed open cut mining areas, but it simply remains in the underlying Permian bedrock and is therefore is not lost from the larger groundwater system. When mining is complete in the Southern Mining Area and Eastern Mining Area, the Triassic/Permian basement starts to repressurise and the predicted flow rate from the Permian basement to the overlying alluvium increases to pre-mining rates within 15 years. Beyond 15 years, there is a net increase in the transfer from the Permian to the alluvium due to the mounding of groundwater within the backfilled Southern and Eastern Mining Areas caused by enhanced increased recharge.

The change in upward flow from the Permian to the individual alluvial units i.e., Narrabri and Gunnedah Formations is dependent on the proximity of the units to the mining areas. Ninety percent of the alluvial transfer loss occurs from the Permian to the Narrabri Formation Aquifer, while just 10% of transfer loss occurs from the Permian to the Gunnedah Formation Aquifer. This is an important point to note because although the Narrabri and Gunnedah Formations are managed as a single aquifer unit under the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003*, the Narrabri Formation contains poor quality water and is not targeted by surrounding users to supply agriculture. The modelling indicates the impact will be largely limited to the Narrabri Formation where the yields and water quality are poorer.

Figure 10.37 graphically represents the cumulative loss from the individual Groundwater Management Zones during mining and post mining.

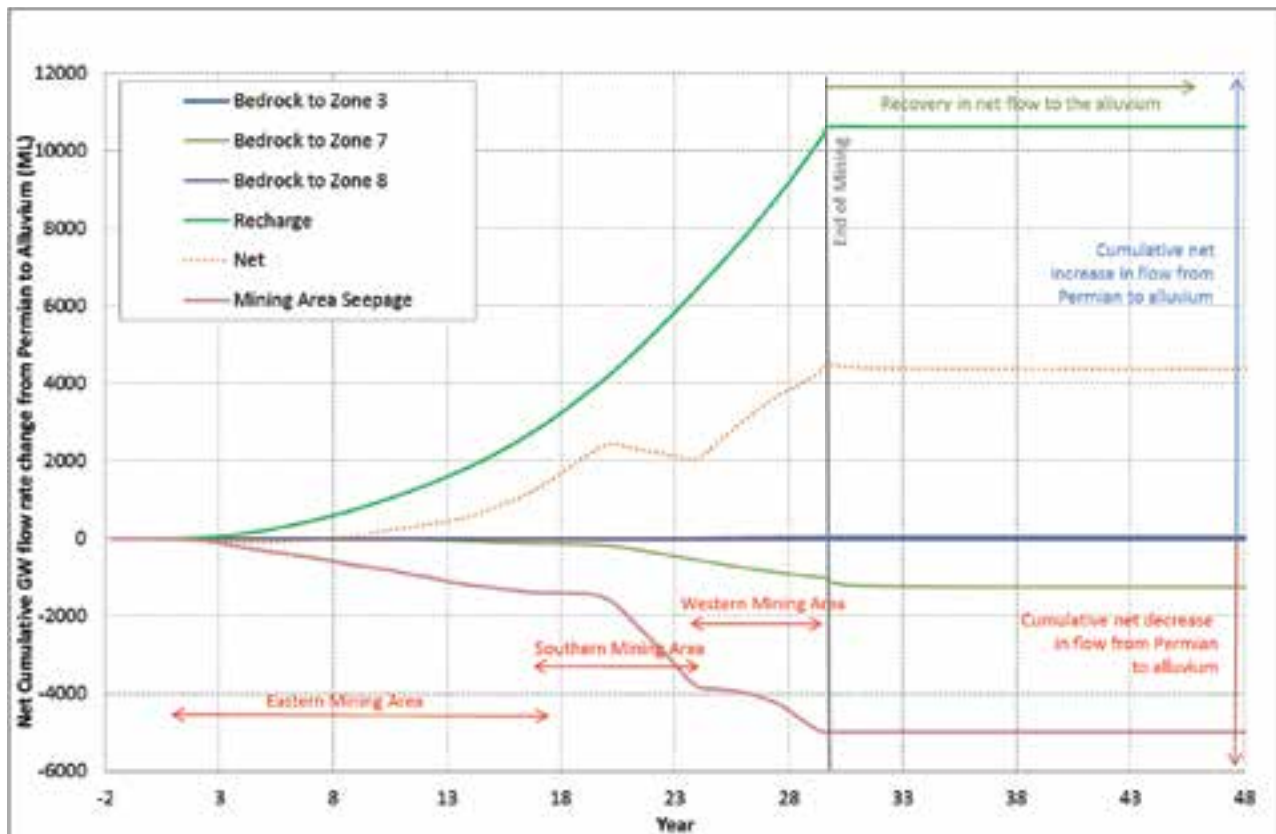


Figure 10.37: Simulated Cumulative Net Change in Flow from Bedrock to Alluvium

Figure 10.37 has both positive and negative scales. The depressurisation of the Permian sequence reduces the upward flow of groundwater from the bedrock to the alluvium and this is represented as a negative value. The mining process also creates overburden areas which have a higher recharge rate than the pre-mining landscape. This means that on a cumulative basis, there is a net gain in groundwater to the aquifer systems over time due to this increased recharge rate.

The most significant loss is from Zone 7 to the south of the Project at 1020.8 ML over the active mining life. The loss from Zone 3 and Zone 8 is very low at 14 ML and 35.5 ML respectively.

Figure 10.37 highlights the impact of the additional recharge to the overburden material on the model water budget, with 10,600 ML added to the groundwater system due to mining. The addition of overburden and the resultant enhanced recharge plays a beneficial role to the project, acting as a buffer for drawdown due to the influx of a total of 10,600 ML to the groundwater system over the life of the Project. As a result, the Project net groundwater flow budget is positive (+4,400 ML) as indicated by the dashed orange line in Figure 10.37. This indicates that the Project contributes a total of 4,400 ML to the groundwater environment over the life of mining. Section 10.12 presents an assessment of the quality of the additional groundwater in the overburden emplacements. The study found the quality of the additional groundwater in the overburden emplacements will be of similar or better quality than the existing Permian groundwater, and will not degrade the current beneficial use category.

Table 10.4 summarises the share components available under the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources* and the predicted water take attributable to the Project.

**Table 10.4: SUMMARY OF WATER AVAILABILITY AND PROJECT WATER TAKE**

Groundwater Management Zone	Share Aquifer Components (ML/year) ¹	Predicted Water Take During Mining		Percentage of Peak Share Component Utilised by Mining	Water Licences held by Shenhua
		Average (ML/year)	Peak (ML/year)		
Zone 3	17,101	0.5	1.1	0.006 %	none
Zone 7	3,697	34	101.8	2.8 %	WAL 12878 – 827 units ² WAL 12892 – 42 units
Zone 8	16,122	-1.2	0.4	0.002 %	WAL 12896 – 164 units

1. Aquifer water licenses only – excludes stock/domestic, local water utility and supplementary units

2. Shenhua holds 2/1000 shares in licence

Table 10.4 demonstrates the Project will take only a very small proportion of the available share components from the surrounding Groundwater Management Zones. The DGRs for the Project require that ‘a description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo’.

The water licences Shenhua hold for Zone 8 fully account for the take of water in that zone predicted by the model. Shenhua will need to obtain share component from Zones 3 and 7 of the Upper and Lower Namoi Groundwater Source to account for the take of water from these zones.

Table 10.4 does not account for the additional groundwater that enters the system through the overburden recharge. When this is considered, there is no net take of groundwater post mining.

10.8.2 Porous Bedrock Aquifers

The *Water Sharing Plan for the NSW Murray-Darling Basin Porous Rock Groundwater Sources* (NOW 2012b) subdivides groundwater sources into the Gunnedah–Oxley Basin MDB Groundwater Source of:

- The “Other” Management Zone, and
- Spring Ridge Management Zone.

The Project Area extends over the ‘Other’ Management Zone, and is adjacent to the Spring Ridge Management Zone (refer Figure 4.1 in Section 4.2).

There is Quaternary alluvium within the ‘Other’ and Spring Ridge Management Zones within the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011*. The water take due to mining presented in this section includes water from both the alluvium and porous rock.

Figure 10.38 presents the net groundwater take from the Porous Rock Groundwater Management Zones. Table 10.5 summaries the net water annual water take from the ‘Other’ and Spring Ridge Water Management Zones under the *Water Sharing Plan for the NSW Murray Darling Basin Porous Rock Groundwater Sources 2011*.

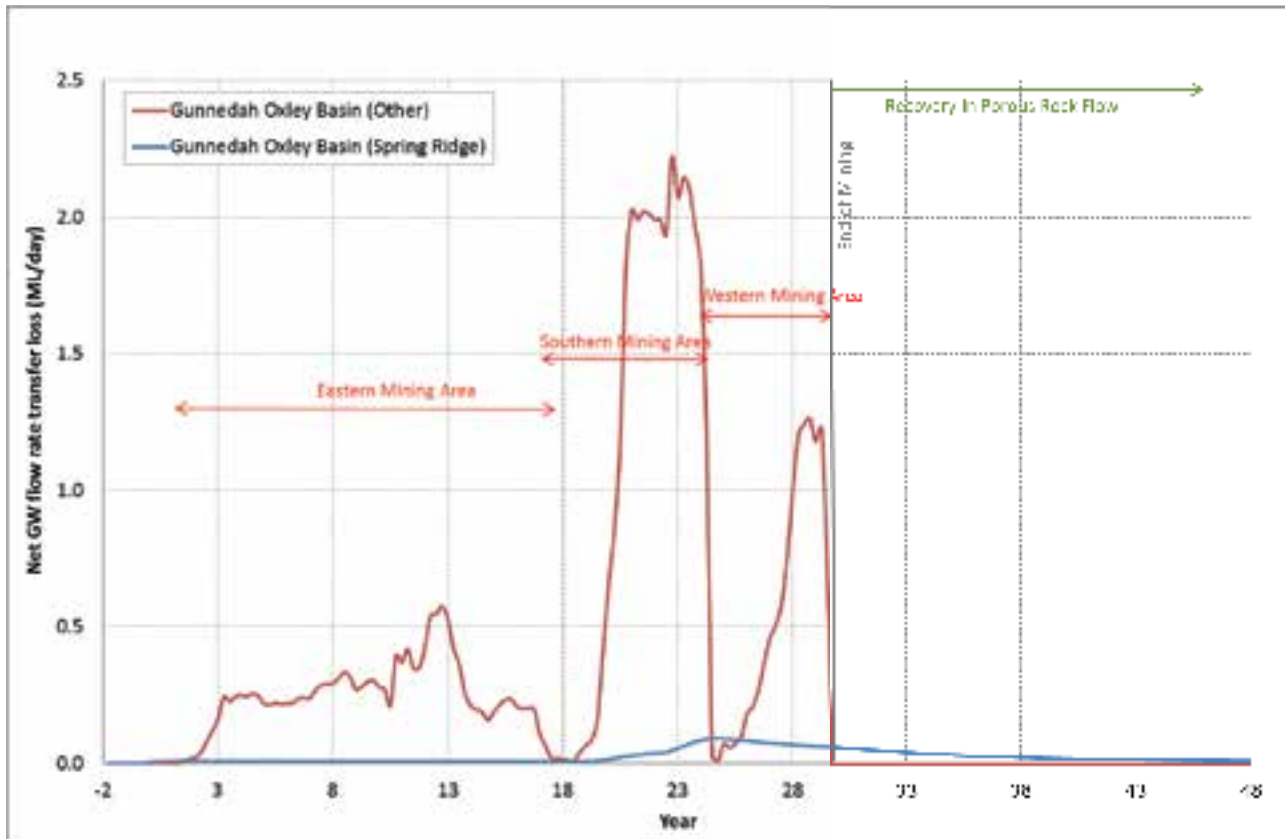


Figure 10.38: Simulated net loss from Porous Rock Management Zones

Table 10.5: NET WATER TAKE FROM POROUS ROCK GROUNDWATER WATER MANAGEMENT ZONES (ML/year)

Year	Water Management Zone	
	'Other'	Spring Ridge
1	0.0	2.7
2	2.1	3.4
3	23.5	3.4
4	79.9	3.4
5	91.2	3.4
6	79.6	3.4
7	84.0	3.3
8	99.2	3.3
9	114.5	3.3
10	105.5	3.3
11	105.9	3.3
12	135.8	3.2
13	190.5	3.2
14	143.1	3.2



**Table 10.5: NET WATER TAKE FROM POROUS ROCK
GROUNDWATER WATER MANAGEMENT ZONES (ML/year)**

Year	Water Management Zone	
	'Other'	Spring Ridge
15	68.7	3.2
16	79.6	3.2
17	74.1	3.2
18	19.3	3.2
19	7.4	3.1
20	65.6	3.7
21	414.5	7.6
22	734.7	11.9
23	742.9	15.0
24	756.3	24.7
25	277.8	32.7
26	27.2	32.1
27	92.9	29.1
28	209.1	26.6
29	429.9	24.4
30	285.5	22.7

Note - negative numbers indicate an increase in transfer rate from Permian to alluvium above Pre-mining conditions

The numerical modelling predicts an average groundwater seepage rate to the open cut Mining Area of 0.5 ML/day (180 ML/year) with a peak of 756 ML/year in Year 24. The groundwater seepage to the proposed mine is largely sourced from storage in the overburden/interburden and the coal seams. As the zone of depressurisation increases, there is a net transfer of water from the 'Spring Ridge' management into the 'Other' management zone which peaks at 32.7 ML/year in Year 25.

10.8.3 Summary of Water Take from Water Sharing Plan Zones

The Project will be required to obtain entitlements from each of the Water Management Zones to offset the predicted impact of the Project. Table 10.6 summaries the predicted water take from each Water Management Zone due to the Project.

Table 10.6 also identifies the water licences currently available in each Water Management Zone, the subsequent total share components available and the Long Term Annual Average Extraction Limits.



Table 10.6: TAKE OF WATER DURING AND AFTER MINING								
Water Source	Predicted Peak Annual Water Take (During Mining)	Predicted Peak Annual Water Take (After Mining)	AWD Factor	Total Share Component Requirement for Project (Units)	Share Component Already held by Shenhua (Units)	Total Number of Licences Issued	Total Share Component Issued (Units)	L TAAEL
Namoi Groundwater ZONE 3	1.1	0*	1.1	1.2	Nil	60 aquifer 28 supplementary water 1 local water utility	17,101 aquifer 8,065 supplementary water 198 local water utility	At least 17,300 ML/yr
Namoi Groundwater ZONE 7	101.8	0*	1.1	112	42	16 aquifer 1 supplementary water	3,697 aquifer 7 supplementary water	At least 3,700 ML/yr
Namoi Groundwater ZONE 8	0.4	0*	1.1	0.4	164	64 aquifer 35 supplementary water 1 local water utility	16,122 aquifer 4,898 supplementary water 50 local water utility	At least 16,000 ML/yr
Porous Rock (Gunnedah-Oxley Basin - Other)	756	0*	1.25	940	Nil	120 aquifer 2 local water utility (Other and Spring Ridge Management Zones combined)	16,784 aquifer 420 local water utility (Other and Spring Ridge Management Zones combined)	199,893 ML/yr (Other and Spring Ridge Management Zones combined)
Porous Rock (Gunnedah-Oxley Basin – Spring Ridge)	33	0*	1.25	42	Nil	120 aquifer 2 local water utility (Other and Spring Ridge Management Zones combined)	16,784 aquifer 420 local water utility (Other and Spring Ridge Management Zones combined)	199,893 ML/yr (Other and Spring Ridge Management Zones combined)
Mooki River	47.5	0*	1.1	53	Nil	29 unregulated river 9 domestic and stock 3 domestic and stock (stock)	29,589.5 unregulated river 23.5 domestic and stock 82 domestic and stock	As calculated under clause 35 of the WSP
Lake Goran	0	0*	1.1	0	1,223 (subject to issuance of certificate of title)	7 unregulated river 2 stock and domestic	32,171 unregulated river 88 stock and domestic	As calculated under clause 29 of the WSP

* long term net gain exceeds predicted losses immediately following mining
LTADEL – Long Term Average Annual Extraction Limit



10.9 Changes to Surface Water Flow and Quality

In the absence of mining, the river and creek network has both losing and gaining stretches. Section 9.2.10 summarised the results of the model calibration, which indicated that losing conditions dominate the Mooki River and Quirindi Creek with only small gaining segments towards the foothills of the Liverpool Range.

Once mining commences, the Permian strata become depressurised, and within the zone of influence, upward flow from the Permian to the alluvium reduces. The resultant lowering of groundwater levels in the Narrabri Formation, although very small, does increase the hydraulic gradient between the bed of the Mooki River and the underlying aquifer. The higher gradient potentially increases the rate of surface water flow from the river to the aquifer.

Figure 10.39 presents the water budgets for the surface water bodies from the predictive model. The flows in the surface water bodies including the Mooki River and Quirindi Creek show no obvious response to mining over the proposed 30-year mining period.

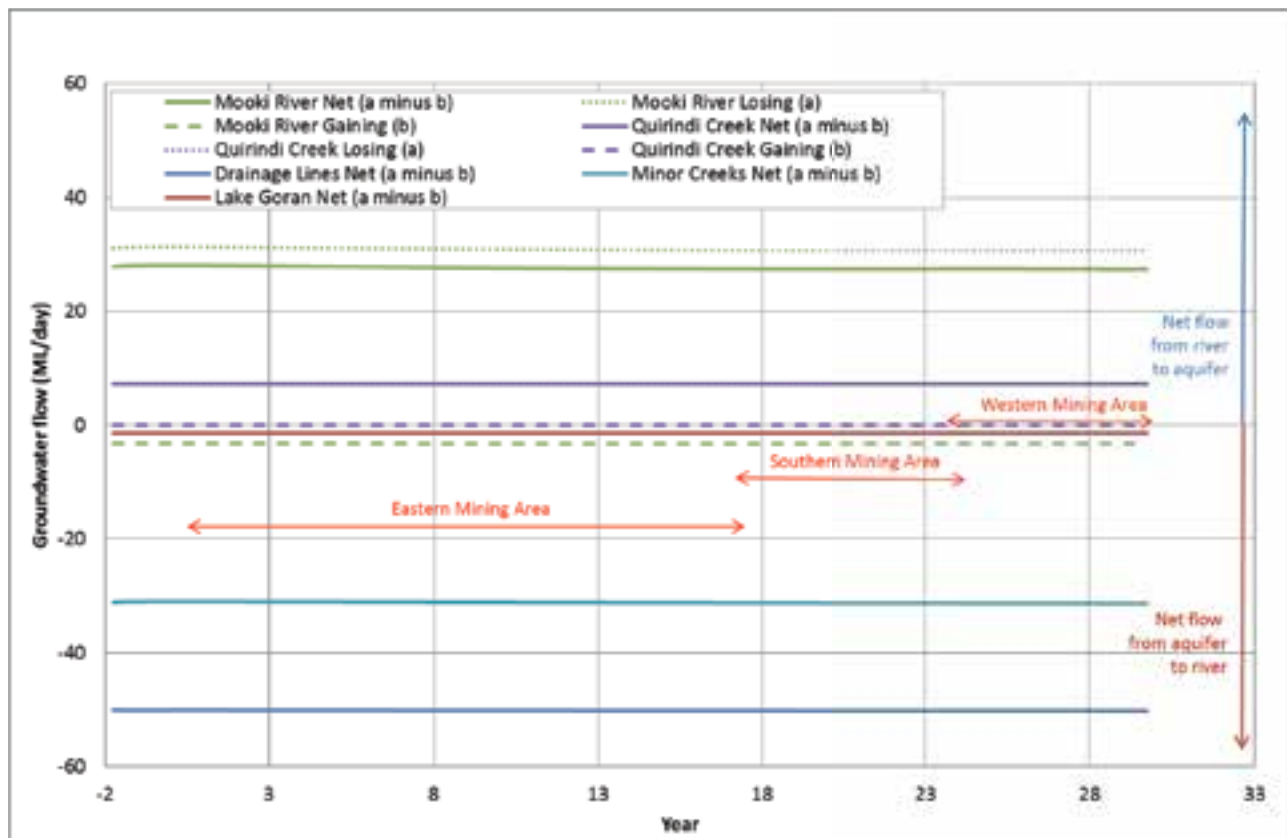


Figure 10.39: Surface Water Budgets

Figure 10.40 presents the net change in the river/creek flows in response to mining. This was determined by subtracting the net river/creek flows in the predictive model from the scenario that removed mining.

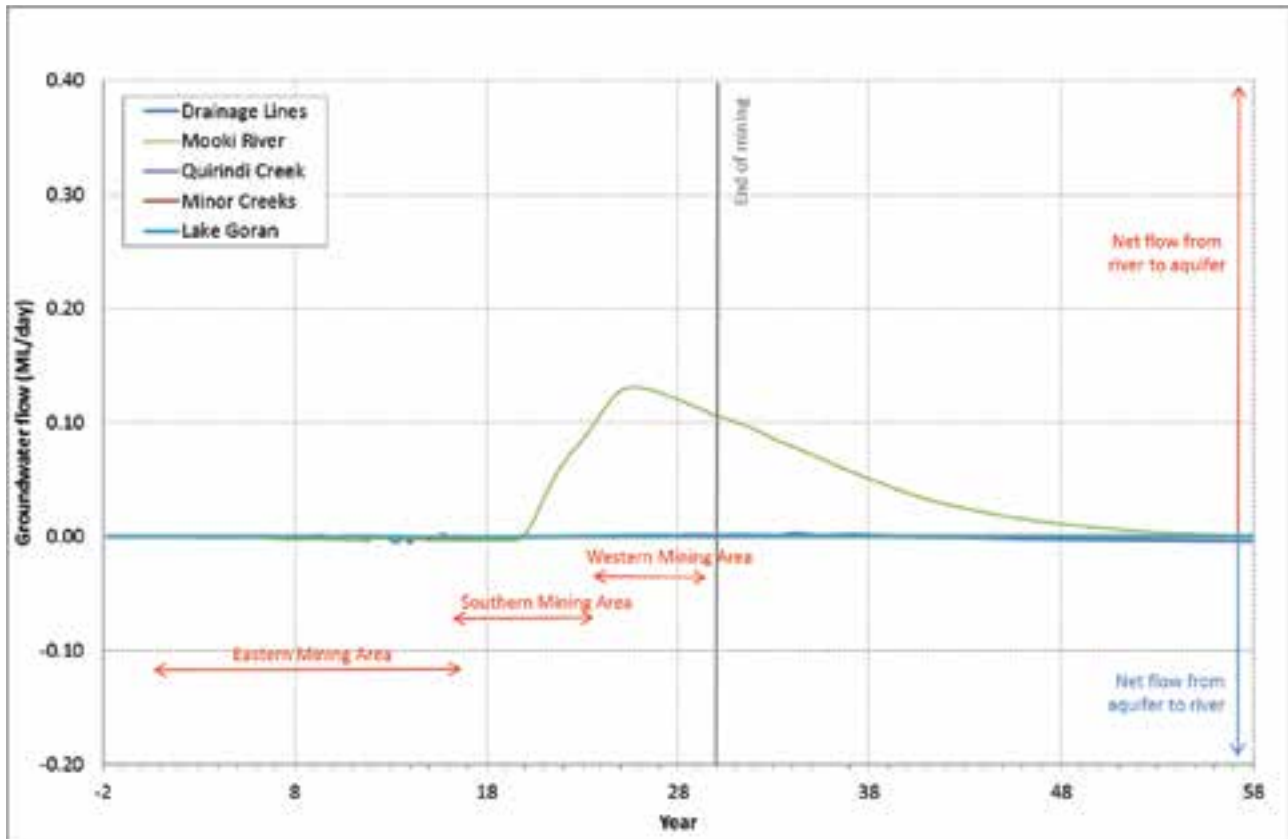


Figure 10.40: Net Change in Surface Water Flow

Figure 10.40 shows a small increase (0.13 ML/day in year 24) in the net flow from the Mooki River to the underlying aquifer, i.e. an increase in ‘losing’ conditions. The other surface water features do not show any significant response to mining. The increase in seepage from the Mooki River to the underlying alluvium of 0.13 ML/day represents an undetectable proportion of the total river leakage along the Mooki River of 0.4%. Figure 10.40 shows that the change in net flow from the Mooki River to the underlying aquifer returns to pre-mining conditions within 30 years of closure of the mine.

Figure 10.40 shows there is no significant impact on Lake Goran where the groundwater level drawdown is not predicted to exceed 0.01 m. Lake Goran is an ephemeral lake and does not receive a significant contribution from groundwater, and therefore will not be impacted by the Project. Water licenses to offset impacts on Lake Goran are not required.

Figure 10.41 shows the cumulative change in surface water flows. The total additional flow from the Mooki River to the underlying aquifer reaches 323 ML at the end of the proposed 30-year mine life. Post mining, the zone of depressurisation continues to radiate outwards into the alluvium and under the Mooki River, and there is a continuing increase in cumulative flow to the underlying aquifer. By about Year 60 (30 years post mining) the zone of depressurisation has fully retracted and there is no further cumulative loss from the Mooki River to the underlying aquifer (shown by the flat lying green line in Figure 10.41). When the post mining loss is considered, the total additional flow through the Mooki River to the underlying aquifer due to the Project is 489 ML, .i.e. an additional 166 ML between Year 30 and Year 60. This is equivalent to an average of 16.3 ML/year over the 30-year mine life.

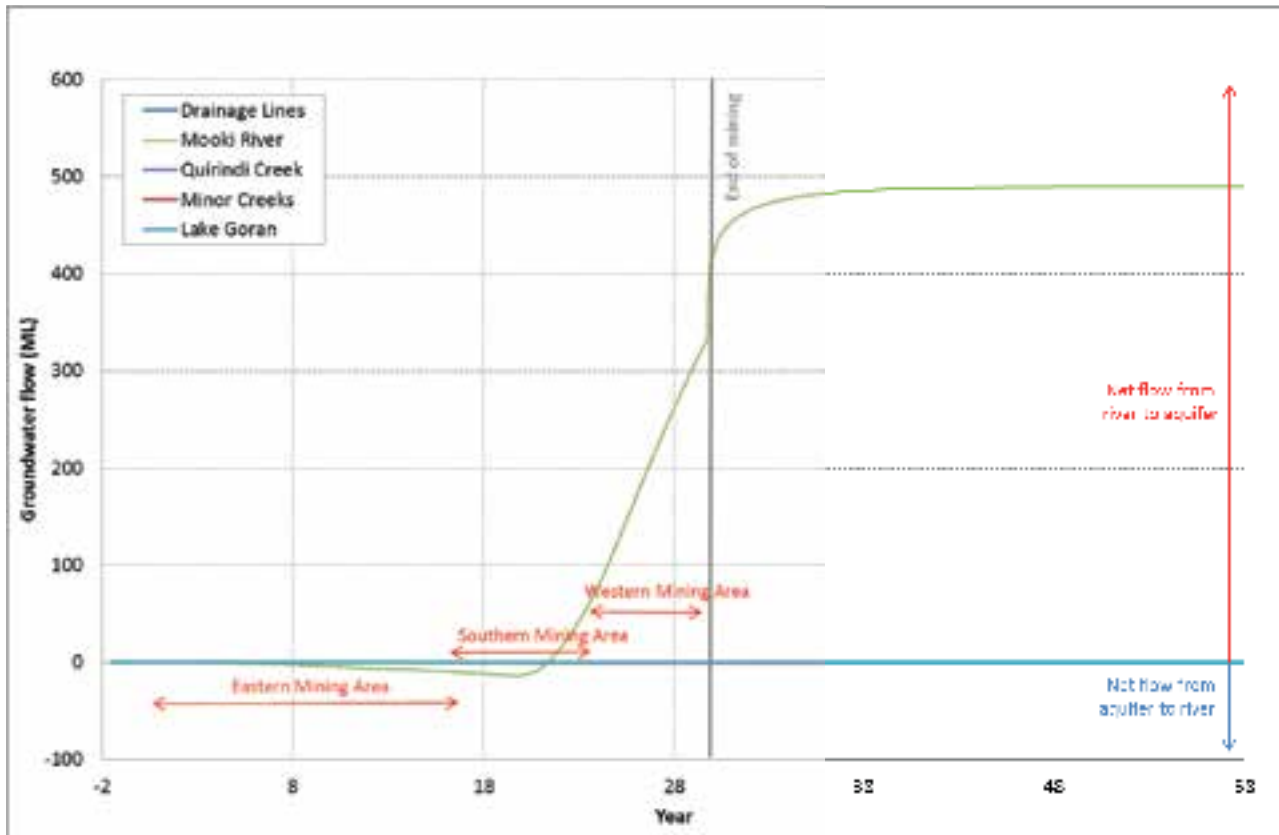


Figure 10.41: Cumulative Change in Surface Water Flow

Shenhua Watermark does not currently hold any water licences to account for the predicted transfer of water from the Mooki River to the underlying alluvium. There are currently 28 water access licences for the unregulated river with total share component of 29,526.5 units. The predicted transfer of water due to the Project is relatively small at 0.05% of the total allowed extraction from the river as represented by the 29,526.5 available units. Shenhua Watermark will need to obtain a water licence to offset this very slight impact.

