Mine Closure 2026 – AB Fourie, G Boggs, J Heyes & M Tibbett (eds)

doi:10.36487/ACG_repo/2615_124

Groundwater modelling for mine closure planning

Genevieve Foley [a], Ali Shokri [a,*], Rikito Gresswell [b], Nikita Calabrese [c]

[a] *GHD Australia*

[b] *ERM, Japan*

[c] *Loy Yang Mine AGL, Australia*

Abstract

Loy Yang mine is a coal mine operated by AGL and located in the Latrobe Valley, approximately 150 km east of Melbourne, Australia. Mining commenced in 1982, supplying coal for power generation for both Loy Yang A (LYA) Power Station and Loy Yang B (LYB) Power Station. LYA power station is currently scheduled to cease operations in 2035. Depressurisation of the confined aquifers commenced in 1986 and is required to maintain safe mining conditions, having reached a maximum volume of 16 GL/y in 2009. Pumping from the shallower M1B aquifer commenced in 2025 and will increase as mining expands eastwards, exposing the aquifer in the batters. Placement of overburden in the western mine floor commenced in 2017. The proposed mine rehabilitation plan includes development of a pit lake by utilising surface water and groundwater sources to achieve a safe and sustainable landform subject to an extensive legislated approvals process.

Groundwater modelling is a critical component of closure planning to assess the stability of the mine floor as confined aquifer pressures recover and the connection between the groundwater system and pit lake. Groundwater modelling provides inputs for other technical studies to inform pit water quality and surface water studies. A groundwater model has been developed using MODFLOW-USG across the Gippsland Basin, with local refinement around Hazelwood, Loy Yang and Yallourn mines to enable mine-scale effects as well as the cumulative mining and rehabilitation impacts of all 3 mines to be considered within a single model.

This paper describes the application of groundwater modelling to support mine closure planning at Loy Yang mine and includes rigorous calibration and benchmarking of the model against long-term groundwater levels and subsidence measurements to increase model confidence while also modelling the potential effects of climate change on post-closure recovery of aquifer pressures. This paper demonstrates how groundwater modelling can be used as a decision-support tool for mine closure planning, linking regional aquifer recovery with mine-scale closure design. By representing the 3 Latrobe Valley mines within a single MODFLOW-USG model, the approach captures both cumulative regional groundwater impacts and local closure risks at Loy Yang mine. The model outputs are used to inform pump bore decommissioning, floor heave risk management, pit lake development and overburden placement requirements.

Groundwater modelling has been used to assess and manage the risk of floor heave during the transition to closure. In the longer term, an assessment of overburden spoil thickness to achieve a sufficient counterweight against predicted recovered aquifer pressures was completed to manage the risk of floor heave and provide a stable landform. Modelling is also in progress to assess the impact of overburden placement providing hydraulic resistance between the unconfined M1B aquifer and pit lake, on long- and short-term M1B aquifer seepage rates.

Keywords: *groundwater, modelling, closure, heave*

---

* Corresponding author.

1 Introduction

Loy Yang mine is a large open cut brown coal mine located in the Latrobe Valley, approximately 150 km east of Melbourne, Victoria, Australia. Stripping of overburden material commenced in 1982, and coal mining commenced in 1984, supplying coal to the adjacent power station. When fully developed, the mine will be approximately 1 to 2 km wide, 6 km long and have a maximum depth of around 200 metres, with a minimum floor elevation of RL-130 m Australian Height Datum (AHD). Mining commenced in the western area, reaching final floor depth adjacent to the western batters, in the early 2000s and then progressed eastwards. Placement of overburden in the western mine floor commenced in 2017. Traralgon Creek is located to the west of the mine and Sheepwash Creek has been diverted around the eastern batters. Mine layout showing the internal overburden placement in the western mine floor area and operational eastern batters is shown in Figure 1.

