GROUNDWATER MONITORING AND MANAGEMENT PLAN

BYERWEN COAL PTY LTD –
BYERWEN COAL PROJECT

18 December 2015

QCOAL GROUP

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1. INTRODUCTION

1.1 Background

This Groundwater Monitoring and Management Plan (GMMP) has been prepared by Byerwen Coal Pty Ltd (Byerwen Coal) to address groundwater related regulatory conditions for the Byerwen Coal Project (the Project).

This GMMP is subject to the requirements of the following documents:

- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) Referral 2010/5778 Approval Conditions (EPBC Conditions) for Byerwen Coal, issued by the Australian Department of Environment (DoE).
- Environmental Authority (EA) – EPML00595013 (Schedule E: Groundwater) issued and administered by the Queensland Department of Environmental and Heritage Protection (DEHP).
  - The EA details the environmental conditions (EA Conditions) imposed by the state of Queensland for each Environmental Value relevant to the EA, to undertake the Project. The conditions have been derived to address anticipated potential impacts of the Project and are developed to be measurable, auditable and outcomes based.

Background data along with detailed impact assessments and proposed mitigations is presented in the following documentation, which has previously been provided to both DEHP and DoE:

- The Byerwen Coal Project Environmental Impact Statement (the EIS) and the subsequent Additional Information to the EIS (the AIEIS) – these documents are collectively referred to as the EIS.
- The Byerwen Coal Project Water Management Plan.
  - The Water Management Plan details the overall surface water management for the Project for surface water.
- The Byerwen Coal Project: Coordinator-General's evaluation report on the environmental impact statement (OCG Report).

Additionally the DEHP Model Mining Conditions Guideline - 130626 EM944 Version 4 (Model Mining Conditions Guideline) provides specific advice on how to comply with EA Conditions and as such has been referred to in preparation of this GMMP.

1.2 Purpose of GMMP

This GMMP has been prepared as a single document to satisfy the requirements for groundwater management and monitoring in the EPBC Conditions and the EA Conditions. The intent of the GMMP is to provide a "live" document which can be readily used and referred to during operations, providing instruction of complying with the EPBC and EA conditions, without unnecessary content or repetition.

A complete list of EPBC Conditions and EA Conditions for groundwater is included in **Section 3**.

Additional information has been included in this GMMP to inform areas of monitoring or management which are considered necessary to satisfy the EPBC conditions and the EA Conditions, but which may not have been explicitly stated in those documents.

1.3 Byerwen Coal Corporate Details

Byerwen Coal is a joint venture between QCoal Pty Ltd and JFE Steel. QCoal is a privately owned Queensland company based in Brisbane and has been active in Queensland coal exploration and mining over the last 25 years. JFE Steel is a subsidiary of the JFE Group of Japan. JFE Steel and associated companies already have direct equity investments in a number of Queensland coal mines.

- Street address:
  - Byerwen Coal Pty Ltd
    Level 15/40 Creek St
    Brisbane QLD 4000
- Postal address:
  - Byerwen Coal Pty Ltd
    PO Box 10630 Adelaide St
    Brisbane QLD 4000
  - Contact numbers: Phone 07 3002 2900

1.4 GMMP Preparation

This GMMP has been prepared by Julian Dobos[1] – Senior Environmental Officer at QCoal.

1.5 Review of GMMP

The GMMP will be subject to internal reviews by an appropriately qualified person[1], with the objective of the review being to determine ongoing suitability of GMMP, or, make recommendations where the GMMP requires revision, as follows:

- Every alternate year (regular review)
- Upon any amendment of the EA relating to groundwater
- Upon significant change in the mine plan, pit layout or mining activities, such that the pit outlines assumed in the GMMP no longer represent an appropriate analogue for the purposes of groundwater impact assessment across the Project.
- As a recommendation or outcome of a groundwater investigation (e.g. EA exceedance)
- As part of any internal or external EA audit recommendation
- As a result of the findings from a review of the groundwater model
- As a result of the findings from review/s undertaken by a suitably qualified expert[2] at the request of the Minister[3].

As the GMMP is a live document intended for operational use, GMMP reviews may also be on an as required basis, if opportunities for refinement of the GMMP are identified during operation. The specific objective and therefore the method/aspects of the review will depend on the reason for the review. However, where a regular review is being undertaken all aspects of the GMMP will be appraised to determine its suitability, adequacy and effectiveness. Results of any review will be implemented into an updated GMMP where required, consistent with the commitment to continual improvement.

1 Appropriately qualified as per the EA definitions: Appropriately qualified person means a person who has professional qualifications, training, skills or experience relevant to the nominated subject matter and can give authoritative assessment, advice and analysis on performance relating to the subject matter using the relevant protocols, standards, methods or literature.

2 Suitably qualified expert as per the EPBC conditions definitions: a person who has professional qualifications, training, skills or experience relevant to the nominated subject matter and can give authoritative assessment, advice and analysis on performance relating to the subject matter using the relevant protocols, standards, methods or literature.

3 Minister as per EPBC conditions definitions: the Minister administering the EPBC Act and includes a delegate of the Minister.

If an updated GMMP includes any changes to the previously identified or modelled potential groundwater impacts, changes to the proposed monitoring and management strategy, or changes to the reporting requirements, then the updated GMMP will be submitted to the Minister[4] for approval.

Details regarding reviews of the groundwater model are discussed in **Sections 7.3.7**.

4 Minister as per EPBC conditions definitions: the Minister administering the EPBC Act and includes a delegate of the Minister.

2. PROJECT DESCRIPTION

2.1 Overview

A full description of the Project is provided in Chapter 2 of the EMP. The Project will be an open-cut coal mine comprising a north and south section, with each section having its own surface infrastructure to service the open cut pits in that section. The north section will have one pit and the south section will have a complex of seven pits. In total the Project will extract up to 15 Mtpa of ROM coal to produce approximately 10 Mtpa of combined coking and thermal coal products for the export market, over a 46 year mining life. It is anticipated that Project civil construction (roads and buildings etc) will commence in the southern section of the Project in late-2015, with extractive mining commencing thereafter.

2.2 Project Location, Tenures and Underlying Landowners

The Project is located in the Whitsunday Regional Council and Isaac Regional Council government areas (in the north and south respectively). It is located approximately 20 km west of the mining township of Glenden and approximately 140 km west of the regional center of Mackay. The Project is situated immediately to the west of the Xstrata Coal's Newlands Mine complex and to the north of the Xstrata Coal's Suttor Creek mine (which contains the Suttor Creek and Wollombi Pits). The location and regional context is shown in **Figure 2-1**.

The Project area comprises six mining leases, defined as ML 10355, ML 10356, ML 10357, ML 70434, ML 70435 and ML 70436. Collectively, the six MLs cover an area of approximately 20,993 hectares. The Collinsville-Elphinstone Road and the Goonyella to Abbot Point (GAP) rail line traverse the Project area. No significant commercial coal seam gas resources have been identified within the Project area and the Project will not impact on other coal, gas or mineral resources in the region.

There are six leasehold (lands lease) properties within or intersected by the Project MLs, as shown in **Figure 2-2** and summarized below:

- Lot 3 SP235898 (formally Lot 3 SP171922) "Colinta North" (lands lease)
    - Colinta Holdings Pty Ltd (a subsidiary of Glencore mining company)
- Lot 14 SP271185 (formally Lot 14 SP225054) "Colinta South" (lands lease)
    - Colinta Holdings Pty Ltd (a subsidiary of Glencore mining company)
- Lot 15 SP256595 (Estate in unallocated State Land)
    - The State of Queensland (Represented by Department of Natural Resources and Mines – Land Act)
- Lot 689 SP235910 (formally Lot 689 SP251696) "Suttor North" (lands lease)
    - Leichhardt Pastoral Pty Ltd (a wholly owned subsidiary of Byerwen Coal)
- Lot 1 SP256594 (formally Lot 1 CP905226) "Wollombi" (lands lease)
    - Mr Christopher Wallin – QCoal Managing Director
- Lot 682 CP906890 "Suttor Creek" (lands lease)
    - Suttor Creek Holding – Private Individual

As such the majority of property in the southern section of the Project is owned by entities associated with Byerwen Coal. Within the former Nebo (now part of Isaac Regional Council) and Bowen (now part of Whitsunday Regional Council) Shires, greater than 95% of land is zoned as rural or open space and recreation. This reflects the land use within the region surrounding the Project, which is a mix of large-scale grazing, cropping, and mining activity. The Project tenements are within land zoned as rural under local planning schemes.

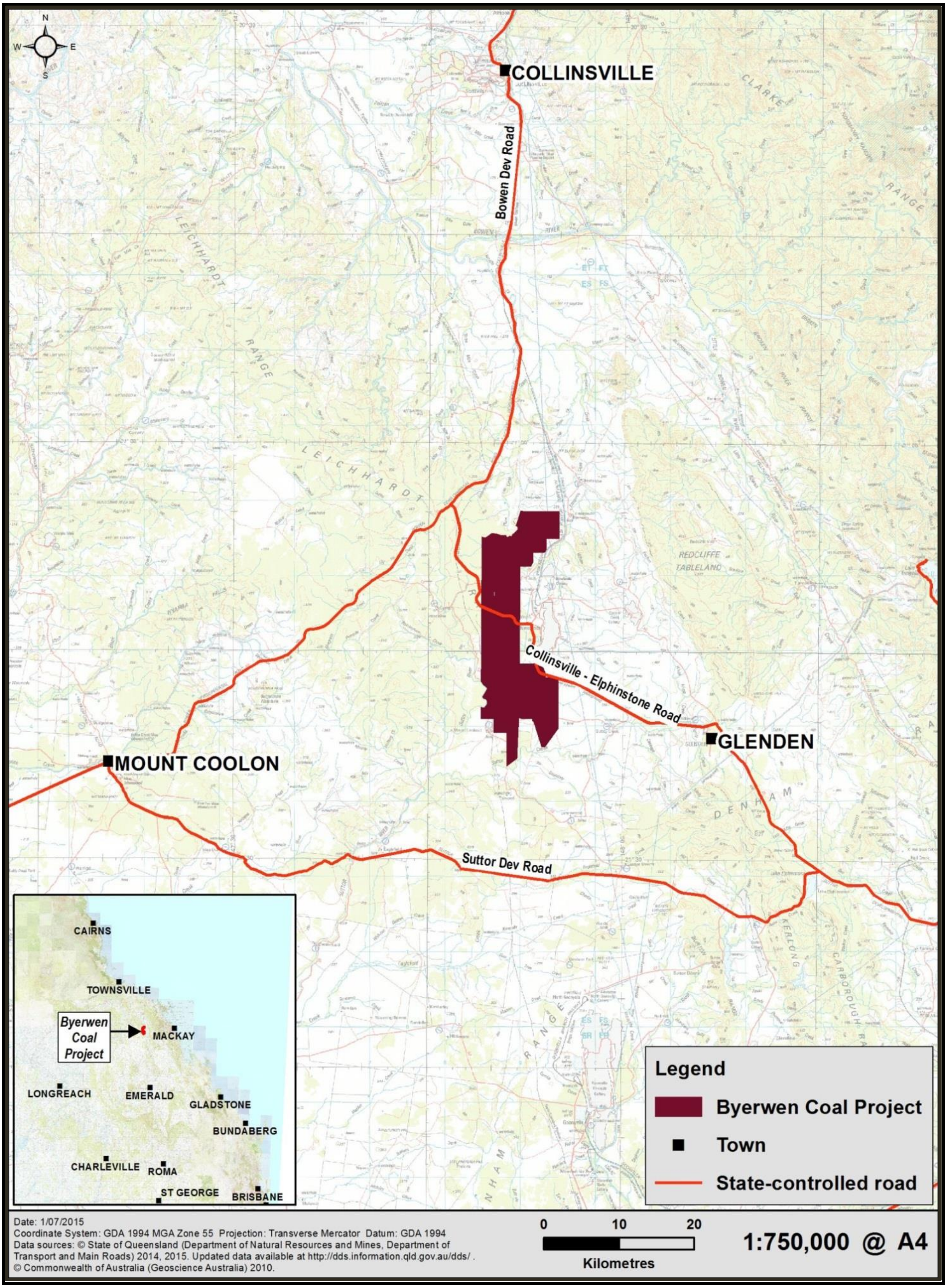


Figure 2-1 Project Location

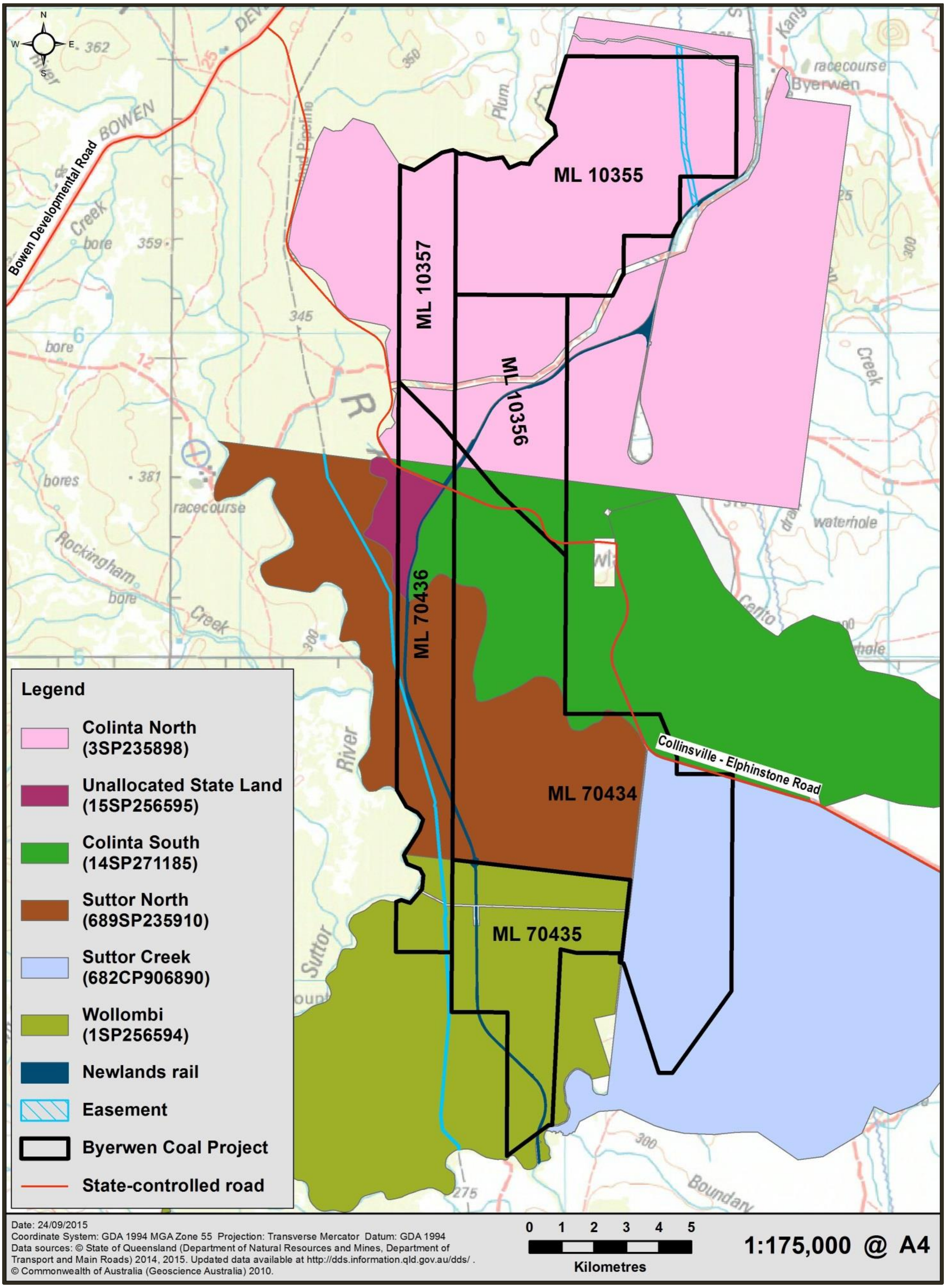


Figure 2-2 Project Tenures and Underlying Properties

2.3 Resource Base and Mining Method

The Project will be an open cut coal mine with a ROM rate of 15 Mtpa, producing approximately 10 Mtpa of product coal for the export market over the 50 year project life. Production from the Project will be high quality coking coal with some thermal coal, mined from four mining zones (north, south, east and west), comprising eight open pits. The south phase comprises mining zones in the south, east and west. The north phase comprises mining zones in the north.

The resource includes coal within the Moranbah and Rangal Coal Measures. The Moranbah Coal Measures represent the main stratigraphic unit of interest in the Project area, and contain up to seven persistent coal seams. The Moranbah Coal Measures are approximately 290 m thick in the project area and strike north-south, dipping to the east at between 4^{o} and 12^{o}. The principal seams of economic interest are the Goonyella Lower (6-8 m thick), Goonyella Middle (6-10 m), and P Rider (2-4.5 m) seams. The main seam of interest in the Rangal Coal Measures is the Leichhardt seam, a correlative of the Upper Newlands seam which averages 6.5 m thick in the neighbouring Newlands Mine and 4.5 m thick in the nearby Suttor Creek Mine.

At the start of a new open-cut area, a box-cut is developed, with the overburden being dumped in an out of pit spoil dump or used to backfill an existing void. Coal mining commences once sufficient overburden is removed to expose the coal seams and involves working a number of blocks in conjunction with one another to develop a staggered pattern in relation to the vertical coal seam horizons. The number of blocks required for coal production depends on the productivity requirement of the pit. Once sufficient floor area is available in the mine pit, dumping then commences in-pit allowing progressive backfilling of the void as mining progresses in defined strips across the resource area. Mining will be via conventional open cut methods, employing a combination of drill and blast, dragline, large excavator, truck and dozer equipment.

2.4 Project Components

The Project comprises a north and south section, each with separate infrastructure. Key elements for each section are presented below:

- North section
  - One open cut pit (North Pit) commencing ~ year 16 of Project mining activities
  - Out of pit spoil dumps will be established during initial years of mining. In-pit dumping will commence once void space is available
  - Coal handling civil works, including a run of mine (ROM) pad
  - Mine haul roads to connect the open-cut pits to the coal processing area
  - A Coal Handling and Preparation Plant (CHPP)
  - A co-disposal facility for CHPP rejects and process water recovery
  - A train load-out facility
  - A rail balloon loop and rail spur connecting to the existing GAP rail line
  - A water management system to manage site stormwater flows, control run-off, prevent erosion, divert clean water and capture and manage mine area runoff and pit water for reuse
  - A Mine Infrastructure Area (MIA) including administration buildings, ablution buildings, sewage storage/treatment and irrigation area, vehicle maintenance workshops and a concrete batching plant
  - Process water storage and distribution system
  - A connection to the existing power originating from Newlands substation, constructed in conjunction with Ergon Energy
  - Water supplied by SunWater and stored in raw water storages

- South section
  - Seven open cut pits:
    - South Pit 1 commencing ~ year 6 of Project mining activities
    - South Pit 2 commencing ~ year 6 of Project mining activities
    - East Pit 1 commencing ~ year 26 of Project mining activities
    - East Pit 2 commencing ~ year 31 of Project mining activities
    - West Pit 1 commencing ~ year 1 of Project mining activities
    - West Pit 2 commencing ~ year 11 of Project mining activities
    - West Pit 3 commencing ~ year 21 of Project mining activities
  - Out of pit spoil dumps will be established during initial years of mining. In-pit dumping will commence once void space is available
  - Coal handling civil works, including a run of mine (ROM) pad
  - Mine haul roads to connect the open-cut pits to the coal processing area
  - A Coal Handling and Preparation Plant (CHPP)
  - A co-disposal facility for CHPP rejects and process water recovery
  - A train load-out facility
  - A rail balloon loop and rail spur connecting to the existing GAP rail line
  - A water management system to manage site stormwater flows, control run-off, prevent erosion, divert clean water and capture and manage mine area runoff and pit water for reuse
  - A Mine Infrastructure Area (MIA) including administration buildings, ablution buildings, sewage storage/treatment and irrigation area, vehicle maintenance workshops and a concrete batching plant
  - Process water storage and distribution system
  - A connection to the existing power originating from Newlands substation, constructed in conjunction with Ergon Energy
  - Water supplied by SunWater and stored in raw water storages

2.5 Mine Layout

Mining will commence on the western side of the Project in the southern section and progress east. An overview of the mining pit layout presented as a colour coded schedule is shown in **Figure 2-3**.

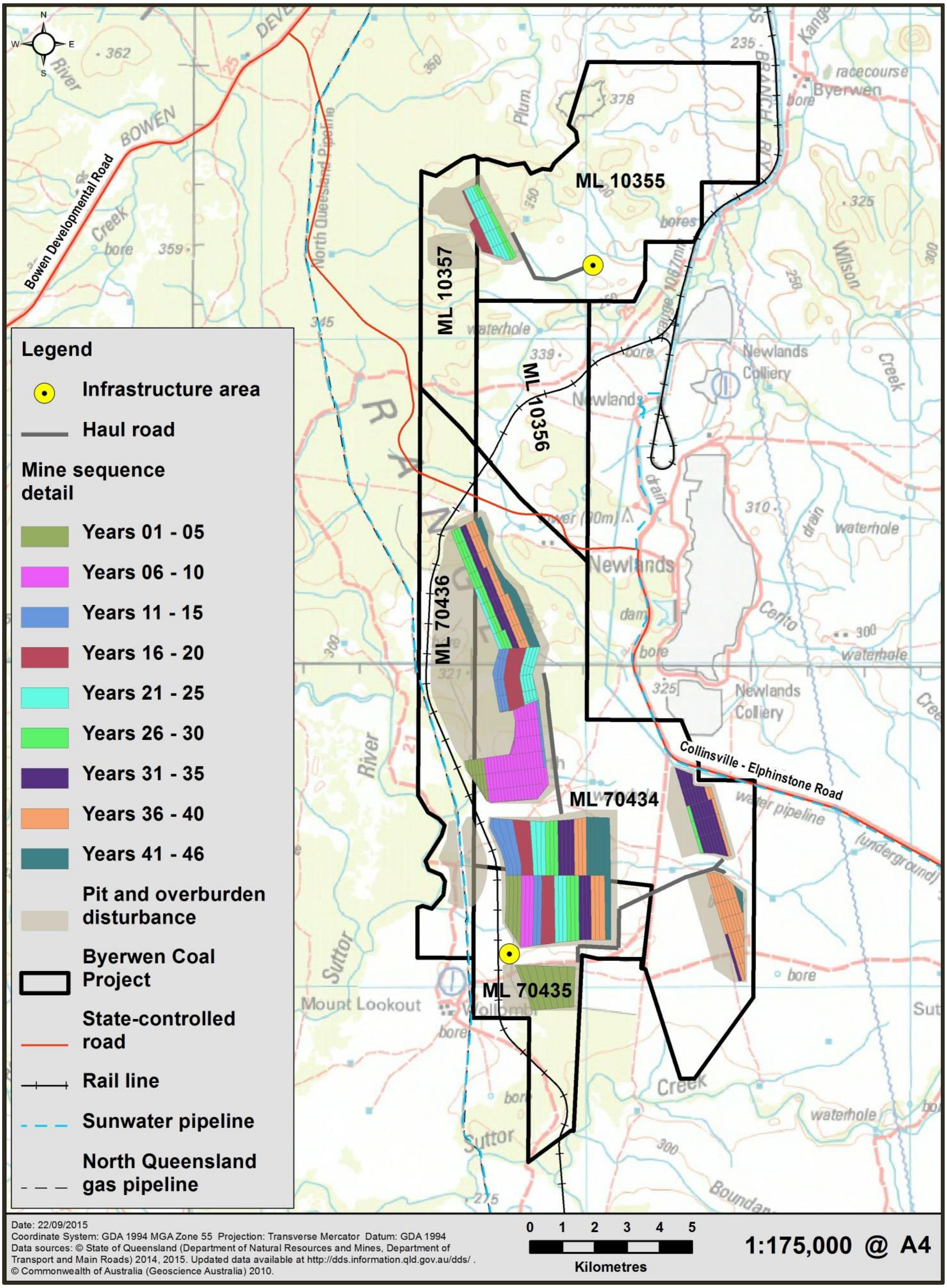


Figure 2-3 Project Layout

2.6 Surface Water Management

During mining operations, the Water Management Plan and the Erosion and Sediment Control Plan will consider key aspects of surface water across the site, including but not limited to:

- Separate mine affected and non-mine affected water circuits;
- Sediment facilities;
- Co-disposal facility and holding facilities;
- Pit water storage;
- Runoff from undisturbed areas being diverted away from disturbed areas;
- Runoff from disturbed areas being captured in sedimentation ponds, with retention times sufficient to settle coarse suspended sediment;
- Rainfall runoff being managed through drainage systems, diversions (where required), levee banks and sedimentation ponds;
- Scour protection will be provided at discharge points if required;
- Water pumped from active pits will also be directed to sediment ponds. Where possible, water collected in sediment ponds will be reused for dust suppression or process water;
- Sediment affected waters will be managed under an Erosion and Sediment Control Plan; and
- Water quality criteria will be in place (as per the EA) for releases for mine affected waters.

