GROUNDWATER STUDY

Appendix G

Appendix G — GROUNDWATER STUDY

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Australasian
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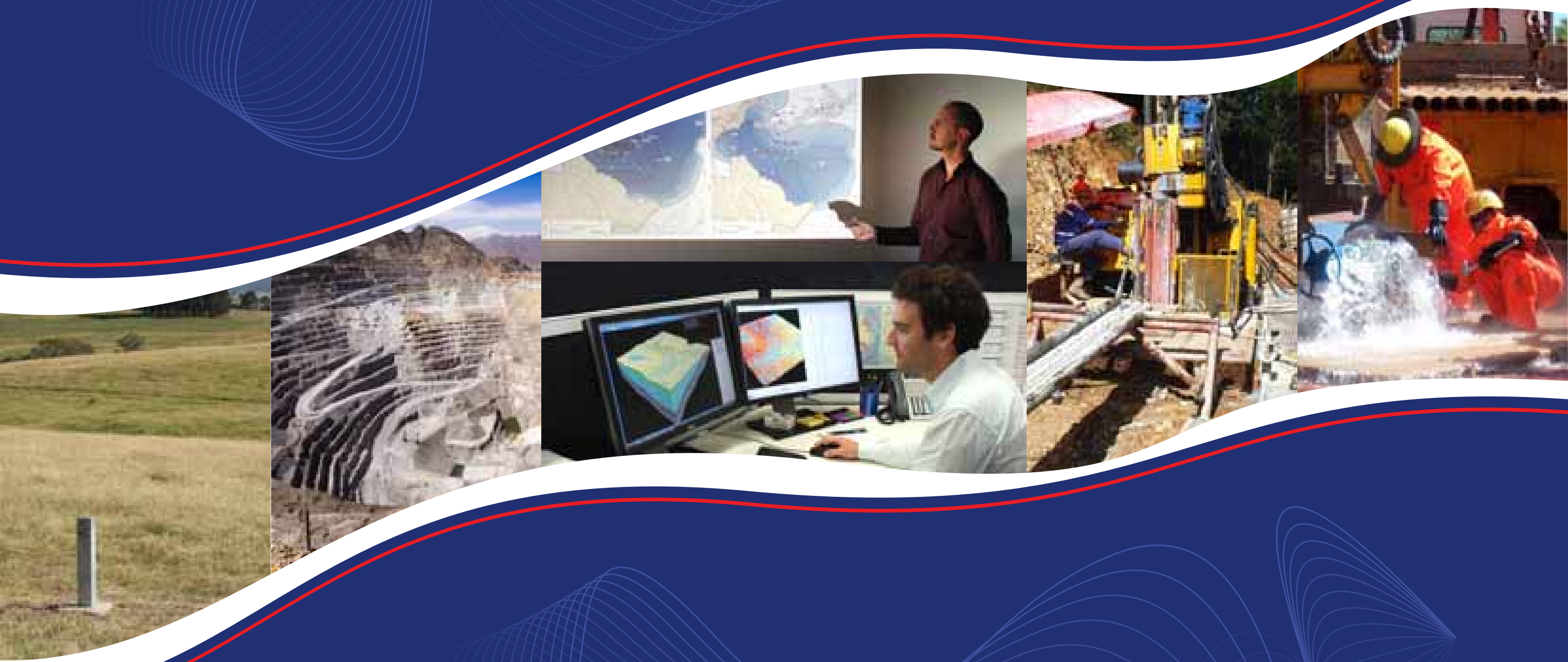
Consultants Pty Ltd
(AGE)



Report on

HVO South Modification 5 Groundwater Study

Prepared for

EMM Consulting Pty Limited

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Executive summary

Coal & Allied Operations Pty Limited and HVO Resources Pty Limited (Coal & Allied) own the Hunter Valley Operations (HVO) mining complex, which is located 24km north-west of Singleton in NSW. Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) were engaged by EMM Consulting Pty Limited to develop a groundwater impact assessment for the HVO South Modification 5 (the proposed modification).

As part of the proposed modification, Coal & Allied proposes to access the deeper Bayswater coal seams within the current approved footprint of Cheshunt Pit and Riverview Pit, and down to the Vaux Seam in South Lemington Pit 2. Due to the proposed deeper mining, there is a need to revise the overburden emplacement strategy and provide an updated final landform, which includes a change in the final void design for Riverview Pit.

The hydrogeological setting of the project area comprises two key stratigraphic units, the Quaternary alluvium and Permian aged Wittingham Coal Measures. The Quaternary alluvium comprises shallow sequences of clay, silty sand and sand, underlain by basal sands and gravels that form a highly productive groundwater source that is suitable for stock water supply, and used sporadically for this purpose. The Wittingham Coal Measures comprise economic coal seams interbedded with relatively low permeability sequences of siltstone, sandstone and shale. The coal measures contain groundwater that is generally moderately saline and not suitable for stock water supply or irrigation.

A contemporary numerical groundwater model was developed to assess the impact of the proposed modification on groundwater resources and users in accordance with relevant regulatory requirements and guidelines. The contemporary model was also used to simulate the currently approved mining to determine the increase in peak water take resulting from the proposal to extract deeper coal seams. The Wittingham Coal Measures are extensively mined within the region; therefore, a large regional-scale numerical groundwater flow model was developed to assess cumulative impacts with other mines at HVO North, Cumnock, Ravensworth, Ashton, HVO South, United, Wambo, Mount Thorley and Warkworth. The numerical model was developed using MODFLOW-USG, and covered approximately 27km from east to west and 39km from north to south. The model comprised up to 71,049 cells per layer, with a total of 34 layers representing the stratigraphy. The groundwater model was peer reviewed by Dr Frans Kalf of Kalf and Associates Pty Ltd.

The modelling indicates the mining will directly remove water from the Permian coal measures, and indirectly alter fluxes of groundwater within the alluvial aquifers and the highly connected streams. The numerical model was used to estimate the direct and indirect water take from each water source, to determine the volumes of water that need to be accounted for with water licenses in accordance with the Aquifer Interference Policy.

A total peak take of 2,664ML/year is predicted for proposed modification (inclusive of the existing approval) from all water sources. Within the total peak take, the model predicts 1,591ML/year of direct take from the Permian groundwater, which is currently regulated under the North Coast Fractured and Porous Rock WSP and an indirect take of 489ML/year from the Hunter Unregulated Water Sharing Plan (WSP) and 584ML/year from the Hunter Regulated WSP. These combined volumes are within previously predicted maximum water takes for the currently approved operations stated in ERM (2008a). The proponent has sufficient water licences to account for the modified project, inclusive of the proposed modification.

The modelling indicates the remodelled approved HVO South operations plus the proposed modification will reduce baseflow to the Hunter River and Wollombi Brook by a peak of 584ML/year and 107ML/year, respectively. The reduced baseflow is considered undetectable (<0.2%) when compared with the average annual flow in the Hunter River (343,137ML/year) and Wollombi Brook (73,883ML/year).

Water balance modelling indicated the final void lake will equilibrate around a level of approximately 30mAHD, which is lower than the level of the regional water table. It will therefore act as a 'sink', drawing in groundwater and creating a long term water take post mining. The model predicts the water take from all water sources will peak towards the end of mining (year 15), then slowly reduce over time as the groundwater system gradually equilibrates to the modified landform. When equilibrium conditions occur, about 400 years post mining, it is estimated that the long term take will be 30ML/year from the Hunter Unregulated WSP, 288ML/year from the Hunter Regulated WSP and 206ML/year under the North Coast Fractured and Porous Rock WSP.

The modelling indicated the proposed modification does not significantly influence the extent or magnitude of groundwater level decline within the alluvial aquifers along the Hunter River and Wollombi Brook. This is because the proposed modification is within the same footprint as the approved mining, and the majority of the drawdown is induced by approved mining of the shallower geological units, which are better connected to the alluvium. The modelling indicated the approved mining will induce some drawdown along the fringes of the alluvium, where the saturated thickness and transmissivity of the aquifer is lower. The drawdown reduces towards the centre of the flood plain where the Hunter River and Wollombi Brook occur, and consequently transmissivity of the alluvial aquifer increases. A number of ecosystems that potentially depend on groundwater have been identified in riparian zones within the flood plain along the Hunter River and Wollombi Brook. In some areas the ecosystems coincide with the fringes of the alluvium where drawdown is predicted to occur. The ecology study within the Environmental Assessment considered the potential for the predicted drawdown to impact upon the functioning of these ecosystems.

The numerical groundwater model identified that the proposed modification will not impact groundwater levels within any private bores by more than the trigger of 2m specified within the NSW Aquifer Interference Policy.

A recovery model was also run with the proposed final void within Riverview Pit. Water balance modelling indicated the final void will gradually fill with groundwater and runoff over time and reach a final pit lake level of approximately 30mAHD. The pit lake water level is around 20m to 30m below pre-mining groundwater levels, indicating that the void will act as a sink in perpetuity and no void water would therefore escape into the surrounding groundwater system. The proposed final void is located further away from the Hunter River compared to the currently approved final void. The greater distance from the river results in a reduced hydraulic gradient and therefore reduces the potential impacts on the alluvial and surface water systems.

In summary the groundwater study identified that proposed mining of the deeper seams within the approved mine footprint will create limited additional impact on the overall alluvial groundwater system, compared to already approved mining. The modelling indicates that the proposed modification accounts for less than 12% of the total indirect alluvial and surface water take for the proposed modification plus remodelled approved HVO South operations.

The greatest drawdowns are visible within the Bayswater Seam, which has not been mined before within Riverview Pit. However, no direct environmental consequences are predicted due to drawdown in the coal seam, as there are no bores or ecosystems relying on this relatively poor quality groundwater system.

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Report on

HVO South Modification 5 Groundwater Study

1 Introduction

Coal & Allied Operations Pty Limited and HVO Resources Pty Limited (Coal & Allied) owns the Hunter Valley Operations (HVO) mining complex, which is an existing open cut coal mine located approximately 24kilometres (km) north-west of Singleton, NSW (Figure 1-1). HVO South is integrated at an operational level with HVO North (together described as 'HVO') and has the ability to move material and associated equipment around HVO including run-of-mine (ROM) coal, product coal, coal rejects, overburden and water as required. The mining activities at HVO are geographically divided by the Hunter River into HVO North and HVO South. While HVO is managed as one operation, HVO North and HVO South each have separate planning approvals.

HVO South operates under PA 06_0261, which was granted by the then Minister for Planning on 24 March 2009, under Part 3A of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). The original approval has been modified on four occasions, predominately relating to administrative matters. The mine is within the Singleton local government area (LGA).

HVO South comprises the Riverview Pit, Cheshunt Pit and South Lemington Pits 1 and 2, Lemington Coal Preparation Plant (LCPP) and all related mining activities and infrastructure such as overburden and tailings emplacement areas and the approved but yet to be constructed conveyor, rail, or haul road option(s) to transport product coal from LCPP to the Wambo rail spur.

Modification to the HVO South project approval (PA 06_0261) is required to enable the implementation of an efficient and flexible mine plan to meet market conditions. PA 06_0261 authorises mining in three main areas namely:

- Cheshunt Pit;
- Riverview Pit; and
- South Lemington Pits 1 and 2.

Existing mining and the proposed modification are further discussed under Section 1.1.

EMM Consulting Pty Limited (EMM) was engaged by Coal & Allied as the lead consultant for the preparation of an environmental assessment (EA) to accompany the application to modify PA 06_0261. Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) was engaged by EMM to develop a groundwater impact assessment as part of the EA. The groundwater impact assessment satisfies relevant NSW government requirements for groundwater assessments.

1.1 Project description

This groundwater assessment examined the groundwater related impacts associated with the modification and compares those to the approved development, as well as the cumulative groundwater impacts of approved and reasonably foreseeable mines.

1.1.1 Approved operations

HVO South generates thermal and semi-soft coking coal for the local and export market. Open cut mining at HVO South is conducted using a dragline and truck and shovel method. Run of Mine (ROM) coal is crushed at the on-site coal handling facilities and product coal is transported by rail to domestic customers and the Newcastle Port for export.

HVO South commenced mining operations in 1997 and is currently approved to continue until 23 March 2030 (Table 1-1). North of the Hunter River, Coal & Allied operates HVO North, which commenced operations over 65 years ago at West Pit. The location of the various mine areas are shown on Figure 1-1 and details about the HVO South and HVO North pits are included in Table 1-1.

Table 1-1 Summary of approved mine workings and target seams

Reference name	Mine area	Basal coal seam	Start date	End date
HVO South	Cheshunt Pit (open cut)	Bayswater	2002	2028
	Cheshunt Pit north-eastern section (open cut)	Vaux	2002	2014
	Riverview Pit (open cut)	Vaux	1997	2028
	South Lemington Pit 1 (open cut)	Bowfield	1998	2024
	South Lemington Pit 2 (open cut)	Bowfield	2015	2020
	Lemington Underground (underground)	Mt Arthur	1971	1992
HVO North	North Pit (open cut)	Vaux	1979	2003
	Alluvial Lands (open cut)	Vaux	1993	2003
	Carrington Pit (open cut)	Bayswater	2000	2021
	West Pit (open cut)	Bayswater to Hebden	1949	2025

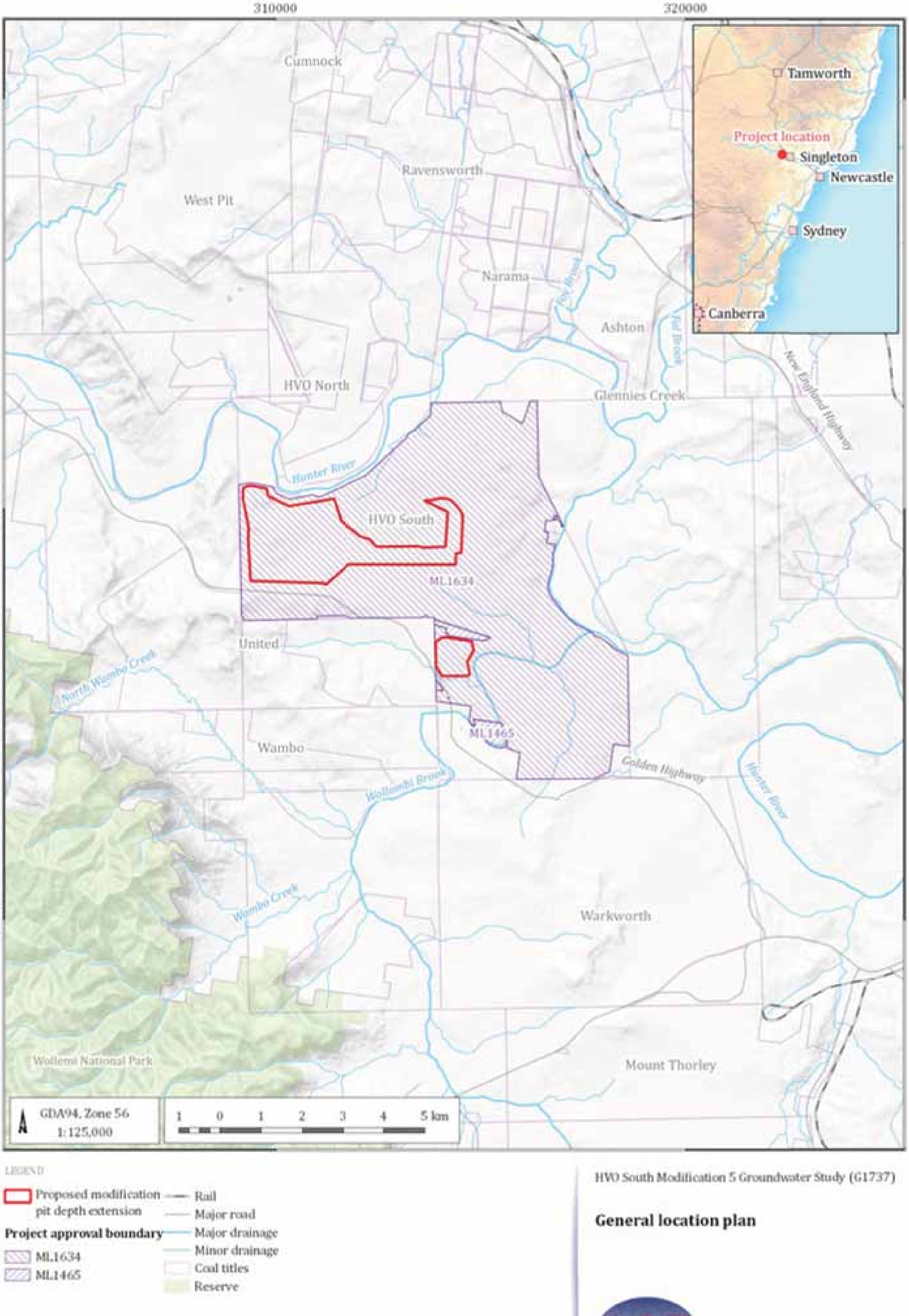
Mining operations first commenced at the now HVO over 65 years ago, in 1949. The current HVO South operation has gone through various modifications to its mine plan during the life of its operations. Since 1998, four groundwater assessments involving numerical groundwater modelling have been conducted for the now approved HVO South mine plan (Cheshunt, Riverview and South Lemington pits). These are:

- Mackie Environmental Research (1998) – developed a one layer regional scale MODFLOW groundwater model to assess the groundwater impacts of a revised mine plan for Cheshunt Pit and Riverview Pit (both to be mined to the base of the Vaux seam).
- Mackie Environmental Research (2005) – developed 12 layer sectional models (2D models) using FEFLOW to assess the impact of reducing the 150m buffer between Cheshunt Pit and the Hunter River alluvium to 100m.
- Rust PPK (1998) – developed a three layer AQUIFEMN model in order to assess the impact of developing South Lemington Pits 1 and 2 (both to be mined to the base of the Bowfield Seam).
- Environmental Resources Management (2008a) – developed two small 3D FEFLOW models with five to six layers, to assess the impact of revising the footprint and deepening mining at Cheshunt Pit (to the base of the Bayswater Seam) and Riverview Pit (to the base of the Vaux Seam), and revising the footprint at South Lemington Pit 1.

Similar groundwater impacts were identified by each of the historic groundwater assessments listed above. These groundwater impacts include:

- Depressurisation of the Permian coal measures and groundwater inflows to the active mine areas, with Permian groundwater level drawdown extending between 2km and over 6km from the mine area.
- Reduced flow of groundwater from the Permian to the alluvium, as well as reduced flow from the alluvium to the Hunter River and Wollombi Brook (ie reduced baseflow contributions).
- Reduced groundwater levels within the alluvium along the Hunter River and Wollombi Brook. However these studies also identified that the dominant River Red Gum communities are largely reliant on a surface water flood regime and as a result, there were no predicted impacts on ecological communities due to alluvial groundwater drawdown.
- Reduced groundwater levels were predicted in one private bore near the town of Warkworth that intersect the Permian coal measures. No other bores were identified as being potentially impacted as drawdown was largely restricted to mine owned land, and alluvial impacts were expected to be buffered by surface water recharge.
- The final landforms showed that the final voids would act as a 'sink', drawing groundwater in and preventing migration of spoil leachate into the alluvial or surface water systems.

Further details about the four groundwater studies completed for the now approved HVO South operations relevant to the proposed modification are included in Section 5.7.



HVO South Modification 5 Groundwater Study (G1737)

General location plan

DATE 1/7/2016

FIGURE No: **1-1**

1.1.2 Approved operations

Mine sequencing at HVO South has the Cheshunt and Riverview pits operating concurrently. The Riverview Pit is currently designed to extract coal down to the base of the Bowfield Seam, but approved to the base of the Vaux Seam. Cheshunt Pit, which is approved to the base of the Bayswater Seam, is designed to advance through the mined areas in Riverview Pit, stepping up from the deeper Bayswater Seam to extract the seams from below the Bowfield Seam, including the Vaux Seam. South Lemington Pits are mined separately to Cheshunt and Riverview and are approved to mine to the base of the Bowfield Seam.

The proposed modification will enable the Cheshunt Pit to continue mining through the Riverview area, extracting the deeper Bayswater Seam, below the Vaux Seam. This is shown conceptually on Figure 1-2. The proposed modification will also enable mining down to the Vaux Seam, below the Bowfield Seam in South Lemington Pit 2. Mining of the deeper seams will occur within the existing approved disturbance footprint.

The mining of the deeper seams will require a revision to HVO South's overburden emplacement strategy. The overburden emplacement strategy requires an increase in dump height in some areas and provides the opportunity to develop a more natural landscape into the post mining landform design using micro-relief design techniques. The change in the mine design also moves the evaporative basin in the final void further from the Hunter River (Figure 1-2). The area of the approved final void (Cheshunt Pit) will be rehabilitated as part of the proposed modification.

The proposed modification also seeks to increase the rate of extraction and processing from 16 Million tonnes per annum (Mtpa) to 20 Mtpa of ROM coal during peak production. This will provide HVO South with flexibility for production interactions with HVO North to meet changing market conditions.

In summary, Coal & Allied is seeking to modify PA 06_0261 to allow:

- the progression of mining of the deeper Bayswater Seam from Cheshunt Pit into Riverview Pit, and mining the Vaux Seam below the Bowfield Seam in South Lemington Pit 2;
- a modification to the currently approved overburden emplacement strategy resulting in, amongst other changes, the relocation and shape of the evaporative basin in the final void and the inclusion of more natural landform with micro-relief design into the post mining landform design;
- an increased rate of extraction from 16Mtpa to 20Mtpa ROM coal at peak production and an increased processing rate of coal extracted from HVO South from 16Mtpa to 20Mtpa of ROM coal across HVO coal preparation plants; and
- removal of redundant prescriptive blasting conditions and replacement with contemporary outcome based conditions.

The proposed modification will not change the approved footprint of disturbance, mining method, employee numbers, integrated tailings and water management across HVO or extend the project approval period. The components listed above are taken collectively to form the 'HVO South Modification 5', which is referred to herein as the 'proposed modification' (Figure 1-2).

1.2 Objectives and scope of work

The objective of this groundwater assessment was to assess the impact of the proposed modification compared to the approved development on the groundwater regime. As well as develop measures to avoid, mitigate and monitor potential impacts and address the requirements of NSW government legislation and policies.

As detailed in Section 3.3.1 of the main EA report (ERM 2016), an opportunities and constraints analysis of conceptual mine plans for HVO South was undertaken by technical specialists, including AGE, as part of the mine plan optimisation process. The main objective of the analysis was to identify opportunities and risks to approval, enabling Coal & Allied to make an informed decision on whether to proceed with seeking modification of the project approval and/or the scope of mining activities to be addressed by that modification and for recommendations to be further considered in the mine planning process. It included a series of workshops and iterations involving mine planners and technical specialists.

The mine has been operational for over 65 years; therefore, the surrounding physical environment is well understood. Surface and groundwater investigations completed for HVO South are based on extensive baseline data from the HVO surface and groundwater monitoring network.

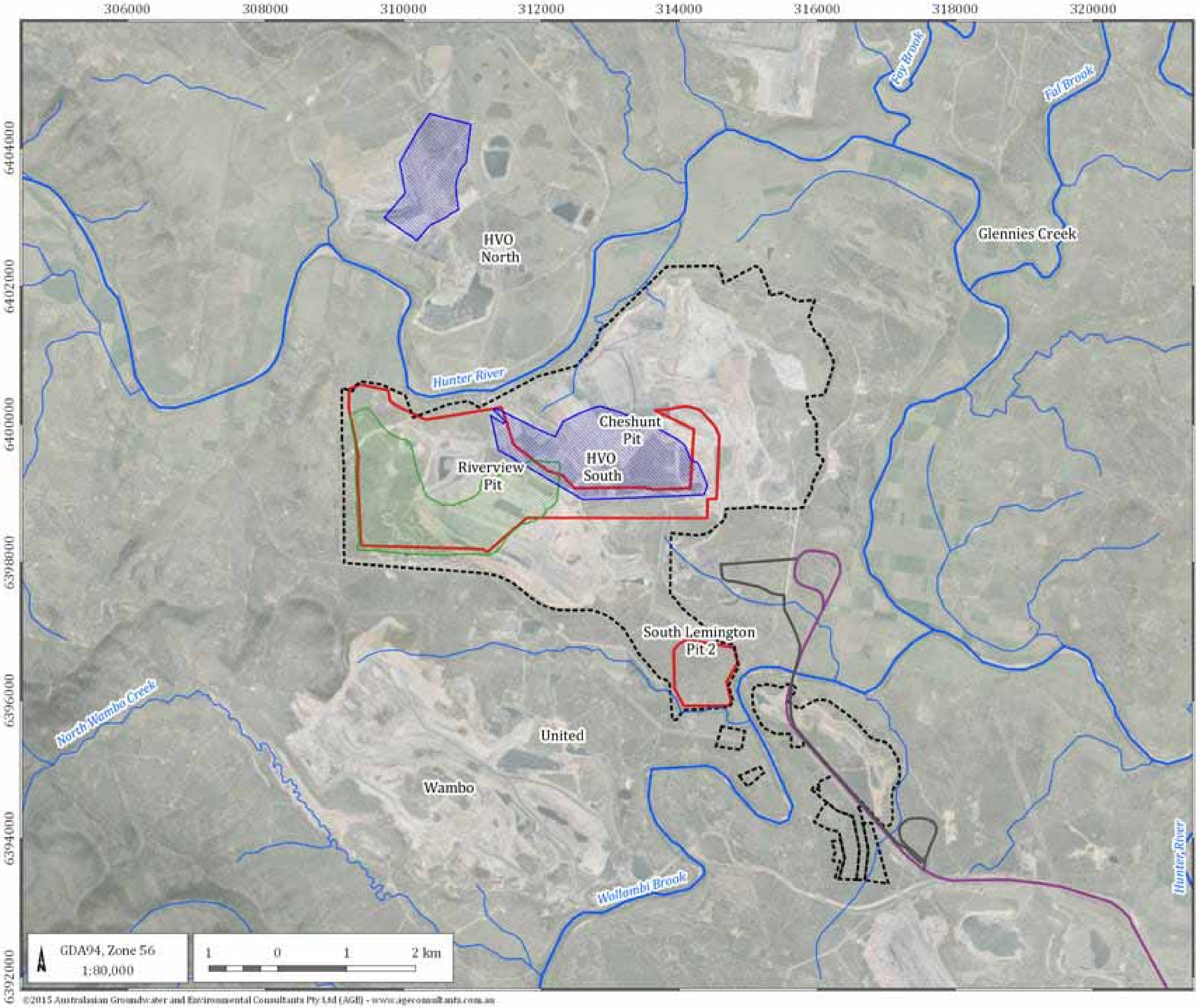
The groundwater impact assessment therefore included consideration of:

- existing background data and any data gaps;
- groundwater sources, including hydraulic properties and quality;
- potential interaction between the mining areas and alluvium and the potential long term impacts on groundwater quantity and quality;
- interaction between adjacent and nearby historical, current and approved future mining operations;
- groundwater interception from the proposed operation from each geologic unit, for input into the water balance modelling being completed as part of a separate surface water study (WRM 2016);
- recovery of groundwater systems and the final void post mining;
- extent of groundwater impacts as a result of the operation of the proposed mine, including long term impacts on regional groundwater levels;
- potential impacts on groundwater dependant ecosystems (GDE);
- potential drawdown and groundwater quality influence in private bores as a result of changes to the regional groundwater system;
- compliance with the NSW Aquifer Interference Policy (AIP) (DPI 2012); and
- proactive mitigation measures and monitoring.

The modification is proposed to commence in 2017 and be completed in 2030. To assess the proposed modification, a new contemporary numerical model was developed based on existing HVO groundwater models and updated with data from the HVO geological model, as well as publicly available data (ie geological maps and groundwater studies for the surrounding region).

The groundwater model was calibrated to replicate steady state (1970 to 2003) and measured transient groundwater levels (2003 to 2015). The transient calibration period was selected to utilise the period of time when more extensive groundwater monitoring data and information on mining became available. The calibration model captured historical mining that occurred at HVO South as well as at surrounding mines that intersected the Wittingham Coal Measures. The historical mining at HVO South is based on the approved mine plan as modelled by ERM (2008a), which was further refined using historic aerial photographs and topographic surfaces in order to capture the actual mine progression.

Following calibration, various model scenarios were run, including the remodelled existing approved mine plan from 2015 onwards, as well as the proposed modification. These scenarios were run to identify the influence of the modification on the groundwater regime by comparing the impacts generated by the approved and proposed mine plan for HVO South.



LEGEND

- Proposed modification pit depth extension
- Major drainage
- Minor drainage
- Approved voids
- Proposed final pit lake
- Approved mine footprint
- Approved infrastructure
- Proposed rail line

HVO South Modification 5 Groundwater Study (G1737)

Proposed modification

DATE
1/7/2016

FIGURE No:
1-2

1.3 Report structure

This report is structured as follows:

- Section 1 – Introduction: provides an overview of the proposed modification, assessment scope and an outline of currently approved activities.
- Section 2 – Regulatory framework: describes the regulatory framework relating to groundwater.
- Section 3 – Environmental setting: describes the environmental setting of the proposed modification, including the climate, terrain, land uses and other environmental relevant features.
- Section 4 – Geological setting: describes the lithology of the main stratigraphic units.
- Section 5 –Hydrogeology: describes the existing local groundwater regime for the proposed modification and surrounds.
- Section 6 and 7 – Impact assessment: describes the proposed mining activities and the potential impacts on the groundwater system. It presents the drawdown and groundwater quality influence on groundwater users and the surrounding environment, as well as describing the level of uncertainty associated with the computer modelling predictions.
- Section 8 and 9 – Compliance with government policy: compares the predicted impacts to the government policy and comments on the level of compliance.
- Section 10 – Groundwater Monitoring and Management Plan: describes the proposed measures for monitoring and management of groundwater impact.
- Section 11 – Conclusions.

Appendix A provides a detailed description of the available field data. This appendix comprises a summary of the investigation methods and includes a detailed summary of bore data for on-site and private bores, groundwater level and quality data for site monitoring bores and permeability data for various hydrogeological units.

Appendix B provides a detailed description of the numerical modelling undertaken for the proposed modification, including details on model construction, calibration and validation. Appendix B also describes the sensitivity analysis undertaken on the numerical groundwater model, including details about the purpose and methodology of the assessment.

2 Regulatory framework

The proposed modification requires consideration of the following NSW Government legislation, policy and guidelines for groundwater:

- *Water Management Act 2000* and the Water Sharing Plan for Hunter Regulated River Water Source, Hunter Unregulated and Alluvial Water Sources and North Coast Fractured and Porous Rock WSP;
- Groundwater Quality Protection Policy;
- Groundwater Dependent Ecosystems Policy;
- Groundwater Quantity Management Policy;
- AIP;
- Strategic Regional Landuse Policy (SRLU Policy); and
- Strategic Regional Landuse Plan – Upper Hunter.

The following sections summarise the intent of the above legislation, policy and guidelines, and how they apply to the proposed modification.

2.1 Water Management Act 2000

The *Water Management Act 2000* provides for the "protection, conservation and ecologically sustainable development of the water sources of the State". The *Water Management Act 2000* provides clear arrangements for controlling land based activities that affect the quality and quantity of the State's water resources. It provides for three primary types of approval in Part 3:

- water use approval – which authorise the use of water at a specified location for a particular purpose, for up to 10 years;
- water management work approval; and
- controlled activity approval, which includes an aquifer interference activity approval – which authorises the holder to conduct activities that affect an aquifer such as activities that intersect groundwater, other than water supply bores and may be issued for up to 10 years.

The Water Management Act 2000 includes the concept of ensuring "no more than minimal harm" for both the granting of water access licences and the granting of approvals. Aquifer interference approvals are not to be granted unless the Minister is satisfied that adequate arrangements are in force to ensure that no more than minimal harm will be done to any water source, or its dependent ecosystems, as a consequence of its being interfered with in the course of the activities to which the approval relates.

2.2 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) is administered by the Department of the Environment (DoE). The *EPBC Act* is designed to protect national environmental assets, known as Matters of National Environmental Significance (MNES). Under the 2013 amendment to the *EPBC Act*, impacts on groundwater resources were included, and are known as the 'water trigger'.

The proposed modification was reviewed in accordance with the Significant impact guidelines 1.3 (DoE, 2013) and referred under the water trigger in December 2015.

The IESC is a statutory body under the *EPBC Act* that provides scientific advice to the Commonwealth Environment Minister and relevant state ministers. Guidelines have been developed in order to assist the IESC in reviewing CSG or large coal mining development proposals that are likely to have significant impacts on water resources. A summary of the IESC guidelines and where they are addressed within the report is included in Appendix D.

2.3 Water sharing plans

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

Department of Primary Industries Water (DPI Water, formerly NSW Office of Water) is progressively developing WSPs for rivers and groundwater systems across NSW following the introduction of the *Water Management Act 2000*. The purposes of these plans are to protect the health of rivers and groundwater, while also providing water users with perpetual access licences, equitable conditions, and increased opportunities to trade water through separation of land and water rights.

Three WSP's apply to the area of aquifers and surface waters which are affected by the proposed modification. These are the WSP for the:

- Hunter Regulated River Water Source (Hunter Regulated WSP);
- Hunter Unregulated and Alluvial Water Sources 2009 (Hunter Unregulated WSP); and
- Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016 (North Coast Fractured and Porous Rock WSP).

The North Coast Fractured and Porous Rock WSP commenced on 1st July 2016 and replaces licensing under the *Water Act 1912,* which covered seepage of groundwater from the Permian and Triassic groundwater at the site. The proposed modification falls within the Sydney Basin – North Coast Groundwater Source of the North Coast Fractured and Porous Rock WSP.

The Hunter Regulated WSP covers the Hunter River surface water flows and highly connected alluvials described in the plan. The Hunter Unregulated WSP includes the unregulated rivers and creeks within the Hunter River catchment, the highly connected alluvial groundwater (above the tidal limit), and the tidal pool areas. In total there are 39 water sources covered by the Hunter Unregulated WSP and nine of these are further sub-divided into management zones.

The proposed modification is located within and adjacent to:

- Hunter Regulated River Water Source, which is divided at Glennies Creek into up-stream and down-stream management zones within the Hunter Extraction Management Unit;
- Hunter Unregulated and Alluvial Water Sources;
- Wollombi Brook Management zone within the Lower Wollombi Extraction Management Unit; and
- Jerrys Management Zone.

The alluvium along the Hunter River and Wollombi Brook are classified as containing both "highly productive" and "less productive" groundwater sources by DPI Water, as discussed further under Section 2.4.

2.4 Aquifer Interference Policy

The *Water Management Act 2000* defines an aquifer interference activity as that which involves any of the following:

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

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

The AIP (Department of Primary Industries 2012) states that:

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

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

Proponents of aquifer interference activities are required to provide predictions of the volume of water to be taken from a water source(s) as a result of the activity. These predictions need to be calculated prior to granting of development consent and these volumes need to be measured and reported annually. The water access licence must hold sufficient share component and water allocation to account for the take of water from the relevant water source at all times.

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

In addition to the volumetric water licensing considerations, the AIP requires details of potential:

- *"water level, quality or pressure drawdown impacts on nearby water users who are exercising their right to take water under a basic landholder right;*
- *water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources;*
- *water level, quality or pressure drawdown impacts on groundwater dependent ecosystems;*
- *increased saline or contaminated water inflows to aquifers and highly connected river systems;*
- *to cause or enhance hydraulic connection between aquifers; and*
- *for river bank instability, or high wall instability or failure to occur."*

In particular, the AIP describes minimal impact considerations for aquifer interference activities based upon whether the water source is highly productive or less productive and whether the water source is alluvial or porous/fractured rock in nature.

A highly productive groundwater source is defined by the AIP as a groundwater source which has been declared in Regulations and datasets, based on the following criteria:

a) has a total dissolved solids (TDS) concentration less than 1,500mg/L; and
b) contains water supply works that can yield water at a rate greater than 5L/s.

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

The Hunter River alluvium and the Wollombi Brook alluvium have bores that meet the criteria of the "highly productive" and "less productive" alluvial water sources categories. The Permian coal measures (porous and fractured rock) are categorised as "less productive".

The AIP defines the following Minimal Impact Considerations for "highly productive" and "less productive" groundwater. Table 2-1 summarises the Minimal Impact Considerations for the "highly productive" Hunter River alluvium and Wollombi Brook alluvium, and the "less productive" Permian coal measures. If these considerations are not met the proposed modification needs to demonstrate to the Minister's satisfaction that the impact will be sustainable, or that "make good agreements" are in place.

Table 2-1 Minimal Impact Considerations for Aquifer Interference Activities (AIP) (DPI Water 2012)

Category	1. Water table	Water pressure	Water quality
Highly productive alluvium – Hunter River and Wollombi Brook Alluvium – basal sands and gravels	1. Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any: (a) high priority groundwater dependent ecosystem; or (b) high priority culturally significant site; listed in the schedule of the relevant water sharing plan; or A maximum of a 2m decline cumulatively at any water supply work. 2. If more than 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any (a) or (b) water sharing plan then appropriate studies(5) will need to demonstrate to the Minister's satisfaction that the variation will not prevent the long term	1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan" pressure head above the base of the water source to a maximum of a 2m decline, at any water supply work. 2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity; and (b) No increase of more than 1% per activity in long term average salinity in a highly connected surface water source at the nearest point to the activity. Redesign of a highly connected (3) surface water source that is defined as a "reliable water supply"(4) is not an appropriate mitigation measure to meet considerations 1.(a) and 1.(b) above. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial water source - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". (d) Not more than 10% cumulatively of the three dimensional extent of the alluvial material in this water source to be excavated by mining activities beyond 200m laterally from the top of high bank and 100m vertically beneath a highly connected surface water source that is defined as a "reliable water supply". 2. If condition 1.(a) is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works. If condition 1.(b) or 1.(d) are not met then appropriate studies are required to demonstrate to the Minister's satisfaction that the River Condition Index category of the highly connected surface water source will not be reduced at the nearest point to the activity. If condition 1.(c) or (d) are not met, then appropriate studies are required to demonstrate to the Minister's satisfaction that: - there will be negligible river bank or high wall instability risks; - during the activity's operation and post-closure, levee banks

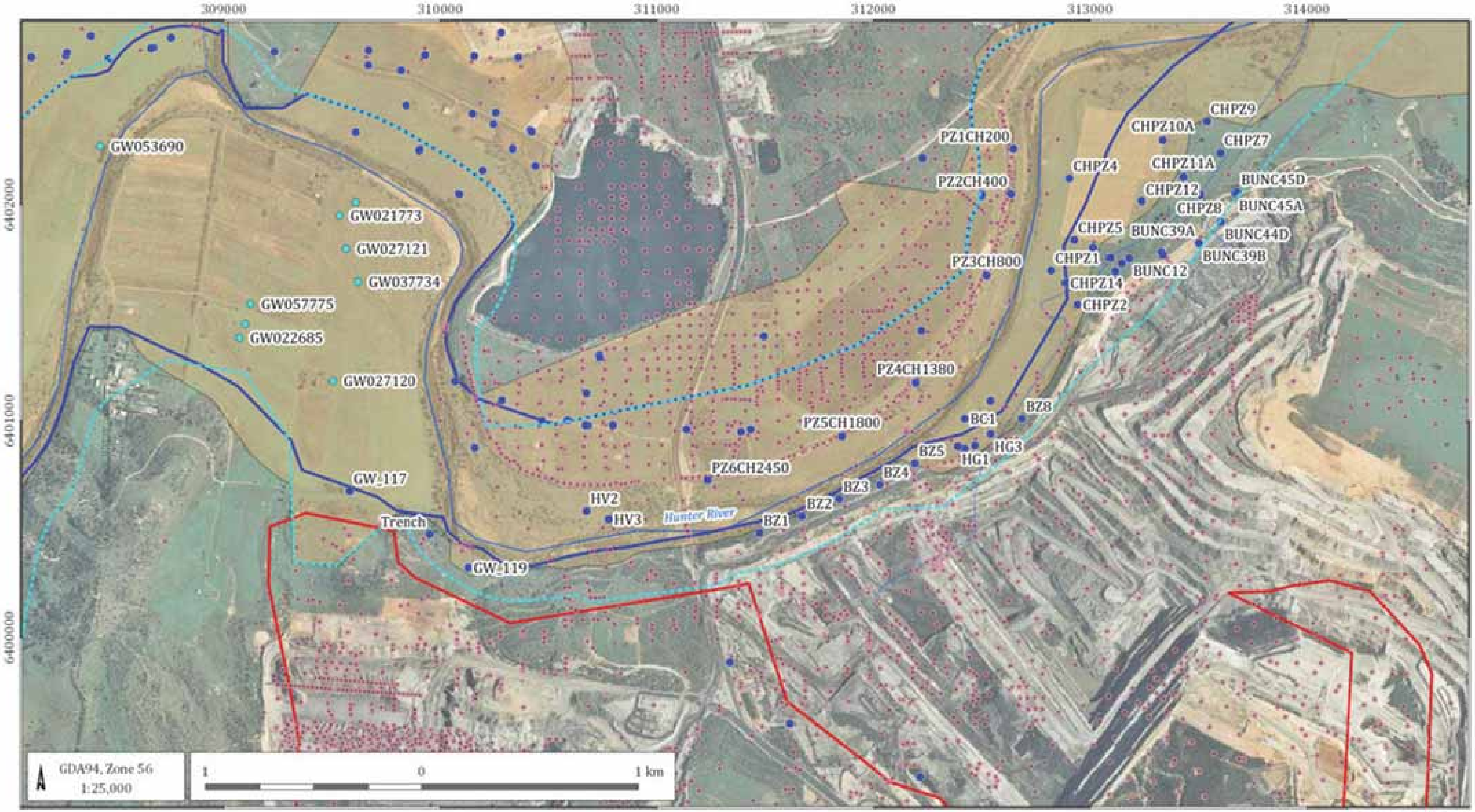
Category	1. Water table	Water pressure	Water quality
	viability of the dependent ecosystem or significant site. If more than 2m decline cumulatively at any water supply work then make good provisions should apply.		and landform design should prevent the Probable Maximum Flood from entering the activity's site; and - low-permeability barriers between the site and the highly connected surface water source will be appropriately designed, installed and maintained to ensure their long term effectiveness at minimising interaction between saline groundwater and the highly connected surface water supply;
Less productive alluvial water source - surficial alluvium associated with major rivers (Hunter River and Wollombi Brook) and tributaries.		1. A cumulative pressure head decline of not more than 40% of the "post-water sharing plan"(2) pressure head above the base of the water source to a maximum of a 2m decline, at any water supply work. 2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	1. (a) Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity; and (b) No increase of more than 1% per activity in long term average salinity in a highly connected surface water source at the nearest point to the activity. Redesign of a highly connected (3) surface water source that is defined as a "reliable water supply"(4) is not an appropriate mitigation measure to meet considerations 1.(a) and 1.(b) above. (c) No mining activity to be below the natural ground surface within 200m laterally from the top of high bank or 100m vertically beneath (or the three dimensional extent of the alluvial material - whichever is the lesser distance) of a highly connected surface water source that is defined as a "reliable water supply". 2. If condition 1.(a) is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works. If condition 1.(b) is not met then appropriate studies are required to demonstrate to the Minister's satisfaction that the River Condition Index category of the highly connected surface water source will not be reduced at the nearest point to the activity. If condition 1.(c) is not met, then appropriate studies are required to demonstrate to the Minister's satisfaction that: - there will be negligible river bank or high wall instability risks; - during the activity's operation and post closure, levee banks and landform design should prevent the Probable Maximum Flood from entering the activity's site; and - low-permeability

Category	1. Water table	Water pressure	Water quality
			barriers between the site and the highly connected surface water source will be appropriately designed, installed and maintained to ensure their long term effectiveness at minimising interaction between saline groundwater and the highly connected surface water supply;
Less productive porous rock – Permian Coal Measures		1. A cumulative pressure head decline of not more than a 2m decline, at any water supply work. 2. If the predicted pressure head decline is greater than requirement 1. above, then appropriate studies are required to demonstrate to the Minister's satisfaction that the decline will not prevent the long term viability of the affected water supply works unless make good provisions apply.	1. Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity. 2. If condition 1 is not met then appropriate studies will need to demonstrate to the Minister's satisfaction that the change in groundwater quality will not prevent the long term viability of the dependent ecosystem, significant site or affected water supply works.

As indicated under the Minimal Impact Considerations (Table 2-1), the AIP requires that impacts on highly and less productive water sources need to be assessed and accounted for. DPI Water has produced a map of groundwater productivity across NSW, which defined the highly and less productive alluvium for the groundwater assessment. The DPI Water Groundwater Productivity map has been produced on a regional scale, therefore the extents were adjusted to align with extent of Quaternary alluvium in the 1:25,000 Geology Map of Singleton (McIlveen 1984). In addition, site-specific data, such as bore lithological logs (exploration and monitoring bores), permeability tests and water quality results, were used to further refine the extent of “highly productive” alluvium.

Figure 2-1 is presented as an example to show the DPI Water mapped extent of “highly productive” groundwater compared to the adjusted extent of “highly productive” alluvium north of Riverview and Cheshunt Pits. The extent of alluvium was previously determined for Cheshunt Pit and Riverview Pit (MER 2005; ERM 2008a). The main changes are localised along the northern edge of Riverview and Cheshunt pits. In order to ground truth the extent north of Riverview Pit, two monitoring bores (GW117 and GW119) and a trench were installed in September 2015. Both bores intersected unconsolidated alluvial sequences with low yields and saline quality water (8,740µS/cm for GW117), indicating they are within the less productive alluvium. Further details about the fieldwork are included in Appendix A, and geological sections based on the site specific data are presented in Section 4.

The numerical groundwater model was developed and results extracted based on the adjusted extent of “highly productive” alluvium. The extent and characteristics of the “highly productive” alluvium is further discussed in Section 4.



LEGEND

- Monitoring bore
- Registered bore
- Exploration hole
- Major drainage
- Minor drainage
- Proposed modification pit depth extension
- Highly productive groundwater (DPI Water)
- Adjusted extent of highly productive alluvium (AGE)
- Quaternary alluvium (1:25k AGE)

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Productive groundwater

DATE
1/7/2016

FIGURE No:
2-1

Quaternary alluvium (1:25k AGE): 1:25,000 Singleton - AGE digitised and adjusted based on site data

2.5 Groundwater quality protection

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

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

Section 5 describes the site-specific groundwater environmental values, quality and use within the proposed modification and surrounds.

2.6 Groundwater dependent ecosystems

The NSW Groundwater Dependent Ecosystems Policy (DLWC 2002) is specifically designed to protect valuable ecosystems which rely on groundwater for survival so that, wherever possible, the ecological processes and biodiversity of these dependent ecosystems are maintained or restored for the benefit of present and future generations. The policy defines GDEs as *"communities of plants, animals and other organisms whose extent and life processes are dependent on groundwater".*

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

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

2.7 Groundwater quantity management

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

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

2.8 Strategic agricultural land

The NSW Strategic Regional Land Use Policy applies to the Hunter Valley in which the proposed modification resides. Biophysical Strategic Agricultural Land (BSAL) is land with high quality soil and water resources capable of sustaining high levels of productivity. BSAL occurs within the footprint of the proposed modification, along the Hunter River Flood plain. In addition, Critical Industry Clusters (CIC) derived from this policy can be equine or viticulture zones, NSW Planning & Environment (2013). These zones were defined by the following criteria:

- a concentration of enterprises that provides clear development and marketing advantages and is based on an agricultural product;
- the productive industries are interrelated;
- a unique combination of factors such as location, infrastructure, heritage and natural resources;
- of national and/or international importance;
- an iconic industry that contributes to the region's identity; and
- potentially substantially impacted by coal seam gas or mining proposals.

Equine zones occur adjacent the Hunter River, approximately 7km upstream of the proposed modification.

3 Environmental setting

3.1 Location

The proposed modification is located 24km north-west of Singleton (Figure 1-1). The closest townships are Warkworth and Jerrys Plains, which are located 2km south and 6km north-west of the proposed modification, respectively (Figure 1-1).

3.2 Climate

The climate in the region is temperate and is characterised by hot summers and mild dry winters. Climate monitoring data collected by the Bureau of Meteorology (BoM) was obtained for Jerrys Plains Station, which is located about 7km to the north-west of HVO South. A number of recording stations are closer to the mine, but do not have a long term rainfall record. The Jerrys Plains Station has 131 years of rainfall data dating from 1884 to present. Interpolated rainfall and evaporation data closer to HVO was also obtained from a SILO data drill (Queensland Government 2015). The location selected for the SILO data drill was at longitude 151.00^0, latitude -32.5^0 decimal and elevation 206m Australian Height Datum (mAHD). Interpolated climatic data was obtained for the period between 01/01/1889 to 19/04/2015. A summary of rainfall data for Jerrys Plains Station and SILO rainfall and evaporation data are shown in Table 3-1.

Table 3-1 Rainfall and evaporation averages

Source	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Jerrys Plains (BoM) Mean rainfall (mm)		77.1	73.1	59.7	44.0	40.7	48.1	43.4	36.1	41.7	51.9	61.9	67.5	645.3
Site SILO data	Mean rainfall (mm)	80.2	79.3	66.0	48.3	42.4	51.3	43.1	36.5	42.3	54.3	63.0	68.7	675.4
	Mean evaporation (mm)	200.2	156.9	138.6	100.0	69.7	52.5	62.1	86.1	116.1	152.4	174.7	204.7	1514.0
	Evap minus rainfall (mm)	120.0	77.6	72.5	51.8	27.3	1.2	19.0	49.6	73.8	98.0	111.7	136.0	838.6

The average annual rainfall recorded at Jerrys Plains is 645mm, with January being the wettest month (77mm). Interpolated rainfall at HVO is slightly higher at 675mm, with 1,514mm evaporation annually. Evaporation exceeds mean rainfall throughout the year, with the highest moisture deficit occurring during summer.

Monthly records from the SILO dataset were used to calculate the Cumulative Rainfall Departure (CRD), also referred to as the rainfall residual mass. The CRD is a summation of the monthly departure of rainfall from the long term average monthly rainfall and provides a historical record of relatively wet and dry periods. A rising trend in slope in the CRD plot indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. The CRD in Figure 3-1 indicates that the district experienced a period of below average rainfall from around 2000 to 2007, a period now known as the 'Millennium Drought'. From mid-2007 to 2012 the region recorded above average rainfall events, followed by generally average rainfall since 2012.

