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Void Closure Plan

Goonyella
Riverside/Broadmeadow
Mine

November 2024

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Void Closure Plan
Goonyella Riverside/Broadmeadow Mine

BMA

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WSP acknowledges that every project we work on takes place on First Peoples lands.
We recognise Aboriginal and Torres Strait Islander Peoples as the first scientists and engineers and pay our respects to Elders past and present.

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Acronyms, abbreviations, and terms

Acronym / abbreviation / term	Description
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AWBM	Australian Water Balance Model
BMA	BHP Mitsubishi Alliance
BRM	Broadmeadow Mine
CHPP	Coal handling and processing plant
CSM	Conceptual site model
DESI	Department of Environment, Science and Innovation
EA	Environmental Authority
FoS	Factor of Safety
GDE	Groundwater Dependent Ecosystems
GRM	Goonyella Riverside Mine
GRBM	Goonyella Riverside/Broadmeadow Mine
IPCC	Intergovernmental Panel on Climate Change
LOD	Land Outcome Document
PCM	Permian Coal Measures
MCM	Moranbah Coal Measures
MIA	Mine Infrastructure Area
ML/year	Megalitres per year
ML	Mining Lease
NUMA	Non-Use Management Area
PMF	Probable Maximum Flood
PMLU	Post-Mining Land Use
PRC plan	Progressive Rehabilitation and Closure Plan
QC	Quality Control
QLD	Queensland
RCP	Representative Concentration Pathway
TSF	Tailings Storage Facility
WBM	Water Balance Model
WQO	Water Quality Objective

1 Introduction

Goonyella Riverside/Broadmeadow Mine (GRBM) is a coal mine, located 30 kilometres (km) north of Moranbah in the Bowen Basin, Central Queensland (QLD). GRBM forms part of the Goonyella Riverside Mine Complex, consisting of Goonyella Riverside Mine (GRM), which is a large and established open cut operation and the Broadmeadow Mine (BRM), an underground longwall operation which is located within the boundaries of the GRBM (BHP, 2019). Operations at GRBM are authorised under Environmental Authority (EA) (EPML00853413) for the following Mining Leases (ML); ML1762, ML1764, ML1802, ML1900, ML700003, ML70121, ML 20193, ML70194, ML70287, ML70288, ML70289, ML70421, ML70468, ML70469, ML70478, ML70479, ML70493, ML70494.

The EA (EPML00853413) is jointly held by BHP Coal Pty Ltd, QCT Resources Pty Ltd, Mitsubishi Development Pty Ltd, Umal Consolidated Pty Ltd, QCT Mining Pty Ltd, QCT Investments Pty Ltd, and BHP Queensland Coal Investments Pty Ltd. Holders of an EA are required to submit a progressive rehabilitation and closure plan (PRC plan) that meets requirements under the *Environmental Protection Act 1994*. A Transition Notice has been issued to BMA by the Department of Environment, Science and Innovation (DESI) for GRBM, requiring a PRC plan be submitted to the administering authority by 29 November 2024.

This void closure plan presents outcomes of technical studies completed to support closure planning and achievement of residual voids that are safe and do not cause environmental harm at GRBM – specifically for the Goonyella, Broadmeadow, Isaac, R32 South, R32 East and Thiess residual voids. This void closure plan is an appendix to the GRBM PRC plan and is required by the DES *Progressive rehabilitation and closure plan (PRC plans) Guideline (version 3.01)*, hereafter referred to as the 'PRC Plan Guideline', dated 16 September 2024.

The technical studies, including the hydrogeology and rehabilitation flood modelling, have been undertaken through an iterative approach with the development of the closure landform design. These iterations have resulted in a closure landform design that includes refinements comprising partial void backfill, increased void crest off-set distances, removal of culverts and other infrastructure from watercourses/floodplains, and changes to flood protection landforms to provide increased protection from flood water. This void closure plan documents how these refinements contribute to minimising environmental harm, as it relates to the GRBM final residual voids.

1.1 Scope and objectives

The GRBM mining pits are currently in various operational stages and are pre-approved as non-use management areas (NUMAs). They will be combined in a final closure landform design as six residual voids – Goonyella, Broadmeadow, Isaac, R32 South, R32 East and Thiess (herein referred to as the GRBM residual voids).

The objective of this void closure plan is to document the rehabilitation and management approach, capturing how BMA will aim to achieve residual voids that are safe and do not cause environmental harm at closure. This void closure plan will also assist to:

- Minimise risk of the residual voids and surrounding areas within the Non-use management area (NUMA) extent
- Minimise active management of the residual voids post-closure
- Avoid unmitigated access to the NUMA by humans and livestock.

The following sections present information as required by sections 3.4 and 3.6.3 of the *PRC Plan Guideline*, specifically:

- Section 3 – Proposed residual voids
- Section 4 – Groundwater
- Section 5 – Flooding assessment
- Section 6 – Void water balance
- Section 7 – Geotechnical stability
- Section 8 – Geochemical stability
- Section 9 – Residual void management.

1.2 Application legislation and guidelines

The following applicable legislation and guidelines have informed the development of this void closure plan:

- Environmental Protection Act 1994 (QLD)
- EA (EPML00853413) dated 26 February 2024
- PRC Plan Guideline (version 3.01) dated 16 September 2024.

2 Site overview

GRBM is a conventional open-cut strip mine located approximately 30 km north of Moranbah, Queensland. Coal mining activities primarily occur within ML1763, with a small portion of mining occurring on the south-eastern portion of ML1764.

Mining involves land clearing, the removal and stockpiling of topsoil material, drilling and blasting of overburden/interburden as required, and stripping of overburden/interburden material, and mining coal using draglines and truck and shovel fleets. As mining progresses, most of the overburden/interburden material is placed in the void of the previous strips. Coal is hauled from the pits for short-term storage at the coal stockpile areas before transport and processing at coal handling and preparation plant (CHPP). Tailings and rejects from the CHPP are disposed of at a tailings storage facility (TSF) or in-pit. The coal product is transported by rail to the Hay Point Coal Terminal for export.

Operations at GRBM began in 1971. The assumed closure dates for the individual residual voids vary, based on the current projected mine plan, as follows:

- 2097 for Goonyella - utilised at the end of open-cut mining for underground access to the neighbouring BMA Red Hill Mine.
- 2061 for Broadmeadow and Isaac - utilised at the end of open-cut mining for underground access to BRM.
- 2037 for R32 South - potential operational use as water storage following final coal extraction.
- 2032 for R32 East.
- 2016 for Thiess - as per BMA instructions for modelling purposes. However, Thiess is being utilised for operational water storage. Actual rehabilitation works will be delayed until operation requirements cease.

An overview of the existing environmental site context within and surrounding GRBM is provided in the PRC plan, and therefore not repeated in this void closure plan. Timing for the residual void closure dates factors in ongoing requirements to access underground mining activities and potential for operation water storage.

3 Proposed residual voids

Residual voids are identified and authorised under Schedule E (Condition E6 and E7) of the EA (which is GRBM's Land Outcome Document (LOD)). Therefore, the six proposed GRBM residual voids are being transitioned as pre-approved NUMAs in the GRBM PRC plan.

The pits will be progressively backfilled with spoil as mining advances, with partial backfill of the final voids planned to assist with flood protection such that the proposed residual voids are not subject to inundation from floodwaters (refer to Section 5). Indicative final dimensions of the residual voids are presented in Table 3.1. A three-dimensional (3D) void design plan for all the GRBM residual voids, including the void lakes, is presented in Figure 3.1.

Table 3.1: Indicative GRBM residual void dimensions

Residual void	Indicative maximum width (m)	Indicative maximum length (m)	Indicative maximum depth (m)
Goonyella	11,630	1,270	324
Broadmeadow	2,450	430	86
Isaac	2,650	210	52
R32 South	1,030	400	79
R32 East	1,600	430	114
Thiess	3,850	390	66

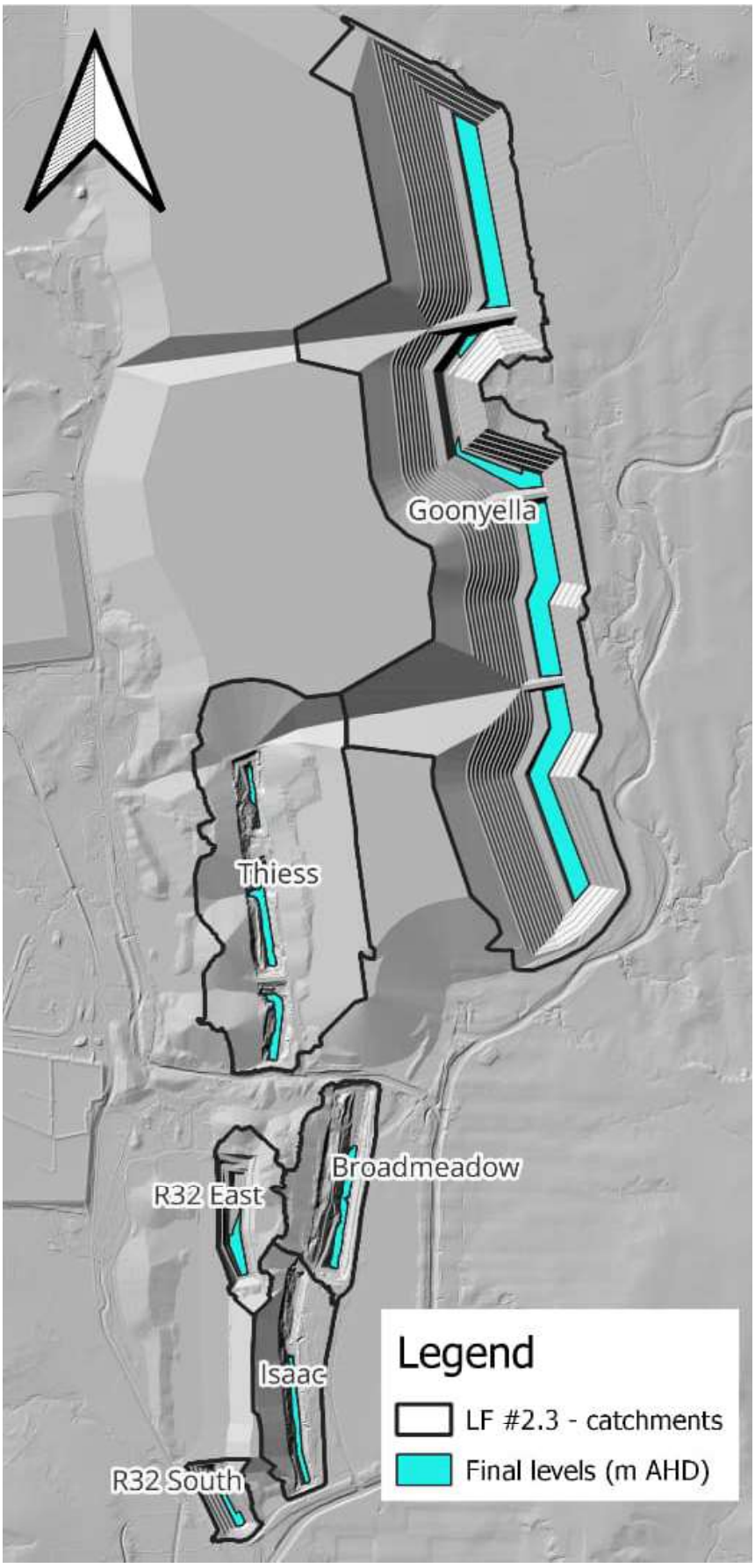


Figure 3.1: 3D void design plan: an overview of GRBM residual voids and void lakes at the end of the water balance model simulation

4 Groundwater

The hydrogeological assessment included conceptual and numerical modelling to determine groundwater interactions with void lakes, and the potential for contaminant transport from GRBM residual voids (AECOM, 2024a). The complete hydrogeological assessment, including details of the model set-up, calibration, and discussion of the results, are provided as an attachment to the PRC plan, and therefore not repeated in this void closure plan. This section summarises the hydrogeological assessment of the GRBM residual voids, as it relates to the rehabilitation and management approach to achieve residual voids that are safe and not cause environmental harm at closure.

A post-mining conceptual site model (CSM) was developed which depicts groundwater interactions with the residual voids. The model graphical representation is presented in Figure 4.1. The CSM's key findings, relevant to post-mining groundwater impacts from the closure state landform, are as follows (AECOM, 2024a):

- Residual void water level predictions including groundwater inflows for the Goonyella residual void stabilise markedly below the post-closure recovered groundwater elevations for all directly impacted hydrostratigraphic units, and below the other five residual void water levels. This groundwater sink effectively limits any migration of contaminants outside of the mining tenure.
- An inward hydraulic groundwater flow gradient within the Moranbah Coal Measures (MCM) coal seam towards three of the six residual voids develops due to:
  - Residual groundwater drawdown within the target MCM coal seams as a result of the approved mining operations.
  - Post-closure ongoing evaporative losses from the residual void lakes.
- Groundwater outflows from the Thiess and Isaac residual voids are predicted to be captured within the Goonyella residual void.
- Predicted groundwater outflows from Broadmeadow residual void during the prediction periods will reduce or cease in the long-term, as indicated by the long-term stabilisation of groundwater and residual void levels.
- The Goonyella residual void captures any infiltration of rainfall through the areas where mine waste has been or is stored (TSF, mine infrastructure areas - MIA, rejects) and spoil/backfill areas. This is supported by the particle tracking simulations.
- There is little to no additional impact on surficial aquifers, including the Isaac River alluvium, caused by the final closure state landform.
- There is little to no impact on environmental receptors such as groundwater dependent ecosystems (GDEs) caused by the final closure state landform. A single potential anthropogenic receptor (water bore) in proximity to the Goonyella residual void is expected to become dry post-closure as a result of residual mine operational dewatering activities. No other anthropogenic receptors are identified to be impacted by the final closure state landform.
- The continuous removal of groundwater through evaporation from the Goonyella residual void lake indicate that groundwater levels in proximity to the residual void will not return to a pre-mining state.

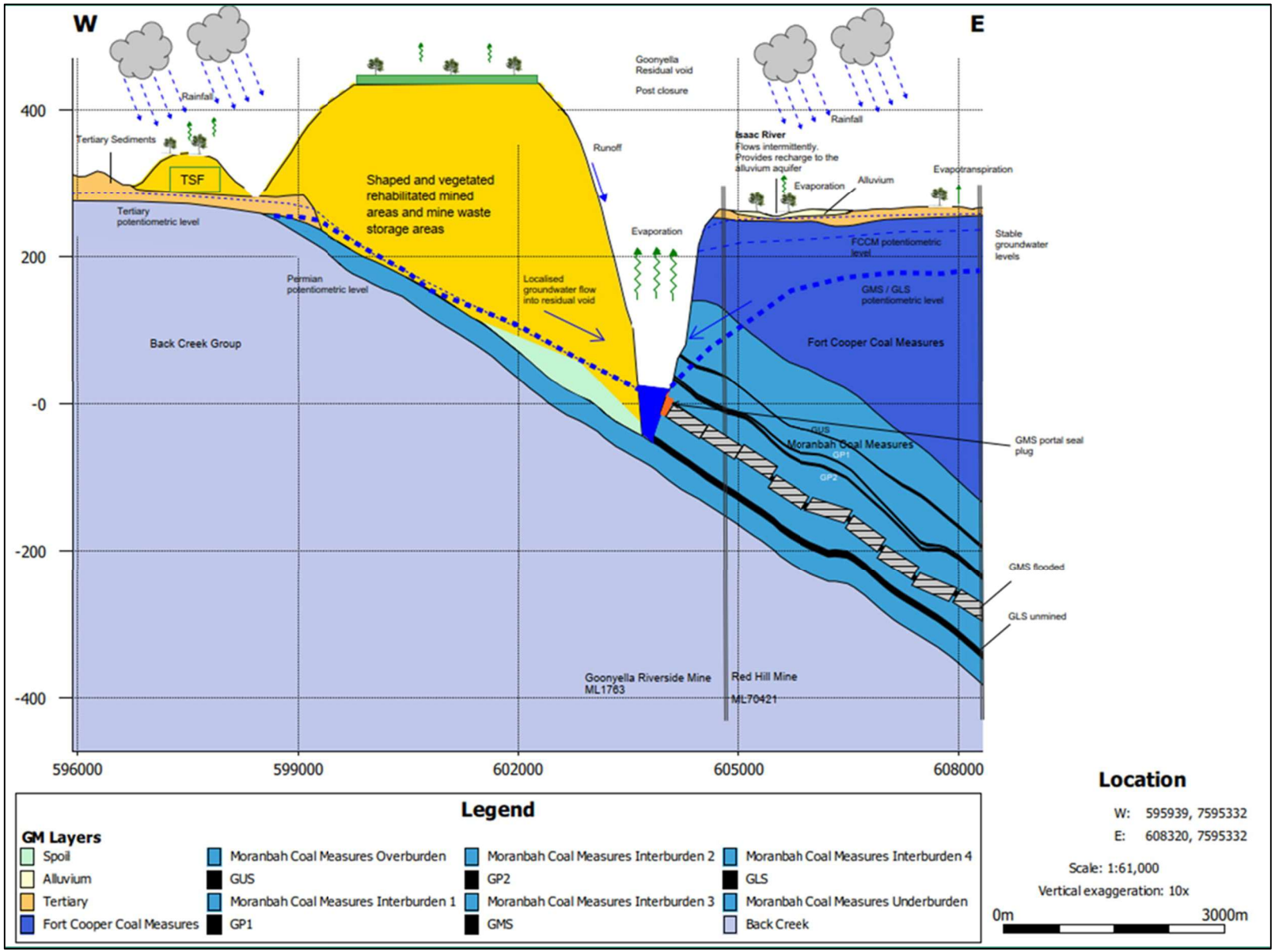


Figure 4.1 Visual depiction of the GRBM post-closure conceptual model (AECOM, 2024a)

Calibrated numerical modelling was also undertaken (AECOM, 2024a) to evaluate the potential impacts of the final closure state landforms for the GRBM residual voids on the groundwater regime. The objectives of the predictive modelling were to:

- Assess the potential groundwater-related impacts at the completion of mining and until conditions stabilise post-rehabilitation.
- Assist in demonstrating the suitability of the final landform for the post-mining land uses (i.e., evaluate the residual voids included in the final landform to determine influence on groundwater resources).
- Demonstrate that the final landforms, including the residual voids, are not causing environmental harm outside of the voids themselves or the mining tenure boundary.
- Provide an understanding of:
  - Groundwater interactions with the residual voids through simulation of the residual void lake water levels and rates of recovery, and the groundwater level and rate of recovery from mining-related drawdown in the groundwater system surrounding the voids.
  - Groundwater inflow to the final residual voids.
  - Changes in hydrogeological conditions (including groundwater levels) from the active mining to stable post-mining conditions.
- Identify areas of potential environmental or anthropogenic risk, such as impacts to water quality, private water supply bores, GDEs or surface water resources where groundwater impact mitigation/control measures may be necessary post-closure.

The final closure state landforms were replicated in the model, including the six GRBM residual voids and the spoil emplacements within the mined-out pits. The model timeframe was developed to commence at the end of mining and simulate through to 2199. The predicted end of mining groundwater level was applied as the starting heads (AECOM, 2024a). The Broadmeadow underground mine and neighbouring Red Hill Mine (RHM) underground mine have been modelled to be actively flooded at end-of-mining. The proximity of RHM to the GRBM site warrants its inclusion in the numerical groundwater model.

Goonyella residual void lake level predictions indicate the lake stabilises at a lower elevation than the post-closure recovered groundwater levels for all directly influenced hydrostratigraphic units, and below the other five GRBM residual void lake elevations. This effectively creates an inward hydraulic gradient towards the Goonyella residual void and a groundwater sink that limits the potential migration of contaminants through groundwater for the entire tenure.

The predicted equilibrium (long-term steady state) of the water table elevation adjacent to the final voids is shown in Figure 4.2 and Figure 4.3 for the Goonyella Middle Seam (GMS) and Goonyella Lower Seam (GLS), respectively. The end of the post-closure simulation (P4) is compared to the end-of-mining simulation (P3).

The groundwater levels in the water table proximal to the residual voids is predicted to remain below pre-mining groundwater levels in the long-term, driven by ongoing groundwater discharge to the residual void lakes and governed by the lake elevations themselves. Long-term inwards groundwater flow gradients are maintained post-mining for four GRBM residual voids (Goonyella, Broadmeadow, Ramp 32 East and Ramp 32 South). Modelled groundwater outflow from the Thiess and Isaac residual voids is predicted to be captured within the Goonyella residual void.

The effect of the active flooding of the RHM on the groundwater drawdown to the east of the GRBM residual voids is evident in the contours for the end of the post-closure simulation. The effect of active flooding of the Broadmeadow underground mine on the GMS drawdown is less evident due to its proximity to the Broadmeadow, Isaac, and Goonyella residual voids and also the relatively deep RHM underground workings that continue to remove water from the system through evaporation and operational dewatering (RHM underground workings continue to operate following the closure of the Broadmeadow underground).

The effect of evaporative losses from the residual void lakes will maintain an inward hydraulic gradient for the tenure, which will be centred on the Goonyella residual void. This residual void will act as a terminal groundwater sink, providing long-term post-mining groundwater contaminant management.

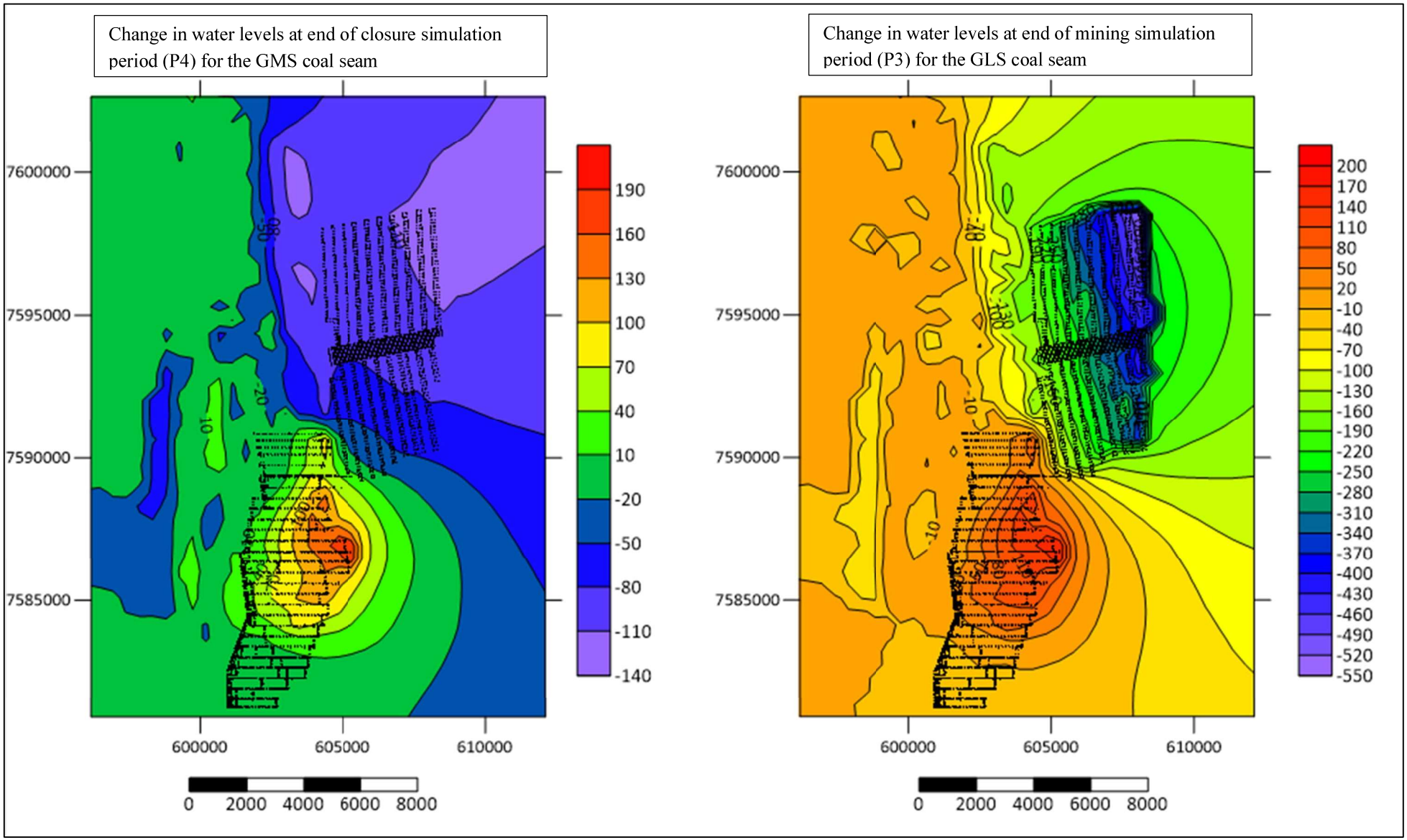


Figure 4.2 Modelled groundwater levels in the GMS at end of closure period – P4 (left) compared to the end-of-mining period – P3 (right) (AECOM, 2024a)

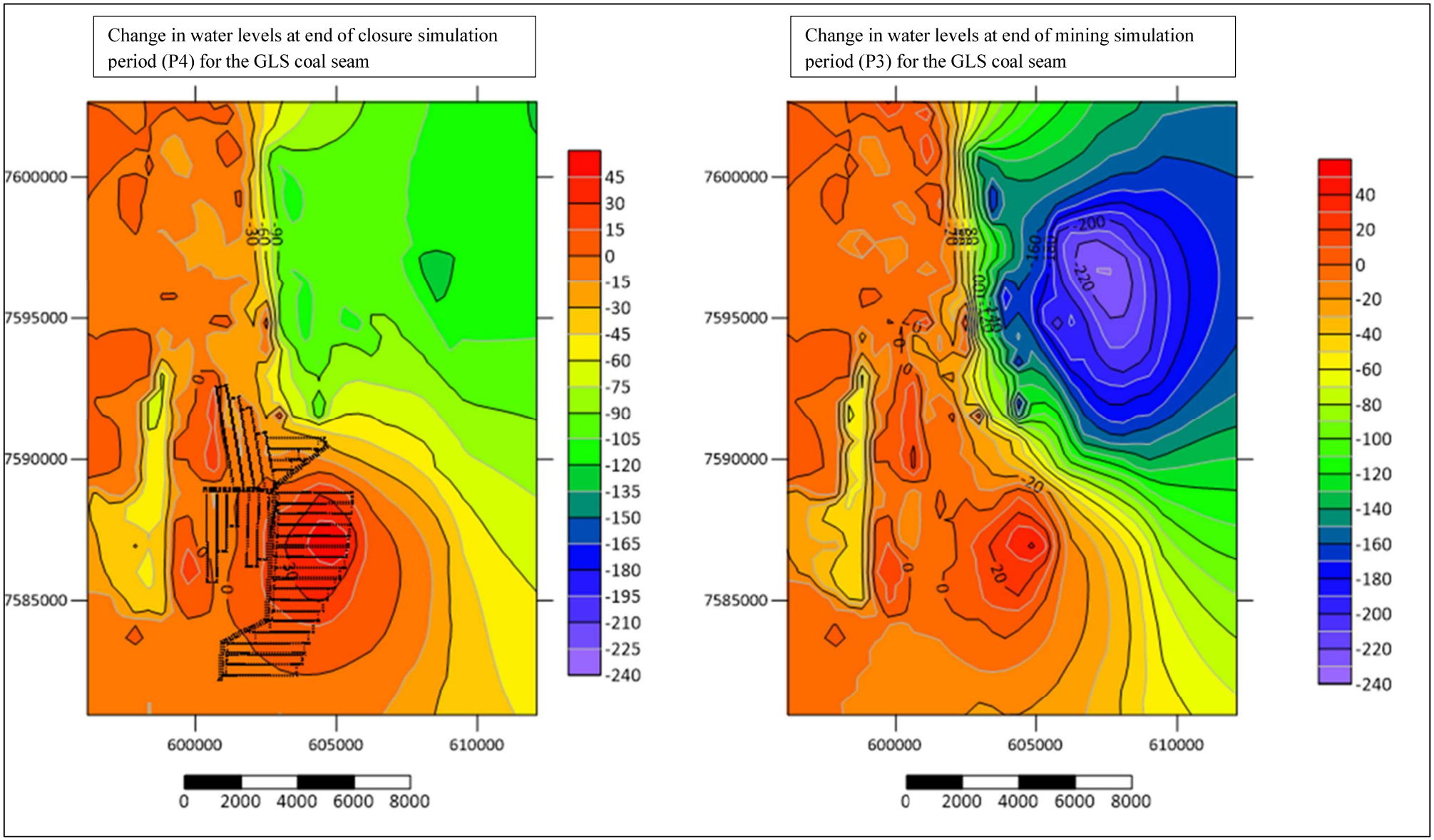


Figure 4.3 Modelled groundwater levels in the GLS at end of closure period – P4 (left) compared to the end-of-mining period – P3 (right) (AECOM, 2024a)

Post-closure, the numerical model predicted the drawdown and recovery of the groundwater levels in the alluvium, which includes surficial cover of either alluvium or Tertiary sediments (Figure 4.4). The modelled drawdown over time indicates there is no change to the zero (no drawdown) contour across the Issac River (indicated by the green cells in Figure 4.4), and ingress into the residual voids stabilises over time.

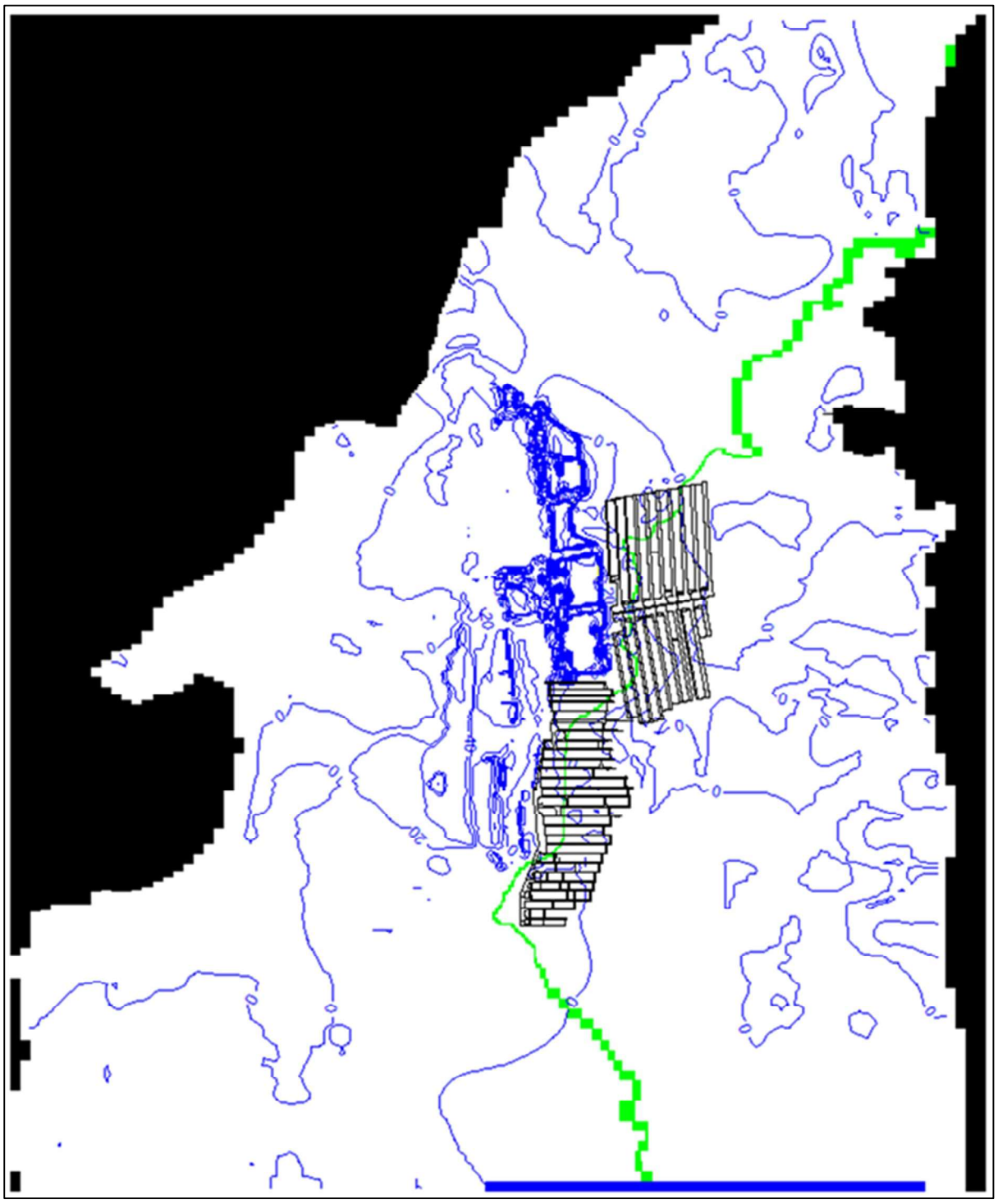


Figure 4.4 Modelled groundwater drawdown levels in the alluvium at the end of the post-closure simulation (AECOM, 2024a)

There are periods of variability in inflows and outflows from spoil and natural/unmined geology of groundwater predicted by the groundwater model for the residual voids.

Fluxes of water into the Goonyella residual void indicate that this residual void acts as a groundwater "sink", where groundwater from the surrounding spoil and natural rock, as well as from the other GRBM residual voids (where outflows are predicted), flow into the Goonyella residual void (Figure 4.5).

Fluxes of water into the Broadmeadow residual void primarily come from the spoil to the west and are maintained for the model duration, driven by evaporation from the residual void. Predictions indicate that water from Broadmeadow residual void will flow into the surrounding natural (unmined) formations due to lower groundwater levels after mining. However, once groundwater elevations reach a level that is higher than the residual void water level, the model predictions over the simulation period suggest the flux to groundwater decreases over time, and the void may eventually become a sink to both spoil and natural rock fluxes (Figure 4.6).

Fluxes of water from the Isaac and Thiess residual voids into both the surrounding spoil to the west of the void and the natural surrounding formations are predicted to occur. However these fluxes are predicted to flow into the Goonyella residual void (Figure 4.7 and Figure 4.8).

Fluxes of water into the Ramp 32 East residual void come from the surrounding natural rock with this void behaving as a groundwater sink. Groundwater fluxes out of the void are minimal and no ingress from the surrounding spoil is predicted (Figure 4.9).

Fluxes of water into the Ramp 32 South residual void originate from the natural geology, with some inflow predicted from the spoil. Similar to Ramp 32 East void, this void behaves as a groundwater sink with only groundwater inflows to the residual void (Figure 4.10).