To protect surface water the AIP requires “no increase of more than 1% per activity in the long term average salinity in a highly connected surface water source at the nearest point to the activity”. As discussed above during operations the predicted depressurisation will increase the rate of seepage from the Mooki River into the underlying aquifer. As the flow of water is from the river into the underlying aquifer, there is no potential for a change in salinity in the surface water source during operations. Post mining the project is expected to slowly reduce the salinity of groundwater around the mined area due to the increased rate of recharge through the backfilled materials. There is no potential for an increase in salinity in surface water sources under this scenario, and the Project is considered to comply with the AIP for this requirement.

The model indicates an increase in net flow to the Mooki River post mining of 0.02 ML/day due to the additional recharge through the spoil material in the Southern and Eastern Mining Areas. This is a very small proportion of the net modelled flow to the Mooki River from the aquifers of 27.3 ML/day, or approximately 0.07% of the net flow. This indicates the Project will comply with the AIP requirement of no increase of more than 1% in the long term average salinity.



10.10 Impact on Groundwater Dependent Ecosystems

Cumberland Ecology (2012) concluded that approximately 50 ha of the Project Boundary has a high potential for the presence of GDEs. Drawdown simulations over this region predict a reduction in the groundwater level may reduce groundwater levels in these areas; however, the presence of a rocky subsoil and poor groundwater quality in these areas would likely preclude the presence of GDEs in the depressurised areas.

Cumberland also concluded that there are no mapped GDEs present in the Quaternary alluvium in the Project area, with the exception of the Fuzzy Bush communities south of the Project. Depressurised Quaternary alluvial regions to the south of the mining areas are dominated by groundwater with high salinity and therefore preclude the existence of groundwater dependent vegetation communities, particularly in the south-west region of the Project Boundary.

The AIP specifies that 40m from a groundwater dependent ecosystem or culturally significant site, cumulative variation in the water table should be less than or equal to 10%. There are no high priority groundwater dependent ecosystems identified in the Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003.

10.11 Post Mining Groundwater Recovery

10.11.1 Recovery Model Setup

The recovery model commenced from the end of mining and used the final groundwater levels as the starting heads. The boundary condition simulating groundwater seepage into the Mining Areas was removed from the model to enable groundwater levels to equilibrate.

A final void will remain at the highwall in the Western Mining Area, with an area of approximately 100 ha and will be up to approximately 60 m deep. Groundwater, surface runoff and rainfall inflows will slowly fill the void forming a water body and eventually reaching an equilibrium water level which will be influenced by the balance of seepages from groundwater, surface runoff/infiltration from the spoil pile and losses from evaporation.

At the cessation of mining, there will be a relatively high hydraulic gradient between the open void and the surrounding aquifers, which will result in relatively rapid seepages. As a water body begins to form in the void, the gradient reduces and the rate of groundwater inflow will slow. Eventually a state of equilibrium will occur where inputs are balanced by outputs and the water level in the water body will have stabilised.

The rate of recovery of groundwater levels in the aquifers will be dependent on rainfall, with years of below average rainfall extending the recovery period, and wet years reducing the time for stabilisation. Evaporation of water from the final void water body results in a continuous flow of groundwater into the void, in an effect known as evaporative pumping. This results in groundwater levels attaining an equilibrium water level at a lower elevation than the pre-mining water level; this however is dependent on the magnitude of catchment inputs.

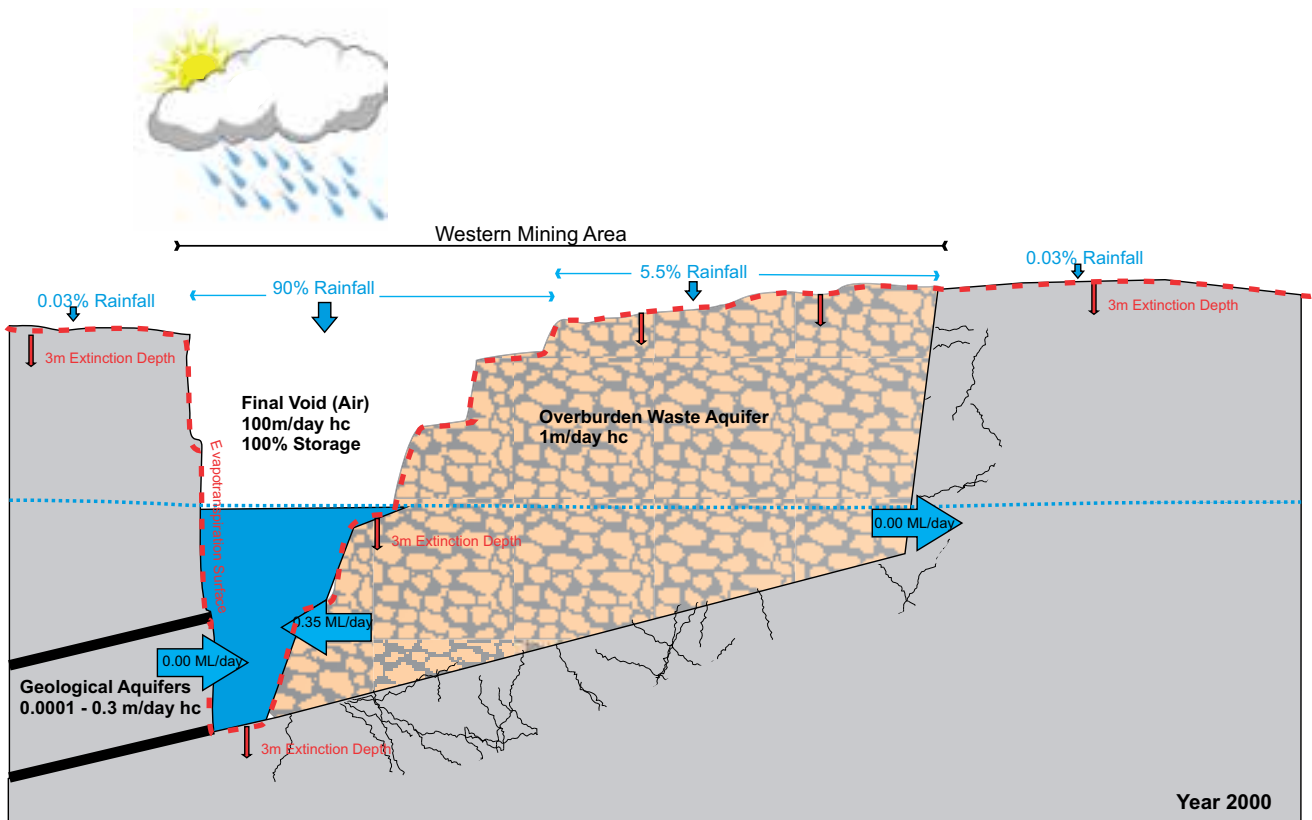
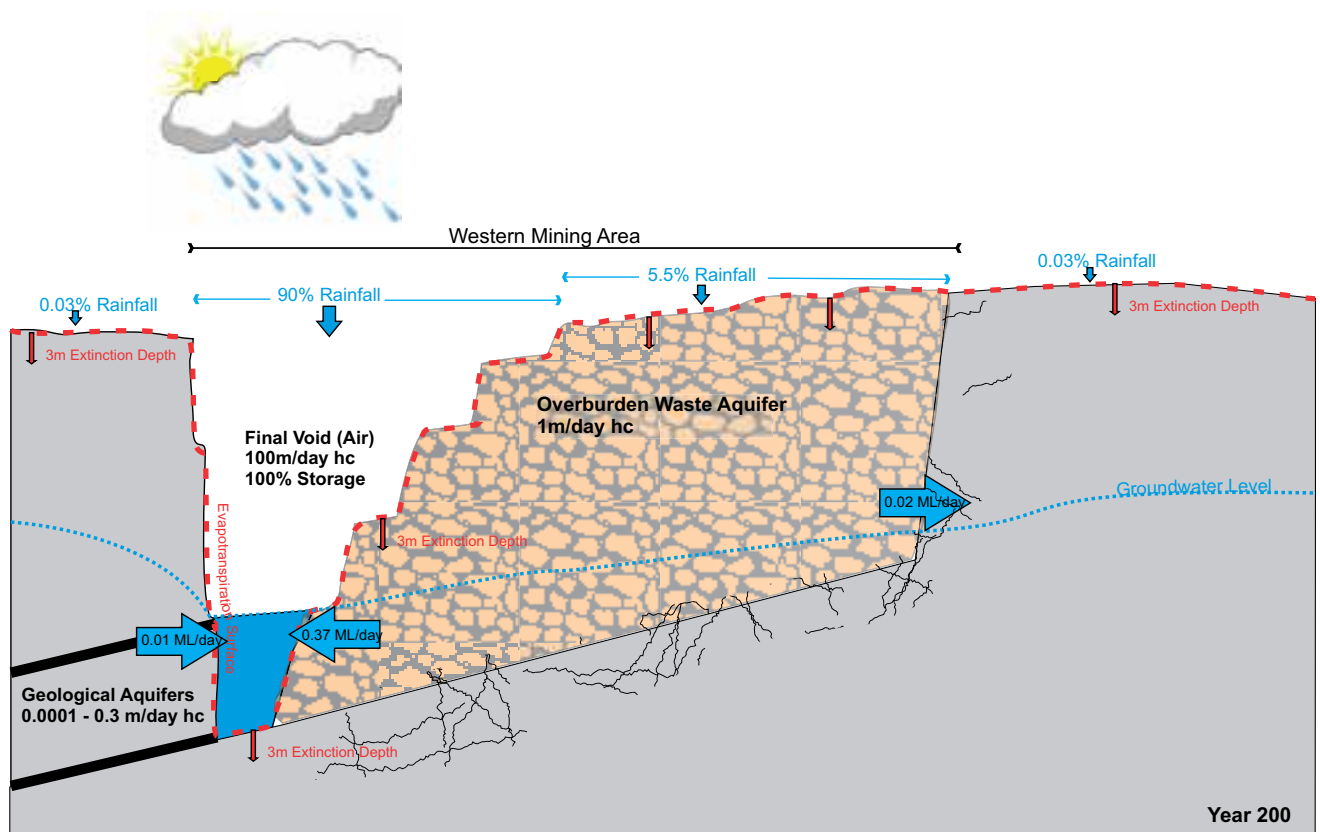
The topography of the final void was loaded into the model and compared to the existing geological layers. The model grid and layer elevations remained identical to the predictive model. Model cell centre elevations that were located above the final void surface and below the original ground surface were assigned a high horizontal and vertical hydraulic conductivity (100 m/day) and storage parameters (specific yield and storage coefficient of 1.0), to simulate free water movement within the void.



Rainfall recharge was applied to the final void water body area to simulate a direct input of rainfall. A rate of 90% of average historic rainfall was adopted to account for rainfall on the mining area walls that does not enter the lake. The evapotranspiration surface was modified to represent the direct evaporation from the mining area water body. The maximum point potential evapotranspiration rate adopted across the final void water body surface was 5.4 mm/day (1970 mm/year), representative of expected evaporation rates from an open water body. Point Potential evapotranspiration is the evapotranspiration that would take place, under the condition of unlimited water supply, from an area so small that the local evapotranspiration effects do not alter local air mass properties. It is assumed that latent and sensible heat transfers within the height of measurement are through convection only. Potential evapotranspiration rates (1970 mm/year) over the pit lake are 12% higher than pan evaporation rates (1752 mm/year) and were therefore considered adequate to ensure consistency across the evapotranspiration rates sourced from Australian Bureau of Meteorology spatially varying sources (BOM, 2012).

Figure 10.42 presents a schematic of the recovery model setup and illustrates how reducing evapotranspiration with depth was applied. Figure 10.42 also presents the void water budget components at Year 200 and Year 2000.

It should be noted that these predictions are indicative only as the model is working well outside its accurate predictive period of approximately 30 years. Assumptions such as predicted rainfall and evaporation will need to be regularly reviewed and combined with future monitoring and model upgrades to improve the confidence in these predictions.



Recovery Model Schematic - Year 200 - 2000

Figure 10.42

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)





10.11.2 Open Void Water Level Recovery – Western Mining Area

Figure 10.43 presents the predicted water level in the Western Mining Area final void post mining.

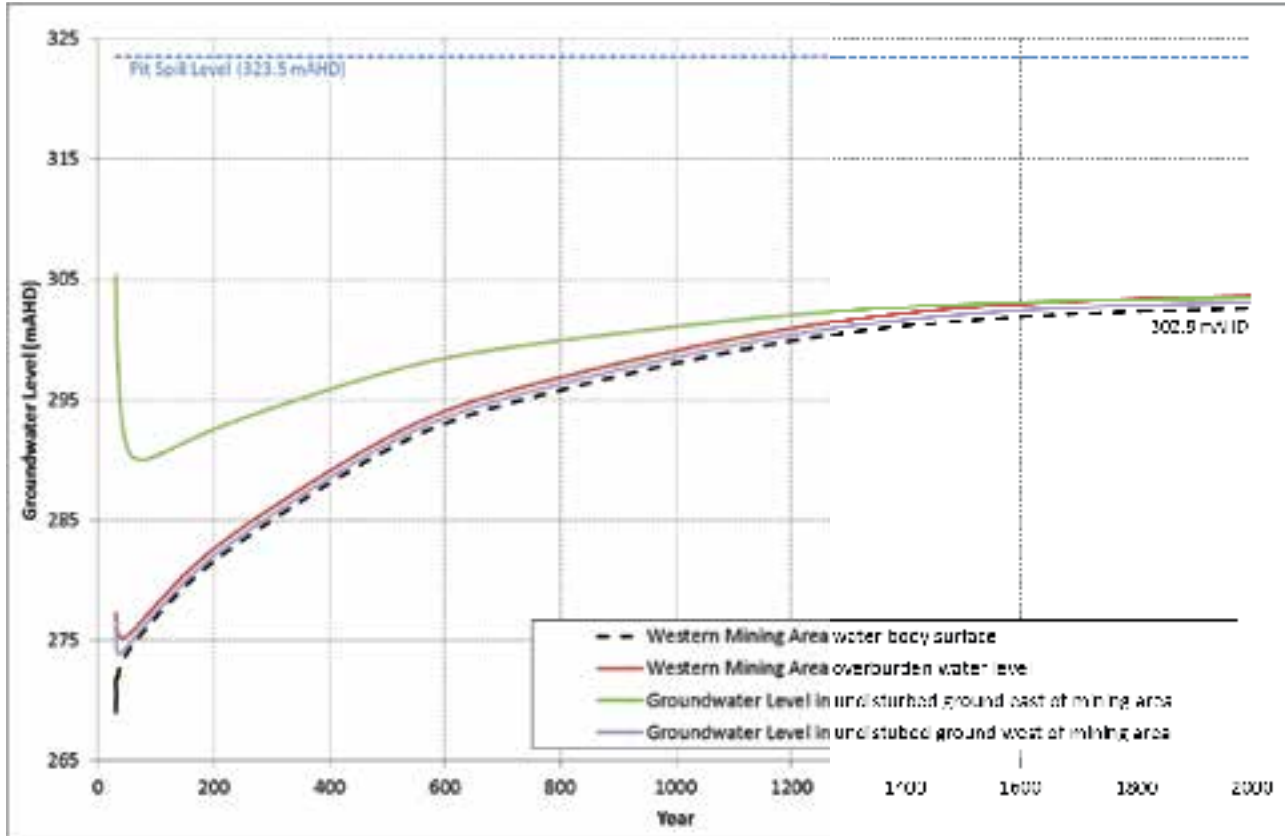


Figure 10.43: Simulated Void Water Level – Western Mining Area

The simulated water level shown in Figure 10.43 is at a point within the deepest part of the final void and spoils. Figure 10.43 shows that the predicted groundwater levels within the Western Mining Area final void will slowly recover and reach equilibrium at about 303 m AHD, after approximately 2000 years post mining. Groundwater levels remain below the regional water table by approximately 1-2 m, indicating the pit lake void will act as a groundwater sink, not a source.

Figure 10.44 illustrates the relationship between the water inputs and the water level in the Western Mining Area overburden and final void water body.

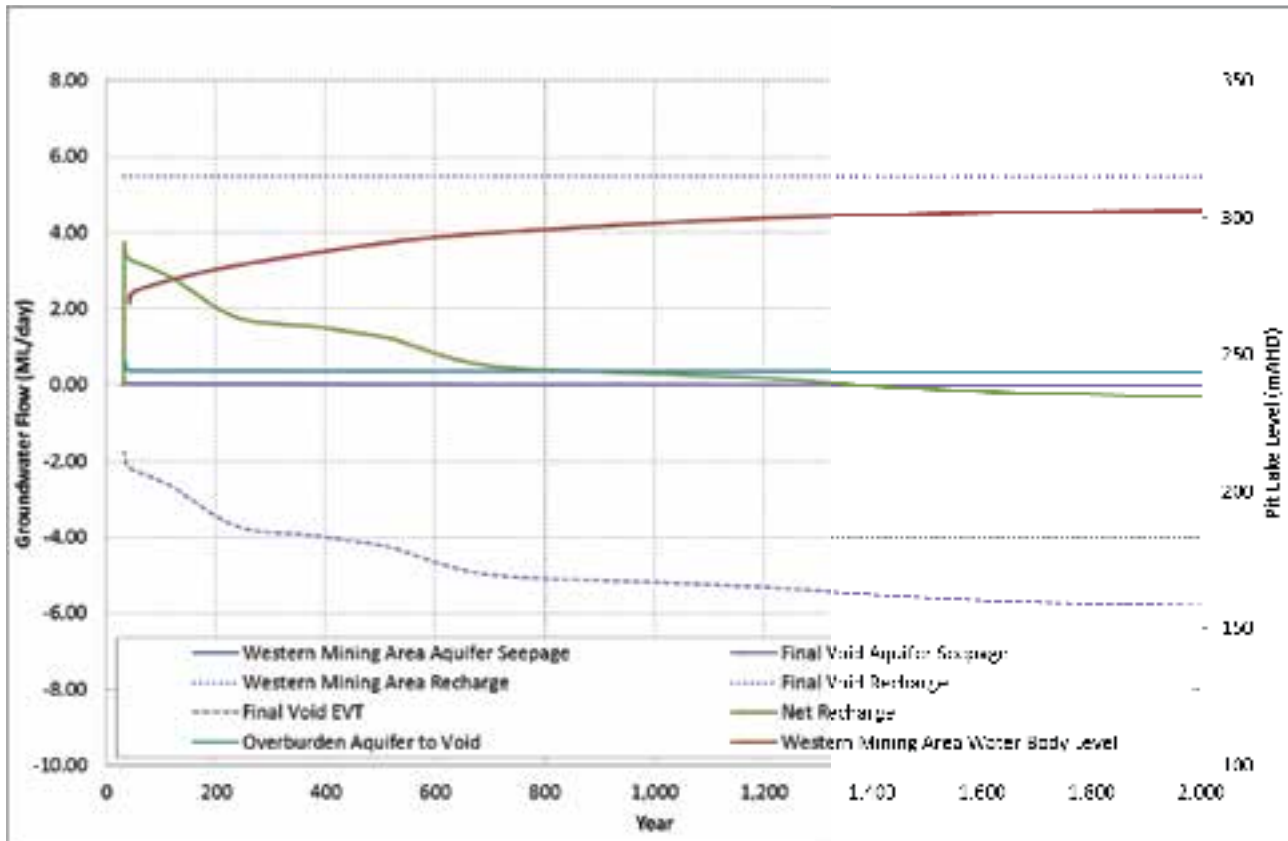


Figure 10.44: Recovery Mining Area Void Budget and Predicted Water Level

Figure 10.44 shows a period of initially rapid recovery followed by a slow return to equilibrium conditions over a period of about 2000 years, after which a net groundwater sink of 0.3 ML/year will remain. This loss is offset by the enhanced rainfall recharge to the spoil in the Eastern and Southern mining areas, which contributes 0.25 ML/day and 0.35 ML/day respectively. This indicates the Project will have a net gain of 0.3 ML/day.

Figure 10.44 also indicates that the water budget for the final void is dominated by rainfall and evaporation, with only a very small contribution from groundwater seepage. WRM (2012) also assessed the recovery of water levels in the final void and the final void water quality using the OPSIM software. They predicted the water level in the final void stabilised at between 275 m AHD and 305 m AHD in the final void after 300 years. The OPSIM model recovered much more quickly than the groundwater model with water levels reaching equilibrium within 300 years.

The OPSIM surface water model indicates the pit lake will recover within 300 years. The more rapid recovery is because the OPSIM model simulates daily rainfall which includes storm events. During these events, the pit lake recovers faster than the groundwater model which uses annual average rainfall rates.

Another factor contributing to the more rapid recovery time in the OPMSIM model is the representation of the open void. Figure 10.45 shows the open void volumes for both the surface water and groundwater models.

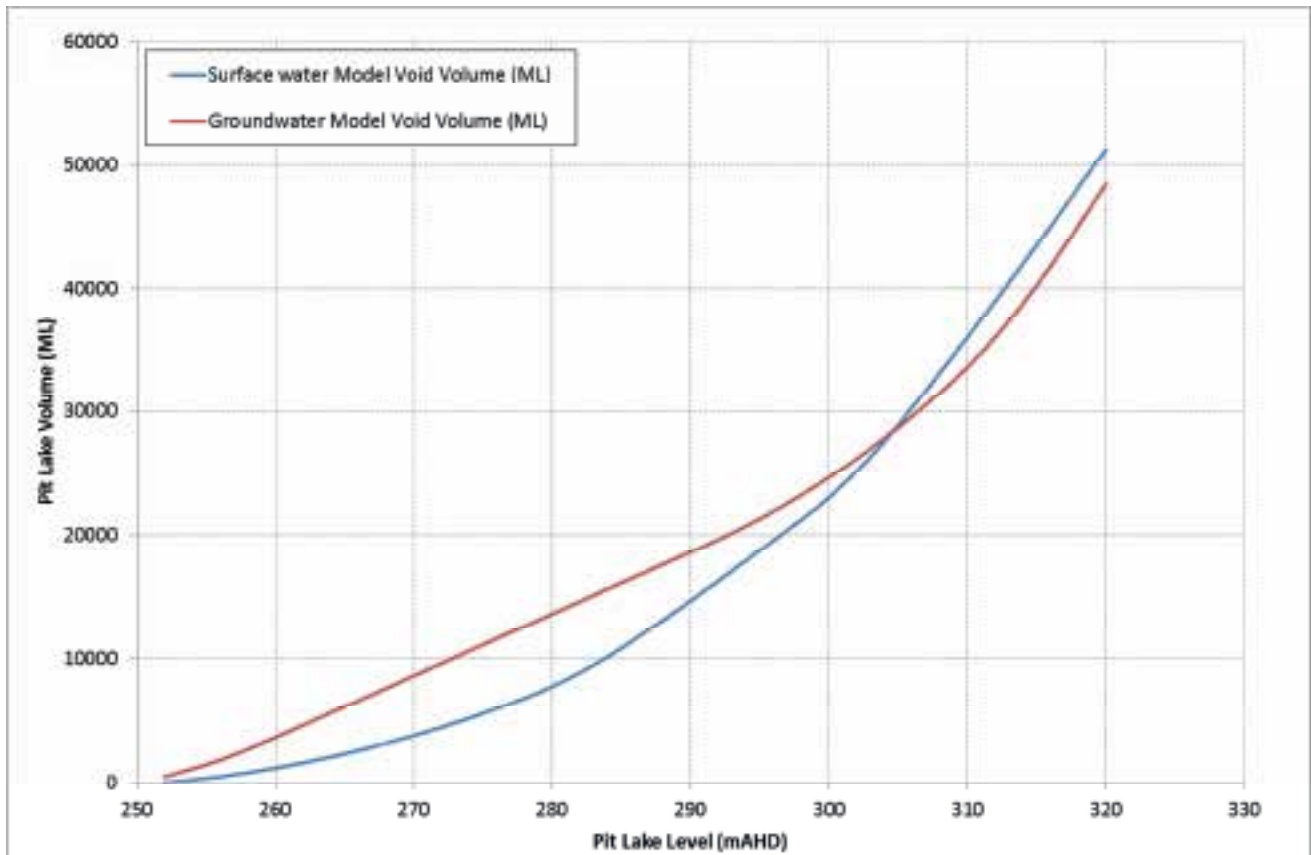


Figure 10.45: Open Void Storage Volumes

Figure 10.45 indicates the volume of open void in the groundwater model is greater than in the surface water model (up to double the volume at a pit lake level of 280 mAHD) and therefore recovery is slowed in the groundwater model.

Both the groundwater model and the OPMSIM model indicate that the water level in the final void will stabilise well below the crest of the open cut mining area, and therefore spillage of water into the environment will not occur.

10.11.3 Backfilled Voids Water Level Recovery – Eastern and Southern Mining Areas

Figure 10.46 shows the predicted water level recovery within the overburden backfilled Southern and Eastern Mining Areas. Groundwater levels in the backfilled Southern Mining Area and Eastern Mining Area are also predicted to recover to above pre-mining levels. This is due to a higher recharge rate on the overburden material than the pre-mining. The higher recharge rate and mounded landform mean that a zone of seepage occurs at the 'spill points' that are topographic low points along the former Mining Area rim.

