Yallourn Rehabilitation Hydrogeological Modelling

Hydrogeological Conceptual Model

EnergyAustralia Yallourn Pty Ltd

01 September 2023

→ **The Power of Commitment**

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[Compliance statement]

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1. Introduction

1.1 Purpose of this report

GHD has been engaged by EnergyAustralia Yallourn (EAY) to develop a conceptual hydrogeological model of the Yallourn Mine. A conceptual hydrogeological model is a simplified representation of complex natural systems, describing the essential features that govern the behaviour of groundwater and its interactions with surface water and groundwater users. The purpose of this report is to present the conceptual hydrogeological model within the context of the planned future rehabilitation of the Yallourn Mine. The information presented in this report would feed into the development of mine rehabilitation scenarios and underpin the construction of a numerical groundwater model used to quantify potential groundwater-related impacts of the rehabilitation.

The development of conceptual models, referred to as “conceptualisation” or “conceptual modelling”, is an iterative process, whereby the understanding of the system behaviour is progressively refined through ongoing collection and analysis of data. The conceptual hydrogeological model presented in this report is a reflection of the current hydrogeological knowledge base of the Yallourn Mine, building on the knowledge gained from many tens of years of mining, monitoring and modelling.

Conceptualisation involves the compilation and analysis of existing information on the geology, hydrogeological properties, groundwater levels and quality, surface water flow and groundwater usage. These data inform key features of the groundwater system that include:

– Hydrostratigraphic units (aquifers and aquitards) and their properties, thickness, lateral extent and connectivity
– Groundwater flow directions and trends in response to natural and anthropogenic (mining-induced) stresses, and how they vary over time
– Groundwater recharge and discharge mechanisms
– Interaction of groundwater with surface water systems and groundwater users
– Potential future groundwater behaviour in response to ongoing mining and subsequent closure, including the role of climate change

The preparation of this report commenced in 2020, with the conceptualisation primarily relying on the data collected up to the end of 2019. Although groundwater data is collected by EAY on an ongoing basis, selecting an appropriate cutoff date is necessary for developing a conceptual model due to the effort required in analysing a substantial volume of data collected over many decades of mining. For this reason, the use of additional data collected since 2020 has been kept to a minimum except where the data has provided additional hydrogeological insights or addressed prior data gaps (for example, data related to groundwater quality and surface water-groundwater interactions).

1.2 Study objectives

The planned future rehabilitation of the Yallourn Mine marks an important hydrogeological transition from the operational phase, when the coal is excavated and aquifers are depressurised to maintain a safe mining condition, to the post-mining phase when the mine will be flooded to form a pit lake. Cumulative effects associated with successive closure of the Latrobe Valley coal mines, in particular the restoration of piezometric heads within the confined aquifers over the long term and associated cumulative effects, are also unique to the Latrobe Valley hydrogeology and form a critical component of rehabilitation planning.

The primary objective of hydrogeological conceptualisation is to clearly outline the existing knowledge of the site hydrogeology and to provide sufficient information and technical basis for supporting the rehabilitation planning for the mine. It represents a necessary first step in the hydrogeological modelling process, consolidating the current understanding of the key hydrogeological processes of the past and present, and those that may occur in the future. It provides the basis for numerical modelling, which will support technical studies required to inform groundwater and surface water licencing aspects of the mine rehabilitation water balance.

Given the long and complex history of mining, it is not feasible for a single consolidated report to provide detailed descriptions of hydrogeological processes occurring at all spatial and temporal scales. The purpose of this report is to focus on the key processes that are considered relevant for setting the hydrogeological context for rehabilitation, with a level of detail considered appropriate for supporting rehabilitation planning. In some cases, targeted hydrogeological assessments are necessary, focusing on specific areas of interest over a specific timeframe. Findings from such assessments are referenced throughout the report (and many more site specific assessments may be carried out in the future).

As per the recommendations of the Australian Groundwater Modelling Guidelines (Barnett et al, 2012), Model Planning has been undertaken prior to the development of the conceptual hydrogeological model to set the context for groundwater modelling and to align modelling expectations. Some of the key groundwater related questions associated with the rehabilitation of the Yallourn Mine, as identified during Model Planning, include the following:

– What would be the changes in piezometric heads (aquifer pressures) in response to rehabilitation and how would this affect ground movement?
– What is the nature of aquifer connectivity, both in horizontal and vertical directions, and how would this influence the piezometric heads and batter stability?
– What would be the cumulative effect of the closure and rehabilitation of all three Latrobe Valley coal mines, especially the effect of the recovery of piezometric heads in the confined aquifers below the Yallourn Mine when pumping ceases at the Hazelwood Mine?
– What would be the hydrogeological implications of different rehabilitation scenarios, such as a pit lake with different lake levels and dry pit?
– What is the influence and significance of geological structures such as the Yallourn monocline (Yallourn fault) on groundwater flow and water balance?
– What is the nature of interaction between groundwater and surface water features such as the Morwell River, Ash Ponds and other local features?
– What would be the effect of mine rehabilitation on water quality? Is there the potential for contaminants to be mobilised to groundwater?
– What would be the long-term effect of mine rehabilitation on groundwater resources and potentially groundwater-dependent ecosystems, including the effects of climate change?

The hydrogeological conceptual model detailed in this report is designed to provide the basis for addressing these key questions, including the subsequent numerical modelling that will be used to quantify the hydrogeological effects of rehabilitation scenarios.

1.3 Rehabilitation context and scenarios

The information contained in this report is designed to assist EAY with the planning of closure and rehabilitation of the Yallourn Mine, to achieve safe, stable, sustainable, non-polluting and visually attractive outcomes. For the mine void and Morwell River, the preferred and approved rehabilitation option is a full pit lake with a lake level of around +33 mAHD.

The full pit lake option limits the reprofiling of the batters and placement of a cover (over exposed coal faces to minimise coal fire risks) to the area above the lake level, with beach areas to allow public access. Due to the high lake level, certain aspects of the current mine water management may no longer apply (such as drainage and pumping of groundwater), although additional measures will likely be required to maintain the lake level and batter stability over the long term. The fill period would be an important focus point of this rehabilitation option, taking into consideration different sources of water available for filling and associated influence on the filling rates.

The full pit lake is preferred, as it offers the opportunity for sustainable secondary land uses with lower long term management costs than other rehabilitation options. For the purpose of understanding risks, alternative rehabilitation options are also considered, each with different set of challenges, ongoing management requirements and opportunities for the future use of the site. These include:

– A rehabilitated dry void, which is likely to require reprofiling of the entire mine batters and placement of a cover over exposed coal faces. Water management across the mine will likely remain largely unchanged from the current operation, potentially necessitating ongoing drainage and pumping of groundwater in perpetuity, with limited public access and future use of the site.

– A partially filled pit lake, with a lake level at around +17 mAHD. The presence of water would limit the reprofiling of the batters and placement of a cover to the area above the lake level, although buttress material will likely be required to stabilise the batters and there will be additional management measures to maintain the lake level and batter stability. As per the dry void option, site access and future use of the site will likely remain limited.

Yallourn North Open Cut, located north of the Yallourn Mine, is currently used as the Yallourn Ash Dump (landfill) and is being regulated by the Environmental Protection Authority (EPA) under a landfill licence. The rehabilitation options for this facility will be driven by the EPA Landfill Licence process and are not documented in this report. For this reason, a detailed assessment of hydrogeological information around this facility is not presented and only the data that is considered relevant to the hydrogeological conceptualisation of the Yallourn Mine has been included.

1.4 Report structure

This report presents the hydrogeological conceptualisation for Yallourn Mine site and is structured as follows:

– Section 2 describes the regional setting of the Yallourn Mine - what is currently known about the geography, hydrology, climate, geology and hydrogeology.
– Section 3 presents a summary of the mine development, the data collected over this period and the geological and hydrogeological models constructed.
– Section 4 presents the mine scale conceptualisation of the hydrogeological regime, based on the analysis and interpretation of the data collected at the mine and surrounding areas.
– Section 5 describes the evolution of the hydrogeological system, and how the processes have changed over time, from pre-mining to mining, and into the future when the mine will be rehabilitated. The section focuses on the hydrogeological processes that are considered relevant to informing rehabilitation planning, building on the analysis of hydrogeological data presented in the preceding sections.

1.5 Assumptions

This report has been prepared on the basis of information provided to GHD by EAY, in addition to published information and data from other relevant studies completed by GHD and others. These include (but not limited to):

– Relevant data supplied by EAY, including the location, construction and measurements from bores/piezometers at the mine and other water related data (such as flow and climate data).
– Distribution and thickness of geological units from the mine geological model
– Published geological information, including maps of regional geology and geological structures
– Publicly available climate, water, topographical and geological data
– Relevant historical reports, including those completed by the mine operators and GHD.

GHD has not independently verified or checked the information and data beyond the agreed scope of work for this report. It has been assumed that the information used and referenced throughout the report is accurate and appropriate for the purpose of developing a hydrogeological conceptual model, as per the scope and objectives outlined in Section 1.1 and Section 1.2.

2. Regional setting

2.1 Overview

Groundwater is derived from rainwater that percolates through cracks and pores in rocks and sediments. In low-lying areas, groundwater discharges at surface whereas in topographically elevated areas the water table rises to higher elevations. The differences in the elevation of hydraulic heads drive the flow of groundwater from topographically higher levels to topographically lower levels. In the upper part of the groundwater system, a local flow system develops due to local undulations in topography and spatial variations in recharge and evapotranspiration. This results in the water table typically being a subdued reflection of the ground surface. Groundwater interacts with surface watercourses along drainage lines, where groundwater can provide baseflow or receive leakage. In the deeper part of the system, groundwater flows via longer flow paths driven by regional differences in hydraulic heads associated with regional differences in topography (Tóth, 1963).

Mines in the Latrobe Valley currently form low points in the regional groundwater system, influencing the groundwater levels and flow directions. Anthropogenic stresses, such as groundwater pumping at the mines, depressurise the aquifers and modify the natural groundwater flow directions. The geology of the region also has an important control on groundwater flow, with variations in material properties and structures resulting in deflections of flow lines.

Section 2 places the Yallourn Mine into regional context, describing the essential components of the hydrological cycle that include the mines, topography, hydrology, land use, climate and geology. An overview of the regional hydrogeology is also presented in this section, to provide a context for more detailed descriptions of local hydrogeology at the mine presented in the subsequent sections.

2.2 Mine location

The Yallourn Mine is in the Latrobe Valley, approximately 150 km east of Melbourne. Moe is located approximately 6 km to the west, Morwell is located 3 km to the south east and Traralgon is located approximately 12 km to the east. In the mid-1920s open pit mining commenced at the Yallourn Open Cut (YOC) and then developed into Mid Field, South Field, Township Field, East Field and currently into Maryvale Field. The YOC (including the Township and South Fields) is now separated from East Field and Maryvale Field by the Morwell River Diversion (MRD).

There are two additional lignite mines in the Latrobe Valley; the Hazelwood Mine, operated by ENGIE Hazelwood, is located 2.5 km to the south and the Loy Yang Mine, operated by AGL, is located approximately 16 km to the southeast, as shown in Figure 1. The Hazelwood Power station and coal mining ceased operation in March 2017 and mine rehabilitation works are currently underway. The Yallourn Mine is currently projected to cease mining in 2028 and AGL has stated a Loy Yang mine closure date of 2035.

Paper Size A3

0 360 720 1,440 2,160 2,880

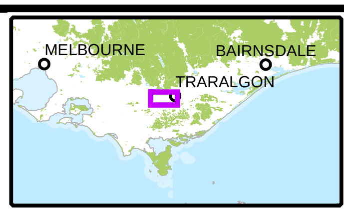
Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- Mine locations
- Freeway
- Highway
- Arterial
- Watercourse
- Pondage
- Lake



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Conceptual Hydrogeological Model

Job Number	12521481.0
Revision	
Date	21/05/2021

Yallourn Mine
Site Location Plan

Figure 1

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180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

Data source: DELWP, VicMap, 2020; ESRI Imagery (see credits) Created by: tworth

2.3 Topography and drainage

2.3.1 Site topography

The landforms of the Latrobe Valley have been developed on sedimentary and volcanic material of Mesozoic and Cenozoic age. The Yallourn Mine is located in the valley of the Morwell River which flows into the Latrobe River to the north of the mine at an elevation of around 45 mAHD. The site is bounded to the west by a topographical ridge of around 190 mAHD, and rises to the north towards the Southern Highlands, as shown in Figure 2. To the east of the mine, the elevation ranges from 40 mAHD close to the Latrobe River to around 100 mAHD near Morwell. The area to the south, towards the Hazelwood Mine, is generally flat with elevation between 40 and 70 mAHD.

2.3.2 Regional drainage and hydrology

Gippsland is drained from the topographically elevated and strongly incised areas of the Great Dividing Range to the coastal strip and lake systems east of Sale. The main rivers draining the Gippsland region, from west to east, are the Latrobe, Tyers, Thomson, Macalister and Avon Rivers. The Latrobe River is located along the northern boundary of the Yallourn Mine, with the closest point around 200 m north of East Field. Lake Narracan is a water storage on the Latrobe River located approximately 1.5 km upstream of the Yallourn power station (Figure 3) and supplies cooling water to the Latrobe Valley power stations.

The Thomson and Macalister Rivers join the Latrobe River in its lower reaches, around 10 km west of where it enters Lake Wellington, east of Sale. The Avon River, to the east, also drains into Lake Wellington and is part of the “lakes system”, connected to the ocean via Lakes Entrance, in the far east of the Gippsland region. The lakes system is estuarine and the flat, low-lying area around Sale and the lakes system is typically very swampy.

The Morwell River is an important hydrological feature of the Yallourn Mine. It is a tributary of the Latrobe River and flows northwards through the mine. It rises in the central and southern Strzelecki Ranges, with a catchment area of around 622 km^2 and an average annual discharge of around 148,500 mega litres (ML) at the Yallourn Mine (based on the infilled daily SILO data from 1889 to 2015 at gauge 226408). The modern day Morwell River wetlands are located to the south, between the Yallourn Mine and Hazelwood Mine (Figure 3).

The original course of the Morwell River has been reshaped and diverted numerous times to allow access for mining at the Yallourn and Hazelwood Mines and for flood protection. The original course of the Morwell River was to the east of YOC and through central East Field as shown in historic mine plans contained in Appendix A (and digitised in Figure 51). Construction of a 5 km channel, referred to as the third Morwell River diversion, was completed in May 1987 and diverted the Morwell River to the south and east of East Field (see Appendix A). This was followed by the fourth Morwell River Diversion (MRD), which is an approximately 3.5 km diversion that traverses the Yallourn Mine, between the two mine voids as shown in Figure 3. The MRD is located on natural alluvial soils, overburden dump, coal and remnant coal dyke. The MRD was commissioned in May 2005 and reconstructed between 2012 and 2014 following the breaching of the western embankment over the alignment of the E110 conveyor tunnel in June 2012 (SMEC, 2019). Additional remedial works have been undertaken by EAY since 2014, including the floodplains adjacent to the MRD, in response to high flow events.

Yallourn Mine surface water features

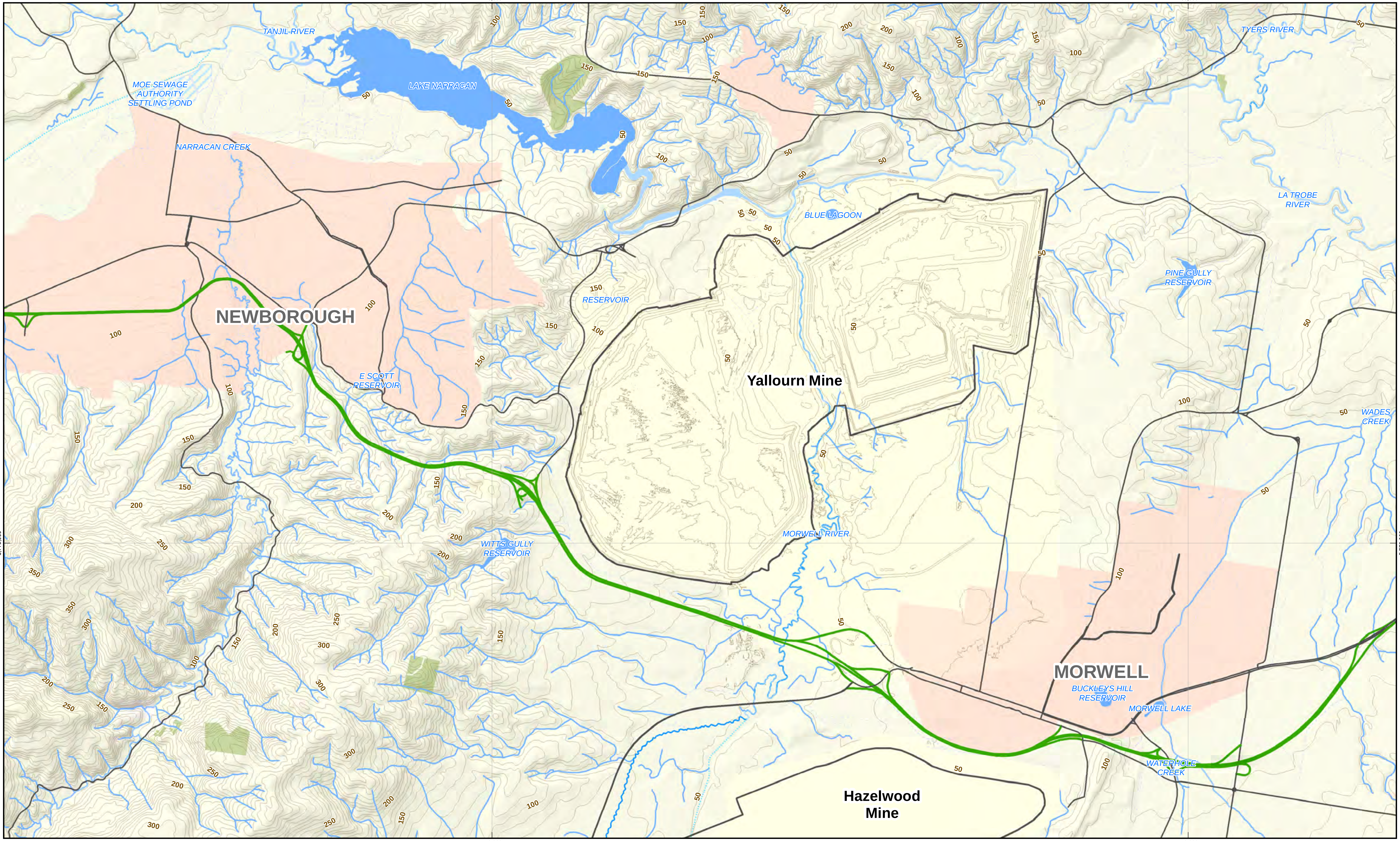
Other surface features associated with the Yallourn Mine include:

– The Fire Service Pond (FSP), which is the mine’s dirty water storage with a capacity of around 9,400 ML and is used for mine fire protection, dust suppression and supplemental power station cooling water. The FSP is located in the southeast section of the YOC.
– The Flocculation Pond (Floc Pond, also referred to as Treatment Pond), located to the south of the FSP where excess water is treated prior to discharge to the Morwell River.
– Township Lake (also known as Lake Placid), east of the Township Field overburden dump in YOC, receives overburden dump drainage (which can be acidic) and waste water from the power station. A dosing plant treats the water prior to discharge to the FSP.
– Witts Gully Reservoir to the south west of YOC is an external fire service water supply for the mine.
– Ash slurry is deposited in the Twin Ash Ponds located north of the Latrobe River in the former Yallourn North Open Cut (YNOC) where it is dried out before being excavated and deposited in the ash landfills, also located in the YNOC. A new Return Water Basin has recently been constructed to replace the existing basin and receive decant water from the ash pond for reuse in the power station.
– Dirty water ponds, including the East Field Sump, North-East Pond and Maryvale Backside Pond, are located in the base of East Field and Maryvale Field to collect runoff.

More detailed descriptions of the current mine water management are presented in Section 4.5.1.

2.4 Land use and vegetation

The Yallourn Mine is located within the Shire of Latrobe City and the Shire of Latrobe Planning Scheme zone map indicates that the mine is within the “Special Use Zone 1 Brown Coal” zone. To the north of the mine, the Latrobe River frontage is zoned “Public Conservation and Resource” and the Maryvale Paper Mill, to the east of the mine, is zoned “Industrial 2”. Farming zones are found to between the mine and township of Newborough to the east and Morwell to the south east as shown Figure 4. Land in the region has been extensively cleared for agriculture and commercial forestry. Remnant vegetation is found along watercourses and isolated pockets generally associated with road reserves and drainage lines. Further descriptions of potential Groundwater Dependent Ecosystems (GDEs) in the Yallourn Mine region are provided in Section 4.11.



Paper Size A3

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Metres

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Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

Mine boundary
Freeway
Highway
Arterial
Watercourse
Pondage
Lake
River
Stream
Channel
Drain/Channel/Other
YAL_EMC_MinePlan_SECV_2020
YAL_YTC_MinePlan_SECV_2020
Township boundary
Yall_Mine_Mask
Hzwd_Mine_Pit_Clip
Contour 10 m
National Parks
Other Parks
Township boundary
Mine_Pit_Clip

MELBOURNE
BAIRNSDALE
TRARALGON

GHD

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Conceptual Hydrogeological Model

Job Number 12521481.0
Revision
Date 21/05/2021

Yallourn
Topography and Site Drainage Figure 2

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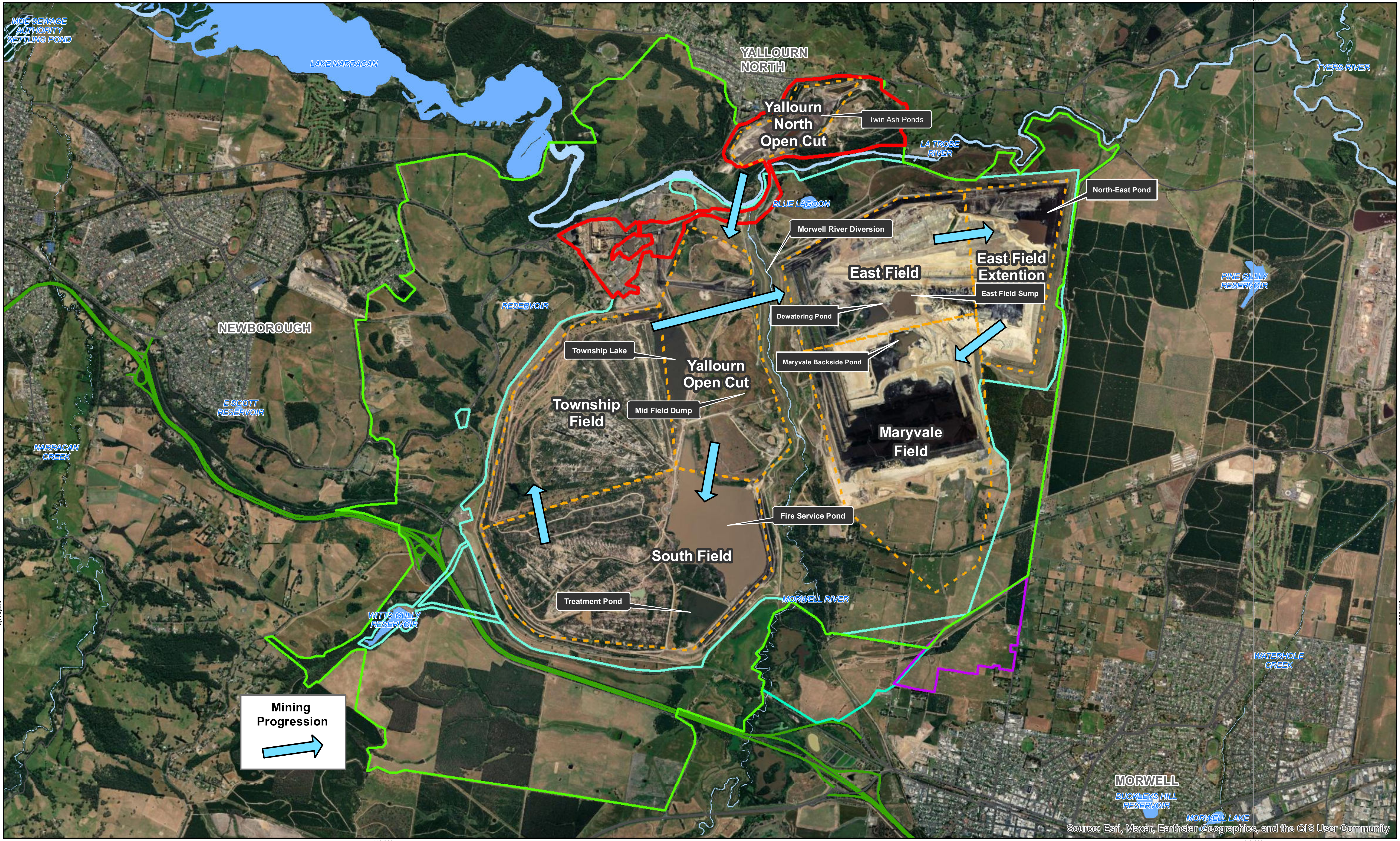
180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

Data source: DELWP, VicMap, 2020; GHD, Mine Boundaries, 2020 Created by: tworth



Paper Size A3

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Metres

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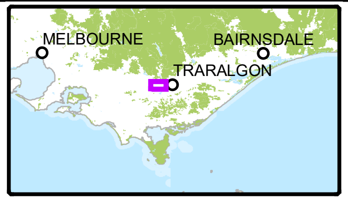
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- Mine_Areas
- Township point
- Freeway
- Highway
- Arterial
- Collector
- Proposed
- Tracks
- Ferry
- Watercourse
- Flat
- Pondage
- Lake
- Swamp
- Power Station Boundary
- Mine Licence Boundary No5003
- Mine Licence Boundary No5216
- Mine Licence Boundary No5304
- RTL Yallourn Energy Interface Boundary



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Conceptual Hydrogeological Model

Job Number	31-12521481
Revision	B
Date	30 Aug 2023

GHD

Yallourn
Mine Site features

Figure 3

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180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

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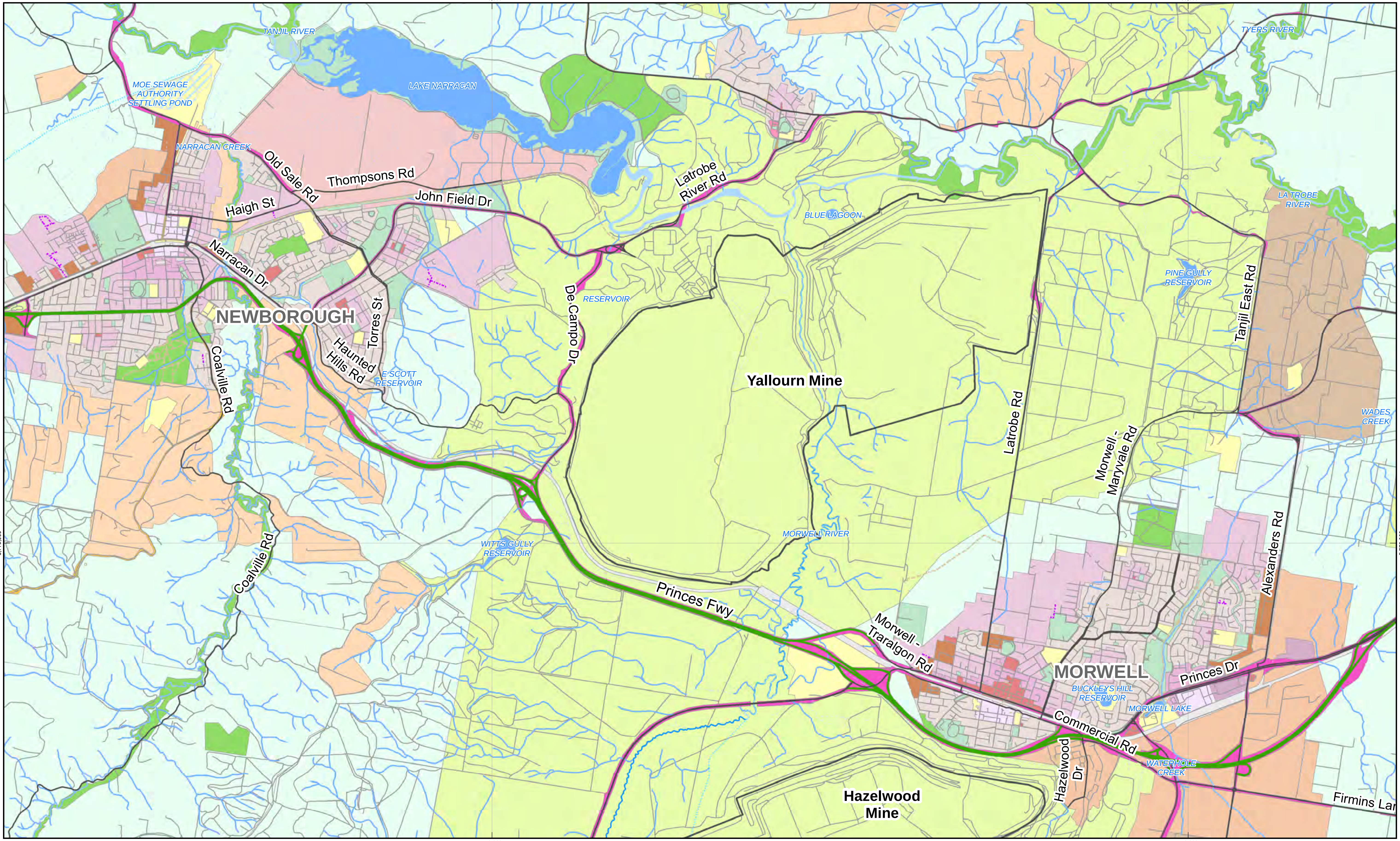

Paper Size A3

0 240 480 960 1,440 1,920

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

Mine boundary
Freeway
Highway
Arterial
Watercourse
Pondage
Lake
River
Stream
Channel
Drain/Channel/Other

Planning zone

Commercial 1
Commercial 2
Farming
General Residential
Industrial 1
Industrial 2
Industrial 3
Mixed Use
Neighbourhood Residential
Public Conservation & Resource
Public Park and Recreation
Public Use
Public use - Transport
Road – Category 1
Road – Category 2
Residential Growth
Rural Living
Special Use
Township
Urban Growth

MELBOURNE
BAIRNSDALE
TRARALGON

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Date 21/05/2021

Planning zone surrounding Yallourn Mine

Figure 4

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Data source: DELWP, VicMap, 2020; GHD, Mine Boundaries, 2020 Created by: tworth

2.5 Climate

2.5.1 Historical climate

Climate in the region is temperate and generally features cool to warm summers and mild to cool winters. Climate data has been sourced from SILO for the Bureau of Meteorology (BoM) Morwell (Latrobe Valley Airport) climate station (station number 085280). BoM has maintained a rainfall record at this site since 1984 and SILO has interpolated the data prior to this period based on the surrounding rainfall records. Mean monthly climate statistics for temperature, rainfall and evaporation are shown in Figure 5.

The long term average annual rainfall is 751 mm with October being the wettest month (76 mm) and February being the driest (46 mm). The long term average annual evaporation is 1,233 mm and the mean monthly evaporation exceeds the mean annual rainfall from September through to April. Rainfall exceeds the evaporation from May through to August.

To interpret the historic rainfall trends, the cumulative monthly precipitation residual (also known as Cumulative Departure from Mean Rainfall) has been calculated from the SILO data. A rise in the precipitation residual indicates above average rainfall and a fall indicates below average rainfall. The annual and monthly rainfall since 1900, along with the cumulative monthly precipitation residual, are plotted in Figure 6. The figure indicates periods of generally below average rainfall from 1901 to 1916, 1937 to 1945, 1961 to 1983, 1997 to 2009 and 2012 to 2016. Conversely, periods of generally above average rainfall were recorded from 1916 to 1937, 1945 to 1961, 1983 to 1997 and 2010 to 2012.

Climate is variable across Gippsland. Figure 7 presents the spatial distribution of long term average annual rainfall in the Moe Swamp Basin and the Gippsland Basin, based on BoM's 1976 to 2005 average gridded rainfall data (the most recent 30-year average data available from BoM). Regions of high rainfall occur over topographically elevated areas in the west, including the Narracan Block, Balook Block and Southern Highlands, with the maximum average rainfall of around 1,100 mm/yr. Rainfall decreases to the east and southeast of the Yallourn Mine, from around 800 mm/yr to around 600 mm/yr in the central Gippsland Basin. Figure 8 presents the spatial distribution of long term average annual evapotranspiration across the Gippsland Basin, based on BoM's 1961 to 1990 average gridded areal actual evapotranspiration data (the most recent 30-year average data). Evapotranspiration varies from around 1,100 mm/yr in topographically elevated areas (the Narracan Block and Southern Highlands) to around 1,300 mm/yr in low-lying areas to the east near Maffra.

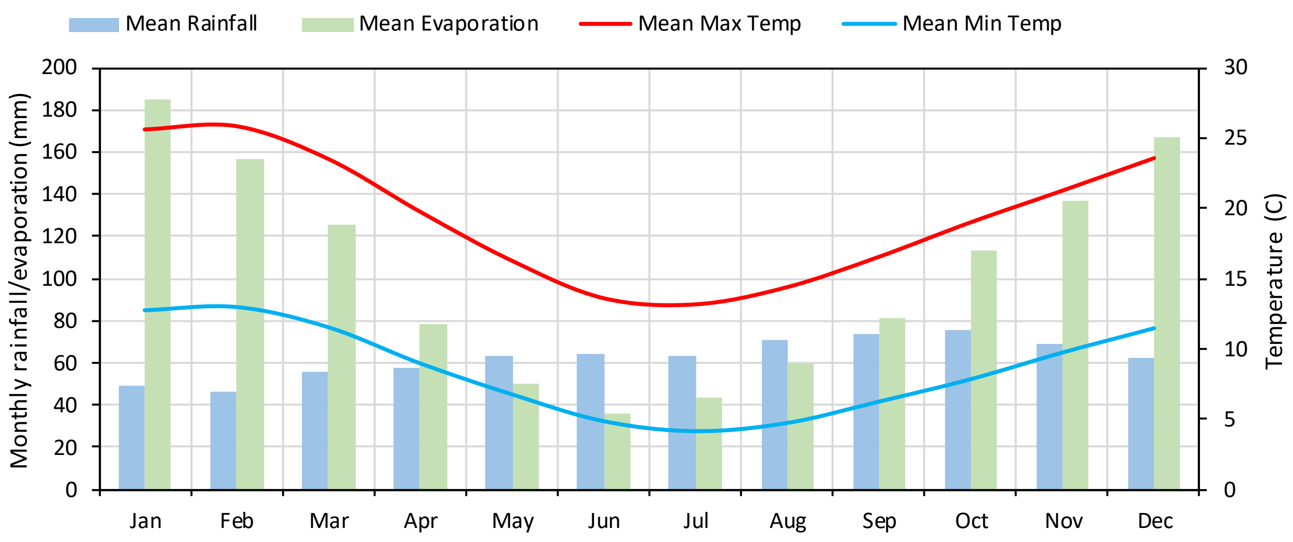


Figure 5 Monthly Climate Statistics – Station 85280

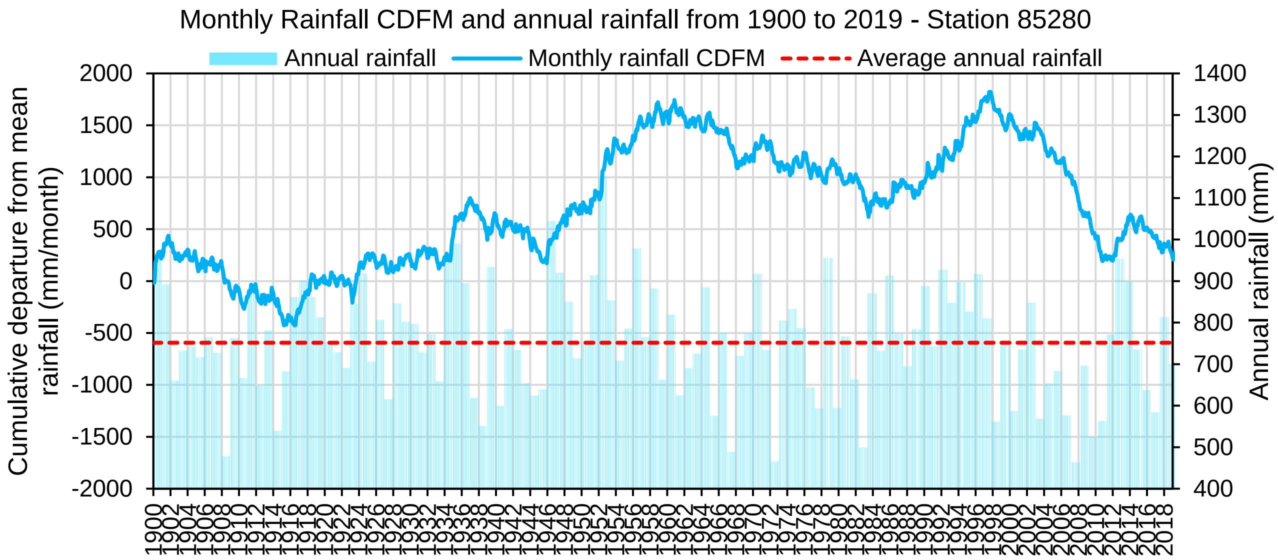


Figure 6 *Long Term Rainfall Trend – Station 8580*

2.5.2 Potential future climate

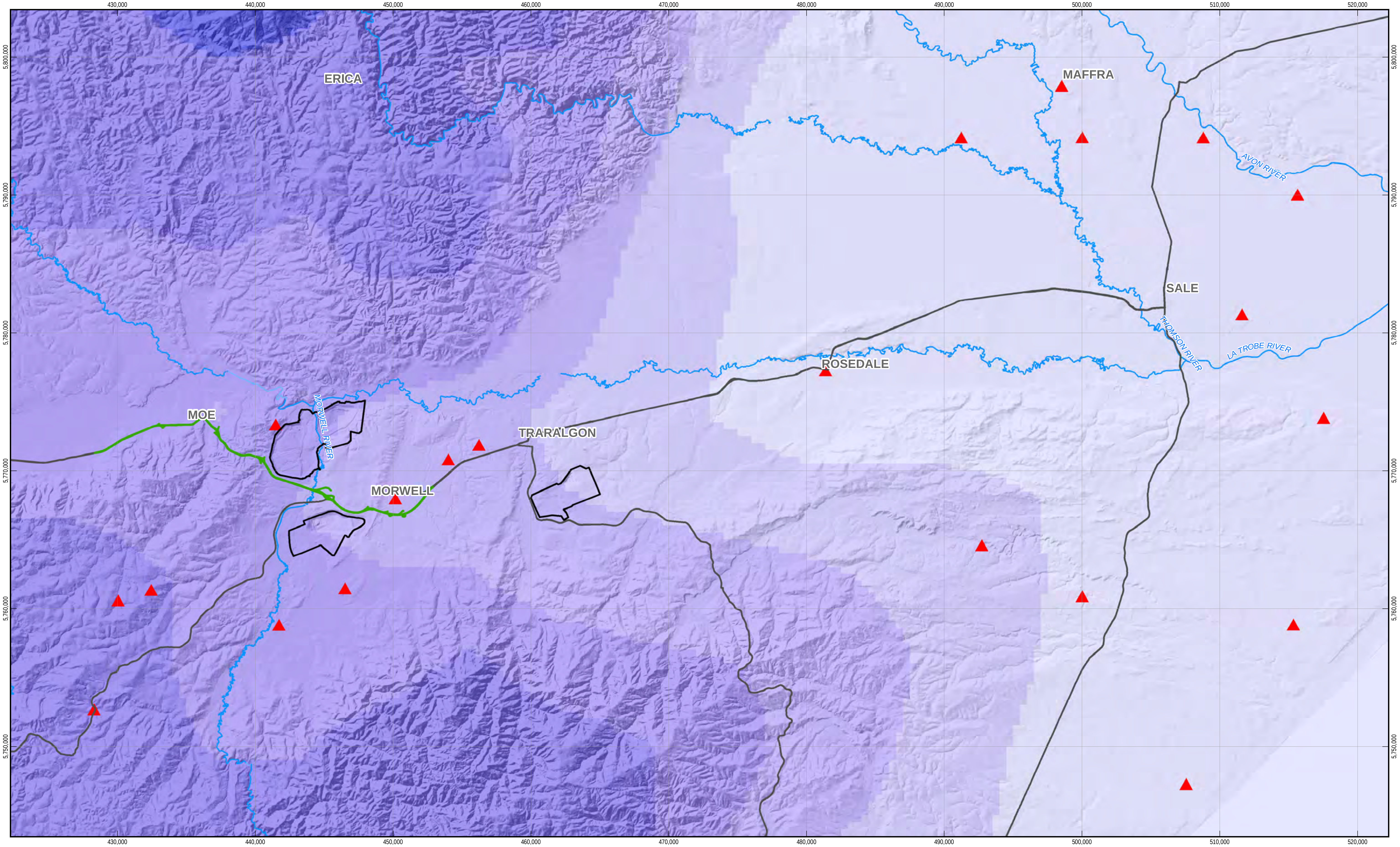
In 2016, the Department of Environment, Land, Water and Planning (DELWP) released "Guidelines for Assessing the Impact of Climate Change on Water Supplies" which documented revised estimates for rainfall, evaporation and runoff factors from 2040 to 2065 for each of Victoria's river basins. The guidelines considered three climate change projections representing low, medium and high impacts on the availability of water from climate dependent sources. Three climate change scenarios are then derived from the 10th percentile, median, and 90th percentile rainfall runoff responses. The guidelines were updated in 2020.

The guidelines also contain recommended methods for estimating climate change impacts on groundwater. The guidelines recognise that shallow unconfined aquifers, classified as those with depth to water of less than 20 m, can respond to climate changes quickly (for example, within 1 to 2 years). The guidelines indicate that for highly responsive unconfined aquifers with a high level of connection to surface water courses (and rainfall), the climate change factors applied to runoff may provide more conservative indications of impacts on groundwater resources than those applied to rainfall.

The guidelines describe the need to apply the best available information to inform the assessment of climate change on recharge, taking into consideration site specific features such as the aquifer types, depth to water and a degree of connection to waterways. The climate change scaling factors may be applied to estimate changes to recharge using simple analytical models or more complex numerical models. Historically, a combination of rainfall-runoff modelling and numerical groundwater modelling has been used in the Latrobe Valley to estimate recharge (see Section 3.3.2). This approach is well suited to incorporating climate change effects, as the scaling factors from the guidelines can be directly applied to the rainfall and evaporation climate inputs to estimate their effects on recharge.

The guidelines state that confined aquifers generally respond slowly or very little to changes in climate and it is unlikely that any climate-induced changes would be discernible within the 50-year planning horizon of the guidelines. Therefore, the guidelines do not consider the effects of climate change on the confined aquifers.

In the context of mine rehabilitation planning, and specifically the long response time of deep confined aquifers, there is the potential for the post-mining recovery period to extend well beyond the 50-year planning horizon of the guidelines. This means uncertainty in far future climate trends would need to be factored into the assessment of potential long term impacts of different rehabilitation scenarios on groundwater resources.



Paper Size A3

0 1,200 2,400 4,800 7,200 9,600

Metres

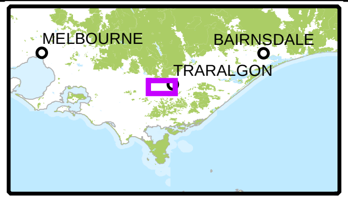
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

Rainfall (1976 02005 BoM)

- 590.5518188 - 658.2325085
- 658.2325086 - 728.8558369
- 728.855837 - 831.8481907
- 831.8481908 - 961.3242927
- 961.3242928 - 1,126.112059
- 1,126.11206 - 1,340.924683
- Mine boundary
- Freeway
- Highway
- River
- Stream
- Drain/Channel/Other
- SILO



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Long Term Average Rainfall Distribution

Figure 7

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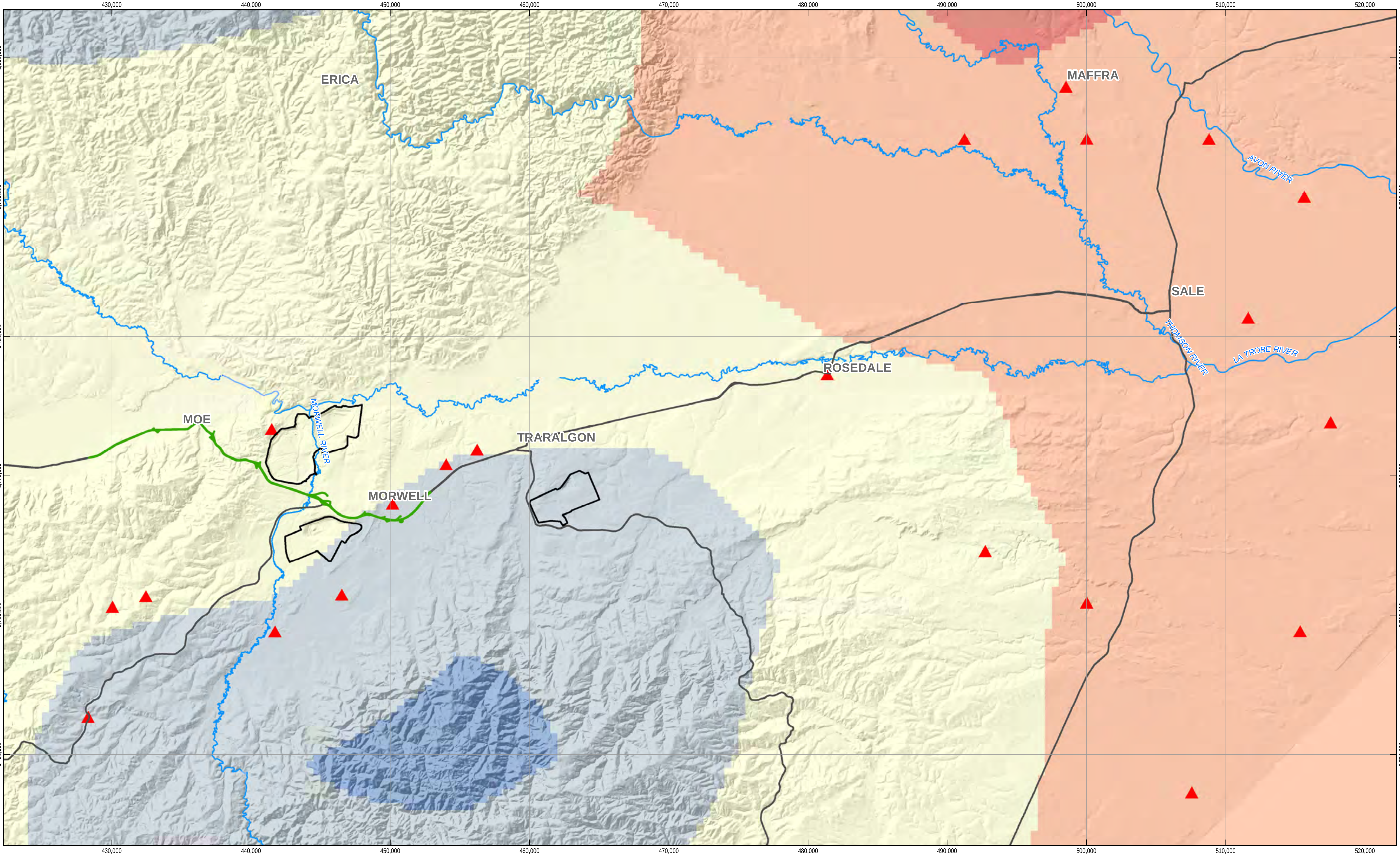
Data source: DELWP, VicMap, 2020; GHD, Mine Boundaries, 2021 Created by: tworth



Paper Size A3

0 1,200 2,400 4,800 7,200 9,600

Metres

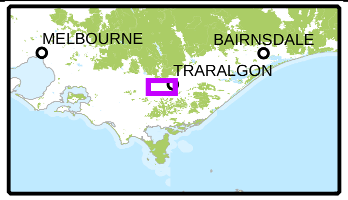
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

Evapotranspiration (1960 - 1990 BoM)

- 1,133 - 1,150
- 1,150 - 1,200
- 1,200 - 1,250
- 1,250 - 1,300
- 1,300 - 1,350
- Mine boundary
- Freeway
- Highway
- River
- Stream
- Drain/Channel/Other
- SILO



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Date	21/05/2021

Long Term Average Pan Evaporation Distribution

Figure 8

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Data source: DELWP, VicMap, 2020; GHD, Mine Boundaries, 2022 Created by: tworth

2.6 Regional geology

2.6.1 Gippsland Basin depositional settings

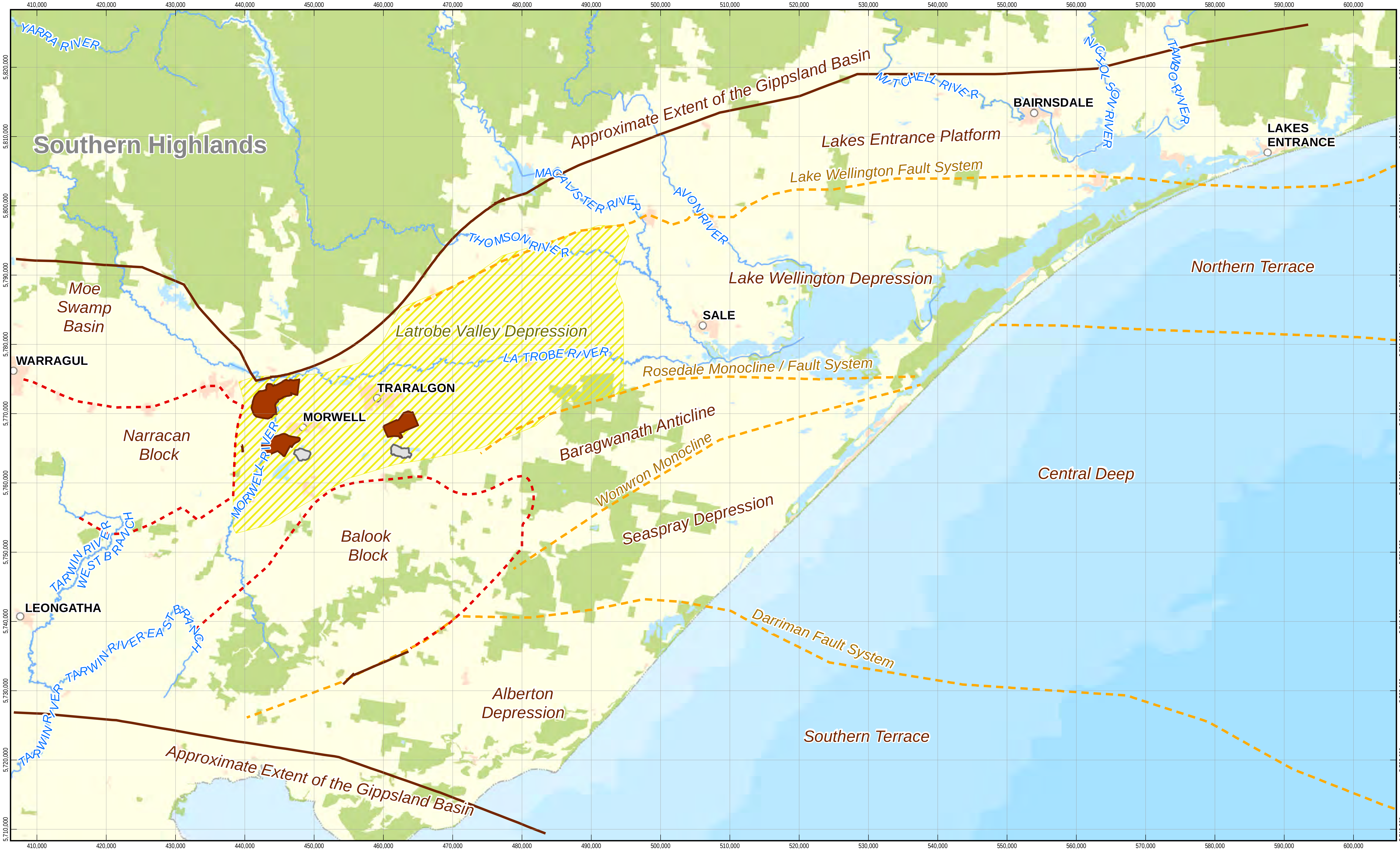
The Gippsland Basin was initiated most likely during the Jurassic period, with rift-related graben development and subsidence occurring during the Cretaceous–Cenozoic period (Holdgate et al, 1995). Non-marine rift-fill sandstone of the Lower Cretaceous age Strzelecki Group outcrops extensively to the south of the study area in the Balook Block, and to the west in the Narracan Block. Episodic basin inversion commencing in the mid-Cretaceous period folded and uplifted the Strzelecki Group, forming the Strzelecki Ranges and causing changes in sedimentation patterns.