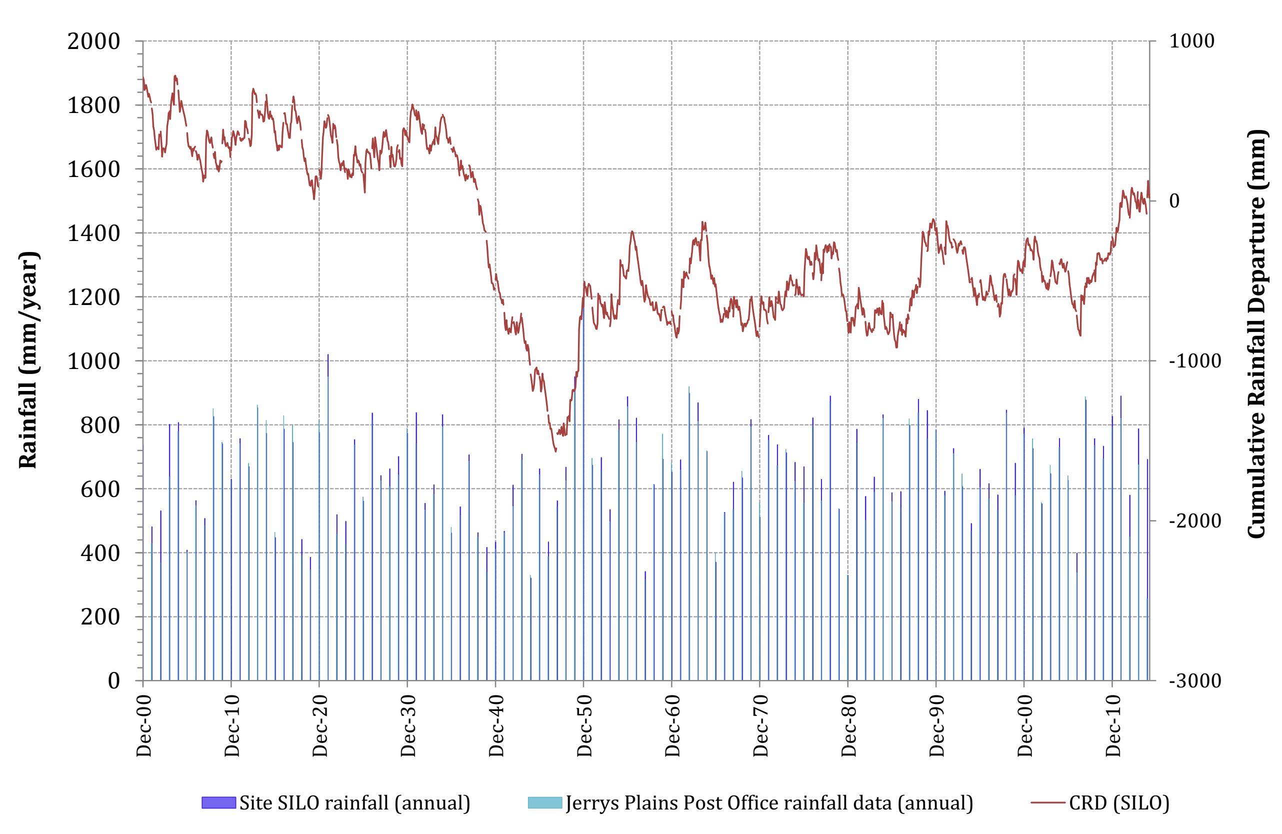


Figure 3-1 Cumulative Rainfall Departure (SILO) and monthly rainfall (Jerrys Plains and site SILO)

The SILO dataset also provides monthly pan evaporation and calculated plant evapotranspiration rates using the Penman-Monteith formulation as shown in Figure 3-2. The bimodal plot indicates higher rainfall, evaporation and evapotranspiration during the summer months. During the mid-year winter months evaporation and evapotranspiration is lowest.

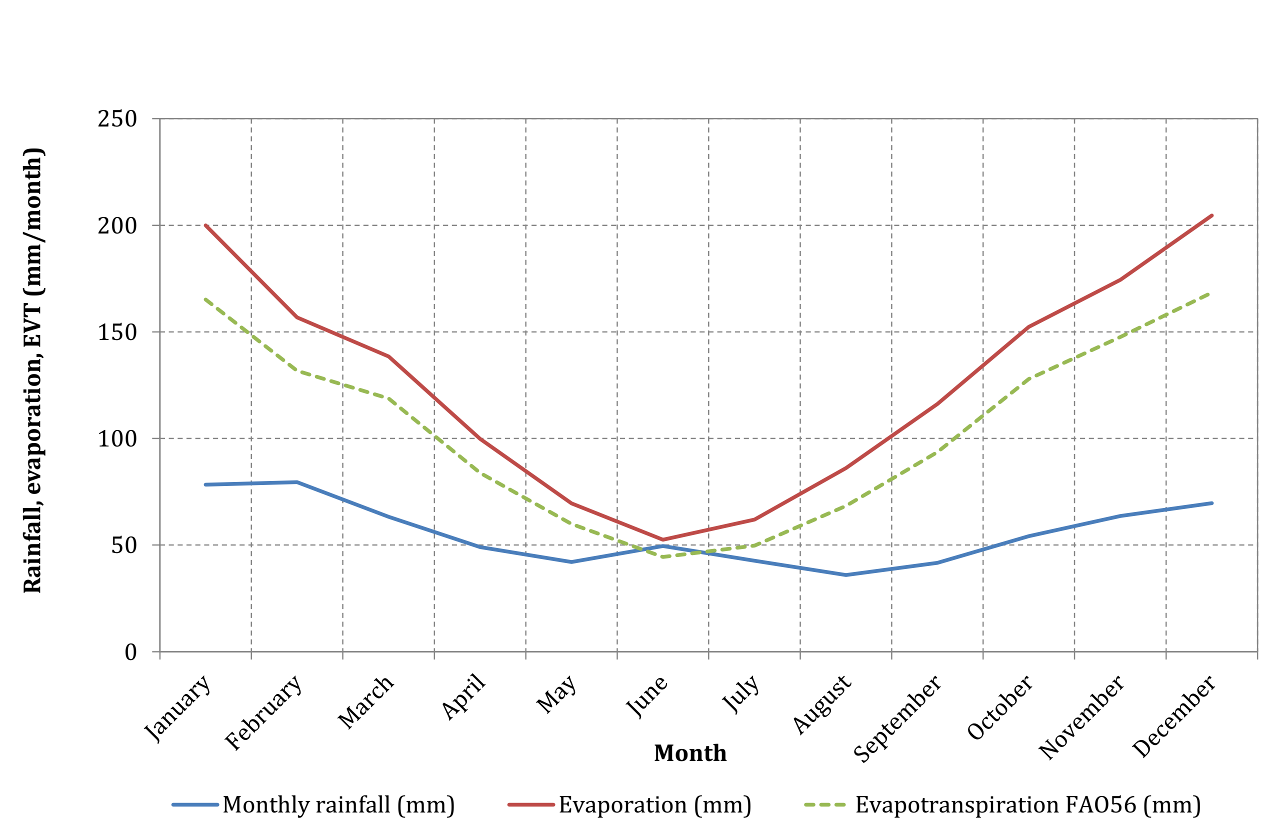


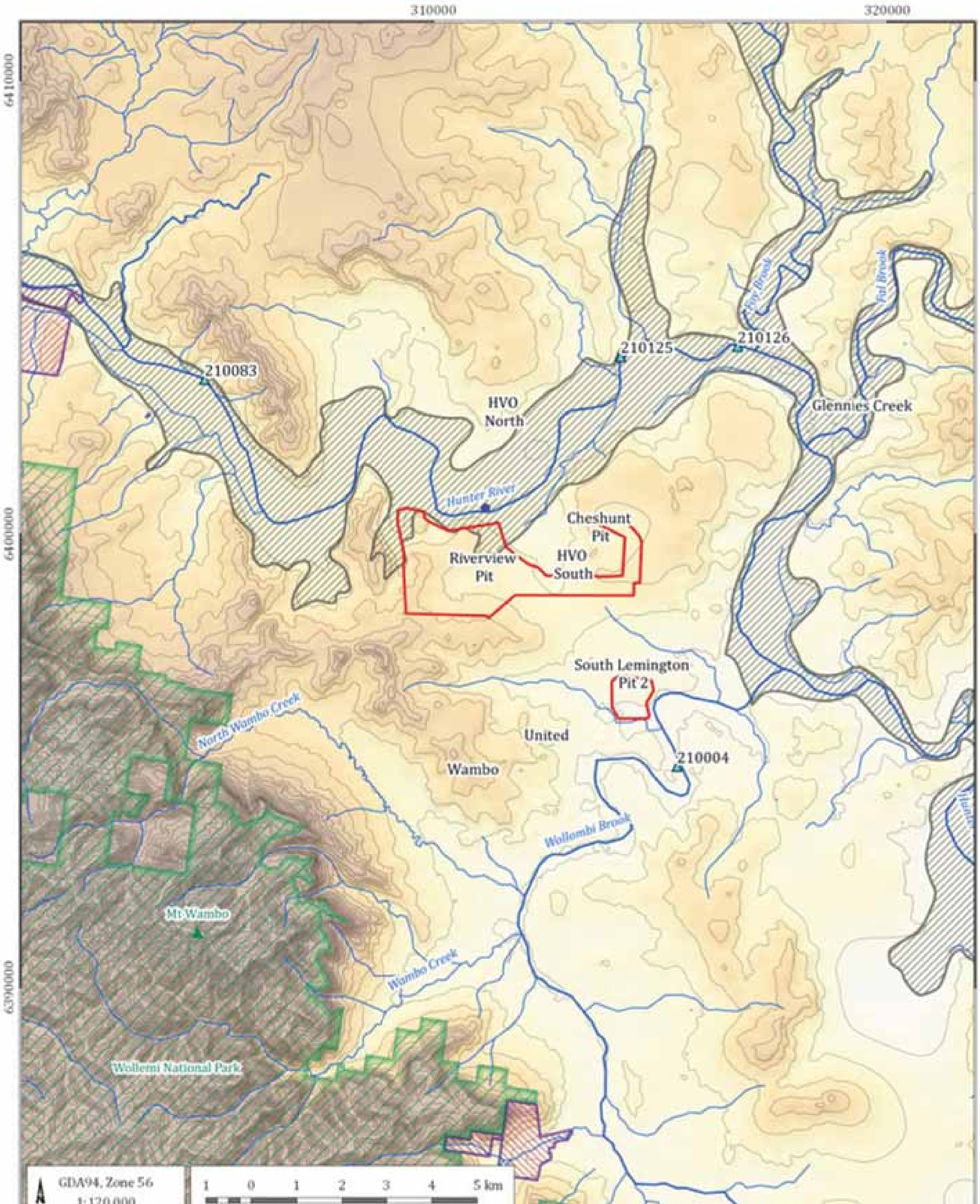
Figure 3-2 SILO average monthly rainfall, evaporation and evapotranspiration

3.3 Terrain

At a regional scale, the terrain is characterised by a steep and incised range to the west, which falls generally towards the low lying floodplains of the Hunter River and Wollombi Brook (Figure 3-3). The main topographic highpoint within the region is Mount Wambo, which is within the Wollemi National Park south-west of the proposed modification.

The project area is gently undulating, with elevation ranging between 110mAHD along the western extent of Riverview Pit, down to 65mAHD at the northern edge of Riverview Pit. Outside of the project area the topography grades into the flat alluvial lands associated with the adjacent water courses. The ground levels in the Hunter River and Wollombi Brook alluvial lands and surrounding area are around 50mAHD to 70mAHD. While west of the project area, within the Wollemi National Park, the elevation generally ranges between 300mAHD and 650mAHD.

The project area is largely cleared of vegetation due to historical farming and mining. Riparian vegetation is present along the Hunter River and Wollombi Brook, including tree species such as the River Red Gum. Wollemi National Park is densely vegetated with various plant communities, including open forests dominated by eucalypt species.



LEGEND

- Proposed modification pit depth extension
- Major drainage
- Minor drainage
- Critical Industry Cluster (Equine)
- Biophysical Strategic Agricultural Land
- Wollemi National Park
- DPI Water stream gauge
- HVO stream gauge (WLP6)
- Contour (mAHD, 20m interval)

Elevation (mAHD)

- 40
- 80
- 120
- 200
- 400
- 600

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Terrain and drainage

AGE

DATE: 1/7/2016

FIGURE No: **3-3**

3.4 Drainage

The project area is drained by the Hunter River and Wollombi Brook and their minor tributary drainage channels. The Hunter River flows in an easterly direction immediately north of the project area, flowing south further downstream. The Wollombi Brook flows in a north to north-easterly direction immediately south of the project area, and joins with the Hunter River. Minor drainage lines are ephemeral in nature, with flows dependent on rainfall events. Figure 3-3 shows the local surface water drainage setting.

At the project area, the Hunter River is within the Hunter Regulated WSP, while the Wollombi Brook is classified as the Lower Wollombi Brook Water Source within the Hunter Unregulated WSP. Real time stream flow data is monitored along the Hunter River and Wollombi Brook at DPI Water gauging stations via the Hunter Integrated Telemetry System (HITS). The closest upstream gauging station along the Hunter River is located 5km north of the project area at the Liddell station (210083). The closest gauging station along Wollombi Brook is at Warkworth (station 210004), which is 1km south of the project area. Figure 3-4 and Figure 3-5 show the stream flow and estimated baseflow at the Hunter River and Wollombi Brook gauging stations respectively.

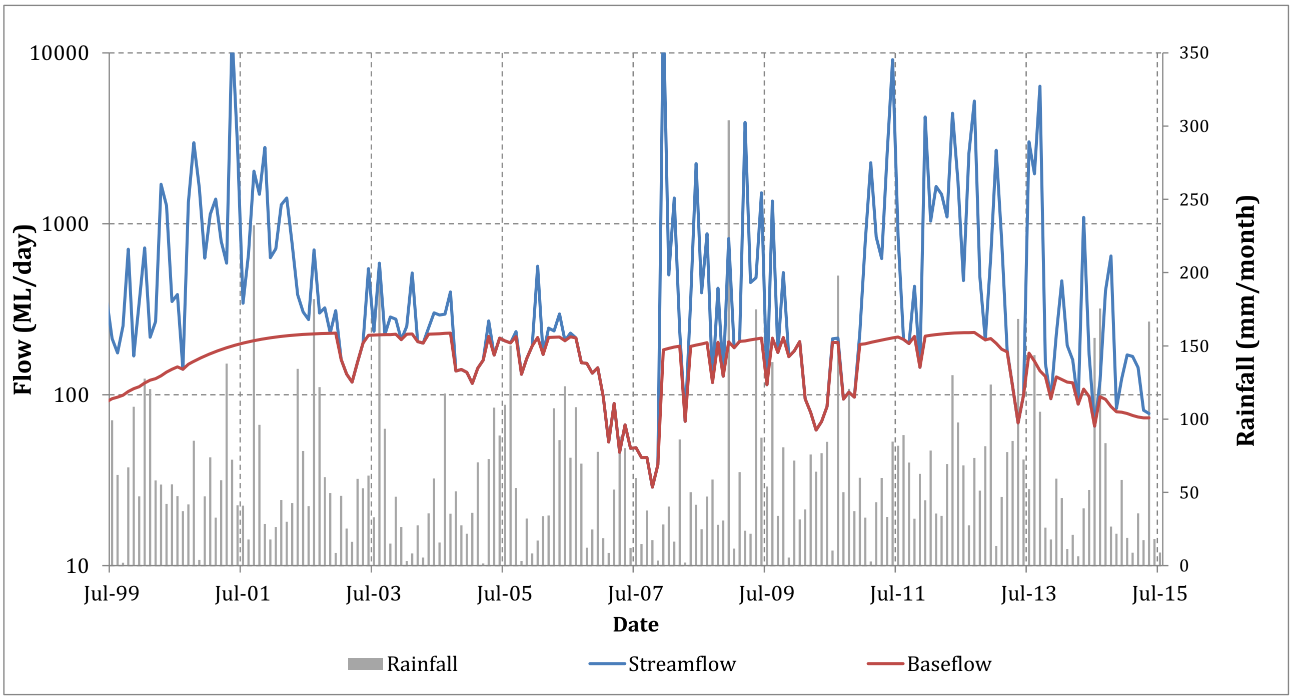


Figure 3-4 Baseflow in Hunter River at Liddell (210083)

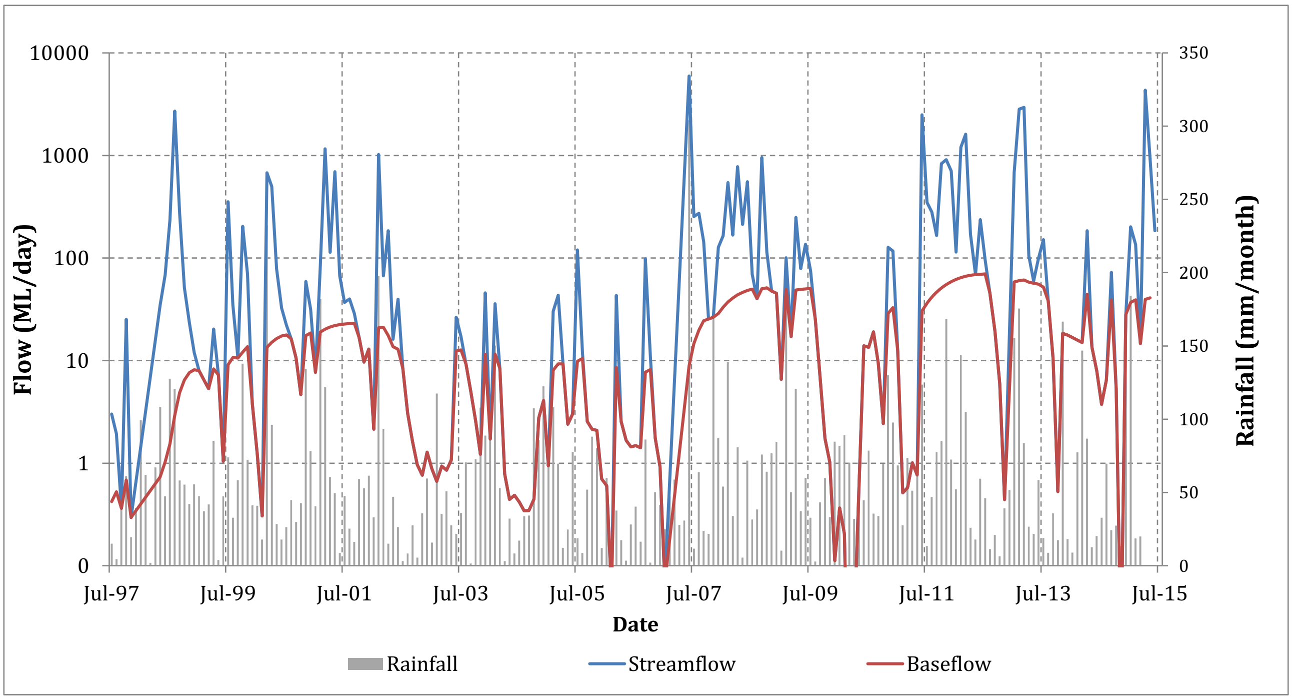


Figure 3-5 Baseflow in Wollombi Brook at Warkworth (210004)

The baseflow was estimated by comparing the monthly rainfall with total monthly stream flow. The results show that surface water flow is largely a function of rainfall and dam releases. Based on averaged monthly flow data from 1997 – 2015 (station 2100083), the Hunter River flows at a rate of 940ML/day (343,137ML/year), which is largely derived from continuous releases from Glenbawn Dam. Figure 3-4 shows that the Hunter River also has a high baseflow contribution of up to 200ML/day. However, the baseflow contribution is likely to be less than estimated due to the releases from Glenbawn Dam, which maintains a permanent flow for downstream users.

Based on averaged monthly flow data from 1997 – 2015 (station 210004), Wollombi Brook flows at a rate of 202ML/day (73,883ML/year). As shown in Figure 3-5, Wollombi Brook receives a lower volume of baseflow contribution, up to 70ML/day (Figure 3-5). However, proportional to total flows, the Wollombi Brook receives a greater percentage of baseflow contributions.

While there are contributions of alluvial groundwater to the major rivers, losing conditions can also occur in different areas and at different times, due to both natural and anthropogenic processes. Both the Hunter River and Wollombi Brook are predominantly gaining water from the surrounding alluvium. However, there are also areas where the river recharges the underlying alluvium (losing), particularly around areas of active mining. As with the rivers, alluvium is also largely gaining groundwater from the underlying Permian coal measures, particularly away from active mining that depressurises the Permian coal measures.

3.5 Land use

Land use in the proposed modification includes coal mining and stock agistment. Surrounding the proposed modification, land use includes coal mining operations and agriculture. Agricultural land use includes:

- beef cattle grazing in open pastures;
- dairy farming;
- improved pasture and cropping along the Hunter River and Wollombi Brook alluvial flood plains; and
- vegetation, including riverine vegetation along drainage lines (i.e., Hunter River) and remnant vegetation within the Wollemi National Park.

Areas zoned as CICs are present within the wider region, with an equine CIC 7km to the north-west (Figure 3-3). No coal seam gas extraction projects are currently operating or proposed in the vicinity of the proposed modification. BSAL has been mapped along the extents of the Hunter River alluvium, as shown in Figure 3-3. Based on the regional mapping, BSAL occurs along the northern end of Riverview Pit and Cheshunt Pit, within the approved mine footprint.

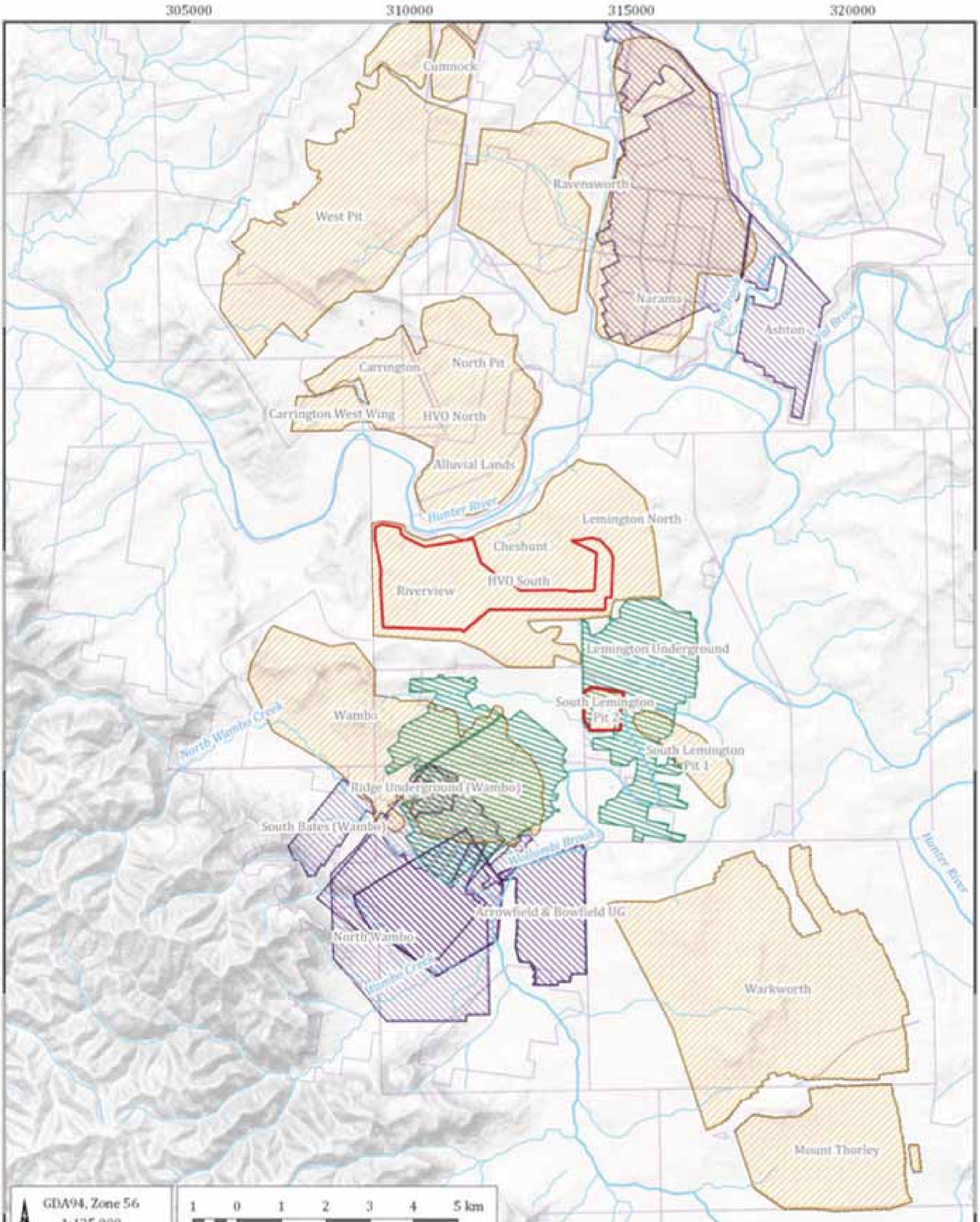
The proposed modification occurs within the Hunter Valley coalfields, which has a long history of mining the Wittingham Coal Measures, dating back to the 1940s (including at the now HVO). Table 3-2 summarises the currently approved mines that intersect the Wittingham Coal Measures, including their approved timeframes and target coal seams. The locations of the approved mines are shown on Figure 3-6.

Table 3-2 Summary of approved mines in Wittingham Coal Measures

Mine	Type	Timeframe	Seams mined
Bulga	Open cut	1990 - 2035	Whybrow to Broonie
	Underground	2003 – 2035	Whybrow to Woodlands Hill
Cumnock Colliery	Open cut	1992 – 2011	Arties and Liddell
	Underground	1949 – 2003	Arties to Barrett
HVO North	Open cut	1949 - 2025	Mt Arthur to Barrett
Mount Thorley Warkworth	Open cut	1980 - 2035	Woodlands Hill to Bayswater
North Lemington	Open cut	1971 - 1999	Warkworth to Vaux
	Underground	1971 - 1992	Mt Arthur Seam
Ravensworth Narama	Open cut	1972 - 2039	Vaux to Barrett
	Underground	2008 -	Pikes Gully to Liddell
United	Open cut	1898 – 1992*	Wambo to Whynot
	Underground	1992 - 2010	Blakefield to Arrowfield
Wambo	Open cut	1974 – 2017*	Whybrow to Whynot
	Underground	1969 – 2032	Whybrow to Bowfield

Note: **the proposed United Wambo Project (open cut) has been included within the groundwater assessment in order to account for all foreseeable cumulative impacts.*

The potential for cumulative groundwater impacts associated with the surrounding land uses is discussed in Section 7.



LEGEND

- Proposed modification pit depth extension
- Coal titles
- Major drainage
- Minor drainage
- Historic and existing open cut mining
- Existing underground mining
- Historic underground mining

HVO South Modification 5 Groundwater Study (G1737)

Historic and existing mining

DATE 1/7/2016

FIGURE No: **3-6**

4 Geological setting

The geological setting was determined using the following data sources:

- publicly available geological maps (Hunter Coalfields map sheets) and reports;
- geological and hydrogeological reports prepared for HVO dating back to the 1990s;
- publicly available geological and hydrogeological reports for surrounding mine operations;
- hydrogeological data held on the DPI Water groundwater database (Pinneena) and the National Groundwater Information System (NGIS) for existing private groundwater bores;
- a 3D geological model developed by the proponent for HVO North and HVO South;
- a 3D groundwater model for HVO North (MER 2003); and
- lithological logs for coal mining exploration holes.

This information also provided the structural framework for developing a 3D numerical groundwater model by AGE. Appendix B provides more detail on the approach to the groundwater modelling.

4.1 Regional geology

The main structural feature of the regional geology is the Sydney Basin. The basin formed in the Late Carboniferous – Early Permian due to igneous rifting and crustal thinning, which resulted in the deposition of Permian and Triassic aged sedimentary sequences. Within the proposed modification, Permian sediments form the Wittingham Coal Measures of the Hunter Coalfields. The coal measures plunge in a general west to south-westerly direction. Consequently the Wittingham Coal Measures outcrop at and to the east of the proposed modification.

Within the proposed modification, the Wittingham Coal Measures comprise economic coal seams, along with overburden and interburden consisting of sandstone, siltstone, tuffaceous mudstone and conglomerate. Along the Hunter River and Wollombi Brook thin Quaternary alluvial deposits unconformably overlie the Permian sediments. The alluvial deposits consist of silt, sand and gravel in the alluvial floodplain of the Hunter River and Wollombi Brook. To the east of the Wollombi Brook is a sequence of aeolian sands, known as the Warkworth Sands Formation, that form a thin capping on the underlying Permian bedrock.

The Permian coal measures are also unconformably overlain by the Triassic Narrabeen Group, which formed from uplift during the Triassic. The Narrabeen Group comprises fluviatile deposits that form the ridges and a high plateau within the Wollemi National Park, west of the proposed modification. Surficial weathering is evident across the project area. The surficial weathering profile is typically present as thin heterogeneous layer of unconsolidated and highly weathered material (regolith) overlying bedrock.

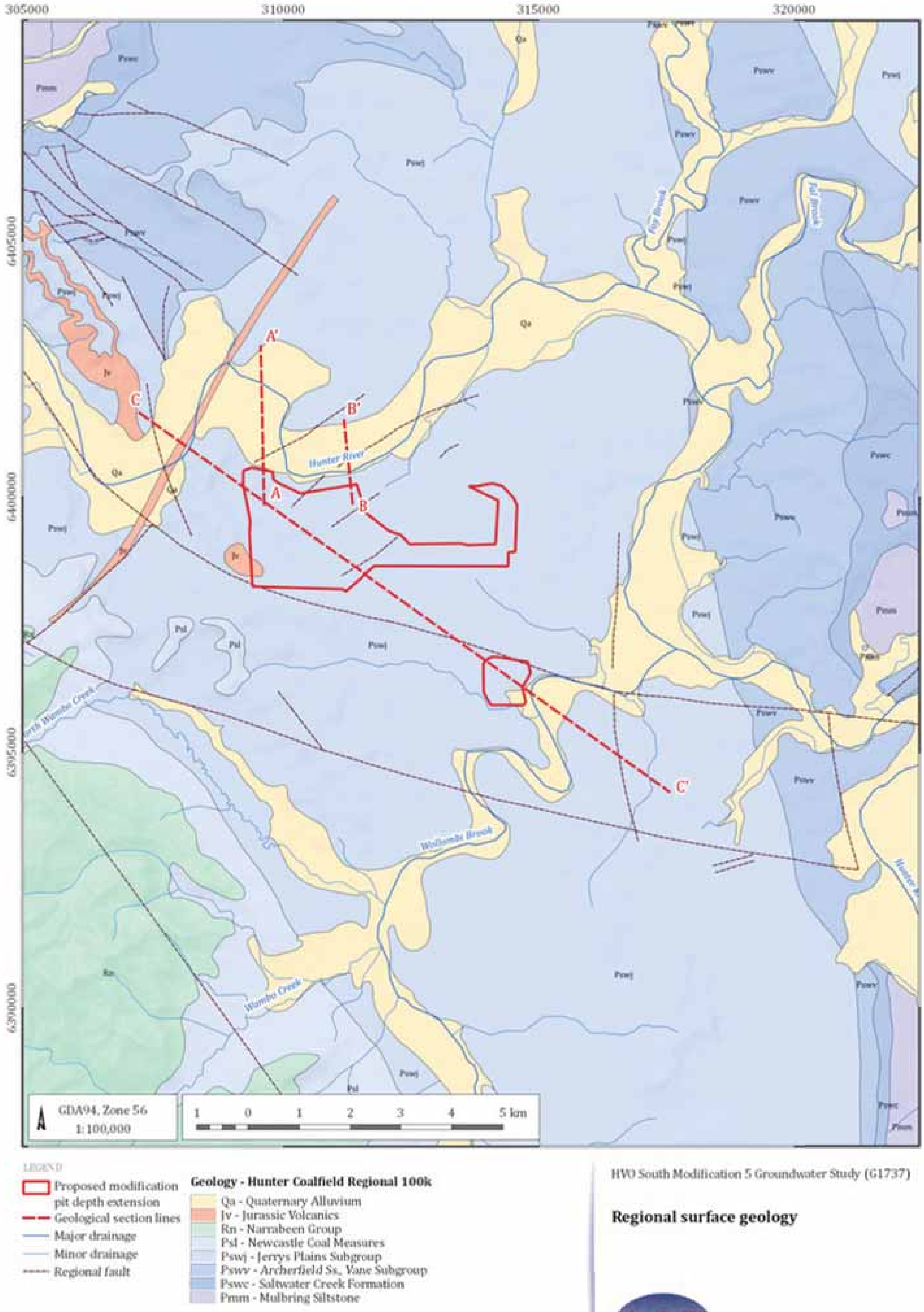
Figure 4-1 shows the regional surface geology across the site and surrounds, based on the 1:100,000 scale regional Coalfields geological map, published by Department of Mineral Resources (Glen & Beckett 1993). The Quaternary alluvium in Figure 4-1 has been digitised based on the 1:25,000 Geology Map of Singleton (McIlveen 1984), Muswellbrook (Summerhayes 1983), Jerrys Plains (Sniffin & Summerhayes 1987) and Doyles Creek (Sniffin *et al* 1988), which are not available in digital format.

Table 4-1 provides a detailed summary of the regional geology and relevant stratigraphic units within the proposed modification and surrounds. Figure 4-2 and Figure 4-3 present geological cross sections based on site geological models and lithological logs from monitoring and exploration holes. The cross sections show the relative distribution of key stratigraphic units across the proposed modification, as well as surface water features and mining. Figure 4-4 shows a map of the local geology at the proposed modification, which is informed by previous field studies.

Table 4-1 Summary of regional geology

Age		Stratigraphic Unit		Description
Quaternary		Quaternary sediments – alluvium (Qa)	Surficial alluvium (Qhb)	Shallow sequences of clay, silty sand and sand.
			Productive basal sands / gravel (Qha)	Basal sands and gravels overlying surficial alluvium along major watercourses (ie Hunter River and Wollombi Brook).
		Aeolian dunes (Czb)		Sand
Tertiary		Silicified weathering profile (Czas)		Silcrete
		Alluvial terraces (Cza)		Silt, sand and gravel
Jurassic		Volcanics (Jv)		Flows, sills and dykes
Triassic		Narrabeen Group (Rn)		Sandstone, interbedded sandstone and siltstone, claystone. Localised at Wollemi National Park.
Permian	Late	Newcastle Coal Measures (Psl)	Glen Gallic Sub-group Doyles Creek Sub-group Horseshoe Creek Sub-group Apple Tree Flat Sub-group	Coal seams, claystone (tuffaceous), siltstone, sandstone and conglomerate.
			Watts Sandstone	Medium to coarse-grained sandstone.
		Wittingham Coal Measures	Jerrys Plains Sub-group (Pswj)	Cyclic coal seam sequence with dark-grey to black laminated shale and siltstone. Coal seams include Whybrow Seam, Redbank Creek Seam, Wambo Seam, Whynot Seam, Blakefield Seam, Glen Munro Seam, Woodlands Hill Seam, Arrowfield Seam, Bowfield Seam, Warkworth Seam, Mt Arthur Seam, Piercefield Seam, Vaux Seam, Broonie Seam and Bayswater Seam.
			Archerfield Sandstone	Bronze-coloured lithic sandstone
			Vane Sub-group (Pswv)	Coal bearing sequences with wedges of sandstone and siltstone. Coal seams include Lemington Seam, Pikes Gully Seam, Arties Seam, Liddell Seam, Barrett Seam and Hebden Seam.
			Saltwater Creek Formation (Pswc)	Sandstone and siltstone, minor coaly bands, siltstone towards base.
	Middle	Mulbring Siltstone (Pmmd/Pmmg/Pmm)		Siltstone, claystone and minor fine grained sandstone.

Note - - - - - - - - - *indicates an unconformable contact*

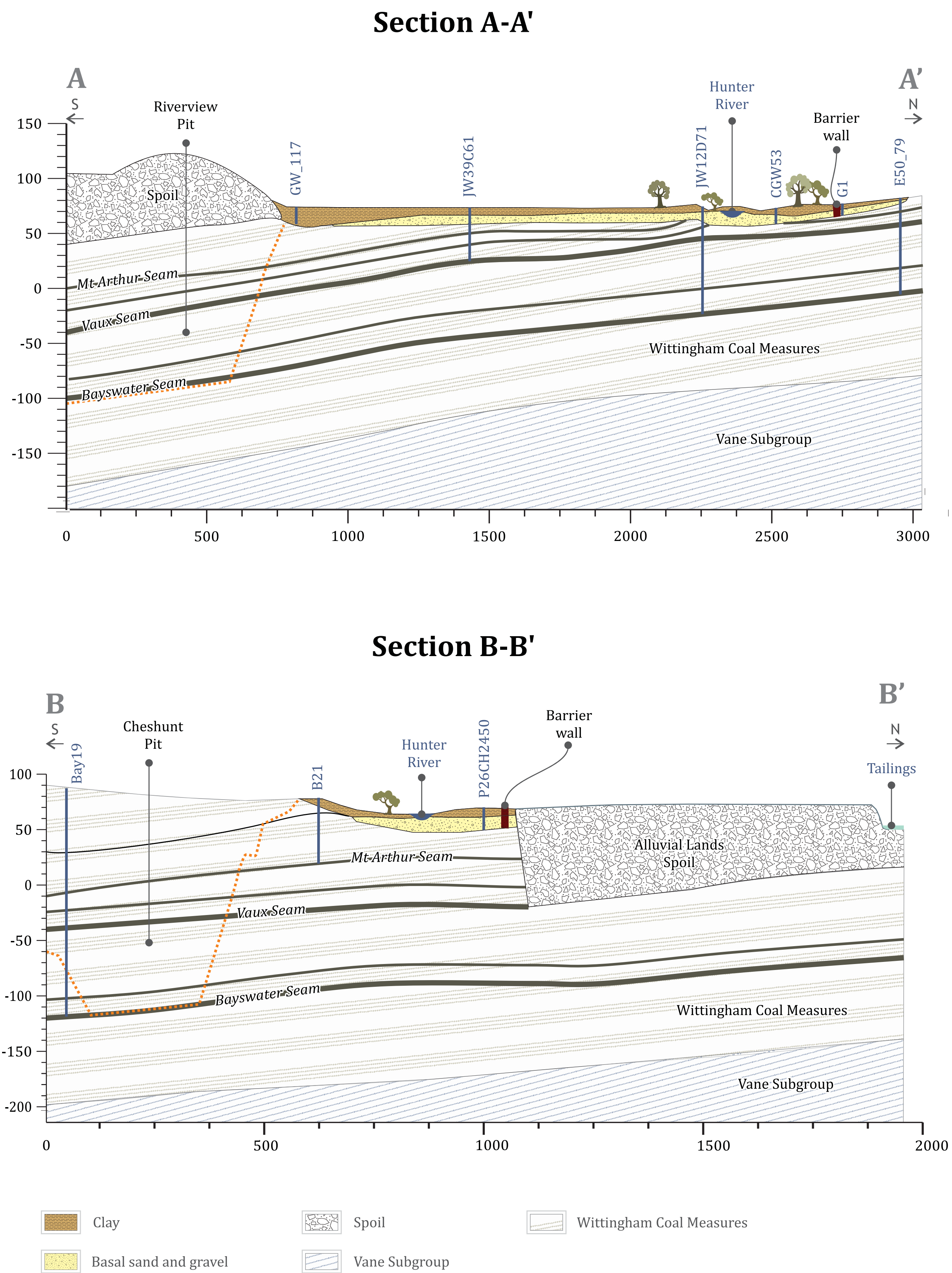


HVO South Modification 5 Groundwater Study (G1737)

Regional surface geology

DATE 1/7/2016

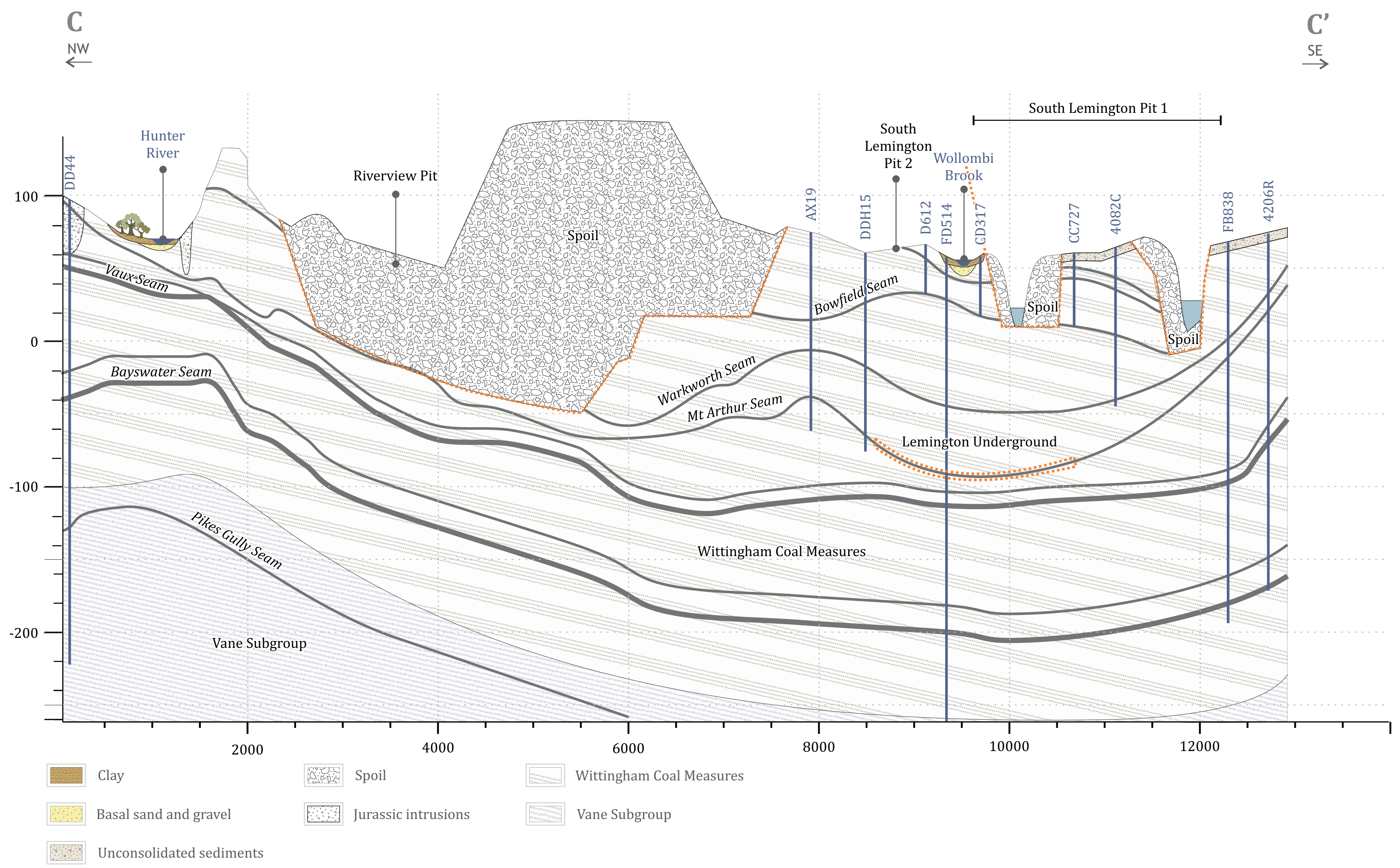
FIGURE No: **4-1**



Geological sections A and B

Figure 4-2

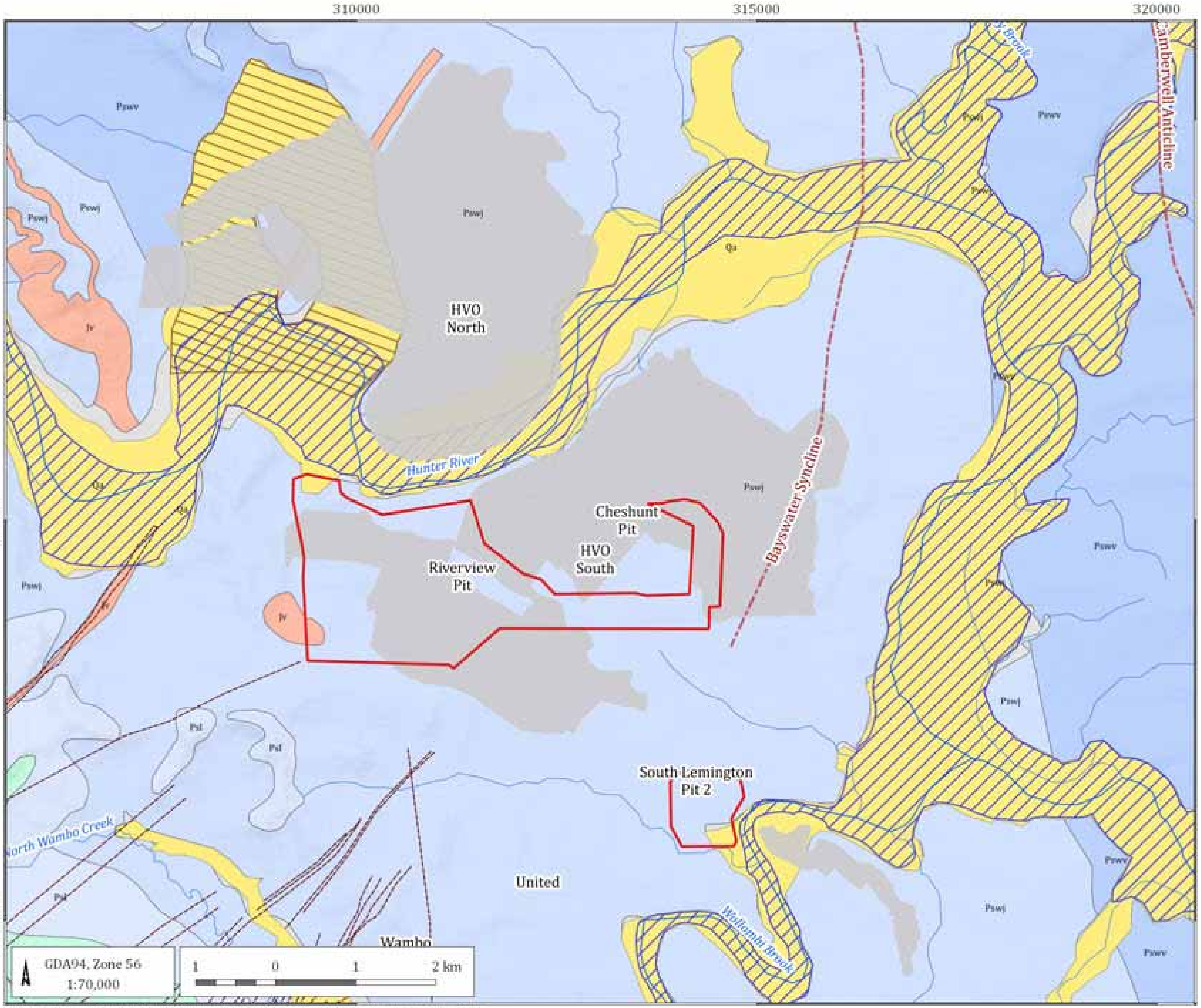
HVO South Modification 5 Groundwater Study (G1737)



Geological section C

Figure 4-3

HVO South Modification 5 Groundwater Study (G1737)



LEGEND

- Proposed modification pit depth extension
- Fault
- Fold
- Drainage
- Highly productive alluvium (AGE)
- Palaeochannel (MER, 2005)
- Alluvium (1:25k AGE)
- HVO mine disturbance area

Geology - Hunter Coalfield Regional 100k

- Qa - Quaternary Alluvium
- Jv - Jurassic Volcanics
- Rn - Narrabeen Group
- Psl - Wollombi Coal Measures
- Pswj - Jerrys Plains Subgroup
- Pswv - Archerfield sandstone, Vane Subgroup

HVO South Modification 5 Groundwater Study (G1737)

Proposed modification surface geology

DATE
1/7/2016

FIGURE No:
4-4

Quaternary alluvium (1:25k AGE): 1:25,000 Singleton - AGE digitised and adjusted based on site data

4.2 Local geology

The following main stratigraphic units occur within the proposed modification and surrounds (from youngest to oldest):

- Quaternary sediments;
- Tertiary volcanics;
- Triassic Narrabeen Group;
- Permian Newcastle Coal Measures;
- Permian Watts Sandstone; and
- Permian Wittingham Coal Measures.

Each of the main stratigraphic units is discussed in further detail below.

Figure 4-4 shows the surface geology of the proposed modification and immediate surrounds. Figure 4-5 and Figure 4-6 present structure contours and thickness contours for the unconsolidated sediments and Permian coal measures.

Jurassic volcanics do not occur within the immediate vicinity of the proposed modification. However, these formations have been described below for completeness.

4.2.1 Quaternary to Tertiary sediments

The Quaternary alluvium along the Hunter River and Wollombi Brook flood plains comprises two distinct depositional units, a surficial fine grained sediment and coarser basal material. The surficial alluvium comprises shallow sequences of clay, silty sand and sands. Along the minor drainage lines the surficial alluvium is typically constrained within 400m of the creeks and is between 7m to 19m thick. Site drill data indicates that alluvium is present within the approved footprint of the proposed modification, at the north-eastern end of Riverview Pit, and at the south-eastern end of South Lemington Pit 2 (Figure 4-4).