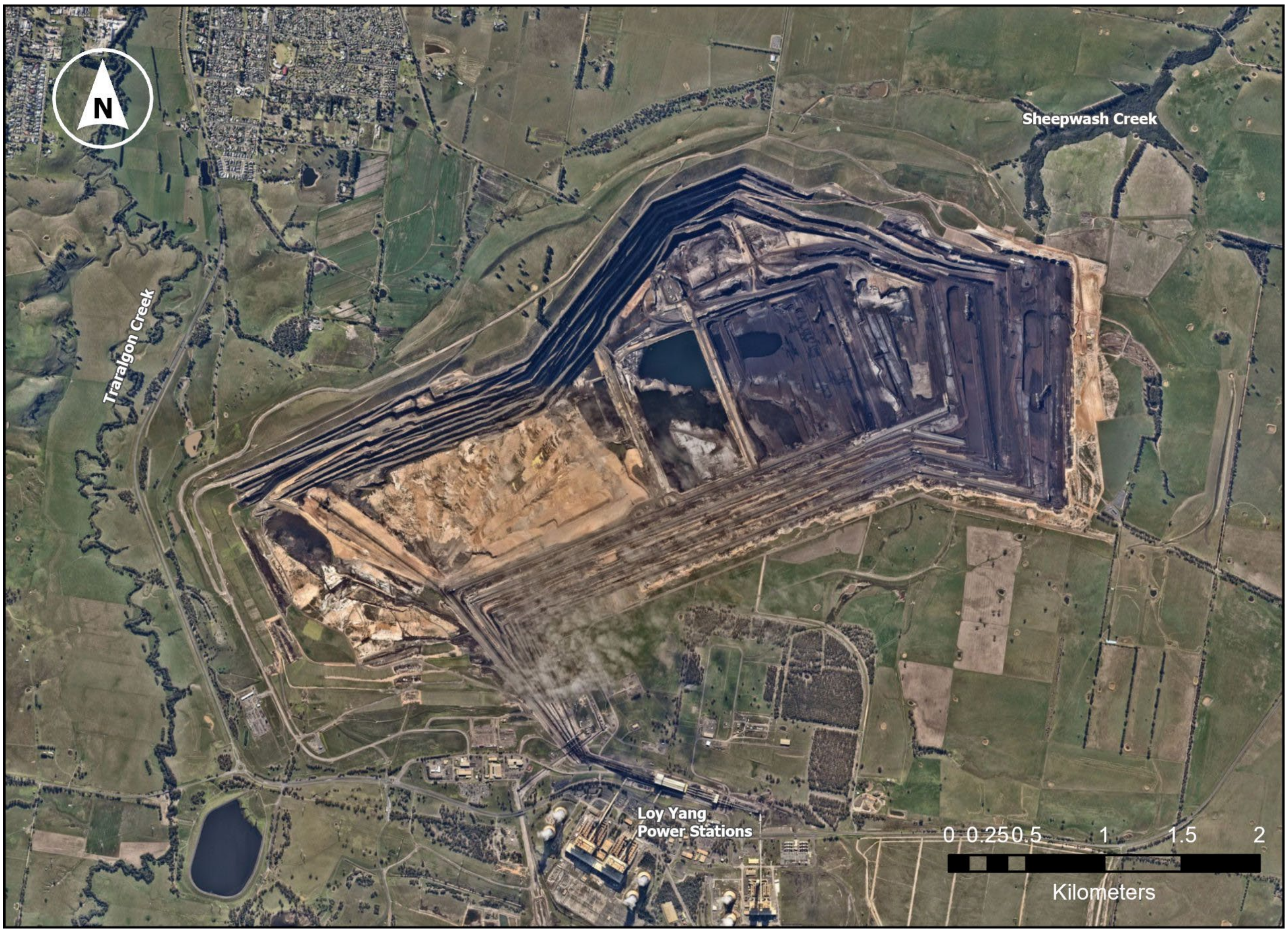

Figure 1 Loy Yang mine site features

Groundwater in the Latrobe Valley flows through layers of surficial sediments and interseams that are separated by thick sequences of brown coal. The undisturbed coal layers are characterised by low hydraulic conductivity and generally act as aquitards that limit groundwater flow; hydraulically separating the intervening interseam layers, which act as aquifers. The interseams are comprised of sand, silt and clay, and their lithology change abruptly due to the mode of fluvial deposition. The interseams can contain local- and regional-scale aquifers, depending on the extent and hydraulic properties of the sands.

Because the interseams are confined by the thick coal layers, groundwater contained within the interseams at depth is pressurised, resulting in subartesian to artesian conditions. When the coal is excavated during mining, floor heave and unstable mining conditions could occur if the upward force from the high pore pressure within the underlying interseams is greater than the weight of the overlying strata. Failure to control excessive pressures in the confined aquifers beneath the mine can result in large, uncontrolled vertical movements of the mine floor, referred to as floor heave. Assessment of the risk of floor heave has been undertaken in Latrobe Valley coal mines by applying the weight balance concept to the mining and rehabilitation stages. The aquifer pressure that is equal to the weight of the overlying material is referred to as the weight balance or equilibrium level, and is controlled by the thickness and density of the overlying in situ strata above the aquifer, the thickness and density of overburden spoil dumps on the mine floor, and the depth of water in the mine void.