2.7 Rehabilitation and Decommissioning

Mine closure planning will consider the choice of post-mining land use. This final land use may not necessarily be the original use and will largely be dependent on pre-mining land suitability, landholder preferences, design of rehabilitated landforms, and the existing use or environmental values of surrounding land.

In accordance with the DEHP guideline 'Rehabilitation requirements for mining projects', the following objectives have been derived for decommissioning and rehabilitation of areas disturbed by the project:

- safe to humans and fauna
- rehabilitated to a stable, non-polluting and self-sustaining condition where the maintenance requirements are consistent with an agreed post-mining land use
- allow for land use capabilities as per an agreed Rehabilitation Management Plan (RMP)
- current and future water quality, other than water quality impacts associated with subsequent land users, to meet defined water quality criteria
- vegetation cover will be established to reduce rates of erosion and sediment loss
- final rehabilitation will be designed as permanent self-sustaining landforms requiring no ongoing maintenance or management.

Progressive rehabilitation of waste rock dumps will be undertaken as mining progresses. This approach allows for:

- more stable landforms having been allowed to settle
- progressive construction to final landform design minimising reshaping at the end of mining
- faster re-use of topsoil into its final form
- contour ripping immediately after topsoil placement to control erosion
- seeding with an appropriate seed mix prior to the wet season to maximise the benefits of subsequent rainfall
- managing direct rainfall and runoff from the rehabilitated landforms into sediment dams until revegetation uptake is stable and adequate to naturally control erosion.

All infrastructure constructed by Byerwen Coal and its contractors during the mining activities, including water storage structures, will be removed from the site at cessation of mining activities, except where agreed in writing by the post mining land owner / holder.

The proponent will develop a Mine Closure Plan four years prior to final coal processing.

3. Approval Conditions for Groundwater

3.1 EPBC Conditions

EPBC Conditions 10, 11, 12 and 13, stipulate groundwater conditions for the project including the preparation, submission and content of a GMMP. Presented in **Table 3-1** are the EPBC Conditions for groundwater and the relevant section within the GMMP where those conditions are addressed.

Table 3-1 EPBC Conditions for Groundwater

EPBC Conditions		GMMP Section
EPBC Condition 10: The approval holder must submit a Groundwater Monitoring and Management Plan (GMMP) to the Department for the Minister's approval. The approved GMMP must be implemented.		**General condition**
EPBC Condition 11: The GMMP must be approved by the Minister in writing prior to the commencement of dewatering activities in the mining pits detailed in Chapter 3 of the Environmental Management Plan.		**General condition**
EPBC Condition 12: The GMMP must include but is not limited to:		
	12-a: the groundwater quality and/or trigger levels as described the Queensland Environmental Authority in force at the time	**Section 5.6.1 Section 5.6.2**
	12-b: a detailed description of the actions, including timeframes, the approval holder will take if groundwater quality and level triggers are exceeded or predicted to be exceeded	**Section 6 (and all subsections)**
	12-c: a strategy to conduct a landholder bore survey to determine water supply bores and water users in the vicinity of the project that may be impacted by mining activities and the potential to incorporate those bores into the groundwater monitoring program.	**Section 4.5** **Section 4.5.2** **Section 4.5.2** **Section 5.7.1**
	12-d: Details of how the existing groundwater monitoring program will be expanded to better determine surface water/groundwater interaction, including monitoring locations, parameters to be measured, monitoring frequency and reporting requirements.	**Section 5.7**
	12-e: a groundwater model to simulate and quantify groundwater drawdown extent and flow impacts on the Suttor River, and validate the assumptions and potential risks and impacts of the project on groundwater resources identified in the EIS documents. The model must be developed with reference to the National Water Commission Groundwater Modelling Guidelines and must include a monitoring strategy to validate the model.	**Section 7 (and all subsections)**
	12-f: the methods, frequency and timeframes in which the GMMP and groundwater model will be reviewed.	**Section 1.5** **Section 7.3.7**
Note 1: The Minister may be written request, require the GMMP be reviewed by a suitable qualified expert. Following any review, the GMMP must be revised and updated accordingly and submitted to the Minister for approval. **Note 2**: The GMMP does not need to be submitted for an early works bulk sample pit. **Note 3**: To ensure efficiency the approval holder may prepare and align the GMMP required under the conditions of approval with the requirements of the groundwater monitoring program required under the Queensland Environmental Authority, as long as the relevant matters under the conditions of this approval are clearly and adequately addressed.		**General condition**
EPBC Condition 13: The approval holder must notify the Department in writing within 10 business days if the groundwater quality and/or trigger levels referred to in Condition 12 of this approval are exceeded and the results of required investigations indicate the exceedence is a result of mining activities. If requested, the approval holder must provide copies of any exceedence investigation documents to the Department in a timeframe agreed in writing by the Department, which state the cause, response and actions undertaken to prevent further occurrences.		**Section 6 (and all subsections)**

3.2 EA Conditions

EA Conditions – Schedule E, stipulate groundwater conditions for the Project including the preparation, submission and content of a groundwater monitoring plan. Presented in **Table 3-2** are the EA Conditions for groundwater and the relevant section within the GMMP where those conditions are addressed.

Table 3-2 EA Conditions for Groundwater

EA Conditions	GMMP Section
EA Condition E1: The holder of this environmental authority must not release contaminants to groundwater.	**General condition**
EA Condition E2 – Groundwater Monitoring: All determinations of groundwater quality and biological monitoring must be performed by an appropriately qualified person.	**Section 5** **Section 5.3.2.3** **Section 5.8**
EA Condition E3 – Groundwater Quality: Groundwater quality and levels must be monitored at the locations and frequencies described in Table E1 – Groundwater monitoring locations and frequency and Figure 1 – Site map, domains and groundwater monitoring locations for quality characteristics identified in Table E2 – Groundwater quality triggers.	**Section 5.1** **Section 5.2.1** **Section 5.2.2**
EA Condition E4: If quality characteristics of groundwater from groundwater monitoring bores identified in Table E1 – Groundwater monitoring locations and frequency reach any of the trigger levels stated in Table E2 – Groundwater quality triggers, the holder of this environmental authority must complete an investigation and take action to minimise the potential for environmental harm.	**Section 5.6.1** **Section 5.6.2** **Section 6 (and all subsections)**
EA Condition E5 – Groundwater standing water level: In the event that groundwater fluctuations in excess of 2 metres per year are detected at the groundwater monitoring locations in Table E1 – Groundwater monitoring locations and frequency, an investigation must be undertaken within 14 days of detection to determine if fluctuations are a result of: a) mining activities; b) pumping from licensed bores; or c) seasonal variation.	**Section 5.6.1**
EA Condition E6: In the event that groundwater fluctuations are a result of mining activities, the environmental authority holder must meet the notification requirement of condition A11 of this environmental authority. *EA Condition A11: Within 10 business days following the initial notification of an emergency or incident, or receipt of monitoring results, whichever is the latter, further written advice must be provided to the administering authority, including the following:* *a) results and interpretation of any samples taken and analysed;* *b) outcomes of actions taken at the time to prevent or minimise unlawful environmental harm; and* *c) proposed actions to prevent a recurrence of the emergency or incident.*	**Section 6 (and all subsections)**
EA Condition E7 – Bore construction and maintenance and decommissioning: The construction, maintenance and management of groundwater bores (including groundwater monitoring bores) must be undertaken in a manner that prevents or minimises impacts to the environment and ensures the integrity of the bores to obtain accurate monitoring.	**Section 5.8**
EA Condition E8 – Stygofauna monitoring: The environmental authority holder must: a) undertake stygofauna assessments prior to the commencement of dewatering activities and after a preceding wet season in accordance with West Australian Guidelines 54 and 54a (2003 and 2007) or any subsequent guidelines of best practice b) implement protection control strategies for any significant species of stygofauna likely to be impacted.	**Section 4.4**

The tables referred to within EA Conditions E3 and E4, detail the monitoring bore locations, monitoring frequency requirements and the water quality triggers to be applied to monitoring results; these particulars are discussed in **Section 5.1** and **Section 5.6** of the GMMP.

4. Groundwater Values

A key objective of monitoring groundwater across the Project area is to track and quantify any change in groundwater conditions and to then quantify any potential unauthorised environmental harm[5] and associated environmental impacts, which may occur to the Project area groundwater values. This information in turn is required for the management of any impacts (prevention, mitigation and responses).

Therefore an understanding of the actual groundwater values across the Project area is required and is discussed in the following subsections.

4.1 Geology of the Project Area

The Project is located in the north Bowen Basin area. A conceptualisation of the Project stratigraphy is presented in **Table 4-1**.

The Permian sedimentary strata around the project area are generally conformable but are largely obscured by younger Tertiary and Quaternary cover.

No large-scale regional faults have been mapped in the project area however these may be obscured by Tertiary and Quaternary cover. Small-scale local faulting is common causing vertical and lateral disruption of the coal seams. Economic coal seams in the area occur in the Rangal, Fort Cooper and Moranbah Coal Measures of the Blackwater Group, which are all of Permian age. The Blackwater Group is comprised of labile sandstone, siltstone, mudstone and thick sequences of interbedded coal and carbonaceous shale.

All of above mentioned Permian geological units contain a proportion of sandstone. Sandstone is traditionally regarded as a groundwater hosting lithology. No distinction between the sandstone contained in the separate Permian units is made for the purposes of this report and they are all similar regardless of the geological unit within which they are incorporated.

The Permian sequence is overlain by green-grey siltstone and lithic sandstone of the Rewan Group of Triassic age. There is only a small area of the Rewan Group on the project area - just to the north of dedicated groundwater monitoring bore BYGW03.

Extensive sediments and sedimentary rocks of Early–Mid Tertiary age include fluvial and lacustrine sediments—notably sandstone, siltstone, mudstone and claystone of the Suttor Formation, up to 60m thick, especially in the northwestern part of the project area, consisting predominantly of indurated mudstone.

Tertiary Basalt flows dominate the central section of the project area in a more or less north – south trending belt that corresponds to the Leichhardt Range. These are shown on Figure 17-1. Basalt erupting on the east side of a palaeo-valley may have diverted the palaeo-drainage westwards. Remnant basalt flows locally underlie the Redcliffe Tableland, and also underlie the Leichhardt and Denham Ranges. The lower basalt is relatively fresh, but the upper basalts are deeply weathered and ferruginised. Fresh basalt forms heavy black clay soils; weathered basalt forms dark red loam, commonly with an ironstone ‘gravel’ of ferruginised mud. The basalt flows are constrained by the Suttor River to the west and Cerito Creek to the east in the project area.

[5] EA Condition A2 states that authorised harm is permitted in accordance with the conditions of the EA.

Residual sand and fine-grained gravel of Tertiary age are encountered in some boreholes on the project area. These are laterally discontinuous and appear to occur as 'shoestrings' (analogous to present-day braided stream deposits). It is interpreted that they are 'bed sand deposits' that occur in the beds of streams that traversed the landscape prior to the eruption of the basalt. These sediments are not exposed at the surface.

Residual soils including blanketing sands, loams and clays cover much of the area. Preferential induration of old valley floor material now stands up locally as inverted relief. Silcretes up to 10m thick, nodular ferricretes and clay-indurated duricrusts also occur.

Deep weathering is responsible for the strongly mottled and bleached profiles of the basalts and the Suttor Formation.

Of the geological units listed in **Table 4-1**, the following are hydrogeologically relevant to the project:

- Tertiary Sand beneath Basalt Flows
- Suttor Formation
- Rangal Coal Measures
- Fort Cooper Coal Measures
- Exmoor Formation
- Moranbah Coal Measures

Table 4-1 Project Stratigraphy

<table>
<tr><th>Age</th><th colspan="2">Unit</th><th>Lithology</th><th>Topography</th></tr>
<tr><td>Quaternary</td><td colspan="2"></td><td>Silt, sand, clay soil.</td><td>Occurs on floodplains of major watercourses and as outwash fan deposits.</td></tr>
<tr><td rowspan="3">Tertiary</td><td colspan="2">Suttor Formation</td><td>Sandstone and conglomerate, locally silicified.</td><td>Breakaways: table-top mesas.</td></tr>
<tr><td colspan="2">Tertiary Basalt</td><td>Olivine basalt, fresh and vesicular in places.</td><td>Slightly elevated lands.</td></tr>
<tr><td colspan="2">Sand below Basalt</td><td>Unconsolidated sand and minor gravel: lag deposits from formerly exposed topography.</td><td>Not exposed at surface.</td></tr>
<tr><td rowspan="3">Triassic</td><td colspan="2">Moolayember Formation</td><td>Micaceous and lithic sandstone and siltstone.</td><td>Recessive: flat areas on Clematis Group tablelands.</td></tr>
<tr><td colspan="2">Clematis Group</td><td>Medium–coarse quartz sandstone & pebble conglomerate.</td><td>Tablelands: steep scarps.</td></tr>
<tr><td colspan="2">Rewan Group</td><td>Green lithic sandstone: red, brown and green mottled mudstone.</td><td>Recessive.</td></tr>
<tr><td>Late Permian</td><td rowspan="2">Bowen Basin</td><td>Blackwater Group includes:
- Rangal Coal Measures
- Fort Cooper Coal Measures
- Moranbah Coal Measures</td><td>Coal: grey, brown, green sandstone: siltstone: shale: chert: minor conglomerate: fossils.</td><td>Generally recessive, subdued.</td></tr>
<tr><td>Early Permian</td><td>Black Creek Group includes:
- Exmoor Formation

- Lizzie Creek Volcanics</td><td>Grey to purple fine sandstone & siltstone: local coarse sandstone: grey carbonaceous shale: coquinite lenses: fossils.

Andesite: subordinate rhyolite and shale.</td><td>Generally recessive sandstone ridges.

Not exposed in project area. Regarded as basement for the hydrogeological regime.</td></tr>
</table>

Geological cross sections have been prepared from borehole geological data collected during exploration drilling across the Project, as follows:

- **Figure 4-1** shows the cross section alignments across the Project pits over aerial photography
- **Figure 4-2** shows the cross section of South Pit 1
- **Figure 4-3** shows the cross section of South Pit 2
- **Figure 4-4** shows the cross section of East Pit 2
- **Figure 4-5** shows the cross section of West Pit 1 south
- **Figure 4-6** shows the cross section of West Pit 1 north
- **Figure 4-7** shows the cross section of West Pit 2 and 3
- **Figure 4-8** shows the cross section of North Pit

With specific regard to the Suttor River, the cross sections for West Pit 2 and 3, West Pit 1 north, West Pit 1 South, and South Pit 1 are presented with the Suttor River to the west to inform interpretation of potential interactions between pits and the Suttor River. Recorded geological data extending as far west towards the Suttor River as exploration has permitted. Of particular note is the West Pit 1 north cross section, indicating recorded geological faulting between the pit and the Suttor River. The cross section also shows that West Pit 1 is within Moranbah Coal Measures, while the Suttor River is underlain by Exmoor Formation (the boundaries between Moranbah and Exmoor are noted as occurring between the Pit and the Suttor River). A comparison of West Pit 1 north and south, cross sections, indicates continuity of the geological characteristics along the western extent of the Project, in particular as they relate to the Suttor River.

Based on extensive geological knowledge of the area and as demonstrated by the geological cross sections, there are clear geological impediments preventing any mechanism of hydraulic connection between the groundwater potentially intersected by the pits, and the Suttor River. In addition due to the faulted and discontinuous geology, hydraulic connectivity within the coal seam aquifers will be at best very limited; therefore direct hydraulic connection between groundwater bearing units across the Project area is also considered unlikely.