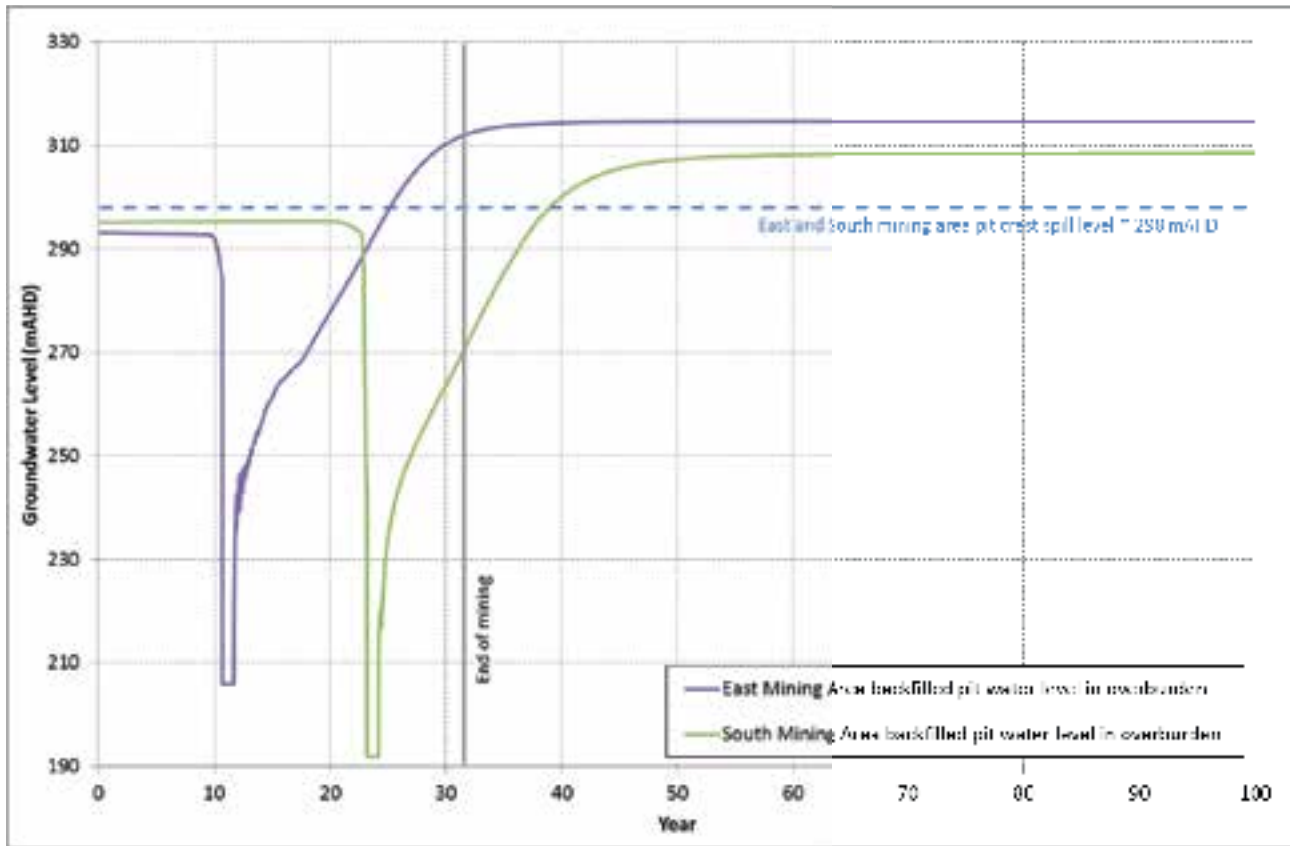
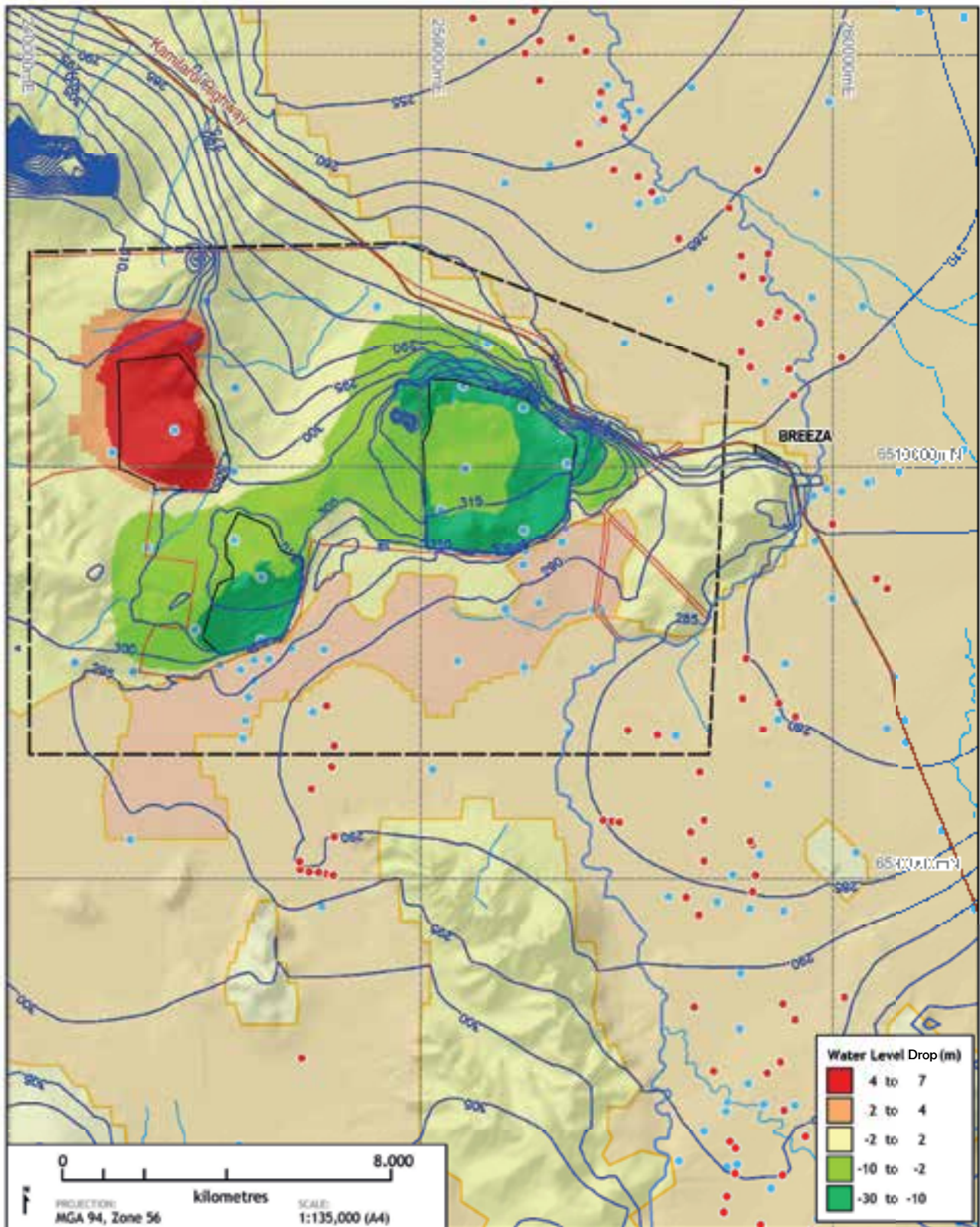


Figure 10.46: Simulated Backfill Water Level – Eastern and Southern Mining Areas

Figure 10.47 shows the extent of the post-mining groundwater mounding around the backfilled Southern and Eastern Mining Areas, and the depressurisation around the open Western Mining Area.

Figure 10.48 and Figure 10.49 presents the post mining simulated heads in cross section for Year 2000, and the pre-mining steady state water levels for comparative purposes.

Figure 10.50 presents the depth to the groundwater table below the final landform surface at Year 30. No seepage is evident around the Southern Mining Area at this time as groundwater levels are still recovering after mining. Figure 10.51 shows the predicted groundwater seepage zones at 2000 years post mining. The model predicts the maximum flows from these seepages around the toe of the Southern and Eastern Mining areas to be 0.08 ML/day. Section 10.12 discusses the quality of the seepage from the backfilled Southern and Eastern Mining Areas.



- LEGEND:
- Pumping Bore
 - Proposed Mining Area
 - Project Boundary
 - Groundwater Level (mAHd)
 - Observation Bore
 - Gunnedah Aquifer Extent
 - Narrabri Aquifer Extent
 - Mooki River
 - Drainage Line / Creek

Watermark Coal Project (G1501)
Groundwater Assessment

**Recovered Groundwater Heads and
Head Change (Year 2000)**



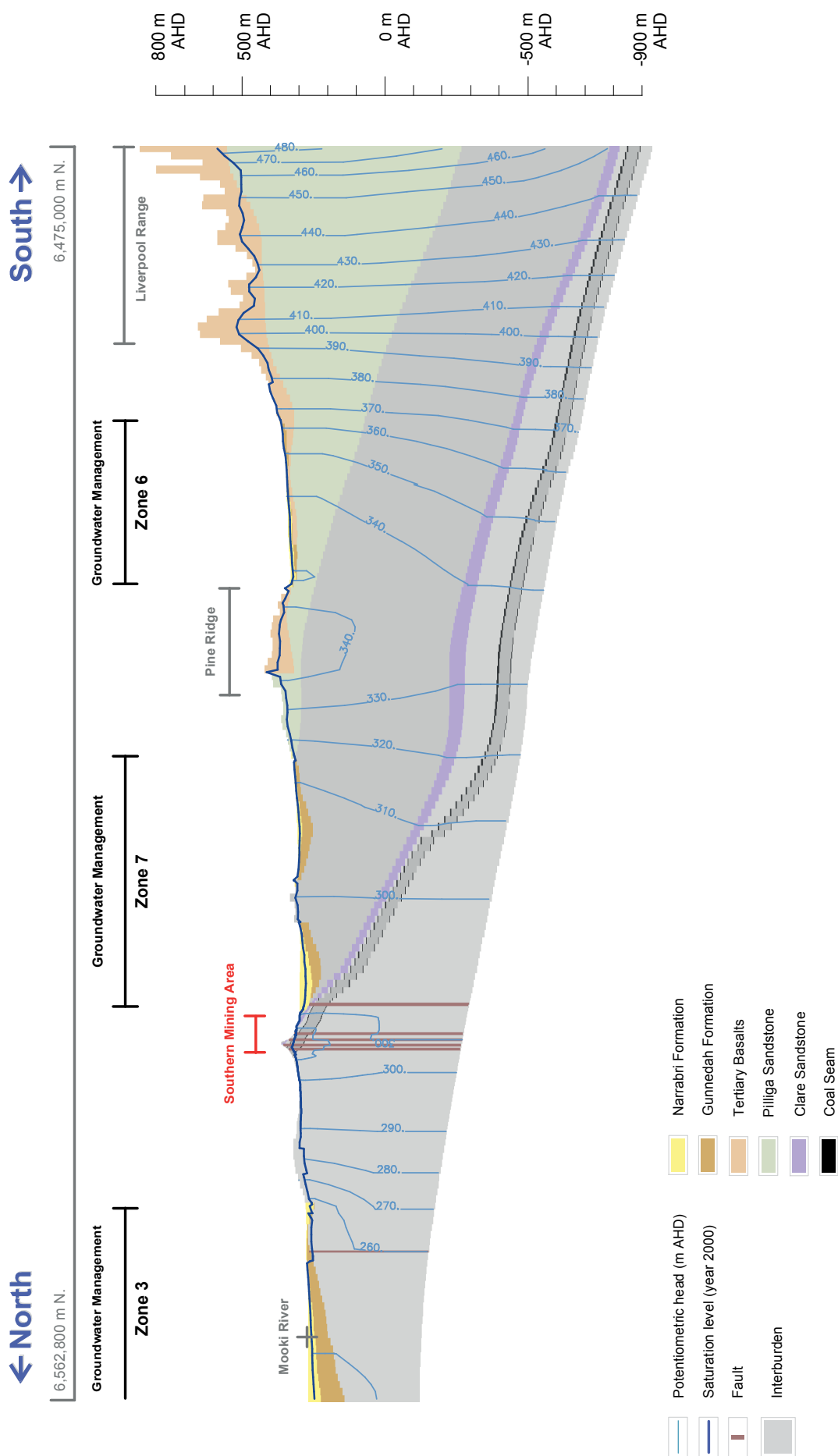
DATE:
18/10/2012

FIGURE No:
10.47



Figure 10.48

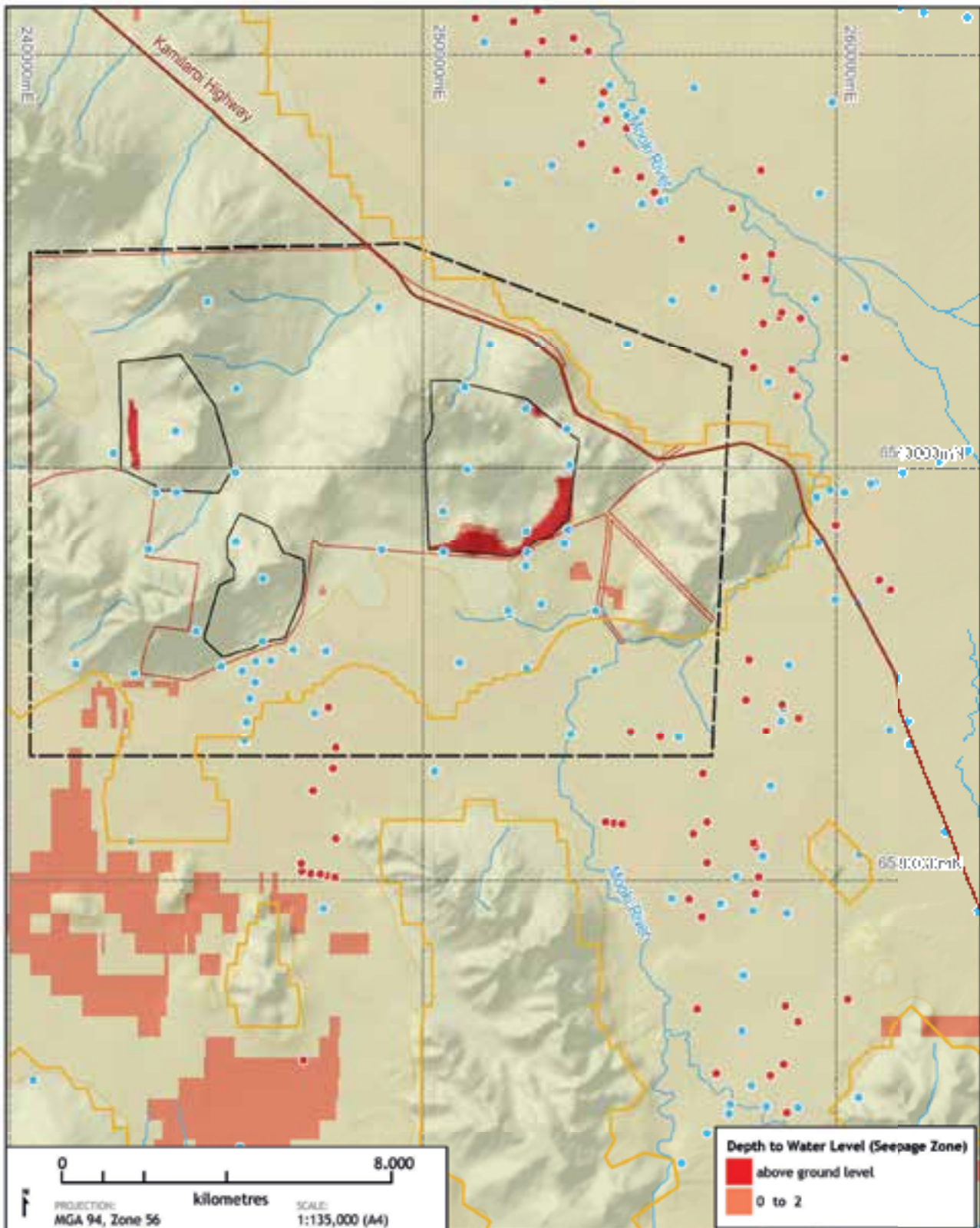
WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



Post Mining Simulated Heads - North-South - Year 2000

Figure 10.49

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



LEGEND:

- | | |
|-------------------------|-------------------|
| Gunnedah Aquifer Extent | Alluvium (1:250k) |
| Observation Bore | Usage Bore |
| Proposed Mining Area | Highway |
| EL 7223 | Project Boundary |
| Drainage Line / Creek | |

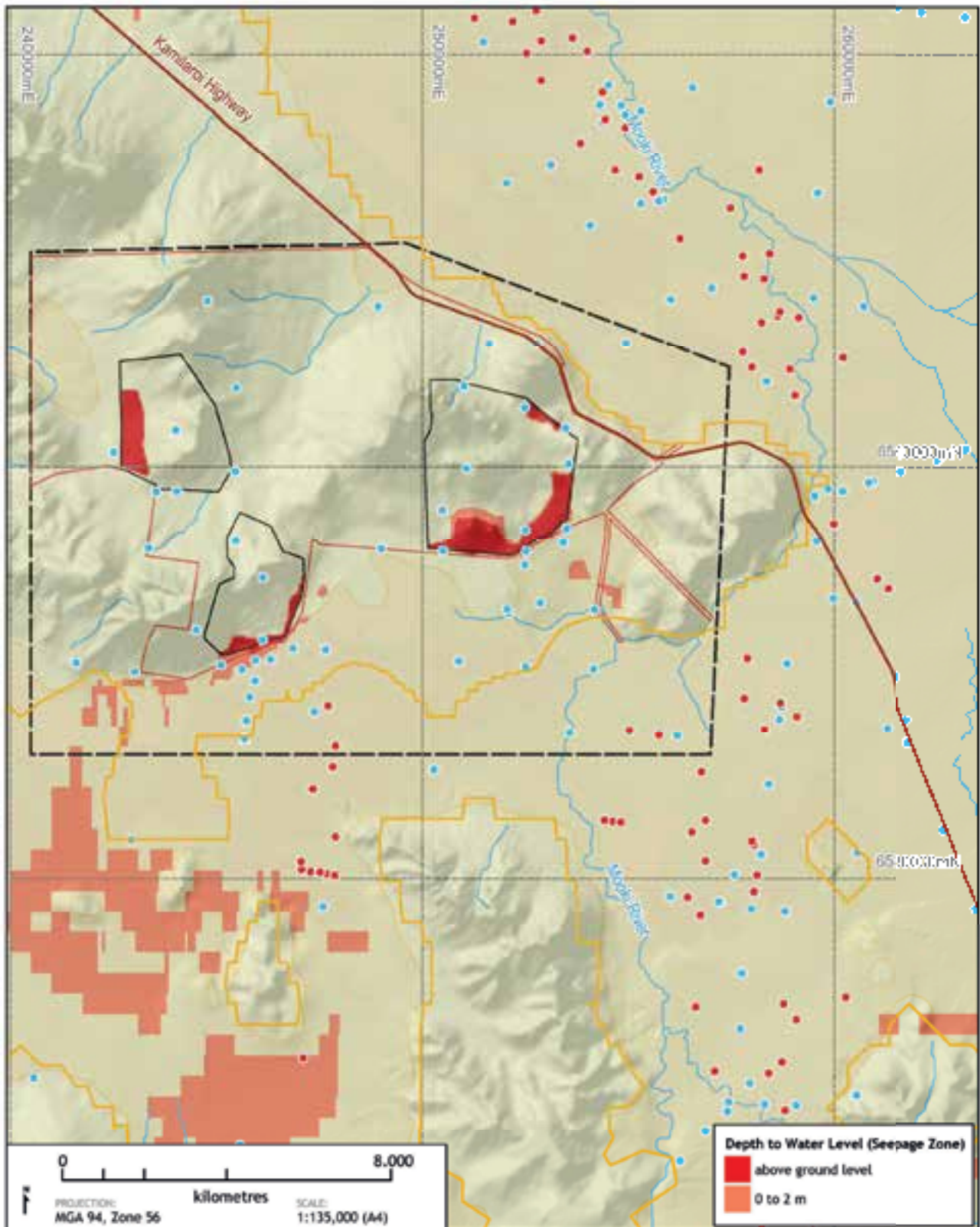
Watermark Coal Project (G1501)
Groundwater Assessment

**Groundwater Seepage Zones
(Year 30)**



DATE:
18/10/2012

FIGURE No:
10.50





10.12 Changes to Groundwater Quality

10.12.1 Methodology

Terrenus Earth Sciences (2012) (refer to Appendix 6) assessed the water quality associated with seepage from the three proposed Mining Areas at the Project. The assessment was undertaken primarily to:

- understand the likely water quality characteristics associated with run-off and seepage from mine spoil (Mining Areas) after mining ceases and post-closure;
- discuss the potential impacts to surface water and groundwater resulting from run-off and seepage from Mining Areas; and
- assist with the management of these Mining Areas with respect to potential surface water and groundwater impacts.

Terrenus Earth Sciences used groundwater modelling data provided by AGE, geochemistry data provided by RGS Environmental, and groundwater chemistry data provided by GHD to assess the likely seepage water quality.

Leachate from mixed spoil materials, comprising fine- to coarse-grained overburden and interburden and a small proportion of coal rejects was conservatively estimated to have an initial salt concentration of up to 5000 mg/L. The concentration of seepage/leachate/run-off was expected to decrease over time (as readily available salt is flushed during the early years).

The concentration of soluble metals in leachate from the column leaching tests was low (below or marginally above the laboratory limit of reporting), and seepage would be expected to also have similarly low concentrations of soluble metals. The pH of leachate from the column leaching tests was pH-neutral to alkaline and seepage would be expected to also have similarly pH-neutral to slightly alkaline pH.

The sections below are reproduced from Terrenus Earth Sciences (2012). Appendix 6 contains the full report.

10.12.2 Eastern Mining Area

“Seepage is predicted by the AGE groundwater model to occur in a zone of about 214 ha along the southern boundary of the Eastern Mining Area, and a smaller zone of about 16 ha (combined area) along the northern boundary of the Eastern Mining Area. Seepage rates of up to 90,000 litres per day (in total) are predicted to occur from about Year 60 (about 30 years after mining ceases).

Applying the estimated maximum salt concentration (5000 mg/L) to these quantities produces a salt load contribution of less than 1 kg of salt per ha of seepage zone per day (on average). A sensitivity analysis undertaken of the seepage rates (more than doubling the rate) and seepage area (reducing the area by half) produces a salt load contribution of 8 kg of salt per ha per day (on average), which is regarded as likely to have a low and insignificant impact on the surrounding environment.”

10.12.3 Southern Mining Area

“Seepage is predicted by the AGE groundwater model to occur in a zone of about 53 ha along the south-eastern boundary of the Southern Mining Area (SMA). Seepage rates of about 30,000 litres



per day (in total) are predicted to occur from about Year 60 (about 30 years after mining ceases), and increasing to about 60,000 litres per day by about Year 400.

Applying the estimated maximum salt concentration (5000 mg/L) to these quantities produces a salt load contribution of about 5.6 kg of salt per ha of seepage zone per day.

A sensitivity analysis undertaken of the seepage rates (more than doubling the rate) and seepage area (reducing the area by half) produces a salt load contribution of 17 kg of salt per ha per day. The impacts of such loads are unclear, and would depend upon the salt receptors. Given that there are no significant surface water drainages in the vicinity of the SMA, it is likely that the salt would accumulate near the toe of the OEA and only be mobilised with significant prolonged rainfall events.”

10.12.4 Western Mining Area

“No seepage (discharge) will occur from the WMA at any time during mining operations or post-closure

10.12.5 Narrabri and Gunnedah Formations

The change in upward flow from the Permian to the individual alluvial units i.e., Narrabri and Gunnedah Formations is dependent on the proximity of the units to the mining areas. Ninety percent of the alluvial transfer loss occurs from the Permian to the Narrabri Formation Aquifer, while just 10% of transfer loss occurs from the Permian to the Gunnedah Formation Aquifer as described in Section 10.8.1. Although the Narrabri and Gunnedah Formations are managed as a single aquifer unit under the *Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003*, only upward flows to the Narrabri Formation will be impacted by the Project. The Narrabri Formation contains poor quality water, and is generally not targeted by surrounding users to supply agriculture.

Post mining as the groundwater level recovers flow from the Southern and Eastern Mining Areas to the adjacent Narrabri Formation will increase, and likely exceed pre-mining rates. The water quality released from the Southern and Eastern Mining Areas will likely be of a better quality than typically encountered in the Narrabri Formation, and therefore no deterioration in the beneficial use of the alluvial groundwater is expected. An improvement in the groundwater quality in the Narrabri Formation is a possibility.

10.12.6 Potential Impacts

“Groundwater in all aquifers in the Project Boundary has a salt concentration of equal to or significantly greater (in some aquifers over 10-times) than the salinity potentially produced from spoil seepage/leachate. Therefore spoil seepage/leachate is expected to have a low to negligible impact on local groundwater resources.”

The AIP minimal impact considerations protect water quality by requiring “*any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity*”. The beneficial use of the groundwater in the Project area varies spatially depending of the salinity of the local groundwater. Generally, the groundwater is brackish to saline and of limited agricultural use, but can be suitable for cattle or sheep in some areas. At closure the backfilled mining areas will capture more water than pre-mining, and this would likely lead to a slow reduction in salinity of groundwater around the mined areas. The work undertaken



by Terrenus Earth Sciences (2012) indicates that beneficial use categories will not change due to the Project, and could potentially improve over time.

10.13 Compaction and subsidence

Groundwater levels in the Upper Namoi Valley have been typically drawn down by approximately 10-20 m from the period between 1980 and 2011 (refer to Figure 9.51). No detectable land subsidence (>0.2 m) has been observed in the Regional Project area since 1991 (pers. comms. Mike Williams, NOW, 2012).

Predicted drawdown extents in the Narrabri Formation are up to a maximum of 15 m at the edge of the alluvial boundary south of the Southern Mining Area and 2 m in the Gunnedah Formation. This predicted drawdown declines to less than 1 m approximately 3.9 m from the Mining Area (refer to Section 10.6).

SRK (2012) Appendix 7 assessed the likely magnitude of consolidation settlement across the alluvium adjacent to the Southern Mining Area due to the predicted depressurisation. SRK used a one dimensional methodology to assess the magnitude of settlement along two section lines where bore hole lithology data was available. The analysis predicted between 15 mm and 30 mm of settlement where a 2 m reduction in groundwater levels was predicted. SRK concluded that once the drawdown reached 3 m, the potential settlement ranged from 40 mm to 80 mm. It was also noted that the black soils have the potential to swell naturally in response to moisture by greater than 40 mm. It should be noted that once the drawdown impact shifts with time, the settled material will rebound.

Appendix 7 contains the letter report prepared by SRK (2012).

11.0 SENSITIVITY AND UNCERTAINTY

11.1 Sensitivity Analysis

A sensitivity analysis was carried out to demonstrate the response of the model to uncertain input parameters. The objective of the sensitivity analysis was to rank the input parameters in terms of their influence on the predicted results. The following perturbations were assessed in the sensitivity analysis:

- a $\pm 50\%$ change in horizontal and vertical hydraulic conductivity of the alluvial aquifers;
- a ± 1 order of magnitude change in horizontal and vertical hydraulic conductivity of the Permian aquifer units and $\pm 50\%$ change in the Clare Sandstone;
- a ± 1 order of magnitude change in the weathering factor of the Permian aquifer units, and $\pm 50\%$ change in the Clare Sandstone;
- a $\pm 50\%$ change in the specific yield of all units in the model;
- a ± 1 order of magnitude change in the specific storage of all units in the model;
- the removal of hydraulic fault barriers from the model;
- a $\pm 50\%$ change in the rainfall recharge rate on the alluvial and regolith aquifers across the model domain;
- a $\pm 50\%$ change in the rainfall recharge rate on the emplaced overburden waste aquifers;



- the removal of enhanced recharge on the emplaced overburden waste aquifers; the removal of break of slope recharge cells proximal to the Southern Mining Area (Watermark West recharge zone – refer to Figure 8.19);
- the removal of diffuse recharge over the Quaternary Alluvium; and
- an upper and lower (90th and 10th percentile) simulation of global climate change (i.e. changing input for EVT and recharge, including overburden waste recharge).

The upper and lower global climate change bounds were modified according to bounds presented in the CSIRO climate change simulations report (CSIRO, 2007). Changes to rainfall and evapotranspiration rates were assigned according to the 2050 high emissions scenario - 10th percentile predictions (15% decrease in rainfall and 3% increase in potential areal evapotranspiration) and 90th percentile predictions (7.5% increase in rainfall and 10% increase in potential areal evapotranspiration).

Table 11.1 summarises the key model outputs resulting from changes in the model parameters. Table 11.1 also presents the steady state model calibration performance statistics and flow budgets to highlight the models sensitivity to the assessed parameter.



