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BHP Mitsubishi Alliance (BMA)

Void Closure Plan

Daunia Mine

March 2023

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Void Closure Plan
Daunia Mine

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RevA	08 March 2023	Draft void closure plan for Daunia Mine
Rev0	30 March 2023	Final void closure plan for Daunia Mine

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Reviewed/Approved by:	Raina Hattingh	30 March 2023	

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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1 Introduction

Daunia Mine (DNM) is an open-cut coal mine which forms part of BHP Mitsubishi Alliance's (BMA) central region mine complex. DNM is located 65 kilometres (km) east of Moranbah in the Bowen Basin, Central Queensland. The site is operated on various Mining Leases (MLs), namely ML1781, ML70115 and ML70116.

Operations at DNM are authorised under Environmental Authority (EA) (EPML00561913), which is jointly held by Central Queensland Coal Associate (CQCA) Joint Venture (comprising QCT Mining Pty Ltd, Mitsubishi Development Pty Ltd, BHP Coal Pty Ltd, QCT Resources Pty Limited, QCT Investments Pty Ltd, Umal Consolidated 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 BHP for DNM and requires a PRC plan be submitted to the administering authority by 01 July 2023.

This void closure plan presents outcomes of technical studies completed to support closure planning and achieve safe, stable and non-polluting residual voids at DNM – specifically the residual voids associated with Titan North Pit and Titan Central Pit (combined in the final closure state landform), Titan East Pit, and Pandora Pit. This void closure plan is an appendix to the DNM PRC plan and is required by the Department of Environment and Science (DES) PRC plan Guideline (version 2.0), referred to as the *PRC Plan Guideline*, dated 17 March 2021.

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 provides protection from flood water. This void closure plan documents how these refinements contribute to minimising environmental harm, as it relates to the final residual voids.

1.1 Scope and objectives

DNM currently has multiple mining pits in various operational stages. Post-closure, the residual voids of these pits are pre-approved as non-use management areas (NUMAs) and will be combined in a final closure state landform design with only three final residual voids remaining: Titan North/Central (that incorporates Titan North and Titan Central), Titan East, and Pandora (herein referred to as DNM residual voids).

The objective of this void closure plan is to document the rehabilitation and management approach showing how BMA will achieve safe, stable, and non-polluting residual voids at closure. This void closure plan will also help to:

- Minimise risk of the residual voids and surrounding areas within the NUMA extents.
- 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 overview.
- Section 4 – Groundwater.
- Section 5 – waterflooding assessment.
- Section 6 – Void water balance.
- Section 7 – Geotechnical stability.
- Section 8 – Geochemical stability.
- Section 9 – Residual void management.

1.2 Applicable legislation and guidelines

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

- *Environmental Protection Act 1994* (EP Act) (QLD).
- EA (EPML00561913) dated 30 June 2022.
- *PRC Plan Guideline* (version 2.0) dated 17 March 2021.

2 Site Overview

DNM is an open cut, strip mine using truck and shovel, and dozer fleets to produce metallurgical coal. Most coal mining activities occur on ML1781 and ML70115. Mining lease 70166 is situated to the west of the current mining pits; this ML includes the DNM coal handling and preparation plant (CHPP), New Chum Creek and a rail corridor.

The mining process involves land clearing, the removal and stockpiling of topsoil material, drilling and blasting of overburden/interburden as required, and stripping of overburden/interburden material using excavators, dozers and trucks. The majority of the overburden/interburden material is placed in the void of the previous strips. Coal is hauled from the pits to the CHPP run-of-mine (ROM) area, or to designated stockpiles. A conveyor transfers product coal from the CHPP to the Train Load-Out (TLO) at the Stanmore Coal Pty Ltd Red Mountain Infrastructure area. Fine and coarse rejects from the CHPP are disposed of in the mining spoil. Product coal is transported by rail to the Hay Point Coal Terminal for export.

Operations at DNM started in 2013, with closure in 2051 for all pits based on the current projected mine plan.

An overview of the existing environment within and surrounding DNM is provided in the PRC plan, and therefore not repeated in this void closure plan.

3 Proposed Residual Voids

Residual voids are identified and authorised under Schedule E (Condition E9) of the DNM EA (as the Land Outcome Document (LOD)). Therefore, the three proposed DNM residual voids are being transitioned as pre-approved NUMAs in the DNM PRC Plan.

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 DNM residual voids, including the void lakes is presented in Figure 3.1.

Table 3.1 Indicative residual void dimensions

Residual Void	Indicative Maximum Width (m)	Indicative Maximum Length (m)	Indicative Maximum Depth (m)
Titan North/Central	1,600	2,800	132
Titan East	500	1,450	126
Pandora	1,200	1,300	92

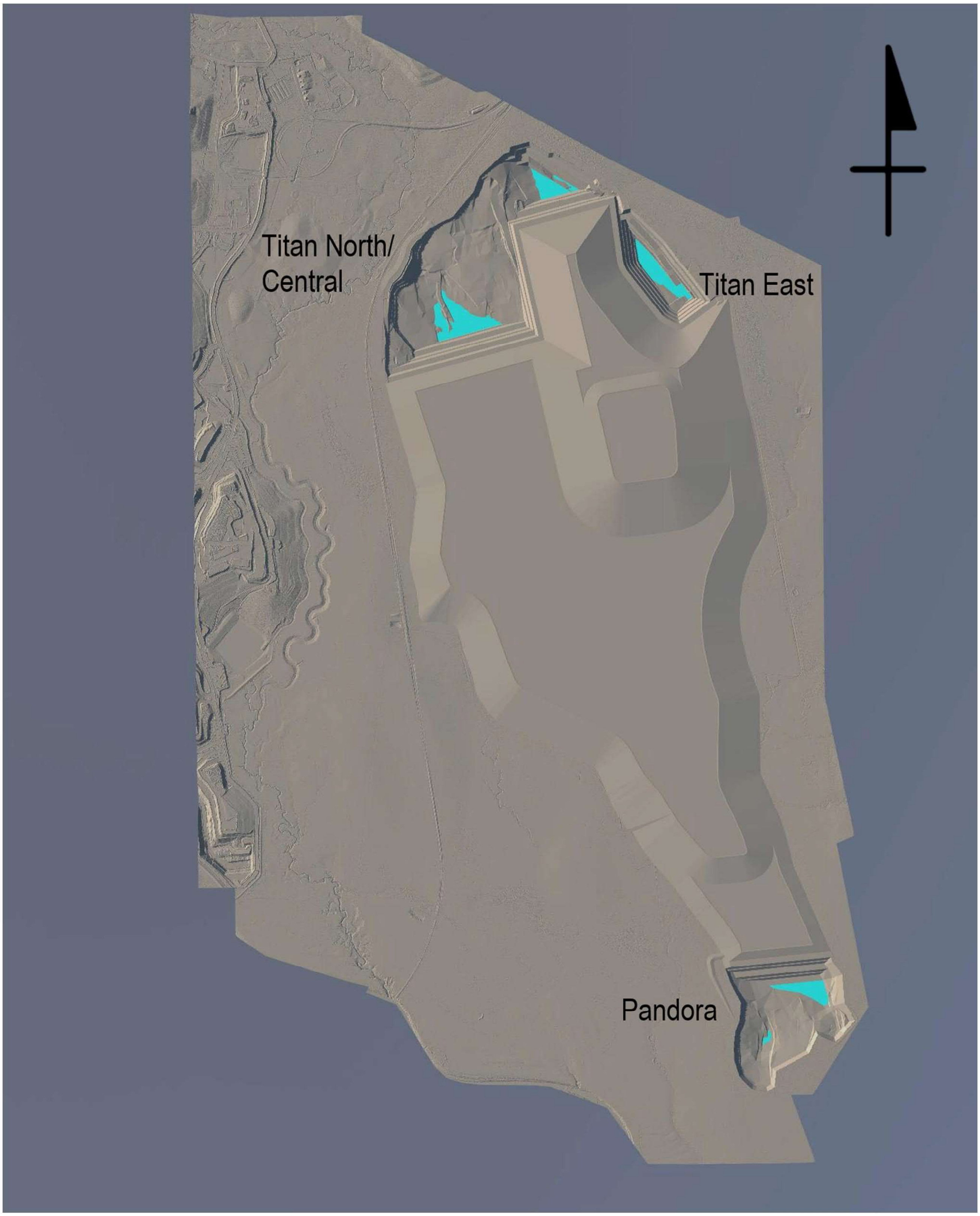

Figure 3.1 3D void design plan: overview of DNM residual voids and void lakes

4 Groundwater

Groundwater assessments were completed to determine groundwater interactions and the potential for contaminant transport at the DNM residual voids (SLR Consulting Australia Pty Ltd, 2023). This section presents the assessment findings, as relevant to void closure at DNM.

A post-mining conceptual site model (CSM) was developed, which depicts groundwater interactions. A visual representation is presented in Figure 4.1 (SLR Consulting Australia Pty Ltd, 2023). The CSM's key findings, relevant to post-mining groundwater impacts for the DNM residual voids, are as follows:

- Void lake formation is predicted, with lake levels stabilising below the pre-mining groundwater elevations and any shallow post-Permian strata including the base of surficial weathering and shallow hydrostratigraphic units (i.e., alluvium and regolith).
- Inward hydraulic flow gradients towards the residual voids will be maintained within the Rangal Coal Measures (RCM) upon stabilisation of groundwater and residual void lake levels. This is driven by evaporative losses from the void lakes, with no outflows of water to the surrounding hydrostratigraphic units predicted to occur.
- Residual voids will continue to capture any seepage from rehabilitated spoil dumps.
- There will be little to no additional impact on surficial aquifers, including the alluvial aquifers, beyond what would have already existed at the time when mining is anticipated to end.
- There will be little to no impact on environmental or anthropogenic receptors.

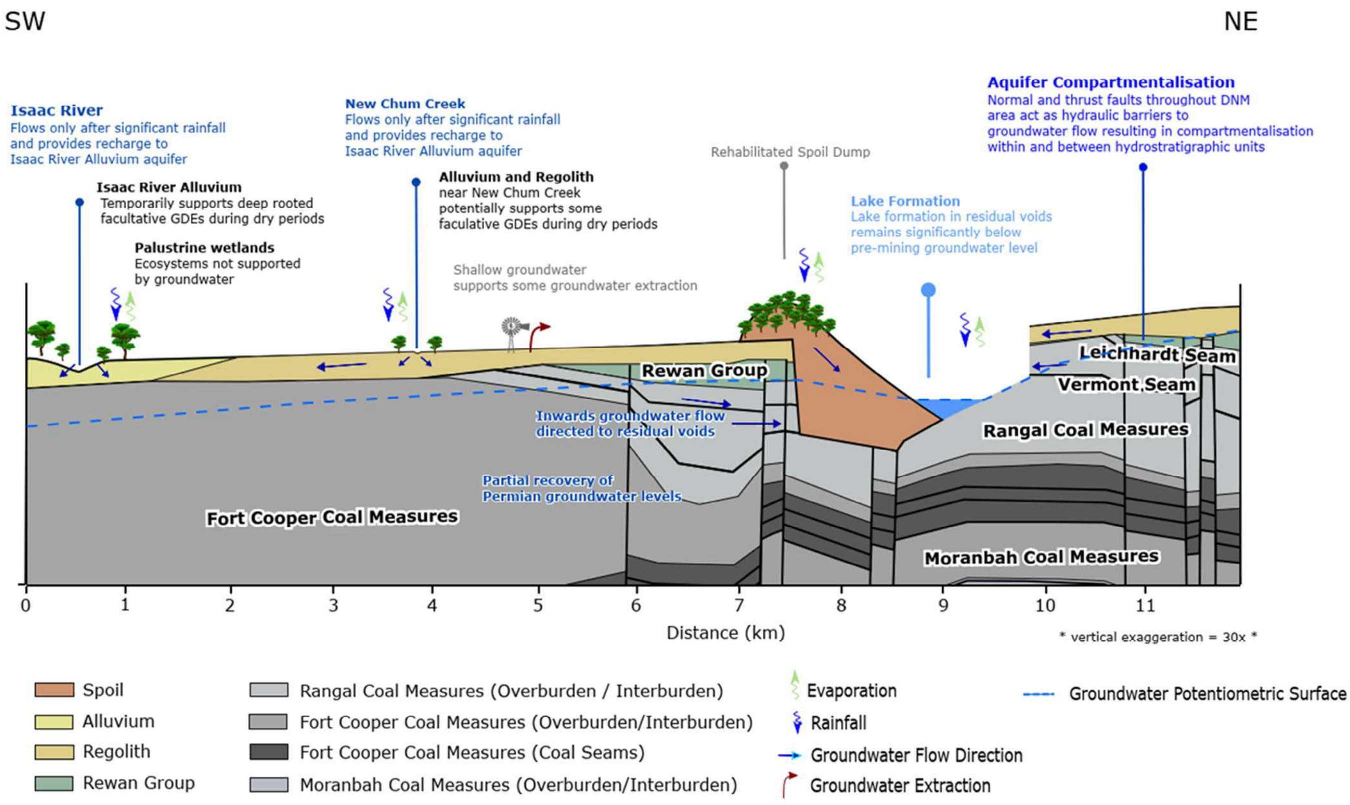

Figure 4.1 Conceptual site model post-mining (SLR Consulting Australia Pty Ltd, 2023)

Calibrated numerical modelling was undertaken (SLR Consulting Australia Pty Ltd, 2023) to evaluate the potential impacts of the final closure state landforms for the DNM residual voids on the groundwater regime. The objectives of the predictive modelling were to:

- Assess groundwater inflow to the final voids.
- Simulate the level and rate of recovery of the void lakes, and the level and rate of mining-related groundwater drawdown recovery in the groundwater system surrounding the voids.
- Identify areas of potential risk, such as private supply bores or groundwater dependent ecosystems (GDEs), where groundwater impact mitigation/control measures may be necessary post-closure.

The final closure state landforms were replicated in the model, including the three DNM residual voids and spoil dumped within mined out pits.

The model timeframe was developed to commence at the end of mining and cover a period of 2,000 years, with over 67 model stress periods (SLR Consulting Australia Pty Ltd, 2023). The predicted end of mining groundwater level was used as the starting heads.

Three climate scenarios (Wetter-R1, Mid-R4, and Drier-R6) from the water balance modelling (refer to Section 6) were adopted to generate three sets of groundwater model predictions to account for climate sensitivity. Groundwater level predictions and the associated discussion herein focus primarily on the mid climate scenario with the Drier-R6 and Wetter-R1 scenarios reported as sensitivities.

The predicted equilibrium (long-term steady state) of the water table elevation adjacent to the final voids is shown in Figure 4.2 for the mid-climate scenario.

The water table is predicted to remain below the pre-mining groundwater levels in the immediate vicinity of each of the residual voids in the long-term, driven by the ongoing groundwater discharge to the void lakes and governed by the lake elevations themselves (Figure 4.2). That is, long-term inwards groundwater flow gradients are maintained post-mining.

Outside of the residual voids themselves, the water table gradients are steepest along the north-east of DNM, adjacent to the Titan East residual void. The gradients surrounding Pandora residual void and to the north and west of Titan North/Central residual void are somewhat shallower (SLR Consulting Australia Pty Ltd, 2023).

Water table drawdown east of DNM extends up to 1 km from the edge of the ML, whereas to the west, drawdown extent is comparatively limited. The water table remains close to pre-mining groundwater elevations in the area along the Isaac River where potential GDEs are mapped (SLR Consulting Australia Pty Ltd, 2023).

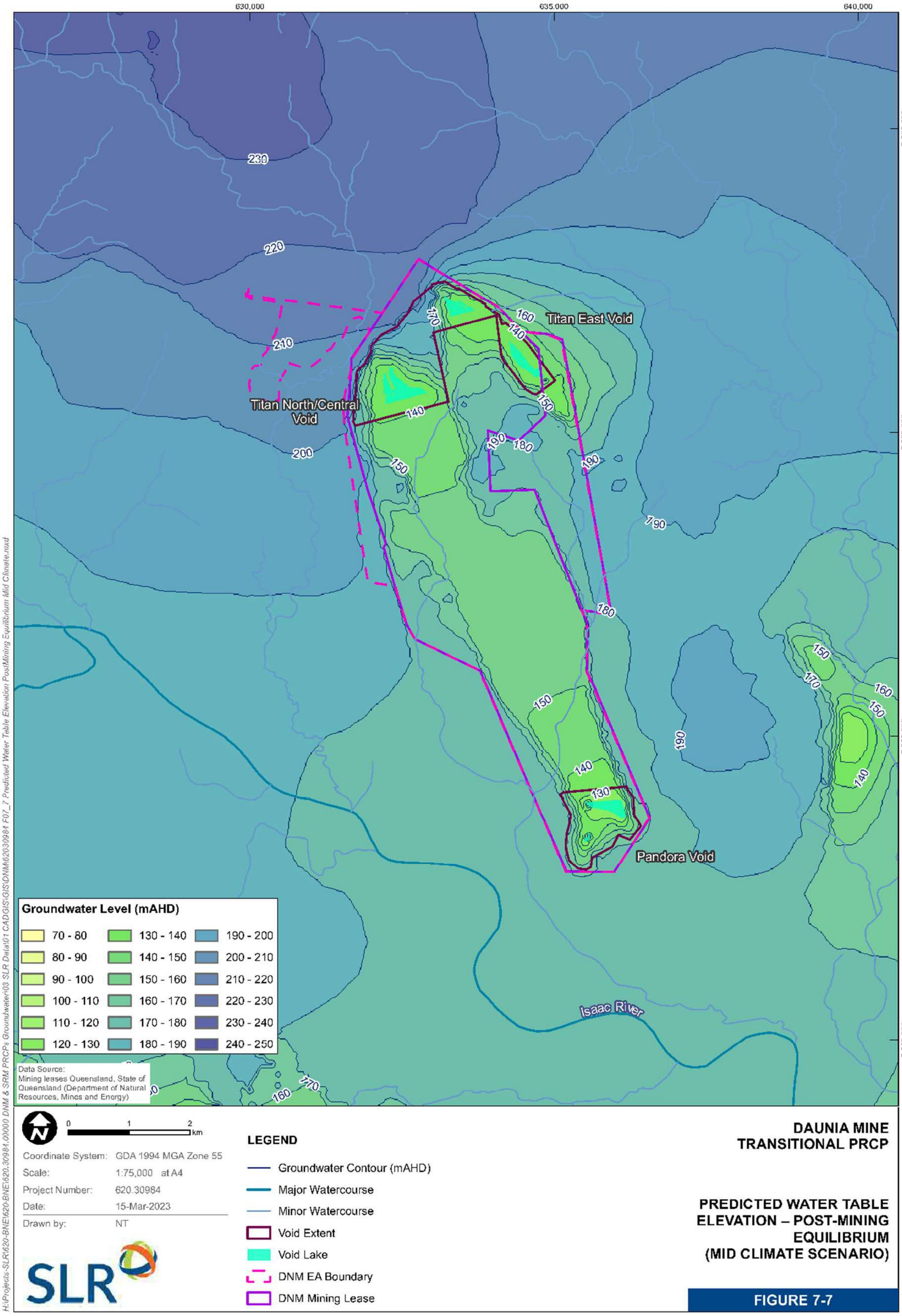

Figure 4.2 Predicted water table elevation – post-mining equilibrium (mid climate scenario) (SLR Consulting Australia Pty Ltd, 2023)

There are periods of fluctuation in inflows and outflows of groundwater predicted by the groundwater model for the Titan East residual void (Figure 4.3) in the first 2 years post-mining, and the first 70 to 80 years post-mining for the Titan North/Central (Figure 4.4) and Pandora (Figure 4.5) residual voids.

During this initial period, groundwater levels are recovering from mine dewatering activities and remain below the residual void lake levels as predicted by the water balance model (WBM) (see Section 6). During this time, modelled groundwater fluxes to the voids are largely controlled by the modelled residual void lake levels that rise and fall periodically according to the climatic simulation applied to the WBM, and how the daily timestep water balance results are translated to the more simplified stress period setup in the groundwater model.

As discussed in Section 6.1, the initial void lake levels will affect when the void lake equilibrium state is reached for each void but not the equilibrium void lake level itself. The initial void lake levels applied are from water balances undertaken prior to development of the final closure state landforms and the starting water levels represent a conservative case that are likely to overestimate the initial potential outflows to groundwater.

Accordingly, there are periods of variable groundwater inflow and outflow predicted by the groundwater model for the Titan North/Central and Pandora voids in the first 70 to 80 years post-mining, as well as some variability in the predicted inflows for all residual voids before the fluctuations begin to smooth out after 150 years post-mining.

Model results display an initial outflow of rainfall derived surface water captured in the residual voids to the spoil surrounding the void lake in the first 2 years post-mining at Titan East residual void, 30 years post-mining at Titan North/Central residual void, and 40 years post-mining at Pandora residual void, as the groundwater levels in the surrounding in-pit spoil landform (and natural geological formations) slowly recover from mining activities. However, as groundwater levels in the spoil and natural geology recover to elevations above the void lakes and lake levels stabilise, the direction of flow out of the void lakes to the spoil is reversed and long-term groundwater inflow to the lakes is established. Post mining, inflow-only conditions prevail after approximately 2 years at Titan East Void, 70 years at Pandora Void, and 80 years at Titan North/Central Void.