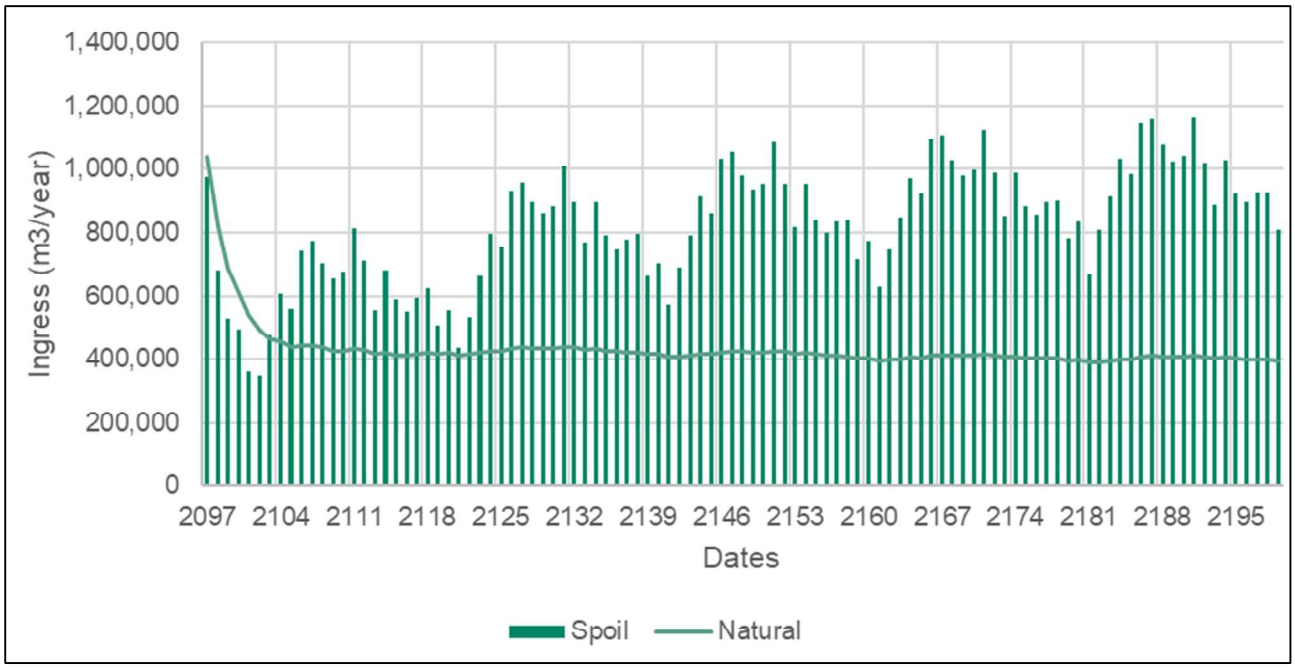


Figure 4.5 Predicted groundwater inflows to the Goonyella residual void (AECOM, 2024a)

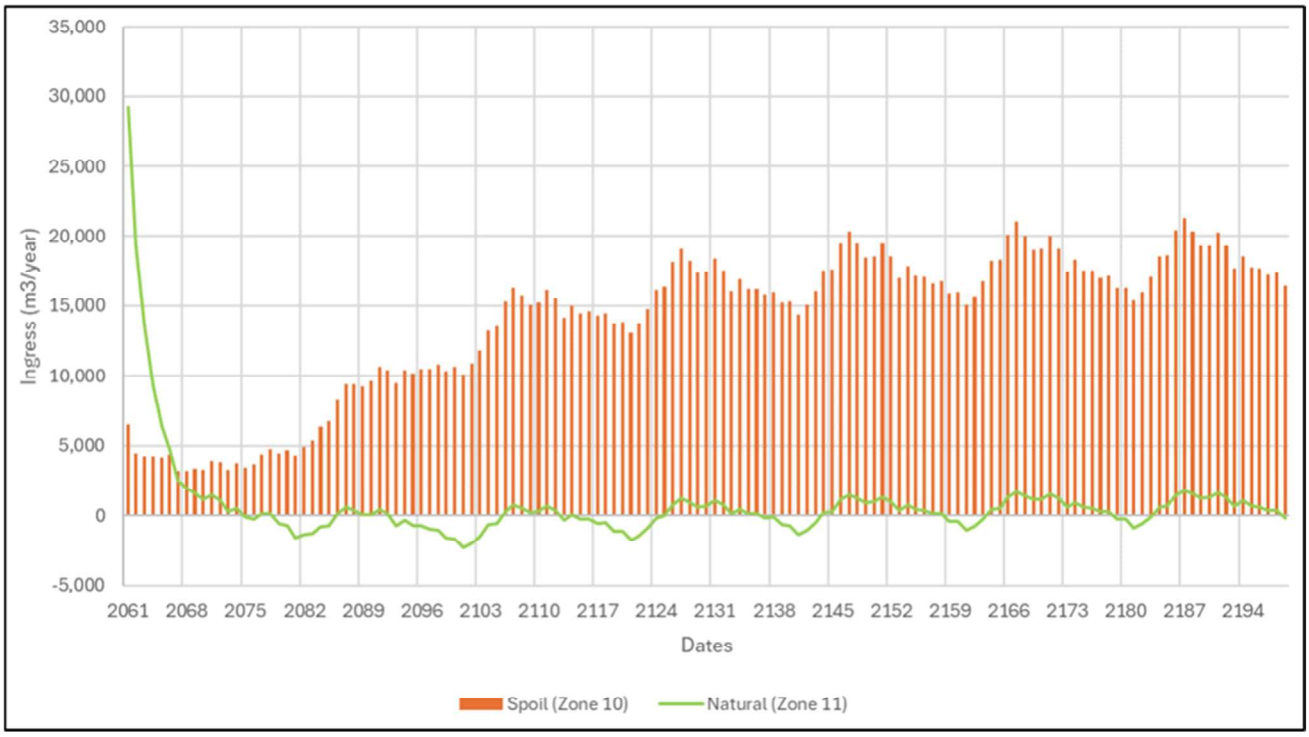


Figure 4.6 Predicted groundwater inflows to the Broadmeadow residual void (AECOM, 2024a)

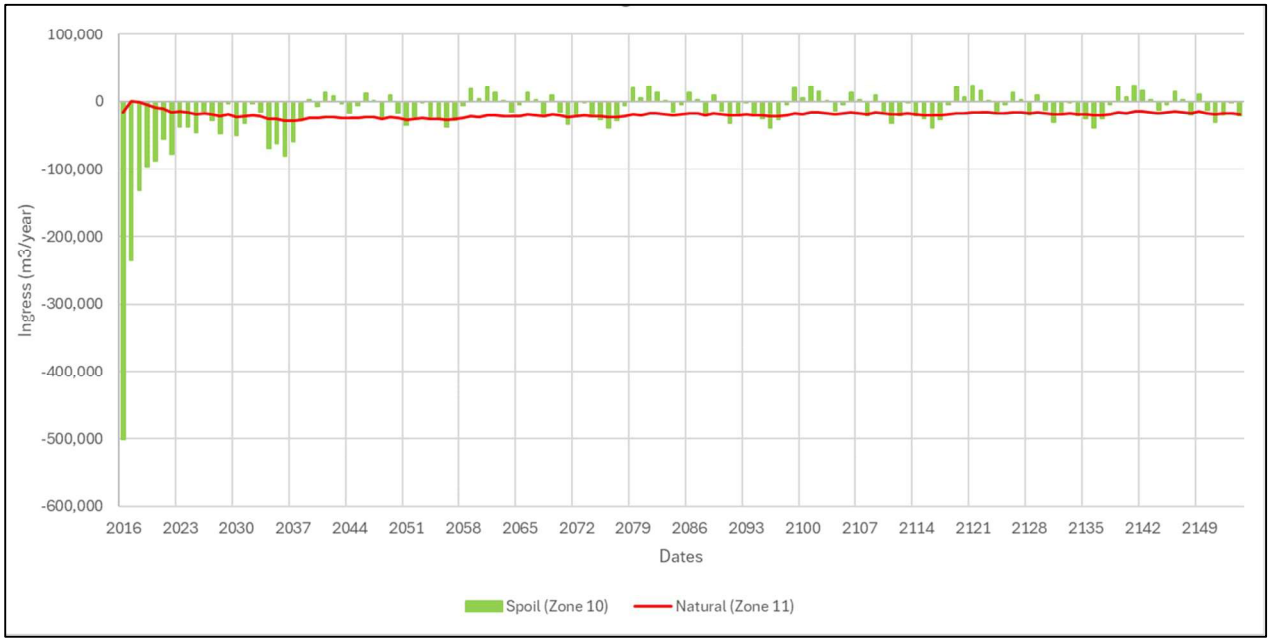


Figure 4.7 Predicted groundwater inflows to the Isaac residual void (AECOM, 2024a)

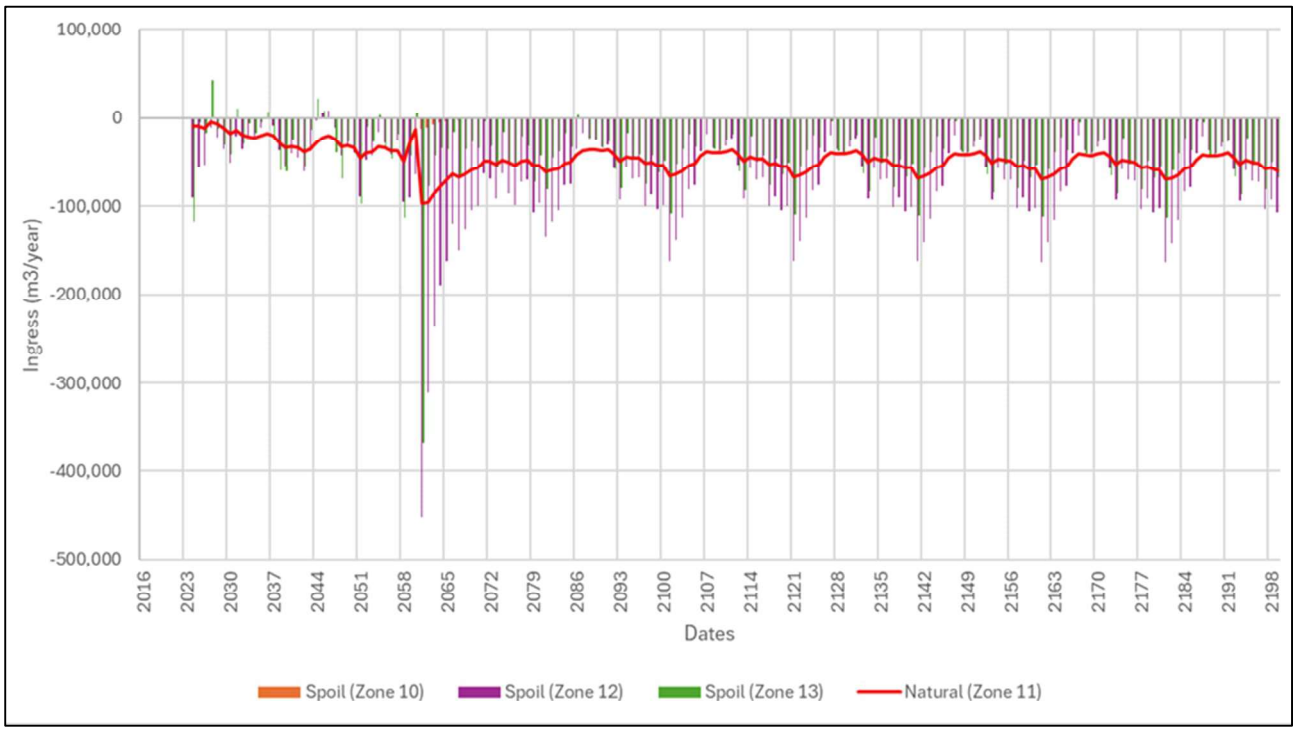


Figure 4.8 Predicted groundwater inflows to the Thiess residual void (AECOM, 2024a)

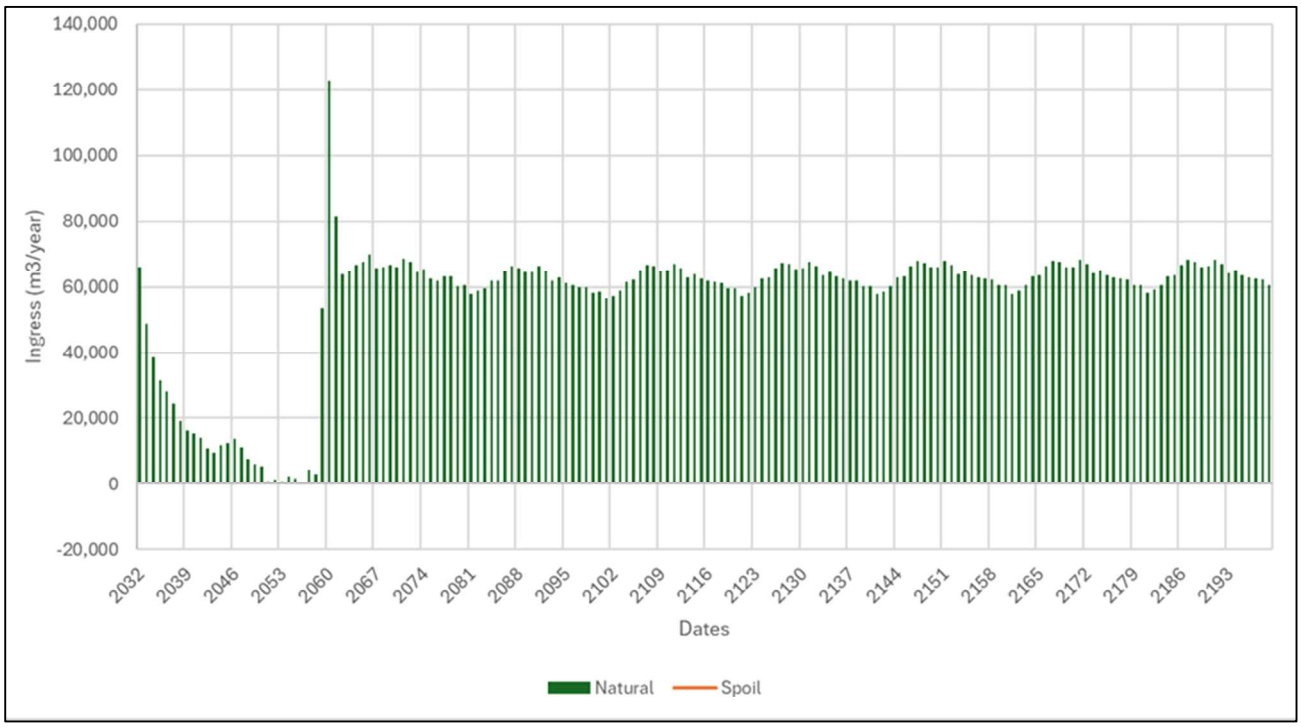


Figure 4.9 Predicted groundwater inflows to the R32 East residual void (AECOM, 2024a)

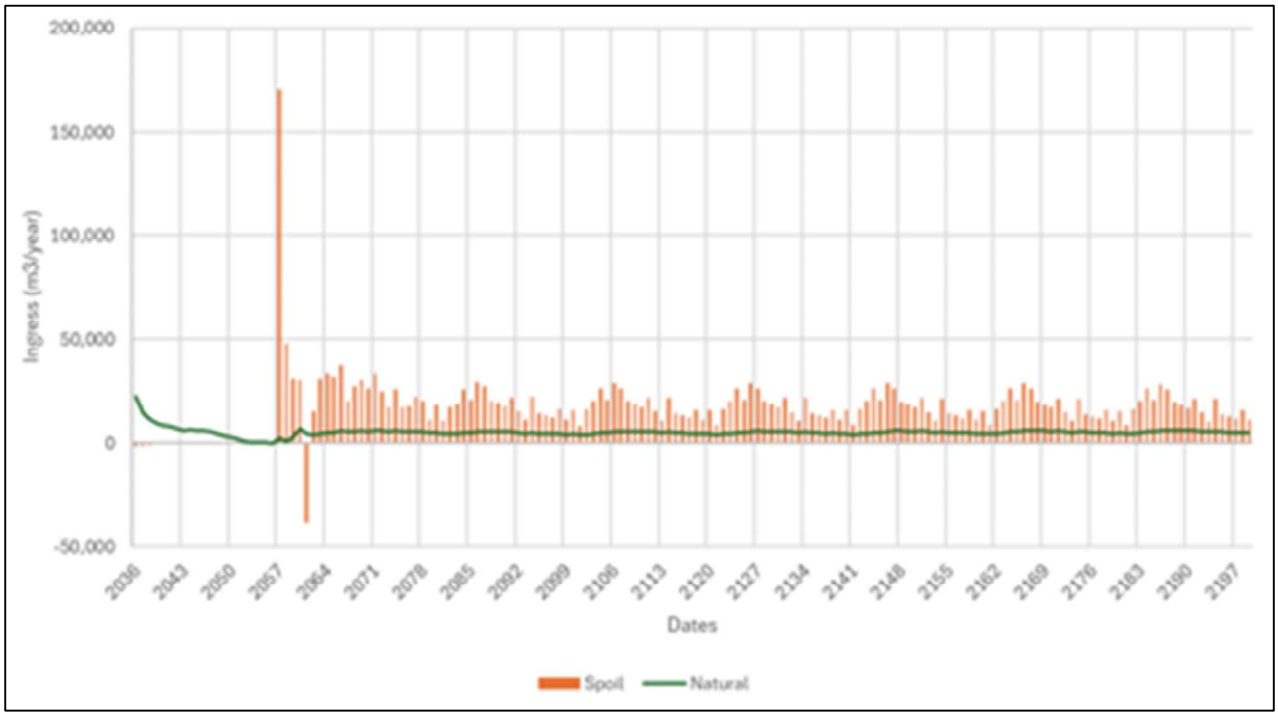


Figure 4.10 Predicted groundwater inflows to the R32 South residual void (AECOM, 2024a)

The residual voids water levels were compared to the surrounding groundwater elevations to determine the potential for the residual voids to interact with the surrounding hydrostratigraphic units (Table 4.1). The modelled groundwater elevations were determined from hydrographs positioned 100 m up gradient and down gradient (west and east) of each void and therefore are not indicative of the overall hydraulic gradient towards the voids.

Table 4.1 Modelled recovered groundwater levels in proximity to the residual voids compared to the modelled void water levels at GRBM

Residual void	Modelled recovered groundwater levels (m AHD) [1]	Modelled mean void water elevation (m AHD) [2]
Broadmeadow	143.5 - 160	155 m
Isaac	177 – 179.5	180
Theiss	187 - 203	202
Ramp 32 East	162.5 - 169	162
Ramp 32 South	173.5 - 176	173
Goonyella	20 - 36	21

[1] As indicated from hydrographs of pilot holes in the model generated to assess the groundwater elevations 100 m up gradient and down gradient (west and east) of the void (AECOM, 2024a)

[2] Section 6

The network of residual voids in the closure state landform is providing long-term management of groundwater from the mining areas. The residual void lakes, through the loss of water via evaporation, maintain an inward hydraulic gradient for the tenure centred on the Goonyella residual void, which acts as a terminal groundwater sink. Any reduction in the residual voids dimensions or increase of void catchments will change the post-mining hydrogeological conditions and reduce the effectiveness of the long-term groundwater management provided by the proposed closure state landform.

The available water quality data suggests water quality within the MCM seams ranges from moderate to brine. The GMS salinity ranges from brackish to brine, while the GLS and Back Creek Group samples indicate high salinity. The pH of the groundwater at GRBM varies, showing typically neutral to weakly alkaline pH for all formations (AECOM, 2024a).

Using the numerical groundwater model, particle tracking to analyse the water movement within the final closure state landform was completed to simulate and assess the movement and fate of water particles through the groundwater system post-mining (AECOM, 2024a).

The particle movement simulation for particles placed within and adjacent to the residual voids (Figure 4.13) indicated that groundwater at GRBM will remain within the final closure state landform (i.e., rehabilitated in-pit spoil and residual voids) in the long-term (AECOM, 2024a). Particles from the Broadmeadow, Isaac pits, Thiess, Ramp 32 East, and Ramp 32 South residual voids were predicted to migrate over time, reaching the Goonyella residual void within the 100-year particle tracking simulation period (Figure 4.11).

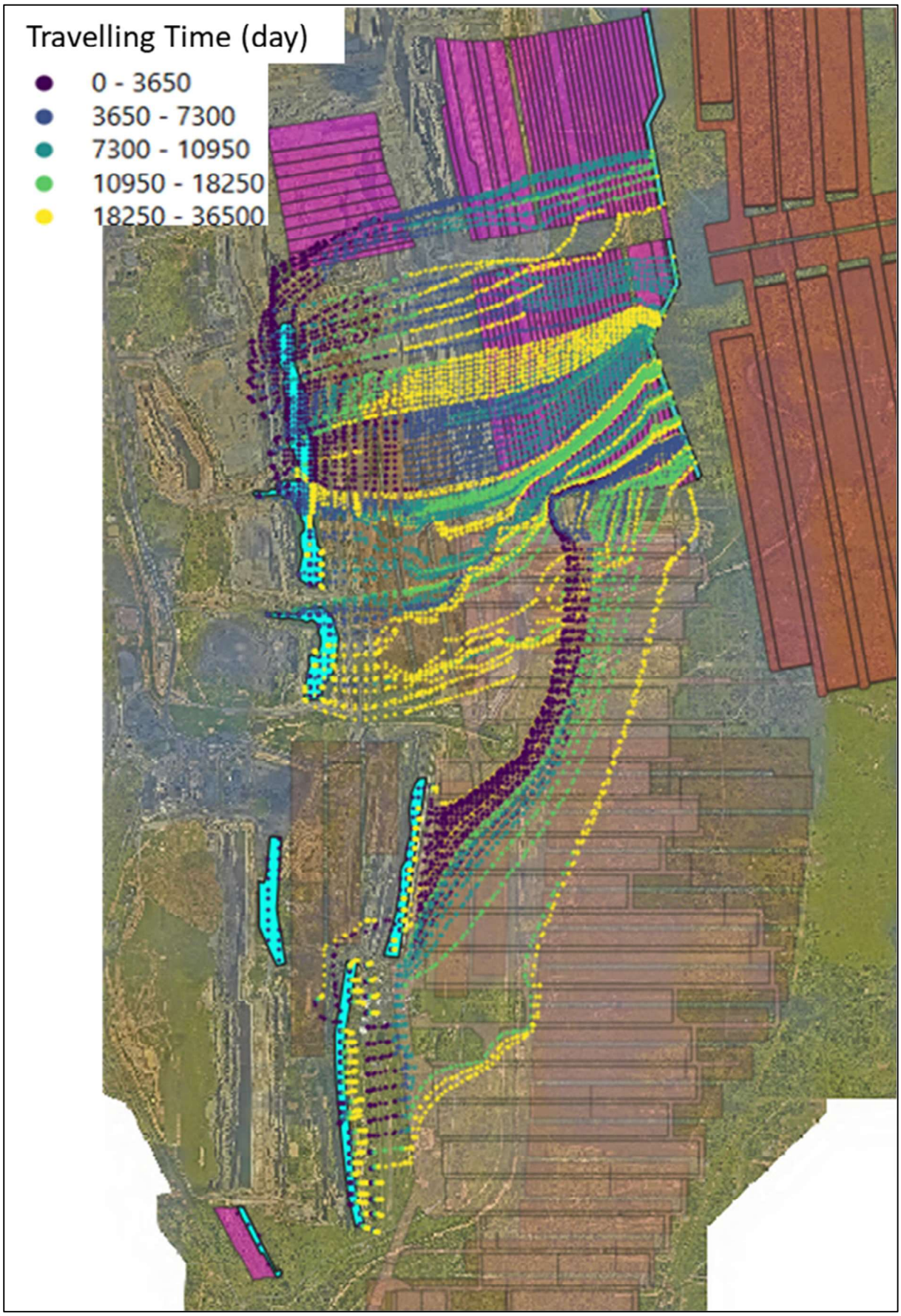


Figure 4.11 Predicted movement of particles from post-closure particle tracking simulation (AECOM, 2024a)

All modelled particles originating in the mining disturbance areas (including those within the voids themselves) are captured within the residual voids on the tenement and do not flow off-site to the receiving environment. The particles placed outside of the residual voids at the potential contaminant sources (MIA, TSFs, rejects) and spoil areas are all predicted to be captured within the residual voids.

Post-closure, particle tracking indicates that water from Broadmeadow, Thiess and Issac residual voids continue to migrate toward Goonyella residual void. All particles will reach the Goonyella Pit within the 100-year particle tracking timeframe, influenced largely by the Goonyella residual void. Particles included immediately adjacent to the Goonyella residual void indicate particle migration towards Goonyella residual void (AECOM, 2024a).

Although very minor outflows from Thiess and Isaac residual voids to the natural geology are predicted to occur, no environmental harm is expected to result beyond the mining tenure from these minor fluctuations as these outflows are re-captured within the Goonyella residual void. This absence of environmental harm is supported by the groundwater modelling, particle tracking simulation, and that no identified third-party bores or GDEs present either within the spoil areas of the residual voids or the GLS or GMS between Thiess, Isaac and Goonyella residual voids. In addition, the water quality model (see Section 8) also indicates that:

- The water quality within the Thiess and Isaac residual void lakes is unlikely to establish acidic conditions; and
- TDS for the Thiess and Isaac residual void lakes remains within the 80th percentile water quality objective (WQO) value for electrical conductivity (as TDS) for the duration of the water quality model simulation period.

As such, any potential outflows are considered to pose minimal risk to the environment if the modelled outflows were to occur.

Potential GDE sites within and adjacent to GRBM mining leases were identified using the Bureau of Meteorology GDE Atlas mapping (Figure 4.12). Some identified potential GDE sites are associated with anthropogenic sources such as dams and therefore, interpretation of potential impacts must consider the limitations of the GDE Atlas mapping.

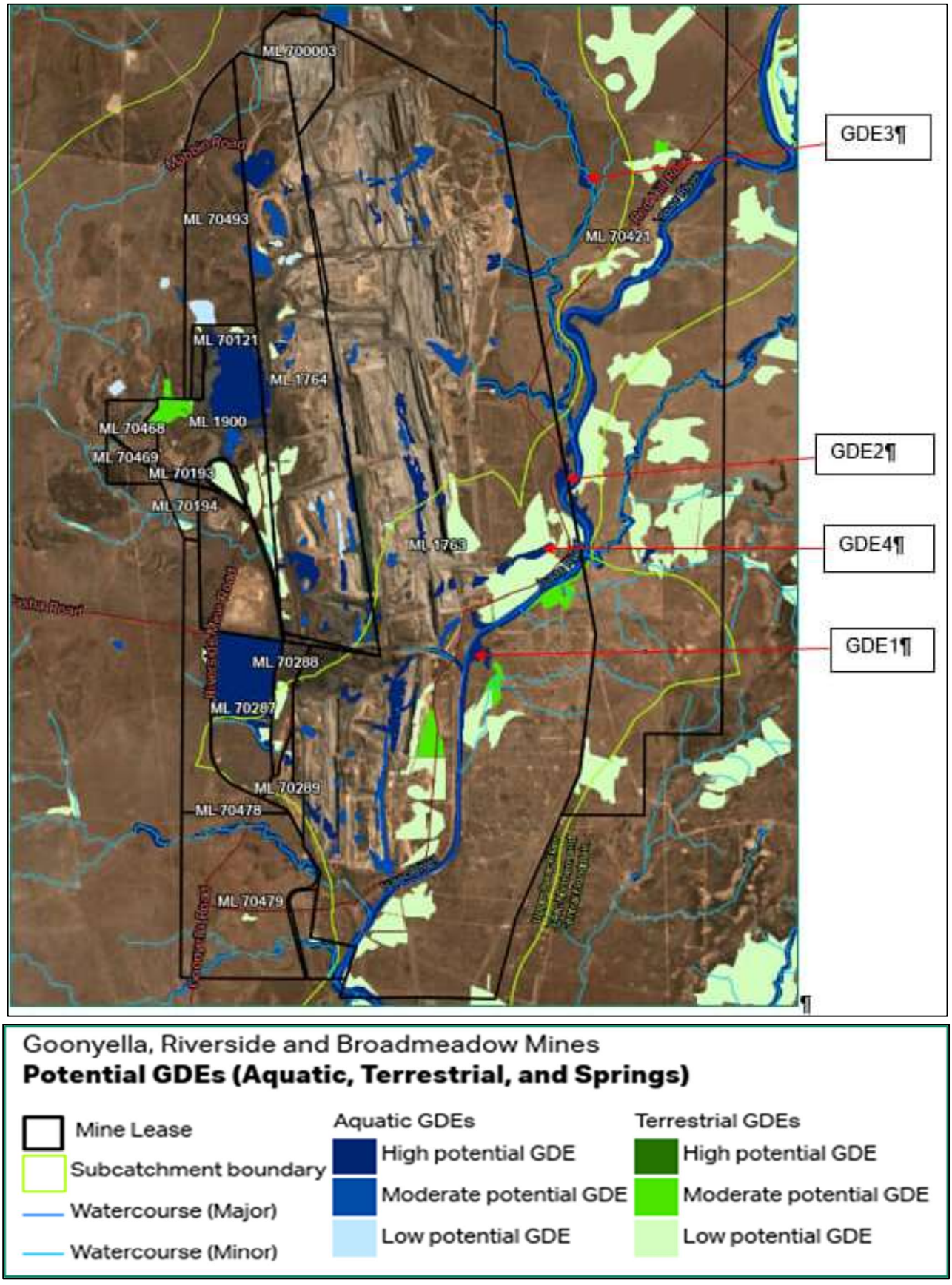


Figure 4.12: Location of potential GDEs adjacent to and within GRBM mining leases (AECOM, 2024a)

Predictive hydrographs were derived from the groundwater model for the four identified potential GDE locations. Post-closure predictions indicate no change in groundwater levels along the Isaac River. Overall, post-closure groundwater conditions, including the presence of residual void lakes, are not expected to impact the potential aquatic GDEs (AECOM, 2024a).

Predictive hydrographs were derived from the groundwater model for the three identified potential third-party water supply bores (18213, 81700 and 81696) (Figure 4.13). Three of the identified supply bores located approximately 20 km from GRBM (182311, 182312, and 132496) are located outside the active model domain and are not expected to be impacted.

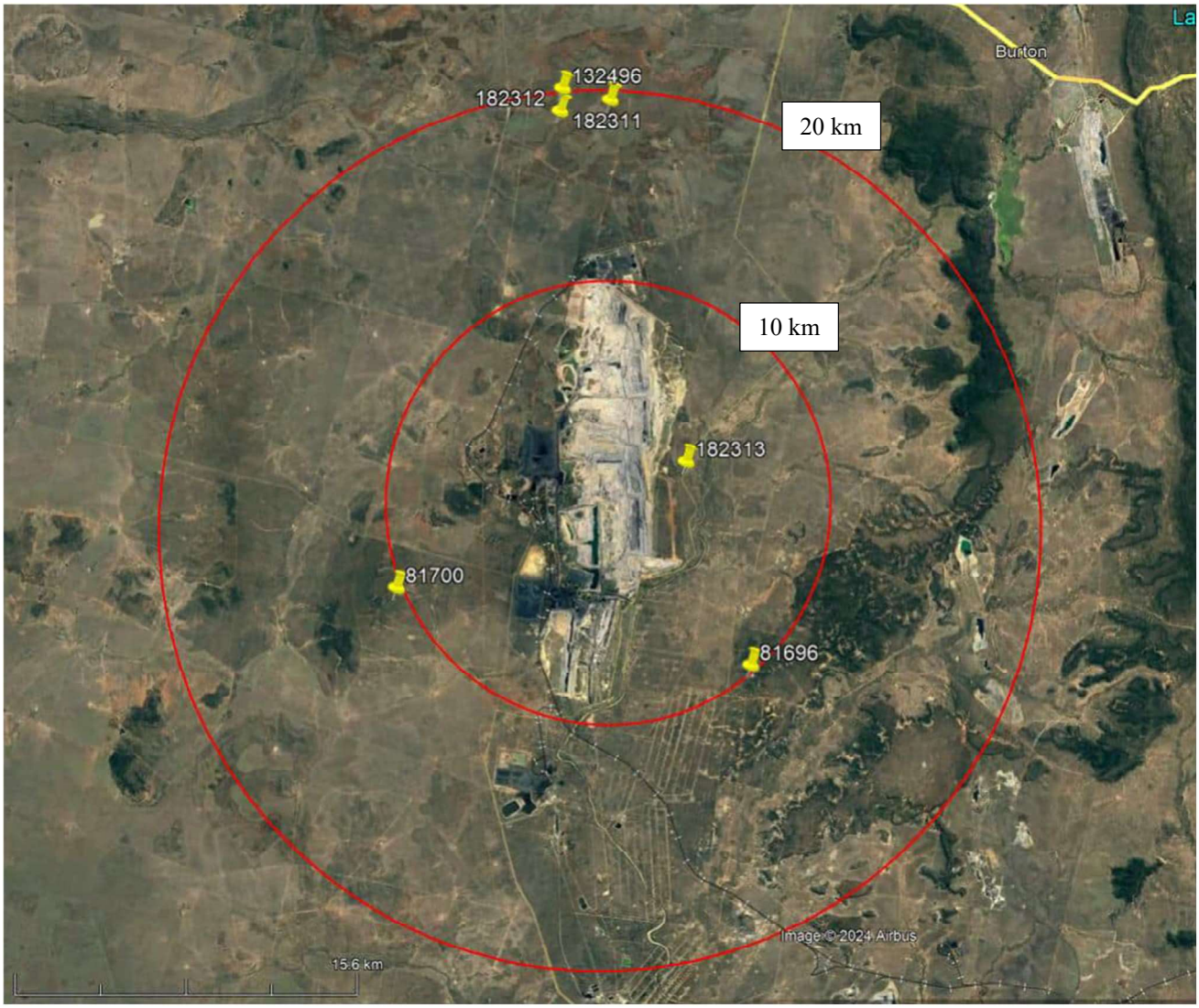


Figure 4.13 Locations of identified third-party water supply bores near GRBM (AECOM, 2024a)

The hydrographs (Figure 4.14 and Figure 4.15) for bores 81696 and 81700, respectively, indicate no predicted alteration to the bore water levels due to GRBM post-closure.

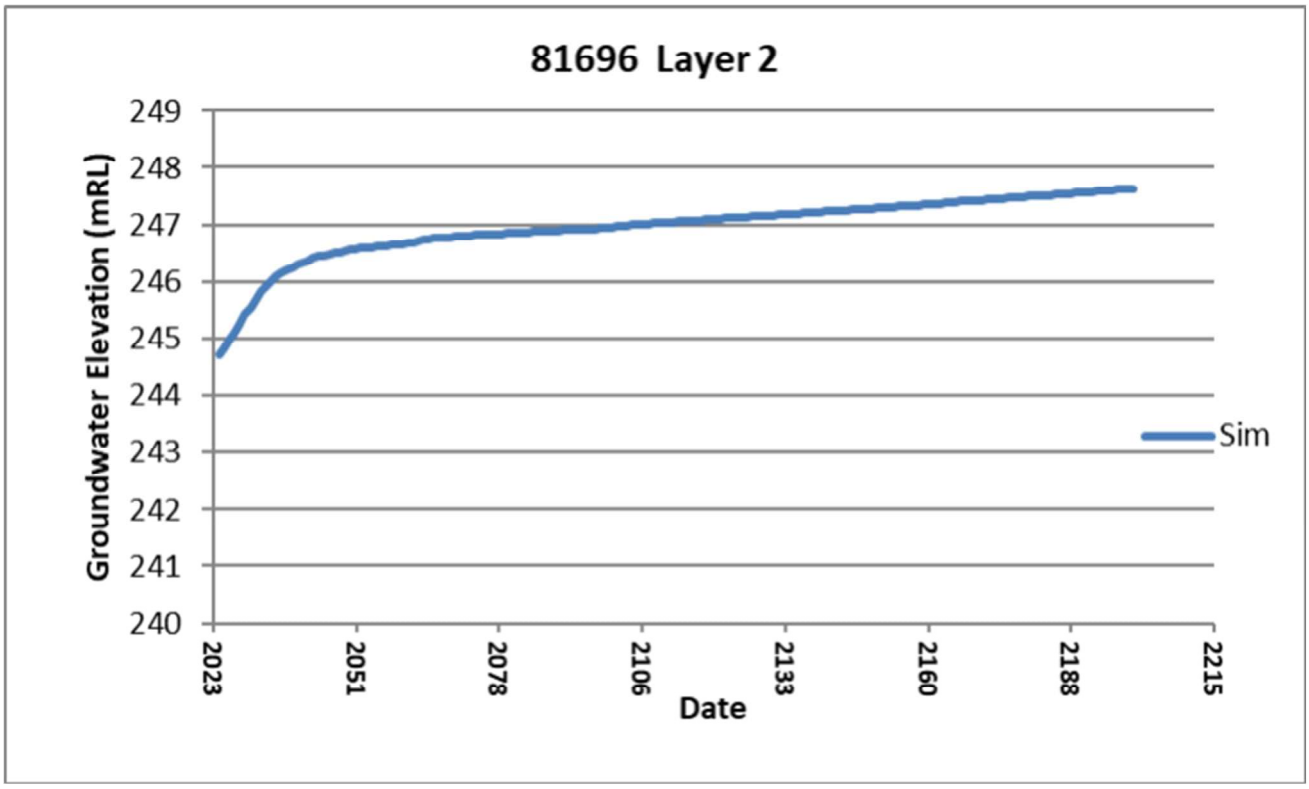


Figure 4.14 Predictive hydrographs for identified third-party water supply bore 81696 near GRBM (AECOM, 2024a)

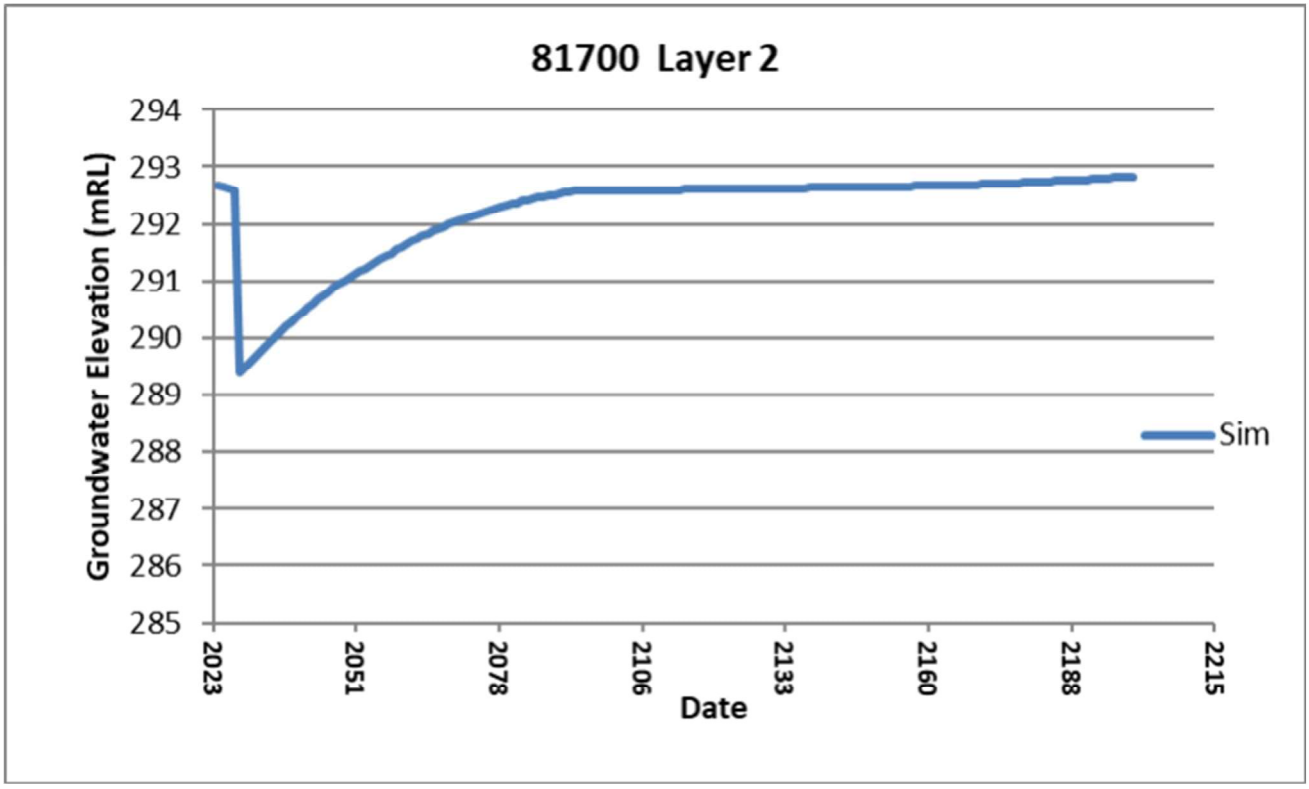


Figure 4.15 Predictive hydrographs for identified third-party water supply bore 81700 near GRBM (AECOM, 2024a)

The hydrograph (Figure 4.16) for bore 182313 shows some predicted long-term post-mining groundwater drawdown (> 5 m) as a result of approved mining activities and not closure-related. This bore is located within the mining tenure in proximity to the Goonyella residual void high-wall. Therefore, it is reasonably assumed not to be used for supply purposes either presently or in the post-mining environment.