The structural zones within the Gippsland Basin are shown in Figure 9. Yallourn Mine is located on the north western margin of the Latrobe Valley Depression, which forms the western end of the Gippsland Basin. The Latrobe Valley Depression is bounded to the north by the Southern Highlands and Lakes Entrance Platform and to the south by the Balook Block and Baragwanath Anticline. The Lake Wellington Depression is located to the east of the Latrobe Valley Depression, with the boundary coinciding with the western limit of the marine transgression and deposition of the Seaspray Group. The thickness and depth of the Gippsland Basin sediments increase to the east, into the Lake Wellington Depression, and offshore in the Central Deep (the principal depo-centre of the basin).

The Moe Swamp sub-basin is located in the north western extremity of the Gippsland Basin, bounded by the Darnum Fault to the west, Palaeozoic and Cretaceous basement to the north and south, and to the east by the regionally significant Yallourn Fault that separates it from the Latrobe Valley Depression.

The lignite seams of the Latrobe Valley Depression were deposited in swamps during renewed rifting in the late Eocene to Miocene epoch. The relatively shallow Latrobe Valley lignite fields lie in paleo-depressions between the Strzelecki Group (and Palaeozoic) blocks west of the marine Seaspray Group. The thickness and uniformity of the lignite seams over large areas of the valley are consistent with slow, steady rates of subsidence. To the north of the Latrobe River, the lignite seams are deeply buried and split into multiple thin sub-seams.

Basin inversion in the Late Miocene reactivated older basin faults, leading to the formation of reverse faults, monoclines and paleo-uplift in the poorly consolidated Latrobe Valley Group. The principal trend of most structures is parallel to the Latrobe Syncline. This fold plunges to the east and runs parallel to the Lower Cretaceous ranges to the south. Erosion of the uplifted Latrobe Valley deposits continued into the Late Pliocene, before deposition of sand, clay and silt of the Plio–Pleistocene Haunted Hill Formation (Birch, 2003). Figure 10 shows the distribution of the Cretaceous to Quaternary units from the 1:250,000 State-wide geological map.



Paper Size A3

0 2,375 4,750 9,500 14,250 19,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- Overburden Dumps
- Mine boundary
- Gippsland Basin
- Structural zone
- Fault systems (sketch)
- Latrobe Valley Depression

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Gippsland Basin Structural Zones

Figure 9

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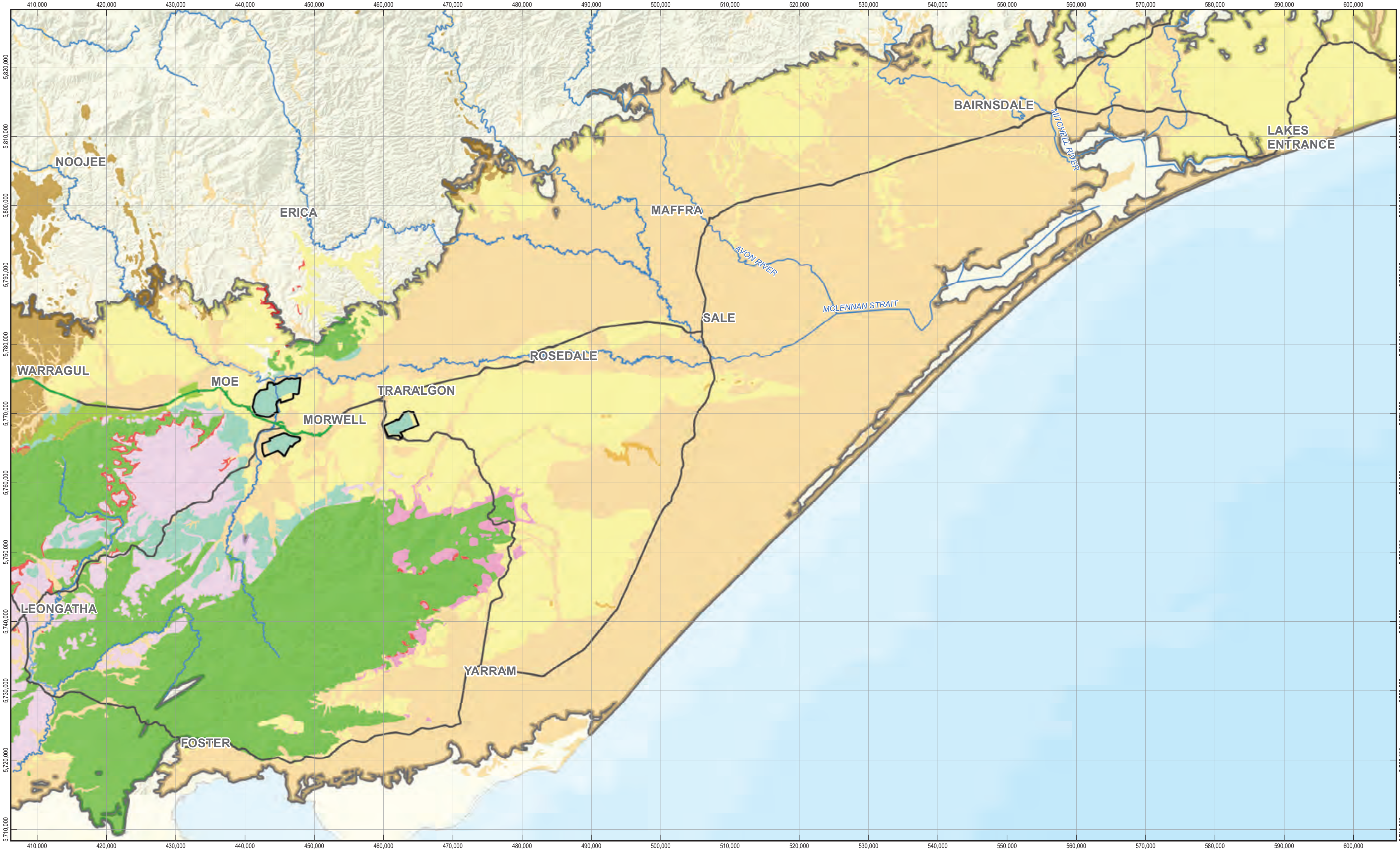
Data source: DELWP, VicMap, 2020; GHD, Mine Boundaries, 2023 Created by: tworth



Paper Size A3

0 2,375 4,750 9,500 14,250 19,000

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- Mine boundary
- Freeway
- Highway
- River
- Stream
- Drain/Channel/Other
- Carrajung Volcanics (P)
- Thorpdale Volcanics (P)
- Latrobe Valley Gr (P)
- Childers Fm (P)
- Strzelecki Gr (K)
- Colluvium (N)
- Haunted Hills Fm (N)
- Gippsland Limestone (N)
- Neerim Volcanics (N)
- Quaternary (Q)

GHD

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Conceptual Hydrogeological Model

Job Number	12521481.0
Revision	
Date	21/05/2021

Gippsland Basin Geological Plan

Figure 10

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Data source: DELWP, VicMap, 2020; GHD, Mine Boundaries, 2024 Created by: tworth

2.6.2 Regional stratigraphy

Three main lignite bearing sequences identified in the Latrobe Valley Depression are the Traralgon, Morwell and Yallourn Formations (Figure 11), belonging to the Latrobe Valley Group (previously referred to as the Latrobe Valley Coal Measures). Individual coal seams are identified by their formation and depth within the sequence, e.g. M1 is the shallowest Morwell Formation coal seam.

Non-coal materials between the seams are termed interseams and these are named according to the overlying coal seam, e.g. M1 interseam underlies the M1 coal seam. The interseams comprise sand, silt and clay and their lithology can change abruptly due to the mode of deposition. The interseams can contain local and regional scale aquifers depending on the extent and hydraulic properties of the sand units.

Volcanism within the basin resulted in the Thorpdale and Carrajung Volcanics. The Thorpdale Volcanics are interbedded with the Morwell Formation sediments particularly in the western sections of Latrobe Valley Depression. The Carrajung Volcanics are found interbedded with the deeper Traralgon Formation.

The Seaspray Group is a succession of marine limestones and marls that accumulated as a facies equivalent of the Latrobe Valley Group. It covers most of the onshore part of the Gippsland Basin near the coast and extends offshore. The Balook Formation is a barrier sand sequence that lies immediately inland of the Seaspray Group and was deposited in the transition zone between the mostly terrestrial lignites and interseams to the west and north and the marine carbonates to the east and south. The Balook Formation extends north-northeast across the Seaspray and Lake Wellington Depressions but is not present across the Baragwanath Anticline and associated structures (GHD, 2010). The regional geological cross section (Figure 12) shows the distribution of the Tertiary stratigraphic units across the onshore section of the Gippsland Basin.

The Lower Cretaceous Strzelecki Group and Palaeozoic sediments form the basement to the younger Cenozoic sediments. The Strzelecki Group consists of volcaniclastic sediments and predominately upwards fining sequence of massive, coarse to fine grained sandstones interbedded with siltstone. The Strzelecki Group outcrops to the south and west of the Latrobe Valley, forming the Balook and Narracan Blocks as shown in Figure 10.

The Palaeozoic sediments comprise a range of geological formations and outcrop to the north of the Gippsland Basin, forming the Southern Highlands. The Devonian Walhalla Group and the Silurian Anderson Creek Formation are the main geological formations, comprising a marine sequence of turbiditic sandstones, siltstones and mudstones.

2.6.3 Geological structures within Latrobe Valley

The Latrobe Valley Depression forms a part of the larger Gippsland Basin and the structures within the depression are extensions of the larger structures associated with the basin. The fundamental basin architecture reflects the reaction to north-northeast to south-southwest directed crustal extension, represented by the Northern and Southern Platforms and Terraces, which are bounded by complex fault systems. The major folds are typically described as monoclines in which coal measure strata are draped over basement faults (Barton, 1979). The monoclines are located both at the margins of and within the sedimentary basin as shown in Figure 13. Between the monoclines, the stratigraphic sequences are gently folded within open synclines and anticlines.

Holdgate et al (2015) identified that structures traditionally thought to represent features of the shallower Cenozoic strata have deeper underlying structures. In particular, the Yallourn and Morwell faults, which influence the depth and thickness of the coal strata, are interpreted as deep basement faults. As shown in Figure 13, these deep basement faults largely align with corresponding monoclines, as previously interpreted by the SEC and Geological Survey.

- The main structural features of the Latrobe Valley Depression include:
- Yallourn Monocline that forms the northern boundary of the Latrobe Valley Depression.
- The Yallourn (also referred to as Haunted Hills) fault, as mapped by the Geological Survey, that separates the Latrobe Valley Depression from the Moe Swamp Basin in the west. Previous SEC work (Brumley and Holdgate, 1983) has shown this feature as a southerly trending extension of the Yallourn Monocline and hence both names have been used interchangeably in the literature to represent this structure.
- Traralgon – Latrobe Syncline, which forms the central axis through the Latrobe Valley Depression.

– Rosedale Monocline, which separates the Latrobe Valley Depression to the north and Baragwanath Anticline to the south. It is the largest anticline structure within the onshore part of the basin.

The approximate extent of the Yallourn and Morwell Formations and the western extent of the marine transgression represented by the Seaspray Group are shown in Figure 13. The uppermost Traralgon Formation (T1) coal extends westwards, between the Loy Yang and Hazelwood Mines and its westerly extent represents the point where the underlying units of the Traralgon Formation are in contact with the basal M2 units of the Morwell Formation.

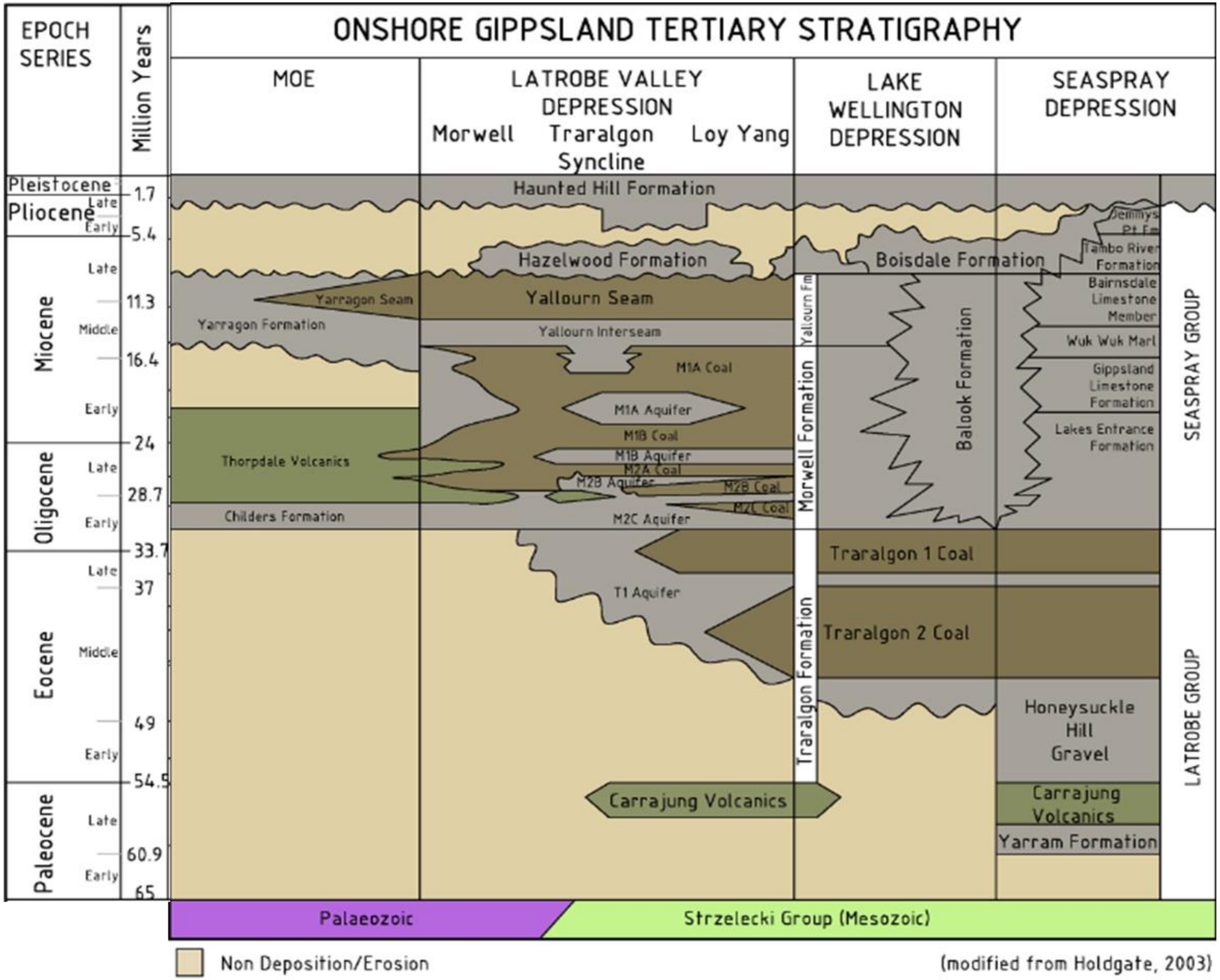


Figure 11 *Gippsland Basin Cenozoic Stratigraphy (after Birch, 2003)*

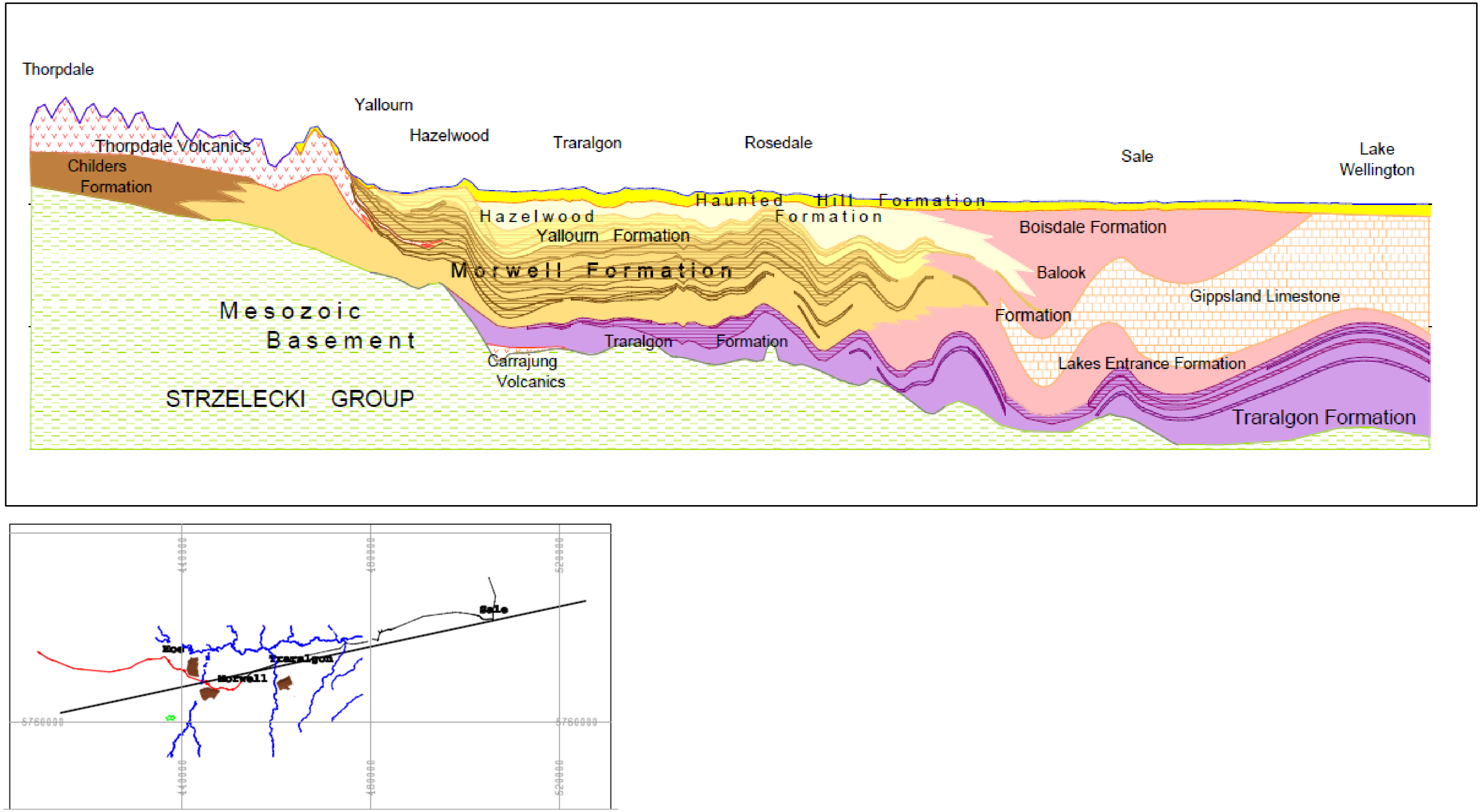


Figure 12 *Onshore Gippsland Basin Regional Cross Section*

2.7 Regional hydrogeology

2.7.1 Aquifer Systems

The hydrogeology of the Latrobe Valley on a regional scale has been described with reference to “aquifer systems”. These are broadly consistent with the definition of shallow, intermediate and regional groundwater flow systems that form within a groundwater basin (Tóth, 1963). The term “system” has been adopted in recognition of the complexity of the regional hydrogeology, characterised by interbedded sequences of sand, gravel and basalt aquifers that are rarely continuous throughout the region resulting in aquifers of variable thickness, lateral extent and interconnectivity.

The three regional aquifer systems of the Latrobe Valley include the following:

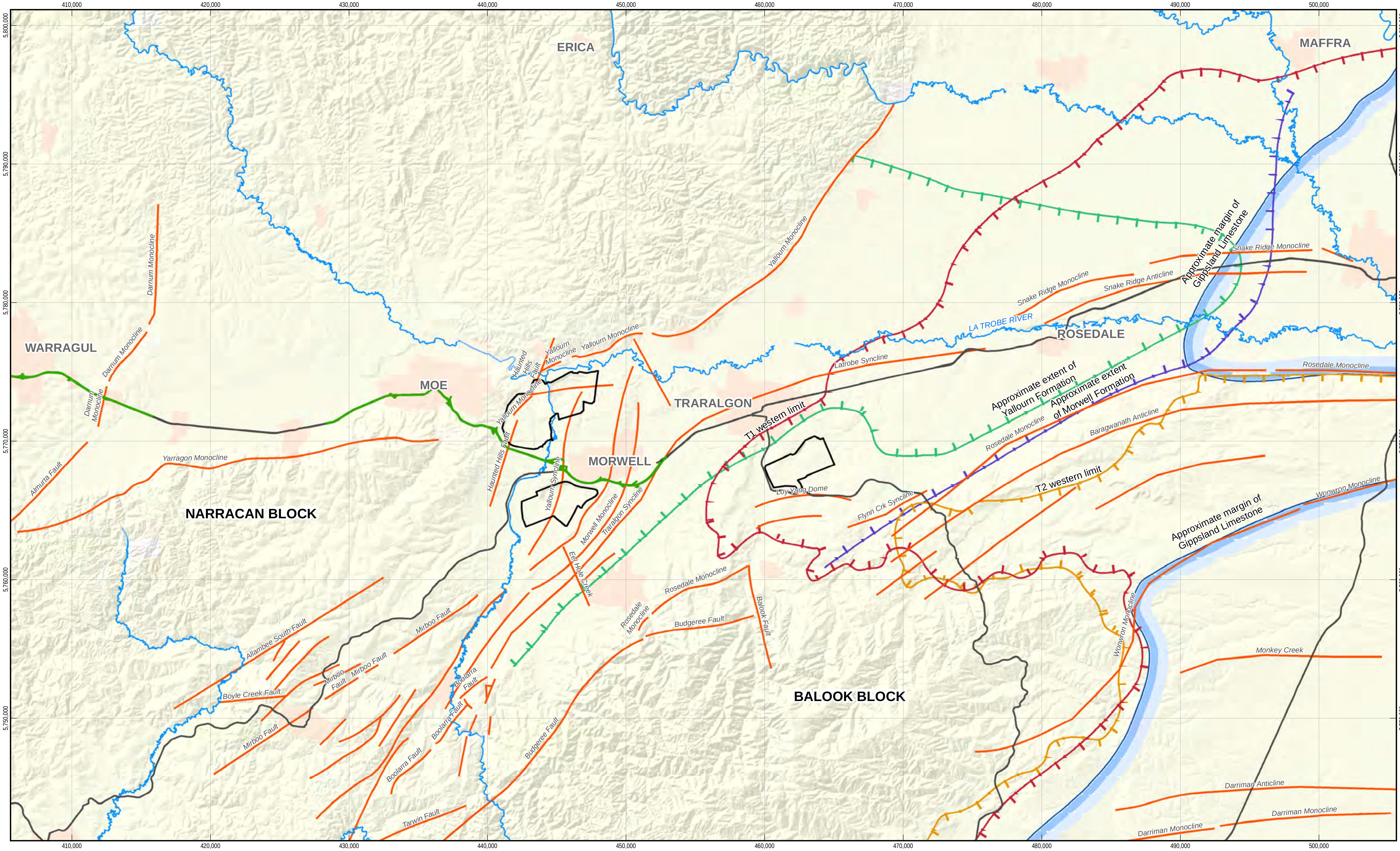
– Shallow Aquifer System (SAS), consisting of unconfined and semi-confined aquifers in the upper part of the stratigraphic sequence that typically hosts the water table. The aquifers of the SAS include the surficial Haunted Hills Formation and alluvial sediments and sands encountered in the Hazelwood Formation and Yallourn Interseam. The SAS provides low yielding supply for domestic and agricultural purposes and has only required dewatering intermittently at the Yallourn Mine. The SAS is analogous to the local groundwater system of Tóth (1963).

– In the western part of the basin the Morwell Formation Aquifer System (MFAS) is generally a confined aquifer system comprised of the M1, M1A, M1B, M2A, M2B and M2C Aquifers. It consists of interbedded sands and clays, between coal seams and, minor fractured basalts within the Morwell Formation. The MFAS extends eastward as far as Kilmany where it meets the barrier sand sequence of the Balook Formation. At the Yallourn Mine, the MFAS is primarily represented by the sand lenses within the M1A Interseam. The confined aquifers of this system generally occur between 100 to 500 m beneath the present surface. The MFAS is analogous to the intermediate groundwater flow system of Tóth (1963).

– The confined M2/TFAS aquifer system is of regional scale and extends across the entire Gippsland Basin. The onshore part consists of interbedded sands, clays, coals and basalts (M2, Traralgon Aquifers), and the offshore section consists of interbedded sandstones, mudstone, coals, and basalts (Latrobe Group Aquifers). Groundwater is extracted from this aquifer system as part of the mining operations at Loy Yang and Hazelwood Mines, for agricultural and industrial supplies in the southern Gippsland Basin, and for offshore oil and gas production. The confined aquifers of this system generally occur between 150 and 1,500 m beneath the ground surface. The M2/TFAS is analogous to the regional groundwater flow system of Tóth (1963).

The distribution of the three regional aquifer systems in the Latrobe Valley area is shown in Figure 14.

As discussed in Section 2.6.3, the westerly extent of the T1 coal is where the underlying TFAS Interseam is in connection with the M2 Interseam, forming the M2/TFAS aquifer system. To the east of the Morwell monocline, the M1 and M2 coals spilt into multiple seams and interseams. Detailed discussion of the distribution of the interseams, which form the aquifer systems, and descriptions of key hydrostratigraphic units at the Yallourn Mine are presented in Section 4.3.2.



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Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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LEGEND

Geological Structures (Geol Survey 250K)

Formation

T1

T2

Morwell

Yallourn

Gippsland Limestone

Mine boundary

Freeway

Highway

River

Stream

Drain/Channel/Other

MELBOURNE BAIRNSDALE TRARALGON

GHD

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Job Number 12521481.0
Revision
Date 21/05/2021

Geological Structures and Formation Extents

Figure 13

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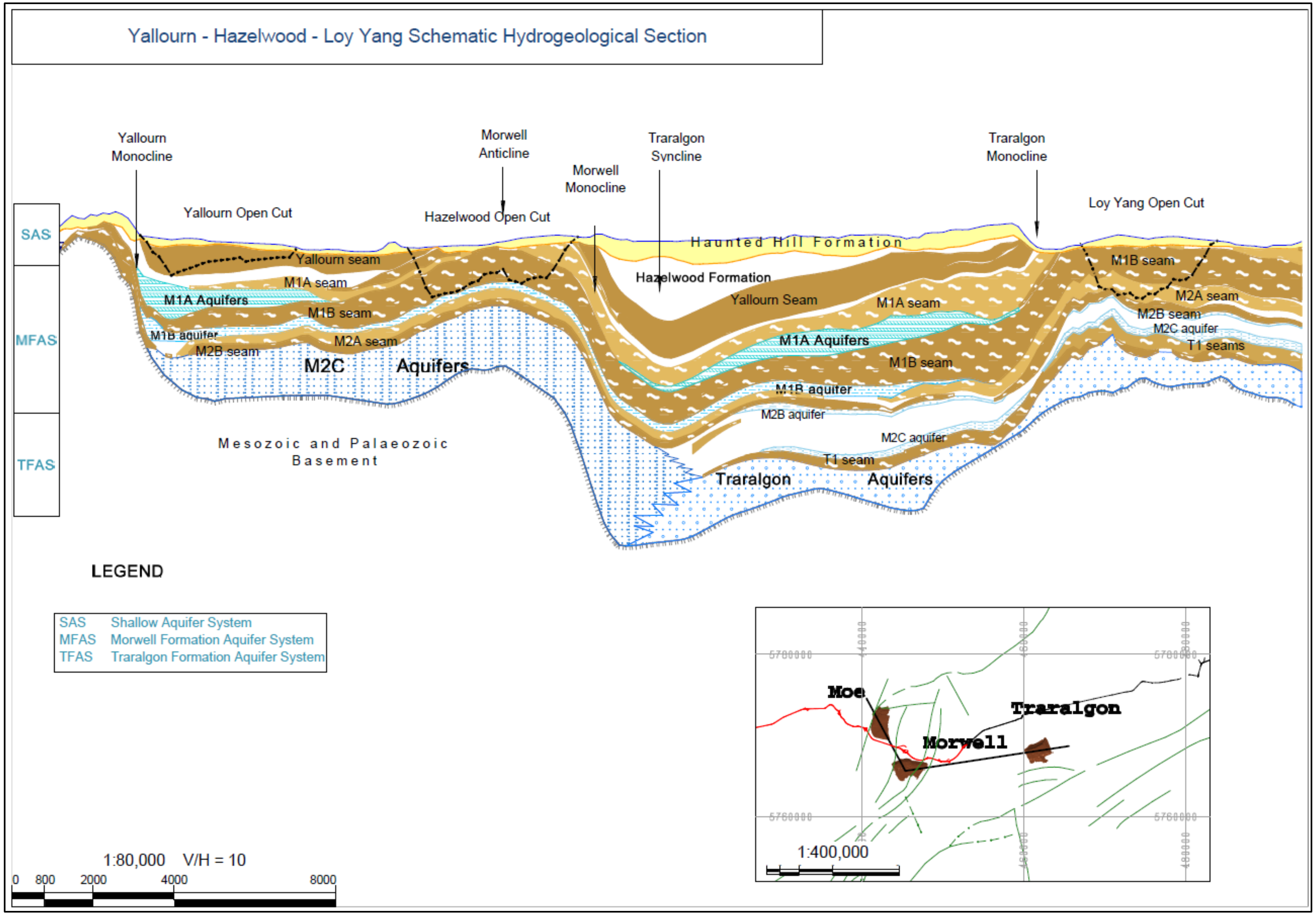


Figure 14 *Yallourn – Hazelwood – Loy Yang Hydrogeological Cross Section*

2.7.2 Aquifer depressurisation and dewatering

Aquifer depressurisation was not required during mining of the Yallourn Open Cut (YOC), which operated until the late 1980s, due to the shallow mining depth. The historical record however revealed that artesian flows occurred from 2 bores drilled in 1934 in the original YOC area. The bores were subsequently covered by overburden.

State Electricity Commission (SEC) investigations prior to the development of East Field from the mid to late 1980s concluded that depressurisation of the Yallourn Interseam and M1A Interseam (M1A aquifer) was required ahead of mining to reduce the risk of mine floor heave. These studies adopted a Factor of Safety of 1.2 consistent with the approach adopted by the SEC elsewhere in the Latrobe Valley. Depressurisation of the M2/TFAS was not required due to the relatively shallow mine depth and pumping at the Morwell mine had lowered the aquifer pressures regionally below the future M2/TFAS target levels (for floor stability) estimated at -30 mAHD (SEC, 1988). Investigations concluded the Yallourn Interseam, which was characterised by very fine grained and silty sand, was not sufficiently permeable for groundwater pumping and high hydraulic conductivity areas occurred only as isolated channel deposits in the East Field area.

Depressurisation of the M1A aquifer was observed prior to the commissioning of the East Field pump bores in 1994. This was attributed to seepage though the coal seam joints particularly to the south suggesting drainage from M1 dewatering at the Hazelwood Mine (referred to as the Morwell Open Cut at the time). A series of M1A aquifer pump bores and free flowing artesian bores were commissioned in East Field from 1994 to reduce aquifer pressures below the required target levels for mine development. From September 2004, M1A aquifer depressurisation was implemented via flow from five artesian bores. M1A aquifer pumping was reinstated in June 2008 at N5056 at around 14 litres per second (L/s) and the artesian bores progressively sealed with the final flowing bore sealed in 2011. In June 2015, bore N6899 was commissioned at 26 L/s to provide depressurisation ahead of the Maryvale Field mining development to supplement the pump bore N5056 that has been operational since 1998. Figure 15 shows the location of the M1A aquifer pumping bores and artesian flowing bores over the mine life.

The SEC studies also concluded that dewatering of the HHF for mining at East Field was required to reduce seepage and improve ground conditions for overburden excavation. Dewatering commenced in 1992 via drainage trenches and pumping bores to reduce seepage from the coarse channel sands which were progressively exposed during mining of East Field. Following excavation of the main sand deposits in the HHF, active overburden dewatering via pumping was no longer required and ended in 2007 with natural drainage providing sufficient dewatering for mining operations. Minor seepage from the HHF continued as mining progressed into East Field Extension and Maryvale Field. Persistent minor seepage occurs in some areas on the permanent batters, typically at the base of the formation (e.g. the western batters of Township Field). During mining of the Maryvale Field overburden excavation, a sandy zone was encountered with increased groundwater seepage resulting in washouts undercutting the batter and localised slumping in the operational face. To address this issue, a flatter batter slope was adopted. Mining has now excavated this sandy zone and seepage has returned to typical low-level conditions.

Paper Size A3

0 95 190 380 570 760

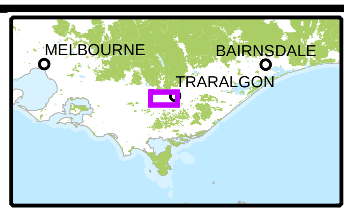
Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- Former Artesian Flow Bore
- Former Pump Bore
- Operational Pump Bore
- Arterial
- Watercourse
- Lake



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Yallourn Mine M1A Aquifer Pump Bore Location Plan

Figure 15

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Data source: DELWP, VicMap, 2020; GHD, Mine Boundaries, 2024 Created by: tworth

3. Mining history and data collection

3.1 Mine development

Mining in the region commenced in late 1880s at the Yallourn North Open Cut (YNOC) which was intermittently operated to 1924 when it became part of the SEC and used to supply the Yallourn power stations and briquette factory. The YNOC mine was closed in 1934, reopened in 1941 and operated until 1963. It has been used as a disposal area for the demolition waste of the Yallourn power stations and hard clean waste from the W Station construction. From 1964 the YNOC has received ash waste from the Yallourn W power station. The Yallourn North Extension open cut was operated by the SEC from 1956 to 1989 as shown in Table 1

Yallourn Open Cut (YOC) commenced overburden removal in 1921 and the first coal was produced in 1924 to supply a temporary power station and then power stations A and B, commissioned in 1928 and 1932 respectively, and the briquette factory commissioned in 1928. Power Stations C, D and E were commissioned from mid-1950s to early 1960s and provided most of the state's electricity until the mid-1960s (see Figure 16).

Mining at YOC progressed to South Field and reached the southern extent by the mid-1960s. The operating faces then progressed to the west and by the late 1970s northwards to Township Field. By 1987 the western side of the mine was excavated through much of the original Yallourn township. A progressive development plan of YOC is shown in Appendix A along with selected plans showing site features discussed in this section. Overburden removed from the YOC operating faces has been deposited in a combination of internal and external dumps. Early in mine development external overburden dumps to the north and east of the mine were formed. A substantial part of these dumps was subsequently moved to form wetlands and landscape in an area to the north of East Field. Internal overburden waste dumping within worked out areas in YOC commenced in the 1940s to the north, progressed to the south and west and was completed in the late 1990s with most of the original mine floor covered with the exceptions of the water storages as discussed in Section 2.3.2. Small external overburden dumps in Westbrook Gully were formed during mining of Township Field.

Mining operation at East Field commenced in the early 1990s, following the completion of the third Morwell River diversion in 1987 to the south and east of East Field. Mining progressed eastwards into the East Field Extension from 2009, following commissioning of the fourth Morwell River diversion in 2005. Mining of Maryvale Field commenced in 2011 and is progressing southwards with completion scheduled for 2028. Internal placement of overburden waste now covers the northern part and southern batters area of East Field and is progressing southwards to Maryvale Field. Figure 3 shows the approximate boundaries of the mining areas and associated progression.

Table 1 Summary of Mining in Yallourn

Field	Years of Operation
Yallourn North Open Cut	Intermittent from 1889 to 1963
Yallourn North Extension	1956 to 1989
Yallourn Open Cut	1921 to 1959
South East Field	1960 to 1969
South West Field	1969 to 1980
Township Field	1980 to 1998
East Field	1994 to 2009
East Field Extension	2009 to 2011
Maryvale Field	From 2011

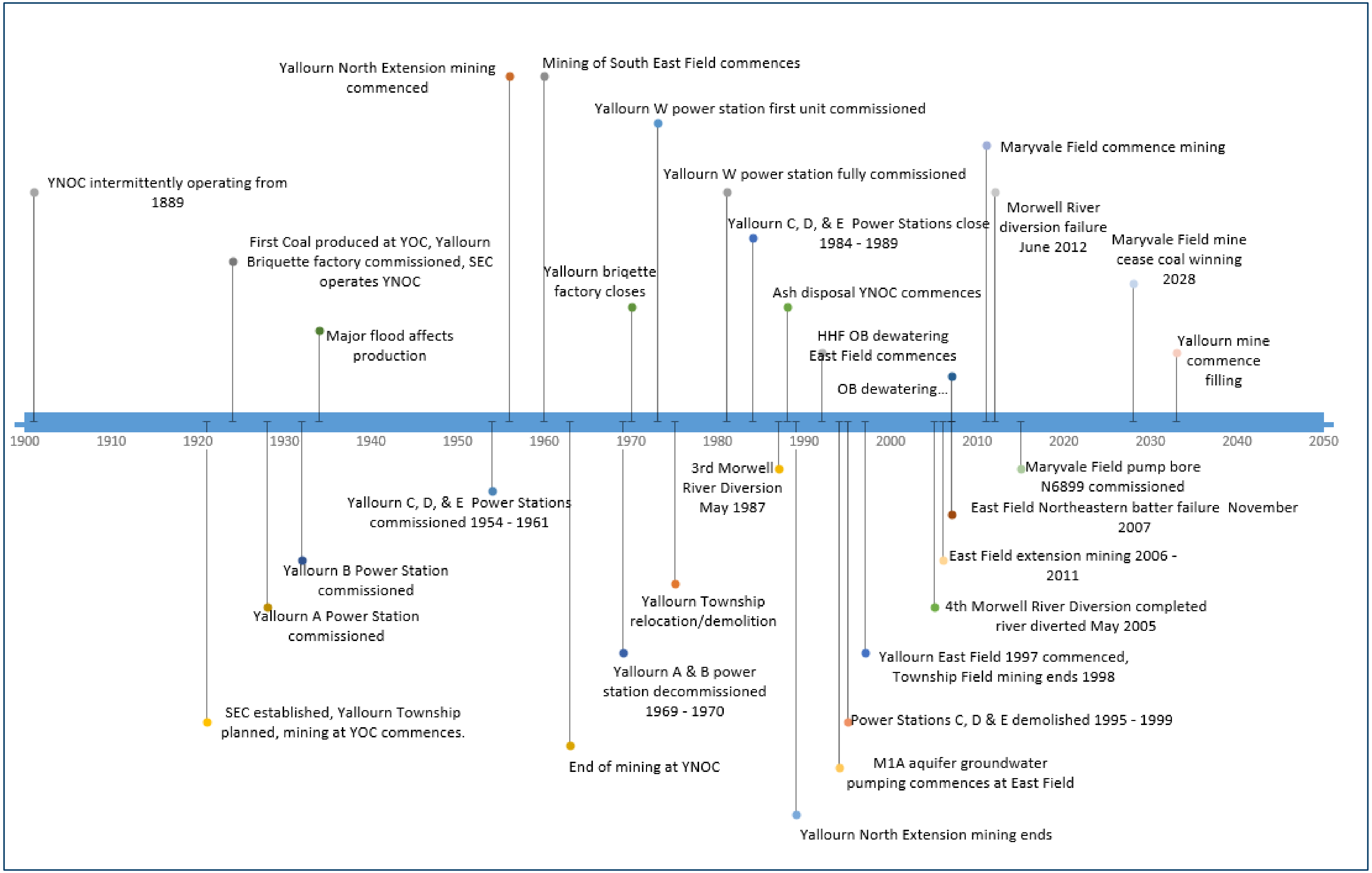


Figure 16 Yallourn Mine Timeline

3.2 Field investigations and data collection

3.2.1 Overview

The knowledge gained from the long history of mining at the Yallourn Mine and collection of a large amount of data over this period has been used to inform the hydrogeological conceptualisation. This section provides a summary of the relevant data collected to date, which underpins the development of the hydrogeological conceptual model.

3.2.2 Drilling and geological investigations

Data from long history of drilling investigations completed at the Yallourn Mine is captured in the Latrobe Valley Coal Bore Database (LVCBD) and includes geological, geophysical, bore installation and survey data. This data has been used to construct and update the site and regional geological models, as discussed in Section 3.3.1. Scanned records of SEC drilling reports are also available along with an extensive archive of SEC geological, geotechnical and hydrogeological reports. EAY also maintains an archive of consultant reports related to site investigations.

3.2.3 Aquifer testing

Estimates of hydrogeological properties are available from aquifer tests undertaken by the former mine owners, SEC, and more recently by EAY. Much of the early tests targeted permeable horizons (sands) within the SAS, whereas the later tests targeted the deeper confined aquifer of the M1/MFAS to ascertain the dewatering requirements for managing floor stability.

GHD has completed reviews of various SEC, Geo-Eng, GHD and EAY records, including hard copies of archived reports, to develop a database of hydrogeological properties for the Yallourn Mine (GHD, 2018). The database includes Tier 1 properties, such as hydraulic conductivity and storage coefficient derived from the analysis of in-situ aquifer testing, and Tier 2 properties such as grain size distribution which may provide qualitative indicators of aquifer properties. The available hydrogeological property estimates are presented in Section 4.4.1.

3.2.4 Groundwater monitoring

3.2.4.1 Yallourn Mine monitoring

Groundwater levels across the Yallourn Mine are monitored using an extensive network of groundwater monitoring bores typically containing vibrating wire piezometers and standpipes. The groundwater level measurements are stored in a monitoring database managed by the mine, with data commencing from around 1981. Prior to this period, the groundwater level measurements from bores at the Yallourn Mine are available from the archived SEC “techbase” database.

The monitoring database contains nearly 400,000 groundwater level measurements from almost 1,200 bores/piezometers. Not all of the bores/piezometers are currently active and many are nested at the same location, providing measurements of piezometric heads at discrete intervals vertically through the stratigraphic profile. The majority of bores/piezometers are constructed within the key aquifers (Haunted Hills Formation, Yallourn Interseam and M1A Interseam) and aquitards (Yallourn Coal and M1A Coal). There are also a large number of bores/piezometers constructed within the fill and overburden (the latter can include natural overburden, effectively representing the Haunted Hills Formation, as well as excavated and dumped overburden).

Although the database contains groundwater level measurements from 1981, the data collected prior to 1993 account for less than 1 % of the total measurements. From 1992 to 2008, the number of groundwater level measurements per year generally remained similar, ranging from around 1,000 to 2,200 measurements per year, while the number of bores/piezometers monitored increased steadily from around 120 to 320. From 2009 onwards, the number of measurements increased significantly, reaching over 18,000 measurements from 550 bores/piezometers in 2012. In 2019, over 75,000 measurements were collected from more than 900 bores/piezometers as shown in Figure 17. The location of all observation bores/piezometers is shown in Appendix B.

Plans of the current monitoring network by formation are shown in: Figure 18 for the Haunted Hills Formation (HHF), Figure 19 for the Yallourn Interseam, Figure 20 for the M1A Interseam and Figure 21 for the Ash Fill (at the power stations and YNOC). Figure 18 also includes bores/piezometers identified as Overburden (OB), since this includes natural (undisturbed) and dumped OB (effectively representing either the HHF or material derived from it, which forms the water table aquifer). Approximate extents of the Yallourn Interseam and M1A Interseam are shown in Figure 19 and Figure 20, respectively. For Figure 18, approximate extents of the outcropping basement rock are shown where the HHF is naturally absent (the HHF is also absent/excavated over the mine void).

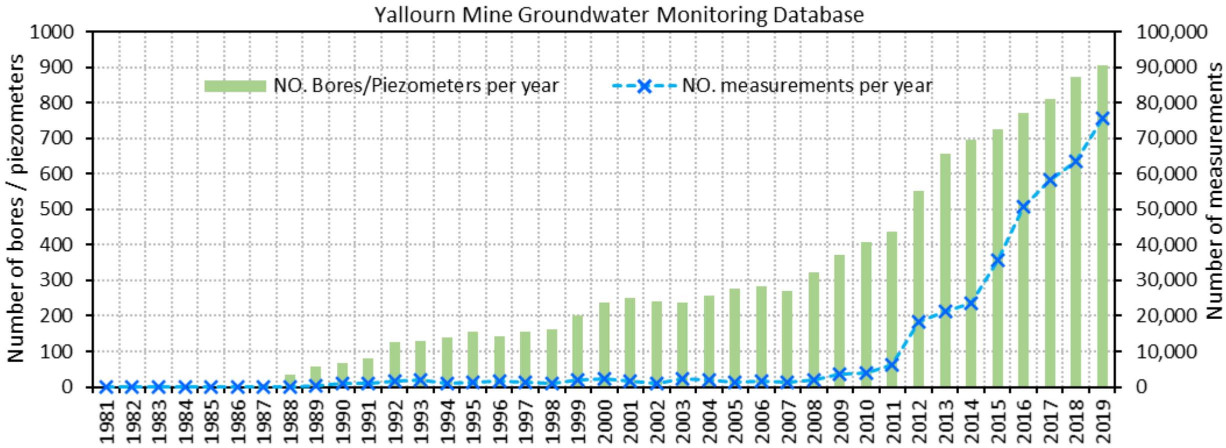


Figure 17 *Yallourn Mine Groundwater Monitoring Database*

3.2.4.2 Morwell River Diversion monitoring

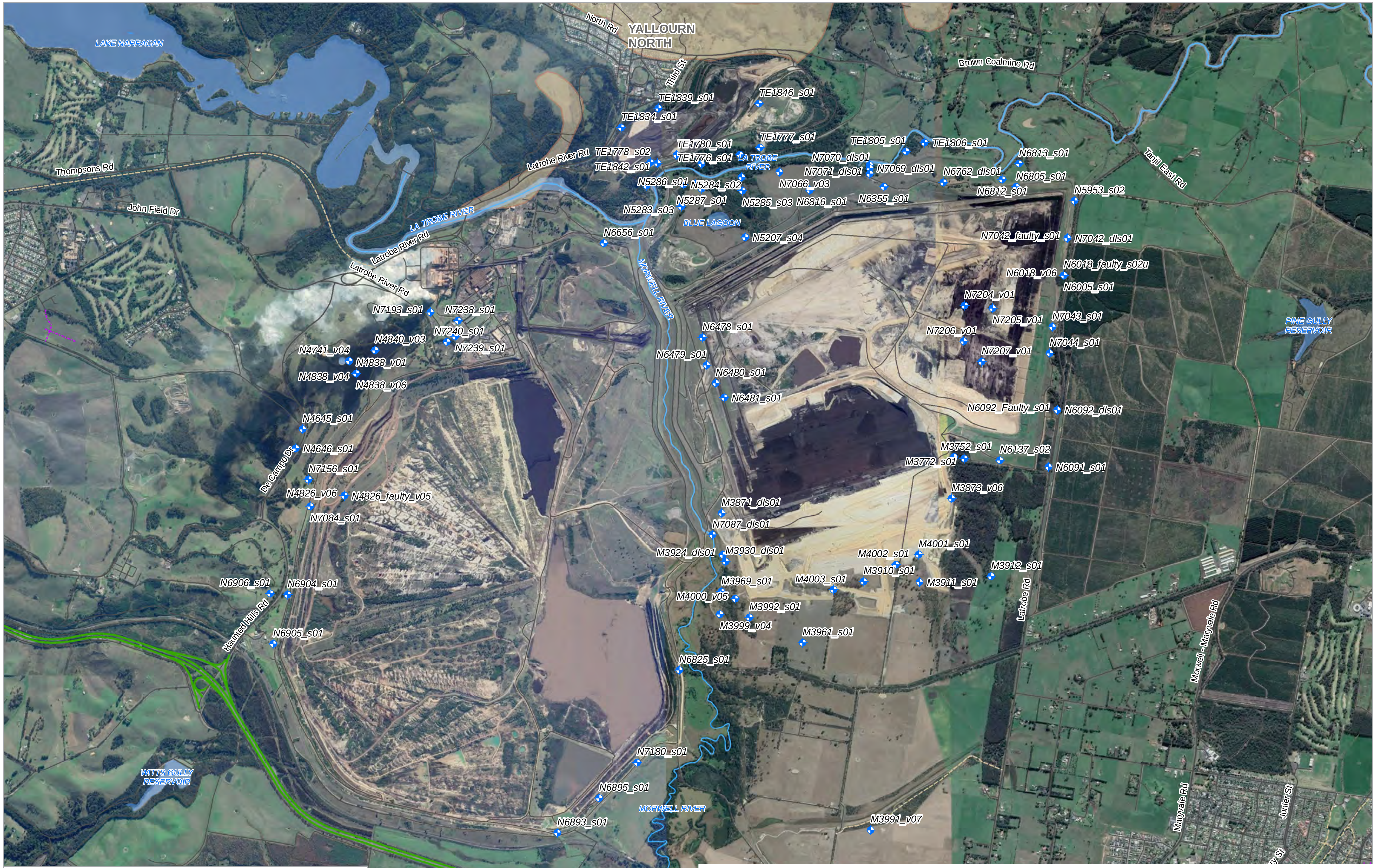
There are 139 piezometers/bores constructed in the Morwell River Diversion (MRD), as shown in Appendix B (refer to the piezometers located on the MRD structure, approximately in the centre of the mine). The data collected from these piezometers/bores are currently reviewed on a monthly basis to identify changes in pore pressures (within variable foundations) and their effect on the structural integrity of the MRD. Annual performance reviews of the MRD were completed in 2018 and 2019 by SMEC, summarising key findings from the ongoing monitoring program. GHD also completed a hydrogeological assessment of an area encompassing the southern section of the MRD, following a period of high flow in June 2021 (GHD, 2022a).

3.2.4.3 Latrobe Valley Regional Monitoring Program

The operators of the three Latrobe Valley coal mines jointly undertake a regional groundwater and land level monitoring and reporting program to assess the cumulative impact of aquifer depressurisation associated with mining operations across the Latrobe Valley. The program was established in the mid-1990s, when the mines were privatised, to continue the monitoring programs originally established by the SEC. It is managed by a committee comprised of representatives from each mine, Southern Rural Water and the Department of Jobs, Precincts and Regions (DJPR). Annual reporting of mine groundwater extractions and monitoring trends is completed and a detailed report is prepared every five years that includes modelling of future groundwater extractions and regional subsidence.

The regional groundwater monitoring network extends from Moe to Stratford and monitoring is completed biannually, providing data on regional water level trends in the major aquifer systems that are the focus of the mine depressurisation programs. There are 70 bores monitoring 86 intervals in the M2/TFAS and 43 bores monitoring 65 intervals in the MFAS. There are limited number of bores (3) monitoring the groundwater levels in the underlying basement rock and in the shallow aquifer system (8 bores monitoring 21 intervals). One bore (190066) monitors groundwater levels in the Gippsland Limestone to the south of Sale. Bore locations plans for the regional monitoring network are shown in Appendix C.

A network of regional land level survey marks has been established to enable monitoring of ground surface levels (Appendix C). The purpose of this network is to monitor changes to ground surface elevations in response to aquifer depressurisation. The marks are surveyed every five years and most recently reviewed and reported in 2019/2020 for the 2020 Five Year Review.