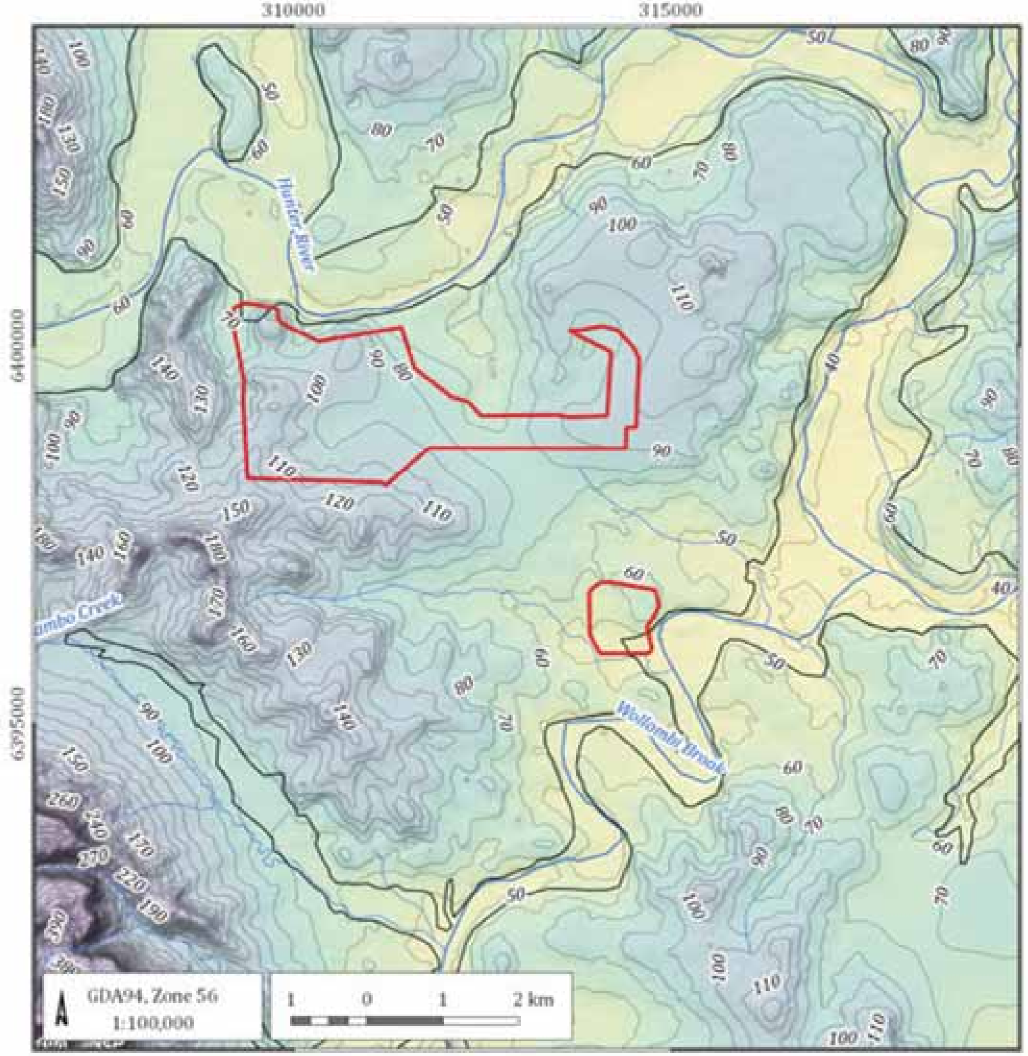
Within the Hunter River and Wollombi Brook flood plains the surficial alluvium is underlain by basal sands and gravels that form a productive groundwater aquifer ('highly productive alluvium'). As shown in Figure 4-4, the basal sands and gravels of the 'highly productive alluvium' do not occur within the approved footprint of the proposed modification, but are present approximately 50m from both Riverview Pit and South Lemington Pit 2.

The basal sands and gravels form a highly productive groundwater source, as described in Section 2.4. Along the Hunter River and Wollombi Brook flood plains the productive basal sands are typically between 7m and 20m thick.

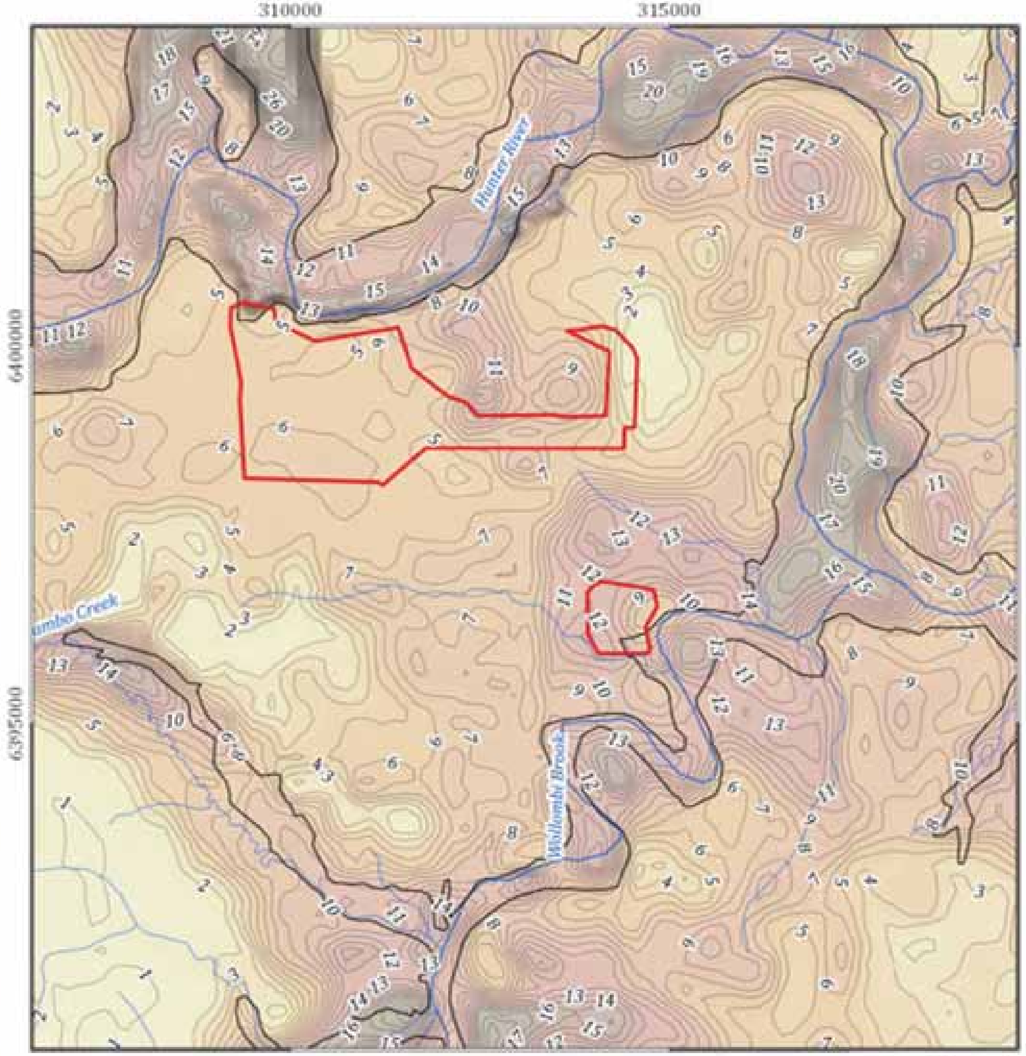
North of the current alignment of the Hunter River and outside the extent of the mapped highly productive alluvium is a palaeochannel. The palaeochannel deposits are contained within an ancient river meander carved into the underlying Permian sediments. Sediments deposited within the palaeochannel comprise silts, sands and gravels that are heterogeneously distributed. Previous studies conducted by Coal & Allied identified that the coarser gravels largely occur within the western limb of the palaeochannel (MER 2010).

Cainozoic silicified weathering profiles (Cza) and alluvial terraces (Czas) also occur outside the proposed modification. The Tertiary deposits comprise silcrete, silts and gravels, and are considered to have comparable lithological characteristic with the unconsolidated weathered bedrock (regolith). The structure, distribution and thickness of the Quaternary alluvium and the regolith are shown on Figure 4-5.

Structure contours of the unconsolidated sediments



Thickness contours of the unconsolidated sediments



LEGEND

- Proposed modification pit depth extension
- Major drainage
- Minor drainage
- Contour
  - Structure (mAHD, 10m interval)
  - Thickness (1m interval)
- Extent of Quaternary alluvium (1:25k AGE)

HVO South Modification 5 Groundwater Study (G1737)

Structure and thickness contours of the unconsolidated sediments

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1/7/2016

FIGURE No:
4-5

Quaternary alluvium (1:25k AGE): 1:25,000 Singleton - AGE digitised and adjusted based on site data
Thickness contours based on CSIRO (2015) Soil and Landscape Grid.

4.2.2 Tertiary volcanics

Minor Tertiary-age intrusions have been observed at outcrop north-west of the proposed modification. A north-east trending dyke occurs west to north-west of the proposed modification, at HVO North.

4.2.3 Triassic Narrabeen Group

The Narrabeen Group comprises quartz-lithic to quartzose sandstone, conglomerate, mudstone and siltstone with rare coal. The unit unconformably overlies the Newcastle Coal Measures and Wittingham Coal Measures to the west of HVO South. The contact between the Triassic and the underlying Permian is marked by an erosional unconformity.

The sequence does not occur at HVO South, but is present over 4km south-west of the development consent. The structure and distribution of the Narrabeen Group was based on existing geological mapping and knowledge and experience in the region.

4.2.4 Permian Newcastle Coal Measures

The Permian aged Newcastle Coal Measures (formerly Wollombi Coal Measures) are present over 4km south-west of HVO South. The coal measures unconformably underlie the Triassic Narrabeen Group and generally dip less than five degrees to the south-west.

The Newcastle Coal Measures comprise tuffaceous claystone, tuff, siltstone, sandstone, conglomerate and minor coal. Coal within the Newcastle Coal Measures generally contains stone and is not considered of economic quality within the region.

4.2.5 Permian Watts Sandstone

The Watts Sandstone overlies the Wittingham Coal Measures and comprises medium to coarse grained sandstone sequences, equivalent to the Waratah Sandstone. The unit was deposited during a marine transgression and is heterogeneously distributed.

The Watts Sandstone is present in places to the west of HVO South, where it occurs as a relatively thin (<15m thickness), deeply weathered unit underlying the Newcastle Coal Measures.

4.2.6 Permian Wittingham Coal Measures

The Permian aged Wittingham Coal Measures unconformably underlie the Triassic Narrabeen Group sediments to the south-west of HVO South, and the Quaternary to Tertiary sediments to the north, south and east of HVO South. The coal measures outcrop within the approved footprint of the proposed modification, with the basal seam (Bayswater Seam) at outcrop to the east.

The Wittingham Coal Measures comprise coal seams interbedded with siltstone, sandstone, shales and conglomerates. The non-coal portions of the sequence are referred to as interburden in the mining context. Mining at HVO South intercepts only the Jerrys Plains Subgroup of the Wittingham Coal Measures. The Jerrys Plains Subgroup is up to 300m thick at HVO South, but regionally it can be up to 600m thick. The structure, distribution and thickness of the Jerrys Plains Subgroup are shown on Figure 4-6.

Within the Jerrys Plains Subgroup there are 15 main coal seams that are mined across the Hunter Valley. In stratigraphic order (youngest to oldest) and using HVO nomenclature, they are the Whybrow, Redbank Creek, Wambo, Whynot, Blakefield, Glen Munro, Woodlands Hill, Arrowfield, Bowfield, Warkworth, Mt Arthur, Piercefield, Vaux, Broonie and Bayswater seams. The Bayswater Seam is underlain by the Archerfield Sandstone, which is a marker bed between the Jerrys Plains Subgroup and the underlying Vane Subgroup of the Wittingham Coal Measures.

It should be noted that seam nomenclature varies slightly between HVO, Wambo and United mines. For the purpose of the proposed modification the HVO nomenclature has been used. The difference in nomenclature between HVO and Wambo is summarised below:

- HVO's Woodlands Hill Seam is equivalent to Wambo's Glen Munro Seam;
- HVO's Arrowfield Seam is equivalent to Wambo's Woodlands Hill Seam; and
- HVO's Bowfield Seam is equivalent to Wambo's Arrowfield Seam and there is a localised seam split at Wambo identified as the Bowfield Seam that is absent at HVO.

All other seams have equivalent nomenclature.

Each coal seam occurs with various splits and plies, with an average coal thickness of 3m, and a total coal thickness of up to 5.5m for most seams. The coal seams are interbedded with units of siltstone, sandstone and shale. The interburden has an average thickness of 25m, and a maximum thickness of up to 90m for each interburden sequence.

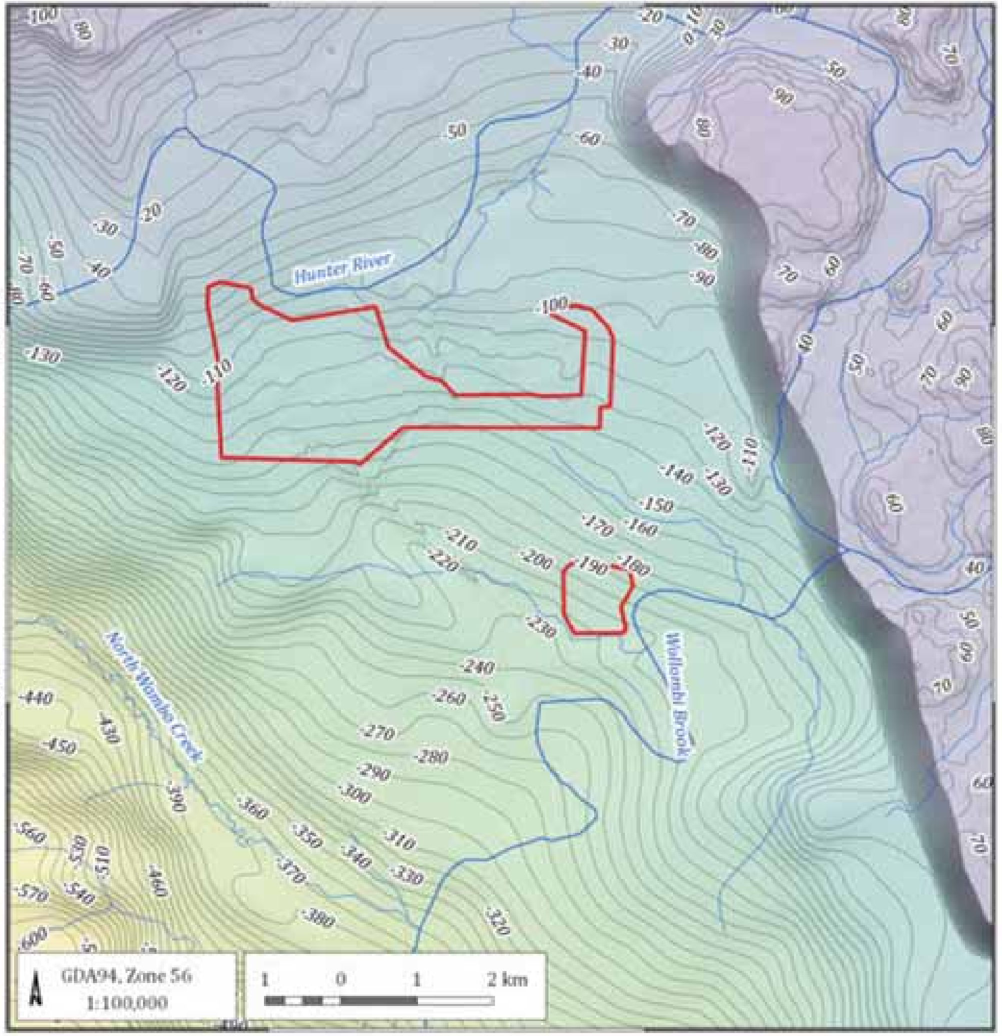
The Permian coal measures occur at outcrop or are unconformably overlain by Quaternary sediments. As a result, the upper Permian stratigraphy underwent a period of weathering. At HVO South the weathered profile of the Permian bedrock extends to around 50m below surface.

4.3 Geological structure

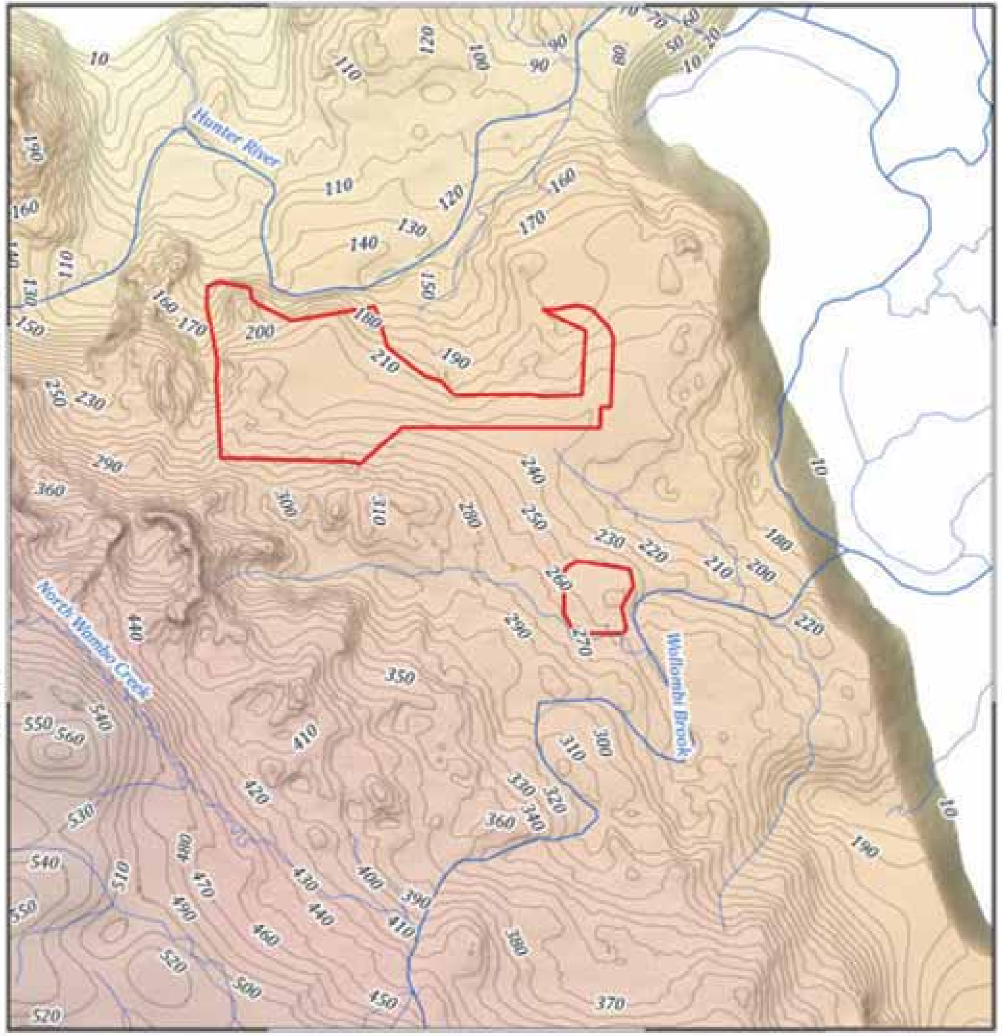
The Permian coal measures are stratified (layered) sequences that have undergone deformation resulting in strata dipping in a general south-westerly direction at HVO South. Regionally, the structure of the coal measures is influenced by large fold structures, including the Camberwell Anticline and the Bayswater Syncline, which occur east of Cheshunt Pit and trend in a north to north-west direction.

North-east to south-west trending faults have been mapped within HVO South (Figure 4-4). The Hunter Valley Cross Fault is mapped in the 1:100,000 Hunter Coalfields geological map as occurring along the southern edge of Riverview Pit, and north of South Lemington Pit 1 and 2. Little is documented about the Hunter Valley Cross Fault; however historic drill logs suggest it is not large with a maximum displacement of approximately 10m.

Structure contours of the Jerrys Plains Subgroup (base of Bayswater Seam)



Thickness contours of Jerrys Plains Subgroup



LEGEND

- Proposed modification pit depth extension
- Major drainage
- Minor drainage
- Contour
  - Structure (mAHD, 10m interval)
  - Thickness (10m interval)

HVO South Modification 5 Groundwater Study (G1737)

Structure and thickness contours of Jerrys Plains Subgroup

DATE
1/7/2016

FIGURE No:
4-6

Structure and thickness contours based on composite geological models.

5 Hydrogeology

5.1 Existing data and monitoring

Coal & Allied has a groundwater monitoring network spanning HVO North and HVO South that has evolved and gradually expanded since establishment of the mines. The network comprises 251 bores and 17 vibrating wire piezometers (VWPs), of which 154 bores and one VWP (3 sensors) are currently monitored as part of the approved HVO groundwater management plan (GWMP). Further details about the monitoring network are included in Appendix A.

Numerous studies have been conducted at HVO South and surrounds due to the long history of mining within the region. Historic data includes field hydraulic testing of key lithological units (eg packer testing, core tests and slug tests), groundwater levels and water quality. The consolidated results are presented in Section 5.2 to Section 5.4.

Additional fieldwork was also completed as part of the proposed modification, in order to address data gaps. The fieldwork included installing additional monitoring bores around HVO South, measuring groundwater levels and conducting in-situ permeability tests on the newly established bores. Groundwater and surface water (Hunter River) quality samples were also collected and tested for a full suite of water quality analytes in order to assess the current beneficial use of groundwater. Results from the sampling event are presented in Appendix A and discussed in Section 5.4.

A census of private water bores (bore census) was also conducted in August 2015, within 4km of the proposed modification pit depth extension. The findings from the bore census are detailed in Appendix A and discussed in Section 5.5.

5.2 Hydraulic parameters

Extensive hydraulic testing has historically been undertaken across the Hunter Valley using field packer testing, lab core permeability testing and slug tests, with the majority of readings compiled as part of a study across the Hunter Valley conducted by Mackie (2009). Alluvial data was largely collected from the Hunter River palaeochannel and "highly productive" alluvium (basal sands and gravels) along the Hunter River, with a total of 59 measurements recorded. Individual coal seams and interburden (siltstone and sandstone) within the Jerry's Plains Sub-group and Vane Sub-group were also tested. In total, there are 303 measurements available for the coal, and 151 measurements for the interburden material, which includes the Archerfield Sandstone.

Figure 5-1 shows the distribution in all available horizontal hydraulic conductivity results for the alluvium, interburden, Archerfield Sandstone and coal.

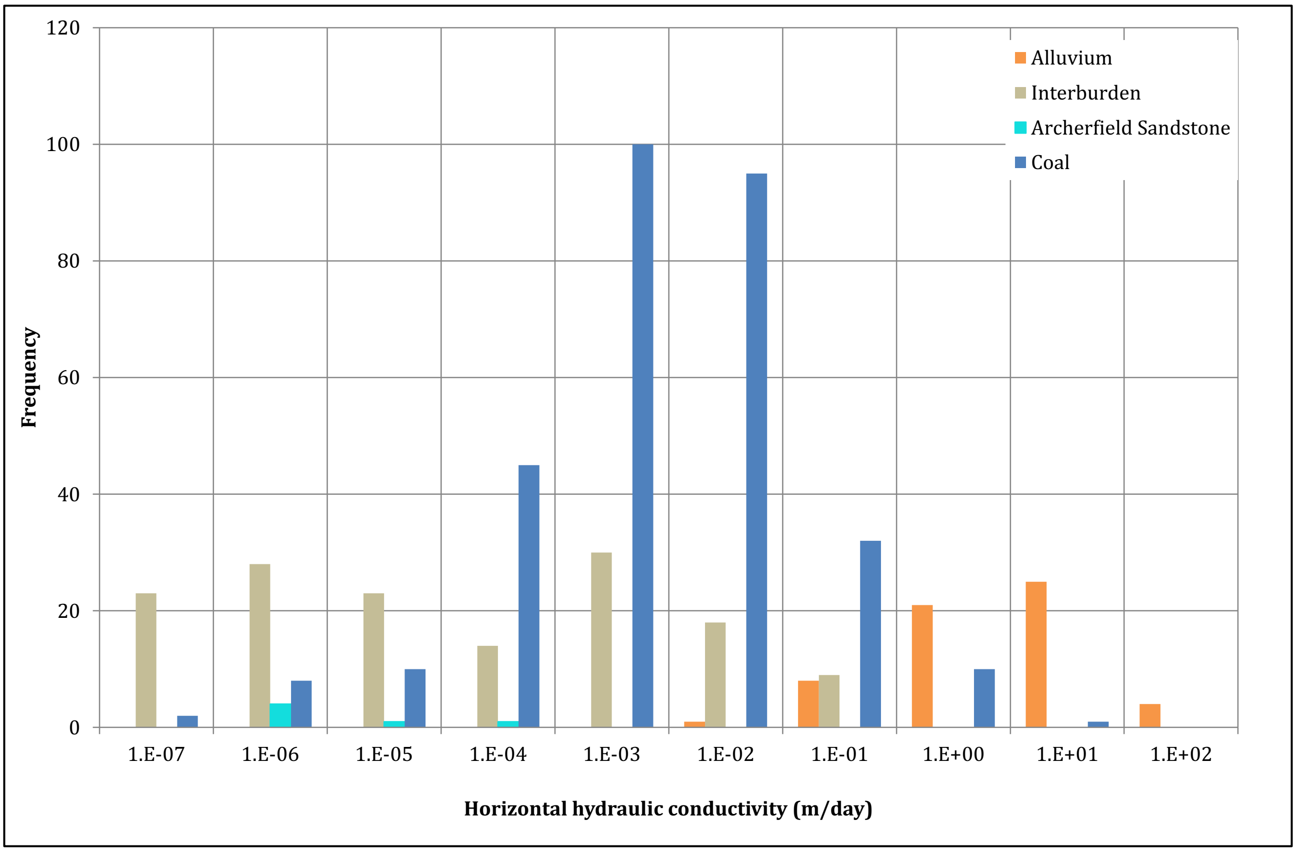


Figure 5-1 Histogram of hydraulic conductivity (Kh) distribution

As expected, the results show that the alluvium has a relatively high hydraulic conductivity, which ranges between 5.3×10^{-2}m/day and 3.70×10^{2}m/day. The coal seams are typically moderately to slightly permeable, with hydraulic conductivity readings generally around 1×10^{-2}m/day, and ranging between 5.24×10^{-7}m/day and 12m/day. The hydraulic conductivity of the interburden material, including the Archerfield Sandstone, is generally less than coal but is highly variable, ranging between 1.87×10^{-7}m/day and 1m/day, depending on the predominance of fractures in the rock mass.

The hydraulic conductivity of the coal seams decreases with depth due to the closure of the cleats with increasing stratigraphic pressure. The hydraulic conductivity versus depth relationships for coal seams is presented in Figure 5-2. The relationship for interburden is presented in Figure 5-3.

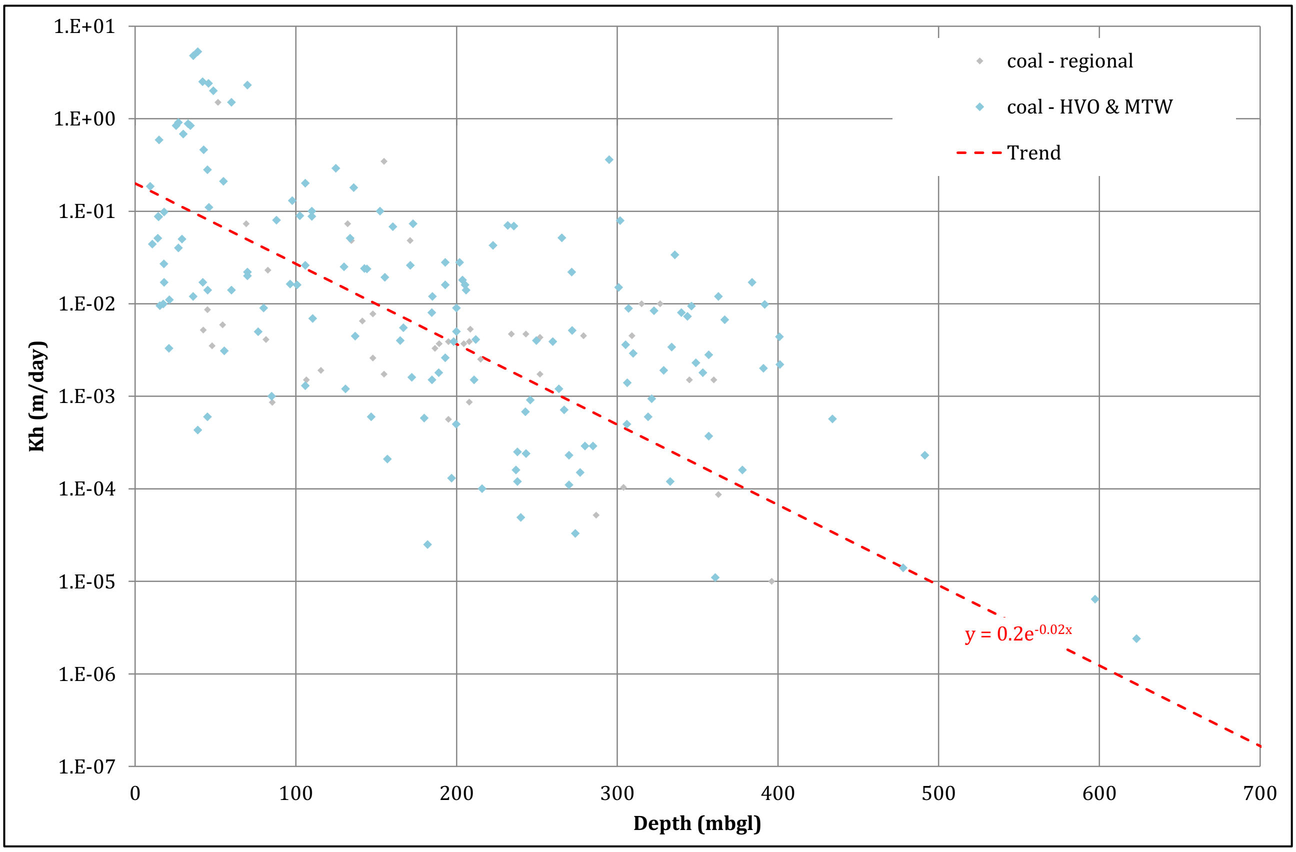


Figure 5-2 Hydraulic conductivity vs. depth – coal

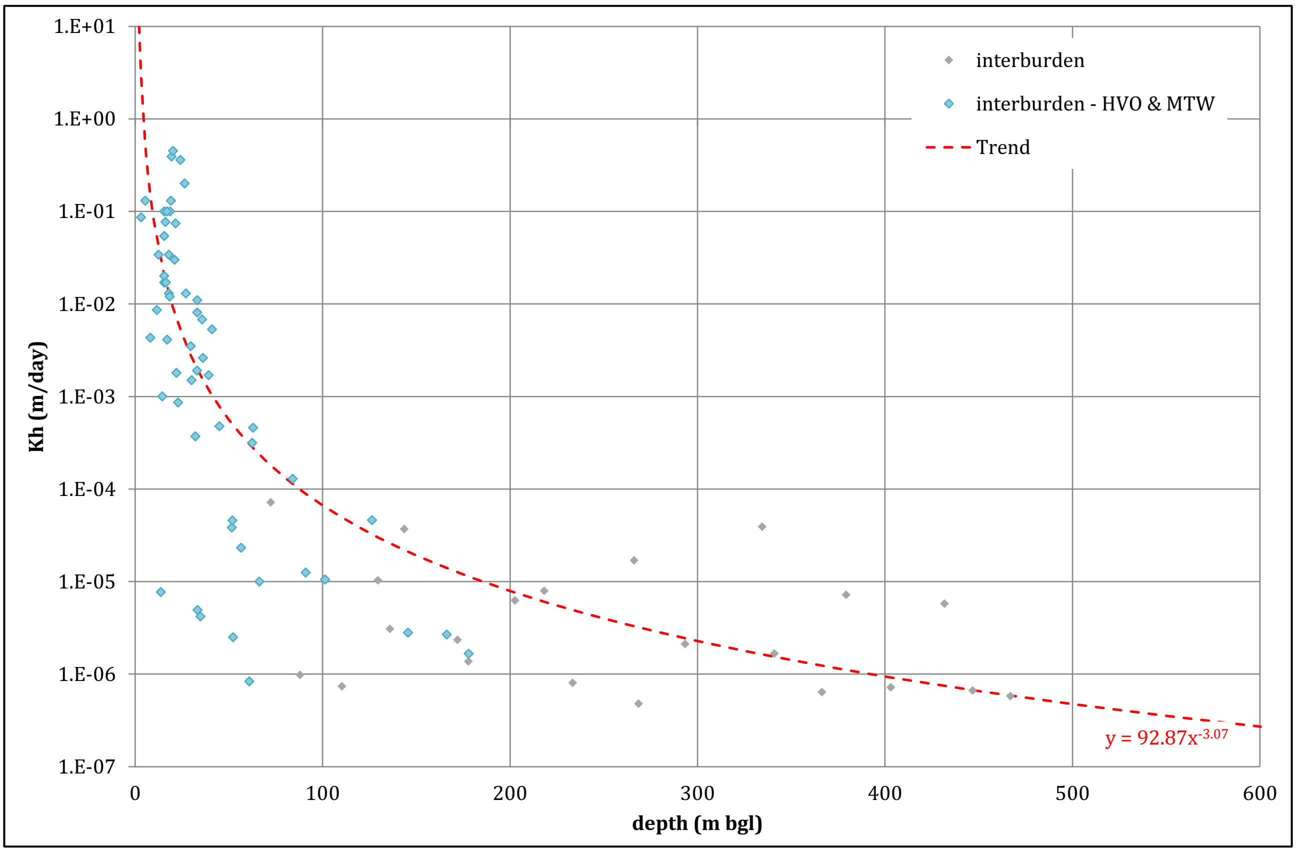


Figure 5-3 Hydraulic conductivity vs. depth – interburden

5.3 Groundwater levels, flow directions and sub-surface recharge

Groundwater levels allow vertical and lateral hydraulic gradients and flow directions to be determined. They can also be used to infer relative hydraulic conductivity between units. Hydrographs were prepared using available historic water level data (Figure 5-5 and Figure 5-6).

Figure 5-4 compares groundwater level trends within the palaeochannel alluvium (4039C_1) and Permian coal seam (Broonie Seam – 4039C_2) within a VWP within the western limb of the palaeochannel at HVO North. Groundwater levels are also presented for palaeochannel alluvial bores CGW53A and CGW54A, which is located in the eastern limb of the palaeochannel. In order to compare between groundwater and surface water trends, the hydrographs also present river elevations recorded by Coal & Allied at the Hunter River north of Riverview Pit (WLP14 and WLP12).

Prior to mining, groundwater flow within the alluvium deviated north from the Hunter River into the western limb of the palaeochannel. This groundwater then flowed back toward the Hunter River, along the eastern limb of the palaeochannel. Mining has subsequently changed the pattern of groundwater flow within the palaeochannel, resulting in the western limb flowing in a southerly direction. Figure 5-4 shows groundwater elevations within the western limb of the palaeochannel range between 60mAHD to 65mAHD, which are higher than Hunter River elevations recorded at WLP14.

In contrast, groundwater levels in the eastern limb range between 57mAHD and 60mAHD, generally below river levels recorded at WLP12. The results also show isolated peaks in alluvial groundwater level, above river levels. This indicates periods where alluvial groundwater may have discharged into the Hunter River. Groundwater levels have also remained relatively constant within the eastern limb of the palaeochannel despite historic mining at Carrington Pit. This is due to installation of a barrier wall through the unconsolidated sediments, which forms a hydraulic barrier to minimise groundwater flow towards the active mine area to the north. These stable groundwater levels also indicate limited hydraulic connection between the palaeochannel alluvium and the underlying depressurised coal measures.

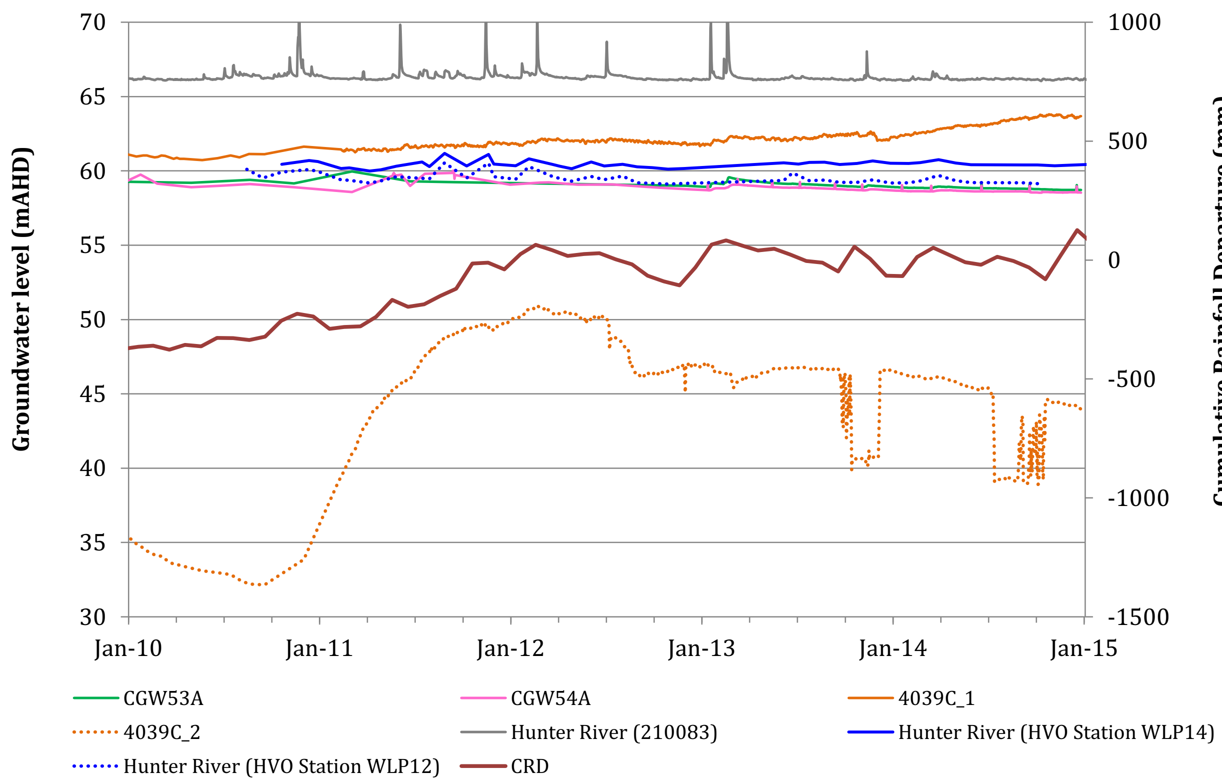


Figure 5-4 Hydrographs comparing groundwater trends and Hunter River levels – Carrington Pit

Figure 5-5 compares groundwater level trends within the alluvium and Permian coal seam (Mt Arthur Seam) within a nested bore along the Hunter River, immediately north of Cheshunt Pit. Groundwater levels are also presented for alluvial bore PZ5CH1800, which is located near BZ1, but north of the Hunter River.

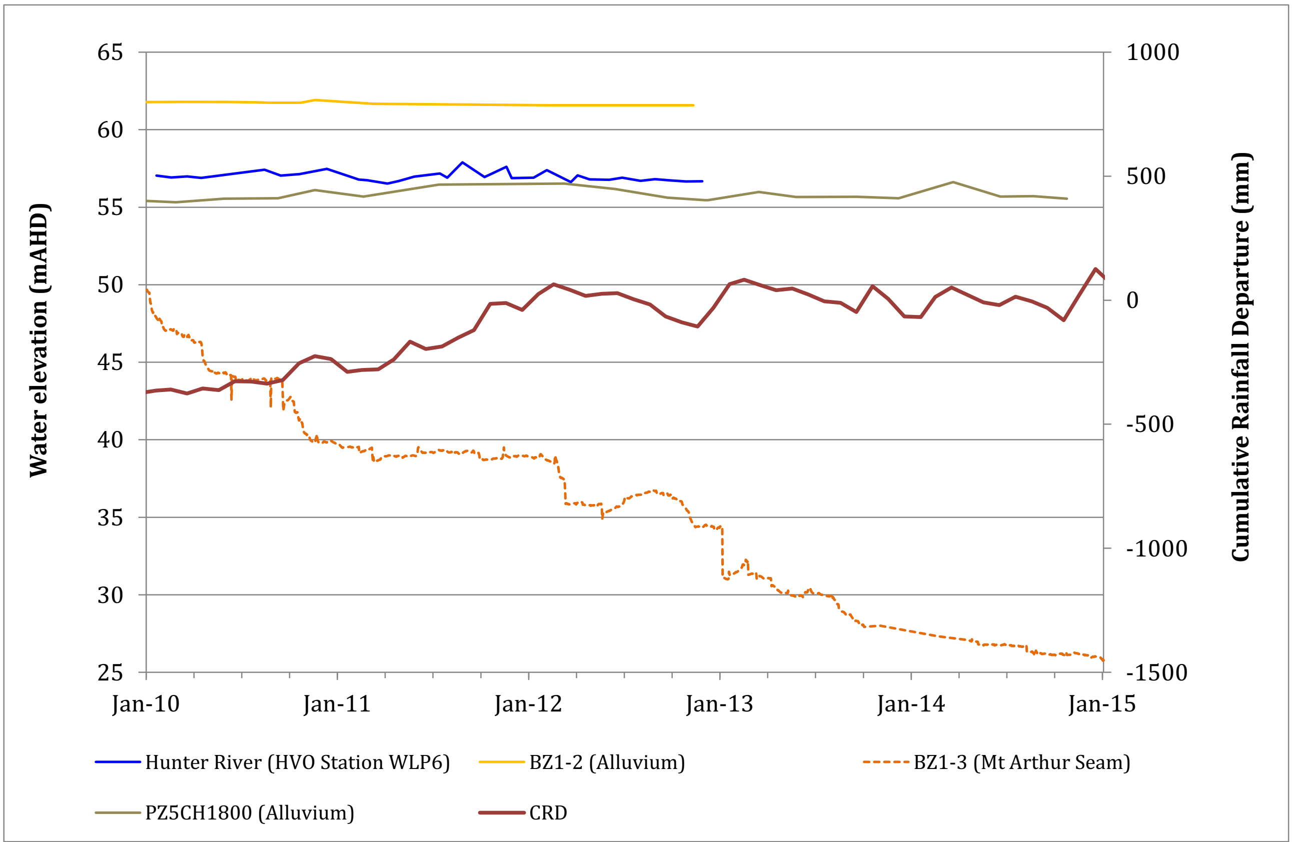


Figure 5-5 Hydrographs comparing groundwater trends and Hunter River levels

Figure 5-6 compares groundwater level trends within the alluvium and Permian coal seam (Bowfield Seam) within a nested bore along the Wollombi Brook, immediately north of South Lemington Pit 1. In order to compare between groundwater and surface water trends, the hydrographs also present stream elevations recorded by Coal & Allied at the Hunter River north of Riverview Pit (WLP6) and by DPI Water in Wollombi Brook at Warkworth (station 210004). Further hydrographs for all site bores are included in Appendix B under the model calibration results.

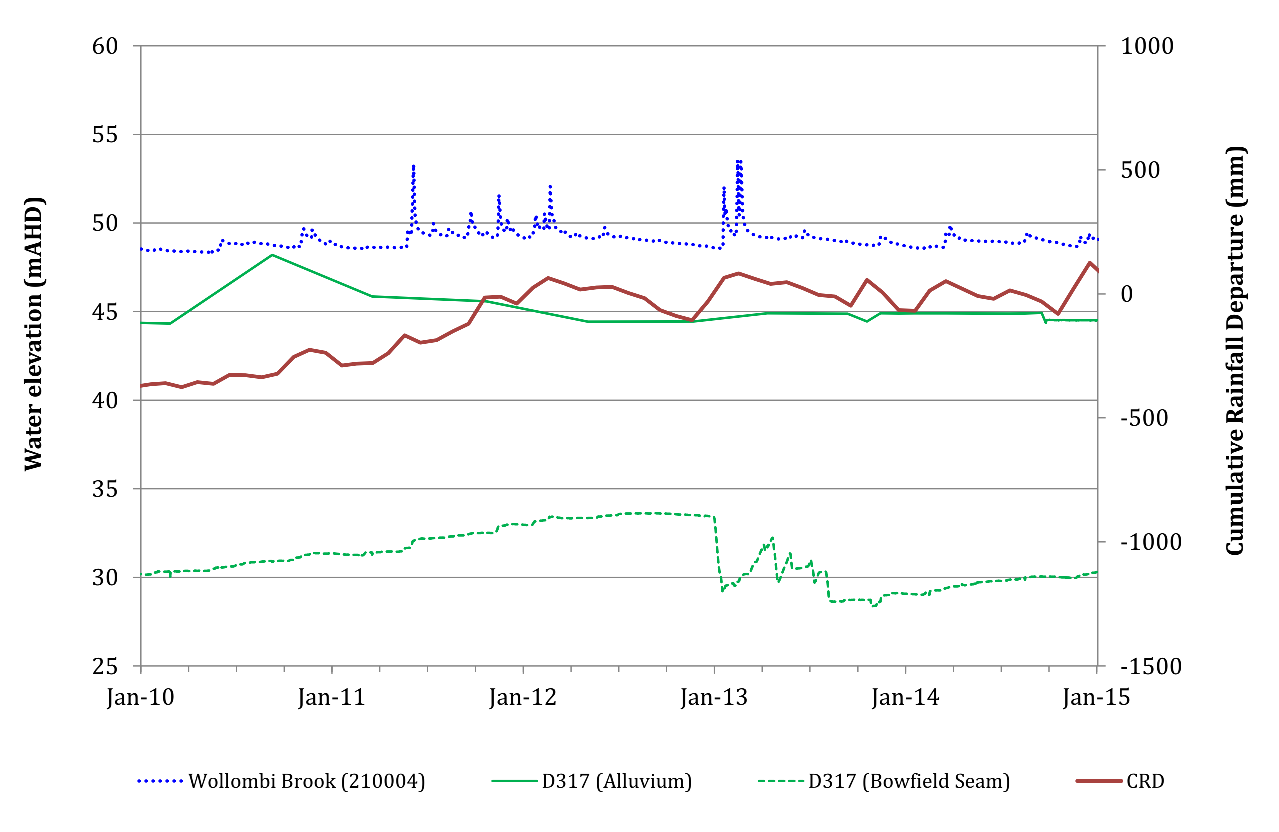


Figure 5-6 Hydrographs comparing groundwater trends and Wollombi Brook levels

Figure 5-5 and Figure 5-6 show variability in groundwater levels within the alluvium, both within and between bores. Recharge to the Quaternary alluvium occurs via 'diffuse' recharge from rainfall and 'focussed' recharge from river and stream flow. While the alluvium is an unconfined unit, the upper sequences of the alluvium (approximately upper 8m) are largely clay rich and less permeable than the basal sands and gravels. As shown in Figure 5-5, groundwater elevations are higher within the clay rich alluvium along the incised southern embankment (BZ1-2) compared to the lower elevation floodplains on the northern side of the Hunter River (PZ5CH1800), where the more permeable basal sands and gravels occur. This shows that the Hunter River is both a losing and gaining system, likely due to the heterogeneous distribution of the Quaternary alluvium and incised nature of the river. Figure 5-6 also shows that the groundwater levels within the alluvium associated with Wollombi Brook around active mine areas are generally 4m below stream levels, as recorded at Warkworth (station 210004). This indicates reduced baseflow contributions from the alluvium within this area.

Figure 5-5 and Figure 5-6 also show that where mining is present the coal seams are depressurised, recording groundwater level elevations around 15m to 30m below alluvial groundwater levels. Therefore, where drawdown due to mining is present, there is limited potential for upward seepage of Permian groundwater to the overlying alluvium.

Potentiometric surfaces for key geological formations (Figure 5-7 to Figure 5-9) were prepared using:

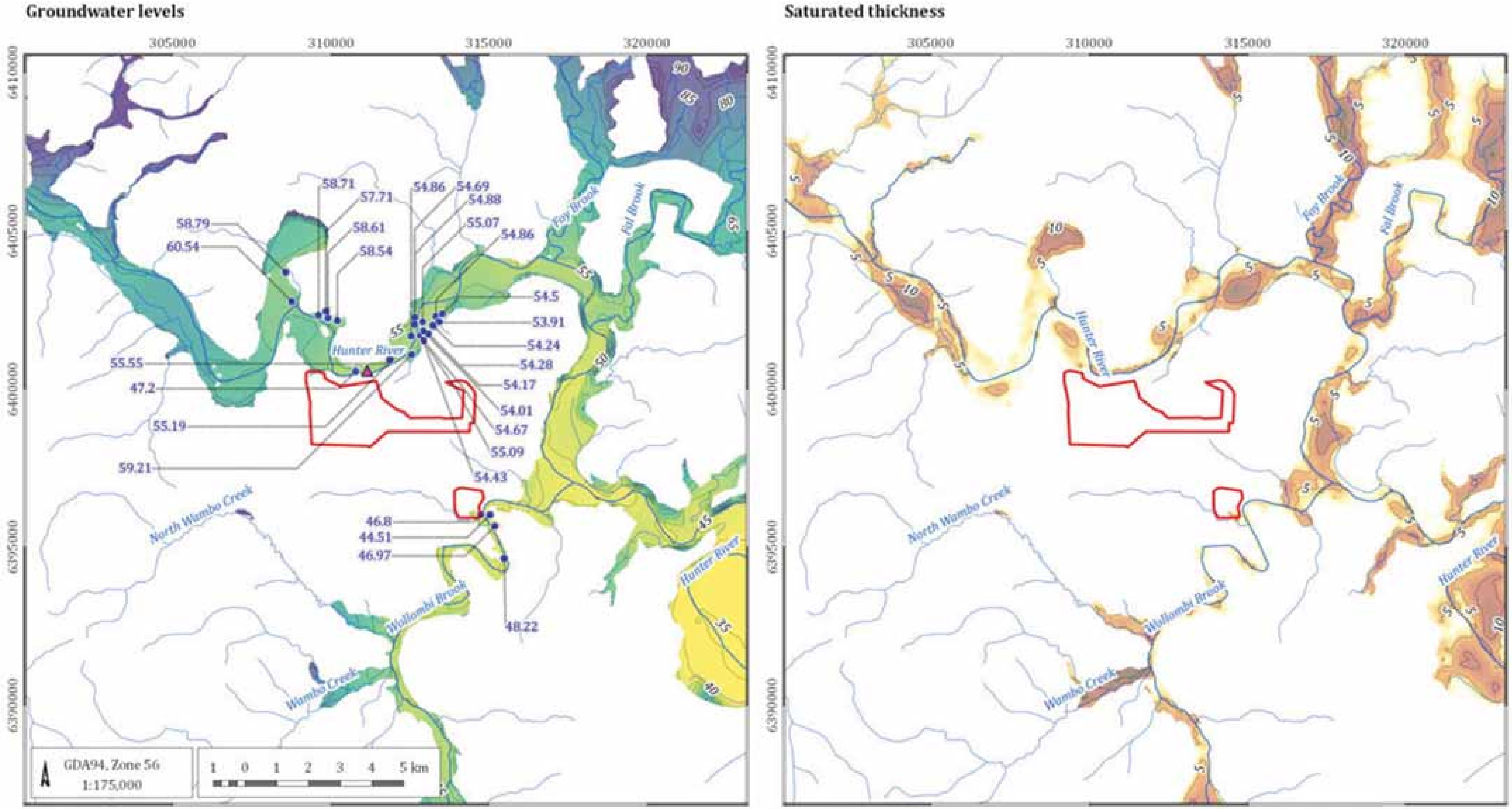
- 2015 levels recorded for site monitoring bores (Appendix A);
- publicly available water levels recorded by surrounding mines; and
- recent available groundwater data for private bores and government monitoring bores, as documented within Pinneena (DPI Water).