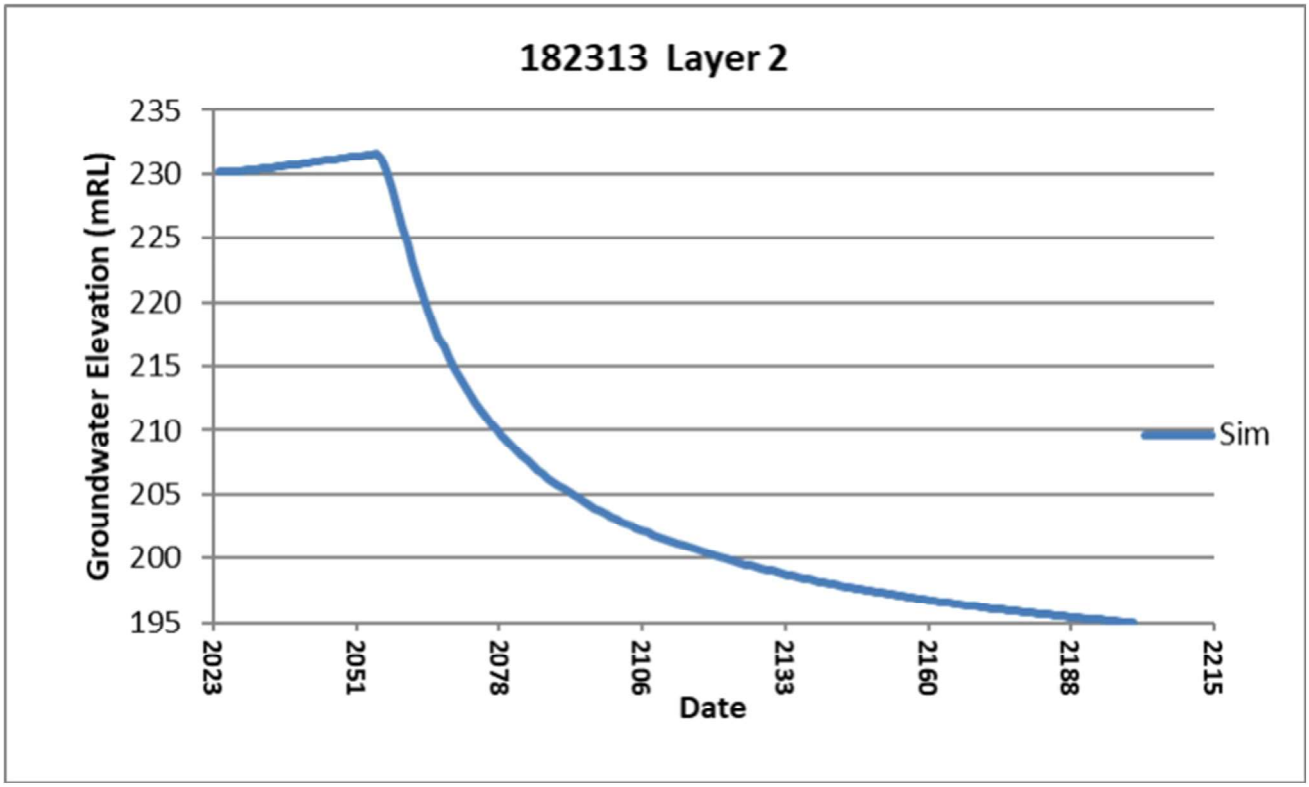


Figure 4.16 Predictive hydrographs for identified third-party water supply bore 182313 near GRBM (AECOM, 2024a)

5 Flooding Assessment

Residual void flooding assessments were completed to determine surface-water interactions, and the drainage and flooding behaviour of surface water in the vicinity of the GRBM residual voids. This section summarises the assessment findings, as relevant to void closure at GRBM. Refer to the main volume of the PRC plan for the complete voids in floodplain and closure-related rehabilitation flooding assessments.

5.1 Void in floodplains

The specific locations of the pre-approved NUMAs are not identified in the LOD (EA EPML00853413), and therefore, in accordance with the DESI PRC Plan Guideline transitional provisions, an assessment of voids in flood plains was undertaken (SLR, 2024).

The perimeters of the final void extents of the closure state landform were included in the voids in floodplain assessment in a re-constructed pre-mining topography. Any final closure landform considerations and/or final void backfill that is intended for flood protection are excluded from the assessment in accordance with the voids in flood plains information sheet (DES, 2020).

The voids in flood plain assessment of the pre-mining landform identified that all the final void's extents associated with the GRBM residual voids would be located, to some extent within the pre-mining landform flood plain of the Isaac River. For the final closure state landform, the residual void extents located within the rehabilitation area flood plain extents of the Isaac River have been reduced and refined and the landform altered to manage the flood risk at closure.

5.2 Closure state landform flooding

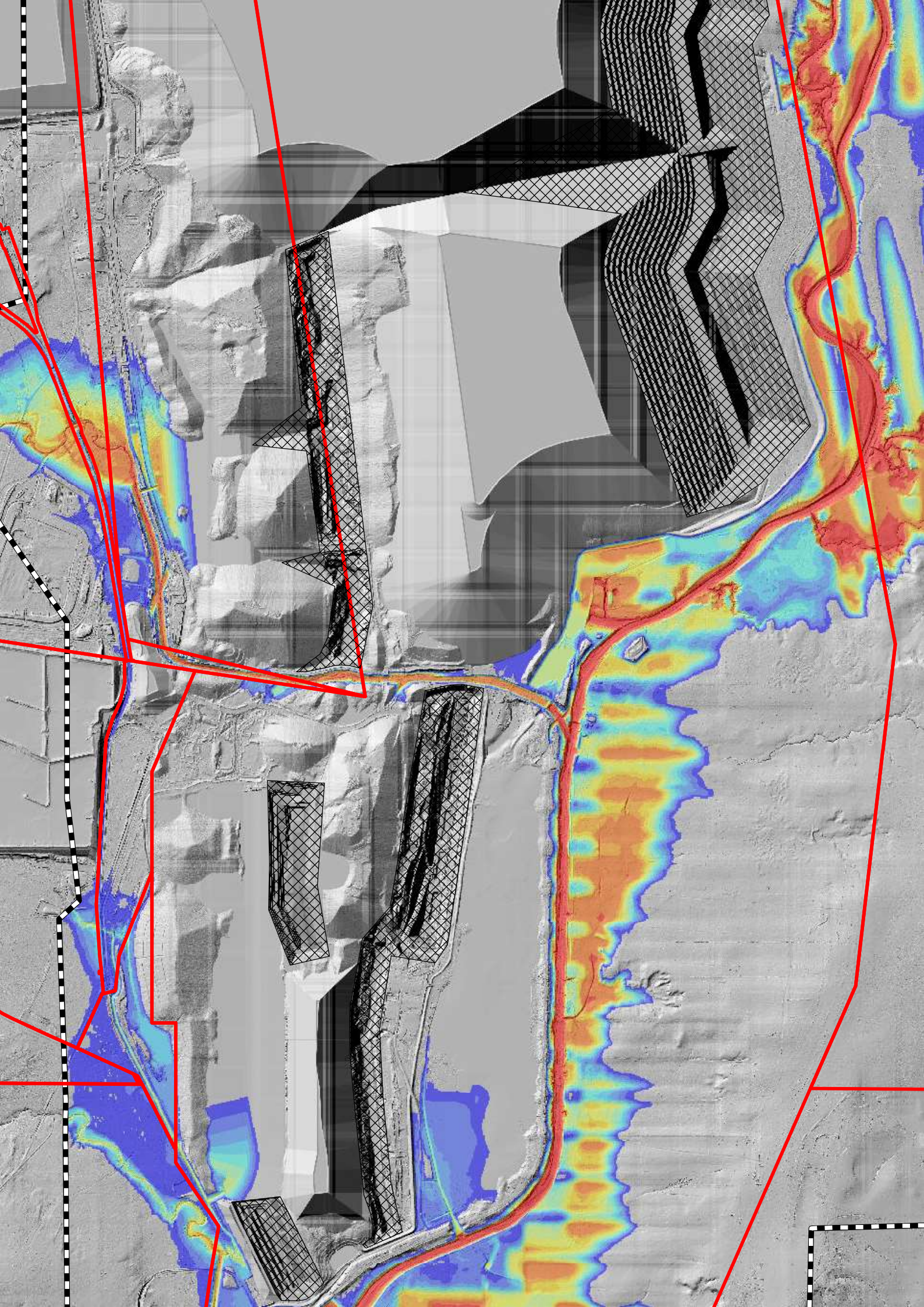
For the final closure state landform, rehabilitation flood modelling was undertaken on a range of design storm events for a range of Annual Exceedance Probability (AEP), including 0.1%, Probable Maximum Flood (PMF), and smaller events in accordance with the DES *PRC Plan Guideline* to predict the interaction of the flood events with the closure state landform.

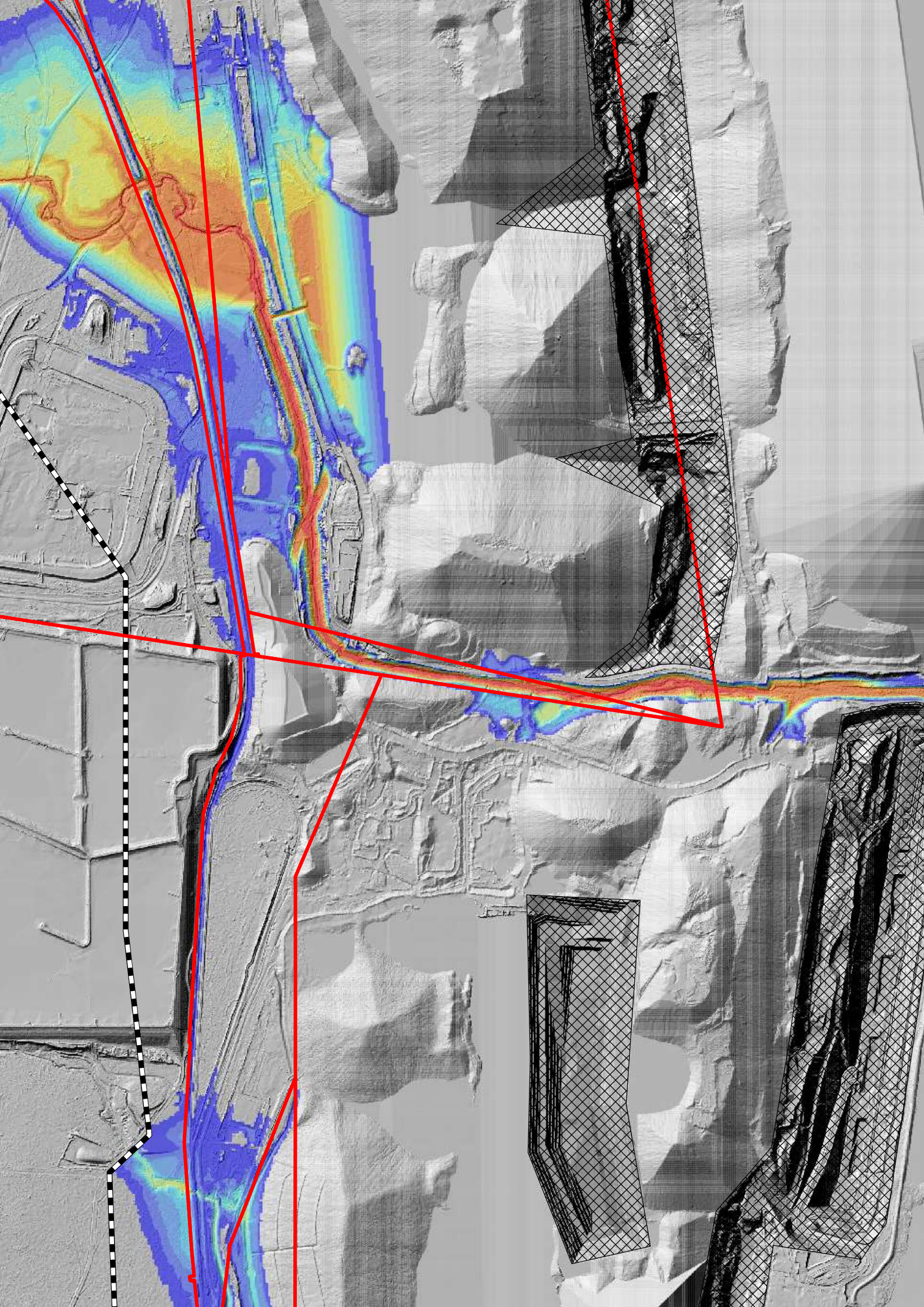
Hydrologic modelling was undertaken to develop the estimated runoff hydrographs that were used to inform the hydraulic modelling. The hydrologic modelling included the catchments of Isaac River, Eureka Creek, Platypus Creek, and Fisher Creek. To incorporate the final closure state landform, the hydrological model catchment configuration, reach lengths and storm definitions were updated.

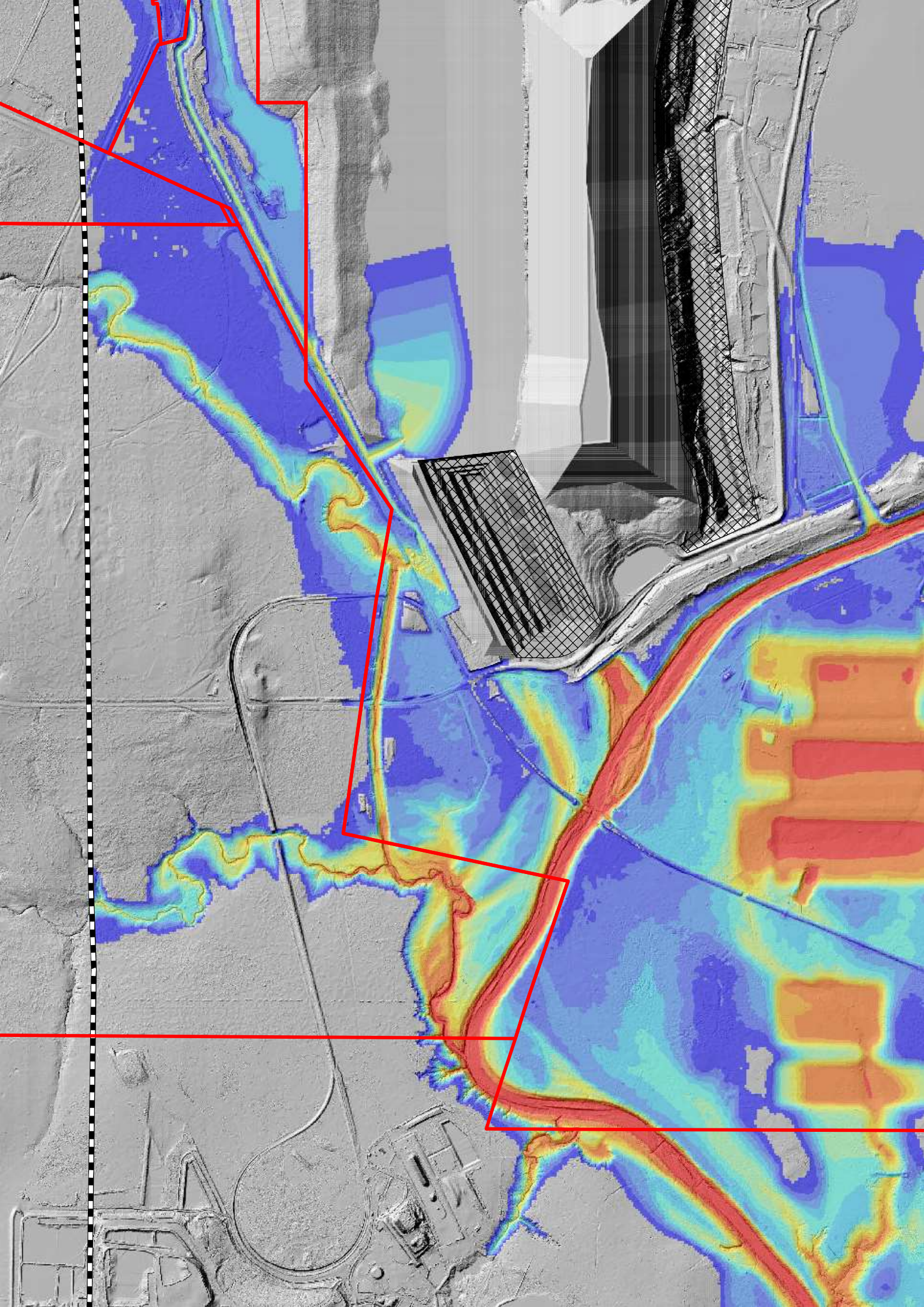
Effects of climate change through the increase in rainfall intensity were considered in the hydrological analysis. The upper climate change scenario was modelled with a 20% rainfall intensity increase (SLR, 2024).

For the final closure state landform, the pits will be partially backfilled with spoil to reduce the extent of the final voids. Spoil placement will be conducted so that the final residual voids of the NUMAs are not impacted by inundation from floodwaters up to and including the 0.1% AEP under the upper climate change scenario. The results of the hydraulic model showed the proposed GRBM residual voids are not subject to inundation from floodwaters up to and including the 0.1% AEP under the upper climate change scenario.

Figure 5.1 to Figure 5.3 show modelled peak flow depths for Isaac River, Eureka Creek, Platypus Creek and Fisher Creek for the 0.1% AEP under the upper climate change scenario.







6 Void water balance

A void water balance assessment was completed to determine the behaviour of the GRBM residual voids in their closure state. The assessment also sought to understand the inherent hydrological closure risks and to inform separate assessments relating to geotechnical and geochemical stability of the voids over time (findings from these separate assessments are presented in Section 7 and Section 8, respectively). Findings from the void water balance assessment, where relevant to void closure at GRBM, are presented below.

6.1 Water Balance Model

A water balance model (WBM) was developed using the software program GoldSim to estimate the changes in the volume of water in the final closure state landform residual voids over time in response to water inflows and outflows. The WBM adds the possible inflows and calculates the possible outflows for every step of the duration over the modelled period. The WBM for the GRBM residual voids incorporated direct rainfall, surface water runoff, groundwater interactions, and evaporation.

A model period of 234 years – from the year 2016 to 2259, with a daily time-step was selected. No operational processes (i.e., pumping or transfers to/from the assessed structures) were considered active for the period modelled.

6.1.1 Catchment areas

The conceptual final closure state landform (LF#2.3) for the GBRM residual voids was used to generate contour lines and calculate the drainage network of the area. The catchment subdivision of each void was estimated by analysing a slope map, generated using the software, QGIS. The slope map recognises zones with 'flat' zones and zones with downward slopes. This information was then used to delimitate the void catchment areas into three land use areas: natural, void, and rehabilitated. The 'natural' area was assigned as the area that will remain undisturbed, when comparing the proposed residual voids' landform and the current topography of the area. The 'void' area was assigned as the area of the residual void itself at the spill level. Finally, the 'rehabilitated' area represents the remaining catchment area of each residual void. The delimitation of each of the areas is presented in Figure 6.1 and Table 6.1.

Table 6.1: Catchment areas for each land use applied to the WBM for the GRBM residual voids

Residual void	Land use (ha)			Total (ha)
	Rehabilitated	Natural	Void	
Goonyella	743	85	1,484	**2,312**
Broadmeadow	119	0	96	**215**
Isaac	178	0	51	**229**
R32 South	17	0	39	**56**
R32 East	76	0	67	**143**
Thiess	672	0	161	**833**

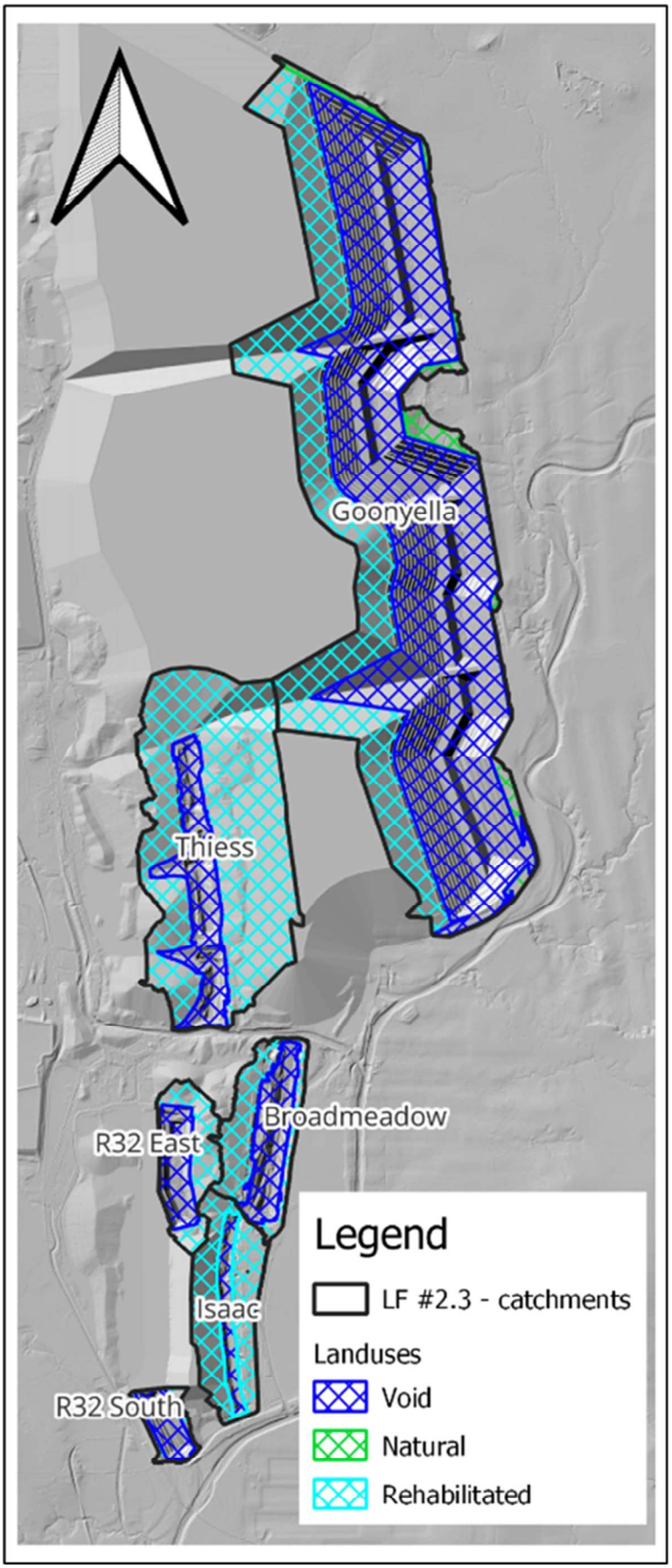


Figure 6.1 Catchment delineation into land use areas applied to the WBM of the GRBM residual voids

The final closure state landform was analysed to determine the spill elevation of each of the voids and is presented in Table 6.2.

Table 6.2: Spill elevation for the GRBM residual voids

Residual void	Spill elevation (m Australian Height Datum (AHD)
Goonyella	254
Broadmeadow	230
Isaac	230
R32 South	240
R32 East	256
Thiess	256

Stage-storage relationships, derived from the closure state landform to obtain the relationship between lake elevation and volume/surface of the lake, are presented in Figure 6.2. These relationships were used in the WBM to estimate the lake surface area and elevation from the lake volume for each time-step.

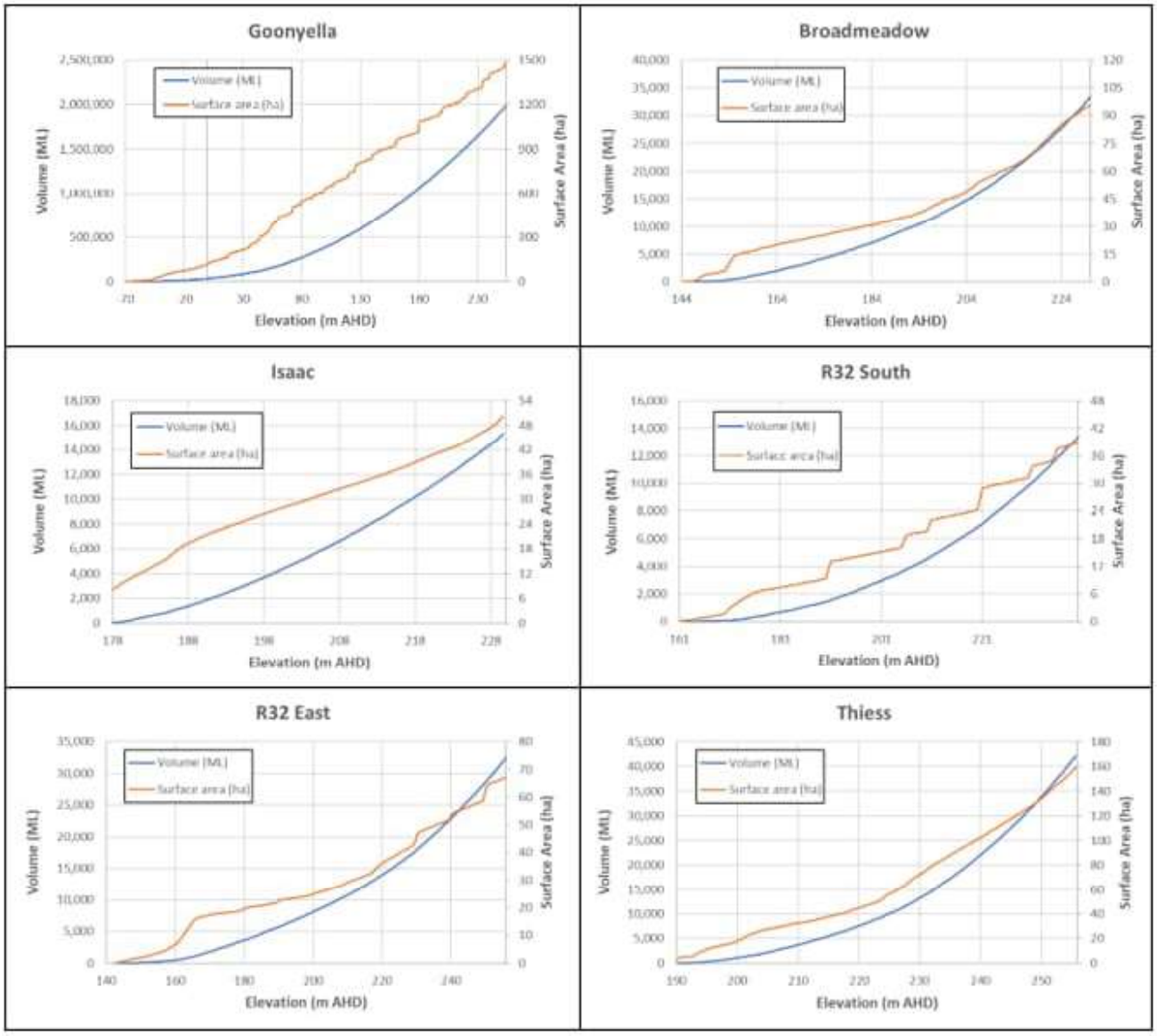


Figure 6.2: Goonyella, Broadmeadow, Isaac, R32 South, R32 East and Thiess residual void stage-storage relationship

6.1.2 *Rainfall, evaporation, and surface runoff*

The amount of surface water runoff resulting from rainfall was calculated using the Australian Water Balance Model (AWBM), a catchment WBM that relates daily rainfall and evapotranspiration to runoff and calculates losses from rainfall for flood hydrograph modelling.

The projected evaporation and rainfall data (BMA, 2023b) was applied to the AWBM to determine the surface runoff that should be input into the WBM. The AWBM contained five storages:

- Three surface storages to simulate partial areas of runoff
- One base flow storage
- One surface runoff routing storage.

The three surface storages have different capacities (small, medium, and large) for each catchment area (BMA, 2023c), as shown in Figure 6.3 and presented in Table 6.3. Each capacity is added together with fractional areas for weights, which are summarised in Table 6.4.

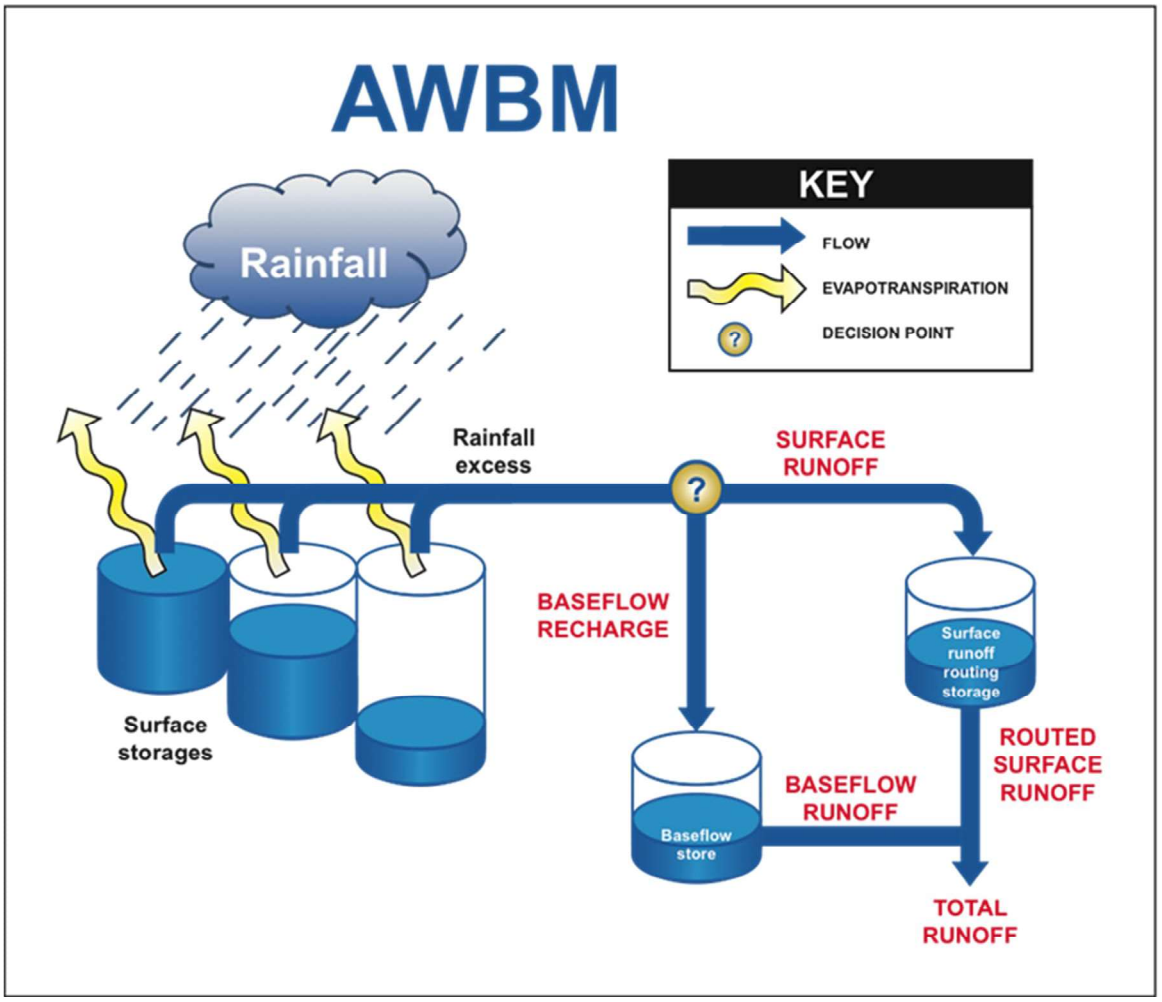


Figure 6.3: Structure of AWBM rainfall-runoff model including small, medium, and large surface storages

Table 6.3: Surface storage capacities (BMA, 2023c) applied to the WBM for GRBM

Land use	Storage capacity (mm)		
	Small	Medium	Large
Natural	10	55	115
Void	5	20	40
Rehabilitated	10	50	110

Table 6.4: Surface storage proportions (BMA, 2023c) applied to the WBM for GRBM

Land use	Small	Medium	Large
Natural	0.134	0.433	0.433
Void	0.134	0.433	0.433
Rehabilitated	0.134	0.433	0.433

Table 6.5 presents the remaining AWBM parameters (baseflow index, channel coefficient and baseflow coefficient). Surface water runoff considers flows as daily averages and does not include the effects of high-intensity and short-duration events.

Table 6.5: Baseflow and channel parameters applied to the WBM for GRBM

Land use	Baseflow index	Channel coefficient (1/day)	Baseflow coefficient
Natural	0.45	0.2	0.6
Void	0	0.1	0.6
Rehabilitated	0.25	0.075	0.7

6.1.3 Climate change considerations

To reasonably represent future climate conditions in the WBM assessment, climate change data was used from the projections of three different models (ACCESS1-0Q, GFDL-CM3Q, MPI-ESM-LRQ) evaluated under two Representative Concentration Pathway (RCP) (4.5 and 8.5), giving six climate realisations. The RCPs consist of projections of greenhouse gas concentrations (pathways) adopted by the Intergovernmental Panel on Climate Change (IPCC).

Simulations were completed for three climate realisations. These realisations were selected to represent a reasonable range of probable climate scenarios based on the climate models used, being the wetter (R3), middle (R4) and the drier (R5) climate ranges. This provides a reasonable potential range of climate impacts for each residual void. A summary of the combined pathways and models considered in each realisation (R#) of the WBM is presented in Table 6.6.

Table 6.6: Climate change scenarios considered in each realisation of the GRBM WBM

Realisation	Climate model	RCP
R3	MPI-ESM-LRQ	4.5
R4	ACCESS1-0Q	8.5
R5	GFDL-CM3Q	8.5

To cover the WBM simulation period of 234 years, the climate projections were applied from 2020 until 31 December 2259. As the climate projections data only cover the interval from 2020 to 2099, the period between January 2080 to December 2099 was repeated to act as the projected rainfall conditions beyond 2099 (as directed by BMA). This methodology is summarised in Table 6.7. To cover the WBM simulation period for Theiss residual void commencing in 2016, historical climate data was applied.