Legend

- HHF Monitoring Bore
- Freeway
- Arterial
- Collector
- Proposed
- Tracks
- Watercourse
- Lake
- River
- Basement outcrops

Paper Size ISO A3

0 0.25 0.5 0.75 1

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Energy Australia Yallourn
Conceptual Hydrogeological Model

Haunted Hills Formation (HHF)
Groundwater Monitoring Bores

Project No. 12521481
Revision No. B
Date 22/08/2023

FIGURE 18

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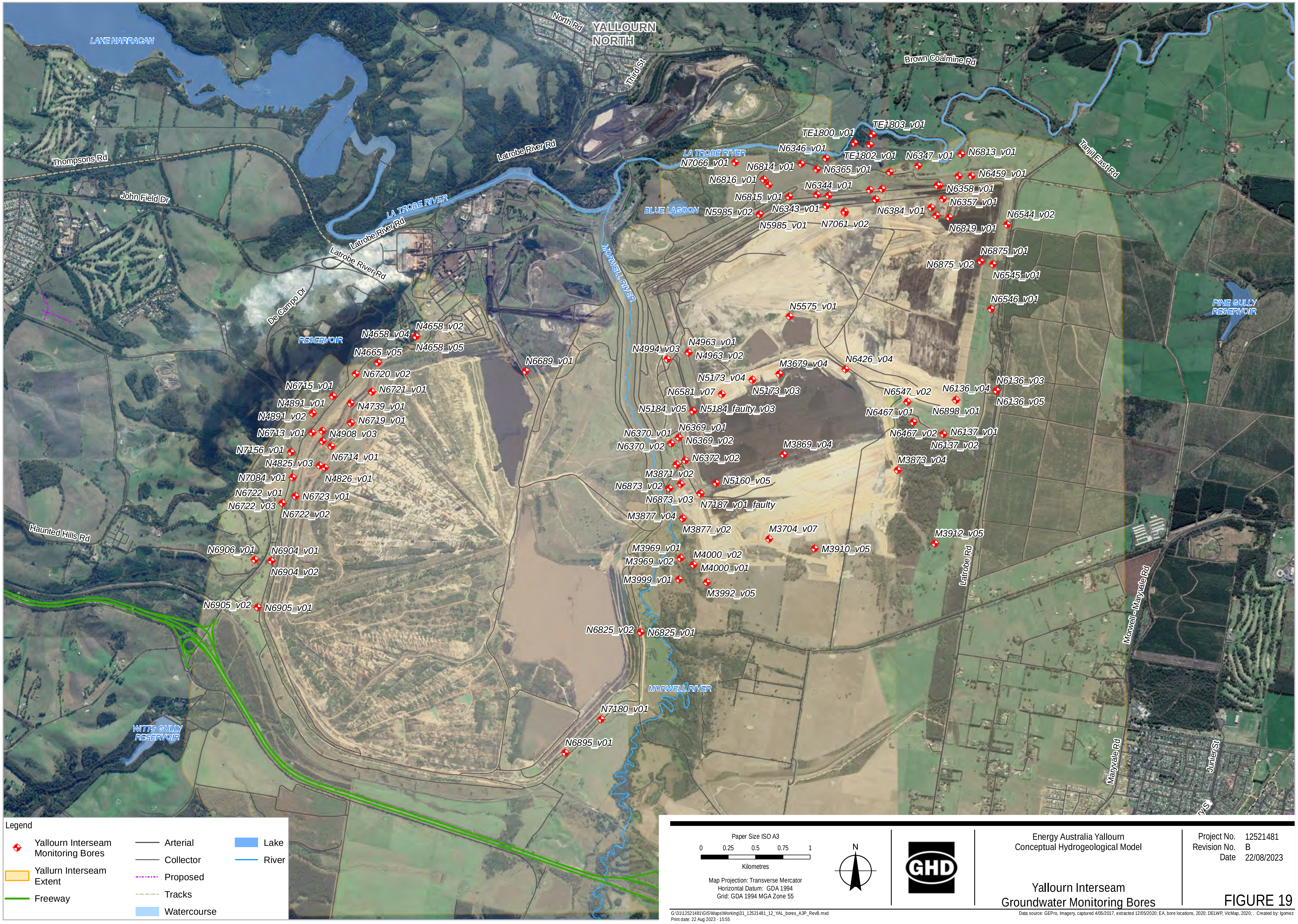
Data source: GEPro, Imagery, captured 4/05/2017, extracted 12/05/2020; EA, bore locations, 2020; DELWP, VicMap, 2020; . Created by: lgomez



Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Energy Australia Yallourn
Conceptual Hydrogeological Model

Yallourn Interseam
Groundwater Monitoring Bores

Project No. 12521481
Revision No. B
Date 22/08/2023

FIGURE 19

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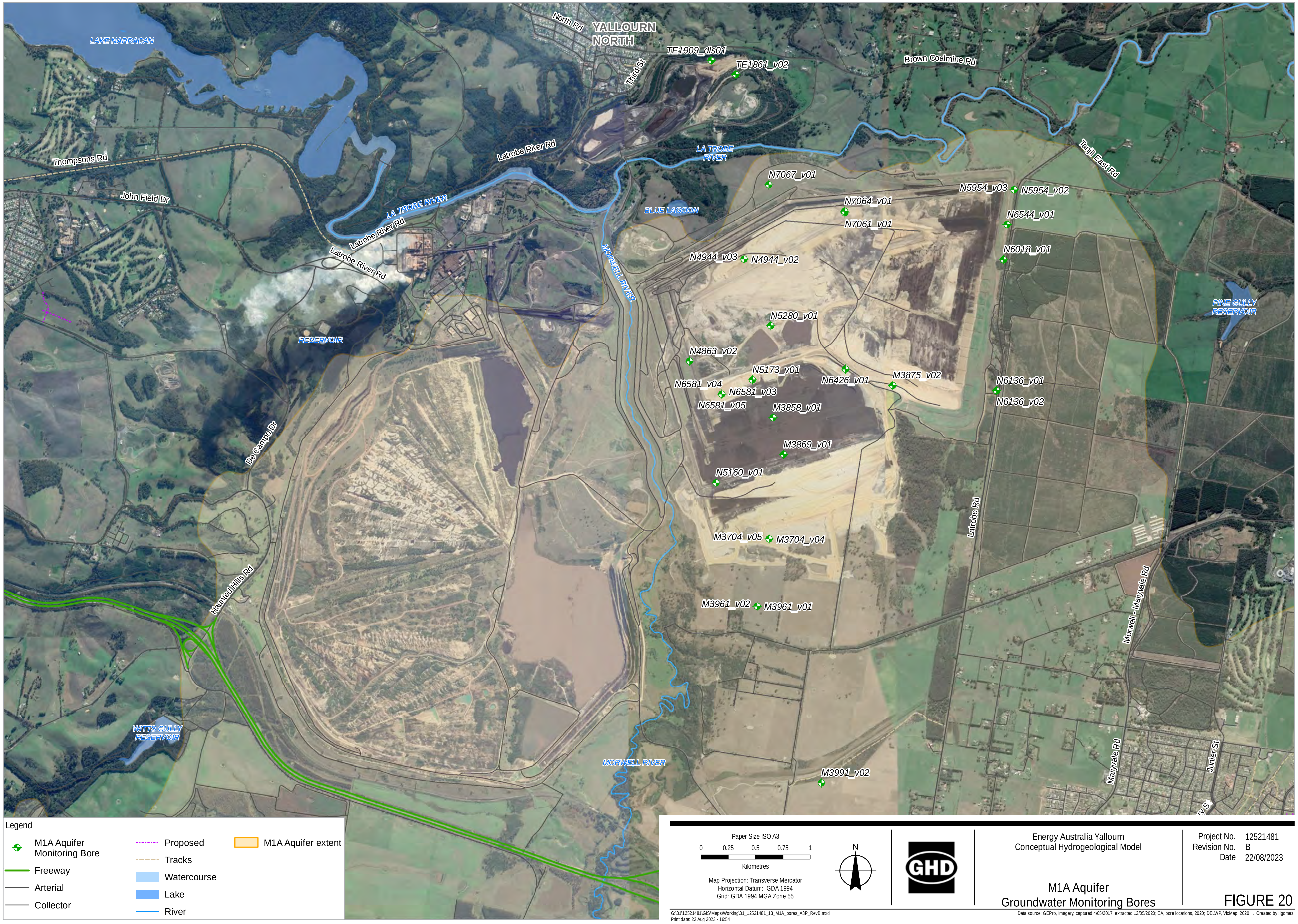
Data source: GEPro, Imagery, captured 4/05/2017, extracted 12/05/2020; EA, bore locations, 2020; DELWP, VicMap, 2020; . Created by: lgomez



Energy Australia Yallourn
Conceptual Hydrogeological Model

M1A Aquifer
Groundwater Monitoring Bores

Project No. 12521481
Revision No. B
Date 22/08/2023

FIGURE 20

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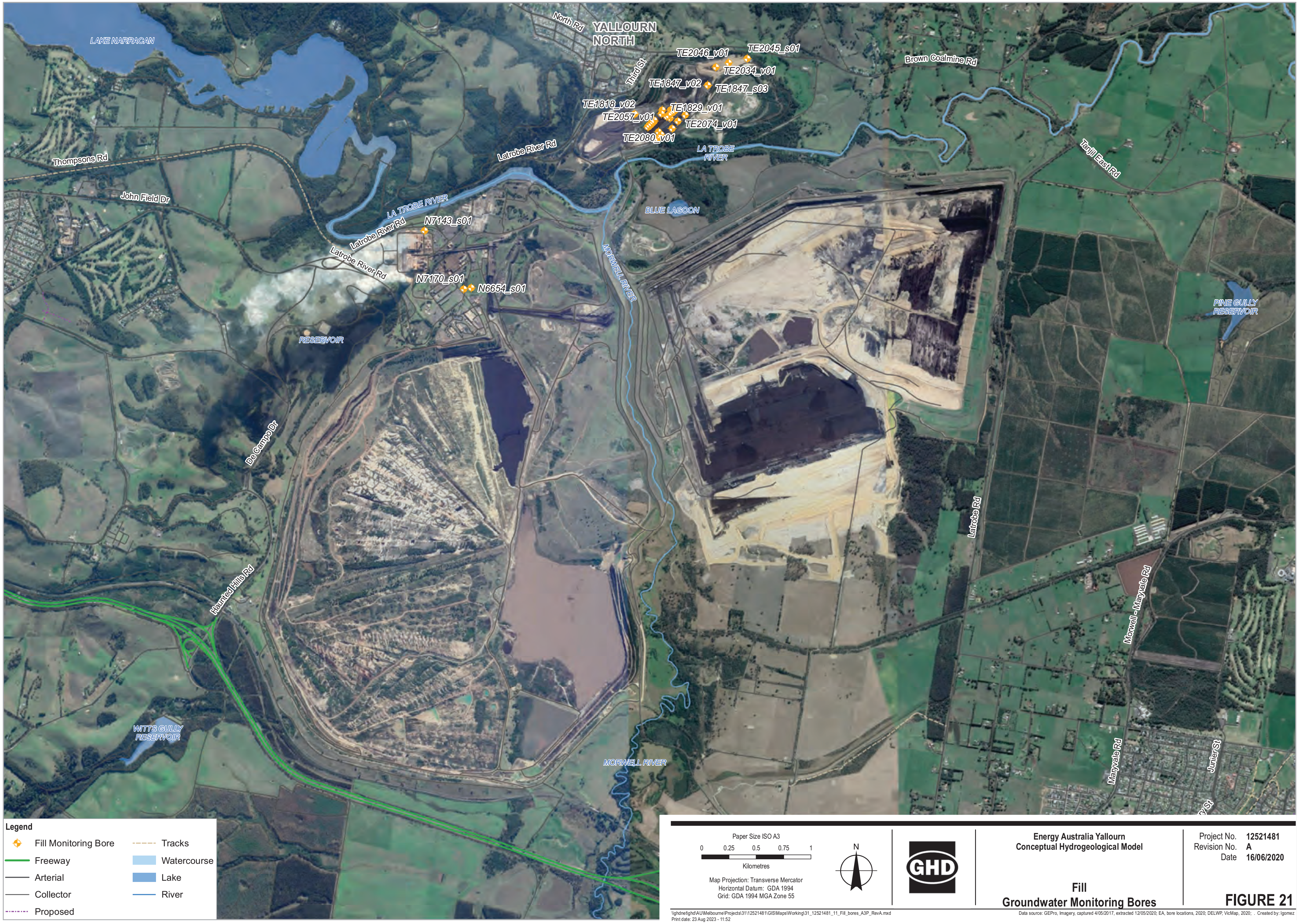
Data source: GEPro, Imagery, captured 4/05/2017, extracted 12/05/2020; EA, bore locations, 2020; DELWP, VicMap, 2020; . Created by: lgomez



Paper Size ISO A3

0 0.25 0.5 0.75 1

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Energy Australia Yallourn
Conceptual Hydrogeological Model

Fill
Groundwater Monitoring Bores

Project No. **12521481**
Revision No. **A**
Date **16/06/2020**

FIGURE 21

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Print date: 23 Aug 2023 - 11:52

Data source: GEPro, Imagery, captured 4/05/2017, extracted 12/05/2020; EA, bore locations, 2020; DELWP, VicMap, 2020; . Created by: lgomez

3.2.4.4 Groundwater Quality Monitoring

There is limited historical groundwater quality data available from the Yallourn Mine, with most of the long-term water quality data focusing on the area between the YNOC ash ponds and the Latrobe River. Groundwater quality sampling in this area commenced in the early 1990s to monitor potential impacts from the ash retention dumps. The water quality data from this monitoring program typically comprised Total Dissolved Solids (TDS), pH, electrical conductivity (EC), sulphate and selected metals (e.g. Cd, Pb, Bo). Samples were collected from monitoring bores constructed in the alluvial aquifer, MFAS and M2/TFAS.

The monitoring bore network and the analytical suite were subsequently expanded to include field chemistry, major ions, metals, TRP (total reactive phosphorous) and nutrients. The location of bores included in the current YNOC monitoring program is shown in Appendix D. Several of these bores are considered to represent background groundwater quality in the alluvium aquifer adjacent to the Latrobe River and the M2/TFAS in upgradient area (highlighted in yellow).

Outside of the YNOC, groundwater quality information has been collected sporadically as part of various investigations which are summarised in Table 2. Most of the data relate to the HHF, with the data available from the M1A Interseam appears to be limited to samples collected during the commissioning of pumping bore N6899.

EAY has recently commenced a groundwater sampling program across the mine, using a network of existing and recently constructed monitoring bores. The groundwater quality results from a sampling round completed in September 2022 are detailed in Section 4.10.

Table 2 Summary of Water Quality Data

Location	Formation	Sampling Suite	Summary Results	Reference
N3294 M2390	M2/TFAS M2/TFAS	TDS, pH, major ions, Fe	TDS 487 mg/L TDS 724 mg/L	Brumley *et al* (1981)
East Field 15 bores	HHF	Field Chemistry, - (Temp, pH, EC) Laboratory TDS	pH 5.2 – 6.9 EC 30 – 160 mS/m TDS 260 – 940 mg/L	1993 YEF Quarterly review
Maryvale MRD M3770, M3773, M3749, M3753, M3742, M3681 N5027	HHF	Field Chem (EC, DO Eh, pH), TDS, major ions, Fe, total P PAH, BTEX, TRP, 11 metals, , NH4 (3770 and 3773 only)	pH 4.6 – 6.3 TDS 160 – 3000 mg/L	Geo-Eng (1998a)
Hearns Oak N6232 N6233	HHF	Field Chemistry TDS, major ions., Fe, Mg, TKN, TOC, NH4	pH 4.5 – 5.4 TDS 120 – 350 mg/L	GHD (2007a)
YOC SW Field OB Dump N6191 N6223	Overburden	Field Chemistry TDS, major ions., Fe, Mg, TKN, TOC, NH4	pH 4.8 – 5.2 TDS 140 – 390 mg/L	GHD (2007b)
East Field N6899 Pump Test	M1A	Field Chemistry (EC, pH, ORP, Temp) DS, major ions., Fe, Mg	pH 5.5 TDS 240 m/L	GHD (2016)

3.2.5 Groundwater extraction

3.2.5.1 Yallourn Mine

Groundwater extractions at the Yallourn Mine commenced in 1992, with pumping from the HHF occurring via drainage trench (the data included in the dewatering investigations report by Geo-Eng, 1993). Pumping data is reported for 10 bores constructed in the HHF although it is noted that up to 21 dewatering bores were operational simultaneously and the pumping data was reported collectively from July 1997 to June 2004. The pumping bores in the HHF were typically pumped only temporarily, usually for less than a year to adequately dewater the shallow aquifer ahead of the advancing overburden excavation face, with total extractions shown in Figure 22.

Pumping from the M1A Interseam (aquifer) dates back to 1994, with the first bore N4934 commissioned in August 1994. Data on the M1A aquifer groundwater extractions is reported over financial year periods from June 1996 to 2008, reducing to monthly extraction volumes thereafter. The extraction volumes are available from 12 bores constructed in the M1A aquifer. As discussed in Section 2.7.2, half of these bores were constructed as pumping bores whereas the other half were flowing bores which recorded a reduction in flows from around mid-2008 onwards after pumping was re-instated at bore N5056. The M1A aquifer flow by bore (Figure 23) shows the majority of the flow originated from three bores N4943, N5056 and N6899 with the other pumping bores and artesian flowing bores generally having low flow rates and shorter operational periods.

The effect of groundwater extractions on groundwater levels is further discussed in Section **4.7.3**.

3.2.5.2 Latrobe Valley

The extraction of groundwater from the M2/TFAS commenced with the drilling of a water supply bore M942 at Maryvale APM in 1945, located to the east of the Yallourn Mine. The bore was artesian and flow was estimated at 70 L/s in 1945, reducing to 23 L/s in 1965. A second water supply bore, M1096, was commissioned in 1952 with an artesian flow rate of around 20 L/s, reducing to 12 L/s in 1966 after which it stopped flowing as a pump was installed in bore M942. This bore continued to operate at between 25 to 35 L/s until pumping ceased in 1975 as surface water sources supplied the mill (Fraser, 1980). The M2/TFAS piezometric heads at M942 have been estimated at around 50 mAHD in 1945, declining to 41 mAHD in 1966 when pumping commenced and further declining to below ground level in the late 1980s (after pumping had ceased). This bore continues to be monitored as part of the regional monitoring network (with vibrating wire piezometers installed) and the current piezometric heads range from around -50 to -65 mAHD.

Regionally, the confined aquifers of the Latrobe Valley aquifer system are heavily depressurised by the pumping bores located at the Hazelwood and Loy Yang Mines. The depressurisation of the confined M1 and M2 aquifers commenced at the Hazelwood Mine in the early 1960s, peaking in the mid-1970s, after which the depressurisation program commenced at the Loy Yang Mine in the mid-1980s. The long-term records of groundwater extraction volumes for each mine are reported as part of the regional groundwater monitoring program and are shown in Figure 24. Regional groundwater pumping as a component of the conceptual water balance is further discussed in Section **4.5.3**.

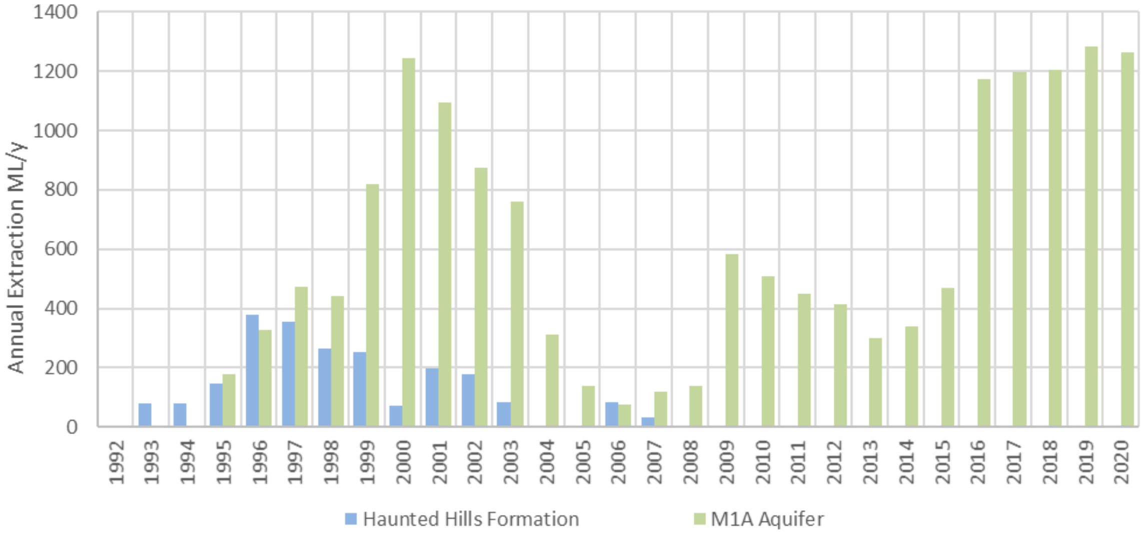


Figure 22 ***Total M1A and Haunted Hills Formation Flows***

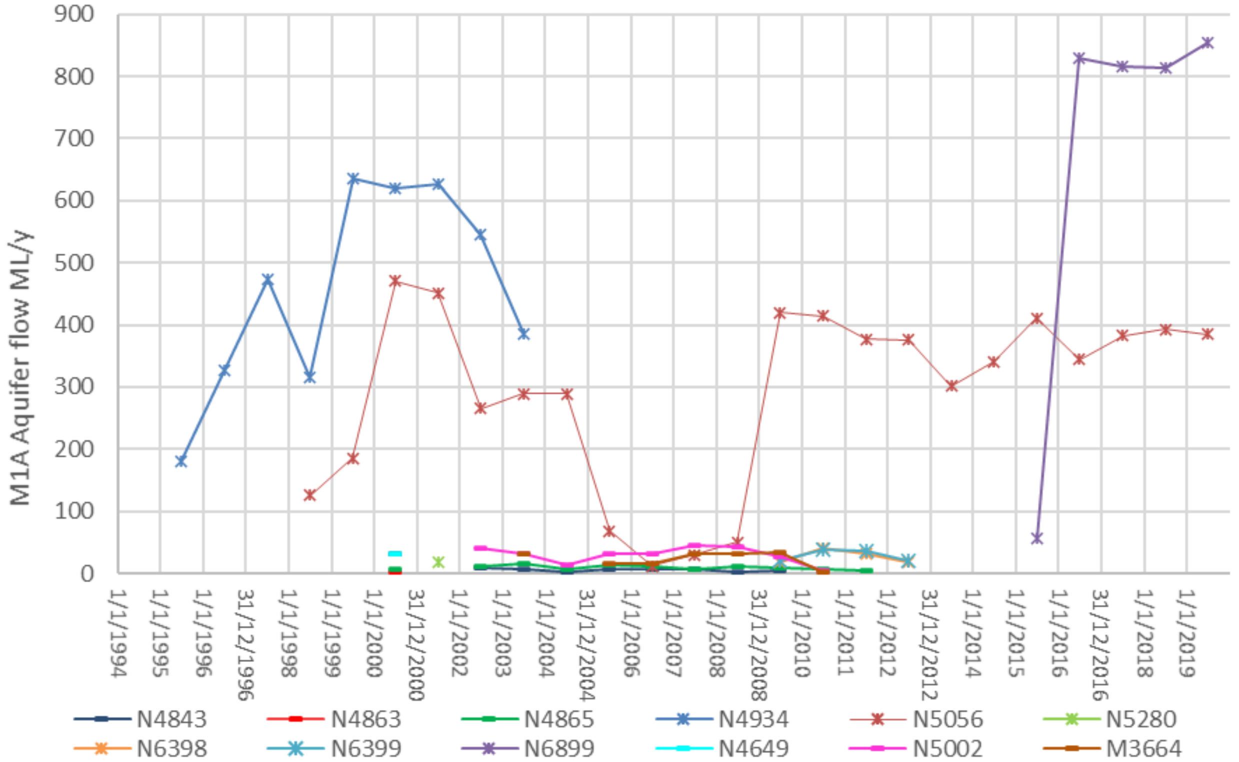


Figure 23 M1A Aquifer Flows by Bore

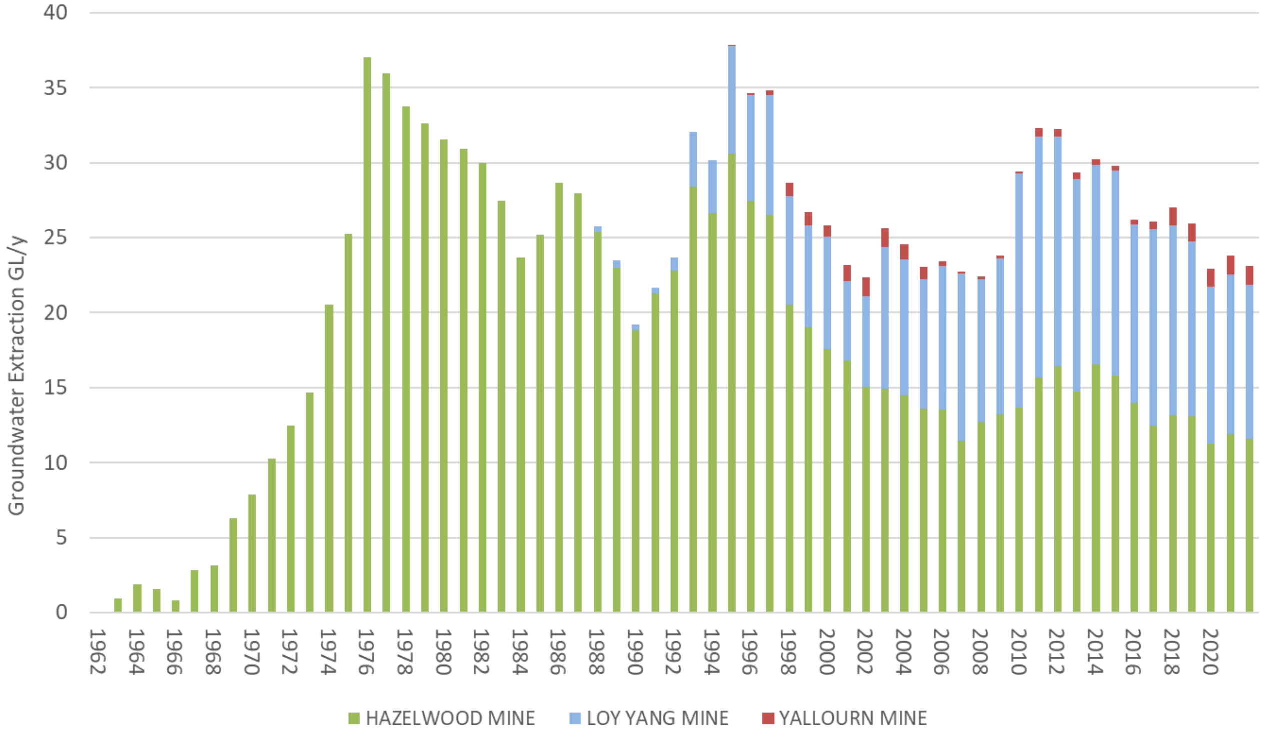


Figure 24 Latrobe Valley Mines Groundwater Extractions

3.2.6 Hydrology

The Latrobe River is heavily impacted by regulation and water management activities, with downstream flow controlled by three major storages: Blue Rock Reservoir on the Tanjil River; Lake Narracan on the Latrobe River (at the confluence of the Tanjil River, Moe River and Narracan Creek); and Moondarra Reservoir on the Tyers River (GHD, 2015a). There are series of diversions that take water away from the river, the most significant being the diversion from Yallourn Weir immediately downstream of Lake Narracan as shown in Appendix E. A number of industrial water users as well as wastewater treatment plants discharge significant volumes of saline water to the river. The lower reaches of the Latrobe River also receive discharge from drains that carry relatively saline water, the majority of which is likely fed by groundwater from high water table areas.

The implication of these water management activities is that the nature of surface water - groundwater interactions, particularly the baseflow behaviour, can be difficult to characterise. Studies undertaken by the Victorian Government indicate that major water courses, such as the Latrobe River and Morwell River, are dominantly gaining systems despite the long-term depressurisation effects of the coal mines and power stations (GHD, 2015a). This is consistent with the conceptualisation that thick sequences of coal within the Yallourn Formation and Morwell Formation act as effective regional aquitards, minimising the effect of depressurisation at depth on shallow groundwater that is maintained by recharge.

Surface water studies have also been completed as part of the LVRRS investigations (Alluvium, 2020), which concluded from previous studies that baseflow to the Latrobe River from Lake Narracan to Scarnes Bridge accounted for 24% of the average daily streamflow and the reach has been classified as an overall losing stream with the largest losses occurring when the stream flows were the highest (GHD, 2013b). Groundwater was estimated to have contributed to 72% of daily flow to the Morwell River in the upper reaches (SKM, 2012) and surface water - groundwater interactions are likely to be negligible in the lower reaches, with the depressurisation at the Hazelwood Mine resulting in locally losing stream conditions close to the mine.

Section **4.9** provides more detailed analysis and conceptualisation of surface water-groundwater interactions, both regionally and locally at the Yallourn Mine.

3.2.7 Ground surface movement

The Yallourn Mine Ground Control Management Plan (GCMP) describes the geotechnical monitoring program which includes an extensive network of survey pins that monitor ground movement at the permanent mine batters, MRD embankment and tunnels, power station site, YNOC ash ponds, overburden dumps and water storages across the site. Appendix B shows the locations of the survey pins.

There is also a network of regional survey marks outside the mining leases for monitoring the cumulative impact of mine depressurisation on ground levels, as discussed in Section 3.2.4.

3.3 Geological and hydrogeological modelling

3.3.1 Geological modelling

The distribution and quality of the Cenozoic brown coal have been modelled on a regional scale in the Victorian Regional Minescape Coal Model, based on over 8,000 bores across the Latrobe Valley. This digital three-dimensional model consists of the roofs and floors of the sixteen thickest brown coal seams and some of the splits off main parent seams. Surfaces for the floor of the Haunted Hills Formation and Strzelecki Group (and Palaeozoic) basement have also been estimated. Surfaces in the model are based on a 200 m grid spacing with grid values interpolated from bores drilled on a nominal 400 m grid. The associated interseams are not included in the model (Jansen et al, 2003). The model was developed in 2002 for the then Department of Primary Industries and was extended in 2008 and again in 2011 to include the Moe Swamp Basin and coastal and southern areas of the Gippsland Basin respectively, as shown in Appendix F. The Gippsland Limestone, Thorpdale Volcanics and Carrajung Volcanics were modelled within the 2011 area. Volcanic intervals include multiple flows and interflow sediment. They were rarely drilled from top to bottom and thicknesses and floors are poorly constrained.

Detailed geological models exist on mine scale, which are developed and maintained by each of the three Latrobe Valley coal operators. The geological model of the Yallourn Mine was initially developed in the 1980s by the SEC.

A Minescape software platform was used at the time and was carried through into privatisation. The model was constructed on the basis of coal seam strata being the only strata of importance, especially in the areas that were targeted for excavation. The model consequently carried an accuracy biased towards Yallourn East Field and Yallourn Maryvale Field. Hydrogeological considerations were not initially taken into account in the early Yallourn geological models.

Geologist Bill Wood maintained the Yallourn Minescape model while employed at Geo-Eng (approximately, 1992-1996) and this continued while employed at TRUEnergy Yallourn. The Minescape model was continually updated by TRUEnergy Yallourn until 2007, up to the time of the Latrobe River failure. Over the ensuing 5 years GHD supported periodic updates to the Yallourn model. In recognition of the need to model some aquifer (sand) layers belonging to the M1A Interseam, five aquifer layers were added to the Yallourn Minescape model by GHD in 2012. The current model is based on 3,955 bores to create strata models of 21 layers on a 50 m grid (the model layers are shown in Appendix D). The 2011 update also included a detailed review of material density assigned to each model layer, which is used in calculating weight balance and trigger level surfaces for a given mine plan. The key limitation of the updated model, with respect to aquifers, is that the bores used to correlate the aquifers are chiefly in Maryvale Field, with very few bores assigned to these layers outside of this key mining area.

Since 2012, the model has been maintained and periodically updated on site by EAY with some oversight by GHD geologists.

3.3.2 Hydrogeological modelling

3.3.2.1 Latrobe Valley Regional Groundwater Model

The Latrobe Valley mine operators maintain the Latrobe Valley Regional Groundwater Model (LVRGM) as part of the regional groundwater monitoring and modelling program. The LVRGM has been refined progressively over time, with each model iteration reflecting the improved hydrogeological knowledge of the region and increased level of modelling sophistication consistent with advances in modelling technology over time.

The history of groundwater modelling dates back to 1980, with the SEC undertaking modelling in five stages. This included the development of regional and mine scale groundwater models at Loy Yang and Hazelwood Mines using the finite element model code AFPM (Aquifer Flow in Porous Media). Since 1996 predictive groundwater modelling has been completed every 5 years. The 1996 and 2000 predictive groundwater modelling was completed using an AFPM model with 7 layers. This finite element model had significant limitations associated with the code’s inability to incorporate storage parameters of the aquitards and the requirement for a fixed head boundary condition in the upper layer.

The LVRGM model was transferred to the MODFLOW platform in 2005. A 2005 steady-state version of the Integrated Resource Model (IRM) developed by Schaeffer (2008) was made available to the Latrobe Valley Regional Monitoring Committee and was used as the basis for developing the first MODFLOW based LVRGM (as part of the 2005 Five Year Review). Further updates to the model were completed for the 2010 Five Year Review, as documented in GHD (2011b), which included the development of historical recharge time series and the addition of the capability to simulate subsidence using MODFLOW’s Subsidence and Aquifer-System Compaction (SUB) package.

In 2012, the LVRGM was updated and re-calibrated and the Loy Yang mine sub-model was nested inside the regional model for AGL- Loy Yang as part of a long-term modelling study. This was achieved using a technique known as “telescopic mesh refinement”, whereby the model outputs from a regional model are used to set boundary conditions for a local model for more detailed simulations at mine-scale.

In 2015, several significant updates to the LVRGM were undertaken in stages to meet the needs of the mine operators and as part of the regional study. The Loy Yang model was fully integrated into the LVRGM for AGL - Loy Yang, using an unstructured grid version of MODFLOW called MODFLOW Unstructured Grids (MF-USG) (GHD, 2015a). Later in 2015, the LVRGM was significantly refined near Hazelwood Mine for GDF Suez Hazelwood Power, to enable detailed representation of geological structures, model parameters and historic mine development and aquifer depressurisation (GHD, 2015c). The LVRGM was further updated as part of the 2015 Five Year Review (GHD ,2016a and 2016b) with predictive groundwater and subsidence modelling completed to year 2025. Calibration of the LVRGM was carried out using the historic groundwater levels and drawdown trends from 351 bores as well as subsidence data across the Latrobe Valley over the period from 1960 to 2015.

The most significant update to the LVRGM to date was completed between 2017 and 2019 for ENGIE Hazelwood, as part of a detailed hydrogeological modelling study to inform closure planning for the Hazelwood Mine. The key updates included:

– The refinement of the model domain and mesh using the more flexible quadtree refinement technique (compared to the previously used nested gridding approach).
– Improved representation of the geology to the west of the Latrobe Valley, where the Thorpdale Volcanics outcrop over the Narracan Block, and towards the edge of the Balook Block where the basement to coal bearing strata outcrops on the edge of the basin.
– Hydrologically realistic simulation of recharge and surface water–groundwater interactions using the rainfall-runoff model PERFECT and MODFLOW's Streamflow-Routing package to simulate more realistic volumes of recharge, run-off, stream flow and baseflow.
– Rigorous automated calibration of the model to piezometric heads from 1,297 bores/piezometers (and variants such as temporal and spatial differences in heads), gauged streamflow at 21 gauges, estimated baseflows at five river reaches, and subsidence measured at 174 survey points.
– Simulation of a range of closure scenarios, including full and partial lakes, climate change and cumulative influence of the closure of all three Latrobe Valley mines.

From 2018 to 2020, the LVRGM was also used inform the regional water studies of the Latrobe Valley Regional Rehabilitation Strategy (LVRRS), providing estimates of potential pit lake fluxes and future groundwater and land levels under various closure scenarios (DELWP, 2019).

3.3.2.2 Integrated Resource Model

The Integrated Resource Model (IRM) was developed by Schaeffer (2008), as part of a PhD study, to simulate the impacts of different groundwater extractions as well as artificial recharge scenarios on groundwater levels within the Gippsland Basin. The model represented the hydrostratigraphy of the Gippsland Basin using 18 layers, which became the basis for the layers adopted in the LVRGM. Spatially variable hydraulic conductivities were assigned based on percentage sand abundance and recharge was assigned to sub-cropping aquifers. Offshore pumping, coal mine dewatering and irrigation in the Yarram region were simulated.

3.3.2.3 ecoMarket models

The ecoMarket groundwater models (GHD, 2010a; 2010b) were developed for the Department of Sustainability and Environment (DSE) to assess potential impacts of land use changes on the water table depth and baseflows. Groundwater models for the Gippsland Basin included the West Gippsland Catchment Management Authority (CMA) region and East Gippsland CMA region. Both models were built in MODFLOW with a large regional domain and a cell dimension of 200 m by 200 m. Seven model layers were used to represent the hydrostratigraphy of the region. The Latrobe Valley mines were simulated within the West Gippsland model using MODFLOW's Drain and Well packages.

3.3.2.4 Gippsland groundwater model / Bioregional Assessment

In 2015 the Department of Economic Development, Jobs, Transport and Resource (DEDJTR) completed groundwater modelling of the Gippsland Basin as part of a package of works referred to as the Water Science Studies to assess potential impacts of possible onshore gas exploration on water users and ecosystems, focusing on the Gippsland and Otway regions (DEDJTR, 2015). The model was also used to support the Gippsland Basin bioregional groundwater assessment completed by CSIRO (DELWP, 2017).

The model layer structure and attribution are based on new stratigraphic mapping and interpretation developed by Geological Survey of Victoria and CSIRO. This interpretation included offshore stratigraphic information, the Victorian Aquifer Framework (VAF), and previous groundwater model data including the ecoMarket models. The model comprised 30 layers, including layers for the coal seams and Cretaceous sediments of the Strzelecki Formation.

4. Mine scale hydrogeological conceptualisation

4.1 Overview

This section provides detailed descriptions of the hydrogeology of the Yallourn Mine, based on the analysis of site specific data collected at the mine as summarised in Section 3.2. The conceptualisation of the hydrogeological system at mine scale involves the analysis of key hydrological processes (stresses) occurring at the mine, how the system responds to these processes and the nature of the subsurface material that controls the stress-response relationship. It builds on the regional hydrogeological setting described in Section 0, which provides the context for more localised and focused description of the hydrogeology at mine scale.

The key components of the hydrogeological conceptual model of the Yallourn Mine include:

– Conceptual model domain that defines the spatial extent of the study area, large enough to capture the key stresses on the groundwater system and their area of influence
– Hydrostratigraphy, which describes the subsurface material that contains groundwater and delineation of units based on similarity in their material properties
– Aquifer properties that control the behaviour of the groundwater system, including resistance to flow and storage properties
– Conceptual water balance, and hydrogeological processes that characterise the components of flow into and out of the system
– Groundwater flow regime, including the piezometric head distribution, groundwater flow directions and groundwater trends that characterise the stress-response relationships
– Aquifer interconnectivity, building on the understanding of hydrostratigraphy, aquifer properties, groundwater flow regime and geological structures
– Surface water – groundwater interactions

4.2 Conceptual model domain

The conceptual model domain defines the extent of the study area, which should be large enough to encapsulate the key hydrological stresses and their area of influence, both in the context of past activities as well as those of the future (Barnett et al, 2012).

The regional hydrogeology of the Gippsland Basin is conceptualised as a semi-enclosed system. Groundwater within the confined aquifers originates from rainfall-recharge along the basin margin and flows towards the offshore extension of the Gippsland Basin, with limited leakage across the underlying basement rock that acts as an effective hydraulic base of the regional flow system. Hydrologically sensible boundaries of the regional groundwater system therefore align with the edge of the basin and structures, where the flow originates. The conceptual model domain therefore follows the boundary of the Gippsland Basin, with the following two exceptions:

– The domain extends into the Moe Swamp Basin, west of the Yallourn Mine, where the groundwater system and its response to mining (or lack thereof) is important for understanding the degree of hydraulic connection across the regionally significant Haunted Hills Fault/Yallourn Monocline.
– The domain extends over the Narracan Block, to the west of the Hazelwood Mine, where the Thorpdale Volcanics outcrop and laterally extend into the Gippsland Basin and interfinger with the MFAS and M2/TFAS, representing a possible pathway of depressurisation to the shallow aquifer.

Figure 25 shows the extent of the conceptual model domain. For the purpose of describing the key features of the mine-scale hydrogeological conceptual model, the domain has been limited to the footprint of the mine and the surrounding area that has the potential to directly interact with the groundwater system of the mine.

There are two specific areas within the conceptual model domain where a detailed assessment of hydrogeological data is not documented in this report. These are the YNOC, which is regulated by the EPA under a landfill licence, and the MRD structure in the middle of the mine, where a targeted network of piezometers is constructed within variable foundations of the MRD for monitoring its structural integrity. Both of these areas are localised and monitored extensively, with periodic reviews and analyses of data that are documented in separate reports (and likely to be subjected to further assessments to inform their respective rehabilitation options). For this reason, hydrogeological data from these two localised areas are not presented in detail except where the data have provided insights into relevant mine-scale processes e.g. to inform the degree of hydraulic connection between the Yallourn Mine and YNOC (Section 4.8.2) and the nature of surface water-groundwater interactions in the Morwell River floodplain (Section 4.9.2.2).

4.3 Hydrostratigraphy

4.3.1 Definition

Hydrostratigraphic Units (HSUs) are zones within the groundwater system comprising materials of similar hydrogeological properties. They are typically delineated based on stratigraphy although the similarity in hydrogeological properties is more important than the rock type, ensuring that the HSUs behave in a similar manner from the point of view of groundwater flow.

The hydrostratigraphy of the Yallourn Mine is characterised by an alternating sequence of aquifers and aquitards. It is a layered aquifer system, consisting layers of unconsolidated sediments (aquifers) whose inter-connectivity is limited by the presence of intervening coal sequences (aquitards).

4.3.2 Aquifers

4.3.2.1 Haunted Hills Formation

The Haunted Hills Formation (HHF) forms an unconfined to locally semi-confined aquifer that represents the uppermost HSU that contains the water table. Its thickness varies from 10 to 50 m and may contain extensive deposits of water bearing sands and gravels, generally along the basal level of the aquifer, interbedded with clay and sandy clay. Significant quantities of groundwater have been intersected within this aquifer in the past, such as during construction of the 3rd Morwell River Diversion excavation works in 1985 and during mining of East Field which necessitated a spear-point dewatering system (GHD, 2011a). The aquifer has been locally drained during mining (via seepage), resulting in the lowering of groundwater levels.

4.3.2.2 Overburden

Throughout the site, the exposed surfaces of natural (in-situ) material have been covered by re-worked overburden material. These covers vary in thickness and are collectively referred to as the Overburden (OB) in this report (sometimes referred to as the “dumped” overburden in various documents, to distinguish from the natural overburden/HHF above the coal). The water table intersects the OB in many locations, with perched water table forming in some places. For this reason, the groundwater levels measured in bores constructed within the OB and HHF are used collectively to define the uppermost saturated level (water table).

4.3.2.3 M1A Interseam

The M1A Interseam is confined by the overlying M1A Coal and comprises discontinuous sand layers interbedded with coal, clay and silt. It has a typical thickness of around 70 m, with a relatively continuous clay unit of around 30 m in thickness separating the upper and lower sand-rich units of around 15 m in thickness (GHD, 2011a). The thickness this unit reduces to the south, through the Maryvale Field area, before pinching out towards the Hazelwood Mine as the M1A and M1B coals merge to form the M1 coal seam.

For geological modelling purposes, four discontinuous but persistent sand layers have been identified in the M1A interseam in the Maryvale Field area. These are the “M1Asl”, generally within the lower 10 m of the interseam, “M1Asm” found in the middle, “M1As1” in the upper 5 to 20 m and “M1As0” in the upper 5 m below the base of the M1A Coal (GHD, 2012). The distribution of these seams is shown in Figure 26. While these four layers are a simplification of extensively braided river systems (formed intermittently during 30 million years of coal formation), the whole interseam thickness is treated collectively as one HSU (M1A aquifer) for the purpose of hydrogeological conceptualisation. Groundwater has been extracted from pumping bores constructed within this aquifer to reduce its pore pressure and maintain floor stability.

4.3.2.4 M1B and M2 Interseams

The M1B and M2 Interseams at the Yallourn Mine are the lateral equivalent of the M1 and M2 aquifers at the Hazelwood Mine, respectively. These form confined aquifers and are depressurised at the Hazelwood Mine to enable safe mining conditions.

The M1B Interseam thins out in the south of Yallourn Mine (in Maryvale Field) and occurs in limited thickness across much of the footprint of the mine. The M2 Interseam is separated from the M1B and M1A Interseams by the thick M2 Coal. Limited drilling into the M2 Interseam at the Yallourn Mine indicates the presence of clay in the upper part of this unit, locally underlain by basalt flows of the Thorpdale Volcanics, similar to the M2 Interseam (aquifer) near the Hazelwood Mine (SEC, 1988).

It is also likely that highly transmissive sand lenses that exist at a deeper level near the Hazelwood Mine are present to some extent beneath the Yallourn Mine. Drilling to the north and west of the Yallourn Mine indicates that M2 Interseam thins towards the regionally significant Haunted Hills Fault/Yallourn Monocline, where the underlying basement becomes shallower (SEC, 1988).

The M1B and M2 Interseams pressures have not posed a risk to floor stability at Yallourn Mine due to their depth and the effects of depressurisation from the adjacent Hazelwood Mine.

4.3.3 Aquitards

The thick sequences of coal are conceptualised to act as aquitards. These include the following:

- Yallourn Coal, which is the youngest coal unit in the Latrobe Valley and has a thickness of around 60 to 100 m. It separates the Haunted Hills Formation/Overburden from the Yallourn Interseam.
- M1A Coal, which is less extensive and has a thickness of around 5 to 35 m. It thins out to the north and pinches out in East Field where the overlying Yallourn Interseam and the underlying M1A Interseam become directly connected.
- M1B Coal, which separates the M1A Interseam from the M1B Interseam and has a thickness of around 30 to 60 m. It directly overlies the M2 Coal where the M1B Interseam pinches out.
- M2 Coal, which is split into M2A and M2B, has a combined thickness of up to around 100 m. Where the M1B Interseam pinches out, the M2 Coal and M1B coal form a thick regional aquitard that separates the underlying highly transmissive M2 Interseam from the overlying aquifers.

Between the Yallourn Coal and M1 (A/B) Coal lies the Yallourn Interseam, comprising a sequence of clay with minor silty sands and coal which is typically 20 to 50 m in thickness. SEC investigations concluded that a low permeability aquifer referred to as the Y1 aquifer occurs within the interseam as a localised channel deposit in the East Field area (SEC, 1988). Although classified as an aquifer, it was found not to be sufficiently permeable to enable groundwater extraction. GHD (2009) also noted the interseam lithology and hydraulic characteristics vary spatially, which means its response to the depressurisation of the underlying M1A Interseam is also likely be variable.

A simplified analysis of borelog lithologies in the bore database (limited to bores in Maryvale Field) estimated that the Yallourn Interseam is predominately comprised of clay (41.6%) and other fine grained sediments (silt and coal, 49.6%) with sand dominant lithology forming only 7.7% of the interseam in this area (GHD, 2011a). On this basis, the Yallourn Interseam is conceptualised to behave primarily as an aquitard, locally exhibiting the characteristics of an aquifer where the hydraulic conductivity is enhanced by the presence of sand. The Yallourn Interseam is considered to form the basal failure surface for major coal block failures (GHD, 2011a). This means the pore pressure in this HSU is critical for managing batter stability, even though it has low productivity and is of limited use as a resource.

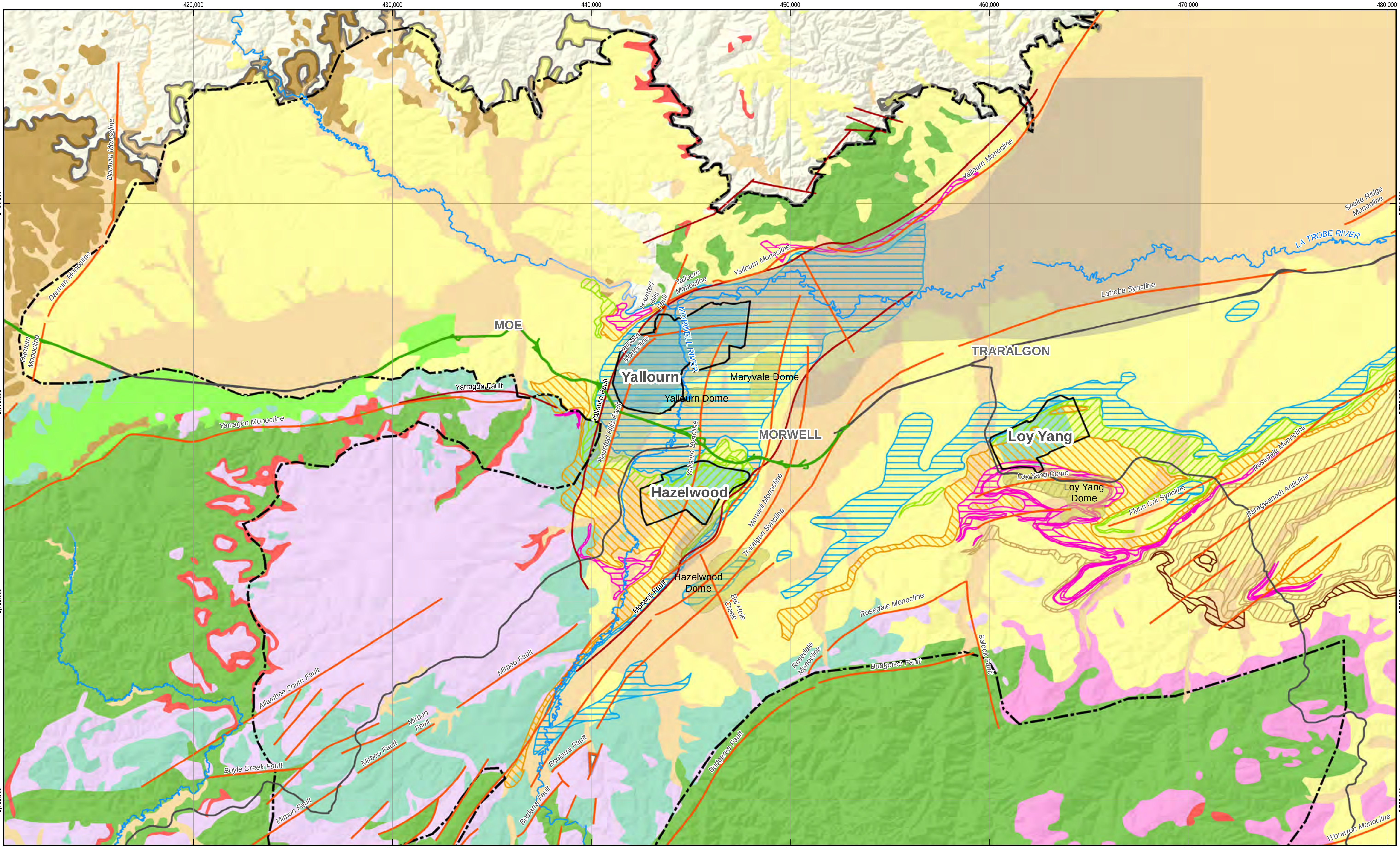
The Basement within the conceptual model domain comprises the Strzelecki Group and Palaeozoic sediments. Recent work by Holdgate et. al. (2015) concluded that there is a significant area of Palaeozoic basement that may underlie the whole of the northern Latrobe Valley area. The Basement is interpreted as a regional aquitard based on its lithologies, permeability testing of the Strzelecki Group and limited responses to dewatering of the overlying aquifers. It forms an effective hydraulic base of the Latrobe Valley groundwater flow system.

4.3.4 HSU extent and thickness

The extent and thickness of the key HSUs described above are presented in Figure 26, using a series of geological cross-sections extracted from the geological model of the mine. These are based on the current mine surface and include the mine void and estimated thickness of the dumped overburden (OB). Also shown in the cross-sections is the planned mine floor of the Maryvale Field area (orange line), highlighting areas of the in-situ material that will be excavated during future mining. The approximate location of MRD is shown in Sections A and B.

As described in Section 4.3.3, the Yallourn Interseam consists of an interbedded sequence of clay, minor sands and coal. The discrete coal horizons within this unit, as currently represented in the geological model, are shown in the cross-sections as thin, spatially limited brown layers within the body of the unit (the white layer) where present. Similarly, individual sand layers within the M1A Interseam are shown as light blue layers (and minor coal, as thin orange layers in Section B).

The spatial extent and the estimated thickness (isopach) of the current internal OB are shown in Figure 27. The isopach has been calculated by subtracting the modelled floor of the original mine void from the current mine surface (August 2021 design surface, assuming that the difference between the two is due to the internal dumps). In addition to the internal OB, the HHF is locally overlain by fill material which is assumed to form part of the OB.