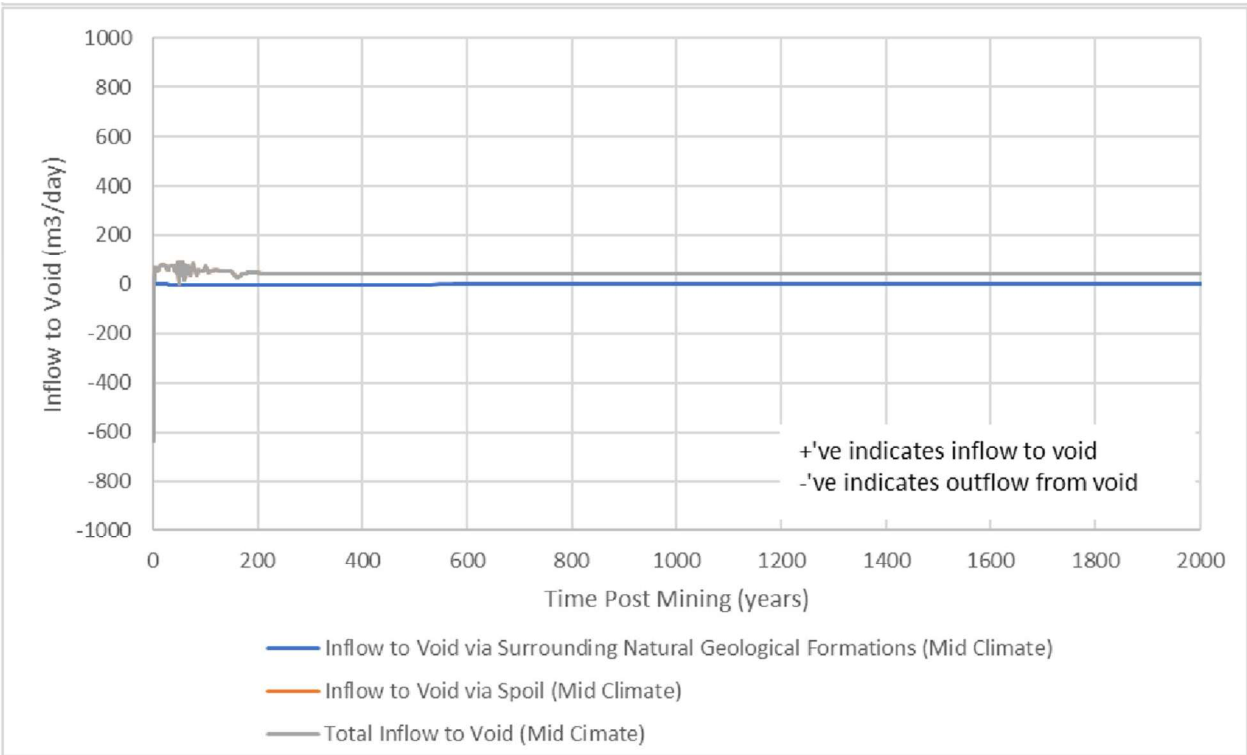

Figure 4.3 Predicted groundwater inflows – Titan East residual void (SLR Consulting Australia Pty Ltd, 2023)

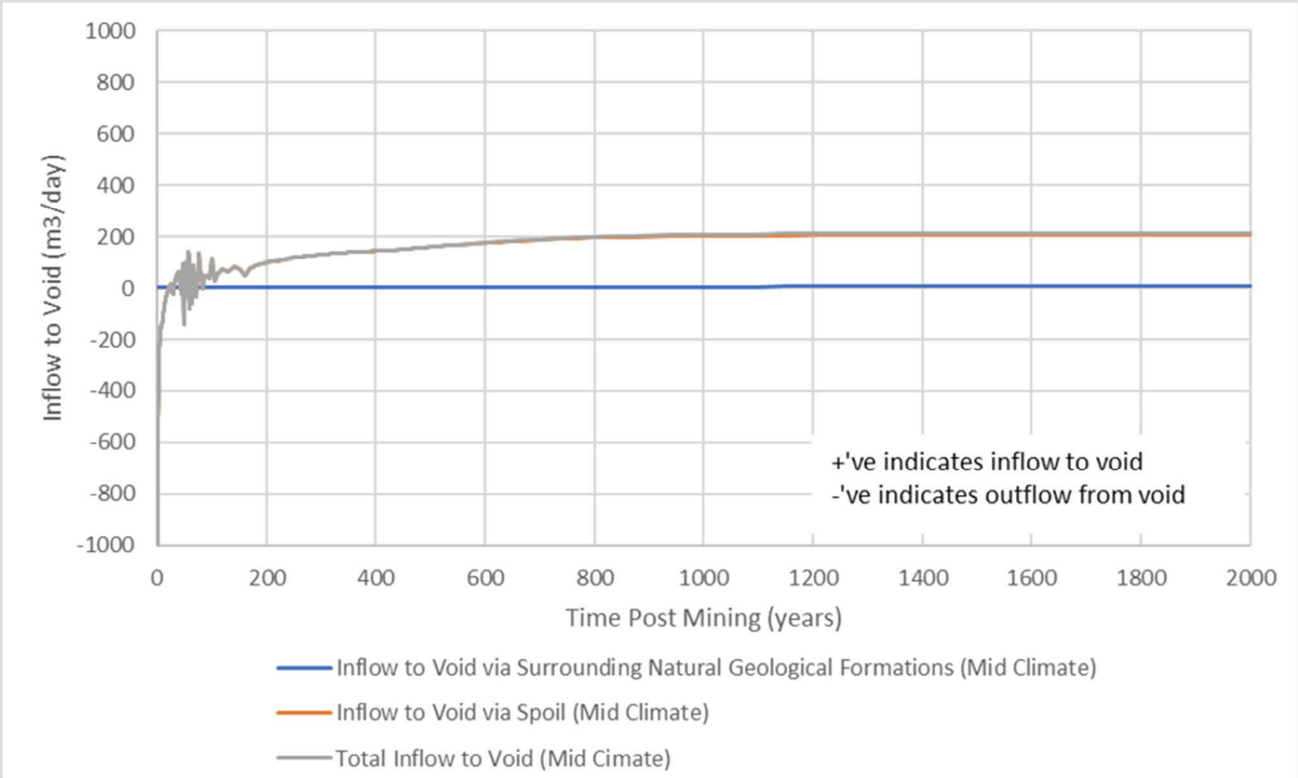

Figure 4.4 Predicted groundwater inflows – Titan North/Central residual void (SLR Consulting Australia Pty Ltd, 2023)

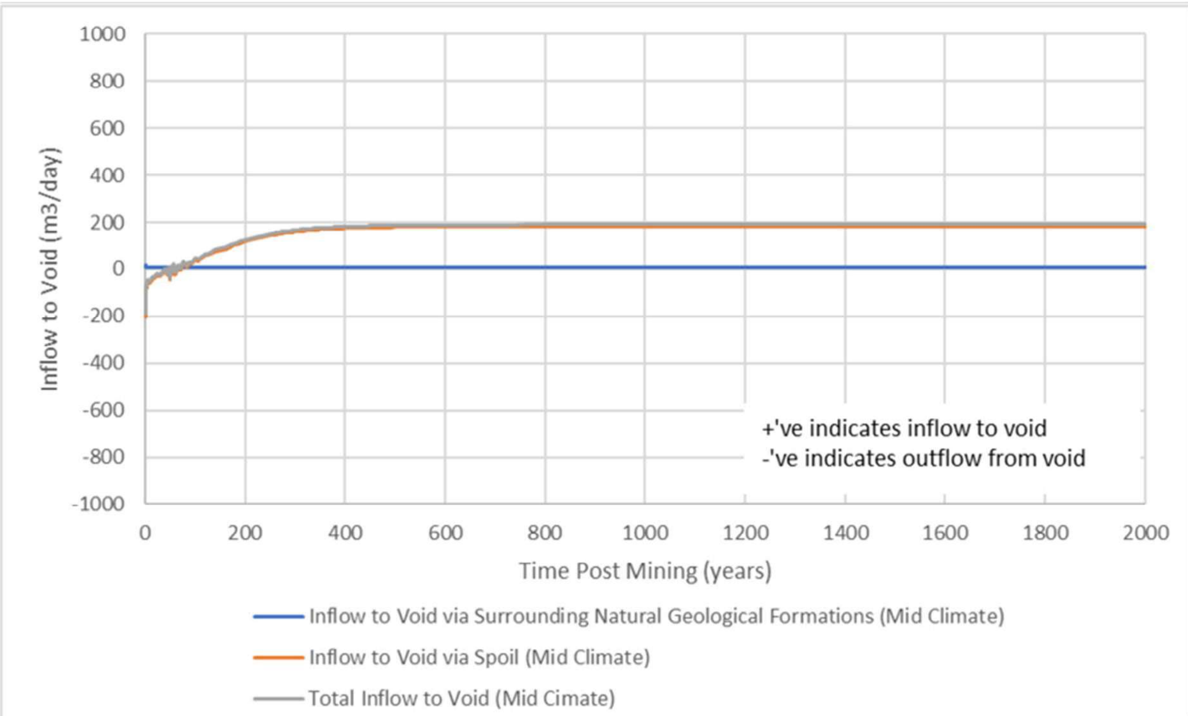

Figure 4.5 Predicted groundwater inflows – Pandora residual void (SLR Consulting Australia Pty Ltd, 2023)

Predictive hydrographs at locations just outside the residual voids (Figure 4.6) show the change in groundwater levels over time for the Leichhardt and Vermont seams of the Permian Coal Measures (Figure 4.7 to Figure 4.9) (note: the hydrograph locations are the same for the Leichardt and Vermont seams). These hydrographs indicate that the initial outflow of water from the residual voids to the spoil does not persist or extend beyond the residual voids themselves. The hydrographs demonstrate that, post-closure, the initial outflow flux of water from the residual voids to the spoil has very little effect on groundwater levels in the early post-closure period. The initial observed water level increase in the hydrographs in Figure 4.8 immediately post-mining in the Titan East Leichardt and Vermont seams is not sustained. The hydrographs continue to decline after this initial increase indicating that the outflow does not result in a significant reversal of the hydraulic gradient due to the absence of a sustained increase in groundwater levels over time. Predicted residual void levels remain significantly below the predicted groundwater levels for the duration of the modelled period indicating no potential for outwards movement of void water to the Leichhardt or Vermont seams outside the residual voids.

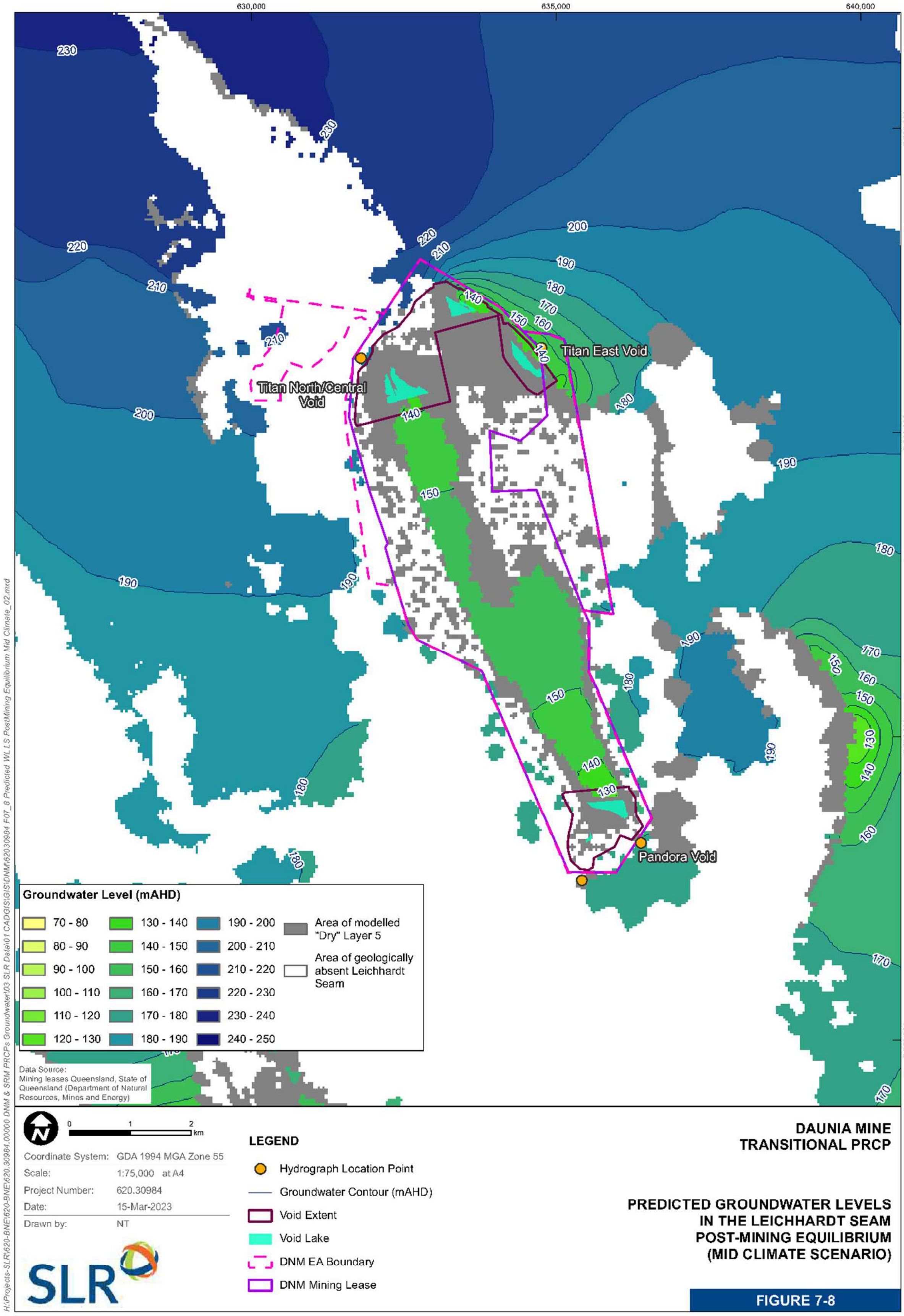

Figure 4.6 Predictive hydrograph locations – Leichardt and Vermont seams (SLR Consulting Australia Pty Ltd, 2023)

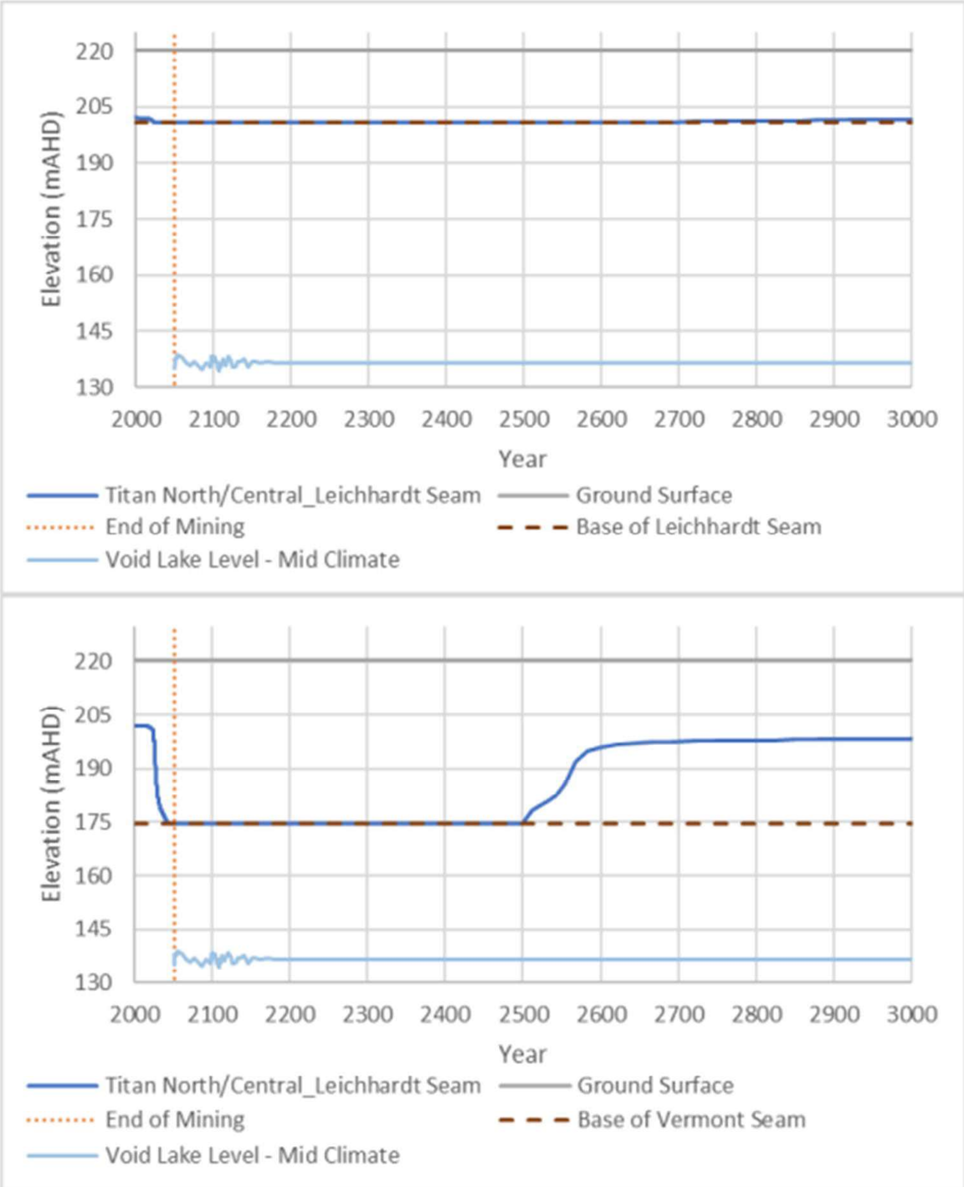

Figure 4.7 Predictive hydrographs for Vermont and Leichardt seams adjacent to Titan North/Central residual void. (SLR Consulting Australia Pty Ltd, 2023)

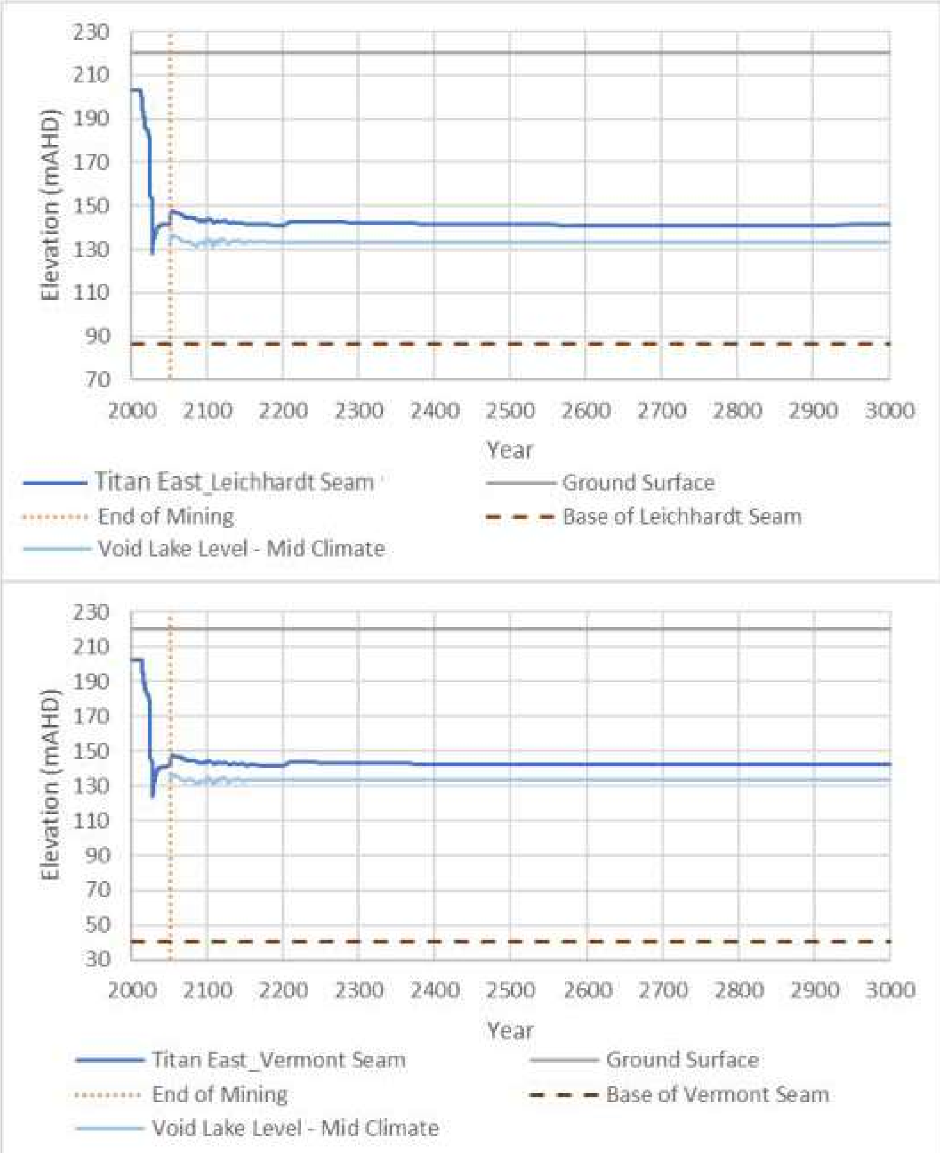

Figure 4.8 Predictive hydrographs for Vermont and Leichardt seams adjacent to Titan East residual void (SLR Consulting Australia Pty Ltd, 2023)

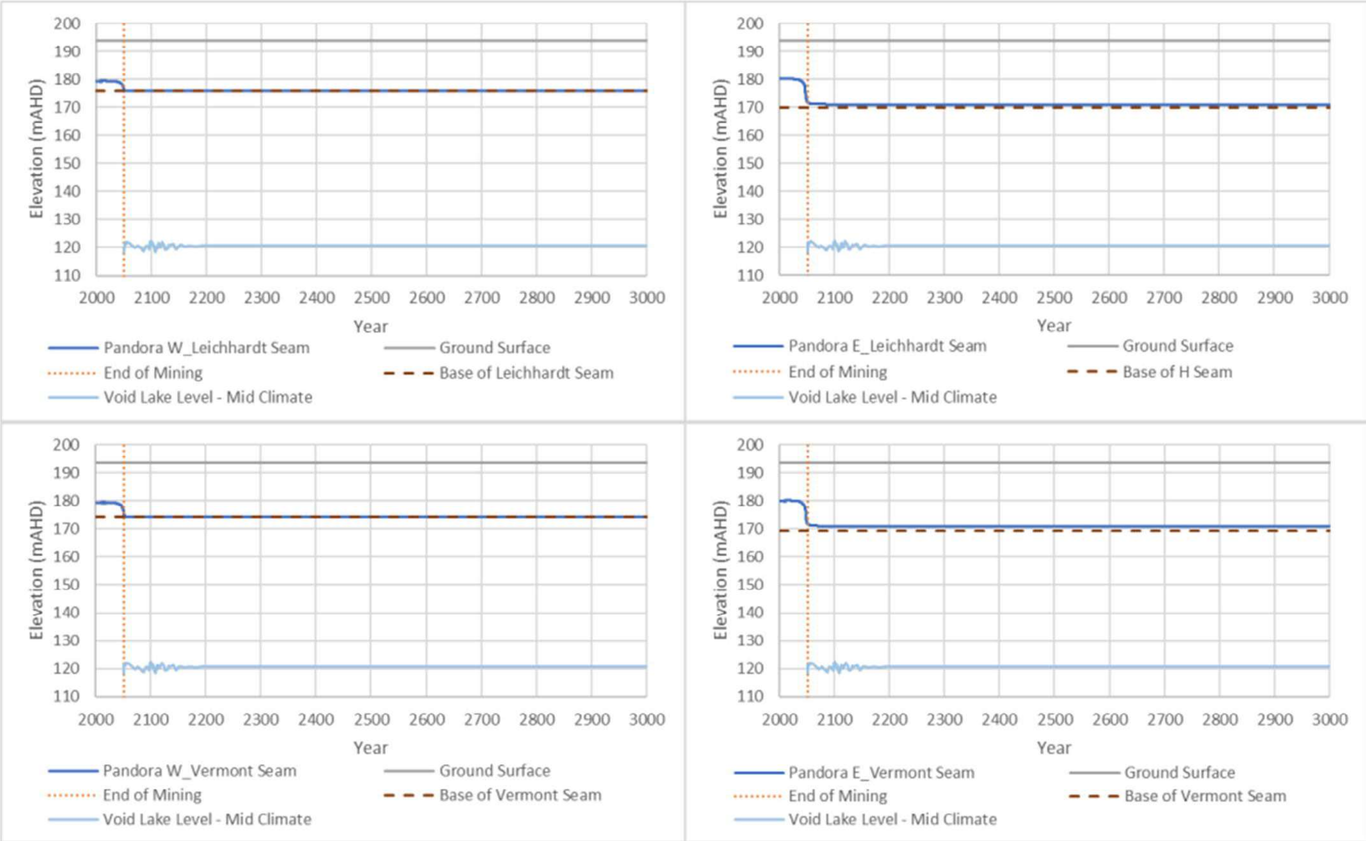

Figure 4.9 Predictive hydrographs for Vermont and Leichardt seams adjacent to Pandora residual void (SLR Consulting Australia Pty Ltd, 2023)

An analysis of the water movement within the final closure state landform, using the mod-PATH3DU code (SLR Consulting Australia Pty Ltd, 2023), was completed to simulate and assess the movement and fate of water particles through the groundwater system post-mining.

The particle movement simulation for particles placed within the residual voids (see Figure 4.10) indicated that groundwater at DNM, including the modelled initial outflows of water from the residual voids to the spoil of the final closure state landform, will remain within the final closure state landform (i.e., rehabilitated spoil and residual voids) in the long-term (SLR Consulting Australia Pty Ltd, 2023). The pathways for particles that are placed within the residual voids at commencement of the simulation do not indicate that they travel outside of the final closure state landform.

Of the particles placed outside of the residual voids, some particles located at the MIA - a potential contaminant source to the west-north-west of Titan North/Central residual void, do not become captured within the final closure state landform but move southwards over the simulation period. No particles are shown to move significantly away from DNM to the broader receiving environment. This potential movement of groundwater beneath the MIA is addressed further within the PRC plan.

The simulation also predicted that all residual avoids would remain as groundwater sinks and the particles do not flow from the residual voids off-site to the receiving environment. All particles originating from DNM remain within the final closure state landform regardless of the climate scenario, with no particles predicted to flow to the receiving environment (SLR Consulting Australia Pty Ltd, 2023).

Although initial outflows of water captured in the residual voids to the spoil is predicted to occur, no environmental harm is expected to result beyond that of the voids themselves from these minor fluctuations. This is due to the initial outflows to the spoil areas returning to the residual voids once groundwater levels and lake levels stabilise. This is supported by the groundwater modelling, particle tracking, and the absence of third-party bores and GDEs within the spoil areas of the residual voids.