The annual mean rainfall data from the different pivotal years were calculated. Pivotal years represent the future average climate of a decade centred around them (CSIRO, 2022). The pivotal years relevant to the WBM simulation period are 2030 (projections from 2021 to 2040), 2050 (projections from 2041 to 2060), 2070 (projections from 2061 to 2080) and 2090 (projections from 2081 to 2099).

Table 6.7: Annual mean rainfall calculated for each climate realisation applied to the GRBM residual voids WBM for each simulated period

Simulation period	Mean annual precipitation (mm)		
	R3	R4	R5
2021 to 2040	597	527	508
2041 to 2060	517	572	546
2061 to 2080	530	496	529
2081 to 2099	569	593	525

The future increase in evaporation was estimated considering:

- Projected period between 2020 and 2099
- Reference period (1986 to 2005).

The result is a value of annual increase of evaporation for each realisation. This factor was applied to the monthly values of evaporation. These factors are presented in Table 6.8.

Table 6.8: Percentage increase of evaporation considered for each realisation from 2024 to 2099

	R3	R4	R5
Mean evaporation 1986-2005 (mm/yr)	1,610	1,597	1,615
2021-2040			
Mean evaporation (mm/yr)	1,617	1,717	1,739
Increase in average evaporation (%)	0.3%	6.3%	9.4%
2041-2060			
Mean evaporation (mm/yr)	1,787	1,921	1,853
Increase in average evaporation (%)	10.9%	15.4%	18.9%
2061-2080			
Mean evaporation (mm/yr)	1,843	2,105	1,979
Increase in average evaporation (%)	14.1%	22.6%	30.4%
2081-2099			
Mean evaporation (mm/yr)	1,760	2,256	2,108
Increase in average evaporation (%)	10.3%	26.7%	40.4%

6.1.4 *Groundwater inflows*

Groundwater inflows to each of the residual voids post-closure were simulated using the numerical groundwater model and time-series data of groundwater flow rates were produced (AECOM, 2024). The modelled groundwater inflow rates applied as inputs to the WBM are presented in Figure 6.4 to Figure 6.9.

Groundwater inflows to the residual voids, as discussed in Section 4, are predicted to equate to between 4 and 17% of the total volumetric inflow by the end of the post-closure simulation (AECOM, 2024a).

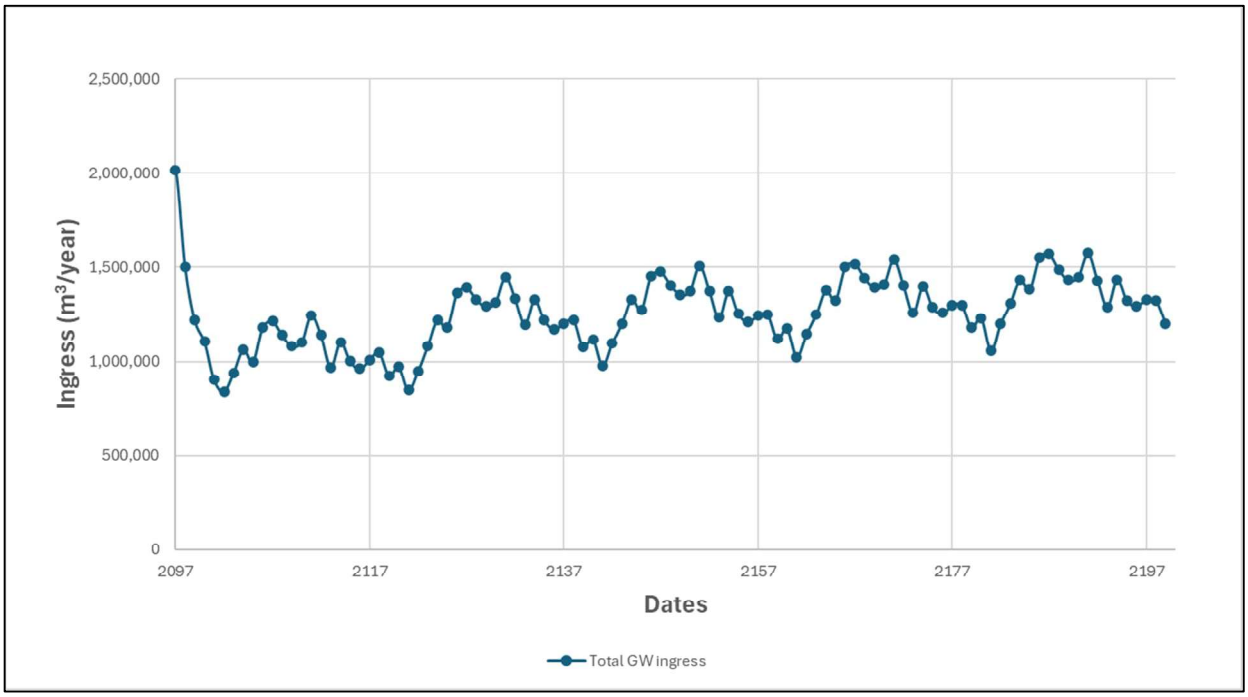


Figure 6.4: Groundwater inflows to Goonyella residual void – generated from (AECOM, 2024)

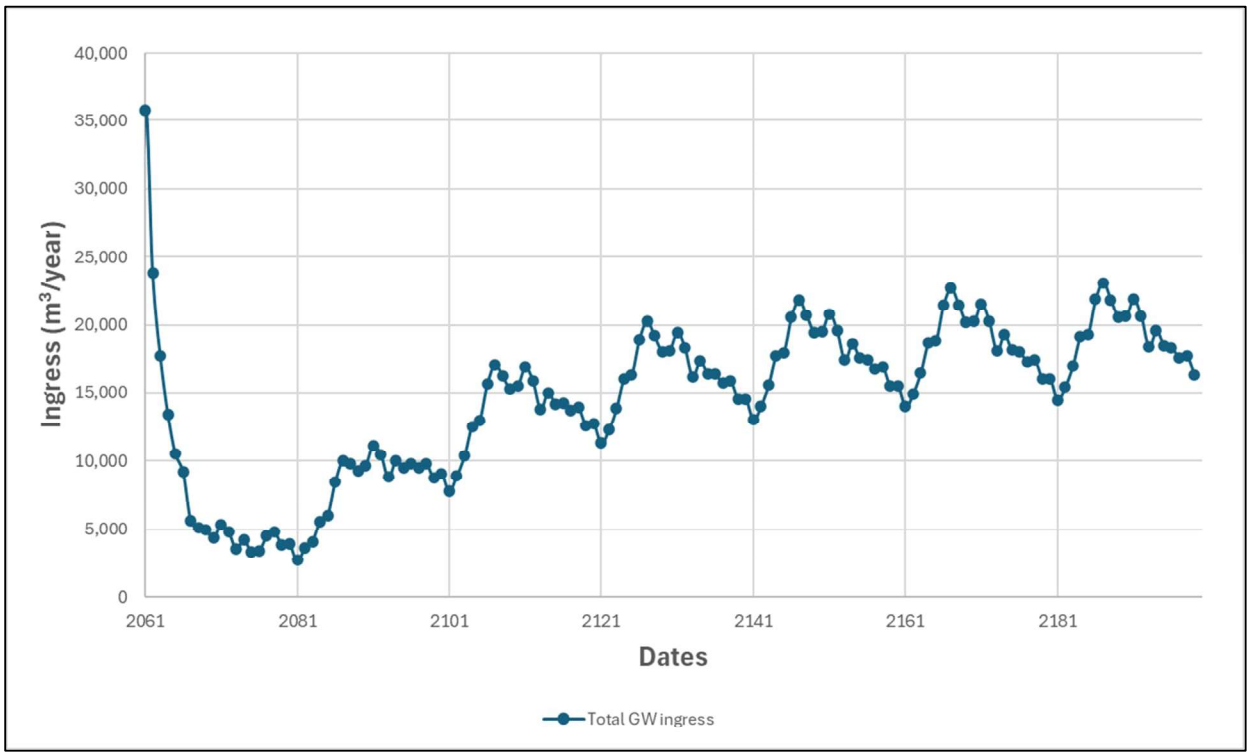


Figure 6.5: Groundwater inflows to Broadmeadow residual void – generated from (AECOM, 2024)

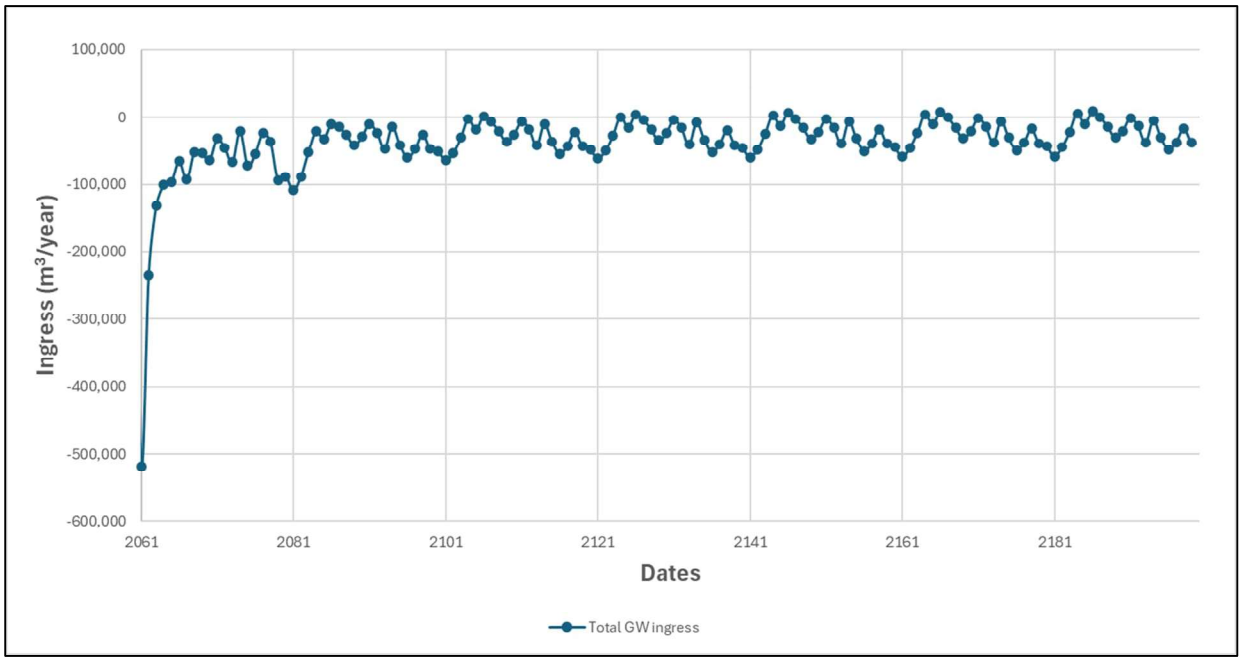


Figure 6.6: Groundwater inflows to Isaac residual void – generated from (AECOM, 2024)

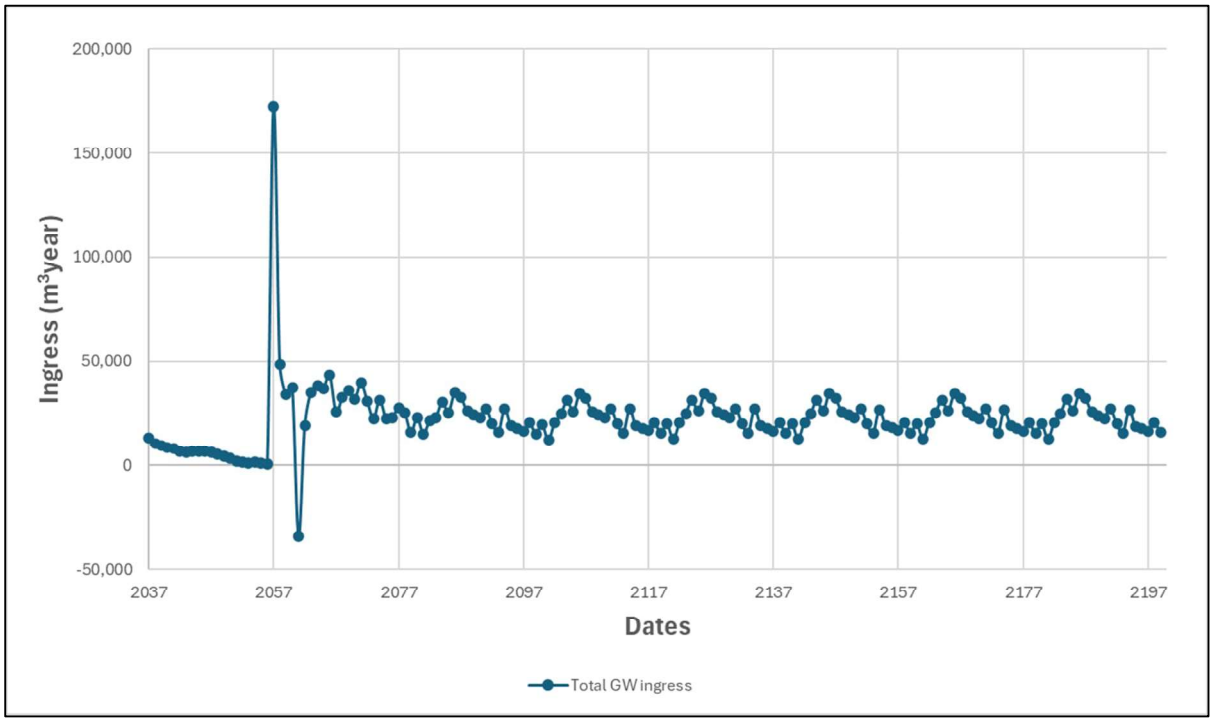


Figure 6.7: Groundwater inflows to R32 South residual voids – generated from (AECOM, 2024)

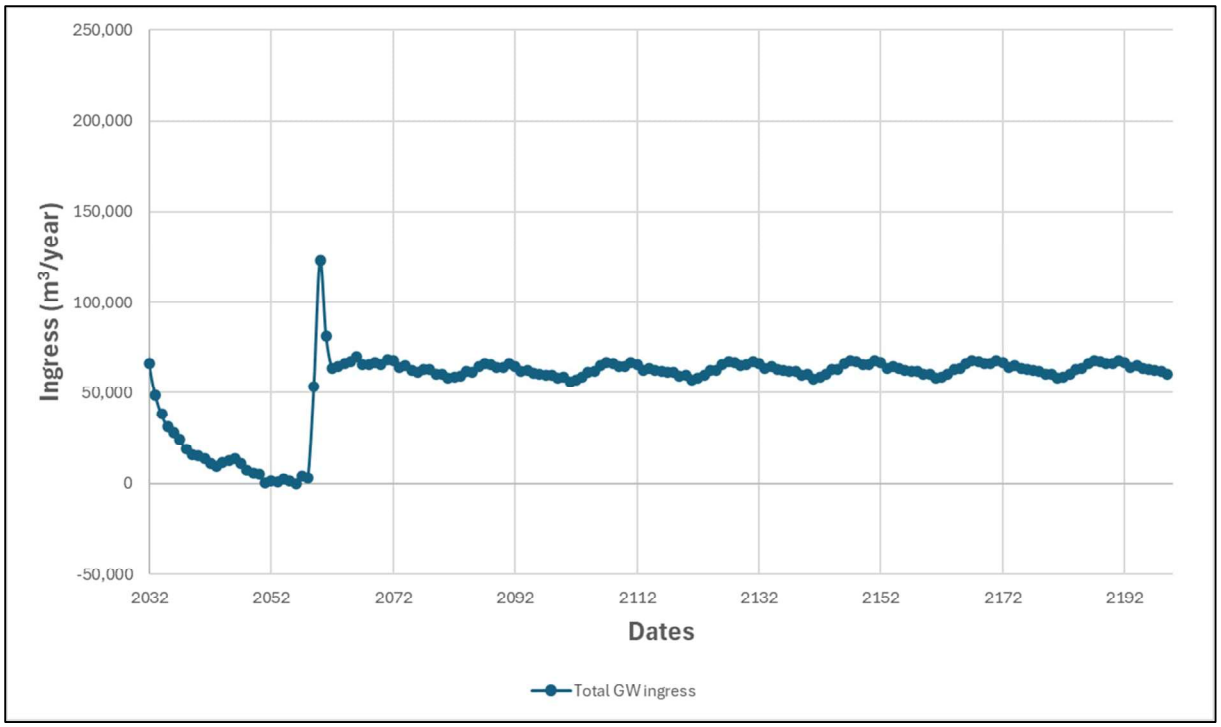


Figure 6.8: Groundwater inflows to R32 East residual void – generated from (AECOM, 2024)

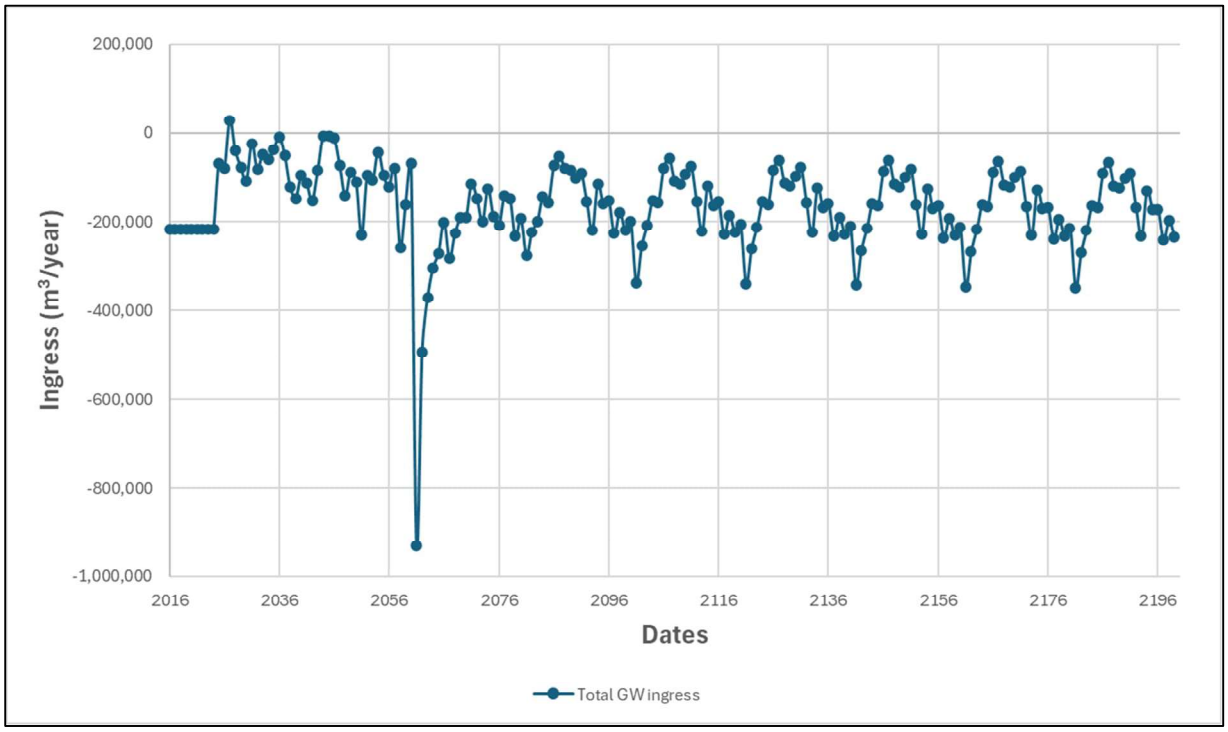


Figure 6.9: Groundwater inflows to Thiess residual voids – generated from (AECOM, 2024). The spike in outflows depicted around 2060 relate to the representation of the flooding of the underground mine in the groundwater model

6.2 Residual void water balance outcomes

6.2.1 Goonyella residual void

By 2259, the end of the simulation period, the differences between mean inflows and mean outflows reduce, and the mean water balance has reached equilibrium. The average annual inflows and outflows were calculated for the final 20 years of the simulation period from 2240 to 2259 and are presented in Figure 6.10. The mean (total) annual inflow to Goonyella residual void is 3,929 megalitres per year (ML/year) for the simulation period of 2240 to 2259, equal to the mean annual outflow for the same period. This indicates that the mean water balance for Goonyella residual void can be considered to have reached equilibrium.

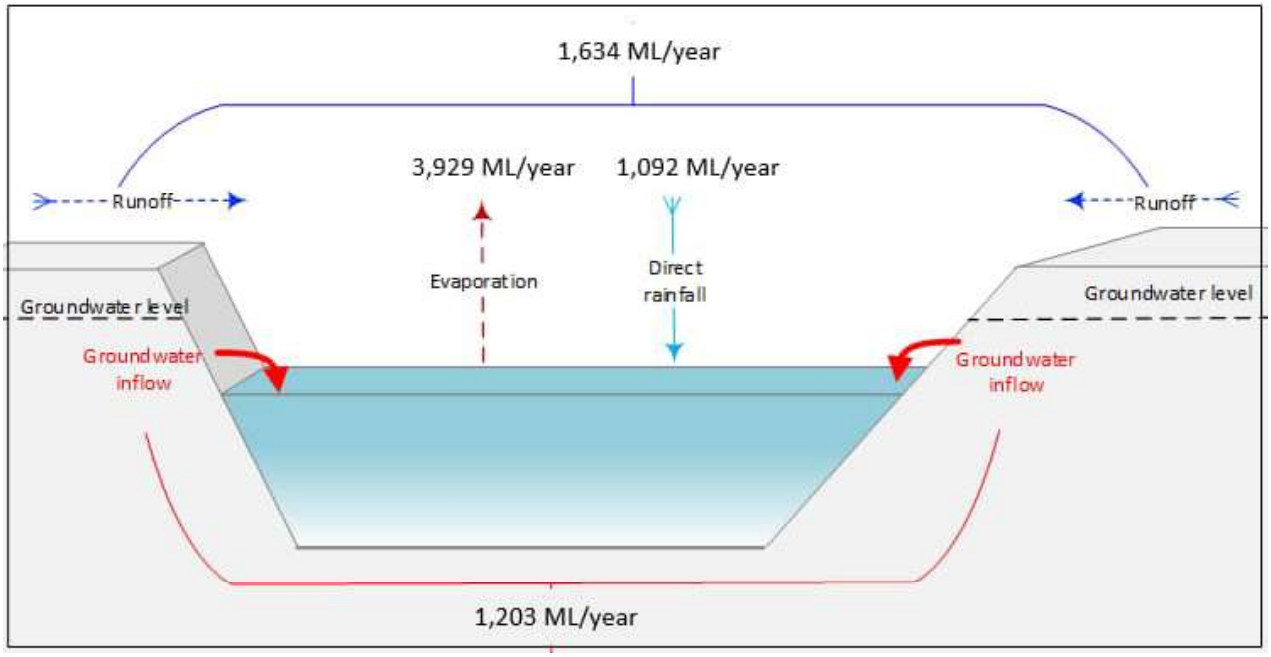


Figure 6.10: Schematic representation of average inflows/outflows simulated for the period from 2240 to 2259 – Goonyella residual void (mean volumes from all realisations – 3, 4 and 5)

The results from the WBM for Goonyella residual void indicate that, after an initial increase in void water level and volumes observed from the beginning of the simulation until the year 2200, the mean void water levels start to stabilise. The mean void water elevation reaches 21 m AHD (Figure 6.11) and the mean void water volume reaches over 69,178 megalitres (Figure 6.12) across all realisations.

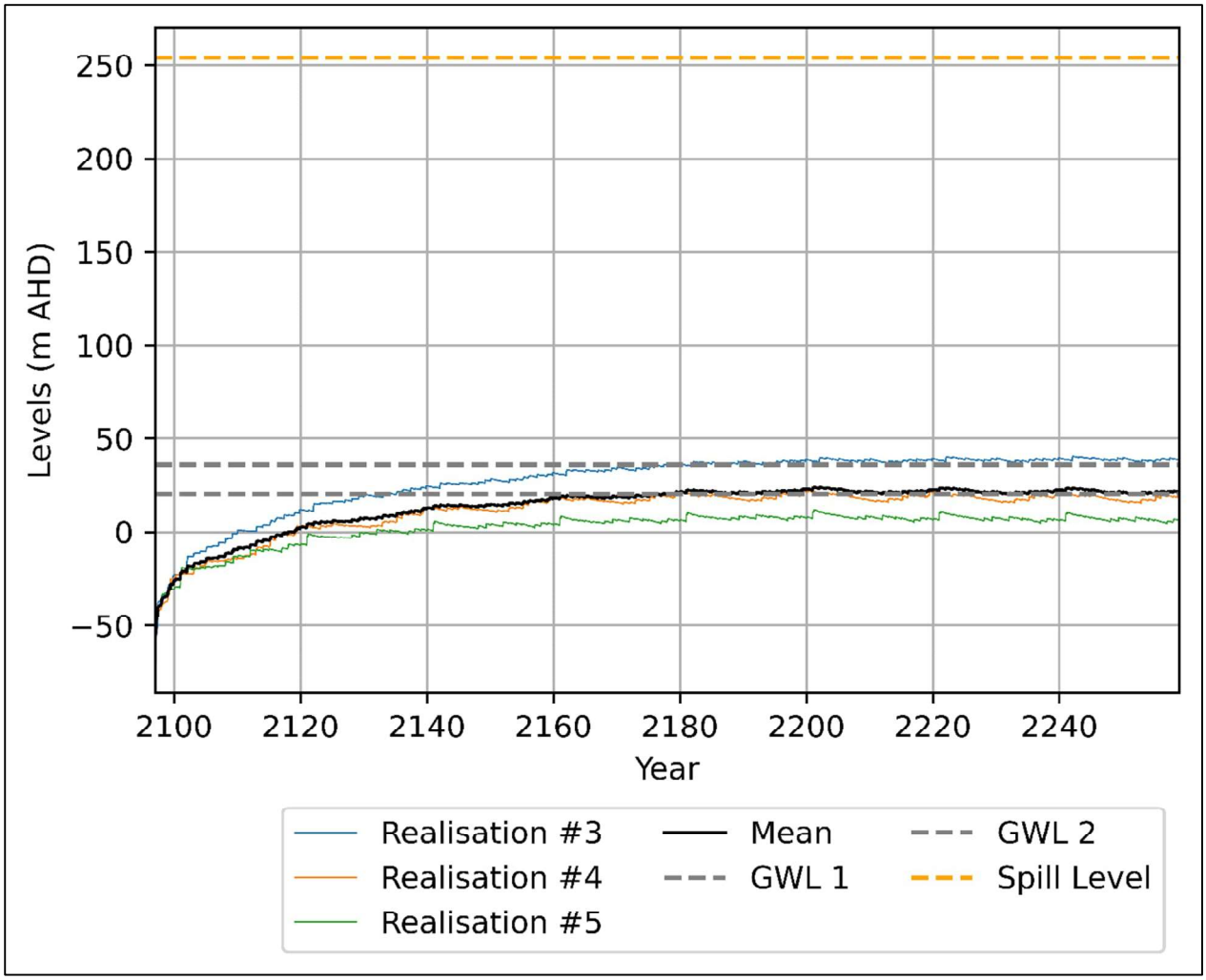


Figure 6.11: Modelled water levels in Goonyella residual void compared to spill level and the recovered post-closure groundwater levels (GWL1 = downgradient, GWL2 = upgradient) (realisations 3, 4, and 5)

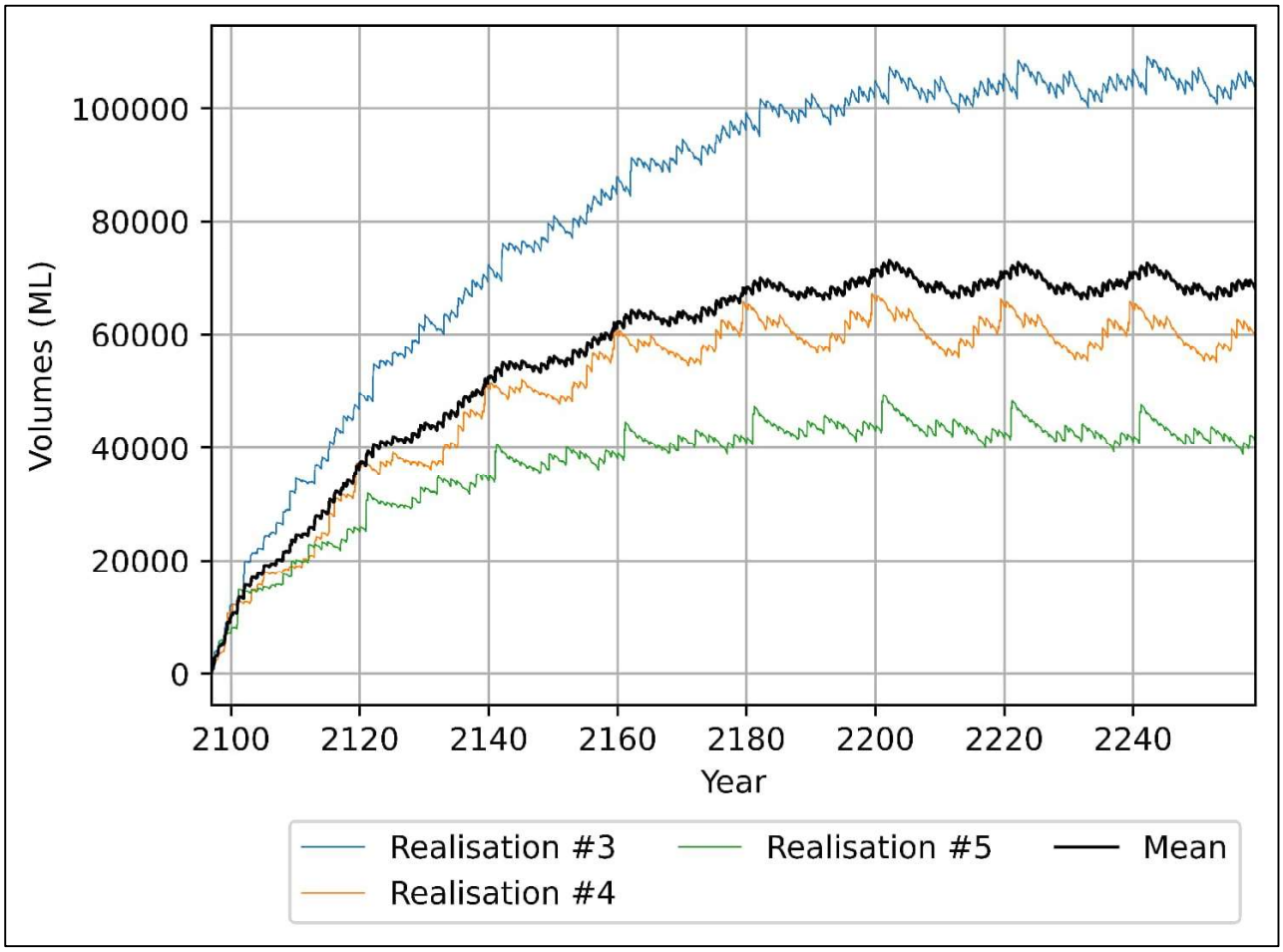


Figure 6.12: Modelled water volumes for Goonyella residual void (realisations 3, 4, and 5)

6.2.2 *Broadmeadow residual void*

By 2199, the end of the simulation period, the differences between mean inflows and mean outflows had reduced, and the mean water balance had reached equilibrium. The average annual inflows and outflows were calculated for the final 20 years of the simulation period from 2180 to 2199 and are presented in Figure 6.13. The mean (total) annual inflow to Broadmeadow residual void is 218 ML/year for the simulation period of 2180 to 2199, equal to the mean annual outflow for the same period. This indicates that the mean water balance for Broadmeadow residual void can be considered to have reached equilibrium.

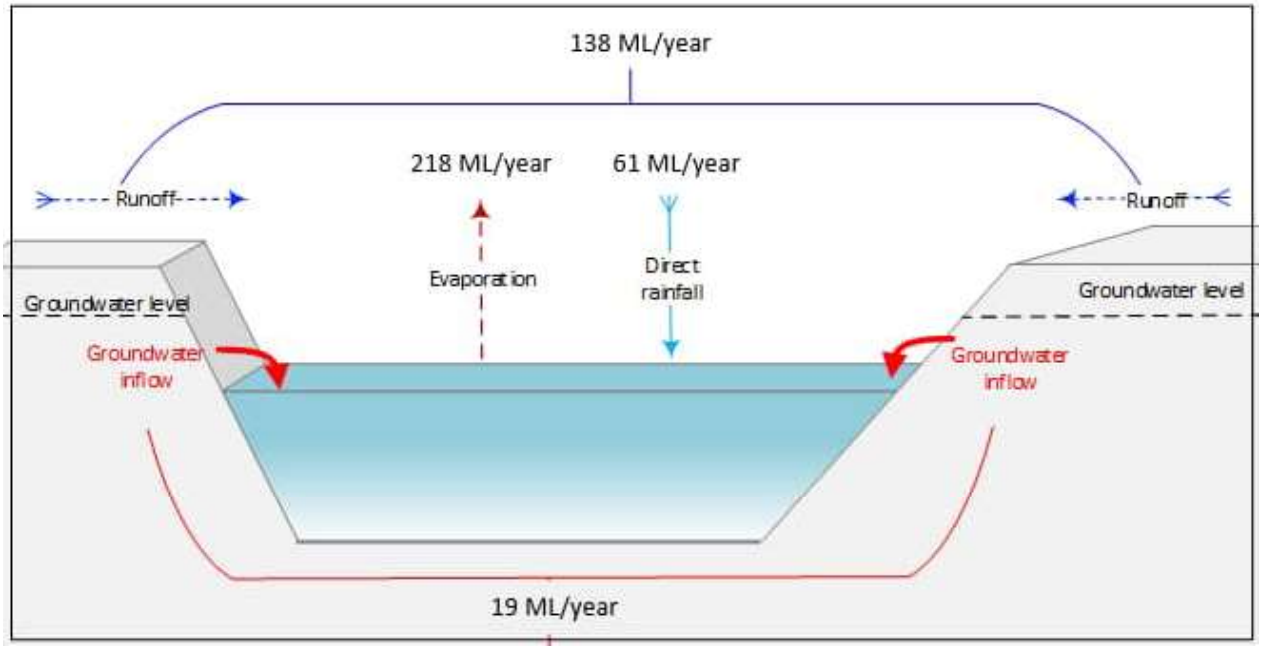


Figure 6.13: Schematic representation of average inflows/outflows simulated for period from 2180 to 2199 – Broadmeadow residual void (mean volumes from all realisations – 3,4, and 5)

The results from the WBM for Broadmeadow residual void indicate that, after an initial increase in void volumes and water level observed from the beginning of the simulation until the year 2100, the mean void water levels start to stabilise. The mean void water elevation reaches 155 m AHD (Figure 6.14) and the mean void water volume of 473 megalitres (Figure 6.15) across all realisations.