Table 11.1: SENSITIVITY ANALYSIS SUMMARY

Parameter	Steady State Calibration Model							Transient Predictive Model					
	RMS	SRMS	Steady State RCH IN	Steady State FH OUT	Steady State EVT	Steady State RIV IN	Steady State RIV OUT	Average Daily Mine Seepage	Maximum Daily Mine Seepage	Average Change in Zone 7 Flow	Maximum Change in Zone 7 Flow	Average Change in Mooki Net Leakage	Maximum Change in Mooki Net Leakage
	m	%	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day
Units													
Baseline	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.51	2.22	0.09	0.28	-0.03	-0.13
hc_alluv +50%	7.14	6.41	246.4	27.8	126.3	17.1	109.4	0.51	2.23	0.10	0.31	-0.01	-0.06
hc_alluv -50%	7.63	6.85	246.4	14.5	137.4	13	107.7	0.50	2.18	0.08	0.23	-0.02	-0.10
perm_hc +1mag	7.12	6.4	246.4	22.3	135.4	15.2	103.9	0.94	3.71	0.24	0.61	-0.12	-0.39
perm_hc -1mag	NC	NC	NC	NC	NC	NC	NC	0.18	1.49	0.01	0.04	0.00	-0.01
weathering_fac +1mag	7.28	6.53	246.4	22.2	130.7	15.2	108.7	0.96	3.53	0.36	1.19	-0.16	-0.53
weathering_fac -1mag	NC	NC	NC	NC	NC	NC	NC	0.40	2.01	0.06	0.19	-0.02	-0.08
no faults	7.30	6.55	246.4	22.1	130.5	15.4	109.3	0.52	2.38	0.09	0.28	-0.03	-0.15
SY +50%	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.51	2.22	0.09	0.28	-0.03	-0.13
SY -50%	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.51	2.21	0.09	0.28	-0.03	-0.13
SS +1 mag	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.78	3.32	0.06	0.19	-0.01	-0.07
SS -1 mag	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.44	2.06	0.11	0.32	-0.04	-0.16
recharge +50%	7.63	6.85	369.7	24.3	174.4	13.4	184.4	0.53	2.26	0.10	0.31	-0.03	-0.13
recharge -50%	6.92	6.21	123.2	18.8	80.4	18.3	42.3	0.47	2.12	0.07	0.22	0.00	-0.02
climate change lower	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.52	2.24	0.09	0.28	-0.03	-0.14
climate change upper	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.49	2.17	0.09	0.28	-0.02	-0.06
Overburden waste rech +50%	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.58	2.34	0.08	0.26	-0.03	-0.13
Overburden waste rech -50%	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.46	2.12	0.11	0.32	-0.03	-0.14
no enhanced overburden rech	7.29	6.54	246.4	22.1	130.4	15.4	109.4	0.42	2.02	0.12	0.35	-0.04	-0.15
No break of SMA bos rech	7.30	6.55	245.7	22.1	129.6	15.5	109.4	0.50	2.20	0.08	0.25	-0.01	-0.05
No black soil recharge	7.06	6.33	192.2	18.6	96.1	19.7	97.2	0.50	2.20	0.06	0.21	-0.05	-0.02

Hc = Horizontal and Vertical Hydraulic Conductivity

Alluv = Quaternary Alluvium

Perm = Permian

Weathering_fac = Hydraulic Conductivity Weathering Factor

SY = Specific Yield

SS = Specific Storage

Rech = Recharge

FH = General Head Boundary Flow

RIV = River Leakage

EVT = Evapotranspiration

RMS = Root Mean Square Residual – a measure of the difference between modelled and predicted values

SRMS = Scaled RMS – ratio of the RMS error to the total head change

BOS = Break of Slope

SMA = Southern Mining Area

NC = Non convergence in Steady State



11.1.1 Calibrated Steady State Model

Table 11.1 demonstrates that the varied input parameters had little influence on the RMS and SRMS. The changes made to the hydraulic conductivity and recharge rates to the alluvial aquifer had the largest impacts on the model error and flow budgets. This is because the majority of the groundwater observation points used for steady state calibration are within the alluvial formations.

11.1.2 Normalised Sensitivity Index – Transient Model Data

The results of the sensitivity analyses were normalised so that the effects of varying parameters can be directly compared. The sensitivity index (S) was calculated as follows:

$$S = \frac{dh}{\frac{dP}{P}}$$

Where:

- S = normalised sensitivity index (e.g. for the mine seepage rate)
- dh = difference in predicted variable between the base case and sensitivity case
- dP = change in input parameter value
- P = initial input parameter value

The sensitivity index was calculated using the transient model data presented previously in Table 11.1. Figure 11.1 presents graphically the sensitivity of the assessed parameters.

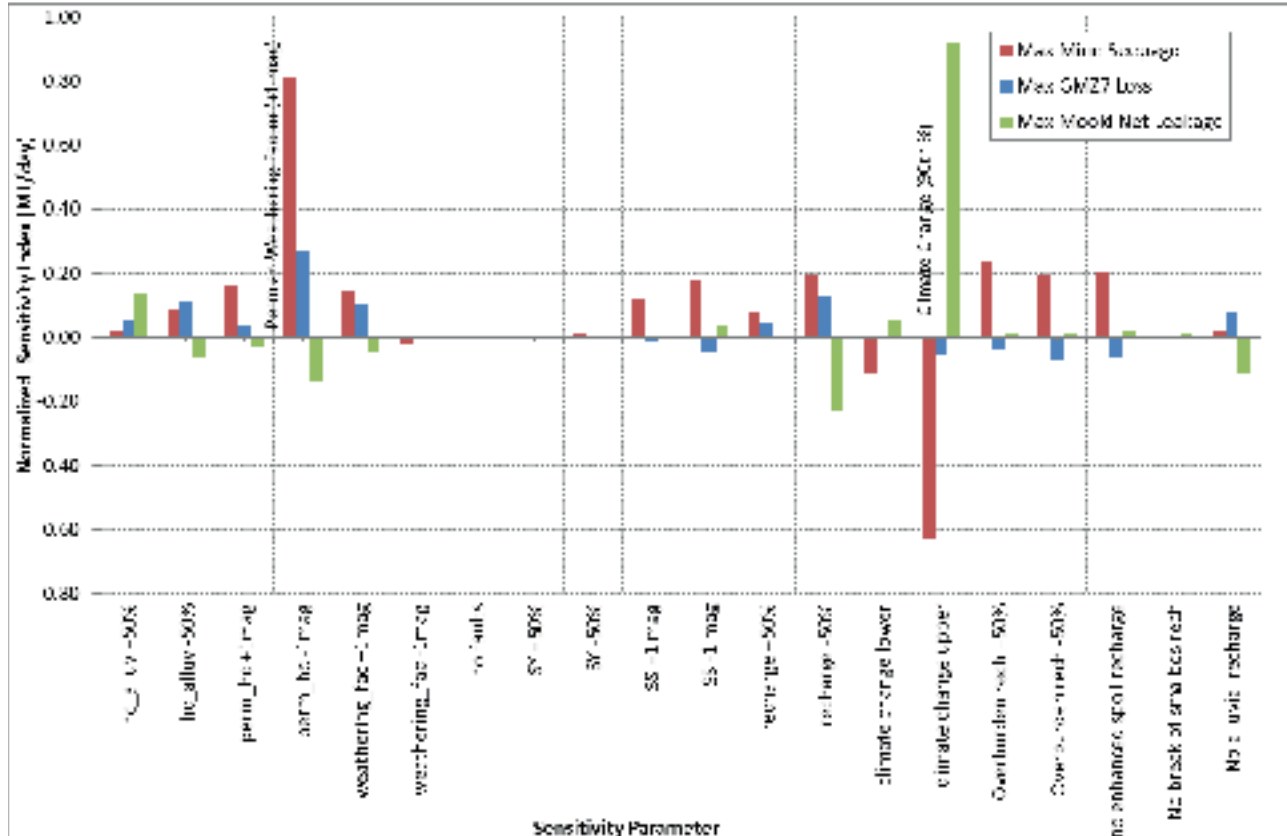


Figure 11.1: Normalized Sensitivity Index of Modelled Parameters



The sensitivity analysis indicates that changes to the Permian hydraulic conductivity had the biggest effect on predicted rates of mine seepage. The predicted reduction in transfer of water between the Permian and the alluvium was also sensitive to the Permian hydraulic conductivity but less so than the mine seepage rate. The predicted mine rate of seepage to the proposed Mining Areas was also very sensitive to specific storage. This is because the specific storage strongly controls the magnitude of the zone of depressurisation and the resultant hydraulic gradients that control the rate of groundwater seepage. The implementation of climate change has high levels of mine seepage sensitivity relative to the changes to the parameter values of recharge and evapotranspiration. However, the changes to the inflows are minimal. The same can be said for the sensitivity of climate change to Mooki River net leakage changes.

Figure 11.1 demonstrates that the model predictions are relatively insensitive to changes in fault conductivity rates, specific yield, and the removal of the southern mining area break of slope recharge.

When it was determined that the predicted seepage rate was most sensitive to Permian hydraulic conductivity, particularly of the Clare Sandstone it was decided to drill and test additional bores. GHD (2012) installed four additional shallow boreholes in the Southern Mining Area targeting the Clare Sandstone aquifer. The purpose of these boreholes was to confirm the values of hydraulic conductivity adopted for the modelling were representative of in-situ conditions. The testing indicated a hydraulic conductivity range of between 0.2 m/day and 2 m/day for the additional boreholes. GHD (2012) report that from eight tests the weathered sandstone reported a range of 0.012 m/day to 3.5 m/day, with a geometric mean of 0.375 m/day and average of 1.1 m/day. The transient model was calibrated with a value of 0.3 m/day for weathered Clare sandstone very similar to the geometric mean. Only a single test was available for the fresh Clare sandstone that reported a value of 0.5 m/day. The model calibrated the fresh Clare sandstone slightly lower than the test value at 0.2 m/day.

The testing of the Clare sandstone indicates that the model was calibrated within the range of the available field observations. The model used a single value of hydraulic conductivity for the Clare sandstone to represent the effective average hydraulic conductivity. The section below discusses the effect of varying the hydraulic conductivity on the predicted seepage rates to the proposed mining areas.

11.1.3 Proposed Mining Area Sump Seepage

Figure 11.2 to Figure 11.4 summarise the sensitivity of the predicted seepage rate to changes in hydraulic conductivity, storage and recharge/evapotranspiration.

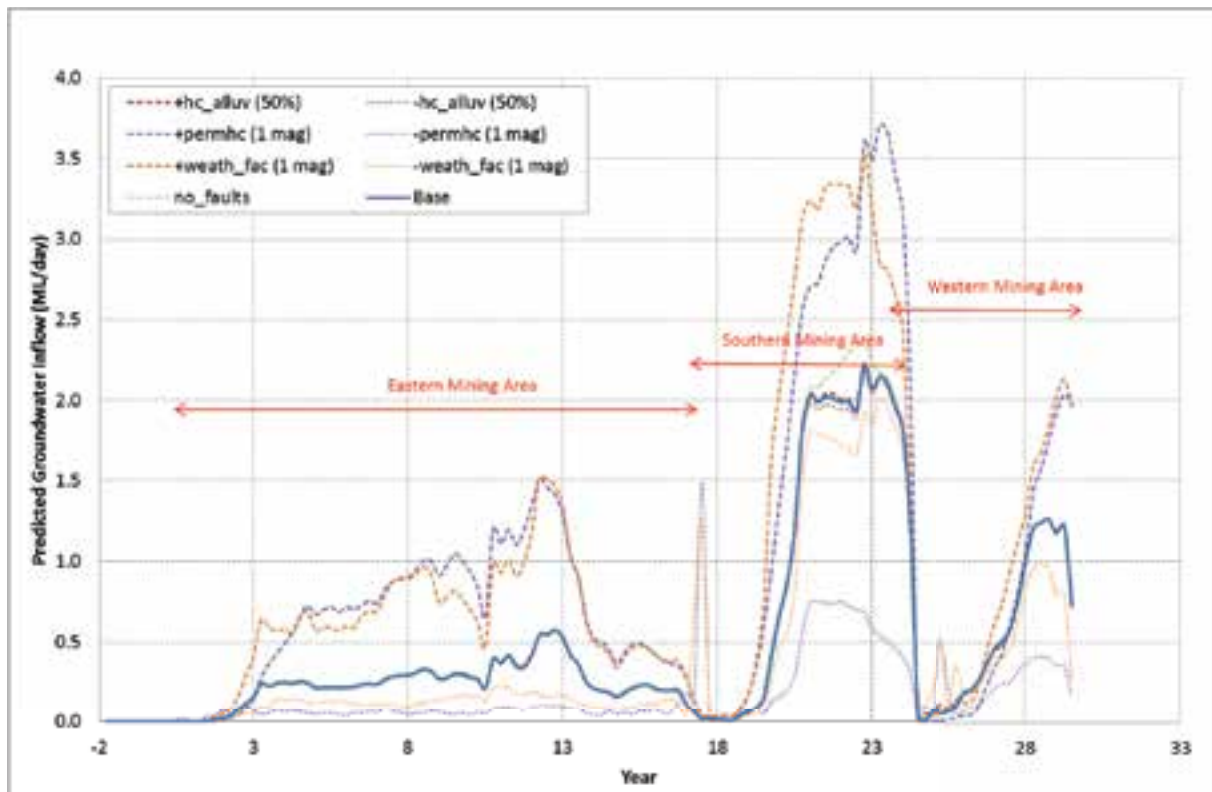


Figure 11.2: Mining Area Seepage Sensitivity – Hydraulic Conductivity

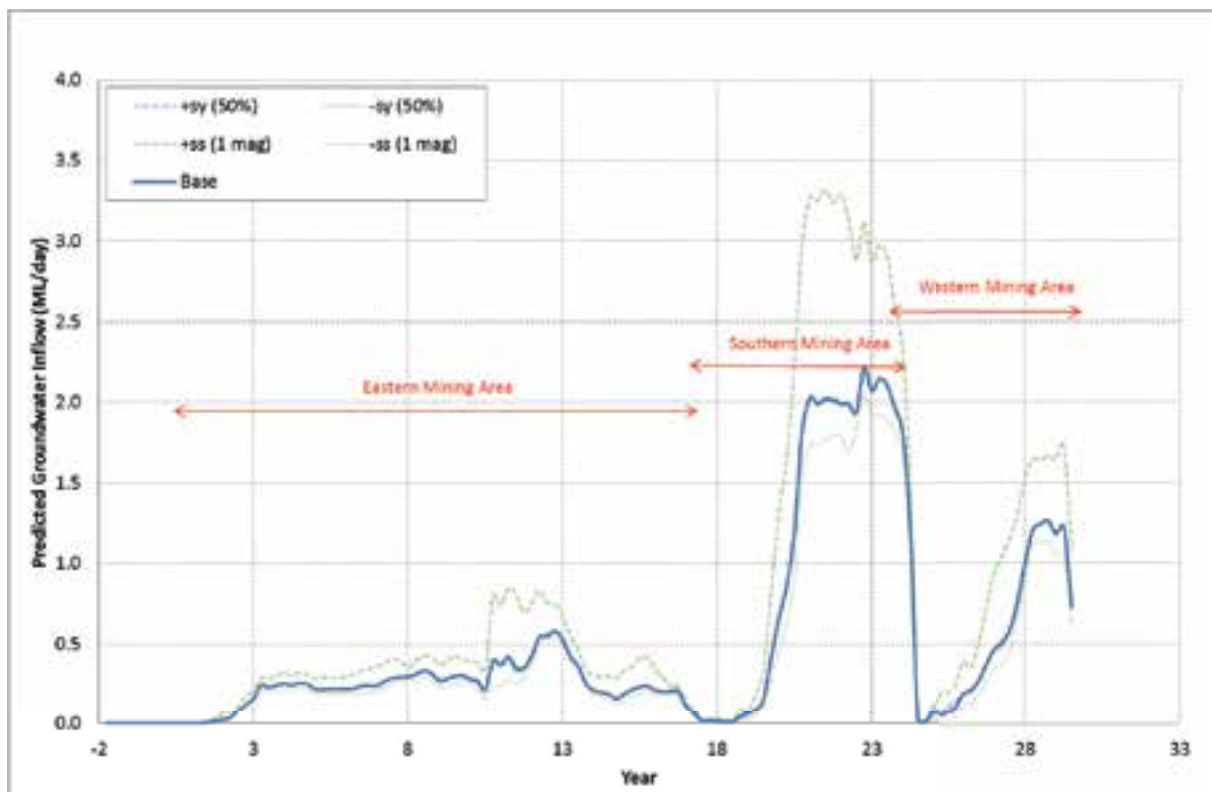


Figure 11.3: Mining Area Seepage Sensitivity – Storage

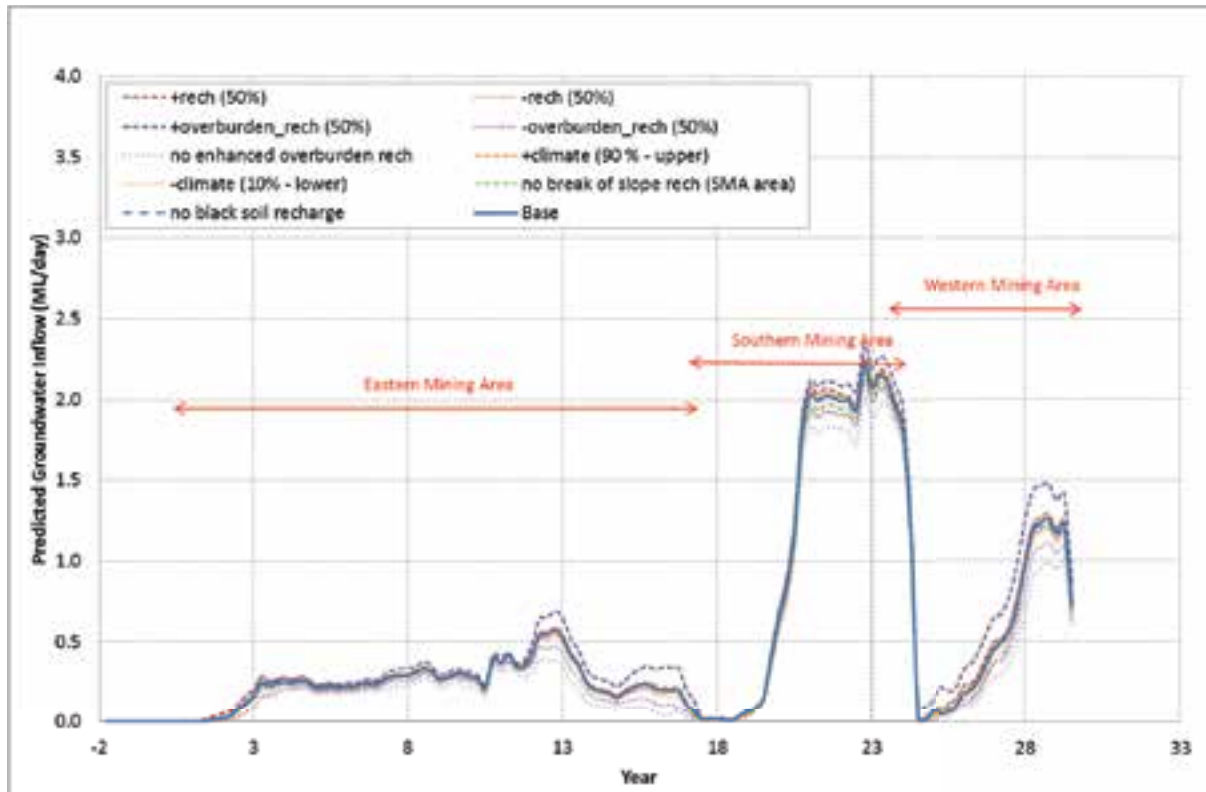


Figure 11.4: Mining Area Seepage Sensitivity – Recharge

As the normalised sensitivity index shows, the predicted Mining Area sump seepages are most sensitive to changes in the Permian hydraulic conductivity. Increasing the Permian hydraulic conductivity by an order of magnitude increases the predicted seepage by an additional 1 ML/day to 1.5 ML/day. Reducing the hydraulic conductivity by an order of magnitude has a similar but opposite effect.

This effect of varying Permian hydraulic conductivity is significant as these units are in direct connection to the proposed Mining Areas. In contrast, varying the alluvial hydraulic conductivity has very little impact on the predicted Mining Area seepage as these units are not in direct connection with the proposed Mining Areas.

Reducing the Permian hydraulic conductivity by an order of magnitude reduces the predicted seepage to about 30% of the base case, except at the start of the southern mining area and in the early stages of the Western Mining Area. This is due to groundwater mounding in these areas in response to a decreased hydraulic conductivity, without modifying the recharge.

Specific storage was the most sensitive storage parameter, with an order of magnitude increase, resulting in an increase above the base seepage rate of about 1.1 ML/day. The predicted seepage was relatively insensitive to an order of magnitude decrease in specific storage, and completely insensitive to the changes made to specific yield.

Varying the recharge and evapotranspiration rates had minimal impact on groundwater seepage rates to the mining area seepages. The overburden recharge rates were the most sensitive. Removing the enhanced overburden recharge reduces Mining Area seepage by a maximum rate of 0.3 ML/day from the baseline results (refer to Figure 11.4).



11.1.4 Groundwater Management Zone 7 Alluvial Transfer Flow

Another key model prediction is the change to the transfer rate of water from the Permian units to the overlying alluvial aquifers. The sensitivity analysis assessed the sensitivity of this prediction to changes in hydraulic conductivity, storage, recharge and evapotranspiration.

Section 10.8 presents the base case for reduction in water transfer for Groundwater Management Zones 3, 7 and 8. The majority of Permian transfer loss occurs within Zone 7 to the south of the proposed mining areas. Figure 11.5 to Figure 11.7 present the sensitivity of the transfer loss prediction.

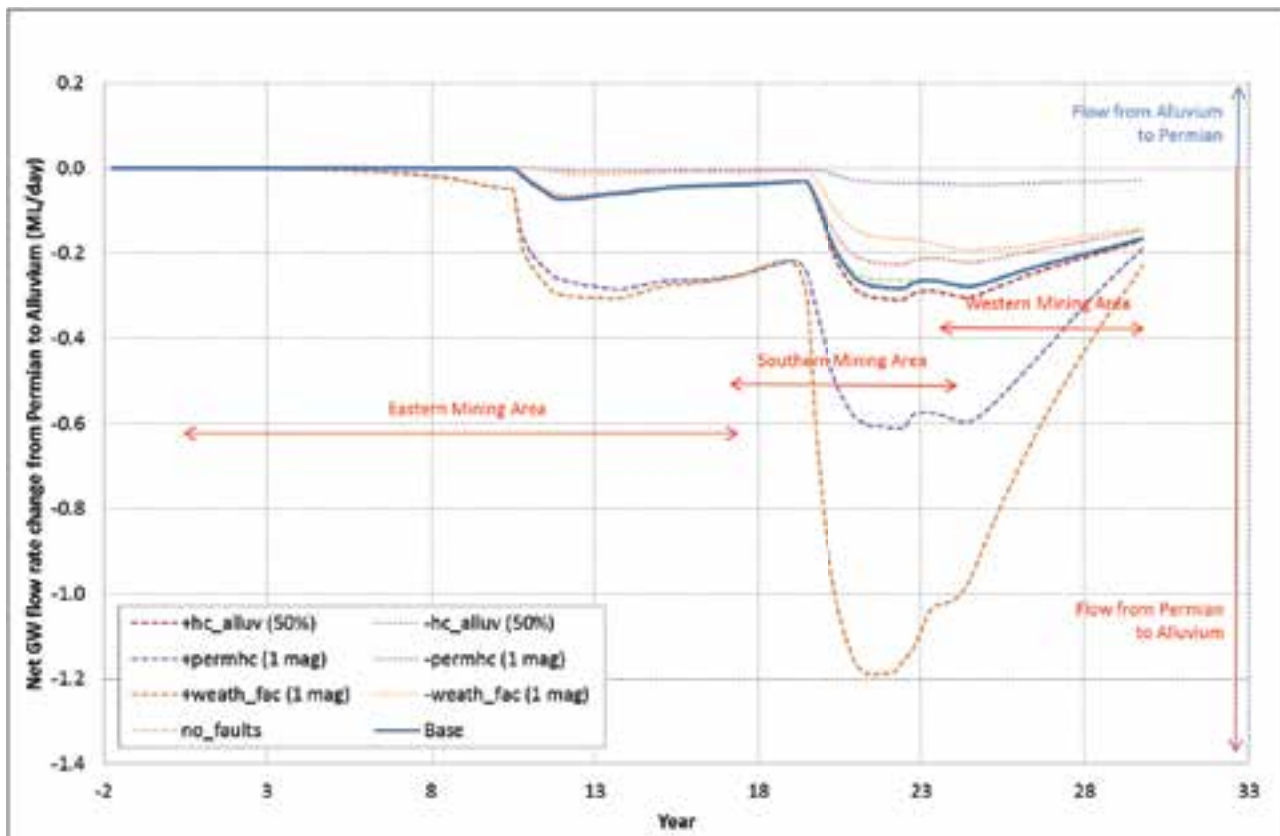


Figure 11.5: Change in Zone 7 Permian to Alluvium Transfer – Hydraulic Conductivity

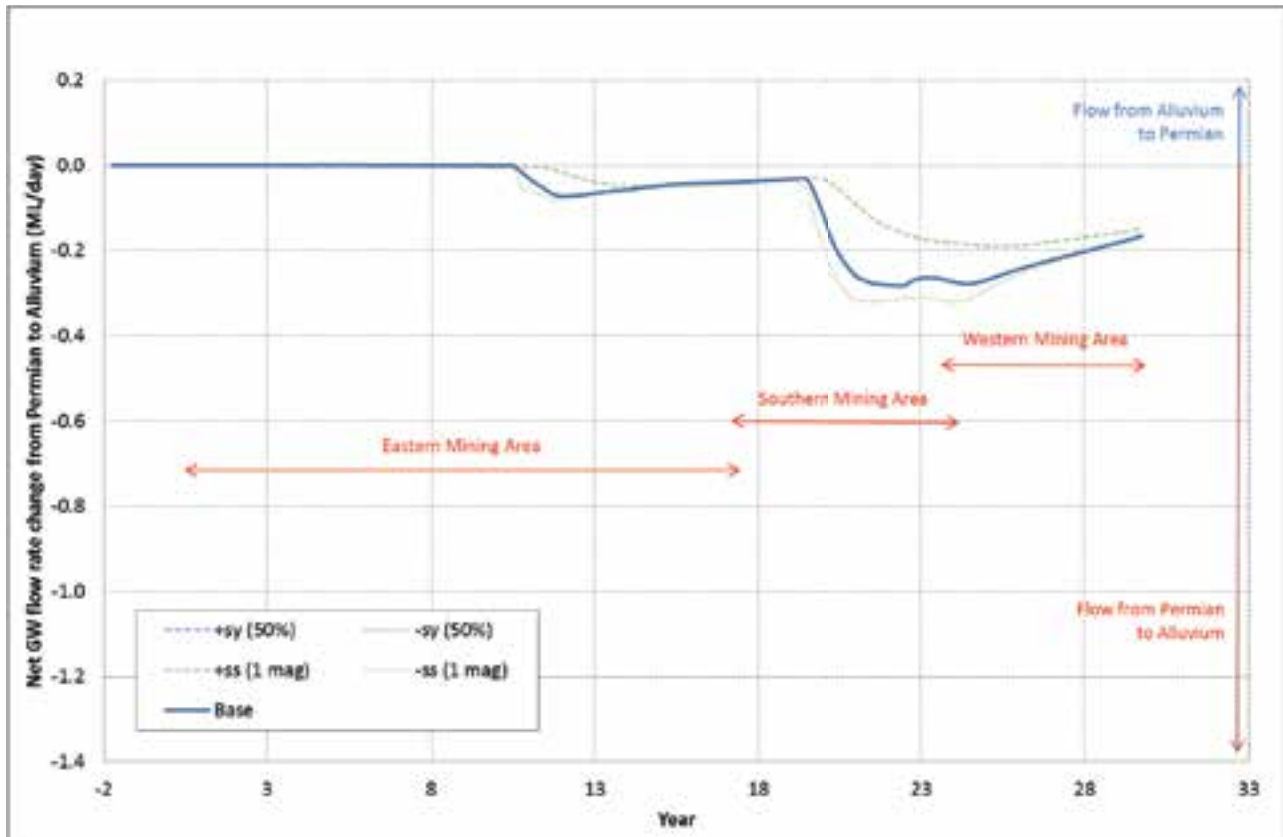


Figure 11.6: Change in Zone 7 Permian to Alluvium Transfer – Storage

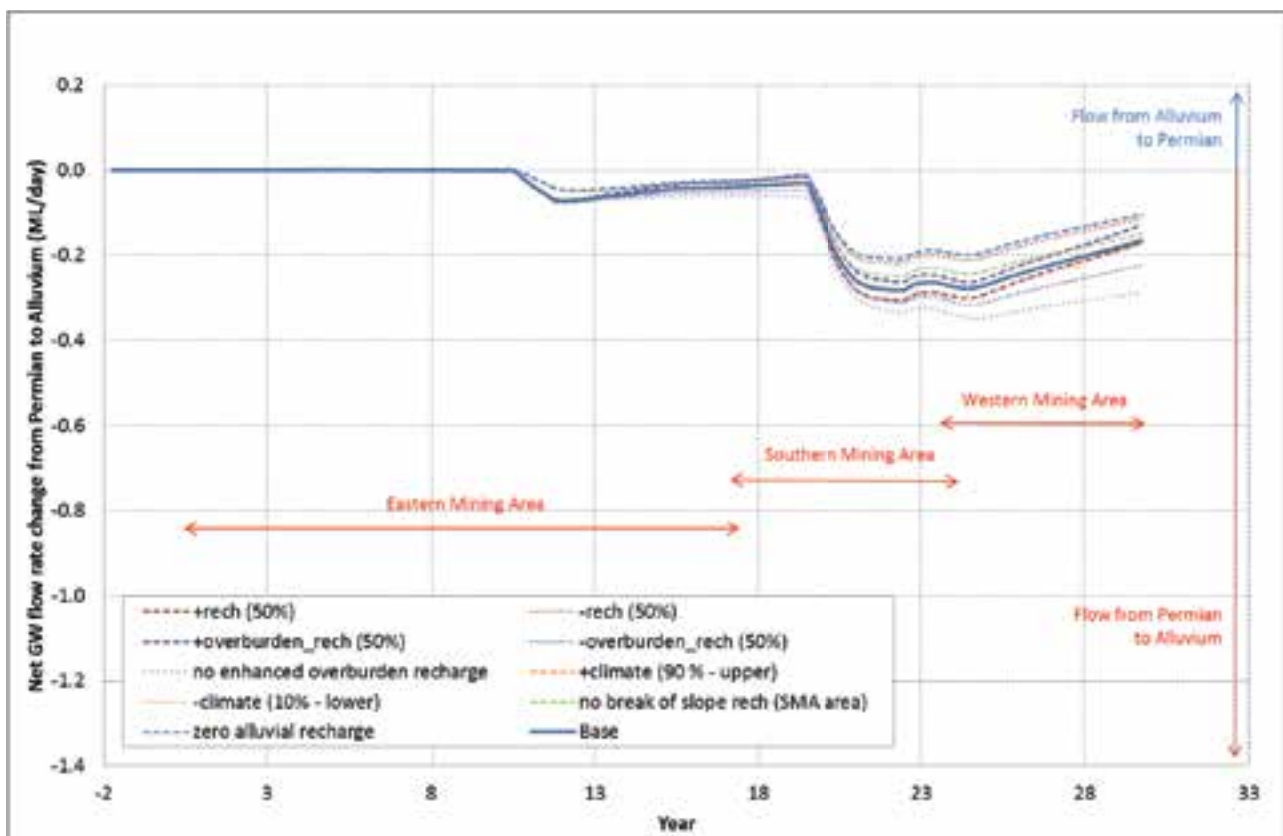


Figure 11.7: Change in Zone 7 Permian to Alluvium Flow Transfer – Recharge



Figure 11.5 to Figure 11.7 demonstrate that the reduction in transfer between the Permian and alluvium is most sensitive to hydraulic conductivity, and relatively insensitive to storage, recharge and evapotranspiration. An order of magnitude increase in the hydraulic conductivity of the weathered zones induces the largest impact reducing the Permian to the alluvium transfer rate by 1.2 ML/day from the base case model.