To maintain safe mining conditions at Loy Yang mine, groundwater pumping and depressurisations of confined aquifers beneath the floor commenced in 1986 for the M2B aquifer, in 1987 for the M2C aquifer and in 1991 for the Traralgon aquifer. The total groundwater depressurisation requirements peaked at around 16 gigalitres (GL) per annum and have since generally ranged from 10 to 14 GL/years. The depressurisation of the confined aquifers over 40 years of mining operations has resulted in the formation of a cone of depression in the piezometric surfaces centred on the mine void. Pumping from the shallower M1B aquifer commenced in 2025 and is expected to continue as mining expands eastwards, exposing the higher permeability zones of the aquifer in the eastern mine floor and batters.

2 Hydrogeological setting

Loy Yang mine lies on the south limb of the Latrobe Syncline, with beds generally dipping to the north. The east–west trending geological structures in the mine area are the Loy Yang Monocline, which aligns with the northern mine batters, and the Loy Yang Dome to the south, in the power station area. The Cenozoic stratigraphy of the Latrobe Valley has been described in Holdgate & Gallagher (2003) and is shown in Figure 2, and basement geology in Holdgate et al. (2015).

The hydrostratigraphy of Loy Yang mine is characterised by an alternating sequence of aquifers and aquitards (GHD 2018). From the surface it is comprised of the following formations:

- The Haunted Hills Formation is predominantly comprised of clay with some sands and sandy clays, typically ranges up to 20 m in thickness and forms an unconfined aquifer at the surface. No dewatering of this aquifer was required due to its low permeability. Localised minor groundwater seepage has occasionally been intersected during mining, resulting in local dewatering of the formation adjacent to the mine batters.
- The Yallourn Formation coal seams and associated clay interseams are only preserved to the north and northeast of the mine area, and act as an aquitard there.
- Over most of the mine area, the Morwell Formation underlies the Haunted Hills Formation. The upper section of the Morwell Formation is comprised of the M1A coal and, where not eroded, is typically 80 m thick. The M1B coal is at around 110 m thickness. The M1A interseam is comprised of clay and silt, and is characterised as an aquitard. Underlying the M1B coal is the M1B interseam, which in the western and central mine area is comprised of predominately clay interbedded with thin, fine sands. The sand layer becomes progressively thicker and medium grained to the east, forming the M1B aquifer that extends over 20 m in thickness to the northeast of mine. This is an intermediate-scale aquifer with moderate permeability and will be excavated as mining progresses eastwards. Depressurisation of the M1B aquifer commenced in late 2025 with the commissioning of 3 pump bores, with yields of up to 40 L/s per bore, to reduce seepage and associated batter instability where the aquifer is exposed in the mine floor, and risk of heave where the aquifer is confined.
- The Morwell Formation M2 sequence includes the M2A (40m typical thickness), M2B (20 m) and M2C (10 m) coals and underlying interseams. The M2A interseam is comprised of clay and silt, and is characterised as an aquitard. The M2B interseam contains several thin, fine-grained sand units, interbedded clays, silts and thin coals. The sands form the M2B aquifer, which is a low-permeability, local-scale aquifer found in the western part of the mine and that pinches out to the east. Limited depressurisation of the M2B aquifer with typical yields of around 5 L/s occurred early in the mine

development until around 2007 to allow mining to reach the final depth, after which the aquifer was unconfined and exposed in the mine floor, with minor seepage to drains and sumps. Underlying the M2C coal is the M2C aquifer, which is interbedded with interseam clays, silts and thin coals. The M2C aquifer sands range in thickness from 5 to 12 m and form a confined aquifer with yields ranging from 10 to 25 L/s per bore.

- The Upper and Lower Traralgon Formation coal seams, with a combined thickness of around 40 to 60 m, are found at the top of the Traralgon Formation and hydraulically separate the underlying Traralgon Formation aquifer sequence from the overlying Morwell Formation. The Traralgon aquifer consists of sequence of interbedded sands, clays and basalt, and is present across the mine area. It is a high-permeability, confined aquifer system that extends across the Gippsland Basin. Depressurisation of this aquifer is required to reduce aquifer pressures in accordance with the mine development plans. Yields at pump bores screened in this formation in the Loy Yang mine area are typically in the 40 to 110 L/s range.
- The low-permeability Strzelecki Group forms the basement to the Tertiary sequence in the Loy Yang mine area and has been intersected at depths ranging between 200 m in the south to 550 m to the northern extent of the mine.