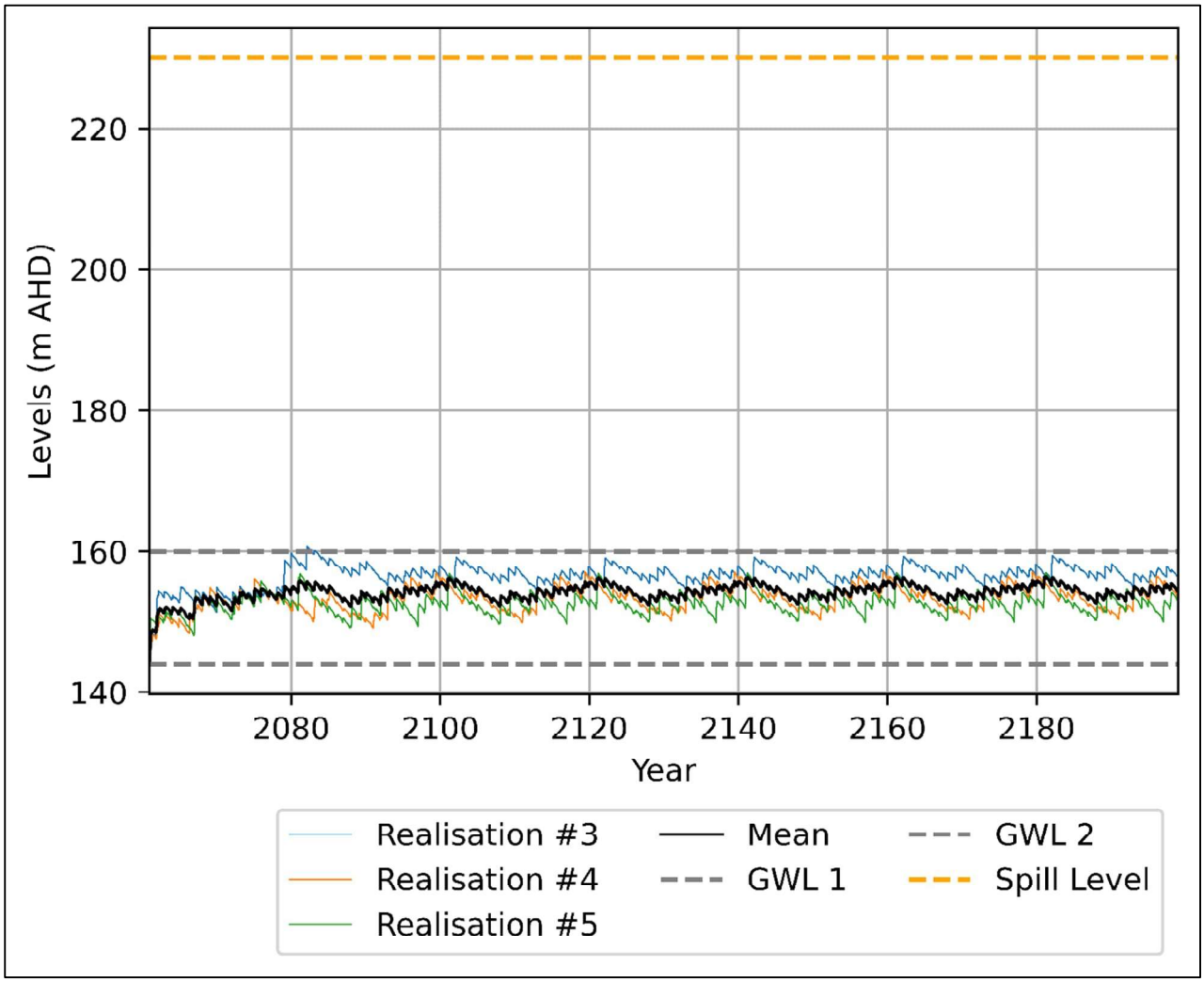


Figure 6.14: Modelled water levels in Broadmeadow residual void compared to spill level and the recovered post-closure groundwater levels (GWL1 = downgradient, GWL2 = upgradient) (realisations 3, 4, and 5)

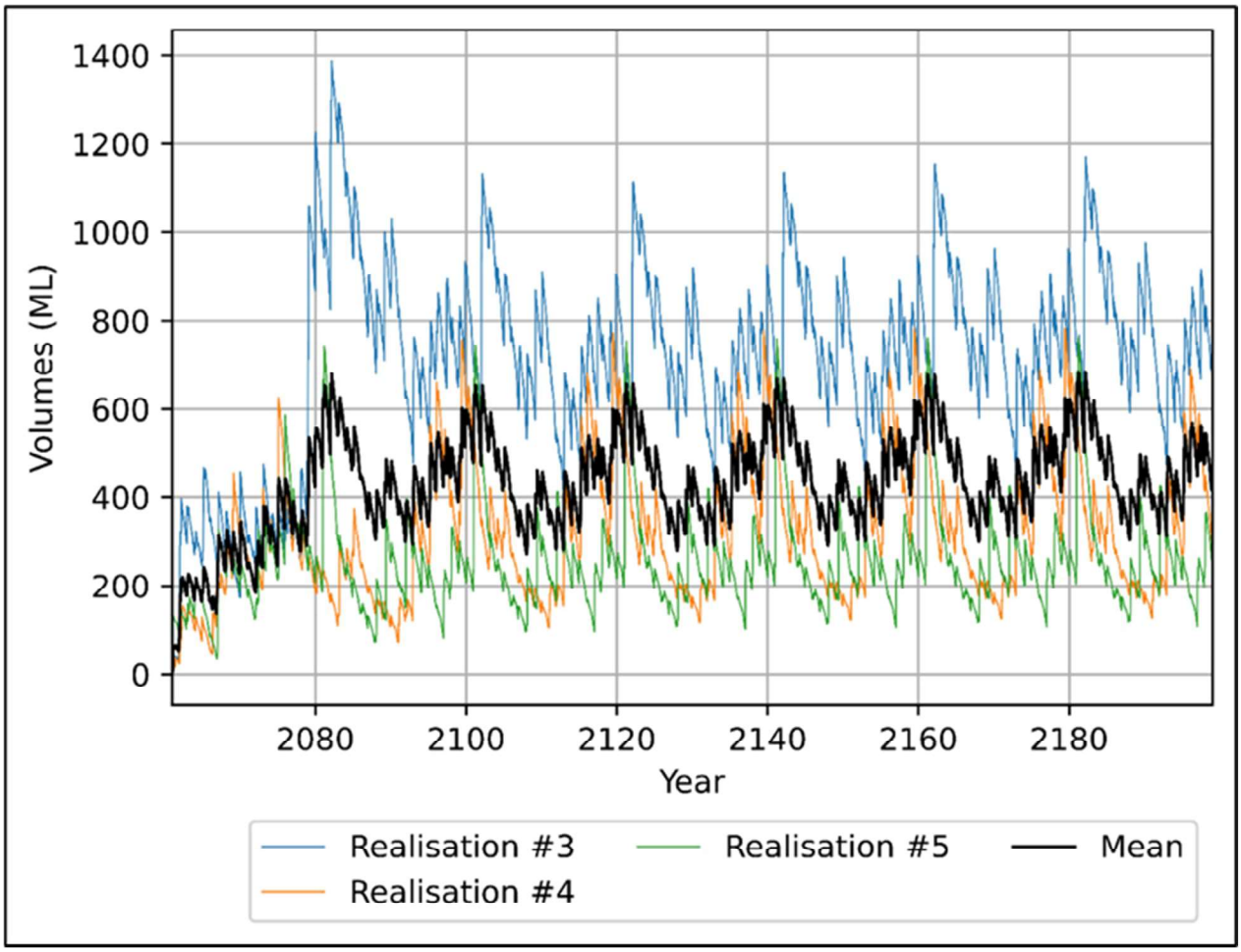


Figure 6.15: Modelled water volumes for Broadmeadow residual void (realisations 3, 4, and 5)

6.2.3 *Isaac residual void*

By 2199, the end of the simulation period, the differences between mean inflows and mean outflows had reduced and the mean water balance had reached equilibrium The average annual inflows and outflows were calculated for the final 20 years of the simulation period from 2180 to 2199 and are presented in Figure 6.16. The mean (total) annual inflow to Isaac residual void is 179 ML/year for the final 20-year period, equal to the mean annual outflow for the same period. The mean annual outflows are the sum of both evaporative losses and modelled groundwater outflows. This indicates that the mean water balance for Isaac residual void can be considered to have reached equilibrium.

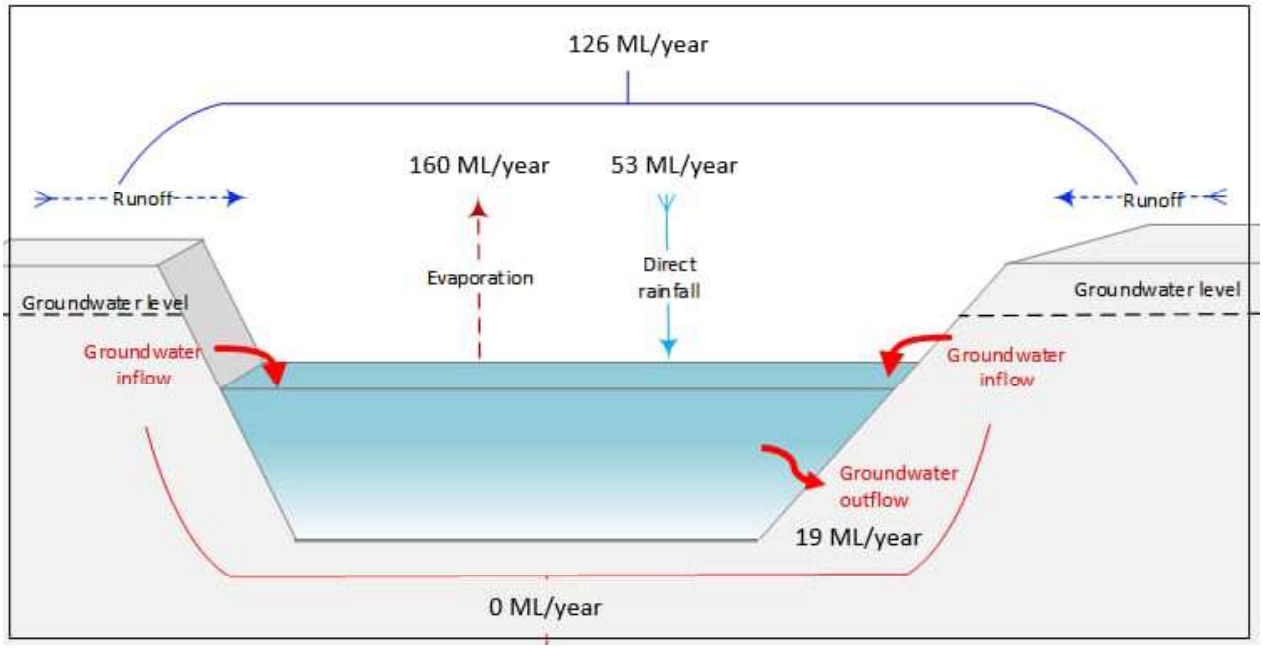


Figure 6.16: Schematic representation of average inflows/outflows simulated for the period from 2180 to 2199 – Isaac residual void (mean volumes from all realisations – 3,4 and 5)

The results from the WBM for Isaac residual void indicate that, after an initial increase in void volumes and water level observed from the beginning of the simulation until the year 2100, the mean void water levels start to stabilise. The mean void water elevation reaches 180 m AHD (Figure 6.17), and the mean void water volume of 162 megalitres (Figure 6.18) across all realisations.

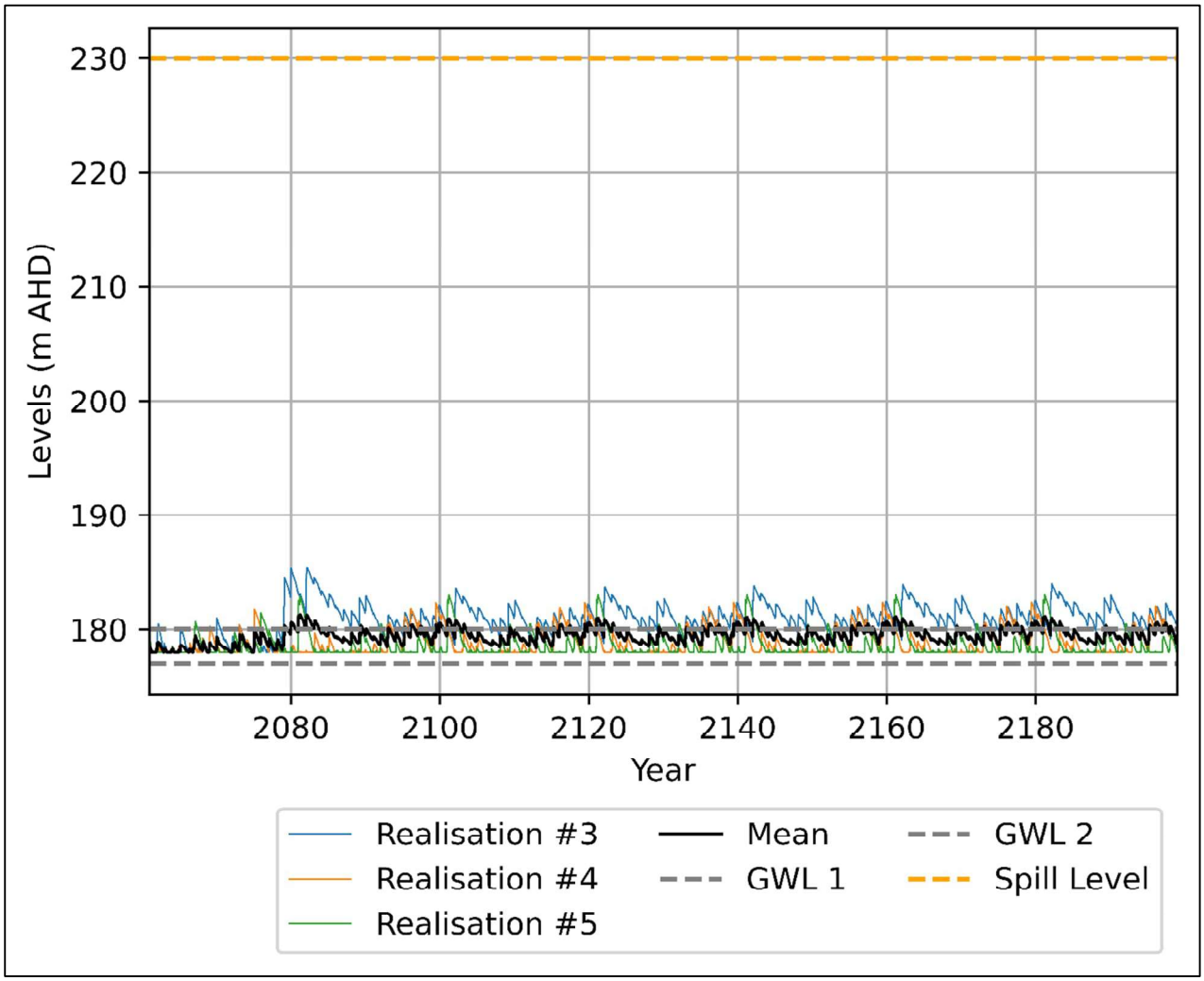


Figure 6.17: Modelled water levels in Isaac residual void compared to spill level and the recovered post-closure groundwater levels (GWL1 = downgradient, GWL2 = upgradient) (GWL) (realisations 3, 4, and 5)

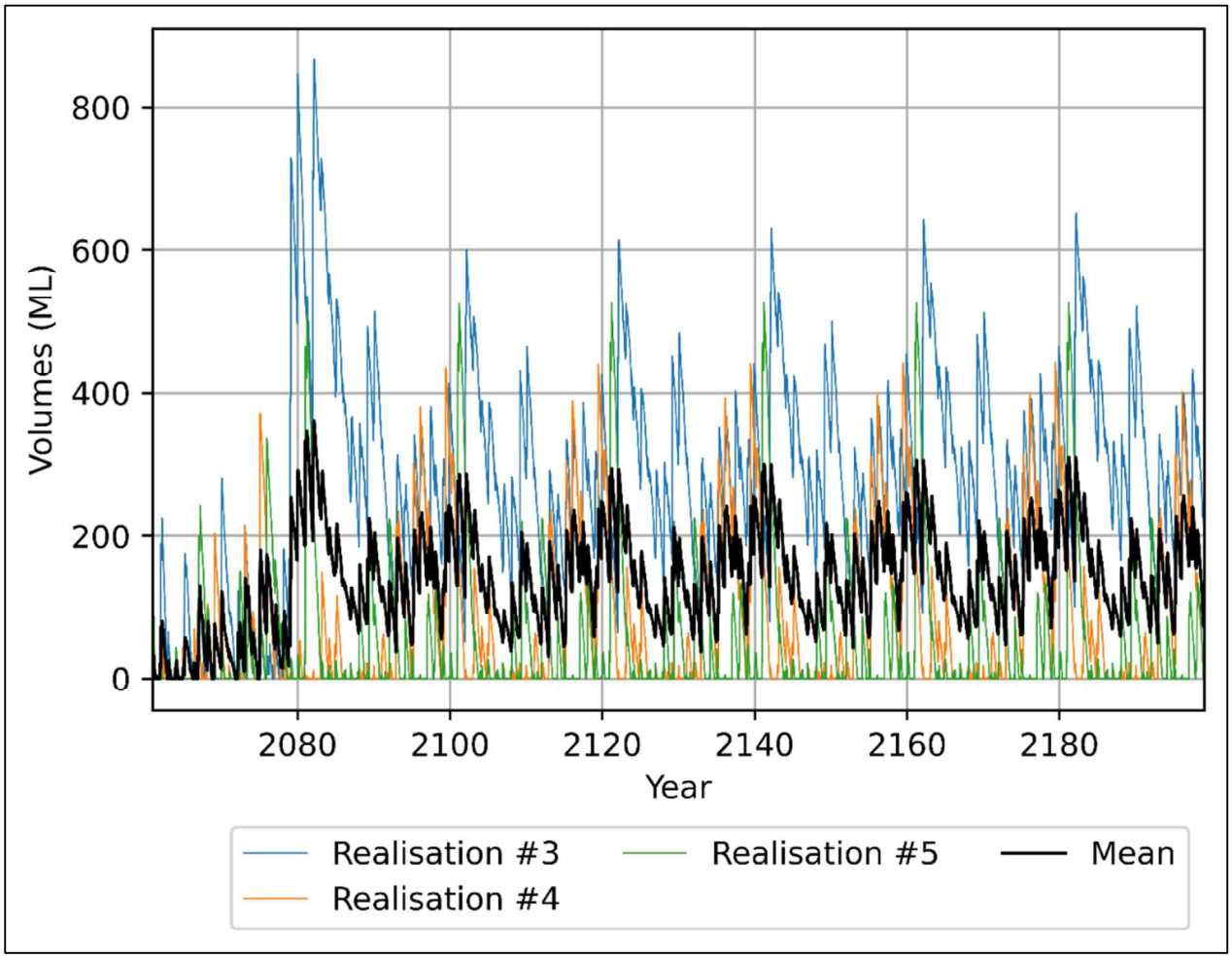


Figure 6.18: Modelled water volumes for Isaac residual void (realisations 3,4, and 5)

6.2.4 R32 South residual void

By 2199, the end of the simulation period, the differences between mean inflows and mean outflows reduce and the mean water balance has reached equilibrium. The average annual inflows and outflows were calculated for the final 20 years of the simulation period from 2180 to 2199 and are presented in Figure 6.19. The mean (total) annual inflow to R32 South residual void is 88 ML/year for the simulation period of 2180 to 2199, equal to the mean annual outflow for the same period. This indicates that the mean water balance for R32 South residual void can be considered to have reached equilibrium.

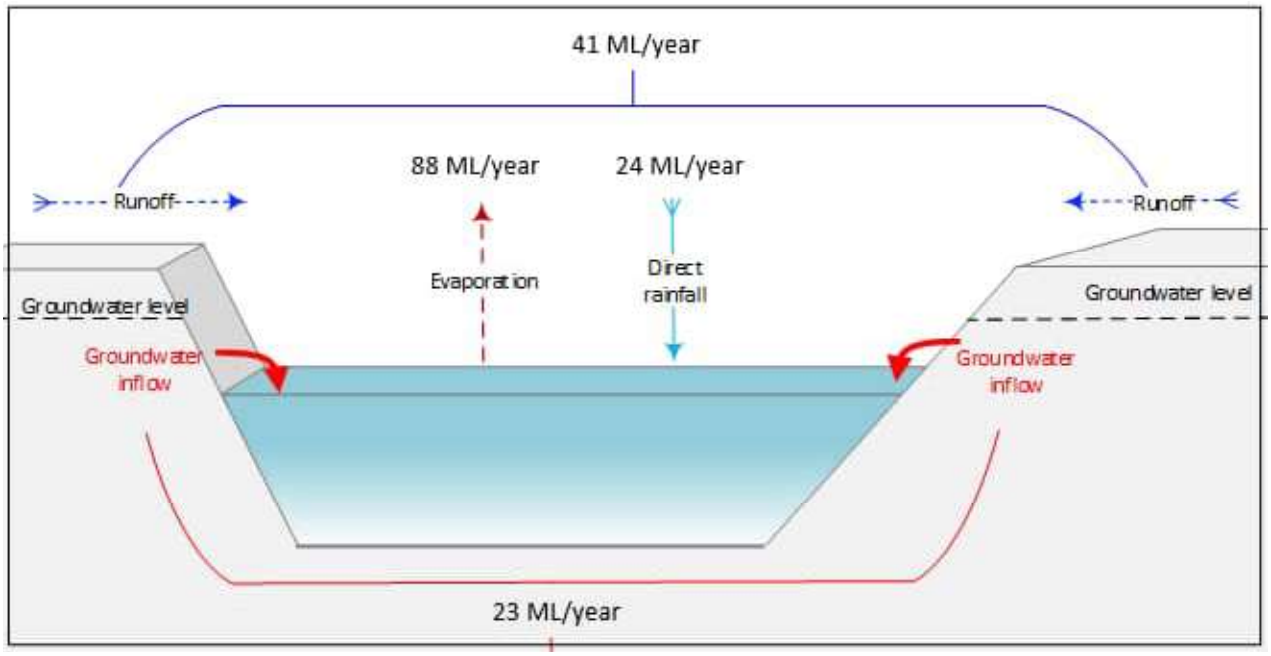


Figure 6.19: Schematic representation of average inflows/outflows simulated for the period from 2180 to 2199 – R32 South residual void (mean volumes from all realisations – 3,4 and 5)

The results from the WBM for R32 South residual void indicate that, after an initial increase in void volumes and water level observed from the beginning of the simulation until the year 2080, the mean void water levels start to stabilise. The mean void water elevation reaches 173 m AHD (Figure 6.20), and the mean void water volume of 190 megalitres (Figure 6.21) across all realisations.

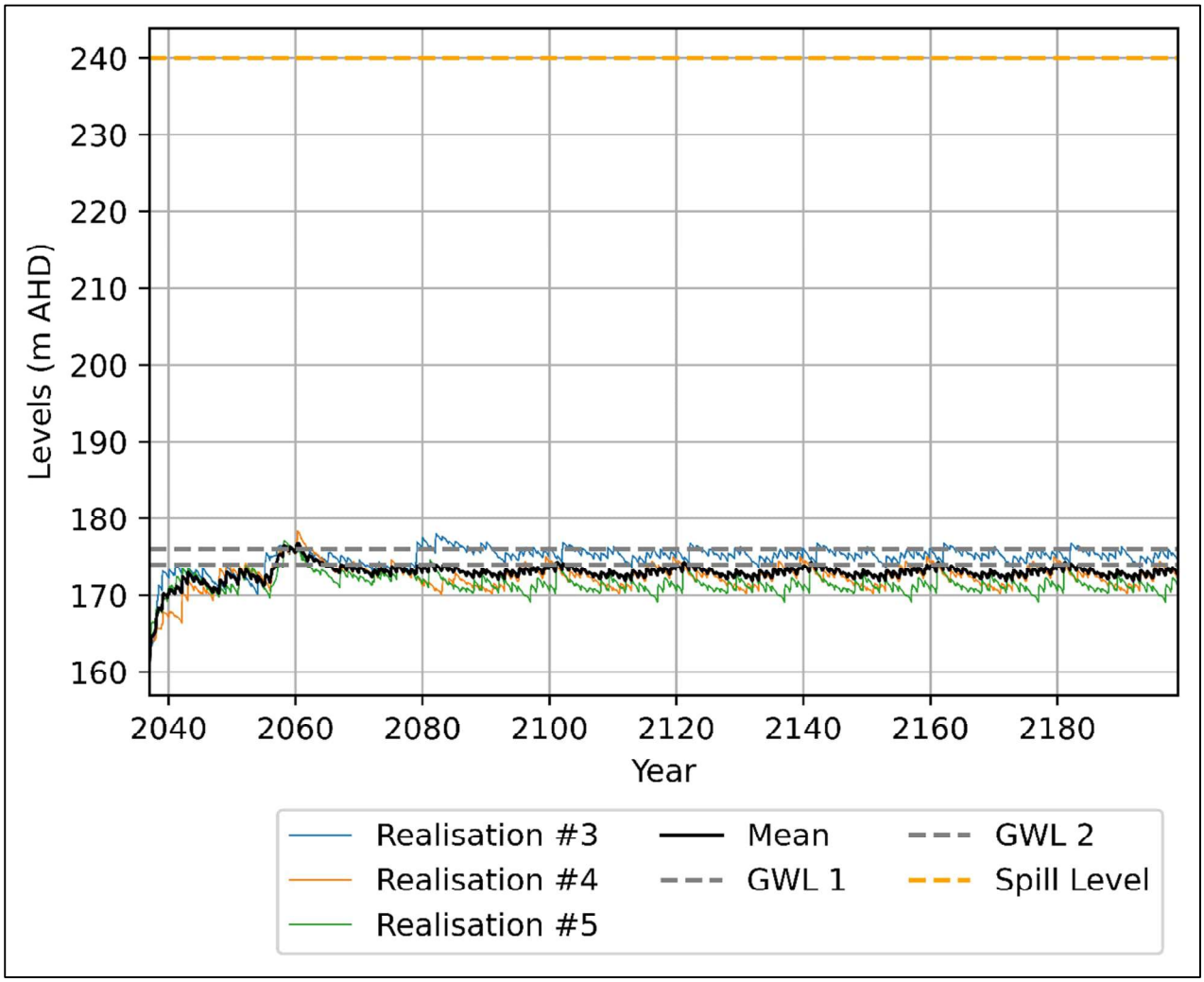


Figure 6.20: Modelled water levels in R32 South residual void compared to spill level and the recovered post-closure groundwater levels (GWL1 = downgradient, GWL2 = upgradient) (realisations 3, 4, and 5)

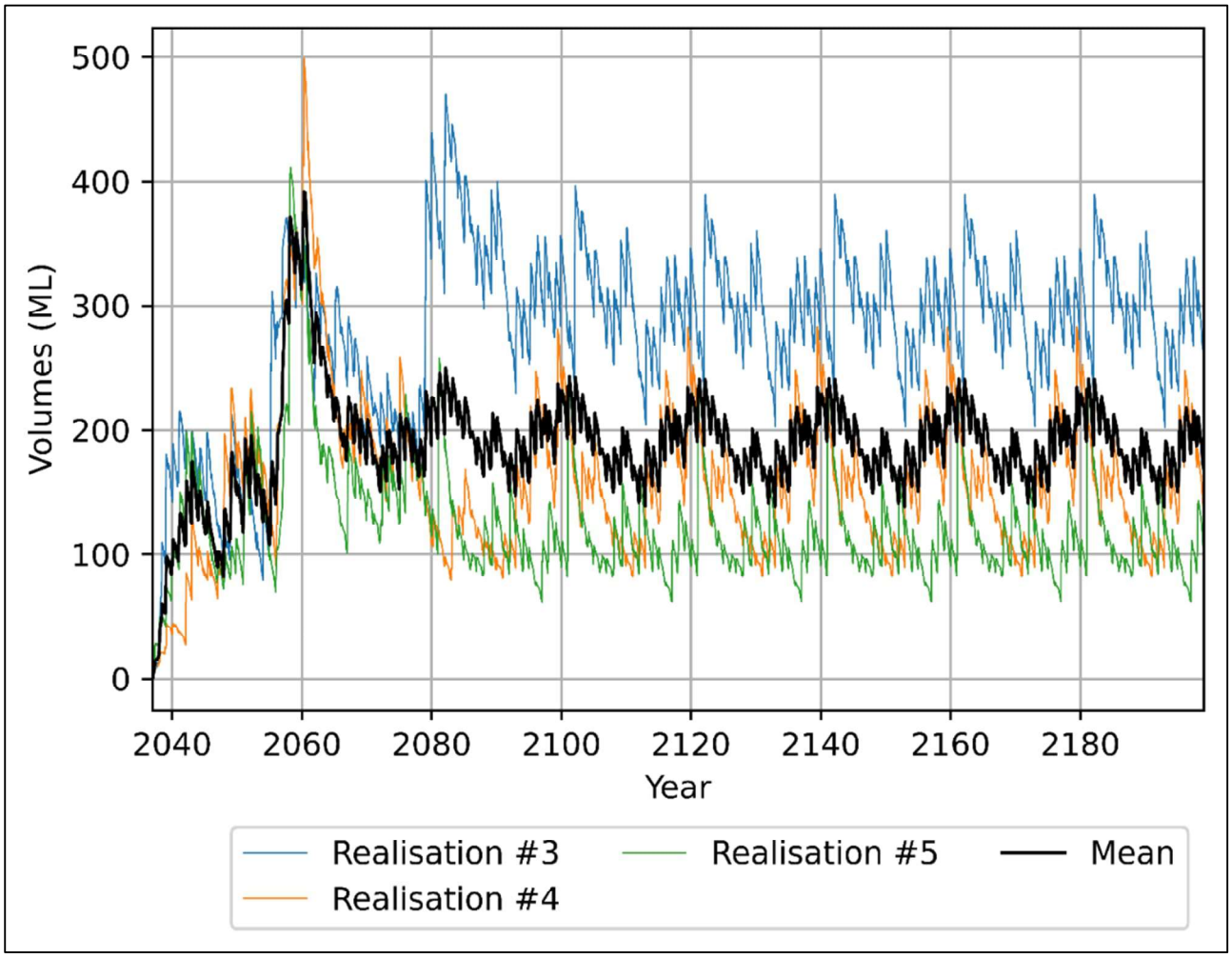


Figure 6.21: Modelled water volumes for R32 South residual void (realisations 3, 4, and 5)

6.2.5 R32 East residual void

By 2199, the end of the simulation period, the differences between mean inflows and mean outflows had reduced, and the mean water balance had reached equilibrium. The average annual inflows and outflows were calculated for the final 20 years of the simulation period from 2180 to 2199 and are presented in Figure 6.22. The mean (total) annual inflow to R32 East residual void is 213 ML/year for the simulation period of 2180 to 2199, equal to the mean annual outflow for the same period. This indicates that the mean water balance for R32 South residual void can be considered to have reached equilibrium.

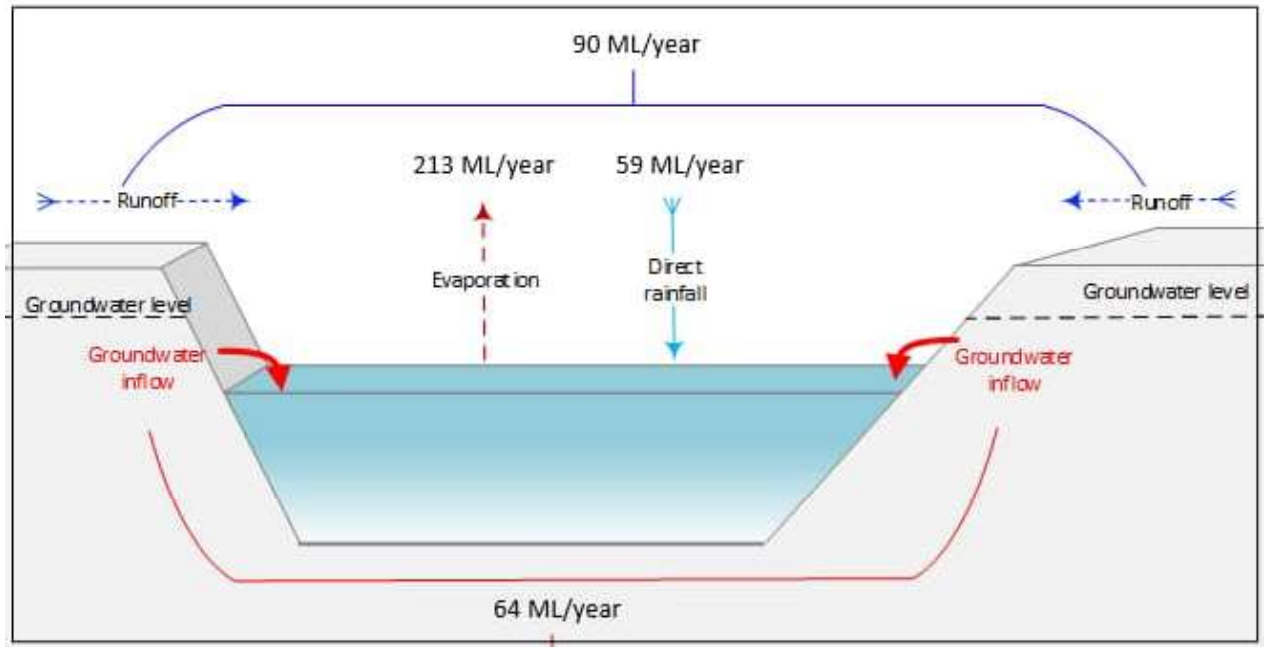


Figure 6.22: Schematic representation of average inflows/outflows simulated for the period from 2180 to 2199 – R32 East residual void (mean volumes from all realisations – 3,4 and 5)

The results from the WBM for R32 South residual void indicate that, after an initial increase in void volumes and water level observed from the beginning of the simulation until the year 2080, the mean void water levels start to stabilise. The mean void water elevation reaches 162 m AHD (Figure 6.23) and the mean void water volume of 709 megalitres (Figure 6.24) across all realisations.