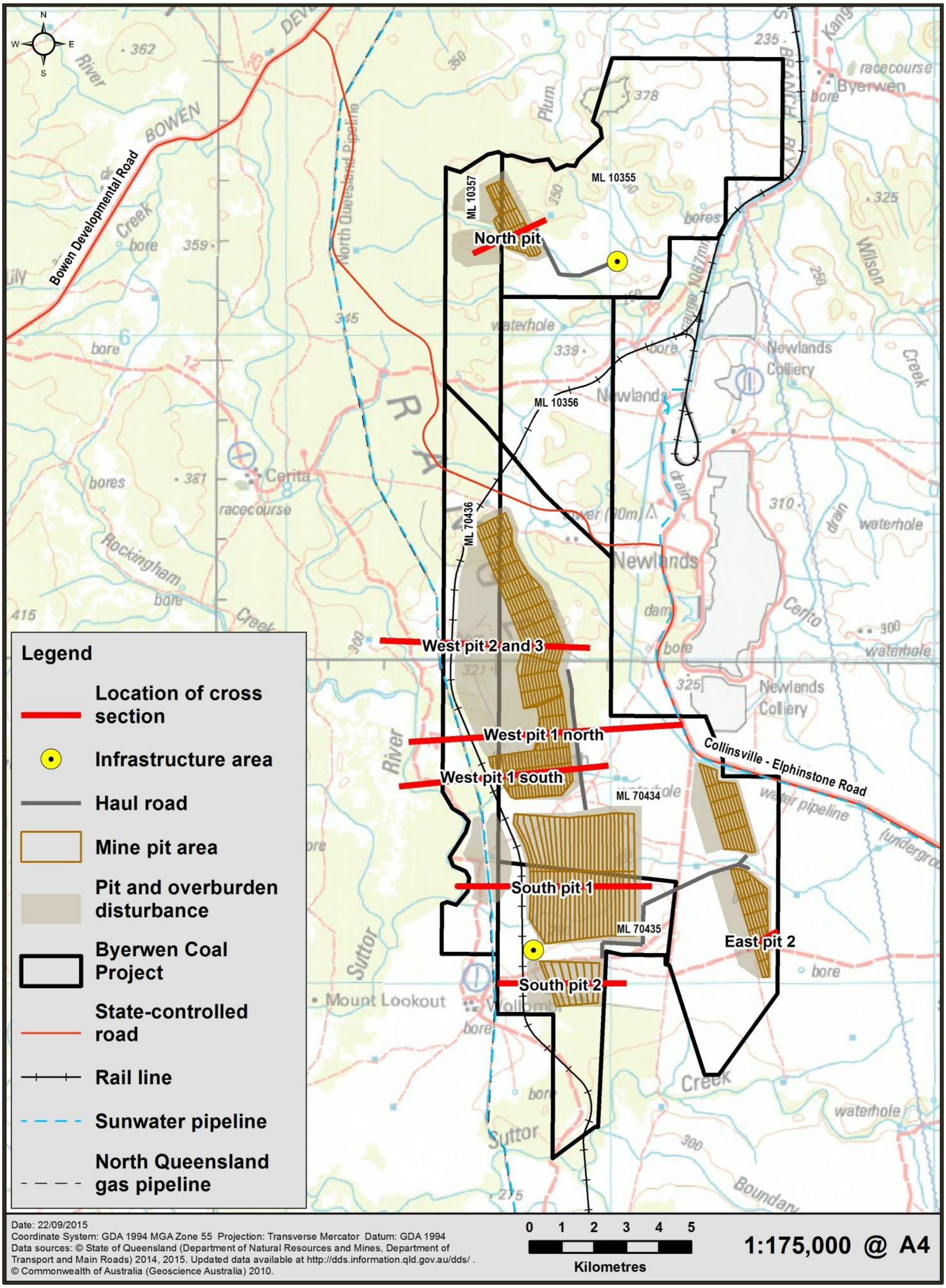


Figure 4-1 Geological Cross Section Alignments

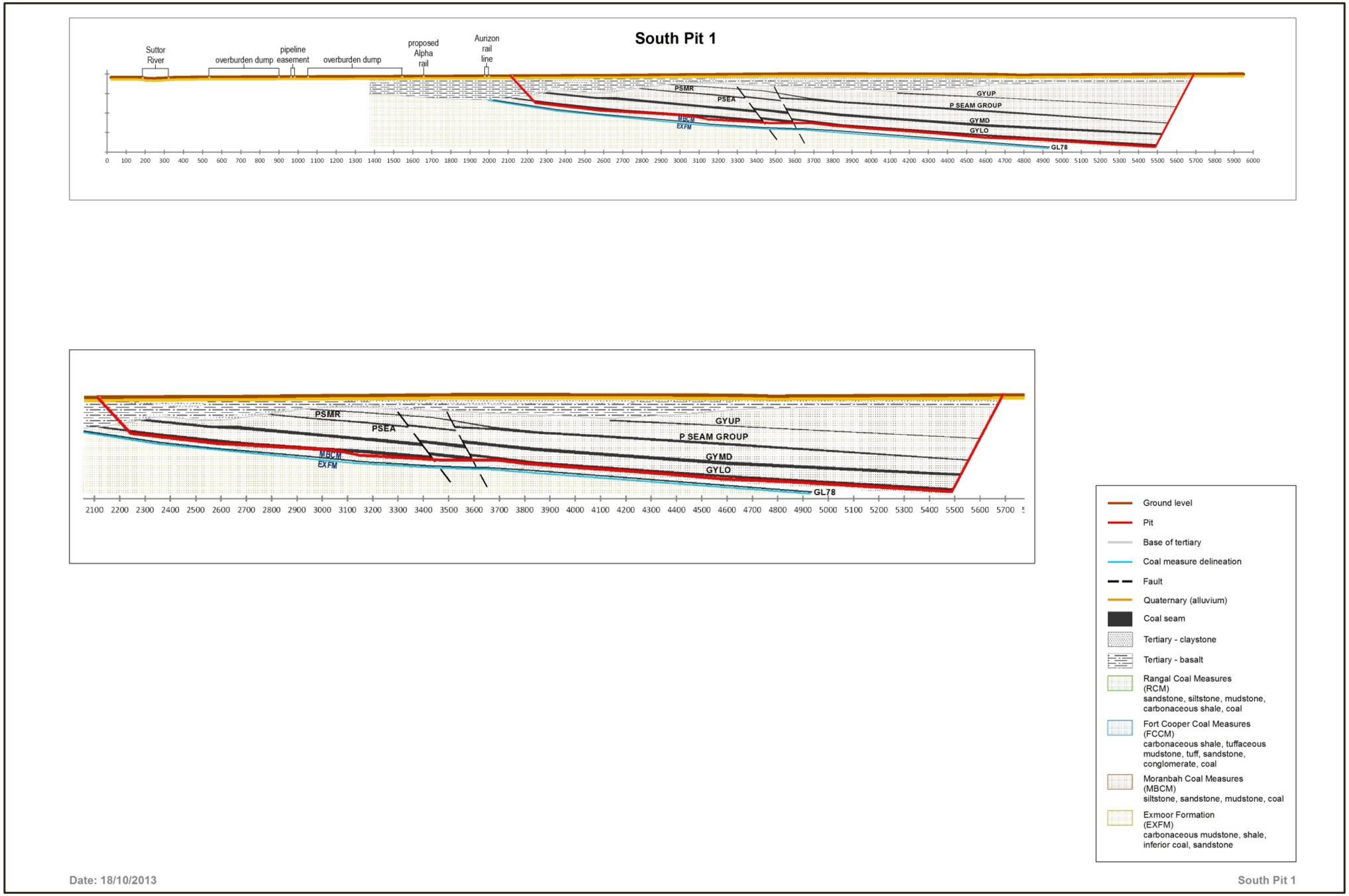


Figure 4-2 Geological Cross Section South Pit 1

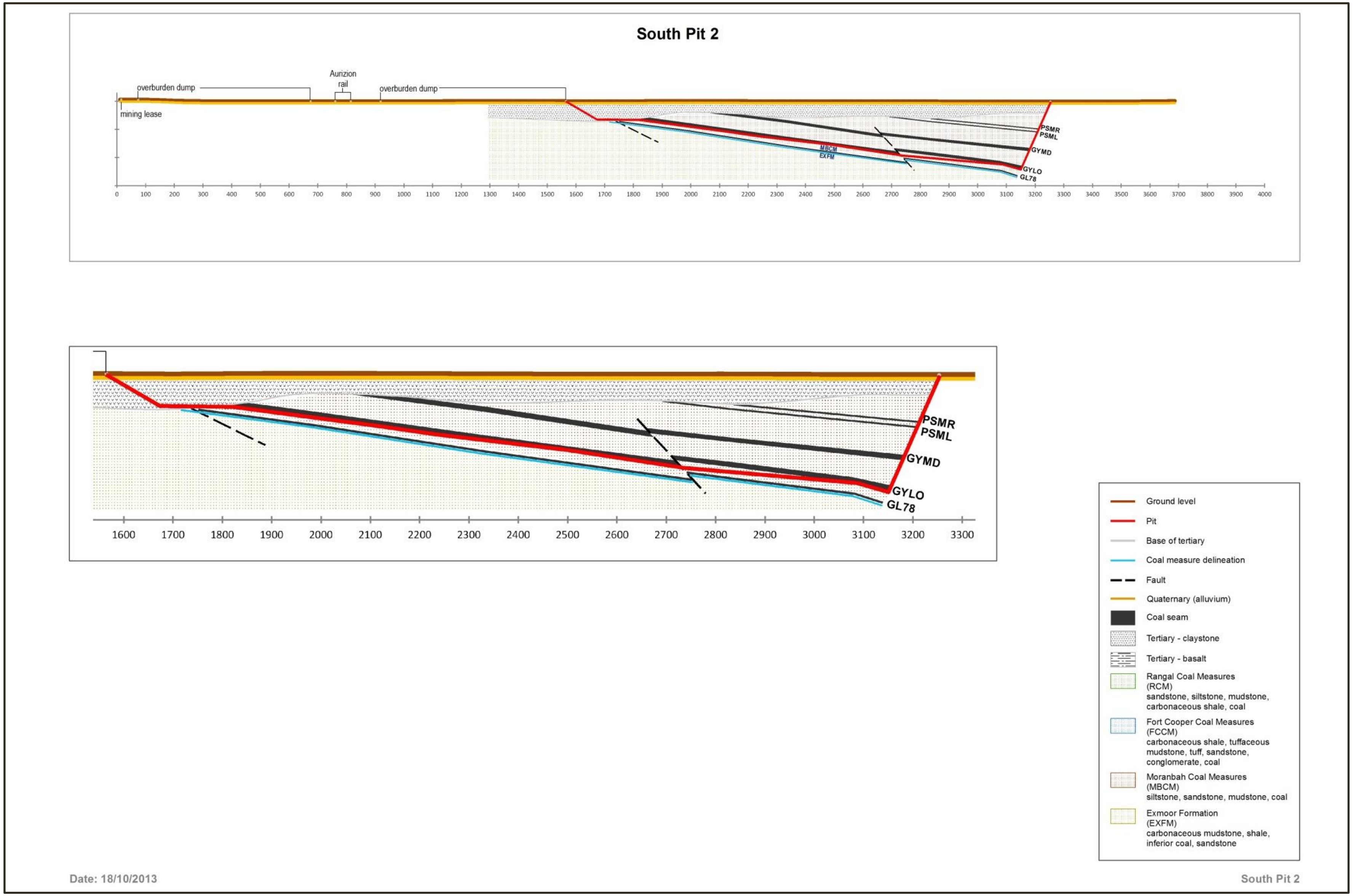


Figure 4-3 Geological Cross Section South Pit 2

Figure 4-4 Geological Cross Section East Pit 2

Figure 4-5 Geological Cross Section West Pit 1 south

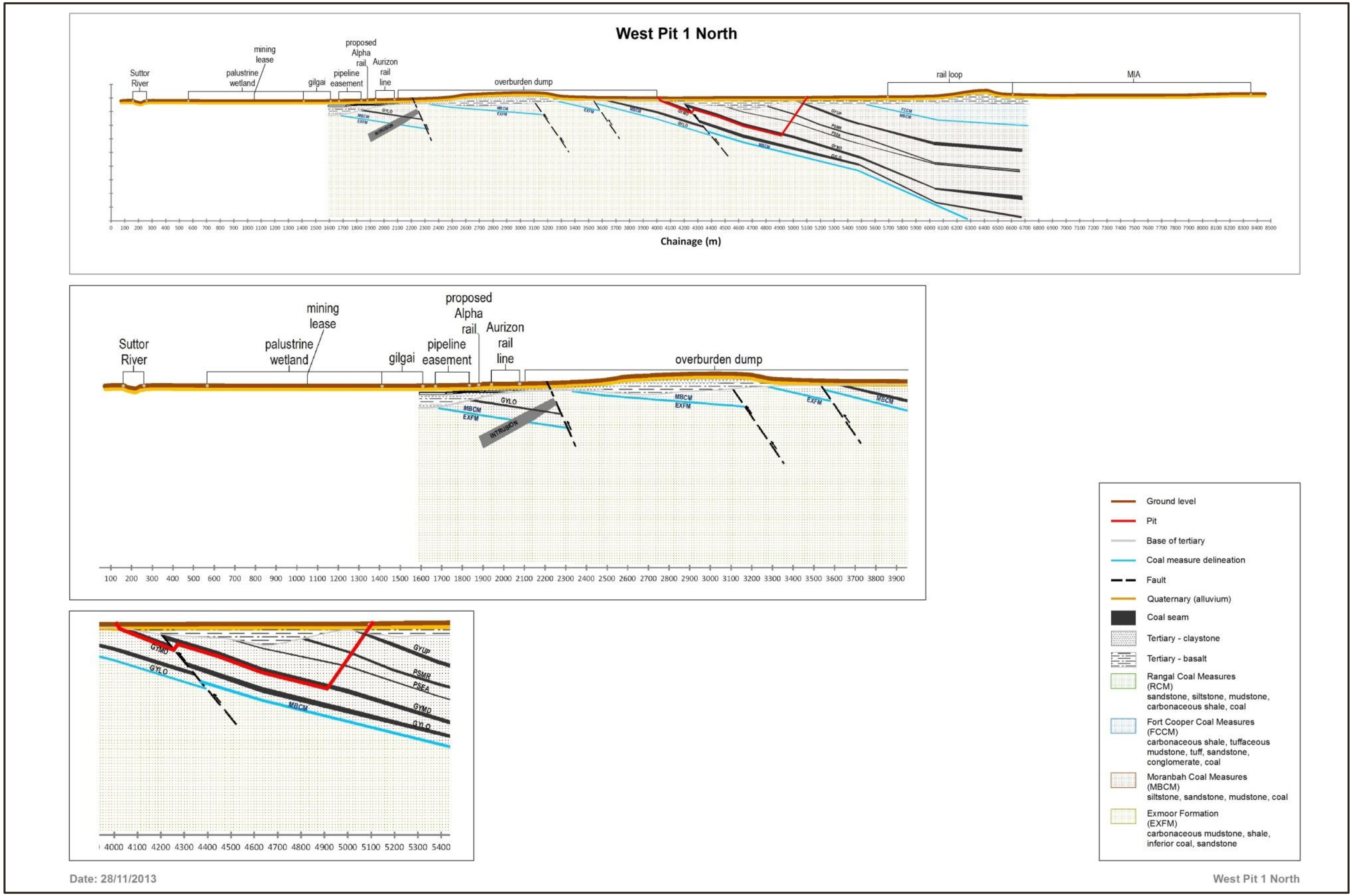


Figure 4-6 Geological Cross Section West Pit 1 north

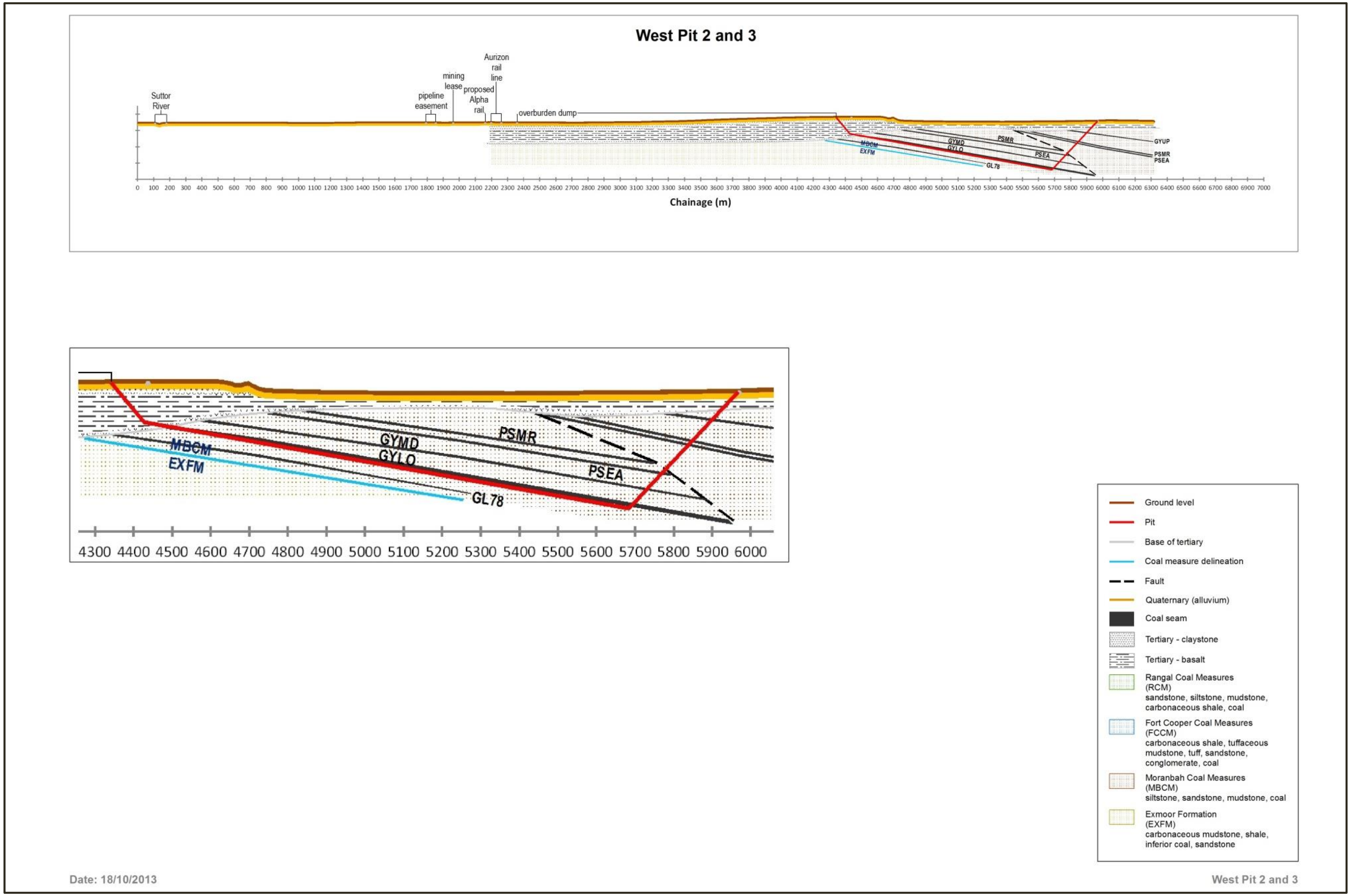


Figure 4-7 Geological Cross Section West Pit 2 and 3

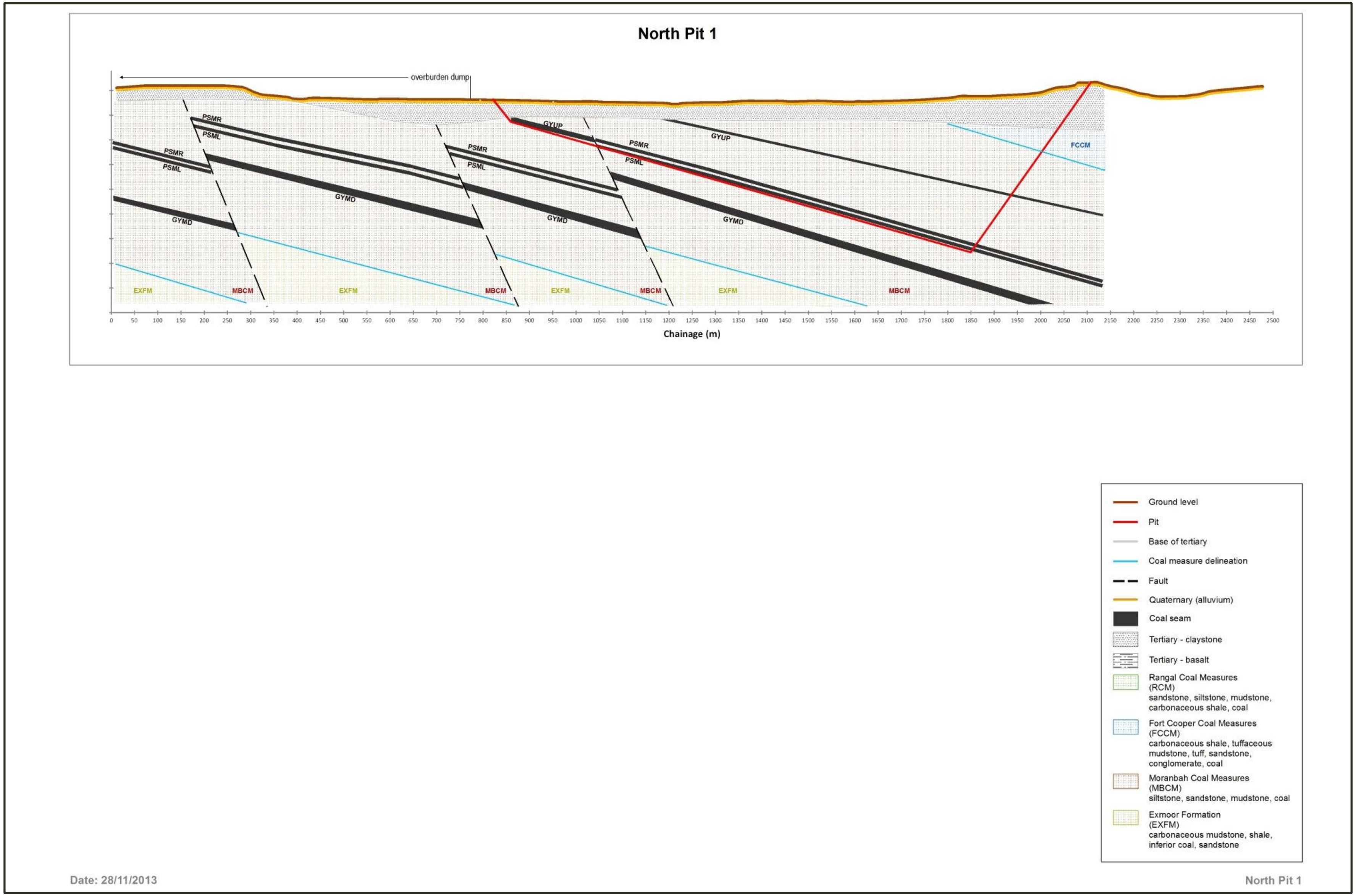


Figure 4-8 Geological Cross Section North Pit

4.2 Groundwater to Surface Water Interactions and Aquifer Connectivity

As part of the EIS baseline groundwater studies, interaction between groundwater and surface water was considered, as well as interaction between various identified groundwater bearing units. Of particular note was the assessment of any potential connection between the groundwater and the Suttor River (which is the main surface watercourse in the vicinity of the Project).

4.2.1 Aquifers and Aquifer Connectivity

Aquifers beneath the Project area potentially occur in a number of stratigraphic units:

- Alluvium: The alluvium is not regarded as an aquifer on the project area.
- Suttor Formation: Poor aquifer, low yields and poor groundwater quality. Any aquifers in this formation would be unconfined or semi-confined.
- Basalt: Low to moderate yield and no reports of significant vesicles. Fracture porosity is the dominant mechanism for storage and flow. Aquifers would be unconfined or semi-confined.
- Tertiary Sand below the Basalt: The Tertiary sand aquifer at the base of the basalt is lensoid and discontinuous but locally high yielding. This aquifer is not used for stock water due to the random nature of occurrence of the basal sands, with landholders tending to rely more heavily on dams and piped water. Any aquifers in this formation would be confined.
- Coal Seams Potentially higher yielding aquifers in sandstone within the Bowen Basin coal measure sequence. Groundwater quality is generally very poor and may be unsuitable for stock. Waters are sodium chloride type with a high total dissolved salt (TDS) content; sulphate content is also high. The aquifers within the sandstone are discontinuous and would be confined.
- Basement (Lizzie Creek Volcanics): Aquifers not reported. Basement aquifers are not regarded as significant to the project, but where present would be confined.

There are no alluvial aquifers of any significance in the Project area. Tertiary sequence aquifers do not appear to be in hydraulic connectivity with the deeper Permian sequence aquifers; however aquifers within the sandstones contained in the Permian coal seams are discontinuous and as such, hydraulic connectivity within the coal seam aquifers will be at best very limited (as evidenced by low hydraulic conductivity values derived from the testing program and presented in the EIS documents).

Groundwater elevation monitoring data for selected dedicated project monitoring bores representing each formation and key lithologies has been reviewed. It is evident from the data that there is no fixed relationship between the groundwater level elevation and the order of accumulation of the coal measure formations, or between the coal seams and other lithologies including the Tertiary. As such, the data confirms that there is a lack of hydraulic connection between hydrostratigraphic units across the project area. A key finding is that the data shows over a 2 year period (baseline studies) that natural groundwater level fluctuations in the dedicated groundwater monitoring bores can vary up to 8 m depending on the bores and hydriostratigraphy.

Geological information across the project area shows that faulting does not extend to the surface through the Tertiary and Quaternary cover.

4.2.2 Groundwater Flow Directions

The standing water level (SWL) is relatively shallow beneath the basalt and much deeper where there is no basalt cover; this suggests that the basalt is a storage mechanism for groundwater and that groundwater within the Tertiary sequences is perched above the underlying Permian sequences.

Both the SWL and thickness of aquifers show wide ranges, reinforcing that there is little hydraulic continuity in the aquifers beneath the Project area. As such it is the regional potentiometric surface for the Permian sequences (groundwater levels from coal seam aquifers) which provides an indication of groundwater flow directions.

Suggested groundwater flow in the Permian sequences are to the north east and to the south with a groundwater divide (mounding) between BYGW02 and BYGW03. It is noted that this groundwater divide correlates to the boundary between surface water drainage sub-catchments which straddle the site namely the Rosella Creek sub-catchment to the north and the Upper Suttor River sub-catchment to the south.

4.2.3 Groundwater to Surface Water Interaction and Groundwater Recharge

Recharge of the Tertiary aquifers occurs by direct infiltration of rainfall. As the Tertiary and Permian sequences are not hydraulically connected the Tertiary aquifers do not contribute recharge to the Permian aquifers. Recharge to the coal measure sandstone aquifers, also occurs via direct (but slow) infiltration of rainfall. The majority of the recharge to the Permian coal sequence aquifers probably derives from slow infiltration through the predominantly clayey Suttor Formation. There is no recharge from the alluvium to the Permian sequence aquifers as there are no significant alluvial aquifers on the project area. In other areas in the Bowen Basin it has been estimated that only about 3% of incident rainfall results in recharge to the consolidated aquifers.

Given the lack of hydraulic connectivity between various aquifers or between aquifers and the quaternary alluvium, as well as the extremely slow recharge rates, any localised drawdown within specific aquifers is considered unlikely to affect the hydrogeological recharge regime in any aquifer, outside the predicted drawdown determined in the EIS. The EIS groundwater modelling results, including initial predicted drawdown, are presented in **Section 7.2**.

As required by the EPBC Conditions (**Section 3.1**), a second confirmatory groundwater modelling study was undertaken as part of this GMMP, with a focus on the potential for the Project to impact the Suttor River, which is presented in **Sections 7.3** and subsections.

4.3 Springs and Groundwater Dependent Ecosystems

As part of the EIS baseline groundwater investigations, springs, swamps, wetlands and Groundwater Dependent Ecosystems (GDEs) were considered. The findings of the EIS indicate that no springs, seeps or swamps have been identified or are known to be connected to groundwater bearing units which have the potential to be impacted (drawdown) during the Project. In addition there is no groundwater-surface water interaction between the aquifer sequences beneath the project area and the watercourses that traverse the Project area. Project mining activities will therefore have no impact on river baseflow.

With the exception of stygofauna (refer **Section 4.4**) it is concluded that there are no GDE which can be impacted by the Project's mining activities. It is noted that there are palustrine, lacustrine (farm dams) and gilgai wetlands within the Project boundary.

The lacustrine (farm dams) and gilgai wetlands are evidently not groundwater fed or connected to groundwater which has potential to be impacted during the project. The palustrine wetland is also not considered to be connected to the hydrostratigraphic units in the targeted mining geology. Springs, swamps, wetlands and GDEs are therefore not considered a groundwater value across the Project site.

However one of the key considerations of the groundwater assessments undertaken during the EIS was the determination of surface water – groundwater interaction, in particular due to the proximity of the Suttor River and Palustrine Wetland. Accordingly, to more clearly define the relationship between the Palustrine Wetland and shallow groundwater (i.e. perched/disconnected), a specific monitoring bore has been installed adjacent the Palustrine Wetland in the tertiary material (as per **Section 5.7**), which will also provide some delineation between the Project operations and the Palustrine Wetland/Suttor River.

4.4 Stygofauna

Baseline stygofauna field surveys were completed on two occasions across the Project as follows:

- A baseline stygofauna pilot study assessment and impact study was undertaken as part of the EIS using data from two sources:
  - sampling of Project bores between 30 November 2011 and 1 December 2011
  - annual sampling of bores in adjacent properties between 2008 and 2012 (the Newlands Mine shares the same hydrogeology, with common aquifers hydraulically connected with sufficient conductivity to allow the movement of stygofauna within the aquifers.
- A second confirmatory stygofauna assessment was undertaken in March 2015 involving the sampling of Project bores, in full satisfaction of EA Condition E8 (see **Section 3.2**).

As required by the EIS ToR and EA Condition E8, stygofauna surveys have been undertaken in accordance with the following:

- Environmental Protection Authority, Western Australia, *Consideration of Subterranean Fauna in Groundwater and Caves during Environmental Impact Assessment in Western Australia No.54*, Environmental Protection Authority, 2003.
- Environmental Protection Authority, Western Australia, *Guidance for the Assessment of Environmental Factors Sampling Methods and Considerations Subterranean Fauna in Western Australia No.54a Technical Appendix to Guidance Statement No.54* Environmental Protection Authority, 2007.

The data from the Project bores (over the 2011 and 2015 surveys) and the Newlands Mine datasets (annually between 2008 and 2012), were combined to generate a comprehensive stygofauna dataset encompassing 88 individual samples collected from 28 bores over an eight year timeframe (2008 to 2015).

A total of 21 samples and/or data points were collected for stygofauna from Project bores over two sampling events (2011 and 2015). Nine groundwater bores recorded the presence of four subsurface taxa (Amphipoda, Cyclopoid Copepoda and two Acarina taxa) which can be classed as stygofauna and obligate groundwater species which are associated with the hypogean and permanent hyporheic environments. These two pilot surveys provide a comprehensive assessment of stygofauna associated with the Project bores.

There were 20 Newlands Mine bores sampled annually for four years, from which only two stygofaunal taxa were recovered from a single bore. It is evident from the Newlands Mine data that stygofauna are low in diversity and abundance from this locality.

Overall, the stygofaunal community within the Project area, was not significant and was characterised by low diversity and abundance when compared to other stygofaunal communities identified from surveys conducted within the Bowen Basin in Queensland (Ecowise Australia, ALS and GHD unpublished data).

The relatively small size of the groundwater taxa present and the small number of specimens of each taxa indicate low connectivity within the aquifers.

To be suitable for stygofauna, aquifers must have sufficient porosity or fractionation (connectivity) for adequate living space, and have a sufficient flux of organic matter (dissolved organic carbon) and dissolved oxygen (Humphreys 2008). The poor hydraulic continuity within the Byerwen project site aquifers in combination with poor recharge characteristics and lack of groundwater-surface water interaction and generally poor groundwater quality, define a subterranean environment which is not conducive to the presence of a significant stygofaunal community and provides a strong argument to explain the low diversity (at the Order/Family level of taxonomic resolution) and abundance of stygofauna recorded within the water bearing zones of the BCP area (and therefore the BSP area).

Collectively, these data suggest that stygofauna (i.e. stygophiles, stygobites and phreatobites) are poorly represented within the Byerwen and Newlands Mine mining lease areas. In addition the Order/Family of the obligate stygofauna collected from both the Newlands Mine and the Byerwen specific surveys are found to occur in all Australian States (Serov, 2002). As such the Order/Family of obligate stygofauna is not endemic to the area.

Stygofauna at the order/family level of taxonomic resolution do not represent a relevant environmental factor in the assessment of the Project.

The proposed Project activities associated (including potential drawdown effects) will not threaten or put at risk the survival of the amphipod and copepod taxa at the Order/Family level of taxonomic resolution. Based on these results, no further survey work or mitigation measures are proposed.

4.5 Groundwater Users

The groundwater associated with the Project has no relevance to the Great Artesian Basin (GAB) Water Resource Plan as the Project area is more than 200 km to the east of the closest section of the GAB. In addition the Water Resource (Burdekin Basin) Plan of 2007 applies only to surface water and not to groundwater.