Figure 5-7 shows the interpolated groundwater contours and saturated thickness of the Quaternary alluvium, representing current (2015) conditions. While Figure 5-8 and Figure 5-9 show the interpolated groundwater contours (current conditions) for the Mt Arthur Seam and Bayswater Seam of the Wittingham Coal Measures. Available water levels at selected monitoring points are also shown in Figure 5-8 and Figure 5-9. Historical groundwater levels for all available bores are presented in Appendix A and Appendix B hydrographs.

Figure 5-7 shows that groundwater within the Quaternary alluvium flows down-gradient. The Hunter River alluvial groundwater flows in an easterly direction, while the Wollombi Brook alluvium groundwater flows in a north to north-easterly direction towards the Hunter River. Figure 5-7 also shows that the Quaternary alluvium is generally unsaturated within the tributaries, with the alluvial groundwater largely restricted to the thicker sequences of sand and gravel ("highly productive" alluvium) along Hunter River and Wollombi Brook.

The Wittingham Coal Measures occur at outcrop to the north and east of HVO South, and also occur beneath weathered regolith and Quaternary alluvium. The Wittingham Coal Measures are saturated across its extent due to the depth of the unit. Figure 5-8 shows groundwater level contours and flow directions for the Mt Arthur Seam, which occurs at outcrop approximately north and east of HVO South. Groundwater flow largely follows the regional topography, flowing in a north-easterly direction. Groundwater levels are generally 30m below surface, ranging between 80mAHD to the south-west, beneath the escarpment of the Wollemi National Park, down to 50mAHD where the unit occurs at subcrop to the north-east along the Hunter River. The groundwater contours also show localised drawdown within active mining areas (ie HVO South and MTW). The coal measures subcrop beneath the alluvium along Hunter River and Wollombi Brook. Water quality results discussed in Section 5.4 indicate that groundwater can flow upward from the underlying coal measures to the Wollombi Brook alluvium. However, as discussed above, this is restricted to areas where the potentiometric head of the Permian coal measures has not been depressurised below the base of alluvium.

Figure 5-9 shows groundwater level contours and flow directions for the deeper Bayswater Seam, which is the lowermost seam proposed to be mined as part of the proposed modification. As with the Mt Arthur Seam, groundwater flow largely follows the regional topography, flowing in a north-easterly direction. The groundwater contours also show localised drawdown within active mining areas (ie Ravensworth, HVO North and HVO South). The groundwater contours for the coal seams indicate recharge from downward leakage from the Narrabeen Group present at Wollemi National Park, as well as from recharge where the unit occurs at outcrop to the north of HVO South. It is likely that localised downward leakage occurs from the Quaternary alluvium, particularly where the more permeable coal seams subcrop beneath the alluvium. Groundwater discharge from the Wittingham Coal Measures currently occurs as discharge to active mining and abstraction bores, as well as upward seepage to the Quaternary alluvium where hydraulic gradients promote this flow.



LEGEND

- Proposed modification pit depth extension
- Major drainage
- Minor drainage
- Monitoring bore (SWL, mAHD)
- Contour
  - Structure (mAHD, 5m interval)
  - Thickness (5m interval)
- Hunter River (HVO station WLP6)

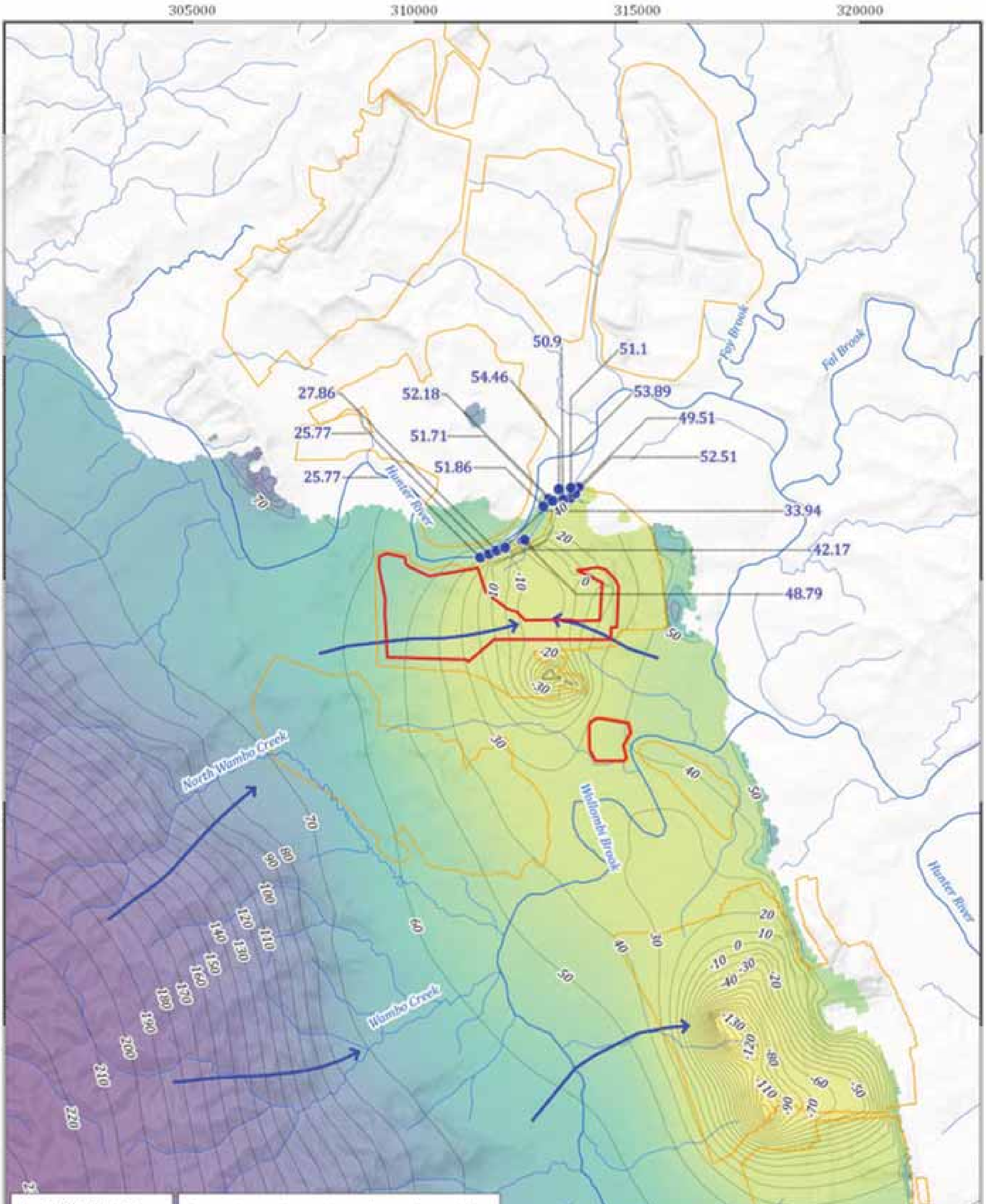
HVO South Modification 5 Groundwater Study (G1737)

AGE

Groundwater levels and saturated thickness - Quaternary alluvium

DATE
1/7/2016

FIGURE No:
5-7



LEGEND
- Proposed modification pit depth extension
- Major drainage
- Minor drainage
- Contour (mAHD, 10m interval)
- Historic and existing open cut mining
- Flow direction
- Monitoring bore (SWL, mAHD)

HVO South Modification 5 Groundwater Study (G1737)

Groundwater levels and flow direction - Mt Arthur Seam

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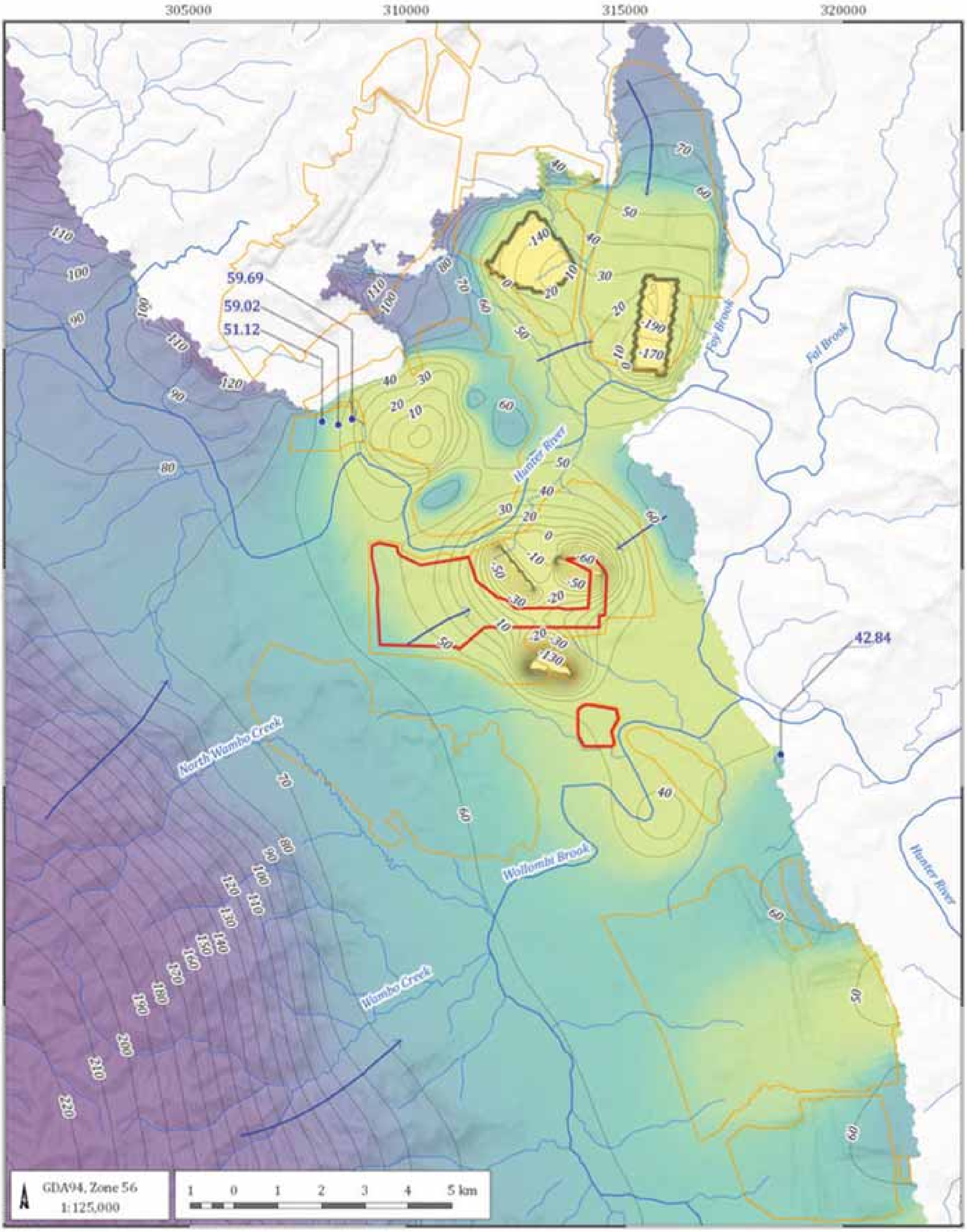
FIGURE No: **5-8**



LEGEND

- Proposed modification pit depth extension
- Major drainage
- Minor drainage
- Contour (mAHD, 10m interval)
- Historic and existing open cut mining
- Flow direction
- Monitoring bore (SWL, mAHD)

HVO South Modification 5 Groundwater Study (G1737)

Groundwater levels and flow direction - Bayswater Seam

DATE 1/7/2016

FIGURE No: **5-9**

5.4 Groundwater quality

This section reports on the characteristics and beneficial use of groundwater within the various geological units across HVO South and surrounds. The main units include the Quaternary alluvium ("highly productive" alluvium and "less productive" alluvium), palaeochannel alluvium, Permian interburden (siltstone/sandstone/shale) and coal. Water quality results for surface water (Hunter River) and spoil are also discussed below. Appendix A presents the groundwater quality data collected during the field investigation, and also incorporates the extensive existing data collected at HVO North and HVO South since 2000.

5.4.1 Groundwater characteristics

Major ion chemistry has been presented based on averaged water quality results for each of the major groundwater units, which is discussed further in Appendix A. Figure 5-10 shows the Mg/Na and Na/SO_4 scatter plots for the averaged water quality results of the main groundwater units (alluvium, interburden, coal and spoil) as well as the surface water (Hunter River and Wollombi Brook).

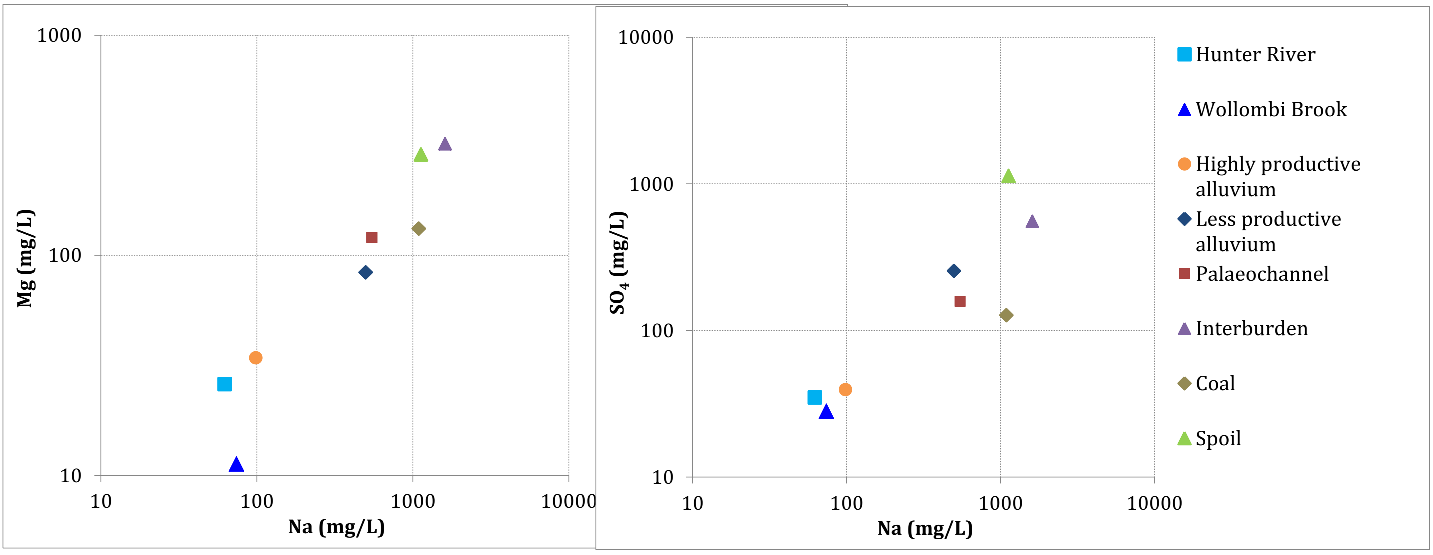


Figure 5-10 Mg/Na scatterplot and Na/SO_4 scatterplot of groundwater quality

Figure 5-10 shows that surface waters have the lowest concentrations of major ions (Na, Mg and SO_4) on average, closely followed by the "highly productive" alluvium. Groundwater within the interburden and spoil show the highest average concentrations of major ions (Na, Mg and SO_4).

5.4.2 Beneficial use of groundwater

Groundwater quality data provides useful information on the beneficial use of the groundwater associated with the major stratigraphic units. Salinity is a key constraint to water management and groundwater use, and can be described by TDS concentrations. TDS concentrations are commonly classified on a scale ranging from fresh to extremely saline. FAO (2013) provide a useful set of categories for assessing salinity based on TDS concentrations as follows:

- Fresh water <500mg/L
- Brackish (slightly saline) 500 to 1,500mg/L
- Moderately saline 1,500 to 7,000mg/L
- Saline 7,000 to 15,000mg/L
- Highly saline 15,000 to 35,000mg/L
- Brine >35,000mg/L

Figure 5-11 presents the available TDS data for the Hunter River and Wollombi Brook as recorded by HVO, as well as the calculated average monthly readings recorded by DPI Water for the Hunter River (station 210083) and Wollombi Brook (station 21004).

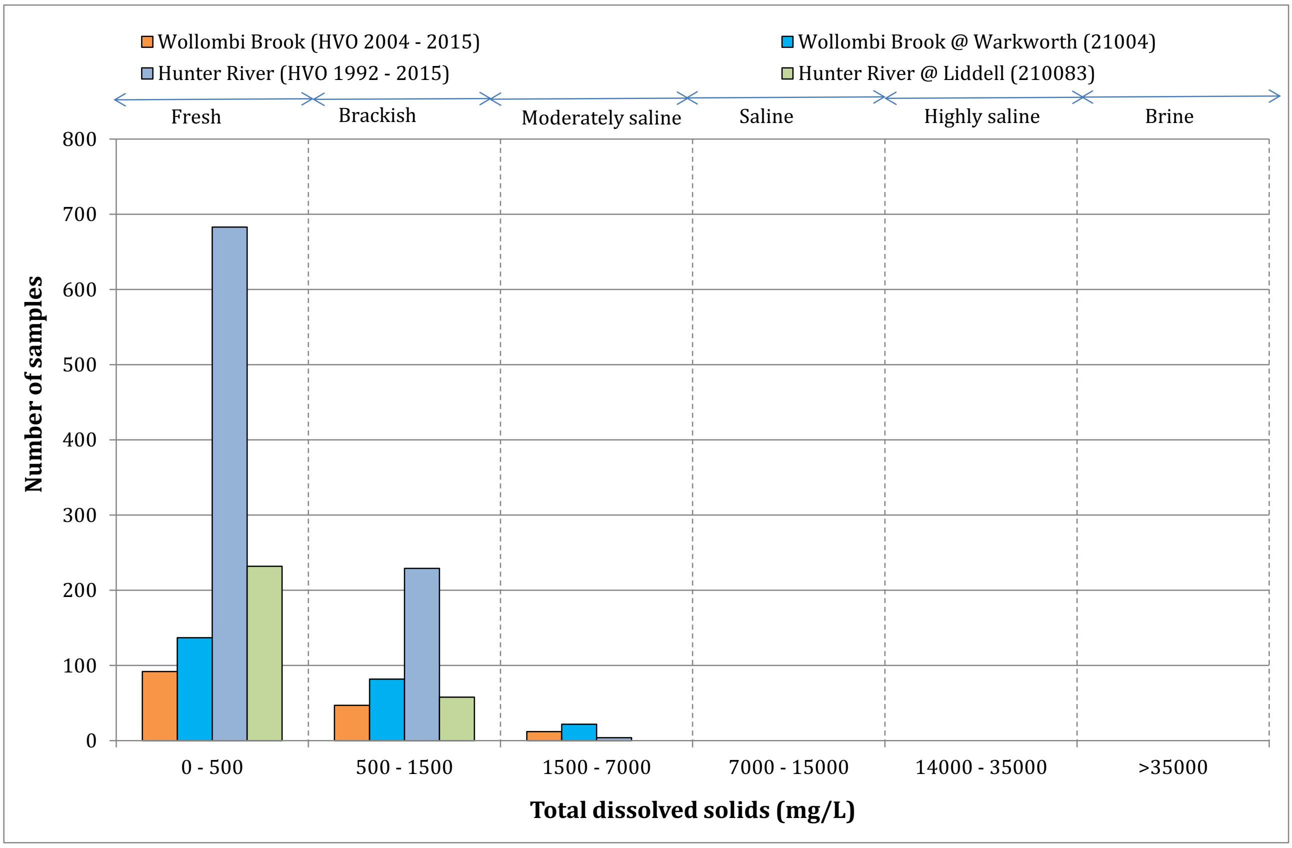


Figure 5-11 Surface water TDS histogram

The distribution of TDS values in Figure 5-11 shows that the water quality within the Hunter River and Wollombi Brook is generally fresh, but can increase in salinity, presumably during low flows.

Figure 5-12 presents the recorded concentration of TDS within the Hunter River since 1991, as recorded by HVO and the average monthly results recorded at the DPI Water stream gauge along Hunter River at Liddell (station 210083). Figure 5-12 shows a relatively good fit between the results collected by DPI Water and HVO. Based on the HVO data, the 5th and 95th percentile for TDS in the Hunter River is 225mg/L and 752mg/L, respectively.

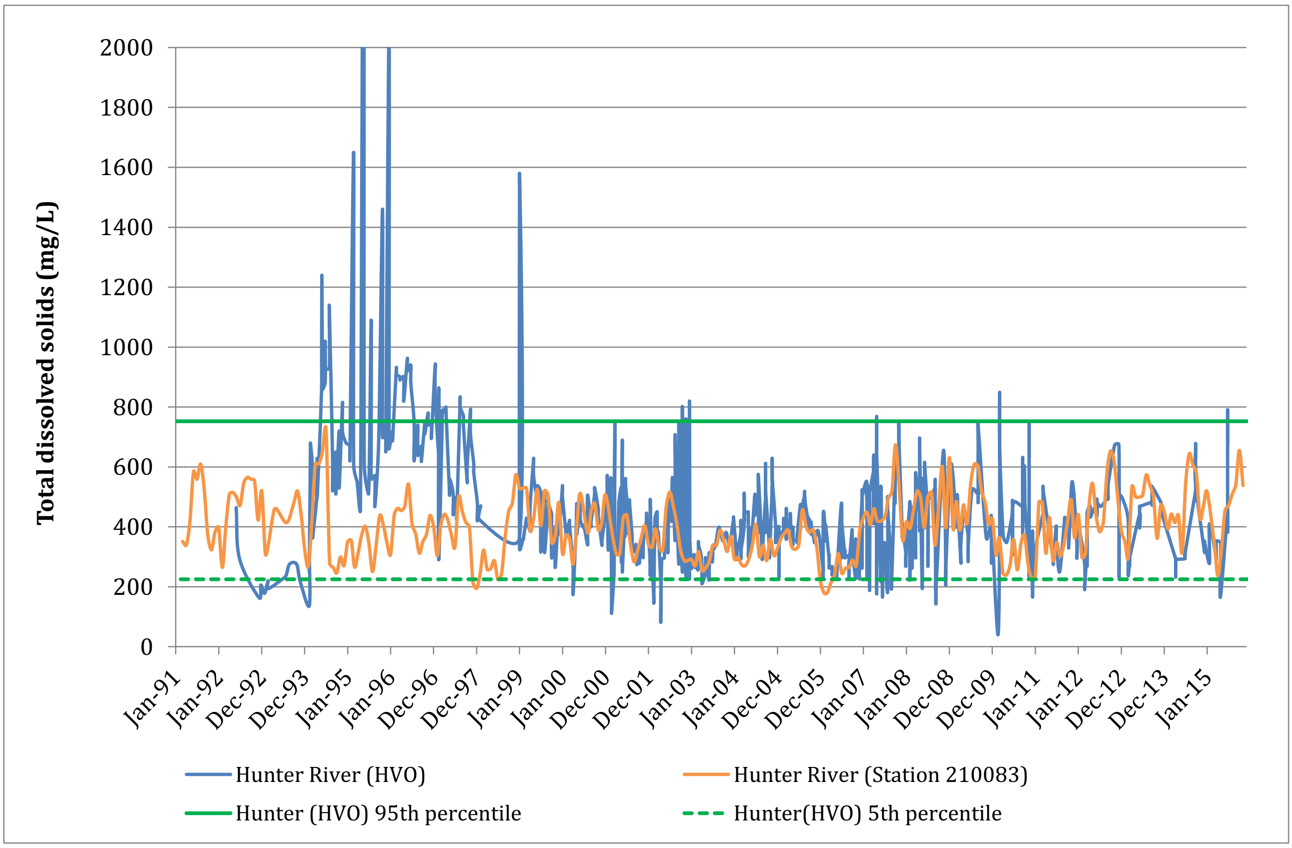


Figure 5-12 Hunter River TDS over time

Figure 5-13 presents the concentration of TDS within Wollombi Brook as recorded by HVO since 2004, and the average monthly results recorded at the DPI Water stream gauge along Wollombi Brook at Warkworth (station 210004). The 5th and 95th percentile of TDS data are also presented in Figure 5-13, based on the more extensive dataset for Wollombi Brook from the DPI Water stream gauge at Warkworth (station 210004). The 5th and 95th percentile for TDS is 108mg/L and 1,817mg/L, respectively.

Figure 5-13 shows the salinity of Wollombi Brook peaked between 2003 and 2007, during the Millennium Drought. Water quality since 2007 has generally been fresher than levels recorded prior to 2003, which likely relates to increased rainfall and possibly a reduction in baseflow from the depressurised Permian stratigraphy from mining in the region.

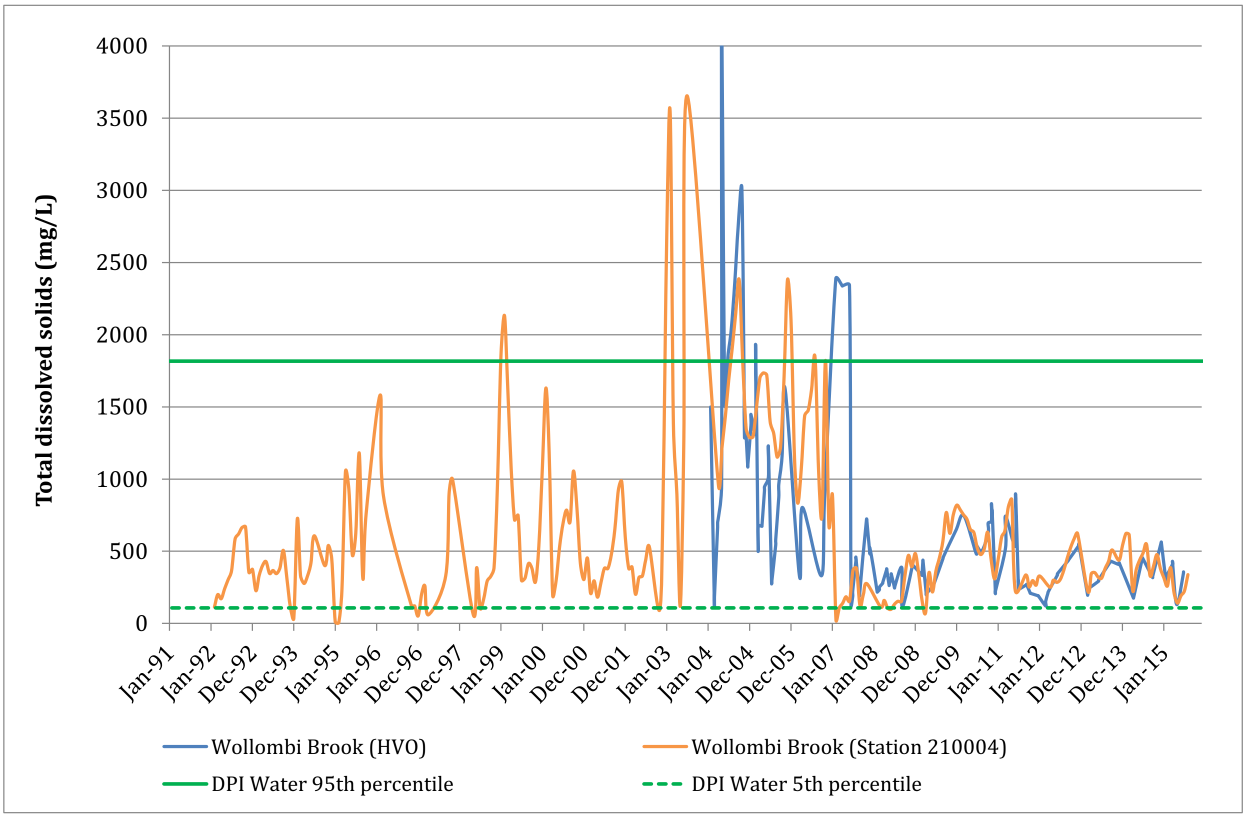


Figure 5-13 Wollombi Brook TDS over time

Figure 5-14 shows a histogram of all available TDS data for the key units monitored across HVO South and surrounds, using the FAO (2013) salinity classification. The alluvial data has been separated spatially by whether they occur within the "highly productive" alluvium or "less productive" alluvium. Water quality results for the palaeochannel north of the Hunter River are also presented for comparison.

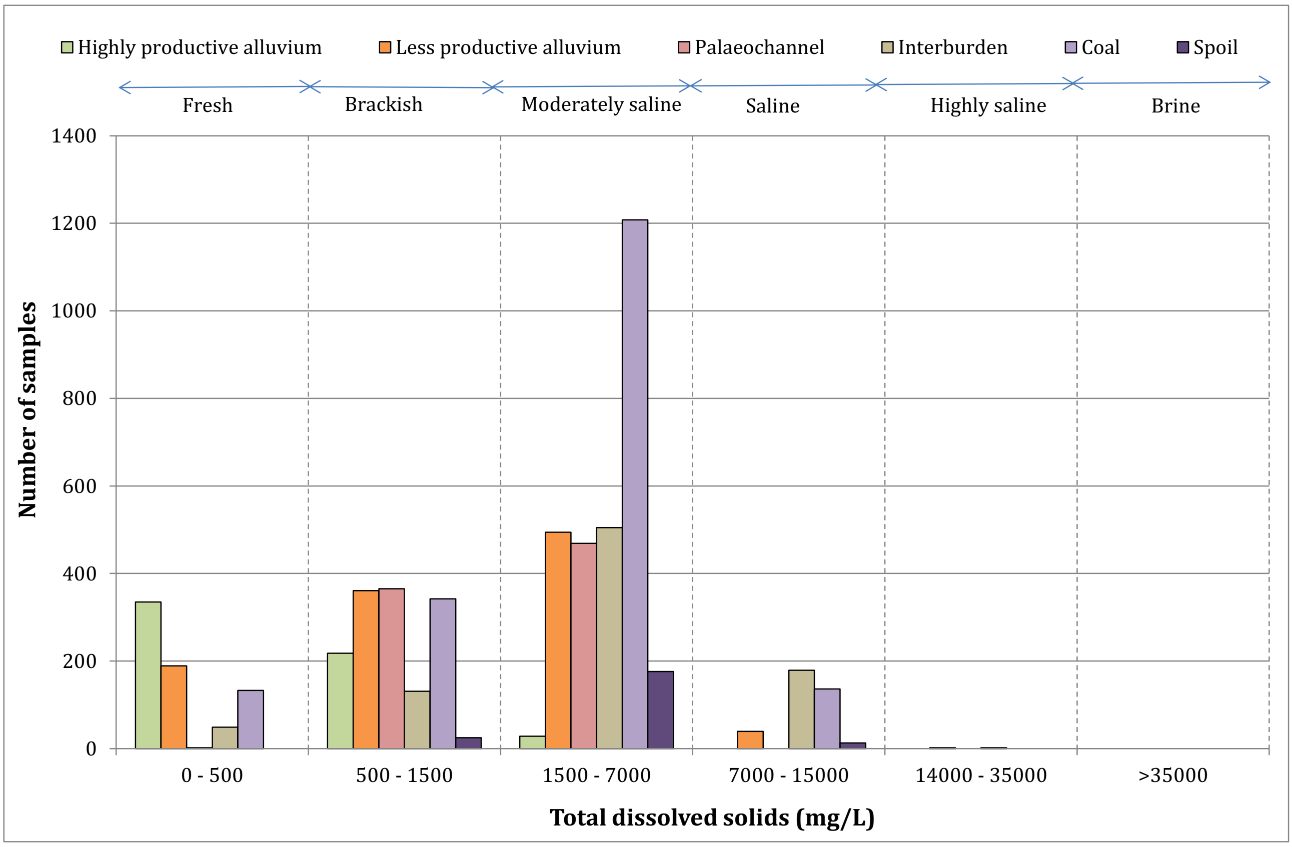


Figure 5-14 Groundwater TDS histogram

The results show that groundwater within "highly productive" alluvium generally has fresh water quality. Figure 5-14 shows that the results range from fresh to moderately saline, with a 5th and 95th percentile for TDS (laboratory and calculated from EC) of 131mg/L and 1,499mg/L. The alluvium within "less productive" alluvium generally has brackish water quality, with results ranging from fresh to saline. Based on the available data, the 5th and 95th percentile for TDS (laboratory and calculated from EC) is 363mg/L and 6,702mg/L, respectively. The higher salinity "less productive" alluvium likely relates to reduced recharge to the "less productive" alluvium and reduced groundwater flushing

The distribution of TDS values shows that groundwater within the palaeochannel is generally moderately saline, but can record brackish water quality. Based on the available data, the 5th and 95th percentile for TDS in the palaeochannel is 831mg/L and 5,657mg/L, respectively.

The water quality results for the Permian stratigraphy indicates that groundwater within the coal is generally moderately saline, with results ranging from fresh to saline. The interburden units are also generally moderately saline, with results ranging from fresh to highly saline. Similar to the Permian units, the spoil water quality is generally moderately saline and ranges between brackish and saline water quality.

For the purpose of this assessment, groundwater quality data has been compared to guideline values from the ANZECC (2000) guidelines for short and long term irrigation and livestock watering (beef cattle). All available water quality results are presented in Appendix A. The results for the alluvium ("highly productive" and "less productive") indicate that the groundwater is not suitable for long term irrigation according to the ANZECC (2000) guideline levels for total manganese.

The results indicate that groundwater within the "highly productive" alluvium is suitable for stock water supply. The averaged laboratory TDS results (Appendix A) show that salinity is below 1,020mg/L in the "highly productive" alluvium, and as detailed above, the 95th percentile for TDS (laboratory and calculated from EC) is 1,499mg/L. These results are below the ANZECC (2000) adverse levels for stock (eg sheep, beef cattle, dairy cattle, horses, pigs and poultry).

The averaged laboratory TDS results for the "less productive" alluvium (Appendix A) show that salinity is generally below 4,610mg/L. However, as detailed above, the 95th percentile for TDS (laboratory and calculated from EC) is 6,702mg/L. The results show that the "less productive" alluvium has a higher salinity compared to the "highly productive" alluvium. In addition, TDS concentrations are recorded above the ANZECC (2000) guideline level for adverse impacts on pigs and poultry (3,000mg/L), dairy cattle (4,000mg/L), beef cattle (5,000mg/L) and horses (6,000mg/L). However, the TDS is below the ANZECC (2000) guideline level for adverse impacts on sheep. Overall, the results indicate that groundwater within the alluvium is not suitable for stock water supply (excluding sheep) in accordance with the ANZECC (2000) guidelines. However, alluvial groundwater is occasionally used for stock (cattle) water supply within the region. This water use is identified in the bore census presented in Appendix A and further discussed in Section 5.5.1.

The results for the Permian stratigraphy (coal and interburden) indicate that the groundwater is not suitable for stock water supply due to elevated salinity levels and total aluminium concentrations. Groundwater within the Permian stratigraphy also records total manganese concentrations above the ANZECC (2000) long term irrigation trigger. Total selenium and concentrations above the ANZECC (2000) guideline level for short-term irrigation is recorded for the coal. The results for spoil show average sulphate concentrations greater than 1,000mg/L, which is above the ANZECC (2000) trigger for stock water supply (pigs). The results also indicate that groundwater within the Permian coal measures and spoil is not suitable for stock water supply or irrigation according to the ANZECC (2000) guidelines, as presented in Appendix A.

5.5 Groundwater use

5.5.1 Registered bores

A search of the National Groundwater Information System (NGIS) database[1] identified 143 registered bores within 4km of the proposed modification pit depth extension. The majority of these bores correspond with HVO site monitoring bores or are abandoned and destroyed water supply bores. An additional two unregistered water supply bores were identified during a bore census and available information (Appendix A).

Excluding abandoned and destroyed bores and Coal & Allied monitoring bores, there are 48 bores located within 4km of the proposed modification, as summarised in Table 5-1 and illustrated in Figure 5-15. There are nine registered bores on private land, which largely intersect the alluvium.

Appendix A includes further details about the nearest registered groundwater supply bores. For bores with no available lithological details, the surface geology map and lithological logs for nearby exploration and registered bores were used to infer the screened lithology.

[1] http://www.bom.gov.au/water/groundwater/ngis/

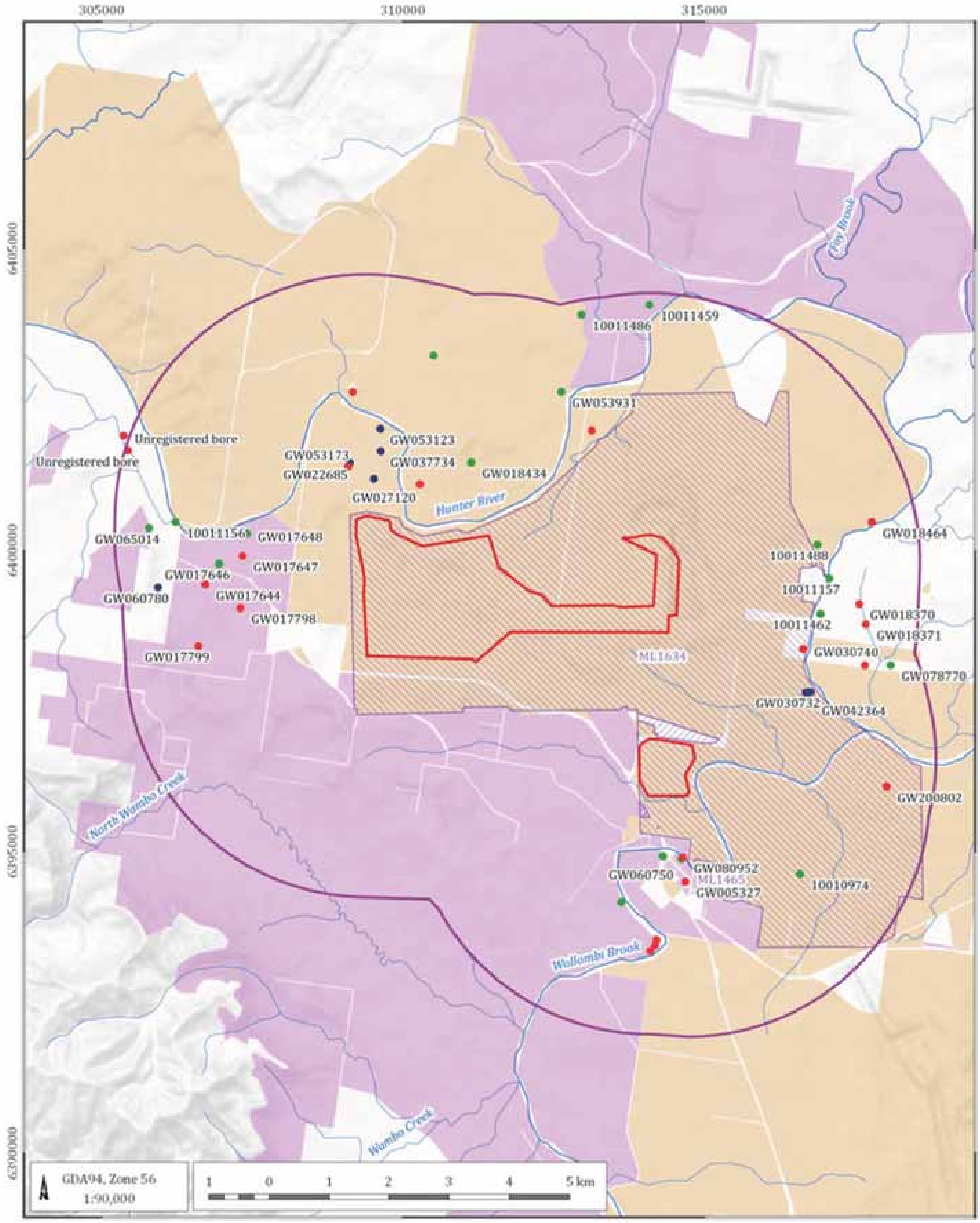
Table 5-1 Existing bores by stratigraphic unit within 4km of proposed modification

Screened unit	Existing bores	Abandoned but usable bores	Total existing and usable bores within 4km
Quaternary alluvium	29	8	37
Wittingham Coal Measures – shallow weathered unit	5	1	6
Unknown	5	0	5
Total	40	9	48

Note: *abandoned and destroyed bores have been excluded, along with known HVO monitoring bores*

The majority of bores are screened within the Quaternary alluvium. Findings from the NGIS database and the bore census (Appendix A) indicate that the main use of groundwater is for stock, with minor irrigation.

One bore in the township of Warkworth (GW060750) and one east of the Hunter River (GW018464) potentially intersect the shallow weathered sequences of the Wittingham Coal Measures for water supply. The remaining bores that intersect the Wittingham Coal Measures are largely used for groundwater monitoring and/or located on mine owned land.



LEGEND

- Proposed modification pit depth extension
- Major drainage
- Minor drainage

Project approval boundary

- ML1634
- ML1465

Groundwater bore status

- Abandoned but usable
- Existing
- Unknown
- 4km buffer
- Mine owned land (Coal and Allied)
- Mine owned land (other)

HVO South Modification 5 Groundwater Study (G1737)

Groundwater use

DATE 1/7/2016

FIGURE No: **5-15**

5.5.2 *Ecosystems that potentially use groundwater*

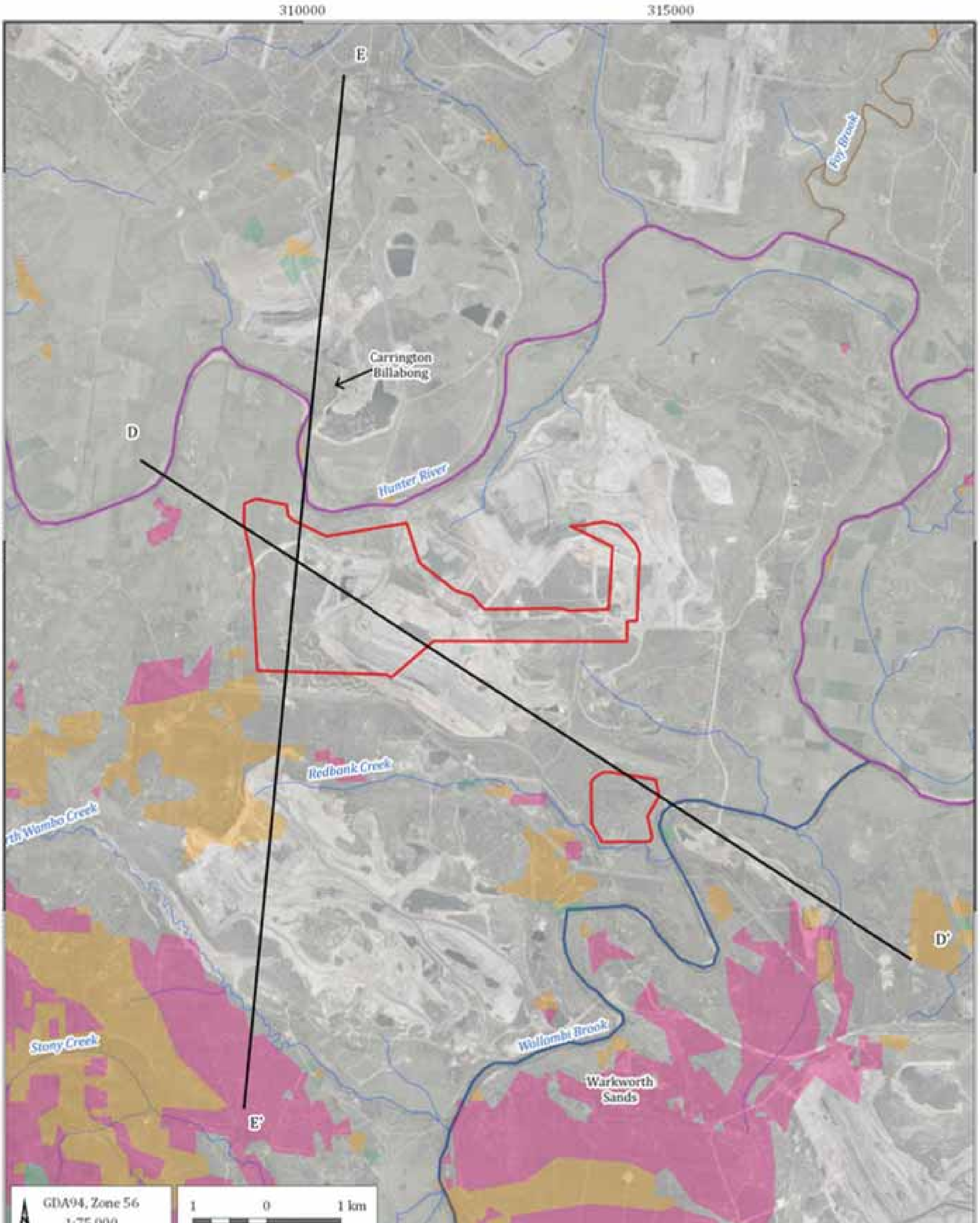
Groundwater Dependent Ecosystems (GDEs) are defined as ecosystems that rely in some part for their survival on groundwater. Dependence ranges from complete reliance for some systems to others that rely partially on groundwater, particularly during times of drought. In general, the majority of Australian ecosystems have little dependence on groundwater; however, there are some localised or extensive ecosystems in Australia with at least a high dependence on groundwater (Hatton and Evans 1998).

The Commonwealth Government has established the National Atlas of Groundwater Dependent Ecosystems (GDEs) (the Atlas), based on the current knowledge of GDEs across Australia. The Atlas shows known and potential GDEs and is considered the most comprehensive inventory of the location and characteristics of GDEs in Australia. The GDE Atlas has been mapped across HVO South in Figure 5-16. There are no GDEs within or adjacent to the proposal along the Hunter River or Wollombi Brook.

Ecology surveys have also been conducted on behalf of the proponent for the HVO South Coal Project (ERM 2008b) and for the nearby Warkworth Continuation Project (Cumberland Ecology, 2014) along the Hunter River and Wollombi Brook. The vegetation mapping from these studies is also shown in Figure 5-16. The surveys found that there are no known threatened aquatic fauna or flora within HVO South. However, an endangered species under the *Threatened Species Conservation Act 1995,* the River Red Gum (*Eucalyptus camaldulensis*), is known to occur along the Hunter River and Wollombi Brook.

Carrington Billabong is an ephemeral freshwater wetland located south of Carrington Pit that has River Red Gums present. As discussed in Section 5.3, despite active mining at Carrington Pit, water levels around Carrington Billabong have remained relatively stable between 57mAHD and 60mAHD. These stable levels are due to installation of a barrier wall through the unconsolidated sediments, up to a height of 65mAHD. In addition, the stable groundwater levels indicate limited hydraulic connection between the palaeochannel alluvium and the underlying depressurised coal measures. Groundwater levels within this area are largely driven by recharge from rainfall and streamflow, particularly following peak flood events. Due to the large storage capacity and relatively low leakage rates (MER 2005) the alluvium remains saturated for prolonged periods between recharge events.

A River Red Gum Restoration Strategy (Umwelt 2007) was prepared by Coal & Allied for the stands of River Red Gum within the HVO South project approval boundary. Further details about ecological communities that potentially use groundwater are discussed in the EIS Ecology report. The interpolated groundwater contours and saturated thickness of the Quaternary alluvium are presented in Figure 5-7.



LEGEND

- Proposed modification pit depth extension
- Major drainage
- Conceptual model section lines

Surface and subsurface GDEs (GDE Atlas)

- High potential for groundwater interaction
- Moderate potential for groundwater interaction
- Low potential for groundwater interaction
- Identified groundwater dependent ecosystems

HVO South EA vegetation mapping (ERM, 2008)

Warkworth Continuation vegetation mapping (Cumberland Ecology, 2014)

HVO South Modification 5 Groundwater Study (G1737)

Ecosystems that potentially use groundwater

DATE 1/7/2016

FIGURE No: **5-16**

5.6 Conceptual model

This section describes the processes that control and influence the storage and movement of groundwater in the hydrogeological system. Figure 5-17 and Figure 5-18 represent cross-sections through HVO South, from west to east and south to north, respectively. The cross sections graphically show the main processes influencing the groundwater regime, including recharge, flow directions and discharge. Figure 5-19 shows a schematic of surface water groundwater interaction along the Hunter River and Wollombi Brook, along with identification of the relevant regulatory framework each zone falls under.