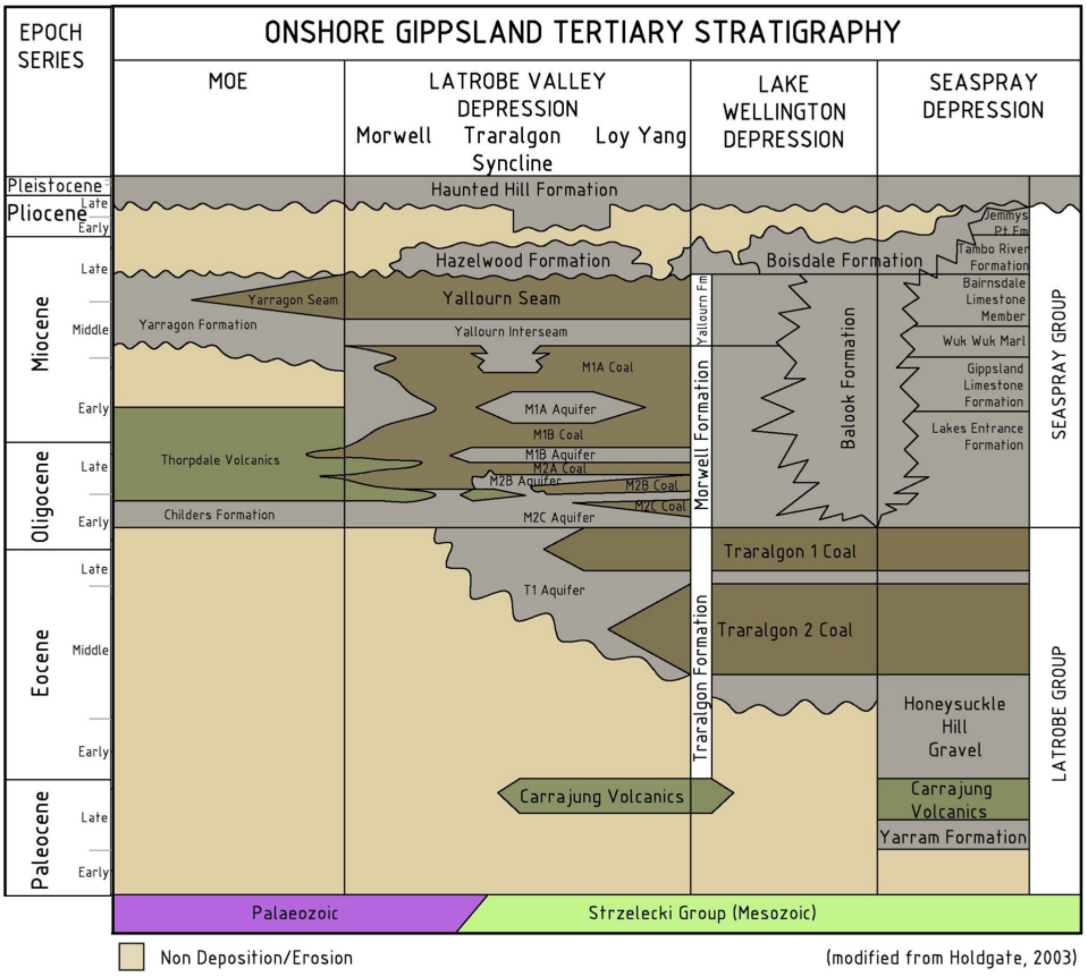

Figure 2 Onshore Gippsland Basin stratigraphy

3 Groundwater model overview

In conjunction with Hazelwood and Yallourn mines, a regional-scale numerical groundwater model has been developed that encapsulates the enclosed groundwater system of the Gippsland Basin to assess the cumulative influence of mining in the Latrobe Valley.

The model was developed in an unstructured grid version of MODFLOW called MODFLOW-USG (Panday et al. 2013), which enables efficient refinement of cells at the mines and along key hydrological features such as surface watercourses while retaining larger cells elsewhere (critical where mine-scale details and regional cumulative effects are both important). The model uses a layered quadtree mesh with cell lengths of 50 m within the Loy Yang mine, locally reducing to 25 m at the pumping bores.