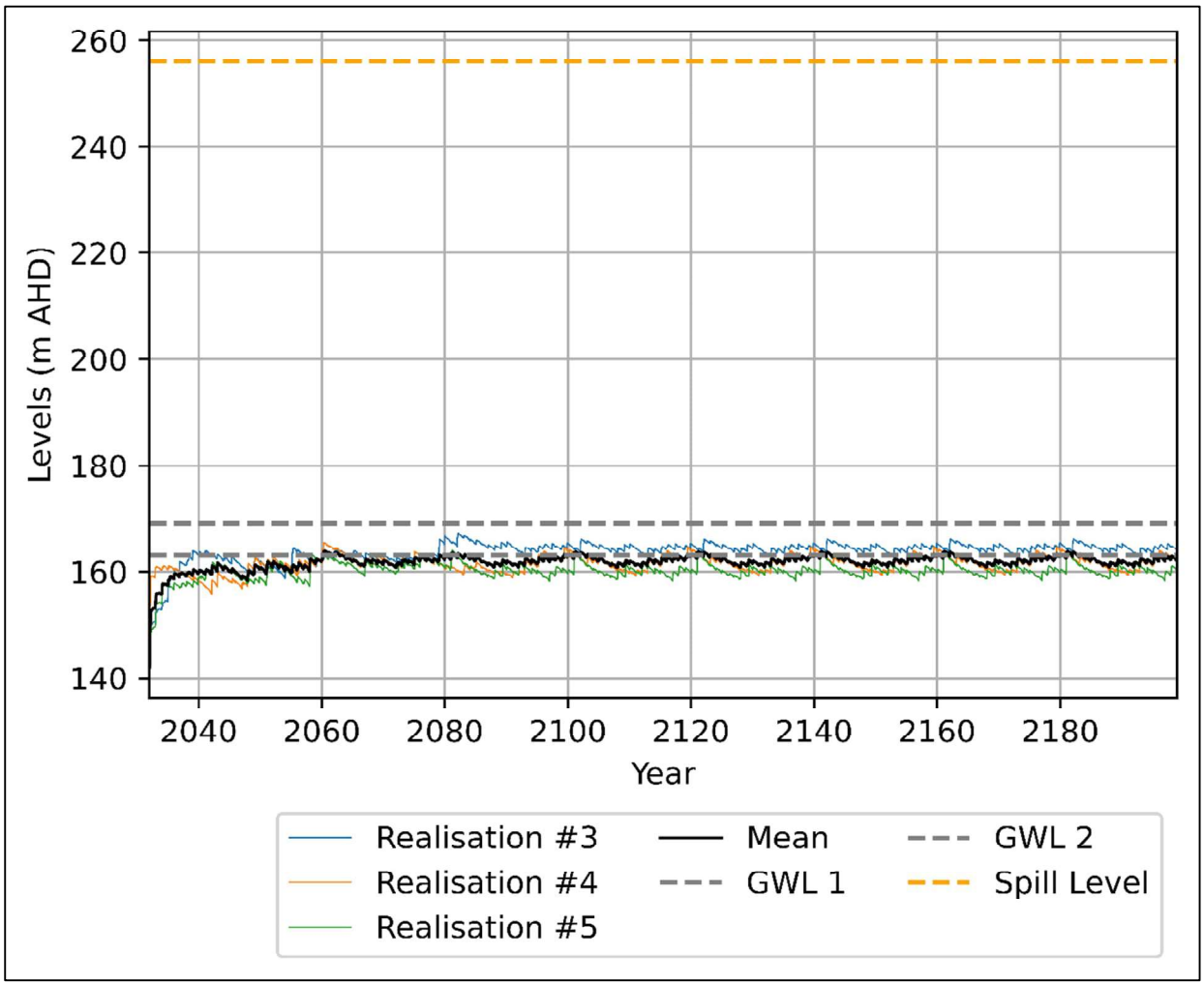


Figure 6.23: Modelled water levels in R32 East residual void compared to spill level and the recovered post-closure groundwater levels (GWL1 = downgradient, GWL2 = upgradient) (realisations 3, 4, and 5)

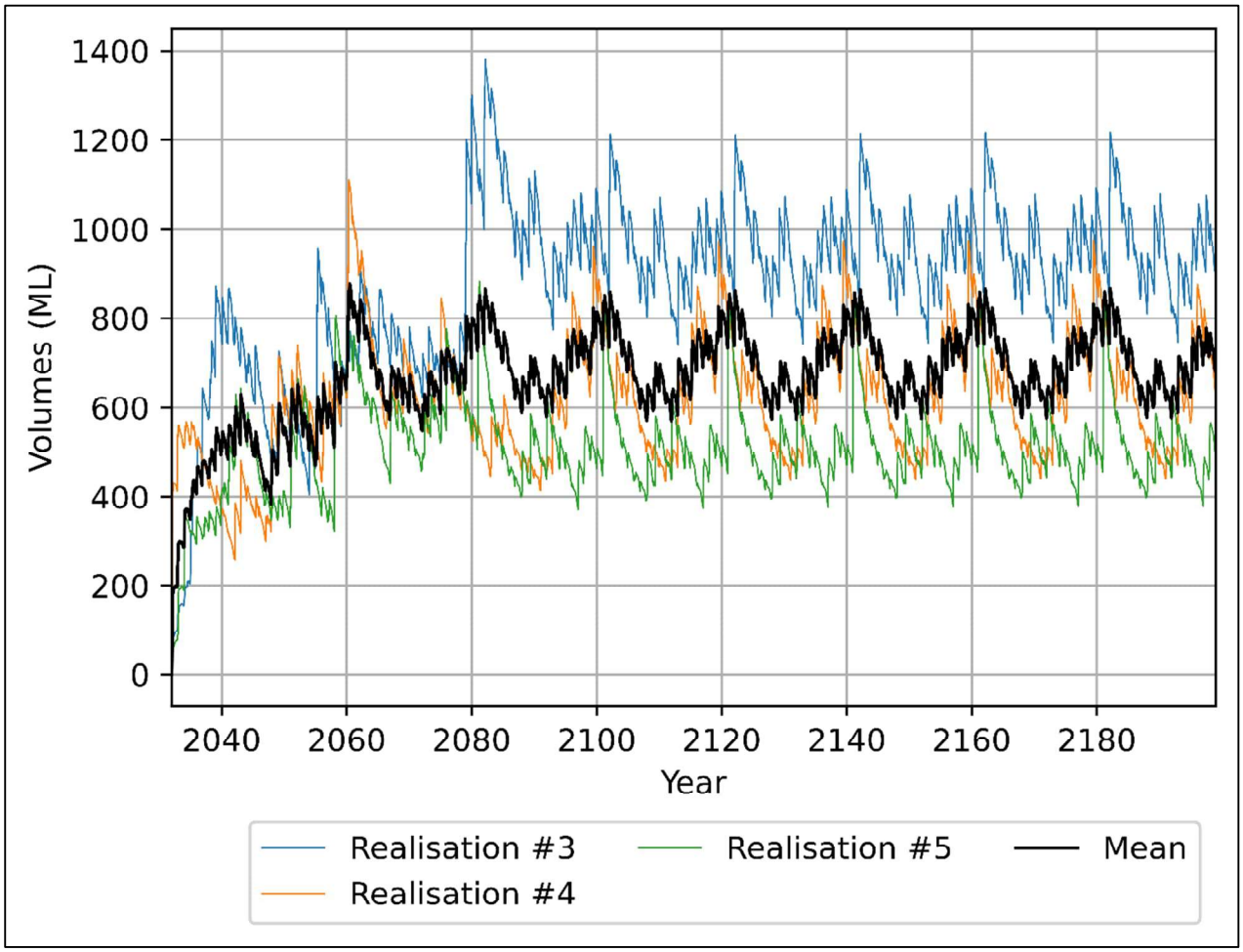


Figure 6.24: Modelled water volumes for R32 East residual void (realisations 3, 4, and 5)

6.2.6 *Thiess residual void*

By 2199, the end of the simulation period, the differences between mean inflows and mean outflows reduce and the mean water balance has reached equilibrium. The average annual inflows and outflows were calculated for the final 20 years of the simulation period from 2180 to 2199 and are presented in Figure 6.25. The mean (total) annual inflow to R32 East residual void is 572 ML/year for the simulation period of 2180 to 2199, and the mean annual outflow is 573 ML/yr for the same period. The mean annual outflows are the sum of both evaporative losses and modelled groundwater outflows. This indicates that the mean water balance for Thiess residual void can be considered to have reached equilibrium

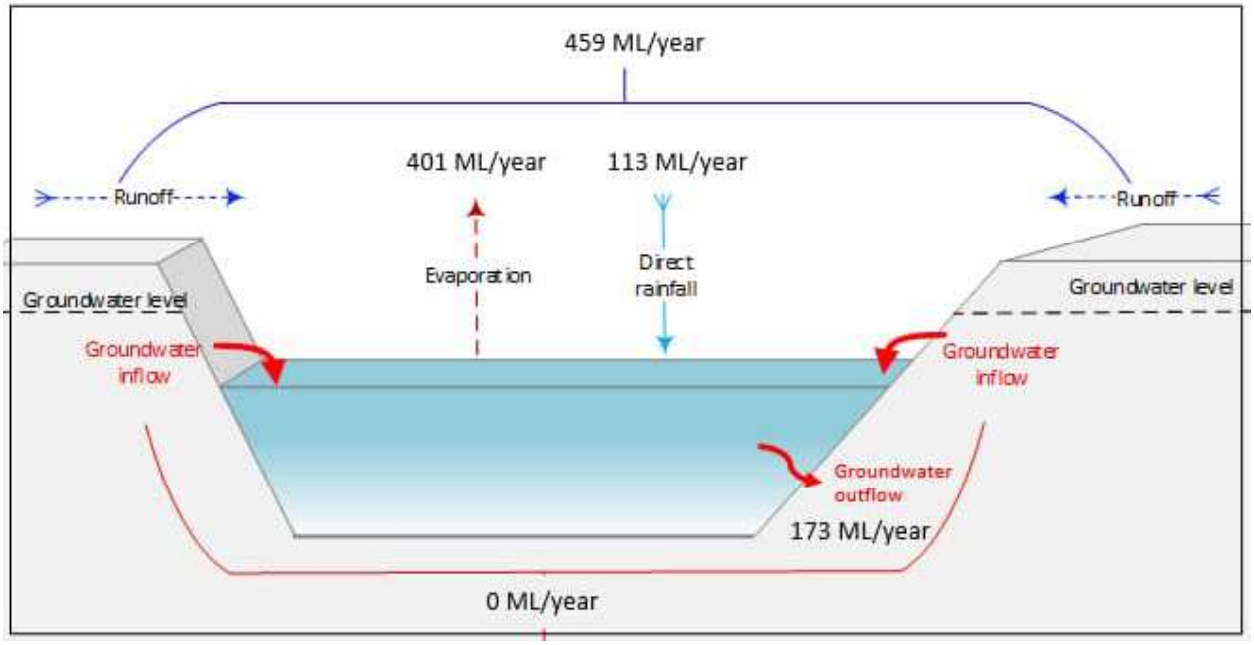


Figure 6.25: Schematic representation of average inflows/outflows simulated for the period from 2180 to 2199 – Thiess residual void (mean volumes from all realisations – 3,4 and 5)

The results from the WBM for Thiess residual void indicate that, after an initial increase in void volumes and water level observed from the beginning of the simulation until the year 2100, the mean void water levels start to stabilise. The mean void water elevation reaches 202 m AHD (Figure 6.25) and the mean void water volume of 1,869 megalitres (Figure 6.26) across all realisations.

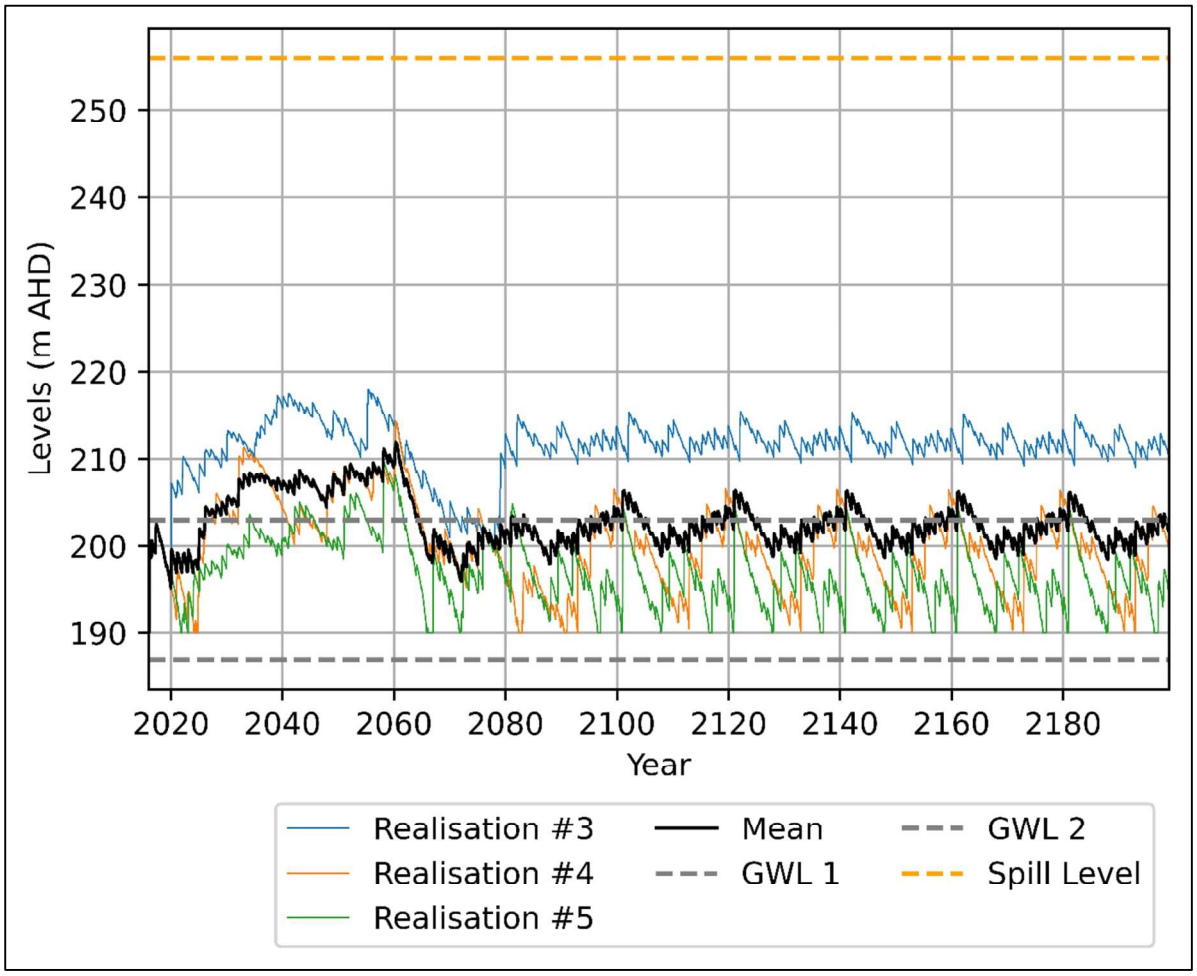


Figure 6.26: Modelled water levels in Thiess residual void compared to spill level and the recovered post-closure groundwater levels (GWL1 = downgradient, GWL2 = upgradient) (realisations 3, 4, and 5)

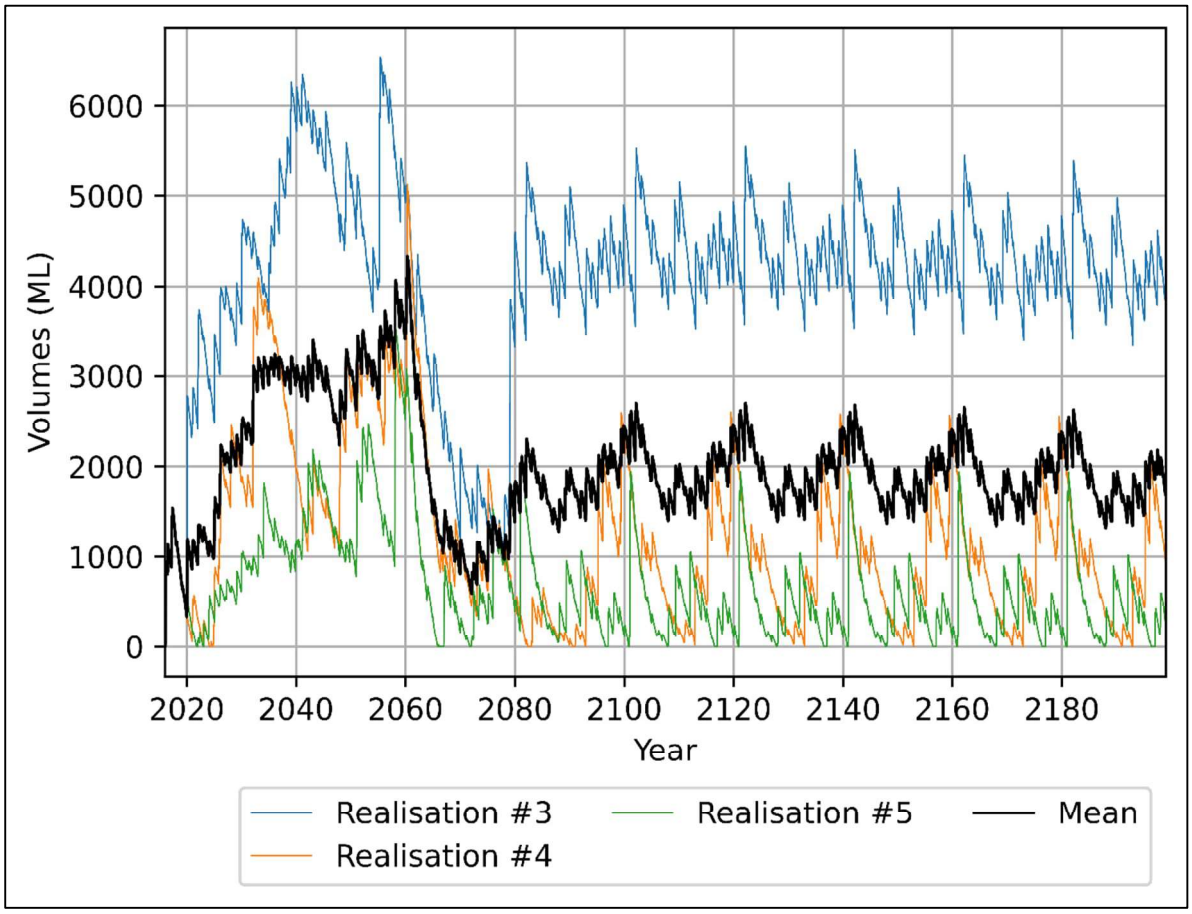


Figure 6.27: Modelled water volumes for Thiess residual void (realisations 3, 4, and 5)

7 Geotechnical stability

Geotechnical stability assessments have been completed to demonstrate that, post-closure, the conceptual void high-wall, end-wall, and low-wall slopes will all exhibit long-term geotechnical stability for the GRBM residual voids. This section presents the assessment findings relevant to void closure at GRBM.

7.1 High-wall and end-wall stability assessment

The method of limit equilibrium was selected to geotechnically assess and quantify the risk of instability for GRBM residual voids' high-walls and end-walls. Limit equilibrium compares forces on a surface with (limiting) strength if the high-wall/end-wall were at the point of failing. Defects may be included explicitly as discrete strata when known, but more often they are implicit within the strengths of broader material layers. The main disadvantage of this method is that it assumes all material along the surface can realise its peak strength at the same time; the significance of any subsequent inaccuracy depends on the load-deformation behaviour of the materials. However, the method is generally accepted by industry as a practical industry method and has therefore been adopted for the PRC plan at GRBM.

Factor of Safety (FoS) computed by limit equilibrium is essentially a ratio of the strength available to hold a slope in place divided by the loads tending to move, or destabilise, material behind the slope face. Thus, an FoS less than one indicates instability, and a value greater than one implies that the slope is stable because the capacity to resist slipping is greater than the forces promoting slipping. A FoS is a relatively coarse and simplified measure of stability that was devised to use as a design methodology. In this context, a minimum value somewhat greater than one is specified to allow for inaccuracies and uncertainties in both the method and the input data.

As a design or performance criterion, the selected minimum FoS should be appropriate to the consequences if instability did occur, which in the closure context in turn relates to land use (Martin & Stacey, 2018). A minimum FoS of 1.5 is often adopted for long-term stability of civil engineering features such as road cuttings and dam walls, that is, features with broad public access. By contrast, a FoS of 1.2 is typically applied to operational design for BMA coal mine pit walls, where stability is required for a shorter time and with limited human exposure.

Pending industry research to develop observational methods and consequence assessment for long-term pit wall stability, BMA has adopted a minimum FoS of 1.5 for closure planning. However, a too-conservative approach could lead to an unnecessary increase in void area and additional land disturbance at the potential expense of adjoining higher-value land uses. Hence, BMA is applying the minimum FoS, not to the physical crest of the pit wall but instead:

- To a distance set-back behind the crest, such that there are no environmental or third-party assets of significant value within that set-back; or
- To the final void walls, which have been located such that their computed set-back does not include any valuable assets.

This approach allows for flexibility to apply improvements in stability practice in the future and translates to both the high-walls and end-walls. At closure, all third-party assets will remain outside any identified zones of instability (i.e., a FoS equal to or less than 1.5). This constraint is illustrated in Figure 7.1. The NUMA extent will include the required set-back to achieve the minimum FoS.

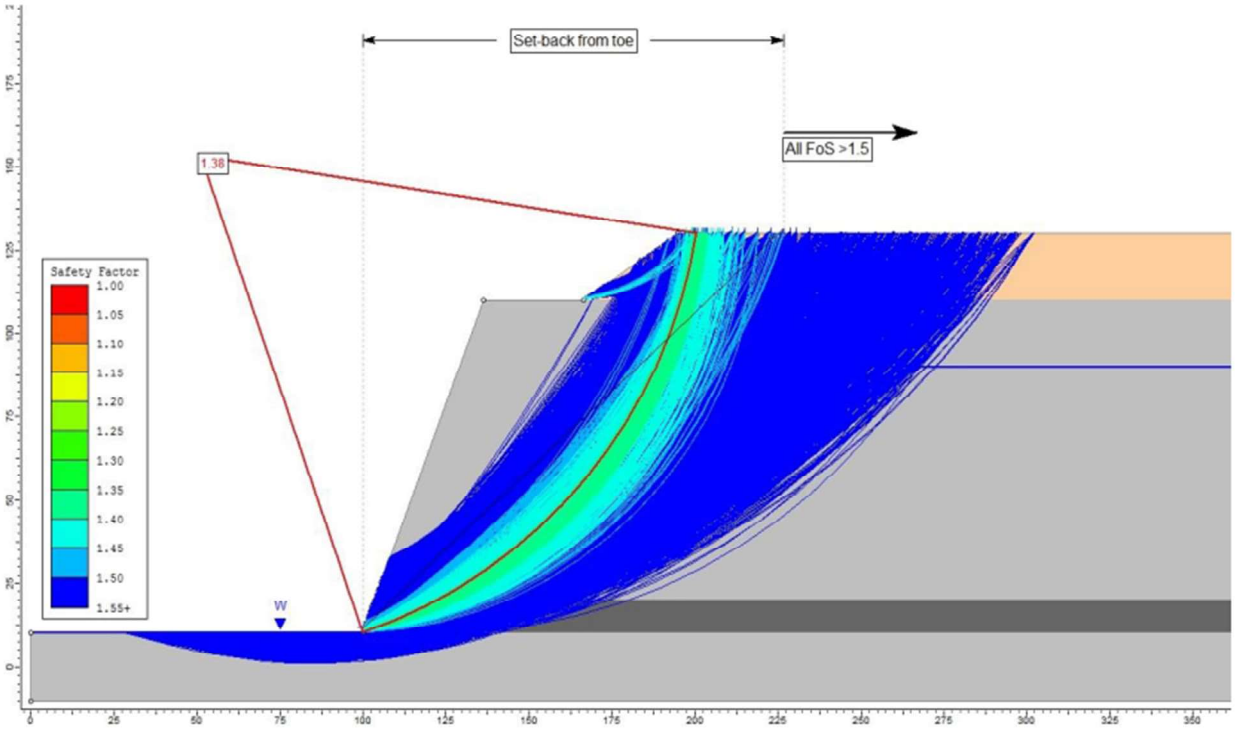


Figure 7.1: Example illustration of set-back to FoS of ≥1.5

BMA has developed a pit wall stability design tool for determining set-backs for long-term pit wall stability at BMA coal mines.

A common engineering approach, when it is anticipated that designs will be required for a large number of similar scenarios, is to undertake upfront a large number of analyses to cover the range of expected scenarios and collate the results into a design tool, for example design charts or empirical formulae or lookup tables. It is important to appreciate that such tools do not omit design analyses, it is simply that all the analyses are carried out first so that when a particular scenario is considered, the result is already available. Set-backs for long-term pit wall stability at BMA coal mines clearly lends themselves to this approach – regional geology is broadly consistent; mining methods constrain the range of efficient wall geometries; and given the number of pits and different planning horizons, there will be a large number of specific scenarios to address over time.

The key features of this design tool are summarised in Sections 7.1.1 and 7.1.2. The design tool is used for initial planning. Individual assessment of each high-wall and end-wall will be undertaken as part of the final pit detailed designs as mining approaches the final pit extents.

7.1.1 Inputs to assessment – regional

7.1.1.1 Regional geology and geotechnical (strength) properties

In the context of wall stability, the important geological boundaries are base of Tertiary and base of weathering; however, for simplicity in the design tool, Tertiary and weathered Permian rocks were treated as one material, which is a conservative approach. Stability analyses (forming the basis of the design tool) used the wall geometry and assumed strength properties summarised in Table 7.1 and Table 7.2 respectively.

Table 7.1: Wall geometry covered by the stability design tool

Aspect	Value range
Average wall angle in Tertiary overburden	35° (constant)
Depth of Tertiary/weathered overburden	1 m to 100 m
Bench width at base of Tertiary overburden	30 m (constant)
Average wall angle in Permian overburden	40° to 70°

Table 7.2: Strength properties applied in the stability design tool

	Cohesion (kPa)	Friction angle (°)	Unit weight (kN/m^3)
Tertiary/weathered	50	30	22
Fresh Permian	450	42	24
Coal	30	35	15

7.1.1.2 Effect of weathering

The effects of weathering on the character and strength of rocks and hence the long-term stability of pit walls only relates to weathering that might occur after cessation of mining, being physical degradation and chemical decomposition. Degradation depends heavily on water ingress and is largely restricted to the surface of pit walls and does not penetrate far enough to cause geotechnical instability. An exception may be when particularly moisture-sensitive rock is below the long-term void water level that is addressed by adopting saturated strength properties.

Chemical decomposition involves reactions of the actual rock minerals to form different minerals (ultimately, clay minerals) and occurs at the crystalline/molecular level at a very slow rate relative to other processes. Chemical weathering only occurs where water and other reactants can reach and therefore occurs mainly at the rock surface and along joints and bedding planes.

Both phases of weathering occur fastest in hot, wet climates – rainfall providing the necessary moisture, and high temperature promoting chemical reactions. The climate at GRBM is hot but not wet and as such only “very slight” ongoing weathering is expected. Very specific situations where even a very small amount of additional weathering might affect pit wall stability are generally localised that may only be apparent when the pit wall is excavated. Generally, these situations cannot be planned for and will be assessed and managed at the end of coal extraction at the detailed design stage for closure.

7.1.1.3 Effect of long-term erosion

Erosion is the detachment of solid particles from the soil or rock mass and the subsequent transport of those particles away from their initial location.

On high-walls and end-walls in the Bowen Basin, erosion in fresh rock is mainly limited to material that has already slaked because the intact rock is too strongly bound for particles to be readily detached. Above the base of weathering, particles are more easily detached. As particles are transported in water flow, erosion develops and progresses over time along flow lines. These are mainly perpendicular to the line of the wall. By contrast, slip failures involve surfaces that are at least sub-parallel to the line of the wall. Consequently, erosion rarely causes geomechanical instability and generally has little impact on geomechanical stability in in-situ pit wall geotechnical stability. Erosion is generally addressed through surface water and erosion control measures rather than by slope stability design. Therefore, it has not been considered further in this assessment.

7.1.2 Effect of significant hydrological events

In Bowen Basin coal mines, weathered overburden is generally susceptible to softening when saturated, especially materials containing significant clay. Water balance modelling for the proposed residual voids at GRBM predicts average and long-term void water levels many metres below the base of weathering. Consequently, void water will only contact fresh rock and so will not affect geotechnical stability of the excavated pit walls.

The most serious potential impact of severe rainfall events would be the inrush of floodwaters to the void. For the final closure state landform, spoil placement will be conducted so that the final residual voids for the NUMA will not be subject to inundation from floodwaters up to and including the 0.1% AEP climate change event with 20% increase in rainfall intensity.

A final mode of instability related to water storage is drawdown failure. This can occur when pore water pressures in the containing earth and rock have equilibrated with the water level in the storage and that water level is then lowered quicker than the containing materials can drain, causing imbalance in the pore pressures. This will not be an issue for voids which contain water passively because evaporation will not lower the water level at a rate to establish this imbalance.

7.1.3 Inputs to assessment – local

Long sections extracted from the current GRBM geological model provided void wall profile data as summarised in Table 7.3.

Table 7.3: Geotechnical profiles for the residual void walls at Goonyella Riverside Mine

Geotechnical profile parameters		Goonyella	Broadmeadow	Isaac	Thiess	R32 East	R32 South
Depth of Tertiary/ weathered overburden (m)	Average Range 90% less than	27 20-36 34	20 19-22 216	23 21-25 25	27 21-42 36	19 18-23 21	28 22-36 34
Thickness of base coal seam (m)	Average Range 90% less than	8.9 6.0-12.1 9.9	6.4 6.2-6.7 6.6	5.7 5.3-6.5 6.1	5.9 4.6-8.5 7.9	6.6 3.6-7.1 7.1	6.8 6.6-7.3 7.1
Depth of fresh overburden (m)	Average Range 90% less than	277 213-317 304	71 41-80 80	55 50-58 58	50 44-60 56	76 67-88 85	41 35-44 44
Total Wall depth (m)	Average Range 90% less than	304 242-342 328	91 62-101 100	77 74-81 80	78 73-87 80	94 89-106 103	69 65-73 72

The depth ranges for Tertiary/weathered and fresh Permian overburdens for the Goonyella, Isaac, R32 East residual voids are within the application limits for the design tool. Coal at the pit base was slightly thicker than 10 m at one end of Goonyella void, however the affected segment was less than 10% of the total pit length and, therefore was not considered significant.

Most of Broadmeadow and Thiess residual voids, except for one segment in Broadmeadow and two segments in Thiess residual voids are within the application limits for the design tool. R32 South residual void was outside the application limits of the design tool. However, for all Broadmeadow and Thiess segments and the R32 South void, the depth of fresh overburden was less than the lower limit for the design tool (50m) and therefore the pit depth was conservatively increased to meet the fresh overburden constraint.

Computations were made with an assumed wall angle of 60°. The computed set-back from the wall toe is not sensitive to the wall angle, but steeper angles are slightly more conservative as they impose greater overburden weight on the

potential slip surface. The thickness of the coal seam at the pit floor for these voids ranged up to 10 m, which is the assumed thickness in the design tool (10 m).

The design tool is used for initial planning only. Individual assessment of each high-wall and end-wall will be undertaken as part of the final pit detailed design stage required as mining approaches the final pit extents and as additional geological and geotechnical data becomes available.

The procedure for estimation of set-back distance developed in the design tool is:

1 If $D_{TW} \leq 47$m, $FoS_{TW} > 1.5$ and $S_{TW} = D_{TW}/\tan(35°)$.

2 Otherwise $S_{TW} = 2.58*D_{TW} - 41.5$.

3 $S_1 = S_{TW} + 30 + D_P/\tan(A_P)$.

4 $FoS_P = 1.208 + 0.0655/\sqrt{D_{TW}} + 13.87/\sqrt{D_P} - 0.0168A_P$; if $FoS_P > 1.5$ then $S_P = D_P/\tan(A_P) + 30 + D_{TW}/\tan(35°)$.

5 Otherwise, $S_P = 0.856*D_{TW}^{1.15} + 3.727*D_P^{0.94} + 39.35\tan(A_P)^{1.09} + 35.01\ FoS_P^{2.49} - 389$.

6 Required set-back from the wall toe = $\max(S_1, S_P)$.

Where:

- D_{TW} = depth of Tertiary/weathered overburden (m).
- D_P = depth of fresh Permian overburden (m).
- A_P = average wall angle in fresh Permian overburden (degrees).
- S_{TW} = set-back for stability in Tertiary/weathered overburden (m), measured from the toe of the weathered overburden batter.
- S_1 = set-back for the whole operational wall design (m), measured from the toe of the whole wall.
- S_P = set-back for stability of whole wall (m), at FoS = 1.5.

The set-back calculation does not consider underground access points. Stability in those areas is a focus during design and operation, but further assessment of long-term geotechnical stability will be undertaken as part of the final assessment when operations cease.

7.1.4 High-wall and end-wall stability assessment results

The results for the GRBM high-walls are summarised in Table 7.4. Set-backs for end-walls will range from the value at the end of each high-wall down to the value coinciding with the excavated wall crest as the exposed wall height reduces.

Table 7.4: Set-backs for long-term wall stability at Goonyella Riverside Mine

Geotechnical profile parameters		Goonyella	Broadmeadow	Isaac	Thiess	R32 East	R32 South
S1 (m)	Average Range 90% less than	176 140-197 189	53 41-59 58	45 43-47 46	46 42-53 49	55 51-61 59	45 42-50 48
FoS_P	Average Range 90% less than	1.05 0.99-1.16 1.01	1.86 1.77-2.18 1.77	2.09 2.03-2.17 2.04	2.13 2.01-2.17 2.07	1.82 1.69-1.91 1.72	2.17 2.17-2.18 2.17
Sp (m)	Average Range 90% less than	497 351-581 557	100 88-107 105	94 91-97 96	99 87-119 110	101 97-106 105	98 91-110 107

Geotechnical profile parameters		Goonyella	Broadmeadow	Isaac	Thiess	R32 East	R32 South
Set-back from toe of wall (m)	Average Range 90% less than	497 351-581 557	100 88-107 105	94 91-97 96	99 87-119 110	101 97-106 105	98 90-110 107

This set-back approach to long-term geotechnical stability offers several options to meet the requirements for mine closure including:

- Stop mining within the pit when the toe of each pit wall reaches at least the set-back distance away from significant permanent assets, including lease boundaries, third-party infrastructure, and Matters of State Environmental Significance.
- Move the asset in question (e.g. relocate a public road).
- Undertake a more detailed geotechnical investigation and wall stability analysis to remove some of the conservatism imposed by the design tool.
- Plan for partial backfill of the residual void. In simple terms, this would reduce the (exposed) wall depth and depth of fresh Permian overburden, reducing the set-back.
- For GRBM, the conceptual voids have been designed with the final void walls the required distance away from significant permanent third-party assets. The design will be refined with detailed individual geotechnical assessment as mining of the pits approaches the final extents. The NUMA extents include the calculated set-back distance to achieve geotechnical stability within the NUMA.
- As stated in section 7.1.3, this assessment does not apply to area around the underground access points within the voids. Stability in these areas is a focus during design and operation, but further assessment of long-term geotechnical stability will be undertaken as part of the final assessment when operations cease.

7.2 Low-wall stability assessment

The geotechnical stability of low-walls has been assessed for the GRBM residual voids with the purpose of demonstrating that, post-closure, void low-wall slopes will exhibit long-term geotechnical stability.

Stability analyses of the low-wall final closure state landform for the GRBM residual voids was undertaken using the two-dimensional (2D) limit equilibrium analysis software Slide2 (version 9.010). Cross-sections were selected that represented the interpreted critical (worst case) low-wall conditions from a stability point of view, targeting areas of greatest spoil height and steepest floor dip. R32 East residual void was not assessed as this void does not contain low-walls. The section locations for the analyses are presented in Figure 7.2 and the corresponding sections are identified as:

- Section 1 (Goonyella residual void).
- Section 2 (Thiess residual void).
- Section 3 (Broadmeadow residual void).
- Section 4 (Isaac residual void).
- Section 5 (Ramp 32 South residual void).

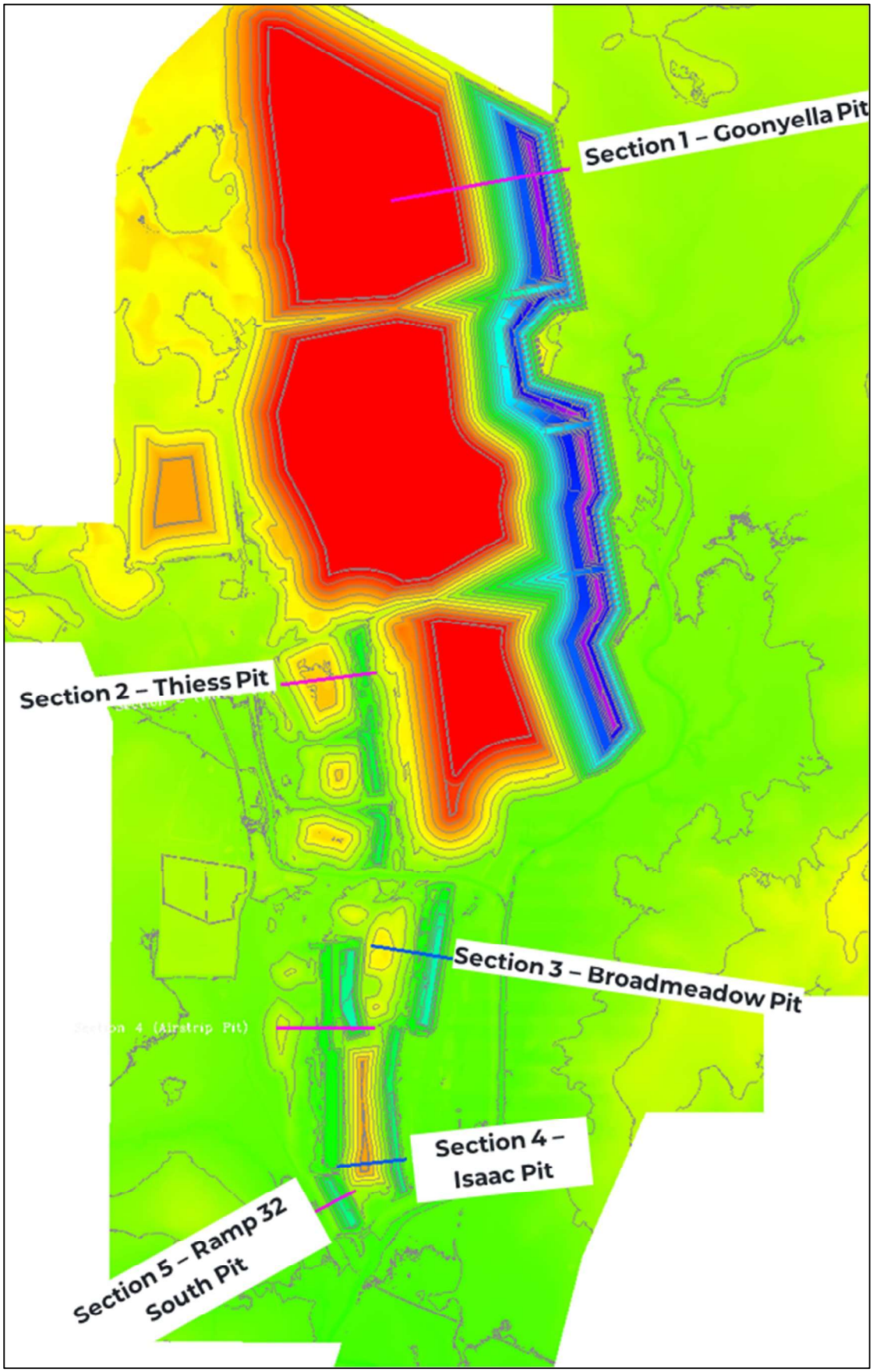


Figure 7.2: Cross-section locations for the GRBM residual voids low-wall stability analyses

For each of the cross-sections, the following analysis cases were considered:

- Slope configuration based on the 3D final closure state landform and 3D final pit floor profile. Two alternative failure mechanisms including:
  - Circular analyses using *Morgenstern-Price*.
  - Non-circular using *Sarma* and *Morgenstern-Price*, non-vertical slices.
- Alternative cases of failure extents, including:
  - Global stability: slip surfaces extending from the Post Mine Land Use (PMLU) area of the low-wall slope to the spoil toe at pit floor level.
  - Local stability: slip surfaces constrained to within the PMLU area of the low-wall slope, outside of the NUMA.