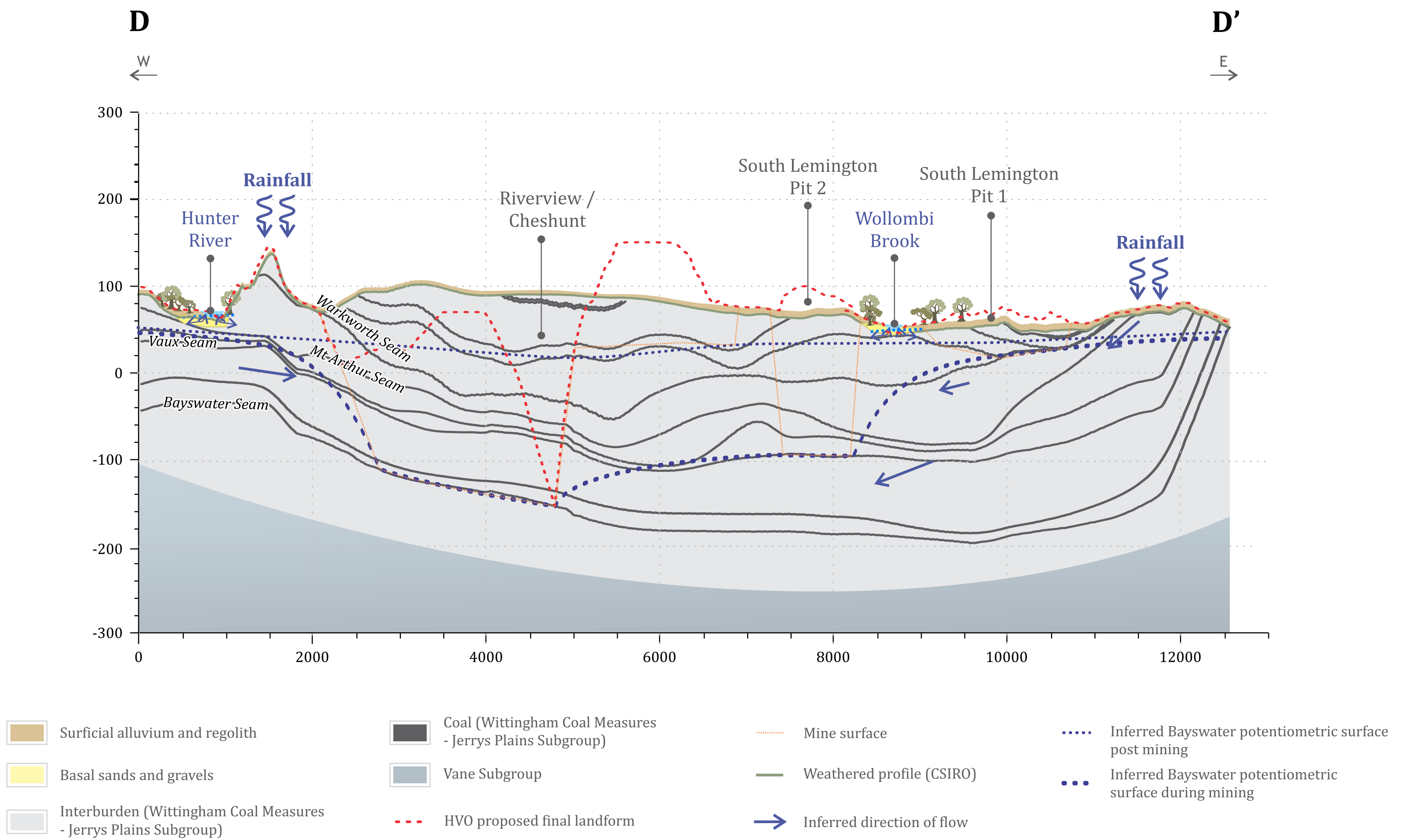
The main groundwater bearing unit occurring near HVO South is the Quaternary alluvium, with less productive groundwater occurring within coal seams of the Wittingham Coal Measures. The Triassic Narrabeen Group, present to the south-west of HVO South, also contains thick sequences of groundwater bearing sandstones.

Groundwater flows from areas of high head (pressure plus elevation) to low head. The Wittingham Coal Measures outcrop north to east of HVO South. Recharge occurs from direct rainfall to the ground surface, infiltrating into the formations through the thin soil cover and weathered profile. The coal measures also occur at subcrop in localised zones beneath alluvium associated with the Hunter River and Wollombi Brook, where the unit is recharged by downward seepage where gradients promote this flow. Recharge also occurs via downward leakage from the Triassic Narrabeen Group and Newcastle Coal Measures to the south-west.

The potentiometric surface and flow direction is a subdued reflection of topography. Groundwater within the Hunter River alluvium flows in an easterly direction, while water within the Wollombi Brook alluvium flows in a north to north-easterly direction towards the Hunter River. The Quaternary alluvium is an unconfined groundwater system that is recharged by rainfall infiltration, streamflow and upward leakage from the underlying stratigraphy, particularly in undisturbed areas (ie away from active mining). Regionally, the Hunter River and Wollombi Brook are predominantly gaining water from the surrounding alluvium, as well as from rainfall and regulated flow (i.e. dam releases). However, there are also areas where the rivers recharge the underlying alluvium. These losing conditions can occur around areas of active mining, where the hydraulic gradient is increased due to depressurisation of the underlying coal measures. Losing conditions also occur within the more topographically elevated tributaries of the main water courses, where the water table is deeper and not connected directly to the streams.

The coal measures form unconfined groundwater systems at outcrop, becoming semi-confined as they dip towards the south-west. The direction of groundwater flow for the Wittingham Coal Measures is influenced by the local geomorphology and structural geology, as well as the long history of mining within the region (Figure 5-8 and Figure 5-9).

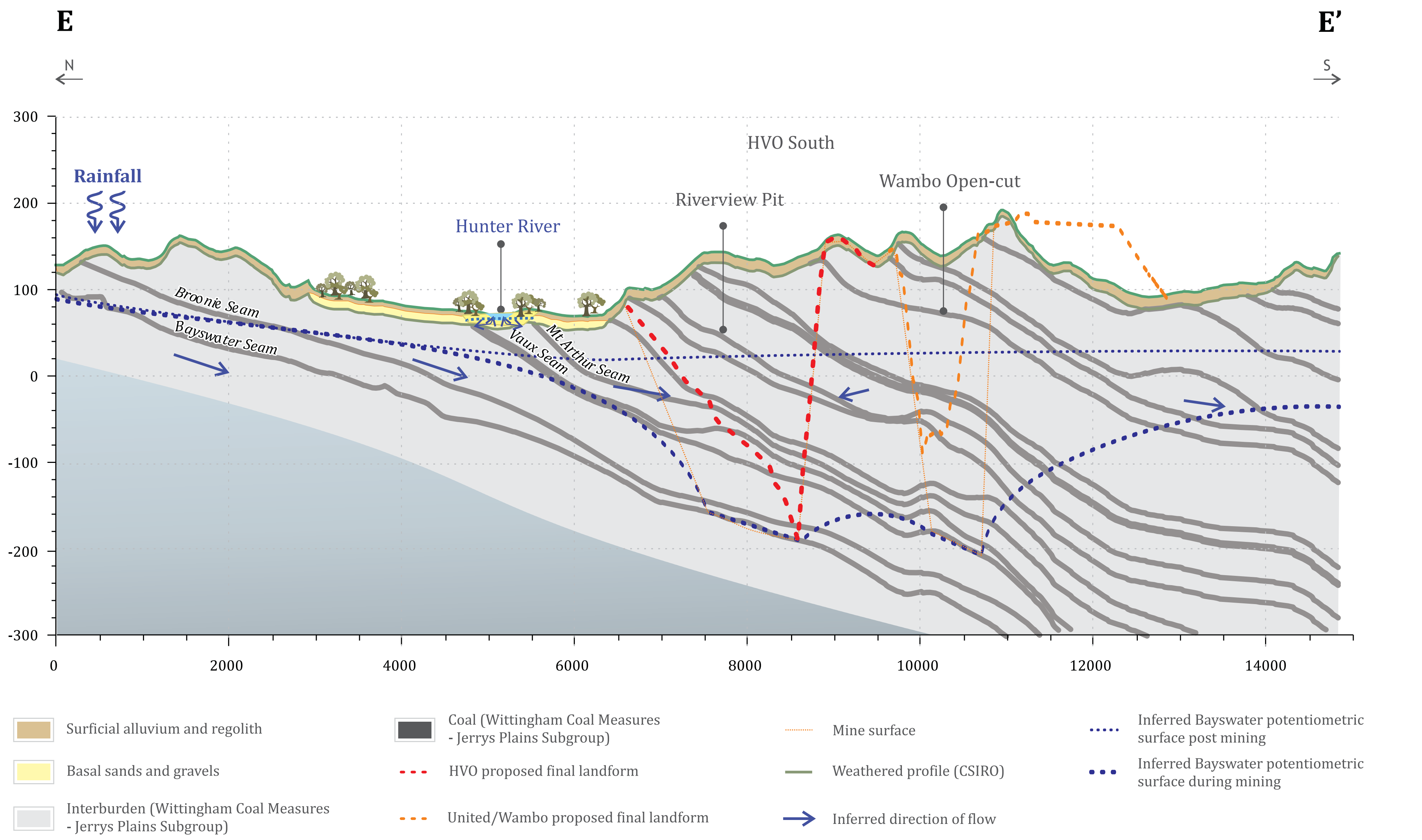
While "less productive" alluvial groundwater does not meet the ANZECC (2000) guidelines for stock water supply, the "highly productive" alluvium is considered suitable for stock water supply. However, the bore census (Appendix A) identified that most agricultural producers (crop and cattle) utilise surface water resources (Hunter River and Wollombi Brook) in preference to alluvial groundwater. There is no significant usage of groundwater from the Permian coal measures, likely due to the poor quality and presence of perennial surface water flows (Hunter River and Wollombi Brook) and the more productive alluvial aquifer.



Schematic section showing conceptual hydrogeology - west to east

Figure 5-17

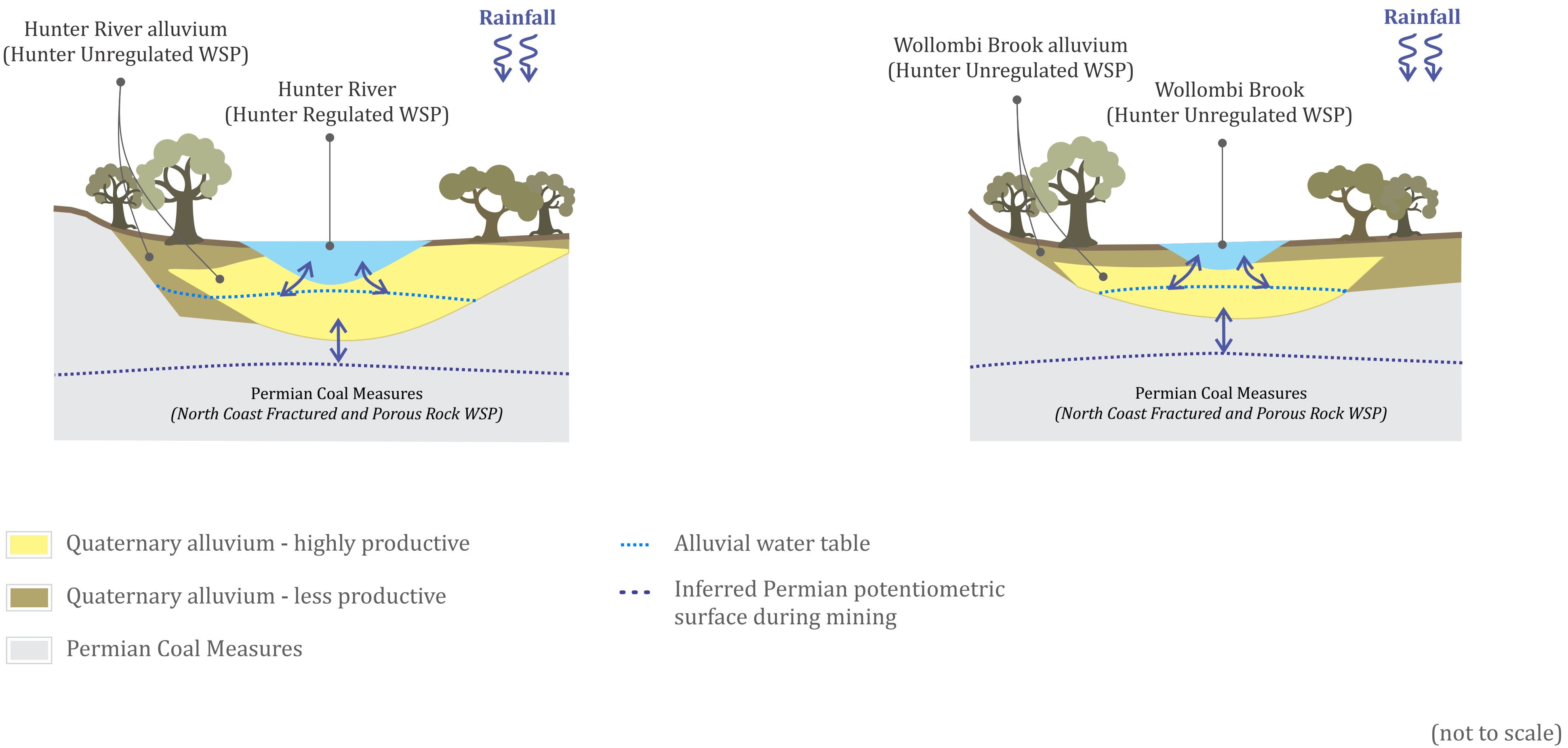
HVO South Modification 5 Groundwater Study (G1737)



Schematic section showing conceptual hydrogeology - south to north

Figure 5-18

HVO South Modification 5 Groundwater Study (G1737)



Schematic showing surface water and groundwater interactions

Figure 5-19

HVO South Modification 5 Groundwater Study (G1737)

5.7 Approved HVO South mine plan and impacts

As discussed in Section 1.1.1, the approved HVO South mine plan has been modified several times and four groundwater assessments have been conducted across Cheshunt, Riverview and South Lemington pits. Section 5.7.1 to Section 5.7.4 describes the findings of the four groundwater studies since 1998.

5.7.1 Mackie Environmental Research 1998 – Cheshunt/Riverview pits

A State significant development application to modify the operations in South Pit to mine down to the base of the Vaux Seam (now known as Riverview and Cheshunt pits within HVO South) within the Hunter Valley No.1 mine, was lodged in 1998. The application involved a revision of the mine plan and continuation of mining for 21 years, largely within the existing mining lease with a minor extension. The groundwater study had a regional scale groundwater model developed by Mackie Environmental Research (MER 1998).

MER (1998) predicted that groundwater level drawdown within the Permian coal measures could extend 2km or 3km from the active mine area. Groundwater intercepted by the approved HVO South mine area was predicted to range between 584ML/year after 10 years of mining, up to 804ML/year by year 15, with only small increases thereafter (MER 1998). Due to the proximity of the mine to the Hunter River and alluvium, MER (1998) also estimated leakage from the river and alluvium due to mining. It was predicted leakage would steadily rise from zero at commencement of mining, to 201ML/year after 21 years.

MER (1998) also predicted that the final void within Riverview Pit would recover within approximately 100 years post mining to an elevation of around 55mAHD. Analysis of spoil leachate found that the long term water quality for the bulk of the spoils is approximately 3,700mg/L, assuming complete leaching. This was up to one third lower than salt concentrations within the in-situ coal measures, therefore some improvement in salinity for the void water quality was expected following mining. In addition, the final void was predicted to act as a 'sink', drawing groundwater in and reducing upward seepage of Permian groundwater to alluvium, also improving alluvial water quality.

5.7.2 Mackie Environmental Research 2005– Cheshunt/Riverview pits

Sectional models (2D models) using FEFLOW were developed by MER (2005) to assess the impact of reducing the 150m buffer between Cheshunt Pit and the Hunter River alluvium to 100m. The assessment predicted a river-alluvium leakage to Cheshunt Pit of:

- 102ML/year for the 150m buffer;
- 142ML/year with a 100m buffer; and
- 222ML/year with a 50m buffer.

The study found that the trend in leakage was not linear with proximity to the river, but instead increased exponentially with decreased distance.

5.7.3 Rust PPK 1997 – South Lemington Pits 1 and 2

Prior to 2000, South Lemington Pits 1 and 2 were owned and operated by a separate mining company. Therefore a separate groundwater study was conducted by Rust PPK (1997) for the approval of South Lemington Pits 1 and 2. A groundwater model was developed to represent the initial mine plan that had a 15 year mine life. The Rust PPK (1997) model predicted the South Lemington Pit 1 would intercept 806ML/year with South Lemington Pit 2 intercepting 274ML/year.

The majority of groundwater inflows were predicted to be from the alluvium associated with Wollombi Brook. Rust PPK (1997) predicted minimal impact on downstream users due to their distance from the mine area and flows within Wollombi Brook, which is the main source of alluvial recharge. Groundwater level drawdown within the Permian coal measures was predicted to extend over 2km south to south-west of the active mine areas. The assessment found that one private bore (GW60750) within the coal measures could be affected by mining (3.4m water level decline), which is located near the town of Warkworth to the south-west.

5.7.4 Environmental Resources Management 2008 – Cheshunt/Riverview/South Lemington pits

The most recent approval for HVO South at Cheshunt, Riverview and South Lemington pits is the project application (PA 06_0261). The application consolidated all existing HVO South development consents and revised the mine plan for Cheshunt Pit, Riverview Pit and South Lemington Pit 1 for a further 21 years of mining.

The change in mine plan included extending the mine footprints slightly, deepening mining within Cheshunt Pit from the already approved Vaux Seam down to the Bayswater Seam. In addition, mining to the approved Vaux Seam in central Riverview pit and extending the Riverview pits to mine the Bowfield Seam and updating the final landform. The groundwater component for the current HVO South mine plan was approved based on the groundwater assessment and findings of ERM (2008a).

ERM (2008a) developed two numerical groundwater models to cover the now approved mine plans for HVO South. The two models separately covered Cheshunt/River and then South Lemington Pits 1 and 2. The models focused on HVO South only, and did not include cumulative impacts from surrounding operations.

The groundwater models were developed following the MDBC (2000) modelling guidelines. The complex geology was simplified into six combined model layers. To represent the progression of mining, various steady state model scenarios were run with the changing mine plans over time. The progression of mining was represented by changing the hydraulic properties of mined out areas and by using well nodes to simulate mine dewatering. The rate of dewatering/seepage was restricted with a groundwater elevation constraint set to the maximum depth of each pit at each time step. The groundwater assessment by ERM (2008a) pre-dates development of the Australian groundwater modelling guidelines (Barnett *et al* 2012) and the NSW Aquifer Interference Policy (AIP) (DPI 2012). However, the groundwater assessment was found to be fit for purpose at the time of submission, and the HVO South mine plan, with the predicted groundwater impacts, achieved approval. The groundwater impacts predicted by ERM (2008a) for the now approved HVO South mine plan are summarised below:

- The groundwater study by ERM (2008a) found that the Hunter River is largely a gaining system around the HVO South mine area. The ERM (2008a) model predicted that the proposed (now approved) HVO South mine plan could reduce baseflow contributions to the Hunter River by up to 69ML/year.
- The model also predicted that the Wollombi Brook is a gaining system around HVO South and that due to the proposed (now approved) HVO South mine plan, there would be a further reduction of baseflow of up to 212ML/year.

- The model predicted that groundwater intercepted into:
    - Cheshunt Pit could range between 281ML/year and 2,672ML/year, with a peak expected in 2010 when mining progression and pit deepening are the greatest;

      Analytical calculations were further used to estimate the peak pumpable volume that may report to the pit, which was estimated to range between 1,841ML/year in summer months and 2,378ML/year in winter months;

      Further factoring in evaporative loss, ERM (2008a) predicted a peak pumpable volume into Cheshunt Pit of 683ML/year;
    - Riverview Pit could range between 44ML/year and 310ML/year, with peak inflows expected between 2009 and 2014.; and
    - South Lemington Pit 1 and Pit 2 were predicted to have a combined peak inflow of 317ML/year.
- Of the predicted seepage, the report details that approximately one third is from Permian groundwater, one third is from alluvium and one third from stored water within the mined out coal measures.
- Groundwater level drawdown predictions for Model 1 (Riverview and Cheshunt pits), representing 2029 conditions compared to December 2005 levels (Figure 5-20) and showed:
    - Shallow groundwater (ie alluvium): 1m drawdown within the Hunter River alluvium north of Cheshunt Pit;
    - Vaux Seam: 1m drawdown extends over 6km west and south-east, beyond the extent of the mine; and
    - Bayswater Seam: 1m drawdown extends approximately 6km south-east and 4km south-west of the active mine area.
- Groundwater level drawdown predictions for Model 2 (South Lemington Pits 1 and 2), representing 2014 and 2019 conditions compared to December 2005 levels (Figure 5-21) showed:
    - Shallow groundwater (ie alluvium): 1m to 31m drawdown within alluvium of Wollombi Brook at South Lemington Pit 2, and up to 41m drawdown within alluvium south of Wollombi Brook at South Lemington Pit 1; and
    - Bowfield Seam: 1m drawdown extends over 6km west and south-east of South Lemington Pit 1 and 2, beyond the extent of the model grid. In 2019 the model also shows up to 11m drawdown around the town of Warkworth, to the south-west of South Lemington Pit 1.
- The groundwater level drawdown could result in reduced available alluvial groundwater to Hunter Floodplain Red Gum complex and a stand of River Red Gums and several isolated trees along Wollombi Brook. However, this was not expected to significantly impact the ecological communities as they rely on surface inundation during peak flow events.
- Groundwater level drawdown, when compared to December 2005 levels, indicated that private groundwater users would not be impacted by the modification.
- The approved final void in Cheshunt Pit was predicted to recover to a pit lake elevation of 0mAHD. The final void was determined to act as a 'sink', drawing groundwater in and preventing migration of spoil leachate into the alluvial or surface water systems. It was predicted it could take over 200 years for salt concentrations within the void to reach the natural salinity levels of the Permian coal measures.
- The approved final landform for South Lemington Pit 1 and Pit 2 did not include a void. Therefore, it was predicted that with recovery of groundwater levels post closure, there is the potential for spoil leachate to flow into the alluvial aquifer. However, it was not considered likely to result in adverse impacts to the surrounding groundwater system.

Figure 5-20 Approved HVO South – drawdown near Cheshunt/Riverview Pits (ERM 2008a)

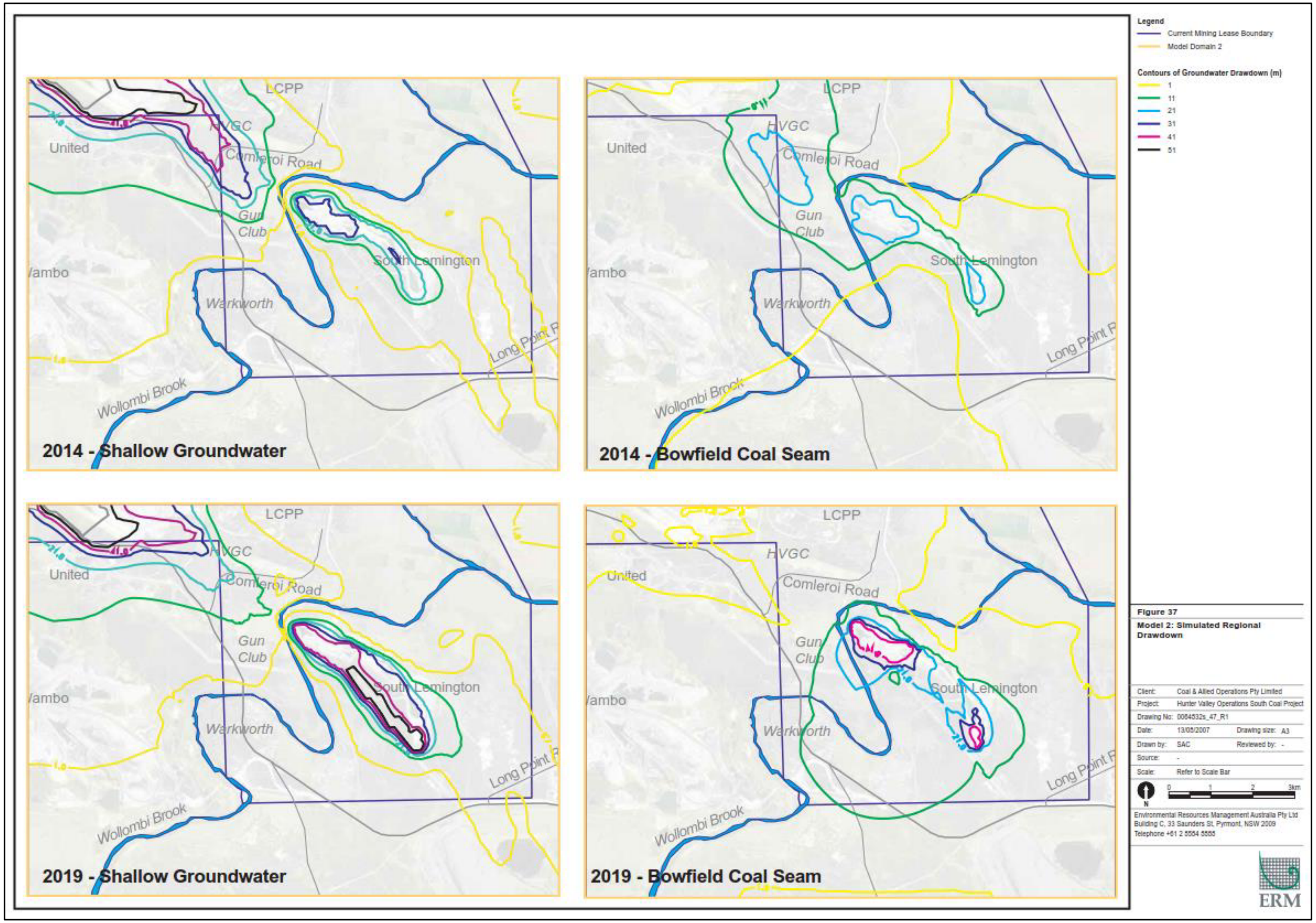


Figure 5-21 Approved HVO South – drawdown near South Lemington Pits 1 and 2 (ERM 2008a)

6 Numerical groundwater model design

This section presents the results from numerical groundwater modelling and is structured as follows:

- Section 6.1 provides an overview of the proposed open cut mining activities.
- Section 6.2 provides an overview of the groundwater model developed to assess the impact of mining. Appendix B provides a detailed technical description of the model development, construction and calibration.
- Section 6.3 provides an overview of the peer review process followed as part of the groundwater assessment.

6.1 Overview of mining

6.1.1 Proposed mine plan

The proposed modification involves progression of mining of the deeper Bayswater Seam from Cheshunt Pit into Riverview Pit and mining the Vaux Seam at South Lemington Pit 2, all within the currently approved mine footprint. The proposed modification is proposed to commence in 2017 and be completed in 2030. Open cut mining will target the Wittingham Coal Measures over the full extent of the mining area. Overburden removal will involve the use of dragline and truck and shovel operations. In order to achieve the most efficient extraction of coal, several mining areas may be active simultaneously. As the open cut pit develops and progresses, overburden will be placed progressively within the mined out areas, with a final void positioned at the southern extent of Riverview Pit.

6.2 Overview of groundwater modelling

A 3D numerical groundwater flow model was developed for the proposed modification using MODFLOW-USG. A detailed description of the modelling work is provided in Appendix B.

The model represented the key geological units as 34 layers, aligned in a general north-south direction. The model extends approximately 27km from east to west, and 39km from north to south comprising up to 71,049 cells per layer, making it spatially a relatively large model (Figure 6-1). The extent of the model is relatively large, in order to include all active mine operations that immediately surround the proposed modification. The surrounding mines captured within the model domain include HVO North, Ravensworth, Cumnock, Ashton, United, Wambo and MTW. Inclusion of the surrounding mines ensures the numerical groundwater model accounts for all potential cumulative groundwater impacts.

The model was built around the conceptual groundwater model summarised in Section 5.6, and detailed in Appendix B. Development of the model was based on existing HVO groundwater models and updated with data from HVO geological model as well as publicly available data (i.e. geological maps and groundwater studies for the surrounding region). The model extends north to include the HVO North and Ravensworth operations, and to the east and south to include the full lateral extent of the Wittingham Coal Measures.

The groundwater model was calibrated to replicate steady state (1970 to 2003) and measured transient groundwater levels (2003 to 2015). The transient calibration period was selected to utilise the period of time when more extensive groundwater monitoring data and information on mining became available. The calibration model captured historical mining that occurred at HVO South as well as at surrounding mines that intersected the Wittingham Coal Measures. The historical mining at HVO South is based on the approved mine plan as modelled by ERM (2008a), which was further refined using historic aerial photographs and topographic surfaces in order to capture the actual mine progression.

Following calibration, the model was used to predict from 2015, the groundwater levels, drawdown and inflow rates in response to the proposed open-cut mine modification in accordance with the proposed mine plan. That is, mining was simulated down to the base of the Bayswater Seam (defined as layer 27 in the model) at Cheshunt Pit and Riverview Pit, and down to the Vaux Seam (layer 25) at South Lemington Pit 2.

The existing approved mine plan from 2015 onwards was remodelled (refer to Section 6) to identify the influence of the proposed modification on the groundwater regime by comparing the impacts generated by the approved and proposed mine plan for HVO South. All currently approved and foreseeable mine plans within the region (ie United Wambo Project, MTW, Ravensworth) were included in order to account for cumulative impacts. Mining was represented in the model using the drain package, with the drain cells set to the base of the target coal seam for each pit. Further details about how mining within the region was represented in the model are included in Appendix B.

The selection of appropriate boundary conditions, locations and alignments was based upon a detailed review of all available geological and hydrogeological information. This included topography and the location of HVO South relative to groundwater users and the surrounding mines. The model was calibrated using existing groundwater levels at representative bores, located within the model domain, that were considered to be reliable. A detailed description of the calibration procedure is provided in Appendix B. The objective of the calibration was to replicate the groundwater levels measured in the site monitoring network and available private bores, in accordance with the Australian groundwater modelling guidelines (Barnett *et al* 2012). The transient calibration achieved a 3.61 per cent scaled root mean square (SRMS) error, which is within acceptable limits (ie 10 per cent), recommended by the Australian groundwater modelling guidelines (Barnett *et al* 2012). The model calibration is therefore considered to be valid.

Post mining conditions were simulated over a period of 1000 years using groundwater levels from the end of mining, using groundwater levels as the starting heads after removal of all mine 'drain cells' in the model. During recovery, the main processes that influence the pit lake water level are direct rainfall recharge, surface water flows from the catchment area, as well as minor contributions for groundwater. As a result, predicted groundwater inflows to the void during recovery were provided to the surface water consultants and the results were incorporated in a high-resolution surface water model. Pit lake level recovery rates from the surface water model were reinstated to the groundwater model using a series of constant heads over time, with a predicted final pit lake level of 30mAHD. This ensured consistency between the surface water and groundwater studies.

In order to assess the drawdown impacts post mining due to the proposed final landform, the approved final landform was also remodelled for comparison. WRM (2016) remodelled the approved final landform and predicted an approved final pit lake level of approximately 32mAHD. Results from the WRM (2016) study were used for the remodelled approved groundwater recovery model scenario. Further details about the assumptions used and recovery model methodology are included in Appendix B.

The sensitivity of the model predictions to the input parameters was conducted and analysed. The analysis included varying model parameters and design features that could most influence the model predictions. The model parameters were adjusted to encompass the range of likely uncertainty in key parameters. Sensitivity analysis included testing the effects of changes in:

- horizontal hydraulic conductivity, specific storage of all geological units and overburden; and
- the rainfall recharge rate across the model domain and overburden.

Appendix B provides a detailed discussion of the sensitivity analyses. The following sections describe the groundwater model predictions.

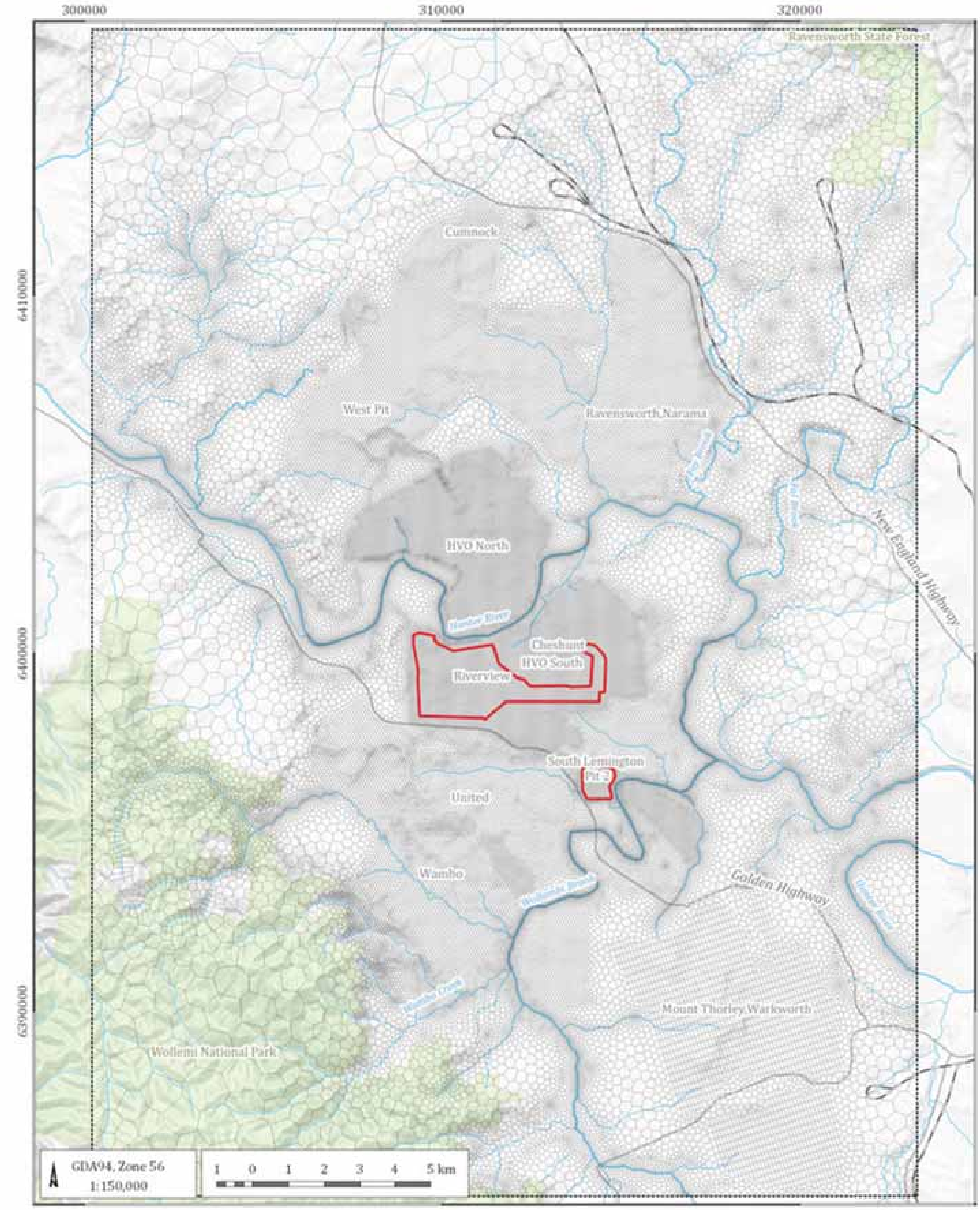
6.3 Peer review

In accordance with the Australian groundwater modelling guidelines (Barnett *et al* 2012) an external peer review was conducted by Dr Frans Kalf of Kalf and Associates Pty Ltd, who has over 47 years of experience in hydrogeological investigations and specialises in peer reviews.

The peer review process included input and involvement from Dr Kalf over the three main stages of numerical groundwater modelling:

- conceptualisation and model development;
- model calibration; and
- model predictions.

The overall peer review report for the groundwater assessment is presented in Appendix C.



LEGEND

- Proposed modification pit depth extension
- Model extent
- Model mesh
- Rail
- Major road
- Major drainage
- Minor drainage
- Reserve

HVO South Modification 5 Groundwater Study (G1737)

Model extent

DATE 1/7/2016

FIGURE No: **6-1**

7 Model predictions and impacts assessment

This section describes the numerical model predictions and potential impacts from the proposed modification including the:

- drawdown in groundwater levels in the alluvium and coal measures as a result of the proposed modification and cumulative impacts (Section 7.1);
- groundwater take (Section 7.2 and Section 7.3;
- drawdown at groundwater users (private bores Section 7.4 and GDE's Section 7.5);
- water licensing requirements (Section 7.6); and
- potential for impacts upon groundwater quality (Section 7.7).

7.1 Zone of groundwater drawdown

7.1.1 During mining

Approved coal mines within the region operate below the water table and therefore extract groundwater. When mines are in close proximity to each other the zone of drawdown generated by each can overlap. Within these overlapping areas, the drawdown from each project combines to create a larger cumulative impact on the groundwater system. Cumulative impacts were accounted for in the groundwater model by representing all currently approved and foreseeable mining operations, along with the proposed modification. The surrounding mines include HVO North, Ravensworth, Cumnock, Ashton, United, Wambo and MTW operations that mine the same economic coal seams of the Wittingham Coal Measures. The mining at these sites was represented within the numerical model by using publicly available mine plans and knowledge of mining within the region. No coal seam gas extraction projects are currently in operation or proposed near HVO South based on publically available information.

As discussed in Section 6, the currently approved mining at HVO South is based on modelling undertaken by ERM (2008), however the approved mine plan was also remodelled with the contemporary numerical model. This version of the model represented the currently approved mine plan at HVO South, and all approved and foreseeable operations within the surrounding region where cumulative impacts were a possibility, but excluded the proposed modification. It is referred to as the 'remodelled approved HVO South' throughout the rest of this document.

This model run was compared to a second model run with all approved and foreseeable operations, plus the proposed modification included. The difference in results between these two scenarios was used to separate the impacts (drawdown and flow changes) due to the proposed modification from the cumulative impacts. The following figures show the predicted drawdown graphically:

- Figure 7 1 shows the cumulative drawdown generated within the Quaternary alluvium for all the currently approved and foreseeable mining operations (left side), as well as the drawdown from the proposed modification only in a separate window (right side).
- Figure 7-2 and Figure 7-3 show the drawdown due to the proposed modification only, as predicted in the Mt Arthur Seam and Bayswater Seam, respectively. It should be noted, this is not the total drawdown in the groundwater system, but the additional drawdown generated by the modification that contributes to the cumulative impacts.
- Figure 7 4 shows the maximum cumulative drawdown within the Quaternary alluvium when the proposed modification is included.
- Figure 7-5 shows the maximum cumulative drawdown predicted within the Mt Arthur Seam when the proposed modification is included.
- Figure 7 6 shows the maximum cumulative drawdown predicted in the Bayswater Seam, again when the proposed modification is included.

The figures show the cumulative drawdown generated for all the remodelled approved and foreseeable mining operations, as well as the drawdown from the proposed modification only. This illustrates the approved impact, and the additional impact that is predicted to be added to the cumulative impact from the proposed modification. The drawdown was calculated by comparing the maximum drawdown in each cell to the simulated 2015 groundwater levels.

Figure 7-1 shows that the remodelled approved HVO South operations are predicted to generate zones of drawdown at the fringes of the alluvium where the mining operations are in relatively close proximity. Figure 7-1 shows the drawdown attributable to the proposed modification occurs in only small, isolated zones to the north and west of Riverview Pit and south of South Lemington Pit 2. It should be noted that the drawdown levels are a reflection of drawdown through the model cells, irrespective of actual saturated thickness within the aquifer. Therefore, water table drawdown can exceed the saturated thickness along the edges of the alluvium in some areas.

Figure 7-4 shows the drawdown within the Quaternary alluvium when the proposed modification is represented by the model, showing the maximum cumulative impact. The drawdown at alluvium along the Hunter River is similar to the remodelled approved drawdown, indicating extension of mining from the Vaux Seam (layer 25) to the deeper Bayswater Seam (layer 27) has only limited impacts on the surficial alluvial system along the Hunter River. In contrast, the predicted drawdown increases slightly in isolated areas of the Wollombi Brook alluvium due the proposed modification. This occurs largely due to the proposed extension of South Lemington Pit 2 from the Bowfield Seam (layer 17) down to the Vaux Seam (layer 25) and its proximity to the alluvium.

Figure 7-2 and Figure 7-3 show the predicted drawdown from the proposed modification only, in the Mt Arthur Seam and Bayswater Seam, respectively. The deeper coal seams are not completely depressurised by the approved mining, and therefore the impact of the proposed modification is evident within the zone of drawdown, particularly the deeper Bayswater Seam. As discussed earlier Figure 7-4 demonstrates how the deeper drawdown within the coal seams does not propagate up to the surficial alluvium. Figure 7-5 and Figure 7-6 show the drawdown for the proposed modification, along with all approved and foreseeable mining within the region to illustrate the total cumulative impact. Figure 7-5 shows cumulative drawdown within the Mt Arthur Seam and Bayswater Seam is extensive as these seams are extracted at most mines within the region.

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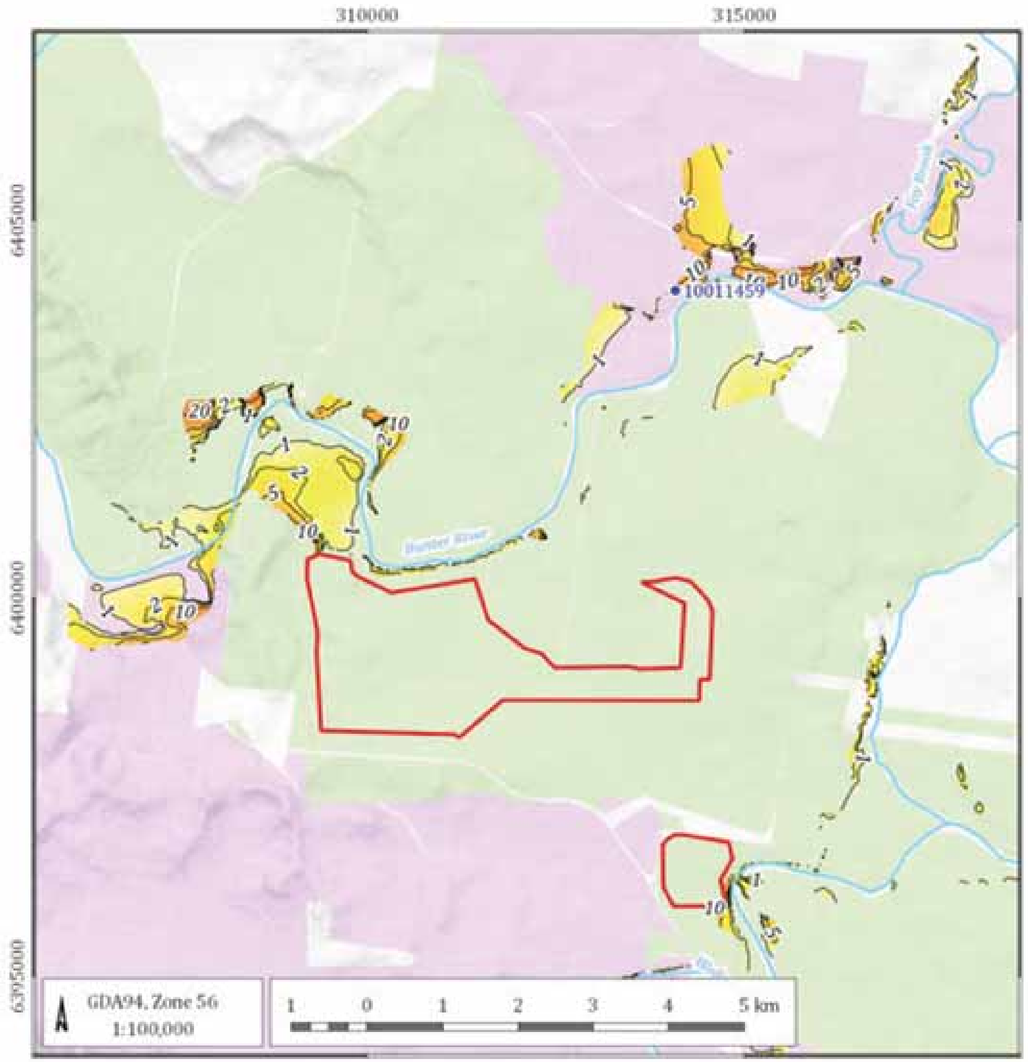
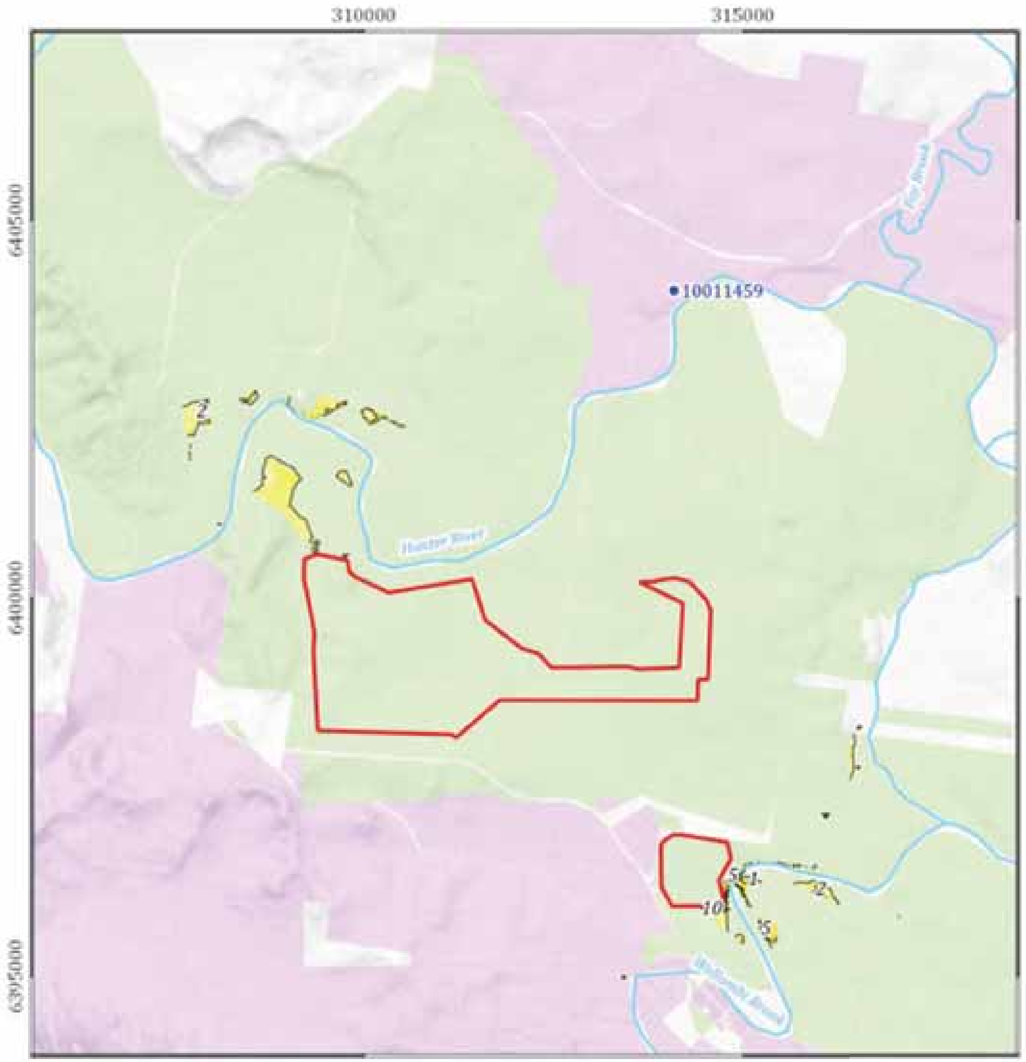
Remodelled approved cumulative drawdown



Additional drawdown due to proposed modification



LEGEND

- Proposed modification pit depth extension
- Model extent
- Quaternary alluvium (1:25k AGE)
- Potentially affected bores
- Drawdown contour (m)
- Major drainage

Land ownership

- Mine Owned (Coal & Allied)
- Mine Owned (other)

Drawdown (m)

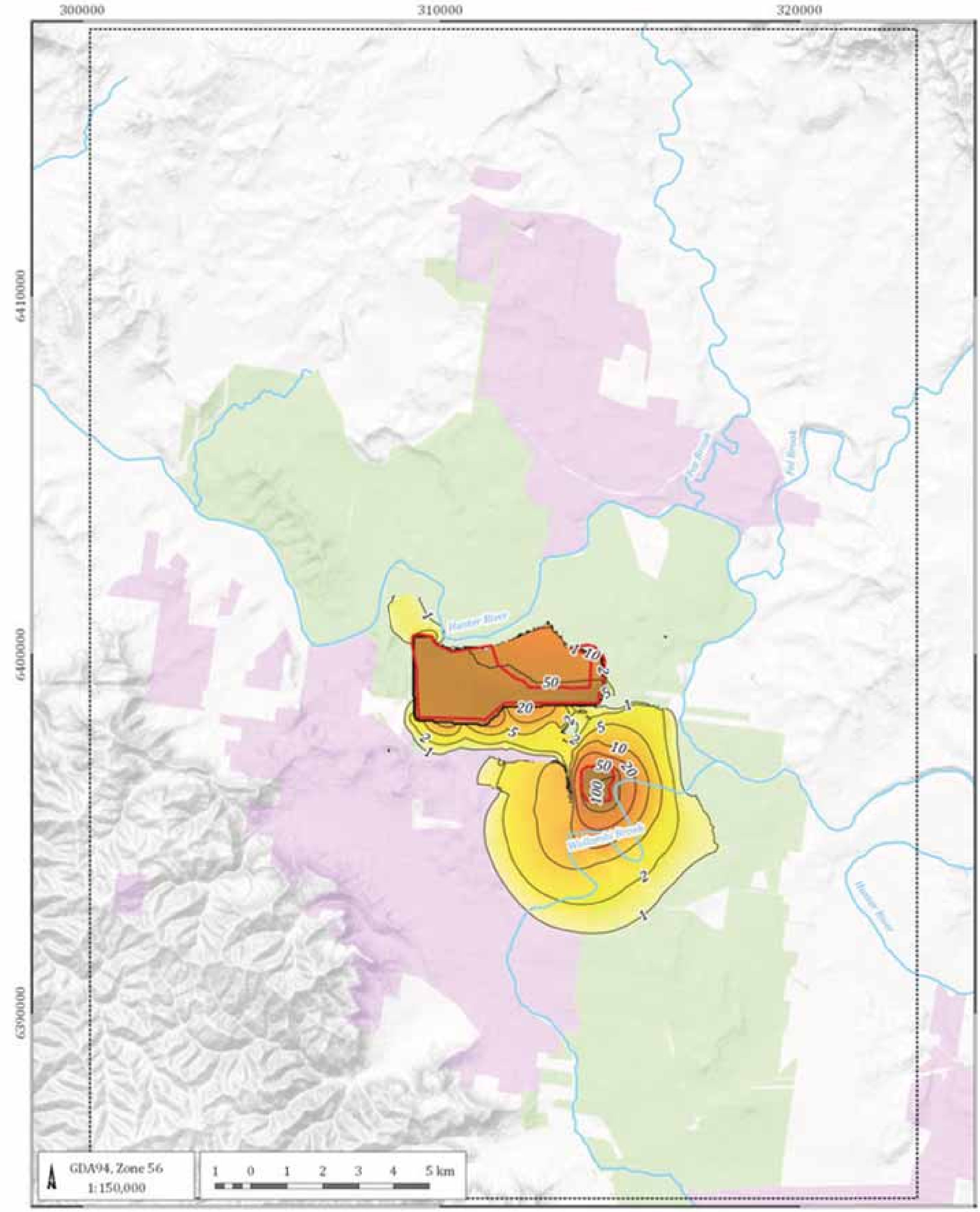
1	20
2	50
5	100
10	200

HVO South Modification 5 Groundwater Study (G1737)