Varying recharge on the alluvial, Tertiary and Permian regolith across the model domain has only a very minor impact on the predicted change in transfer from the Permian to the alluvial aquifers.

The influence the increased recharge rate has on rebounding pressures in the Permian post mining is evident in Figure 11.7, as removing this recharge has the most significant effect on the transfer rate. The predicted reduction in transfer was insensitive to changes made to the model to simulate reduced rainfall and higher rates of evapotranspiration forecast to occur with climate change.

11.1.5 Mooki River Net Groundwater Leakage

The last key prediction analysed in sensitivity analysis was the change in net leakage from the Mooki River to the underlying aquifer systems. The base case predicts that mining will increase the rate of leakage from the river to the underlying aquifer by up to 0.13 ML/day. Figure 11.8 to Figure 11.10 present sensitivity of the predicted Mooki River net leakage to hydraulic conductivity, storage, recharge and evapotranspiration.

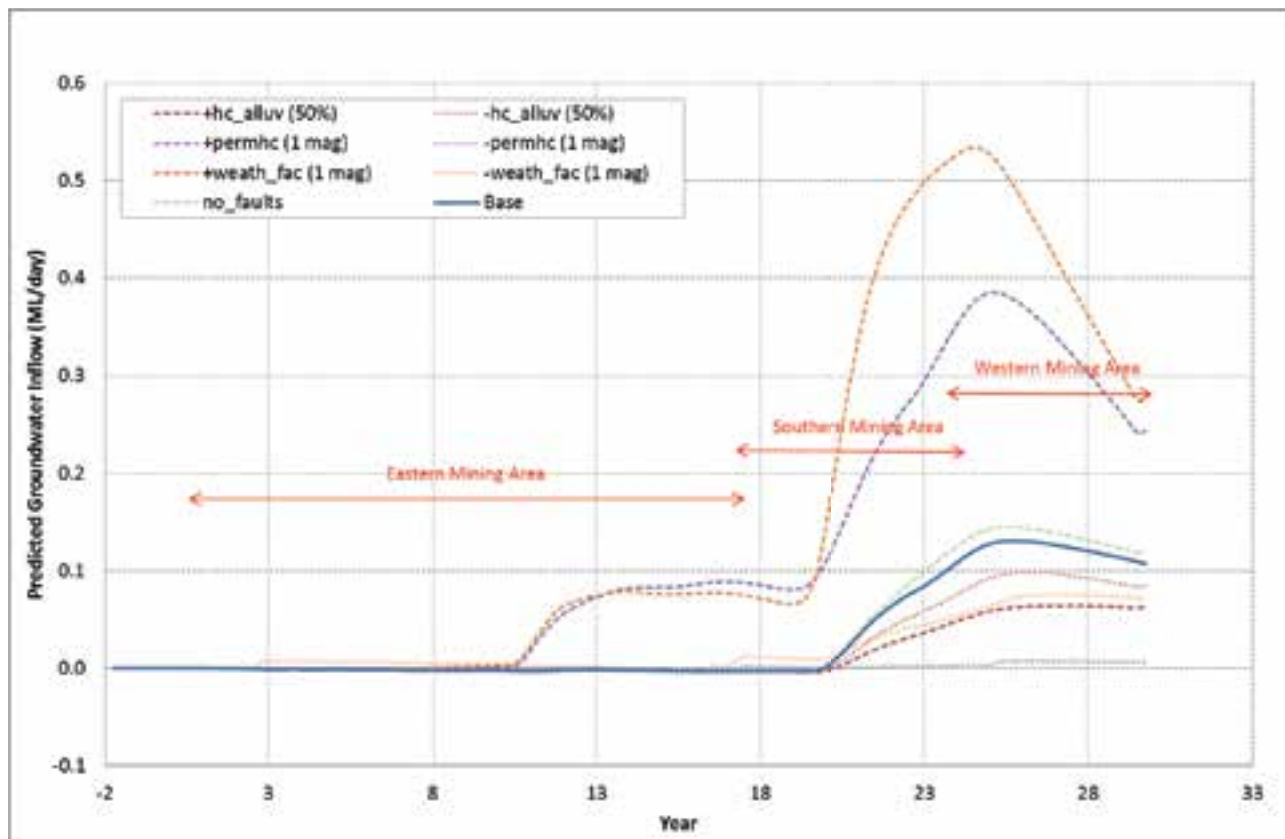


Figure 11.8: Change in Mooki River Net Leakage – Hydraulic Conductivity

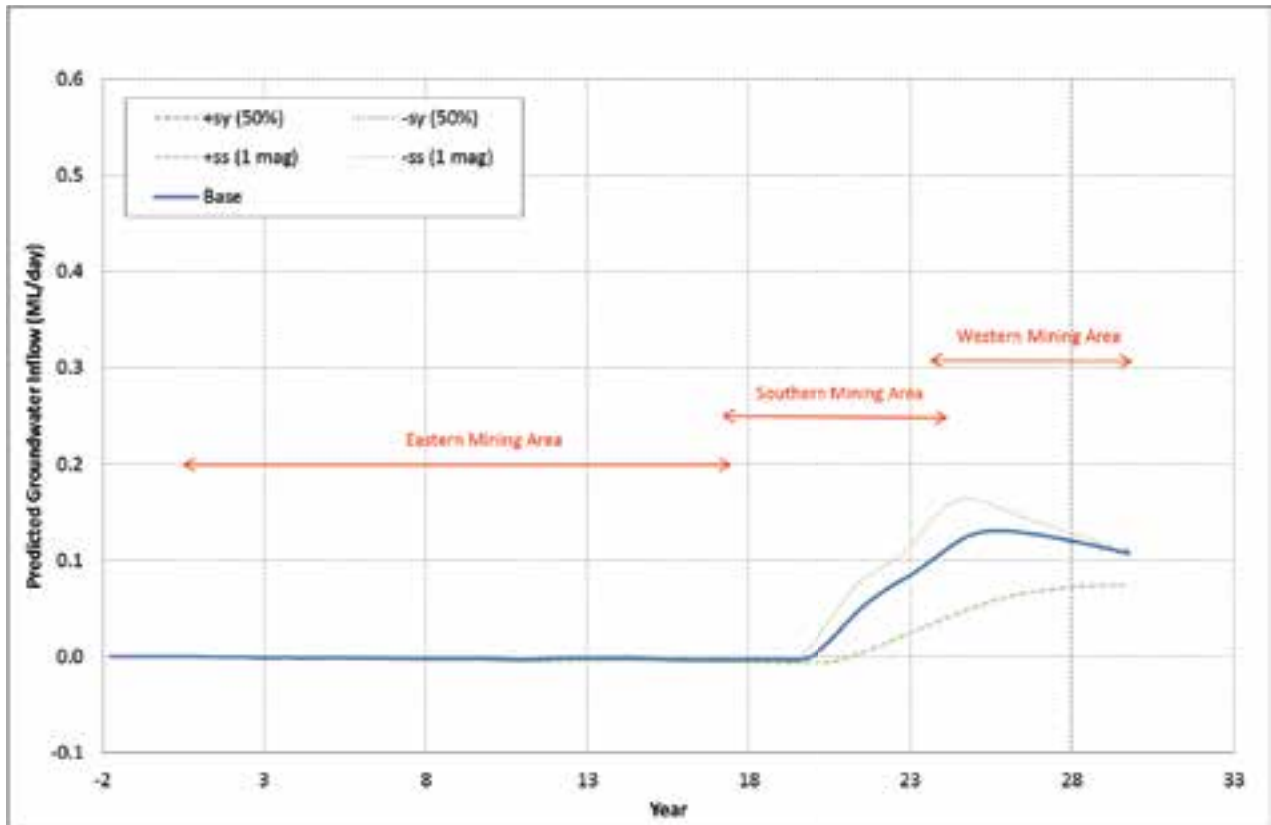


Figure 11.9: Change in Mooki River Net Leakage – Storage

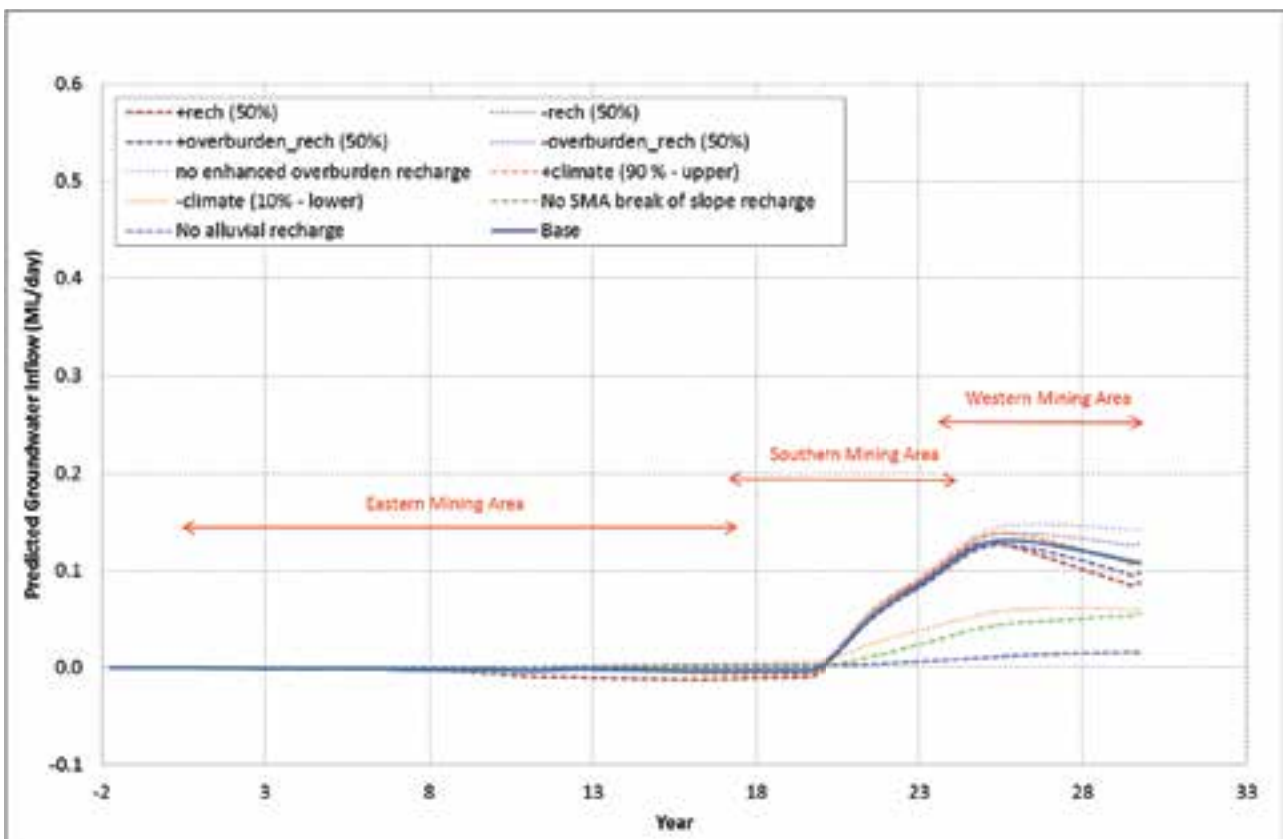


Figure 11.10: Change in Mooki River Net Leakage – Recharge



As found previously, the Mooki River net leakage is the most sensitive to hydraulic conductivity increases in the Permian aquifer formations. Simulations indicate that varying the Permian aquifer hydraulic conductivity increases the net leakage from the Mooki River to the groundwater system from a predicted maximum of 0.13 ML/day for the base case, to a predicted maximum of 0.53 ML/day.

Increasing the specific storage reduces the change in Mooki River leakage rates from 0.13 ML/day to 0.07 ML/day (50% decrease), due to the reduced radial drawdown from mining area seepage.

Increases to the recharge rate have minimal impacts on the predicted river leakage. With lower recharge values on the alluvial aquifer and break of slope zones, river leakage increases and outflow decreases (see Table 11.1). This is due to a regional lowering of groundwater levels that occurs which reduces the impacts from mining drawdown to the budget, particularly to the east of the Project Boundary.

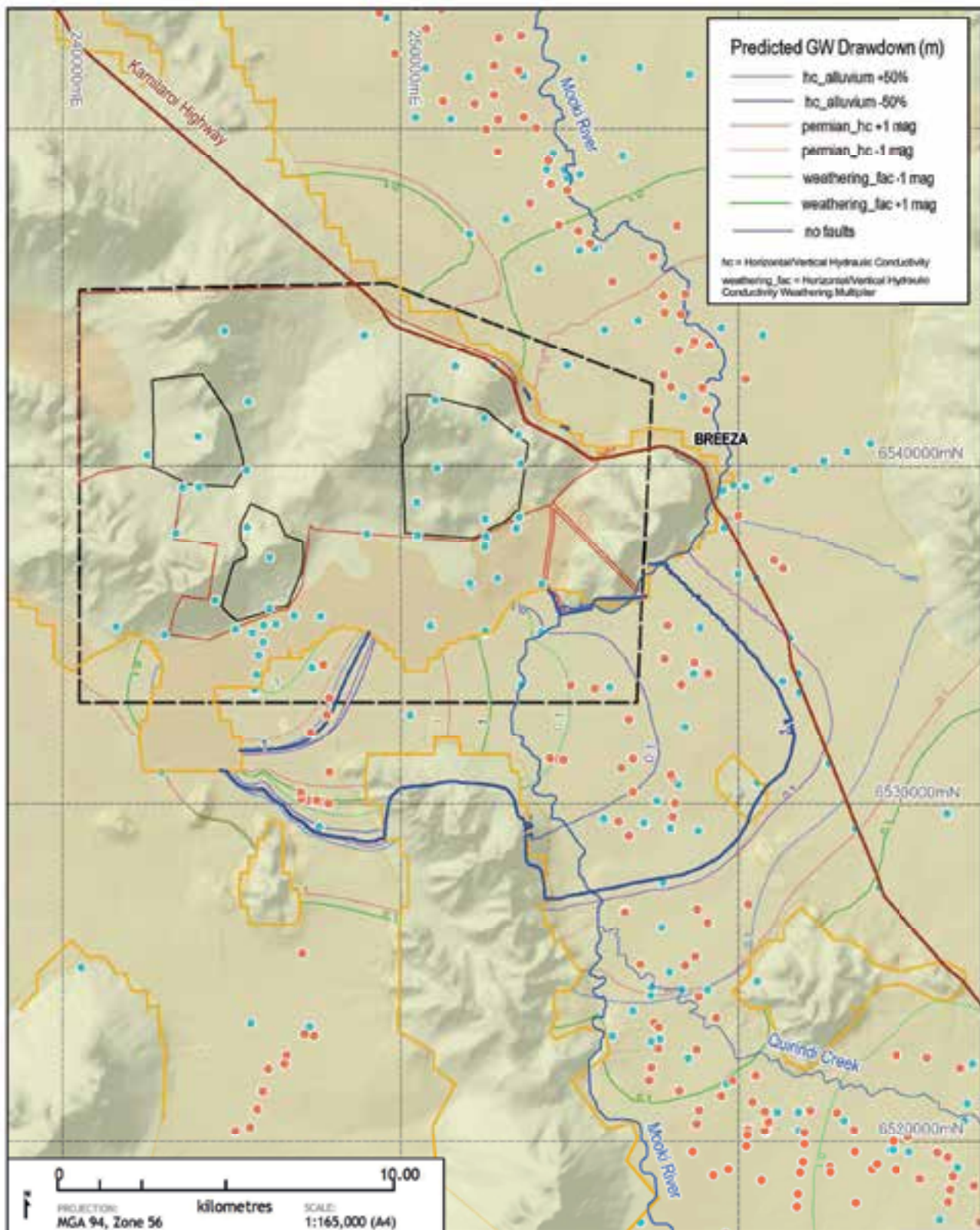
11.1.6 Zone of Depressurisation

The sensitivity of the predicted zone of depressurisation in the Gunnedah Formation and the Melvilles coal seam to model parameters was also assessed. Figure 11.11 to Figure 11.16 present snap shots where drawdown is most extensive from the Mining Areas at Year 25 when the Southern Mining area is active.

Drawdown in the Gunnedah formation aquifer is most sensitive to changes in the Permian hydraulic conductivity and specific storage. Figure 11.11 shows the 1m drawdown contour extends from a distance of 3.9 km for the base case, to 6.7 km when the Permian hydraulic conductivity is increased by an order of magnitude. Reducing the hydraulic conductivity of the weathered zone by an order of magnitude reduces the extent of the 1 m drawdown contour to 2.2 km from the Southern Mining Area. Changes to the hydraulic conductivity of the alluvium rates have a negligible impact on the extent of depressurisation, typically varying the drawdown about ± 0.5 km from baseline.

Varying the specific storage extends the 1 m drawdown contour in the Gunnedah Formation from 2.2 km to 4.3 km. Drawdown in the Melvilles seam ranges from 0.5 km to 6.2 km when specific storage is varied as shown in Figure 11.15. The zone of depressurisation is insensitive to changes in specific yield.

The zone of depressurisation in the Gunnedah Formation and Melvilles coal seam is relatively insensitive to recharge and evapotranspiration. Varying these parameters changes the zone of depressurisation by ± 1 km and ± 0.6 km, respectively.



LEGEND:

- | | |
|---------------------------|------------------------------------|
| — Gunnedah Aquifer Extent | • Usage Bore |
| • Observation Bore | — Highway |
| — Proposed Mining Area | — Drawdown Contour (m) - Base Case |
| — EL 7223 | □ Project Boundary |
| — Alluvium (1:250k) | |

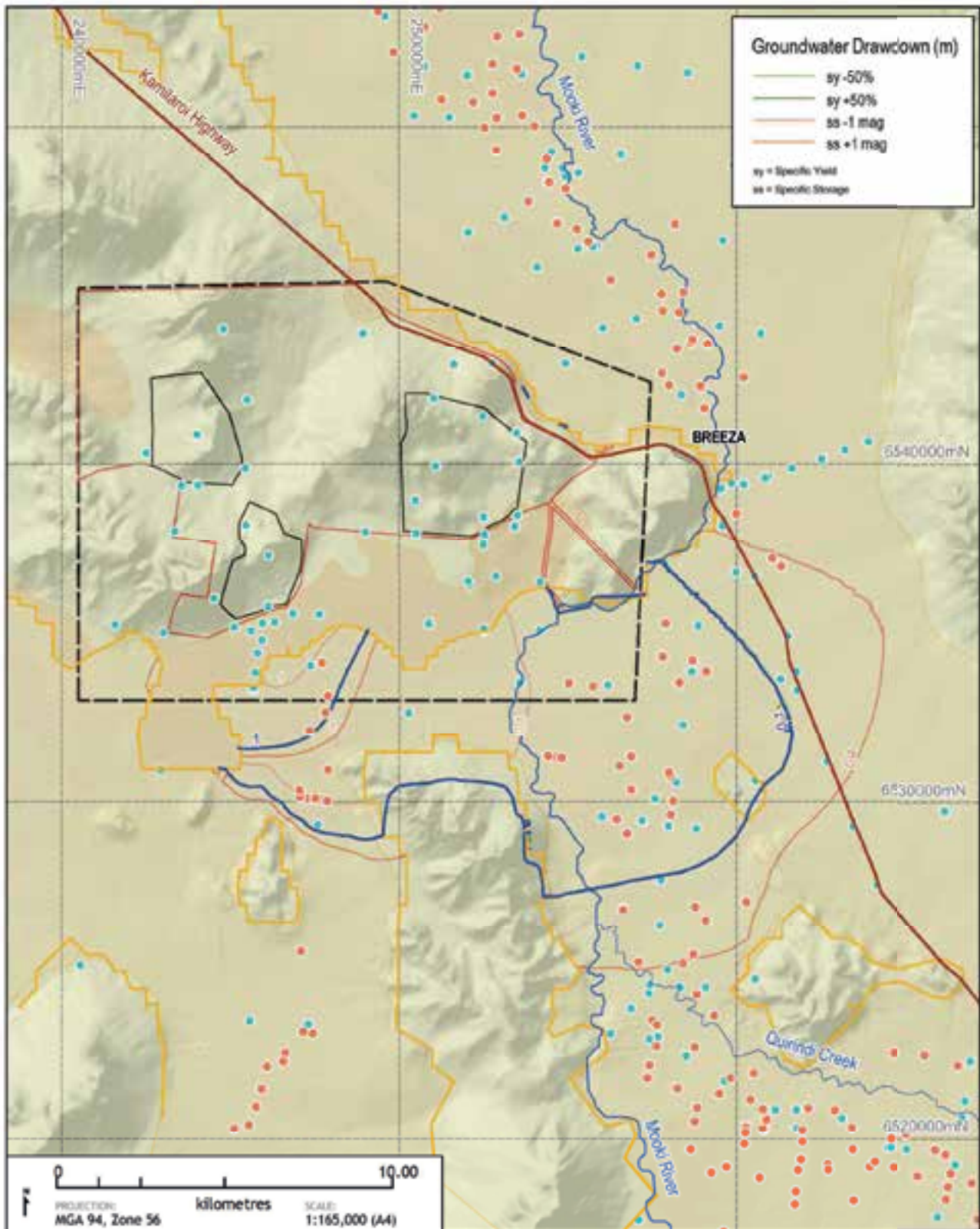
Watermark Coal Project (G1501)
Groundwater Assessment

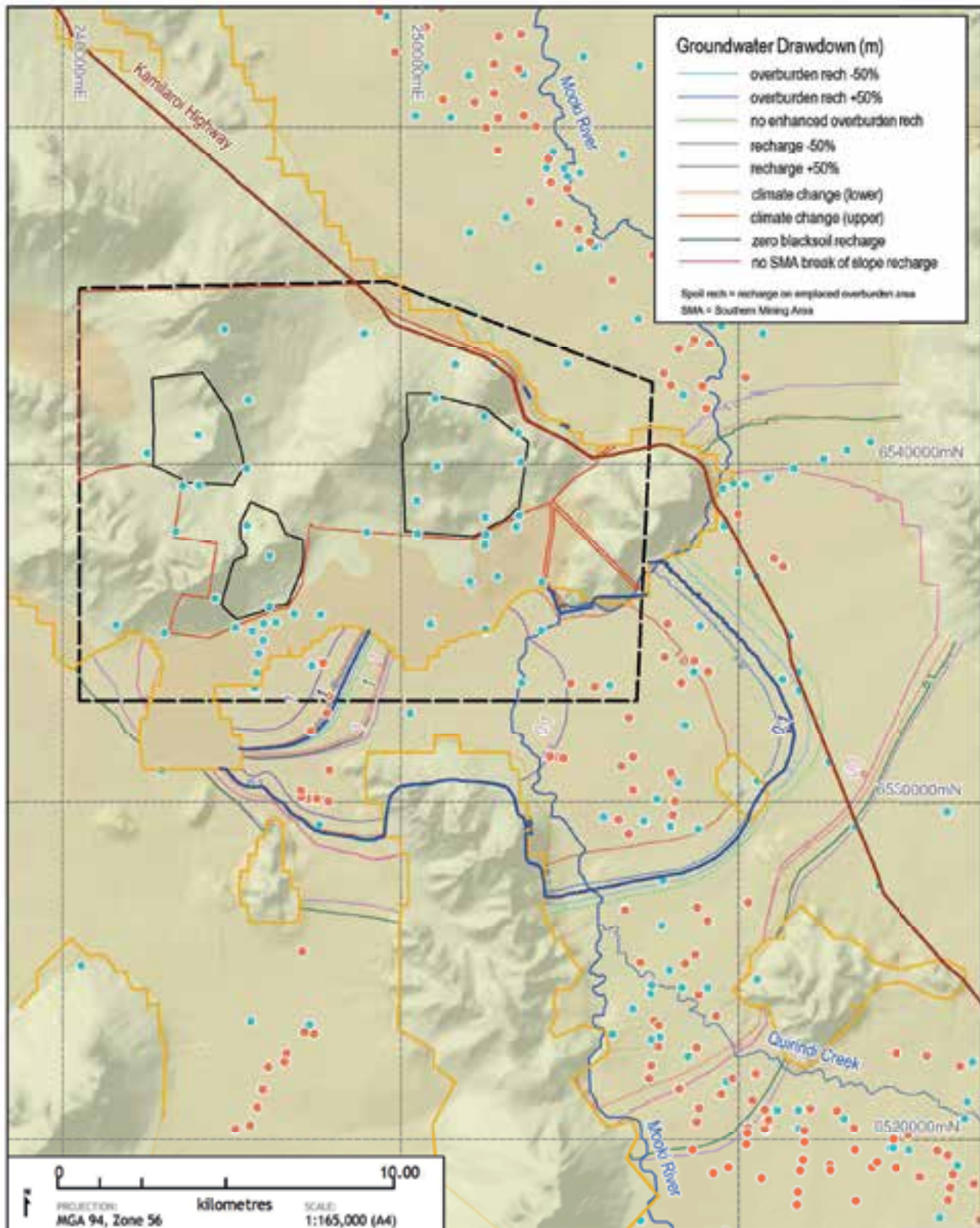
**Gunnedah Formation Drawdown
Sensitivity - Hydraulic Conductivity
- Year 25**