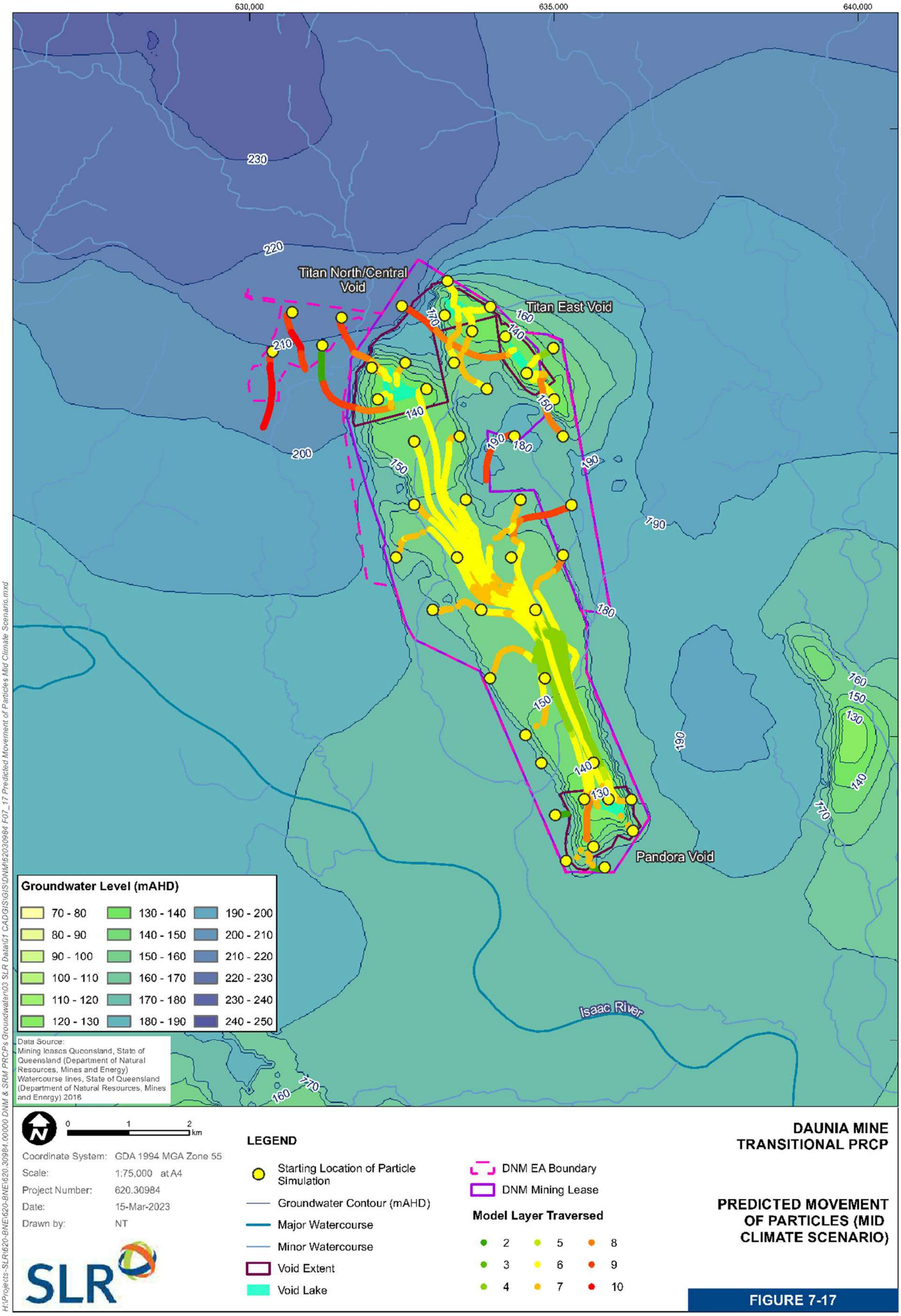

Figure 4.10 Predicted movement of particles from particle tracking – mid climate scenario (SLR Consulting Australia Pty Ltd, 2023)

Predictive hydrographs, derived from the groundwater model, at the potential GDE sites identified in and adjacent to the DNM area (Figure 4.11) indicate that most water table drawdown in the vicinity of the potential GDEs is predicted to occur prior to the end of mining (i.e., associated with approved DNM mining operations), with comparatively little additional drawdown occurring over the post-mining period.

Given the initial predicted depth to the water table prior to DNM operations commencing exceeds 10 m, this is at a depth that indicates the total plant groundwater use would be negligible (SLR Consulting Australia Pty Ltd, 2023). Some recovery of the groundwater levels is also evident in the post-mining period. (Note: there was no difference in the hydrographs for the drier or wetter climate scenarios).

The hydrographs suggest that the additional drawdown impacts that occur post-mining are residual impacts from approved previous active mining activities (i.e., a time lag from active mining); as well as regional scale effects from DNM along with several other approved nearby mining operations, rather than new impacts caused by the final closure state landform design. Therefore, significant impacts to GDEs are not anticipated from the final closure state landform design (SLR Consulting Australia Pty Ltd, 2023).

Predictive hydrographs were derived from the groundwater model for the 10 identified third-party water supply bores with sufficient information to attribute a source aquifer (Figure 4.11). These hydrographs show negligible additional post-mining groundwater drawdown at most bores and recovery of groundwater levels in some of these bores. The maximum, yet still relatively small drawdown (approximately 0.4 m), is predicted post-mining for the third-party water supply bore (Bore 3) located approximately 2.7 km south of the Pandora residual void. (Note: there was no difference in the hydrographs for the drier or wetter climate scenarios).

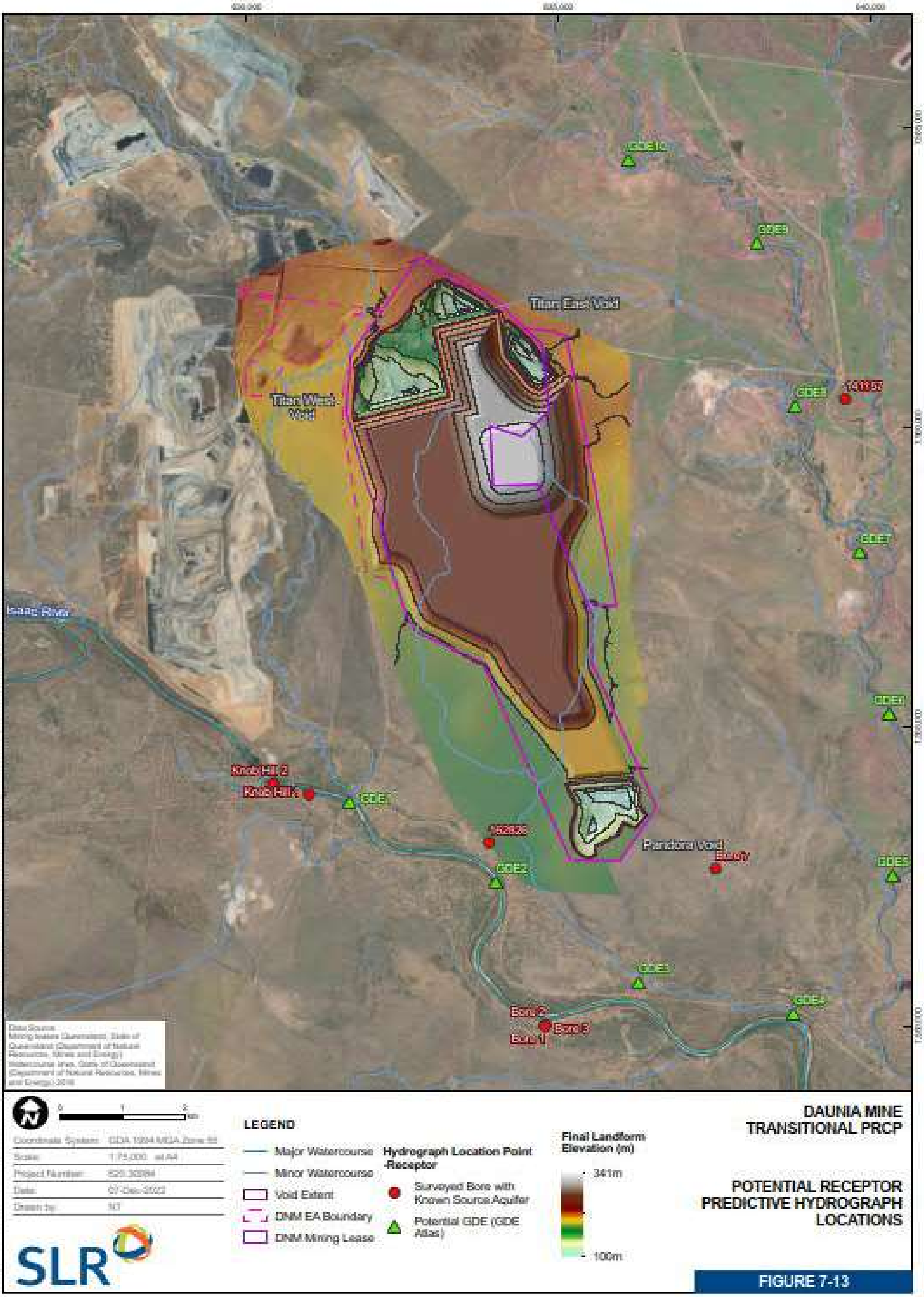

Figure 4.11 Locations of potential GDEs and third-party water supply bores (SLR Consulting Australia Pty Ltd, 2023)

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 Titan East, Titan North/Central and Pandora residual voids. This section presents the assessment findings, as relevant to void closure at DNM.

5.1 Voids in floodplains

The locations of the pre-approved NUMAs (three DNM residual voids) are not identified in the LOD (EA EPML00561913). Therefore, in accordance with Section 3.4 of the DES *PRC Plan Guideline* transitional provisions, an assessment of voids in flood plains has been undertaken. As a conservative approach, the final void extents used for the voids in flood plain assessment were the preliminary extents of the final voids - prior to any final closure state landform design considerations and final void land forming that provides for flood protection.

The flood plain assessment of the pre-mining landform identified that Pandora Pit would be partially located within the modelled floodplains of the Isaac River. The remaining pits are located outside the floodplain in the 0.1% AEP event (SLR Consulting Australia Pty Ltd, 2023a). It should be noted that this initial hydraulic modelling was conducted on the initial landform design locations, not the final closure state landform. For the final closure state landforms, the extents of the residual voids have been reduced and refined to reduce the environmental impact through out-of-pit land-forming for the final residual voids and placement of landforms such as spoil dumps.

5.2 Rehabilitated landform flooding

For the final closure state landform, rehabilitation flood modelling was undertaken to predict the 0.1% AEP flood event inundation extent, including the predicted peak flood levels (including Probable Maximum Flood) and depths for post-mining conditions (WMS Engineering, 2022). Hydrologic modelling estimated runoff hydrographs that informed the hydraulic modelling. The programs XP-Rafts and TUFLOW 2D were utilised for the hydrologic and hydraulic modelling and the catchments of the Isaac River, New Chum Creek and North Creek were included. The hydraulic model was developed, covering the three watercourses, to determine flood behaviour around the final closure state landforms associated with the residual voids.

Effects of climate change through the increase in rainfall intensity were considered in the hydrological analysis, with the upper climate change Representative Concentration Pathways (RCPs) 8.5 at or above the 90th percentile (RCP 8.5 P90) scenario modelled as the upper rainfall for a 28% rainfall intensity increase. RCPs are projections of greenhouse gas and aerosol concentrations (pathways); together with land use change, they are consistent with a set of broad climate outcomes adopted by the Intergovernmental Panel on Climate Change and used by the climate modelling community.

For the final closure state landform, the final residual voids are not impacted by inundation from floodwaters from the Isaac River or New Chum Creek up to and including the 0.1% AEP under the climate change RCP 8.5 P90 scenario. Modelling indicated that the Pandora residual void was subject to minor floodwater ingress under the RCP 8.5 P90 scenario due to the presence of a drainage feature to the east of the residual void (WMS Engineering, 2022). The climate scenario is considered conservative for assessing the flood risk. With the WBM predicting the available storage capacity in Pandora residual void of between 26,800 and 27,800 ML before reaching the groundwater level, if the floodwater ingress eventuated, the volume of floodwater ingress predicted (approx. 1,800 ML) is not expected to impact the available storage capacity (and, hence, sink functionality) of the residual void.

Figure 5.1 shows the final closure state landform and the modelled peak flow depths for Isaac River and New Chum Creek for the 0.1% AEP under the climate change RCP 8.5 P90 scenario.

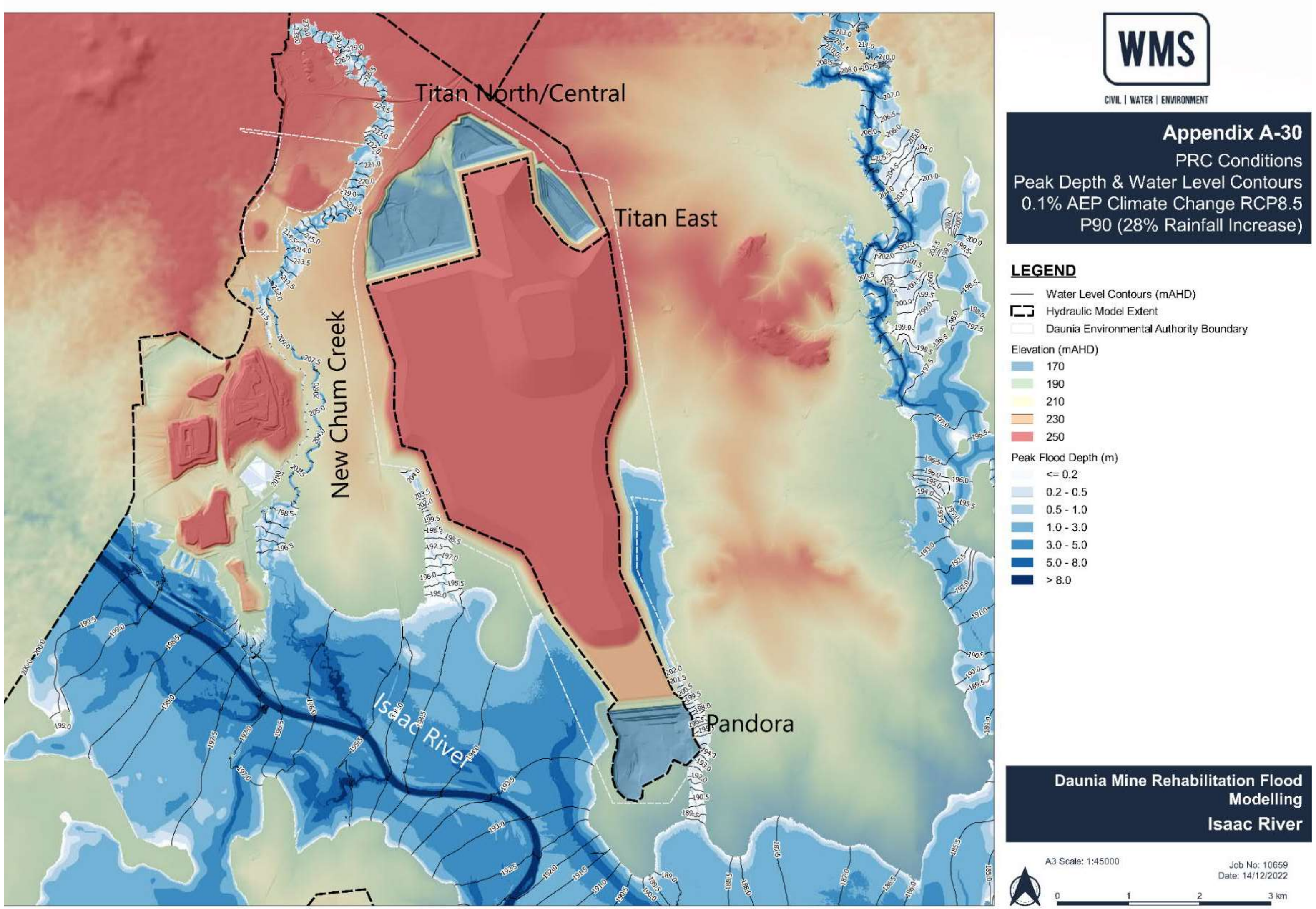

Figure 5.1 Modelled peak flood depths for Isaac River and New Chum Creek for the final closure state landform (0.1% AEP climate change RCP 8.5 P90 scenario) (WMS Engineering, 2022)

There are several locations across the DNM final closure state landform where floodwaters make contact with the landforms. However, as these locations are at the edge of the floodplain, the velocities and stream power are generally low. Locations where velocity and stream power are higher than the surrounding areas will be managed in accordance with Section 9 as required.

A Flood Risk Profile (FRP) was developed based on the hydrologic and hydraulic model results, using the framework provided in BHP's Risk Management Guideline. The FRP outcome was that the risk in terms of Maximum Foreseeable Loss was rated below four and therefore no control measures are required to be identified (WMS Engineering, 2022).

6 Void Water Balance

A void water balance assessment was completed to determine the behaviour of the DNM 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 DNM, 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 landforms 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 DNM residual voids incorporated direct rainfall, surface water runoff, groundwater interactions, and evaporation. A model period of approximately 149 years was selected - this covered the period for the different closure years for the pits based on the current projected mine plan, from the first closure year (2051) through to 2199, with a daily time-step. No operational processes (i.e., pumping or transfers to/from the assessed structures) were considered as being active for the period modelled.

6.1.1 Catchment areas

The conceptual final closure state landform for the DNM residual voids limits the surface catchment areas as far as practicable and are primarily limited to the low-wall areas (Figure 6.1). This final closure state landform was used to generate contour lines and calculate the drainage network of the area; these were then used to delineate the catchment areas for all voids. The catchment subdivision of each void was estimated by analysing a slope map, generated using the software *QGIS*. This slope map recognises zones with ‘flat’ slopes and zones with downward slopes. This information was then used to delineate the void catchment areas into three areas: natural, void, and rehabilitated. The natural zone was assigned as the area that will remain undisturbed, while comparing the proposed residual voids’ landform and the current topography of the area. The ‘rehabilitated’ and ‘void’ area make up the remainder of the catchment areas for each void. The delineation of each area is presented in Figure 6.1 and Table 6.1.

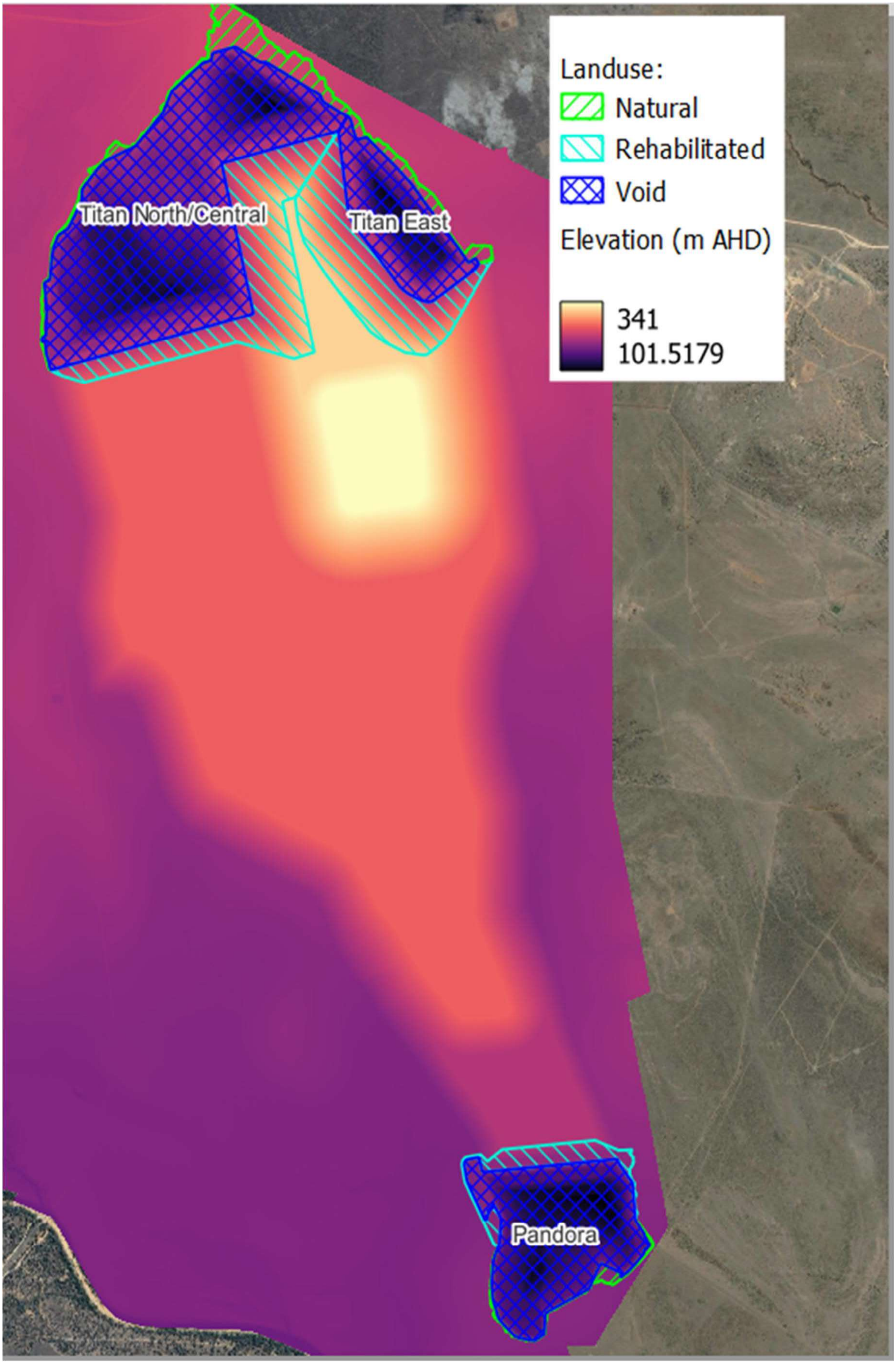

Figure 6.1 Catchment delineation for the Daunia residual voids water balance modelling

Table 6.1 Catchment areas for the Daunia residual voids water balance modelling

Surface Catchment	Titan East (Ha)	Titan North/Central (Ha)	Pandora (Ha)
Natural	10	29	3
Rehabilitated	77	100	21
Void	66	275	120
Total	**153**	**404**	**144**

Stage-storage relationships were derived from the residual voids closure landform to obtain the relationship between lake elevation and volume/surface of the lake, as shown in Figure 6.2 to Figure 6.4. These relationships were used in the WBM to estimate the lake surface area and elevation based on the lake volume for each modelled time-step.