Paper Size A3

0 800 1,600 3,200 4,800 6,400

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

LEGEND

- T1 Seam
- T2 Seam
- M2 Seam
- M1B Seam
- M1A Seam
- Yallourn Seam
- Deep Fault
- Basement Highs
- Paleozoic: deep
- Geological Structures (Geol Survey 250K)
- Model Domain Boundary
- Mine boundary
- Freeway
- Highway
- River
- Stream
- Drain/Channel/Other
- Carrajung Volcanics (P)
- Thorpdale Volcanics (P)
- Latrobe Valley Gr (P)
- Childers Fm (P)
- Strzelecki Gr (K)
- Colluvium (N)
- Haunted Hills Fm (N)
- Gippsland Limestone (N)
- Neerim Volcanics (N)
- Quaternary (Q)

MELBOURNE
BAIRNSDALE
TRARALGON

GHD

EnergyAustralia Yallourn Pty Ltd
Conceptual Hydrogeological Model

Job Number	12521481.0
Revision	B
Date	21/05/2021

Conceptual Hydrogeological Model Domain

Figure 25

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180 Lonsdale Street Melbourne VIC 3000 Australia **T** 61 3 8687 8000 **F** 61 3 8687 8111 **E** melmail@ghd.com **W** www.ghd.com

Data source: DELWP, VicMap, 2020; GHD, Mine Boundaries, 2024 Created by: tworth

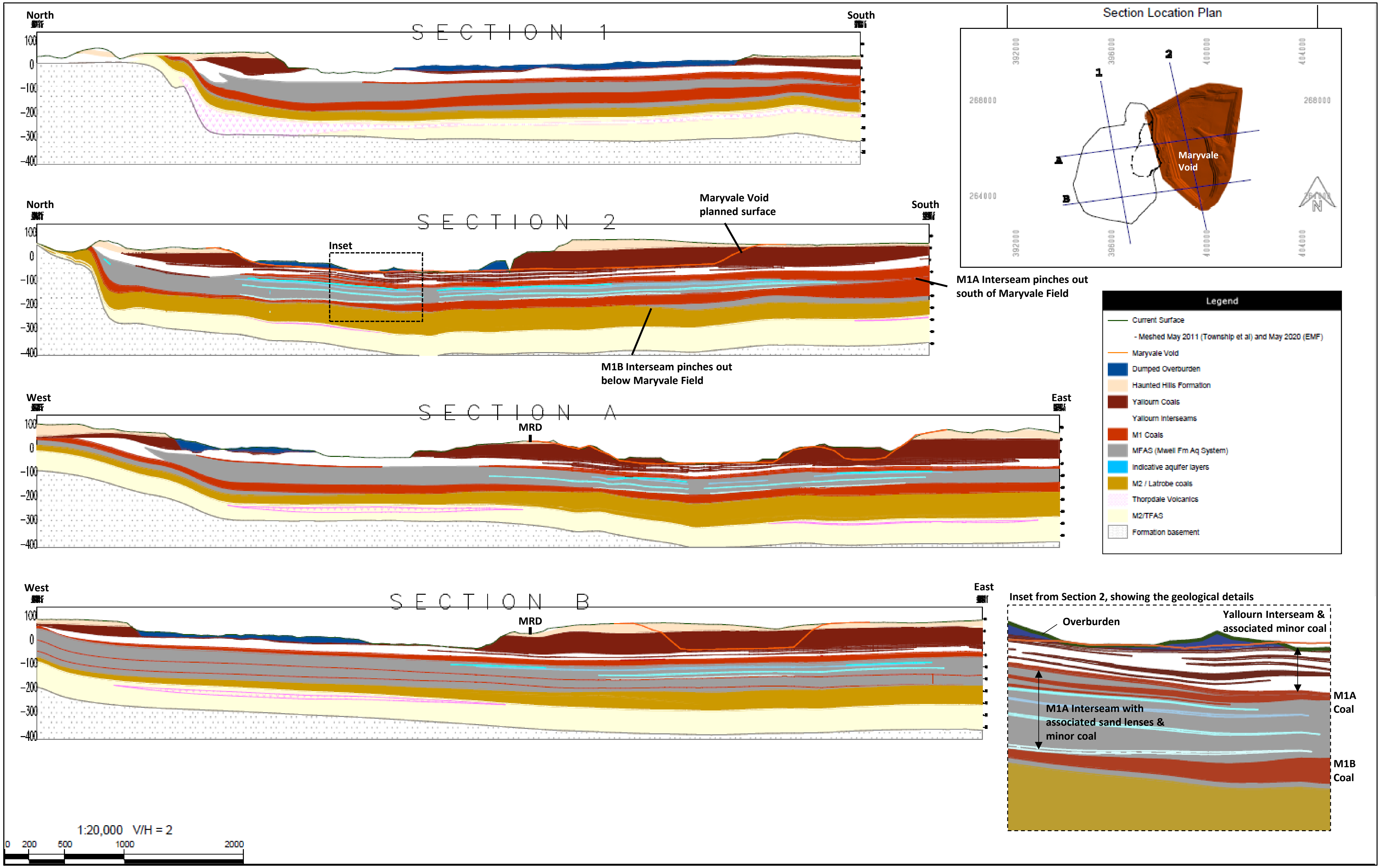
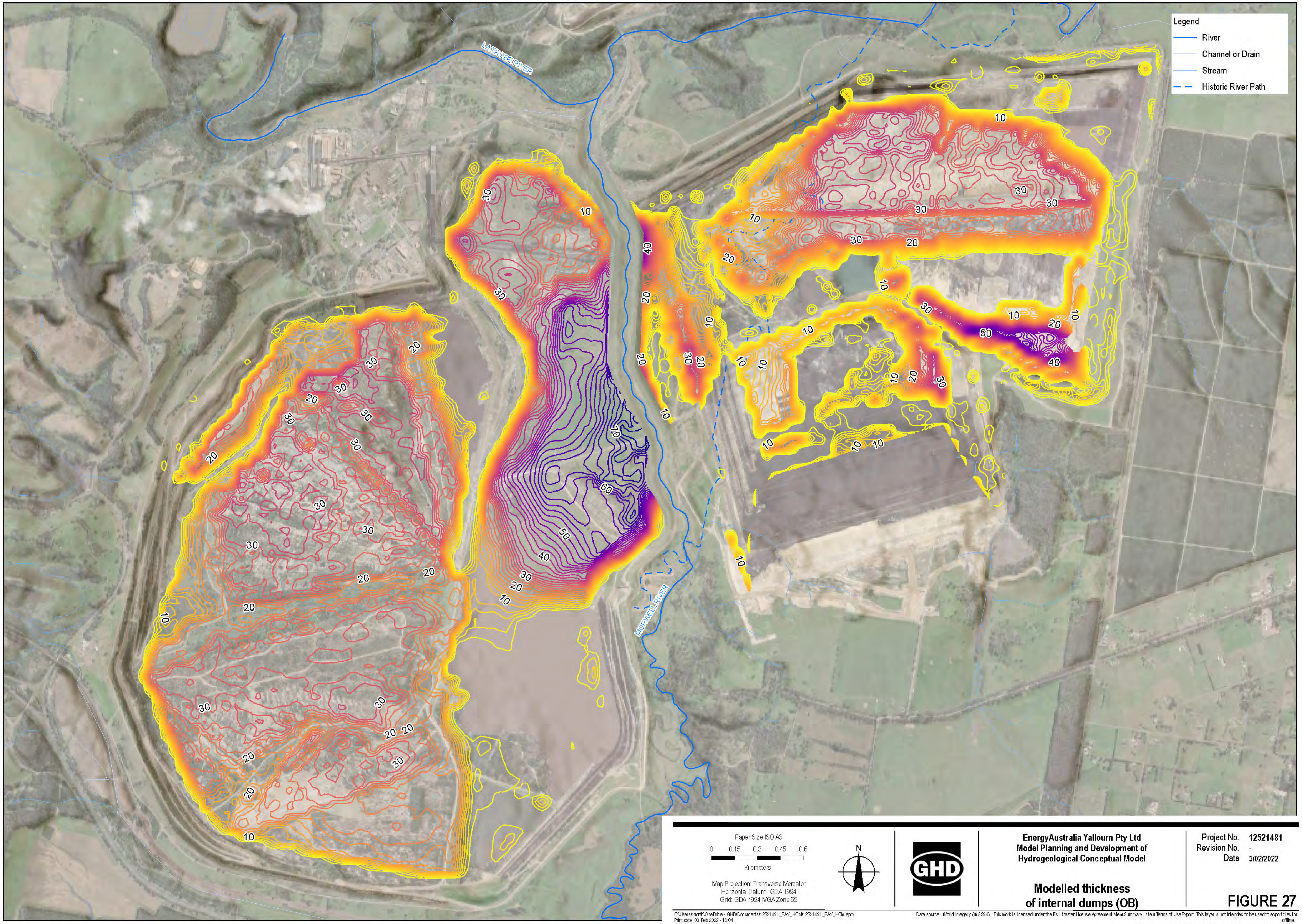


Figure 26 Yallourn Mine Cross Sections



EnergyAustralia Yallourn Pty Ltd
Model Planning and Development of
Hydrogeological Conceptual Model

Modelled thickness of internal dumps (OB)

Project No. 12521481
Revision No. -
Date 3/02/2022

FIGURE 27

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4.4 Hydrogeological Properties

4.4.1 Aquifer testing

Table 3 and Table 4 summarise the results of pumping tests undertaken within the HHF/OB and M1A Interseam respectively. The test results have been reported as either hydraulic conductivity (K) or transmissivity (T). Where available, estimates of storage coefficient are provided. These generally lie within the typical range of values for specific yield (unconfined) and specific storage (confined), potentially reflecting the semi-confined nature of sand horizons within these aquifers.

The most recent pumping test was completed in 2015 on bore N6899 for determining a suitable pumping rate to meet the dewatering requirements (GHD, 2016). The aquifer properties estimated from the analysis of this pumping test data are included in Table 4, based on the Theis solution for confined aquifers. Bore N6899 is screened at 5 discrete sand intervals with a combined thickness of 6 m. Assuming flow into the bore is primarily along these sand intervals, the hydraulic conductivity of sands would equate to around 8 m/d.

Estimates of hydraulic conductivity from the HHF/OB are also available from the grain size distribution of samples taken from multiple depths at 5 m depth intervals. These range from 0.01 to 755 m/d, with a geometric mean of around 4 m/d based on 173 samples from 13 locations. GHD (2018) did not identify the method of deriving hydraulic conductivity from grain size distribution, although SEC (1979) refers to an unpublished method developed by the SEC (Barton, 1970) and a method by Beard and Wyle (1973) based on porosity. While there is lower confidence in these estimates, the geometric mean value of 4 m/d is within the range of values derived from the pumping tests and is considered generally representative of the HHF/OB.

Table 3 Aquifer Test Results – Haunted Hills Formation/Overburden

Investigation	Location	Yield (L/s)	Result
SEC (1979) DD145 Pumping test	East Field	0.05 – 0.1 L/s (24 hrs) 1.54 L/s (6 hrs)	K = 4 m/d S = 0.00001 to 0.001
AGC (1981) Pumping test	3rd MRD Southern area		K = 0.1 to 10.1 m/d
SEC (1981) FE21 Constant head test	3rd MRD		K = 0.0014 to 0.5 m/d
SEC N3476 and M2389 pumping test	East Field (adjacent to MRD)		K = 4 m/d S = 0.0004 to 0.0064
Geo-Eng (1992) 1046/1 M3558 pumping test (9 observation bores)	East Field	5.2 L/s (24 hrs)	K = 2 to 90 m/d S = 0.00025 to 0.007
Geo-Eng (1992) 1046/1 N4465, N4606 and N4607 rising head slug tests	East Field	N/A	K= 26, 0.7 and 0.8 m/d
Geo-Eng (1993) 1157/10 M3603 and M3604 pumping tests	East Field	0.7 L/s (4 days) 3.5 to 5.25 L/s (6 days)	K = 2 m/d, S = 0.003 K = 5 m/d, S = 0.002
Geo-Eng (1996) 1150/13 N5059 and N5061	East Field	1 – 1.6 (8 days)	T = 31.9 – 66.6 m^2/d (44 m^2/d geometric mean) K =2.8 - 6.4 m/d (4.5 m/d geometric mean) S = 0.021 -0.11
Geo-Eng (1998b) 1150/5129/14 12 bores M3741 -M3756	Maryvale MRD		K =0.01 to 0.47 m/d
GHD (2007a) N6232 and N6233	Hearns Oak		K =0.18 K= 2.16

Table 4 Aquifer Test Results – M1A Interseam

Investigation	Location	Yield	Result
Geo-Eng (1994) 1157/18 N4934 pumping test	East Field	16 L/s (23 hrs), 21 L/s (7 hrs)	K = 15 m/d
Geo-Eng (1995) 1157/29 N4934 long term pumping	East Field (Upper & Middle M1A)	13.5 L/s (long term)	T = 94 – 139 m^2/d T = 20 – 31 m^2/d
GHD (2016) N6899 pumping test	Maryvale Field	25 L/s (20 hrs)	T = 49 m^2/d K = 8 m/d (for sands) S= 0.0003

4.4.2 Coal seam testing

Durie (1991) summarised the earlier SEC investigations into the permeability of brown coal. Trollope et al (1965) concluded that the permeability of the intact brown coal in the Latrobe Valley varies with the coal type and moisture content but is generally in the range of 3.6×10^{-6} m/d to 3.6×10^{-4} m/d at the natural moisture contents and is of the same order as that for natural clays. For coals of the Morwell Formation, Green (1970) obtained an average value of 1.8×10^{-7} m/d.

Durie (1991) noted that the macro permeability of the coal seams is governed by the joints and faults associated with geological structures and higher permeability zone in the coals have been encountered on the Loy Yang dome in the range of 3.6×10^{-7} m/d to 3.6×10^{-3} m/day.

In-situ permeability testing of the M1 Coal in the Hazelwood Mine batters was completed by Brown (1970), based on the assumption that the values previously obtained from laboratory testing of uncracked coal samples do not approximate the in-situ values at the batter scale. The results indicated a bulk permeability of the M1 coal mass of 1.7×10^{-3} m/d. This is around one order of magnitude higher than the upper range of values reported in Durie (1991) and is likely to reflect locally elevated bulk permeability in the area adjacent to the batters caused by ground movement during coal excavation and associated fracturing and opening of coal joints.

Golder (2014) summarised the results of constant head field permeability testing of the Yallourn Coal undertaken by SEC, reporting values ranging from 1×10^{-3} to 0.3 m/d. These are greater than the typical range of values of coal seams, although SEC reported that these high values are potentially influenced by fractures in coal or leakage past bore casing into more permeable materials. A hydraulic conductivity value of 7×10^{-4} m/d was also derived by SEC from a laboratory permeameter test (Golder, 2014).

As part of the Latrobe Valley Brown Coal Mine Batter Stability Research Project, permeability testing of the in-situ Yallourn Coal was undertaken at two locations between the Latrobe River and the crest of East Field northern batters (west of the remediated northeast batters that failed in 2007). Field testing included packer testing at 3 m intervals from around 69 m to 79 m depths, which yielded estimated hydraulic conductivity of 8.6×10^{-3} to 1.7×10^{-2} m/d (Baumgartl, 2020). These were approximately two orders of magnitude higher than the 5.2×10^{-6} to 3.5×10^{-4} m/d hydraulic conductivity estimates derived from laboratory permeability testing, which reflect the differences between the undisturbed coal matrix and batter scale properties enhanced by larger discontinuities (Baumgartl, 2020).

4.4.3 Model-derived properties

A summary of hydrogeological properties of relevant HSUs derived from previous numerical groundwater modelling studies undertaken within the Gippsland Basin are provided in Table 5 These include earlier modelling studies by Fraser (1980), Evans (1983), Bolger (1987), SKM (1999) and Nahm (2002), which are summarised by Schaeffer (2008), and more recent studies undertaken by GHD and Victorian Government. It is important to recognise that different models were built with different objectives in mind, with different scales and modelling approaches influenced by the availability of data and software capability at the time of modelling. In general, these model-derived values are likely to reflect regional averages in hydrogeological properties.

Table 5 Model-derived Regional Hydrogeological Properties

Unit	Kh (m/d)	Kv (m/d)	Sy (-)	Ss (-/m) / S (-)	Source
Haunted Hills Formation	5		0.01		4
	0.1	0.005	0.02	0.08[a]	6
	2	0.002 – 4.21	0.1	0.001[a]	7
	3.2	0.48	0.1	1E-5	8
Yallourn Coal	2E-6 – 0.1	1E-5		2.5E-5 – 2E-4	5
	0.002	3E-4	0.1	1E-5	8
Yallourn Interseam	5E-6 – 0.9	4.6E-4		1E-6 – 2.5E-5	5
	0.77	0.115	0.1	1E-5	8
M1 Seam		5E-5			1
	2E-6 – 0.1	1E-5		1.4E-6 – 9.3E-4	5
	0.045 – 0.22	0.0068 – 0.033	0.02	1E-5	8
M1 Interseam	4			5E-5	1
	0.5 – 1.2b			2E-4	2
	0.2 - 5		0.06	2.5E-5	3
	7.7E-5 – 40.4	6.4E-4 – 0.052		8E-8 – 1.3E-4	5
	0.97	0.13	0.1	0.001a	7
	0.16 – 9.7	0.16 – 1.2	0.1	1E-5	8
M2 Seam		3E-4 – 1.2E-3[c]			1
		1E-6[d]			3
	1E-5 – 0.1	1E-5		3.4E-7 – 1E-3	5
	0.42	0.00112	0.1	0.001[a]	7
	0.41	0.062	0.1	1E-5	8
M2 Interseam	0.5 - 12			1E-5	1
	0.2 - 8		0.015 – 0.06	4E-6 - 5E-4	3
	4E-4 – 20.7	0.28 – 0.34		1E-6 – 0.056	5
	1.63	0.3	0.1	0.001[a]	7
	6.12	0.39	0.1	1E-5	8
Basement	1E-10 – 1E-5	1E-9		4.5E-6 – 1E-5	5
	0.0025 – 0.01	6E-4 - 1E-3	0.02	4E-5 – 5E-3	6
	4E-4 – 2.4E-3	1E-4 - 6E-4	0.1	0.001[a]	7
	2E-4 – 0.01	1E-5 - 1E-3	0.02	1E-5	8

Sources:

1. Fraser (1980) Initial mathematical modelling studies Volume 1
2. Evans (1983) Regional groundwater investigation of the Latrobe Valley, Stage 2 mathematical modelling studies
3. Bolger (1987) Regional groundwater investigations of the Latrobe Valley Stage III mathematical modelling studies
4. Nahm (2002) The hydrogeology of the Gippsland Basin and its role in the genesis and accumulation of petroleum
5. Schaeffer (2008) Scaling point based aquifer data for developing groundwater models: Application to the Gippsland Groundwater system
6. GHD (2010a) East Gippsland CMA Groundwater Model. Transient model development report
7. GHD (2010b) West Gippsland CMA Groundwater Model. Transient model development report
8. DELWP (2017) Groundwater numerical modelling for the Gippsland Basin bioregion

Notes:

a. storage coefficient represents storativity
b. represents values for M1 and M2 aquifers combined
c. lower end of the range represents fractured M2 coal
d. represents values for M1 and M2 coals combined

4.5 Conceptual water balance

4.5.1 Mine water management

An overview of the current mine water management is provided in this section based on the site-wide water balance assessment completed to date by EAY. This includes the transfer of water from various sources across the site and associated quantities estimated from the available information (note that not all movement of water is metered/quantifiable). The mine water management is presented graphically in Figure 28, with reference to key water features of the mine, and is summarised as follows:

- The Power Station primarily sources its water from the Latrobe River. The annual surface water volume pumped from the Latrobe River ranges from around 21 to 33 gigalitres (GL), calculated using the monthly volume of water pumped from 2006 to the end of 2019. It is estimated that around 13 to 19 GL of water pumped to the Power Station is lost per year due to evaporation from the cooling towers.
- Slurry from the Power Station is pumped to the Ash System in the Yallourn North Open Cut (YNOC) at around 8 to 11 GL/year, after accounting for the presence of solids/ash (based on the flow meter readings at the Power Station and Ash Ponds from 2010 to 2017, assuming an ash content of 1.49 %). A portion of this water is returned to the Power Station, along with the run-off and groundwater seepage captured in the YNOC, at around 6 to 9 GL/year.
- Surplus water from the Power Station is gravity fed to Township Lake, located in Township Field (also referred to as Lake Placid), which then flows into the Fire Service Pond located to the south. Around to 6 to 15 GL of annual outflow into Township Lake is estimated from the v-notch weir daily measurements collected between 2015 and 2018.
- Fire Service Pond also receives water collected in the Dewatering Pond in East Field and Maryvale Field, which is pumped at a rate of around 5 to 7 GL/year (estimated using the operating hours of the pumps at a typical pumping rate, from 2015 to 2019). This includes groundwater extracted from the confined M1A Interseam (aquifer) and groundwater/run-off collected in the East Field Sump and Maryvale Backside Pond. Water collected in the North-East Pond is gravity-fed to the East Field Sump, which is then fed (via horizontal bore) to the Maryvale Backside Pond and pumped to the Dewatering Pond. Water in the East Field Sump was previously pumped directly to the Dewatering Pond before the horizontal bore was constructed in 2021 to connect the East Field Sump with the Maryvale Backside Pond.
- Water from the Fire Service Pond is pumped to the Floc Pond, which is then pumped to the Morwell River. The discharge of water to the Morwell River is estimated to range from 12 to 18 GL/year based on the data from 2006 to 2019. It is assumed that water is pumped from the Fire Service Pond to the Floc Pond at roughly the same rate. Water from the Fire Service Pond is also pumped to Witts Gully Reservoir, which is used for fire mitigation and dust suppression. Data from 2018 indicates that water is transferred at a rate of around 2.5 GL/year.

4.5.2 Groundwater recharge

Groundwater contained within the Gippsland Basin originates from rainfall-derived recharge. Creeks and rivers locally act as a losing system, particularly following periods of high rainfall, supplying recharge to the water table. Recharge to the confined aquifer systems is conceptualised to be primarily via vertical leakage from the SAS, occurring towards the edge of the basin where the confined aquifers subcrop beneath the surficial cover of the SAS.

Schaeffer (2008) describes potential spatial variations in recharge due to spatial variations in the abundance of permeable material in the surficial cover, with recharge (or leakage) into the confined aquifers potentially limited to isolated areas such as along Wilderness Creek and fractured basalt of the Thorpdale Volcanics to the southwest of the Yallourn Mine.

Estimates of potential recharge rates in the Gippsland Basin have been derived using several methods. Nahm (2002) derived a preliminary estimate of average recharge of 12 mm/y (or 1.2% of average rainfall, assuming 1000 mm/yr rainfall) over the Latrobe River catchment (4,666 km^2 area) based on a simple flow net analysis. Schaeffer (2008), during calibration of the IRM, derived recharge estimates that were broadly consistent with the estimate derived by Nahm (2002). A localised model of the Sale Water Protection Area (SWPA) developed by

SKM (2006) used diffuse recharge of 5 mm/yr with higher seasonal recharge of 20 mm/yr in irrigation areas. The lower diffuse recharge rate is consistent with the lower rainfall in the SWPA some distance from the mines (Section 2.5.1). Varma et al (2010) estimated recharge across the onshore Gippsland Basin to be 1% of rainfall based on the chloride mass balance analysis, consistent with the earlier works by Nahm (2002) and Schaeffer (2008). These recharge rates represent diffuse recharge from rainfall and exclude contributions from stream leakage.

The regional scale groundwater modelling studies by the Victorian Government utilised recharge models to estimate spatially and temporally varying recharge. The West Gippsland Groundwater Model (GHD, 2010b), developed as part of the ecoMarkets project, utilised recharge rates calculated from Victorian Government's Environmental Systems Modelling Platform (EnSym), which originated from the Catchment Analysis Tool (CAT). The spatially aggregated long-term (1975 to 2005) average annual recharge rate was around 80 mm/yr for the entire model domain, equal to around 8 % of annual rainfall, locally exceeding 100 mm/yr in the area around the Yallourn Mine. The Gippsland groundwater model, developed for the onshore natural gas water science studies, utilised a similar approach, applying time series of spatially variable recharge from the CAT model to the MODFLOW model (DEDJTR, 2015). The spatially aggregated recharge from 1972 to 2012 ranged from 20 to 173 mm/yr, with an average of around 75 mm/yr. The BoM's Australian Landscape Water Balance (AWRA-L) model, based on a similar water balance approach, estimates the 10th and 90th percentile long term (1911 – 2016) average deep drainage to be 43 and 101 mm/yr respectively at the Yallourn Mine. Therefore, the landscape water balance modelling approach of Ensym/CAT/AWRA generates estimates of recharge that are much higher than the prior estimates from groundwater modelling and chloride mass balance.

The most recent estimate of diffuse recharge in the area of Yallourn Mine is available from the latest iteration of the LVRGM, which was updated between 2017 and 2019 for ENGIE Hazelwood to inform closure planning of the Hazelwood Mine. The long term average annual recharge is around 13 mm/yr, with the maximum of around 68 mm/yr. These recharge rates are more consistent with those estimated by Nahm (2002), Schaeffer (2008), SKM (2006) and Varma et al (2010) although the recharge rates were not based on rigorous calibration to piezometric heads at the Yallourn Mine.

The implication of the information currently available is that recharge is highly uncertain, with nearly an order of magnitude difference in the estimated values from previous studies utilising different methodologies.

4.5.3 Groundwater discharge

Under natural conditions, the M2/TFAS aquifer system is thought to have flowed to the east and discharged offshore where the sediments are exposed in the continental shelf (Nahm 2002). Natural discharge from the confined MFAS is thought to have been in the eastern parts of the basin, including deflection of flow upwards to discharge to the shallow aquifer system due to the lateral facies transition to low permeability marine sediments. The main discharge mechanism for the local (shallow) groundwater system would have included evapotranspiration along drainage lines as well as potential baseflow to surface courses and discharge to low-lying swampy areas.

Since European settlement in Gippsland, significant areas were drained for farming and groundwater pumped for mining, offshore oil and gas, agricultural and industrial applications have collectively resulted in the lowering of aquifer pressures in the confined aquifers. Groundwater pumped at the Hazelwood and Loy Yang Mines represents the major discharge mechanism that dominates the groundwater balance for the confined aquifers, producing regional sinks in the potentiometric surfaces at the respective mines. At regional scale, the 2015 Gippsland Basin bioregional assessment stated that the aquifer depressurisation for coal mining is not considered to have affected the groundwater levels in the shallow Quaternary and HHF aquifers (Yates *et al,* 2015).

At local scale, mining resulted in the discharge of shallow groundwater via seepage from the HHF exposures on the batters and also from horizontal drains drilled into the Yallourn Coal. These flows are typically low and considered to be a minor component of the conceptual water balance. Figure 28 indicates the approximate locations of groundwater seepage from the base of the HHF in the exposed batters, as identified during a field visit in February 2021. Photographs of these seepage zones are included in Figure 29, showing wet patches on the batter surface with discrete flow and ponding of water along perimeter drains. These discrete zones of groundwater seepage are understood to occur in several locations throughout the mine.

As outlined in Section 3.2.5, pumping bores have been used historically to extract groundwater from the HHF and M1A aquifer. Most of these required only temporary extraction, particularly for the HHF. There are currently two pumping bores extracting groundwater from the M1A aquifer at a total rate ranging from around 0.6 to 1.2 GL/year.

Discharge in the Moe Swamp Basin is considered to be upwards to the water table and surface water system since lithological and structural barriers restrict groundwater flow eastwards into the Latrobe Valley (Brumley and Holdgate, 1983).

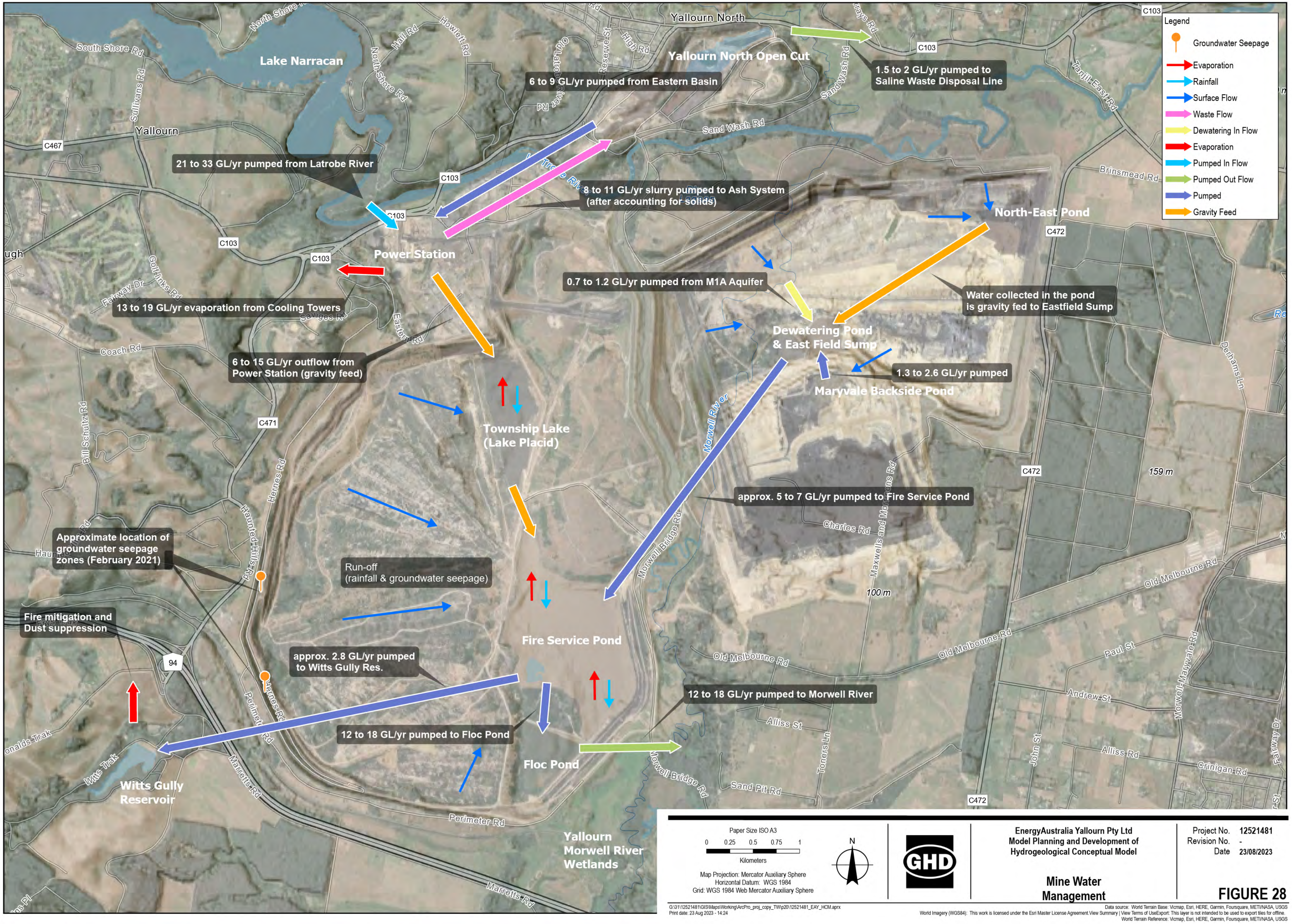

Legend
Groundwater Seepage
Evaporation
Rainfall
Surface Flow
Waste Flow
Dewatering In Flow
Evaporation
Pumped In Flow
Pumped Out Flow
Pumped
Gravity Feed
Lake Narracan
Yallourn
Yallourn North
Yallourn North Open Cut
6 to 9 GL/yr pumped from Eastern Basin
1.5 to 2 GL/yr pumped to Saline Waste Disposal Line
21 to 33 GL/yr pumped from Latrobe River
8 to 11 GL/yr slurry pumped to Ash System (after accounting for solids)
North-East Pond
Power Station
13 to 19 GL/yr evaporation from Cooling Towers
0.7 to 1.2 GL/yr pumped from M1A Aquifer
Water collected in the pond is gravity fed to Eastfield Sump
Dewatering Pond & East Field Sump
6 to 15 GL/yr outflow from Power Station (gravity feed)
1.3 to 2.6 GL/yr pumped
Maryvale Backside Pond
Township Lake (Lake Placid)
approx. 5 to 7 GL/yr pumped to Fire Service Pond
Approximate location of groundwater seepage zones (February 2021)
Run-off (rainfall & groundwater seepage)
Fire mitigation and Dust suppression
Fire Service Pond
approx. 2.8 GL/yr pumped to Witts Gully Res.
12 to 18 GL/yr pumped to Morwell River
12 to 18 GL/yr pumped to Floc Pond
Floc Pond
Witts Gully Reservoir
Yallourn Morwell River Wetlands
Morwell River
159 m
100 m
Paper Size ISO A3
0 0.25 0.5 0.75 1
Kilometers
Map Projection: Mercator Auxiliary Sphere
Horizontal Datum: WGS 1984
Grid: WGS 1984 Web Mercator Auxiliary Sphere
N
GHD
EnergyAustralia Yallourn Pty Ltd
Model Planning and Development of Hydrogeological Conceptual Model
Mine Water Management
Project No. 12521481
Revision No. -
Date 23/08/2023
FIGURE 28

Figure 29 HHF Groundwater Seepage (February, 2021)

4.6 Groundwater levels and flow directions

4.6.1 Pre-mining

Fraser (1980) estimated the pre-mining piezometric heads of the confined aquifers to be around 50 mAHD for the MFAS, similar to the pre-mining ground level and around 60 mAHD for the M2/TFAS. The bores drilled into the confined aquifers between the Yallourn and Hazelwood Mines encountered flow at surface (artesian condition) with a piezometric head of around 58 mAHD in the deep M2 aquifer prior to dewatering of the Hazelwood Mine. It is likely that the pre-mining piezometric heads at the Yallourn Mine ranged from around 50 to 60 mAHD, similar to those estimated at the Hazelwood Mine.

4.6.2 Existing condition

Groundwater levels and flow directions are described with reference to the contours of piezometric heads constructed from piezometers/bores within the key aquifer units that include the HHF/OB, Yallourn Interseam and M1A Interseam. The contours are generated using average piezometric heads from 2019, representing the period with the largest number of observations, and reflect the current groundwater flow condition. As the piezometric heads are influenced by factors such as climate, pumping and mining, the contours and associated flow directions would have varied over time. The changes in groundwater regime over time are described in Section 5.

Figure 30 shows the interpreted groundwater contours of the HHF/OB aquifer, effectively representing the surface of the water table (collectively referred to as the “Haunted Hills Formation” in the figure). Within the footprint of the mine, the water table mostly resides within the dumped OB whereas the HHF/undisturbed OB generally forms the uppermost saturated unit outside of the mine, where shallow groundwater is maintained by recharge and locally by stream leakage. In generating the contours, the current surface of the mine has been used to guide the contours in areas where the piezometers/bores are missing. In some places, the HHF/OB is absent, in which case the current surface of the mine has been used to constrain the contours e.g. in the Maryvale Field area, as discussed below.

The contours indicate convergence of flow lines towards the mine, consistent with the conceptualisation that the mine acts as the point of discharge of shallow groundwater. Steep horizontal hydraulic gradients (closely spaced contours) occur from the grass level (ground surface outside of the mine void), where the water table is maintained by recharge, to the mine. The piezometric heads in the northeast corner of the Eastfield overburden dump are broadly consistent with the floor elevation, where the local low point depresses the water table. In the Maryvale Field area, the mine floor is less than -55 mAHD and the contours have been modified to reflect the expected flow towards this low point (with the contours constrained along the boundary of the Maryvale void).

Figure 31 and Figure 32 present the interpreted groundwater contours of the Yallourn Interseam and M1A Interseam, respectively. These contours generally indicate convergence of flow lines towards the mine and pumping bores in the M1A Interseam, with the cone of depression centred on the bores with the highest pumping rates. The similarity in the contours of these two aquifers indicate a degree of hydraulic connection close to the pumping bores where the M1A Interseam pumping is inducing a downwards leakage from the Yallourn Interseam. The influence of pumping and vertical hydraulic connection between these two aquifers is discussed in Section 4.7.3.

The piezometric heads in the Yallourn Interseam are also strongly influenced by other mining activities, such as the placement of horizontal drains into the coal batters and pressure dissipation associated with the removal of the overlying coal. For example, the lowest piezometric head in the Yallourn Interseam shown in Figure 31 is located in the Maryvale Field area and not in the immediate vicinity of the pumping bores in the M1A Interseam. This is likely due to the excavation of coal in the adjacent area to levels below -55 mAHD, causing the coal to drain and the pressure within the Yallourn Interseam to dissipate in the mine floor.

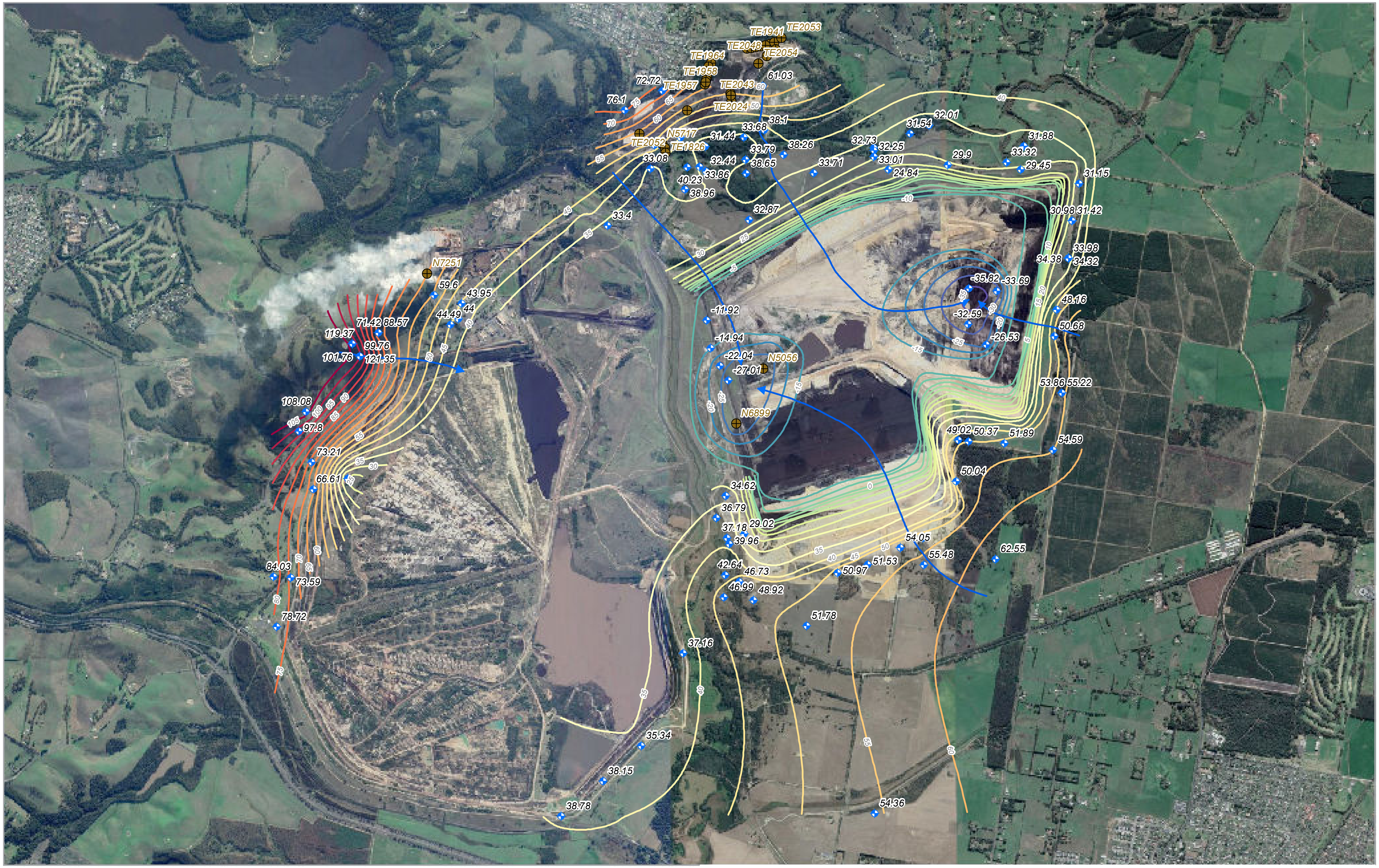
Table 6 compares the average 2019 groundwater levels (piezometric heads) calculated at selected Yallourn Interseam piezometers in the Maryvale Field and East Field areas against the elevation of mine floor and top of Yallourn Interseam. In some locations the piezometric heads are close to or slightly above the mine floor elevation although the top of the interseam is below the mine floor (confined by either the Yallourn Coal or internal OB or both, resulting in a locally artesian condition).

It is possible that the Yallourn Interseam locally forms the uppermost saturated unit in the Maryvale Field area where there is currently limited to no overlying material. If so, the surface of the water table within the mine void could traverse across more than one unit, from the OB in East Field to the Yallourn Interseam in Maryvale Field where the water table is locally depressed by the pressure relief effect associated with the removal of the overlying coal. The influence of these mining activities on the piezometric heads is discussed further in Section 4.7.4.

Table 6 Yallourn Interseam Piezometric Heads and Mine Floor

Piezometer ID	Easting	Northing	2019 Avg head (mAHD)	2019 Mine Floor (mAHD)*	Top of Yallourn Interseam (mAHD)#
M3679_v04	445818.496	5773206.288	-48.40	-42.96	-55.84
M3869_v04	445855.558	5772468.077	-55.15	-22.07	-51.94
N4963_v01	444988.344	5773402.131	-54.63	-13.90	-22.06
N4963_v02	444988.344	5773402.131	-40.27	-13.90	-22.06
N4994_v03	444794.267	5773341.147	-34.92	-5.17	
N5160_v05	445239.264	5772210.401	-26.29	-16.18	-50.91
N5173_v03	445571.035	5773151.095	-43.69	-44.63	-53.27
N5173_v04	445571.035	5773151.095	-49.23	-44.63	-53.27
N5184_v05	445028.671	5772866.779	-34.32	-23.80	-43.44
N5575_v01	445910.964	5773731.691	-38.96	-23.65	-54.80
N6369_v01	444898.046	5772623.771	-25.63	3.07	
N6369_v02	444898.046	5772623.771	-22.72	3.07	
N6372_v02	444956.133	5772415.547	-26.73	0.34	
N6384_v01	447207.578	5774725.115	-7.49	19.57	-37.51
N6402_v01	446700.580	5774800.637	-21.88	23.68	-43.62
N6402_v02	446700.580	5774800.637	-22.02	23.68	-43.62
N6403_v01	447254.493	5774654.916	-24.27	-1.14	-35.39
N6426_v04	446423.287	5773248.968	-38.92	-40.68	-46.01
N6547_v02	446989.164	5772949.678	-12.49	9.53	-40.74
N6581_v07	445292.783	5773020.551	-35.87	-39.80	-55.97
N6819_v01	447371.361	5774636.728	-25.84	-0.01	-38.71
N7061_v02	446418.572	5774675.912	-23.21	14.19	-48.43
N7064_v02	446415.346	5774693.028	-21.61	18.97	-48.43

**Floor elevations extracted using an elevation grid constructed from surveyed contours and are approximate*
#Yallourn Interseam top elevation extracted using an elevation grid constructed from contours derived from the mine geological model



Legend

- M1A pump bore locations
- HHF Monitoring Bore (Ave 2019 groundwater level)
- Groundwater Flow Direction

Groundwater level (mAHD)

-35, -30, -25, -20, -15, -10, -5, 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105

Paper Size ISO A3

0 0.25 0.5 0.75 1

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Energy Australia Yallourn
Conceptual Hydrogeological Model

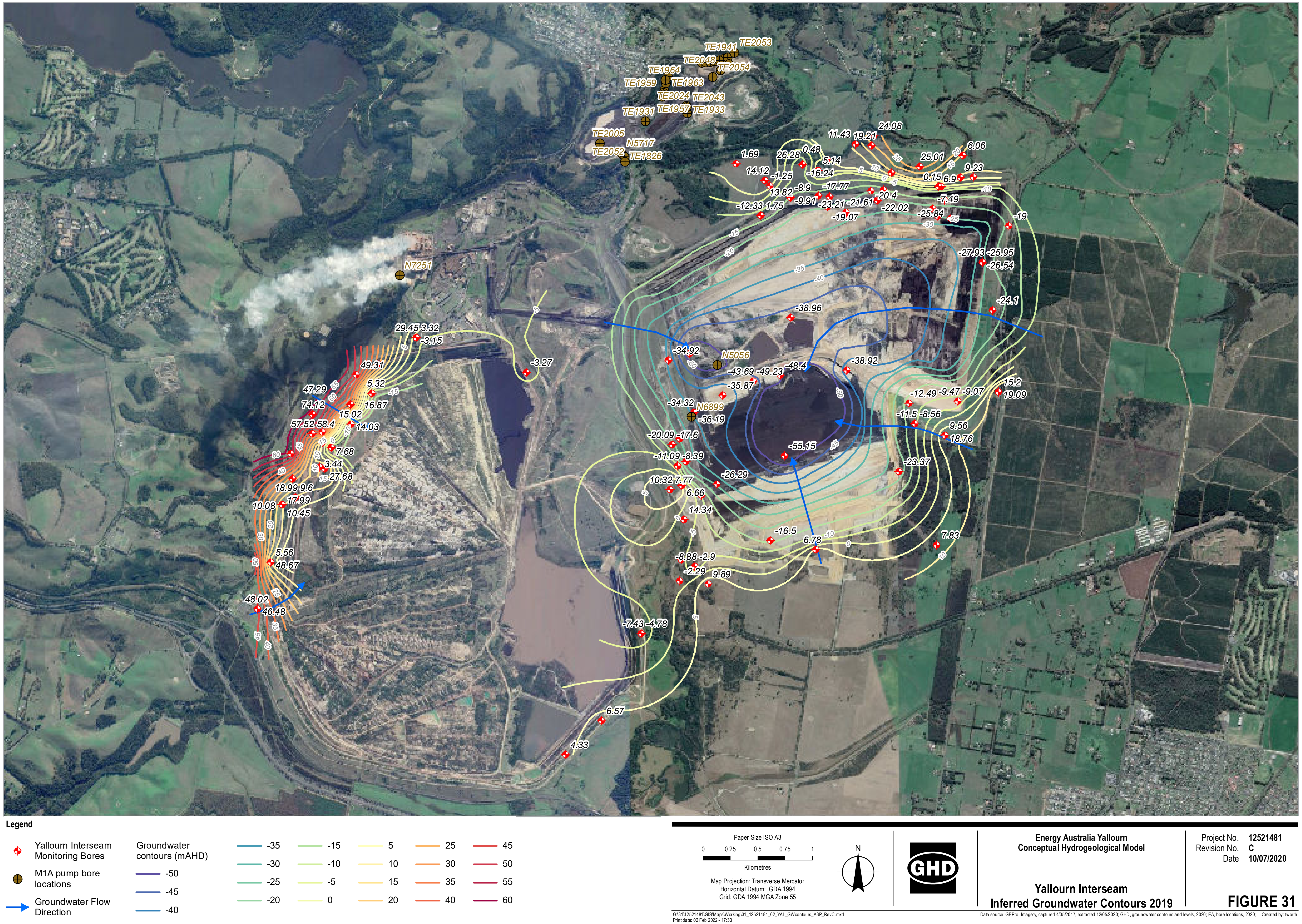
Haunted Hills Formation (HHF)
Inferred Groundwater Contours 2019

Project No. **12521481**
Revision No. **B**
Date **16/06/2020**

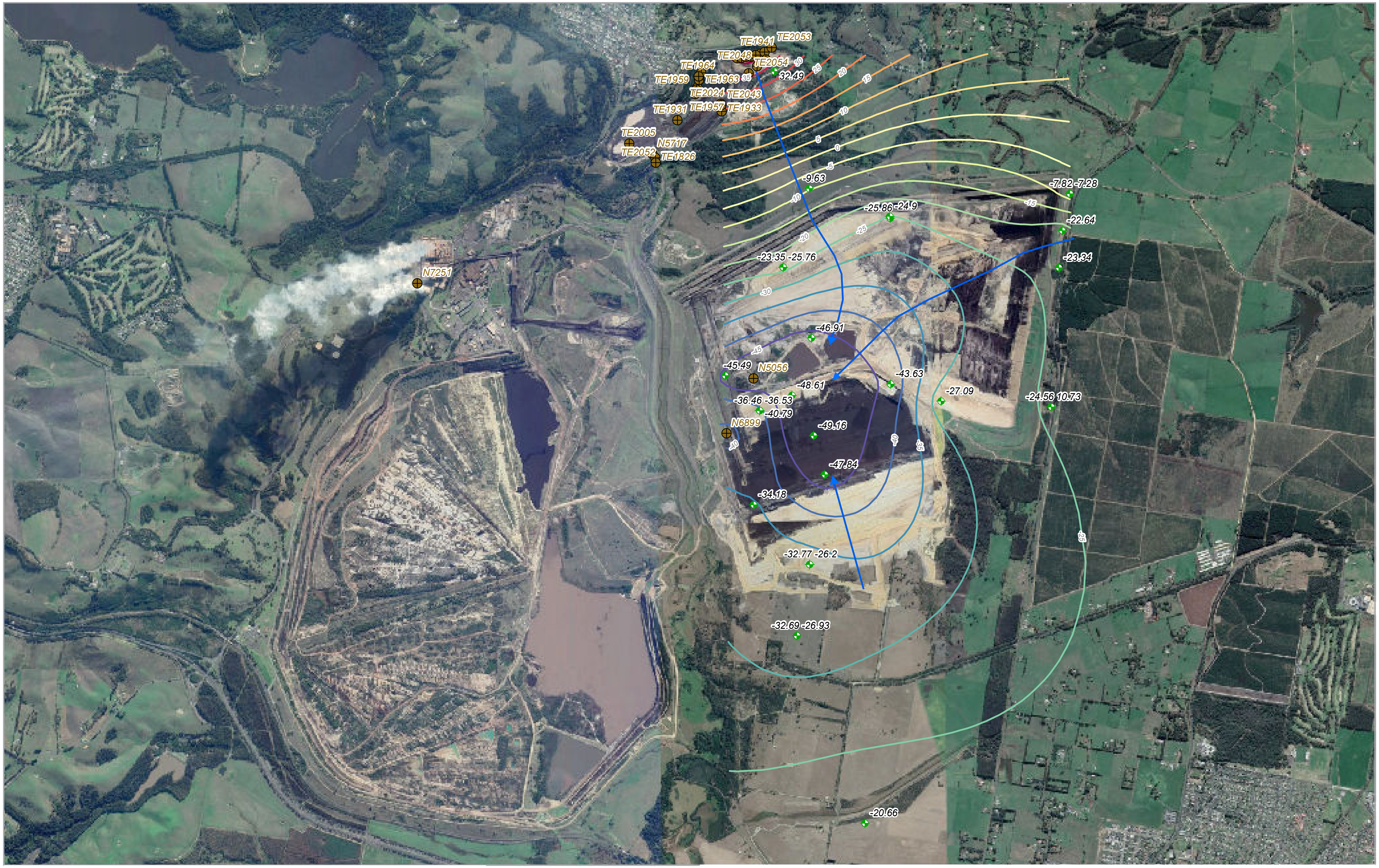
FIGURE 30

G:\31\12521481\GIS\Maps\Working\31_12521481_01_HHF_GWcontours_A3P_RevB.mxd
Print date: 02 Feb 2022 - 17:30

Data source: GEPro, Imagery, captured 4/05/2017, extracted 12/05/2020; GHD, groundwater contours and levels, 2020; EA, bore locations, 2020; . Created by: tworth



Legend
Yallourn Interseam Monitoring Bores
M1A pump bore locations
Groundwater Flow Direction
Groundwater contours (mAHD)
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Paper Size ISO A3
0 0.25 0.5 0.75 1
Kilometres
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55
N
GHD
Energy Australia Yallourn
Conceptual Hydrogeological Model
Project No. 12521481
Revision No. C
Date 10/07/2020
Yallourn Interseam
Inferred Groundwater Contours 2019
FIGURE 31



Legend

- M1A Aquifer Monitoring Bore
- M1A pump bore locations
- Groundwater Flow Direction

Groundwater Contour (mAHD): -45, -40, -35, -30, -25, -20, -15, -10, -5, 0, 5, 10, 15, 20, 25, 30, 35, 40

Paper Size ISO A3

0 0.25 0.5 0.75 1

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Energy Australia Yallourn
Conceptual Hydrogeological Model

M1A Interseam
Inferred Groundwater Contours 2019

Project No. **12521481**
Revision No. **B**
Date **16/06/2020**

FIGURE 32

G:\31\12521481\GIS\Maps\Working\31_12521481_03_M1A_GWcontours_A3P_RevB.mxd
Print date: 02 Feb 2022 - 17:37

Data source: GEPro, Imagery, captured 4/05/2017, extracted 12/05/2020; GHD, groundwater contours and levels, 2020; EA, bore locations, 2020; . Created by: tworth

There are no groundwater monitoring bores in the M2/TFAS in the Yallourn area as this is not considered a significant aquifer for mining operations at the Yallourn Mine (although it is monitored as part of the regional monitoring network, due to the significant influence of aquifer depressurisation at the other mines). The interpreted potentiometric contours from the recent Five-Year Review (GHD 2022b) (Figure 33) indicate that the Hazelwood Mine continues to be a sink within this confined aquifer system, with the piezometric heads beneath the Yallourn Mine estimated to decrease from around 0 mAHD in the north to -50 mAHD in the south.