Maximum additional drawdown due to proposed modification - Quaternary alluvium

DATE
1/7/2016

FIGURE No:
7-1



LEGEND

- Proposed modification pit depth extension
- Model extent
- Drawdown contour (m)
- Major drainage

Land ownership

- Mine owned (Coal & Allied)
- Mine owned (other)

Drawdown (m)

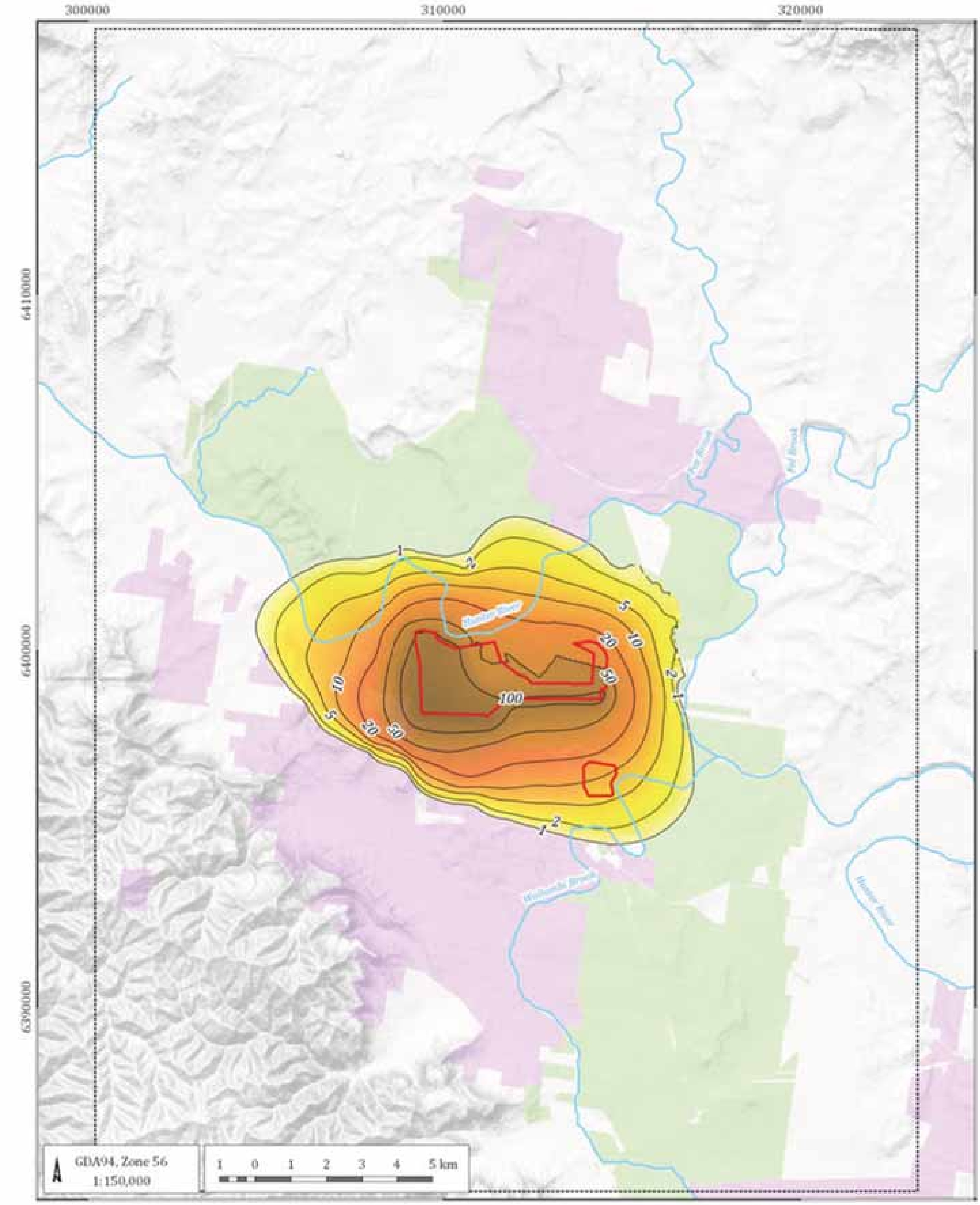
- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

HVO South Modification 5 Groundwater Study (G1737)

Maximum additional drawdown due to proposed modification - Mt Arthur Seam

DATE 1/7/2016

FIGURE No: **7-2**



LEGEND

- Proposed modification pit depth extension
- Model extent
- Drawdown contour (m)
- Major drainage

Land ownership

- Mine owned (Coal & Allied)
- Mine owned (other)

Drawdown (m)

- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

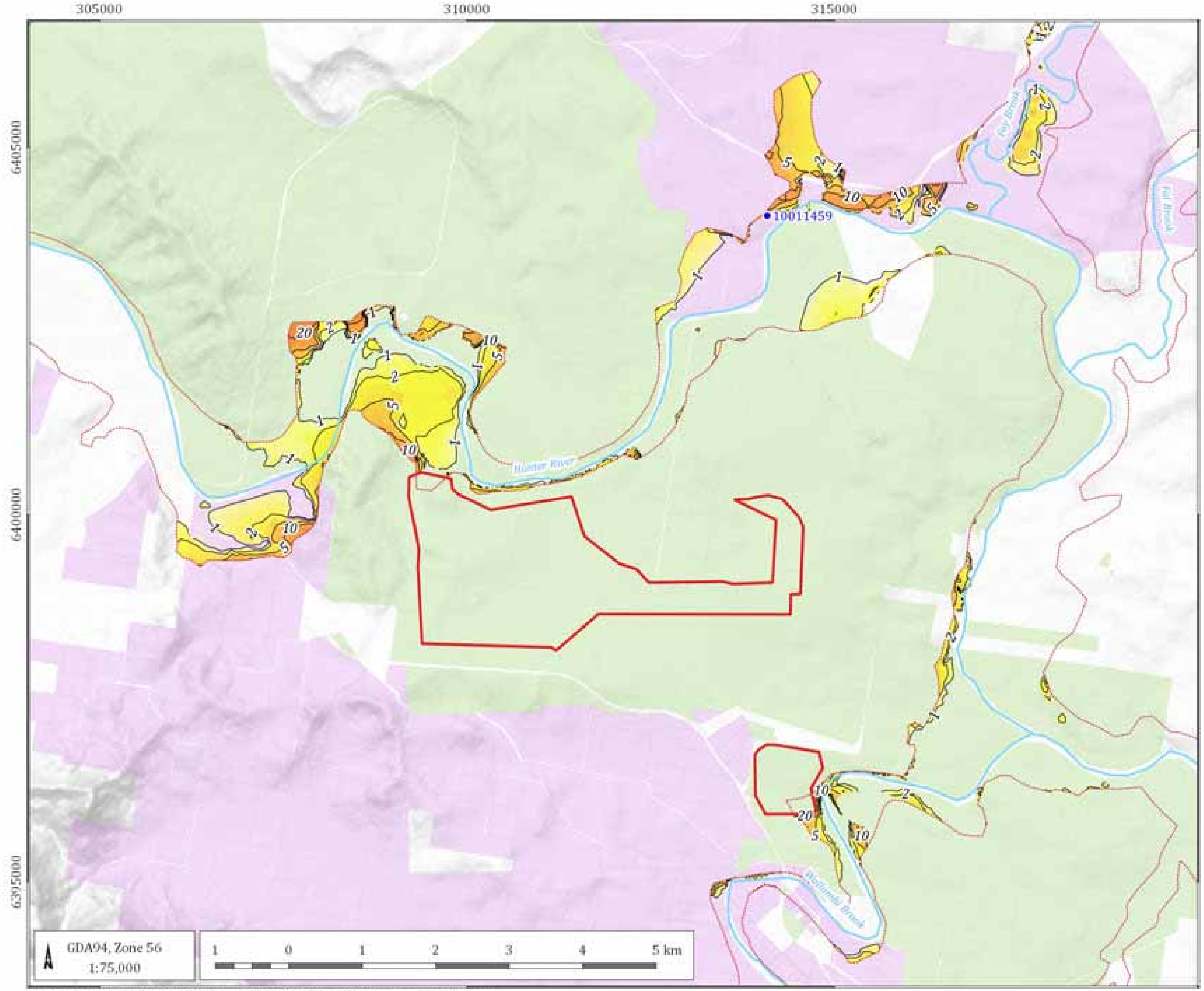
HVO South Modification 5 Groundwater Study (G1737)

Maximum additional drawdown due to proposed modification- Bayswater Seam

AGE

DATE 1/7/2016

FIGURE No: **7-3**



LEGEND

- Proposed modification pit depth extension
- Model extent
- Quaternary alluvium (1:25k AGE)
- Potentially affected bores
- Major drainage

Land ownership

- Mine Owned (Coal and Allied)
- Mine owned (other)
- Drawdown contour (m)

Drawdown (m)

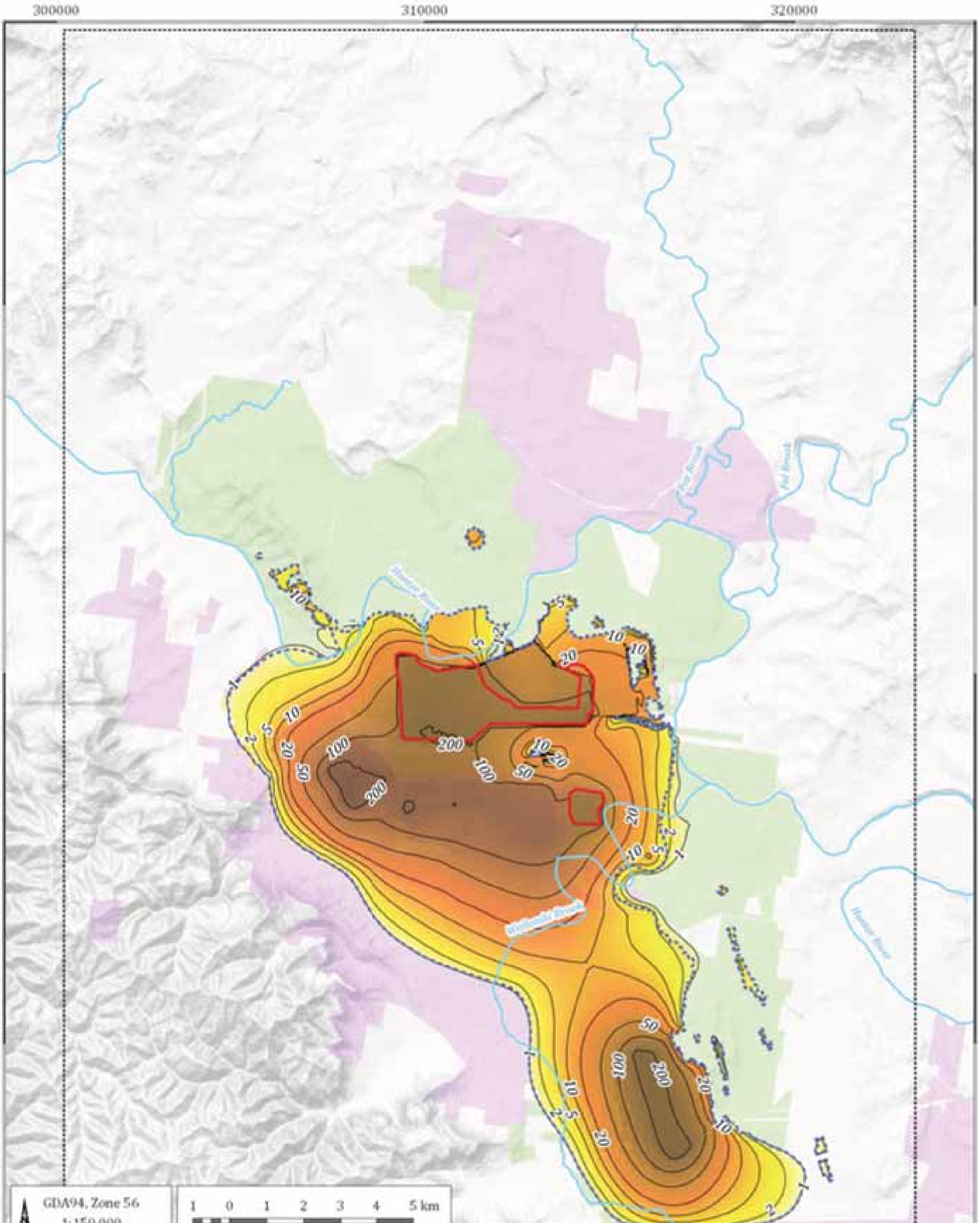
- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

HVO South Modification 5 Groundwater Study (G1737)

Maximum cumulative drawdown due to all mines including proposed modification - Quaternary alluvium

DATE
1/7/2016

FIGURE No:
7-4



LEGEND

- Proposed modification pit depth extension
- Model extent
- Drawdown contour (m)
- 1m remodelled approved cumulative drawdown extent
- Major drainage

Land ownership

- Mine Owned (Coal and Allied)
- Mine owned (other)

Drawdown (m)

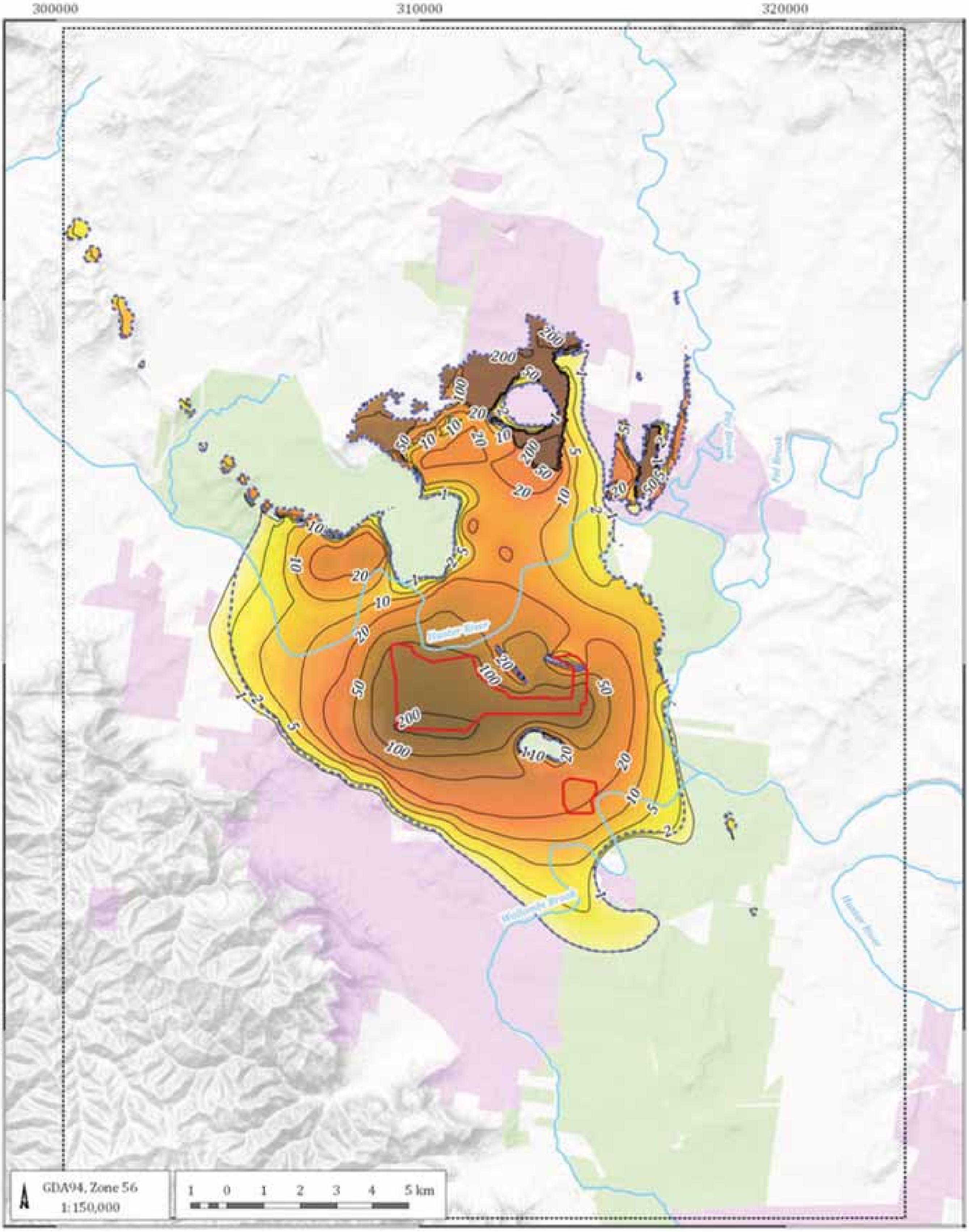
- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

HVO South Modification 5 Groundwater Study (G1737)

Maximum cumulative drawdown due to all mines including proposed modification - Mt Arthur Seam

DATE 1/7/2016

FIGURE No: **7-5**



LEGEND

- Proposed modification pit depth extension
- Model extent
- Drawdown contour (m)
- 1m remodelled approved cumulative drawdown extent
- Major drainage

Land ownership

- Mine Owned (Coal and Allied)
- Mine owned (other)

Drawdown (m)

- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

HVO South Modification 5 Groundwater Study (G1737)

Maximum cumulative drawdown due to all mines including proposed modification - Bayswater Seam

DATE 1/7/2016

FIGURE No: **7-6**

7.1.2 After mining

Post mining conditions were simulated using the numerical model. Appendix B and Section 6.2 summarise the set-up of the model. The sections below describe the post mining predictions for potentiometric surface and water table recovery.

Post mining conditions were simulated over a period of 1000 years. Mine 'drain cells' were removed from the model and groundwater levels from the end of mining used as initial heads. Groundwater inflows to the void during recovery were provided to the EIS surface water consultants and the results were incorporated in a surface water balance model. Pit lake level recovery rates from the surface water model were then fixed within the groundwater model using a series of constant heads over time. This allowed daily rainfall runoff processes that occur with the surface water model to be indirectly represented within the groundwater model and ensured consistency between the surface water and groundwater studies. With the constant heads in place, the groundwater model was run for 1000 years in order to simulate the recovery of the groundwater system. Figure 7-7 shows the predicted water level within each pit void as it recovers with time.

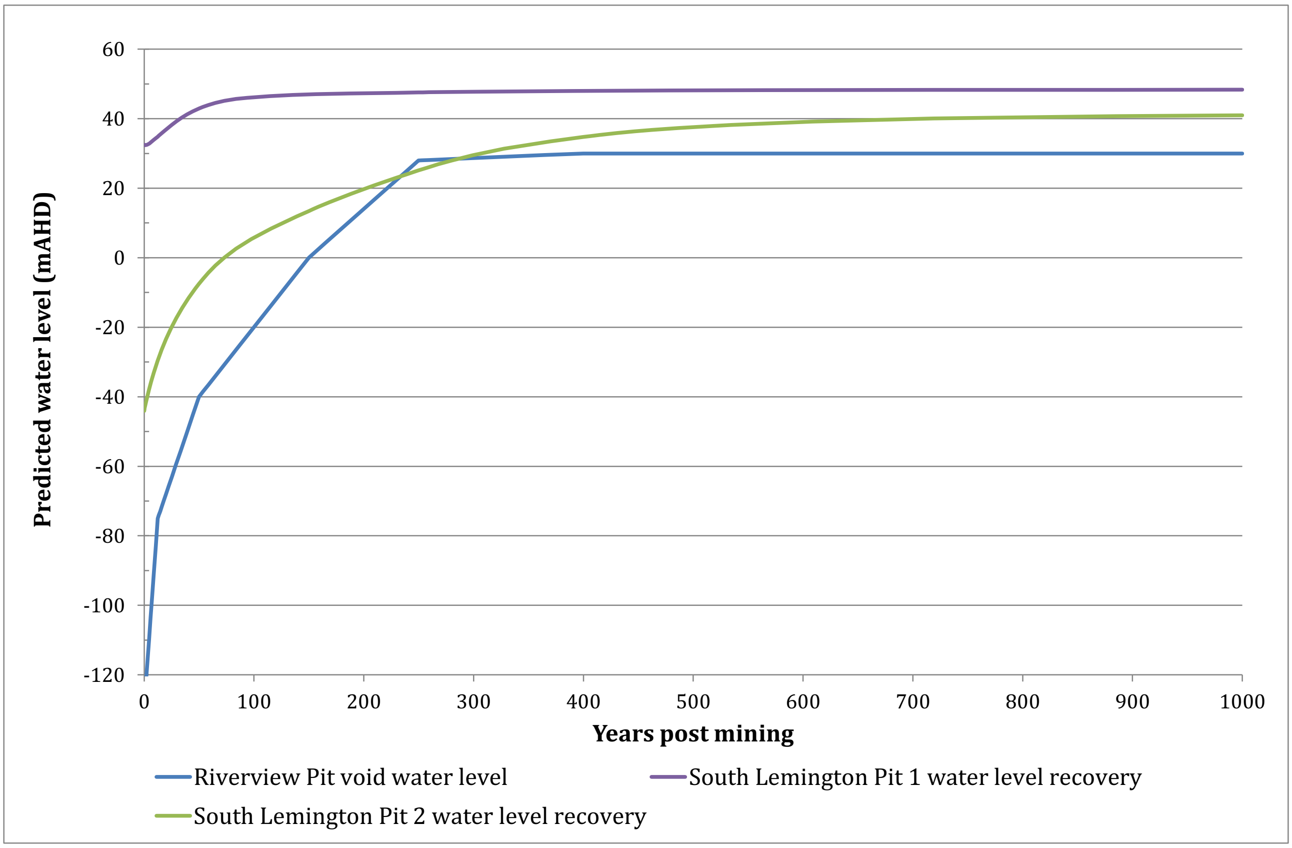


Figure 7-7 Pit lake recovery for proposed final landform

Water balance modelling by WRM (2016) indicates that the Riverview pit final void and associated in-pit overburden emplacement will gradually fill with water and groundwater over time and reach a final pit lake level of approximately 30mAHD.

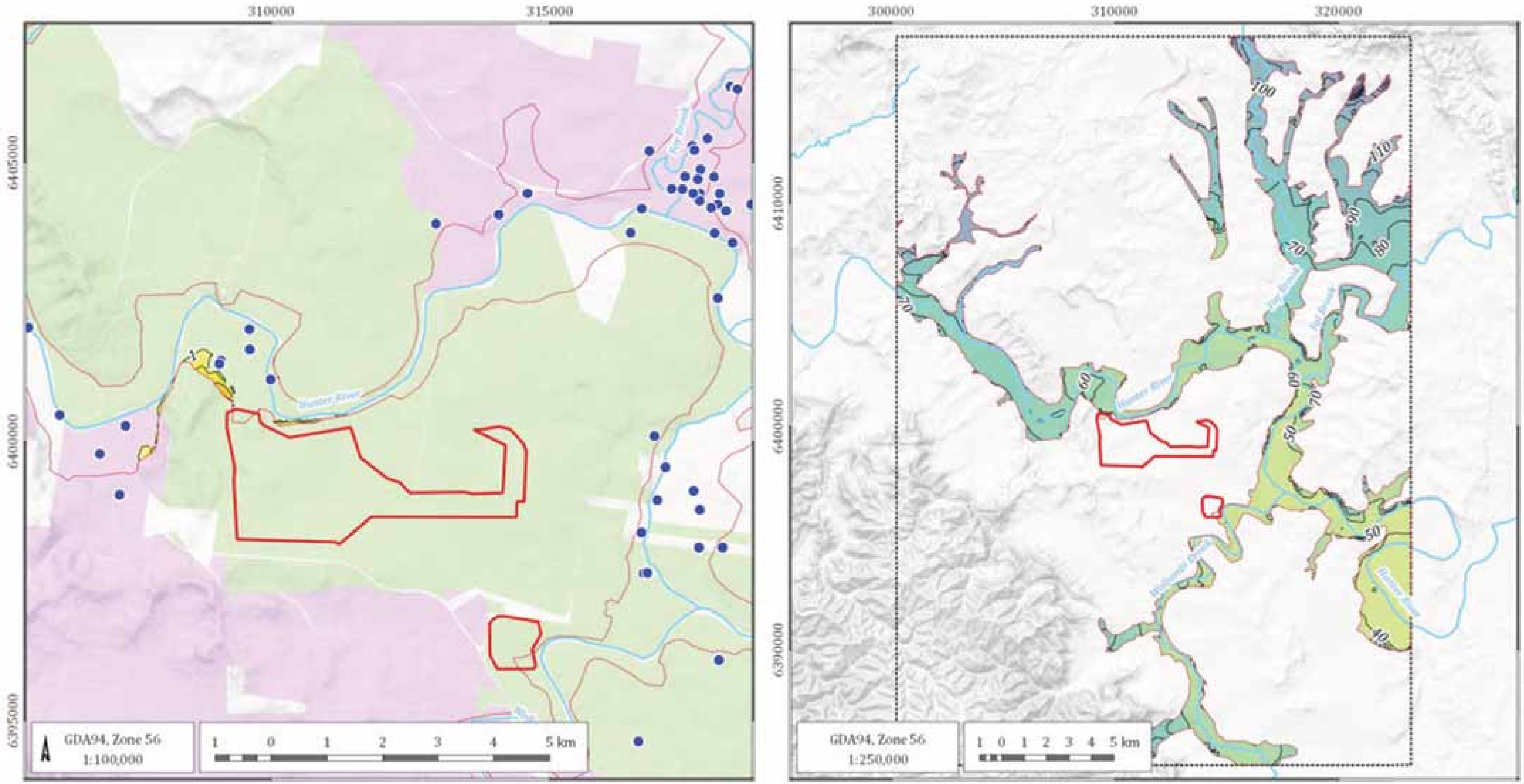
For the proposed final landform, the Riverview Pit lake water level is predicted to be about 20m to 30m below pre-mining groundwater levels, indicating that the void will act as a sink in perpetuity with no escape of contained void water. These results correspond with previous recovery modelling for the approved HVO South and HVO North operations, with the approved final voids also expected to form a groundwater 'sink'. The proposed final void is located further away from the Hunter River compared to the currently approved final void, which reduces the hydraulic gradient and potential impacts on the alluvial and surface water system in the long term.

South Lemington Pit 1 and Pit 2 will be backfilled at closure. The numerical model predicts post mining groundwater levels will rise and re-saturate the backfilled spoils, but not reach the re-profiled land surface at each of these pits. At South Lemington Pit 2 groundwater levels will recover to about 41mAHD, about 37m below the re-profiled land surface. At South Lemington Pit 1 water levels will recover to about 48mAHD, some two metres below the lowest point of the final void landform at about 50mAHD.

At closure of the mining operations, a steep hydraulic gradient toward the mining areas will have developed. The recovery and filling process will slowly decrease the hydraulic gradient towards the pits, progressively reducing the magnitude of drawdown immediately surrounding the mined areas, and establishing a new equilibrium groundwater level. Figure 7-8 to Figure 7-10 show the predicted extent and magnitude of drawdown attributable to the proposed modification when the groundwater system reaches equilibrium post mining within the Quaternary alluvium, the Mt Arthur Seam and Bayswater Seam respectively. The figures also show the equilibrated groundwater levels for each of the groundwater systems, which highlight where long-term cumulative impacts occur. The figures show the drawdown retracts and centres around the proposed final void post mining. The magnitude of drawdown also reduces, but a footprint of residual impacts remain at equilibrium due to the changes in the landform.

Drawdown due to project

Potentiometric surface



LEGEND

- Proposed modification pit depth extension
- Model extent
- Quaternary alluvium (1:25k AGE)
- Registered bore (Alluvium)
- Drawdown contour (m)
- Major drainage

Land ownership

- Mine Owned (Coal & Allied)
- Mine Owned (other)

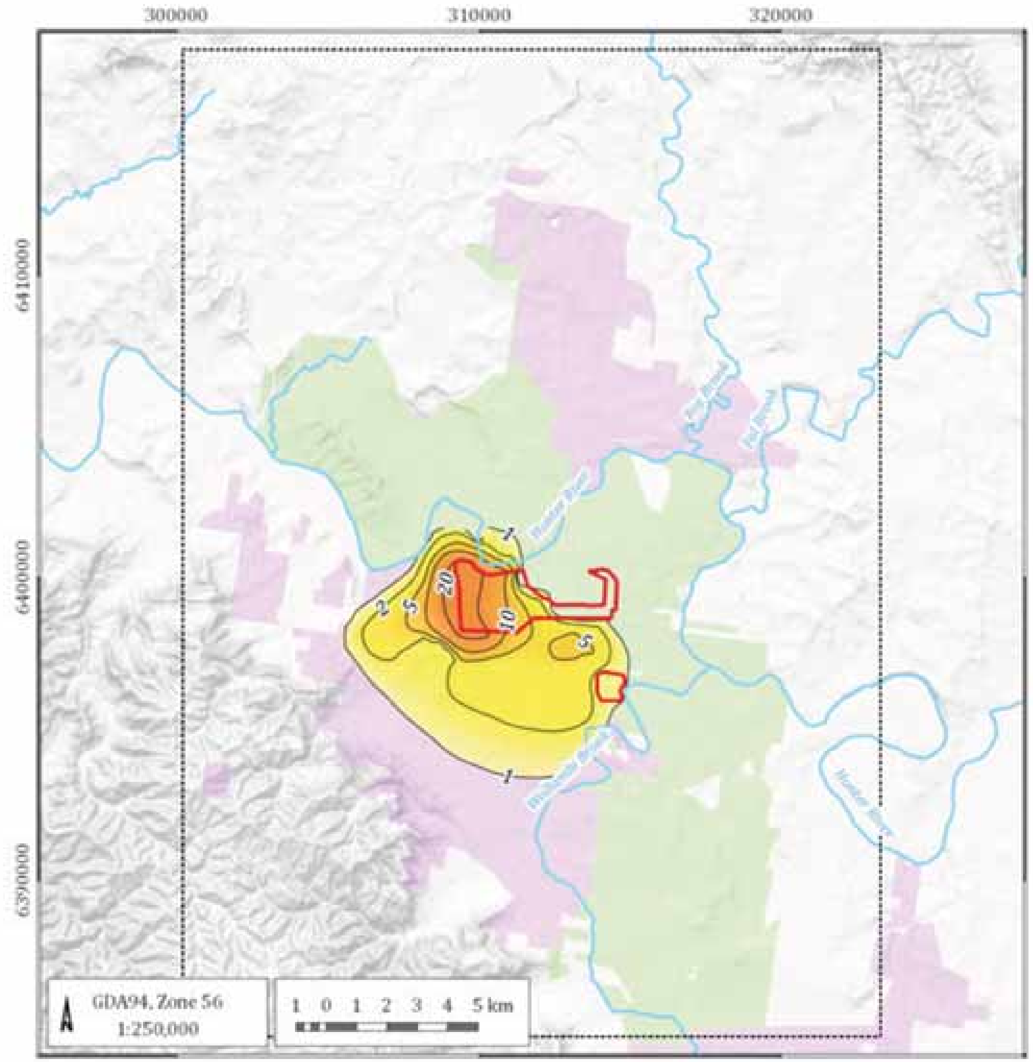
HVO South Modification 5 Groundwater Study (G1737)

Post mining equilibrium - drawdown and potentiometric surface - Quaternary alluvium

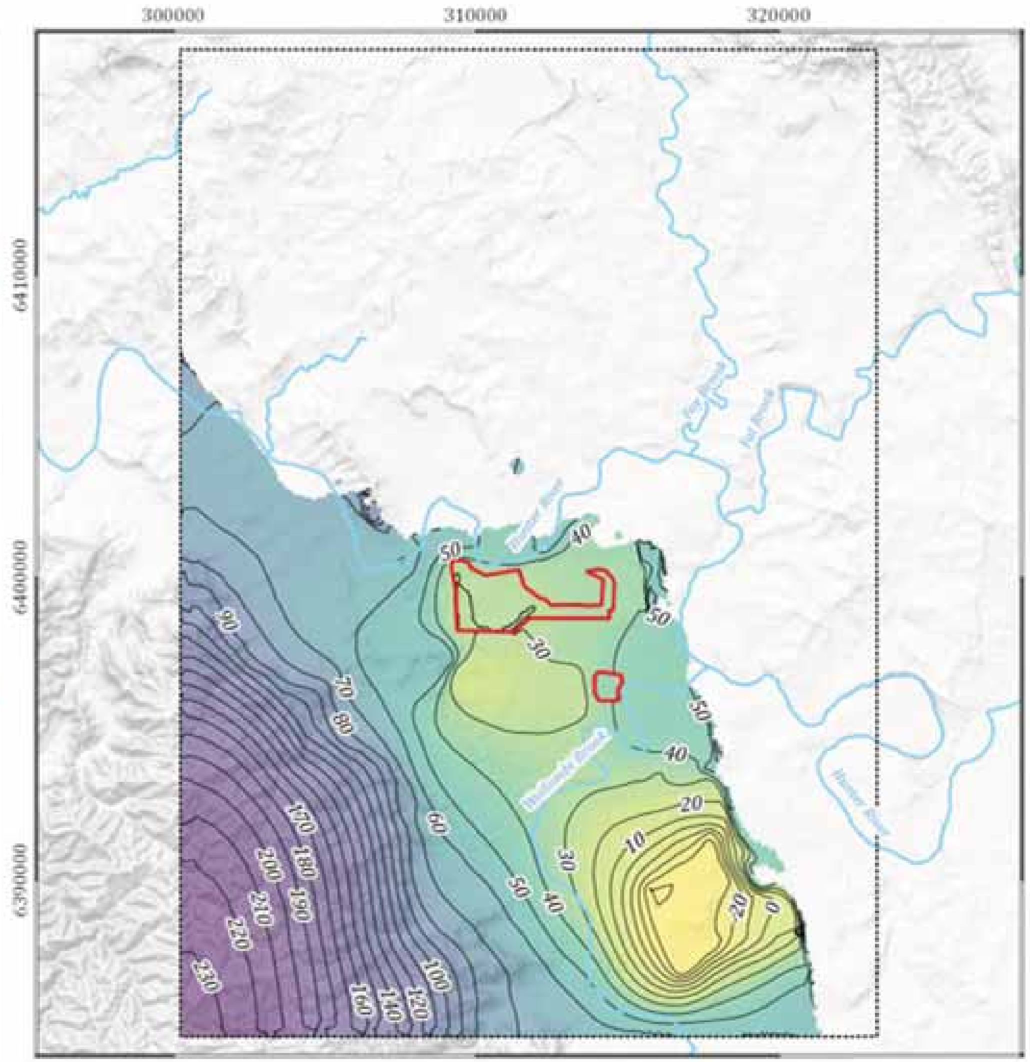
DATE
1/7/2016

FIGURE No:
7-8

Drawdown due to project



Potentiometric surface



LEGEND

- Proposed modification pit depth extension
- Model extent
- Quaternary alluvium (1:25k AGE)
- Drawdown contour (m)
- Major drainage

Land ownership

- Mine Owned (Coal & Allied)
- Mine Owned (other)

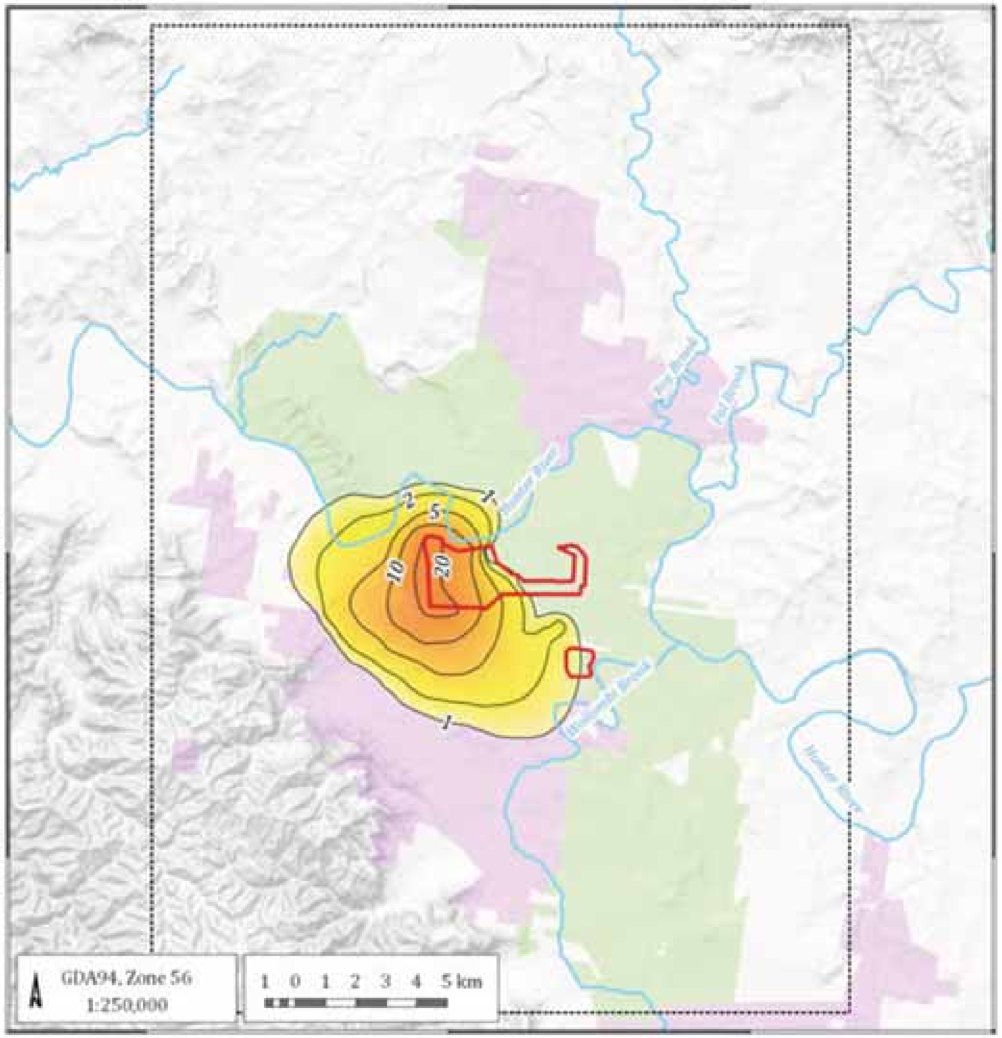
HVO South Modification 5 Groundwater Study (G1737)

Post mining equilibrium - drawdown and potentiometric surface - Mt Arthur Seam

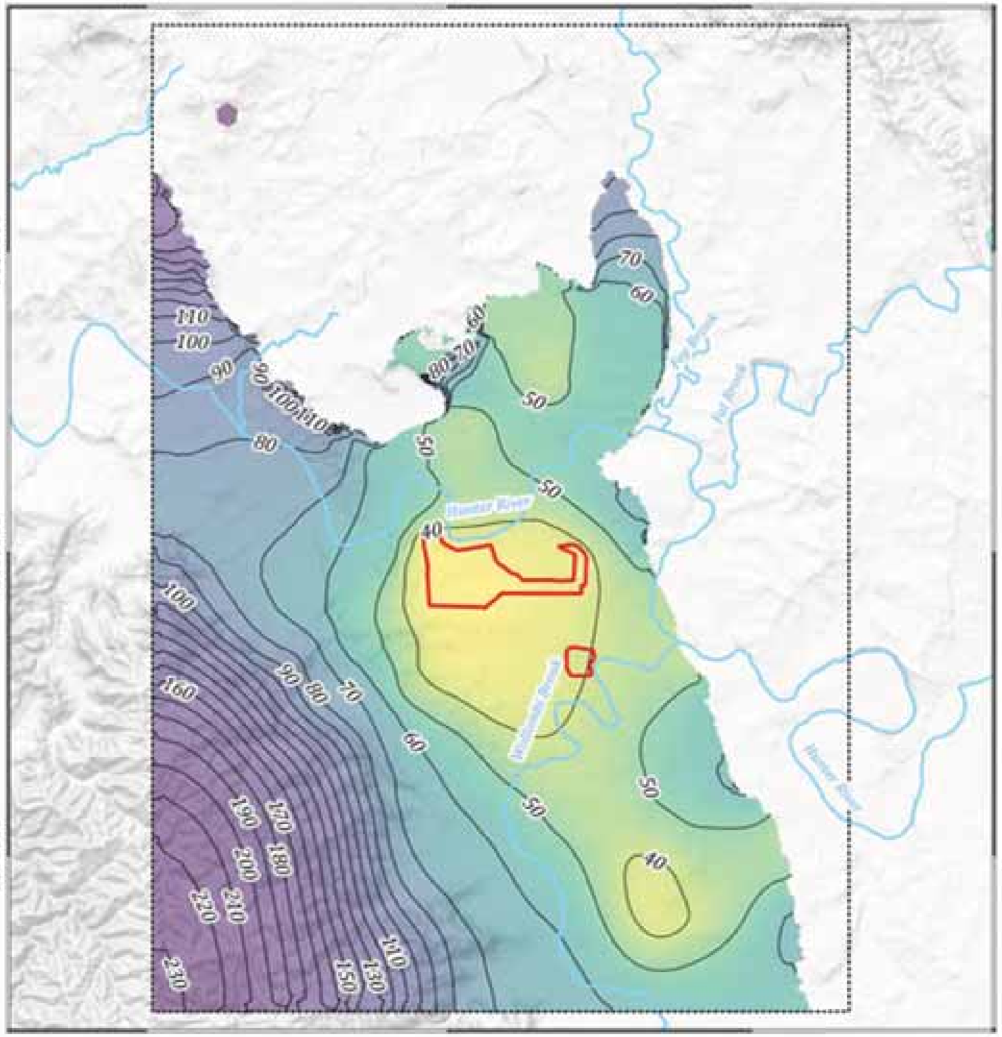
DATE
1/7/2016

FIGURE No:
7-9

Drawdown due to project



Potentiometric surface



LEGEND

Proposed modification pit depth extension

Model extent

Drawdown contour (m)

Major drainage

Land ownership

Mine Owned (Coal & Allied)

Mine Owned (other)

HVO South Modification 5 Groundwater Study (G1737)

Post mining equilibrium - drawdown and potentiometric surface - Bayswater Seam

DATE
1/7/2016

FIGURE No:
7-10

7.2 Groundwater directly intercepted by mining area

7.2.1 During mining

Figure 7-11 shows the volumes of groundwater predicted to be intercepted from the Permian coal measures by both the proposed modification and the remodelled approved mining at HVO South. It also breaks down the volumes predicted to be intercepted by each mining area.

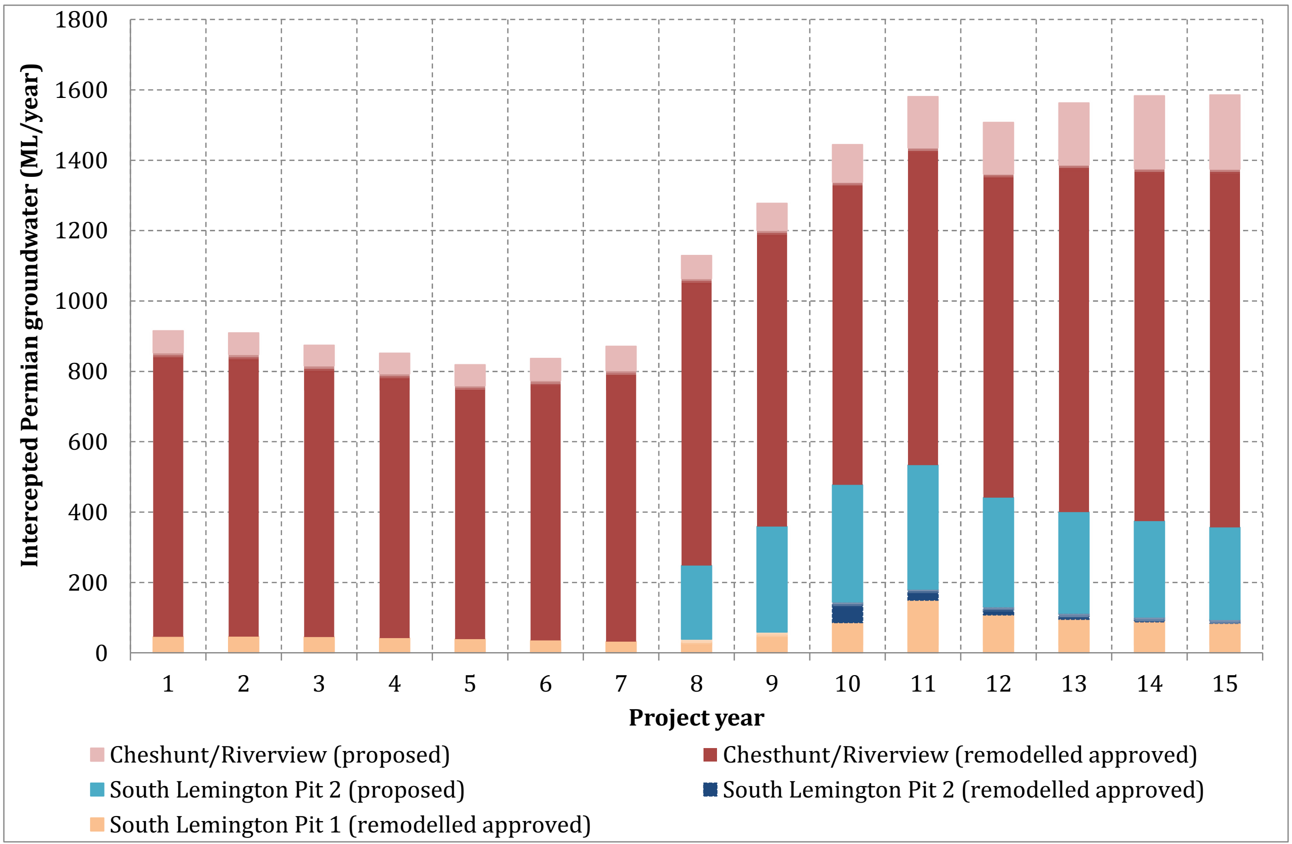


Figure 7-11 Simulated groundwater intercepted from Permian coal measures by proposed and approved mining

Figure 7-11 shows the volume of groundwater intercepted from the Permian coal measures for the remodelled approved mining plus the proposed modification peaks at 1,591ML/year in year 11. The proposed modification accounts for about one third of the groundwater intercepted, with the remainder occurring due to the approved mining.

ERM (2008a) predicted a peak of 3,299ML/year, which comprised 2,672ML/year of groundwater intercepted by the Cheshunt Pit, 310ML/year due to the Riverview Pit and 317ML/year for South Lemington Pits 1 and 2. The current modelling results are less than the maximum predicted by previous versions of the numerical model, and are due to differences in underlying assumptions. The current version of the model was informed by more monitoring data allowing calibration to a longer timeframe, and is therefore considered to provide improved estimates of the volume of groundwater intercepted from the Permian by mining activities.

7.2.2 After mining

The water level within the pit void is predicted by WRM (2016) to recover to a long term equilibrium of 30mAHD for the proposed modification, and 32mAHD for the approved final void. Surface water balance models indicate after 300 years the water level within the void has largely recovered. Post closure the groundwater system will reach a new equilibrium due to the changes induced in the groundwater system by mining activities. The modelling indicates the remodelled approved HVO South plus proposed modification will induce upward leakage from the Permian coal measures into the proposed final void at an initial rate of 597ML/year 12 years post mining, reducing to 206ML/year around 400 years post mining.

7.3 Groundwater indirectly intercepted by mining

In order to comply with the AIP, all groundwater take, either direct or indirect, must be accounted for. This section discusses the indirect take associated with alluvium and surface water flow (Hunter River and Wollombi Brook), but during mining and post mining. Further details about the changes in fluxes occurring within the alluvium and rivers resulting from depressurisation of the underling Permian are included in Appendix B.

7.3.1 During mining

The model was used to determine the potential for mining to interfere with the alluvial groundwater systems and provide estimates of indirect 'water take' in accordance with the AIP. Mining will not directly intercept alluvial aquifers, however, an indirect impact or 'water take' occurs as the Permian strata become depressurised and the volume of groundwater flowing from the Permian to the alluvium within the zone of depressurisation progressively reduces. Whilst this alluvial groundwater does not necessarily enter the mine workings, the volume of groundwater entering the alluvial groundwater systems is reduced by lower pressures within the Permian due to mining, and this has been considered 'water take' that needs to be accounted for with water licences.

The model predicted an indirect take from the Hunter River alluvium of 838ML/year for the remodelled approved HVO South plus the proposed modification, and 131ML/year from the Wollombi Brook alluvium. The proposed modification accounts for less than 10% of the total indirect alluvial take from the Hunter River and Wollombi Brook alluvium combined, with the majority of water take occurring due to approved mining.

Previous modelling of mining at HVO South did not estimate 'water take' from the alluvium using the methodology described above. However; ERM (2008a) did conclude that about one third of mine pit inflows were likely to be from alluvium for Cheshunt and Riverview pits. This equates to 994ML/year of alluvial groundwater intercepted by the approved HVO South operations.

A reduction in groundwater flux from the Permian strata into the overlying alluvium also has the potential to reduce the rate of groundwater discharge into the Hunter River and Wollombi Brook (ie baseflow rate). The model predicted a combined peak indirect take from the Hunter River of 584ML/year and 107ML/year from Wollombi Brook for the remodelled approved HVO South plus the proposed modification. The proposed modification accounts for less than 12% of the total indirect take from the Hunter River and Wollombi Brook combined, with the majority due to approved HVO South operations. When the baseflow loss is compared to the average stream flows within the Hunter River (343,137ML/year) and Wollombi Brook (73,883ML/year), the reduction in baseflow contribution due to the remodelled approved HVO South plus proposed modification accounts for only a minor proportion (0.2%) of total flows.

When considering the water budgets it is important to note the underlying assumptions in the model. The model assumes direct hydraulic connection between the river and the aquifer, and no limit on the volume of water that can leak from the river into the underlying aquifer. In reality 'losing zones' where river water moves downwards into the underlying alluvial aquifer can be physically separated from the underlying water table in the aquifer by unsaturated zones. In this case drawdown within the alluvium or Permian strata does not increase the rate of flux from the river as it does in the model. Where the river and the aquifer are directly connected through the saturated zone, the 'water take' from the alluvium directly accounts for 'water take' from the river, and therefore there is no need to account for this water separately with water licenses.