The results for the low-wall stability assessment analyses for GRBM residual voids that returned the lowest FoS are presented in Sections 7.2.1 to 7.2.5.

7.2.1 Goonyella residual void

The geotechnical stability assessment for Goonyella residual void concluded that, for the final closure state landform:

- The minimum FoS for all potential slip surfaces affecting the low-wall slope outside the NUMA was > 1.5.
- The stability requirements of a FoS ≥1.5 for the overall slope and for slopes outside the NUMA are met.

A summary of the analysis results are provided in Table 7.5, and depicted in Figure 7.3 and Figure 7.4.

Table 7.5: Summary of low-wall geotechnical stability analysis results for Goonyella residual void

Section	Low-wall spoil height (m)	Minimum Factor of Safety	
		Overall slope (global stability)	Slope outside NUMA (local stability)
1	400	1.62	2.32

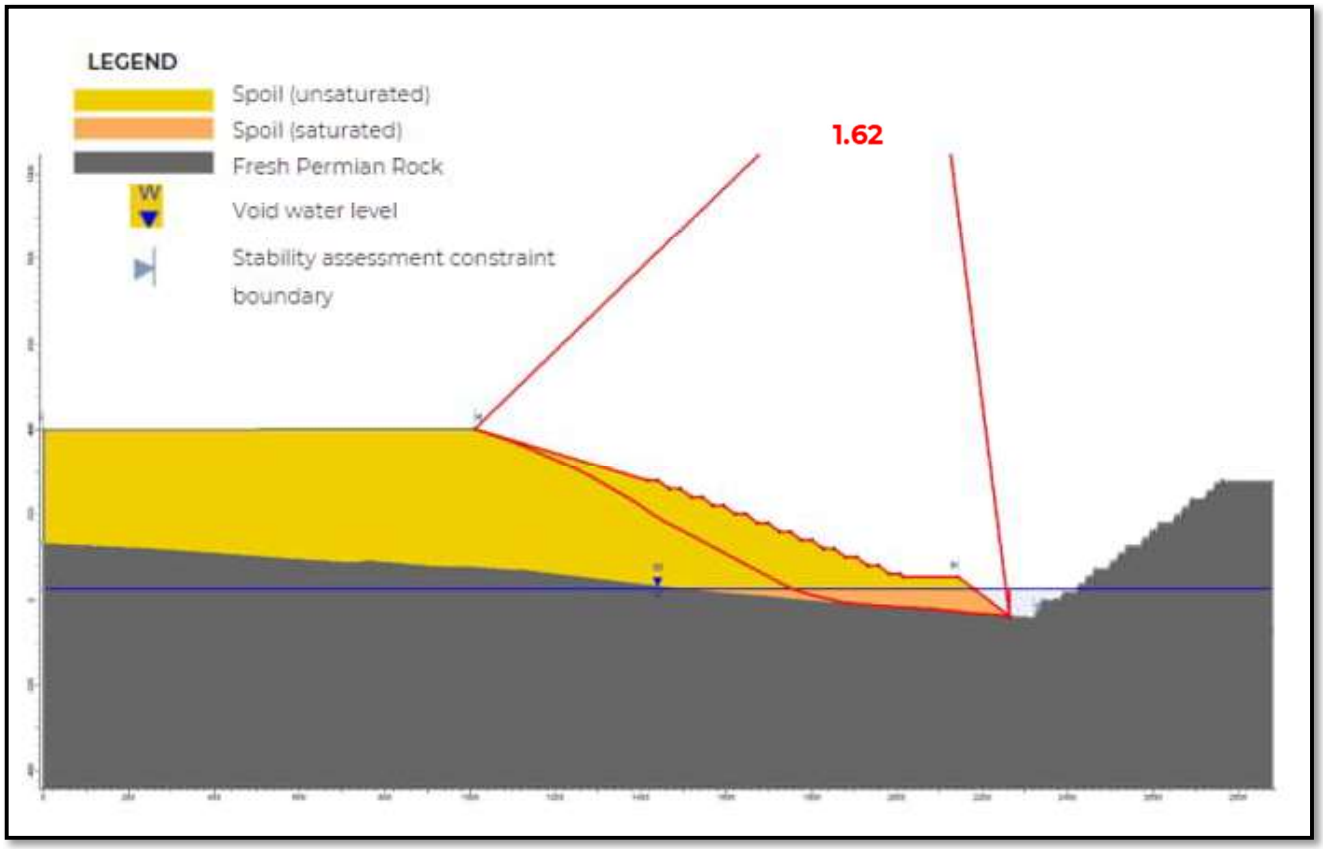


Figure 7.3: Goonyella residual void (cross-section 1) – global stability (Morgenstern-Price, non-circular)

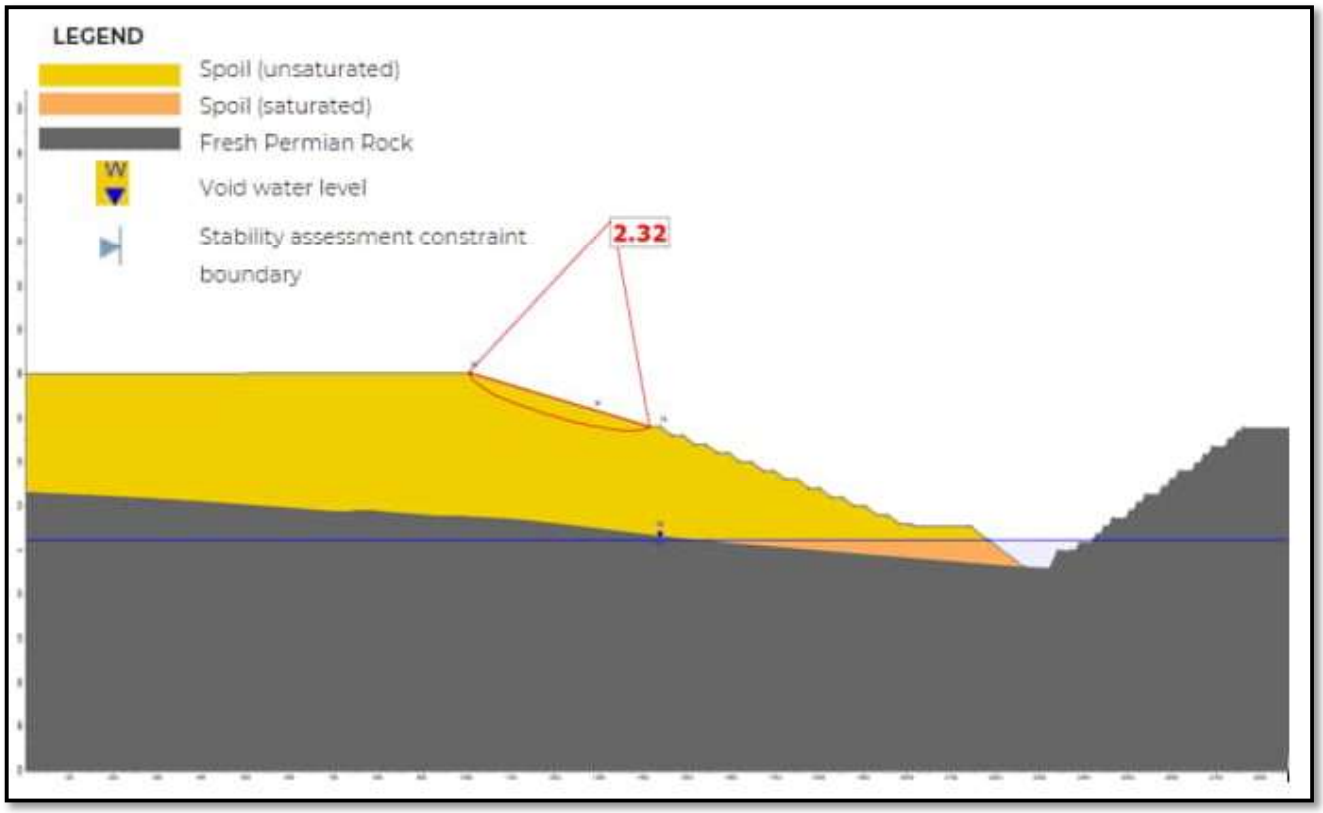


Figure 7.4: Goonyella residual void (cross-section 1) – local stability (Morgenstern-Price, non-circular)

7.2.2 *Broadmeadow residual void*

The geotechnical stability assessment for the Broadmeadow residual void concluded that, for the final closure state landform:

- The minimum FoS for all potential slip surfaces affecting the low-wall slope outside the NUMA was > 1.5.
- The stability requirements of a FoS ≥1.5 for the overall slope and for slopes outside the NUMA are met with the inclusion of management measures.

A summary of the analysis results is provided in Table 7.6, and depicted in Figure 7.5 and Figure 7.6.

Table 7.6: Summary of low-wall geotechnical stability analysis results for Broadmeadow residual void

Section	Low-wall spoil height (m)	Minimum Factor of Safety	
		Overall slope (global stability)	Slope outside NUMA (local stability)
3	263	2.84	4.67

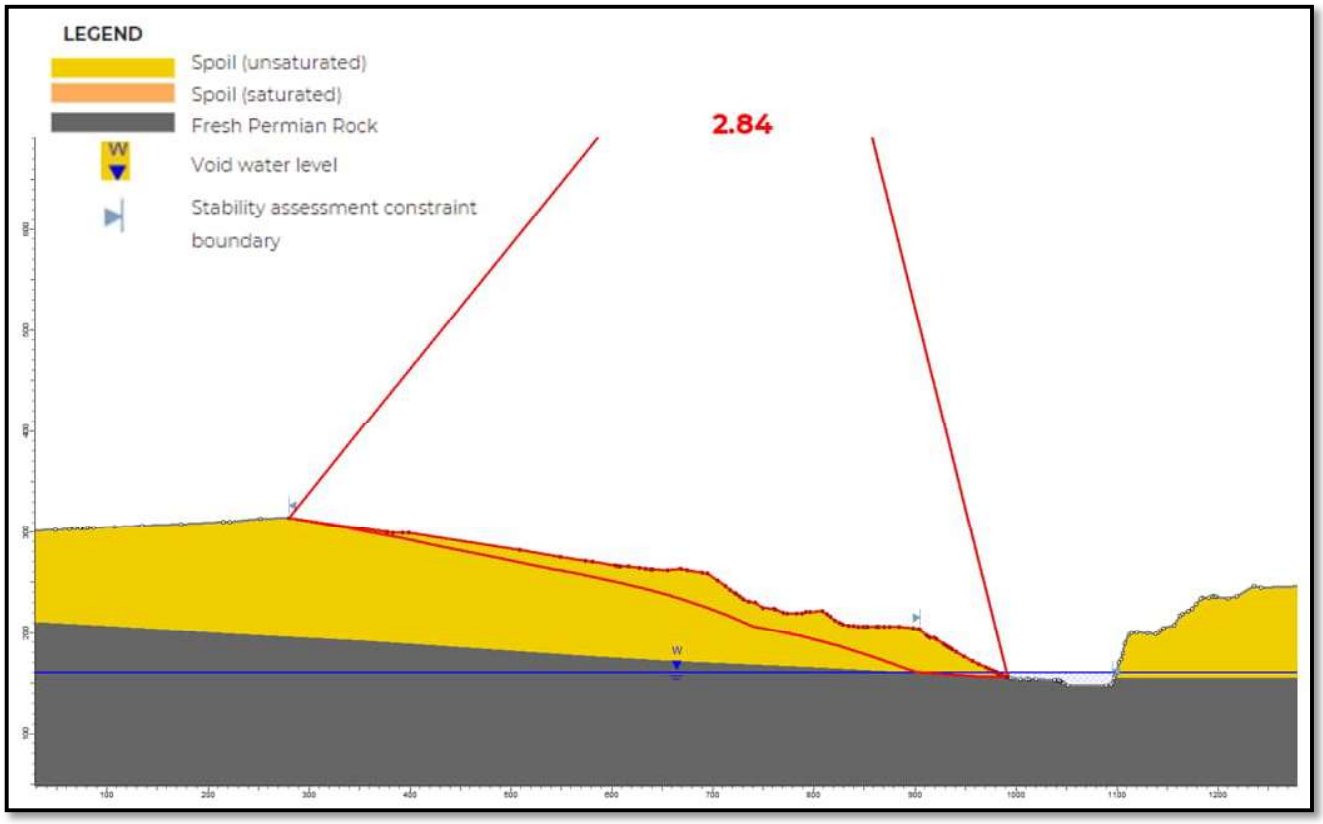


Figure 7.5: Broadmeadow residual void (cross section 3) – global stability (Morgenstern-Price, non-circular)

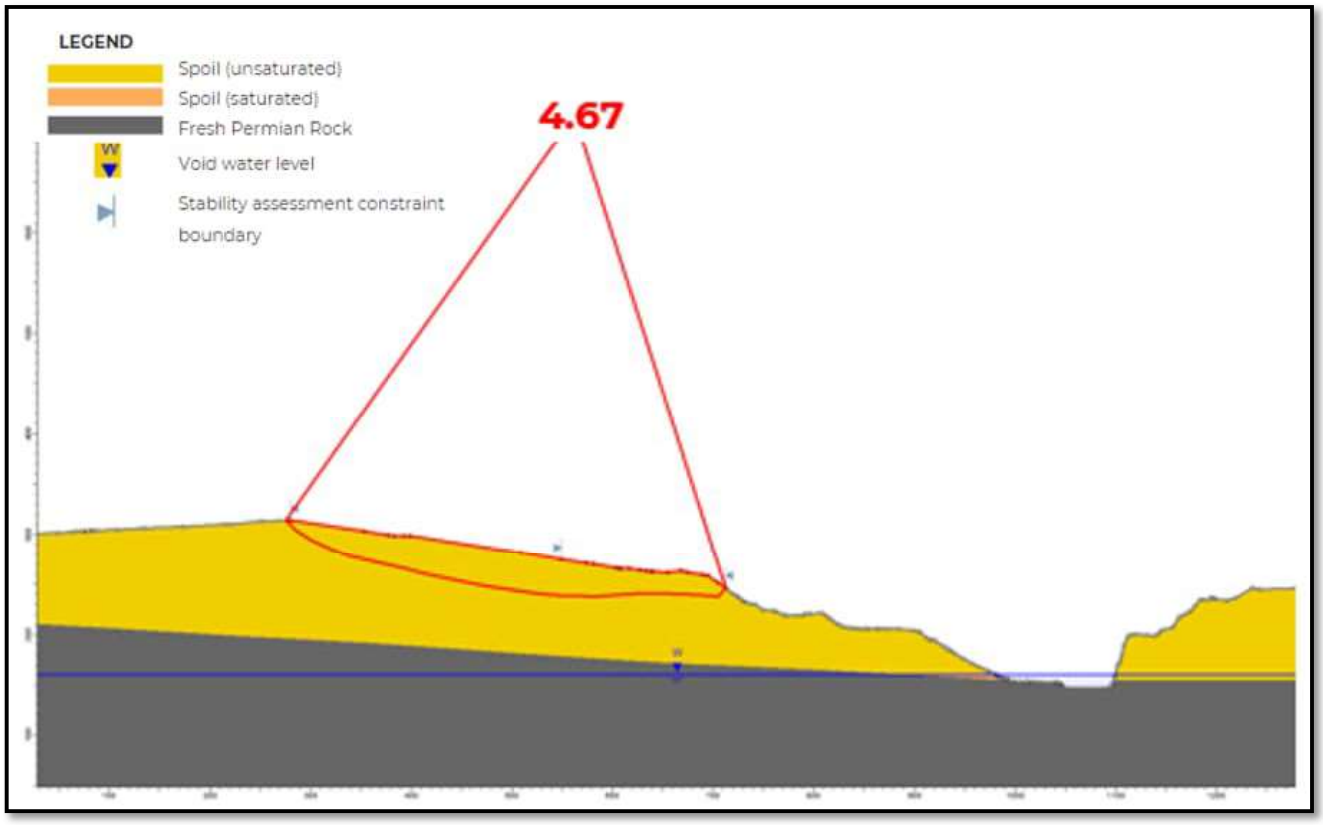


Figure 7.6: Broadmeadow residual void (cross section 3) – local stability (Morgenstern-Price, non-circular)

7.2.3 *Isaac residual void*

The geotechnical stability assessment for Isaac residual void concluded that, for the final closure state landform:

- The minimum FoS for all potential slip surfaces affecting the low-wall slope outside the NUMA was > 1.5.
- The stability requirements of a FoS ≥1.5 for the overall slope and for slopes outside the NUMA are met.

A summary of the analysis results are provided in Table 7.7, and depicted in Figure 7.7 and Figure 7.8.

Table 7.7: Summary of low-wall geotechnical stability analysis results for the Isaac residual void

Section	Low-wall spoil height (m)	Minimum Factor of Safety	
		Overall slope (global stability)	Slope outside NUMA (local stability)
4	340	1.79	2.38

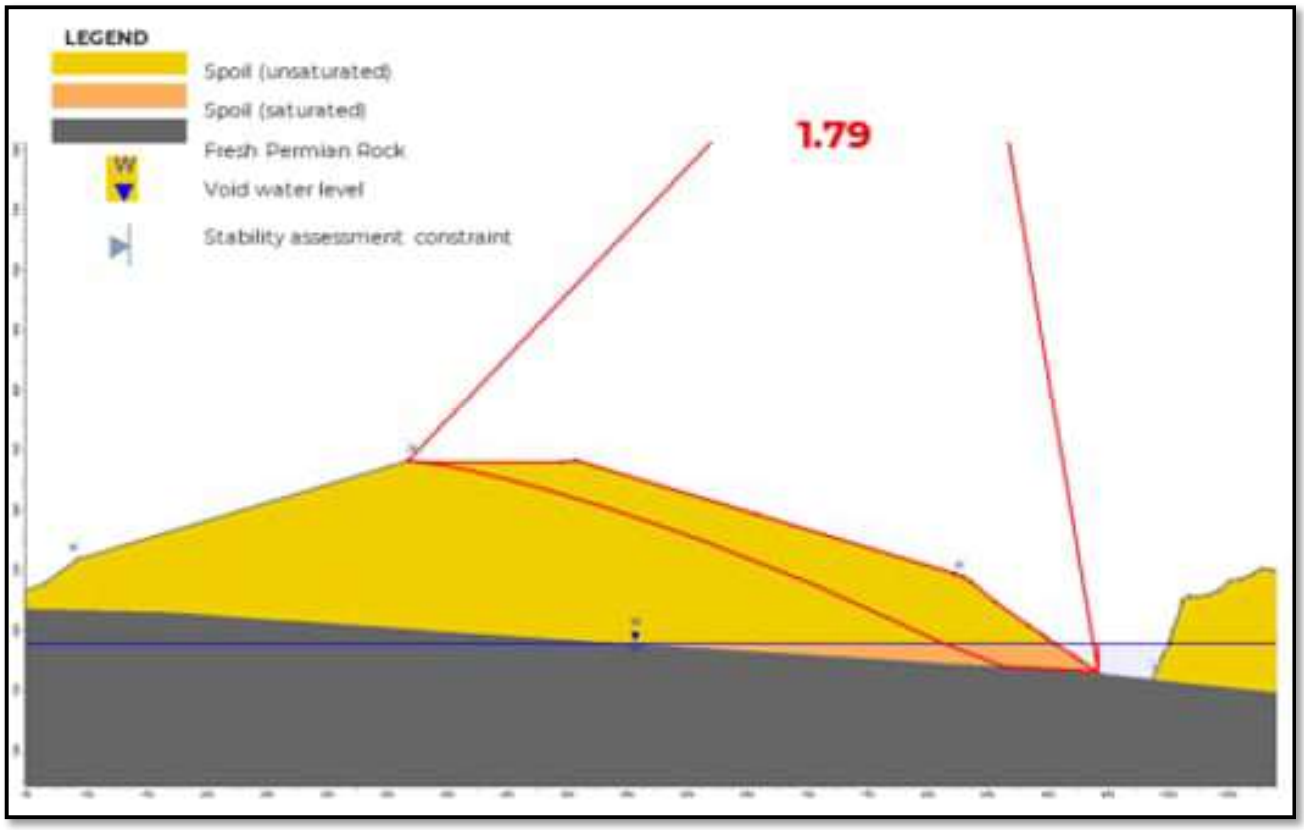


Figure 7.7: Isaac residual void (cross section 4) – global stability (Morgenstern-Price, non-circular)

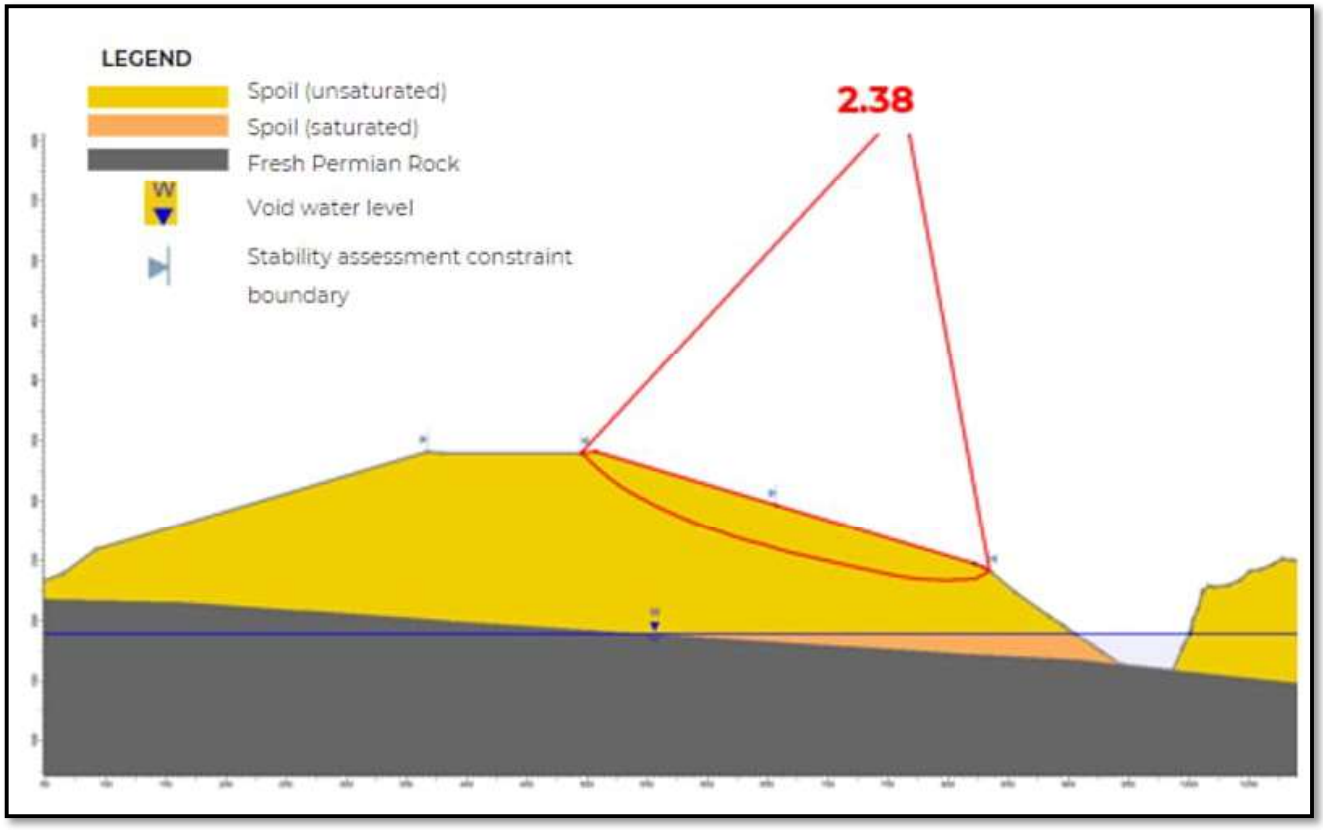


Figure 7.8: Isaac residual void (cross-section 4) – local stability (Morgenstern-Price, non-circular)

7.2.4 R32 South residual void

The geotechnical stability assessment for R32 South residual void concluded that, for the final closure state landform:

- The minimum FoS for all potential slip surfaces affecting the low-wall slope outside the NUMA was > 1.5.
- The stability requirements of a FoS ≥1.5 for the overall slope and for slopes outside the NUMA are met.

A summary of the analysis results is provided in Table 7.8, and depicted in Figure 7.9 and Figure 7.10.

Table 7.8: Summary of low-wall geotechnical stability analysis results for R32 East residual void

Section	Low-wall spoil height (m)	Minimum Factor of Safety	
		Overall slope (global stability)	Slope outside NUMA (local stability)
5	250	1.96	6.81

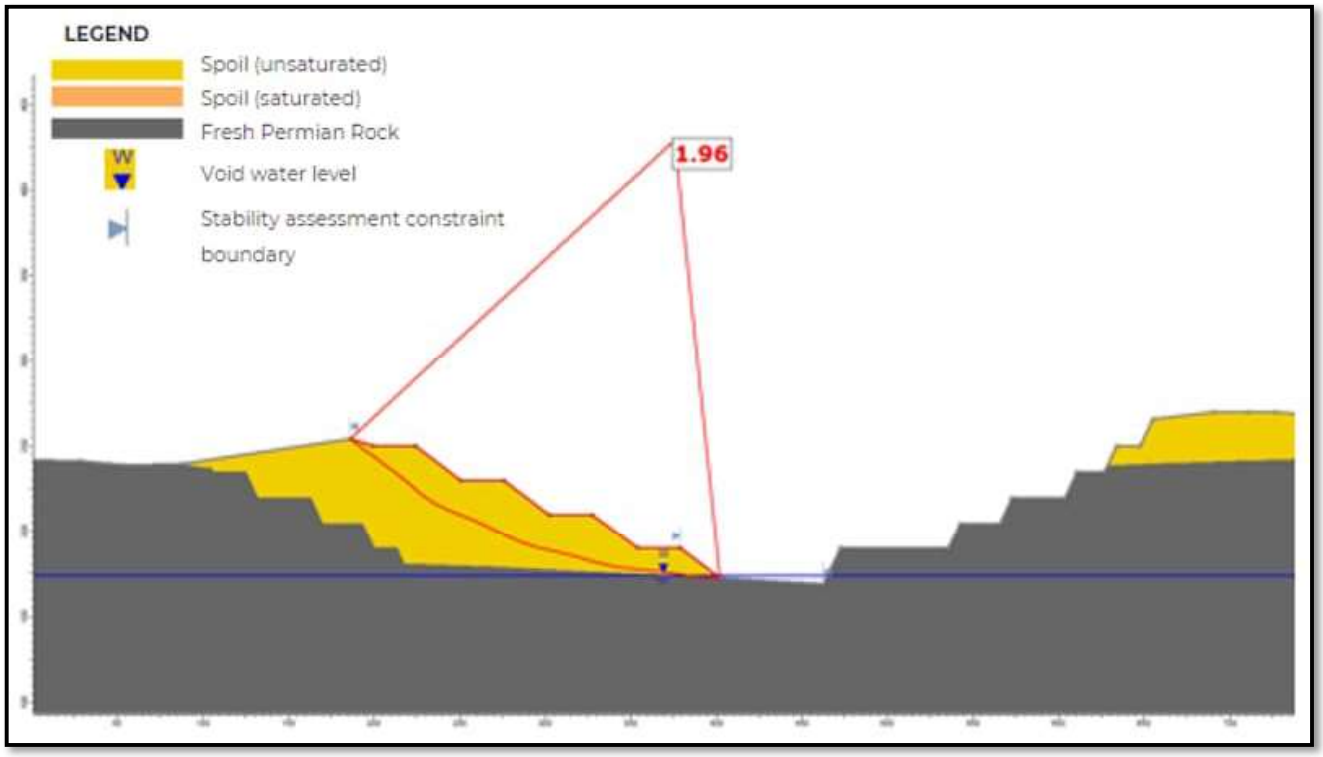


Figure 7.9: R32 South residual void (cross-section 5)– global stability (Morgenstern-Price, non-circular)

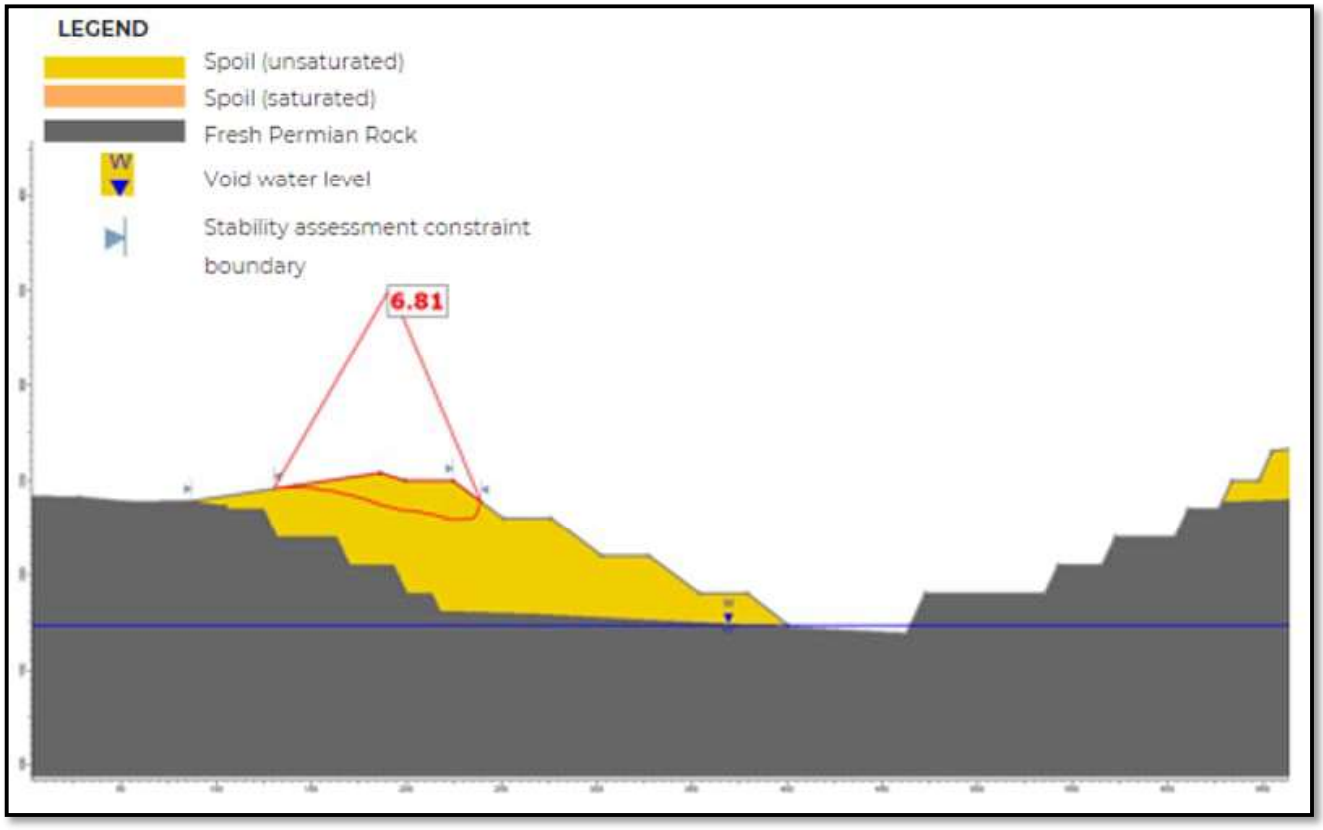


Figure 7.10: R32 South residual void (cross-section 5)– local stability (Morgenstern-Price, non-circular)

7.2.5 *Thiess residual void*

The geotechnical stability assessment for Thiess residual void concluded that, for the final closure state landform:

- The minimum FoS for all potential slip surfaces affecting the low-wall slope outside the NUMA was > 1.5.
- The stability requirements of a FoS ≥1.5 for the overall slope and for slopes outside the NUMA are met.

A summary of the analysis results are provided in Table 7.9, and depicted in Figure 7.11 and Figure 7.12.