As such there is currently no legislation or other water resource plan that refers to groundwater in the Belyando-Suttor section of the Burdekin Basin (which contains the Project area); therefore, consideration of anthropogenic groundwater values for the Project area relates to potential groundwater usage by landholders on or adjacent to the Project.

4.5.1 Private Groundwater Facilities and Registered Bores

As part of the groundwater studies undertaken during the Project approvals process, searches of the Queensland Government Groundwater Database (GWDB) were undertaken. The GWDB is a repository for information (including location, depth, ownership, operational status etc.) on individual groundwater bores registered in Queensland and provides a main source of information on groundwater use in the Project area. The GWDB is currently administered by the Department of Natural Resource Management (DNRM) as at July 2015 and was previously administered by the former Department of Environment and Resource Management (DERM).

The GWDB was searched twice for registered bores in and surrounding the Project area, prior to the preparation of this GMMP:

- March 2012 as part of the early stages of the groundwater studies for the EIS; and
- October 2014 to confirm the previous search results and include any updated registered bores.

In preparation of this GMMP a third confirmatory search of the GWDB was undertaken in May 2015, via the DNRM "Globe[6]" geospatial portal, which provides a graphical interface of the GWDB over aerial photography using Google Earth™. Presented in **Figure 4-9** are the registered bores in and around the Project area, shown over the real property boundaries. A radial distance of 5 km from the Project area boundary is shown on **Figure 4-9** for information purposes as an initial conservative distance to consider groundwater users in the Project area.

[6] DNRM Globe (State of Queensland, 2014) is a GIS layer based geospatial data interface administered by DNRM, using Google Earth™ https://www.business.qld.gov.au/business/support-tools-grants/services/mapping-data-imagery/queensland-globe

As at May 2015 there are 38 bores on the GWDB (see **Table 4-2**), which are in, or are within, 5 km of the Project area, of which:

- 13 are purpose built monitoring boreholes installed by Byerwen Coal for the Project.
- 25 are not Project groundwater monitoring bores, of which:
    - 10 are abandoned or destroyed and therefore are not considered further in this GMMP.
    - 2 are methane drainage test wells[7] (one of which is stated as abandoned) and are therefore not considered further in this GMMP
    - 1 is located on Lot 1 SP256594 “Wollombi” (lessee Mr Christopher Wallin – QCoal Managing Director). As such this bore is not in use and is not considered as a landholder bore or point of groundwater usage to be considered in this GMMP.
    - 12 are located on third party properties, are not listed as abandoned and are not designated monitoring bores.

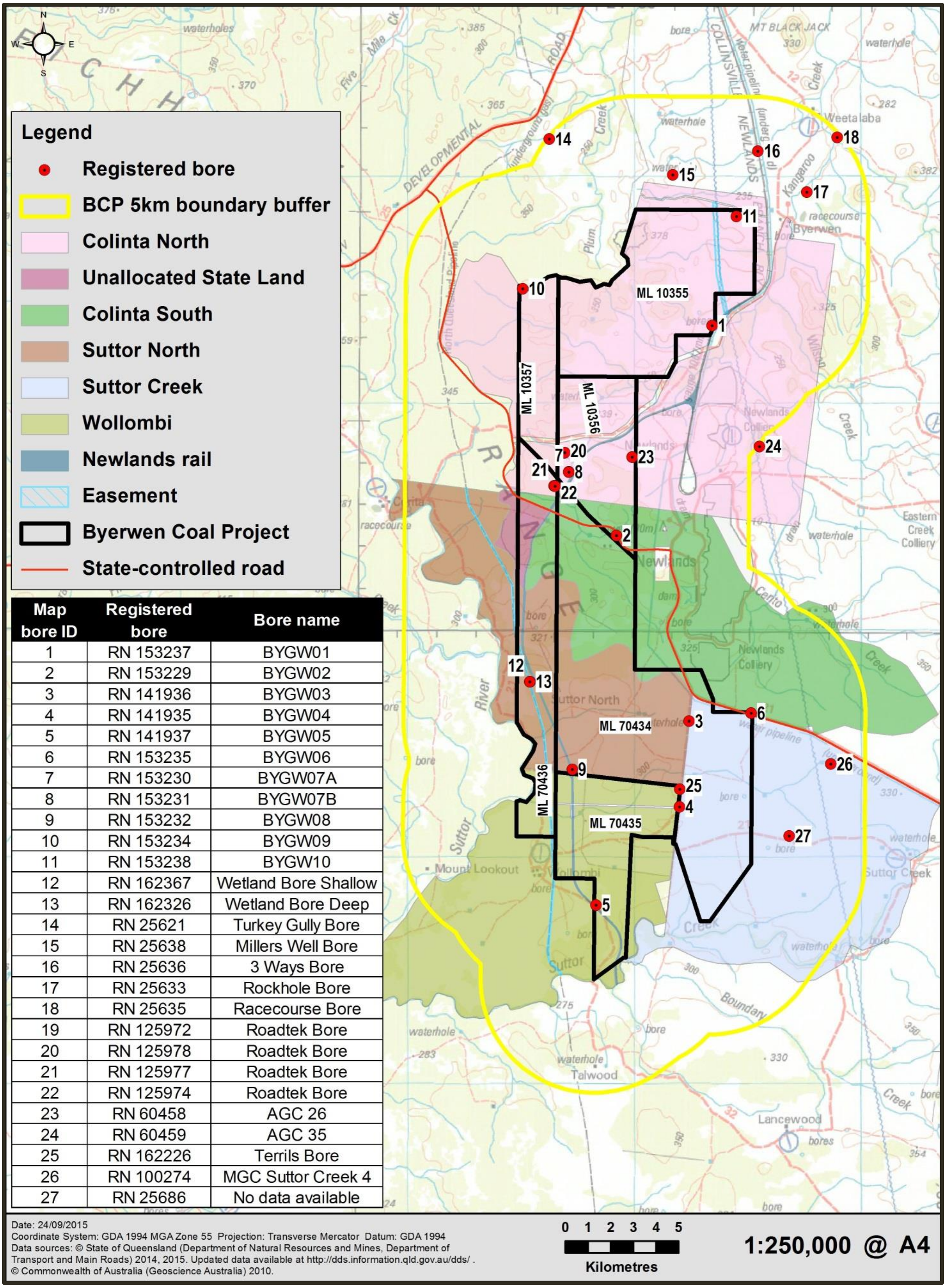
[7] Additional data on registered bores is available on the Queensland Digital Exploration Reports System (QDEX)

Table 4-2 Registered Bores with 5km of the Project (May 2015 DNRM source data)

Registration Number	Bore Name	Property	Longitude (decimal degree, GDA94)	Latitude (decimal degree, GDA94)	Status
RN 153237	BYGW01	Lot 3 SP235898 (Colinta North)	147.8998	-21.12792	Byerwen Project monitoring bore
RN 153229	BYGW02	Lot 14 SP271185 (Colinta South)	147.85975	-21.21175	Byerwen Project monitoring bore
RN 141936	BYGW03	Lot 689 SP235910 (Suttor North)	147.89096	-21.28558	Byerwen Project monitoring bore
RN 141935	BYGW04	Lot 1 SP256594 (Wollombi)	147.88707	-21.31966	Byerwen Project monitoring bore
RN 141937	BYGW05	Lot 1 SP256594 (Wollombi)	147.85187	-21.359	Byerwen Project monitoring bore
RN 153235	BYGW06	Lot 682 CP906890 (Suttor Creek)	147.9174	-21.28224	Byerwen Project monitoring bore
RN 153230	BYGW07A	Lot 3 SP235898 (Colinta North)	147.83931	-21.18642	Byerwen Project monitoring bore
RN 153231	BYGW07B	Lot 3 SP235898 (Colinta North)	147.83924	-21.18657	Byerwen Project monitoring bore
RN 153232	BYGW08	Lot 689 SP235910 (Suttor North)	147.84149	-21.30497	Byerwen Project monitoring bore
RN 153234	BYGW09	Lot 3 SP235898 (Colinta North)	147.81932	-21.11361	Byerwen Project monitoring bore
RN 153238	BYGW10	Lot 3 SP235898 (Colinta North)	147.90988	-21.08439	Byerwen Project monitoring bore
RN 162367	Wetland Bore Shallow	Lot 689 SP235910 (Suttor North)	147.8233	-21.27019	Byerwen Project monitoring bore
RN 162326	Wetland Bore Deep	Lot 689 SP235910 (Suttor North)	147.8232	-21.2702	Byerwen Project monitoring bore
RN 25621	Turkey Gully Bore	Lot 4 SP171921 (Fig Tree)	147.8302623	-21.05399677	Existing
RN 25638	Millers Well Bore	Lot 2 CP866147 (Weetaliba)	147.88277	-21.06794	Existing
RN 25636	3 Ways Bore	Lot 2 CP866147 (Weetaliba)	147.91888	-21.05829	Existing
RN 25633	Rockhole Bore	Lot 2 CP866147 (Weetaliba)	147.93971	-21.07455	Existing
RN 25635	Racecourse Bore	Lot 2 CP866147 (Weetaliba)	147.9524824	-21.0526076	Existing
RN 125976	Roadtek Bore	Lot 3 SP235898 (Colinta North)	147.7889957	-21.1356507	Abandoned and destroyed
RN 125972	Roadtek Bore	Lot 3 SP235898 (Colinta North)	147.8372829	-21.1789212	Existing
RN 125978	Roadtek Bore	Lot 3 SP235898 (Colinta North)	147.837437	-21.1789024	Existing
RN 125977	Roadtek Bore	Lot 3 SP235898 (Colinta North)	147.8330221	-21.1921059	Existing
RN 125974	Roadtek Bore	Lot 3 SP235898 (Colinta North)	147.8334079	-21.1921944	Existing
RN 125975	Roadtek Bore	Lot 3 SP235898 (Colinta North)	147.8335163	-21.1926184	Abandoned and destroyed
RN 125971	Roadtek Bore	Lot 14 SP271185 (Colinta South)	147.8326975	-21.1977904	Abandoned and destroyed
RN 125973	Roadtek Bore	Lot 14 SP271185 (Colinta South)	147.8425634	-21.2064238	Abandoned and destroyed
RN 60458	AGC 26	Lot 3 SP235898 (Colinta North)	147.8661	-21.18048	Existing
RN 60459	AGC 35	Lot 3 SP235898 (Colinta North)	147.92027	-21.17601	Existing

Registration Number	Bore Name	Property	Longitude (decimal degree, GDA94)	Latitude (decimal degree, GDA94)	Status
RN 162226	Terrils Bore	Lot 1 SP256594 (Wollombi)	147.8871884	-21.31262989	Existing (not is use as owned by QCoal Managing Director)
RN 100092	MGC Suttor Creek 2	Lot 682 CP906890 (Suttor Creek)	147.9508173	-21.30232955	Plugged and abandoned (stratigraphic methane drainage test well*)
RN 100274	MGC Suttor Creek 4	Lot 682 CP906890 (Suttor Creek)	147.9513729	-21.30232954	Existing (methane drainage production test well*)
RN 25686	**No data available**	**Lot 682 CP906890 (Suttor Creek)**	**147.93387**	**-21.33111**	**Existing**
RN 85442	Red Heffer Paddock	Lot 2 SP245736 (Lancewood)	147.8441532	-21.4218666	Abandoned and destroyed
RN 85443	No data available	Lot 2 SP245736 (Lancewood)	147.855264	-21.41668141	Abandoned and destroyed
RN 85441	No data available	Lot 2 SP245736 (Lancewood)	147.8593381	-21.42668141	Abandoned and destroyed
RN 63241	No data available	Lot 682 CP906890 (Suttor Creek)	147.9341515	-21.36668138	Abandoned and destroyed
RN 63239	No data available	Lot 682 CP906890 (Suttor Creek)	147.9471144	-21.36631093	Abandoned and destroyed
RN 63240	No data available	Lot 682 CP906890 (Suttor Creek)	147.9497069	-21.35816282	Abandoned and destroyed

*Additional data on registered bores is available on the Queensland Digital Exploration Reports System (QDEX)



Map bore ID	Registered bore	Bore name
1	RN 153237	BYGW01
2	RN 153229	BYGW02
3	RN 141936	BYGW03
4	RN 141935	BYGW04
5	RN 141937	BYGW05
6	RN 153235	BYGW06
7	RN 153230	BYGW07A
8	RN 153231	BYGW07B
9	RN 153232	BYGW08
10	RN 153234	BYGW09
11	RN 153238	BYGW10
12	RN 162367	Wetland Bore Shallow
13	RN 162326	Wetland Bore Deep
14	RN 25621	Turkey Gully Bore
15	RN 25638	Millers Well Bore
16	RN 25636	3 Ways Bore
17	RN 25633	Rockhole Bore
18	RN 25635	Racecourse Bore
19	RN 125972	Roadtek Bore
20	RN 125978	Roadtek Bore
21	RN 125977	Roadtek Bore
22	RN 125974	Roadtek Bore
23	RN 60458	AGC 26
24	RN 60459	AGC 35
25	RN 162226	Terrils Bore
26	RN 100274	MGC Suttor Creek 4
27	RN 25686	No data available

Figure 4-9 Registered Bores

4.5.2 Landholder Bore Survey

The EPBC Condition 12-c (**Section 3.1**) requires that a strategy to conduct a landholder bore survey is included as part of the GMMP, to identify any groundwater users in Project area that may be impacted by mining activities and the potential to incorporate any previously unidentified bores into the groundwater monitoring program.

As per **Section 4.5.1**, registered bores in and within 5 km of the Project have been identified. As such the purpose of a landholder bore survey is inherently to identify bores on properties across the Project area, which are known to the landholder, but are not registered in the GWDB (unregistered bores).

In satisfaction of EPBC Condition 12-c, a landholder bore survey has effectively been completed; relevant properties have been identified in **Section 2.2** and landholders (or representatives) of the relevant properties have provided information on bores (specifically unregistered bores) as follows:

- Lot 3 SP235898 “Colinta North”
    - Owned by Colinta Holdings Pty Ltd (subsidiary of Glencore mining company)
    - Submission by Colinta Holdings to the Queensland Government dated 5/9/14, regarding infrastructure on “Colinta North”, including registered and unregistered bores.
    - Submission identified four unregistered bores as follows:
        - “Shelly’s Bore” @ Lat: -21.097503°, Long: 147.879437°
        - “70 Paddock Bore” @ Lat: -21.171397°, Long: 147.851381°
        - “ 66 Unequipped Bore” @ Lat: -21.192231°, Long: 147.833331°
        - “Holding Paddock 66 Bore” @ Lat: -21.185004°, Long: 147.834996°
        - Additionally the submission identified “66 Bore” @ Lat: -21.178338°, Long: 147.838330°; however this bore has been confirmed as one of the existing Roadtek bores (see **Section 4.5.1**) and registered as a Roadtek bore
- Lot 14 SP271185 “Colinta South”
    - Owned by Colinta Holdings Pty Ltd (subsidiary of Glencore mining company)
    - Submission by Colinta Holdings to the Queensland Government dated 5/9/14, regarding infrastructure on “Colinta South”, including registered and unregistered bores.
    - Submission did not identify unregistered bores on “Colinta South”
- Lot 15 SP256595 (Estate in unallocated State Land)
    - Owned by State of Queensland (Department of Natural Resources and Mines - Land Act)
    - Excised out of “Colinta South” property, with the new title created 19/11/14.
    - As such the 5/9/14 submission by Colinta Holdings for “Colinta South” provides landholder information for this lot.
- Lot 689 SP235910 “Suttor North”
    - Owned by Leichhardt Pastoral Pty Ltd (a wholly owned subsidiary of Byerwen Coal)
    - Documented survey undertaken with Mr Christopher Wallin on 27/11/13
    - Survey results indicate no knowledge of unregistered bores within the “Suttor North” property
- Lot 1 SP256594 “Wollombi”
    - Owned by Mr Christopher Wallin – QCoal Managing Director
    - Documented survey undertaken with Mr Christopher Wallin on 27/11/13
    - Survey results indicate no knowledge of unregistered bores within the “Wollombi” property

- Lot 682 CP906890 “Suttor Creek”
    - Owned by Suttor Creek Holding – Private Individual
    - Documented telephone survey was undertaken by Byerwen Coal with landholder representative[8] on 23/11/13
    - Survey results indicate no knowledge of unregistered bores within the “Suttor Creek” property

The results of the landholder bore survey indicate four unregistered bores on the Project area.

[8] Name has been withheld for privacy reason, but can be released upon request subject to landholder approval

5. Groundwater Monitoring Program

Groundwater monitoring should include manual measurement of water levels, collection of field water quality parameters and collection of samples for subsequent laboratory analysis; in addition monitoring may include downloading of level loggers (where installed).

All groundwater monitoring must be undertaken by an appropriately qualified person as defined by the EA, as per the requirements of the below (and any updates thereof):

- Department of Environment and Heritage Protection (2009) Monitoring and Sampling Manual 2009, Version 2, July 2013.
- AS/NZ 5667 11 1998 (Water Sampling Guidelines – Part 11 Guidance of sampling of groundwater).
- Australian Governments Groundwater Sampling and Analysis – A Field Guide (2009:27 GeoCat#6890.1)

5.1 EA Bores (Locations, Monitoring Frequency and Targeted Formations)

The bores which are required to be monitored, the location and elevation of each bore, as well as the required monitoring frequency, are stipulated in the EA Condition E3 (EA Table E1).

The below table (**Table 5-1**) presents the information from EA Table E1, with the addition of the geological formations screened for each bore. The bore locations are presented in **Figure 5-1**.

The bores listed in **Table 5-1** (EA Table E1) are designated as:

- Groundwater Monitoring Reference Bores
  - Groundwater Reference Bores are monitored as per EA Condition E3 (EA Table E1) and have been selected to provide ongoing baseline during operations, against which the results from compliance bores can be compared.
  - <u>As such these bores are not subject to the stated quality and level trigger limits as per EA Condition E4 and E5</u>.
- Groundwater Compliance Bores
  - Groundwater Compliance Bores are monitored as per EA Condition E3 (EA Table E1) and have been selected to provide information as to the condition of groundwater potentially affected by Project operations.
  - <u>As such these bores are subject to the stated quality and level trigger limits as per EA Condition E4 and E5, as well as subject to comparison against the designate Reference Bores.</u>
- Third Party Bores
  - Third Party Bores are monitored as per EA Condition E3 (EA Table E1) and represent specific bores in the vicinity of the Project, which belong to a third party. As such, monitoring of these bores is to be undertaken in order to establish if there is any change in quality or functionality (level) within those specific bores.
  - <u>As such these bores are subject to the stated quality and level trigger limits as per EA Condition E4 and E5, as well as subject to comparison against the designate Reference Bores.</u>

Table 5-1 EA – Table E1 Bore Locations including Targeted Formations

Monitoring Point [A]	Longitude (decimal degree, GDA94	Latitude (decimal degree, GDA94)	Surface RL (mAHD) [B]	Monitoring Frequency	Formation
Groundwater Monitoring Reference Bores [C]					
BYGW02	147.85975	-21.21175	288.505	Quarterly	Fort Cooper Coal Measures
BYGW05	147.85187	-21.35900	301.311	Quarterly	Exmoor Formation
BYGW06	147.91740	-21.28224	314.946	Quarterly	Rangal Coal Measures
Groundwater Compliance Bores					
BYGW01	147.89980	-21.12792	232.12	Quarterly	Rangal Coal Measures
BYGW03	147.89096	-21.28558	304.939	Quarterly	Fort Cooper Coal Measures
BYGW04	147.88707	-21.31966	299.773	Quarterly	Fort Cooper Coal Measures
BYGW07A	147.83931	-21.18642	263.42	Quarterly	Tertiary sand
BYGW07B	147.83924	-21.18657	263.671	Quarterly	Basalt
BYGW08	147.84149	-21.30497	290.281	Quarterly	Basalt
BYGW09	147.81932	-21.11361	359.04	Quarterly	Moranbah Coal Measures
BYGW10	147.90988	-21.08439	245.616	Quarterly	Rangal Coal Measures
Wetland Bore	147.82330	-21.27019	294	Quarterly	Tertiary clay +
Third Party Bores					
RN 25633	147.93971	-21.07455	To be confirmed	Prior to commencement of operational mining activities in close proximity to these bores and then quarterly for 12 months after operational mining activity commences.	Moranbah Coal Measures**
RN 25636	147.91888	-21.05829	To be confirmed		Blackwater Group*
RN 25638	147.88277	-21.06794	To be confirmed		Basalt**
RN 25686	147.93387	-21.33111	To be confirmed		Upper Carboniferous*
RN 60458	147.86610	-21.18048	To be confirmed		Blackwater Group*
RN 60459	147.92027	-21.17601	To be confirmed		Blackwater Group*

A Monitoring is not required where a bore has been removed as a direct result of the mining activity.
B RL must be calculated from the nearest 5cm from the top of the bore casing.
C Reference sites must:
(i) have a similar flow regime;
(ii) be from the same bio-geographic and climatic region;
(iii) have similar geology, soil types and topography; and
(iv) not be so close to the test sites that any disturbance at the test site also results in a change at the reference site.
+ Installed in tertiary material as per OCG Report.
* Aquifer unit as reports in DNRM groundwater database as at Jan 2014
** Aquifer unit interpreted by Rob Lait and Associates Pty Ltd (Jan 2014)

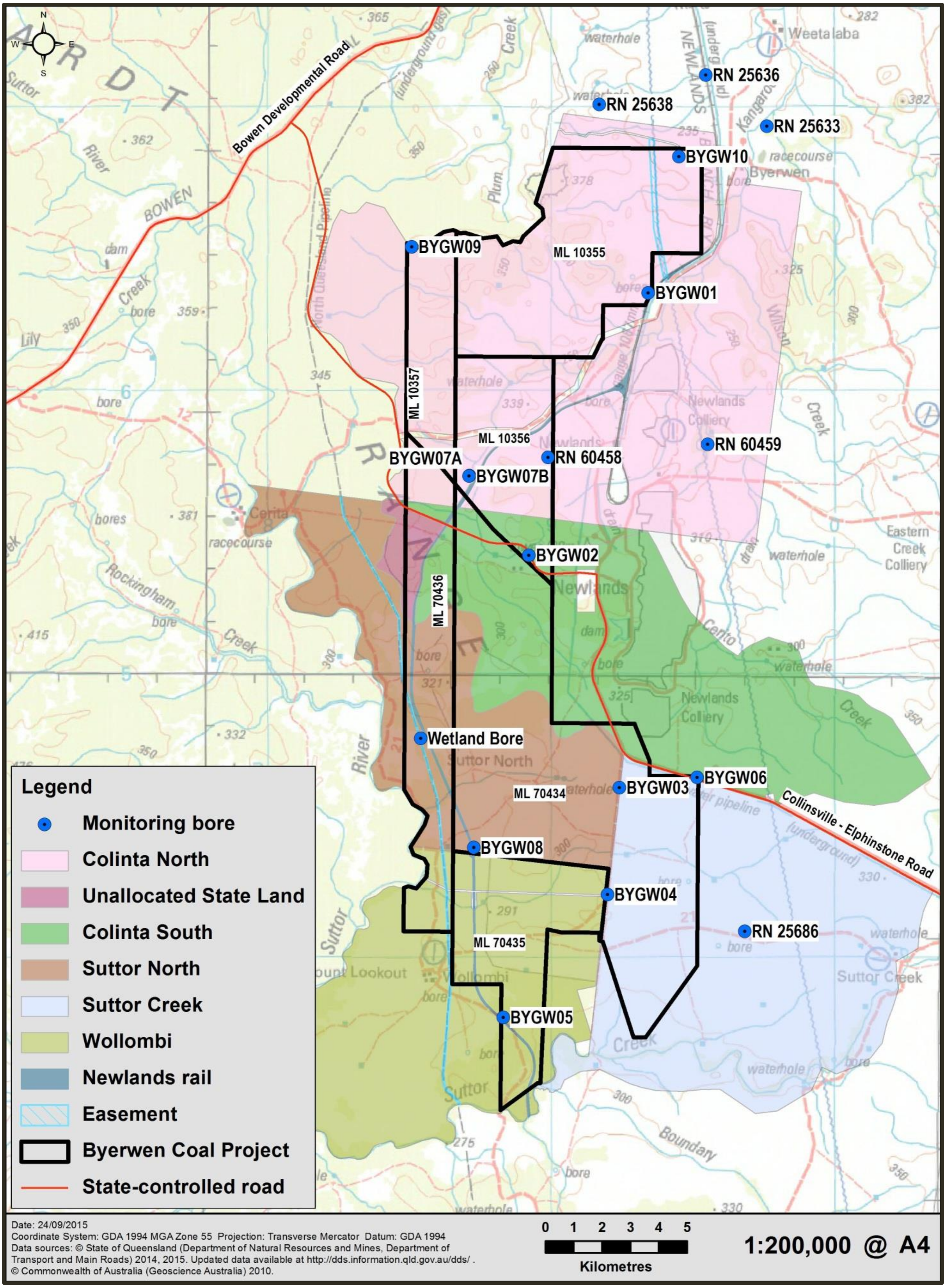


Figure 5-1 Byerwen EA Monitoring Bore Locations

5.2 Required Monitoring Parameters

Groundwater monitoring is required to track changes in physical (groundwater level) and chemical (groundwater quality) parameters.