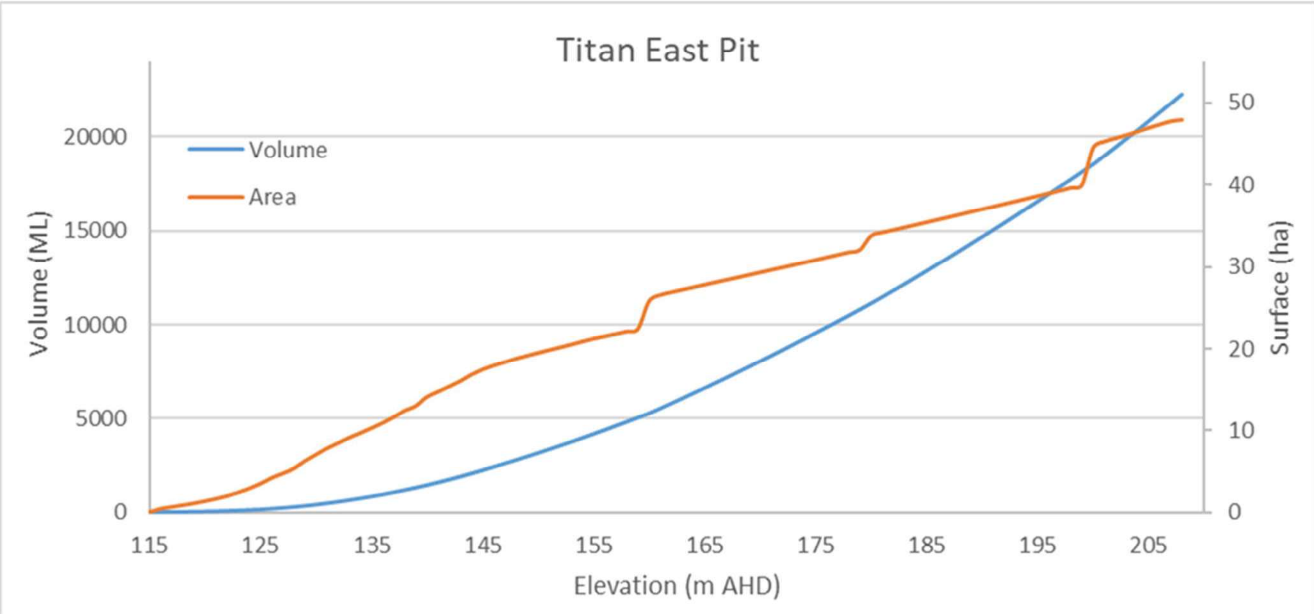

Figure 6.2 Titan East residual void stage-storage relationship used for water balance modelling

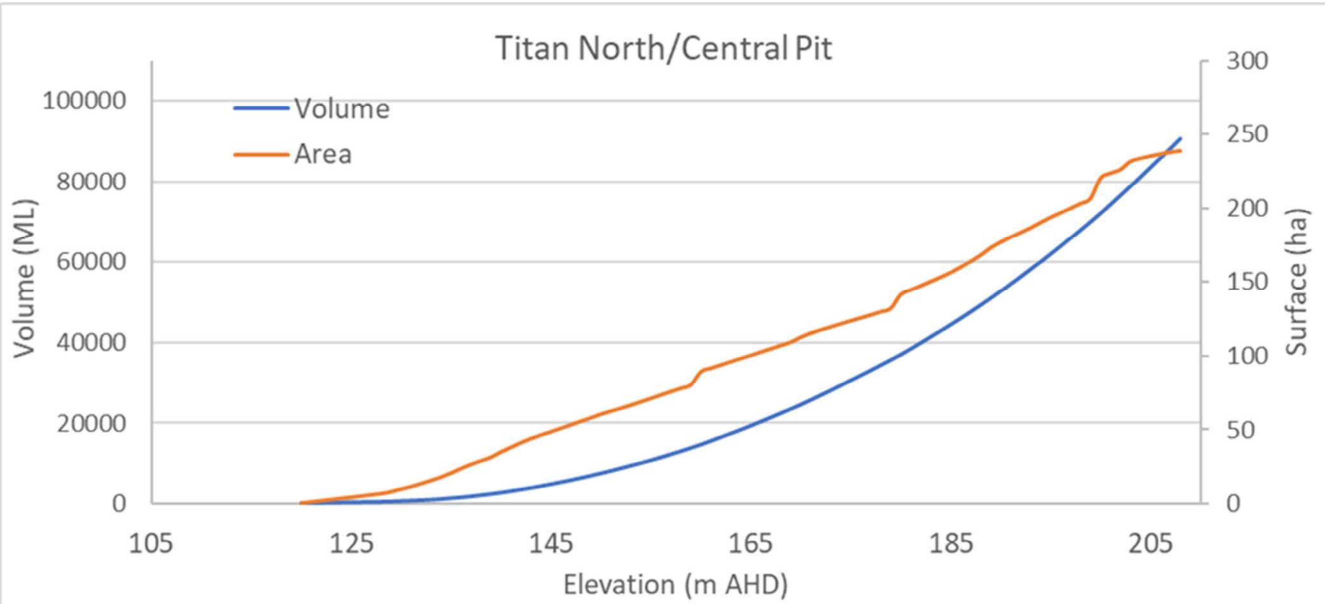

Figure 6.3 Titan North/Central residual void stage-storage relationship used for water balance modelling

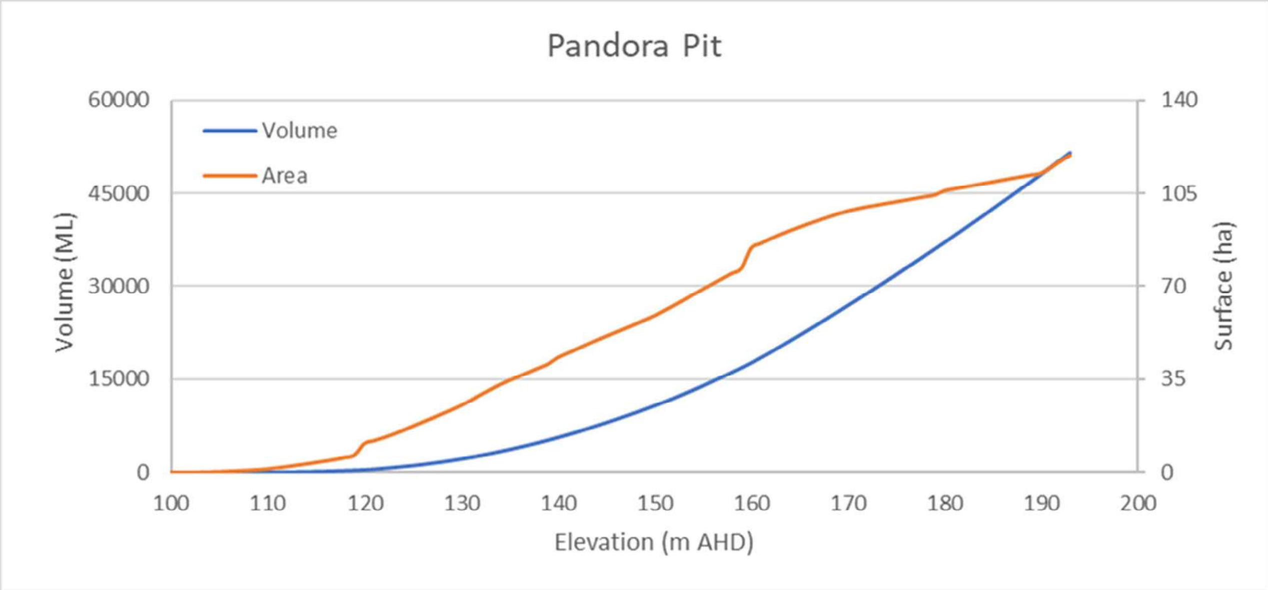

Figure 6.4 Pandora residual void stage-storage relationship used for water balance modelling

At the start of the WBM, the *Rational Method* was applied to estimate the initial void lake level at equilibrium for the DNM residual voids (WRM, 2021). The initial void lake levels were derived from water balance estimates undertaken prior to achieving the catchment area reductions of the final closure state landforms. Therefore, the initial void lake levels are likely to represent a conservative case where more water is present in the void lakes initially. The final closure state landform was analysed to determine the spill elevation of each of the voids. Estimated initial void lake levels and spill elevations (in metres Australian Height Datum (m AHD)) used in the WBM are presented in Table 6.2.

Table 6.2 Initial void lake levels and spill elevation for each residual void at Daunia

	Titan East	Titan North/Central	Pandora
Initial void lake level (m AHD)	133	133	116
Spill level (m AHD)	208	208	193

To determine the impact that these conservative initial void lake levels may have on final void lake levels, a sensitivity analysis was completed. Different initial void lake levels were applied for each void and run through all three climate realisations (climate realisations explained in Section 6.1.4). The different initial void lake levels used are presented in Table 6.3 and the mean final void lake levels (across the three climate realisations) are presented in Figure 6.5 to Figure 6.7.

The sensitivity analysis indicates that for all the cases studied in this assessment, the initial void lake level does not influence the final volumes/levels obtained at the end of the simulation period but appears to affect when the equilibrium state is reached. The analysis tends to result in an overall convergence of all the sensitivity cases for all three residual voids.

Table 6.3 Changes to initial void lake level parameters for Daunia water balance model sensitivity analysis

Change in initial void lake elevation (m)	Initial void lake elevation (m AHD)		
	Titan East	Titan North/Central	Pandora
20	153	153	136
10	143	143	126
-10	123	123	106
-20	113	113	96

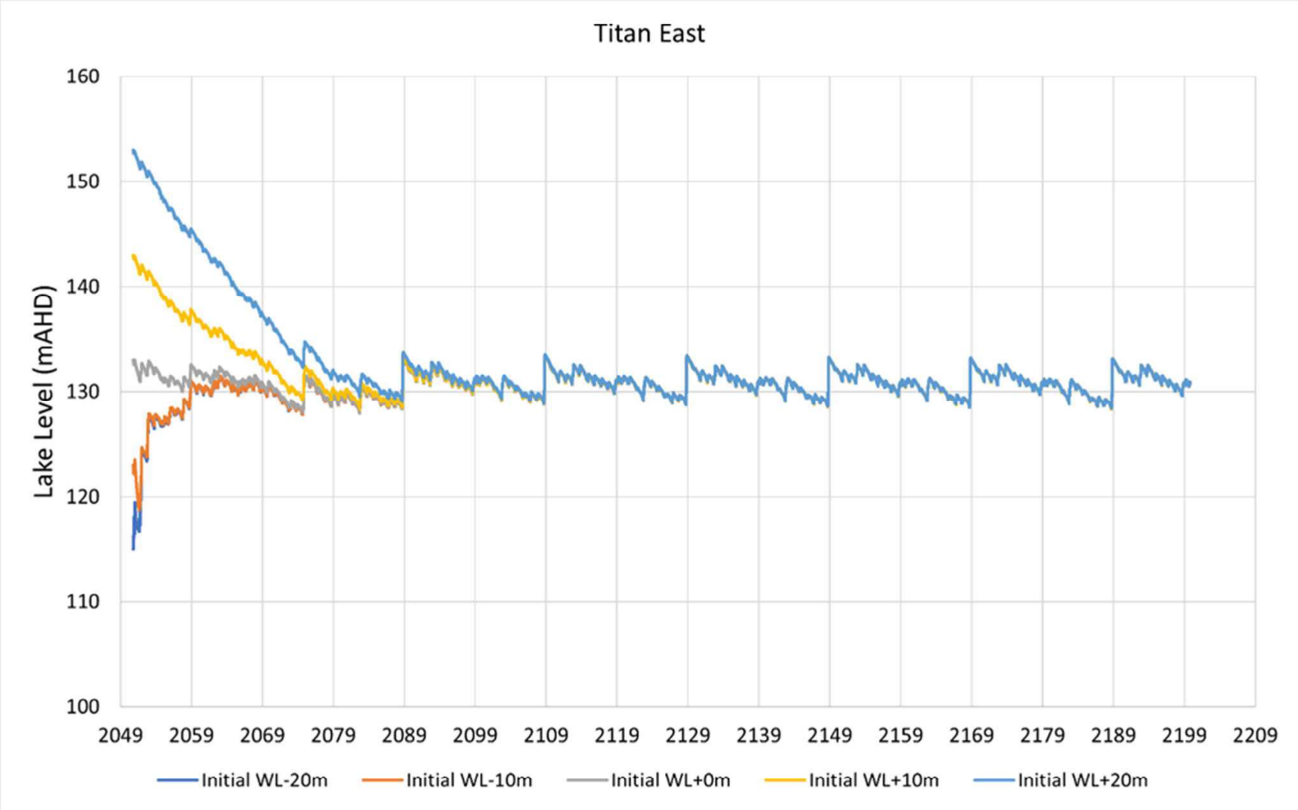

Figure 6.5 Sensitivity analysis results for changed initial void lake level for Titan East residual void (lake level)

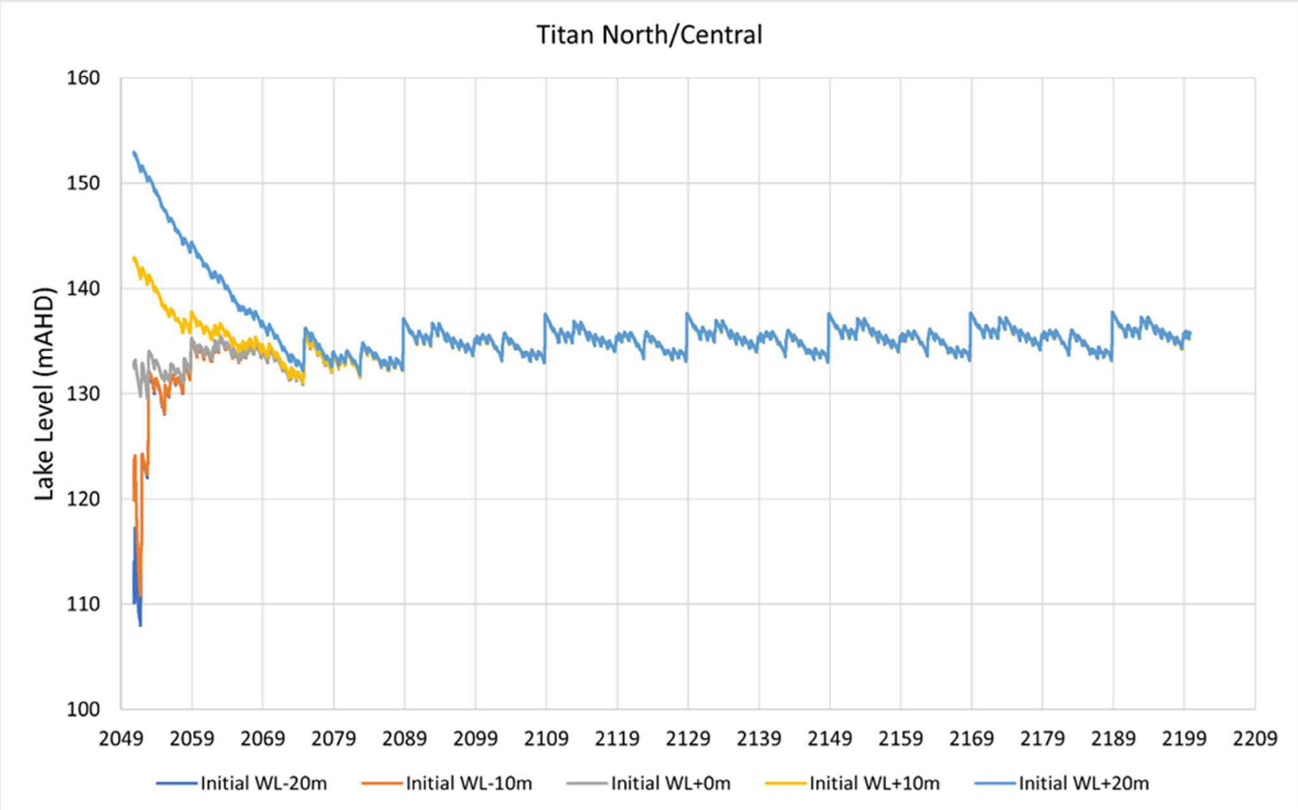

Figure 6.6 Sensitivity analysis results for changed initial void lake level for Titan North/Central residual void (lake level)

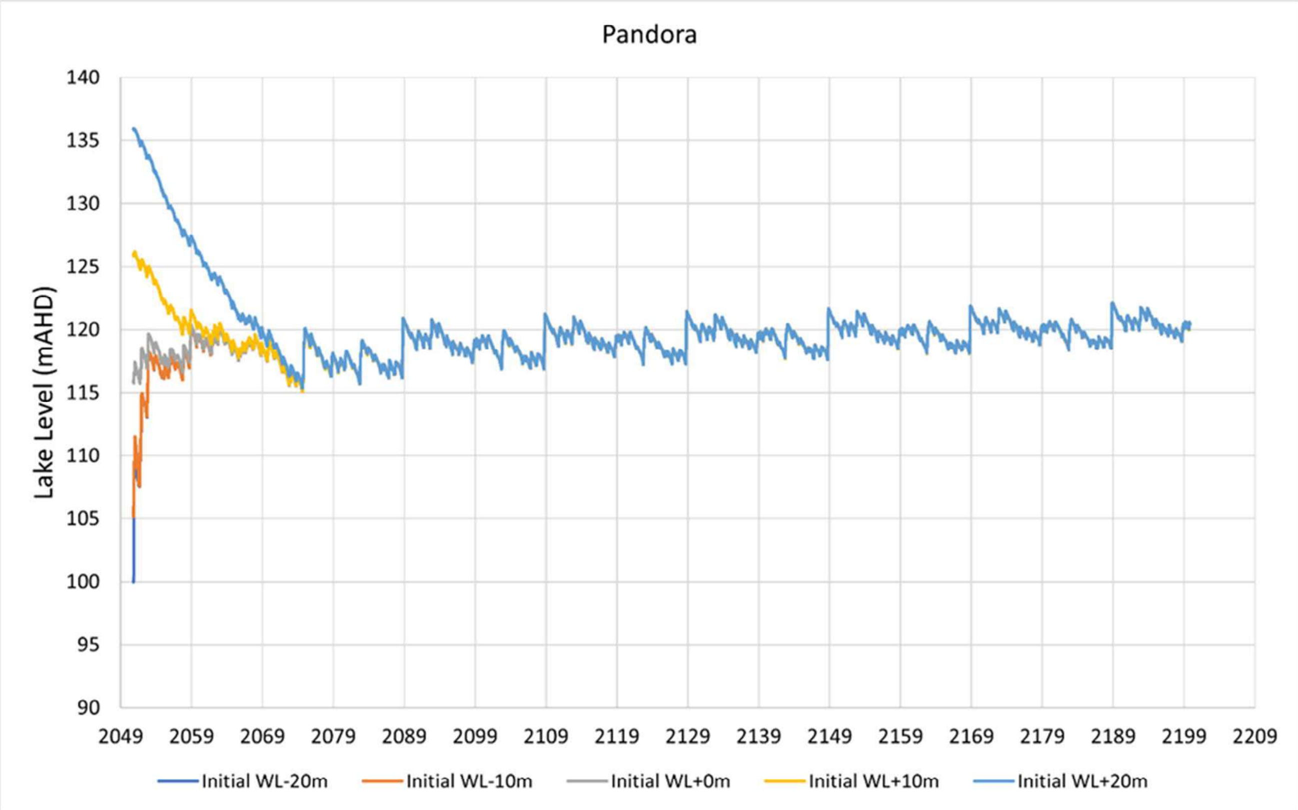

Figure 6.7 Sensitivity analysis results for changed initial void lake level for Pandora residual void (lake level)

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 supplied by BMA (BMA, 2022) 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, as shown in Figure 6.8 and presented in Table 6.4. Each capacity, in millimetres (mm), is added together with fractional areas for weights, which are summarised in Table 6.5.

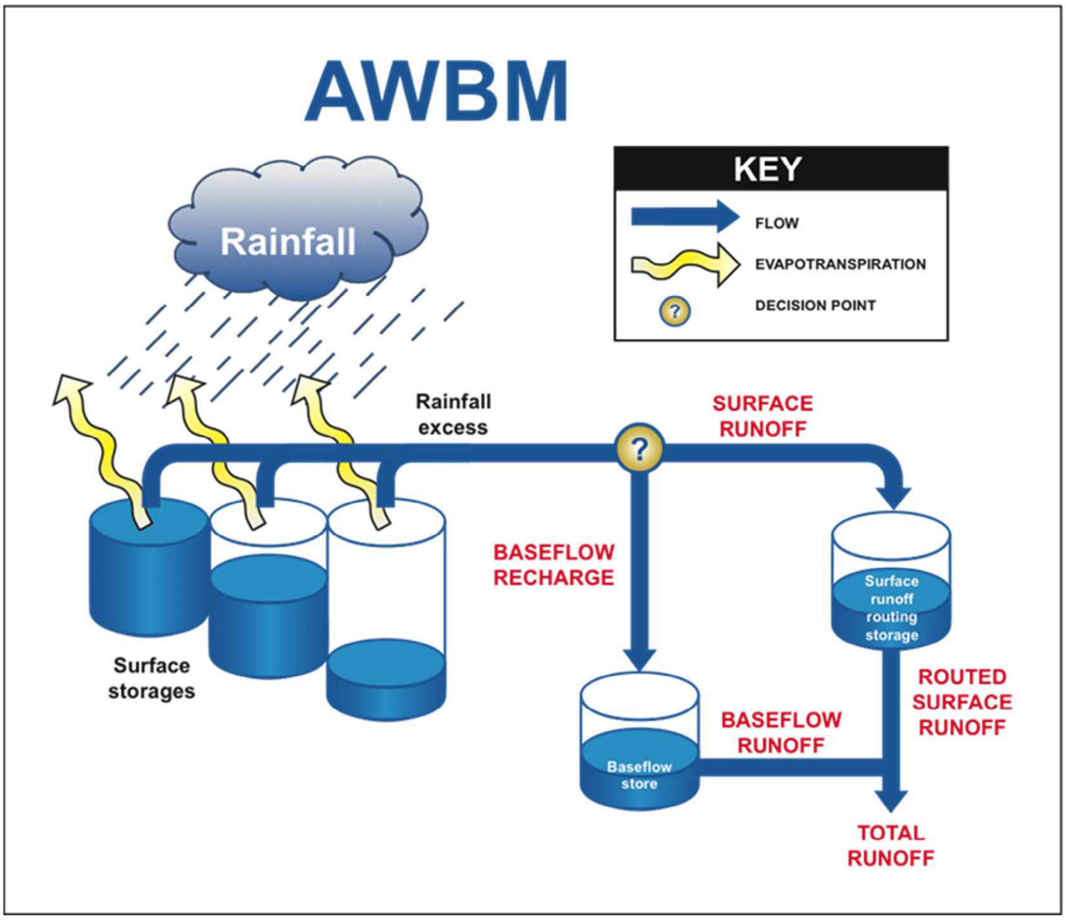

Figure 6.8 Structure of Australian Water Balance Model rainfall-runoff model, including small, medium, and large surface storages

Table 6.4 Surface storage capacities applied to the water balance model for Daunia residual voids (BMA, 2022)

Area	Small (mm)	Medium (mm)	Large (mm)
Natural	10	80	200
Void	5	20	35
Rehabilitated	10	70	175

Table 6.5 Surface storage proportions applied to the water balance model for Daunia residual voids (BMA, 2022)

Area	Small (mm)	Medium (mm)	Large (mm)
Natural	0.134	0.433	0.433
Void	0.134	0.433	0.433
Rehabilitated	0.134	0.433	0.433

The baseflow and channel parameters required for the AWBM are summarised in Table 6.6. Surface water runoff considers flows as daily averages and does not include effects of high intensity and short duration events.

Table 6.6 Baseflow and channel parameters applied to the water balance model for Daunia residual voids (BMA, 2022)

Area	Baseflow index	Channel coefficient (1/day)	Baseflow coefficient (1/day)
Natural	0.35	0.1	0.7
Void	0.1	0.1	0.6
Rehabilitated	0.35	0.075	0.7

6.1.3 Groundwater inflows

Closure simulations for the three climate scenarios (see Section 6.1.4) were conducted using a numerical groundwater model (SLR Consulting Australia Pty Ltd, 2023). Time-series data from these simulations, showing groundwater inflow rates into each of the DNM residual voids post-closure, are presented in Figure 6.9 to Figure 6.11. These inflow rates were used in the WBM. The numerical groundwater model's time-series inflow rates allow for potential seepage between the voids.

As discussed in Section 4, the initial and periodic modelled groundwater outflows from the residual voids are largely controlled by the initial lake levels adopted and the modelled residual void lake levels that respond to the climatic simulation applied to the WBM. The groundwater fluxes are also controlled by how the water balance results are translated to the groundwater models stress period set-up. The seasonality of the precipitation - as discussed in the '*Climate change considerations*' section below, generates a seasonality of volume stored in the voids, particularly in the case of R6 climate change simulation. A rapid increase in the residual void lake levels and volumes is observed due to a storm event of almost 500 mm occurring over a period of three days around the year 2088 to 2089, which is repeated every 20 years. The corresponding modelled cyclical groundwater outflows are less dramatic as the groundwater levels recover. As discussed in Section 4, these minor modelled fluctuations to the spoil areas return to the residual voids once groundwater levels and lake levels stabilise. The groundwater modelling and particle tracking indicate that no environmental harm is expected to result beyond that of the residual voids themselves.