Table 7.9: Summary of low-wall geotechnical stability analysis results for Thiess residual void

Section	Low-wall spoil height (m)	Minimum Factor of Safety	
		Overall slope (global stability)[a]	Slope outside NUMA (local stability)[b]
2	320	3.05	3.90

[a] Sarma non-vertical slices
[b] Morgenstern-Price, non-circular

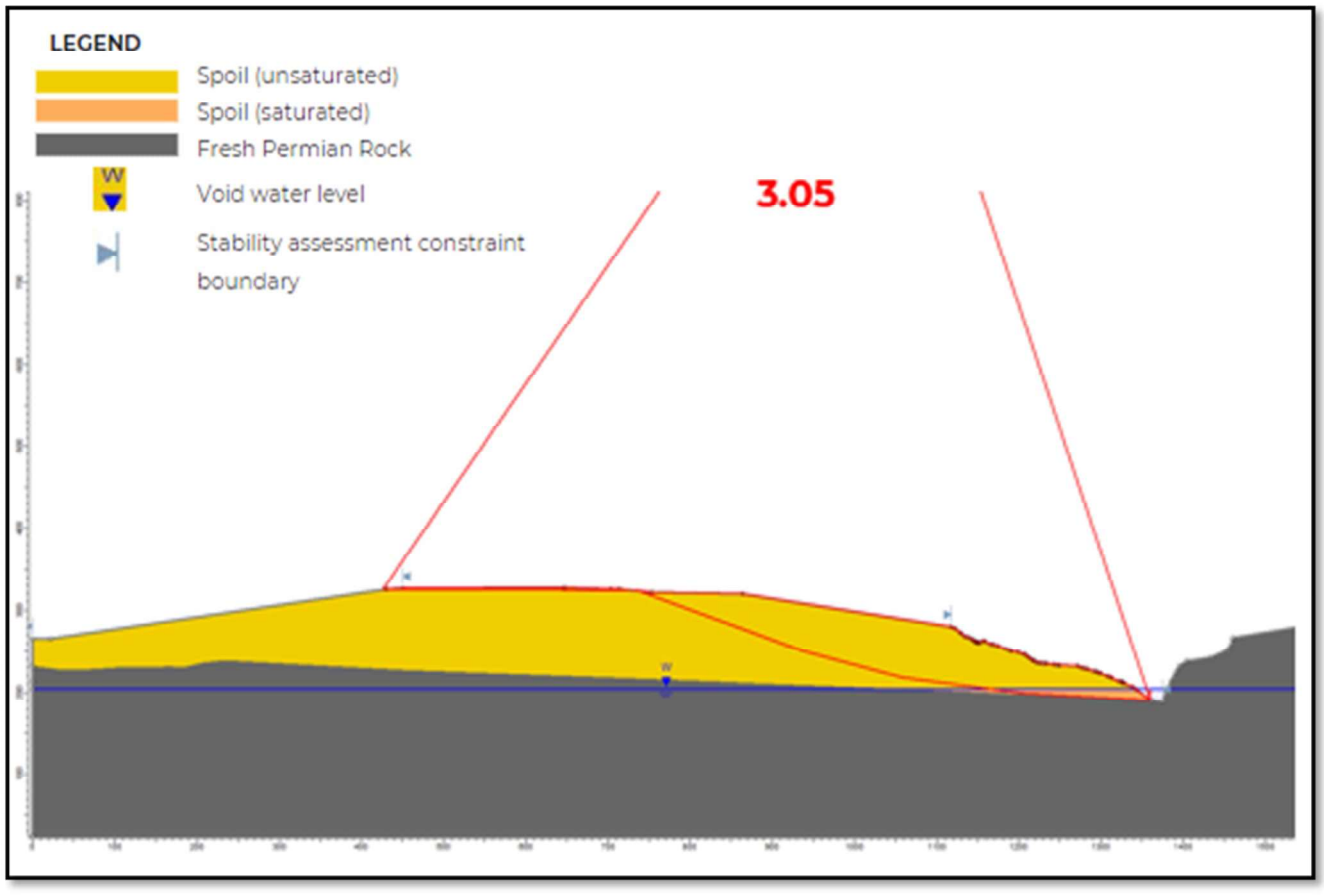


Figure 7.11 Thiess residual void (cross-section 2)– global stability (Sarma Non-vertical Slices)

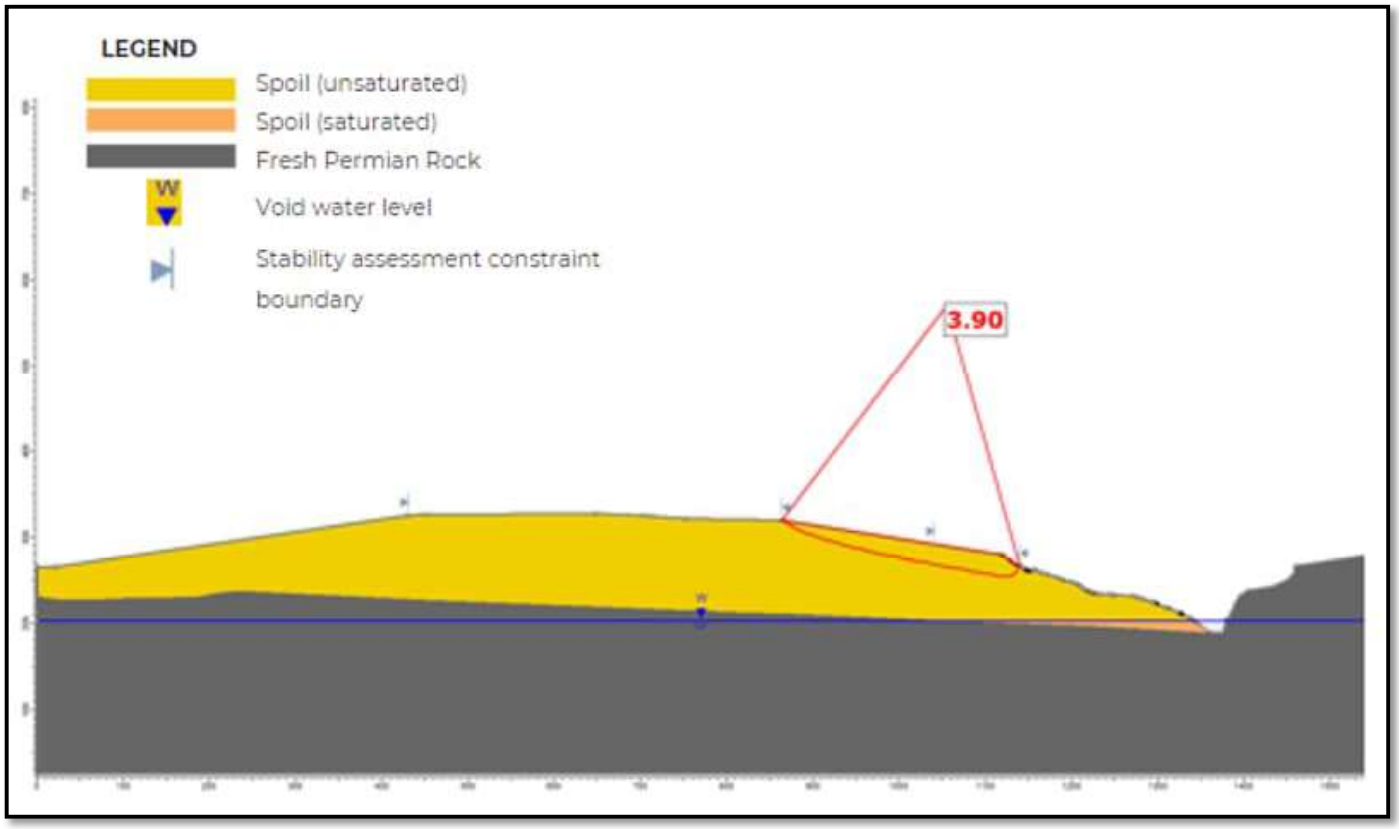


Figure 7.12: Thiess residual void (cross-section 5)– local stability (Morgenstern-Price, non-circular)

7.2.6 Assumptions

The following assumptions were made and used to inform the low-wall geotechnical stability assessments:

- The current assessment of the stability of the conceptual low-wall closure state landform at GRBM is preliminary in nature and has been based on the best inputs and assumptions available at the time of undertaking this assessment. These will be reviewed and verified over time, as mining approaches the final void limits.
- This assessment has not considered any potential effects of surface erosion on the stability of the low-wall spoil slopes.
- The agreed minimum FoS for any potential slip surfaces affecting low-wall slopes outside the NUMA is 1.5, as per the requirements of the EA Table E1.
- The equilibrium residual void lake levels assumed for the low-wall stability analyses were based on the results of the WBM (Section 6).
- Material parameters were provided by BMA and are presented in Table 7.10

Table 7.10: Material strength parameters adopted for low-wall stability analyses

Material	Bulk unit weight of intact rock (kN/m^3)	Cohesion (kPa)	Angle of friction (°)
Spoil (down dip, unsaturated)	18	40	30
Spoil (down dip, saturated)	20	23	25
Fresh Permian rock	24	450	42

- The spoil material was assumed to be homogeneous throughout, with all spoil above the void water equilibrium level assigned the same material parameters (spoil down dip, unsaturated), and all spoil below the void water equilibrium level assigned the same material parameters (spoil down dip, saturated).
- Any weak seams that might have been present within the sub-floor strata were assumed to have been treated by disrupting them with floor ripping or blasting, as required by BMA current operating procedures. Therefore, no such structures have been considered present in the current preliminary stability assessment of the conceptual low-wall slopes.
- No clay-rich spoil or mud will be present on the pit floor at the time when spoil is dumped there. Appropriate floor preparation was assumed to have been completed prior to placing the spoil on the pit floor, as required by BMA current operating procedures. Therefore no ‘weak layer’ was assumed to be present at pit floor level.

8 Geochemical stability

A geochemical assessment has been undertaken to identify the geochemical characteristics of high-wall material and mine waste materials (spoil and rejects) and model the resulting effects on long-term water quality of void lakes within the final closure state landform for the GRBM residual voids.

The objectives of the geochemical assessment were to:

- Predict the changes in water quality of GRBM residual voids in a long-term closure scenario.
- Determine, at a conceptual level (by comparison to published Water Quality Objective (WQO) specific for groundwater[1]), whether the predicted void lake water quality may impact the surrounding environment in a closure setting.
- Determine, at a conceptual level, if stratified conditions are likely to develop within the voids.

This geochemical assessment builds directly on the void water balance assessment undertaken for the GRBM residual voids (see Section 6) and covers the same timeframe: a period of 108 - 183 years post-closure (2091 through 2199) for all residual voids[2]. Within these timeframes, the water level in the void lakes reaches an equilibrium.

8.1 Water quality model

8.1.1 Geochemical materials

The geologic materials and associated mine waste materials (spoil and rejects) may react with water and release or immobilise solutes, according to their geochemical characteristics. Material interactions considered in the water quality model include:

- Highwall lithologies interacting with rainfall/runoff.
- In-pit spoil and rejects covered with non-carbonaceous interburden interacting with rainfall/runoff (infiltration of rainfall through the spoil and rejects was not included).
- Natural catchment interacting with rainfall/runoff. The natural catchment is assumed to be composed of weathered materials.

For the purposes of the geochemical assessment, the lithological materials present in the excavated walls of the GRBM residual voids, and their distribution were classified into five lithological domain groupings (Table 8.1). The relative proportions of each lithological group on current and future post-closure highwalls were derived from the stratigraphic distribution (meterage) of each material within selected drill holes.

[1] As identified in the GRBM hydrogeological assessment (AECOM, 2024a) the Isaac River Sub-basin Zone 34 WQOs (DEHP, 2011) for groundwater resources (aquatic ecosystem protection) have been considered for comparison. The values for the "deep" depth (>30 m) were selected for comparison based on the depth of the residual voids and anticipated depth to groundwater. These values are not specific to residual void lake closure objectives, and therefore should be treated as reference values only for initial benchmarking purposes.

[2] Goonyella residual void WBM was extended to 2259 to confirm equilibrium was achieved. There was no considerable change to the residual void lake level between 2199 and 2259 (refer to Section 6.2.1).

Table 8.1: Proportions of lithologies in the excavated GRBM void walls (high-wall database)

Lithology grouping	Excavated high-wall exposure (%)					
	Goonyella	Broadmeadow	Isaac	Thiess	R32 East	R32 South
Weathered, non-carbonaceous	10.3	25.2	25.2	43.9	34.4	23.0
Weathered, carbonaceous/coal	1.3	0.8	0.8	3.2	2.6	2.0
Fresh, non-carbonaceous	70.6	60.5	60.5	38.0	53.0	63.0
Fresh, carbonaceous	5.5	1.5	1.5	3.7	5.0	6.0
Coal	10.2	7.7	7.7	9.4	5.0	6.0
Unknown	2.1	4.3	4.3	1.8	0.0	0.0

8.1.2 Geochemical source terms

The geochemical source terms were derived from the BMA environmental geochemistry database. The environmental geochemistry database includes the results of analyses performed on drill core material collected at GRBM.

For the derivation of the groundwater source term, groundwater data from 2006 to 2024 that included monitoring information from 116 monitoring bores was used. No distinction was made between aquifers where groundwater bores are screened in different aquifers. The data used for the derivation of these source terms and the derived source terms are summarised in Table 8.2 and Table 8.3.

Table 8.2: Summary of data used to derive geochemical source terms for the GRBM residual voids

Source term (water balance)	Comment	n	Source
Natural catchment runoff	Represented by the average value of leachate from weathered rock of drill core samples. A ratio of non-carbonaceous/carbonaceous weathered rock was estimated based on the high-wall composition.	25	GRBM drill core database
Rehabilitated catchment runoff (in pit spoil runoff)	Represented by the average value of leachate data from fresh non-carbonaceous drill core samples, as Permian interburden was specified as the cover material for final landform.	97	GRBM drill core database
High-wall runoff	Based on the exposed lithological domains on the high-wall, the average leachate data for each lithological domain/grouping were weighted according to the proportions of high-wall exposure.	142	GRBM drill core database
Groundwater inflow	Represented by the average groundwater quality for the locations/ aquifers from the GRBM groundwater database, an equal proportion of each aquifer domain was considered. The 'pe' values were calculated based on field oxidation-reduction potential measurements.	503	GRBM groundwater database
Rainfall	Typical rainwater composition for southeastern Australia (Carroll, 1962).	-	-

Notes: '-' indicates not available; n= number of samples; pe = electron activity expressed in factors of 10: pE = -log(e-)

Table 8.3 Summary of select geochemical source terms (median results) derived from GRBM data sources

Parameter	Unit	Weathered non-carbonaceous	Weathered carbonaceous	Fresh, non-carbonaceous	Fresh, carbonaceous	Coal	Groundwater	Rainfall-runoff (natural)	Rainfall-runoff (overburden)
pH	pH units	8.0	6.7	9.4	9.5	8.9	6.4 - 7.5	7.9	9.4
Log of electron activity (pe)	-	10.1	10.1	10.1	10.1	10.1	2.65 – 4.61	10.1	10.1
Alkalinity	mg $CaCO_3$/L	111	53	248	160	185	319 - 436	107	248
Sulphate (SO4)	mg/L	210	428	93	50	11	81 – 1612	224	93
Chloride (Cl)	mg/L	381	182	84	86	36	4241 - 6278	369	84
Calcium (Ca)	mg/L	11	14	2.39	1.43	2.92	209 - 242	12	2.39
Potassium (K)	mg/L	14	16	8.82	3.66	4.17	9.8 - 23	14	8.82
Magnesium (Mg)	mg/L	11	14	1.95	1.43	2.08	181 - 495	11	1.95
Sodium (Na)	mg/L	353	288	204	151	99	2154 - 3662	349	204
Fluoride (F)	mg/L	2.36	1.98	0.713	0.959	1.00	0.00150	2.34	0.713

8.1.3 *Geochemical model approach and development*

The water quality model was run for major cations and anions per the availability of data. The results for each time-step were calculated using the geochemical modelling code PHREEQC (Parkhurst, 2013) with the Minteq.v4 thermodynamic database, derived from the MINTEQA2 version 4 database (USEPA, 1998).

The geochemical model contained the following features:

- Source-terms were mixed for annual timesteps, with inflow/outflow proportions calculated from the GoldSim water balance.
- Modelling was incremental, with the output for the void lake from the previous timestep used as the input for the next time step.
- Geochemical reactions, such as mineral precipitation/dissolution, gas exchange, and sorption.

The following assumptions apply to the water quality model:

- At all times, the void lake is fully mixed, and geochemical reactions occur within the modelled time-step. The kinetics of reactions are represented by the source-terms and were considered stable in the long-term (steady state).
- Mineral precipitates are retained within the void lake and may undergo dissolution again.
- There is no interaction between the high-wall material and spoil below the established void lake water level.
- The release of coal bed methane is not a significant process and does not drive groundwater or lake chemistry towards more reducing conditions.
- The modelled minor outflows from Isaac and Thiess residual voids (~0.06 ML/day and ~0.5 ML/day respectively) to the groundwater system have the same composition as the water in the void lake. However, evaporative losses from the GRBM residual void lakes creates an inward hydraulic gradient centred on the Goonyella residual void.
- There is no infiltration of rainfall or groundwater through the in-pit waste to the void lake.
- Stratification is assessed at a conceptual level based on a total dissolved solids (TDS) threshold. Seasonal temperature, wind patterns and other impacts on mixing are not considered.
- The geochemical model does not account for biological processes.

A model sensitivity test was performed to highlight the role of the geochemical controls (within the model) on predicted water quality. The two simulations are summarised in Table 8.4 and were performed for the mean water balance scenario.

Table 8.4: Model sensitivity simulations

Simulation	Atmospheric CO_2 equilibrium	Mineral precipitation	Surface adsorption
Base case	Equilibrium at $10^{-3.38}$ (420 ppm)*	Equilibrium	Adsorption onto ferrihydrite
No geochemical controls	No equilibrium	No equilibrium	No sorption

Note: *420 parts per million (ppm) is representative of 2024 atmospheric CO_2 concentrations. Variation with time (i.e., geochemical climate change scenarios) is not included in current model scenarios.

A conceptual level assessment of potential chemical stratification was conducted based on the evolution of TDS, which can be used to approximate the fluid density of the fully mixed void lake. Stratification assessment is provided in Section 8.2.

Quality control carried out throughout the model duration observed the log of the electron activity (pE) and mass of water remained within a suitable range.

8.2 Residual void water quality outcomes

The rehabilitation requirement in Table E1 of the EA identifies electrical conductivity (EC) as a key indicator. However, the water quality model outcomes are focused on TDS (discussion is also included for pH) as TDS is the actual measurement of the amount of total solids dissolved in water, whereas EC is a measurement of the ability of those dissolved solids to conduct electricity. Therefore, TDS is modelled within the water quality model.

The criteria for TDS were derived from the EC values referenced in Table E1 of the EA (the Isaac River Sub-basin Zone 34 WQOs) applying a 0.67 factor (considered acceptable for freshwater). The WBM and groundwater model outcomes indicate that the GRBM residual voids will create an inward hydraulic gradient centred on the Goonyella residual void creating a post-closure groundwater sink. Therefore, the comparison of the water quality model outcomes against the EC range of values from the Isaac River Sub-basin Zone 34 WQOs are for interpretive purposes only, as no modelled groundwater outflows from the modelled residual void lakes beyond the tenure boundaries are expected.

Further discussion is focused on the available modelled results for TDS (and pH) and a comparison to the corresponding published WQO specific for groundwater and the baseline groundwater quality (Table 8.5).

Table 8.5 Select WQO value screening thresholds applied to GRBM residual void lake water quality (DEHP, 2011) and baseline groundwater quality (AECOM, 2024a)

Parameter	Units	Deep groundwater (>30 m)			Baseline groundwater quality
		20th Percentile	50th Percentile	80th Percentile	Permian interburden
EC	µS/cm	3,419	6,100	16,000	7,030 – 18,800
TDS*	mg/L	2,291	4,087	10,720	4,710 – 12,596
pH	-	7.4	7.8	8.03	7.38 – 8.38

Notes: *TDS calculated from EC assuming conversion factor of 0.67

The results for the geochemical modelling for the modelled residual voids at GRBM for TDS and pH are presented for scenarios with and without geochemical controls/reactions (i.e., mineral precipitation, sorption, and gas exchange).

TDS:

Based on the outcomes of this assessment, the modelled void water quality in the GRBM residual voids is predicted to evolve through time. TDS is simulated to systematically increase over time post closure, primarily driven by evapoconcentration and the input of groundwater. The TDS concentrations retain a 20-year cyclicity from the WBM with minor seasonal variation. Brackish conditions develop in Isaac and Thiess residual voids within the modelled simulation period. Brackish to mildly saline conditions develop in Goonyella residual void. Brackish to brine (hyper-saline) conditions develop in the Broadmeadow, R32 South and R32 East residual voids.

The TDS concentrations are all modelled to increase throughout the simulation; however, the rate of TDS increase is largest within the Broadmeadow, R32 South and R32 East residual voids. Except for Thiess residual void, no residual void achieves an equilibrium TDS water quality composition by the end of the model simulation period. However, Isaac residual void also comes close to equilibrium.

Within the modelled simulation period, the predicted TDS concentrations (Figure 8.1) when compared to the 80th percentile WQO (10,720 mg/L) are as follows:

- For Thiess and Isaac residual voids, remain below the WQO.
- For Goonyella residual void, remain below the WQO for approximately the first 50 years.
- For Broadmeadow, R32 South and R32 East residual voids, become elevated above the WQO early.

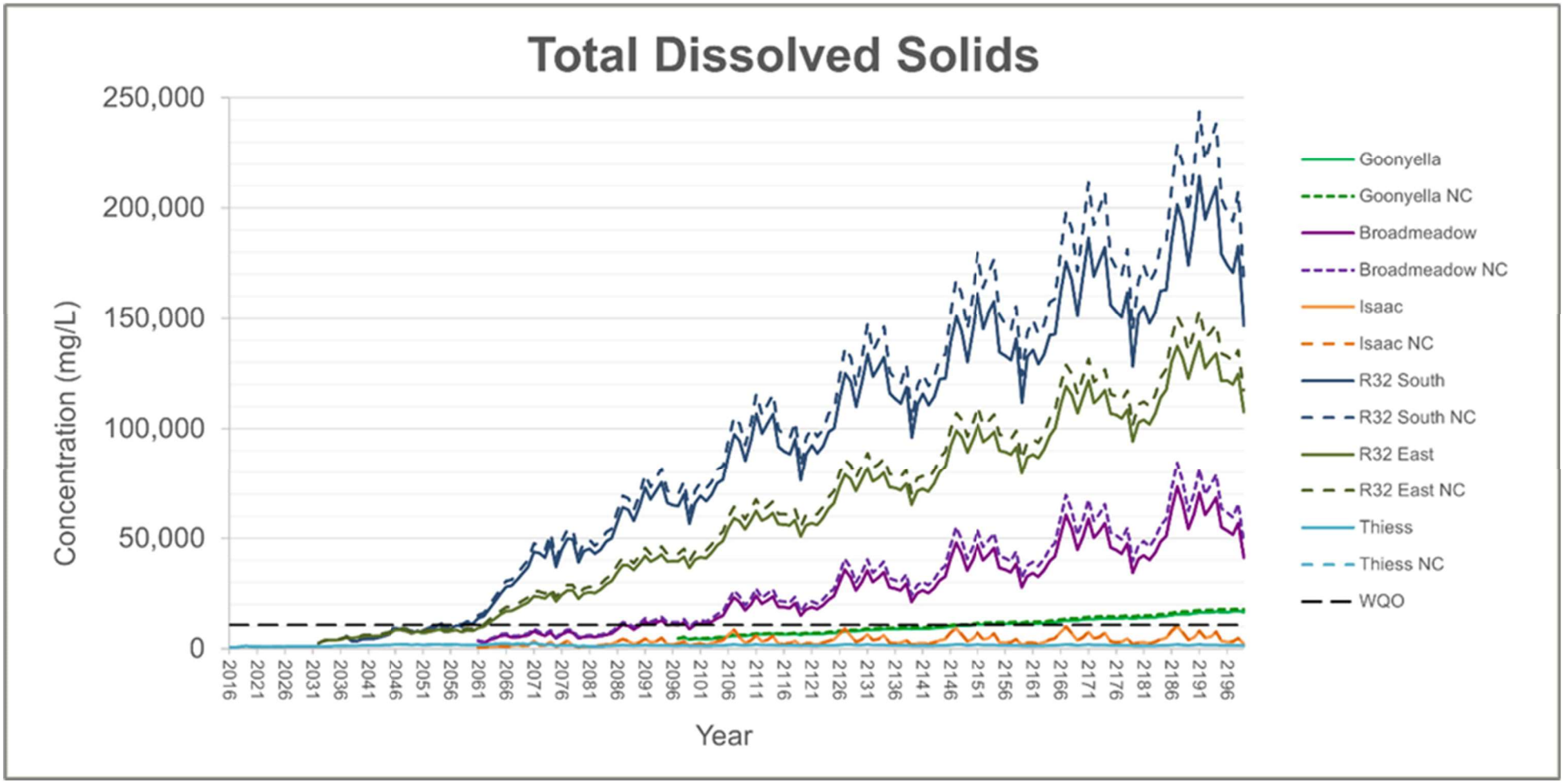


Figure 8.1: Summary of predicted TDS conditions in the GRBM residual voids (NC = no geochemical controls, WQO = 80th percentile)

pH:

Acidic conditions are unlikely to form within any of the GRBM residual voids (Figure 8.2). The modelled pH remains within the circum-neutral to alkaline range (pH 6.4 to 9.4) throughout the simulation period.

Within the modelled simulation period, the predicted pH for Isaac, Thiess and Broadmeadow residual voids surpass the 80th percentile WQO (8.03).

When geochemical controls are applied, the modelled pH for Goonyella residual void surpasses the 80th percentile WQO for pH (8.03). Without geochemical controls, Goonyella void remains below the 20th percentile WQO (7.4) for most of the simulation period.

Within the modelled simulation period, modelled pH levels in R32 South and R32 East residual voids initially surpasses the 80th percentile WQO for pH (8.03) before reducing to and remaining below the 20th percentile WQO (7.4), particularly without geochemical controls applied.

The simulation with geochemical controls results in a higher pH by the end of the simulation than without geochemical controls. The main geochemical control is CO2 degassing which raises pH, resulting in calcite/magnesite precipitation and dissolution that reduces and raises pH, respectively. These geochemical processes are driven by the input of sources of alkalinity (dissolved inorganic carbon) via surface runoff and groundwater to the void lake.

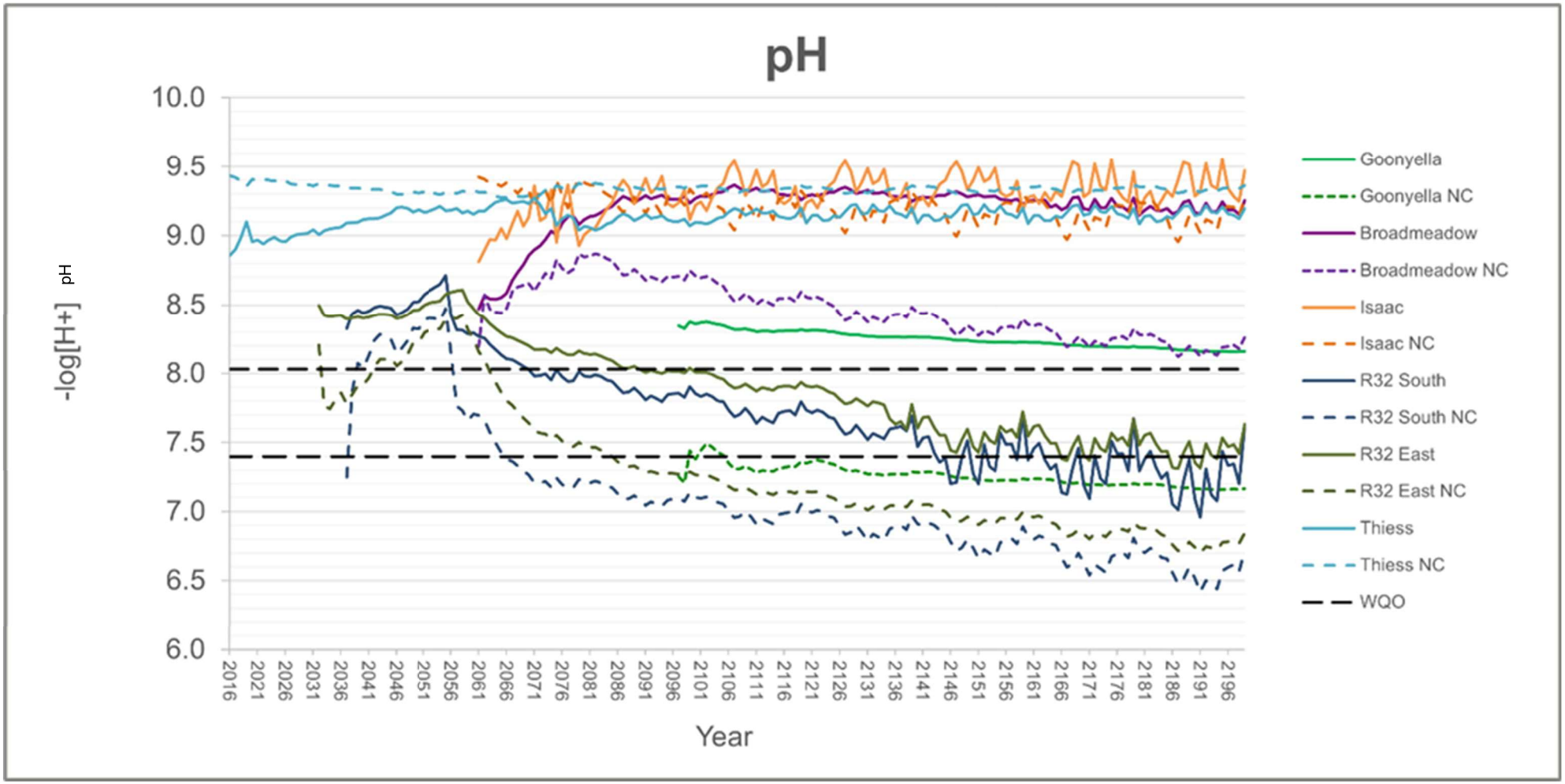


Figure 8.2: Summary of predicted pH conditions in the GRBM residual voids (NC = no geochemical controls, WQO = lower 20th to upper 80th percentile)

Stratification:

The steep sides of the voids, high TDS and the water depth present favourable conditions for stratification in all GRBM residual voids. The water of higher density (cooler or more saline) has the potential to become isolated at depth. Hydrodynamic/limnological analysis is required to assess the potential for onset of thermal/chemical stratification, and the importance of seasonal mixing processes and groundwater mixing inputs. However, as the residual voids are considered NUMAs and modelled as groundwater sinks, further stratification assessment is not warranted.

8.2.1 Qualifications

The following caveats and limitations apply to the water quality model for the GRBM residual voids:

- Available data at the time of modelling was used to represent the relevant geochemical interactions. Availability of additional data in future may result in alternative model outputs.
- The relative proportions of each lithological group on current and future post-closure highwalls were assumed to remain constant, even with the elevation of water levels.
- Water movements are based on complementary studies (groundwater and water balance). These studies constrain the model duration and the water sources.
- Screening was performed against Isaac River Sub-basin Zone 34 WQOs (DEHP, 2011) for groundwater resources (aquatic ecosystem protection). The criteria for TDS were derived from the WQO electrical conductivity value using a 0.67 factor that is considered acceptable for freshwater.

9 Residual void management

A summary of the key findings from the technical studies (presented in Sections 4 to 8) used to inform the development of residual void management measures is presented below:

- Groundwater modelling and WBM results indicate the formation of void lakes in all GRBM residual voids. Void lake levels are modelled to equilibrate below both the base of shallow geologic formations and recovered groundwater levels in the deeper geology for the Goonyella, Ramp 32 South and Ramp 32 East residual voids. Water movement out of the Broadmeadow, Thiess and Isaac residual voids through the deeper geology is predicted to be captured in the deeper Goonyella residual void.
- Continued evaporation from the void lakes will result in ongoing groundwater inflow towards the tenure with the GRBM residual voids, creating an inward hydraulic gradient centred on the Goonyella residual void.
- No additional impact beyond that which already exists at the end of mining is expected on surficial aquifers, including the shallow geological formation, and little to no impact on environmental or anthropogenic receptors (e.g. water extraction bores) is expected.
- WBM results predict that the residual voids at GRBM are at low risk of overtopping. The GRBM residual voids achieve the mean void water levels and volumes in Table 9.1 at the end of the simulation; these are well below the spill elevations for the respective voids.

Table 9.1 Mean void water levels and volumes for the GRBM residual voids

Residual void	Spill elevation (m)	Mean void water elevation (m AHD)	Mean void water volume (megalitres)
Goonyella	254	21	69,178
Broadmeadow	230	155	473
Isaac	230	180	162
R32 South	256	173	190
R32 East	240	162	709
Thiess	256	202	1,869

- The final closure state landforms have been designed such that the geotechnical stability for the low-walls of the GRBM residual voids achieved a FoS ≥1.5. Therefore, the low-walls of the final closure state landforms can be considered geotechnically stable.
- With regards to high-walls and end-walls, at closure, the NUMA extents include identified set-back zones to achieve a FoS ≥1.5. All third-party assets will remain outside of these extents.
- At closure, the GRBM residual voids will be bunded and fenced with appropriate signage erected - where restricting access to the residual voids is required to maintain safety for humans and livestock.
- The final closure state landform has been designed so that the final residual voids associated with GRBM are not subject to inundation from floodwaters up to and including the 0.1% AEP plus 20% rainfall intensity increase climate change event.

All six GRBM residual voids will be retained as NUMAs. To support attainment of NUMA voids that are safe and do not present an unacceptable risk of off-tenure environmental harm, the management strategies presented in Table 9.2 will be implemented.

Table 9.2 GRBM residual void closure context (safe, not cause environmental harm) and management considerations

Residual void closure aspect	Closure objective		Residual void closure context	Management consideration
	Safety	Env. harm		
Geotechnical stability	✓	-	— Stability outside of the NUMA extents = FoS ≥1.5 — Set-back distances for long-term pit wall stability have been defined by geotechnical analysis for all residual voids for high-walls, end-walls and low-walls. — Setbacks are included within the NUMA extent to ensure stability and that no assets (BMA, third-party, or of significant environmental value) are retained within this boundary at closure.	— As mining approaches the final limits, re-assess the geotechnical set-backs based on the latest available data. — Review and adjust the mine plan and final closure state landform, if needed, to account for any revised set-back requirements. — Use a minimum FoS≥1.5 as a guidance for ongoing void closure planning. (This may be refined over the mine life should industry research provide optimised guidance on observational methods and consequence assessment).

Void hydrology	✓	✓	— All GRBM final residual voids in the final closure state landform are not subject to inundation from floodwaters up to and including the 0.1% AEP event under the upper climate change rainfall intensity scenario based on rehabilitation flood modelling completed. — As the water levels remain well below the voids' spill points for all GRBM residual voids, the voids will not overtop and environmental harm beyond that of the void itself is not expected. Therefore, no management activities required. <u>For Goonyella residual void:</u> — After 2200, mean water levels start to stabilise, with simulated mean inflows of 3,929 ML/year being the same as mean outflows. This indicates that the mean water balance has reached an equilibrium. <u>For Broadmeadow residual void:</u> — After 2100, mean water levels start to stabilise, with simulated mean inflows of 218 ML/year being the same as mean outflows. This indicates that the mean water balance has reached an equilibrium. <u>For Isaac residual void:</u> — After 2100, mean water levels start to stabilise, with simulated mean inflows of 179 ML/year being the same as mean outflows. This indicates that the mean water balance has reached an equilibrium. <u>For R32 South residual void:</u> — After 2080, mean water levels start to stabilise, with simulated mean inflows of 88 ML/year being the same as mean outflows. This indicates that the mean water balance has reached an equilibrium. <u>For R32 East residual void:</u> — After 2080, mean water levels start to stabilise, with simulated mean inflows of 213 ML/year being the same as mean outflows. This indicates that the mean water balance has reached an equilibrium. <u>For Thiess residual void:</u>	— Residual void catchments are minimised as far as practicable and predominantly include only the low-wall areas and the voids themselves. — At cessation of mining activities, review and update the void water balance modelling, incorporating identified changes to the voids' final closure state landforms and spill point elevations, starting water levels, rainfall and evaporation, surface water runoff and groundwater inflows, and climate projections. — Although not identified in current modelling, if future modelling identifies an unacceptable risk of environmental harm outside the tenure boundary, then management strategies to be implemented. — Obtain certification from an appropriately qualified person that the residual voids will not cause environmental harm beyond the tenure boundary. — If necessary, identify and implement mitigation measures for appropriate protection works of landforms where floodwaters from watercourses interact with final closure state landforms.

Residual void closure aspect	Closure objective		Residual void closure context	Management consideration
	Safety	Env. harm		
			— After 2100, mean water levels start to stabilise, with simulated mean inflows of 572 ML/year being similar to the mean outflows of 573 ML/year. This indicates that the mean water balance has reached an equilibrium.	
Void hydrogeology	-	✓	— Mining-related dewatering activities have lowered groundwater levels that will result in suppression of the water table centred on the GRBM residual voids. — Void lakes are predicted to form in residual voids post-mining. Water levels in these void lakes are modelled to remain below the shallow geological units due to evaporative effects on the void lakes. — An inward hydraulic gradient is modelled to establish, centred on the Goonyella residual void. Ongoing groundwater inflow towards the tenure is expected. — Modelled outflows from Broadmeadow, Thiess and Isaac residual voids are retained within Goonyella and do not leave the tenure boundary. — The evaporative losses from the GRBM residual void lakes create a long-term inward hydraulic groundwater gradient centred on the Goonyella residual void, thereby providing long-term groundwater management for the mining disturbance areas. — Modelling, including particle tracking, indicates that infiltration of rainfall from the spoil, minor outflows from Thiess and Isaac residual voids, mine industrial area, and other disturbed areas within the tenure will migrate towards and be captured within the residual voids. Groundwater flow is not expected to flow off-tenure toward the receiving environment, minimising the risk of environmental harm due to the proposed final closure state landform.	— At cessation of mining activities, review and update the groundwater modelling, incorporating updated void WBM outputs and in-field groundwater sampling data, as required. — Although not identified in current modelling, if future modelling identifies an unacceptable risk of environmental harm outside the tenure boundary, management strategies are to be developed and implemented to minimise the harm. — Obtain certification from an appropriately qualified person that, upon completion of mining, residual voids do not present an unacceptable risk of environmental harm beyond the tenure boundary.

Residual void closure aspect	Closure objective		Residual void closure context	Management consideration
	Safety	Env. harm		
Void water quality	-	✓	— There are no significant sources of acid generation associated with GRBM's closure-related surface water hydrology, and acidic conditions are unlikely to develop in the voids. — TDS in all GRBM residual voids increases over time with Thiess residual void reaching an equilibrium with seasonal fluctuations. TDS in Isaac residual void almost reaches an equilibrium. — Preliminary, high-level screening base on predicted TDS levels suggest that all GBRM residual voids may become chemically stratified. — GBRM residual voids do not present an unacceptable risk of environmental harm beyond that of the mining tenures as an inward hydraulic groundwater gradient establishes, centred on the Goonyella residual void.	— At cessation of mining activities, review and update the void geochemical assessment including additional or refined data from in-pit surface water samples, surface- and groundwater samples, and biochemical modelling. — Although not identified in current modelling, if future modelling identifies an unacceptable risk of environmental harm outside the tenure boundary, then management strategies to be developed and implemented. — Obtain certification from an appropriately qualified person that the residual voids will not present an unacceptable risk of environmental harm beyond the tenure boundary.
Void access control	✓	-	— Access to the residual void will be restricted for humans and livestock.	On cessation of mining activities: — Construct a safety bund at the geotechnical set-back distance. — Erect fencing and signage (where required) around the perimeter of the safety bund. — Obtain certification from an appropriately qualified person that the residual void is safe to humans and livestock. — Underground access points within voids are closed in accordance with appropriately qualified person recommendations.

10 Conclusion

This void closure plan provides outcomes of technical studies completed to support closure planning and achievement of residual voids at GRBM that are safe and do not cause environmental harm– specifically the Goonyella, Broadmeadow, Isaac, R32 East, R32 South and Thiess residual voids. This void closure plan is an appendix to the GRBM PRC plan and has been complied in terms of the requirements of the *PRC Plan Guideline.*

The documented technical studies – including water balance, hydrogeological, rehabilitation flooding, geochemical and geotechnical stability modelling - have been undertaken through an iterative approach with the development of the closure state landform design. These iterations have resulted in a closure landform design that minimises the area of the voids, provides protection from flood water, and contributes to minimising environmental harm as it relates to the final residual voids.

This plan (and associated supporting technical studies) may be required to be updated should amendments to the site's PRC plan be required.

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