7.3.2 After mining

The potential for a residual indirect 'water take' to occur from the alluvial groundwater systems post mining was assessed using the numerical model, including the assumption that there would be no mining within the region beyond 2039. The model predicted that the groundwater regime will equilibrate around 400 years post mining.

At equilibrium (400 years post mining) the groundwater model predicted an indirect take from the Hunter River alluvium of 318ML/year for the remodelled approved HVO South plus the proposed modification. The model predicted that the remodelled approved HVO South operations plus the proposed modification would have no indirect water take from the Wollombi Brook alluvium 400 years post mining.

As discussed above, the numerical model assumes direct hydraulic connection between the river and the alluvium. As a result, with the long term indirect take from the Hunter River alluvium, there is also predicted to be a reduction in baseflow contribution to the Hunter River of 288ML/year at post mining equilibrium. With no predicted take from the Wollombi Brook alluvium, there is no predicted long term take from the Wollombi Brook when the groundwater system reaches equilibrium. Instead a slight increase in baseflow contributions of 9ML/year approximately is predicted 400 years post mining.

7.4 Drawdown in registered bores

Groundwater level drawdown due to the proposed modification is largely restricted within the extent of land owned by Coal & Allied. There is one bore (10011459) not on land owned by Coal & Allied with drawdown due to the proposed modification and with cumulative drawdown of greater than 2m. Bore 10011459 is on land owned by Glencore (Ravensworth Mine). No private bores outside of mine-owned land are predicted to be impacted by the proposed modification.

Bore 10011459 is believed to intersect the Quaternary alluvium north of the Hunter River, with a bore depth of around 12m. Cumulative drawdown from approved operations plus the proposed modification indicates that groundwater levels at bore 10011459 could decline by 2.7m (Figure 7-1). This decline is mostly due to already approved operations and surrounding operations, with the proposed modification only contributing a minor additional decline of 0.3m. The minor additional decline due to the proposed modification does not trigger the Level 1 minimal impact considerations under the AIP. This is due to the cumulative impacts from the remodelled approved operations already exceeding 2m. No impacts due to the proposed modification are predicted at post mining equilibrium for registered bores on private or other mine owned land.

7.5 Drawdown at ecosystems

As detailed under Section 5.5.2, no plant species listed as threatened under the *Threatened Species Conservation Act 1995* were identified within HVO South or surrounds, however ecosystems that potentially use groundwater have been identified from several studies conducted within the region.

The location of the identified ecosystems within the Quaternary alluvium along the Hunter River and Wollombi Brook are shown in Figure 7-12 and Figure 7-13, respectively. Six ecosystem areas within the zone of cumulative drawdown have been labelled E1 to E6 for the purpose of this report. E1 to E3 are located within Hunter River alluvium north of Riverview Pit, while E4 to E6 are located within alluvium along Wollombi Brook, near South Lemington Pits 1 and 2.

The figures have three windows that allow the following drawdown to be compared within the Quaternary alluvium:

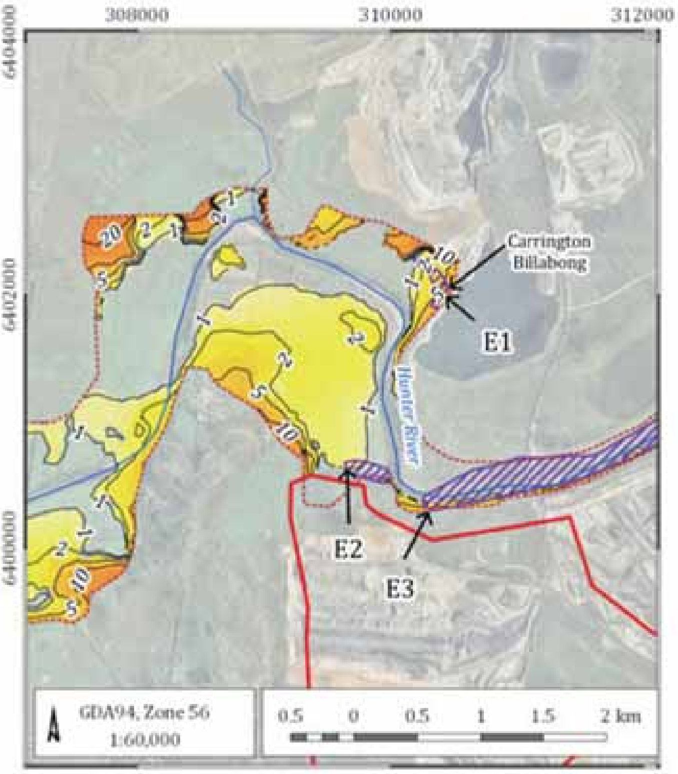
- predicted maximum cumulative drawdown for the approved operations compared to 2015 water levels;
- predicted maximum cumulative drawdown for the approved operations compared to 2015 plus additional drawdown generated by the proposed modification; and
- predicted drawdown attributable to the proposed modification only.

Figure 7-12 shows that drawdown within the alluvium is most significant along the fringes of the alluvium and reduces in proximity to the Hunter River. The model predicts that the proposed modification will not decrease alluvial groundwater levels by more than 0.5m at identified ecosystems (E1 to E3) along the Hunter River. Figure 7-13 shows that ecosystems are predicted to experience a decline in alluvial groundwater levels as a result of already approved operations.

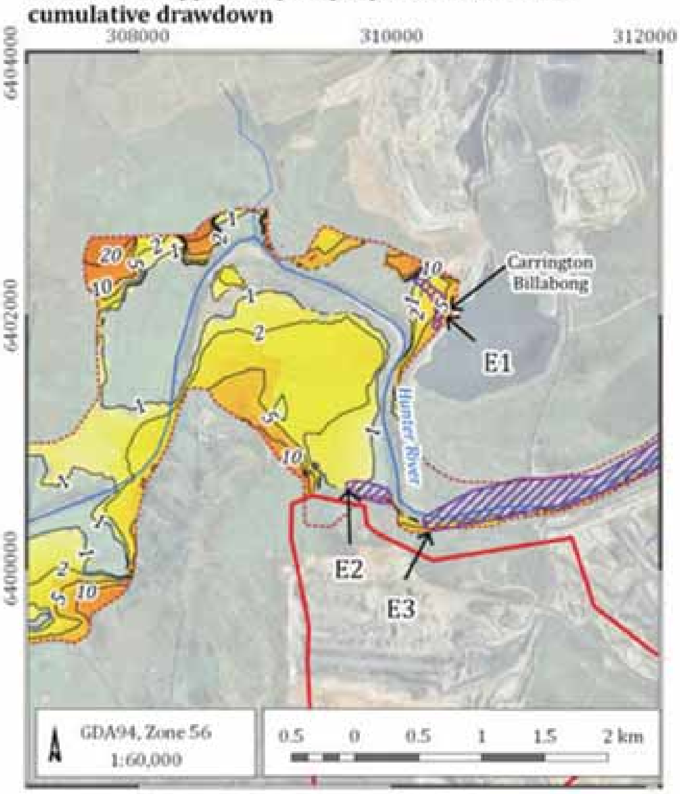
The proposed modification involves deepening of South Lemington Pit 2, which is located north of Wollombi Brook. Groundwater levels within the alluvium adjacent to South Lemington Pit 2 (ie at E4 and E6) are predicted to decline by up to 2.8m due to the proposed modification. Approved operations are also predicted to cause a decline in water levels at ecosystem areas E4 and E6 by up to 7m. Groundwater levels south of Wollombi Brook (E5) are predicted to decrease by less than 1m due to the proposed modification.

Figure 7-12 and Figure 7-13 show the proposed modification does not result in any increase in the zone of drawdown at the identified ecosystems beyond the spatial extent already predicted to occur due to the approved mining. The ecology study within the Environmental Assessment considered the potential for the predicted drawdown to impact upon the functioning of these ecosystems.

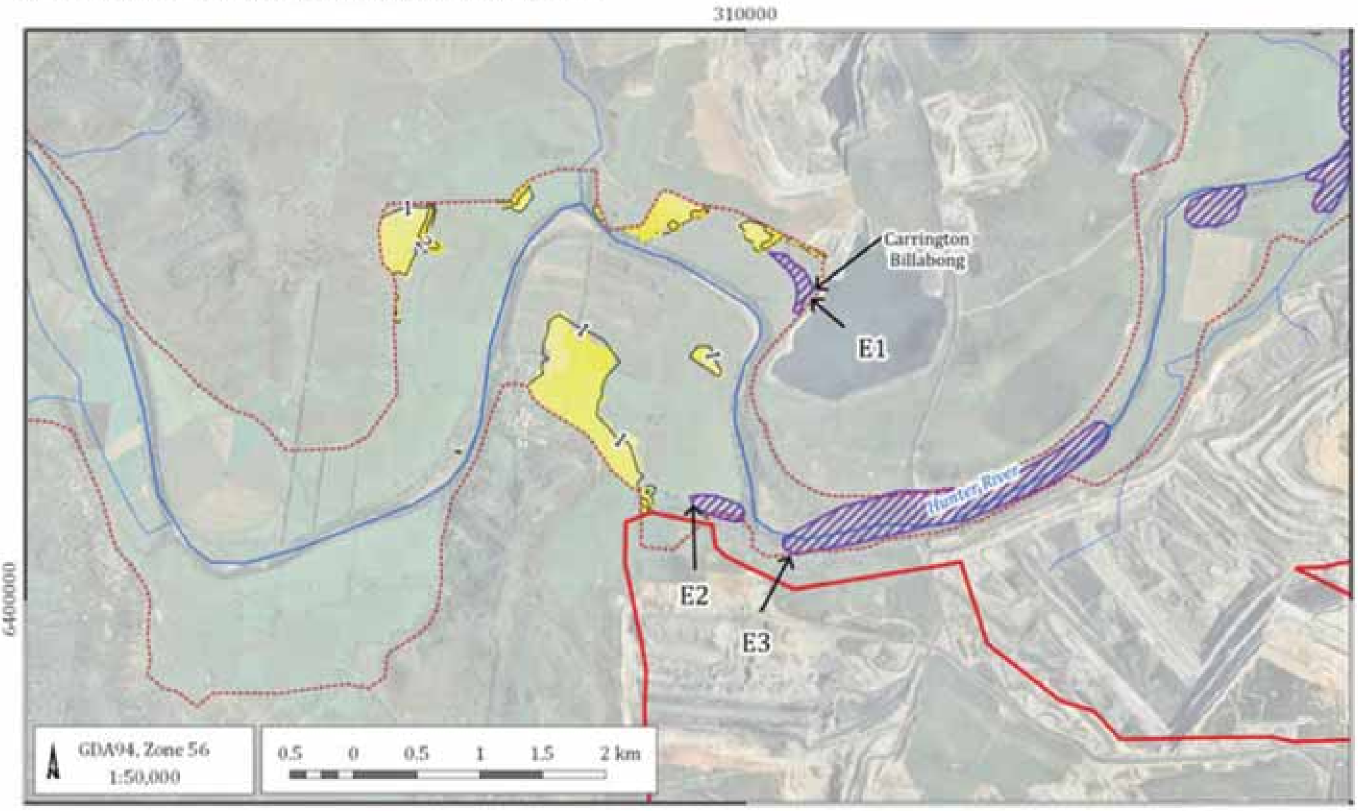
Remodelled approved cumulative drawdown



Remodelled approved plus proposed modification cumulative drawdown



Additional drawdown due to proposed modification



LEGEND

- Proposed modification pit depth extension
- Quaternary alluvium (1:25k AGE)

Drawdown contour (m)

- Major drainage
- Minor drainage

HVO South EA vegetation mapping (ERM,2008)

- River Red Gums

Modelled drawdown (m)

- 1
- 2
- 5
- 10
- 20
- 50
- 100
- 200

HVO South Modification 5 Groundwater Study (G1737)

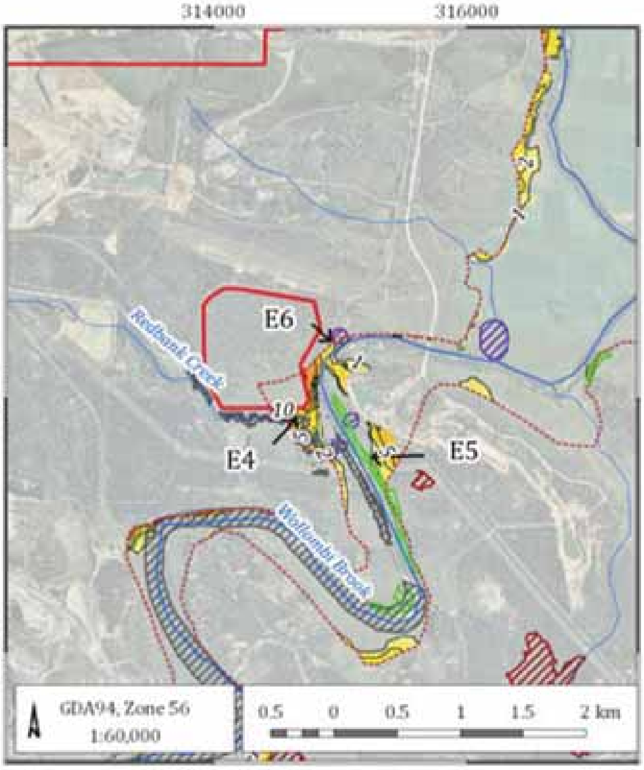
Predicted drawdown in Hunter River alluvium and ecosystems that potentially use groundwater

AGE

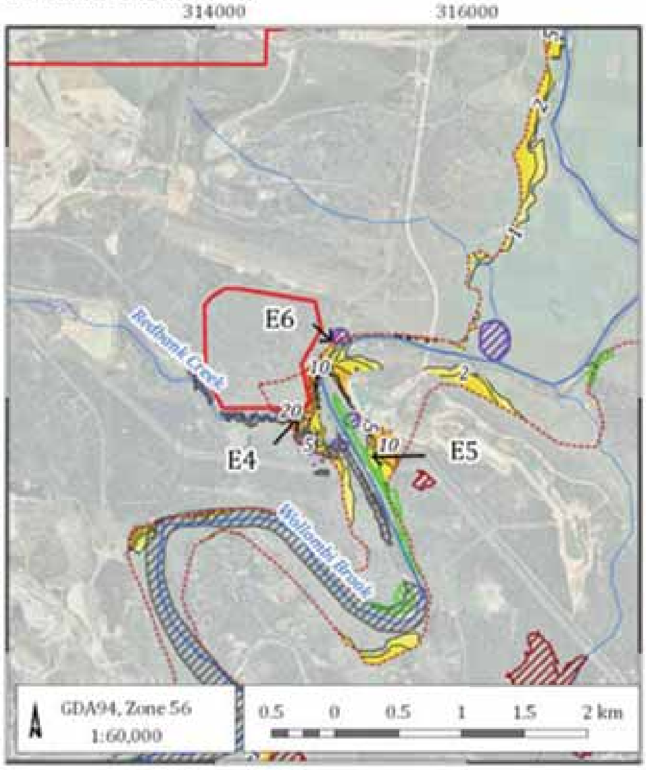
DATE 1/7/2016

FIGURE No: **7-12**

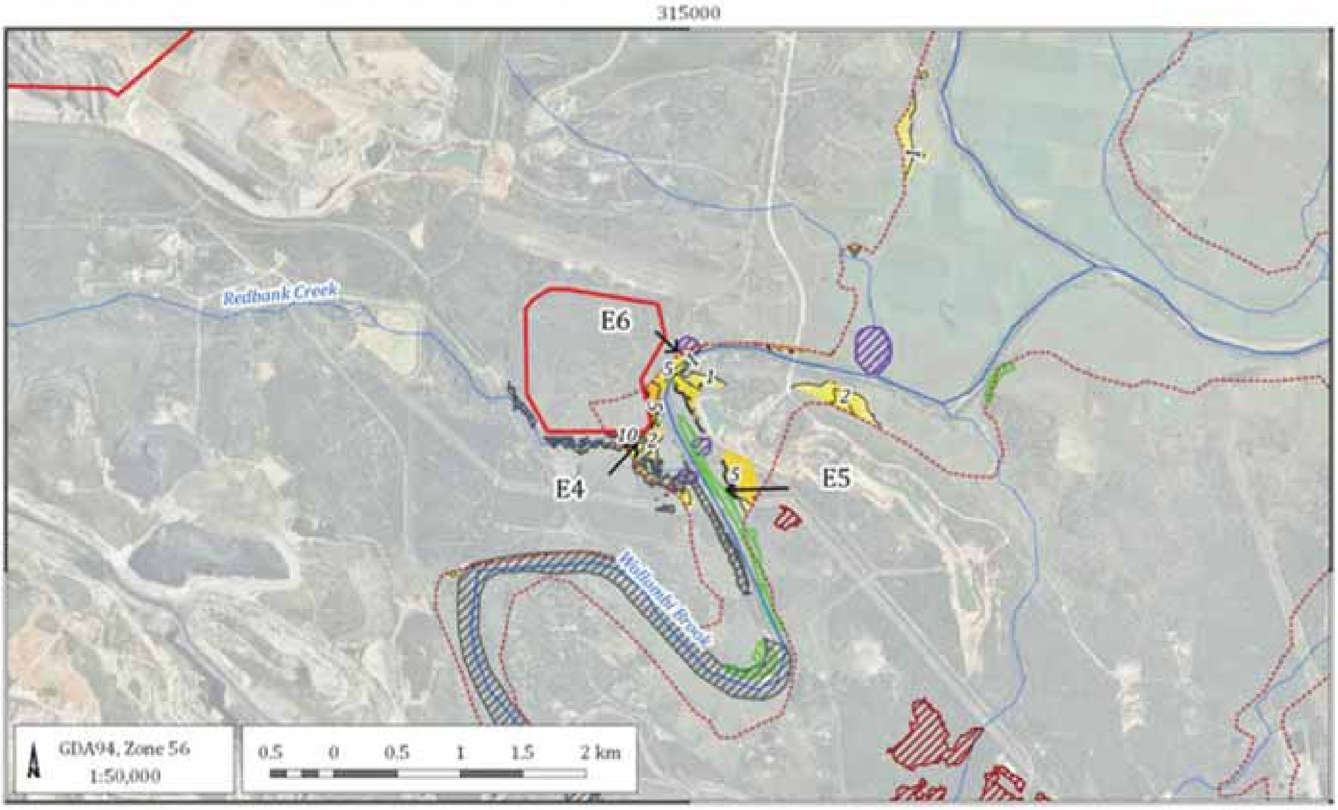
Remodelled approved cumulative drawdown



Remodelled approved plus proposed modification cumulative drawdown



Additional drawdown due to proposed modification



LEGEND

- Proposed modification pit depth extension
- Quaternary alluvium (1:25k AGE)
- Major drainage
- Minor drainage
- Drawdown contour (m)

Modelled drawdown (m)

1, 2, 5, 10, 20, 50, 100, 200

HVO South EA vegetation mapping (ERM, 2008)

- River Red Gums
- Hunter Floodplain Red Gum Woodland

Warkworth Continuation vegetation mapping (Cumberland Ecology, 2014)

- Warkworth Sands Woodland
- Hunter Valley River Oak Forest

HVO South Modification 5 Groundwater Study (G1737)

Predicted drawdown in Wollombi Brook alluvium and ecosystems that potentially use groundwater

DATE 1/7/2016

FIGURE No: **7-13**

7.6 Water take

The AIP requires the accounting for all groundwater take, either directly or indirectly. Groundwater intercepted from the mining area is considered a direct take from the Permian groundwater system, whilst the changes in fluxes occurring within the alluvium and rivers resulting from depressurisation of the underling Permian is considered an indirect take. This section discusses the peak direct and indirect take of groundwater due to the proposed modification and the remodelled approved HVO South operations. Annual predictions of direct water take from the Permian coal measures are discussed in Section 7.2. The indirect water take from alluvial groundwater systems and surface water are discussed in Section 7.3. The annualised volumes of indirect take from the various sources are also presented in Appendix B.

As discussed in Section 2, groundwater and surface water at HVO South is considered to be regulated as follows:

- Hunter Unregulated and Alluvial Water Sources WSP – alluvial groundwater;
- Hunter River Regulated Water Source WSP – Hunter River surface water; and
- North Coast Fractured and Porous Rock WSP - groundwater from the coal measures.

HVO South falls within the 'Glennies Creek Management Zone', 'Jerrys Management Zone' and 'Lower Wollombi Brook Water Source' of the 'Hunter Unregulated and Alluvial Water Sources WSP.

The approach to management of water in the Permian units has recently changed with commencement of North Coast Fractured and Porous Rock WSP on the 1st July 2016. This plan replaces hardrock aquifer licensing under the *Water Act 1912* and brings management of groundwater from the hard rock aquifers under the *Water Management Act 2000*.

7.6.1 During mining

Table 7-1 presents the calculated direct and indirect water take under the relevant water sharing plans during mining.

Table 7-1 Annual groundwater take for each management plan - during mining

Model year	'Water take' (ML/year) accounted under			
	Hunter Regulated WSP (Indirect)	Hunter Unregulated WSP (Indirect)		North Coast Fractured and Porous Rock WSP (Direct)
		Upstream Glennies Creek Water Source	Lower Wollombi Brook Water Source	
1	0	167	0	917
2	39	316	1	911
3	107	340	2	876
4	159	**358**	0	853
5	205	348	5	821
6	246	355	5	839
7	286	355	5	875
8	327	350	8	1134
9	366	326	22	1284

Model year	'Water take' (ML/year) accounted under			
	Hunter Regulated WSP (Indirect)	Hunter Unregulated WSP (Indirect)		North Coast Fractured and Porous Rock WSP (Direct)
		Upstream Glennies Creek Water Source	Lower Wollombi Brook Water Source	
10	403	314	60	1460
11	436	280	88	**1591**
12	468	327	96	1510
13	507	238	127	1563
14	548	261	124	1581
15	**584**	254	**131**	1582
Maximum	**584**	**358**	**131**	**1591**

The values for the Hunter Regulated WSP are derived from the indirect take from the Hunter River, as discussed in Section 7.3 and detailed in Appendix B. The water take under the Hunter Unregulated WSP is derived from indirect take from the Hunter River alluvium, Wollombi Brook alluvium and Wollombi Brook (refer Section 7.3 and Appendix B). The indirect take from the Hunter alluvium is partially comprised of water from the Hunter River, which is managed under the Hunter Regulated WSP. Therefore the total indirect take for the Hunter Unregulated WSP is considered to be the indirect take from Hunter River alluvium minus the induced Hunter River take. The same process is used to ensure there is no double accounting of groundwater and surface water take from Wollombi Brook. These final calculated volumes are presented in Table 7-1, while the full annual results for each component can be found within Appendix B.

Water licence entitlements held by the proponent, and predicted peak take for the current approved and proposed modification (inclusive of the existing approval) are presented in Table 7-2.

Table 7-2 Water licensing and predicted maximum take

Water Source	Water Sharing Plan	Water Source – Management Zone	Maximum Take (ML)		HVO Total Share Component (units or ML/year)	Water Access Licence No.	WAL Share Component (units or ML/year)
			Current Approved	Current Approved & Predicted Take with HVO South Mod 5			
Hunter River Surface Water	Hunter Regulated River WSP	Zone 1B/2A	555	584	4,665	*WAL 962; *WAL970; *WAL1006; *WAL1070	3165; 500; 500; 500
Hunter River Alluvium	Hunter Unregulated and Alluvial Water Sources WSP	Hunter Regulated River Alluvial Water Source - Upstream Glennies Creek Management Zone	253	358	383	WAL 18127	383
Wollombi Brook	Hunter Unregulated	Lower Wollombi	74	131	144	WAL 23889	144

Water Source	Water Sharing Plan	Water Source – Management Zone	Maximum Take (ML)		HVO Total Share Component (units or ML/year)	Water Access Licence No.	WAL Share Component (units or ML/year)
			Current Approved	Current Approved & Predicted Take with HVO South Mod 5			
Surface Water and Alluvium	and Alluvial Water Sources WSP	Brook Water Source					
Permian Coal Seams	North Coast Fractured and Porous Rock Groundwater Sources WSP *Commenced 1/7/16 - Previously Water Act 1912*	Sydney Basin – North Coast Groundwater Source	1,113	1,591	4,840	#WAL 39798; WAL 40462; WAL40463; WAL40466	1,800; 2,400; 180; 460

Note: ** WALs also linked to Hunter River pump stations for water supply purposes if required*
 # WAL 39798 also linked to Bore for water supply purposes if required

As presented in Table 7-2, peak take is predicted for the proposed modification (inclusive of the current approval) from all water sources includes:

- indirect take of 489ML/year from the Hunter Unregulated WSP, which comprises:
    - up to 131ML/year from the Lower Wollombi Brook Water Source;
    - up to 358ML/year from the Upstream Glennies Creek Water Source;
- indirect take of up to 584ML/year from the Hunter Regulated WSP; and
- direct take of up to 1,591ML/year from the North Coast Fractured and Porous Rock WSP.

The estimated take for approved HVO South operations and the proposed modification are within the relevant license entitlements held by the proponent. These combined volumes are also within previously predicted maximum water takes for the currently approved operations stated in ERM (2008a). The HVO South operations were approved in March 2009 based on the results from a model developed by ERM (2008a), which estimated the maximum take of groundwater of 2,672ML/year from the Cheshunt Pit, 310ML/year from Riverview Pit and 317ML/year from South Lemington Pits 1 and 2.

7.6.2 After mining

Post mining the water take gradually reduces over time as mine pits fills and the groundwater system equilibrates to the modified landform. This groundwater system takes around 400 years to equilibrate post mining. The modelling indicates that when equilibrium conditions return post mining, there will be a residual water take that requires long term water licensing.

Table 7-3 summarises the predicted equilibrium 'water take' for the approved mining plus the proposed modification.

Table 7-3 Groundwater peak take– post mining equilibrium (400 years)

Water Source	Calculated 'water take'		'Water take' accounted under		
	Model output	Presented in Appendix B	Hunter Regulated WSP	Hunter Unregulated WSP	North Coast Fractured and Porous Rock WSP
Hunter river alluvium	318[a]	Figure B-17		30 (a minus b)	
Hunter river baseflow	288[b]	Figure B-21	288[b]		
Wollombi Brook alluvium	0[c]	Figure B-18		0 (c minus d)	
Wollombi Brook baseflow	+9[d]	Figure B-22		0*	
Permian	206	Section 7.2.2			206
TOTALS			**288**	**30**	**206**

Note: ** the net gain predicted for the Wollombi Brook baseflow has not been considered in water licensing*

7.7 Water quality

This section describes the potential for changes in groundwater quality changes due to the proposed modification.

7.7.1 Overburden emplacement areas and final void lakes

Overburden will continue to be placed within the open-cut pit and progressively rehabilitated during mining. Under the proposed modification, water will evaporate from the void lake surface, and draw in groundwater from the surrounding geological units. Evaporation from the lake surface will concentrate salts in the lake slowly over time. However, as noted previously this gradually increasing salinity will not pose a risk to the surrounding groundwater regime as the final void will remain a permanent 'sink'.

MER (1998) analysed the quality of water interacting with mine spoils and found that the long term water quality for the bulk of the spoils is approximately 3,700mg/L, assuming complete leaching. As detailed in Section 5.4, the Permian coal measures are predominately classified as moderately saline, with a salinity of between 1,500mg/L and 7,000mg/L. As concluded by MER (1998), the water quality from the recharged spoil could provide some improvement in salinity for the void water quality post mining. However in the long term the final void is predicted to act as a 'sink', slowly drawing groundwater in and concentrating salt within the void lake over time.

South Lemington Pit 1 and Pit 2 will be backfilled at closure. The numerical model predicts post mining groundwater levels will rise and re-saturate the backfilled spoils, but not reach the re-profiled land surface at each of these pits. At South Lemington Pit 2 groundwater levels will remain about 30m below the land surface and a hydraulic gradient will be established that promotes groundwater flow towards the proposed final void lake at the adjacent United Mine under the United Wambo Project. This means any poor quality water in the South Lemington Pit 2 will ultimately be captured in the final void sink that forms at United Mine.

South Lemington Pit 1 will form a flow through system with groundwater passing through the spoils and into surrounding geological units including the Wollombi Brook alluvium. The mine spoil leachate has previously been estimated to approximate the chemistry of the current coal measures groundwater (ERM 2008a). As discussed earlier in the report, Wollombi Brook naturally receives moderately saline discharge through upward leakage from the Permian coal measures. As such, it is not considered likely to result in adverse increased salinity to the surrounding groundwater system.

7.7.2 Alluvial groundwater systems

During mining the flow from the Permian coal measures into the overlying alluvium is predicted to reduce due to the proposed modification. In the short term this will reduce the salt load within groundwater reaching the alluvial systems, potentially having a beneficial effect on water quality. Post mining the Permian groundwater systems will slowly re-pressurise and flow to the alluvial groundwater systems will increase. This is a natural process that occurs in the absence of mining.

7.7.3 Hydrocarbons

There is virtually no potential for hydrocarbons to enter groundwater. All refuelling activities occur in areas with adequate bunding and provision for immediate clean-up of spills. All chemicals will be transported, handled and stored in accordance with relevant Australian Standards. These controls represent standard practice and a legislated requirement at mine sites.

7.8 Model uncertainty

The uncalibrated uncertainty in the model predictions was assessed using a sensitivity analysis where model inputs were changed individually to assess the changes to the model predictions. The model parameters were adjusted to encompass the range of likely uncertainty in key parameters of hydraulic conductivity, recharge and river vertical hydraulic conductivity.

The sensitivity analysis identified that changes in hydraulic conductivity had the greatest influence on baseline calibration, pit inflows and extent of groundwater level drawdown. As detailed in Section 5, Appendix A and Appendix B, extensive field data for hydraulic conductivity is available from studies conducted across HVO and surrounding mines. Further details about the sensitivity analysis are presented in Appendix B.

8 NSW Aquifer Interference Policy

Table 8-1 to Table 8-3 below compare the groundwater impact predictions for the incremental change due to the proposed modification against the requirements under the NSW AIP (DPI Water 2012).

Table 8-1 Accounting for or preventing the take of water

AIP requirement		Proponent response
1	Described the water source (s) the activity will take water from?	Based on the AIP, the groundwater system impacted by the proposed modification can be separated into two systems, as follows: • porous and/or fractured consolidated sedimentary rock of the Permian coal measures (less productive aquifer); and • groundwater within alluvium associated with the Hunter River and Wollombi Brook (both highly productive and less productive zones). (Refer Section 2)
2	Predicted the total amount of water that will be taken from each connected groundwater or surface water source on an annual basis as a result of the activity?	Technical report Section 7and Appendix B – Section B4. The peak water take for the proposed modification, including the existing remodelled approval for HVO South is predicted as follows: • reduction in alluvium contribution to Hunter River surface water of 584ML/year; • reduction in alluvium contribution to Wollombi Brook surface water of 107ML/year; • reduction in transfer of water from Permian coal measures to alluvium of Hunter River of 838ML/year; • reduction in transfer of water from Permian coal measures to alluvium of Wollombi Brook of 131ML/year; and • interception of water from the Permian coal measures of 1,591ML/year. (Refer technical report Section 7.6 and Appendix B – Section B4)
3	Predicted the total amount of water that will be taken from each connected groundwater or surface water source after the closure of the activity?	The water take from each water source will peak in the final year of mining and slowly reduce post mining as the groundwater system slowly reaches a new equilibrium. The long term water take at equilibrium conditions (400 years post mining) is estimated at: • reduction in alluvium contribution to Hunter River surface water of 288ML/year; • reduction in alluvium contribution to Wollombi Brook surface water of 0ML/year; • reduction in transfer of water from Permian coal measures to alluvium of the Hunter River of 318ML/year; • reduction in transfer of water from Permian coal measures to alluvium beneath Wollombi Brook to the of 0ML/year; and • extraction of water from the Permian coal measures of 206ML/year. (Refer technical report Section 7.6 and Appendix B – Section B4)
4	Made these predictions in accordance with Section 3.2.3 of the AIP? (page 27)	Based on 3D numerical modelling. (Refer Appendix B and Section 6 and 7)

AIP requirement		Proponent response
5	Described how and in what proportions this take will be assigned to the affected aquifers and connected surface water sources?	The model predicts a peak take from the Permian (North Coast Fractured and Porous Rock WSP*)* of 1,591 ML/year at Year 15. The model predicts a peak indirect take of 489ML/year under the Hunter Unregulated WSP and 584ML/year under the Hunter Regulated WSP*.* These volumes are within previously predicted maximum water takes for the currently approved operations stated in ERM (2008a). (Refer Section 7)
6	Described how any licence exemptions might apply?	The proposed modification is not seeking application of any licence exemptions.
7	Described the characteristics of the water requirements?	Groundwater directly intercepted in mining areas, and indirectly influences adjacent alluvial systems, but is not required for mining operations. (Refer Section 6.1)
8	Determined if there are sufficient water entitlements and water allocations that are able to be obtained for the activity?	HVO South has sufficient water entitlements for currently approved operations and additional water take from the proposed operations, as detailed in Table 7-2.
9	Considered the rules of the relevant water sharing plan and if it can meet these rules?	The WSP allow for access and trading for take of groundwater. These licenses can be purchased from the market and the project can meet the rules of the relevant WSP's.
10	Determined how it will obtain the required water?	Taking of the water cannot be avoided or prevented is accounted for with the water licenses held by the proponent.
11	Considered the effect that activation of existing entitlement may have on future available water determinations?	The proposed modification accounts for less than 12% of the total indirect alluvial and baseflow take, with the majority due to approved HVO South operations. Comparing these takes to total entitlements, as an example the draft report card for the Hunter Regulated River Water Source (DPI Water 2015) indicates current surface water entitlements total 292,591/year. The proposed modification plus approved operations have a predicted peak additional take of up to 584ML/year, which is a very small proportion of the available entitlements (0.2%). Current groundwater entitlements for the Lower Wollombi Brook water source are 5,071 units (or 5,071ML/year at full available water determination (AWD)). Current surface water entitlements for the Lower Wollombi Brook water source are 6,663 ML/year. The model predicts peak take 131ML/year from the alluvium and of 107ML/year from Wollombi Brook. Of this, the proposed modification accounts for around 60ML/year, which is a small portion of the available entitlements (<0.1%) and therefore no impact on AWD is expected. (Refer technical report Section 7.6 and Appendix B – Section B4)
12	Considered actions required both during and post-closure to minimise the risk of inflows to a mine void as a result of flooding?	The proposed final landform has designed the void to be located outside of the flood limits of the Hunter River and Wollombi Brook. (Refer EIS Surface Water Study)

AIP requirement		Proponent response
13	Developed a strategy to account for any water taken beyond the life of the operation of the Project?	Allocate existing and future water entitlements to the project water takes to license take of water as necessary. Coal & Allied will undertake, in consultation with DPI Water, to license for the maximum predicted take over the life of the project (during and post). At mine closure the water licenses will be matched to the predicted take, with excess licenses released to the market. (Refer Section 7.6)
	Will uncertainty in the predicted inflows have a significant impact on the environment or other authorised water users? Items 14-16 must be addressed if so.	The proposed modification is located in an area where groundwater use is relatively limited. Whilst there is a level of inherent uncertainty in the predicted inflows, the sensitivity analysis suggests a significant change in the impacts on users is unlikely. (refer Appendix B Section B5)
14	Considered any potential for causing or enhancing hydraulic connections, and quantified the risk?	Open cut mining does not induce significant and wide spread fracturing of strata.
15	Quantified any other uncertainties in the groundwater or surface water impact modelling conducted for the activity?	A sensitivity analysis has been completed to identify parameters that demonstrate most substantial changes in the predictions. (refer Appendix B Section B5)
16	Considered strategies for monitoring actual and reassessing any predicted take of water throughout the life of the Project, and how these requirements will be accounted for?	Continued ongoing monitoring and verification of modelling results. (refer Section 10)

Table 8-2 Determining water predictions

AIP requirement		Proponent response
1	Addressed the minimum requirements found on page 27 of the AIP for the estimation of water quantities both during and following cessation of the proposed activity?	Based on detailed modelling completed in accordance with Australian groundwater modelling guidelines (Barnett *et al* 2012). (refer Section 7.6 and Appendix B Section B5)

Table 8-3 Other requirements

AIP requirement		Proponent response
1	Establishment of baseline groundwater conditions?	Hydrographs of groundwater monitoring have been provided for a network of monitoring bores in the region. Water quality and level data has been collected since 2000 for some of the key groundwater units and tested for a selection of analytes. (Refer Appendix B)

AIP requirement		Proponent response
2	A strategy for complying with any water access rules?	No cease to pump rules have been established for the Lower Wollombi Brook water source. The Hunter Unregulated WSP requires a cease to pump rule be established by 2019. The operation will consult with DPI Water to ensure compliance with the requirements of the Hunter Unregulated and Alluvial Water Sharing Plan for the Hunter River and porous rock.
3	Potential water level, quality or pressure drawdown impacts on nearby basic landholder rights water users?	No private bores are predicted to be impacted >2m due to the proposed modification. A single bore on land owned by the Ravensworth mine (10011459) is predicted to decline by a maximum of 2.7m. This decline is predominantly due to already approved operations. (Refer Section 7.4)
4	Potential water level, quality or pressure drawdown impacts on nearby licensed water users in connected groundwater and surface water sources?	No private bores are predicted to be impacted >2m due to the proposed modification. A single bore on land owned by the Ravensworth Mine (10011459) is predicted to decline by a maximum of 2.7m (total cumulative drawdown). This decline is predominantly due to already approved operations, with the proposed modification only contributing 0.3m of drawdown. (Refer Section 7.4)
5	Potential water level, quality or pressure drawdown impacts on groundwater dependent ecosystems?	Risk of drawdown at identified ecosystems potentially dependent on groundwater is detailed in Section 7.5 and discussed in Ecology Assessment.
6	Potential for increased saline or contaminated water inflows to aquifers and highly connected river systems?	No mining activity below the ground surface will occur within 200m laterally from the top of high bank. Study identified the main final void will form a sink containing groundwater within the void lake. (Refer Section 7.1.2)
7	Potential to cause or enhance hydraulic connection between aquifers?	Open-cut operations are not predicted to enhance hydraulic connection between aquifers.
8	Potential for river bank instability, or high wall instability or failure to occur?	N/A.
9	Details of the method for disposing of extracted activities (for CSG activities)?	N/A.

There are two levels of minimal impact considerations specified in the AIP. If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable. Where the predicted impacts are greater than the Level 1 minimal impact considerations then the AIP requires additional studies to fully assess these predicted impacts. If this assessment shows that the predicted impacts do not prevent the long-term viability of the relevant water-dependent asset, then the impacts will be considered to be acceptable. It is also predicted that during mining groundwater levels within a bore on Ravensworth land (10011459) could decline by 2.7m. This decline is mostly due to already approved operations. As the cumulative impacts from already approved operations exceed 2m, the minor additional decline due to the proposed modification does not exceed the Level 1 minimal impact considerations under the AIP. Overall, the modelling indicates no drawdown in private bores exceeding the Level 1 minimal impact considerations.

9 EPBC Water Resources Guideline

In June 2013 the Federal Government enacted changes to the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), to provide that 'water resources' are a matter of national environmental significance in relation to coal seam gas and large coal mining development. This change is referred to as the 'water trigger'. In December 2013, the Federal Department of Environment (DoE) released the guideline *Significant Impact Guidelines 1.3: Coal seam gas and large coal mining developments - impacts on water resources* (water resource guideline) which outlines a 'self-assessment' process that assists proponents to identify if their project is likely to have a significant impact on water resources.

This section considers the impact of the proposed modification against the water resource guideline with respect to groundwater resources. It compares the predicted impacts against the DoE guidelines to determine if the project could have a significant impact on water resources. It also considers the potential for cumulative impacts with other developments.

Groundwater is held within the cleats in coal seams prior to mining. During mining a portion of the groundwater will naturally drain from the coal into the mining area, whilst the remaining volume will be retained bound by capillary action to the coal matrix. It is inherent in coal mining that this groundwater held within the coal will be removed during extraction of the coal and cannot be avoided. The water held within the coal seam is typically of limited use due to high concentrations of dissolved salts.

The guidelines indicate that the proposed modification must have '*a real or not remote chance or possibility that it will directly or indirectly result in a change to*' the '*hydrology*' or '*water quality*' of the water resource. This change must be of '*sufficient scale or intensity as to reduce the current or future utility of the water resource for third party users*'. Third party users can include '*environmental and other public benefit outcomes, or to create a material risk of such reduction in utility occurring*'. Furthermore, '*Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the water resource which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts*'.

9.1 Water availability to users

Section 7.6 outlines that no private bores record a cumulative drawdown of >2m due to the proposed modification. A single bore on land owned by the Ravensworth mine (10011459) is predicted to decline by a maximum of 2.7m due to cumulative impacts from approved and the proposed modification. This decline is predominantly due to already approved operations. This finding is consistent with the previous assessments by MER (2005) and ERM (2008a).

9.2 Water availability to the environment

The numerical modelling indicates the depressurisation due to mining will reduce the flow of Permian groundwater to the alluvial aquifers of the Hunter River and Wollombi Brook. This will potentially result in lowering of groundwater levels around the fringes of the alluvium in some areas.

The proposed modification targets a deeper coal seam that is not well connected to the surficial alluvial water resources and therefore does not significantly increase the drawdown beyond that predicted to occur due to the currently approved operations.

The predicted drawdown within the alluvium is most significant along the fringes of the alluvium and reduces with proximity to the Hunter River. Six areas have been identified where ecosystems occur that could potentially use groundwater. The identified ecosystems occur within the Quaternary alluvium along the Hunter River and Wollombi Brook. The proposed modification will not decrease alluvial groundwater levels by more than 1m at all identified ecosystems along the Hunter River. Groundwater levels south of Wollombi Brook, near South Lemington Pit 1, are predicted to decrease by less than 1m due to the proposed modification. Groundwater levels within the alluvium adjacent to South Lemington Pit 2 (ie at E4 and E6) are predicted to decline by up to 2.8m due to the proposed modification. Approved operations are predicted to cause an additional decline in water levels in these areas by up to 7m.

The proposed modification does not result in any additional drawdown beyond the extents already predicted to occur due to the approved mining. The ecology study within the Environmental Assessment considered the potential for the predicted drawdown to impact upon the functioning of these ecosystems.

9.3 Water quality

Modelling determined that the water level within the final void would recover to a quasi-equilibrium level of 30mAHD. This level is approximately 20m to 30m below the pre-mining groundwater level and means that the final void will act as a sink to groundwater flow, preventing flow of water back into the groundwater systems. Under the proposed modification**,** water will evaporate from the void lake surface, and draw in groundwater from the surrounding geological units. Evaporation from the lake surface will concentrate salts in the lake slowly over time. The gradually increasing salinity will not pose a risk to the surrounding groundwater regime as the final void will remain a permanent 'sink'. South Lemington Pits 1 and 2 will be backfilled and will not have final void lakes forming.

9.4 Cumulative impacts

Approved coal mines within the region operate below the water table and therefore extract groundwater. When mines are in close proximity to each other the zone of drawdown generated by each can overlap. Within these overlapping areas, the drawdown from each project combines to create a larger cumulative impact on the groundwater system. Cumulative impacts were accounted for in the groundwater model by representing all currently approved and foreseeable mining operations, along with the proposed modification. The surrounding mines include HVO North, Ravensworth, Cumnock, Ashton, United, Wambo and MTW operations that mine the same economic coal seams of the Wittingham Coal Measures.

Section 7.1 outlined the change in groundwater levels due to the proposed modification compared to the cumulative impact of approved and foreseeable operations. The results indicate that the proposed modification results in a relatively limited additional impact on top of the impact from already approved and foreseeable operations. This is because the proposed modification remains within the currently approved footprint and targets mining of deeper seams that are not well connected to shallow overlying alluvial aquifers.

Appendix B outlined the change in alluvial and surface groundwater flow for the cumulative approved operations and the proposed modification, both during and after mining at the proposed modification. The modelling indicates that the proposed modification accounts for less than 12% of the total indirect alluvial and baseflow take, with the majority due to approved HVO South operations. The modelled water take is comparable with previously estimates for the currently approved operations at HVO South.

9.5 Avoidance or mitigation measures

The mine plan avoids the flood plain and does not intersect the alluvial aquifers. The impacts on the alluvial aquifers are therefore indirect, and occur through the depressurisation of the underlying Permian coal measures. Locating the mining outside the alluvial flood plain effectively mitigates the impact upon the alluvial aquifer and connected streams. The groundwater seepage to the mining areas cannot be prevented, and must be removed to ensure safe operating conditions within the mining areas.

If the proposed modification interferes with any private groundwater user possessing a water supply work, and mitigation measures are not feasible, make good measures with affected land owners will include:

- ensuring the bore owner has access to a similar quantity and quality of water for the water bore's authorised purpose for example by:
  - bore enhancement by deepening the bore or improving its pumping capacity;
  - constructing a new water bore; and
  - providing a supply of an equivalent amount of water of a suitable quality by piping it from an alternative source.

The make good agreements will also allow for the provision to the water bore owner of compensation (monetary or otherwise) for the bore's impaired capacity.

10 Groundwater monitoring and management plan

Management of water resources is integrated at HVO. Management occurs in accordance with the HVO Water Management Plan (WMP), which was prepared in consultation with the now DPI Water and EPA, approved in May 2014 and updated in July 2015 (Coal & Allied, 2015).

The plan fulfils the requirements of the HVO Environmental Protection Licence 640, project approval for HVO South (PA 06_0261), development consent for HVO North (DA 450-10-2003) together with commitments made in the respective environmental assessments, environmental impact statements and relevant legislation, standards and guidelines. A link to the WMP is provided below:

http://www.riotinto.com/documents/20150717_HVO_water_management_plan_Approved_Final.pdf

10.1 Water level monitoring plan

Groundwater monitoring at HVO South is currently undertaken in accordance with the HVO groundwater monitoring program (GMP), which is included in the HVO WMP. Currently manual groundwater level monitoring is conducted on a monthly, quarterly or 6-monthly basis, in addition to daily readings recorded dataloggers.

Groundwater levels will continue to be monitored as per the existing HVO WMP. Ongoing monitoring will enable natural groundwater level fluctuations (such as responses to rainfall) to be distinguished from potential groundwater level impacts due to depressurisation resulting from proposed mining activities. Ongoing monitoring of groundwater levels will also be used to assess the extent and rate of depressurisation against model predictions.

Yearly reporting of the water level results from the monitoring network will be included in the annual review. The annual review will also identify if any additional monitoring sites are required, or if optimisation of the existing monitoring sites should be undertaken.

10.2 Water quality monitoring plan

Currently groundwater monitoring is conducted at HVO on a quarterly or 6-monthly basis for field water quality (EC and pH), and on a six monthly to annual basis for more comprehensive water quality analysis at selected bores. The comprehensive water quality suit is stipulated within the HVO WMP.

Groundwater quality sampling of existing monitoring bores will continue in order to detect any changes in groundwater quality during and post mining. Similar to the water level monitoring, yearly reporting of the water quality results from the monitoring network should be included in the annual review. The annual review should consider if any additional monitoring sites are required, or if optimisation of the existing monitoring sites, frequency of sampling and analytical suite should be undertaken. The HVO GMP also considers the optimal sites for monitoring of groundwater quality over the life of mining.

10.3 Trigger levels

The aim of trigger levels is to provide mine management with an early warning mechanism that identifies water quality trends departing from historical values. The existing HVO WMP details that key water quality triggers include pH, EC and total suspended solids (TSS). In the absence of applicable ANZECC (2000) criteria, the 95th percentile of the available data is adopted and compared to monitoring results on a monthly basis. Water quality trigger levels at the 95th/5th percentile, based on baseline data, are considered adequate to identify mine related impacts, while still accounting for natural and seasonal variations.

10.4 Future model iterations

Every five years the validity of the model predictions would be assessed and if the data indicates significant divergence from the model predictions, an updated groundwater model would be constructed for simulation of mining.

10.5 Data management and reporting

Data management and reporting would include:

- annual assessment of departures from identified monitoring data trends and comparison against specified trigger levels;
- formal annual review of depressurisation of coal measures and alluvial aquifers undertaken by a suitably qualified hydrogeologist;
- annual reporting (including all water level and water quality data); and
- all groundwater data stored in a database with suitable QA/QC controls.

11 Conclusions

This report describes the groundwater related impacts associated with Modification 5 under PA 06_0261. As part of the modification two key changes to the currently approved mine plan are proposed that will influence the groundwater regime:

- deepening of already approved pits (Riverview Pit, Cheshunt Pit and South Lemington Pit 2) which target coal seams of the Wittingham Coal Measures; and
- revised final landform with a change in the placement of the final void.

As discussed in Section 1.1.1, previous groundwater assessments have been conducted for the now approved HVO South mine plan. This groundwater assessment builds upon the knowledge and data presented in these previous studies for the purpose of assessing the impact of the proposed modification. A numerical groundwater model was developed to represent the local geological and hydrogeological regime, which are described in Section 4 and Section 5, respectively. The numerical groundwater model covered a large domain due to extensive historic and approved mining of the Wittingham Coal Measures within the region. Existing and approved mines represented in the model include HVO North, Ravensworth, Cumnock, Ashton, United, Wambo and MTW.

The key conclusion from the groundwater assessment are summarised as follows:

- The model predicts a peak take from the Permian (North Coast Fractured and Porous Rock WSP) of 1,591ML/year at Year 15. The model predicts a peak indirect take of 489ML/year under the Hunter Unregulated WSP and 584ML/year under the Hunter Regulated WSP. These combined volumes are within previously predicted maximum water takes for the currently approved operations stated in ERM (2008a). No private bores are predicted to have a cumulative impact of >2m due to the proposed modification. A single bore on land owned by the Ravensworth mine (10011459) is predicted to decline by a maximum of 2.7m due to cumulative impacts from approved and the proposed modification. This decline is predominantly due to already approved operations.
- There are no mapped GDE's within or adjacent to the proposed modification. Ecological surveys from previous assessments have identified ecosystems in the vicinity with potential to use groundwater. The model predicts that groundwater drawdown due to the proposed modification is generally below 1m at these ecosystems along the Hunter River and south of Wollombi Brook. The greatest decline in alluvial groundwater levels due to the proposed modification are within localised areas north of Wollombi Brook, adjacent to South Lemington Pit 2. Modelled alluvial groundwater levels are predicted to decline by up to 2.8m due to the proposed modification, on top of a decline of up to 7m for approved mining. The proposed modification does not result in any additional areas of drawdown beyond the extent already predicted to occur due to the approved mining. The ecology study within the Environmental Assessment considered the potential for the predicted drawdown to impact upon the functioning of these ecosystems.
- Final voids will remain a permanent sink, capturing groundwater, and preventing any degradation in groundwater quality.