5.2.1 Standing Water Level (SWL) monitoring

Monitoring of groundwater level is required in all bores listed in **Section 5.1,** to track change in groundwater levels and to identify if any changes are associated with mining operations.

Requirements for monitoring of water level are stipulated in EA Condition E3 and E5.

5.2.2 Water quality monitoring

Monitoring of groundwater quality is required in all bores listed in **Section 5.1**, to track change in groundwater quality and to identify if any changes are associated with mining operations.

Requirements for monitoring of water quality are stipulated in EA Condition E3 and EA Table E2, which lists prescribed parameters, as presented below in **Table 5-2**.

Table 5-2 EA Required Groundwater Quality Parameter List

Water Quality Parameters
Aluminium
Antimony
Arsenic
Iron
Molybdenum
Mercury
Selenium
Silver
Total Dissolved Solids (TDS)
Electrical Conductivity (EC)
Sulphate
Calcium
Magnesium
Sodium
Potassium
Chloride
Carbonate
Bicarbonate
Total Petroleum Hydrocarbons (TPH)
pH

All quality parameters require samples to be collected and delivered to a laboratory for analysis, with the exception of pH and electrical conductivity (EC); pH and EC may be determined either by laboratory analysis or by using a field water quality meter. It is also noted that measurements of EC can be used to give an estimate of TDS.

With respect to metals, analysis should be undertaken for total and dissolved metals, with the EA trigger and limits being applied to dissolved concentrations only.

5.3 Monitoring Methodology

5.3.1 Water level measurements

Water level measurements can be undertaken either manually or by automated loggers or both. Data from loggers should be used in conjunction with manual measurements as a confirmatory measure.

5.3.1.1 Manual Level Measurements

Manual measurement of water level within a bore should be undertaken at each monitoring event (regardless of the presence of automated level loggers). Two measurements are required in order to determine groundwater depth below ground level (bgl), as per the below:

1. Measure and record the bore top of casing (ToC) height to ground level
2. Measure and record and the depth to water within the bore from the ToC
    - Where non-aqueous phase liquid (NAPL) is present an interface probe is required and measurements should be taken from ToC to NAPL level in addition to water level
3. Calculation: *Groundwater depth bgl = Water level from ToC – Height of ToC to ground level*

Additional physical monitoring should be undertaken to ensure continued functionality of the bore:

4. Total depth of the bore measured from the top of casing (to track any silting up of the bore)
5. Condition of the bore (evidence of interference, damage etc)

Water level measurements are generally undertaken using water level sensors (dippers). Use/servicing/maintenance/calibration of dippers or interface probes should always be in accordance with manufacturer’s instructions.

5.3.1.2 Level loggers

Some wells may have groundwater level loggers installed, which are pressure transducers that log (record) pressure at given time intervals (e.g. every 6 hours). Loggers are installed below the prevailing water level within the bore at a known depth from the ToC. The pressure data is used to calculate the water level and provides a log of any changes in level. Where a level logger is installed the battery should be checked, the logged data downloaded and the memory cleared, on a regular basis as per manufacturer’s instructions.

Data from loggers is downloaded into software (specific to the logger manufacturer). Data compensation is required to adjust the raw logged data for barometric pressure (i.e. air pressure) and the installation depth of the sensor. As such one additional logger must be installed above the water level in a bore, to specifically record barometric pressure and be downloaded in the same manner as the water level loggers.

Once compensated correctly, level data should be representative of groundwater level (bgl) and be available for interpretation. The method of barometric and installation depth compensation, level calculations, will be as per the specific manufacturer’s software.

Installation/downloading of data/servicing/maintenance/calibration of the loggers should always be in accordance with manufacturer’s instructions and software requirements.

Of the bores listed **Table 5-1** (EA Table E1), four have loggers installed as at May 2015:

- BYGW05

- BYGW07A
- BYGW07B
- BYGW09

5.3.2 Water quality sampling

5.3.2.1 Purging

Water samples collected from monitoring bores for the purposes of groundwater quality monitoring, are intended to represent the groundwater within the surrounding formation i.e. therefore sampling for water quality from bores should be of fresh formation water and disturbed standing bore water.

Selection of purging methodology will depend on the particulars of each bore and the conditions at the time of monitoring. Methods, or exceptions to the adopted methods due to field circumstances (such as inclement weather, equipment failure, blockages etc.), should be recorded on the field sheets.

For this reason there are a number of methods of purging/sample collection which can be employed including air purging, pumping, hand bailing, hydroseleeves and low flow/micro purge. Once representative water is recovered, water quality sampling should be undertaken.

5.3.2.2 Field water quality parameters and analytical sample collection

Methods for water collection for sampling will depend on the method of purging; as such the selection of methodology will depend on the particulars of each bore and the conditions at the time of monitoring.

Based on the required water quality parameters (see **Section 5.2.2**), field water quality parameters are not required for EA compliance purposes. However, the collection of field parameters can assist in the bore purging process depending on the method (i.e. can demonstrate when fresh formation water is being recovered) and also as a comparative data point in the interpretation of laboratory data (i.e. compare field pH and laboratory pH). As such where a calibrated water quality meter is available, field parameters should be recorded on the field sheet – temperature, pH and EC as a minimum; dissolved oxygen, ORP and turbidity should also be recorded where possible.

Once field parameters are recorded (if applicable), laboratory analytical samples should be collected in the appropriate sample containers (**Section 5.4.3**) for the analytical parameters stated in EA Table E2 (**Section 5.2.2**).

A Chain of Custody (CoC) form should then be completed (**Section 5.5.2.1**) and samples transported to the selected analytical laboratory (**Section 5.3.2.5**).

5.3.2.3 Field QA/QC

During monitoring of groundwater, field quality control and quality assurance (QA/QC) procedures and methods should be observed at the direction of the appropriately qualified person who is undertaking the monitoring, in consideration of the below:

- Department of Environment and Heritage Protection (2009) Monitoring and Sampling Manual 2009, Version 2, July 2013.
- AS/NZ 5667 11 1998 (Water Sampling Guidelines – Part 11 Guidance of sampling of groundwater).
- Australian Governments Groundwater Sampling and Analysis – A Field Guide (2009:27 GeoCat#6890.1)

5.3.2.4 Storage/Transport of samples

In general samples should remain chilled after collection during storage and transportation; however correct storage of samples after collection should be as per the recommendations stated by the selected laboratory and as per the relevant sample container. Samples once collected in the appropriate container have recommended holding times (i.e. maximum times that a sample can be stored prior to analysis) which vary depending on the desired laboratory analyses and the sample container. Storage and transport of samples should consider the recommended holding times for the various water quality parameters as stated by the selected laboratory for the required analysis and the relevant sample container

Sample containers which have the potential to break during transportation, such as glass bottles, should be protected (e.g. bubble wrap sleeves are usually provided with the container).

5.3.2.5 Laboratory analyses

Any analytical laboratories engaged to undertake analyses as part of EA compliance monitoring must be accredited by the National Association of Testing Authorities (NATA) for the requested analyses. Submission of samples to analytical laboratories will be accompanied by the appropriate CoC form, filled out to include the required analyses and reporting information.

Laboratories to which samples are sent for analyses will be considered the primary laboratory. Where a triplicate sample (inter-laboratory sample) is taken and is required to be forwarded to a secondary laboratory for inter-laboratory quality control purposes, that laboratory will be considered the triplicate laboratory. Accordingly, the CoC must state be that the triplicate sample is to be forwarded by the primary laboratory to the triplicate laboratory.

It is noted that NATA accredited laboratories will generally undertake laboratory quality control procedures including surrogates, blanks, method blanks etc. The quality control results should be reviewed by the recipient prior to acceptance of the groundwater laboratory results from any laboratory.

5.4 Monitoring Equipment

5.4.1 Equipment

For groundwater sampling, the adopted methodology (and accordingly the equipment) should meet all requirements under the EA Conditions, EPBC Conditions and the prescribed water sampling guidelines. Consultants/contractors undertaking groundwater sampling must demonstrate the methodology is compliant with the above. All equipment must be in serviceable condition and be operated as per the manufacturer's instructions, including decontamination procedures between sampling locations, where required for multi-use equipment (such as pumps).

5.4.2 Calibration

Monitoring equipment requiring calibration should be calibrated and maintained according to the manufacturer's instructions. Calibration records should be kept by the person/s undertaken the monitoring for a minimum period of five (5) years and provided to Byerwen Coal upon request.

5.4.3 Sample Containers

The correct sample containers required for collection/transport of samples (bottles, vials and jars) should be available for sample collection at the time of monitoring. Different sample containers are required for different analytes (quality parameters). For example, the container required for samples to be analysed for metals is different to the container required for samples to be analysed for nutrients.

The appropriate sample containers required for the proposed laboratory analyses should be established by the person/s undertaken the groundwater monitoring; in general the laboratory selected for analyses will provide the appropriate containers upon request.

5.5 Monitoring Documentation and Data Management

5.5.1 Field sheets

Byerwen Coal will provide a specific field sheet template to be completed by consultants/contractors when undertaking groundwater monitoring. The field sheet has spaces for each of the required field measurements to be recorded. Field sheets should be completed for every sampling point, including for sample points which are dry upon inspection and should be filled out in their entirety. Field sheets will be scanned and provided to Byerwen Coal.

As a minimum the field sheets will require the following data to be recorded:

- Name of sampler, data/time of monitoring and weather conditions
- Bore identification number and overall condition of bore (evidence of interference)
- Water level measurements (**Section 5.3.1.1**)
- Actions taken to download any automated level logger (**Section 5.3.1.2**)
- Water quality sampling – methods, volumes, purge data, field quality parameters and analytical sample collection (**Section 5.3.2**)

5.5.2 Laboratory Documentation

5.5.2.1 Chain of Custody

Byerwen Coal will provide a specific CoC form template, to be completed by consultants/contractors when submitting samples to an analytical laboratory. CoCs should be completed in full and be submitted with the samples. Byerwen Coal groundwater samples should not be on CoCs with samples from other sites or samples of other types (such as surface water). Byerwen Coal's representative must be marked on the CoC as the recipient of laboratory documentation.

5.5.2.2 Analytical Reports

Laboratory analytical reports should be sent to Byerwen Coal's representative as per the CoC form.

5.5.3 Data Management

Monitoring records, reports and data associated with monitoring groundwater as per the EA Conditions must be kept for a minimum of five (5) years. Byerwen Coal will maintain two groundwater databases:

- a level database comprising manual and automated level logger results
- a quality database comprising field and laboratory quality results

5.6 Monitoring Results Interpretation - EA Trigger Level and Compliance

Once accepted, processed and input into the relevant groundwater database (**Section 5.5.3**), groundwater level and quality monitoring data will require comparison against the trigger limits for the various parameters, as prescribed in the EA.

5.6.1 Groundwater Level Compliance (Investigation Level Thresholds)

All bores stated in **Section 5.1** should be monitored for level as per EA Condition E3 (**Section 5.2.1**).

Groundwater level monitoring data should be compared against the prescribed groundwater level investigation trigger thresholds as stated in the EA (EA Condition E5).

EA Condition E5 stipulates that the groundwater level investigation trigger threshold is a fluctuation in excess of 2 metres per:

- If results do not exceed the threshold or are from a designated reference bore (as per **Section 5.1** and **Table 5-1**) then no actions are triggered.
- If results exceed the threshold and are from a designated compliance bore (as per **Section 5.1** and **Table 5-1**), then an investigation is triggered (presented in **Section 6**).

5.6.2 Groundwater Quality Compliance (Quality Trigger Limits)

All bores stated in **Section 5.1** should be monitored for quality as per EA Condition E3.

Groundwater quality monitoring results should be compared against the prescribed triggers and limits stated in EA Table E2, as per EA Condition E4. The below table (**Table 5-3**) presents the groundwater quality triggers and limits from EA Table E2, for the prescribed quality parameters (**Section 5.2.2**) and is therefore subject to change as per the EA.

Table 5-3 EA – Table E2 Groundwater quality trigger limits

Parameter		Units	Contaminant Triggers
Aluminium		(mg/L)	1.092
Antimony		(mg/L)	0.001
Arsenic		(mg/L)	0.009
Iron		(mg/L)	0.5
Molybdenum		(mg/L)	0.071
Mercury		(mg/L)	0.0001
Selenium		(mg/L)	0.01
Silver		(mg/L)	0.003
Total Dissolved Solids (TDS)	Tertiary and Early Permian	(mg/L)	17810
	Late Permian	(mg/L)	7449
Electrical Conductivity (EC)	Tertiary and Early Permian	µs/cm	20977
	Late Permian	µs/cm	11430
Sulphate		(mg/L)	914.00
Calcium		(mg/L)	797.27
Magnesium		(mg/L)	278.50
Sodium		(mg/L)	3340.00
Potassium		(mg/L)	60.95
Chloride		(mg/L)	7018.3
Carbonate		(mg/L)	77.9
Bicarbonate		(mg/L)	735.0
Total Petroleum Hydrocarbons (TPH)		µg/L	238.5
pH		pH units	6.13 - 12.72

With respect to metals, analysis should be undertaken for total and dissolved metals, with the EA trigger and limits being applied to dissolved concentrations only.

When groundwater quality monitoring results are compared to the triggers and limits (as per EA Condition E4):

- If results do not exceed the quality triggers limits, or are from a designated reference bore (as per **Section 5.1** and **Table 5-1**) then no actions are triggered.
- If results exceed the quality triggers or limits (EA Condition E4) and are from a designated compliance bore (as per **Section 5.1** and **Table 5-1**), the actions presented in **Section 6** are triggered.

5.7 Expansion of Groundwater Monitoring Program

One of the key considerations of the groundwater assessments undertaken during the EIS was the determination of surface water – groundwater interaction, in particular due to the proximity of the Suttor River and Palustrine Wetland (see **Section 4.2.3** and **Section 4.3**).

For this reason one of the bores which are required to be monitored (**Section 5.1**) is specifically located adjacent the Palustrine Wetland in the tertiary material, to provide some delineation between the Project operations and the Palustrine Wetland/Suttor River.

To facilitate continued improvement of the groundwater monitoring program and to ensure that key data is being captured, the groundwater monitoring program will be evaluated against monitoring and modelling data, to identify data gaps and opportunities for expansion to undertake additional monitoring.

The results of operational groundwater monitoring and the results of the verification of the groundwater model against the monitoring data, will be used to identify opportunities to fill potential data gaps. More specifically, once operational groundwater monitoring data over several seasons is available and verification of the groundwater model has been attempted/completed, potential data gaps can be identified where additional monitoring may be required, including:

- Locations
- Targeted depths
- Quality parameters
- Frequency of monitoring to improve temporal resolution of data
- Frequency of reporting

Once the groundwater model has been reliably verified against operational monitoring data, the model can be used to identify areas where potential groundwater impact in relation to surface water might occur (if any sort of surface water/groundwater interaction were to occur); those identified areas will be assessed for additional bore installation and monitoring (if none already exist in the area). Any additional bores would be installed by licenced water borers and registered with the Queensland DNRM, with any additional monitoring results to be reviewed by a suitably qualified expert[9].

5.7.1 Inclusion of Identified Registered and Unregistered Landholder Bores

The potential for inclusion of any of the registered landholder bores identified in **Section 4.5.1** and unregistered bores identified in **Section 4.5.2** into the groundwater monitoring program, will be considered as part of the expansion of the groundwater monitoring program discussed in **Section 5.7**.

[9] Suitably qualified expert as per the EPBC conditions definitions: a person who has professional qualifications, training, skills or experience relevant to the nominated subject matter and can give authoritative assessment, advice and analysis on performance relating to the subject matter using the relevant protocols, standards, methods or literature.

5.8 Bore Construction, Maintenance and Decommissioning

The drilling and installation of water bores will be undertaken by licenced drilling contractors, in accordance with the conditions of the EA pertaining to waste management, spill prevention and response, emergency/incident reporting and general environmental duty of care. Bores will be cased and constructed to prevent any hydraulic connection between various strata through the bore annulus.

As part of the monitoring methodology (**Section 5.3**), monitoring includes a physical inspection of the condition of the bore for evidence of interference or damage. Monitoring will be undertaken by appropriately qualified persons, who will be required to record any issues with bore operation. Level monitoring (**Section 5.3.1.1**) includes the physical measurement of total bore depth. If this measurement differs from previous records or from the bore construction report, it may be an indication of silting up or cracked/damaged casing or screen. If the monitoring results include anomalous results or comments, the condition of the bore will be confirmed as part of any investigation, which may require the use of a “down hole” camera to further identify the issue.

In the event that condition of the bore is confirmed as requiring maintenance, the corrective actions will depend on the identified issue and cause, but may include flushing out with clean water or re-development (continuous pumping). If the issue cannot be corrected *in-situ*, the bore may be re-drilled and re-installed in the same location (over drill the existing bore and install a new bore) or a new bore may be installed adjacent the faulty bore as a replacement.

At the cessation of groundwater monitoring (i.e. post rehabilitation) the bores may either be handed over to the landholder (upon specific agreement) or decommissioned. In general, decommissioning involves grout being poured into the bore to completely fill the casing to ground level (or just below) and the cutting off of surface standpipe. In this way no cavity remains and there can be no bore related connection between various strata.

6. Trigger and Limit Exceedances

6.1 Exceedance Procedure

Where a groundwater monitoring result exceeds the triggers and/or limits for either level or quality (**Section 5.6**), the EPBC Conditions and EA Conditions (**Section 3**) stipulate a sequence of comparison, investigation, notification and reporting actions as presented in **Figure 6-1**. Discussion on investigations, corrective actions and notification/reporting requirement is provided in the following sub-sections.

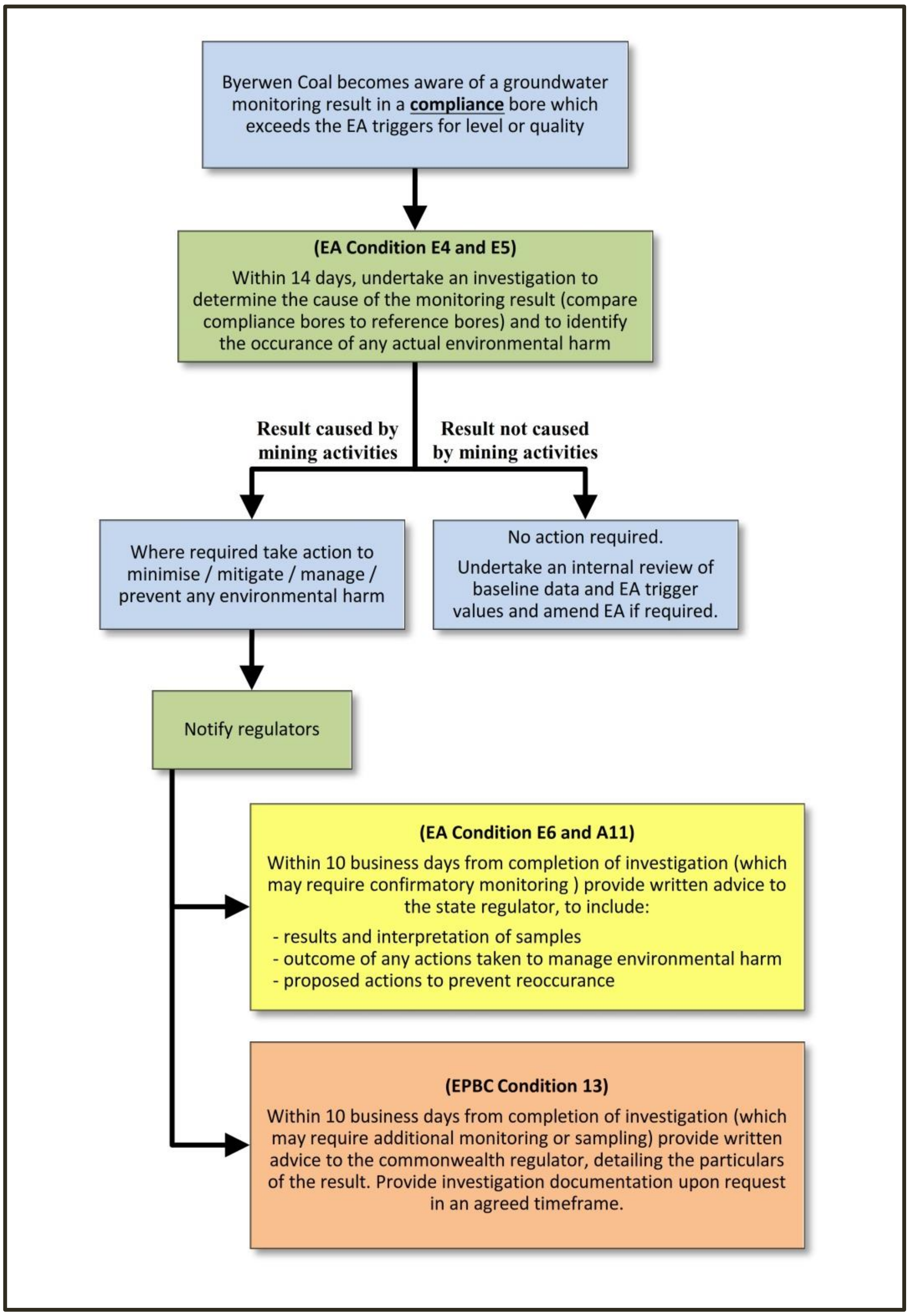
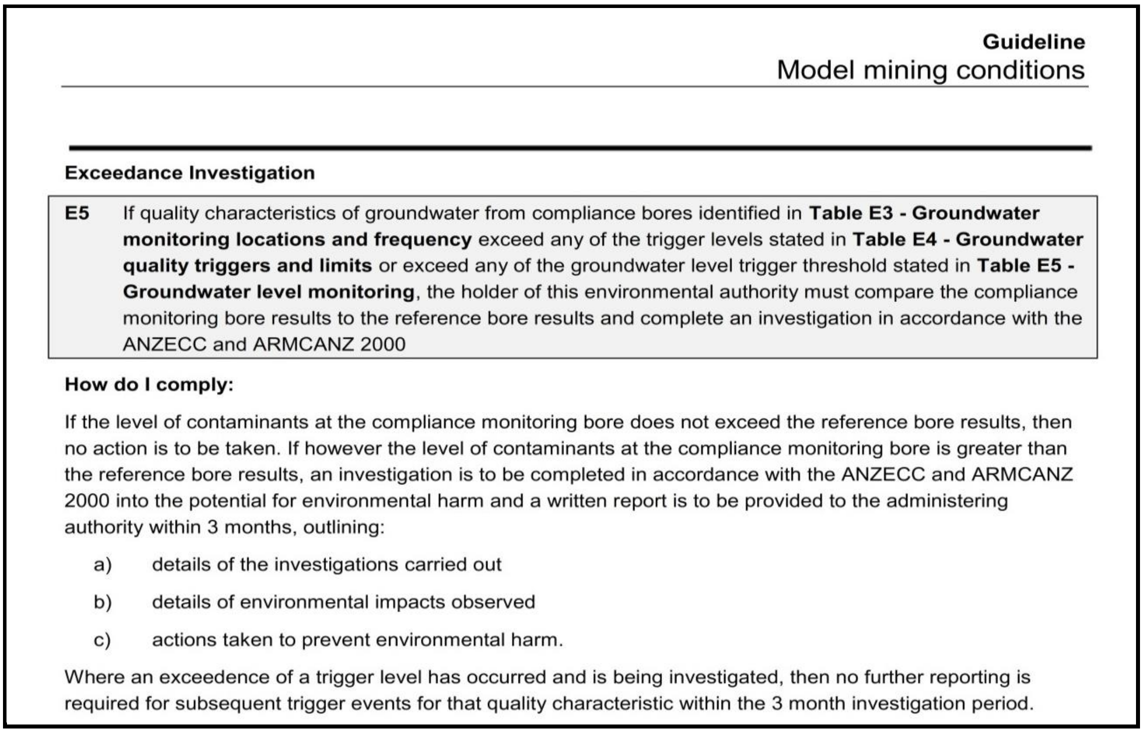


Figure 6-1 Exceedance Investigation, Notification and Reporting Requirements

A summary of the investigation methods for exceedance is as follows:

1. If the result is from a reference bore then no investigation is required
    a. A review of the groundwater data and EA trigger or limit values may be undertaken
2. If the result is from a compliance bore, then compare the compliance bore result against the result from the relevant reference bore/s
    a. If the compliance bore result is less than the reference bore result, then no investigation is required and a review of the groundwater data and EA trigger or limit values may be undertaken
    b. If the compliance bore result is greater than the reference bore result, an investigation is required along with requirements for regulatory notification. If the findings of the investigation recommend actions to prevent any environmental harm, those actions should be carried out.