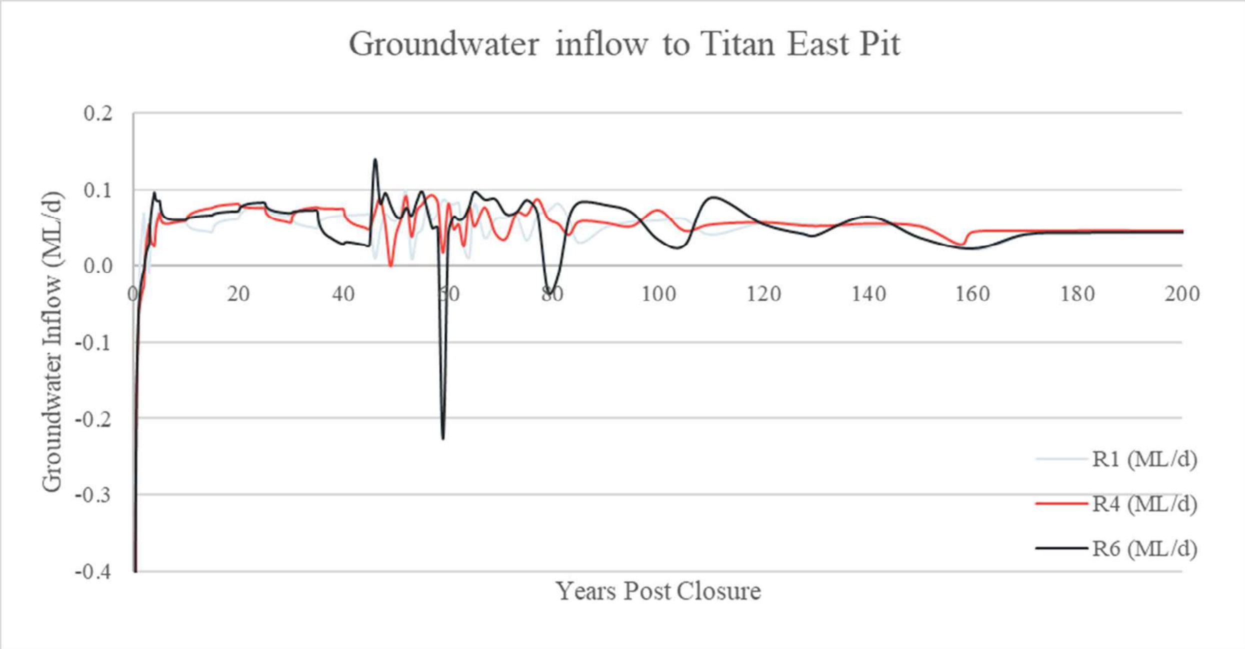

Figure 6.9 Groundwater inflows to Titan East residual void (SLR Consulting Australia Pty Ltd, 2023)

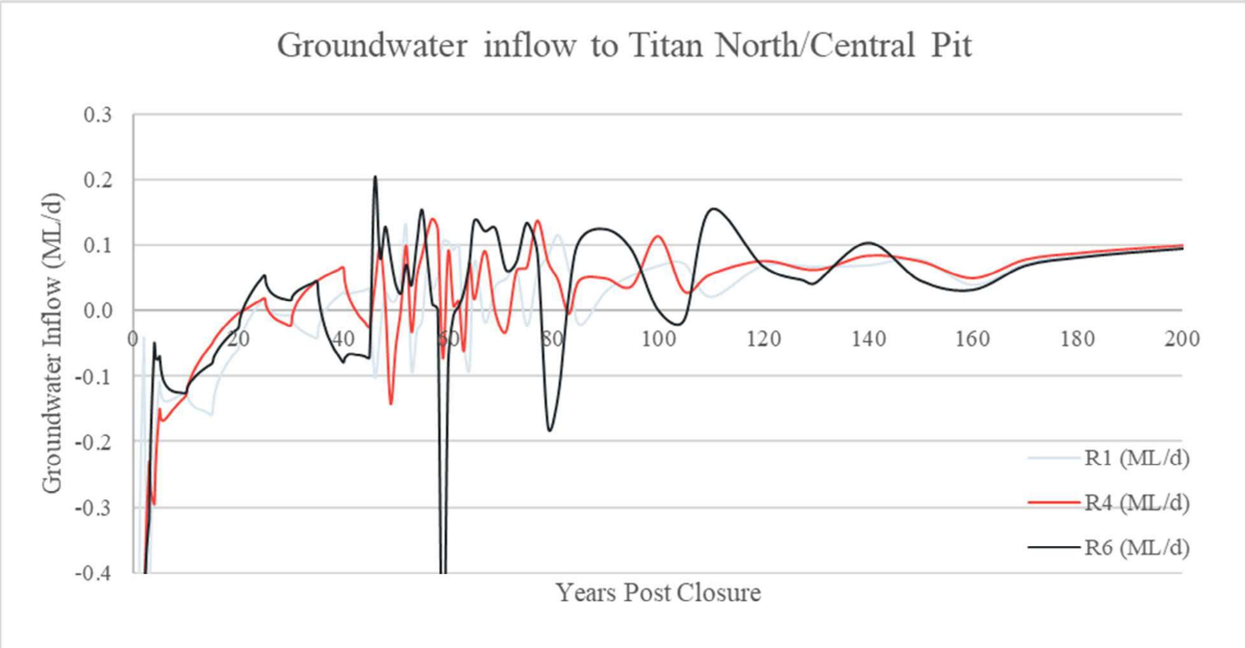

Figure 6.10 Groundwater inflows to Titan North/Central residual void (SLR Consulting Australia Pty Ltd, 2023)

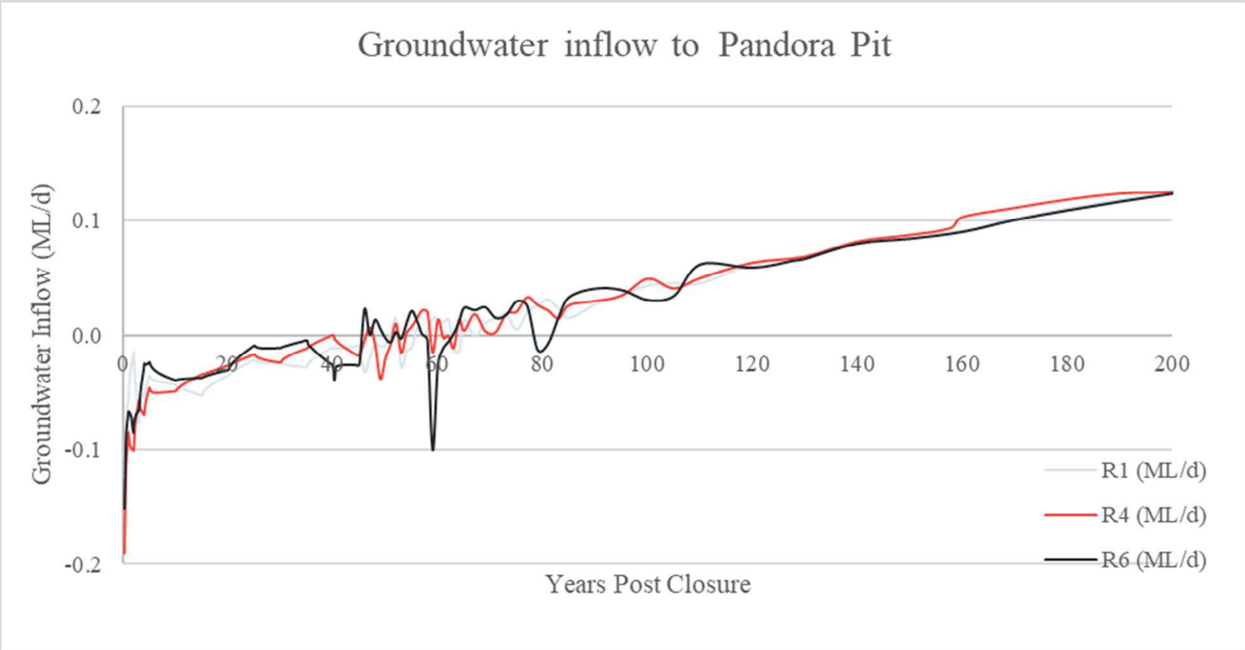

Figure 6.11 Groundwater inflows to Pandora residual void (SLR Consulting Australia Pty Ltd, 2023)

6.1.4 Climate change considerations

To reasonably represent future climate conditions in the WBM, climate change data was used from the projections of three different climate models (Access 1-0Q, GFDL-CM3Q, and MPI-ESM-LRQ), which were evaluated under two RCPs (4.5 and 8.5).

To cover the WBM simulation period of 149 years, the climate projections were applied from the final operational year for DNM being 2051, until 31 December 2199.

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 maximum (R6), middle (R4) and the minimum (R1) ranges. This provides a reasonable potential range of climate impacts for each void. A summary of the combined pathways and models considered in each realisation (R#) of the WBM is presented in Table 6.7.

Table 6.7 Climate change scenarios considered in each water balance model realisation for Daunia residual voidl

Realisation	Climate Model	RCP
R1	ACCESS1-0Q	4.5
R4	ACCESS1-0Q	8.5
R6	MPI-ESM-LRQ	8.5

As the climate projections 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. This approach is presented in Table 6.8 and the resultant calculated annual mean rainfall data from 2080 to 2099 is presented in Figure 6.12.

Table 6.8 Rainfall data used for each simulated period for Daunia residual voids water balance model

Simulated period	Data used	
	From	To
01-01-2051 to 31-12-2099	01-01-2051	31-12-2099
01-01-2100 to 31-12-2119	01-01-2080	31-12-2099
01-01-2120 to 31-12-2139	01-01-2080	31-12-2099
01-01-2140 to 31-12-2159	01-01-2080	31-12-2099
01-01-2160 to 31-12-2179	01-01-2080	31-12-2099
01-01-2180 to 31-12-2199	01-01-2080	31-12-2099

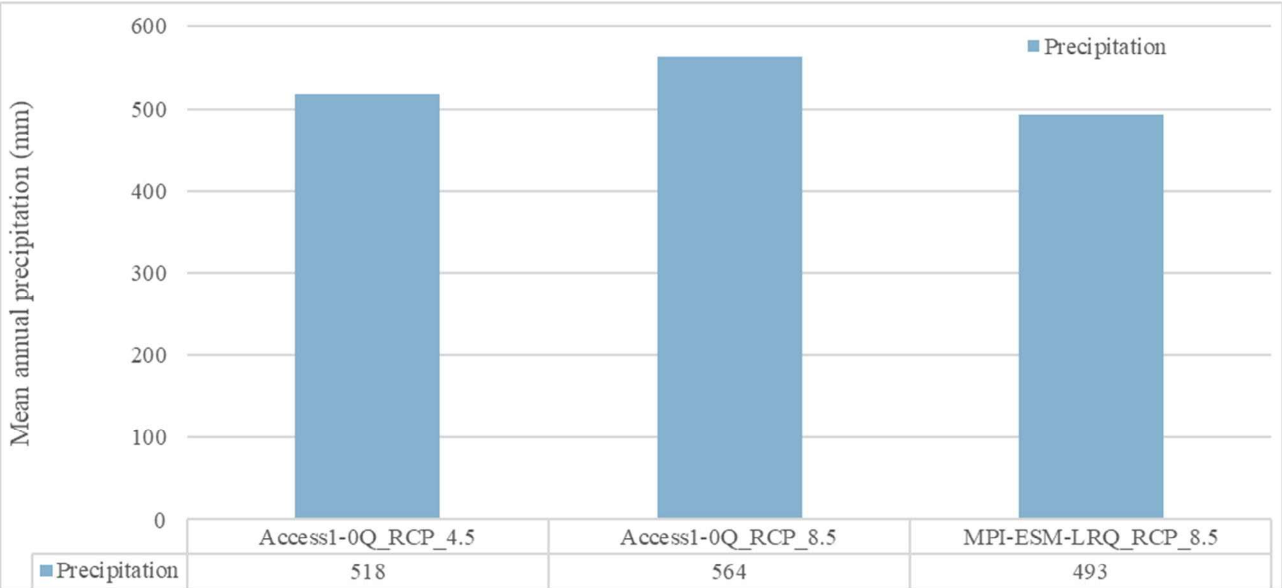

Figure 6.12 Annual mean rainfall for the period from 2080 to 2099 for (left to right) wetter (R1), mid (R4), drier (R6) applied to the Daunia residual voids water balance model

The future increase in evaporation was estimated considering:

— Projected period: 2080 and 2099.

— Reference period: 1986 to 2005.

The result is a unique value showing the annual evaporation increase for each climate change scenario. This factor was applied to the monthly evaporation values. These factors are presented in Table 6.9.

Table 6.9 Percentage increase of evaporation considered for each realisation from 2080 to 2099 applied to the Daunia residual voids water balance model

	RCP 4.5	RCP 8.5	
	R1 (ACCESS1-0Q)	**R4 (ACCESS1-0Q)**	**R6 (MPI-ESM-LRQ)**
Mean evaporation 1986-2005 (mm/yr)	1,594	1,597	1,616
Mean evaporation 2080-2099 (mm/yr)	1,818	2,044	2,087
Increase in average evaporation (%)	14	28.0	29.2

6.2 Residual void water balance

As a result of projecting rainfall conditions beyond 2099 through the repetition of the period between January 2080 to December 2099, the seasonality of the applied precipitation to the WBM generates a seasonality in all DNM void lake levels. Following a storm event around the year 2088 to 2089, a rapid increase in the pit lake levels and volumes is observed, particularly in the R6 simulation that is then repeated approximately every 20 years.

6.2.1 Titan East 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 6.13. The mean (total) annual inflow to Titan East residual void is 148 ML/yr for the simulation period of 2080 to 2199. The mean annual outflow for the same period is 148 ML/yr. This indicates that the mean water balance for Titan East residual void can be considered to have reached equilibrium.

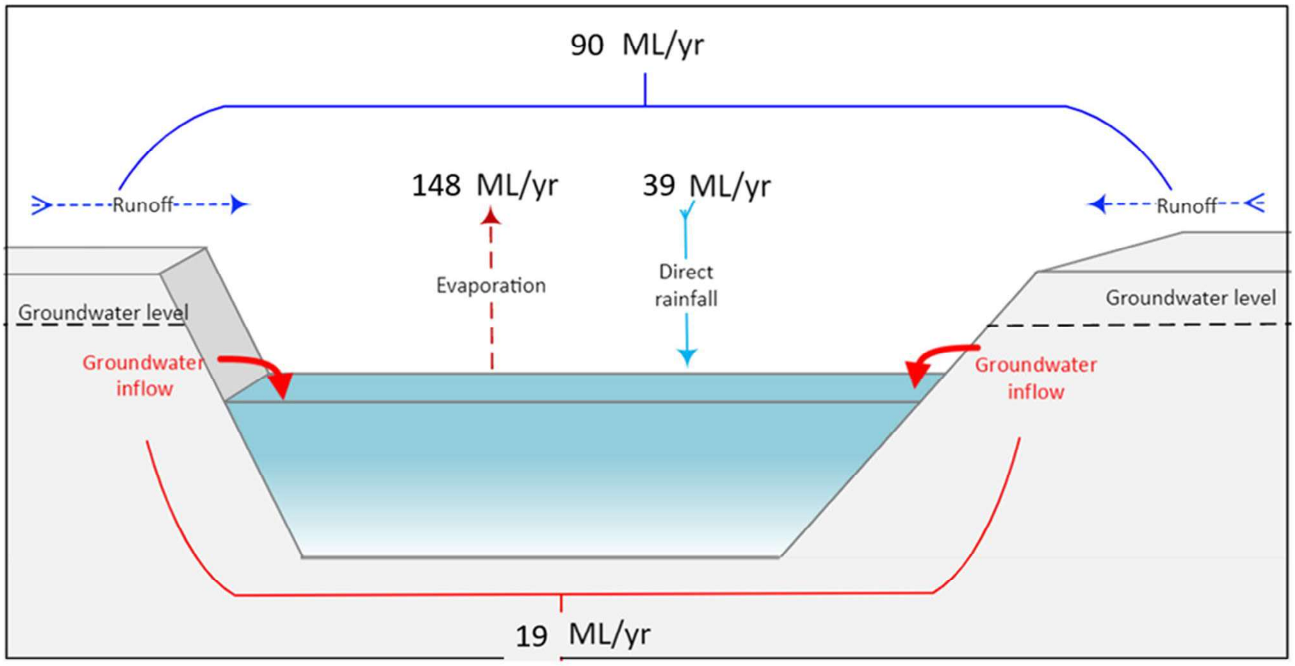

Figure 6.13 Average inflows/outflows simulated for the period from 2180 to 2199 – Titan East residual void (all realisations)

The results from the WBM for Titan East residual void indicate that, after the year 2090, the mean void water levels start to stabilise. The mean void water elevation reaches 133 m AHD and the mean void water volume reaches 500 ML by the end of the simulation across all realisations (as shown in Figure 6.14 and Figure 6.15).

The water levels remain below the surrounding groundwater level (198 m AHD), and hence remain below the void spill point (208 m AHD) for the duration of the simulation (Figure 6.14). Therefore, there is a very low risk of the void overtopping, and the void is modelled to act as a groundwater sink for all the scenarios considered.

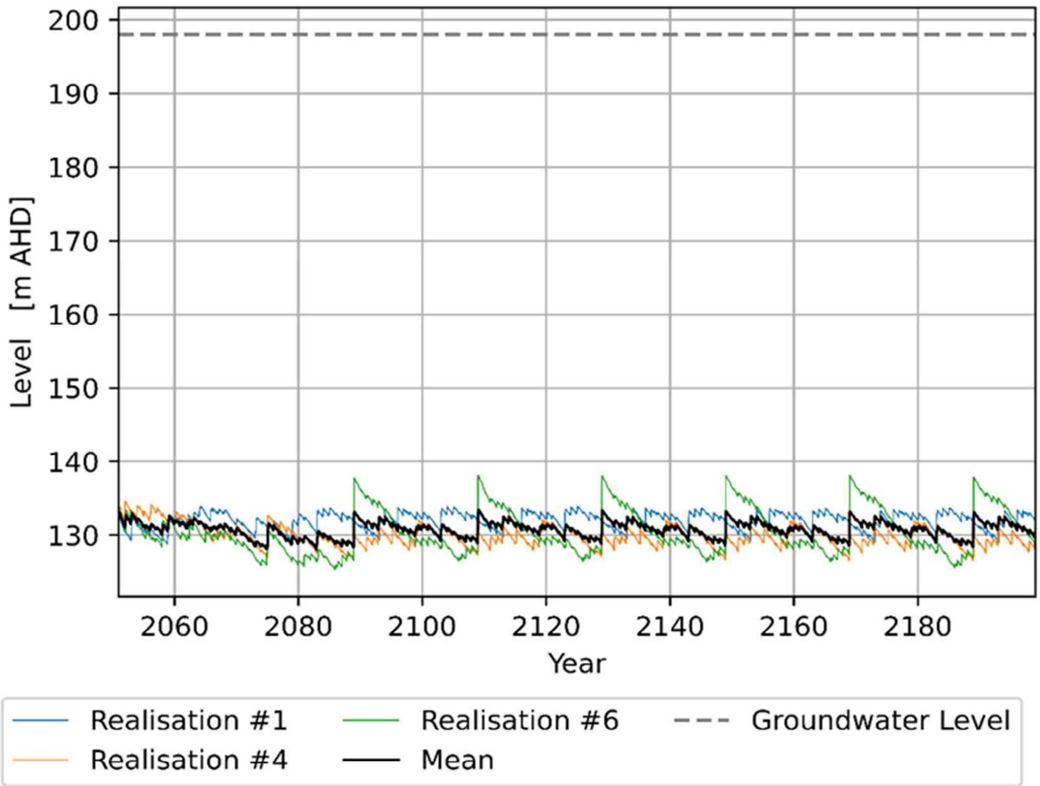

Figure 6.14 Modelled water levels in Titan East residual void compared to surrounding groundwater levels (All realisations)

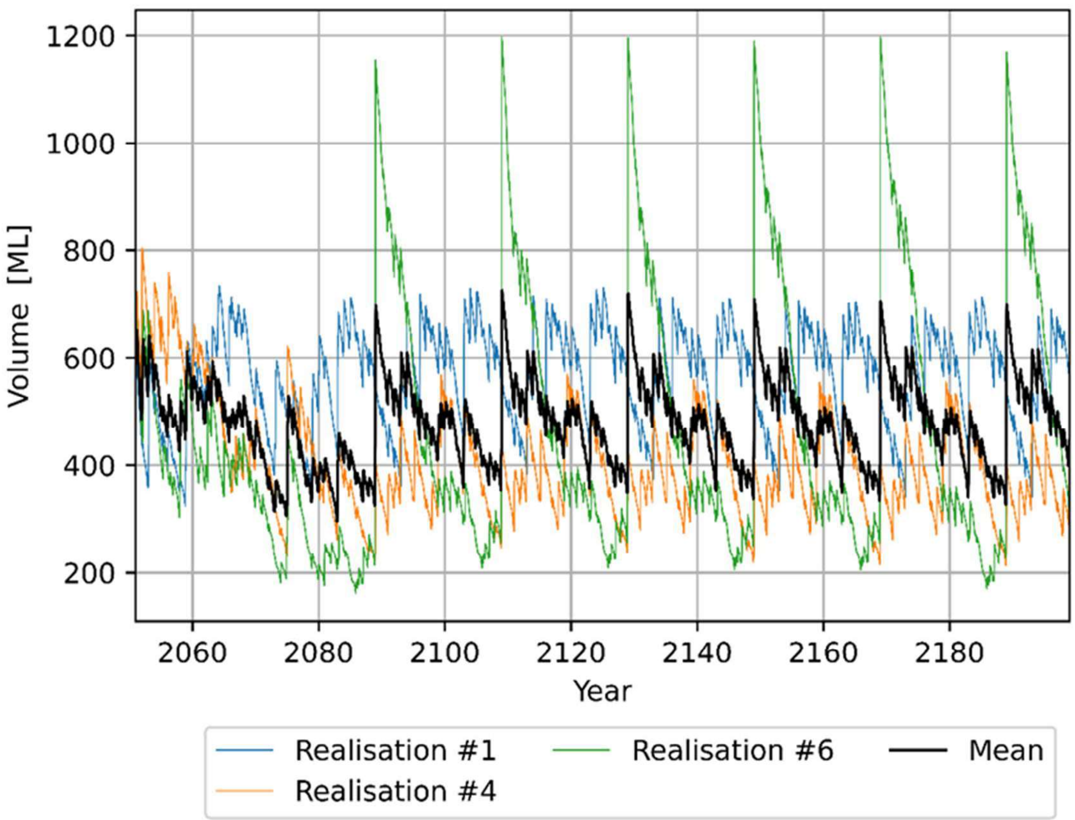

Figure 6.15 Modelled water volumes in Titan East residual void (All realisations)

6.2.2 Titan North/Central 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 6.16. The mean (total) annual inflow to Titan North/Central residual void is 437 ML/yr for the simulation period of 2180 to 2199. The mean annual outflow for the same period is 435 ML/yr. This indicates that the mean water balance for Titan North/Central residual void will have reached equilibrium.