DATE:
18/10/2012

FIGURE NO:
11.11





LEGEND:

- | | |
|-------------------------|----------------------------------|
| Gunnedah Aquifer Extent | Usage Bore |
| Observation Bore | Highway |
| Proposed Mining Area | Drawdown Contour (m) - Base Case |
| EL 7225 | Project Boundary |
| Alluvium (1:250k) | |

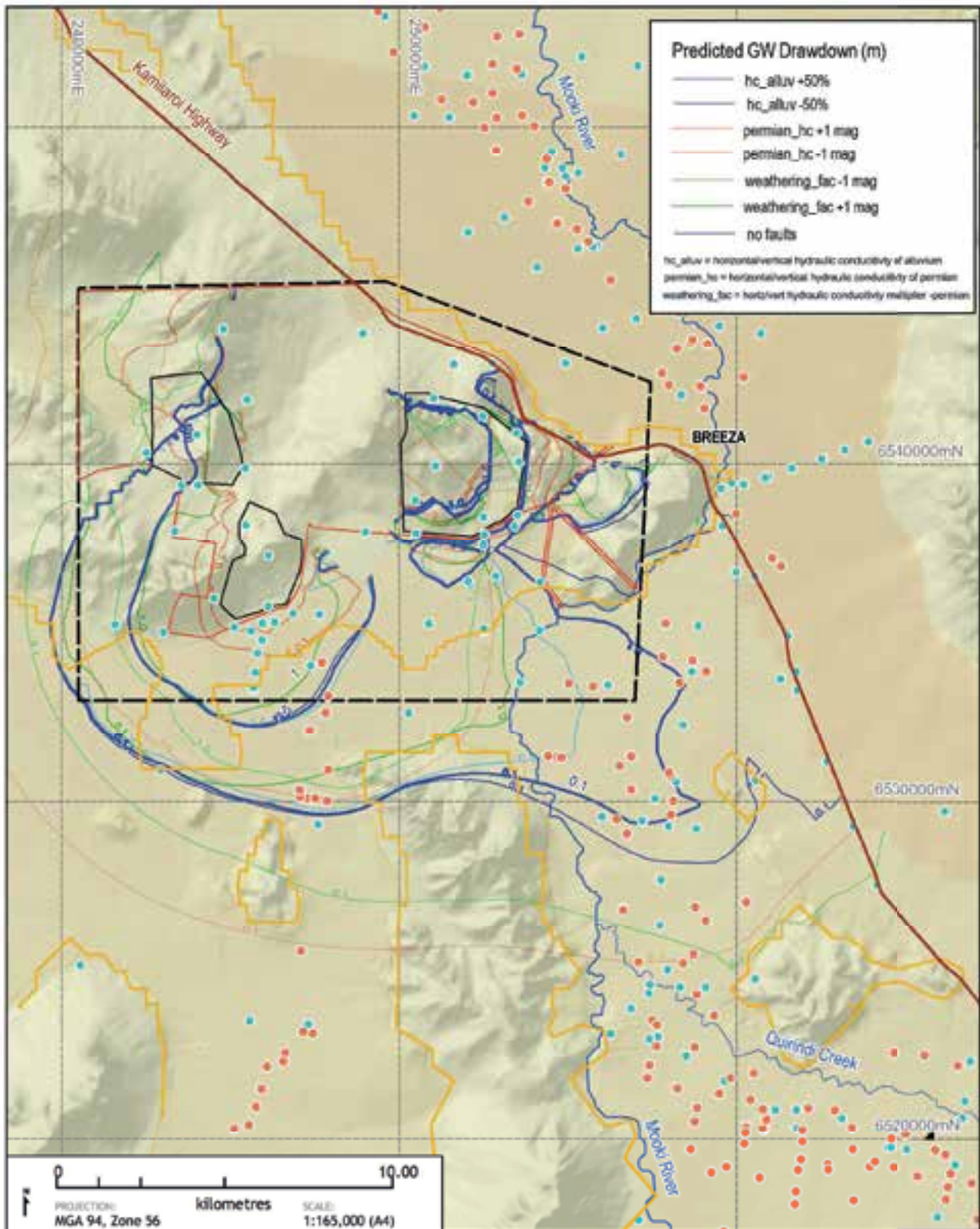
Watermark Coal Project (G1501)
Groundwater Assessment

**Gunnedah Formation Drawdown
Sensitivity - Recharge - Year 25**



DATE:
18/10/2012

FIGURE NO:
11.13



LEGEND:

- Gunnedah Aquifer Extent
- Observation Bore
- Proposed Mining Area
- EL 7223
- Alluvium (1:250k)
- Usage Bore
- Highway
- Drawdown Contour (m) - Base Case
- Project Boundary

Watermark Coal Project (G1501)
 Groundwater Assessment

**Melville's Seam Drawdown Sensitivity
 - Hydraulic Conductivity - Year 25**



DATE:
 18/10/2012

FIGURE NO:
 11.14



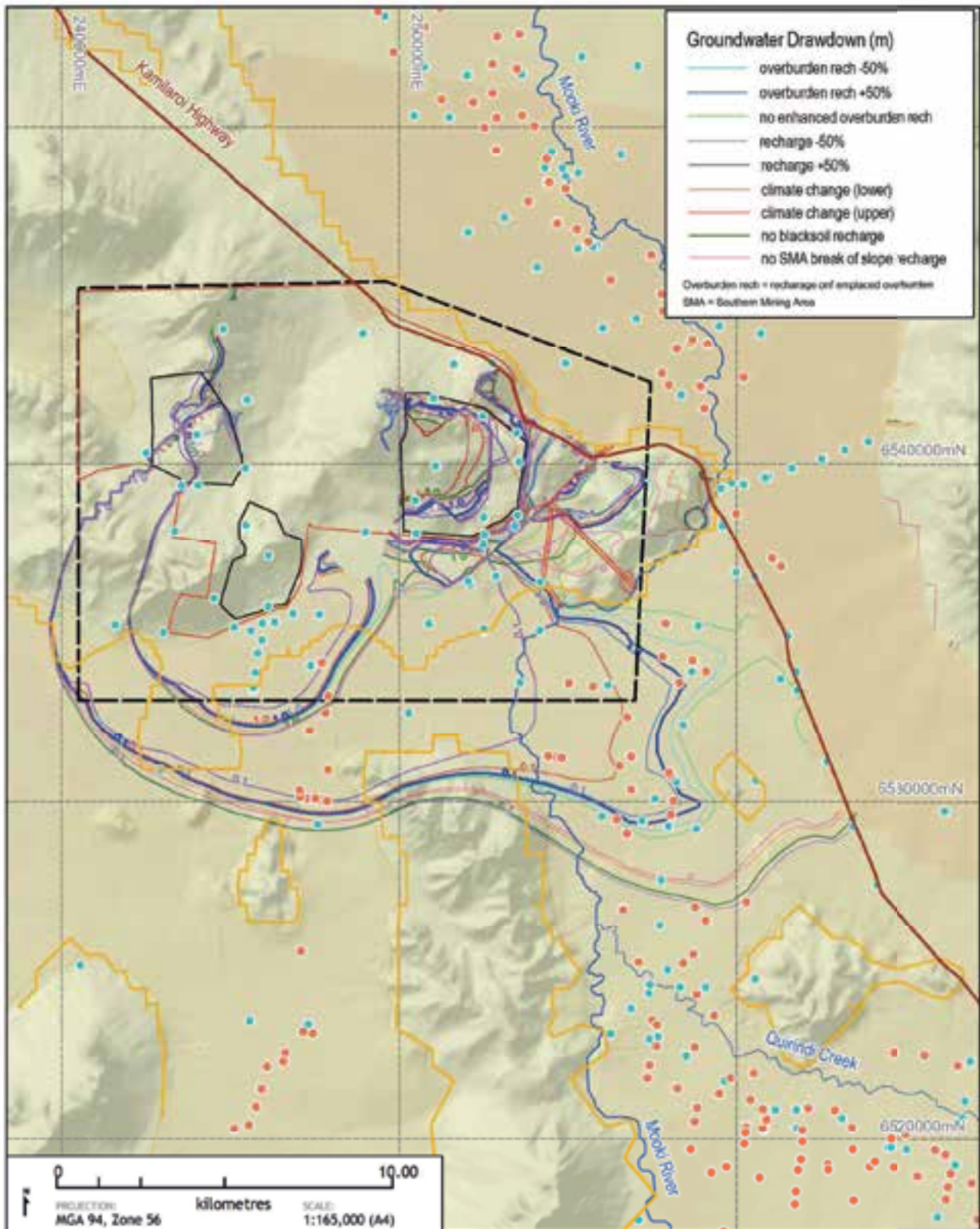
- Watermark Coal Project (G1501)
-
- Groundwater Assessment

Melvilles Seam Drawdown Sensitivity - Storage - Year 25



DATE: 15/10/2012

FIGURE 11.15



LEGEND:

- Gunnedah Aquifer Extent
- Observation Bore
- Proposed Mining Area
- EL 7223
- Alluvium (1.250k)
- Usage Bore
- Highway
- Drawdown Contour (m) - Base Case
- Project Boundary

Watermark Coal Project (G1501)
Groundwater Assessment

**Melville Seam Drawdown Sensitivity
- Recharge - Year 25**



DATE:
18/10/2012

FIGURE NO:
11.16

11.1.7 Open Void Water Level Recovery

The recovery model was rerun with model parameters to represent potential changes in future climate. Changes to rainfall and evapotranspiration rates were assigned according to the 2050 high emissions scenario - 10th percentile (15% decrease in rainfall and 3% increase in potential areal evapotranspiration) and 90th percentile predictions (7.5% increase in rainfall and 10% increase in potential areal evapotranspiration).

Figure 11.17 shows the water level recovery for the baseline scenario and the two climate change scenarios simulated. The sensitivity analysis shows that under the climate change scenarios, the void remains as a sink for groundwater flow. The model predicts a slightly lower void lake level for the 90th percentile climate change scenario.

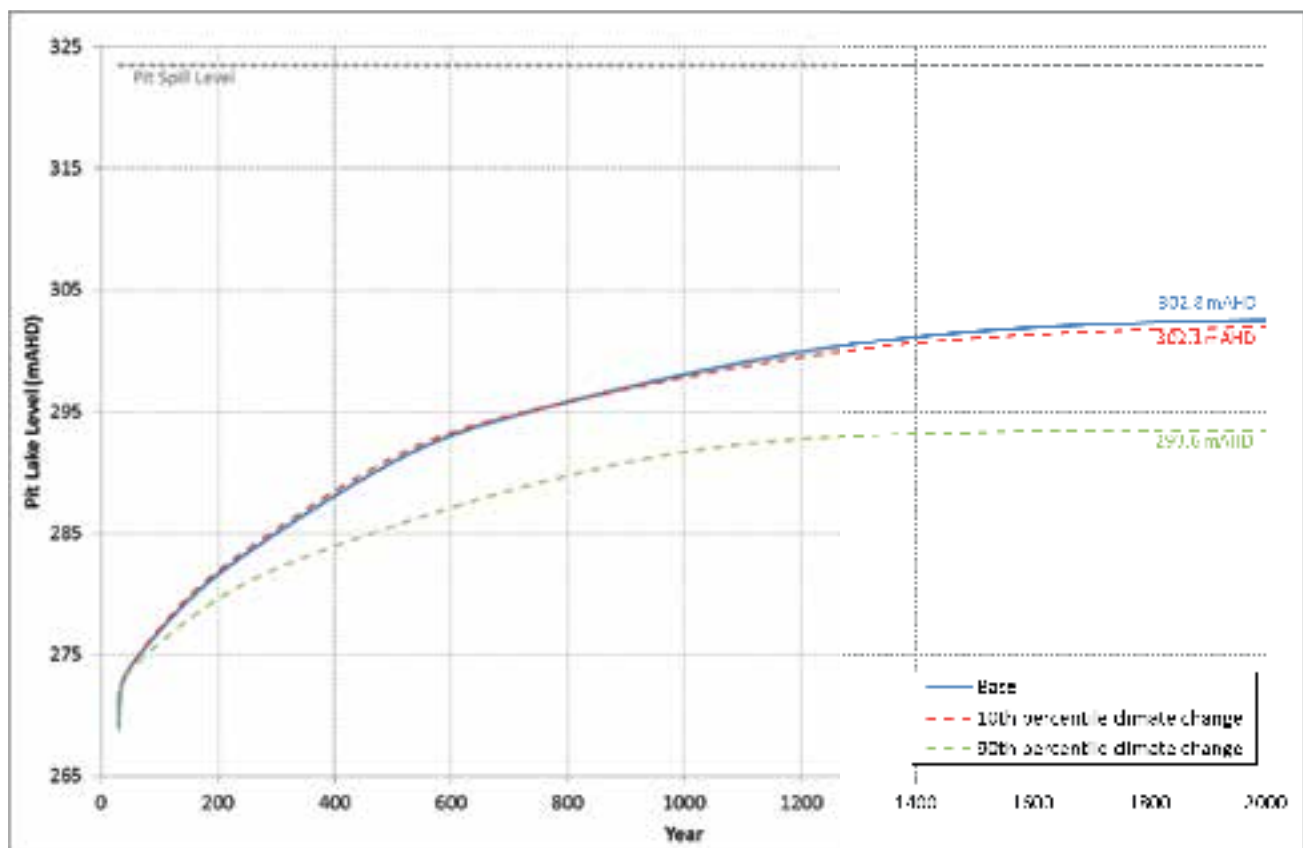


Figure 11.17: Open Void Water Level Sensitivity

11.1.8 Sensitivity Classification

The Murray Darling Basin Modelling Guidelines (Middlemis, 2000) recommends classifying sensitivity by the resultant changes to the model calibration and predictions. The four sensitivity types are as follows:

- Type I: Insignificant changes to calibration and prediction;
- Type II: Significant changes to calibration – insignificant changes to predictions;
- Type III: Significant changes to calibration –significant changes to predictions;
- Type IV: Insignificant changes to calibration –significant changes to predictions.



Types I-III are of no concern as the impacts on predications is insignificant, and the model is a calibrated, high complexity model. “Type IV is a cause for concern: non- uniqueness in a model input model input might allow a range of valid calibrations but the choice of value impacts significantly on a prediction (Middlemis, 2000).”

Using the data presented in Section 9.2.2 and Section 11.1, the model input parameters and generally classified as follows:

- | | |
|--------------------------------------|---------------|
| • Horizontal hydraulic conductivity: | Type III |
| • Vertical hydraulic conductivity: | Type III |
| • Specific yield: | Type I |
| • Specific Storage: | Type I - III |
| • Recharge and evapotranspiration | Type II - III |

The concern of non-uniqueness of a calibrated parameter set is explored in Section 11.2 through calibration constrained Monte Carlo uncertainty analysis.

11.2 Uncertainty Analysis

11.2.1 Introduction

The analysis described in the preceding section explored the sensitivity of the model predictions to changes in the calibrated parameters. Analysis of the uncertainty of model outputs where parameters are not subject to calibration is referred to as “uncertainty analysis”. Model calibration does not necessarily result in a unique set of parameter values, especially if the model employs a number of parameters to simulate system complexity, hence parameter and predictive variability can still be large.

A calibration-constrained Monte Carlo analysis was carried out with the following objectives:

- (i) describe a numerically-tractable approach for quantification of uncertainty for this model, and
- (ii) report the results of applying the methodology to estimate the potential uncertainty associated with the 30-year development of the open cut mining areas as described in 10.0 of the main report.

Detailed reporting of the methodology, implantation, results and recommendations is presented as Appendix 8.

Calibration-constrained Monte Carlo methods for predictive uncertainty analysis seek to generate many different parameter sets that enable the model to match the observed data within a level of misfit that is commensurate with measurement errors associated with that data.

A pragmatic approach to this study was sought which balanced the information inherent in the current pre-development calibration dataset with stochastic generation of parameters on the basis of an adopted set of parameter statistical properties that respected current hydrogeological understanding and “professional intuition and experience”. In other words, an acceptable level of “de-calibration” was sought given that only a pre-development measurement dataset was available. To achieve this, a Monte Carlo approach was adopted, whereby prior probability



distributions for parameters were treated as multi-Gaussian with means centred on the calibrated parameter set.

The analysis employed the use of stochastic parameter generation by allowing random heterogeneity to be represented on a cell-by-cell basis to better represent the type of aquifer variability that exists in the real world. Each spatial parameter field was thereby generated using a cell-by-cell stochastic field generator. Parameter bounds used for calibration were also enforced, with the intervals between respective parameter bounds corresponding roughly to 95% pre-calibration parameter confidence intervals on the basis of hydrogeological interpretation and inference.

Exploration of the uncertainty of a model prediction was to be accomplished by running the model repeatedly using a suite of random parameter realisations, collecting cell-based and site-specific outputs, and building empirical predictive probability distributions and computing common statistical measures on the basis of these model run outcomes. Random parameter sets were accepted or rejected based on the calibration objective function computed for each realization. Thus, of the 500 random parameter sets generated, the 50th percentile was adopted as a cut-off level for acceptance (i.e. 250 realisations).

11.2.2 *Parameterisation*

Hydraulic Parameters

The level of parameterisation detail in the alluvium layers was considered acceptable for exploration of predictive uncertainty and thus remained unchanged for stochastic parameter generation. Pilot points and covariance matrices based on one or a number of presumed variograms were used to characterize parameter field variability.

For layers 3 to 11, the layer-wide hydraulic conductivity parameters were “re-constituted” as spatially variable fields by employing stochastic field generation to produce cell-by-cell variability in the fresh and weathered zones of each layer, excluding the coal seam layers. For the coal seam layers, spatial variability in hydraulic conductivity was introduced through the agency of pilot point multipliers (totalling 59 and 61 in the Hoskissons and Melvilles coal seams respectively), while the K0 (zero depth) coefficient was also included in the stochastic parameter generation process. Stochastic field generation to produce cell-by-cell variability was also applied to represent the primary and secondary storage characteristics of layers 3 to 11. Spoil parameters were also explored in the uncertainty analysis.

General-head boundary (GHB) cells used to represent down-valley flow along the northern boundary were also included in the uncertainty analysis as pilot-point based conductance parameters. In addition, a pilot point based parameterisation scheme was used to provide for adjustment of evapotranspiration rate; a suite of 68 pilot point multipliers were utilised.

The original parameterisation of faults was scrutinised for the uncertainty analyses by delineating the faults into 25 zones for the purpose of assignment of the hydraulic characteristic value.

Recharge and Discharge

Recharge percentage rates of the zones and subzones of the groundwater simulation were explored, as was the annual recharge rates.

The 5 zones of river cells representing riverbed permeability for Quirindi Creek, Mooki River, minor creeks, drainage lines and Lake Goran were extended to a total of 14 zones for uncertainty analyses, whereby the Mooki River was subdivided into 10 subzones given its relative importance.



Another modification to the model parameterisation was the addition of landholder extraction rate zonal multipliers in each of the six management zones to evaluate the influence of noise in the licensed bore datasets on predictive uncertainty.

Details of the parameter ranges applied, and further detail to the Monte Carlo approach is outlined in Appendix 8.

11.2.3 *Model Prediction Types and Output Measures*

Analysis of the uncertainty of a prediction requires that the prediction(s) be made by the model using all of the parameter fields calculated using the Monte Carlo based methodology described in Appendix 8. Thus for a proposed 30-year open cut coal mine development within the EL 7223, the following predictions were considered:-

- sump seepage rates for proposed mining areas over time;
- groundwater management zone 7 alluvial transfer flow over time;
- Mooki River net groundwater leakage over time; and
- maximum spatial extent of aquifer depressurisation at the 1m impact level.

With the exception of sump seepage rate predictions, each of the predictions noted above were evaluated relative to a “no development” baseline prediction of system response.

To interpret this abundance of outputs a statistical approach was adopted, the mean, median, and the 90th percentile and 10th percentile for a given output were computed from the 250 realisations.

11.2.4 *Proposed Mining Area Sump Seepage*

Figure 11.18 summarises the uncertainty of the predicted sump seepage rate over time within the open-cut voids. Generally, the calibrated base case falls below the median and mean inflow predictions, particularly in the first half of the mine life. The upper and lower bounds of the predictions are similar to those ascertained from sensitivity analysis results, confirming the robustness of the model and the mining area inflow predictions.

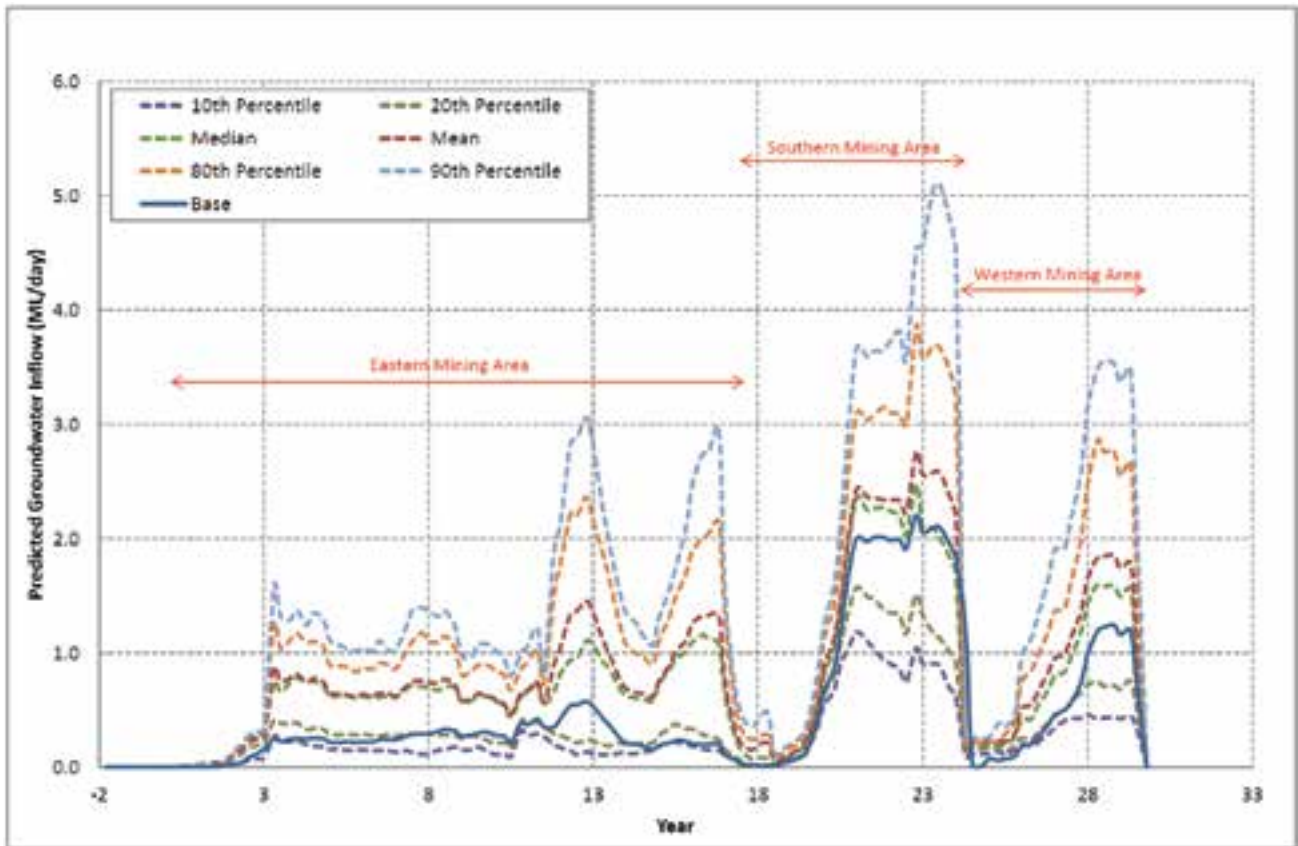


Figure 11.18: Mining Area Sump Seepage Uncertainty

11.2.5 Groundwater Management Zone 7 Alluvial Transfer Flow

Figure 11.19 presents the uncertainty statistics of the reduction in transfer between the Permian and alluvium. The calibrated base case falls slightly below the median and mean transfer flow change predictions during the last ten years of mining. Similar to the mining area inflows, the upper and lower bounds are similar to those presented in the sensitivity analysis results.

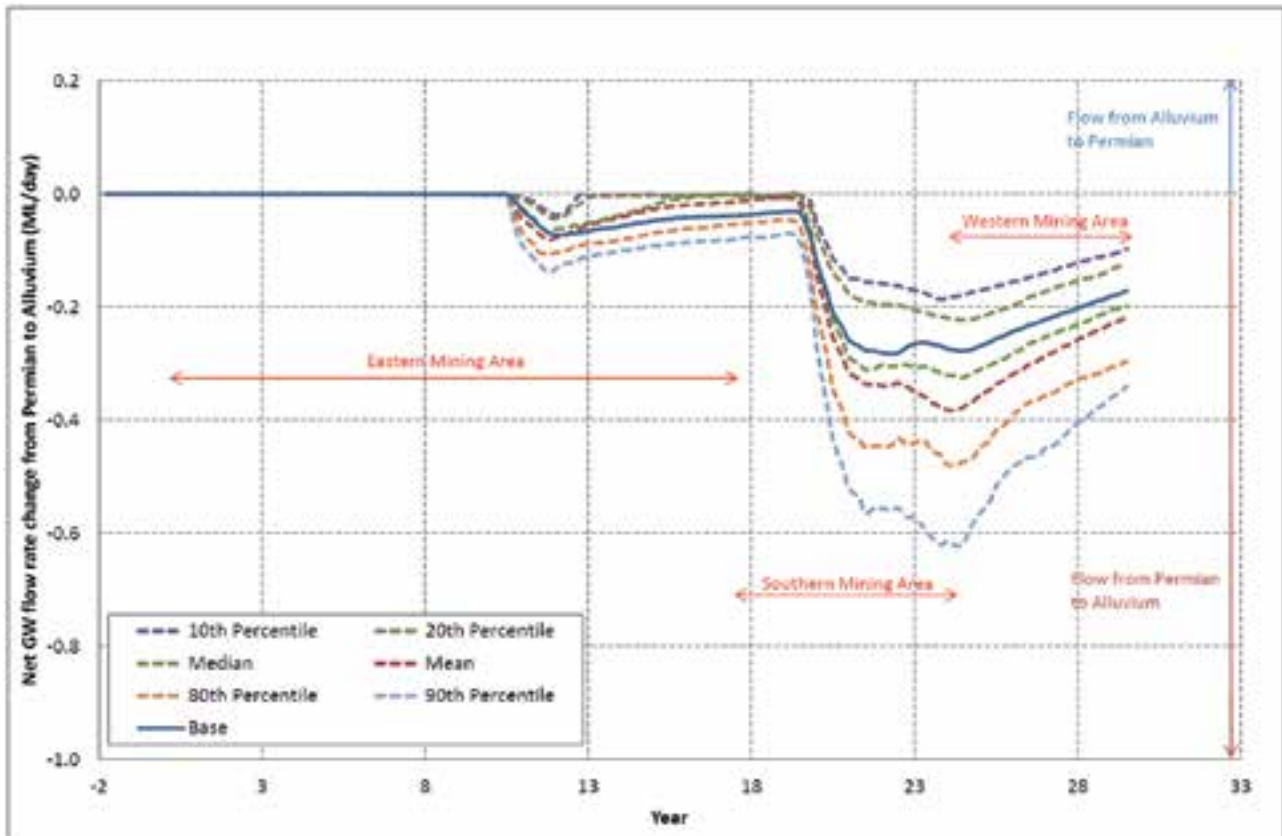


Figure 11.19: Groundwater Management Zone 7 – Alluvial Flow Loss Uncertainty

11.2.6 Mooki River Net Groundwater Leakage

Figure 11.20 presents the uncertainty statistics of the increase in groundwater leakage from the Mooki River to the alluvium. The calibrated base case falls slightly above the median and mean leakage flow change predictions during the last ten years of mining. The upper and lower bounds are similar to those presented in the sensitivity analysis results, again confirming the robustness of the model and the Mooki River leakage change predictions.