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13 Glossary and acronyms

AGE	Australasian Groundwater and Environmental Consultants Pty Ltd
AIP	Aquifer Interference Policy
AL	Assessment Lease
BSAL	Biophysical Strategic Agricultural Land
CIC	Critical Industry Cluster: Industry clusters that meet the following criteria: - there is a concentration of enterprises that provides clear development and marketing advantages and is based on an agricultural product; - the productive industries are interrelated; - it consists of a unique combination of factors such as location, infrastructure, heritage and natural resources; - it is of national and/or international importance; - it is an iconic industry that contributes to the region's identity; and - it is potentially substantially impacted by coal seam gas or mining proposals.
CRD	Cumulative Rainfall Departure
DPI Water	Department of Primary Industries – Water Division
EC	Electrical Conductivity
EA	Environmental Assessment
EMM	EMM Consulting Pty Limited
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EVT	Evapotranspiration
GDE	Groundwater Dependent Ecosystem
HITS	Hunter Integrated Telemetry System
HVO	Hunter Valley Operations
IESC	Independent Expert Scientific Committee
LGA	Local Government Area
MNES	Matters of National Environmental Significance
Mtpa	Million tonnes per annum
MTW	Mount Thorley Warkworth Operations
NGIS	National Groundwater Information System
PEST	Parameter Estimation Software
Pinneena	NSW Office of Water supplied database of registered groundwater bores
ROM	Run of Mine

SILO	SILO is a database of historical climate records for Australia
SMB	Soil Moisture Balance
SRMS	Scaled Root Mean Square
TDS	Total Dissolved Solids
VWP	Vibrating Wire Piezometer
WSP	Water Sharing Plan

Appendix A

Fieldwork Appendix

Appendix A

HVO South Modification 5 Field Investigation Report

A1 Introduction

This appendix describes the field investigation work undertaken during the EIS. The field work was designed to capture sufficient data to conceptualise and develop a numerical groundwater model of the project area. The field investigation included:

- installing additional monitoring bores;
- measuring groundwater levels;
- collecting samples for water quality analysis;
- measuring the hydraulic conductivity of key stratigraphic units with slug tests; and
- conducting a survey of surrounding private bores (bore census).

The sections below describe the field investigations and the raw data.

A2 Groundwater monitoring network

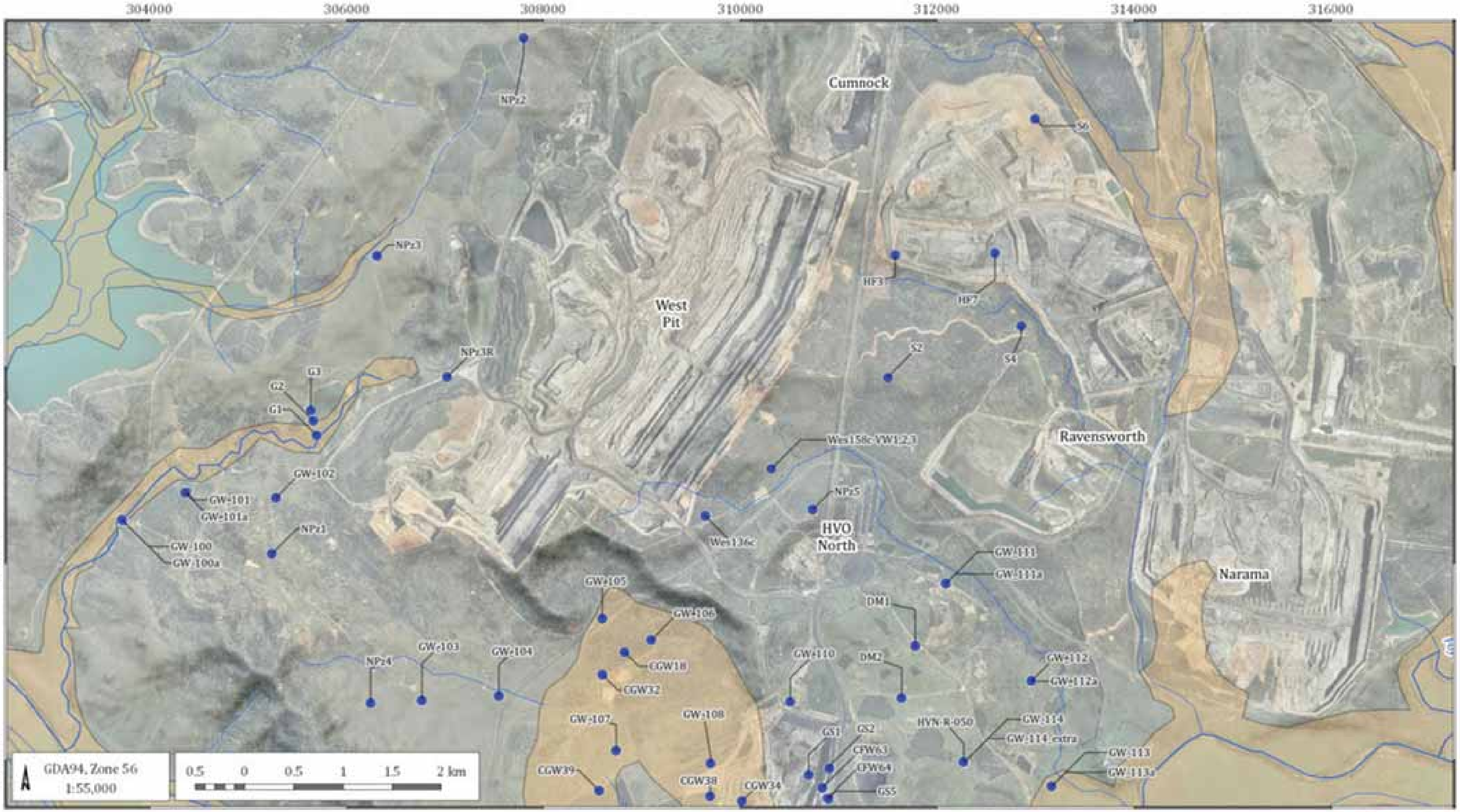
A2.1 Existing network

HVO has a groundwater monitoring network that comprises a total of 251 bores and 17 vibrating wire piezometers (VWP) with 31 sensors. The network was established from the year 2000, and extends across West Pit, HVO North, HVO South, Lemington and Southern. Over time, several of the bores have been abandoned and destroyed due to mine progression and deterioration. A list of all bores and VWPs installed across the project area is included in Appendix A1. The location of the full monitoring network is shown in Figure A- 1 to Figure A- 3.

The proponent currently monitor 155 bores and two VWP sensors, with an additional 126 monitoring points that are no longer monitored but have available historical data, as summarised in Table A- 1.

Table A- 1 Site monitoring network summary

Bore status	Number of bores				
	Total	Alluvium/ regolith	Coal measures – sandstone/ siltstone	Coal measures - coal	Spoil
Existing	156	52	21	71	12
Abandoned but usable	29	5	7	5	12
Historical bore (abandoned & destroyed)	97	20	24	44	9



LEGEND

- Monitoring point
- Major drainage
- Minor drainage
- Quaternary alluvium (1:25k AGE)

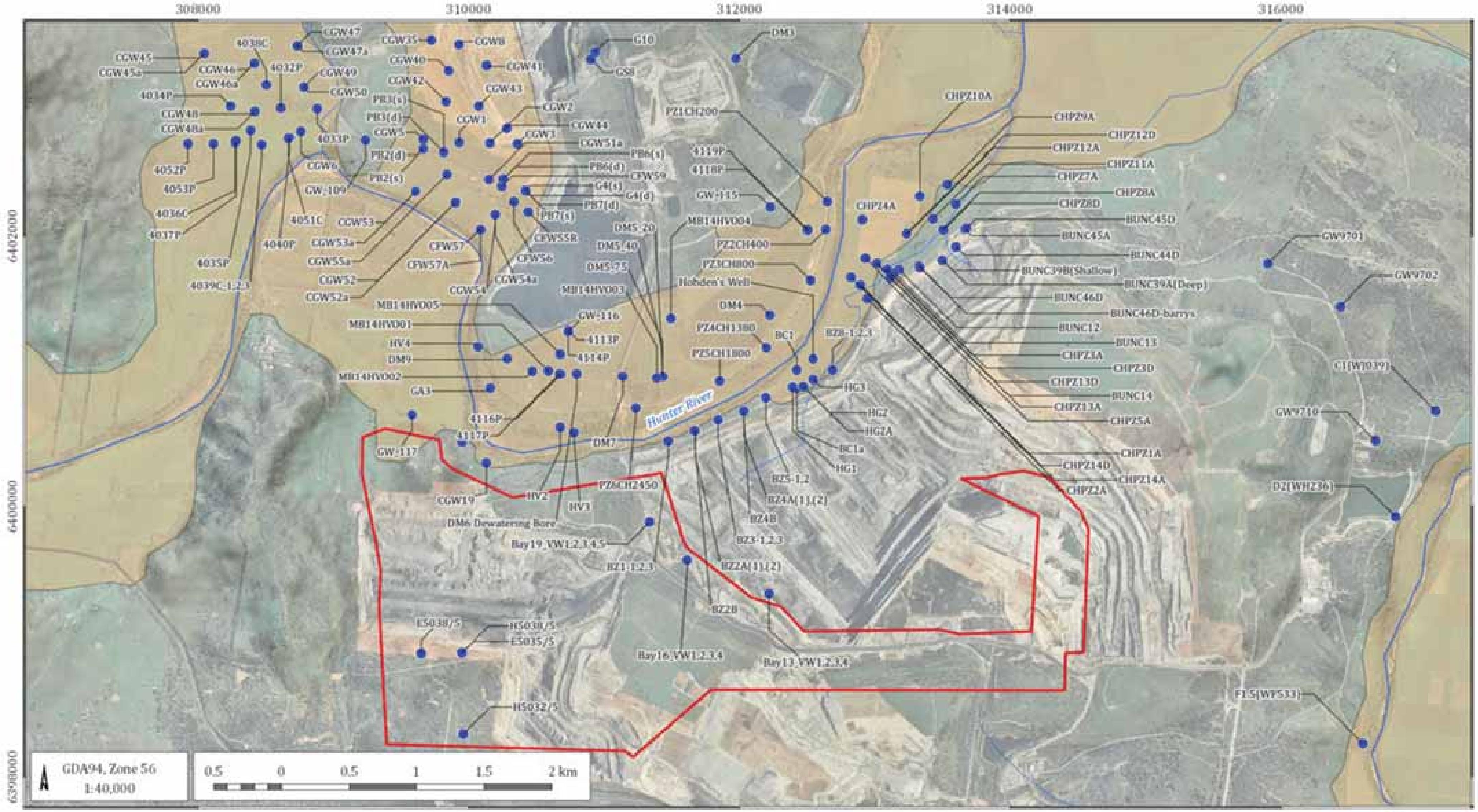
AGE

HVO South Modification 5 Groundwater Study
Field Investigation Report (G1737)

HVO North groundwater monitoring network

DATE
08/01/2016

FIGURE No:
A-1



LEGEND

- Proposed modification pit depth extension
- Monitoring point
- Major drainage
- Minor drainage
- Quaternary alluvium (1:25k AGE)

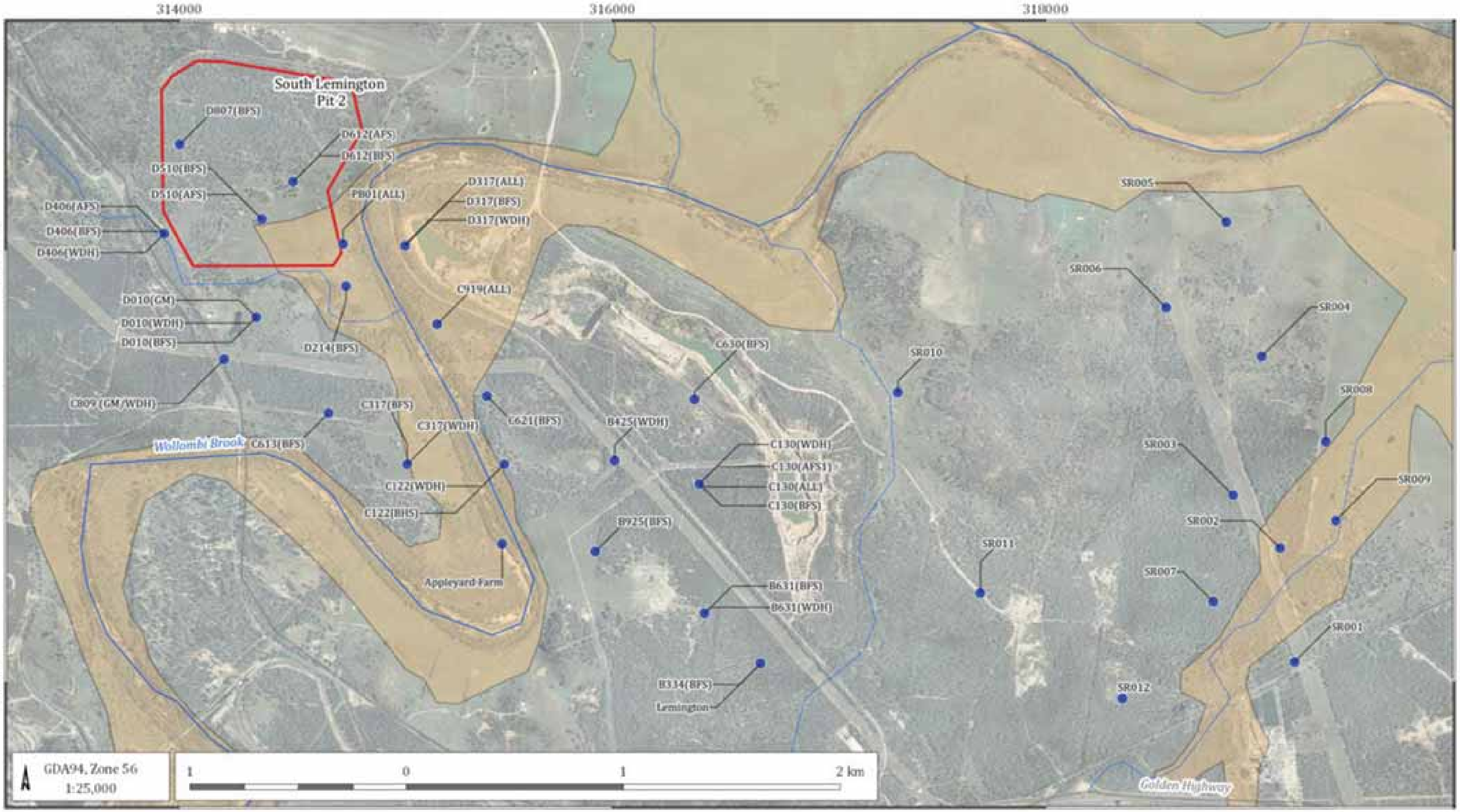
HVO South Modification 5 Groundwater Study
Field Investigation Report (G1737)

HVO South groundwater monitoring network

DATE
08/01/2016

FIGURE No:
A-2

Quaternary alluvium (1:25k AGE): 1:25,000 Singleton - AGE digitised and adjusted based on site data



LEGEND

- Proposed modification pit depth extension
- Monitoring point
- Major drainage
- Minor drainage
- Quaternary alluvium (1:25k AGE)

HVO South Modification 5 Groundwater Study
Field Investigation Report (G1737)

Lemington South groundwater monitoring network

DATE
08/01/2016

FIGURE No:
A-3

Quaternary alluvium (1:25k AGE): 1:25,000 Singleton - AGE digitised and adjusted based on site data

A2.2 Installation of additional bores

Whilst a significant network of bores exists at the site, a review of available information identified a number of gaps. Two monitoring bores were installed and one trench excavated in September 2015 to fill the data gaps. The purpose of the bores was to:

- confirm the extent, thickness and characteristics of the Quaternary alluvium associated with the Hunter River;
- test the hydraulic properties of the Quaternary alluvium to validate the model assumptions; and
- establish bores to be utilised as part of the ongoing monitoring program and obtain baseline data.

Drilling and construction of the monitoring bores was conducted by Lucas Drilling, led by Harold Martin (DL 2309). Geologists from Coal & Allied managed the drilling program and geologically logged the samples. The bores were drilled using rotary mud drilling techniques and constructed in accordance with the requirements of the *Minimum Construction Requirements for Water Bores in Australia, Edition 3, February 2012*. The monitoring bores were constructed with 50mm diameter, flush threaded, Class 18 uPVC with Class 18 machine slotted (0.4mm aperture) uPVC screen. A filter pack of clean gravel of 5mm diameter was placed in the annulus to a height that covered the screened interval. Bentonite pellets were placed above and below the filter gravel to form a seal to hydraulically isolate the screened section whilst the remainder of the annulus was sealed by pumping a cement / bentonite grout via a tremie line. A steel lockable protector was cemented around the protruding casing at the surface.

The bore construction details are summarised in Table A- 2, and photographs of the lithology stored in chip trays at one meter intervals is shown in Figure A- 4 and Figure A- 5 for GW117 and GW119, respectively. Bore logs are also shown in Appendix A-2.

Table A- 2 Bore construction details

Hole ID	GW117	GW119
Type	Monitoring bore	Monitoring bore
Easting	309578.89	310128.52
Northing	6400676.28	6400322.47
Date installed	22/9/2015	24/9/2015
Ground elevation (mAHD)	68.34	73.50
Casing height (mAHD)	69.18	74.31
Screen interval (mbGL)	9.9 – 15.8	10 – 13
Gravel pack (mbGL)	8 – 15.8	8 – 13.5
Geological unit	Quaternary alluvium	Regolith
Lithology	Upper clay layer and pebbles, sub-angular, poorly sorted within a granular matrix.	Clay
Water level (mbTOC)*	10.26	12.15

Hole ID	GW117	GW119
Flow rate during development (L/s)	<0.1 L/s	Negligible
Field EC (µS/cm)*	8,740	-
Field pH*	6.9	-

Notes: *Coordinates in MGA 94 Zone 56*

** Water level and water quality recorded during sampling event on 9th October 2015 – field water quality reported after four well volumes purged from bore.*

Figure A- 4 GW117 geology chip samples

Figure A- 5 GW119 geology chip samples

A trench was also excavated to confirm the extent of alluvium north of Riverview Pit. The trench was located at 309951E/6400477N (GDA94 Zone 56). Loamy soil was intersected to a depth of 0.5m, below which unsaturated weathered sandstone was encountered. Figure A- 6 shows the proximity of the trench to the Hunter River (left) and the excavated trench (right) with the thin soil cover and shallow weathered sandstone of the Permian aged Wittingham Coal Measures.

Figure A- 6   Trench location and trench lithology

A3 Groundwater sampling and testing

A3.1 Groundwater levels

Coal & Allied monitor groundwater levels within the site monitoring network on a quarterly to annual basis. Bores equipped with dataloggers and the VWPs also record data approximately four times a day.

Appendix A-3 presents a 'snap shot' of the most recent groundwater levels for each of the site monitoring bores.

A3.2 Groundwater quality

In September 2015, the newly installed monitoring bores, a selection of private bores visited during the bore census (Section A4) and two water sampling points (WLP7 and WLP16) were sampled and sent to a NATA accredited laboratory for analysis as part of the EIS. Samples from bores were collected by purging a minimum three bore volumes and until field water quality parameters (pH, EC and temperature) had stabilised. Field water quality probes were calibrated daily prior to use. Prior to purging, the standing water level (SWL) was measured with a water level dipper.

Groundwater samples collected during the field investigations were analysed for the following suite of parameters:

- physio-chemical indicators – pH, electrical conductivity (EC), total dissolved solids;
- major Ions – calcium, fluoride, magnesium, potassium, sodium, chloride, sulphate;
- total alkalinity as $CaCO_3$, HCO_3, CO_3;
- dissolved and total metals – aluminium, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, strontium, silver, uranium, vanadium and zinc; and
- nutrients – nitrite, nitrate, total nitrogen and phosphorous.

The water quality results from the September 2015 monitoring event, along with all available historic water quality data collected by Coal & Allied and available data from neighbouring mine operations. The historic water quality data collected by Coal & Allied dates from 2001 to present, and was collected as part of the existing surface water and groundwater monitoring program. The extensive historic groundwater quality data includes over 4000 readings for field EC and pH (each), and generally over 600 readings for major ions and metals.

Table A- 3 provides a summary table comparing the water quality results across the main groundwater bearing units, the alluvium ("highly productive", "less productive" and palaeochannel), coal measures (interburden and coal) and spoil. The results are also compared against the ANZECC (2000)[1] livestock drinking guidelines and irrigation guidelines (long-term and short-term).

[1] ANZECC, (2000), "Australian Water Quality Guidelines for Fresh and Marine Waters", Australia and New Zealand Environment and Conservation Council and the Agricultural and Resource Management Council of Australia and New Zealand.

Table A- 3 Water quality summary

Analyte		Unit	ANZECC (2000) Short term irrigation	ANZECC (2000) Long term irrigation	ANZECC (2000) Stock Water	Hunter River	Wollombi Brook†	Palaeo-channel	Less productive alluvium†	Highly productive alluvium	Interburden†	Coal	Spoil
pH (Field)	Av.	pH unit	6.0 - 8.5	6.0 - 8.5	-	8.1	7.7	7.4	7.3	7.2	7.2	7.2	7.1
	Min.					5.5	6.4	6.7	5.8	6.3	5.9	6.1	6.1
	Max.					9.1	8.8	8.6	9.9	8.3	9.9	9.9	8.8
EC (Field)	Av.	µS/cm	-	-	-	693	1084	4243	4609	1019	7487	7041	6915
	Min.					70	105	1009	13	21	17	500	1189
	Max.					1490	7310	11830	27900	8050	23100	23100	13280
TDS (Laboratory)	Av.	mg/L	-	-	3,000 - 13,000*	506	311	2789	2068	569	**5873**	**6405**	**5242**
	Min.					81	116	426	212	24	74	692	794
	Max.					3800	898	6650	8894	2600	15200	15200	10790
TSS (Laboratory)	Av.	mg/L	-	-	-	37	16	-	81	162	80	290	50
	Min.					1	1	-	16	1	2	290	12
	Max.					988	815	-	268	8900	580	290	111
Silicon (t)	Av.	mg/L	-	-	-	14	9	31	30	23	23	23	11
	Min.					3	7	13	12	14	12	12	0
	Max.					19	13	42	75	30	56	56	16
Chloride (t)	Av.	mg/L	-	-	-	212	0	717	1019	147	2513	2899	1634
	Min.					202	0	245	21	60	3	213	188
	Max.					222	0	2620	3510	574	7740	7740	3830
Calcium (t)	Av.	mg/L	-	-	1000	34	10	80	120	48	129	116	120

Analyte		Unit	ANZECC (2000) Short term irrigation	ANZECC (2000) Long term irrigation	ANZECC (2000) Stock Water	Hunter River	Wollombi Brook†	Palaeo-channel	Less productive alluvium†	Highly productive alluvium	Interburden†	Coal	Spoil
	Min.					2.7	1.8	18.0	3.0	9.0	2.0	10.0	14.0
	Max.					66	19	243	2877	196	2172	288	232
Sodium (t)	Av.	mg/L	-	-	-	62	74	547	498	98	1606	1729	1125
	Min.					14	11	41	16	36	13	140	258
	Max.					174	276	1790	2500	735	4350	4350	2130
Magnesium (t)	Av.	mg/L	-	-	-	26	11	120	84	34	321	309	287
	Min.					2.70	2.10	31.00	0.05	8.00	0.11	6.00	33.00
	Max.					50	36	377	386	111	2590	726	592
Sulphate (t)	Av.	mg/L	-	-	1000 – 2400 (pigs)	35	28	158	255	39	554	642	**1134**
	Min.					8.2	5.7	6.0	0.5	4.0	0.5	0.5	128.0
	Max.					80	129	822	1930	364	7470	7470	2560
Potassium (t)	Av.	mg/L	-	-	-	3.8	5.2	7.2	42.9	3.9	48.3	38.1	30.2
	Min.					2.0	3.9	0.5	0.5	0.5	1.4	1.4	13.0
	Max.					7	7	56	1874	28	1586	390	58
Iron (d)	Av.	mg/L	-	-	-	0.3	1.0	0.3	1.4	0.4	0.5	0.5	4.7
	Min.					0.00	0.15	0.01	0.01	0.01	0.01	0.01	0.02
	Max.					1.3	1.8	3.2	28.6	8.2	6.6	6.6	38.8
Aluminium (t)	Av.	mg/L	20	5	5	2.0	1.0	**6.5**	**11.1**	**12.8**	**11.8**	**14.9**	**1.2**
	Min.					0.060	0.060	0.005	0.003	0.003	0.020	0.020	0.005
	Max.					12	5	160	410	260	255	255	20

Analyte		Unit	ANZECC (2000) Short term irrigation	ANZECC (2000) Long term irrigation	ANZECC (2000) Stock Water	Hunter River	Wollombi Brook†	Palaeo-channel	Less productive alluvium†	Highly productive alluvium	Interburden†	Coal	Spoil
Arsenic (t)	Av.	mg/L	2	0.1	0.5	<0.001	0.001	0.002	0.002	0.001	**0.2**	**0.2**	0.04
	Min.					<0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Max.					<0.001	0.002	0.07	0.02	0.01	8.00	8.00	0.25
Barium (t)	Av.	mg/L	-	-	-	0.1	0.1	0.2	0.3	0.2	19.4	23.6	0.1
	Min.					0.00	0.03	0.019	0.005	0.018	0.01	0.01	0.02
	Max.					0.6	0.1	2.7	6.1	1.5	660	660	0.4
Beryllium (t)	Av.	mg/L	0.5	0.1	-	<0.001	-	-	<0.001	<0.001	-	-	-
	Min.					<0.001	-	-	<0.001	<0.001	-	-	-
	Max.					<0.001	-	-	<0.001	<0.001	-	-	-
Boron (t)	Av.	mg/L	refer to guideline	0.5	7 (cattle)	0.04	0.03	0.10	0.06	0.04	0.2	0.2	0.1
	Min.					0.00002	0.02500	0.03	0.03	0.02	0.03	0.03	0.03
	Max.					0.2	0.1	0.4	0.5	0.2	0.8	0.8	0.2
Cadmium (t)	Av.	mg/L	0.05	0.01	0.01	<0.0001	-	-	<0.0001	-	<0.0001	-	-
	Min.					<0.0001	-	-	<0.0001	-	<0.0001	-	-
	Max.					<0.0001	-	-	<0.0001	-	<0.0001	-	-
Chromium (t)	Av.	mg/L	1	0.1	1	0.0008	-	-	0.0008	0.0008	0.001	-	-
	Min.					0.0005	-	-	0.0005	0.0005	0.001	-	-
	Max.					0.001	-	-	0.0010	0.0010	0.001	-	-
Cobalt (t)	Av.	mg/L	0.1	0.05	1	<0.001	-	-	<0.001	<0.001	0.002	-	-
	Min.					<0.001	-	-	<0.001	<0.001	0.002	-	-

Analyte		Unit	ANZECC (2000) Short term irrigation	ANZECC (2000) Long term irrigation	ANZECC (2000) Stock Water	Hunter River	Wollombi Brook†	Palaeo-channel	Less productive alluvium†	Highly productive alluvium	Interburden†	Coal	Spoil
	Max.					<0.001	-	-	<0.001	<0.001	0.002	-	-
Copper (t)	Av.	mg/L	5	0.2	1 (cattle)	0.002	-	-	1.1	<0.001	1.0	-	-
	Min.					0.001	-	-	0.001	<0.001	0.001	-	-
	Max.					0.003	-	-	8.5	<0.001	4.3	-	-
Iron (t)	Av.	mg/L	10	0.2	-	0.6	-	-	46.5	0.003	13.7	-	-
	Min.					0.4	-	-	0.1	0.003	0.2	-	-
	Max.					0.8	-	-	397	0.003	123.0	-	-
Lead (t)	Av.	mg/L	5	2	0.1	<0.001	-	-	0.03	<0.001	0.04	<0.001	<0.001
	Min.					<0.001	-	-	0.001	<0.001	0.001	<0.001	<0.001
	Max.					<0.001	-	-	0.1	<0.001	0.3	<0.001	<0.001
Lithium (t)	Av.	mg/L	2.5	2.5	-	<0.005	-	0.01	0.02	0.01	0.2	0.2	0.05
	Min.					<0.005	-	0.0005	0.0005	0.0005	0.003	0.003	0.008
	Max.					<0.005	-	0.3	0.6	0.1	1.0	1.0	0.1
Manganese (t)	Av.	mg/L	10	0.2	-	0.1	**0.3**	**0.9**	**2.6**	**0.7**	**1.9**	**2.9**	**0.7**
	Min.					0.02	0.07	0.004	0.0030	0.0005	0.006	0.006	0.03
	Max.					0.4	1.1	15	60	4	61	61	2
Mercury (t)	Av.	mg/L	0.002	0.002	0.002	<0.0001	-	-	<0.0001	<0.0001	-	-	-
	Min.					<0.0001	-	-	<0.0001	<0.0001	-	-	-
	Max.					<0.0001	-	-	<0.0001	<0.0001	-	-	-
Molybdenum (t)	Av.	mg/L	0.05	0.01	0.15	<0.001	-	-	0.003	0.004	-	-	-

Analyte		Unit	ANZECC (2000) Short term irrigation	ANZECC (2000) Long term irrigation	ANZECC (2000) Stock Water	Hunter River	Wollombi Brook†	Palaeo-channel	Less productive alluvium†	Highly productive alluvium	Interburden†	Coal	Spoil
	Min.					<0.001	-	-	0.003	0.001	-	-	-
	Max.					<0.001	-	-	0.00	0.01	-	-	-
Nickel (t)	Av.	mg/L	2	0.2	1	0.002	-	-	0.018	0.001	0.02	-	-
	Min.					0.002	-	-	0.003	0.001	0.002	-	-
	Max.					0.002	-	-	0.06	0.00	0.10	-	-
Selenium (t)	Av.	mg/L	0.05	0.02	0.02	0.03	0.004	0.006	0.004	0.004	**0.06**	**0.06**	0.006
	Min.					0.0001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Max.					0.5	0.01	0.02	0.02	0.02	0.5	0.50	0.05
Strontium (t)	Av.	mg/L	-	-	-	0.3	0.2	1.8	1.1	0.5	5.4	5.4	3.0
	Min.					0.101	0.05	0.4	0.1	0.3	0.2	0.2	0.001
	Max.					1	0.5	7	13	2	14	14	6
Zinc (t)	Av.	mg/L	2	2	20	0.009	0.02	0.1	0.2	0.3	0.1	0.1	0.1
	Min.					0.002	0.003	0.001	0.003	0.003	0.003	0.003	0.003
	Max.					0.07	0.3	5	11	16	2	2	2

Notes: *Values below the limit of reporting were set at half of the limit for the calculations.*

** Maximum concentration at which good condition might be expected, with 13,000 mg/L for sheep, 5,000 mg/L for beef cattle, 4,000 mg/L for dairy cattle, 6,000 mg/L for horses and 3,000 mg/L for pigs and poultry.*

† Includes water quality data from HVO and available water quality data collected at neighbouring mines.

A3.3 Hydraulic testing

In order to assess the hydraulic properties of the alluvium at the project area, falling head tests were conducted by AECOM on the two newly installed monitoring bores GW117 and GW119 on 9th October 2015. Tests were performed by pouring 10 litres to 20 litres of water down the bore casing and monitoring the groundwater level response until the SWL recovered to pre-test levels. This procedure provides for the analysis of a hydraulic conductivity of the geological material in the immediate vicinity of the bore screen.

The bores are both within the Quaternary sediments, and were therefore analysed using the Bouwer and Rice (1976)[2] method for unconfined aquifers. Interpretation of the falling head tests are provided in Appendix A-3 and a summary of the results are shown in Table A- 4. Aquifer storage properties (specific yield and specific storage) are not able to be determined from falling head tests.

Table A- 4 Hydraulic conductivity results

Bore	Geological unit	Lithology	Volume of slug (L)	Length of test (minutes)	Base of screen (mbGL)	Hydraulic conductivity (m/day)	Analysis method
GW117	Alluvium	Gravel	15.86	6:35 minutes	15.8	2.80×10^{-1}	Bouwer & Rice
GW119	Regolith	Clay	26.65	4 days	13.0	7.09×10^{-4}	Bouwer & Rice

Note: *NR – not recorded due to slow recovery* *mbGL – metres below ground level*

A4 Bore census

A review of the National Groundwater Information System database[3] indicates there are 143 registered bores within 4km of the proposed modification pit depth extension. The majority of these bores correspond with HVO site monitoring bores or are abandoned and destroyed bores. Excluding abandoned and destroyed bores and Coal & Allied monitoring bores, there are 46 registered bores located within 4km of the proposed modification. In August 2015, Coal & Allied conducted a bore census of 26 of the registered bores located within the immediate vicinity of the proposed modification. The bores were located on private agricultural land (crop and cattle) as well as land owned by Coal & Allied. During the census two unregistered bores were identified. Table A- 5 presents a summary of the data held within the government database and from the bore census, while Figure A- 7 shows the location of the all known private landholder bores.

Water quality samples were collected from two of the existing bores, GW022685 and GW030731. Table A- 5 presents a summary of observations made during the bore census, and further details are presented in Appendix A4.

[2] Bouwer, H. and Rice, R.C., (1976), *"A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells"*, Water Resources Research, Vol. 12, No. 3, pp. 423-428.

[3] http://www.bom.gov.au/water/groundwater/ngis/

Table A- 5 Bore census results

Registered number	Coal & Allied bore census	Easting	Northing	Ground elevation (mAHD)	Date drilled	SWL (mbgl)	EC (µS/cm)	pH	Yield (L/s)	Bore depth (mbGL)	Aquifer	Status	Bore use	Comment
Unregistered bore	-	305430	6401656	76	-	8.2				9.8	Alluvium	EX	Stock	Well at least 50 years old, 1m concrete well, casing 0.6m above surface. Windmill in place and pumps at rate of 2.4L/minute. Used for stock water supply year round.
Unregistered bore	Coal & Allied	305357	6401901	79.0	-	10.15	1767	8.1		10.68	Alluvium	EX	Stock	Concrete well approx. 200m south of GW029155. Within irrigated paddock.
GW005327	-	314683	6394498	-	-	-	-	-	-	-	Alluvium	EX	Unknown	Mine owned land - other
GW017644	-	306708	6399431	75.3	1/01/1959	-	salty*	-	-	11.6*	Weathered Permian	EX	Irrigation	Bore located on Wambo mine land
GW017646	-	306937	6399774	72.7	1/01/2009	-	3,001-7,000*	-	-	11*	Alluvium	Unknown	Unknown	Bore located on Wambo mine land
GW017647	-	307326	6399905	72.0	1/01/2019	-	7,001-10,000*	-	-	9.1*	Alluvium	EX	Unknown	Bore located on Wambo mine land
GW017648	-	307397	6400276	70.3	1/01/1954	-	3,001-7,000*	-	25.26*	12.8*	Alluvium	Unknown	Irrigation	Bore located on Wambo mine land
GW017798	-	307290	6399042	86.6	1/01/1959	-	1,001-3,000*	-	-	12.2*	Weathered Permian	EX	Unknown	Bore located on Wambo mine land
GW017799	-	306598	6398412	108.7	1/01/2029	-	Salty*	-	-	12.2*	Weathered Permian	EX	Unknown	Bore located on Wambo mine land
GW018370	-	317573	6399111	55.7	1/01/1937	-	-	-	-	11.9*	Alluvium?	EX	Unknown	Bore not visited, located on east side of Hunter River.
GW018371	-	317683	6398775	55.3	1/01/1958	-	-		-	12.2*	Alluvium?	EX	Unknown	Bore not visited, located on east side of Hunter River.
GW018434	-	311134	6401457	23.2	1960	-	-	-	-	11*	Alluvium?	Unknown	Water supply	On Coal & Allied owned land.
GW018464	-	317783	6400471	54.8	1/03/1960	-	-	-	-	13*	Shale	Unknown	Unknown	Bore not visited, located on east side of Hunter River.

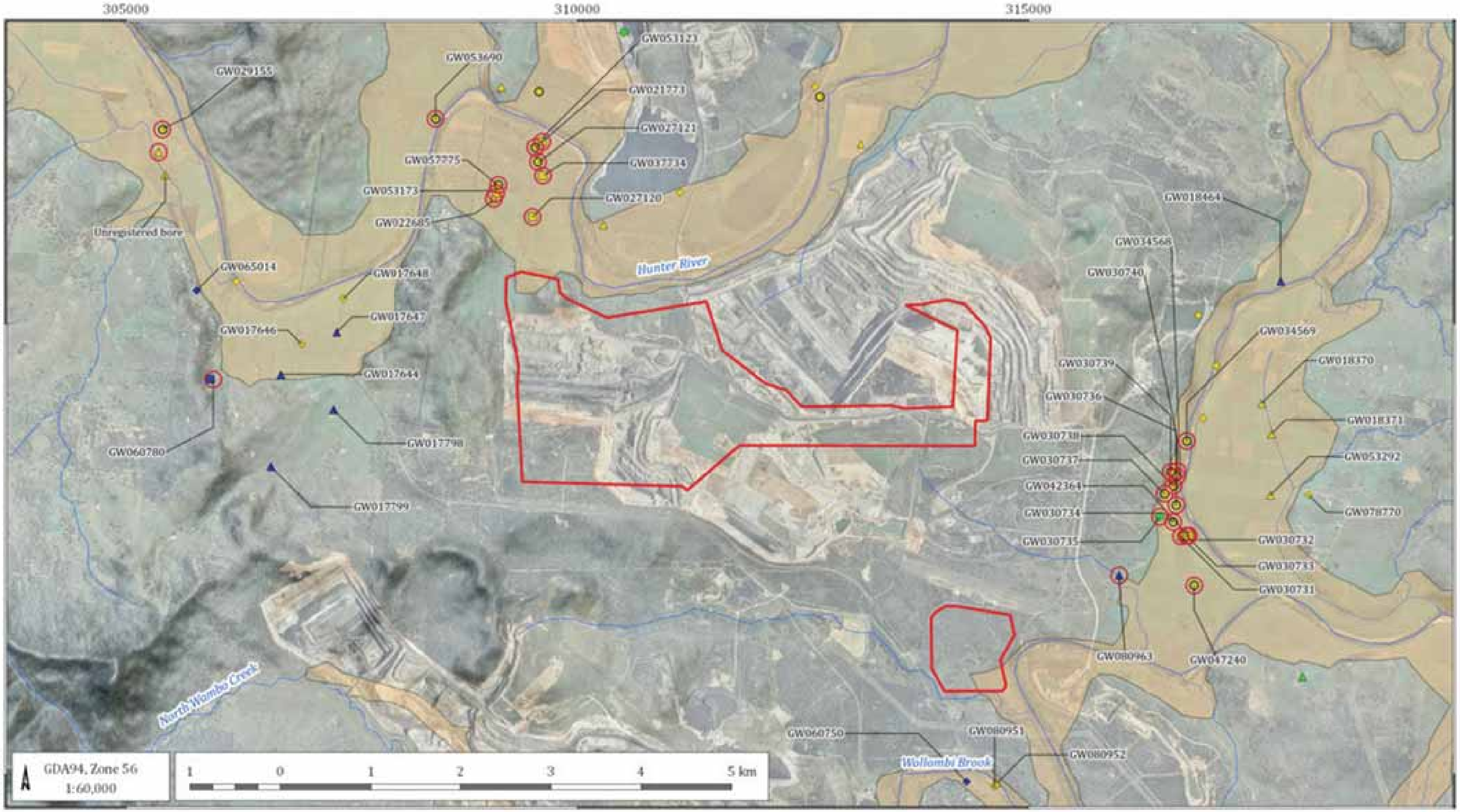
Registered number	Coal & Allied bore census	Easting	Northing	Ground elevation (mAHD)	Date drilled	SWL (mbgl)	EC (µS/cm)	pH	Yield (L/s)	Bore depth (mbGL)	Aquifer	Status	Bore use	Comment
GW018549		313134	6401987	63.6	1960	-	-	-	-	9.1*	Alluvium	EX	Unknown	On Coal & Allied owned land.
GW021773	Coal & Allied	309559	6401872	79.0	1/01/1953	-	501-1,000*	-	11.37*	12.5*	Alluvium	AD	Irrigation	Bore blocked. On Coal & Allied owned land.
GW022685	Coal & Allied	309088	6401184	75.0	1/03/1965	10.67	1022	7.2	Continuous use	14.6	Alluvium	EX	Stock	Concrete well with pump infrastructure in place. Continuously used for stock and domestic supply. Water quality sample taken. On Coal & Allied owned land.
GW027120	Coal & Allied	309501	6401185	77.0	1/08/1964	10.75	822	7.8	25.26*	13.4	Alluvium	AU	Irrigation	Concrete well at surface with metal lid. Currently disused. On Coal & Allied owned land.
GW027121	Coal & Allied	309563	6401648	78.0	1/03/1965	-	-	-	1.26*	15.8*	Alluvium	AD	Irrigation	Below surface cement well filled in with soil. On Coal & Allied owned land.
GW029155	Coal & Allied	305661	6402042	76.0	1/01/1968	-	0-500*	-	-	10.1*	Alluvium	AD	Stock	Bore possibly destroyed during 2007 floods, covered with soil.
GW030731	Coal & Allied	316680	6397640	63.0	-	13.33	2460	7	No Pump	17.02	Alluvium	AU	-	Steel bore with marker post, disused. Water quality sample taken.
GW030732	Coal & Allied	316743	6397646	69.0	-	8.17	-	-	-	16	Alluvium	AU	Monitoring bore	Concrete well. Has old pump infrastructure in place but not in use.
GW030733	Coal & Allied	316743	6397646	69.0	-	12.91	-	-	-	15.9	Alluvium	AU	Monitoring bore	Concrete well with metal lid. In paddock, disused.
GW030734	Coal & Allied	316595	6397799	62.0	1/02/1979	14.4*	-	-	-	16.5	Alluvium	AD	Monitoring bore	Bore destroyed, star picket at location, in paddock.
GW030735	Coal & Allied	316484	6397827	62.0	1/03/1979	13.8*	-	-	-	-	Alluvium	AD	-	Unable to locate bore
GW030736	Coal & Allied	316628	6397985	54.1	1/02/1979	14.45*	-	-	-	17.5	Alluvium	AD	Monitoring bore	Unable to locate bore
GW030737	Coal & Allied	316500	6398112	63.0		-	-	-	-	-	Alluvium	AD	-	Bore destroyed, covered in vegetation.
GW030738	Coal & Allied	316598	6398200	55.8	1/03/1979	-	-	-	-	-	Alluvium	AD	-	Unable to locate bore

Registered number	Coal & Allied bore census	Easting	Northing	Ground elevation (mAHD)	Date drilled	SWL (mbgl)	EC (µS/cm)	pH	Yield (L/s)	Bore depth (mbGL)	Aquifer	Status	Bore use	Comment
GW030739	Coal & Allied	316569	6398354	58.1	1/03/1979	-	-	-	-	-	Alluvium	AD	-	Unable to locate bore
GW030740	Coal & Allied	316640	6398365	63.0	1/04/1979	12.31	2540	7.4	-	16.3	Alluvium	EX	Monitoring bore	100 mm PVC casing in steel monument. Used for monitoring (HVO land)
GW034568	Coal & Allied	316634	6398301	63.0	1/06/1971	-	-	-	-	12.2*	Alluvium	AD	-	No bore found at location. Mine surface water pump present at location.
GW034569	Coal & Allied	316745	6398696	55.1	1/06/1971	-	-	-	-	12.2*	Alluvium	AD	Industrial	Unable to locate bore
GW037734	Coal & Allied	309553	6401502	83.0	1/01/1965	11.36	1022	7.5	15.16*	13.4	Alluvium	AU	Irrigation	Concrete well structure in paddock. No pump infrastructure present, appears disused. On Coal & Allied owned land.
GW042364	Coal & Allied	316824	6397645	63.0	-	12.77	1077	7.2	-	13.3	Alluvium	AU	Unknown	Steel bore with marker post, was used for irrigation but hasn't been used for some time.
GW045123		309153	6402621	81.8	-	-	-	-	-	12.2*	Alluvium	EX	Domestic	On Coal & Allied owned land.
GW047240	Coal & Allied	316827	6397095	55.2	1/01/1952	-	-	-	-	12.7*	Alluvium	AD	Irrigation	Unable to locate bore
GW053123	Coal & Allied	309631	6402062	78.0	1/03/1981	12.55	993	7.6	-	13.1	Alluvium	AU	Irrigation	Concrete well structure, disused. On Coal & Allied owned land.
GW053173	Coal & Allied	309101	640317	76.0	1/03/1981	13.38	967	8.1	10.1*	14.8	Alluvium	AU	Irrigation and stock	Concrete well with old pump infrastructure present, but appears disused. On Coal & Allied owned land.
GW053292	-	317670	6398097	53.3	1/08/1981	-	-	-	-	10*	Alluvium	EX	Irrigation	Bore not visited, located on east side of Hunter River.
GW053690	Coal & Allied	308423	6402268	77.0	1/07/1982	-	-	-	7.58*	11.3*	Alluvium	AD	Irrigation	Unable to locate bore
GW053931		312626	6402625	67.1	1980	-	-	-	-	10.4*	Alluvium	Unknown	Irrigation	On Coal & Allied owned land.
GW057775	Coal & Allied	309074	6401517	78.0	1/03/1981	-	-	-	-	13.4	Alluvium	AD	-	Unable to locate bore. On Coal & Allied owned land.

Registered number	Coal & Allied bore census	Easting	Northing	Ground elevation (mAHD)	Date drilled	SWL (mbgl)	EC (µS/cm)	pH	Yield (L/s)	Bore depth (mbGL)	Aquifer	Status	Bore use	Comment
GW060326		314104	6393348	58.3	-	-	-	-	-	9.8*	Alluvium	EX	Mine use	Mine owned land - other
GW060327		314181	6393441	57.9	-	-	-	-	-	9.8*	Alluvium	EX	Mine use	Mine owned land - other
GW060328		314205	6393534	57.7	-	-	-	-	-	10*	Alluvium	EX	Mine use	Mine owned land - other
GW060750	-	314310	6394923	59.0	1/02/1985	-	-	-	-	24.4*	Weathered Permian	Unknown	Domestic	Bore not visited, located in township of Warkworth at HVO owned land.
GW060780	Coal & Allied	305961	6399379	104.1	unknown	18.62	1552	7.1	No Pump	25.5	Weathered Permian	AU	Stock and domestic	Steep bore within vegetation on Muller property. Uncapped and appears disused (no pump infrastructure present).
GW065014	-	305777	6400368	85.0	15/01/1991	-	-	-	-	14.5*	Weathered Permian	Unknown	Irrigation	Bore located on Wambo mine land
GW080516		312899	6394954	71.9	-	-	-	-	-	15*	Weathered Permian	AD	Irrigation	Mine owned land - other
GW080519		313622	6394161	57.1	-	-	-	-	-	10.5*	Alluvium	Unknown	Unknown	Mine owned land - other
GW080951	-	314619	6394878	55.0	15/04/2005	-	-	-	-	3.14*	Alluvium	Unknown	-	Bore not visited, located in township of Warkworth.
GW080952	-	314643	6394904	54.0	15/04/2005	-	-	-	-	1.59*	Alluvium	EX	-	Bore not visited, located in township of Warkworth.
GW080963	Coal & Allied	315997	6397208	59.0	7/10/2005	31.8	1258	5.9	-	81.3	Weathered Permian	EX	Monitoring bore	100mm PVC bore with steel riser, equipped with datalogger.
GW200682	-	310511	6403229	85.5	-	-	-	-	-	30.4*	Unknown	Unknown	Unknown	On Coal & Allied owned land.
GW200802	-	318025	6396083	70.9	-	-	-	-	-	11.9*	Unknown	EX	Irrigation	On Coal & Allied owned land.
GW201230	-	310284	6401095	69.8	-	-	-	-	-	-	Alluvium	EX	Exploration	On Coal & Allied owned land.
10010974	-	316585	6394626	67.89	-	-	-	-	-	-	Alluvium	Unknown	Unknown	On Coal & Allied owned land.

Registered number	Coal & Allied bore census	Easting	Northing	Ground elevation (mAHD)	Date drilled	SWL (mbgl)	EC (µS/cm)	pH	Yield (L/s)	Bore depth (mbGL)	Aquifer	Status	Bore use	Comment
10011156	-	306218	6400469	66.03	-	-	-	-	-	-	Alluvium	Unknown	Unknown	Private
10011157	-	317069	6399534	50.28	-	-	-	-	-	-	Alluvium	Unknown	Unknown	Private
10011459	-	314088	6404069	71.51	-	-	-	-	-	-	Unknown	Unknown	Unknown	Mine owned land – other (Ravensworth)
10011462	-	316923	6398946	55.75	-	-	-	-	-	-	Alluvium	Unknown	Unknown	Private
10011486	-	312965	6403904	71.54	-	-	-	-	-	-	Unknown	Unknown	Unknown	On Coal & Allied owned land.
10011488	-	316873	6400094	64.73	-	-	-	-	-	-	Alluvium	Unknown	Unknown	On Coal & Allied owned land.

Note: *Coordinates are in MGA94, Zone 56*
EX – existing bore
AD – abandoned and destroyed
** - value derived from Pineena*
AU – abandoned but in usable condition



LEGEND

- Proposed modification pit depth extension
- Quaternary alluvium (1:25k AGE)
- Bore census
- Major drainage
- Minor drainage

Groundwater bore status

- Abandoned and destroyed
- Abandoned but usable
- Existing
- Unknown bore status

Groundwater bore lithology

- Alluvium
- Permian
- Unknown geology

HVO South Modification 5 Groundwater Study
Field Investigation Report (G1737)

Bore census

DATE
16/06/2016

FIGURE No:
A-7

Quaternary alluvium (1:25k AGE): 1:25,000 Singleton - AGE digitised and adjusted based on site data