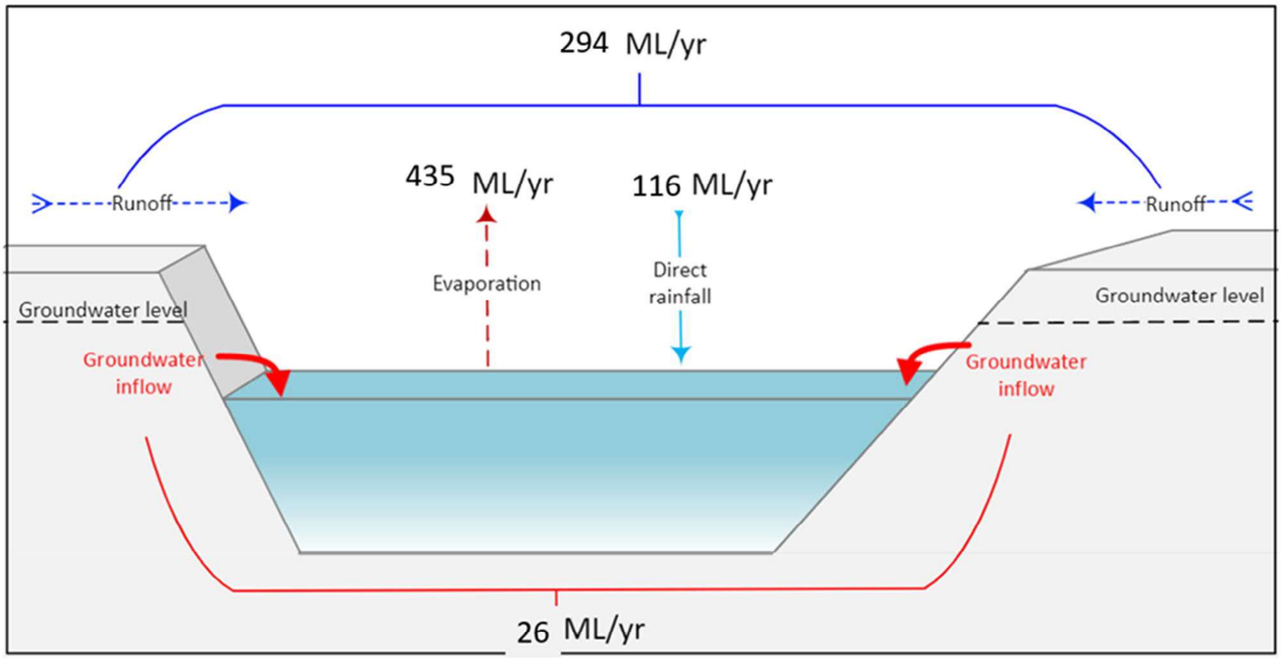

Figure 6.16 Average inflows/outflows simulated for period from 2180 to 2199 – Titan North/Central residual void

The results from the WBM for Titan North/Central residual void indicate that after the year 2090, the mean void water levels start to stabilise. The mean void water elevation reaches 135 m AHD and the mean void water volume reaches 1,250 ML by the end of the simulation across all realisations (as shown in Figure 6.17 and Figure 6.18).

The water levels remain below the surrounding groundwater level (198 m AHD) and hence remain below the spill point (208 m AHD) for the duration of the simulation (Figure 6.17). Therefore, there is a very low risk of the void overtopping, and the void is modelled to act as a groundwater sink for all the scenarios considered.

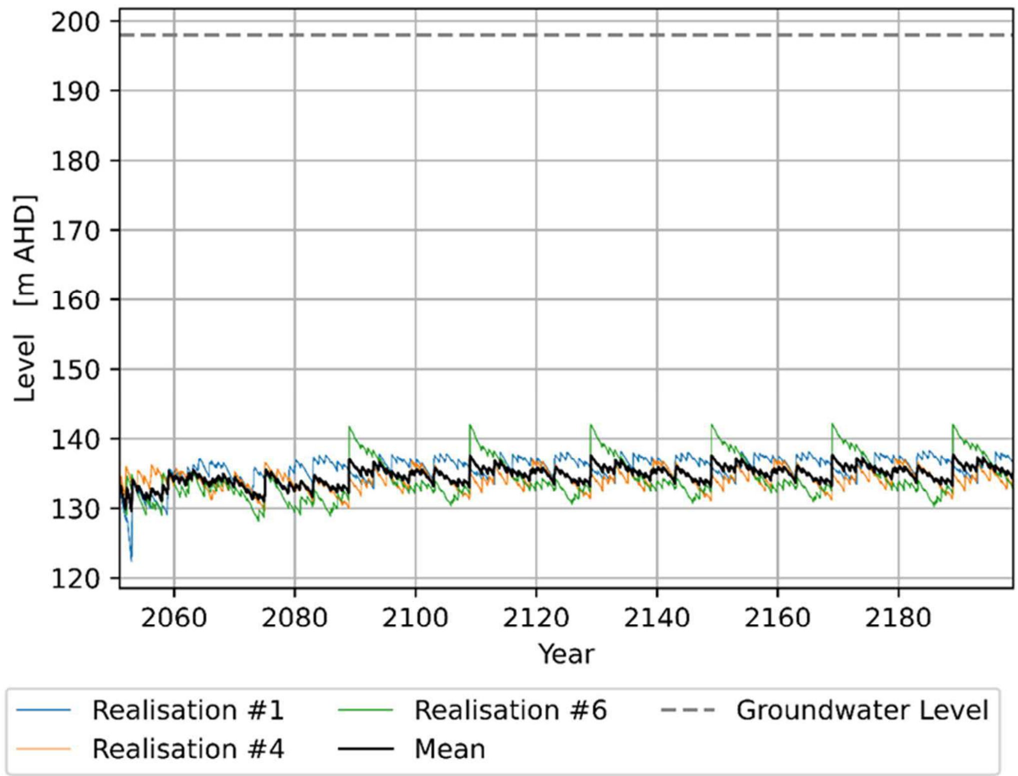

Figure 6.17 Modelled water levels in Titan North/Central residual void compared to surrounding groundwater levels (all realisations)

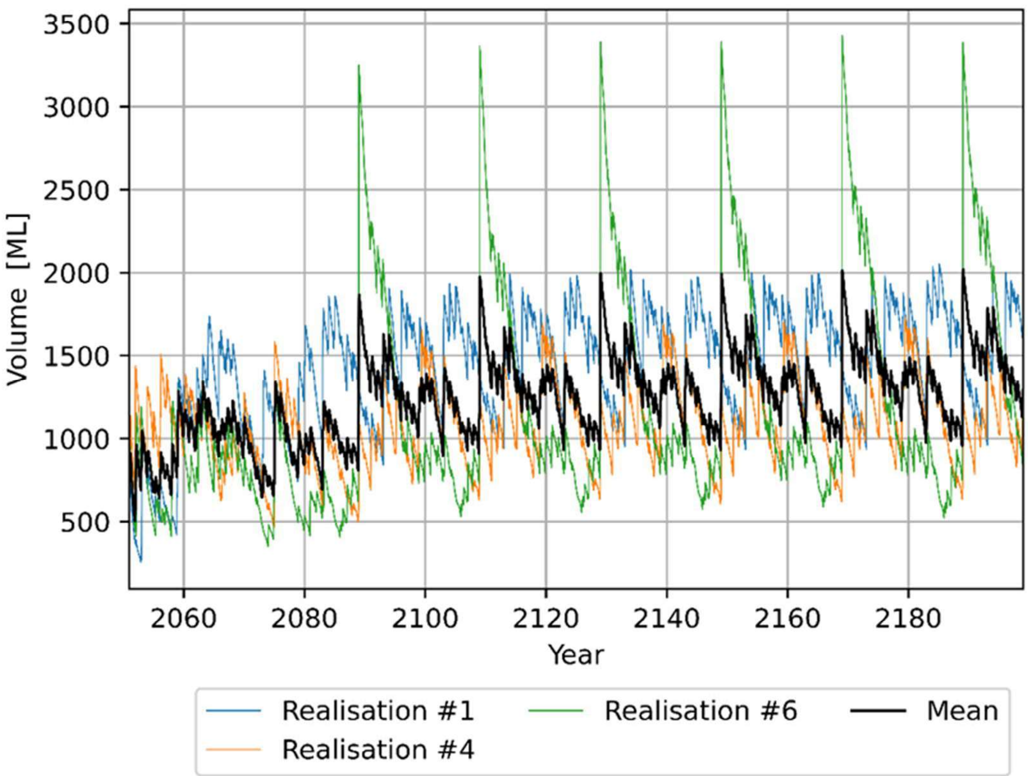

Figure 6.18 Modelled water volumes in Titan North/Central residual void (All realisations)

6.2.3 Pandora 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 Pandora residual void is 196 ML/yr for the simulation period of 2180 to 2199. The mean annual outflow for the same period is 195 ML/yr. This indicates that the mean water balance for Pandora residual void can be considered to have reached equilibrium.

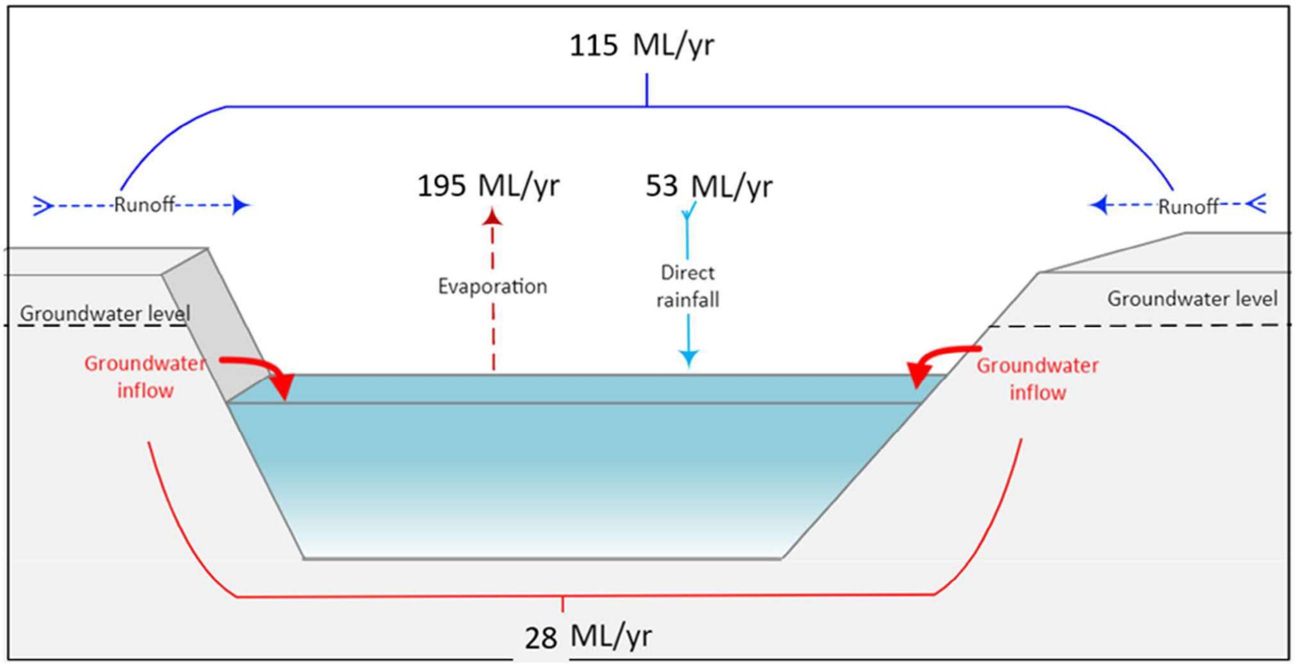

Figure 6.19 Average inflows/outflows simulated for period from 2180 to 2199 – Pandora residual void

The results from the WBM for Pandora residual void indicate that, across all realisations, the void water levels tend to rise for most of the simulation period. The mean void water levels start to stabilise around the year 2180, reaching a mean void water elevation of 120 m AHD and a mean void water volume of 500 ML by the end of the simulation across all realisations (as shown in Figure 6.20 and Figure 6.21).

The water levels remain below the surrounding groundwater level (170 m AHD) and hence remain below the spill point (193 m AHD) for the duration of the simulation (Figure 6.20). Therefore, there is a very low risk of the void overtopping, and the void is modelled to act as a groundwater sink for all the scenarios considered.

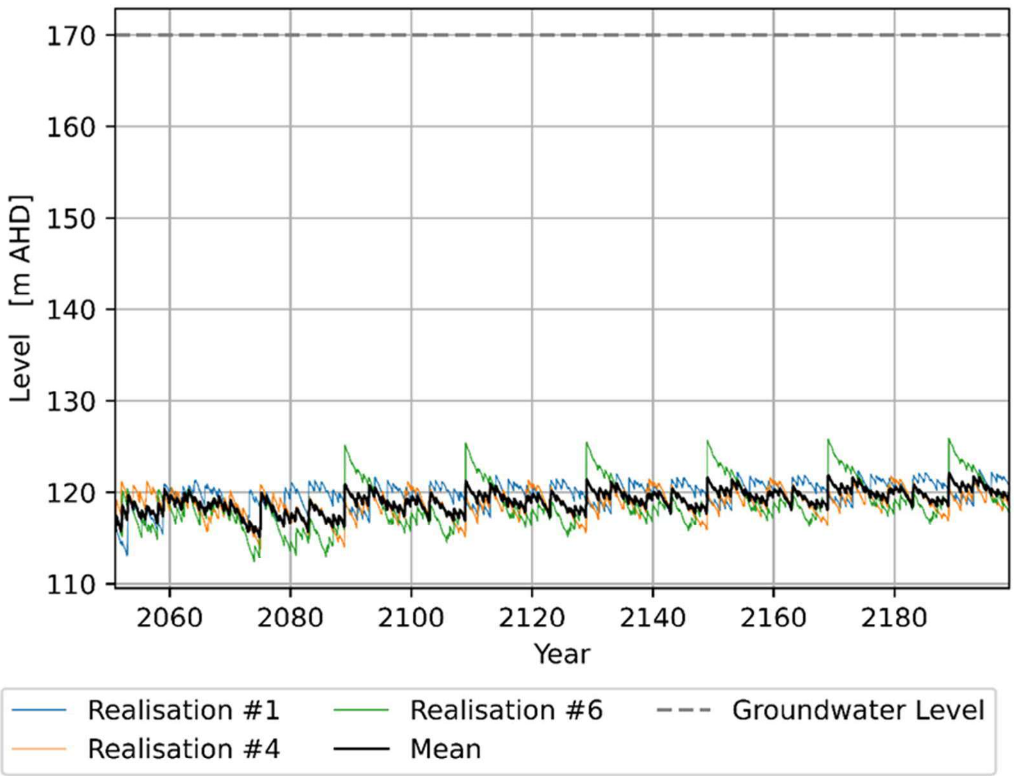

Figure 6.20 Modelled water levels in Pandora residual void compared to surrounding groundwater levels (all realisations)

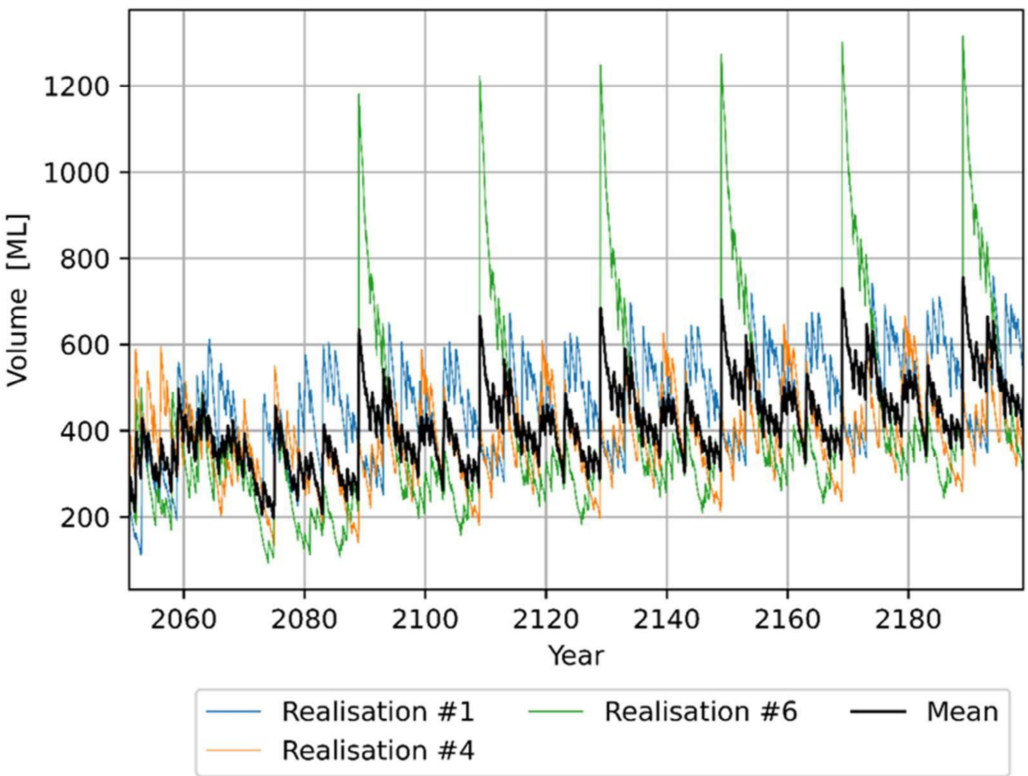

Figure 6.21 Modelled water volumes in Pandora residual void (All realisations)

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 DNM residual voids. This section presents the assessment findings relevant to void closure at DNM.

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 DNM 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 particular materials. However, the method is generally accepted by industry as a practical industry method and has therefore been adopted for the PRC Plan at DNM.

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, a FoS less than 1 indicates instability, and a value greater than 1 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 1 is specified to allow for inaccuracies and uncertainties in both the method and the input data. When a slope is actually constructed, much of the uncertainty disappears. If a slope exists and is not moving then it is obviously stable under current conditions, regardless of any computed measure. The important consideration should then be whether there is potential for those current conditions to change in a way that would then adversely affect stability.

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 and 1.3 are typically applied to operational design for 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.

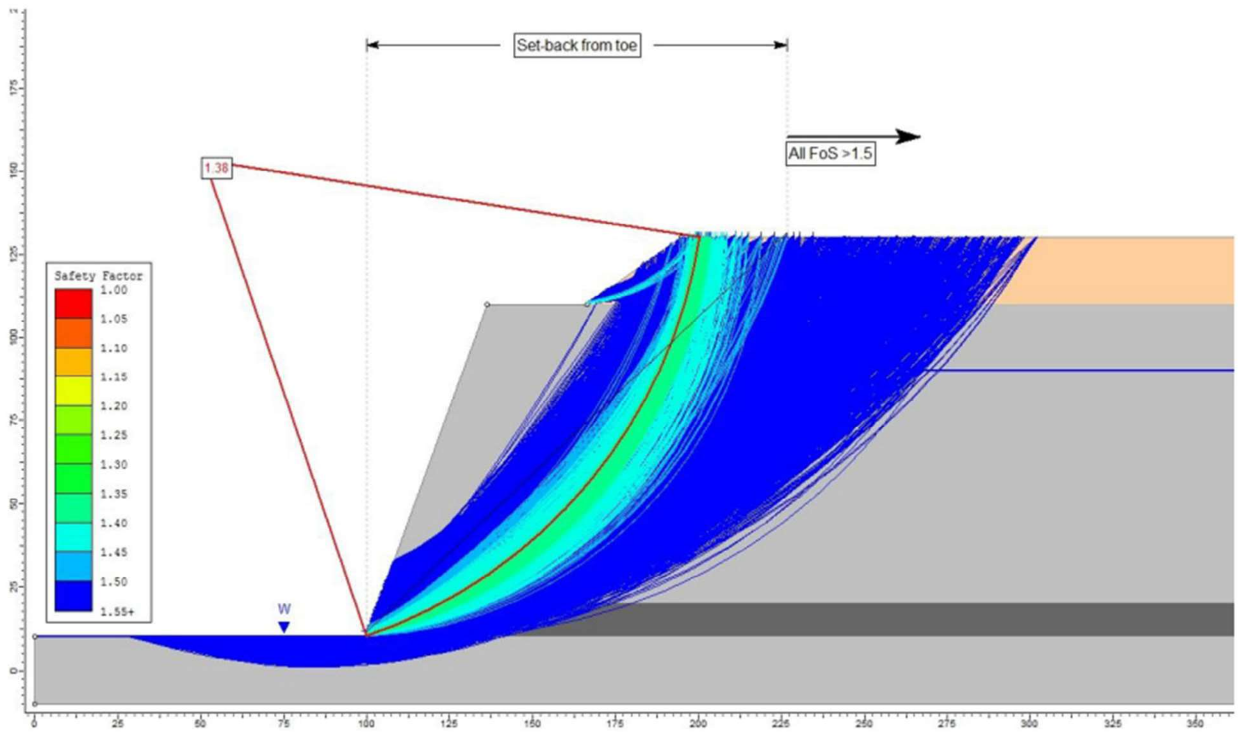

Figure 7.1 Set-back to a FoS of ≥1.5

The key features of the stability analyses are summarised in Sections 7.1.1 and 7.1.2.

7.1.1 Inputs to assessment – regional

7.1.1.1 Regional geology and geotechnical (strength) properties

In the Bowen Basin, predominantly Permian age coal measure sedimentary rocks are unconformably overlain by younger, mainly Tertiary age, sediments. At some locations, the latter contain laterally confined basalt that was deposited in the early Tertiary. In the context of wall stability, the important geological boundaries are base of Tertiary and base of weathering; however, for simplicity, Tertiary and weathered Permian rocks were treated as one material which is a conservative approach. Assumed strength properties for the DNM high-walls are presented in Table 7.1.

Table 7.1 Strength properties applied in stability analyses of high-walls at Daunia

Material type	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

It is obvious that weathering affects the character and strength of rocks. However, weathering that has occurred over geologic time before the pit wall is excavated is automatically accounted for in the strength properties adopted for operational wall design and so has no additional geomechanical impact on rehabilitation and post-mining landforms. Hence, additional effects of weathering on long-term stability would only relate to weathering that might occur after cessation of mining.

There are two phases to weathering: physical degradation and chemical decomposition. Degradation starts almost as soon as the rock face is exposed and is essentially larger fragments or rock breaking down into smaller fragments. This breakdown, or 'slaking', is mainly caused by salt crystals adsorbing moisture and swelling, by clay minerals adsorbing moisture and swelling (although salts are usually involved as well) and less commonly by cementing minerals being dissolved in water. Rainfall and in-pit storage cause immediate slaking in susceptible materials, but humidity can produce the same result over a couple of years. Because degradation depends so heavily on water ingress, it 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, but this is addressed by adopting saturated strength properties and therefore does not need to be considered separately.

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

Both phases of weathering occur fastest in hot, wet climates – rainfall providing the necessary moisture, and high temperature promoting chemical reactions. The climate at DNM is hot but not wet and as such only "very slight" ongoing weathering is expected. There may be very specific situations where even a very small amount of additional weathering might affect pit wall stability, most notably where weak degradable strata underlie more resistant strata. As the degradable material ravels and falls away, the harder layer loses support and may subsequently fall. This is generally a localised scenario that may only be apparent when the pit wall is excavated. Hence it cannot generally be planned for but 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. Most commonly, detachment occurs due to mechanical means – the impact of raindrops and the energy of flowing water – and the transport is also provided by flowing water. In this scenario, the severity of erosion depends on the character of the material – how easily particles are detached – and increases with catchment size and surface slope, both of which increase the volume and velocity of runoff flow. In dispersive material, detachment can also occur by chemical means. In this case, the bonds and ionic charges within the material are such that clay particles will "disperse" into even static water that is not applying mechanical energy. However, flowing water is still required for the transport phase of erosion.

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. Even if an unusual arrangement of intersecting erosion gullies created the potential for a wedge-type failure, it would be addressed through surface water and erosion control measures rather than by slope stability design.

Weathering and long-term erosion will generally have little impact. This is not to say that erosion is not a rehabilitation issue in its own right, but it is generally not a significant factor in pit wall geotechnical stability. Therefore, it has not been considered further in this assessment.

7.1.1.4 Effect of significant hydrological events

In Bowen Basin coal mines, weathered overburden is generally susceptible to softening when saturated, especially materials containing significant clay. Unweathered (fresh) coal measure rocks generally do not show significant strength loss on wetting, as evidenced by the large number of inactive pits that contain water without any noticeable change in wall stability. Particular claystones/mudstones may be more sensitive to moisture, but these tend to start slaking soon after exposure to humid air, and so are apparent during mining when wall designs can be amended to mitigate any impact on wall stability.