The model consists of 18 layers to represent key hydrostratigraphic units (HSUs) and their interconnection. The surfaces of the HSUs were derived from a combination of mine-scale geological models, a regional coal model (Jansen et al. 2003), existing groundwater models and layers from the Victorian Aquifer Framework. Model parameters such as hydraulic conductivities and specific storage were assigned to the model cells on a hydrostratigraphic basis. That is, the model cells were grouped into aquitards and aquifers, and parameter values were assigned to them accordingly. Figure 3 shows the model grid and layers in the Loy Yang mine area.

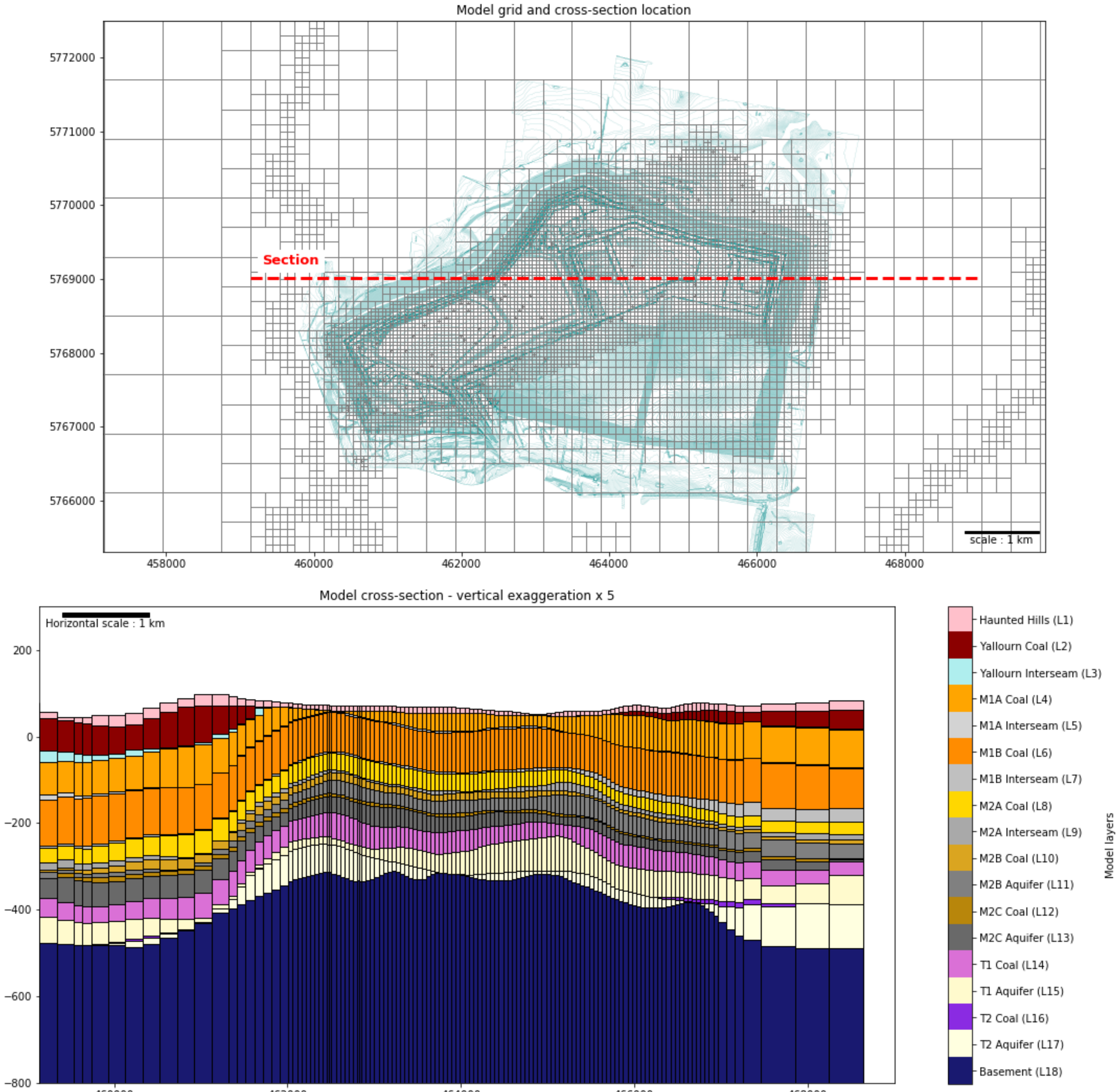

Figure 3 Model grid and cross-section at Loy Yang mine

Boundary conditions were prescribed to the groundwater model to simulate key hydrogeological processes such as pumping, mine excavation, recharge, evapo-transpiration, streamflow and surface water–groundwater interactions. Recharge and evapo-transpiration were simulated using the cropping and soil moisture balance model PERFECT (Littleboy et al. 1989). PERFECT uses daily climate and broad-scale land use and soil mapping data to partition daily rainfall into run-off, evaporation, transpiration, soil storage changes and deep drainage.