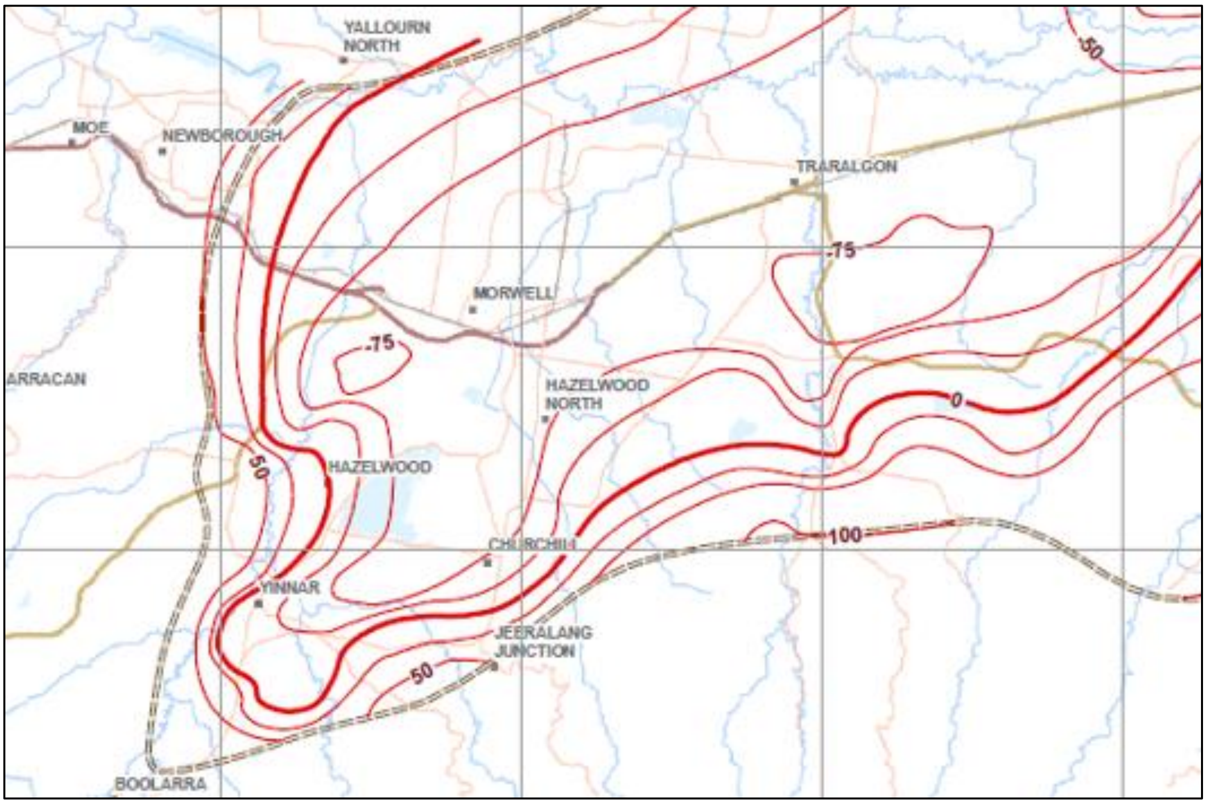


Figure 33 Interpretated Potentiometric Surface 2020 M2/TFAS (after GHD, 2022b)

4.7 Groundwater trends

4.7.1 Stress-response relationship

When hydrological stresses such as recharge and pumping are imposed on the hydrogeological system, changes in groundwater levels are observed. Temporal trends in groundwater levels reflect the combined influence of hydrological stresses and how they vary over time in response to climate and mining operations. This section describes the stress-response relationships observed in the monitoring data based on the analysis of hydrographs from representative bores/piezometers.

Hydrographs have been chosen where the influence of stresses such as recharge and pumping are discernible. The bore/piezometer names in the hydrographs use the letter “s” to refer to standpipe/bore and “v” to refer to piezometer. The number that follows the letter refers to the sensor number of nested piezometers, as recorded in the Yallourn Mine database. While there is a large number of bores and piezometers, not all contain continuous records spanning over sufficient time to assist with the interpretation of long-term trends (refer to Section 4.7.2). Additionally, not all data is considered reliable due to uncertainty in the structural integrity of the bores and seals between piezometers. Data that is considered to be representative has been chosen and presented in the following sections.

4.7.2 Long term climate induced trends

presents hydrographs of bores/piezometers with long term data showing the influence of climate. These bores are generally shallow, constructed within the uppermost aquifer, and located some distance from the mine void where the temporal trends are not dominated by the influence of mining. The hydrographs are plotted with the cumulative departure from mean (CDFM) rainfall to indicate wetter periods and drier periods. From 1990 to 1998, there was a period of above average rainfall, followed by the Millennium Drought from 1998 to 2009. The wet period in 2010 and 2011 marked the wettest two-year period on record, with significant rainfall in late 2010 and early 2011. This is followed by a period of generally below average rainfall, indicating drier recent conditions.

All hydrographs shown in have trends that follow the rainfall CDFM, indicating the shallow aquifers are sensitive to rainfall-derived recharge. Groundwater levels rise during wet periods, due to the cumulative effect of above average recharge progressively replenishing aquifer storage. During dry periods, there is a net declining trend as recharge is insufficient to maintain the water table. The hydrographs indicate long term seasonal variations of around 2 m with the exception of N4891_v02 constructed within the Yallourn Interseam, which shows a long-term range of up to around 17 m from the peak in 1996 to the low point in 2019. It should be noted that the trends observed in some of the piezometers, such as N4891_v02, are likely to be partly influenced by the mining activities, which are further discussed in Section 4.7.4. The data collected since 2014 at N4891_v02 shows annual variations of around 1 m, with an increase of up to 2 m in 2019 following a period of high rainfall in August, which are considered more representative of the typical range of variations due to recharge.

4.7.3 Pumping induced trends

4.7.3.1 M1A Interseam

Figure 35 presents hydrographs from piezometers constructed within the M1A Interseam where the effect of groundwater extractions can be seen. Also shown in the figure is the hydrograph of total monthly groundwater extraction rates, so the relationship between pumping and groundwater levels can be easily identified. The hydrographs are taken from piezometers located at different distances from the pumping bores (indicated on each hydrograph relative to pumping bore N5056), to show spatial differences in response to pumping.

The hydrographs show a net declining trend over time in response to pumping, with a steeper rate of decline during periods of higher pumping and temporary recovery/stabilisation during the period of low pumping between 2004 and 2008. The piezometers located closer to the pumping bores show larger overall declines (drawdown) in response to pumping, with the most pronounced fluctuations in response to short term changes in pumping rate observed at piezometer N5173_v01. The decrease in drawdown with an increase in distance from the pumping bores is best demonstrated in Figure 36, which shows around 20 m of additional drawdown at N4863_v02 since 1996 compared to M3794_v05, with the difference in piezometric heads between the two piezometers increasing over time. Similarly, the second chart on Figure 36 shows less drawdown in piezometers further to the northeast when the pumping rate increased in 2015 (combined pumping from N5056 and N6899). In general, the M1A Interseam over the mine shows a radial flow response to pumping typical of a laterally continuous confined aquifer, with spatial differences reflecting spatial variability in aquifer properties.

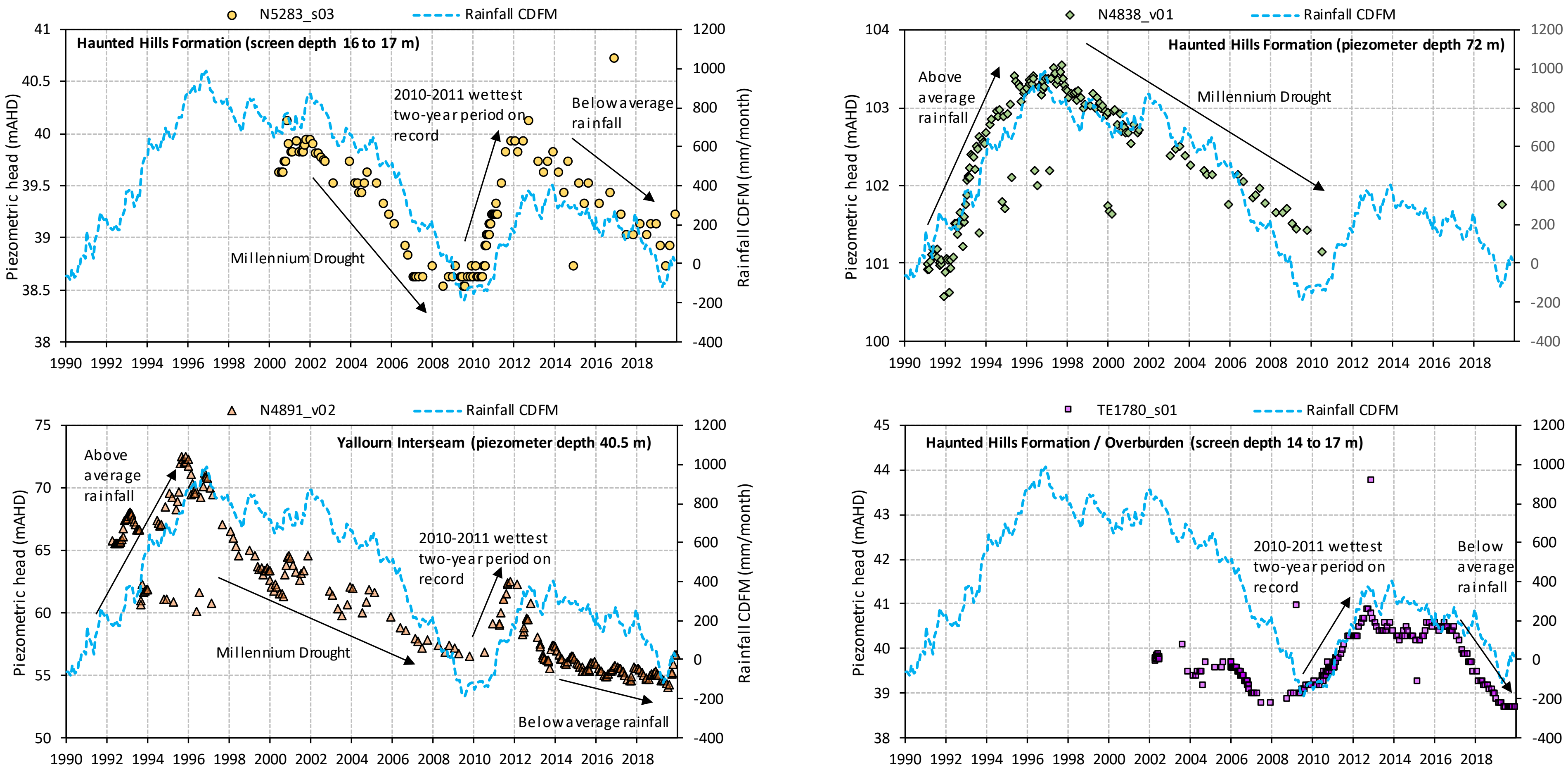


Figure 34 Hydrographs – Climate Induced Trends

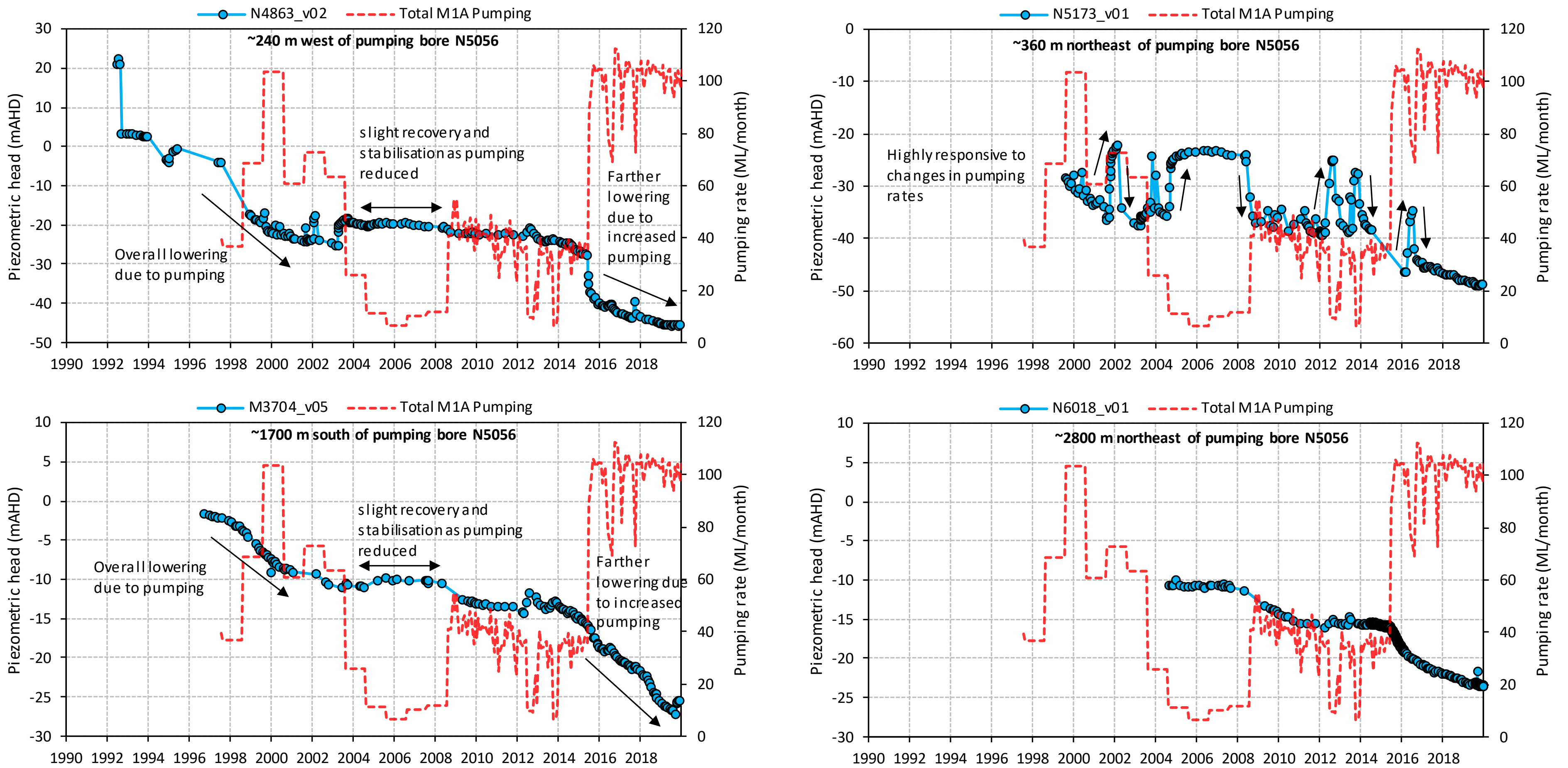


Figure 35 M1A Interseam Hydrographs – Pumping-induced Trends

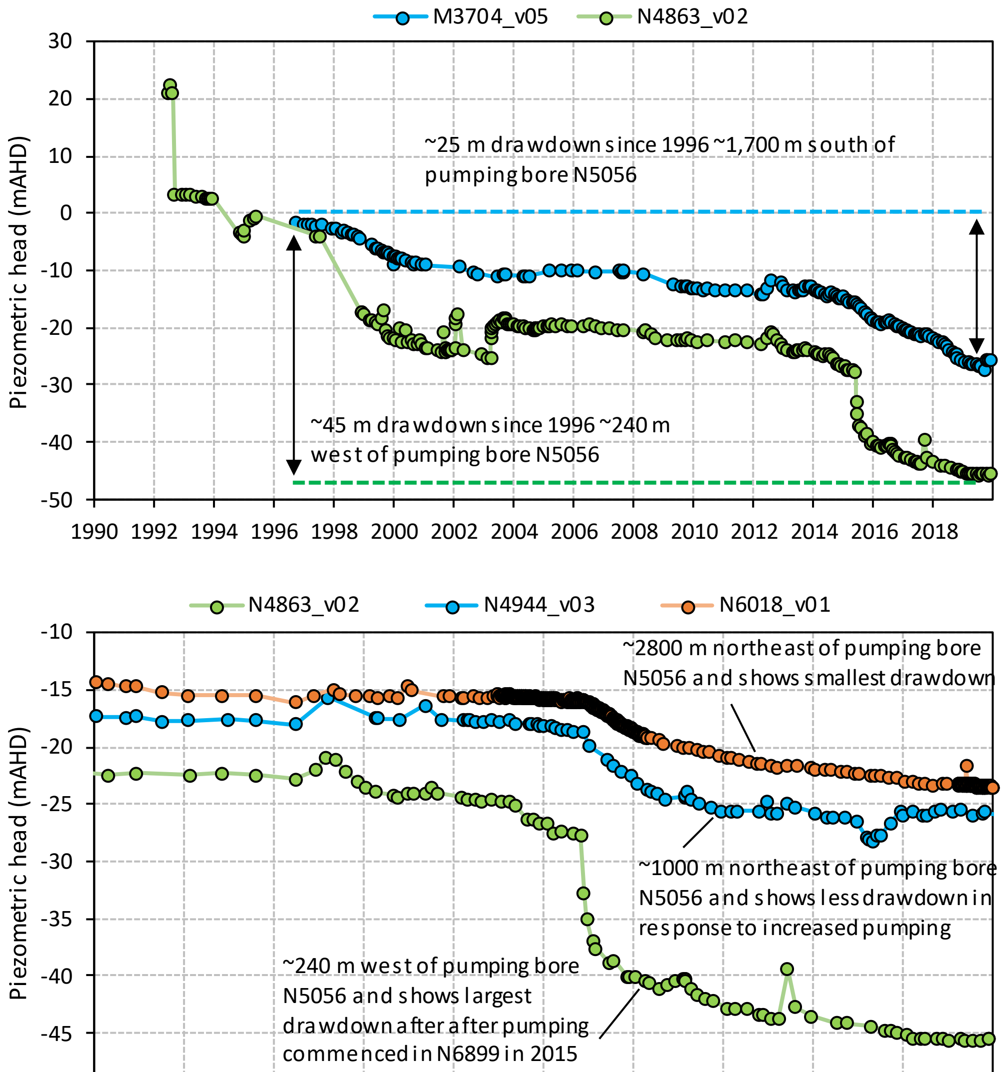


Figure 36 Hydrographs – Pumping Response at Different distances

4.7.3.2 Yallourn Interseam

The hydrographs from some of the piezometers constructed within the overlying Yallourn Interseam show declining trends that appear to be partly influenced by pumping occurring in the underlying M1A Interseam, indicating a degree of hydraulic connection between the two HSUs.

Figure 37 compares the hydrographs of two nested sites, M3704 and N5173. At M3704, drawdown in the Yallourn Interseam is similar to that of the underlying M1A Interseam. Both of these piezometers show gradual responses to changes in pumping, with the Yallourn Interseam response more subdued possibly due to resistance to flow in the vertical direction. The downward vertical hydraulic gradient remains consistent over time, with the downward leakage into the underlying M1A Interseam. At nested site N5173, much closer to the pumping bore, the vertical hydraulic gradient periodically reverses during times of low pumping as the M1A Interseam pressures rapidly recover. In contrast, the Yallourn Interseam is less responsive to changes in the pumping rate, particularly after 2015 where the piezometric heads are steady despite a large increase in pumping. This indicates more limited connection with the M1A Interseam at this location.

Also shown in Figure 37 are more recent hydrographs from piezometers within the Maryvale Field area where both the Yallourn and M1A Interseams show an overall declining trend. However, it should be noted that the declining trend in this area, particularly in the upper part of the Yallourn Interseam, is also strongly influenced by the mine progression and placement of horizontal drains which are discussed in Section 4.7.4. For example, piezometric heads in M3867_v03 and M3869_v04 show drops much steeper than those in the M1A Interseam, which cannot be attributed solely to pumping. GHD (2009) also noted that the Yallourn Interseam pore pressures were lower than those of the M1A Interseam in the mine floor area, and concluded that there was little connection between these two HSUs in some places, with the depressurisation of the Yallourn Interseam likely to be influenced by factors other than pumping (such as seepage to the mine floor).

In summary, pumping in the M1A Interseam is likely a contributing factor for the depressurisation in the Yallourn Interseam albeit to a varying degree depending on the depth of the Yallourn Interseam below the mine floor. The influence of other mining activities and the level of hydraulic connection that exists between the two HSUs is likely to be influenced by the thickness and properties of the intervening M1A Coal, as discussed in Section 4.8.1.

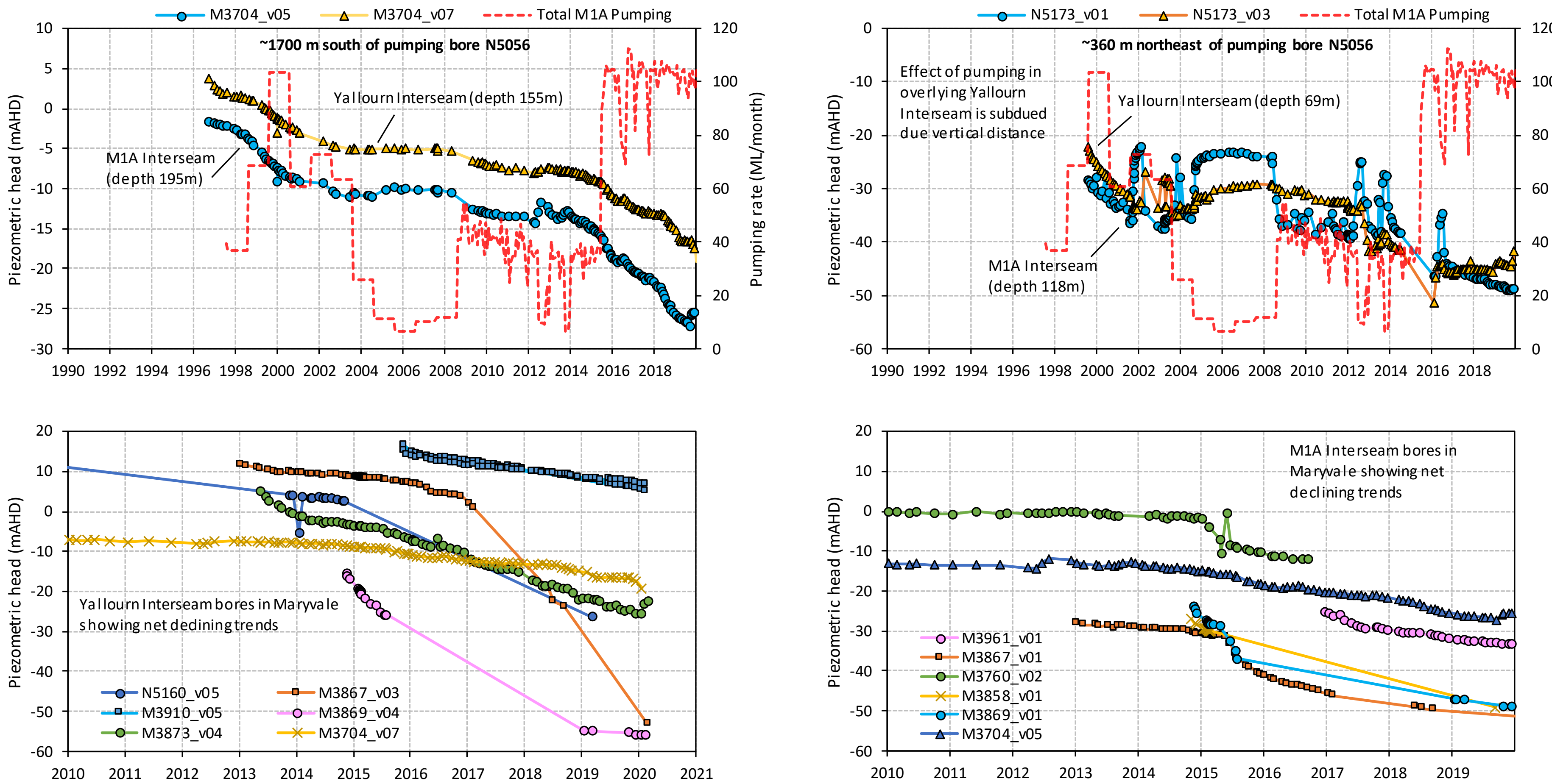


Figure 37 *Hydrographs – Pumping Response in M1A Interseam and Yallourn Interseam (top – nested sites, bottom – Maryvale)*

4.7.4 Other mining induced trends

4.7.4.1 Pressure loading

Temporary changes in piezometric heads have been observed due to pressure loading effects associated with the placement of overburden material. These are typically characterised by a sharp spike in the piezometric heads when the load is placed, followed by a gradual dissipation of pore pressure. The response to the pressure loading effect becomes more subdued deeper in the stratigraphic profile, characterised by a smaller spike that rises more gradually.

Figure 38 compares the piezometric heads from piezometers in the HHF/OB against the Morwell River level, adjacent to Maryvale Field. A sharp increase in piezometric heads can be seen in mid-2017, which is not related to surface water – groundwater interaction as evidenced by the static water level in the Morwell River at that time. Figure 39 presents an example of a nested site, where the pressure loading effect on the piezometric head becomes more subdued with increase in depth.

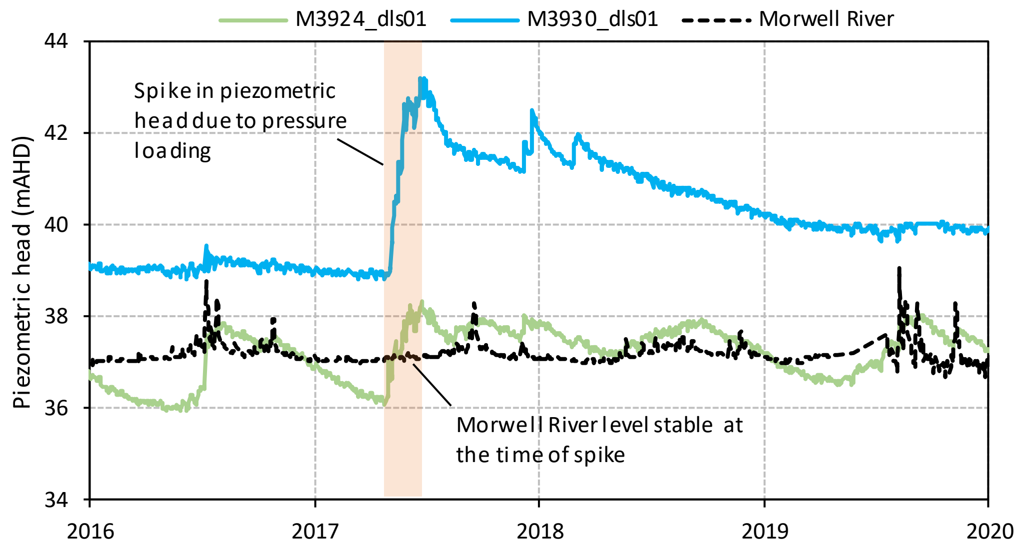


Figure 38 Pressure Loading Effect on Shallow Aquifer

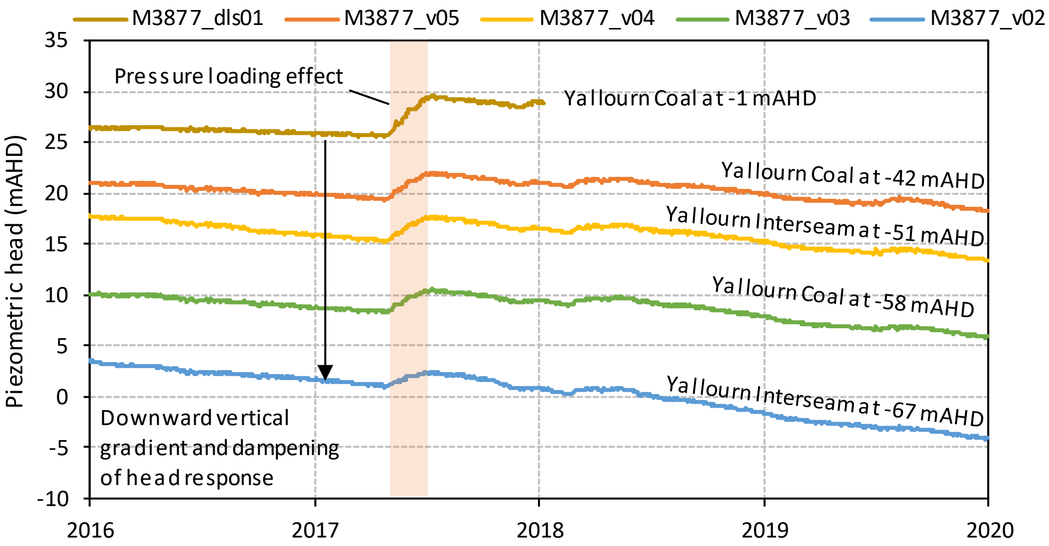


Figure 39 Pressure Loading Effect with Depth

4.7.4.2 Pressure dissipation

The Ground Control Management Plan (GCMP) documents the use of sub-horizontal drains drilled into the coal batters to relieve hydraulic pressure in the Yallourn Coal. The pressure reduction in the drains may result in local depressurisation of the upper part of the Yallourn Interseam, depending on the degree of hydraulic connection between the horizontal drains and flow paths (fractures) within the coal, and their connection with the underlying Yallourn Interseam.

Similarly, a rapid pressure reduction in the upper part of the Yallourn Interseam is often correlated with the mine progression, when the excavation of coal results in the draining of groundwater from the newly excavated coal faces and mine floor, resulting in the rapid dissipation of hydraulic pressure within the exposed coal and the underlying interseam. Figure 40 shows examples of hydrographs from the Yallourn Interseam where rapid reductions in piezometric heads have been observed as the mine progresses to the south into the Maryvale Field area. These effects are typically characterised by around 40 to 50 m drop in piezometric heads over 2 to 3 years as the mine progresses, followed by stabilisation of heads at a level approximately equal to the adjacent floor elevation. This effect can also be seen in the interpreted piezometric surface of the Yallourn Interseam, where the current low point matches the mine floor elevation (Figure 31). This is consistent with GHD (2009), which concluded that declines in Yallourn Interseam pore pressures appear to be responsive to mine expansion and sensitive to the proximity of the interseam to the mine floor.

The depressurisation of the Yallourn Coal and Yallourn Interseam via a combination of horizontal drains and drainage out of the excavated faces has been an integral part of managing pore pressure in these units to maintain batter stability. This differs from the deeper M1A Interseam, which is not directly connected to the mine floor and requires active depressurisation via pumping bores.

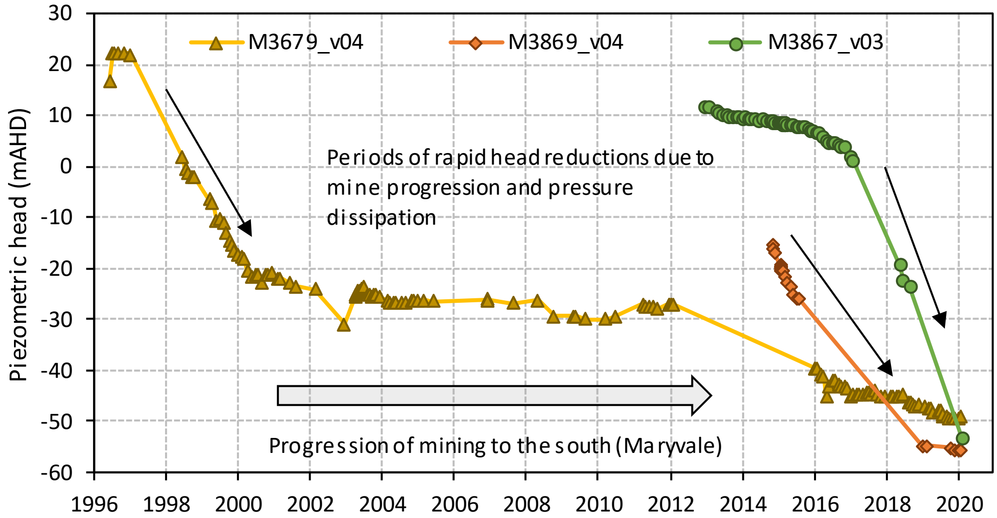


Figure 40 Pressure Dissipation Effect

4.8 Aquifer interconnectivity

4.8.1 Vertical connectivity

There is a large number of nested monitoring sites. Section 4.7 presents examples of hydrographs from selected nested sites, showing the distribution of piezometric heads and how the stress-response relationship varies along the vertical profile. In this section, the vertical connectivity across a broader area of the mine is characterised based on the review of data from multiple nested sites. For the purpose of characterising the inter-aquifer connection, only the piezometers constructed in the aquifers (not coal) have been used to calculate aquifer-to-aquifer vertical hydraulic gradients. These are summarised in Table 7, using the piezometers constructed in the highest and lowest aquifers at each nested site. Based on the data availability, piezometric heads from 2012 to 2019 have been used to calculate the average vertical hydraulic gradient for each year. The minimum, maximum and average vertical hydraulic gradients from this monitoring period are summarised in Table 7.

Although the data are not evenly distributed at each nested site, Table 7 provides the following insights:

– The vertical hydraulic gradient is generally downwards, reflecting the influence of mining and extraction of groundwater from the confined M1A Interseam imposing a downward vertical hydraulic gradient.
– The downward vertical hydraulic gradient is typically around 0.3 to 0.5, which is steep and is consistent with the presence of thick intervening coal layers acting as aquitards, limiting the vertical hydraulic connection by their low vertical hydraulic conductivity.
– The downward vertical hydraulic gradient is largest between the HHF/OB and Yallourn Interseam/M1A Interseam. This reflects the influence of the intervening Yallourn Coal and recharge at surface that maintains the shallow groundwater level in the HHF/OB.
– Negative vertical hydraulic gradients at some locations indicate upward flow. The upward hydraulic gradient is generally around 0.1, which is smaller than the downward hydraulic gradient measured elsewhere. These occurs at locations some distance from the pumping bores where the influence of pumping in the M1A Interseam is smaller (e.g. M3760, N6112) or where the effect of pumping is dampened by the limited vertical connectivity (e.g. M5173, refer to Section 4.7.3).
– The upward vertical hydraulic gradients are also recorded between the Yallourn Interseam and M1A Interseam in Maryvale Field due to pressure dissipation in the Yallourn Interseam as mining progresses (e.g. M3858 and M3869, also M3867 between these two aquifers). In this area, a downward gradient occurred across the intervening M1A Coal until pressure dissipation in the Yallourn Interseam caused a reversal in the vertical gradient as shown in Figure 41.

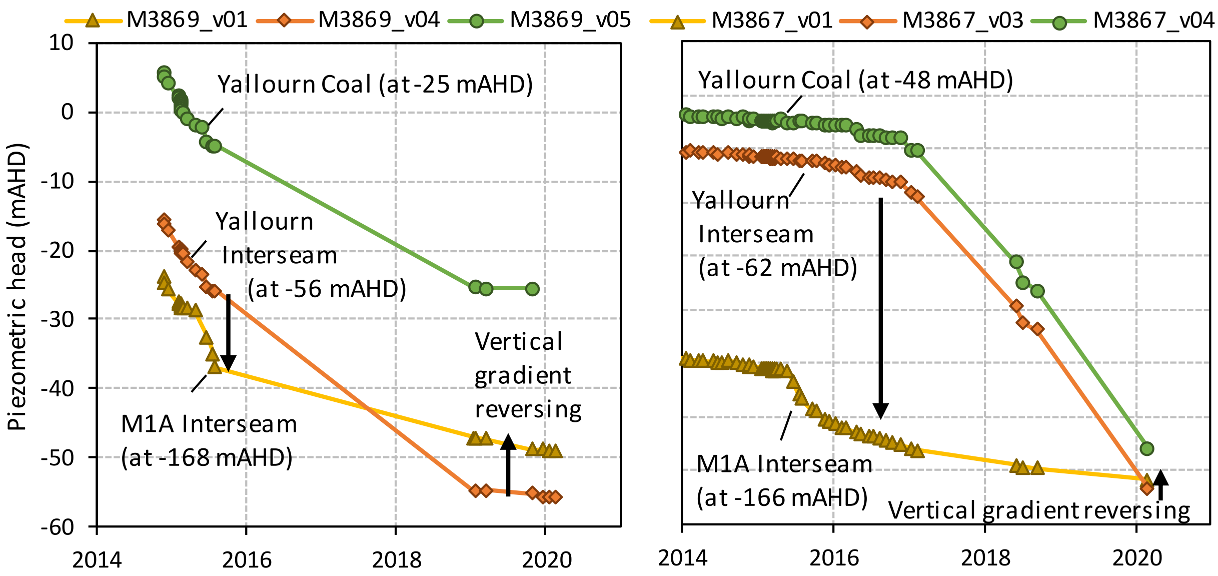


Figure 41 ***Vertical Hydraulic Gradient Reversal Due to Mining***

Table 7 Vertical Hydraulic Gradient (2012 – 2019) at Nested Sites

Nested piezometers		HSU		Elevation		Vertical hydraulic gradient		
M3760_v05	M3760_v02	YAL	M1A	-49.15	-103.95	-0.242	0.176	-0.105
M3858_v04	M3858_v01	YAL	M1A	-60.45	-172.45	-0.022	-0.014	-0.018
M3867_s01	M3867_v01	OB	M1A	37.73	-166.27	0.371	0.46	0.411
M3869_v04	M3869_v01	YAL	M1A	-56.23	-167.73	-0.07	0.076	0.027
M3871_dls01	M3871_v02	OB	YAL	32.88	-65.93	0.51	0.524	0.517
M3873_v06	M3873_v04	HHF	YAL	43.97	-68.032	0.582	0.655	0.622
M3910_s01	M3910_v05	HHF	YAL	41.63	-49.37	0.392	0.492	0.444
M3912_s01	M3912_v05	HHF	YAL	62.73	-34.27	0.497	0.564	0.533
M3961_s01	M3961_v01	HHF	M1A	41.07	-145.93	0.412	0.452	0.433
M3969_s01	M3969_v01	HHF	YAL	40.12	-63.38	0.416	0.438	0.425
M3991_v07	M3991_v02	OB	M1A	52.75	-114.25	0.443	0.449	0.446
M3992_s01	M3992_v05	OB	YAL	47.92	-52.08	0.373	0.39	0.382
M3999_v04	M3999_v01	OB	YAL	47.22	-54.277	0.461	0.486	0.474
M4000_v05	M4000_v01	OB	YAL	46.82	-67.18	0.478	0.488	0.483
N4741_v06	N4741_v01	OB	M1B	118.6	74.2	0.575	0.575	0.575
N4826_v06	N4826_v01	OB	YAL	24.5	-22	-0.152	-0.081	-0.125
N5160_s06	N5160_v01	OB	M1A	36.6	-164.9	0.332	0.351	0.342
N5173_v04	N5173_v01	YAL	M1A	-67.6	-133.1	-0.129	-0.01	-0.065
N6018_v06	N6018_v01	HHF	M1A	34.2	-137.1	0.337	0.337	0.337
N6112_v05	N6112_v02	YAL	M1A	-51.45	-123.25	-0.117	0.163	-0.02
N6136_v05	N6136_v01	YAL	M1A	-19.12	-90.92	0.48	0.608	0.545
N6426_v04	N6426_v01	YAL	M1A	-47.1	-126.1	0.011	0.06	0.023
N6544_v02	N6544_v01	YAL	M1A	-47.81	-66.81	0.191	0.914	0.668
N6581_v07	N6581_v03	YAL	M1A	-68.55	-139.55	-0.0004	0.069	0.033
N6762_dls01	N6762_v01	OB	YAL	30.204	-54.35	0.166	0.186	0.176
N6805_s01	N6805_v01	OB	YAL	29.813	-55.19	0.374	0.449	0.431
N6813_s01	N6813_v01	OB	YAL	29.01	-51.99	0.345	0.415	0.4
N6816_s01	N6816_v01	OB	YAL	26.01	-68.27	0.143	0.211	0.189
N6825_s01	N6825_v01	HHF	YAL	35.11	-49.94	0.488	0.526	0.513
N6895_s01	N6895_v01	HHF	YAL	38.87	-34.13	0.397	0.463	0.432
N6904_s01	N6904_v01	HHF	YAL	71.82	-4.91	0.797	0.887	0.844
N6905_s01	N6905_v01	HHF	YAL	76.07	-10.05	0.313	0.374	0.355
N6906_s01	N6906_v01	HHF	YAL	75.9	4.88	0.234	0.426	0.362
N7066_v03	N7066_v01	OB	YAL	38.1	-41.9	0.417	0.457	0.44
N7067_v02	N7067_v01	YAL	M1A	-51.45	-89.45	0.221	0.46	0.304
N7084_s01	N7084_v01	OB	YAL	65.04	10.04	0.812	0.823	0.818
N7156_s01	N7156_v01	OB	YAL	66.14	36.14	0.424	0.433	0.428
N7180_s01	N7180_v01	OB	YAL	33.22	-20.79	0.519	0.533	0.526

HHF – Haunted Hills Formation, OB – Overburden, YAL – Yallourn Interseam, M1A – M1A Interseam

Where the M1 Coal is thin or absent (e.g. in East Field), the vertical hydraulic connection between the Yallourn Interseam and M1A Interseam is greater than in areas such as Maryvale Field. Figure 42 shows the hydrograph of a piezometer located in the Yallourn Interseam in East Field, where the M1 Coal is thin. The hydrograph indicates strong response to pumping in the underlying M1A Interseam, including near instantaneous changes in piezometric heads as the pumping rate changes. At nested sites, N4918 and N4920, located in the MRD, the vertical gradient between the Yallourn Interseam and M1A Interseam is 0.2 and 0.04, respectively, based on the most recent (March 2020) piezometric data.

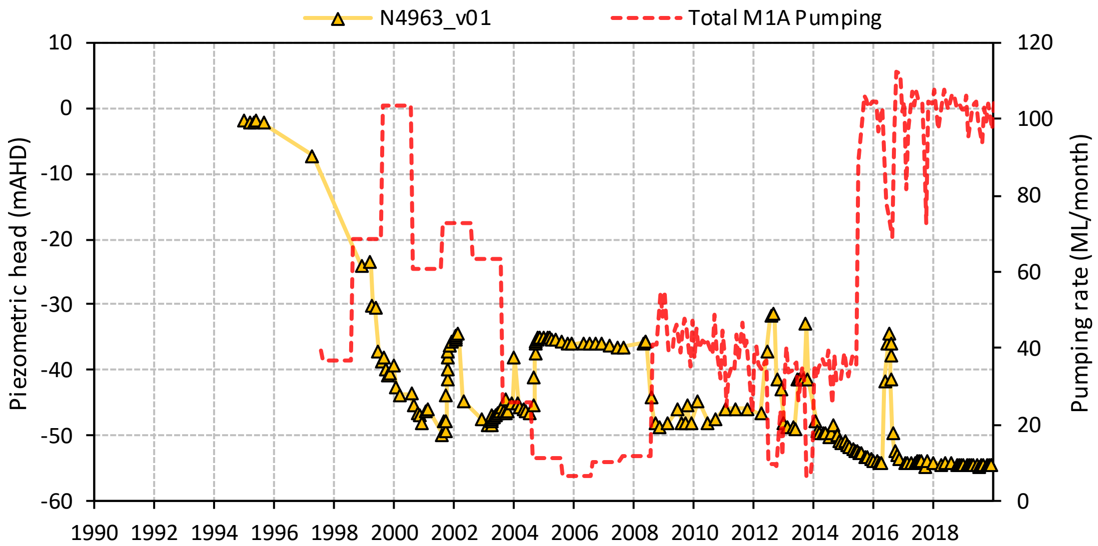


Figure 42 ***M1A Pumping Influence in Yallourn Interseam Due to Thin M1 Coal***

Although the Yallourn Coal is conceptualised to generally act as an aquitard, vertical hydraulic connectivity is locally enhanced by joints and faults that have been observed and mapped at numerous locations where the Yallourn Coal is exposed in the batters e.g. in Township Field. These are generally northwest to southeast trending and are known to be steeply dipping. They are often closed in-situ but can open up during mining due to pressure relief as the weight of the adjacent material is removed. Some of the joints mapped in the exposed batters are also filled with loosely cemented sand.

The most compelling evidence of joints and faults acting as potential preferential pathways comes from the large and rapid pore pressure increases observed in the coal and interseams following a major flood event in June 2021. An instantaneous pore pressure increase of up to around 26.8 m was observed in the M1A Interseam (in the M1AS1 sand layer) at a depth of around 160 mbgl, as well as at multiple levels spanning from the M1A Interseam to Yallourn Coal (with the groundwater level almost reaching the peak river level). The timing, depth and magnitude of pore pressure responses, coupled with observed flow loss into cracks at surface, strongly suggest that flood water directly recharged the deeper aquifer system via sub-vertical pathways that are most likely associated with pre-existing joints. The conceptualisation of these mechanisms and pathways are described in detail in GHD (2022a).

In the context of closure and rehabilitation planning, it is important to recognise that the hydrogeological properties of the Yallourn Coal and connectivity between the aquifers are more likely to be enhanced (at least locally) in the batters and within the vicinity of the mine voids than regionally, where the coal is conceptualised to generally act as aquitard.

4.8.2 Horizontal connectivity

4.8.2.1 Connection with Hazelwood Mine

The Yallourn Interseam extends to the northern boundary of the Hazelwood Mine, becoming shallower and thinner as the overlying Yallourn Coal thins to the south of the Yallourn Mine. This interseam is not actively dewatered at the Hazelwood Mine and due to its limited presence, thickness and low permeability, the degree of horizontal connection with the Yallourn Mine is limited.

The M1A Interseam becomes thinner to the south of the Yallourn Mine and pinches out before reaching the Hazelwood Mine, resulting in the merging of the M1A Coal and M1B Coal into a thick sequence of M1 Coal mined at Hazelwood. Therefore, the M1 Interseam at the Hazelwood Mine is below the M1B Coal. For this reason, the M1A Interseam at the Yallourn Mine is not directly connected to the M1 aquifer that is depressurised at the Hazelwood Mine although it may be connected to the underlying M1B Interseam where it occurs. In some areas of the Yallourn Mine, the M1B and M2 Coals join together to forming the thick Latrobe Seam and the intervening M1B Interseam pinches out. Figure 44 shows schematically the joining of the M1A, M1B and M2 Coals (refer to Section B), laterally disconnecting the M1A and M1B Interseams.

Prior to active dewatering of the M1A Interseam, the horizontal hydraulic gradient was southerly with the piezometric heads declining in 1988 at a rate of around 0.3 m/year (SEC, 1988), increasing to around 1 to 2 m/year in 1993 in East Field (Geo-Eng, 1994). This slow declining trend was interpreted to be the result of induced leakage across the intervening coal layers due to the depressurisation of the underlying M1 aquifer at the Hazelwood Mine (SEC, 1988; GHD, 2011a). As the M1 aquifer (M1B Interseam) pinches out in Maryvale Field, the downward leakage would have occurred in in the southern area of the Yallourn Mine, resulting in the southerly flow direction observed at the time. Following active dewatering of the M1A Interseam commencing in the 1990s, the hydraulic gradient has been reversed due to the cone of depression centred at the pumping bores in East Field (see Figure 32 and Section 4.6.2).

The connectivity of the deeper M2 Interseam (aquifer) is not well understood due to the limited information at the Yallourn Mine. There are several regional bores that were drilled and monitored by SEC between the Yallourn Mine and Hazelwood Mine which indicated low piezometric heads by the mid-1980s due to the depressurisation at the Hazelwood Mine. The closest bore to the Yallourn Mine, 23831, recorded less than – 50 mAHD piezometric head in the 1980s. As discussed in Section 4.6.2 it is highly likely that the cone of depression in the M2 aquifer extends below the Yallourn Mine, albeit the effect on the overlying aquifer is limited by the presence of thick coal aquitard (M2 Coal and M1B Coal combined).

4.8.2.2 Connection with Moe Swamp Basin

Brumley and Holdgate (1983) completed a hydrogeological assessment of the Moe Swamp Basin and concluded that it is separated from the western end of the Latrobe Valley Depression by the Haunted Hills Fault /Yallourn Monocline, which forms an effective hydraulic barrier. The 1983 Moe Swamp Basin geological cross section, as shown in Figure 43, indicates the Haunted Hills Fault/Yallourn Monocline to be located along the elevated ridge between the two basins. It is noted that the Childers Formation in the Gippsland Basin in this figure is now referred to as the M2/TFAS. A significant displacement of strata along the fault is shown on the cross-section, with the deep aquifers of the Morwell and Childers Formations abutting the Basement and physically disconnected from the aquifers on the other side of the fault. This truncation of the aquifers by the fault is represented consistently in several detailed investigations in this area post-dating Brumley and Holdgate (1983) as shown in Figure 44 (fault is highlighted in red, for clarity).

Figure 45 shows a cross-section of the Moe Swamp Basin based on the layers from the Victorian Aquifer Framework (VAF). The VAF layers are coarse and align closely with the geological formations within which the aquifers (interseams) and aquitards (coal) are grouped into one unit. Although the layers are coarse, the displacement along the fault can be seen in the cross-section. Unlike the cross-sections shown in Figure 43 and Figure 44, the VAF assumes continuity of the Morwell Formation across the fault although this is limited to the upper part. The deeper level of the Morwell Formation, and the Childers Formation, corresponding to the M2 aquifer, is truncated by the fault, indicating a physical separation of the M2 aquifer.

The lack of hydraulic connectivity due to the physical separation of the aquifers is supported by the long-term groundwater monitoring data. The bores within the Moe Swamp Basin show no discernible impacts of mine-induced depressurisation despite the head difference increasing between the two basins over time as mining progressed in the Latrobe Valley. The groundwater levels in the Moe Swamp Basin are significantly higher, generally stable over the monitoring period and respond more strongly to climatic variations compared to the bores in the adjacent Latrobe Valley Depression in the vicinity of the Yallourn Mine. The hydrographs supporting the lack of connectivity across the fault are shown in Figure 46 for the M1/MFAS and Figure 47 M2/TFAS. The bores within the Moe Swamp Basin are 160 to 240 m deep, except for bore 230034 located towards the edge of the basin (60 m deep) which shows fluctuations due to its proximity to a pumping bore. The Gippsland Basin Bioregional Assessment Context Statement (Yates *et al*, 2015) also concluded there is a restricted hydraulic connectivity between the two basins based on the water level trends.

The monitoring data from regional SEC bores also indicate sharp contrasts in piezometric heads in the confined aquifers where the Haunted Hills Fault/Yallourn Monocline trends southward, between the Yallourn and Hazelwood Mines. For example, bore 23831 recorded less than – 50 mAHD piezometric heads in the 1980s due to the depressurisation of the M2 aquifer. In contrast, bore 24652, located only 450 m to the south recorded piezometric heads of more than 40 mAHD in the 1980s, albeit at a shallower depth (Figure 48). Additionally, there are several regional bores located within this inferred area of the fault where the piezometric heads within the confined aquifers have remained generally elevated despite significant drawdown occurring closer to the mines. This indicates a compartmentalisation effect within the fault zone, which significantly limits hydraulic connection with the mines, consistent with the lack of mining-induced effects observed in the Moe Swamp Basin.