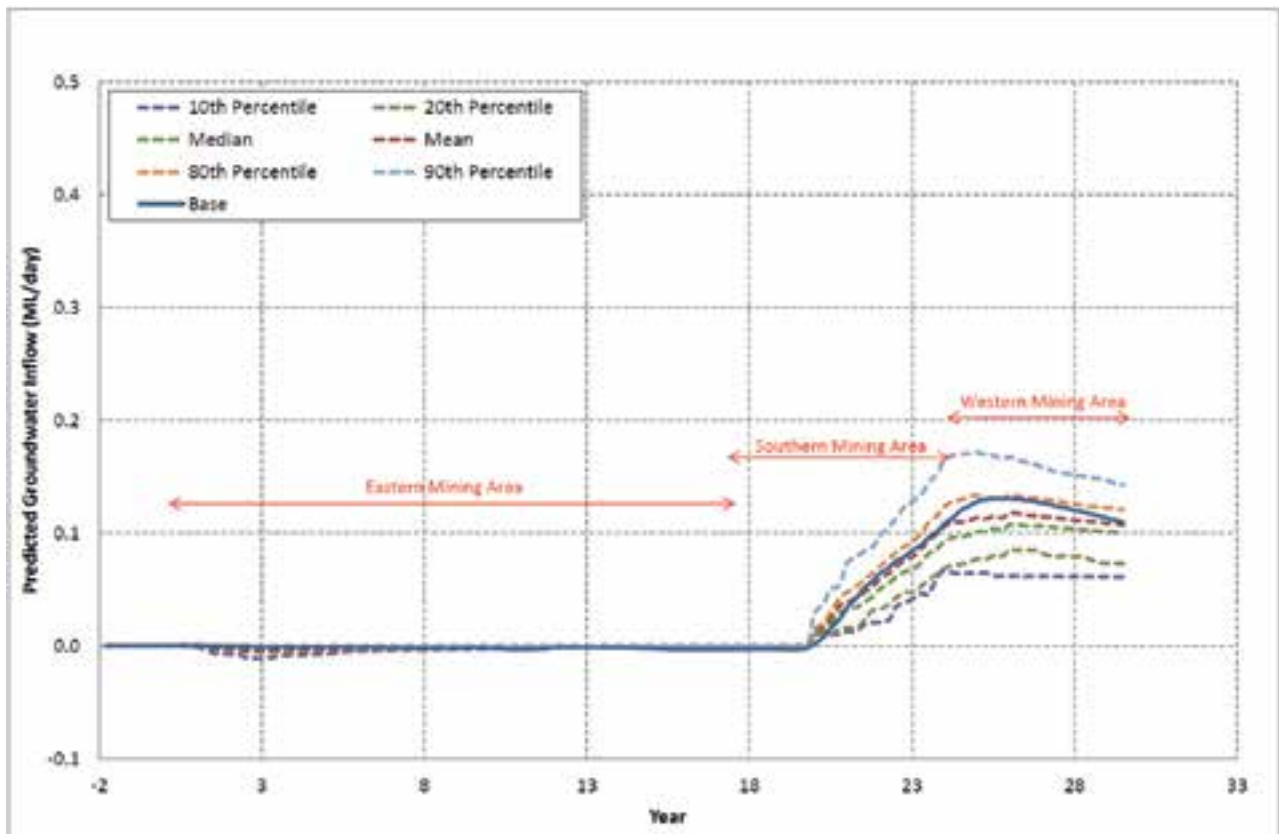
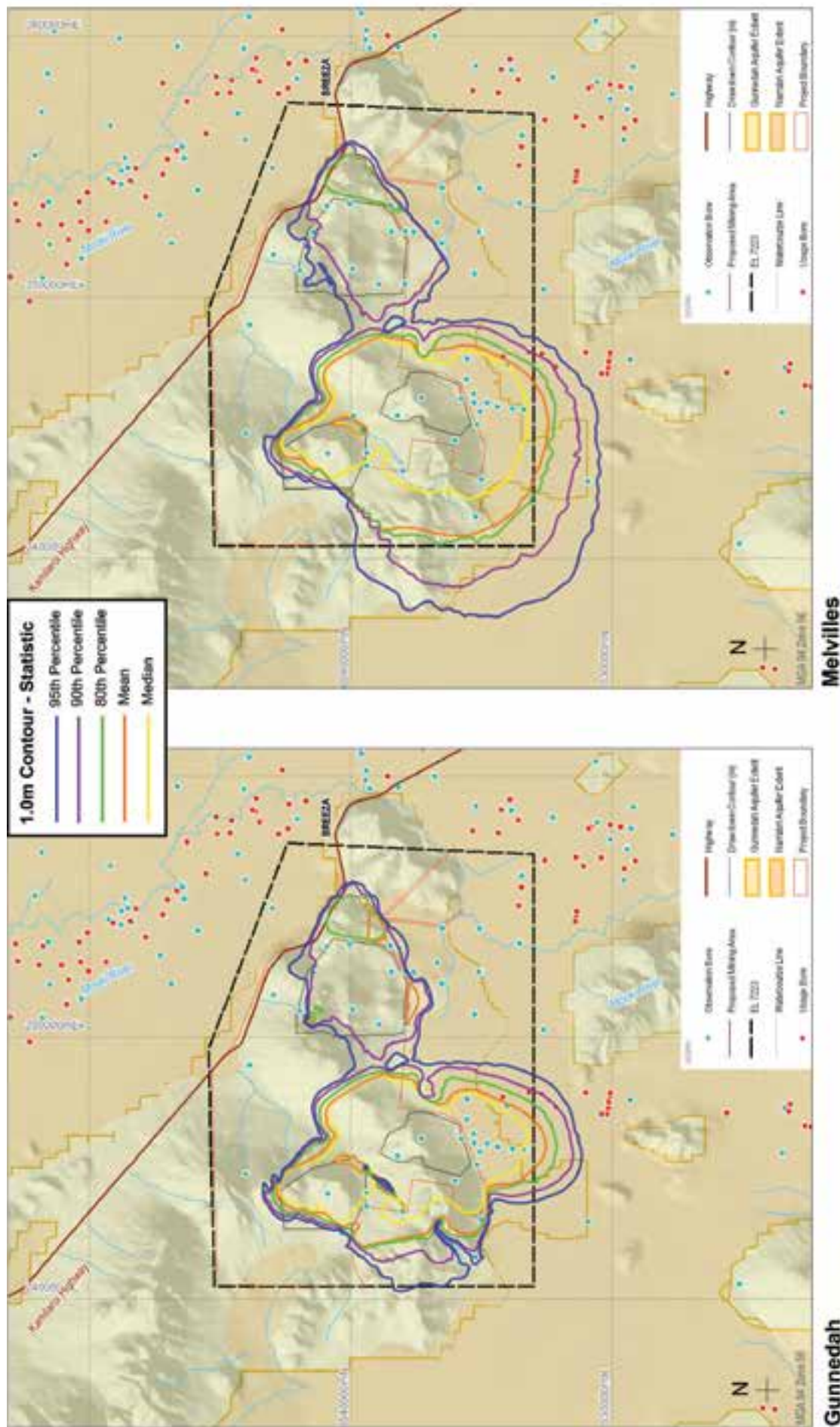


Figure 11.20: Mooki River Net Groundwater Leakage Uncertainty

11.2.7 Zone of Depressurisation

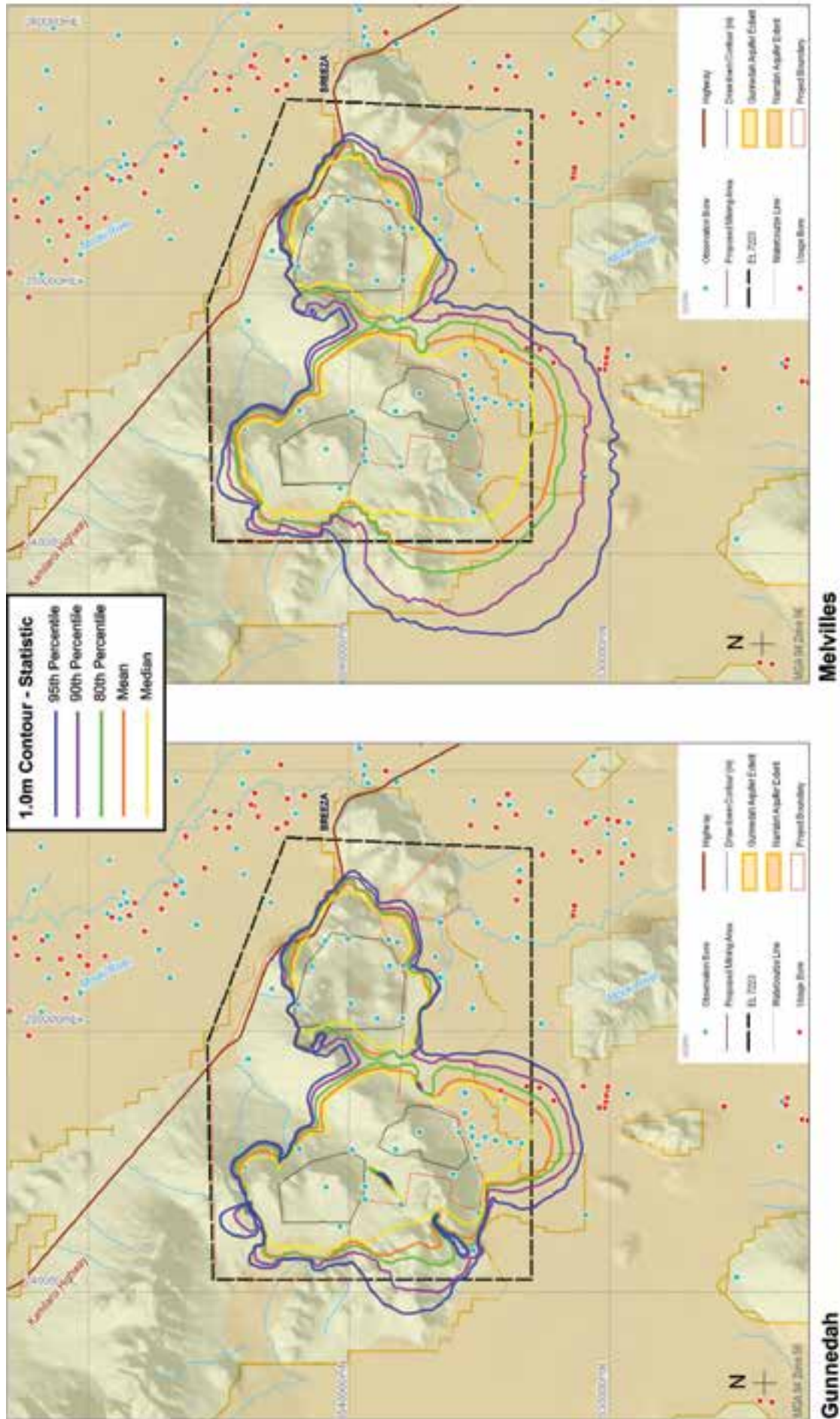
The uncertainty of the predicted zone of depressurisation in the Gunnedah formation and the Melvilles coal seam was investigated for Year 25 when the Southern Mining area is active and for the maximum impact drawdown recorded in every model cell over time; these are shown in Figure 11.21 and Figure 11.22 respectively.



Uncertainty of Aquifer Depressurisation -25.5 Years - Statistical Analysis

Figure 11.21

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (6/15/01)



Uncertainty of Aquifer Depressurisation - Maximum All Time - Statistical Analysis

Figure 11.22

WATERMARK COAL PROJECT - GROUNDWATER ASSESSMENT (G1501)



The 1 m uncertainty drawdown contours are somewhat less constrained than the values presented in the sensitivity analysis. Base case predictions for both the Gunnedah Formation and Melville Seam lie slightly outside of the median and mean uncertainty predictions. This provides confidence in the drawdown extents presented for the base case predictions and implies the base case represents a conservative approximation of potential groundwater drawdown impacts.

11.2.8 *Summary and Conclusions*

The results of this study have helped to characterise the level of potential uncertainty associated with key predictions made by the model. Broadly speaking, the predictive model uncertainty was consistent with the outcomes of the sensitivity trials, but provides a more robust and detailed appraisal of potential uncertainty bounds.

This work provides a demonstration of the utility of uncertainty analysis for the current model structure with an appropriate level of observance to historical observations. More detailed explorations of uncertainty are recommended as further system response data becomes available and as the model assemblage is adjusted in future.

11.3 Model Limitations

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

It is important for the reader to understand that models can only approximate natural phenomena that occur in groundwater systems. Although it is well calibrated, there remain limitations for long-term predictive use. As with all models, the Project model should follow an evolutionary path and be updated as more data, particularly in the areas proposed for mining becomes available. The following limitations have been identified and will provide focus areas for future work. The main limitations of the model are as follows:

- Aquifer Properties – The model assumed that the hydraulic properties of the Tertiary, Jurassic, Triassic and Permian interburden aquifers and spoils were uniform across the entire model domain. In reality, the permeability of the aquifers is variable and this variability can result in a less uniform zone of depressurisation than that predicted by the numerical model. The values for hydraulic conductivity and storage properties of spoil are representative of spoil material in the Hunter Valley. The behaviour of the properties of the spoil at the project site may be different.
- Uncertain Starting Conditions – Only limited data was available regarding the initial hydraulic heads in the bedrock outcrop areas.
- Unknown Boundary Conditions – This particularly applies to the basement hydraulic properties, and leakage to and from water bodies throughout the region. Values used in model inputs in these areas were subjective, and based on very limited data.



- Limited Geological and Hydrogeological Data – Outside the Project Boundary only sparse data were available for the bedrock units.
- Limited Temporal Data – Excellent temporal data was available for the alluvial aquifers, but temporal data (pre-2009) such as spatial recharge, groundwater level fluctuation and changes in hydraulic properties such as aquifer and aquitard storativity was limited for the bedrock formations. Model calibration could be improved if these data were available, although another level of model complexity would be created.

12.0 CUMULATIVE EFFECT OF MULTIPLE PROJECTS

Other proposed mining and gas projects within the Liverpool Plains area would also depressurise the Permian strata. If the zones of depressurisation due to open-cut, underground coal mining and groundwater extraction for coal seam gas (CSG) mining overlap, there will be enhanced drawdown in these zones. The brief for the Namoi Water Study Model (Schlumberger, 2012) was to assess the potential cumulative impacts associated with proposed mining and coal seam gas projects within the Namoi Catchment.

The Namoi Water Study had access to data from the CSG industry, and data collected by the BHP Carooona project, which is the largest area of potential mining activity in the Watermark model domain. Shenhua Watermark did not have access to the CSG or BHP Carooona data to utilise in an assessment of the cumulative impacts. It was therefore decided to use the results of the *Namoi Water Study* to address the potential cumulative impacts.

The following sections summarise the results of the cumulative impact assessment undertaken as part of the *Namoi Water Study* (SWS, 2012a,b).

12.1 Setup

12.1.1 Predictive Scenarios

Schlumberger Water Services (Australia) Pty Ltd (SWS) were appointed the Independent expert for the *Namoi Catchment Water Study* and were charged with the development of an integrated suite of models (the SWS Model) to assess the nature and extent of potential effects from coal and gas developments on the water resources of the catchment. The purpose of the Study was to collate and analyse quality controlled data to assist in identifying and quantifying risks associated with coal mining and CSG developments on water resources (SWS, 2012b). The following sections present the modelled cumulative impacts and compare the SWS Model to the Shenhua Project model to highlight both the differences and similarities.

The SWS Model was developed using the MODFLOW 2000 numerical code and covered an area of approximately 30,380 km² (310 km x 180 km) at 1 km by 1 km cell size (plan view). A total of 20 geological layers were simulated, representing 1,116,000 cells, a similar number to the AGE Watermark Model. The cell size was set to a uniform values

The predictive scenarios start in July 2010 and were intended to quantify the potential cumulative influence of the proposed developments on a regional scale over a 90-year model simulation. Scenario 2 included approved and possible mines (10 open cut and 2 underground mines) and coal seam gas production (2 gas fields). Scenario No. 2 assessed the cumulative impacts for the purposes of this study. Table 12.1 and Figure 12.1 presents the mining and coal seam gas



activities simulated in the cumulative scenario. Note that the possible Caroon Coal Project was included in Scenario 2.

Table 12.1: SWS PREDICTIVE MINING SIMULATIONS				
Scenario	Mines	Mining Year	Coal Seam Gas	Coal Seam Gas Year
SWS No. 2	Werris Creek and Extension	2010 - 2029	Eastern Star Gas Pilot holes	<2010 - 2011
	Boggabri	2010 - 2013	ESG Narrabri	2014 - 2100
	Tarrawonga	2010 - 2015	Santos	2010 - 2100
	Sunnyside	2010 - 2014	Bando	2015 - 2100
	Rocglen and extension	2010 - 2019		
	Canyon	Not reported		
	Narrabri North	Not reported		
	Boggabri Extension	2013 - 2040		
	Tarrawonga Extension	2015 – 2028		
	Maules Creek	2012 - 2033		
	Shenhua Watermark	2013 - 2043		
	BHP Caroon	2014 - 2052		

The mining and CSG activities in this scenario were complete within the first 35 years of the simulation, allowing for 25 years of groundwater recovery.

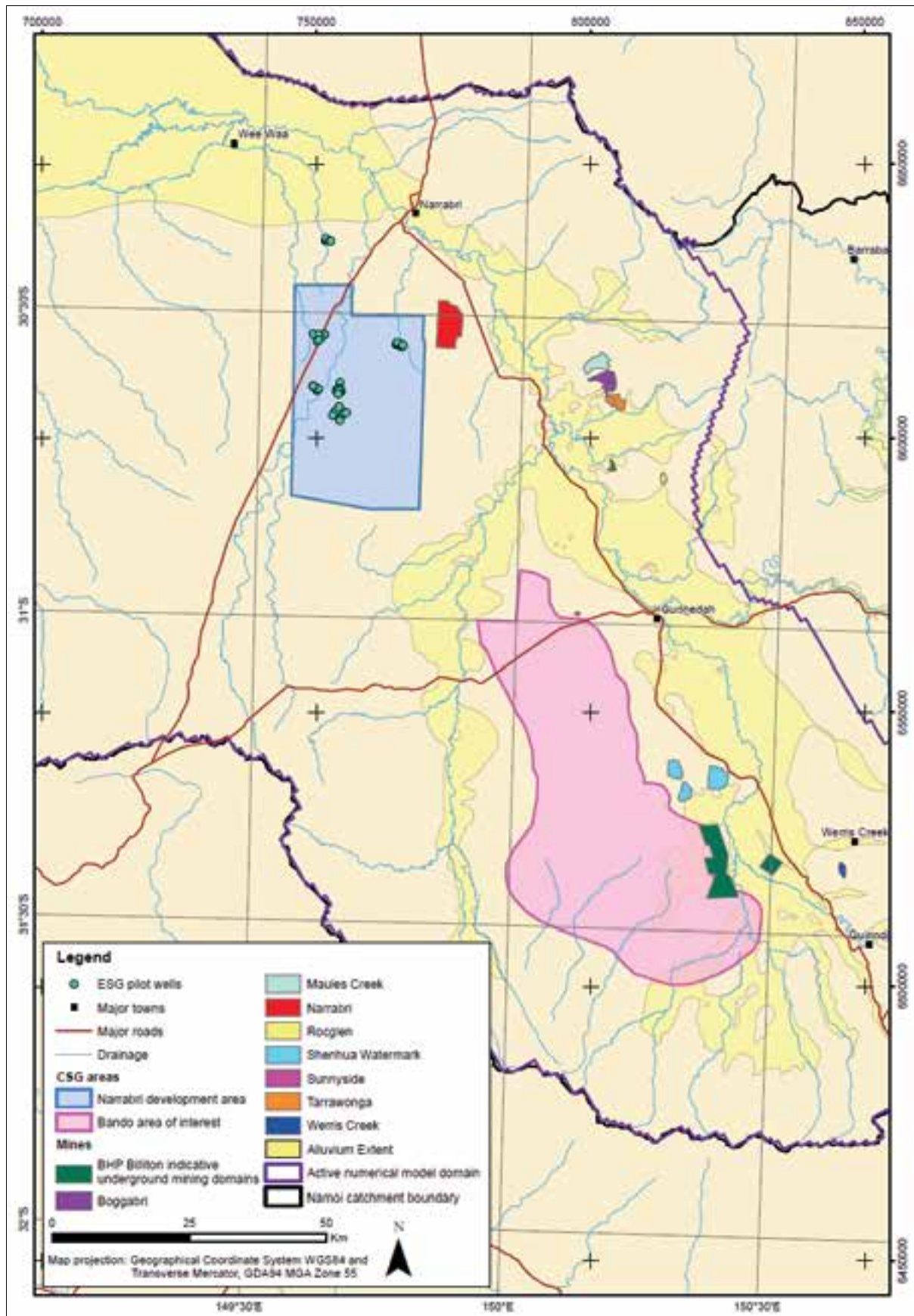


Figure 12.1: Mining and Coal Seam Gas Activities in the SWS Model (SWS, 2012a)



12.1.2 Assumptions

The SWS Model assumed that:

- open cut mines intercept all rainfall within the mining area extent which is then removed from the system;
- no advanced groundwater abstraction is required for any mining areas or underground projects;
- once open cut mines are rehabilitated the drains are removed and surface water flow returns to 'pre-mine' rates;
- goafing, or 'cracking' of the roof material is simulated and extends upwards to the base of the Garrawilla Volcanics where present, to ground surface or the base of the alluvium;
- changes to the hydraulic parameters of the 'cracked' formations (no more than 200 m above the coal seam) were applied in the model from the start of the simulation onwards;
- goafing simulated by increasing the coal seam hydraulic conductivity to 10 m/day, and increasing the hydraulic conductivity of affected layers by 3.5 times (horizontal) and 10 times (vertical);
- mined coal seams were simulated using a specific yield and storage coefficient of 50%;
- hypothetical mines were distributed evenly throughout the catchment, based on depth to coal, coal thicknesses and location of alluvium;
- CSG wells were simulated using MODFLOW MNW wells in layers where coal is present;
- CSG fluid flow assumed to be single phase (i.e. liquid [water] without gas);
- CSG abstraction occurred evenly over the extent of each field in coal seam formations greater than 5 m thick at depths between 200 – 1000 mbgl; and
- Landholder abstraction was simulated based on historical pumping trends and rainfall estimates.

12.2 Results

12.2.1 Groundwater Levels

Figure 12.2 to Figure 12.4 show the predicted groundwater drawdown in the Gunnedah Formation Aquifer throughout the cumulative model simulation (2030, 2060 and 2100). Generally, groundwater drawdown in the Gunnedah Formation aquifer is less than 1.5 m and is of a similar magnitude in Zone 7 to that predicted by the Shenhua Watermark Project model (refer Section 10.6). The key points to note are as follows:

- Zone 3: The SWS Model predicted depressurisation of between 0 m and 0.5 m in areas of this zone in 2030, 2060 and 2100. The depressurisation is most extensive in 2060.
- Zones 7 and 8: The SWS Model predicts depressurisation covers most of these zones in the three output years. In 2030, the most drawdown occurs in the north of Zone 7 (between 0.5 and 1 m). In 2060, the maximum drawdown is between 1 m and 1.5 m (over most of Zone 7) and in 2100, it is similar to 2060.
- Zones 1, 6 and 10: No drawdown is predicted in 2030 in the SWS Model. In 2060 and 2100, most of these zones are predicted to experience drawdown between 0 m and 0.5 m.

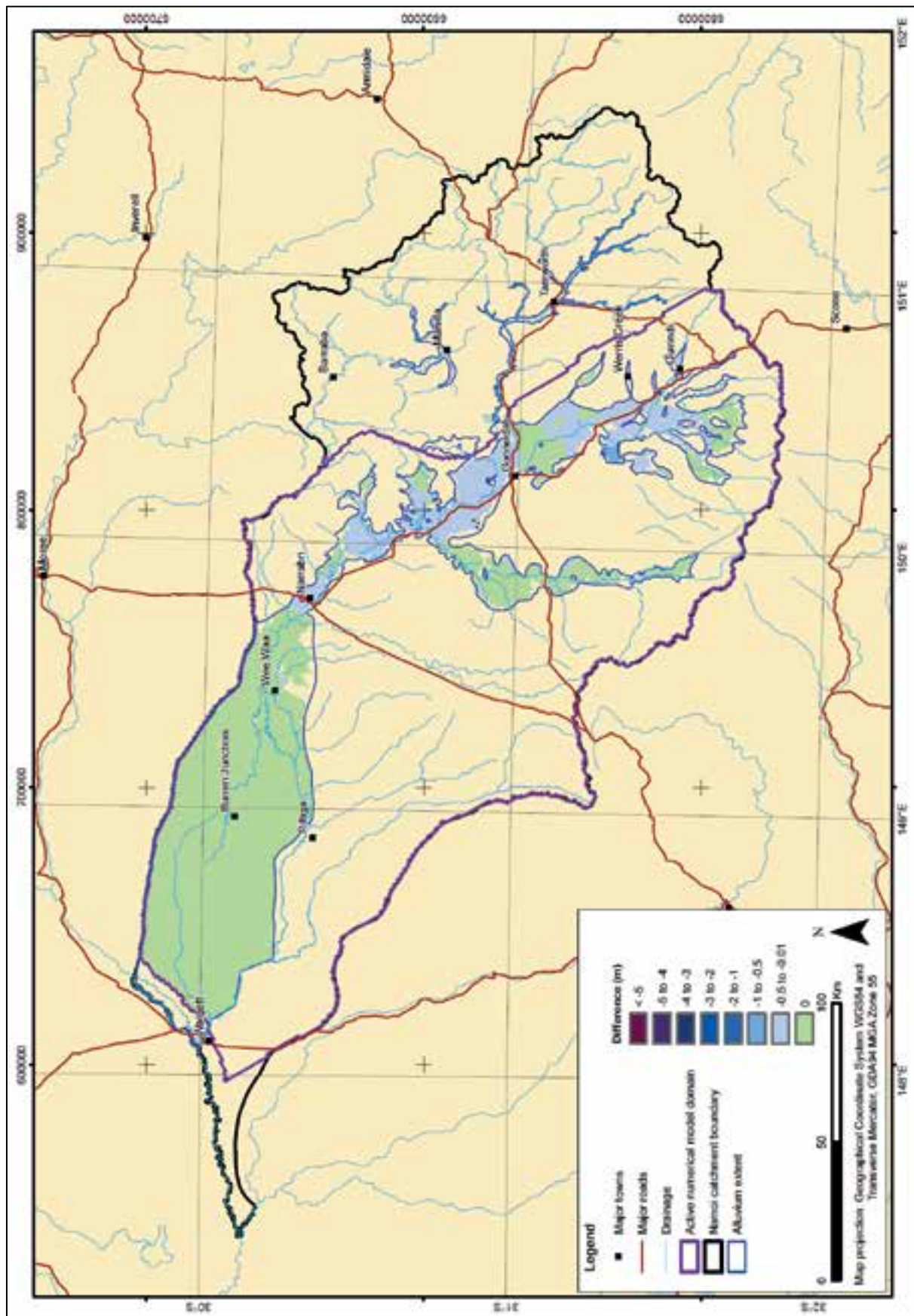


Figure 12.2: Cumulative Groundwater Drawdown – Gunnedah Fm. – 2030 (SWS, 2012a)