Surface watercourses and surface water bodies were simulated using the Streamflow-Routing (SFR) package and River (RIV) package, respectively. The formation of pit lakes and their interaction with groundwater were simulated using MODFLOW-USG's LAK package (Merritt & Konikow 2000). The advantage of the LAK package over head-dependent boundaries such as the RIV package is that the lake stage is computed based on accurate accounting of the lake water balance and stage–storage relationship, ensuring that the interaction between the lake and groundwater is consistent with the components of flow into and out of the lakes.

Subsidence was simulated using the SUB package (Höffmann et al. 2003), which computes subsidence as sums of compressible layer compaction based on changes in piezometric heads and prescribed elastic and inelastic skeletal storage values (based on typical values for representative lithologies derived from previous studies). The use of the SUB package means the interbed storage changes associated with the compaction of compressible sediments are accounted for in the computation of piezometric heads and to model water balance.

4 Groundwater modelling to support closure planning

The calibrated groundwater model is capable of simulating the long-term mine depressurisation effect on the piezometric heads of the confined aquifers, resulting in more than 100 m of drawdown from the pre-mine level of around 50 m AHD. To provide critical inputs to the closure planning studies, mine closure scenarios can been modelled with a range of pit lake filling rates and groundwater and surface water sources over a simulation period of 200 years. The model will continue to be further developed based on feedback from an independent third-party peer review process and as additional data becomes available.

The hydrogeological issues assessed for mine closure planning are associated with managing aquifer pressures during the transition to closure, including the staged decommissioning of the pump bores within the mine footprint and, in the longer term, work to establish a stable landform that allows for the recovery of confined aquifer pressures by a combination of the placement of overburden on the mine floor and development of a pit lake to RL 45 m AHD.

4.1 Transition to closure – confined aquifers

The current confined aquifer depressurisation system includes Traralgon and M2C aquifer pump bores within the mine footprint at elevations ranging from RL −96 to −24 m AHD. The pump bores at lower elevations will be required to be sealed and decommissioned in accordance with the Minimum Construction Requirements for Water Bores in Australia (NUDLC 2020) in advance of being flooded by the rising pit lake. The risk identified, primarily for the M2C aquifer, is that the decommissioning of multiple M2C pump bores early in the transition period will result in aquifer pressures rising at a greater rate than the increase in the weight balance surface (due to the rising pit lake level), increasing the potential for floor heave to occur.

To assess this risk, a series of maps has been generated for the early stages of filling to show the relationship between the simulated piezometric heads (assuming a medium climate change scenario) and the weight balance surfaces of the M2C aquifer. These have been generated by subtracting the predicted piezometric heads of the M2C aquifer from the weight balance surface at critical lake levels (−90, −75, −60 and −50 m AHD, and using the heads computed at the time the lake reaches those levels). The maps show the smallest difference between the weight balance surface and piezometric heads of 25 m occurs in the earliest stage of filling, when the lake level is at −90 m AHD (Figure 4) and increases over time to around 55 m at the lake level of −50 m AHD. The results show the risk of floor heave is low during the early closure phase as M2C pressures are predicted to remain below weight balance values and no additional pump bores are likely be required to manage M2C aquifer pressures during this transition period.