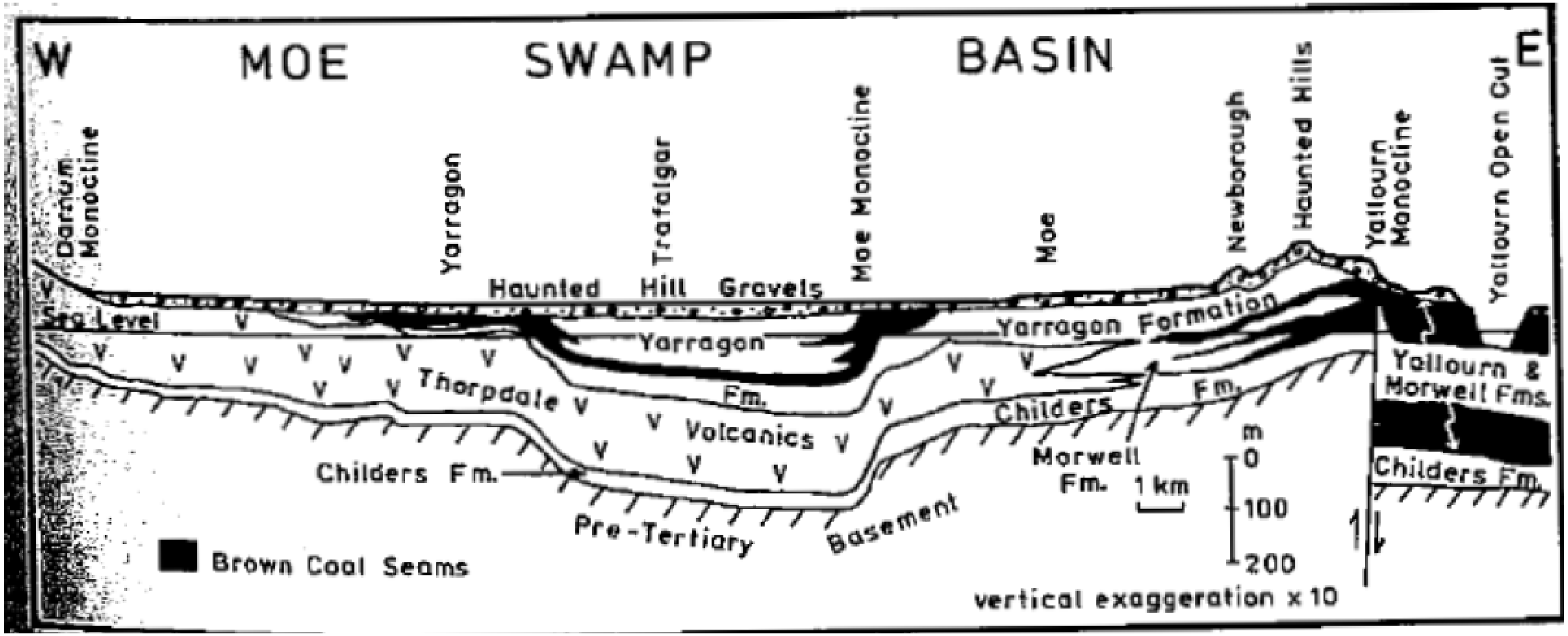
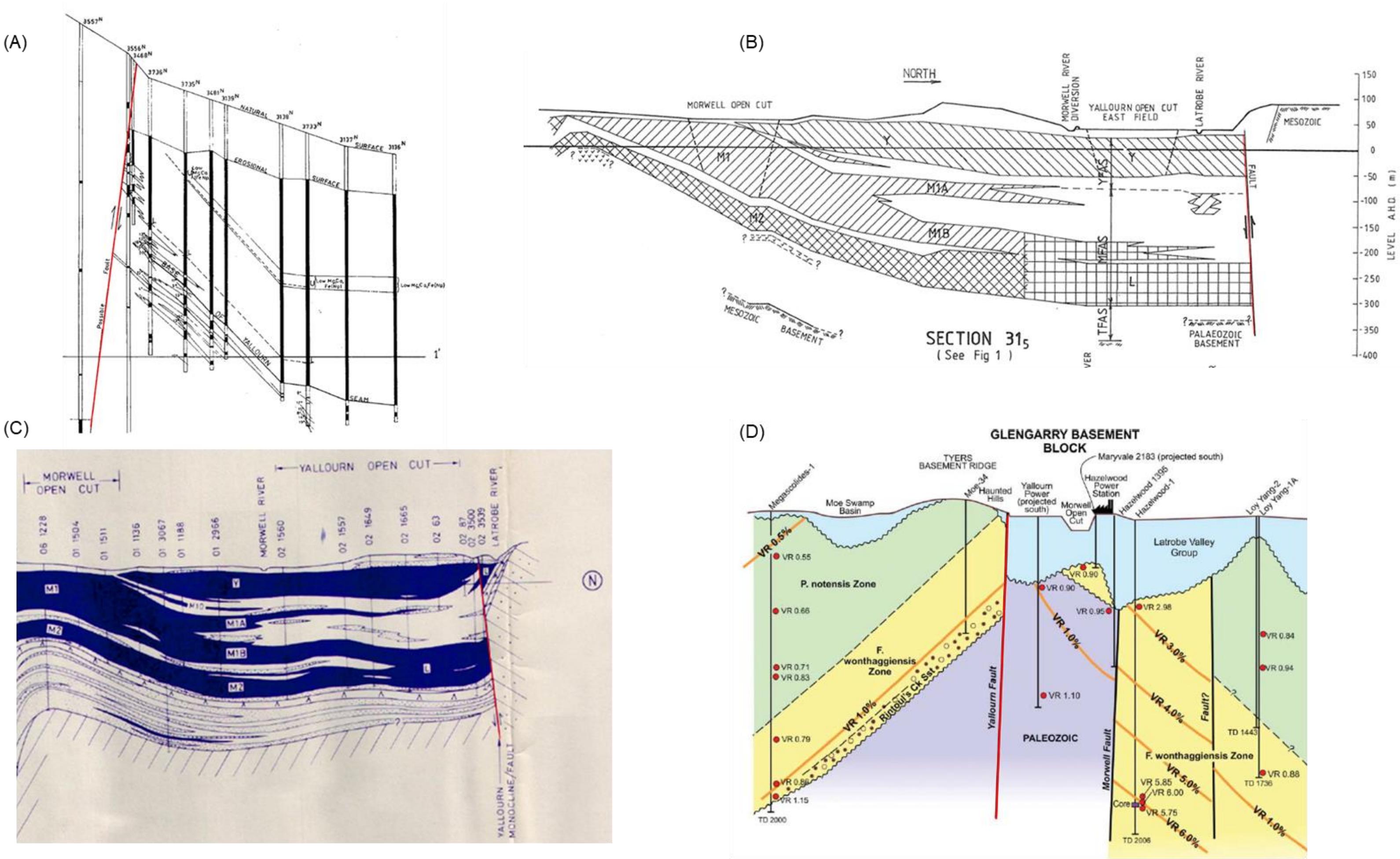


Figure 43 *East to West Cross Section of Moe Swamp Basin (after Brumley and Holdgate, 1983)*



Reference: (A) South to North cross-section from "SEC (1984), Yallourn Open Cut, Stability of Permanent Batters in the Hernes Oak and Yallourn Township Areas, Report DD200"
(B) North to South cross-section from "SEC (1988), Yallourn Open Cut East Field Aquifer Dewatering Review. Report DD228"
(C) North to South cross-section from "SEC (1987), Further Latrobe Valley Regional Groundwater Bore Cross-sections. Geological Report NO. 42"
(D) From "Holgate et al (2015), Pre-Cenozoic geology of the Latrobe Valley Area - Onshore Gippsland Basin, S.E. Australia, Australian Journal of Earth Sciences (2015)"

Figure 44 Haunted Hills Fault (Yallourn Moncline) Geological Cross Sections

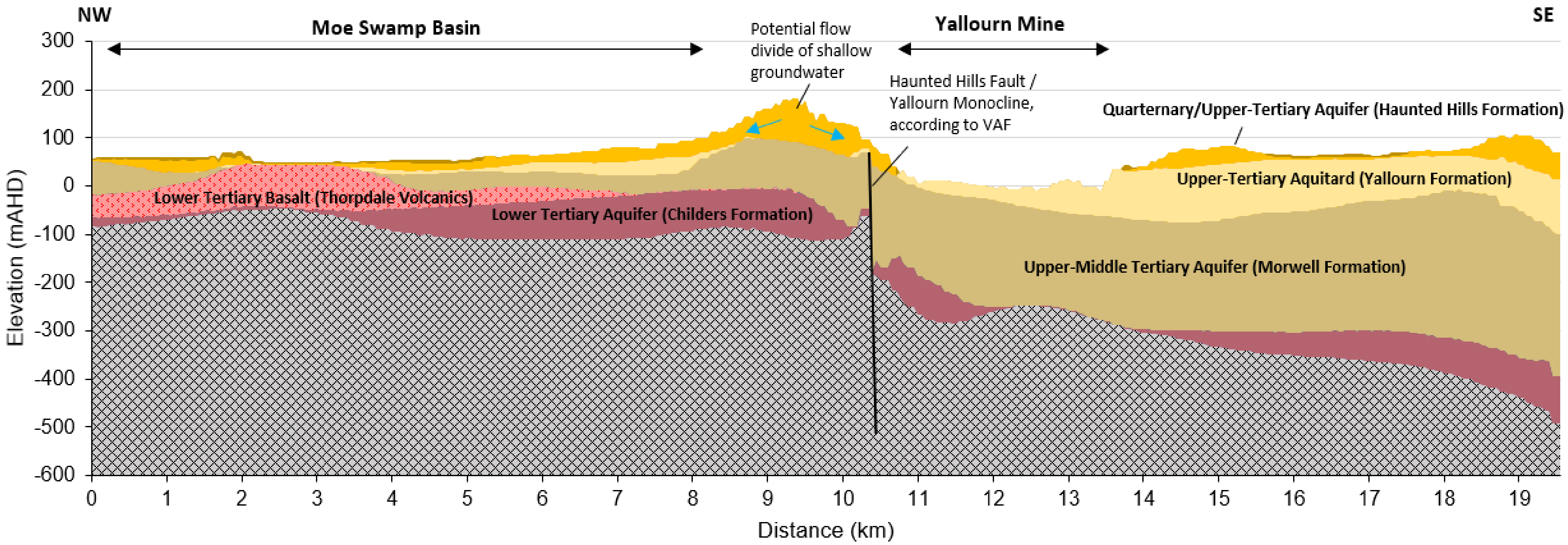
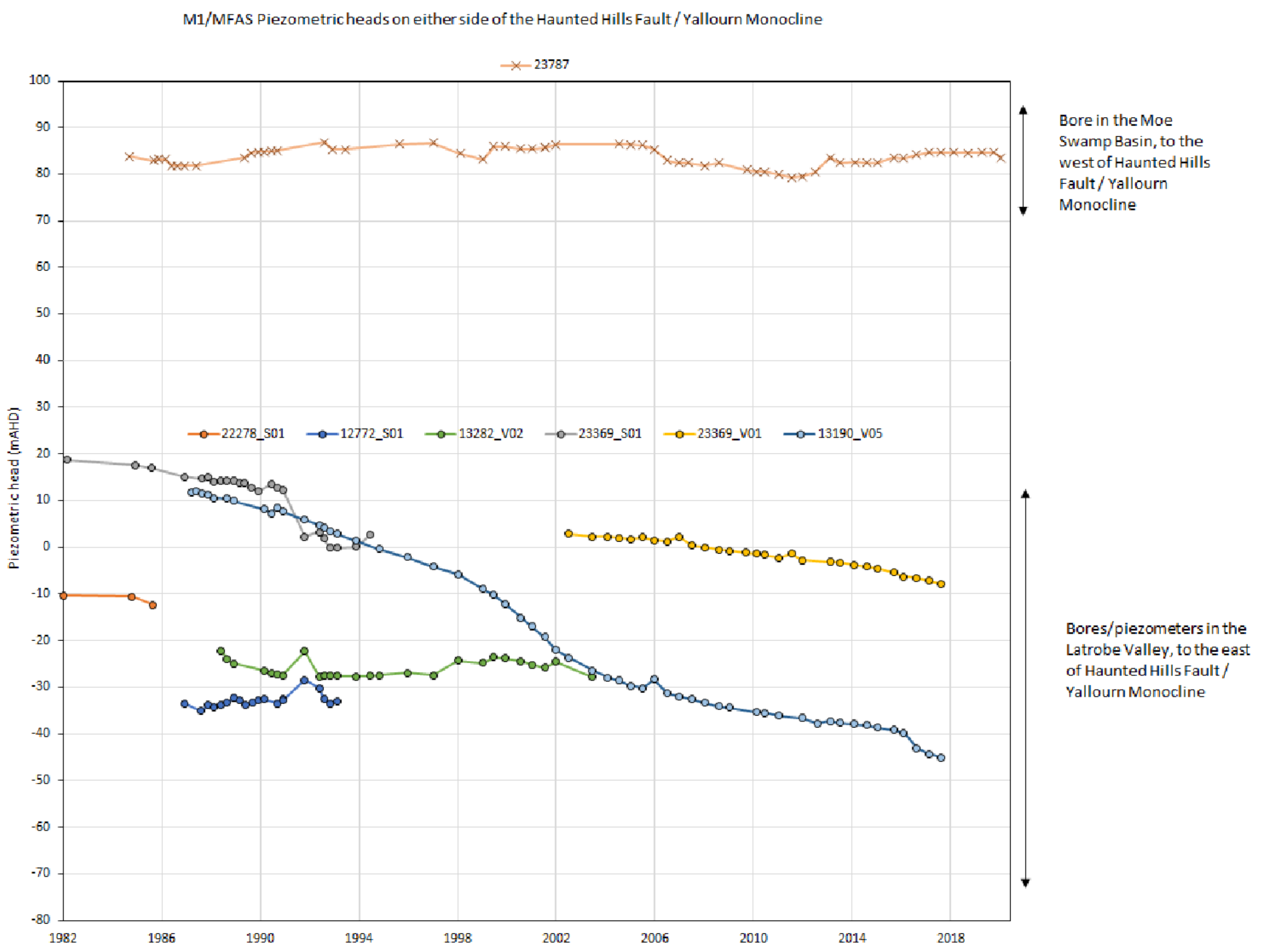
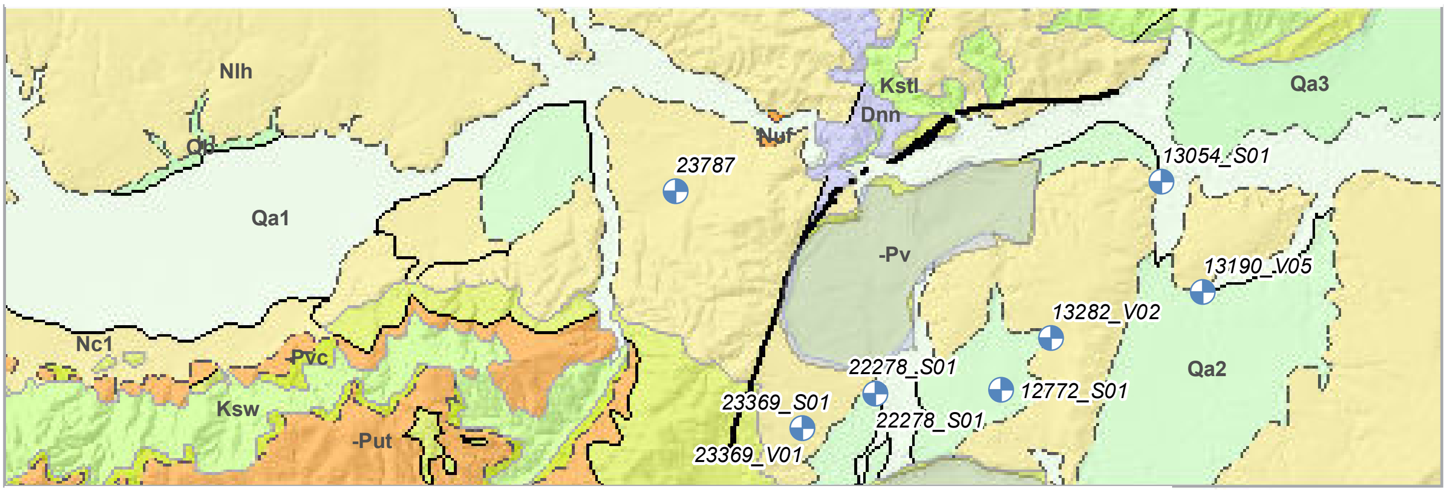


Figure 45 Cross Section of Moe Swamp Basin Based on Layers from Victorian Aquifer Framework (VAF)





Legend

- M1/MFAS hydrograph bore
- Mine boundary
- Yallourn Fault (EAY)

Geological structure 250k

- conformity
- disconformity
- faulted contact
- geological unit boundary
- unconformity

Geological unit 250k

- Thorpdale Volcanic Group (-Put)
- LaTrobe Valley Group (-Pv)
- Childers Formation (-Pvc)
- Norton Gully Sandstone (Dnn)
- Kstl
- Wonthaggi Formation (Ksw)
- Incised colluvium (Nc1)
- Haunted Hills Formation (Nlh)
- Fumina Basalt (Nuf)
- Alluvium (Qa1)
- Alluvial Terrace Deposits (Qa2)
- Alluvial Terrace Deposits (Qa3)
- Alluvium and colluvium (Qb)

Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

EnergyAustralia Yallourn
Conceptual Hydrogeological Model

M1/MFAS heads
Moe Swamp Basin and Latrobe Valley

Project No. **12521481**
Revision No. **A**
Date **16/06/2020**

FIGURE 46

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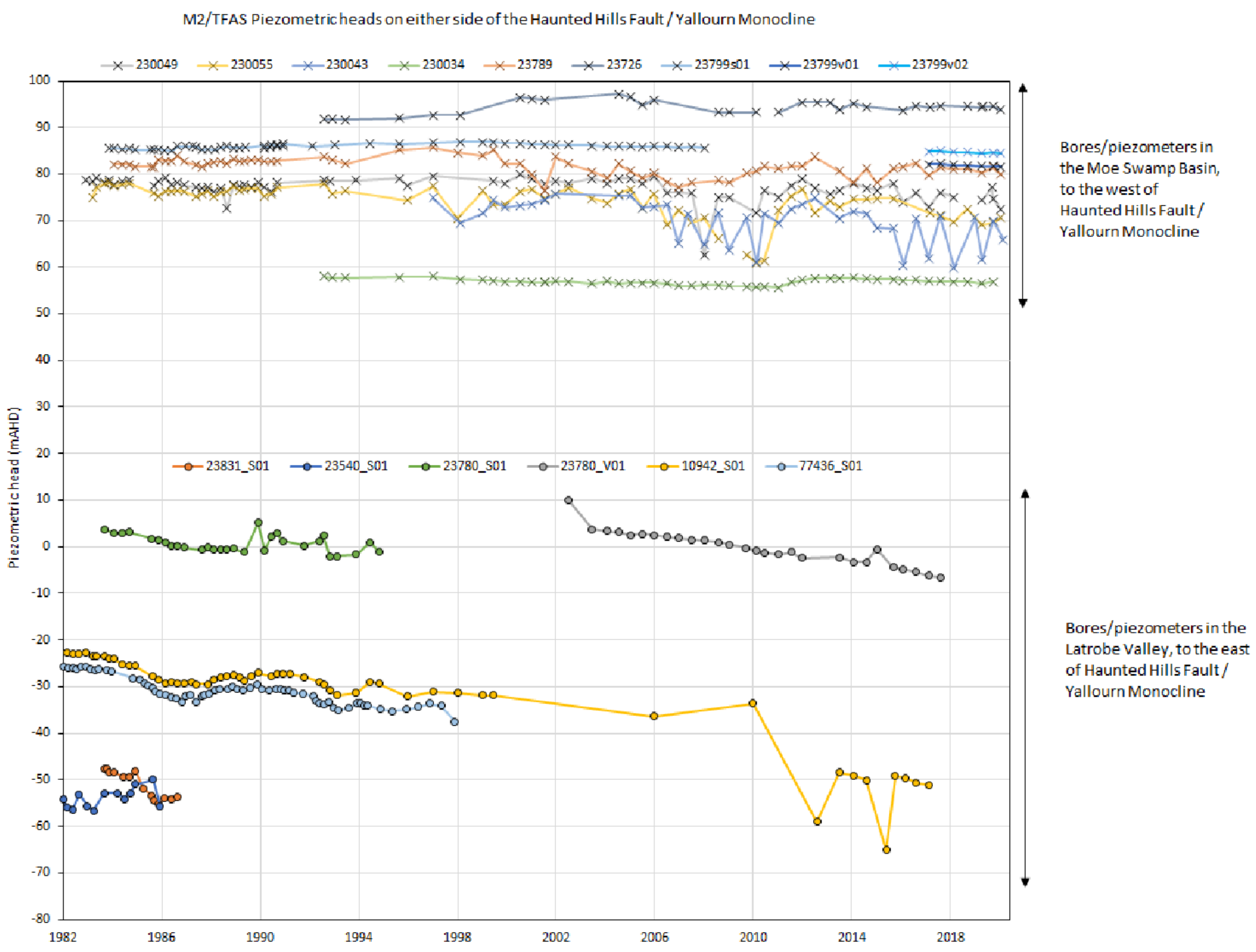
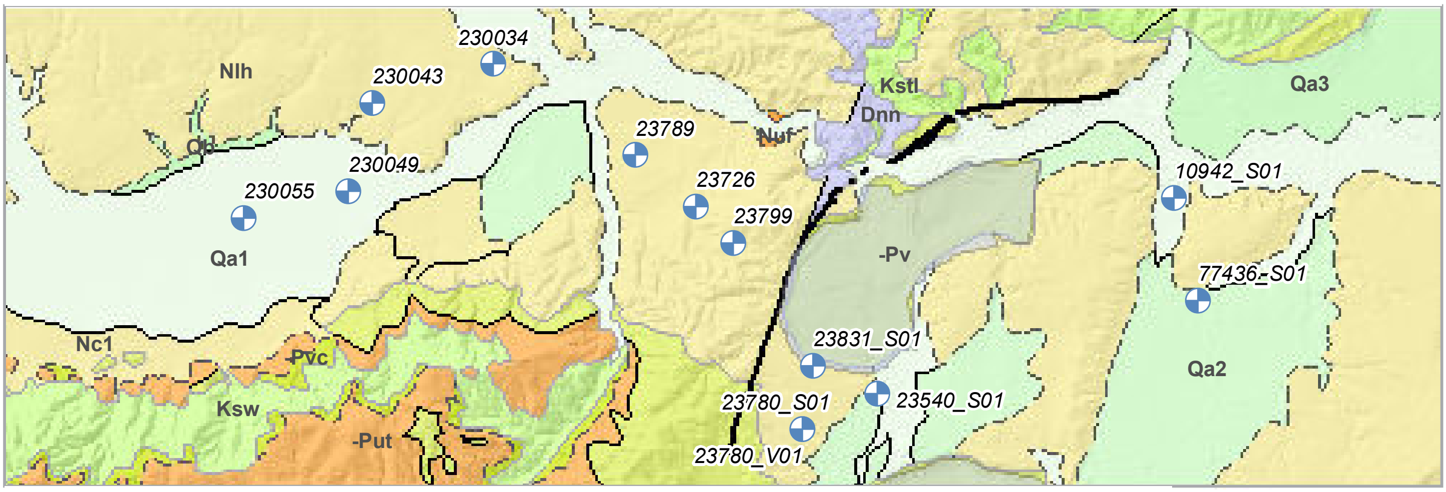
Data source: GHD, hydrographs, 2020; EAY, bore locations, 2020; . Created by: tworth





Legend

- M2/MFAS hydrograph bore
- Mine boundary
- Yallourn Fault (EAY)

Geological structure 250k

- conformity
- disconformity
- faulted contact
- geological unit boundary
- unconformity

Geological unit 250k

- Thorpdale Volcanic Group (-Put)
- LaTrobe Valley Group (-Pv)
- Childers Formation (-Pvc)
- Norton Gully Sandstone (Dnn)
- Kstl
- Wonthaggi Formation (Ksw)
- Incised colluvium (Nc1)
- Haunted Hills Formation (Nlh)
- Fumina Basalt (Nuf)
- Alluvium (Qa1)
- Alluvial Terrace Deposits (Qa2)
- Alluvial Terrace Deposits (Qa3)
- Alluvium and colluvium (Qb)

Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

EnergyAustralia Yallourn
Conceptual Hydrogeological Model

M2/MFAS heads
Moe Swamp Basin and Latrobe Valley

Project No. 12521481
Revision No. A
Date 16/06/2020

FIGURE 47

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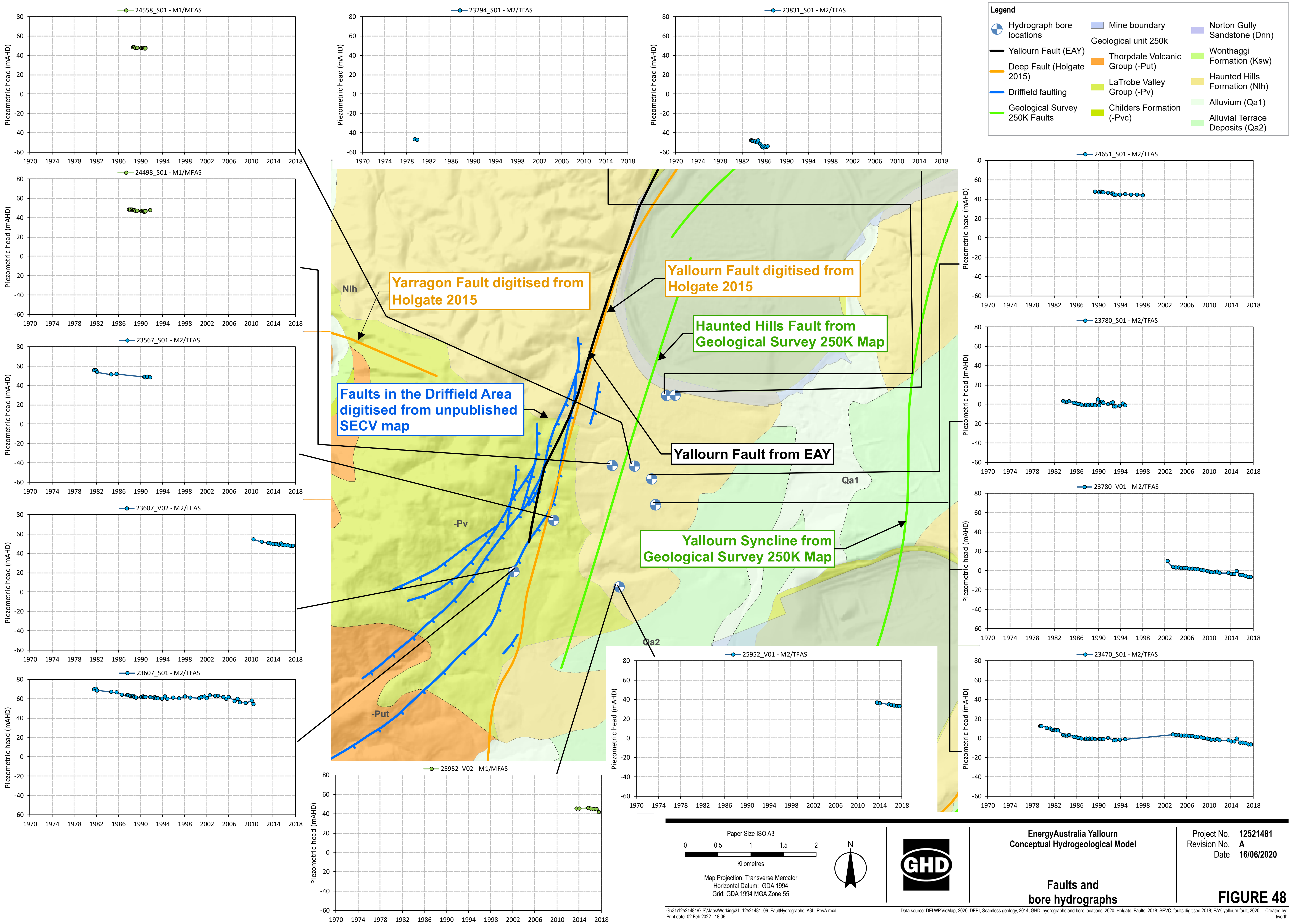
Data source: GHD, hydrographs, 2020; EAY, bore locations, 2020; Holgate, faults, 2018; SECV, faults, digitised 2018. Created by: tworth



Paper Size ISO A3

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Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

EnergyAustralia Yallourn
Conceptual Hydrogeological Model

Project No. 12521481
Revision No. A
Date 16/06/2020

Faults and bore hydrographs

FIGURE 48

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Data source: DELWP,VicMap, 2020; DEPI, Seamless geology, 2014; GHD, hydrographs and bore locations, 2020; Holgate, Faults, 2018; SECV, faults digitised 2018; EAY, yallourn fault, 2020; . Created by: tworth

4.8.2.3 Connection with Yallourn North Open Cut

The Yallourn North Open Cut (YNOC) is located on three synclinal basins (Western, Central and Eastern) immediately to the northwest of the Haunted Hills Fault/Yallourn Monocline. The mining of coal within the Morwell Formation (Latrobe Coal) ceased in 1963 and the basin was allowed to be filled initially with water and subsequently by dumped overburden and ash.

The YNOC has been conceptualised as a recharge zone of the confined M1 and M2 aquifers because of their proximity to the surface, with hydraulic connection between the lined ash ponds and the aquifers evidenced by the aquifer pressure response to pond levels and deterioration of groundwater quality (SEC, 1983). The aquifer pressures and groundwater quality have been monitored by a dedicated network of bores and piezometers, with pumping bores operated by EAY to manage aquifer pressures and batter stability.

The degree of horizontal connection of the aquifers at the YNOC with those of the adjacent East Field can be inferred from their physical continuity and differences in groundwater levels measured in piezometers. Over a relatively short distance across the Haunted Hills Fault/Yallourn Monocline, the Morwell and Traralgon Formations plunge steeply. Geological cross-sections presented in a number of earlier works by SEC, Geo-Eng and GHD indicate near vertical layers, as shown in Figure 49 While the cross-sections assumed continuity of layers, the steeply dipping nature over short distances suggests a high likelihood of physical displacement of strata similar to the interpretations shown in Figure 44.

There are bores/piezometers constructed within the M1A Interseam at the YNOC, measuring piezometric heads of around 32 to 42 mAHD which are much higher than the -9 mAHD heads measured at the nearest piezometer located around 1 km down gradient (see Figure 32). This indicates limited influence of pumping at East Field, with heads at the YNOC more closely reflecting those of the overlying fill. It is also noted that the salinity of groundwater in the M1A Interseam beneath the Yallourn Mine is around an order of magnitude lower than that of groundwater in the YNOC. Based on the information currently available, the confined aquifers of the YNOC are considered poorly connected to those of East Field and are more strongly influenced by local recharge and pumping.

At a shallower level, the piezometric heads at the YNOC are generally elevated, ranging from 60 to 76 mAHD along the northern boundary (where the M1/M2 Coal, collectively referred to as the Latrobe Coal, subcrops), decreasing to less than 40 mAHD towards the Latrobe River (within the HHF/OB/Fill). Figure 50 shows the interpreted shallow groundwater contours in the area of the YNOC and East Field northern batters, using the average 2019 groundwater levels from bores constructed within the uppermost saturated part of the profile (generally in the HHF, OB and Fill). The primary pathway of connection between the YNOC and Latrobe River is thought to be via the alluvial sands of the Latrobe River, which is interpreted to locally intersect the fill within the ash ponds (Geo-Eng, 1997).

On the southern side of the Latrobe River, there is an inferred groundwater divide separating the northerly flow component towards the Latrobe River and southerly flow component towards East Field. The groundwater divide is likely to be maintained by rainfall recharge between the river and the mine, which act as local groundwater sinks/discharge points. Locally elevated groundwater levels occur in the former area of the Blue Lagoon effluent treatment system, which consisted of two large lakes that may have acted as an additional source of recharge. Prior to the failure of the East Field northeast batter, a sand and gravel channel of around 4 m in thickness along the basal level of the HHF/OB was considered a potential preferential pathway of shallow groundwater between the Latrobe River and East Field (SEC, 1979). The convergence of groundwater flow towards the Latrobe River suggests that shallow groundwater adjacent to the YNOC is likely to be intercepted by the river, with low potential for discharge to East Field.

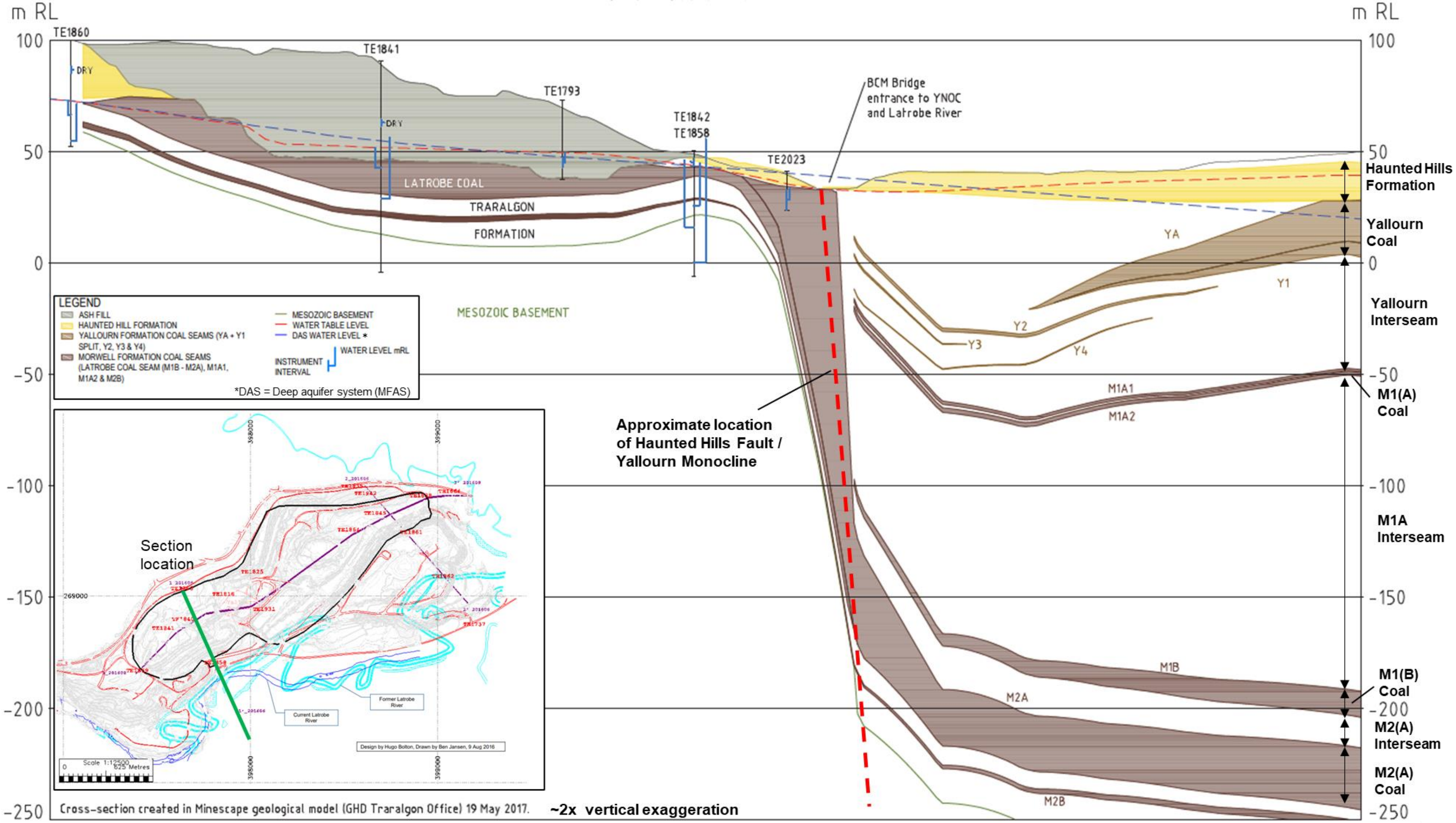
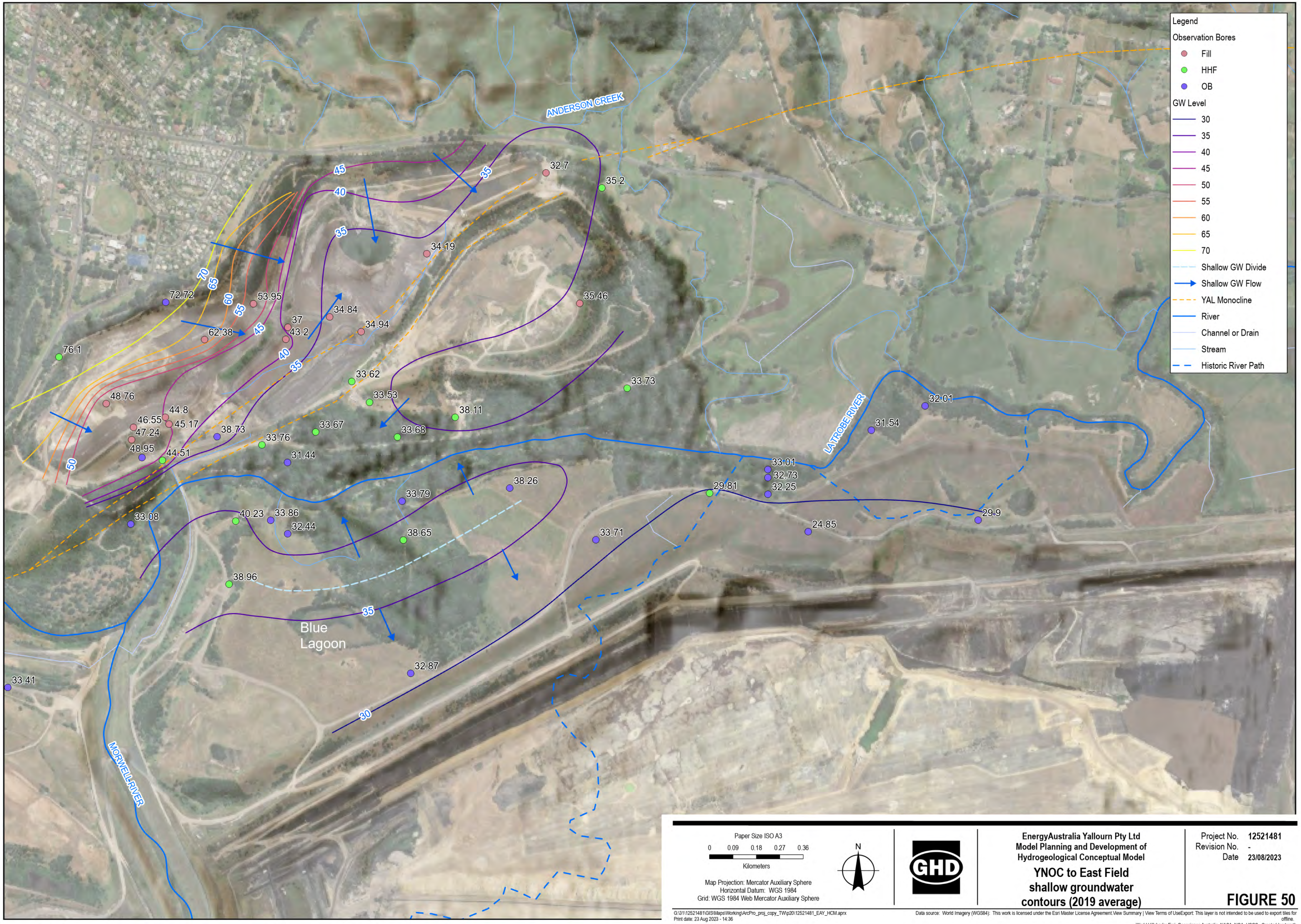


Figure 49 Cross Section of Yallourn North Open Cut (after GHD, 2017)



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YNOC to East Field shallow groundwater contours (2019 average)

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Revision No. -
Date 23/08/2023

FIGURE 50

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Data source: World Imagery (WGS84): This work is licensed under the Esri Master License Agreement.View Summary | View Terms of UseExport: This layer is not intended to be used to export tiles for offline. World Hillshade: Esri, Geoscience Australia, NASA, NGA, USGS. Created by: tworth

4.9 Surface water – groundwater interaction

4.9.1 Regional overview

As discussed in Section 3.2.6, the Latrobe River is heavily impacted by regulation and water management activities, with downstream flow controlled by three major storages: Blue Rock Reservoir, Lake Narracan and Moondarra Reservoir (GHD, 2015a). There are series of diversions that take water away from the river and a number of industrial water users as well as wastewater treatment plants that discharge significant volumes of saline water to the river. As a result, the nature of surface water - groundwater interactions along the Latrobe River and Morwell River can be highly uncertain.

The surface water-groundwater interactions of the major water courses in the Latrobe Valley have been assessed in the following regional studies:

– The Latrobe River and Morwell River were broadly classified as a gaining system (receives baseflow) in the Secure Allocation Future Entitlement (SAFE) project, according to the baseflow indices derived from recursive digital filtering of stream flow at key gauges (SKM, 2012). However, much of the Latrobe River downstream of Lake Narracan (and north of the Yallourn Mine) was unclassified, due to the significant effects of flow regulation by the three reservoirs, which precludes reliable application of the digital filter method. For the Morwell River, up to around 72 % of stream flow in the upper reaches was thought to originate from groundwater (SKM, 2012), reducing to around 13 % of stream flow in the lower reaches (GHD, 2013b).

– The stream leakage computed for the wet and dry periods using the ecoMarkets West Gippsland groundwater model indicates a small amount of leakage (loss) from the Morwell River through the Yallourn Mine and a variable gaining and losing condition along the Latrobe River north of the mine. The simulated stream leakage rates, both losing and gaining, are small and both rivers were classified as baseflow neutral at and immediately adjacent to the Yallourn Mine (within the -0.04 to 0.05 ML/d range for every 200 m cell, as reported in GHD, 2010b). The model simulates a gaining condition for the Morwel River further upstream of the Hazelwood Mine, consistent with the findings of the SAFE project. A gaining condition is also simulated along the Latrobe River, upstream of Township Field (towards Lake Narracan) and downstream of East Field. The lower simulated baseflow to the Latrobe River immediately north of the mine is potentially due to the drainage of shallow groundwater into the mine.

– Of the several baseflow characterisation studies undertaken within the Latrobe River catchment, GHD (2015a) provides baseflow estimates that are of most relevance to the study area. GHD (2015a) characterised baseflow behaviour using gauged stream flows and electrical conductivity (EC) data via mass balance analysis, based on the refinement of a method developed for DELWP over several studies beginning in 2012 (GHD, 2013a, 2013b, 2015a and 2015b). GHD (2015a) validated the method against detailed field sampling for the Mitchell River in East Gippsland and GHD (2015b) undertook further field data collection and validation on the Latrobe River catchment upstream of Lake Narracan and on the Thomson / Macalister Rivers. Of particular relevance to the Yallourn Mine is the baseflow gains to the Morwell River at Yallourn (226408) gauge, which are estimated to be around 60 ML/d with the lower and upper bounds ranging from 4 to nearly 800 ML/d (much higher than the rates simulated by the ecoMarkets model). The estimated baseflows to the Latrobe River are available further downstream, between Scarnes Bridge and Rosedale, which typically range from 1 to 100 ML/d.

An important conclusion of GHD (2015a) is that baseflow estimates within the Latrobe River catchment are uncertain, particularly the baseflows to the Latrobe River between Lake Narracan and Sale, due to the significant discharge rates and EC of water returned to streams from industries, which are themselves uncertain. In this sense, the baseflow estimates from the DELWP studies and others should be viewed as approximate indicators of reach-scale baseflow characteristics. For example, regional studies suggest that the Morwell River is generally gaining in the upper reaches (upstream of the mines) and receives small to negligible groundwater contributions in the lower reaches due to the lowering of the water table near the Hazelwood and Yallourn Mines. Similarly, the Latrobe River is likely to be variably gaining and losing along the northern boundary of the Yallourn Mine. These reach-scale baseflow characteristics can be useful, for example, for benchmarking the performance of numerical models.

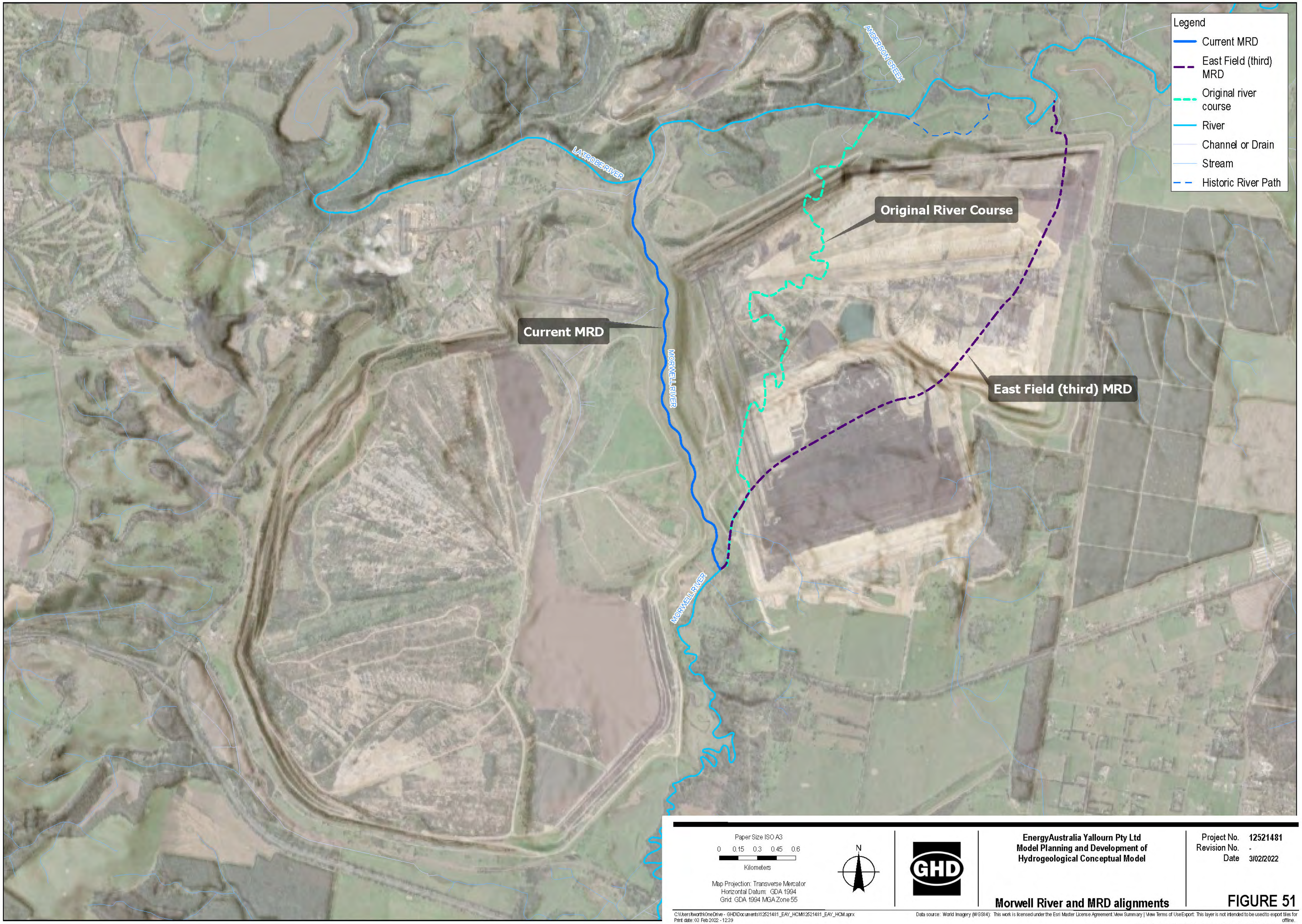
The following sections detail the analysis of surface water – groundwater interactions based on the groundwater levels collected from bores/piezometers constructed within the vicinity of the Morwell River and Latrobe River.

4.9.2 Morwell River Diversion

4.9.2.1 MRD alignments

The original course of the Morwell River extended through central East Field, in the northeast direction and to the east of the current MRD (terminating at the Latrobe River around 1.9 km northeast of the current point of termination). To enable mining of East Field, this section of the Morwell River was diverted to the south and east of East Field via a 5 km channel referred to as the third MRD (after the earlier diversion around the Hazelwood Mine and minor diversion in the upstream section of the Yallourn Mine). The third MRD (also known as the East Field MRD) was completed in May 1987 and consisted of a 3.8 km long buried “low flow” pipeline of 3 m in diameter. This was followed by the fourth MRD, which extends approximately 3.5 km to the north between the two mine voids, to enable mining into Maryvale Field. The fourth MRD represents the current alignment, which was commissioned in May 2005 and reconstructed between 2012 and 2014 following the breaching of the western embankment over the alignment of the E110 conveyor tunnel in June 2012.

Figure 51 shows the approximate alignments of the original Morwell River and third and fourth MRDs. These have been digitised from various historical plans (such as those included in Appendix A) and aerial images.



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Revision No. -
Date 3/02/2022

Morwell River and MRD alignments

FIGURE 51

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Data source: World Imagery (WGS84): This work is licensed under the Esri Master License Agreement. View Summary | View Terms of Use Export: This layer is not intended to be used to export tiles for offline.
World Hillshade: Esri, Geoscience Australia, NASA, NGA, USGS. Created by: tworth

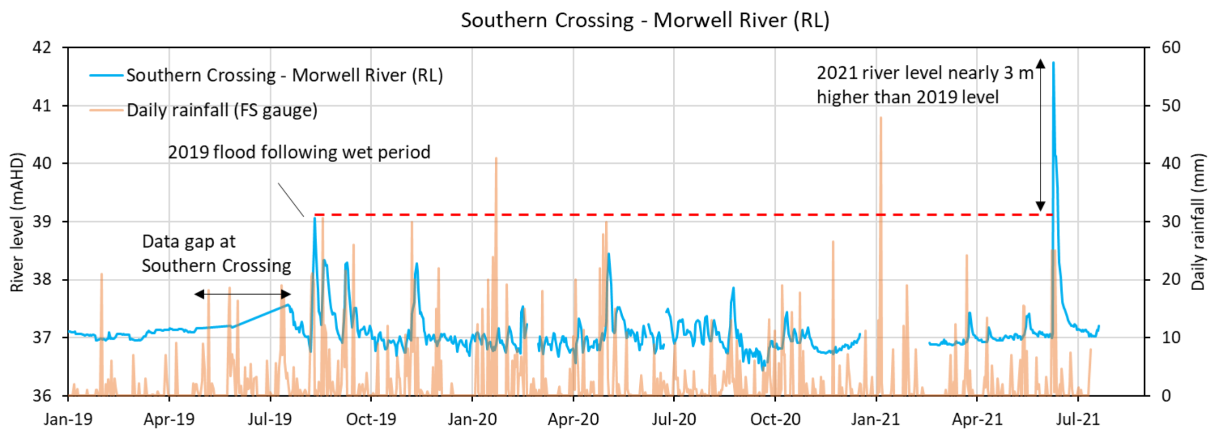
4.9.2.2 MRD interactions with groundwater systems

The interaction between surface water and groundwater, particularly in the upstream (southern) end of the MRD and associated floodplain, has been analysed in several hydrogeological assessments (such as GHD, 2020b, 2022a).

In the last decade, the Morwell River experienced several significant flooding events that necessitated measures to manage the flood waters and associated groundwater level changes (and ground movement resulting from them). In 2012, a major flood event caused the floodplain near the Fire Service Pond to become inundated. As a result, an emergency diversion of surface water from the floodplain into the Fire Service Pond was required. A period of high rainfall in July and August 2019 also resulted in the flooding of the Morwell River floodplain, which led to the formation of a local groundwater mound in the Yallourn Coal in an area close to Siphon Pond (a surficial feature that facilitated the siphon pump operations during the MRD failure in June 2012). The groundwater mound was first identified in May/June 2020 following the establishment of monitoring bores/piezometers along the crest of the Fire Service Pond batters and the floodplain. In order to minimise the movement of the batters due to this accumulation of coal pore pressure, a remedial program was implemented which included the installation of horizontal drains into the Fire Service Pond batters and backfilling of the Siphon Pond and billabongs on the floodplain (where flood-induced recharge is likely have occurred).

More recently, a high rainfall event in early June 2021 resulted in high stream flow and flooding, with the peak river level reaching nearly 3 m above the peak river level recorded during the 2019 flood event. This can be seen in Figure 51, which compares the river level at the Morwell River Southern Crossing with the daily rainfall data from the Fire Service Workshop rain gauge. The significant flood event also led to large and rapid pore pressure increases (of up to around 26.8 m) in the underlying coal and interseams, indicating the presence of potential pathways that hydraulically connected the flood water with the deeper aquifer systems (as discussed in Section 4.8.1).

Figure 52 Morwell River Southern Crossing river level and rainfall (after GHD, 2022a)



Shallow groundwater within the Morwell River floodplain is hydraulically connected to the river, as evidenced by the seasonal variations in the groundwater levels that reflect those of the river level. Hydrographs of shallow bores/piezometers near the Southern MRD Crossing indicate that periods of high river level (wet months) coincide with periods of higher groundwater levels and vice versa (see Figure 53). Table 8 summarises the depth of these piezometers and their proximity to the Southern MRD Crossing.

The groundwater levels at bores close to the river (N7087, N7098, N7182 and N7185) are generally below the river level, indicating the Morwell River is generally acting as a losing system (recharging the groundwater system during high flow periods). This is consistent with the generally losing condition simulated by the ecoMarkets West Gippsland model and regional studies indicating that most of the baseflow is likely to originate in the upstream reaches of the Morwell River (away from the mine, given the water table at the mine is locally depressed by the presence of the mine voids). As the river level recedes following wet months, the groundwater level temporarily becomes greater than the river level at some locations, indicating possible discharge of groundwater back into the river as baseflow (a temporary gaining condition, potentially sustained by bank storage). The bores in the floodplain, further away from the river (M3924, M3930 and M3936), show groundwater levels that are generally above the river level (with bore M3930, furthest from river, showing less seasonal fluctuations).

The effect of June 2021 flooding can be clearly identified from the large spike in the groundwater levels in Figure 53 (also seen in the data from additional shallow bores/piezometers installed in the floodplain in 2020). In general, the bores closest to the river experienced the largest increase although the magnitude of response (and associated spatial variations) are likely to be influenced by factors such as recharge mechanisms and the distribution of the lower sand layer in the HHF. GHD (2022a) identified several possible recharge mechanisms in the floodplain during periods of high river level, including the pooling of surface water in local depressions/billabongs, preferential infiltration via buried sand/gravel lenses or palaeochannel and direct leakage from the Morwell River where the bottom of the river is close to or in contact with the lower sand layer of the HHF. The remedial works undertaken by EAY in 2020 (such as the filling of the billabongs and interception of buried sand/gravel lenses on the floodplain) are likely to have resulted in more even distribution of flood water compared to the prior flood events, although the magnitude of response to the June 2021 event suggests that some preferential recharge is likely to be still occurring in the floodplain.

As discussed in Section 4.8.1, flood water in the Morwell River floodplain is locally connected to the deeper aquifer system (through the Yalloun Coal and into M1A Interseam) via preferential pathways that are most likely associated with pre-existing sub-vertical joints and fractures. This means during major flooding events, such as the June 2021 flood, the deeper aquifer system can be locally recharged by surface water (GHD, 2022a).