Water balance modelling for the proposed voids at DNM predicts average and long-term void water levels tens of metres below the base of weathering. Void water is only expected to contact fresh rock and so will not affect geotechnical stability of excavated pit walls. The most serious potential impact of severe rainfall events would be the inrush of floodwaters to the void. In theory, an initial inflow could scour a new channel through the ground between the void and the watercourse, thus directing more water into the void at a greater flow rate. For the final closure state landform, the pit voids will be mitigated from flooding from the Isaac River and New Chum Creek either by out-of-pit land-forming with spoil to reduce the extent of the pit; or a flood protection landform. The final residual voids will not be subject to inundation from floodwaters from the Isaac River and New Chum Creek up to and including the 0.1% AEP climate change RCP 8.5 P90 event.

There is one other mode of instability related to water storage, namely 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, so that the pore pressures are no longer balanced out. This will not be an issue for voids which contain water passively because evaporation and small capacity pumps will not lower the water level quickly enough to establish this imbalance. Stability under drawdown would be a consideration for post-mining land uses (PMLUs) involving movement of large volumes of water, such as large-scale irrigation and pumped hydro energy storage, but such uses are not proposed for DNM residual voids.

7.1.2 Inputs to assessment – local

Geologically, DNM is located within a shallow basin structure immediately east of the New Chum Fault. Consequently, the layout of the residual voids is not typical of Bowen Basin mines in that instead of approximately linear north-south aligned voids, Titan and Pandora void walls will be arcs respectively bounding the northern and southern limits of the mined area. Long sections extracted from the current DNM geological model provided void high-wall profile data for the segments reaching coal floor, as summarised in Table 7.2.

Table 7.2 Geotechnical profiles for the residual void high-walls at Daunia

Geotechnical profile parameters		Titan	Pandora
Depth of Tertiary overburden (m)	Average	2	5
	Range	0 – 4	3 – 6
	90% less than	3	6
Depth of Tertiary/weathered overburden (m)	Average	22	26
	Range	0 – 33	22 – 31
	90% less than	31	29
Thickness of base coal seam (m)	Average	2.0	3.6
	Range	0 – 2.7	3.2 – 4.6
	90% less than	2.3	4.0
Depth of fresh overburden (m)	Average	45	21
	Range	3 – 85	4 – 57
	90% less than	83	51
Total wall depth (m)	Average	67	46
	Range	25 – 116	30 – 84
	90% less than	108	82

7.1.3 High-wall and end-wall stability assessment results

For the stability analyses, seven cross-sections were selected - four in the Titan voids and three in the Pandora void, to cover the range of final wall geometries including the deepest parts of each void. The relevant geometric parameters and results for these cross sections are summarised in Table 7.3. For all cross-sections analysed, the minimum FoS was greater than 1.5. Therefore, the void walls are considered geomechanically stable at the crests and no additional set-back is imposed.

Table 7.3 Setbacks for long-term wall stability for Daunia high-walls

Cross Section	Depth of Tertiary/ weathered (m)	Depth of fresh Permian (m)	Average wall angle in fresh Permian (°)	Factor of Safety at crest	Set-back from toe of wall (m)
Titan XS1 - NW	22	54	23	3.43	Wall crest
Titan XS2 - NNW	27	15	10	1.81	Wall crest
Titan XS3 - NNE	33	85	28	3.29	Wall crest
Titan XS4 - NE	31	73	28	3.12	Wall crest
Pandora XS1 - E	20	73	19	3.89	Wall crest
Pandora XS2 - SSE	27	20	5	1.87	Wall crest
Pandora XS3 - W	22	41	10	1.84	Wall crest

7.2 Low-wall stability assessment

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

A stability analyses of the low-wall final closure state landform for the DNM residual voids was undertaken using the 2-dimensional (2D) limit equilibrium analysis software *Slide2* (version 9.010). Three 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. The section locations for the analysis are presented in Figure 7.2 and the corresponding section are identified as:

— Section 1 (Titan North / Central residual void).

— Section 2 (Titan East residual void).

— Section 3 (Pandora residual void).

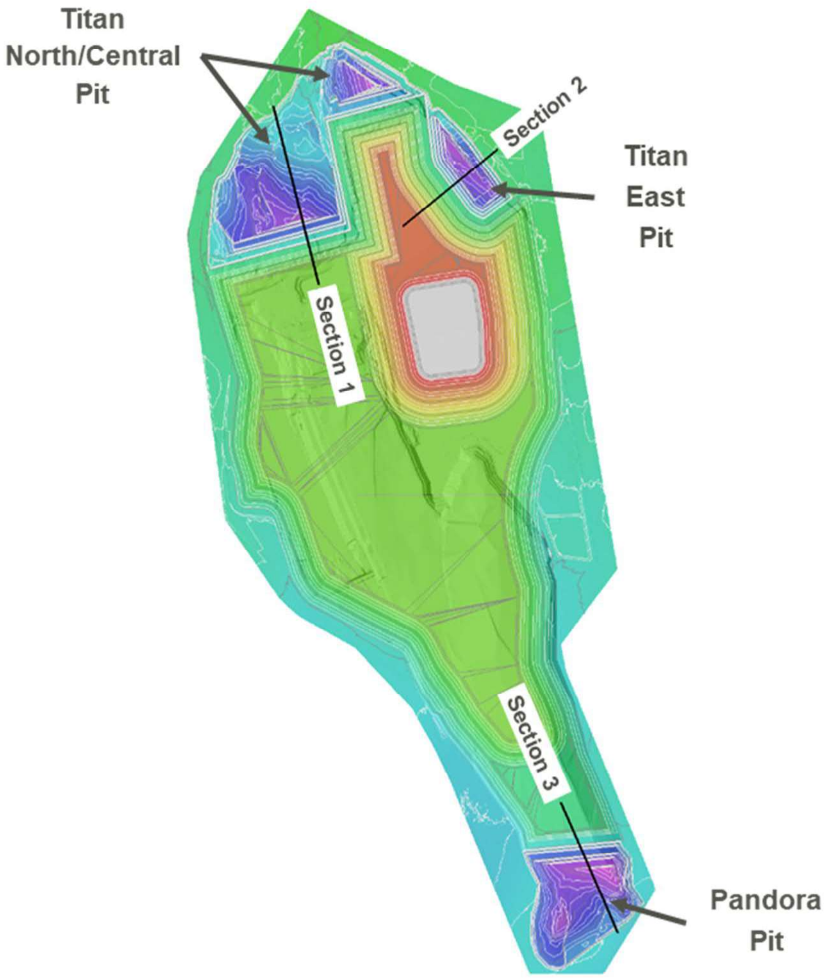

Figure 7.2 Low-wall geotechnical stability cross-section locations for the Daunia residual voids

For each of the three 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 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 for DNM residual voids are presented in Sections 7.2.1 to Section7.2.4.

7.2.1 Titan East residual void

The geotechnical stability assessment for Titan East residual void (cross-section 2) 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 greater than 1.5. Therefore, the final closure state landform satisfies the stability requirements of a FoS greater than 1.5 for the overall slope and for slopes outside the NUMA (See Table 7.4, Figure 7.3 and Figure 7.4).

Table 7.4 Summary of low-wall stability analysis results for Titan East residual void

Section	Low-wall spoil height (approx.) (m)	Minimum Factor of Safety	
		Overall Slope (Global stability)	Slope outside NUMA
2	186	3.3	2.8

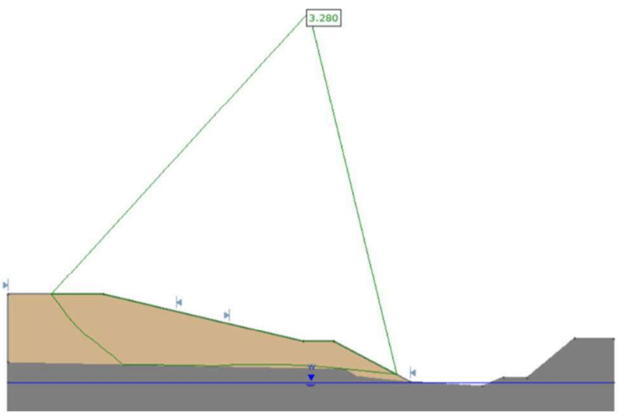

Figure 7.3 Titan East residual void low-wall geotechnical stability assessment (cross-section 2) - global stability

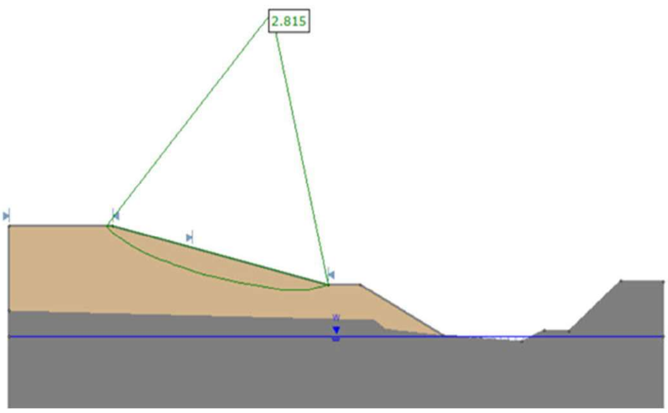

Figure 7.4 Titan East residual void low-wall geotechnical stability assessment (cross-section 2) - slope outside non-use management area

7.2.2 *Titan North/Central residual void*

The geotechnical stability assessment for Titan North/Central residual void (section 1) 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 greater than 1.5 and that the final closure state landform satisfies the stability requirements of a FoS greater than 1.5 for the overall slope and for slopes outside the NUMA (Table 7.5, Figure 7.5, and Figure 7.6).

Table 7.5 Summary of low-wall stability analysis results for Titan North/Central residual void

Section	**Low-wall spoil height (approx.) (m)**	**Minimum Factor of Safety**	
		Overall Slope (Global stability)	Slope outside NUMA
1	143	2.6	3.4

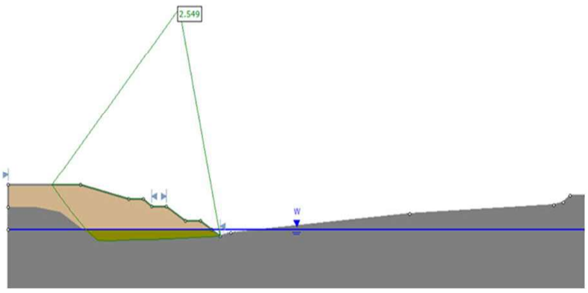

Figure 7.5 Titan North/Central residual void low-wall geotechnical stability assessment (cross-section 1) - global stability

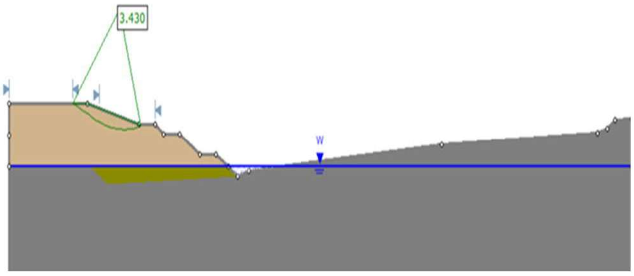

Figure 7.6 Titan North/Central residual void low-wall geotechnical stability assessment (cross-section 1) – slope outside non-use management area

7.2.3 *Pandora residual void*

The geotechnical stability assessment for the Pandora residual void (cross-section 3) concluded that, for the final closure state landform, the minimum FoS for all potential slip surfaces affecting the low-wall slope outside the NUMA satisfies the stability requirements of a FoS greater than 1.5. For the overall low-wall slope, the initial closure state landform was altered to include a low-wall bench at the edge of the NUMA boundary to meet the required minimum FoS of 1.5 for the final closure state landform, as shown in Table 7.6, Figure 7.7 and Figure 7.8.

Table 7.6 Summary of stability analysis results for Pandora residual void

Section	**Low-wall spoil height (approx.) (m)**	**Minimum Factor of Safety**	
		Overall Slope (Global stability)	Slope outside NUMA
3	110	4.2	5.4

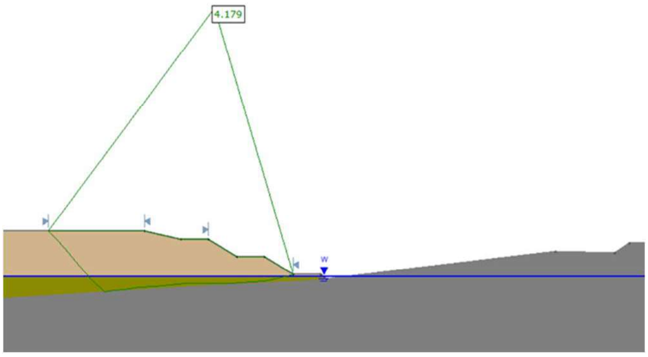

Figure 7.7 Pandora residual void low-wall geotechnical stability assessment (cross-section 3) - global stability, with bench at the edge of the non-use management area boundary

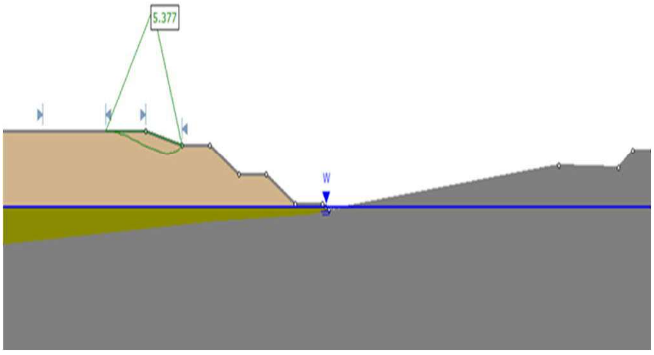

Figure 7.8 Pandora residual void low-wall geotechnical stability assessment (cross-section 3) - slope outside non-use management area, with bench at the edge of the non-use management area boundary

7.2.4 Assumptions

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

- The current assessment of stability of the low-wall final closure state landform at DNM is preliminary in nature. It has been based on inputs and assumptions that will be reviewed and verified as mining approaches the final void limits and more geological and geotechnical data becomes available.
- This assessment has not considered any 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 was assigned a FoS equal to 1.5 (in accordance with EA condition E3 and Table E1).
- The final void water equilibrium levels for the low-wall stability analyses were based on the results of the WBM.
- The spoil material was assumed to be homogeneous throughout, with all spoil above the pit water equilibrium level assigned the same material parameters, and all spoil below the pit water equilibrium level assigned the same material parameters.
- 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 long-term geochemical water quality of void lakes within the final closure state landforms for the DNM residual voids.

The objectives of the geochemical water quality model were to:

- Predict the changes in water quality of DNM residual voids in a long-term closure scenario.
- Determine, at a conceptual level (by comparison to EA groundwater trigger values), 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 DNM residual voids (see Section 6) and covers the same timeframe: a period of 149 years post-closure (2051 through 2199). Within this timeframe, the water level in the void lakes reach 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. Materials 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 (seepage through spoil not included).
- Non-carbonaceous interburden used for covering the outside of the landform interacting with rainfall/runoff.
- 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 DNM 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. Material that had no lithological classification (classified as unknown) was reallocated to carbonaceous and non-carbonaceous domains using the ratio of carbonaceous to non-carbonaceous materials.

Table 8.1 Proportions of lithologies in the excavated Daunia void high-walls for the residual void geochemical modelling

Lithology grouping	Excavated high-wall exposure (%)		
	Titan East	Titan North/Central	Pandora
Weathered non-carbonaceous	29.1	49.5	54
Weathered carbonaceous/ coal	1.4	5.6	7
Fresh non-carbonaceous	59.5	38.7	33.2
Fresh carbonaceous	2.9	1.2	1.6
Fresh coal	7.2	5	4.2
Total:	**100**	**100**	**100**

8.1.2 Geochemical source terms

The geochemical source terms were derived from the BMA environmental geochemistry data that includes results of analyses and leach testing undertaken on drill core material collected at DNM.

Drill core data is useful for this initial assessment but may not accurately represent field solute release rates over the longer timeframes associated with closure, due to differences in reactive surface area in laboratory and field tests and the inability of short-term leach tests to account for transient processes such as sulfide oxidation. However, static test data generally represent a conservative scenario, as the first flush of fluid during testing: removes accumulated weathering products; and solute concentrations often decrease with repeated leaching.

For the derivation of the groundwater source term, groundwater data from 2009 to 2022 that included monitoring information from 16 monitoring bores was used. Groundwater bores are screened in three main aquifers – alluvial aquifers, Tertiary and Permian aquifers. No distinction was made between these aquifers for the derivation.

The derivation of these source terms and the source term values are summarised in Table 8.2 and Table 8.3.

Table 8.2 Summary of data sources used to derive geochemical source terms for the residual voids at Daunia

Source term (Water balance)	Comment	n	Source
Initial void lake	Currently, there is no water accumulated in any of the DNM voids to enable analysis to derive source terms. The initial void lake is assumed to be oxidised groundwater (pe = 8.0).	-	-
Natural catchment runoff	Median of compiled DNM leach test result from weathered non-carbonaceous drill core samples	33	DNM Drill core data
Rehabilitated catchment runoff (in pit spoil runoff)	Median of compiled DNM leach test results from fresh non-carbonaceous drill core samples (Permian interburden specified as cover material for final closure state landform)	58	DNM Drill core data
High-wall runoff	BMA's drill core data for the DNM site was used to derive source terms for each lithological domain/grouping. The median of all leach test results for each domain was combined for each pit in the proportions of their highwall exposure (Section 8.1.1). Filtered alkalinity is defined on a subset of samples (75 of 125) due to laboratory filtration methods.	125	DNM Drill core data
Groundwater inflow	Median water quality from DNM groundwater data; assumed pe = 4.0	~330	DNM Groundwater data
Rainfall	Pure water equilibrated with atmospheric CO_2	-	-

Notes: *'-' indicates not available*

N = number of samples

pe = electron activity expressed in factors of 10: pE = -log(e-)

Table 8.3 Summary of geochemical source terms (median results) derived from Daunia's data sources

Parameter	Unit	DNM drill core leach test data					DNM ground-water	Rainfall
		Weathered non-carbonaceous	Weathered carbonaceous/ coal	Fresh non-carbonaceous	Fresh carbonaceous	Fresh coal		
pH	pH units	8.5	8.2	9.2	9.2	8.0	7.7	5.5
pe*1	pe units	8.0	8.0	8.0	8.0	8.0	4.0	8.0
Measured (filtered) Alkalinity	mg $CaCO_3$/L	67.5	-	80	63	23	464	-
Measured (unfiltered) Alkalinity	mg $CaCO_3$/L	6800	218	498	161.9	96.2	-	-
Calculated Alkalinity*2	mg $CaCO_3$/L	43.2	74.3	121.8	101.3	90.6	198.8	5.10^{-5}
PHREEQC Calculated TDS	mg/L	212 (223)	142 (185)	167 (196)	139 (166)	103 (150)	6459 (6582)	-
Cl*3	mg/L	85	59	20 (49.6)	11.7 (38.8)	11 (58.9)	3700	-
F	mg/L	0.95	-	0.4	0.7	0.2	0.4	-
SO_4	mg/L	9	12	18	19	24.5	21	-
N	mg N/L	0.1	-	0.3	0.8	0.05	1.9	-
Ca	mg/L	7.5	11.6	3	0.75	14	195	-
Mg	mg/L	4.8	8.8	2	0.5	7	80	-
Na*3	mg/L	62 (73.2)	47	68	62	30.5	2110 (2247)	-
K	mg/L	2	2.4	6	3	2	11	-
n samples		11 to 55	0 to 7	21 to 95	4 to 20	9 to 33	305 to 331	-
Charge % error		-6.5%	+27.5%	+14.1%	+15.6%	+34.9%	-2.4%	n/a
Charge balance		+Na	+C(4)	+Cl	+Cl	+Cl	+Na	n/a
Used to represent:		Highwall and natural catchment runoff	Highwall runoff	Highwall, rehab catchment and spoil runoff	Highwall runoff	Highwall runoff	Groundwater inflow	Direct rainfall

Notes: *1 *Assumed value for modelling purposes*

*2 *Calculated alkalinity based on using carbon species to achieve charge balance.*

*3 *Adjusted for charge balance. Charge balanced adjusted value indicated in brackets.*

'-' indicates not measured; treated as a concentration of zero

8.1.3 Geochemical model approach and development

The geochemical model was run for major cations, anions, and selected metal(loid)s per the availability of data. Further discussion is focused on pH and total dissolved solids (TDS) as identified in the rehabilitation requirements of the EA (EPML00561913).

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 (US EPA, 1998).

The geochemical model was run as follows:

- Source terms were mixed for monthly 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 being used as the input for the next time step.
- Geochemical reactions enabled, such as mineral precipitation/dissolution, gas exchange and sorption.

The following assumptions apply to the geochemical model:

- At all times, the void lake is fully mixed, geochemical reactions occur within the modelled timestep and are not kinetically controlled. Mineral precipitates are retained within the void lake.
- Solute release from high-wall rock and spoil does not occur below the lake water level. Mineral solids initially present in the void lake are not accounted for in the current model (i.e., submerged high-wall, spoil, regolith, and talus).
- The release of coal bed methane is not a significant process and does not drive groundwater or lake chemistry towards more reducing conditions.
- Although expected to be minor, seepage from the void to the groundwater system has the same composition as the void lake.
- There is no seepage of infiltrated rainfall or groundwater through the in-pit waste to the void lake.
- Stratification is assessed at a conceptual level based on a 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 geochemical controls on predicted water quality. The geochemical controls considered include mineral precipitation (and subsequent dissolution), gas exchange with the atmosphere and sorption. The two simulations are summarised in Table 8.4 and were performed for the mean water balance scenario.

Table 8.4 Geochemical model sensitivity test simulation parameters for the residual voids at Daunia

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

*Notes: *420 parts per million (ppm) is representative of current (2022) 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.

8.2 Residual void water quality

The following sections present the results of the geochemical modelling for the void lakes at DNM for pH and TDS. The results are presented for scenarios with and without geochemical controls/reactions (i.e., mineral precipitation, sorption, and gas exchange).

8.2.1 Titan East residual void

Based on the outcomes of this assessment, the void water quality in Titan East residual void is predicted to evolve over time with TDS simulated to increase following closure, as a result of evapo-concentration. The pH remains stable and within the EA range for the modelled period, with a higher pH under the geochemical control simulation. Titan East residual void is considered a NUMA and current groundwater (Section 4) and water balance (Section 6) modelling indicated the residual void remains a sink after the void lake levels have reached equilibrium post-closure. The model results for pH and TDS at Titan East residual void are presented in Figure 8.1 and Figure 8.2, respectively. The seasonality in the DNM void lake levels identified in the WBM (Section 6) also influence the TDS seasonally within the void lakes (see Figure 8.2).

The results are summarised as follows:

pH:

- Acidic conditions are unlikely to form in the Titan East residual void lake, with models indicating a stable pH within the EA range for the modelled period.
- The simulation with geochemical controls results in a higher pH than the simulation without geochemical controls. The main geochemical control is CO_2 degassing which raises pH, resulting in calcite/magnesite precipitation that reduces pH. These geochemical processes are driven by the input of groundwater (a source of dissolved inorganic carbon) to the void lake.

TDS:

- TDS concentrations increase with time, indicating the development of saline conditions. TDS concentrations exceed both the lower and upper EA-derived trigger values in the years 2070s to 2080s whether geochemical controls are applied or not.
- The TDS concentration variations retain a 20-year cyclicity from the WBM void lake levels and display minor seasonal variations. The increase in TDS concentration is primarily driven by evapo-concentration.
- TDS concentrations are lower in simulations with geochemical controls due to the removal of calcium, magnesium and alkalinity through magnesite and calcite precipitation. Geochemical controls do not lead to an 'equilibrium' state for water quality (i.e., constant TDS). Other mineral phases predicted to precipitate do not significantly affect TDS.

Stratification:

- The steep sides of the void and the elevated TDS present favourable conditions for stratification. However, the maximum water depth is relatively shallow (~18 m at deepest point) and therefore well mixed conditions are expected to dominate. Water of higher density (cooler or more saline) may still 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.

Quality Control (QC):

- The log of the electron activity (pe) and water mass conservation stay within a suitable range throughout the model duration.

EA exceedance occurrences for Titan East residual void are presented in Table 8.5.