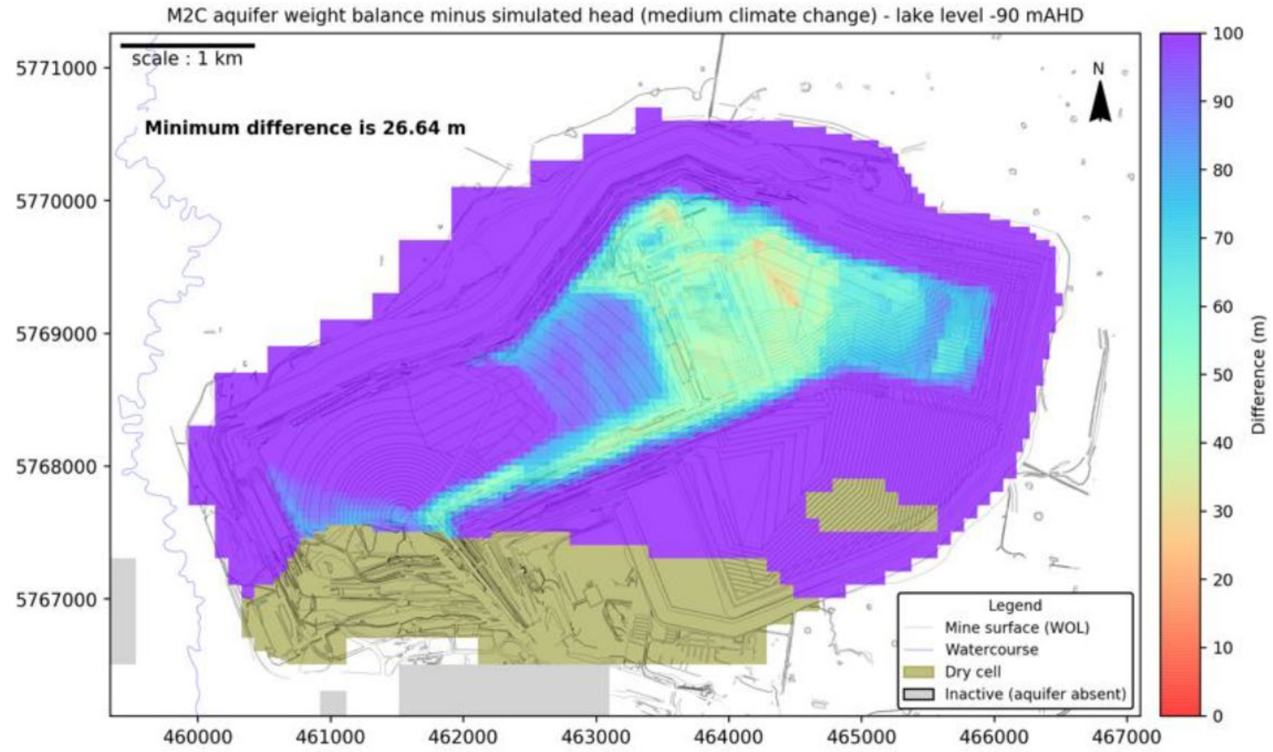

Figure 4 M2C aquifer predicted heads below weight balance surface at RL -90 m pit lake

4.2 Transition to closure – unconfined aquifers

The low-permeability M2B aquifer was previously exposed in the western mine area and has been covered by the internal overburden dump. The M2B aquifer pinches out in the eastern mine area and is not considered significant for rehabilitation due to its low permeability and limited exposure below the overburden dump.

In contrast, the moderate permeability M1B aquifer will be unconfined where exposed in the future mine floor and the risk of interseam washout and associated batter instability will need to be managed, along with the risk of floor heave where the aquifer is confined to the east. Aquifer depressurisation from pump bores to the north and east of the mine is required to reduce aquifer pressures during mining to manage these risks. During the early closure period the M1B aquifer pumping volume will be required to progressively decrease during the mine filling period to minimise seepage from the pit lake to the aquifers (and recirculation of pumped groundwater). This reduction in flow is modelled by scaling down the pumping rate at individual bores and progressive decommissioning of individual bores. The timing and sequence of the M1B aquifer pump bore decommissioning is currently being revised to determine the optimal arrangement of pumping that can balance the rate of mine filling with the rate of leakage (to allow for the most efficient filling). An iterative modelling approach is being adopted to ascertain the relationship between key decision variables (pumping) and performance targets (such as the fill duration). The feasibility and effectiveness of overburden placement in the areas where the M1B aquifer is exposed or present at shallow depth to act as a hydraulic barrier to reduce lake seepage during the early closure phase is also being assessed.

4.3 Overburden placement for long-term stability for confined aquifers

Development of a pit lake and overburden placement on the mine floor provides a counterweight for the future increases in the confined aquifer pressures below the mine floor following mine rehabilitation. The proposed final mine plan including overburden dumps and a pit lake level to RL 45 m AHD was used to determine the weight balance surfaces for the confined M2C and Traralgon aquifers across the mine. The far future piezometric heads are based on a quasi-steady-state simulation to year 2222, representing a condition close to the full recovery of the confined aquifer pressures. It should be noted, however, that there is uncertainty in the future climate conditions and associated recharge rates, rendering predictions of full recovery uncertain. The modelling currently assumes the medium climate change condition, but prior modelling experience suggests that differences of several metres are possible, depending on future climate assumptions and will be assessed further in future studies.