Table 8 Shallow Piezometers Near Southern MRD Crossing

Piezometer	Depth (m)	HSU	Distance from Southern MRD Crossing (m)
N7087_dls01	5.5	HHF	69
N7098_dls01	14	HHF	166
N7182_v01	7.7	HHF	170
N7185_v01	9.2	HHF	153
M3924_dls01	8.5	OB	253
M3930_dls01	5.3	HHF	310
M3936_dls01	5.5	HHF	350

HHF – Haunted Hills Formation, OB – Overburden

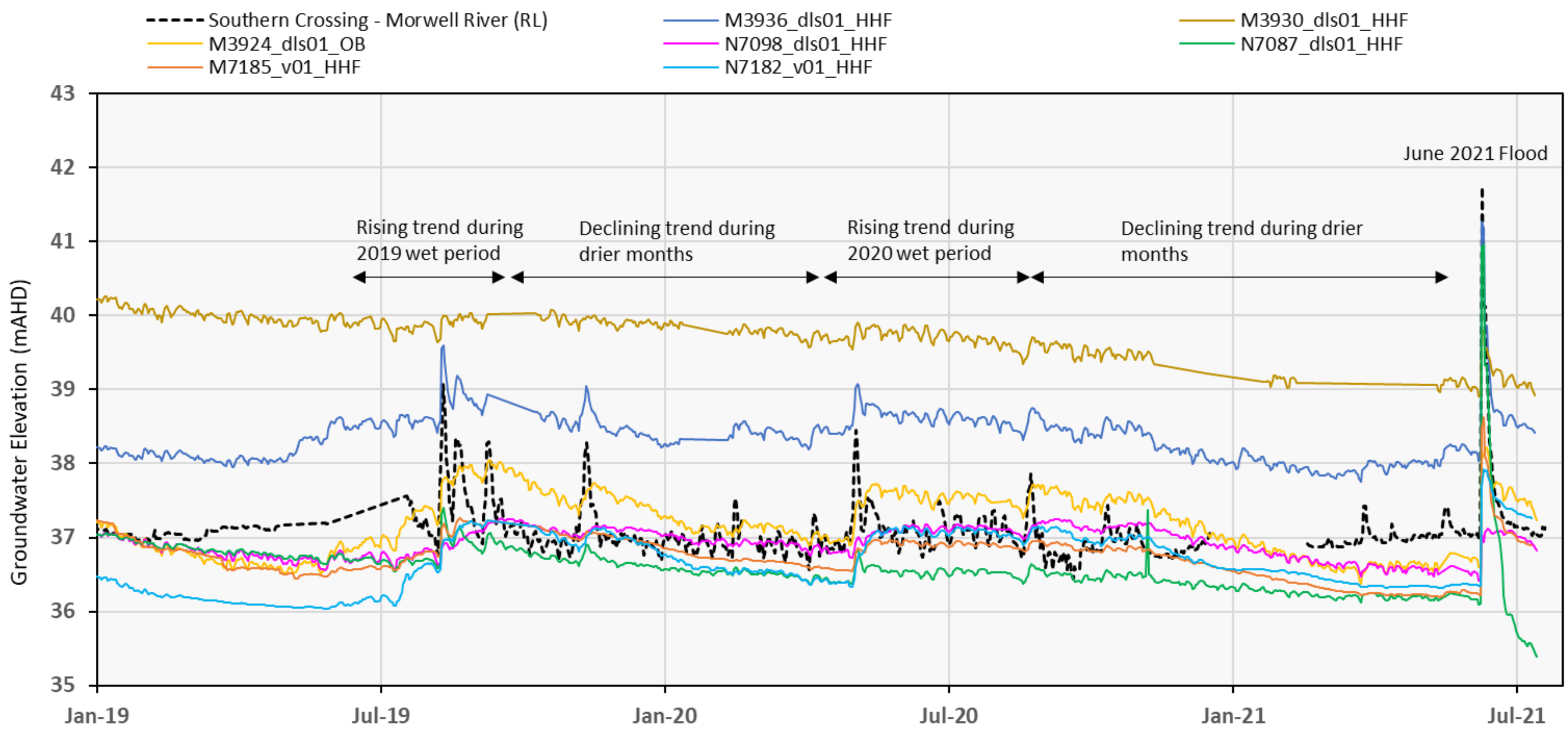


Figure 53 MRD Surface Water – Groundwater Interaction (after GHD, 2022a)

4.9.3 Latrobe River

The Latrobe River has been reshaped following the failure of the East Field northeast (Latrobe River) batters in 2007, which involved around six million cubic metres of overburden and brown coal materials extending 250 m into the pit and 500 m laterally (Baumgartl, 2020). The batter failure extended back to the original course of the Latrobe River, resulting in the diversion of the river into the mine. The batter failure was caused by the block sliding of coal along the basal failure plane at or close to the contact between the Yallourn Coal and clay in the underlying Yallourn Interseam. This has been attributed to insufficient drainage of pore pressures within the cracks and fractures of the coal and depressurisation of the Yallourn Interseam (via pumping of the M1A aquifer). After extensive remedial works, the failed section of the Latrobe River was relocated approximately 300 to 400 m north of its original alignment (see Figure 50).

The shallow groundwater contours presented in Figure 50 indicate groundwater locally flowing towards the Latrobe River from the north. The presence of locally elevated groundwater levels to the south of the river, forming an interpreted local groundwater divide, means there is also a component of groundwater flow from south. There is no river stage data at this location, although the convergence of groundwater flowlines towards the river means this part of the Latrobe River between YNOC and East Field is likely to be gaining some groundwater, particularly where the groundwater level is elevated adjacent to YNOC.

The bores further downstream of the river, adjacent to the East Field northeast batters, indicate groundwater levels declining towards the mine. This suggests groundwater flow to the south, where the HHF is locally drained by the mine, potentially resulting in leakage of surface water (losing condition).

There is limited groundwater data further upstream, adjacent to the Power Station and Township Field. Data from stream gauge 226401A, located approximately 1 km northeast of the Power Station, indicate that the river stage can be 3 to 4 m higher during very high flow/wet periods. It is likely that the Latrobe River is variably gaining and losing as it flows adjacent to the northern boundary of the mine, depending on the relationship between the river stage and groundwater and how they vary seasonally.

4.9.4 Surface water features

4.9.4.1 Fire Service Pond

Fire Service Pond is a large open water feature that was established in 1980. The surface water level of the pond is typically around -5 mAHD, with a standing water depth of around 15 m at the deepest point. The pond sits on the mine floor, either directly above the Yallourn Interseam or on a thin layer of in-situ Yallourn Coal. The telemetry logging of the pond water level (by piezometer 7188) indicates seasonal fluctuations from around -6 to -3 mAHD with periods of high pond water level coinciding with periods of high rainfall (and run-off). The pond water level is also influenced by the transfer of water to and from the pond (from the Dewatering Ponds in East Field and Maryvale Field and to Floc Pond and Witts Gully Reservoir, as discussed in Section 4.5.1).

The piezometric head of the underlying Yallourn Interseam, measured at piezometer N6825 located on the batter crest, is at similar elevations to the pond water level with similar seasonal trends. Therefore, the Fire Service Pond is likely to be hydraulically connected to the Yallourn Interseam. From 2018 to 2019, the pond level was higher than the piezometric head in the Yallourn Interseam, indicating downward seepage. Since 2020, the head gradient has reversed, with the pond level dropping below the piezometric heads. This means the direction of flux into and out of the Fire Service Pond varies over time.

The piezometric heads measured at different elevations within the Yallourn Coal indicate a downward vertical hydraulic gradient through the coal profile. At N6825, the head recorded by a piezometer (sensor v04) installed at around -17 mAHD (slightly higher than the bottom of the pond at around -20 mAHD) has been consistently above the pond level. This means there would be some seepage of groundwater from the coal batters, where the fractures/joints occur at surface or are intersected by horizontal drains. In contrast, the head recorded at a deeper piezometer (sensor v03) installed at around -36 mAHD, below the floor of the pond, has been above the pond level prior to 2020 and below the pond level since 2020. This means there is seasonally variable seepage into and out of the Yallourn Coal where it occurs below the Fire Service Pond, similar to the Yallourn Interseam.

Given the similar pond and groundwater levels and generally low hydraulic conductivity of the Yallourn Coal and Yallourn Interseam, the rate of exchange of fluxes between surface water and groundwater is expected to be very small compared to other components of flow entering and leaving the pond (which maintain the pond as a near permanent feature). This has relevance to closure, when the pit is planned to be filled to form a lake. The long-term presence of the Fire Service Pond suggests that the piezometric head in the Yallourn Interseam would be expected to equilibrate with the lake level as the pit is filled, with the leakage expected to form a small component of the total lake water balance.

Figure 54 shows a schematic cross-section across the northern Fire Service Pond batters and the Morwell River floodplain, where a localised groundwater mound was previously identified in the Yallourn Coal following the flooding of the billabong. Also shown in the figure is the Fire Service Pond, including its inflow and outflow components, and hydrographs comparing the pond level against the piezometric heads at piezometer N6825. At this location, the piezometric head in the Yallourn Interseam is higher than the piezometric head in the basal level of Yallourn Coal, which could be due to the confining effect of the overlying coal and the component of lateral flow through the more transmissive interseam.

The nature of surface water – groundwater interaction is expected to be similar at Township Lake, which is a more recent feature established in 2011.

4.9.4.2 Yallourn Morwell River Wetlands

The Yallourn Morwell River Wetlands were constructed in the early 2000s, on the Morwell River floodplain around 600 m southeast of the Fire Service Pond. The wetlands are surface water-fed, although there are currently no bores in this area to confirm the degree of connectivity with local shallow groundwater. The interpreted shallow groundwater contours shown in Figure 30 suggest groundwater flow across the wetlands towards the mine, with the interpreted groundwater levels close to the ground elevation (around 40 to 45 mAHD). This means the wetlands have the potential to be a local sink to the groundwater system or a flow-through feature.

It is unlikely that the current hydrological regime of these wetlands will be materially altered by the closure of the mine, given that they are located on higher elevations than the current mine or the proposed pit lake level of around 33 mAHD. This means the interpreted groundwater flow direction would remain towards the mine, from the region of higher groundwater levels to the east, with groundwater continuing to drain into the mine as per the existing condition.

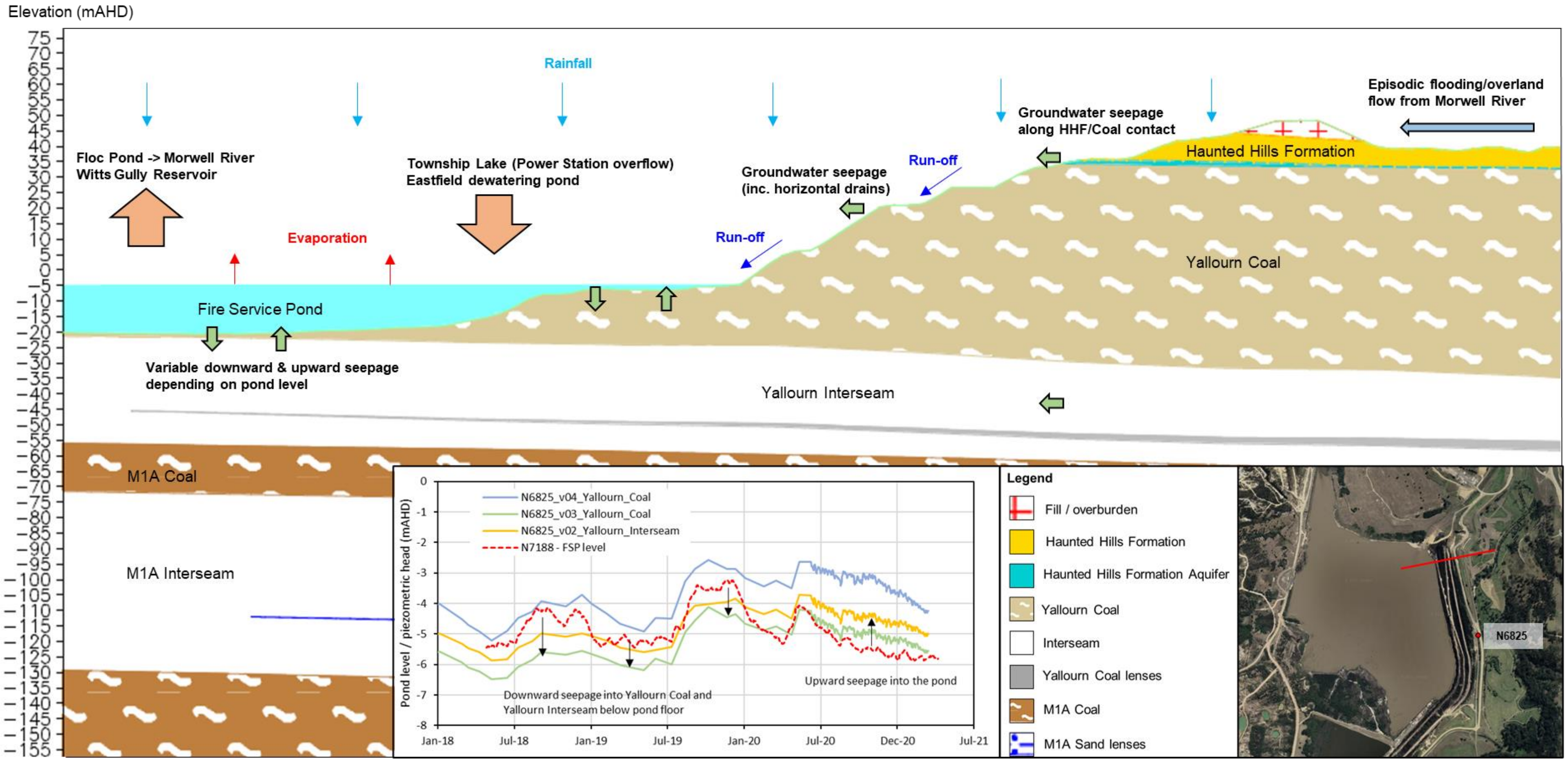


Figure 54 *Fire Service Pond Surface Water – Groundwater Interaction (modified after GHD, 2021a)*

4.10 Hydrogeochemistry

There is limited historical information on groundwater quality at the mine as groundwater monitoring during operation has primarily focused on groundwater levels (pore pressures) and associated effects on geotechnical stability. In an ongoing effort to improve the understanding of groundwater quality and to assist with rehabilitation planning, EAY has commenced a groundwater sampling program using a network of existing and recently constructed monitoring bores located in the periphery of Township Field, East Field, and Maryvale Field.

Results of groundwater sampling undertaken by EAY in September 2022 have been made available to GHD and are summarised in this section. Groundwater samples were collected from 19 monitoring bores in total, with Figure 55 showing the location of these bores and the different hydrostratigraphic units (HSU) sampled at each location. A summary of the available data is provided in Table 9.

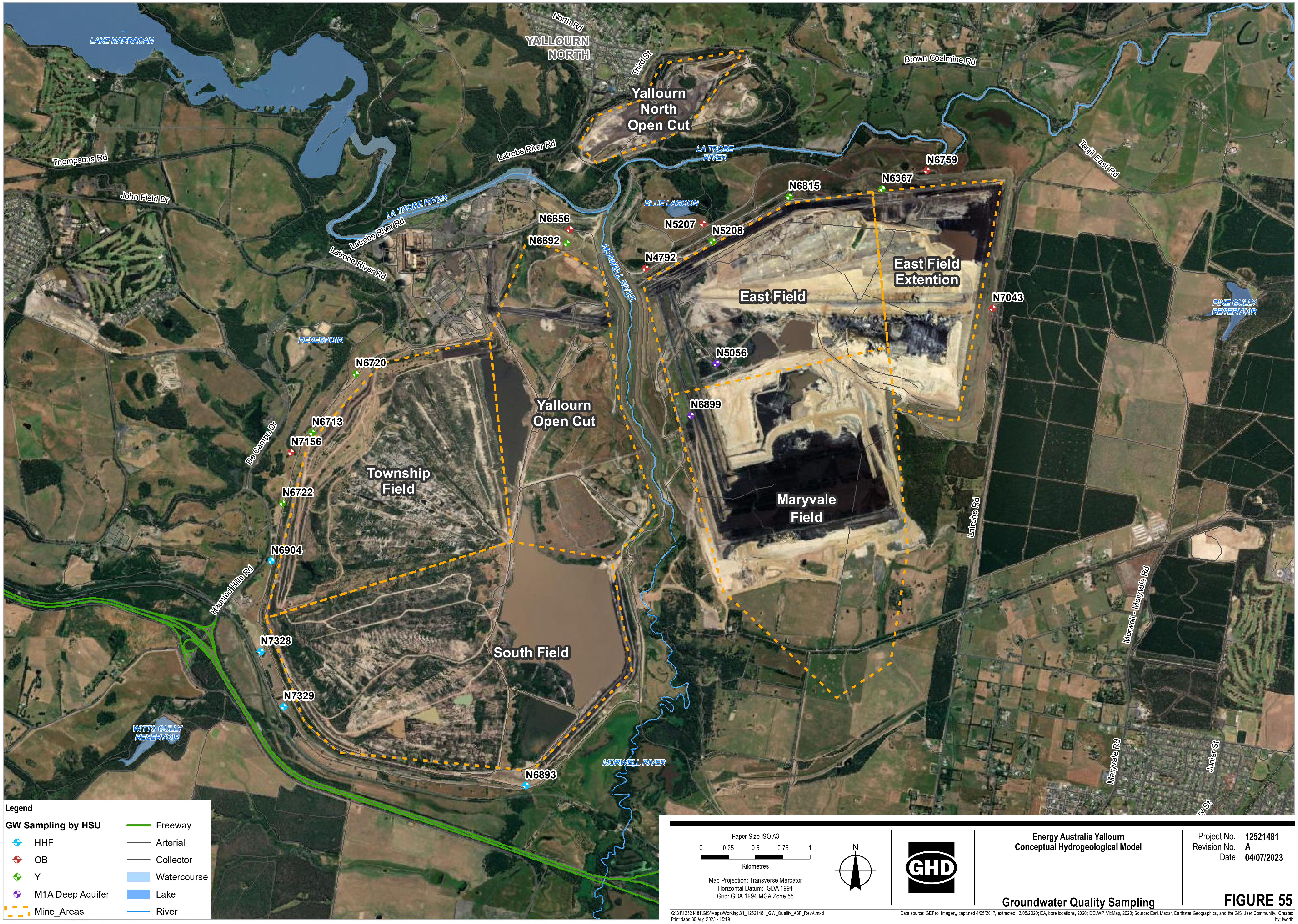
The HSUs monitored include the Haunted Hills Formation (HHF), Overburden (OB), Yallourn Coal (Y) and M1A Interseam, although most of the groundwater quality data is sourced from the Yallourn Coal and the Overburden Table 10 presents a summary of the groundwater quality parameters. An analysis of water types has been undertaken using a piper plot and the major cations and anions concentrations, as shown in Figure 56. The groundwater quality data indicate the following:

- The salinity of Yallourn Coal ranges from 220 mg/L at the Western Batters- Hernes Oak, to up to 1,200 mg/L observed in the East Field, above the Latrobe River Batters.
- The HHF also shows a wide variability in groundwater salinity, ranging from less than 60 mg/L in areas close to topographic ridges and inferred rechange zones at Hernes Oak (near the bores recording long term climate induced trends, as discussed in Section 4.7.2), to up to 770 mg/L adjacent to Floc Pond Batters. The salinity is higher and more variable in the East Field and Maryvale areas. Similarly, the salinity of bores in the Overburden ranges from 190 mg/L at Hernes Oak and 640 mg/L in East Field.
- The samples of M1A Interseam (aquifer) groundwater collected from pumping bores N6899 and N5056 indicate low salinity, with a Total Dissolved Solids (TDS) concentration of 300 mg/L and 210 mg/L respectively.
- The pH levels range from 5 to 6 pH units for the different HSUs, which is in line with the historical data (Table 2).
- The piper plot analysis indicates that the four HSUs identified showed a similar distribution, except for the Overburden which showed no dominant type and a wider spread of mixed water types (reflecting their heterogeneous nature). The majority of the samples are characterised as a sodium chloride groundwater type.

Table 9 EAY September 2022 Groundwater Quality Sampling Program

Location	Bore ID	Date constructed	MGA55 Easting (m)	MGA55 Northing (m)	Total Depth (m)	Screen depth (From - to, m)	Hydrostratigraphic unit (HSU)	SWL (m)	Gral Parameters	Major Elements	Trace Metals	Ionic Balance	Organics
Latrobe Road (east of East Field)	N7043		447768.4	5773805.44	27		OB	24.0	✓	✓	✓	✓	✓
East Field (above Latrobe River Batters)	N6759	Dec 2021	447166.7	5775064.03	10	4.6-7.6 31.2-28.2	OB	2.2	✓	✓	✓	✓	✓
	N6367	May 2008	446758.81	5774894.49	54	19-37 -15.7 to -33.79	Y	17.8	✓	✓	✓	✓	
	N6815	July 2012	445907.01	5774826.73	96	42-45 -16.9 to -19.9	Y	29.7	✓	✓	✓	✓	
East Field (above Northern Batters)	N5207	April 2000	445118.37	5774577.8	81	18-21 35.2-32.2	OB	21.3	✓	✓	✓	✓	
	N5208	April 2000	445206.12	5774418.23	57.9	40-42.5 -10.7 to -13.2	Y	27.5	✓	✓	✓	✓	
	N4792	Feb 1990	444594.61	5774170.52	16.4	7.4-10.4 35.8-32.8	OB	7.8	✓	✓	✓	✓	✓
Latrobe South Batters	N6692		443874.98	5774400.91	35	31-34 9.8-6.8	Y	29.0	✓	✓	✓	✓	
	N6656		443900.84	5774526.84	19.95	12.9-18.9 34.5-28.5	OB	12.3	✓	✓	✓	✓	
YTF Western Batters / Hernes Oak	N6720	Nov 2011	441944.49	5773206.8	90	46.5-49.5 28.1-25.1	Y	22.5	✓	✓	✓	✓	
	N6713	Aug 2012	441544.11	5772669.95	94	30-33 34-31	Y	5.4	✓	✓	✓	✓	
	N7156	Apr 2017	441350.76	5772488.7	47	7-13 72.1-66.1	OB	5.7	✓	✓	✓	✓	✓
	N6722	Apr 2016	441273.2	5772024.15	100	57.5-60.5 24.2-21.2	Y	54.1	✓	✓	✓	✓	
	N6904	Apr 2013	441170.21	5771496.13	90	8-11 74.8-71.8	HHF	9.8	✓	✓	✓	✓	
YTF Hernes Oak / SW Batters	N7329	Dec 2021	441285.74	5770163.18	127	15-18 76.1-73.1	HHF	5.5	✓	✓	✓	✓	
	N7328		441074.6	5770667.09	94	14-20 79.7-73.7	HHF	9.9	✓	✓	✓	✓	
Above Floc Pond Batters	N6893	Feb 2013	443497.55	5769442.43	82	9.5-12.5 41-38	HHF	12.6	✓	✓	✓	✓	✓
M1A bores	N6899		445007.23	5772825.5	160		M1A Deep Aquifer		✓	✓	✓	✓	
	N5056	Dec 2013	445240.37	5773298.41	81.5	73-77 -106 to -110	M1A Deep Aquifer		✓	✓	✓	✓	

MGA55 coordinates calculated from SEC coordinates supplied by EAY; Hydrostratigraphic Units: HHF – Haunted Hills Formation, OB – Overburden, Y- Yallourn Coal; SWL: Standing Water Level ; General parameters: pH, Electrical Conductivity, Dissolved Oxygen, Alkalinity, Acidity, Hardness, Total Dissolved Solids.



Energy Australia Yallourn
Conceptual Hydrogeological Model

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Revision No. A
Date 04/07/2023

Groundwater Quality Sampling

FIGURE 55

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Print date: 30 Aug 2023 - 15:19

Data source: GEPro, Imagery, captured 4/05/2017, extracted 12/05/2020; EA, bore locations, 2020; DELWP, VicMap, 2020; Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community. Created by: tworth

Table 10 Groundwater Quality Physical Parameter Summary

Physical parameter	Samples	Dissolved Oxygen (mg/L)			pH			Conductivity @25˚C (mS/m)			Total Dissolved Solids (mg/L)		
HSU	No	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
HHF	4	4.50	6.70	5.80	4.90	5.30	5.08	10	130	42.75	59	770	254.00
OB	6	1.80	6.40	5.02	4.80	6.60	5.73	31	110	53.17	190	640	316.67
Y	7	3.10	6.60	4.89	4.90	5.40	5.17	37	200	78.57	220	1200	471.43
M1A Deep Aquifer	2	5.70	6.60	6.15	5.70	6.30	6.00	35	50	42.5	210	300	255.00

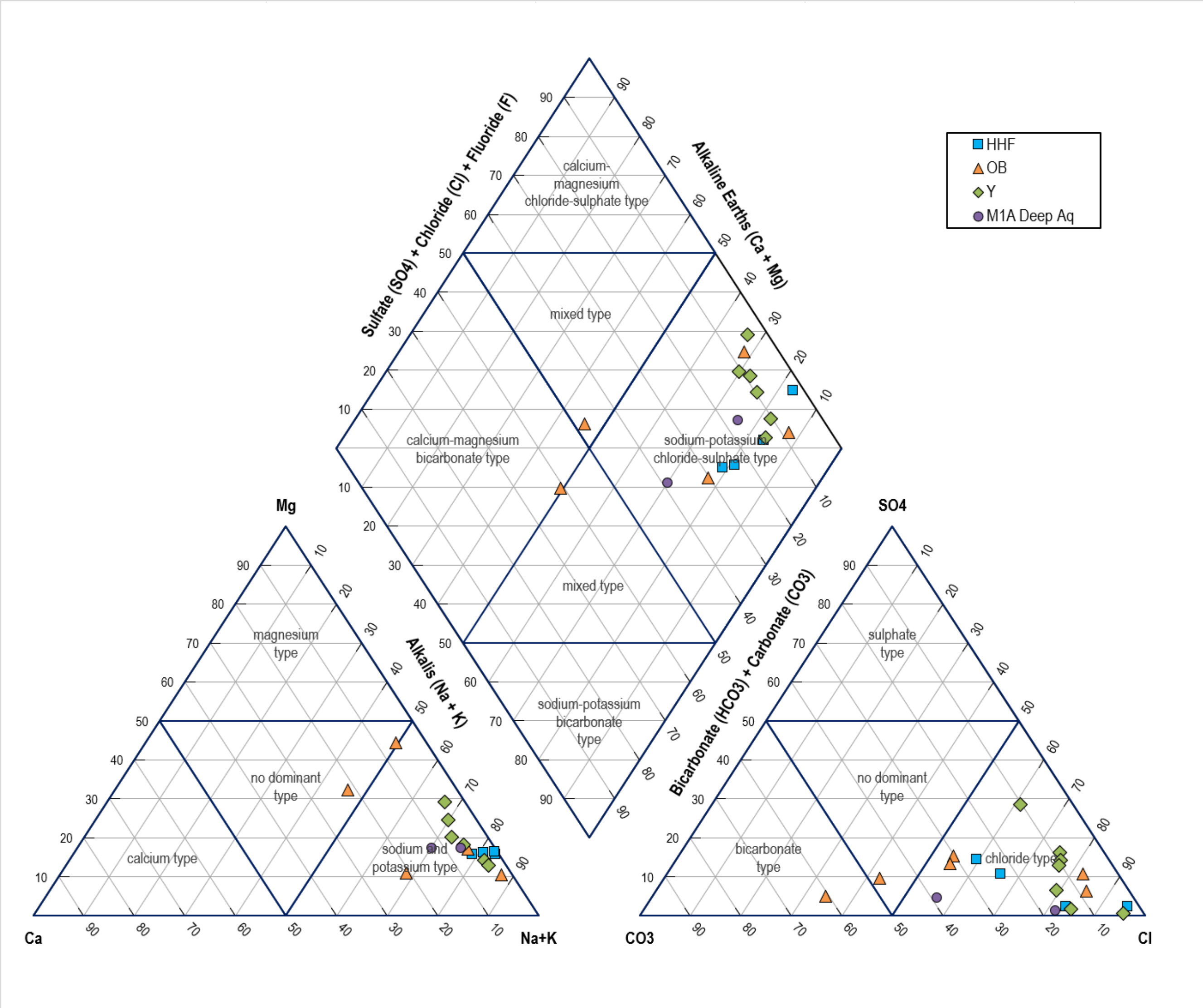


Figure 56 Piper Plot Water Types

4.11 Groundwater-dependent ecosystems

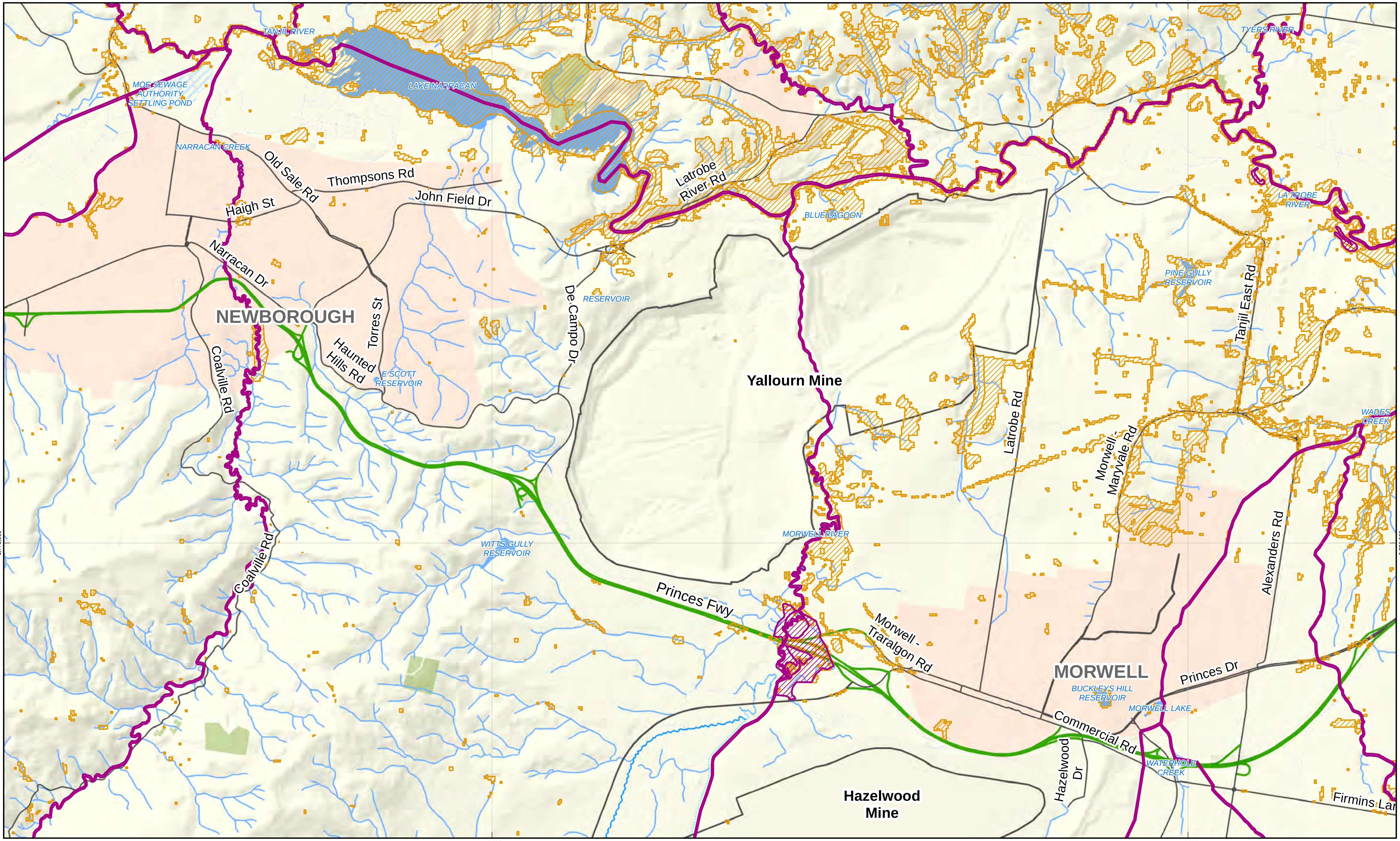
The Australian groundwater dependent-ecosystem (GDE) toolbox provides a framework to assist with the identification of GDEs and their water requirements (Richardson et al., 2011). The toolbox classifies three types of GDEs based on the role of groundwater in maintaining biodiversity and ecological condition:

- Aquifer and cave ecosystems (Type 1) where groundwater-inhabiting ecosystems (e.g.stygofauna) reside, commonly in karst and fractured rock aquifer systems
- Ecosystems dependent on the surface expression of groundwater (Type 2), including wetlands, lakes, seeps, springs, and river baseflow systems where the water table extends above the land surface as a visible expression
- Ecosystems dependent on subsurface presence of groundwater (Type 3), including terrestrial vegetation where the root zone lies within the capillary fringe of the water, either permanently or episodically

The GDE Atlas presents the current knowledge of ecosystems that may depend on groundwater across Australia. A search of the GDE Atlas shows that vegetation/trees along the Morwell River to the south and Latrobe River to the north of the Yallourn Mine are identified as having high potential for groundwater dependence. This is expected near major water courses, particularly those that are gaining baseflow, due to typically shallow depth to groundwater in the riparian zone (generally within 8 m of ground surface based on the piezometers near these rivers). The GDE Atlas also identifies trees in the area to the east of Maryvale Field as having moderate to high potential for groundwater dependence. The piezometers between Maryvale Field and the boundary of this vegetated area indicate typical depth to groundwater of around 6 to 10 m, although this increases to more than 30 m further to the east, following rising topography.

Given the long history of mining, the presence of trees in these areas implies that mining has not yet affected the availability of shallow groundwater (or soil moisture in the capillary fringe above the water table) to the extent that significant adverse impacts on vegetation health have been realised. This is generally supported by the presence of shallow groundwater, which is maintained by recharge (and locally leakage from the rivers) with drainage into the mine typically confined to areas immediately adjacent to the mine. Anecdotal observations in the field also indicate vegetation growth in areas where the batters are locally saturated or where water pools along drainage lines, suggesting local presence of groundwater at depths that can be readily accessed by these trees.

In the area adjacent to Maryvale Field, the impact of mining is subject to ongoing monitoring. It is understood that a drainage line feeding into this area directs some surface run-off following rainfall, which may serve an important function in replenishing the soil moisture. If the drainage pattern is modified in the future such that surface run-off is directed elsewhere, the trees may become more reliant on groundwater to meet their water requirements (if groundwater is accessible). If this is the case, the lowering of the water table due to seepage into Maryvale Field has the potential to further limit the availability of water to these trees.



Paper Size A3

0 240 480 960 1,440 1,920

Metres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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LEGEND

GDE Type

- Ecosystems that rely on the surface expression of groundwater
- Ecosystems that rely on Subsurface presence of groundwater
- Mine boundary
- Freeway
- Highway
- Arterial
- Watercourse
- Pondage
- Lake
- River
- Stream
- Channel
- Drain/Channel/Other
- National Parks
- Other Parks
- Township boundary
- Mine_Pit_Clip

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EnergyAustralia Yallourn Pty Ltd
Conceptual Hydrogeological Model

Job Number	12521481.0
Revision	
Date	24/01/2022

Groundwater Dependent Ecosystems

Figure 57

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Data source: DELWP, VicMap, 2020; BOM, GDE data, 2016; GHD, Mine Boundaries, 2020 Created by: tworth

5. Transitioning to rehabilitation – evolution of hydrogeological system

5.1 Overview

Following mining, there will be a long period of recovery of the groundwater system, which will tend towards the pre-mining condition except where the conditions have been permanently modified from those of the past. The mine rehabilitation options currently under consideration include a full pit lake, and the groundwater system will tend towards a new dynamic equilibrium with respect to the final landform that will be different to the pre-mining condition. The surrounding groundwater extraction activities will also have an important influence on the recovery of the groundwater levels.

Processes that influence the groundwater system before, during and after mining occur at different spatial and temporal scales. This section presents the current conceptualisation of how the groundwater system at the Yallourn Mine has changed over time and how it is likely to change into the future, for the purpose of informing the rehabilitation planning and long-term recovery of the groundwater system post-mining. Schematic hydrogeological cross-sections summarising the key hydrogeological processes are also presented in this section. The conceptualisation excludes subsidence and associated recovery, which is primarily a geotechnical issue (and will be documented separately).

5.2 Pre-mining

Prior to mining, the groundwater flow direction within the confined aquifers at the Yallourn Mine is likely to have been in the northeast direction along the Morwell River valley and to the east from the elevated basin margin. Artesian aquifer pressures are likely to have occurred in the M2/TFAS, as artesian conditions were recorded in low-lying areas at the Hazelwood Mine to the south and at Maryvale APM to the east. Pre-mining artesian piezometric heads have been estimated at approximately 60 mAHD in the M2/TFAS and around 50 mAHD in the MFAS. An upward flow/hydraulic gradient from the confined artesian MFAS to the shallow groundwater systems was likely along drainage lines and low-lying areas.

Prior to the commencement of groundwater pumping at Maryvale APM in 1945, and aquifer depressurisation associated with the development of the coal mines from the 1960s, very few stresses would have been imposed on the groundwater system. The hydrological stresses would have been limited to those associated with a natural range of variations in recharge and evapotranspiration. Groundwater pumping would have been limited to small scale farm use, generally from the shallow aquifers where bore construction costs are typically low.

The groundwater systems prior to mining, particularly those associated with the confined aquifers at depth can be conceptualised to have been in a quasi-steady state condition. Such condition is characterised by a balance between long term average recharge and discharge, with groundwater flow rates controlled by the hydraulic conductivities in the horizontal and vertical directions.

The data indicate that significant depressurisation of the confined aquifer systems in the Latrobe Valley has not affected the confined aquifer pressures in the Moe Swamp Basin to the west, supporting the conceptualisation that this basin is hydraulically separated from the Latrobe Valley by faulting and truncation of geological units. This disconnection of the groundwater systems, which would have occurred for a long period prior to mining, has remained throughout mining and is expected to continue far into the future after rehabilitation.

5.3 Mining

Cones of depressurisation in the M2/TFAS have developed in the region in response to the Maryvale APM pumping from 1945 to 1975 to the east, and Hazelwood Mine pumping to the south from 1969. As the development of the Yallourn Mine has not required depressurisation of the M2/TFAS, the lowering of piezometric heads in the deep aquifer system at the mine has been largely due to pumping at the Hazelwood Mine (given its proximity, high extraction volumes and long pumping history). The pumping would have caused a very large reduction in piezometric heads at depth beneath the Yallourn Mine, relative to the natural range of variations, potentially exacerbated by the presence of the Haunted Hills Fault acting as a regionally significant hydraulic (no flow) boundary. Similarly, a large reduction in piezometric heads would have occurred to the south in response to the MFAS (M1B) pumping at the Hazelwood Mine from 1960. These changes to the groundwater system observed during mining are insensitive to recharge as the water balance is dominated by the much larger volumes of groundwater extracted from the confined aquifers.

Pumping of the M1A Interseam at Yallourn from 1994 resulted in depressurisation at the mine that was necessary for enabling safe mining of East Field and Maryvale Field. Nonetheless, its regional effects are likely to have been limited in comparison to those associated with the Hazelwood Mine aquifer depressurisation program due to the much lower pumping volumes and restricted extent of the M1A Interseam. At the Yallourn Mine, the M1A Interseam has been observed to show confined aquifer responses to groundwater pumping but otherwise limited response to the progression of mining (and excavation of coal above it). In contrast, the Yallourn Interseam pressures appear to show responses to both pumping and mining, including upward leakage to the mine floor and downward seepage into the underlying M1A Interseam where the aquifer pressure has been lowered by pumping. The observed responses at the mine are complex and are likely to be influenced by a combination of factors such as the material properties and distribution of coals and interseams, and their proximity to the sources of stresses (such as pumping bores and excavated mine floor).

The progressive development of the Yallourn Mine has resulted in a gradual expansion of a zone of dewatered HHF in the areas adjacent to the mine batters. On a regional scale, the current information suggests that there is limited drawdown in the shallow aquifer from the pumping of the confined M1A Interseam due to the presence of the thick Yallourn Coal and M1 Coal and clays which act as aquitards that limit the influence of pumping on the water table.

The Morwell River is characterised as having a net gaining condition upstream of the Yallourn Mine, with groundwater providing baseflow. Closer to the mine, the locally dewatered HHF creates variably gaining and losing conditions for the Morwell River and MRD depending on climate. During periods of high flow and flooding, leakage of surface water to the water table occurs from the river and floodplain, a portion of which eventually seeps into the water storages and dirty water ponds in the base of the pits. The amount of leakage from the surface water features within the mine is likely to be variable, influenced by the properties of the subsurface material and the differences in surface water and groundwater levels. For the YNOC ash ponds, the lined ponds are located at a higher elevation relative to the adjacent Latrobe River and the local flow directions are influenced by pumping, topography and interactions with the river.

5.4 Post-mining

The preferred and approved rehabilitation option is the full pit lake, although dry void and partially filled pit lake options are under consideration for the purpose of understanding rehabilitation risks. The significance of these different rehabilitation options on the groundwater system at the Yallourn Mine is depth dependent, becoming increasingly important higher up in the stratigraphic profile.

The different rehabilitation options are not expected to make material differences to the hydrogeological processes occurring in the deep M2/TFAS, given the piezometric heads/pressure in this aquifer system will be primarily controlled by the pumping and rehabilitation of the adjacent Hazelwood Mine and Loy Yang Mine. The exception to this would be if this groundwater resource is utilised for filling the pit lake and /or maintaining the lake level at the Yallourn Mine.

In the overlying M1 Interseam, the hydrogeological processes would be more sensitive to different rehabilitation options due to different requirements for managing the aquifer pressure to ensure safe and stable final landform, including vertical connections with the overlying Yallourn Interseam.

The local hydrogeological processes of the shallow water table aquifer would be expected to be most sensitive to different rehabilitation options due to the direct connection with the mine (and locally with the pit lake) and interaction with the Morwell River as well as the Latrobe River. Although the Yallourn Coal and Yallourn Interseam are conceptualised as aquitards, the hydrogeological changes arising from different rehabilitation options (such as changes to coal pore pressure profiles in the batters) are also an important point of consideration for managing geotechnical (batter stability) issues.

The following sections describe the conceptualisation of key hydrogeological processes in the confined and unconfined aquifers in the context of different rehabilitation options currently under consideration for the Yallourn Mine.

5.4.1 Confined Aquifers

5.4.1.1 M2 Interseam

The progressive rehabilitation of the Latrobe Valley coal mines is expected to result in the sealing and decommissioning of the pumping bores, followed by the recovery of the piezometric heads in the deep confined aquifers. The recovery at the pumping bores will initially be quick as the confined (elastic) storage is replenished by the flow from the surrounding area of the aquifers (under the influence of steep hydraulic gradients imposed by pumping). This is evidenced by the magnitude and rate of short-term recoveries observed numerous times during mining in response to temporary pumping outages. Over time, the lateral flow will affect a larger radius and the duration of recovery will become sensitive to regional averages in hydraulic conductivity, both horizontal and vertical, and long-term average recharge that replenishes the aquifer storage.

The elevation to which the piezometric heads in the M2/TFAS would ultimately recover depends on the influence of surrounding extraction activities and long-term climate (particularly regional recharge). If this groundwater resource is utilised at the Yallourn Mine to fill or top up the pit lake, the restoration of artesian heads below the mine would be delayed or locally limited for the duration of pumping. Although there are currently no bores in the M2/TFAS below the Yallourn Mine, the management of deep confined aquifer pressure is unlikely to be necessarily from the point of view of weight balance and stability due to the depth of the M2 Interseam. Weight balance calculations undertaken by GHD (2021) indicate a potential risk only in a local area within central Maryvale Field under the dry void scenario, due to the potential for the M2 aquifer piezometric heads to recover to a level close to the calculated minimum weight balance level.

5.4.1.2 M1A Interseam

The recovery of the M1A Interseam piezometric heads will depend partly on the changes to the M1 aquifer pumping regime at the adjacent Hazelwood Mine and largely on the requirement of different rehabilitation options to maintain pumping at the Yallourn Mine to ensure stability.

For the dry void option, the mine water management would be expected to remain similar to the current operational condition assuming that ongoing pumping from the M1A Interseam is necessary to prevent floor heave and ensure batter stability. This would depend on the weight balance of the rehabilitated mine, which will be influenced by factors such as the weight of the overburden material placed on the mine floor and the long-term recovery of aquifer (upward) pressure (which will be sensitive to regional recharge, with the wetter climatic condition facilitating faster and greater recovery and vice versa). Weight balance calculations undertaken by GHD (2021) indicate that ongoing pumping will likely be required under the dry void scenario due to the low weight balance levels calculated for the M1 Interseam in central Maryvale Field and adjacent to the eastern batters of the Fire Service Pond where the overburden cover is limited.

If pumping is ceased, the recovery of the M1A Interseam piezometric heads could lead to an upward vertical hydraulic gradient between the overlying Yallourn Interseam, with the rate of upward seepage depending on the thickness and properties of the intervening M1 Coal and associated hydrogeological properties. The thinning of the M1 Coal to the north means the pressure in the Yallourn Interseam is expected to be particularly sensitive to the pressure changes in the underlying M1A Interseam.

For the full pit lake option, the weight of lake water will likely render ongoing pumping of the M1A Interseam unnecessary. Under this scenario, the pumping bores could be decommissioned and the M1A Interseam piezometric heads allowed to recover. The vertical hydraulic gradient between the MA1 Interseam and Yallourn Interseam, and associated upward seepage, would be expected to be small as the piezometric heads in the Yallourn Interseam would be expected to equilibrate with the lake level over time. Pumping may be necessary during the transitional filling period, until the lake level reaches a point where the MA1 Interseam pressure is no longer deemed to pose risk on the mine stability.

For the partial lake option, the weight balance calculations indicate the potential for the long term M1A Interseam piezometric heads to locally exceed the weight balance levels in central Maryvale Field and in the area adjacent to the eastern batters of FSP (GHD, 2021). However, the calculated level of exceedance is in the order of a few metres (4 m or less), assuming the recovered M1A Interseam heads of as much as 50 mAHD. Depending on the influence of future climate and the interaction of the aquifers with the lake level, the weight balance exceedance may not be realised under the partial lake scenario (or to the extent that would necessitate pumping of the M1A Interseam in perpetuity).

5.4.1.3 Yallourn Coal and Interseam

Although the Yallourn Coal and Yallourn Interseam are considered as aquitards, ongoing management of piezometric heads would be necessary to a varying degree to ensure batter stability, particularly in areas of preferential flow/enhanced hydraulic conductivity.

For the dry void option, horizontal drains would be required to maintain stable pore pressures similar to the existing conditions. For the partial pit lake option, horizontal drains may be limited to the area above the lake level whereas the full pit lake option would no longer require horizontal drains if the lake level can be maintained.

The management of pore pressures in the batters is subject to further geotechnical assessments.

5.4.2 Unconfined aquifer

5.4.2.1 Dry void option

For the shallow aquifer, the dry void option would result in the continuation of the current hydrogeological conditions and processes. The HHF close to the mine batters will remain dewatered, with a locally depressed water table and localised seepage into the void which would be maintained by recharge (and enhanced during wet periods due to leakage from the surface water systems).

If ongoing pumping of the M1A Interseam is deemed necessary for the dry void option, existing water features such as the Fire Service Pond, Floc Pond and Dewatering Pond would be expected to be maintained (for ongoing dewatering, storage and fire management). These would remain hydraulically connected to the OB and Yallourn Interseam exposed along the floor of the mine.

If/where the M1A Interseam piezometric heads are allowed to recover, an upward vertical hydraulic gradient could develop between the M1A Interseam and Yallourn Interseam where the latter is close to the mine floor and its heads are likely to remain low due to the presence of the void. Areas further away from the mine void that are less sensitive to the changes in the pumping regime may show little changes to the natural hydraulic gradients between he M1A Interseam and Yallourn Interseam e.g. the downward vertical hydraulic gradient, as typically observed, may persist after the pumping bores are decommissioned.

The connection between surface water and groundwater, particularly at depth via sub-vertical joints and fractures, would remain an important consideration for the ongoing management of pore pressures and batter stability. Over time, joints and fractures may open up (due to ground movement), providing new pathways for channelling flood water. This has the potential to lead to localised build-up of pore pressure within the Yallourn Coal and potentially all the way into the M1A Interseam (similar to the pore pressure response observed following the June 2021 major flooding event). The reprofiling of the batters and other ongoing management measures would require consideration of the shallow groundwater dynamics and associated connectivity with the deeper aquifers.

Further assessments and modelling will be required to examine the effect of the dry void option on the shallow groundwater system, taking into consideration the implications of the mine remaining a water table sink and measures required to manage groundwater seepage (and associated effects on groundwater quality).

5.4.2.2 Partial and full pit lake options

For the partial lake option, the shallow aquifer will continue to be drained as per the dry void option; however, the Yallourn Interseam piezometric heads would recover along the floor of the mine as this formation becomes re-saturated by the lake water and equilibrates with the lake level. This may lead to some downward seepage into the M1A Interseam if its heads are maintained low by pumping during (and possibly after) filling. The rate of seepage (loss of lake water) into the aquifer, both for the partial and full pit lake options, is expected to be small compared to other components of the lake water balance given the low hydraulic conductivity of the underlying material (OB/Yallourn Coal/Yallourn Interseam) and large potential surface areas of the lake (subject to rainfall, run-off and evaporation).

With the full pit lake option, the dewatered HHF adjacent to the batters could be locally re-saturated by the lake water, depending on the relationship between the final lake level, base of the HHF and existing groundwater level. Seepage from the HHF would initially be towards the lake, but as the lake level rises, seepage of lake water into the HHF may occur temporarily if the lake level reaches above the base of the HHF where the aquifer has been drained. Over time, the water table adjacent to the mine would rise in response to rainfall-derived recharge and equilibrate with the final lake level (causing the water table in the HHF to rise as a whole, assuming the pit lake level remains stable). This would maintain the flow of groundwater towards the pit lake over the long-term, with the rate of seepage depending on the hydrogeological properties, hydraulic gradients and future climate.

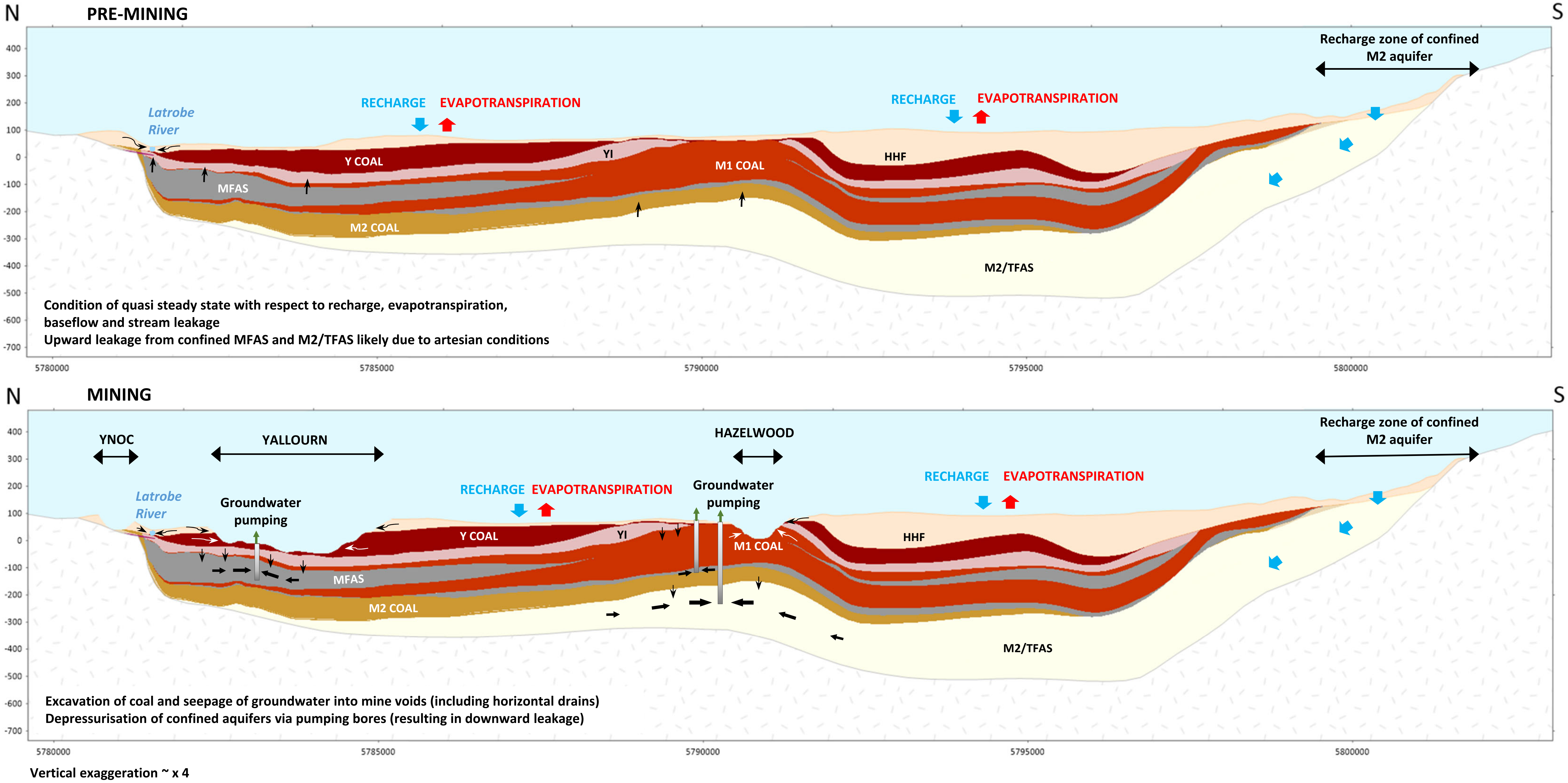
At the proposed lake level of +33 mAHD, the re-saturation of the HHF may occur over an area adjacent to the East Field northeast (Latrobe River) batters where the shallow groundwater level is currently at around 30 mAHD. This has the potential to cause some of the lake water to temporarily discharge into the Latrobe River (via the shallow aquifer), resulting in increased baseflow. The potential effect of this increased baseflow would need to be assessed in the context of changes to the stream flow characteristics arising from other rehabilitation and management activities. Similarly, an eco-hydrogeological assessment, informed by data and findings from numerical modelling, would be necessary to assess possible effects on GDEs that may be associated with the Latrobe River.