The comparison between reference and compliance bores is undertaken as the initial stage of an investigation as per the Model Mining Conditions Guideline on exceedance investigations (**Figure 6-2**); the selected reference and compliance bores are designated in EA Table E1 (presented in **Table 5-1** of this document), as well as the third party bores.



Guideline
Model mining conditions

Exceedance Investigation

E5 If quality characteristics of groundwater from compliance bores identified in **Table E3 - Groundwater monitoring locations and frequency** exceed any of the trigger levels stated in **Table E4 - Groundwater quality triggers and limits** or exceed any of the groundwater level trigger threshold stated in **Table E5 - Groundwater level monitoring**, the holder of this environmental authority must compare the compliance monitoring bore results to the reference bore results and complete an investigation in accordance with the ANZECC and ARMCANZ 2000

How do I comply:

If the level of contaminants at the compliance monitoring bore does not exceed the reference bore results, then no action is to be taken. If however the level of contaminants at the compliance monitoring bore is greater than the reference bore results, an investigation is to be completed in accordance with the ANZECC and ARMCANZ 2000 into the potential for environmental harm and a written report is to be provided to the administering authority within 3 months, outlining:

a) details of the investigations carried out

b) details of environmental impacts observed

c) actions taken to prevent environmental harm.

Where an exceedence of a trigger level has occurred and is being investigated, then no further reporting is required for subsequent trigger events for that quality characteristic within the 3 month investigation period.

Figure 6-2 Model Mining Conditions Guideline – Exceedance Investigation

In the event that a review of groundwater monitoring data indicates a specific quality or level parameter is trending towards the respective trigger value, an initial internal appraisal will be undertaken of that particular parameter across the monitoring network. The appraisal will be completed in preparation for any required investigations which may undertaken if the trigger limit is actually exceeded.

6.2 Investigations into Exceedance of Trigger or Limits

Where a compliance bore monitoring result has exceeded a trigger or limit for level or quality, and the subsequent comparison indicates the result is greater than the relevant reference bore, an investigation is required.

Investigations will be entirely dependent on the particulars of the exceedance but should include:

- Details of the exceedance
  - Location (bore) and date of the sample/measurement/logged data point
  - The exceedance result itself, comparison against triggers/limits, comparison against reference bore
- Examination into cause
  - non mining causes: e.g. sampling/measurement error, climactic influences, natural variation (comparison against historical datasets)
  - mining related causes: e.g. dewatering, spills, seepage
- Examination of consequence
  - Has the exceedance resulted in any unauthorised environmental harm and evaluation of any associated environmental impacts?

If the investigation into the cause concludes it is not mining related then no further actions are required, however, a review of EA trigger and limit values may be undertaken.

If the investigation concludes that the exceedance is the result of mining activities and that the exceedance caused unauthorised environmental harm which has resulted in identified environmental impacts, then actions to minimise/mitigate/manage the impacts associated with the unauthorised environmental harm should be implemented. In addition measures should be implemented to aid in the prevention of further occurrences of the unauthorised harm and associated environmental impacts.

6.3 Actions to Minimise Impacts and/or Prevent Further Occurrences

Where mining activities have been shown to cause unauthorised environmental impacts to groundwater with resultant environmental harm on groundwater values, minimisation and preventative actions may be required. Examples of potential groundwater impacts include:

- Potential to drawdown regional groundwater levels by pit dewatering.
- Potential contamination of groundwater through seepage of waste rock dumps and in-pit rejects.
- Pollution of groundwater from surface activities may occur from seepage of co-disposal facilities and accidental release of hydrocarbons (e.g. fuels and oils) or other contaminants.

The specific actions required will be dependent on the particulars of the groundwater value, the specific impacts which have occurred, and the mechanisms and activities identified in the investigation as the cause/s.

Actions may include:

- Detailed hydrogeological/groundwater review and assessment
- Review of mining procedures
- Redrilling of bores
- Review of mine closure plans
- Review of GMMP and/or groundwater model
- Compensation
- Contaminated land assessments and remediation planning

Additional actions may also include the preparation of detailed response plans where more comprehensive investigations/actions have been identified as being required; these may include:

- conducting a full risk assessment
- developing a conceptual model identifying and assessing sources, pathways and receptors
- assessment of how and the rate at which inter aquifer leakage may be occurring

- assessment of the potential effects on the receiving environment and the need for further investigation/ assessment

It is noted that emergencies and incidents relating to spills and seepage occurrences are addressed specifically and separately in the EA Conditions, with separate and specific conditions for reporting, management, investigations, remediation and prevention.

6.4 Notification and Reporting

The Project has notification and reporting requirements to DEHP under the EA Conditions, and to DoE under the EPBC Conditions. EA and EPBC conditions are presented in **Section 3** and are discussed below.

6.4.1 EA Conditions – Notification and Reporting

EA Condition E6: *In the event that groundwater fluctuations are a result of mining activities, the environmental authority holder must meet the notification requirement of condition A11 of this environmental authority.*

EA Condition A11: Within 10 business days following the initial notification of an emergency or incident, or receipt of monitoring results, whichever is the latter, further written advice must be provided to the administering authority, including the following:

a) results and interpretation of any samples taken and analysed;
b) outcomes of actions taken at the time to prevent or minimise unlawful environmental harm; and
c) proposed actions to prevent a recurrence of the emergency or incident.

As per the Model Mining Conditions Guideline for Exceedance Investigation (**Section 6.1**), if an exceedance of a trigger or limit occurs in a compliance bore and the exceedance value is greater than the relevant reference bore value, an investigation is required to determine the cause of the results.

As per EA Condition E6, if the investigation indicates that the exceedance is the results of mining activities DEHP will be notified within 10 business days as per EA Condition A11. The written notification should outline the exceedance, the investigation details, the cause, any environmental impacts and any actions taken to prevent reoccurrence or to mitigate those impacts.

6.4.2 EPBC Conditions – Notification and Reporting

EPBC Condition 13: *The approval holder must notify the Department in writing within 10 business days if the groundwater quality and/or trigger levels referred to in Condition 12 of this approval are exceeded and the results of required investigations indicate the exceedence is a result of mining activities. If requested, the approval holder must provide copies of any exceedence investigation documents to the Department in a timeframe agreed in writing by the Department, which state the cause, response and actions undertaken to prevent further occurrences.*

As such the notification and reporting requirements of the EPBC Conditions to the DoE align with the notification and reporting requirements of the EA to DEHP; specifically, DoE would be notified of an exceedance and provided with investigation results (if requested) in line with DEHP.

This approach prevents unnecessary notifications being received by DoE and ensures consistent notification and reporting timeframes between DoE and DEHP.

7. Groundwater Modelling

7.1 Background

The EPBC Conditions include two conditions which relate to the requirement for a groundwater model as per the below:

- EPBC Condition 12-e: "*a groundwater model to simulate and quantify groundwater drawdown extent and flow impacts on the Suttor River, and validate the assumptions and potential risks and impacts of the project on groundwater resources identified in the EIS documents. The model must be developed with reference to the National Water Commission Groundwater Modelling Guidelines and must include a monitoring strategy to validate the model."*
- EPBC Condition 12-f: "*the methods, frequency and timeframes in which the GMMP and groundwater model will be reviewed."*

A groundwater model was developed and presented as part of the EIS, with subsequent refinements to the model based on state and commonwealth regulatory reviews as part of the AIEIS, culminating in the completed EIS groundwater model. However as part of the EPBC Conditions, the GMMP must include a groundwater model developed independently to the EIS groundwater model, for comparison and impact assessment.

Byerwen Coal liaised with the DoE who determined that the modelling methodology adopted for EPBC Condition 12-e should be fit for purpose and appropriate for the level of risk apparent across the Project area, but did not stipulate a specific type or method of model. However, further advice provided by the DoE to Byerwen Coal (email advice to Byerwen Coal dated 19/12/14) states that "*I can confirm that a numerical model is not required to address condition 12 (f) of EPBC 2010/5778, i.e. an analytical groundwater model is acceptable.*"

Accordingly Byerwen Coal engaged Australasian Groundwater and Environmental Consultants Pty Ltd[10] (AGE) to develop an analytical groundwater model for inclusion in this GMMP (the GMMP groundwater model), in satisfaction of the EPBC Conditions and in reference to the National Water Commission Groundwater Modelling Guidelines (**Section 7.3.5**).

A summary of the EIS groundwater modelling is provided in **Section 7.2** and subsections. The GMMP groundwater model methods, key assumptions and results, along with a review of the EIS groundwater modelling and a comparison of the GMMP groundwater model against the EIS groundwater model, are provided in **Section 7.3** and subsections.

7.1.1 GMMP Groundwater Model: Objectives

The requirements of the EPBC Conditions were used to identify the following key objectives for the GMMP model:

- Quantify the extent of any groundwater drawdown associated with the Project;
- Establish if this has any impact on the flow in the Suttor River and if so quantify any loss of flow;
- Use the model to validate (confirm) the findings of the EIS in relation to potential risks and impacts on any groundwater resources (values) such as any third party groundwater users, identified across the Project area.

[10] AGE are recognised as industry experts in groundwater with extensive experience in groundwater modelling, coal mining operations, impact assessment and the hydrogeology of the north Bowen Basin.

The identified objectives are a key consideration in determining the required outputs of the model (i.e. what does the GMMP groundwater model have to be able to do to achieve the key objectives); this in turn informs the modelling approach and methods which is considered most suitable.

As such in order to achieve the stated objectives of the EPBC Conditions, the GMMP groundwater model is required to provide the following general outputs:

- conceptualise interactions between various groundwater bearing units (interconnectivity) across the Project area;
- quantify groundwater inflows into mining pits;
- quantification maximum potential drawdown extents;
    - consideration of individual Project pits (pit drawdown)
    - consideration of the Project pits collectively (cumulative Project drawdown)
    - consideration of any relevant external potential sources of drawdown using SWL monitoring data
- conceptualisation of the relationship between groundwater and the Suttor River (surface to groundwater connectivity);
- where any drawdown extents have been shown to encroach on the Suttor River and the conceptualisation shows a connection between the Suttor River and the groundwater, quantify any potential impacts (loss of flow) on the Suttor River; and
- where any drawdown extents have been shown to encroach on any identified groundwater resources/values (such as water supply bores), quantify any potential impacts.

7.2 EIS Groundwater Model Overview

As part of the EIS groundwater studies, the EIS groundwater model was developed using the Marinelli and Niccoli (2000) analytical modelling approach (analytical model). The following subsections summarise the outcomes of the EIS groundwater model to allow for confirmation and comparison against the results from the GMMP groundwater model.

7.2.1 EIS Groundwater Model Method

The EIS groundwater model provided the following key outputs:

- individual pit inflows
- potential maximum drawdown extents (using maximum pit depths and dimensions) for each pit
- the cumulative drawdown associated with overlapping individual drawdown extents

These outputs were used to assess:

- whether potential drawdown extended to the Suttor River
- whether potential drawdown extended to third party groundwater bores currently in use
- whether drawdown extended to the palustrine wetland

In addition pit inflow data from the EIS groundwater model, was used as input for operational water balance modelling and final void water level modelling, undertaken as separate surface water and final void modelling assessments.

The findings of the EIS concluded that the groundwater had low value across the Project area for:

- springs and GDEs (**Section 4.3**)
- stygofauna (**Section 4.4**)
- groundwater users (**Section 4.5**), and
- notably that the groundwater to surface water interactions (connection to the Suttor River) were found to be limited (**Section 4.2**).

As such the Marinelli and Niccoli (2000) method adopted for the EIS groundwater model, was considered highly suitable for the EIS. This is particularly so given the conservative assumptions inherent in the analytical model method, but also the conservative values adopted for the various model inputs. The Marinelli and Niccoli (2000) method uses a series of hydrogeological equations to calculate steady state or long term average inflows into a mine pit. In practice, due to the nature of the proposed mining operations, steady-state conditions are unlikely to develop. For example, development of smaller pits (such as South Pit 2) pit is expected to be completed within 5 years.

The conceptual drawdown cone associated with dewatering operations in this pit will gradually expand as groundwater inflows into the pit are pumped out; however, given the relatively short period of mining in this pit it, it is likely that the drawdown cone associated with this pumping will not have reached steady-state by the end of mining in that pit. At the cessation of mining in that pit dewatering operations will cease and hence the drawdown cone will begin to gradually contract.

In terms of the cone of influence of dewatering operations, the assumption of steady-state conditions in the analytical model therefore represents a specific measure of conservatism, or 'worst' case scenario assessment.

The results of the analytical model considered:

- hydraulic conductivities;
- standing pit water;
- pit dimensions and schedules;
- the effect of decreased saturated thickness near the pit wall (Dupuit-Forchheimer approximation);
- the distributed nature of recharge to the water table; and
- upward flow through the pit floor.

The analytical model was completed for a range of assumed input values. The full details of the EIS modelling method is presented in the EIS and AIEIS documents, which include information on:

- actual analytical model equations
- conceptual hydrogeological assumptions
- specific hydrogeological parameter values which were assumed as inputs to the equations; and
- the iterative method of calibration for various modelled outputs.

7.2.2 EIS Groundwater Model Results

7.2.2.1 Drawdown Extent

The EIS groundwater model was initially used to derive a conservative maximum drawdown from the deepest pit (South Pit 1) across the Project, as an analogous conservative maximum for all pits on the Project. As part of the AIEIS, the EIS groundwater model was then used to determine the drawdown extent of all individual pits and to specifically consider the characteristics of each pit, such as varying pit bench depths as they progress from west to east over the life of each pit. Mining commences on the eastern extent of the pits and progress west, following the dip of the coal seams; as such pits will be shallow in the west and deeper in the east, which has an effect on the modelled drawdown.

The groundwater model results for the maximum potential drawdown for each pit have been provided in Table 7-1. It is noted that for some pits the time between commencement of shallow mining in the east, to the cessation of mining at western extent of the pit, can be in excess of 30 years (such as for South Pit 1). To allow for consideration of this in the analytical modelling approach, the EIS groundwater model results presented in Table 7-1, conservatively assume all pits are open at their maximum respective extents simultaneously, providing a conservative approach for impact assessment of groundwater values within potential drawdown extents).

Table 7-1 EIS groundwater model summary of results

Pit name*	Maximum drawdown extent (m)	Pit inflows (m^3/day)	Pit inflows (L/s)
North Pit	3,825	319.7	3.7
East Pit 1	800*	mining above the water table	
East Pit 2	800	13	0.15
West Pit 1	1,400	89.9	1.04
West Pit 2	2,300	13.8	0.16
West Pit 3	2,300	96.8	1.12
South Pit 1	2,300	260.1	3.01
South Pit 2	2,000	91.6	1.06

Note - Source: Byerwen Coal Project EIS, Chapter 8 - Water Management

* While the EIS documents determined that East Pit 1 was above the water table and as such would have nil inflow, an assumed 800m was applied as per the adjacent East Pit 2 for the purposes of a conservative impact assessment of surrounding groundwater values.

Presented in **Figure 7-1** are the EIS groundwater model drawdown results from **Table 7-1**, with the maximum potential drawdown extents considered cumulatively across the Project area. Also presented in **Figure 7-1** are registered bores (**Section 4.5.1**), unregistered bores (**Section 4.5.2**), EA monitoring bores (**Section 5.1**) and the palustrine wetland (**Section 4.3**).

7.2.2.2 Potential Suttor River Impacts

As expected for pits where there is a pronounced difference in bench depths from west to east, the modelled drawdown is proportionate. The EIS groundwater model drawdown results, considering pit depth progression and spatial extents, indicate:

- Drawdown does not extend under the Suttor River at any point
    - The maximum conservatively estimated potential drawdown extent is 650 m from the Suttor River; as such no impact on baseflow is expected.
- Drawdown does not go under the palustrine wetland.
- The proposed groundwater monitoring installation on the east of the palustrine wetland is ideally located for monitoring of this finding.

These results also reaffirm the findings associated with the revised geological cross sections showing geological impediments to hydraulic connections from the pits to the Suttor River or palustrine wetland

7.2.2.3 Potential Groundwater User Impacts

The EIS groundwater model concluded that three third party landholder bores (see **Section 4.5.1** and **Section 4.5.2**) are within the maximum predicted drawdown as follows:

- RN 125977 Roadtek bore on Lot 3 SP235898: Long 147.8330221 Lat -21.1921059 (registered)
- RN 125974 Roadtek bore on Lot 3 SP235898: Long 147.8334079 Lat -21.1921944 (registered)
- " 66 Unequipped Bore" on Lot 3 SP235898: Long 147.833331 Lat -21.192231 (unregistered)

These three bores are all located on "Colinta North" owned by Colinta Holdings Pty Ltd (subsidiary of Glencore mining company). Information from the landholder of "Colinta North" (see also **Section 4.5.2**) indicates that none of these are in use or are equipped for use, as at the time of this GMMP.

Accordingly the EIS groundwater model did not identify any groundwater users within the estimated cone of influence of any of the proposed open pits, therefore, no impacts on groundwater levels in any known water supply well was anticipated.

In addition no known springs or GDEs exist in the estimated cones of depression modelled in the EIS groundwater model.

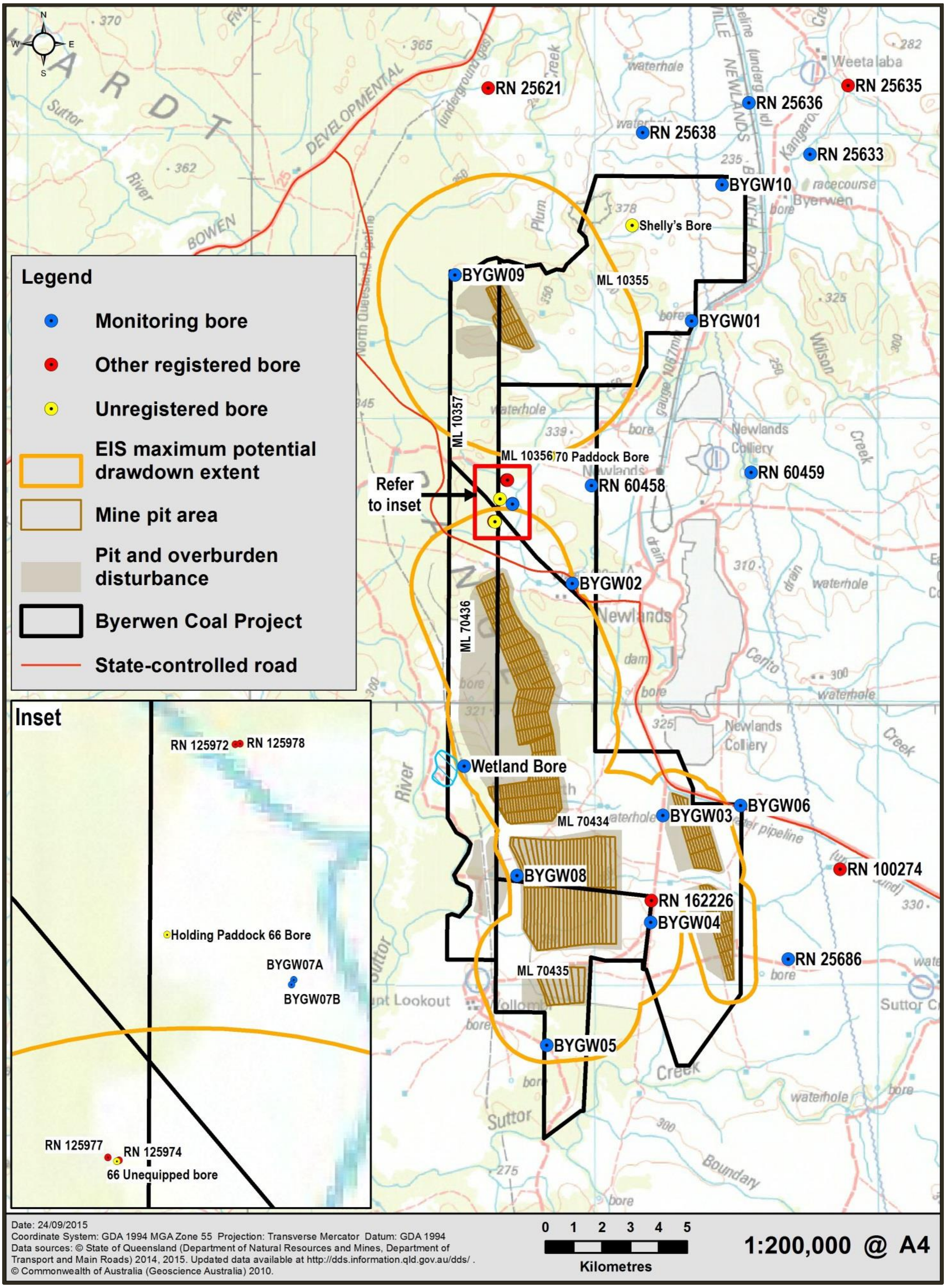


Figure 7-1 EIS Analytical Model Results – Drawdown Extent Map

7.2.2.4 Summary

Based on the groundwater assessments, investigations into groundwater values and resources and the EIS groundwater modelling assessment undertaken, the EIS concluded that:

- there are clear geological impediments preventing any mechanism of hydraulic connection between the groundwater potentially intersected by the pits, and the Suttor River;
- due to the faulted and discontinuous geology, hydraulic connectivity within the coal seam aquifers will be at best very limited;
- direct hydraulic connection between groundwater bearing units across the Project area is also considered unlikely.
- maximum potential drawdown for the Project varies for each pit and collectively:
    - There are currently no groundwater users within any drawdown area
    - There are no springs or GDEs in the distance which can be impacted
    - Drawdown does not extend to the Suttor River with the closet point being 650m away
- Quality of key hydrogeological units (as per **Section 4.2.1**):
    - Alluvium: The alluvium is not regarded as an aquifer on the project area.
    - Suttor Formation: Poor aquifer, low yields and poor groundwater quality.
    - Basalt: Low to moderate yield and no reports of significant vesicles.
    - Tertiary Sand below the Basalt: Aquifer is not used for stock water due to the random occurrence of the basal sands, with landholders relying more on dams and piped water.
    - Coal Seams: Quality is generally very poor and may be unsuitable for stock. Sodium chloride type with a high total dissolved salt (TDS) content and high sulphate content.

As such the overall finding of the EIS and in particular the EIS groundwater model was that the potential risk to groundwater resources (users) and the Suttor River is low.

7.3 GMMP Groundwater Model

7.3.1 Conceptual Model: Surface Water – Groundwater Connectivity

7.3.1.1 Concepts and Previous Conclusions

Depressurisation and drawdown within the groundwater systems due to mining can only impact upon the Suttor River if there is a direct hydraulic connection between the Suttor River and the groundwater system being depressurised; therefore understanding the nature of this connectivity is important when assessing potential impacts.

Water courses can be classified according to their connectivity with groundwater as either, 'gaining' or 'losing'. Losing stream can be further subdivided into 'losing-connected' or 'losing disconnected'. **Figure 7-2** shows these concepts graphically in cross section through a hypothetical stream and aquifer system.

The EIS assessed the potential interconnection based on data within the mining leases and on the long term water level data from Registered bore RN12030094 which is located near the Suttor River approximately seven kilometres west of the North Pit. It was concluded there is little or no interconnection between the Suttor River or any of the major watercourses and the groundwater system. This conclusion was based on the following observations:

- water levels are generally deep, between 20 m to 80 m below ground (mbGL);
- drilling information suggests there is little to no alluvial sediments present across the mining lease; and
- generally there are thick sequences of low permeability sediments associated with the Suttor Formation and the Permian sediments.