The results show the recovered confined aquifer pressures are predicted to be below weight balance values across the mine floor for the TR and M2C aquifers. Recovered M2C aquifer pressures are predicted to be within 2 m of weight balance in the southwestern mine floor area with the current mine plan. As noted, the uncertainty in future climate conditions has the potential to impact recovered pressures by several metres and revision of the overburden dump design with targeted placement in areas requiring additional weight is in progress. The revised overburden dump design will increase the difference between the recovered M2C aquifer pressure and weight balance values to account for climate uncertainty.

The difference between the far future piezometric heads for the TR aquifer and weight balance surface for a RL 45 m AHD pit lake is several tens of metres with the minimum difference of around 26 m. The risk of floor heave due to the long-term recovery of the TR aquifer pressure is therefore considered low.

4.4 Overburden placement for hydraulic resistance

The long-term impact of overburden placement in the areas where the M1B aquifer is exposed or present at shallow depth in the mine floor on groundwater seepage is being assessed. Of particular interest is the seepage volumes into and out of the pit with and without placement of an overburden hydraulic barrier, and the influence of this on pit water balance and pit water quality studies.

5 Conclusions

Groundwater modelling has provided a practical decision-support framework for mine closure planning at Loy Yang mine. The regional MODFLOW-USG model allows the recovery of confined aquifer pressures, pit lake development, pump bore decommissioning, floor heave risk and overburden placement requirements to be assessed within a single modelling framework.

The modelling indicates that the risk of floor heave during the early closure transition is low, with predicted M2C aquifer pressures remaining below the calculated weight balance surface during the staged filling of the pit lake. In the longer term, predicted recovered pressures in the Traralgon aquifer remain several tens of metres below weight balance, while the M2C aquifer represents the more critical case. The modelling has therefore been used to guide targeted overburden placement in areas where additional counterweight is required.

Ongoing modelling of the M1B aquifer will further assess the hydraulic connection between the pit lake and the M1B aquifer system, including the potential benefit of overburden placement as a hydraulic resistance layer. These results will provide key inputs to mine water balance, pit lake water quality and surface water studies. Overall, the modelling demonstrates the importance of integrating groundwater recovery, geotechnical stability and pit lake evolution when planning for mine closure.

Acknowledgement

The authors thank Dwayne McAlpine from AGL Loy Yang for his support and assistance with undertaking this project.

References

GHD 2018, *Geology of Loy Yang Mine*, report to AGL Loy Yang.

Holdgate, G & Gallagher, S 2003, 'Tertiary', in W Birch (ed.), *Geological Society of Australia Special Publication*, vol. 23. Geological Society of Australia (Victoria Division), Melbourne, pp 324-335.

Holdgate, G, Wallace, M & Forbes, S, 2015, 'Pre-Cenozoic geology of the Latrobe Valley area – Onshore Gippsland Basin Australia' Australian Journal of Earth Sciences. http://dx.doi.org/10.1080/08120099.2015.1085901

Höffmann, J, Leake, S, Galloway, D & Wilson, A 2003, *MODFLOW–2000 ground-water model — User guide to the Subsidence and Aquifer-System Compaction (SUB) Package*, U.S. Geological Survey Open-File Report 03–233.

Jansen, B, Say, P & Maher, S, 2003, *Digital Geological Model of the Latrobe Valley Coal Resources*, Geological Survey of Victoria unpublished report 2003/2.

Littleboy, M, Silburn, D, Freebairn, D, Woodruff, D & Hammer, G 1989, *PERFECT: A simulation model of Productivity, Erosion, Runoff Functions to Evaluate Conservation Techniques*, Queensland Department of Primary Industries Bulletin, QB89005, p. 135.

Merritt, ML & Konikow, LF 2000, *Lake-Aquifer Interaction Using the MODFLOW Groundwater-Water Flow Model and the MOC3D Solute-Transport Model*, U.S. Geological Survey Water-Resources Investigations Report 00-4167.

Panday, S, Langevin, CD, Niswonger, RG, Ibaraki, M & Hughes, J 2013, 'MODFLOW–USG Version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation', *Groundwater Book 6, Modeling Techniques, Techniques and Methods 6–A45*.

National Uniform Drillers Licensing Committee 2020, *Minimum Construction Requirements for Water Bores in Australia*, 4th edn.