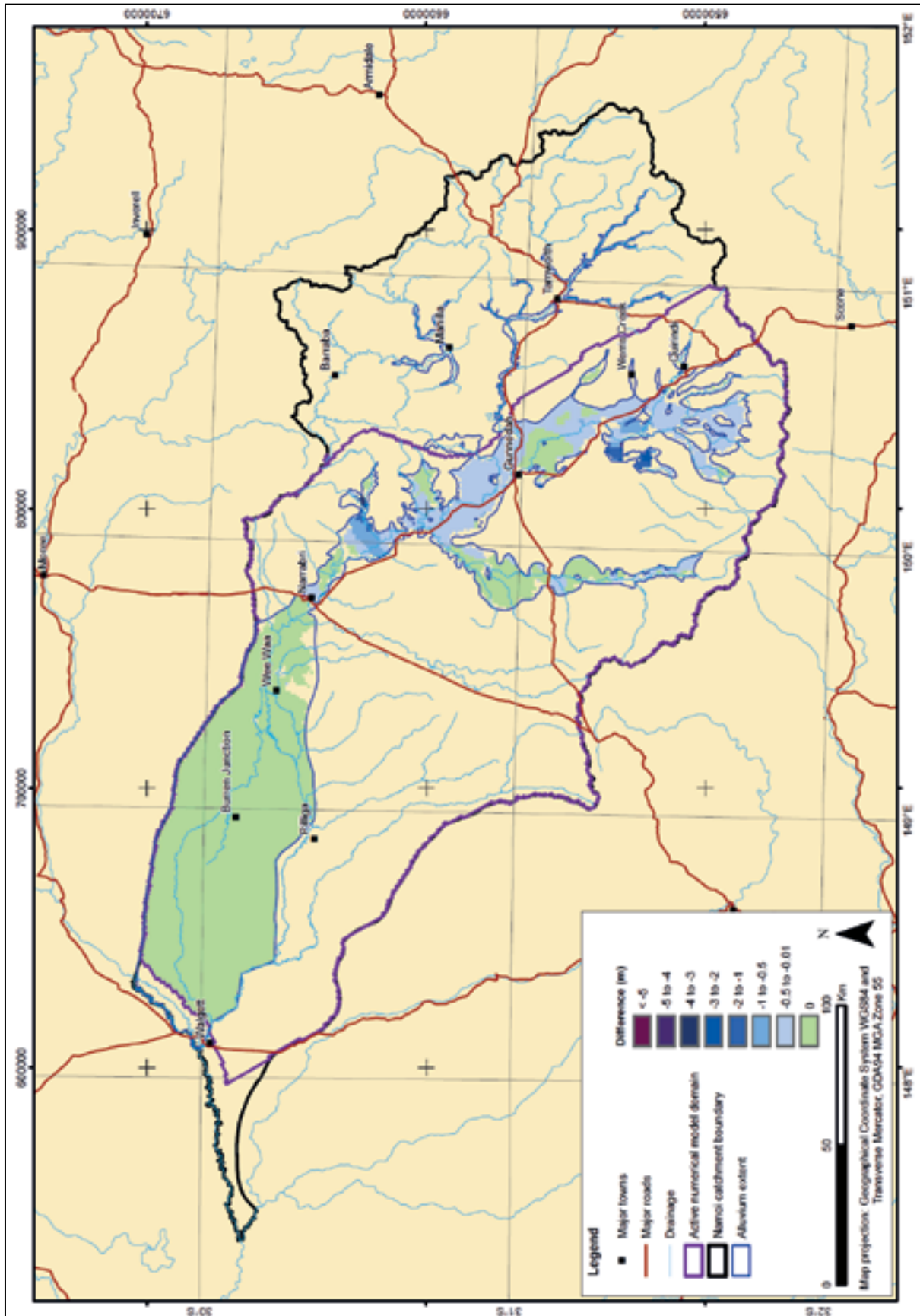


Figure 12.3: Cumulative Groundwater Drawdown – Gunnedah Fm. – 2060 (SWS, 2012a)

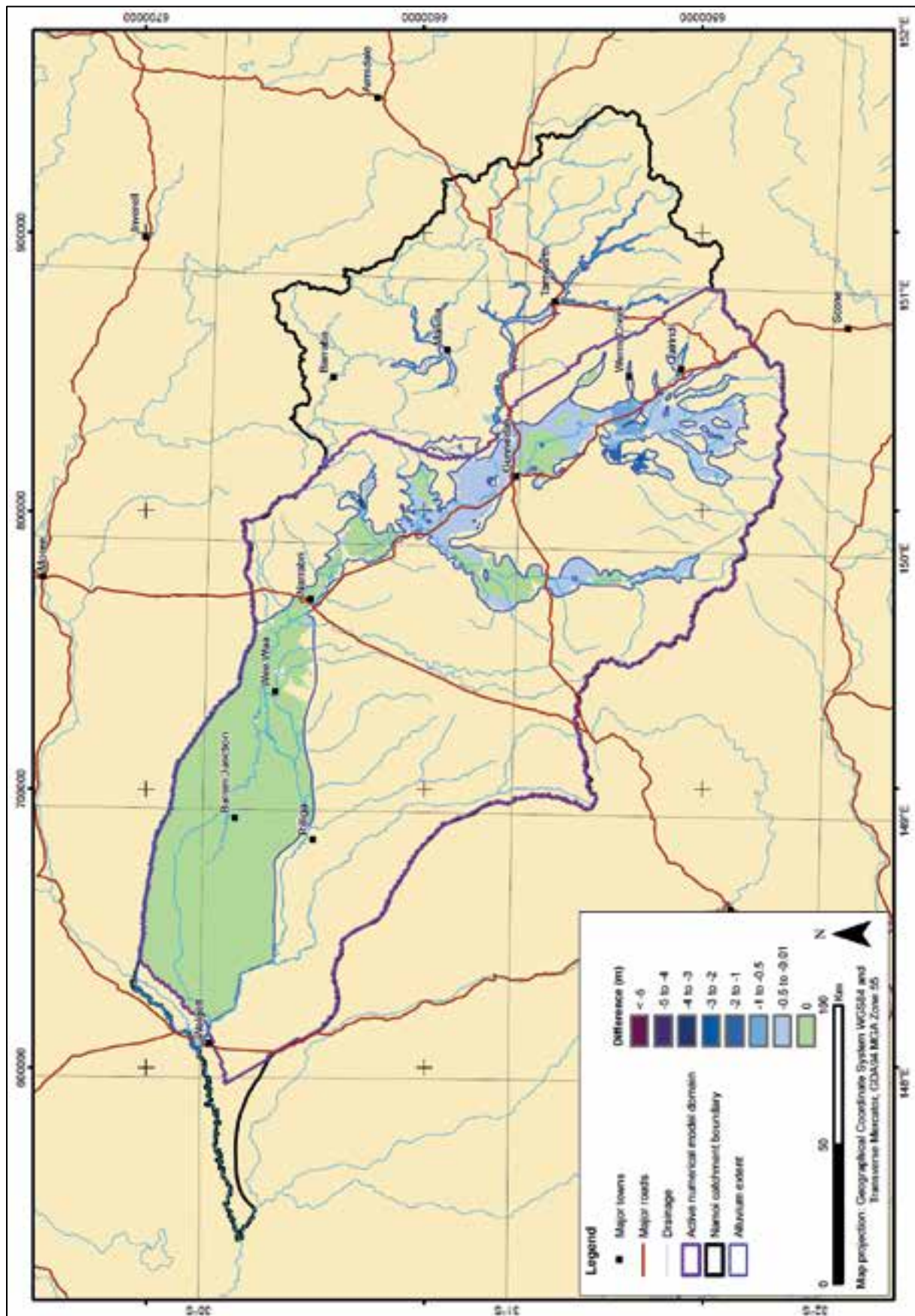


Figure 12.4: Cumulative Groundwater Drawdown – Gunnedah Fm. – 2100 (SWS, 2012a)



12.2.2 Water balance

Predicted changes to river leakage as a result of groundwater drawdown in the SWS Model are consistent with the Shenhua Watermark model, which predicts a maximum loss of 0.1 ML/day as leakage from the Mooki River (refer Section 10.9). Leakage from rivers to groundwater is relatively unchanged from 2010 to 2020. Leakage increases to 0.4 ML/day from 2040 to 2100. Groundwater flow from the bedrock to the Upper Namoi alluvium reduces by 1.0 ML/day from 2010 to 2060.

12.2.3 Discussion

The SWS Model did not report a model run where only the Watermark Project is operating. However, the cumulative impact modelling produced a zone of depressurisation around the Project in the northern area of Zone 7. The Shenhua Watermark model indicated that depressurisation greater than 1m in the Gunnedah Formation Aquifer is limited to Zone 7 and extends approximately 3.9 km from the Southern Mining Area. The *Water Study* model indicated that the drawdown in the Gunnedah Formation Aquifer extended slightly further, with the 1 m drawdown contour 5 km from the Southern Mining Area. The more extensive zone of depressurisation is presumably due to the cumulative impact of the BHP Carooona Project and the Project operating concurrently.

13.0 SUMMARY AND CONCLUSIONS

The hydrogeological study for the Project commenced in tandem with the exploration program for EL 7223 in 2009 and has included four phases of drilling and field investigations. An extensive monitoring network has been installed over this three year period which includes 87 monitoring bores, 9 large diameter bores for test pumping and 32 vibrating wire piezometers. Monitoring of groundwater levels and quality in the network commenced in 2009 and over three years of baseline data has been collected from the early bores. This network is significantly more extensive than for any other mining project in the region and comparable with more developed mines with longer history in the Hunter Valley.

Field testing indicated that the permeability of the coal in the Project Boundary is relatively low, and significantly lower than has been measured at other proposed mining areas within the Gunnedah Basin. The main aquifer unit identified within the Project Boundary is the Clare Sandstone, a relatively coarse and porous unit, particularly where subjected to weathering. The finer grained interburden units are not considered aquifers with hydraulic conductivity similar to aquitards. A significant aquifer adjacent to the Project Boundary is the Gunnedah Formation aquifer that has been heavily developed for agriculture and domestic water supplies and is in a stressed condition due to uptake of allocations.

A conceptual model of the hydrogeological regime was gradually built-up over the exploration phase using data from the field investigations and information gathered by other investigators in the Liverpool Plains. This conceptual understanding of the structure and behaviour of the aquifer systems in the area was used as the basis for a numerical groundwater model. The purpose of the model was to simulate the historical groundwater trends and to predict the effect of mining on the surrounding groundwater regimes.

Prior to development of the model, it was recognised that leaving open voids in the open cut mining areas after mining was completed would have the potential to result in a long term flow of groundwater into the voids. There was also concern of a continuing leakage from adjacent Gunnedah Formation aquifers into the voids post mining. These were considered adverse environmental outcomes and the mine was planned to ensure the mining voids were backfilled to

ground level and above, ensuring no long term drainage of groundwater into the mining area voids. The final landform will consist of a void in the western section of the Western Mining Area only.

The mine plan incorporates a minimum 150 m buffer zone of bedrock between the crest of the proposed Mining Areas and the black soil plains. In the Southern Mining Area, due to the batter on the mining area walls, the toe of the open cut mining area where the lowest coal seam will be exposed will be up to approximately 1.4 km from the edge of the Gunnedah Formation aquifer. At this edge, the Gunnedah Formation is still relatively thin and the proposed Southern and Eastern Mining Areas are a further 3.8 km from the centre of the main palaeochannel where the Gunnedah Formation is relatively thick and water supplies are most productive. This significant buffer distance prevents the direct connection of water between the Gunnedah Formation aquifer, and the proposed Mining Areas. Figure 13.1 shows the proposed Mining Areas and buffer distances to the surrounding aquifers.

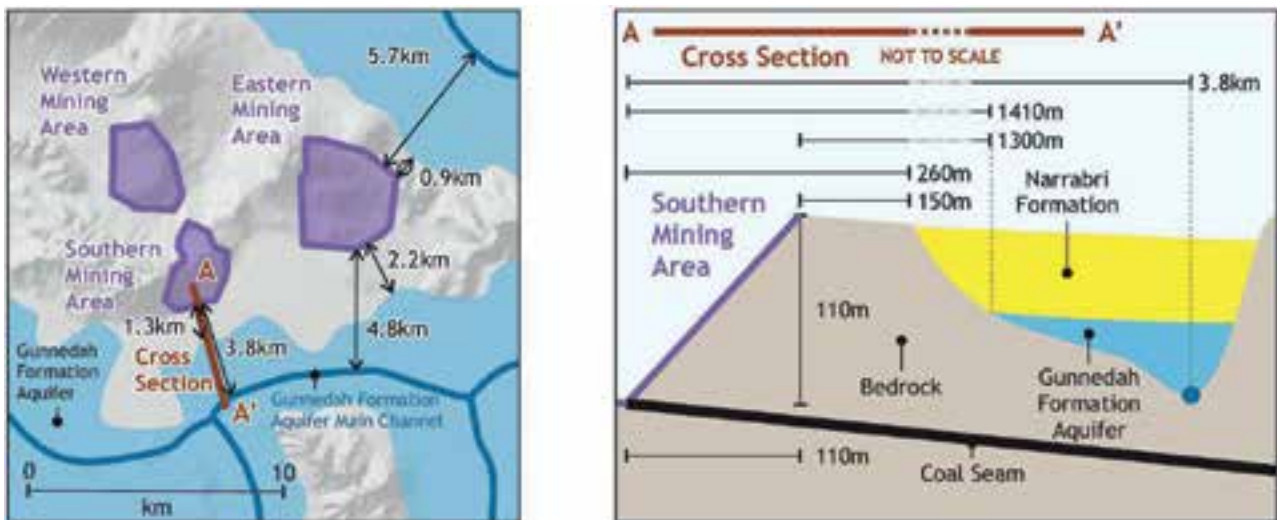


Figure 13.1: Proposed Mining Areas and Aquifer Offset Distances

Numerical modelling indicated that the seepage of groundwater from the Permian aquifers to the proposed Mining Areas would average approximately 0.5 ML/day over the life of the Project. The proposed Eastern Mining Area is elevated on the side of a ridge line and groundwater levels are relatively deep which means the predicted groundwater seepage rates to this mining area are relatively low, and it is likely there will be periods when this mining area is dry with no requirement for pumping. Other mines active in the Gunnedah Basin have observed similar rates of seepage from dry conditions with flows up to 0.5 ML/day.

When mining moves to the proposed Southern Mining Area, seepage rates will increase as the Clare Sandstone unit is present in this area and has a higher permeability than other Permian geological units. Flows up to 2 ML/day are predicted to occur for a number of years as the mining advances towards the south through higher permeable material.

The seepage to the proposed Mining Areas is largely water that drains from fractures and pore spaces in the bedrock and coal seams. The numerical models predict this drainage of Permian water will depressurise the bedrock to the south of the Mining Areas. This pressure change in the bedrock may reduce the rate of groundwater transfer from the Permian bedrock up into the overlying alluvium by up to approximately 0.5 ML/day. When mining is complete in the Southern Mining Area and Eastern Mining Area, the bedrock starts to repressurise and the predicted flow rate from the Permian to the overlying alluvium increases and returns to pre-mining rates over



time. There will therefore be no net impact on the alluvial aquifer system water supplies due to the Project. Private bores within 10 km of the Project extract on average 142 ML/year per bore from the alluvial aquifers. The predicted reduced transfer of water from the Permian into the alluvial aquifers due to mining is equivalent to less than the annual usage from one average bore within the surrounding 10 km. It is therefore insignificant and will be accounted for by appropriate water access licences with relevant share component /allocation (as required by the *Water Management Act 2000*).

On the edge of and adjacent to EL 7223, there are five bores where the modelling predicts the zone of depressurisation may reduce groundwater levels by between 0.5 m and 1.5 m. All of these bores are deep enough for yields to not be significantly impacted by this small reduction in water levels.

No groundwater dependent ecosystems or stygofauna communities were identified within the zone where a depressurisation of groundwater levels is predicted.

Predictions from the modelling work indicate negligible effect on alluvial aquifer systems outside the Project Boundary. Ongoing monitoring of the aquifer systems is critical for ensuring minimal impact on highly productive alluvial groundwater systems beneath the adjoining Liverpool plains. In particular, regular monitoring of key adjacent private bores within the zone of depressurisation would provide the groundwater behaviour information essential for validation of modelling predictions and early warning of diversion from the predictive trends. Section 14.0 below outlines recommended groundwater management measures for the Project.

A peer review of the groundwater modelling undertaken for the open cut mining for the Watermark Coal Project was carried out Noel Merrick of Heritage Computing (2012). Peer review was conducted progressively at key milestones, including: model conceptualisation, model calibration, model prediction, and final reporting. The final version of the Peer Review report has been included as Appendix 9.

The Peer review concluded, *“the Watermark Coal Project groundwater model has been developed competently and is regarded as ‘fit for purpose’ for addressing the potential environment impacts from three open cut mining operations and estimating indicative dewatering rates.”* (Merrick, 2012)

14.0 GROUNDWATER MANAGEMENT AND MITIGATION

This section presents a recommended program of ongoing monitoring to validate the predictions of the groundwater model. The outcome of the current investigation is that the impacts of the proposed Project are negligible and that mitigation measures, apart from accounting for take of water with appropriate water licences, are not required. However, a range of potential mitigation measures is provided should impacts be unacceptable.

14.1 Monitoring Network

Shenhua Watermark installed a significant network of monitoring bores as part of the Project Environmental Impact Statement. Should the Project receive approval, additional monitoring bores should be installed within the predicted zone of depressurisation. The purpose of the monitoring bores will be to assess the extent and rate of depressurisation against model predictions.



Monitoring of water levels and flows from key private bores within, and adjacent to the zone of depressurisation is also recommended. The sites for the additional monitoring will be determined post approval during development of the Water Management Plan. NOW and adjacent landholders will be consulted during development of the Water Management Plan.

14.2 Water Level Monitoring Plan

Shenhua Watermark has manually monitored groundwater levels on a fortnightly/monthly basis in the majority of the groundwater monitoring bores. Vibrating wire piezometers have also been installed and record pore pressures automatically using data loggers. This monitoring should continue for the life of the Project.

Yearly reporting of the water level results from the monitoring network should be included in the Annual Review. The Annual Review should consider if any additional monitoring sites are required, or if optimisation of the existing monitoring sites should be undertaken.

14.3 Water Quality Monitoring Plan

14.3.1 Analytical Suite

Shenhua Watermark currently collect groundwater samples from the monitoring bore network on a quarterly basis for laboratory analysis. Groundwater samples are tested for:

- pH, electrical conductivity (EC), dissolved oxygen (DO), temperature, oxidation-reduction potential (field measurements);
- major cations - calcium, magnesium, sodium and potassium;
- major anions - chloride, sulphate, carbonate / bicarbonate;
- minor anions - nitrate, nitrite, fluoride, reactive phosphorous;
- selected metals - arsenic, cadmium, chromium, copper, iron, lead, nickel, zinc.

The water management plan should consider the optimal sites for monitoring of groundwater quality during the life of the Project.

Similar to the water level monitoring yearly reporting of the water quality results from the monitoring network should be included in the Annual Review. The Annual Review should consider if any additional monitoring sites are required, or if optimisation of the existing monitoring sites, frequency of sampling and analytical suite should be undertaken.

14.3.2 Trigger Levels

The aim of trigger levels will be to provide mine management with an early warning mechanism that identifies water quality trends departing from historical values.

The trigger levels will be derived for water quality parameters as part of the development of the Water Management Plan. This will include analysis of historical pre-mining water quality data. Statistical data for each monitoring bore such as maximum, minimum, average and standard deviation for key parameters such as TDS (EC), sulphate, and pH will be determined as part of the plan. Once mining commences, monitoring results for each indicator parameter are plotted against time, with control limits of mean + standard deviation, mean + 2 standard deviations and mean + 3



standard deviations. Control criteria are set such that one observation above mean + 3 standard deviation, or two consecutive observations more than mean + 2 standard deviations, or five successive observations above mean + standard deviation would constitute a trigger or alarm. If there is a period of no alarms (e.g. after, say, 12 observations), the mean and standard deviations could be recalculated and the control lines adjusted to provide better precision. Figure 14.1 is an example of a control chart and when alarms are triggered.

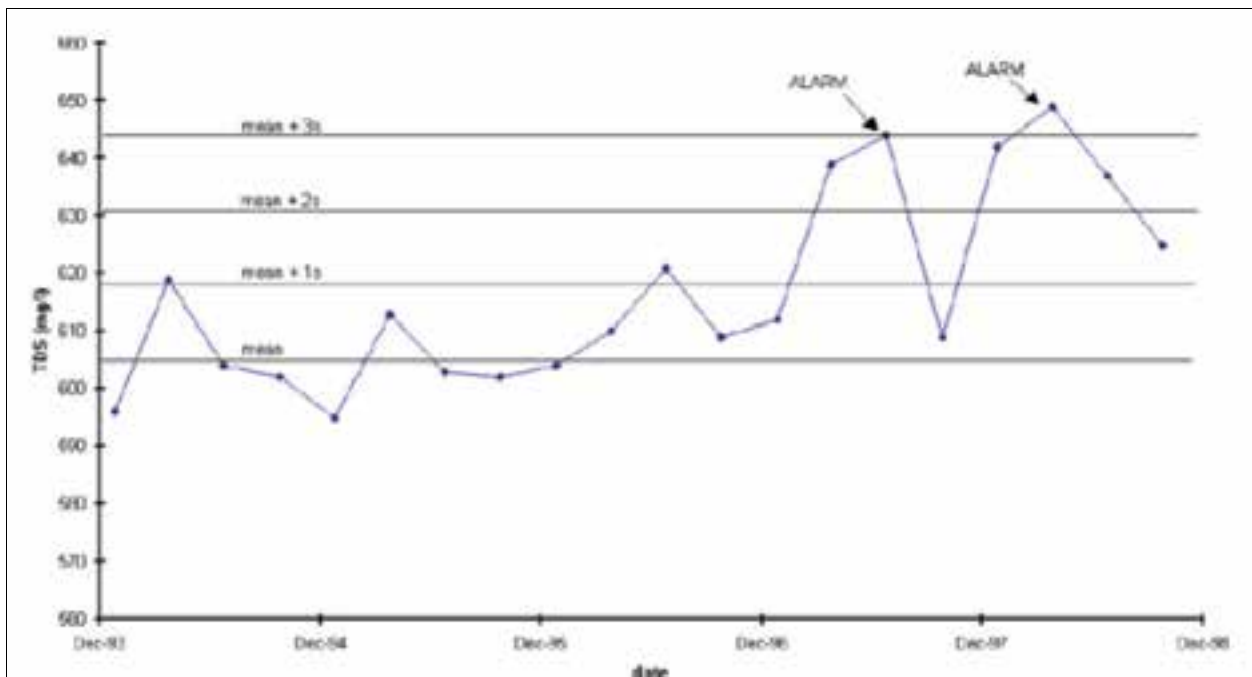


Figure 14.1: Example Control Chart (from DERM (2010))

Should post mining water quality data for these selected key parameters reach the trigger levels, then further detailed analysis of all water quality data will occur. Should this analysis indicate trends not consistent with historical variation, then mitigation process and strategies as discussed in Section 14.8 will be implemented.

14.4 Mine Water Seepage Monitoring

It is recommended that monitoring of mine water seepage be undertaken, particularly to identify seepage rates and quality. Samples should be collected of any pumped seepage with the objective of providing an early indication of any mixing of shallow alluvial groundwaters with the Permian strata. Analysis should be similar as for the groundwater monitoring bores. The seepage monitoring program should include:

- recording of the time, location and estimated volume of any unexpected increased groundwater outflow from the highwall and endwall;
- measurement of water pumped from the Mining Areas preferably using flow meters or other suitable gauging apparatus;
- monitoring quality of water pumped from the mining areas (same analytical suite as groundwater);



- correlation of rainfall records with mining area seepage records so groundwater and surface water can be separated; and
- monitoring of coal moisture content.

14.5 Local & Regional Hydrogeological Studies

On-going assessment during mining is recommended for the following:

- estimation of the rate of diffuse rainfall recharge through the spoil and the hydraulic conductivity of the emplaced material; this will require installing piezometers in the spoils and collecting water samples if a saturated zone is present;
- the coal seam properties – measurements of coal rank, cleat spacing and cleat aperture should be made to further assess the permeability of the coal – this can be done as part of resource exploration drilling programs;
- in-pit water sources – water samples collected from in-pit sumps should be fingerprinted to determine the source of the water and the significance of contribution from the alluvial systems;
- geological structures in the Mining Areas – as more detailed advance drilling is undertaken in the proposed Mining Areas, the potential for structures that could transmit water from the alluvial aquifers should be assessed; and
- extent of the Gunnedah Formation to the south and northeast of Project Boundary if the area is accessible.

14.6 Future Model Iterations

After 24 months of operation, the assumptions on the geology, hydrogeology and hydraulic properties of the model in the Mining Area should be compared to the initial data input. If these data indicate substantial differences (previously unrecognised information) to those interpreted, these data should be incorporated into the model and revised predictions made and reported. Every five years the validity of the model predictions should be assessed and if the data indicates significant divergence from the model predictions, an updated groundwater model should be constructed for simulation of mining.

14.7 Data Management and Reporting

It is recommended data management and reporting include:

- Annual assessment of departures from identified monitoring data trends;
- Formal review of depressurisation of coal measures and alluvial aquifers should be undertaken annually by a suitably qualified hydrogeologist;
- Annual reporting (including all water level and water quality data; and
- All groundwater data should be stored in a database customised for the Project and with suitable QA/QC controls.



14.8 Management and Mitigation Strategies

Management of groundwater beneath and adjacent to the Project will involve the establishment of a robust surface and groundwater level and quality monitoring program, for all groundwater and surface water sources. Operational reporting will occur at frequencies suited to the mine development and be part of the basis of annual reporting to key stakeholders.

Should monitoring indicate the changes in groundwater levels and quality, and surface water flow and quality are more extensive or significant than predicted, mitigation measures will be considered. Mitigation measures that may be considered following discussion with relevant government authorities include:

- injection of water into the depressurised aquifers;
- grouting and cut off measures;
- sourcing of additional water from other sources; and
- treatment of mine water.

Mitigation measures proposed by Namoi water study will also be considered. If mitigation measures are not feasible, 'make good' measures with affected land owners could be carried out, including:

- ensuring the bore owner has access to a similar quantity and quality of water for the water bore's authorised purpose for example by:
 - bore enhancement by deepening the bore or improving its pumping capacity;
 - constructing a new water bore; and
 - providing a supply of an equivalent amount of water of a suitable quality by piping it from an alternative source;
- carry out a plan to monitor the water bore, for example, by undertaking periodic bore assessments.



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16.0 GLOSSARY

AGE - Australasian Groundwater and Environmental Consultants Pty Ltd.

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 that can store ground water and also transmit it slowly from one aquifer to another.

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

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

BoM – Bureau of Meteorology

BHPB – BHP Billiton Pty. Ltd.

CHPP – Coal Handling and Preparation Plant

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.



CRD – Cumulative Rainfall Departure

CSG – Coal Seam Gas

DGR – Director General's Requirements

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

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

DoP - NSW Department of Planning

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.

EA – Environmental Assessment

EARs - Environmental Assessment Requirements as outlined by the Director General.

EC – Electrical Conductivity

EIS – Environmental Impact Statement

EL – Exploration Licence

EMA – Eastern Mining Area

EP&A Act – Environmental Planning and Assessment Act

EPNRMB – Eyre Peninsula Natural Resources Management Board

EVT - Evapotranspiration

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

FOI – Freedom of Information Request

GAB – Great Artesian Basin

GDE – Groundwater Dependant Ecosystem

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

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



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

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

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

HFB – Horizontal Flow Barrier Package

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

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

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

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

LGA – Local Government Area

MDB – Murray Darling Basin

MSNES – Matter of National Environmental Significance

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

Monitoring Bore (Piezometer) - A non-pumping well (bore), generally of small diameter, which 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.

NOW - New South Wales Office of Water

NWQMS – The National Water Quality Management Strategy

OEA – Overburden Emplacement Area.

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.

PAH - Polycyclic aromatic hydrocarbons

PEST – Parameter Estimation software is a tool used to automatically optimise modelled parameters to replicate measured observations, e.g., Groundwater levels from monitoring bores.



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.

PVC – Polyvinyl Chloride

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

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

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

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

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

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

ROM – Run of Mine - Of or pertaining to coal that is ungraded.

SEWPaC – Department of the Sustainability, Environment, Water, Population and Communities.

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.

SRMS – Scaled Root Mean Squared error.

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

SVDA – Singular Value Decomposition Assist is a technique in PEST which facilitates highly parameterized model calibration with minimal prior simplification by first assessing the sensitivity of each parameter and its correlation to all other parameters.

SWS – Schlumberger Water Services

TEM - Transient Electromagnetic Survey



TDS – Total Dissolved Solids

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

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

vwp – Vibrating Wire Piezometer

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

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

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

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

WSP - Water Sharing Plan.

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