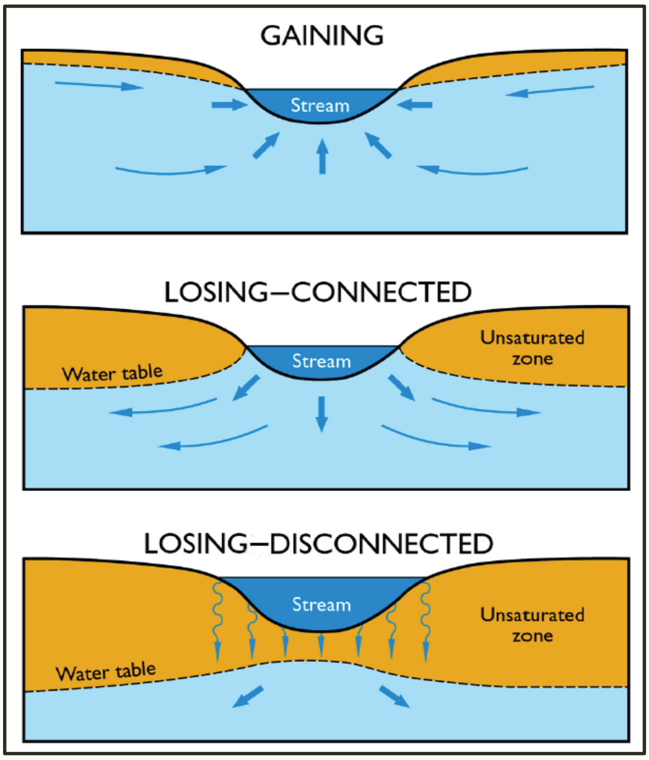


Figure 7-2 Groundwater – surface water connectivity (source NSW Government 2010)

The EPBC conditions of approval (EPBC Condition 12-e) require validation of the potential drawdown extent and flow impacts on the Suttor River, identified in the EIS. As such as part of the GMMP groundwater model, the topography, geology and hydrogeology were examined along a series of cross sections across the Suttor River to better understand the nature of the groundwater-surface water connectivity and the potential impact of the Project. The cross sections and the connectivity are described in the following sub-sections.

7.3.1.2 Suttor River Cross Sections

Three cross-sections are presented to show the nature of connectivity between the Suttor River and the groundwater system. The cross-sections are presented in **Sections 7.3.1.2.1 to 7.3.1.2.3** and are constructed using geological data from the Byerwen geological model and the surface geological mapping from the Byerwen (8455) digital geological map sheet. Surface elevation is from LIDAR and SRTM terrain data. Where section lines extend beyond the observed limit of the Project's geological model, the extent of units was inferred based on experience in the region. Water level data was sourced from three datasets, these include:

- registered bores data (RN12030094);
- measured water levels from the Byerwen groundwater monitoring network; and
- water levels measured in exploration drill holes.

Water levels were inferred from measurements proximal to each section line; where there were anomalous conflicting water levels the more conservative data was used. There was limited data available on groundwater levels directly within the alluvium immediately adjacent to the Suttor River, and therefore the water table was inferred after a site inspection by AGE (2015 dry season) of the river bed, where it crosses the Bowen Developmental Road upstream of the Project area.

Figure 7-3 and **Figure 7-4** show the Suttor River crossing the Bowen Development Road upstream of the Project. The Suttor River is ephemeral with a sandy bed and a channel well defined by large eucalypts in a thin riparian zone either side of the river. River alluvium appears localised, restricted to terraces extending less than 20 m either side. **Figure 7-4** shows a water hole less than 1 m deep in the Suttor River bed during the winter dry season, with no indicators of surface flow for some time and no rainfall for several weeks prior; as such the water hole likely reflects the water table within the local alluvium.

Figure 7-3 Suttor River at Bowen Development Road (looking south)

Figure 7-4 Suttor River water table, below Bowen Development Road

Figure 7-5 shows the location of three cross section lines to illustrate the interconnection between Suttor River and the groundwater system. Photographs shown in **Figure 7-3** and **Figure 7-4** of the Suttor River at the Bowen Development Road crossing were taken along Section line A - A'.

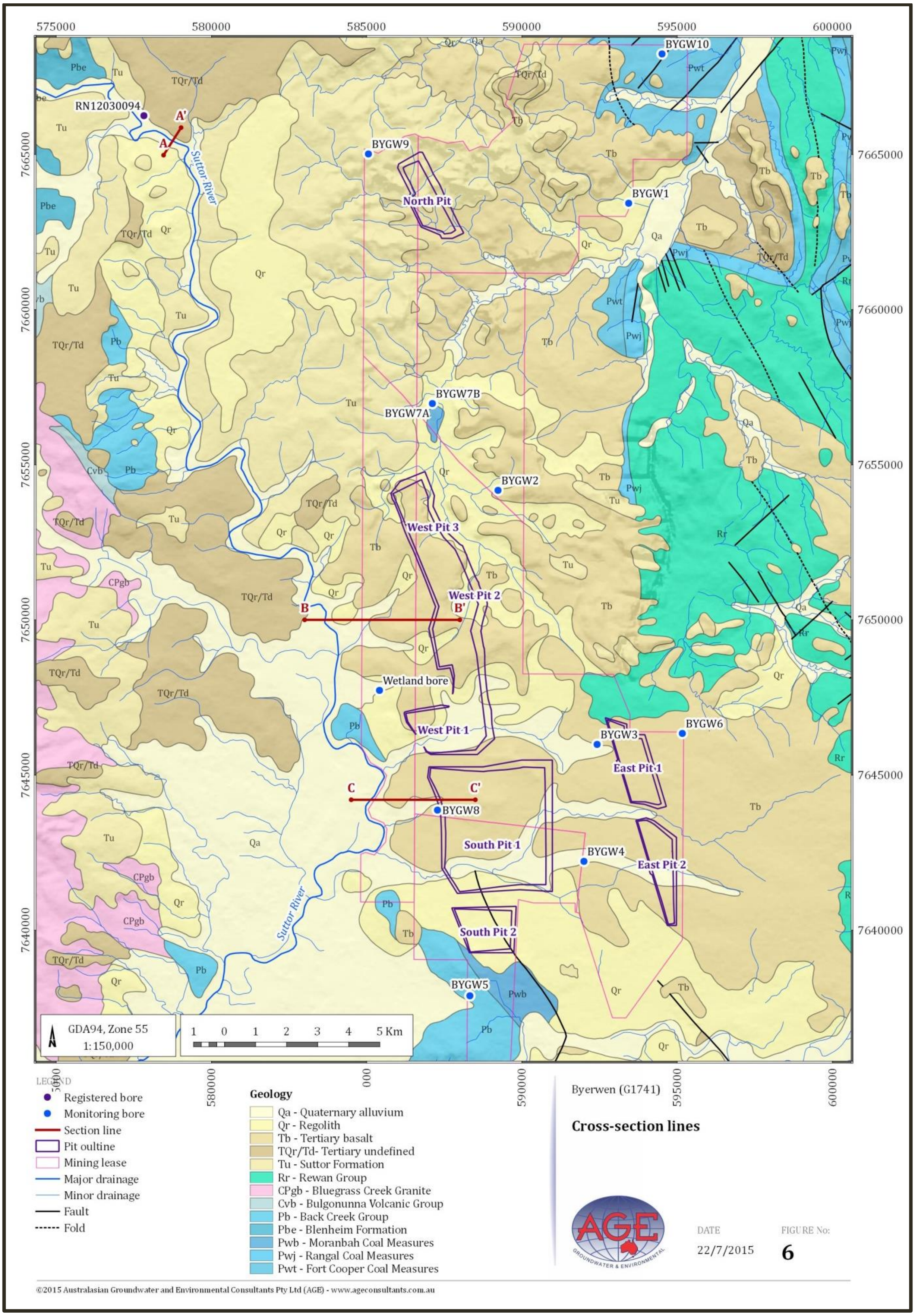


Figure 7-5 Cross-section lines

7.3.1.2.1 Cross section A - A’

Figure 7-6 shows the geology and hydrogeology along Section line A - A’.

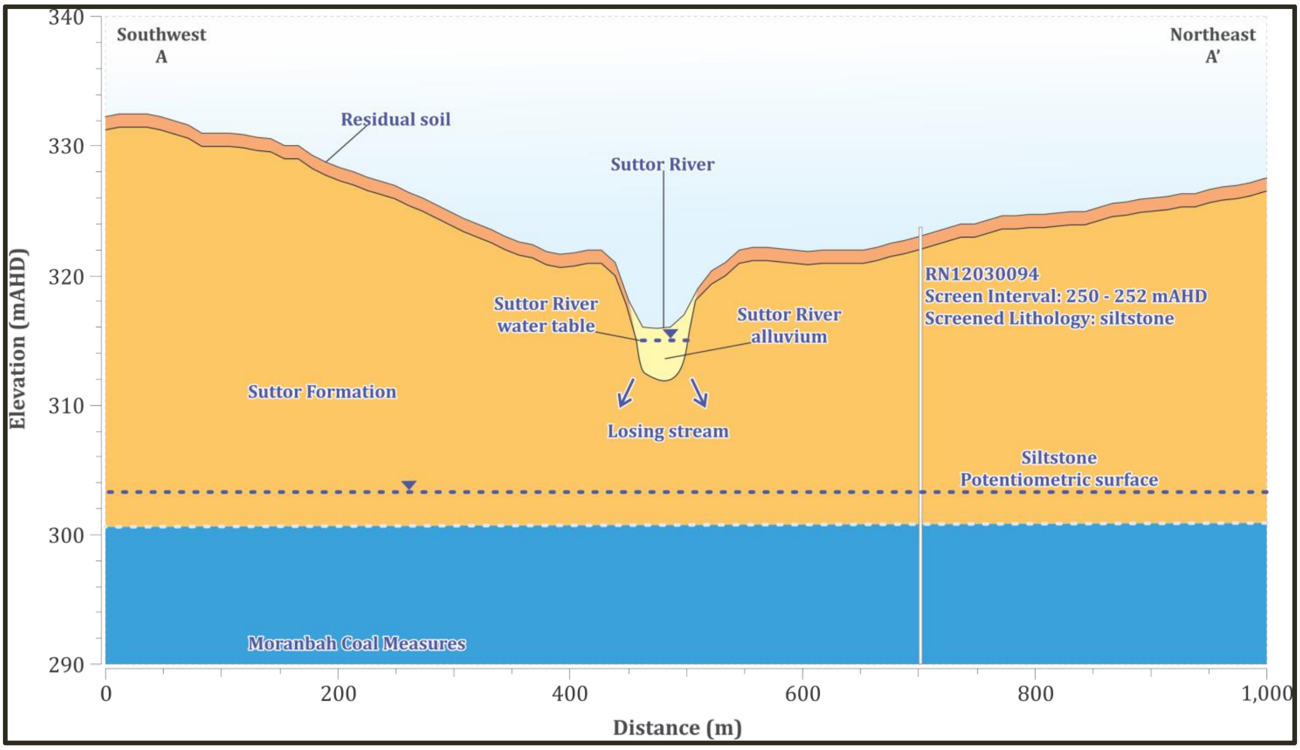


Figure 7-6 Cross-section A - A’

This cross section of line A - A’ (see **Figure 7-3** and **Figure 7-4** for photographs) is one kilometre in length and traverses the Suttor River in a northeast-southwest direction approximately one kilometre downstream of DNRM registered bore RN12030094, which is located along the true left (north-eastern) bank. The lowest point of the stream bed is approximately 316 m above Australian height datum (mAHD). The water table in the alluvium is conservatively estimated at one metre below the base of the river bed based on the photographs (see **Figure 7-3** and **Figure 7-4**).

Figure 7-7 presents the hydrograph data for registered bore RN12030094; the data shows the average water level has remained relatively stable over the last 20 years at approximately 302 mAHD (24 mbGL). Assuming the water level in the Suttor River alluvium is at 315 mAHD (as per the observed water hole one metre below the base of the river bed), the water level in the underlying Permian sediments is 13 m below the water level in the river alluvium. At this point the Suttor River can be classified as a ‘losing disconnected stream’ and therefore is not fed by groundwater.

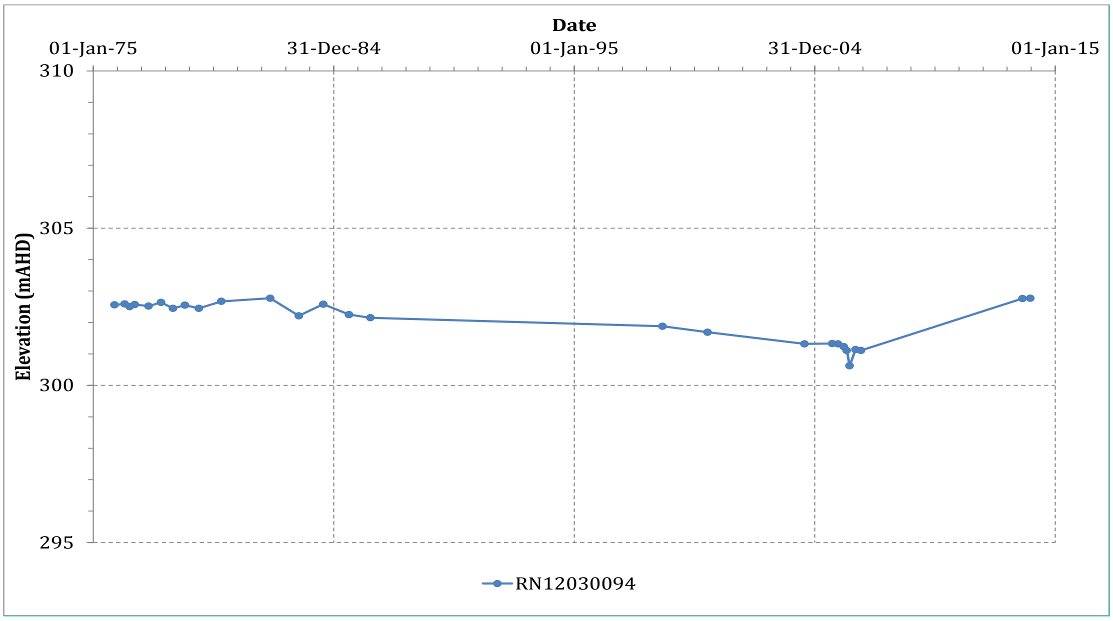


Figure 7-7 Hydrograph for Bore RN12030094

7.3.1.2.2 Cross section B - B'

Section line B - B' (refer to **Figure 7-5**) is longer at five kilometres in length and traverses the Suttor River and West Pit 2 & 3. **Figure 7-8** presents a cross-section along Section line B - B'. Water level data from monitoring bores (BYGW02 and BYGW03), and exploration holes (BY045 and BY062) indicate the water level is approximately 260 mAHD in this area. The LIDAR data indicates the river bed is at around 283 mAHD. Assuming the water table in the alluvium is 282 mAHD, the Suttor River would be a 'losing disconnected stream' at this location.

Section B - B' crosses an area of the Project with a thick Tertiary basalt cover, the thickest sequences correlating with a northwest trending palaeo-valley. Water level data indicates a significant thickness of basalt, with saturated basal sand. The basalt groundwater system is highly anisotropic[11] and the permeability of the unit is primarily via fracture flow. This is evident in the exploration hole data where airlift yields are highly variable between holes within the same lithology. Where fracturing in the basalt is present below the Suttor River, water is expected to drain away rapidly enhancing the disconnection between the river and the groundwater.

7.3.1.2.3 Cross section C - C'

Section line C - C' (refer to **Figure 7-5**) is four kilometres in length and traverses the Suttor River and South Pit 1. **Figure 7-8** presents a cross-section along Section line C - C'. Water level data from monitoring bore BYGW08 and exploration holes (BY083, BY321, and BY407) indicate the water level is approximately 249 mAHD in this area. The LIDAR data indicates the river bed is approximately 278 mAHD. Assuming the water level in the Suttor River alluvium is at 277 mAHD, the water level in the underlying Permian sediments is 28 m below the water level in the alluvium indicating the river at this point is best classified as a 'losing disconnected stream'.

The Byerwen geological model does not extend the full length of section line C - C' so the thickness of the Tertiary basalt below Suttor River has been inferred. Water level data indicates the Tertiary units are potentially unsaturated below Suttor River, and only the area of thicker sediments within the eastern half of the section line contains groundwater.

[11] Anisotropy: a substance exhibits properties with different values when measured in different directions

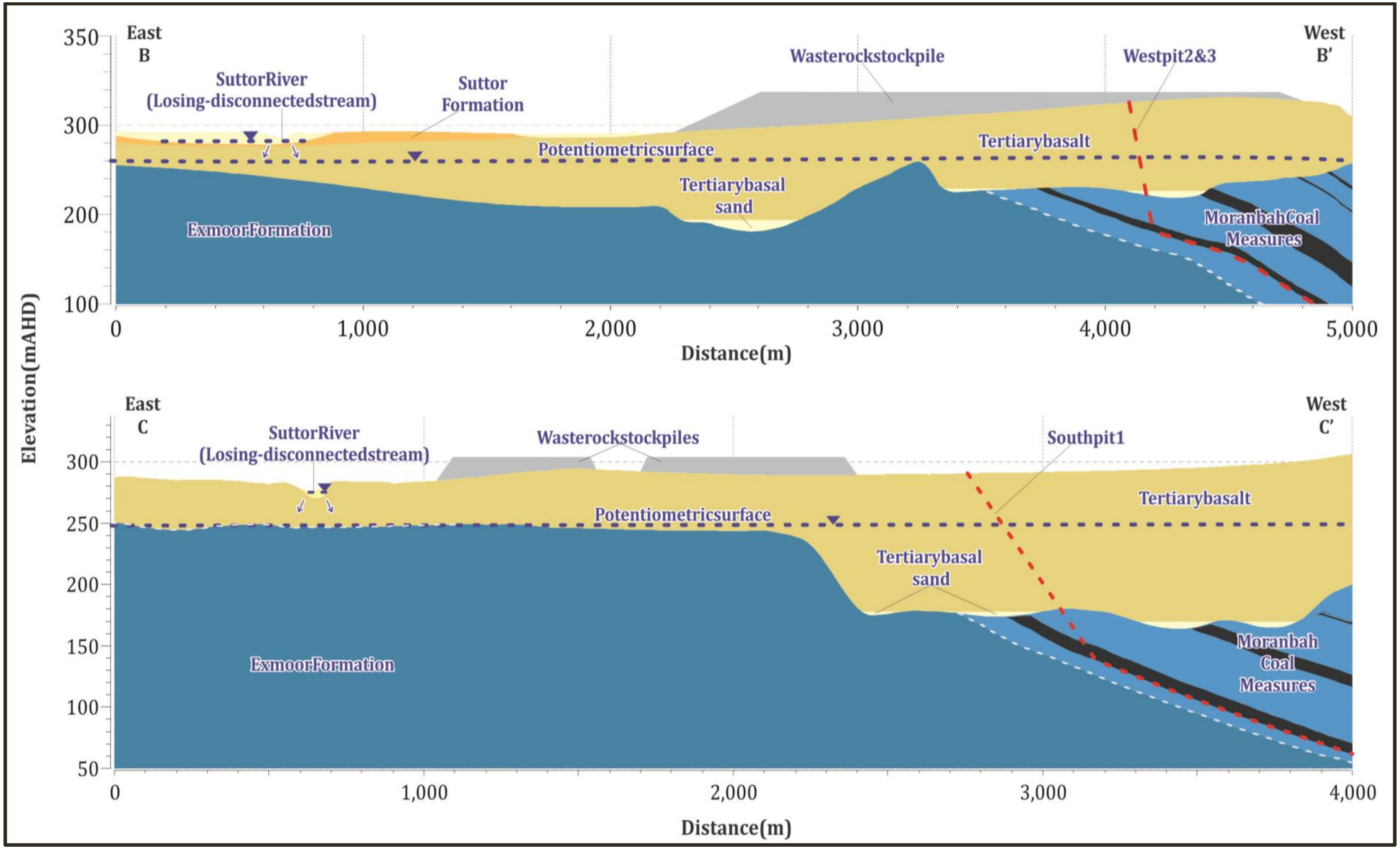


Figure 7-8 Cross-sections B - B' and C - C'

7.3.1.3 Nature of Connectivity to the Suttor River

The EPBC Conditions require confirmatory information on the potential impact of the Project on the Suttor River. Depressurisation and drawdown within the groundwater systems due to mining can only impact upon the Suttor River if there is a direct hydraulic connection between these sources, regardless of whatever drawdown may occur (including drawdown which might occur beneath the Suttor River). Therefore understanding the nature of this connectivity is important when assessing potential impacts.

For the Suttor River to be a gaining stream (and therefore susceptible to drawdown impacts) the surrounding water table must be above or at the same level as the river. The cross-sections indicate the groundwater level is well below the river level indicating it forms a 'losing disconnected stream' in the stretch adjacent to the Project area. This conclusion has been reached by inferring water level data to the river. Whilst a borehole immediately adjacent to the river would be required to physically observe this conclusion, it is not considered necessary to confirm the conclusions of this GMMP groundwater modelling study.

Discharge of groundwater to the river is improbable based on the available data, but there is potential for mounding of groundwater levels under the river due to seepage of river water (refer to **Figure 7-2**). The mounding of groundwater associated with a "losing disconnected stream" would recharge the groundwater system but remain hydraulically disconnected. This process will continue and be unaffected during and beyond the Project life, regardless of any drawdown which may occur.

7.3.2 Review of EIS Impact Assessment, Pit Inflows and Drawdown

The DoE approved the Project, issuing EPBC Conditions which included requirements that a study and model be undertaken into validating the assumptions and potential risks and impacts of the Project on groundwater resources, which were identified in the EIS. Based on the findings of this report that the Suttor River is a losing disconnected river, there can be no drawdown related impacts from the Project on the Suttor River. As such the overall findings from the EIS documents that the Suttor River has a negligible risk of impact from drawdown can therefore be considered as confirmed, by virtue of the confirmed lack of connection.

Further review of Project groundwater impacts (in addition to the potential Suttor River impacts identified in the EIS documents) was also undertaken as part of this GMMP groundwater modelling study, by reviewing the EIS groundwater model and then developing the GMMP groundwater model as a comparison for estimated pit inflows and the extent of potential drawdown.

The EIS documents assessed the groundwater inflows to the pits and drawdown extents, with the EIS methodology and results summarised in **Section 7.2** and subsections, with a review undertaken by AGE as follows.

The EIS documents used the method developed by Marinelli & Niccoli (2000) to estimate groundwater inflows and drawdown due to the Project. The analytical method estimates potential drawdown and groundwater inflow to a circular pit. The method calculates groundwater inflow from two separate layers. Firstly, Zone 1 considers steady state unconfined horizontal radial flow to the pit wall. Secondly, Zone 2 represents flow into to the base of the pit. Key assumptions for the Marinelli & Niccoli (2000) method include:

- the pit is cylindrical;
- the pit floor is modelled as one side of a circular disc;
- uniformly distributed recharge to the water table occurs within the drawdown extent; and
- Zone 1 and Zone 2 are separated by a no flow boundary

The method was developed for hard rock mines and quarries where the pit is generally circular and groundwater inflow from the pit floor is an important consideration. The method also assumes unconfined conditions, therefore, the saturated thickness of Zone 1 decreases closer to the pit.

The EIS documents used a conservative approach to calculate groundwater inflows and potential drawdown, by calculating the drawdown extent for each pit based on hydrogeological data from proximal bores and the geometry of each pit. The EIS documents assume no groundwater inflow via the pit floor, therefore all groundwater inflow to the pit will be through the pit walls. In actuality the pit floor will account for a very small proportion of groundwater in the pit due to the significantly lower vertical conductivity of the under-burden compared to the coal seams and the basalt. It is therefore considered valid to exclude the contribution of water from the pit floor for the purposes of environmental impact assessment.

Appendix A presents a summary of the data and assumptions made in the EIS Marinelli & Niccoli (2000) model, used to calculate pit inflows and maximum drawdown extent for all pits. The Project area was divided into eight pit areas; the geometric mean of hydraulic conductivity data from monitoring bores proximal to each pit was used to estimate inflows. Two scenarios were considered, being a low and a high hydraulic conductivity case.

Table 7-1 (see **Section 7.2.2.1**) presents the results for the pit inflows and the maximum zone of depressurisation for each pit, predicted in the EIS groundwater model using the Marinelli & Nicolli (2000) method. **Figure 7-1** (see **Section 7.2.2.1**) presents the results for the maximum zone of depressurisation across the Project, predicted in the EIS groundwater model using the Marinelli & Nicolli (2000) method.

The Marinelli & Niccoli (2000) method assumes an unconfined groundwater system. This means the saturated overburden including the Permian sediments, the Tertiary basalt, and the Suttor Formation, along with the coal seams are represented as a massive, hydraulically uniform rock mass. In reality the hydraulic nature of all groundwater systems in the Project area is highly heterogeneous. Although, the Marinelli & Niccoli (2000) method will not model this in detail and designed to consider that level of detail, if conservative parameters are applied then it can approximate impacts in a multi-layered system.

As a method of validation of the EIS documents, a comparable assessment of inflows and drawdown using an alternative groundwater modelling methodology was completed (the GMMP groundwater model), to enable a direct comparative validation of results. The methodology and results of the GMMP groundwater model are summarised in **Section 7.3.3**).

7.3.3 Perrochet & Musy Analytical Model Results

To allow a more direct and appropriate review, comparison and validation of results between the EIS analytical groundwater model and the GMMP groundwater model, an alternative analytical groundwater monitoring method was utilised

The Perrochet & Musy (1992) analytical model, presents formulae for modelling inflows to drains and the limit of influence (drawdown) of the drain. **Appendix B** presents a summary of the data and assumptions made in the GMMP Perrochet & Musy (1992) groundwater model, used to calculate pit inflows and maximum drawdown extent for all pits. **Appendix C** presents the conceptualisation, and the calculations utilised by Perrochet and Musy (1992).