The effect of a full pit lake on shallow groundwater quality would depend on factors such as the long-term quality of lake water, the degree of interaction between the pit lake and adjacent aquifers and how they are connected with surface water features such as the Morwell River. Detailed modelling of surface water and groundwater systems will be required to address these questions.

The Yallourn Morwell River Wetlands, located southeast of the Fire Service Pond, are potentially connected to groundwater, albeit at a higher elevation (around 40 to 45 mAHD) than the proposed lake level of +33 mAHD. This means the regional groundwater flow across this feature would remain towards the mine and the wetlands are unlikely to be influenced by the rehabilitation of the mine.

5.5 Schematic hydrogeological cross-sections

Schematic representations of key hydrogeological processes are included in Figure 58 and Figure 59, showing how these processes have changed over time (from before and during mining) and how they may change in the future (during and after rehabilitation). These are projected on to a north to south cross-section through the Yallourn Mine and Hazelwood Mine, showing the distribution of major units and their relationship with the hydrogeological processes such as pumping and seepage. The rehabilitation option is assumed to be the full pit lake, requiring ongoing pumping during filling and decommissioning of pumping bores once the filling has been completed.



Paper Size ISO A3

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Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

EnergyAustralia Yallourn
Hydrogeological Conceptual Model

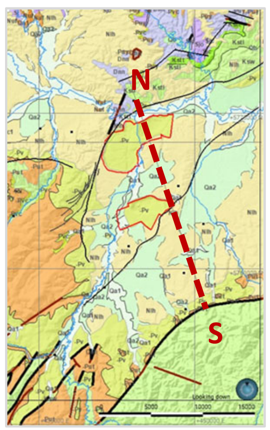
Schematic Hydrogeological Cross Section
Pre-mining & mining stages

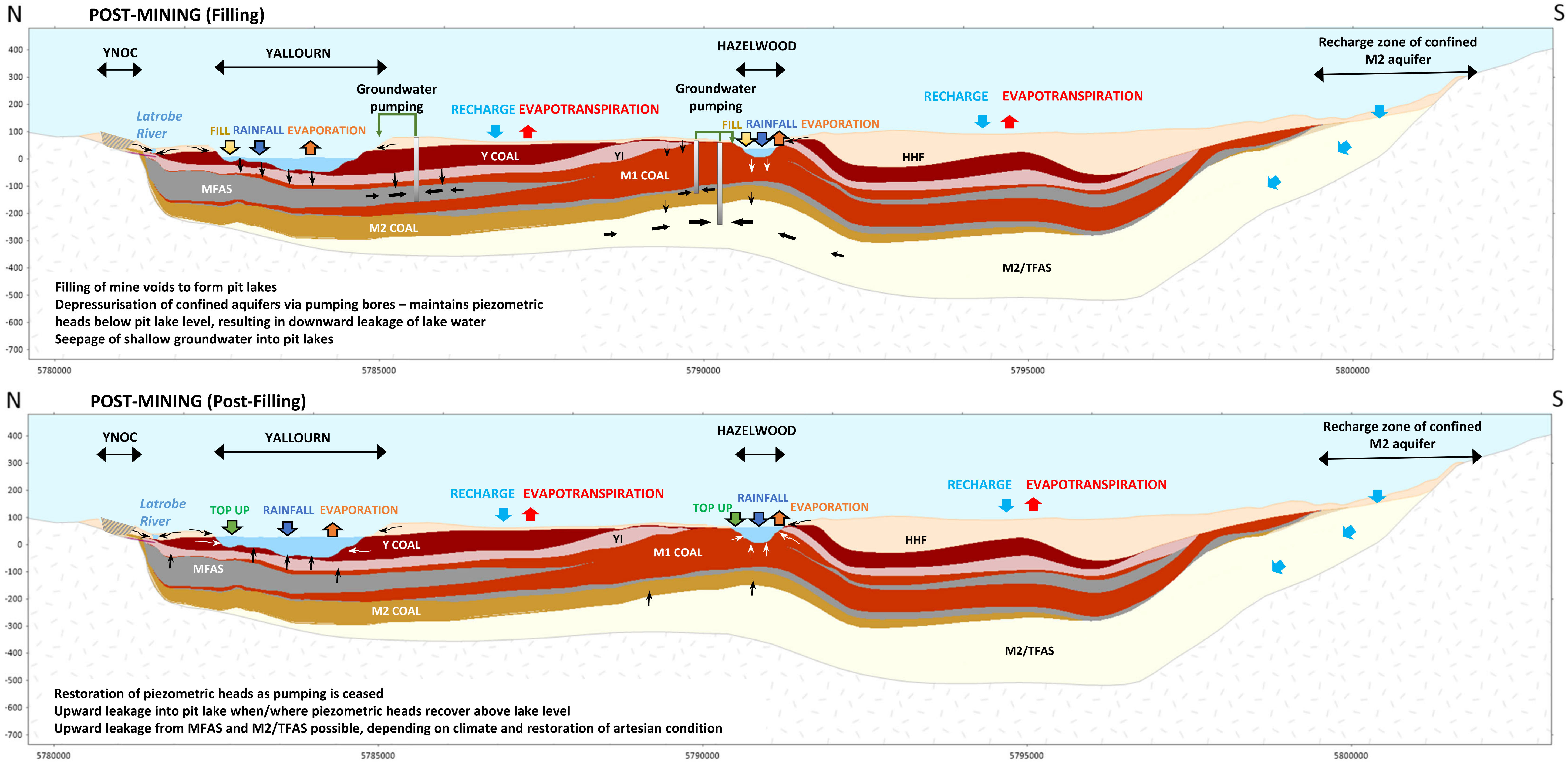
Project: **12521481**
Revision No. A
Date: 28/08/2023

FIGURE 58

- Haunted Hills Formation (HHF)
- Yallourn Coal (Y COAL)
- Yallourn Interseam (YI)
- M1 Coal (M1 COAL)
- Morwell Fm Aquifer System (MFAS)
- M2 Coal (M2 COAL)
- M2/ Traralgon Formation Aquifer System (M2/TFAS)
- Basement

- RECHARGE
- EVAPOTRANSPIRATION
- RAINFALL
- EVAPORATION
- FILL
- TOP UP
- SEEPAGE/LEAKAGE
- PUMPING INDUCED FLOW





Vertical exaggeration ~ x 4

Paper Size ISO A3

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Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

GHD

EnergyAustralia Yallourn
Hydrogeological Conceptual Model

Schematic Hydrogeological Cross Section
Post-mining filling & post-filling stages

Project: **12521481**
Revision No. A
Date: 28/08/2023

FIGURE 59

- Haunted Hills Formation (HHF)
- Yallourn Coal (Y COAL)
- Yallourn Interseam (YI)
- M1 Coal (M1 COAL)
- Morwell Fm Aquifer System (MFAS)
- M2 Coal (M2 COAL)
- M2/ Traralgon Formation Aquifer System (M2/TFAS)
- Basement

- RECHARGE
- EVAPOTRANSPIRATION
- RAINFALL
- EVAPORATION
- FILL
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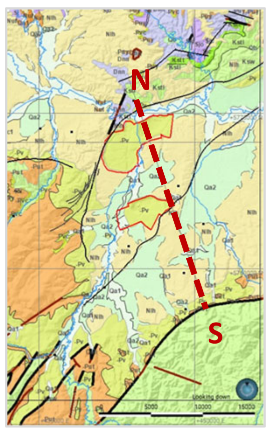
- PUMPING INDUCED FLOW



6. Knowledge gaps and further data collection

This report presents the current hydrogeological conceptualisation of the Yallourn Mine. Key features of the groundwater system have been described, with relevant supporting data and knowledge gained from the long history of mining, monitoring and modelling in the Latrobe Valley. The potential future groundwater behaviours are discussed in the context of rehabilitation options that include a full pit lake.

This process has also identified gaps in the current hydrogeological knowledge and EAY are undertaking further works to address some of these data gaps. However, not all knowledge gaps can be resolved through collection of additional data prior to rehabilitation (for example, it would not be feasible to replicate the regional effects of a full pit lake until the void is filled). In some cases, insights gained from a combination of field data and groundwater modelling would be necessary to inform groundwater-related risks associated with the rehabilitation of the mine. As outlined in Section 1, the hydrogeological conceptualisation of the Yallourn Mine will continue to be refined and improved through ongoing data collection, analysis and modelling.

In the context of rehabilitation planning, the following data gaps are considered relevant for ongoing investigations and data collection:

- Currently limited groundwater quality data, which is being addressed by EAY's sampling program. Results from a single round of sampling were reviewed and incorporated into this report.
- Uncertainty in the current surface of the water table across the western area of the mine (and the nature of interaction with the underlying aquifers) due to the absence of bores and limited groundwater level (as well as quality) data in this part of the mine.
- Limited data on the hydrogeological properties of some of the in-situ material, specifically the internal (dumped) Overburden, Yallourn Coal and Yallourn Interseam. While the hydraulic conductivity of coal batters can be enhanced by joints and fractures, the long-term regional changes in aquifer pressures following rehabilitation would also be sensitive to the bulk average properties of the in-situ material. The exchange of fluxes between the pit lake and underlying groundwater system would also depend on the hydrogeological properties of the material along the floor of the mine. It is understood that EAY are planning to undertake further sampling of in-situ material and analysis of their physical properties (including laboratory analysis of hydraulic conductivity) to address this data gap.
- Limited data near some hydrological features such as the Morwell River Wetlands, where site specific baseline data may be necessary to characterise the nature of surface water-groundwater interactions and to demonstrate the expected low-level impacts of rehabilitation on these features. It is understood that a separate assessment of GDEs is currently being undertaken and a more detailed eco-hydrogeological conceptual model would be developed to inform risks on potentially sensitive groundwater receptors.
- A lack of site specific groundwater monitoring data for the M2/TFAS. Although this is recognised as a data gap, it is not considered significant in the context of rehabilitation planning due to the depth of the aquifer and limited hydraulic connection with the shallower (more critical) aquifers. Uncertainty associated with the impact of long-term recovery of the M2/TFAS aquifer pressures could be addressed using a numerical model, based on the information available from the surrounding areas of Latrobe Valley(including the aquifer depressurisation effects at the Hazelwood and Loy Yang Mines).
- Detailed understanding of the lithology, extending deep into the M2/TFAS, which may be required to assess mine floor stability risks when the confined aquifer pressure recovers following rehabilitation (or if a dry void option is considered). It is understood there are four deep bores drilled through the M2/TFAS with relevant lithological data, which is potentially sufficient for the purpose of undertaking weight balance calculations when used in conjunction with all other drilling information captured in the mine geological model.
- Hydrogeological characteristics of the M2/TFAS or M1/MFAS aquifer outside of the mine footprint, if these aquifers are to be used in the future for maintaining the pit lake level (as top up water). In this case, additional data would be necessarily to confirm the location of extraction, the aquifer's capacity to support the required yields and associated licensing requirements.

7. References

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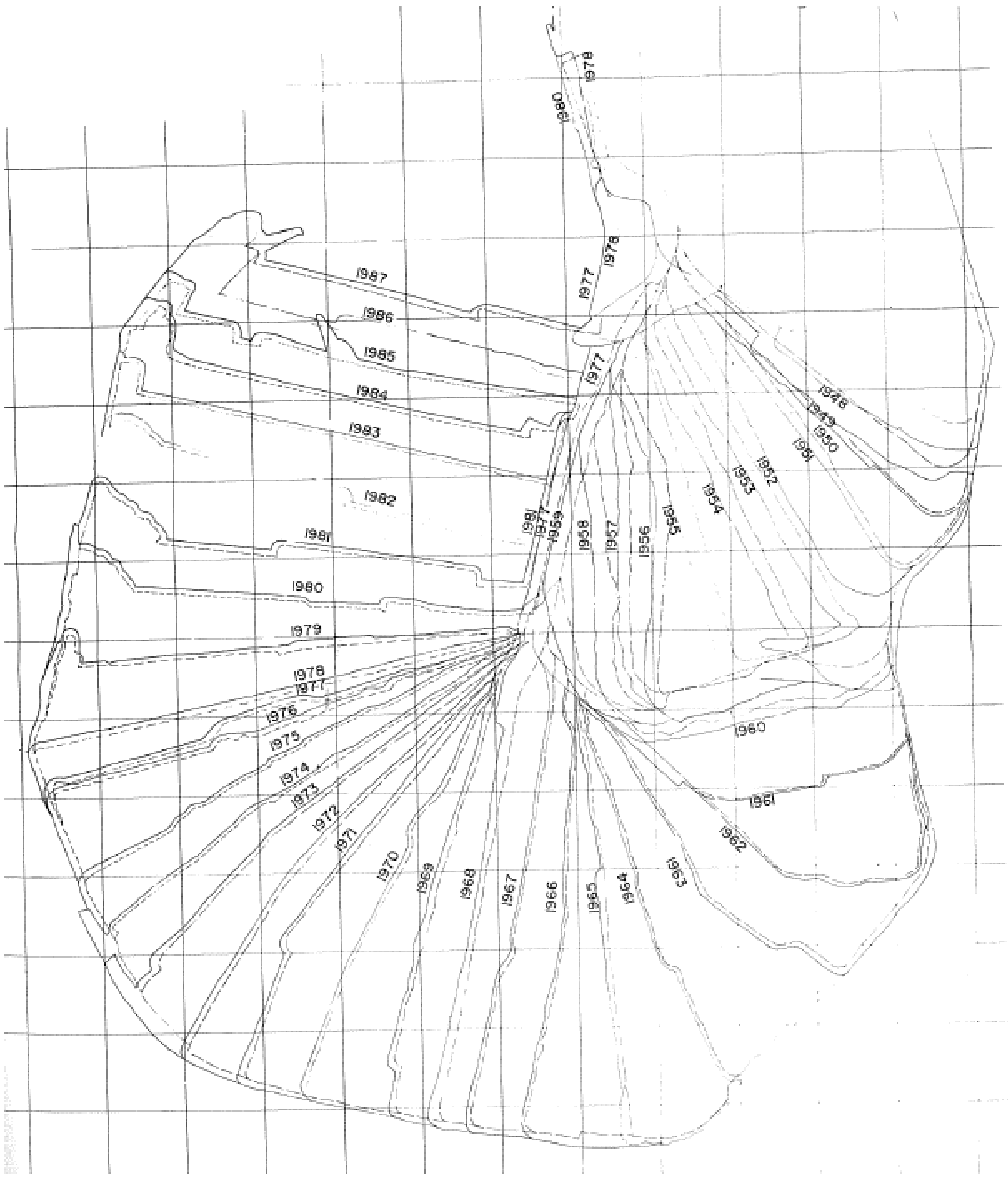
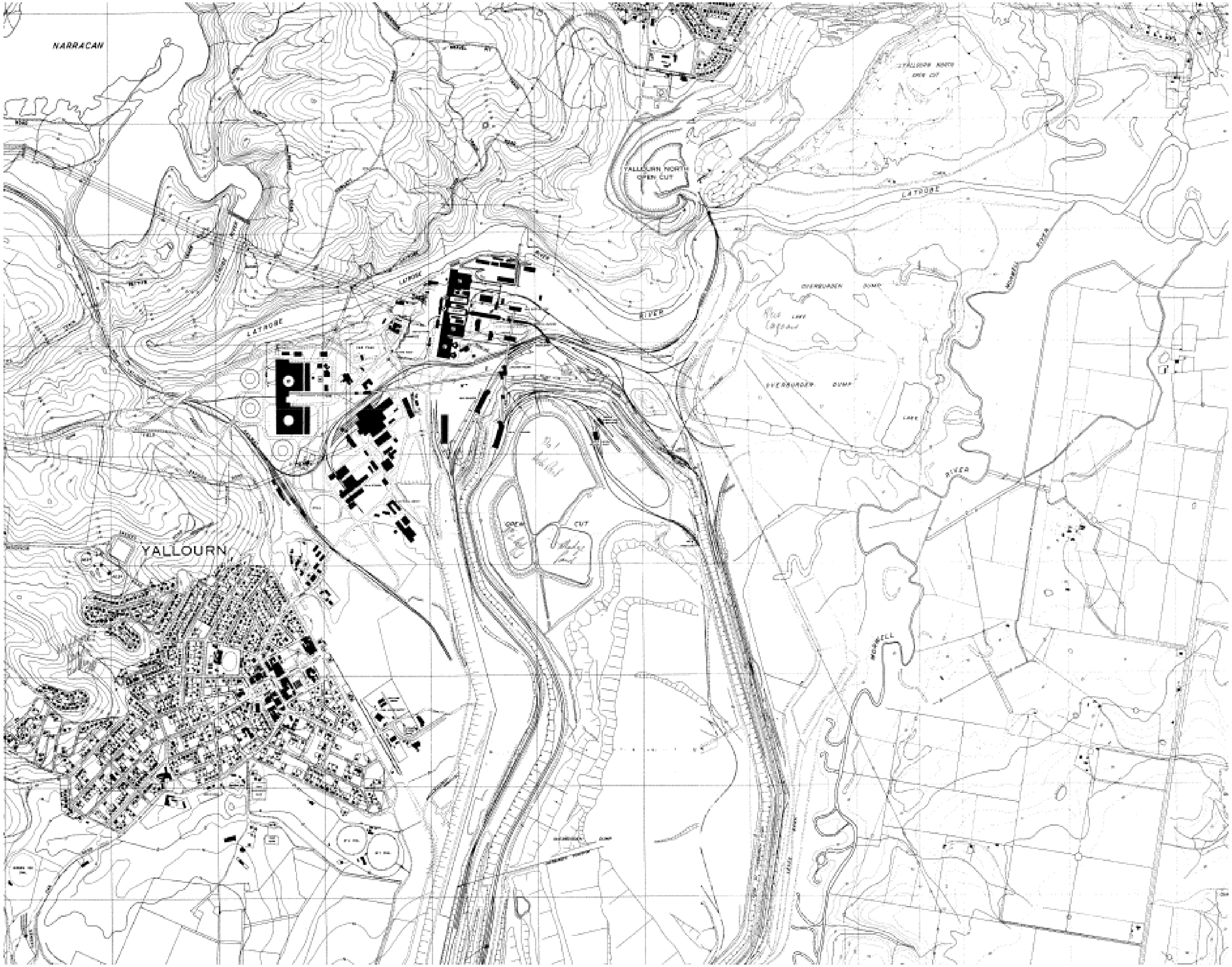
Appendices

Appendix A

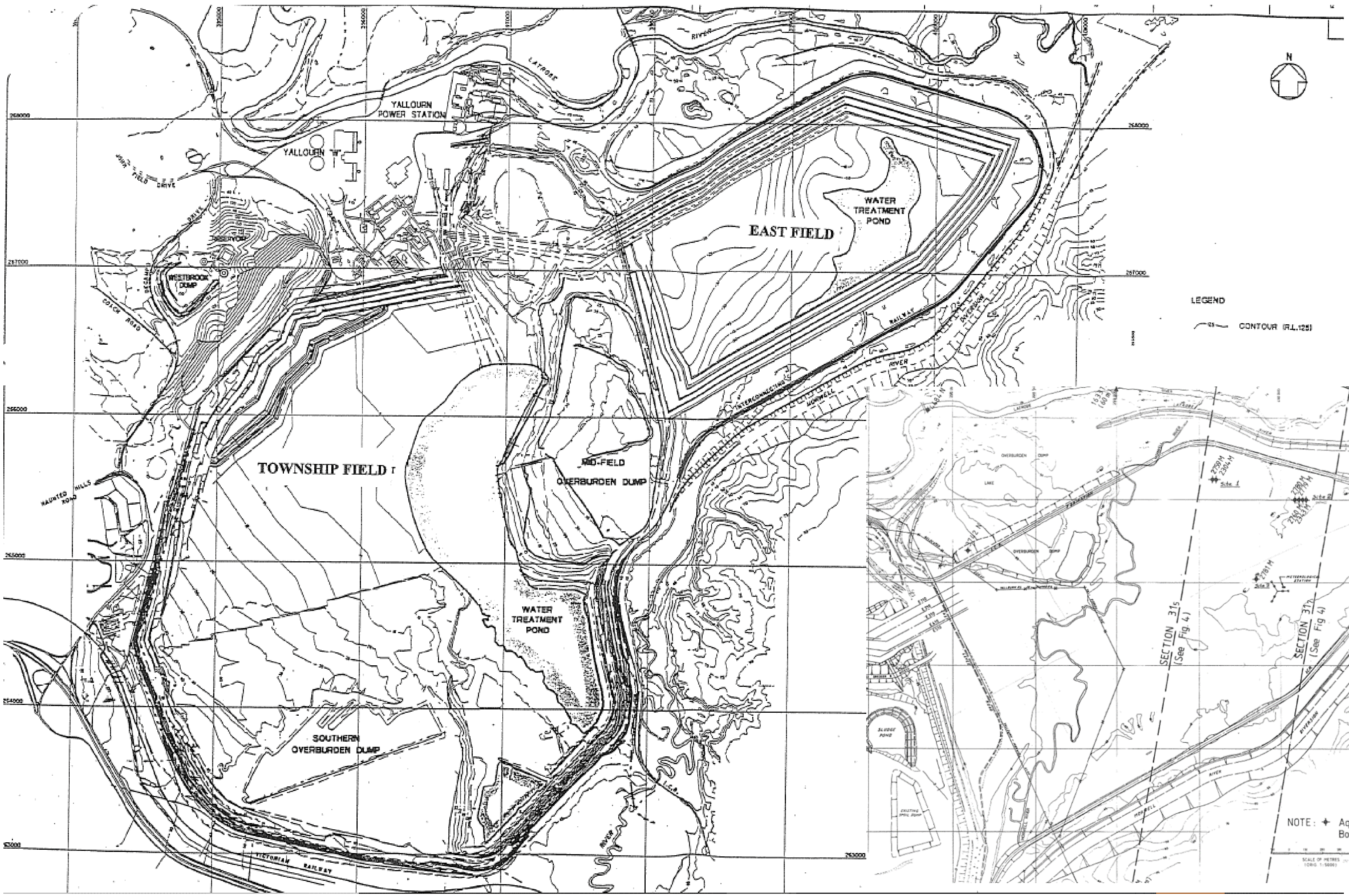
Mine Development and Site Plans



YOC Progressive Development area (from Vines 1989)



YOC Site Plan approximately 1965



Third Morwell River Diversion for East Field Development

Appendix B

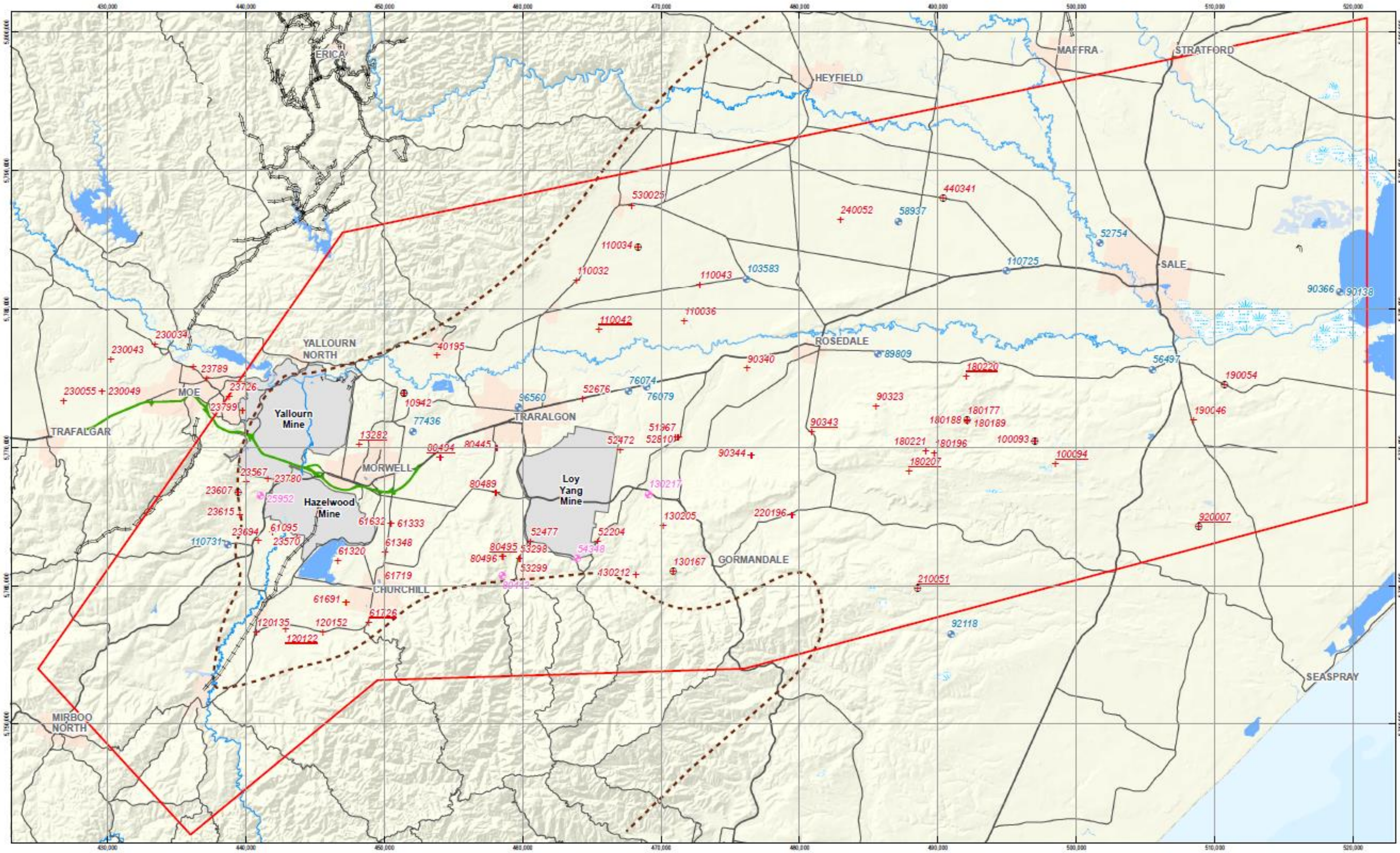
Yallourn GCMP Monitoring Plans

Yallourn Mine Observation Bores Locations March 2018

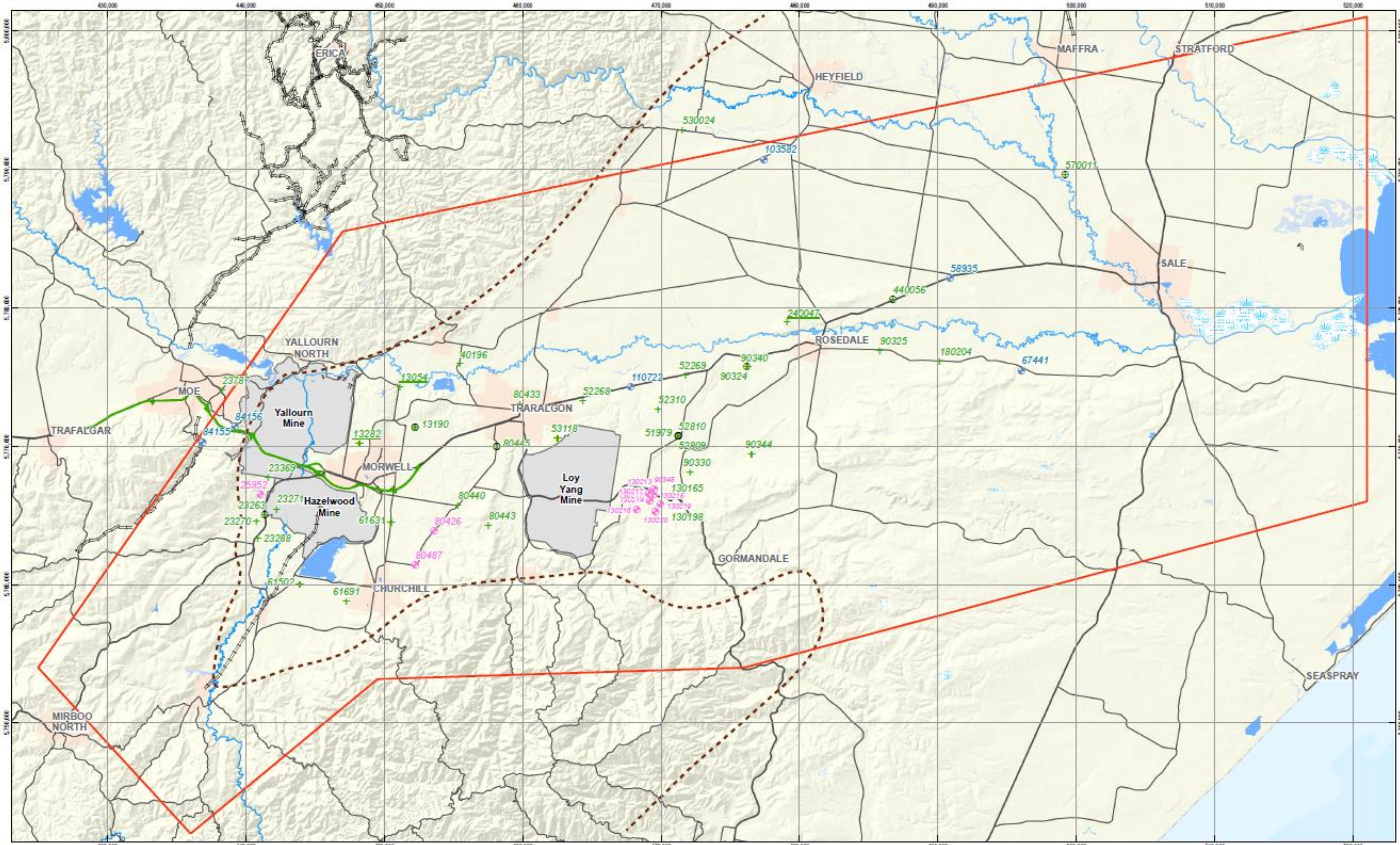
Yallourn Mine Survey Pin Locations

Appendix C

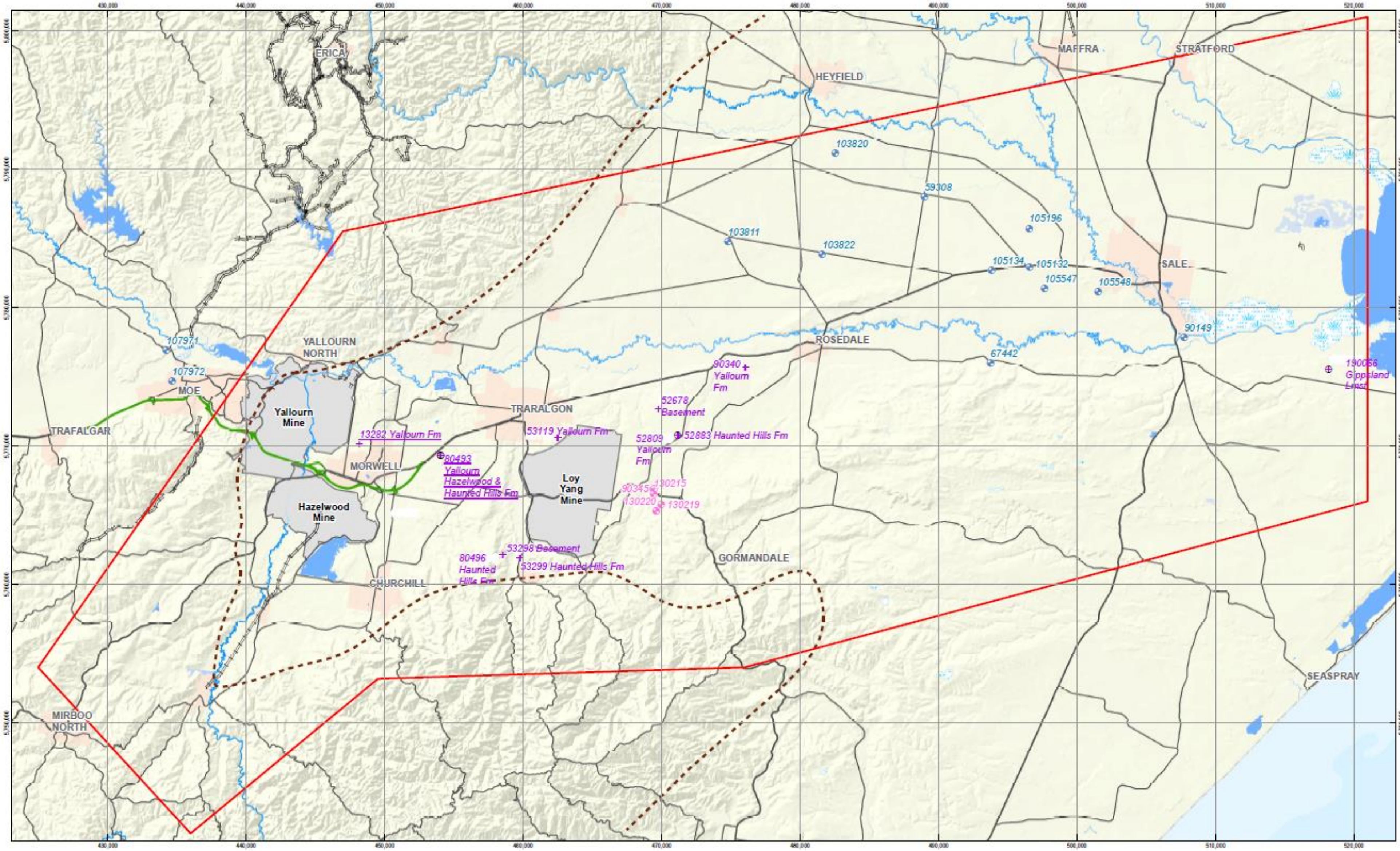
Latrobe Valley Regional Monitoring Program



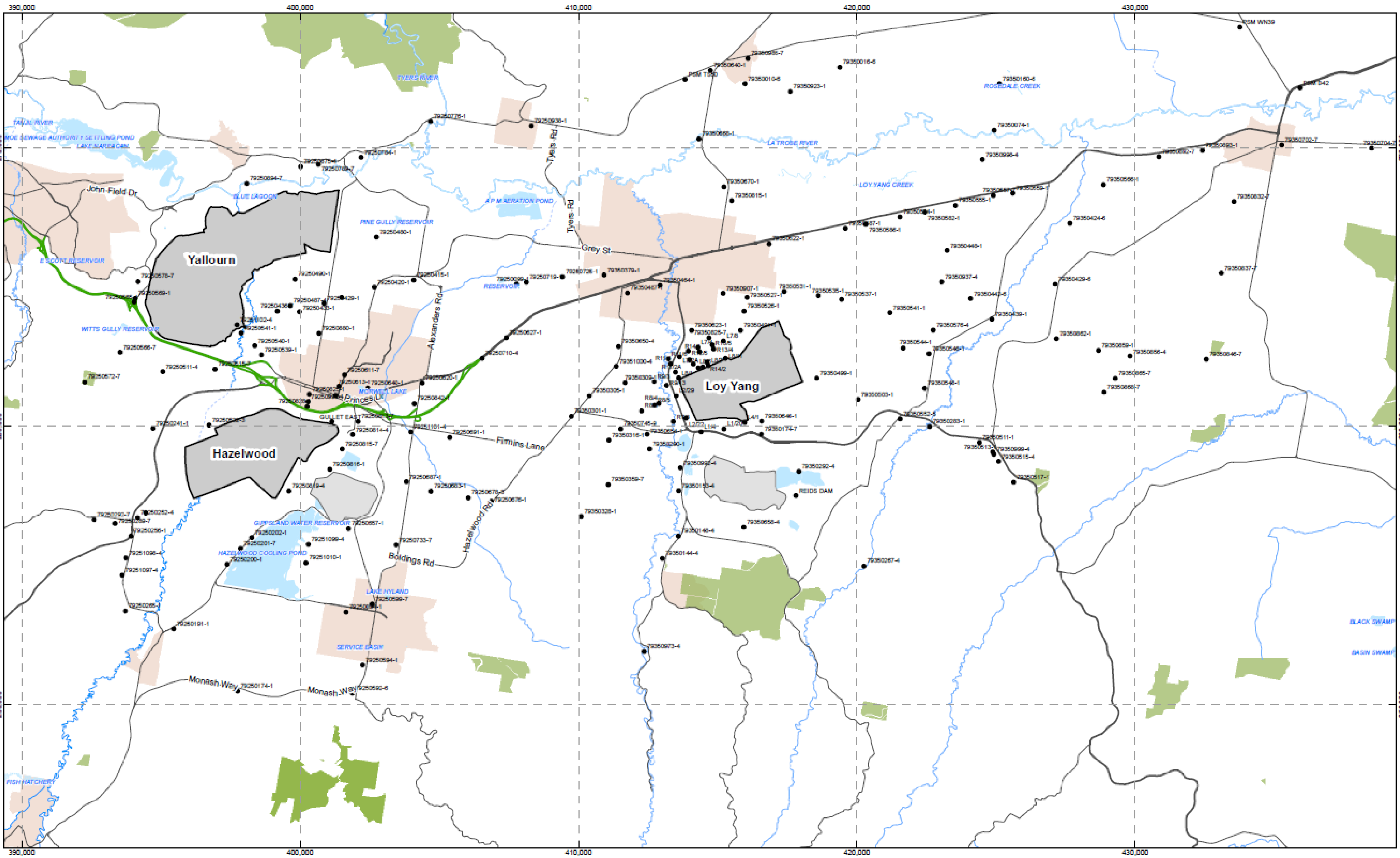
M2/TFAS Monitoring Bore Location Plan



MFAS Monitoring Bore Location Plan



SAS, Limestone and Basement Monitoring Bore Location Plan



Regional Survey Marks

Appendix D

YNOC Groundwater Quality Monitoring Program

Field Water Quality Parameters

- pH;
- Electrical conductivity (EC);
- Dissolved oxygen (DO);
- Redox potential (Eh); and
- Temperature.

Laboratory Analysis Program

- pH
- EC
- Alkalinity
- TDS
- Filtered Metals
- Total Metals
- BOD
- COD
- Total Kjeldahl Nitrogen
- Ammonia
- Nitrate
- Nitrite
- Major Anions[1]
- Major Cations[2]
- Fluoride
- Total Recoverable Hydrocarbons (TRH)

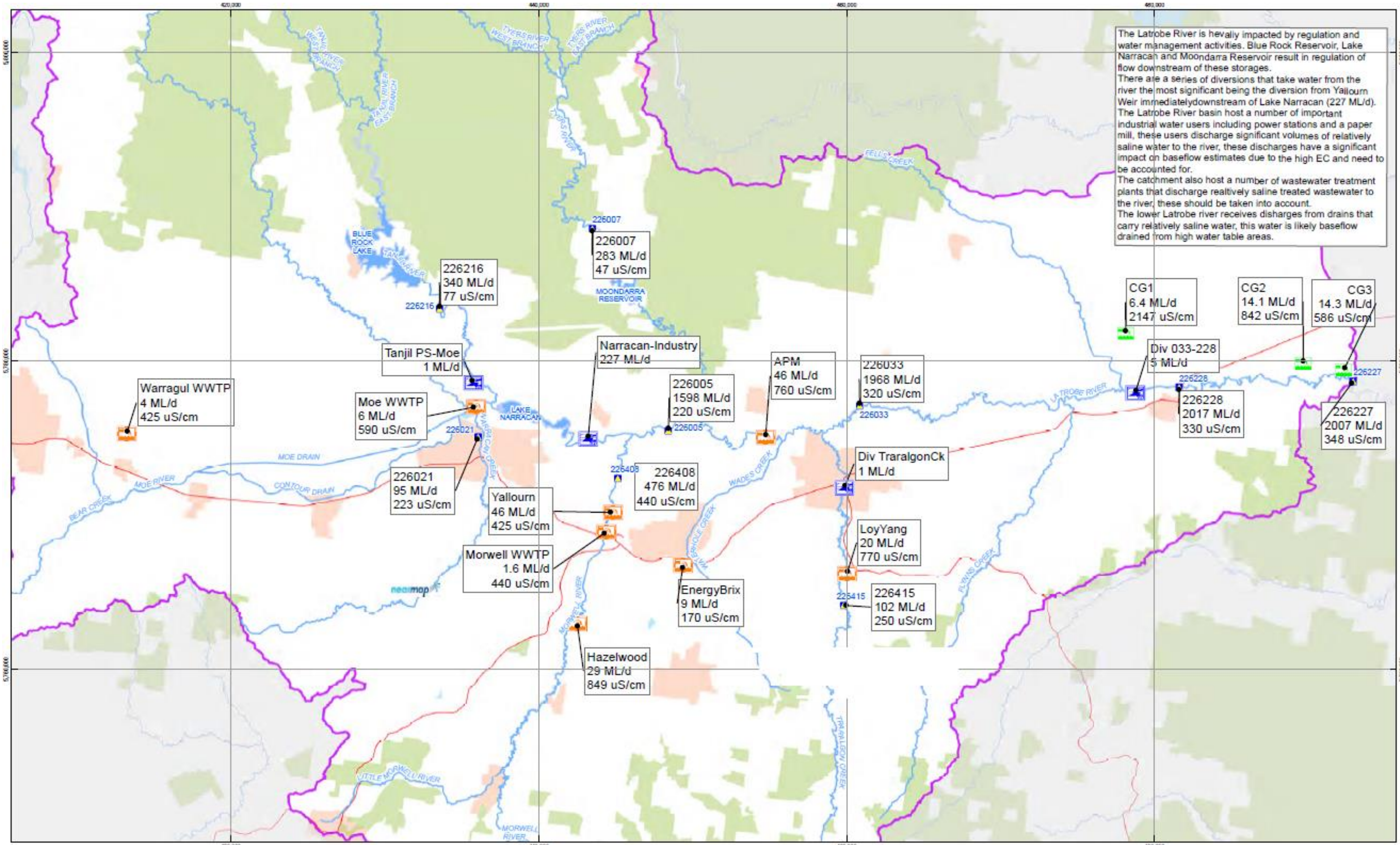
Note: 1 – Chloride, Sulfate, Alkalinity; 2 – Sodium, Calcium, Potassium, Magnesium

(from GHD 2018)

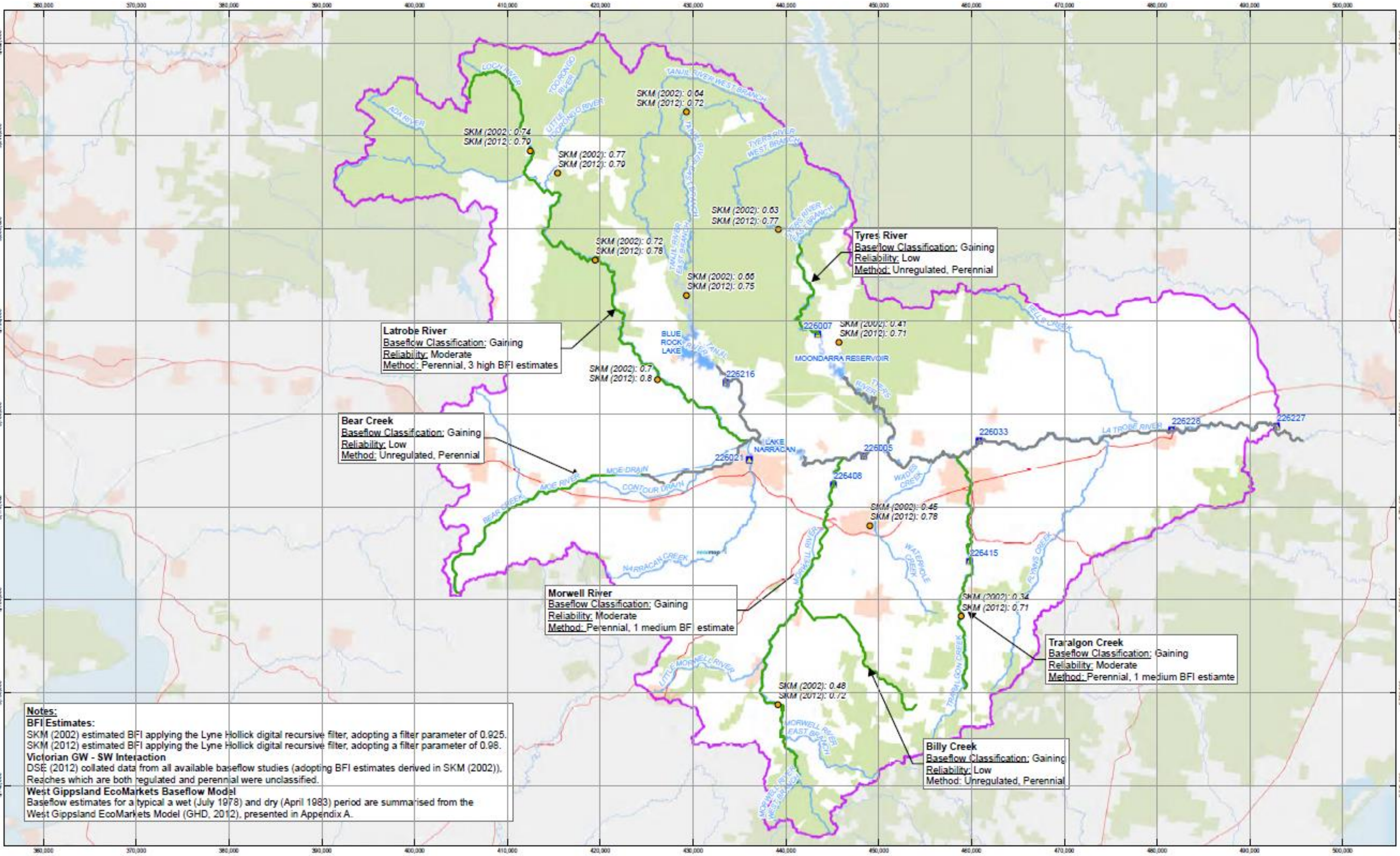
Background Water quality bores: Alluvium bores (yellow highlight) N5283, N5285, N5286, N5287, M2/TFAS bore (orange highlight) TE1844, TE1909

Appendix E

Surface Water Hydrology Plans



Latrobe River Water Management (after GHD,2015a)



Latrobe River SAFE Baseflow Studies (after GHD,2015a

Appendix F

Geological Model Development

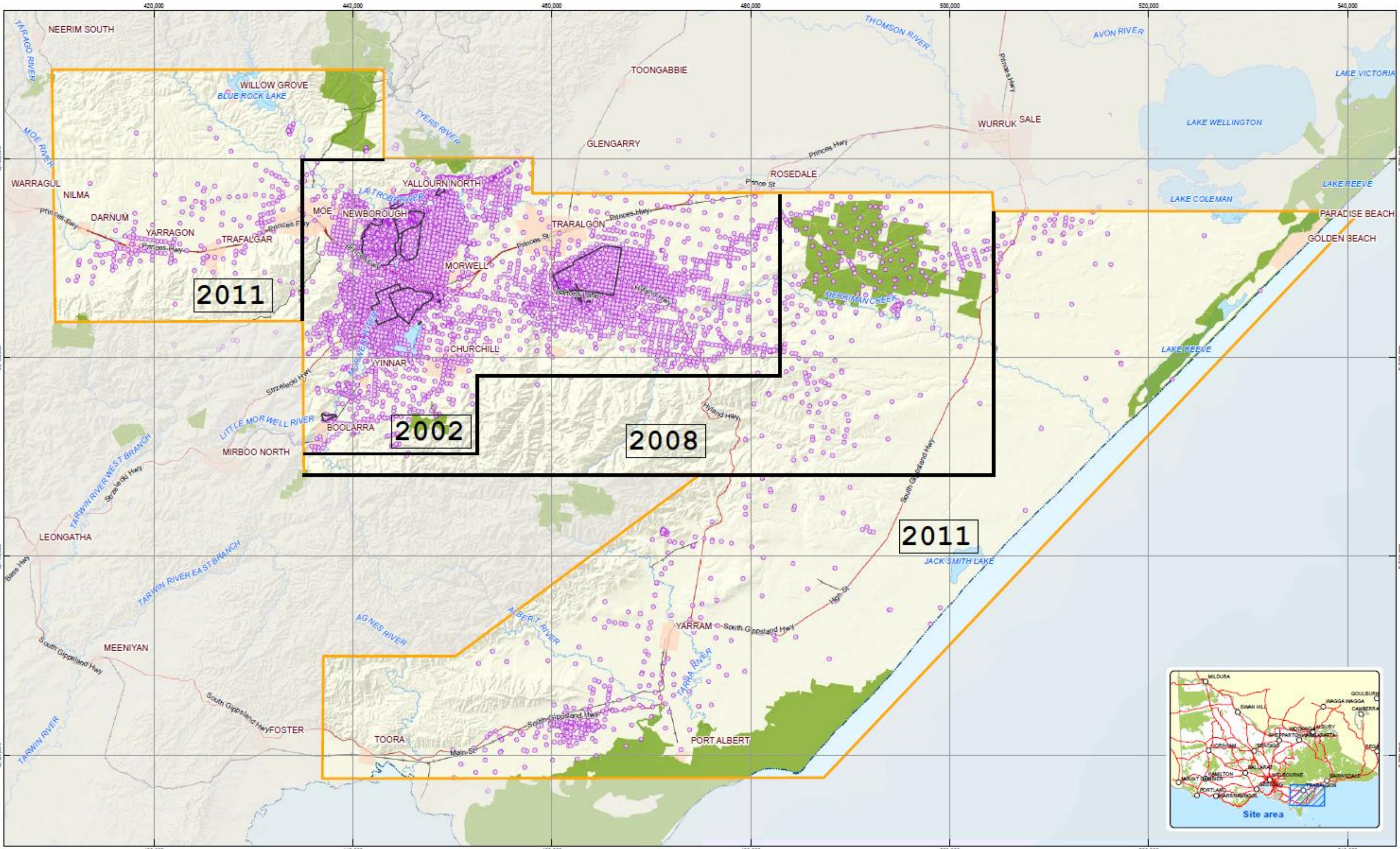
Victorian Regional Minescape Coal Model Layers

Formation	Seam / sub-seam / splits		Comment
Yallourn	Y	Y1	The splits Y+, Y3 and YP have been incorporated into the parent seam Y.
		Y2	
Morwell	M10		
	M1A	M1A1	The split M1A3 has been incorporated into the parent seam M1A.
		M1A2	
	M1B	M1B1	
		M1B2	
	M2	M2A	The M2C split (not shown) was not modelled. The split M2A1 has been incorporated into the parent split M2A.
		M2B	
Traralgon	TP		
	T1		The splits TRL and TRU have been incorporated into the parent seam T1.
	T2		

Yallourn Minescape Model Layers

Elemental Units

	Name	Type	Relationship	Unit Relationship	Continuity	E
▶	HHF	Interval	Contiguous	HHFA	Continuo	-
2	HHFA	Interval	Nonconformable		Pinch	-
3	YA	Interval	Conformable		Pinch	-
4	Y1	Interval	Conformable		Pinch	-
5	Y2	Interval	Conformable		Pinch	-
6	Y3	Interval	Conformable		Pinch	-
7	Y4	Interval	Conformable		Pinch	-
8	Y5	Interval	Conformable		Pinch	-
9	M1AR	Interval	Conformable		Pinch	-
10	M1A1	Interval	Conformable		Pinch	-
11	M1A2	Interval	Conformable		Pinch	-
12	M1A3	Interval	Conformable		Pinch	-
13	M1AS0	Interval	Conformable		Pinch	-
14	M1AS1	Interval	Conformable		Pinch	-
15	M1ASM	Interval	Conformable		Pinch	-
16	M1ASL	Interval	Conformable		Pinch	-
17	M1B	Interval	Conformable		Pinch	-
18	M2A	Interval	Conformable		Pinch	-
19	M2B	Interval	Conformable		Pinch	-
20	THO	Interval	Conformable		Pinch	-
21	BSMT	Surface	Conformable		Continuo	-
*						



Location of bore data used for regional geological model ghd.com

The Power of Commitment