The Perrochet & Musy (1992) model is applied to open cut mining pits in the case of the Project, because an open cut coal mine such as the Project, has open pits where the length is many times the width as they follow a coal seam down dip; therefore the pit is hydrogeologically analogous to an elongated drain. As such the formulas presented by Perrochet & Musy (1992) can be used to analytically model the potential magnitude of drawdown and inflow.

Perrochet & Musy (1992) is also consistent with several key assumptions in the Marinelli & Niccoli (2000) method, in that they are both for unconfined aquifers and both assume an isotropic rock mass. As such the adoption of Perrochet & Musy (1992) is considered an appropriate modelling method to compare and validate the EIS findings with regard to potential risks and impacts on the groundwater values in the Project area.

To provide a clear comparison to the Marinelli & Niccoli (2000) method presented in the EIS documents, the same input parameters for the low hydraulic conductivity scenario as were used in the EIS groundwater model (see **Appendix A**) were adopted for the GMMP groundwater model (see **Appendix B**).

Table 7-2 presents the results from the GMMP groundwater model (calculation methods presented in **Appendix C**).

Table 7-2 Pit inflows and drawdown - Perrochet & Musy method

Pit name*	Maximum drawdown extent (m)	Pit inflows (m^3/day)	Pit inflows (L/s)
North Pit	5,372	162.1	1.9
East Pit 1	967	27.3	0.3
East Pit 2	967	43.4	0.5
West Pit 1	2,947	91.4	1.1
West Pit 2	3,081	58.7	0.7
West Pit 3	3,081	165	1.9
South Pit 1	3,745	167.9	1.9
South Pit 2	902	14.3	0.2

* This study has interpreted a slightly higher water table surrounding East Pit 1 than was determined in the EIS documents due to updated dataset. Hence this study determined a measure of inflow whereas the EIS documents determined that East Pit 1 was above the water table with a proportionate nil rate of inflow.

Presented in **Figure 7-9** is the plotted representation of the maximum predicted zone of depressurisation (the drawdown) estimated in the EIS groundwater model using the Marinelli & Nicolli (2000) and the GMMP groundwater model Perrochet & Musy (1992) methods. The zone of drawdown is generally comparable between the two methods, with some boundaries aligning very closely, particularly along the south western section of the modelling, along the Suttor River.It is noted that the GMMP model drawdown, extends a further ~1.5 km from both West Pit 1 and North Pit, than the EIS groundwater model; however it does not encroach on the Suttor River with North Pit drawdown still >1km from the Suttor River at its closets point.

As is expected the drawdown is more extensive on the down dip of the highwall (generally the eastern side of the pits shown on **Figure 7-9**) where a larger thickness of strata are exposed within the pits, and less extensive on the up dip sides (generally the western side of the pits) where the more permeable coal seams outcrop and the depth of the pits are less.

Both analytical methods assume a very low recharge rate (~4mm/year); as such it was observed that by applying a slightly higher recharge rate of 5 mm/year using the Perrochet & Musy(1992) method, the extent of potential drawdown is reduced by approximately 500 m. This indicates the notable difference in results that the adoption of conservative input values has on the GMMP model.

The GMMP groundwater model predicts the pit inflows are between 0.2 L/s and 1.9 L/s. This assumes groundwater inflows only occur from the high-wall, with no groundwater inflow from the pit floor or below the waste rock, as the pit is progressively backfilled.

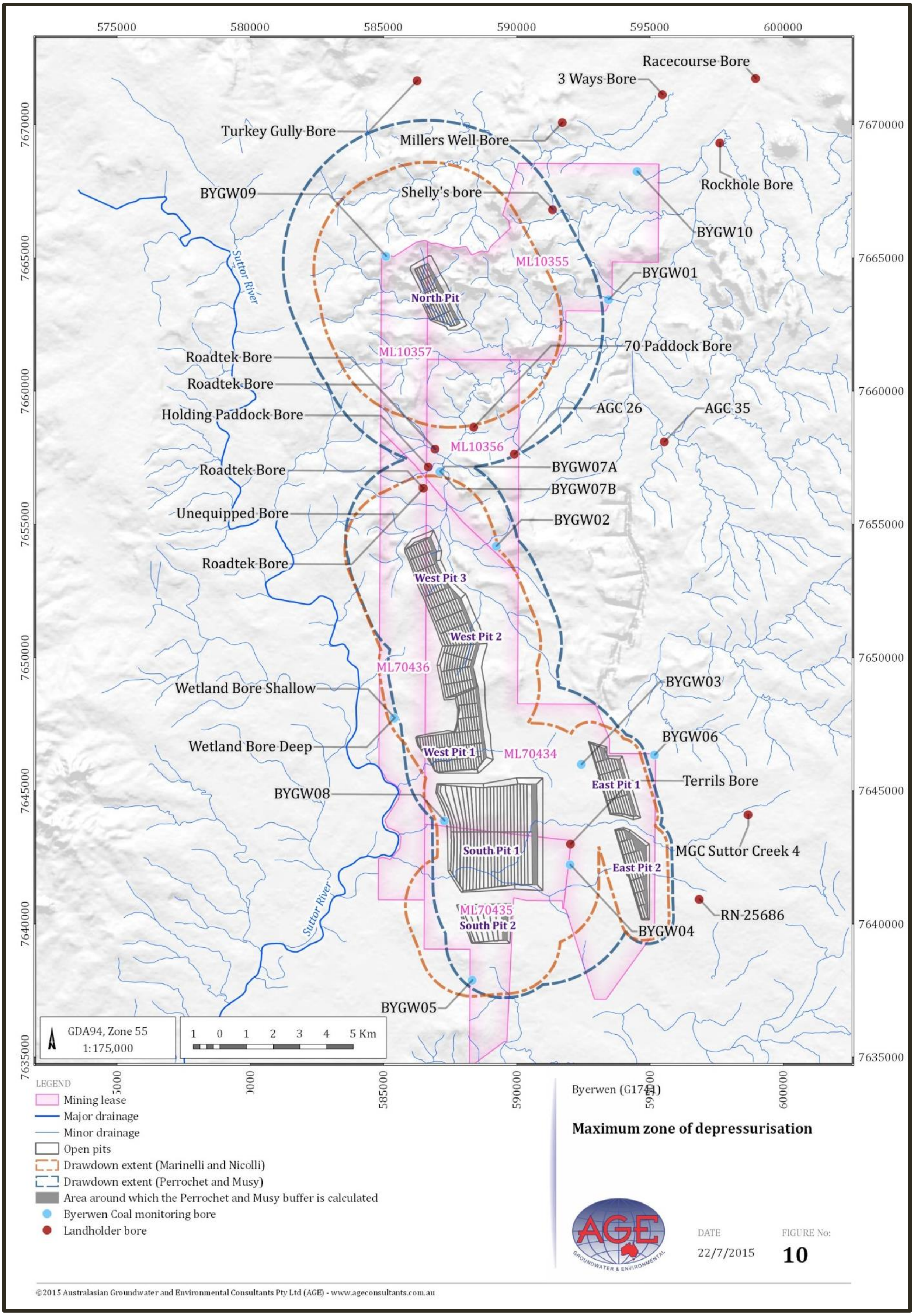


Figure 7-9 Maximum zone of depressurisation (EIS and GMMP model comparison)

7.3.4 Comparison of the EIS and GMMP Groundwater Models

The two methods for predicting drawdown provide comparable estimates for the maximum zone of depressurisation due to mining at the Project area. Both methods indicate that drawdown would be greater on the high wall sides (eastern sides) of the pits where the pit depths are greater. The EIS documents estimate drawdown will extend between 800 m to 3,800 m around the pits, with the largest zone of depressurisation predicted from North Pit due to the higher hydraulic conductivity of that area. The GMMP groundwater model using the Perrochet & Musy(1992) method, predicts drawdown will be between 900 m and 5,300 m from the pits with the maximum extent of depressurisation also occurring around the North Pit.

Drawdown in an unconfined system means the rock mass is physically dewatered as the water table decreases, whereas in a confined system the drawdown is a pressure response but the aquifer remains saturated. Applying an unconfined model to a confined system will under predict the extent of depressurisation. To accommodate this, the EIS groundwater model used conservative input parameters to avoid under prediction of impacts. Both methods also assume drawdown will reach a steady state condition, which in reality does not occur, and is therefore a conservative assumption inherent in the modelling method and the associated predictions.

Pit inflows presented in the EIS documents are inflows towards a cylinder, representing groundwater flowing into the pit from all four sides. In reality the low wall side will consist of spoil material and inflow from the low wall will come primarily from rainfall recharge to the spoil, with only a very minor component coming from upwelling and from through-flow below the spoil. It is expected the inflows will be primarily from the highwall and therefore could be half the predicted inflow from the analytical methods. Based on this the estimates given in the EIS documents are again considered conservative.

Although the two analytical methods predict comparable impacts, neither considers the groundwater storage in the overlying basalt. The EIS documents consider the basalt as an unconfined to semi-confined groundwater system, while the basal sand and the Permian groundwater systems are confined. The EIS documents also state the Tertiary groundwater systems are perched above the Permian. This interpretation is considered open to further review, in consideration of where the coal seams sub-crop; regardless of how this aspect is interpreted, it has no bearing on the potential impacts of the Project on the Suttor River or groundwater users, and as such is somewhat ancillary for the Project case.

Table 7-3 presents groundwater level data of the Tertiary groundwater monitoring bore and the closest exploration holes. The data shows that water levels in the Permian sediments and the basalt are comparable, suggesting a Perched groundwater system is unlikely.

Table 7-3 Comparison of water levels between the basalt and Permian sediments

Hole ID	Easting	Northing	Elevation	Type	Distance and direction from monitoring bore (m)	Open section / screened interval	SWL (mAHD)	Hydro-stratigraphic unit
BYGW08	587279	7643867	290.3	monitoring	-	56.5 - 65.5	246.9	Tertiary basalt
BY321	587927	7644447	295.3	exploration hole	870 NE	112 - 222	251.2	Tertiary / Permian?*
BY407	588925	7644259	316	exploration	1,700 E	120 - 322	248.5	Permian
BY083	587664	7643359	289	exploration	630 SE	66 - 180	251.2	Permian
BYGW07A	587122	7656990	263.4	monitoring	-	65-69	242.2	Tertiary basal
BYGW07B	587115	7656973	263.7	monitoring	-	46-52	240.8	Basalt
BY073	587136	7656971	263.1	exploration	20 SE	97 - 265	251.7	Permian
BY797	586621	7656925	271	exploration	500 W	108 - 287	247.7	Permian

* Although the EIS / AIEIS documents consider exploration hole BY321 has some contribution from the Tertiary, this cannot be confirmed

The hydraulic properties of the basalt can vary considerably as groundwater is primarily stored within fractures and vesicular zones. Massive zones without either of these properties will have a very low permeability. Furthermore, highly weathered basalt breaks down to clay with a very low permeability. Therefore, shallow highly weathered areas of basalt will generally not contain significant volumes of groundwater and can act as low permeability barrier to seepage. In contrast vesicular and fractured zones can store very large volumes of groundwater. Both analytical and numerical models assume an unconfined porous groundwater system and therefore neither approach replicates the highly heterogeneous groundwater system of the basalt.

There is potential for high groundwater inflows where pits intersects the thickest sequences of fresh, fractured and/or vesicular basalt. Airlift yield data in the EIS documents suggest some holes in the basalt produced very high airlift rates, upwards of 18 L/s. In contrast many holes did not intersect groundwater in the basalt, this conflicting observation highlighting the variability within this unit. There is a potential for discrete fracture sets, with the potential to hold significant volume of groundwater, to be intersected resulting in high inflow rates over the short-term. It is also just as probable that there will be fracture sets and vesicular zones which store water but are not intersected by the pit, and are not well connected to other fractured/vesicular zones and therefore will not drain in response to mining. These zones will act to buffer the drawdown response. The analytical methods represent the basalt as a porous medium resulting in an even drawdown response around the mine, without accounting for fracture sets which do not get drained by mining; therefore analytical models will generally over predict the zone of depressurisation, again representing an inherent measure of conservatism within the methodology.

7.3.5 Groundwater Modelling Guidelines

It is noted that written confirmation was provided to Byerwen Coal by the DoE, stating that an analytical model was considered suitable to satisfy EPBC Condition 12-e and 12-f, and a numerical model was not required (see **Section 7.1**).

This study was undertaken with reference to the National Water Commission Groundwater Modelling Guidelines[12] (the Guidelines) as per EPBC Condition 12-e. The Guidelines outline the groundwater modelling process, providing a sequence of model development from planning, developing and reviewing the adequacy of the proposed approach, through to reporting on groundwater modelling results. The Guidelines then provide detailed guidance on the individual steps of the groundwater modelling process, with particular detail provided on the methodology of numerical modelling, which may be required for more complex systems and/or for medium to high risk areas.

Accordingly a conceptual model of the hydrogeology was developed as per the Guidelines and used to undertake a risk assessment on the Suttor River. The study determined the project was low risk to the Suttor River due to the losing disconnected relationship between the river and the groundwater table. Therefore an analytical model was considered appropriate to predict the level of impact to the groundwater system. The specific design of the analytical model was selected based on the hydrogeological data collected at the project area. As per the guidelines this approach was then reviewed for adequacy and was determined to be fit for purpose as a comparative review of the EIS findings, and considered to be suitable given the conceptualisation and overall low risk in the area.

As such, reference to the sections of the guidelines which specifically deal with numerical models was not applicable or required.

[12] Barnett B., Townley L.R., Post V., Evans R.E., Hunt R.J., Peeters L., Richardson S., Werner A.D., Knapton A. and Boronkay A., (2012), *"Australian groundwater modelling guidelines"*, Waterlines report, National Water Commission, Canberra, June 2012.

7.3.6 Conclusions

The three cross sections prepared (**Figure 7-6** and **Figure 7-8**) all indicate the groundwater level in the Tertiary basalt and basal sand, as well as the Permian sediments, are between 12 m to 28 m below the Suttor River bed level. This indicates the length of Suttor River to the west of the Project area is a losing stream and is disconnected from the groundwater system. A losing disconnected stream is not impacted by fluctuations in the groundwater table and therefore cannot be impacted by any drawdown associated with the Project, regardless of the potential extent. Specifically, the proposed pits will not directly intersect the alluvium and even if depressurisation extends below Suttor River, whilst this is improbable, the losing disconnected nature of the river means it will not be impacted.

The analytical approach adopted for the EIS groundwater model for estimating inflow and drawdown, represents a simplified groundwater regime as it assumes gross values for complex hydrogeological interactions. The same assumptions are made for the GMMP groundwater model. As the Suttor River has been identified as having no connection to groundwater and as there are a very limited number of private landholder groundwater users which are relatively distant from the mining area, there is no potential for significant impacts. Accordingly the Marinelli & Niccoli (2000) method adopted in the EIS and the Perrochet & Musy (1992) method adopted for the GMMP groundwater model, are considered suitable and fit for purpose (i.e. assessing the potential groundwater impacts).

Therefore complex hydrogeological/hydrological modelling is not considered necessary for the purposes of impact assessment. According the EIS groundwater model is considered suitable and fit for purpose for the environmental impact assessment of the Project. This is especially so with the adoption of conservative assumptions and inputs into the modelling equations, which give a legitimately conservative estimate of potential drawdown distances, against which impact assessments to groundwater values can be undertaken and management measures developed if required.

The groundwater regime is not considered a sensitive area. Whilst drawdown within the groundwater system is expected around the mine, there will be no consequences for the Suttor River or groundwater users. In these low risk cases a simplified methodology to assess impacts is acceptable, and as such the analytical approaches are appropriate.

The key groundwater findings of the EIS (as follows) are considered validated:

- There is no connection between the Suttor River and the groundwater in the Project area which may experience drawdown, as such regardless of whatever drawdown may occur the Suttor River would not experience resultant effects;
- The extent of drawdown modelled in the EIS is considered suitable for the purposes of assessing potential impacts;
    - including for the identification of potential groundwater users within the potential drawdown extents
- The inflow values modelled in the EIS for inflow of groundwater into the various pits is considered suitable for assessing related potential impacts
- Quality of groundwater across the Project area is varied between geological units and location within the Project area, but is in general considered to be of intermittent occurrence, moderate to low yield, and of poor quality (sodium chloride type with a high total dissolved salt (TDS) content and high sulphate content).

The validation of these findings is based on:

- on a review of the hydrogeological data
- the development of a conceptual groundwater model
- the results of an analytical model developed for this GMMP using a different set of hydrogeological equations to those used in the EIS.

7.3.7 Recommendations

A validation of the groundwater predictions made in the EIS and GMMP groundwater models will be completed. Such a validation will be undertaken by reviewing model predictions against groundwater level monitoring data in existing wells and groundwater levels observed in new explorations holes, with the aim of determining the ongoing suitability of the existing conceptual model and identify if impacts are occurring outside the range predicted by analytical models. The timing of the first attempted validation will be dependent on the results of the groundwater monitoring. Specifically, once active dewatering commences on the Project, groundwater level monitoring results will be reviewed (as they are received), to identify changes in groundwater level associated with mining activities; if and when the first instance of mining related groundwater change is identified a validation and review of the models will be undertaken. Thereafter reviews of the suitability of the model will be undertaken on as required basis, appropriately contingent of the results of groundwater monitoring.

In the event that impacts are being detected outside of the range of model predictions, then the development of further modelling will be considered to address the specific observations which have been made; this may require the installation of additional bores to target specific geology or locations.

APPENDIX A: Assumptions for the Marinelli & Nicolli analytical model

Assumptions for the Marinelli & Nicolli analytical model:

Parameter	North Pit	East Pit 1	East Pit 2	West Pit 1	West Pit 2	West Pit 3	South Pit 1	South Pit 2
Depth of pit	220	140	140	280	280	270	350	135
effective radius of the pit (m)[A]	207.81	375	312.5	937.5	562.5	500	1,250	625
Pre-mining standing water level (mAHD)	237.81	239.3	239.3	256.5	256.5	256.5	240	239.3
Rainfall recharge(mm/year)[B]	3.95							
Rainfall recharge (m/day/m^2)	1.1 x 10-5							
Hydraulic parameters averaged from bore	BYGW01, BYGW09, BYGW10	BYGW03, BYGW04, BYGW05, BYGW06, BYGW08	BYGW03, BYGW04, BYGW05, BYGW06, BYGW08	BYGW02, BYGW03, BYGW08	BYGW02, BYGW03, BYGW08	BYGW02, BYGW03, BYGW08	BYGW03, BYGW04, BYGW05, BYGW06, BYGW08	BYGW03, BYGW04, BYGW05, BYGW06, BYGW08

Source: *Rob Lait & Associates (2013)*

Note: [A]*Effective radius calculated as the circumference is equal to the combined length of the pit walls*

[B]*Rainfall recharge assumed as 1 % of rainfall during the wet season recharges the groundwater system*

APPENDIX B: Assumptions for the Perrochet & Musy analytical model

Assumptions for the Perrochet & Musy analytical model:

Parameter	North Pit	East Pit 1	East Pit 2	West Pit 1	West Pit 2	West Pit 3	South Pit 1	South Pit 2
Depth of pit	220	140	140	280	280	270	350	135
Pit length (m)	2500	2200	3500	4500	1600	2600	3800	1230
pit width (m)	160							
effective radius of the pit (m)	80							
Pre-mining standing water level (mAHD)	234.3	239.3	239.3	256.5	256.5	256.5	239.3	239.3
Saturated thickness of the pit wall (m)	187.4	81.9	81.9	242.3	242.3	232.3	291.9	76.9
Rainfall recharge (mm/year)	3.95							
Rainfall recharge (m/day/m2)	1.1 x 10-5							
Hydraulic parameters averaged from bore	BYGW01, BYGW09, BYGW10	BYGW03, BYGW04, BYGW05, BYGW06, BYGW08	BYGW03, BYGW04, BYGW05, BYGW06, BYGW08	BYGW02, BYGW03, BYGW08	BYGW02, BYGW03, BYGW08	BYGW02, BYGW03, BYGW08	BYGW03, BYGW04, BYGW05, BYGW06, BYGW08	BYGW03, BYGW04, BYGW05, BYGW06, BYGW08

Note: *[a]Rainfall recharge assumed as 1 % of rainfall during the wet season recharges the groundwater system*

APPENDIX C: Perrochet & Musy (1992) analytical model equations

Perrochet & Musy (1992) present formulae for estimating inflows to drains and the limit of influence of the drain, i.e. the drawdown. Because open cut coal mine generally have a length many times their width as the follow a coal seam down dip the pit can be likened to an elongate drain. As such the formulas presented by Perrochet & Musy are useful for estimating the potential magnitude of drawdown and inflow.

Figure B 1 presents the analytical model for Perrochet & Musy method; the formula for inflows is as follows:

$$Q(t) = \frac{\left(2K_2 d(t) + K_1(H-D)\right)(H-D)}{L(t)}$$

where:

Q	=	rate of groundwater inflow per unit length of face at time, t ($m^3/s/m$)
K_1	=	hydraulic conductivity layer 1 (m/s)
K_2	=	hydraulic conductivity layer 2 (m/s)
D	=	depth seepage face to impervious boundary (m)
H	=	hydraulic head (m)
L(t)	=	calculated limit of influence (m) as below
L(0)	=	initial limit of depression zone (m)
d(t)	=	calculated equivalent depth (m)

The equivalent depth is calculated as follows:

$$d(t) = \frac{\pi D L(t)}{4D\ln\left(\frac{D}{u}\right) + \pi L(t)}, L(t) > 2D$$

$$d(t) = \frac{\pi L(t)}{4\ln\left(\frac{2L(t)}{u}\right)}, L(t) < 2D$$

where:

u	=	wetted perimeter of the drain

The length of the depression zone at time t is calculated as follows:

$$L(t)=\sqrt{\left(L_0^2-\frac{(2K_2d+K_1(H-D))(H-D)}{i}\right)e^{-\left(\frac{8i}{\mu_1(4-\pi)(H-D)}\right)t}+\frac{(2K_2d+K_1(H-D))(H-D)}{i}}$$

where:

μ_1	=	drainable porosity layer 1
i	=	rainfall recharge

The length of the depression zone for a given drawdown Δ m is calculated as follows:

$$x(t)=L(t)\left(1-\sqrt{1-\frac{(H-\Delta-D)^2}{(H-D)^2}}\right)$$

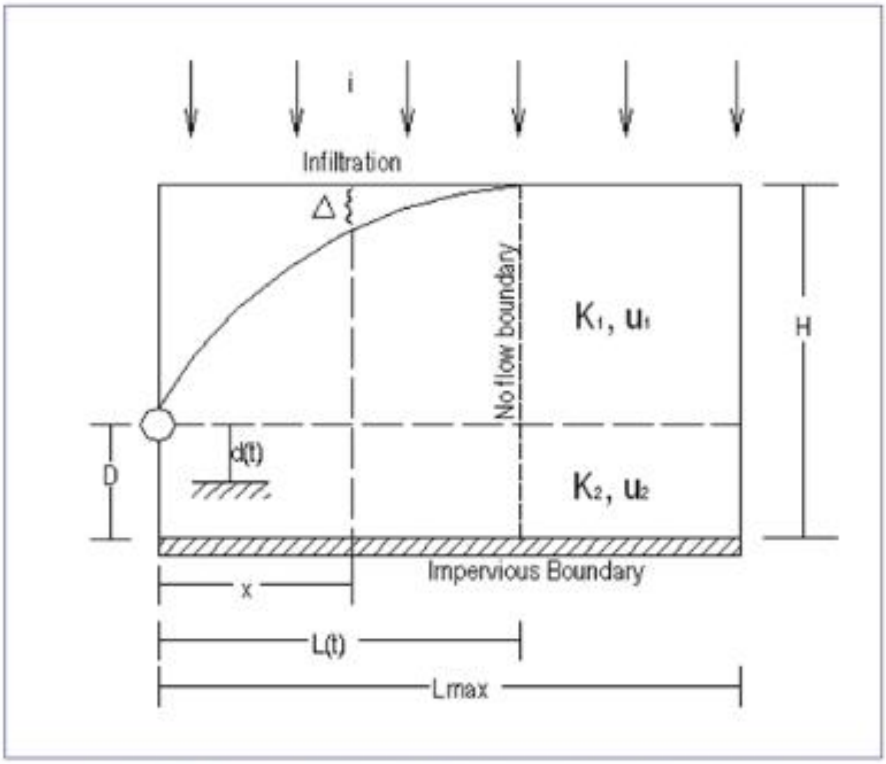


Figure B 1 Analytical model for inflow into a drain