Table 8.5 Occurrence of geochemically modelled Titan East residual void EA exceedance by decade

Parameter	Exceedance occurrence (by decade)			
	EA Minimum trigger value		EA Maximum trigger value	
	Geochemical controls	No geochemical controls	Geochemical controls	No geochemical controls
pH	n/a	n/a	n/a	n/a
TDS	2070	2070	2070	2070

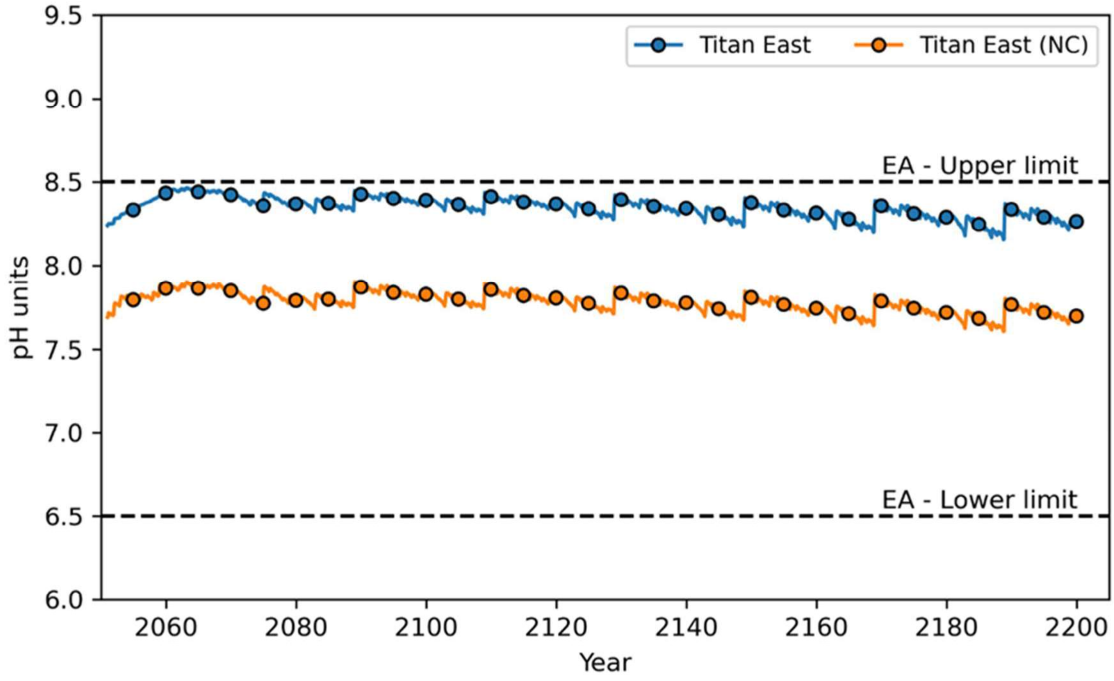

Figure 8.1 Titan East residual void water quality pH evolution over the simulation period (NC=no geochemical controls)

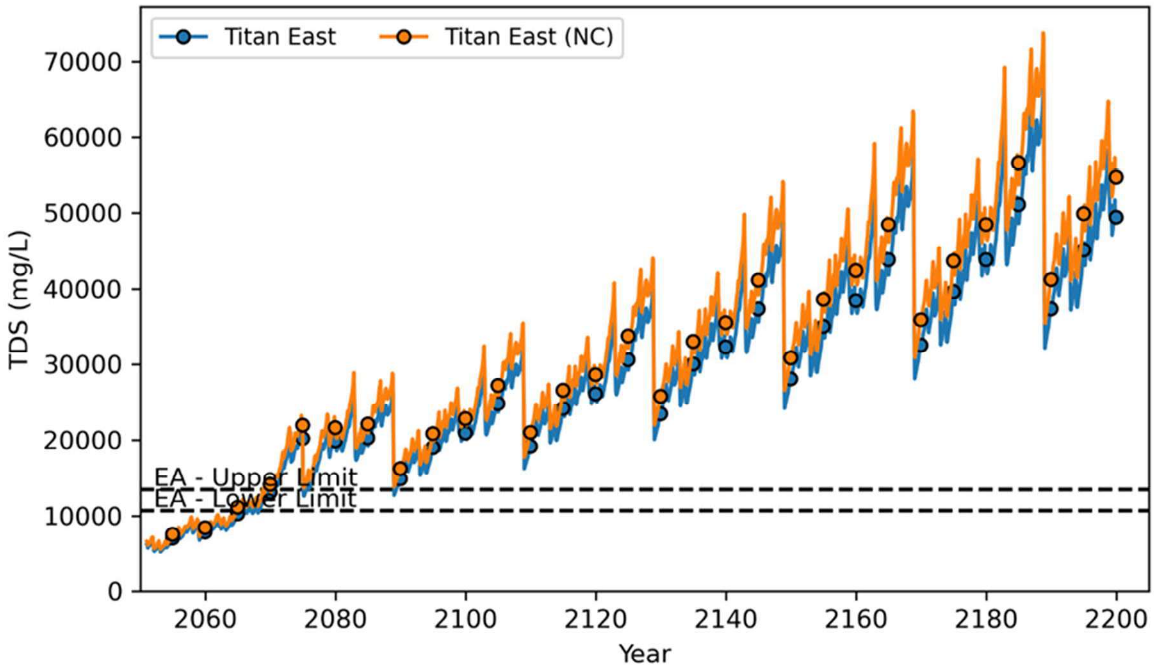

Figure 8.2 Titan East residual void water quality TDS evolution over the simulation period (NC=no geochemical controls)

8.2.2 Titan North/Central residual void

Based on the outcomes of this assessment, the void water quality in Titan North/Central residual void is predicted to evolve through time with TDS simulated to increase following closure as a result of evapo-concentration. The pH increases in both simulations to above the EA upper limit until it stabilises at mildly alkaline conditions under the geochemical control simulation. The pH for the simulation without geochemical controls peaks at mildly alkaline conditions before declining and returning to within the EA range. A higher pH is observed under the geochemical control simulation. Titan North/Central residual void is considered a NUMA and current groundwater (Section 4) and water balance (Section 6) modelling indicated the residual void remains a sink after the void lake levels have reached equilibrium post-closure. The model results for pH and TDS at Titan North/Central residual void are presented in Figure 8.3 and Figure 8.4 respectively.

As is the case for Titan North/Central residual void as well, the seasonality in the DNM void lake levels identified in the WBM (Section 6) also influence the TDS seasonally within the void lake (see Figure 8.4).

The results of the geochemical assessment are summarised as follows:

pH:

- Acidic conditions are unlikely to form in the Titan North/Central residual void lake with models indicating pH exceeding the upper EA range. Mildly alkaline conditions are predicted to develop and exceed the upper EA trigger value from the 2060s in both simulations. In simulations without geochemical controls, pH begins to decrease in the 2090s and falls below the upper EA criteria in the 2150s. In simulations with geochemical controls, the pH stabilises however remains above the upper EA range for the modelled period.
- The simulation with geochemical controls results in a higher pH than the simulation without geochemical controls. The main geochemical control is CO_2 degassing which raises pH, resulting in calcite/magnesite precipitation that reduces pH. These geochemical processes are driven by the input of groundwater (a source of dissolved inorganic carbon) to the void lake.

TDS:

- TDS concentrations increase with time, primarily driven by evapo-concentration, and retained a 20-year cyclicity from the WBM with minor seasonal variation. TDS concentrations fluctuate around both the lower and upper EA-derived trigger values from the 2160s whether geochemical controls are being applied or not., An initial reduction in TDS up to around 2060 is driven by the initial void lake level (assumed to be groundwater), inflows of rainfall and run-off and seepage out of the initial void lake.
- TDS concentrations are lower in simulations with geochemical controls due to the removal of calcium, magnesium, and alkalinity through magnesite and calcite precipitation. Geochemical controls do not lead to an 'equilibrium' state for water quality (i.e., constant TDS concentration). Other mineral phases predicted to precipitate do not significantly affect TDS concentration.

Stratification:

- The steep sides of the void and elevated TDS present favourable conditions for stratification. However, the maximum water depth is relatively shallow (~17 m at deepest point) and therefore well mixed conditions are expected to dominate. Water of higher density (cooler or more saline) may potentially still 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.

QC:

- The log of the electron activity (pe) and water mass conservation stay within a suitable range throughout the model duration.

EA exceedance occurrences for Titan North/Central residual void are presented in Table 8.6.

Table 8.6 Occurrence of geochemically modelled Titan North/Central residual void EA exceedance by decade

Parameter	**Exceedance occurrence (by decade)**			
	EA Minimum trigger value		**EA Maximum trigger value**	
	Geochemical controls	**No geochemical controls**	**Geochemical controls**	**No geochemical controls**
pH	n/a	n/a	2060	2060
TDS	2180	2180	2190	2190

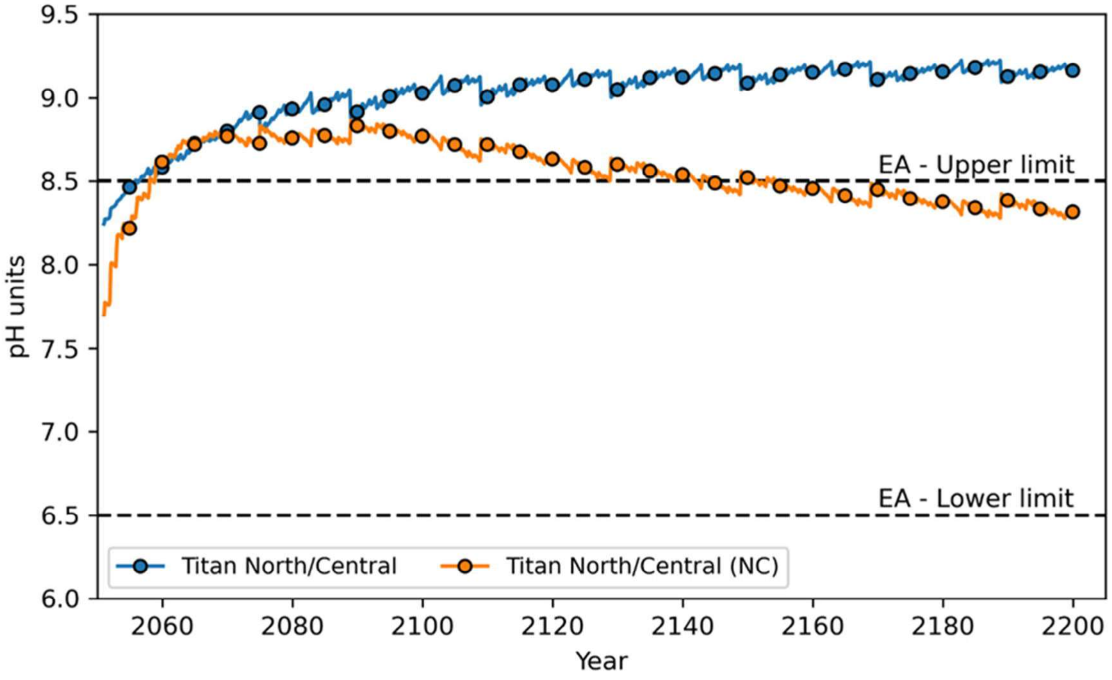

Figure 8.3 Titan North/Central residual void water quality pH evolution over the simulation period (NC=no geochemical controls)

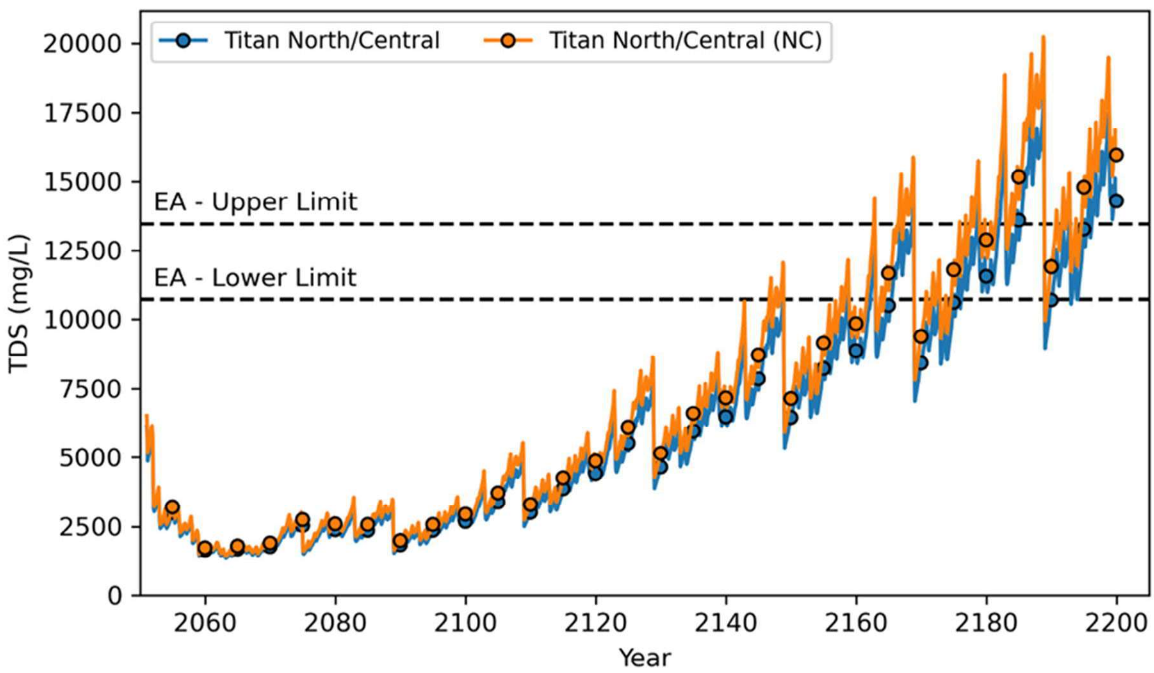

Figure 8.4 Titan North/Central residual void water quality TDS evolution over the simulation period (NC=no geochemical controls)

8.2.3 Pandora residual void

Based on the outcomes of this assessment, the void water quality in Pandora residual void is predicted to evolve through time with TDS simulated to increase due to evapo-concentration following closure. The pH increases in both simulations to above the EA upper limit until it generally stabilises at mildly alkaline conditions under the geochemical control simulation.

The pH for the simulation without geochemical controls peaks at mildly alkaline conditions before declining and returning to within the EA range. A higher pH is observed under the geochemical control simulation. Pandora residual void is considered a NUMA and current groundwater (Section 4) and water balance (Section 6) modelling indicated the residual void remains a sink after the void lake levels have reached equilibrium post-closure. The model results for pH and TDS at the Pandora residual void are presented in Figure 8.5 and Figure 8.6, respectively.

As is the case for Pandora residual void as well, the seasonality in the DNM void lake levels identified in the WBM (Section 6) also influence the TDS seasonally within the void lake (see Figure 8.6).As is the case for Pandora residual void as well, the seasonality in the DNM void lake levels identified in the WBM (Section 6) also influence the TDS seasonally within the void lake (see Figure 8.4)

The results of the geochemical assessment are summarised as follows:

pH:

- Acidic conditions are unlikely to form in the Pandora residual void lake with models indicating pH exceeding the upper EA range. Mildly alkaline conditions are predicted to develop and exceed the upper EA trigger value from the 2060s in both simulations. In simulations without geochemical controls, pH begins to decrease in the 2090s and falls below the upper EA criteria in the 2150s. In simulations with geochemical controls, the pH generally stabilises with a decline later in the model period, however, remains above the upper EA range for the modelled period.
- The simulation with geochemical controls resulted in a higher pH than the simulation without geochemical controls. This main geochemical control was CO_2 degassing which raises pH, resulting in calcite/magnesite precipitation that reduces pH. These geochemical processes were driven by the input of groundwater (source of dissolved inorganic carbon) to the void lake.

TDS:

- TDS concentrations increase with time, indicating the development of saline conditions. TDS concentrations fluctuate around both the lower and upper EA-derived trigger values from the 2160s irrespective of whether geochemical controls are applied. An initial reduction in TDS up to around 2060 is driven by the initial void lake level (assumed to be groundwater), inflows of rainfall and run-off and seepage out of the initial void lake.
- TDS concentrations increase with time, primarily driven by evapo-concentration, and retained a 20-year cyclicity from the WBM with minor seasonal variation.
- TDS was lower in simulations with geochemical controls due to the removal of calcium, magnesium and alkalinity through magnesite and calcite precipitation. Geochemical controls did not lead to an ‘equilibrium’ state for water quality (i.e., constant TDS). Other mineral phases predicted to precipitate do not significantly affect TDS concentrations.

Stratification:

- The steep sides of the void and elevated TDS present favourable conditions for stratification. However, the maximum water depth is relatively shallow (~22 m at deepest point) and therefore well mixed conditions are expected to dominate. Water of higher density (cooler or more saline) may potentially still 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.

QC:

- The log of the electron activity (pe) and water mass conservation stay within a suitable range throughout the model duration.

EA exceedance occurrences for Pandora residual void are presented in Table 8.7.

Table 8.7 Occurrence of geochemically modelled Pandora residual void EA exceedance by decade

Parameter	Exceedance occurrence (by decade)			
	EA Minimum trigger value		EA Maximum trigger value	
	Geochemical controls	No geochemical controls	Geochemical controls	No geochemical controls
pH	n/a	n/a	2060	2060
TDS	2160	2160	2180	2180

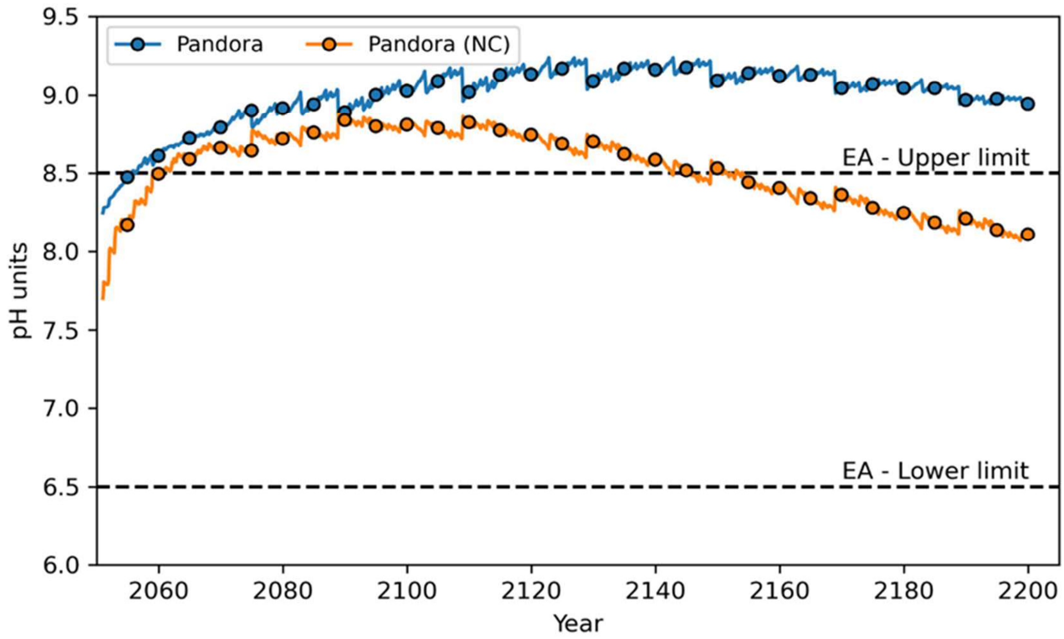

Figure 8.5 Pandora residual void water quality pH evolution over the simulation period (NC=no geochemical controls)

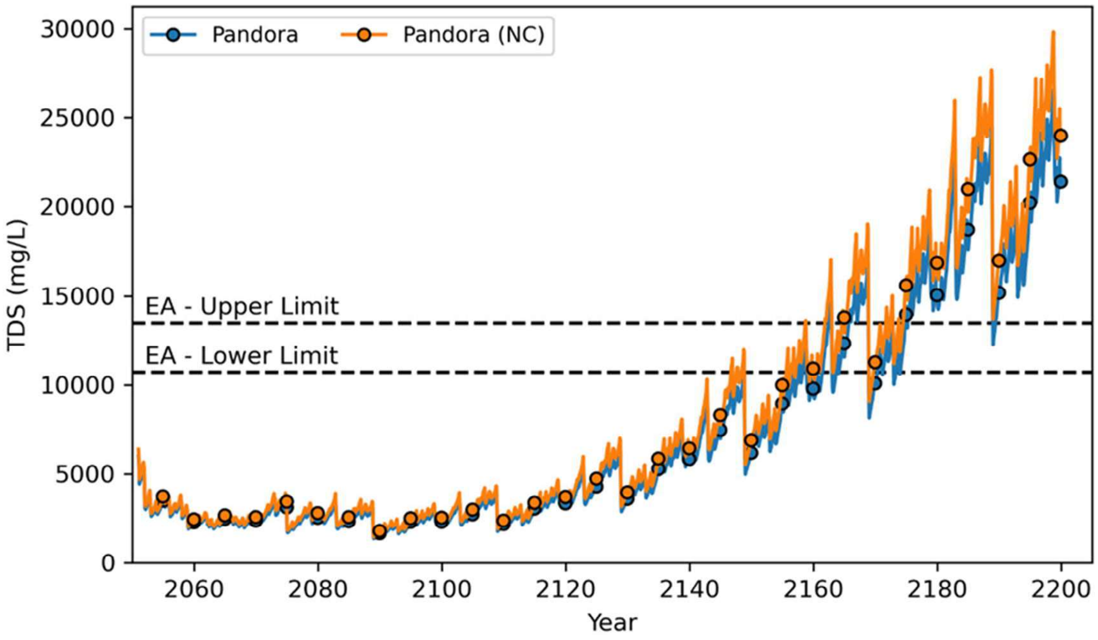

Figure 8.6 Pandora residual void water quality TDS evolution over the simulation period (NC=no geochemical controls)

8.2.4 Qualifications

The following caveats and limitations apply to the water quality model, in relation to the TDS and pH modelling, for the DNM residual voids:

— Available data at the time of modelling was used to represent relevant geochemical interactions. Availability of additional data in future may result in different model outputs.

— Water movements are based on complementary studies (groundwater and water balance). These studies constrain the model duration and the water sources. Most notably, it is currently not possible to quantify in-pit seepage through spoil.

— Screening was performed against EA criteria for groundwater contaminant trigger values. The criteria for TDS were derived from the EA electrical conductivity value using a 0.67 factor that is considered acceptable for freshwater.

9 Residual Void Management

A summary of key findings from the technical studies (presented in Sections 4 to Section 8), which should be used to inform development of residual void management measures, are presented below:

- Groundwater modelling and WBM results indicate the formation of void lakes, with lake levels stabilising significantly below the pre-mining groundwater elevations and any shallow post-Permian strata, including the base of surficial weathering and shallow hydrostratigraphic units (i.e., alluvium and Permian/Tertiary sediments). Evaporative discharge from the void lakes will result in continued inwards hydraulic flow gradients to the voids and no outflow in the long-term with voids continuing to capture any seepage from spoil dumps.
- No additional impact beyond that which already exists at the end of mining is expected on surficial aquifers, including the shallow alluvium, and little to no impact on environmental or anthropogenic (e.g., water extraction bores) receptors is expected. All three residual voids are expected to act as groundwater sinks.
- WBM results predict that the voids will not overtop. Titan East residual void will reach a mean void water elevation of 133 m AHD and a mean void water volume of 500 ML. Titan North/Central residual void will reach a mean void water elevation of 135 m AHD and a mean void water volume of 1,250 ML. Pandora residual void will reach a mean void water elevation of 120 m AHD and a mean void water volume of 500 ML. At the end of the simulation, all three residual void lakes are well below the spill elevations for the respective pits.
- The final closure state landforms have been designed such that the geotechnical stability for the low-walls achieved a FoS equal to or greater than 1.5. Therefore, the low-walls of the final closure state landforms can be considered stable for all residual voids.
- With regards to high-walls and end-walls, at closure, the final closure state landforms for all residual voids achieve a FoS of greater than or equal to 1.5 and therefore can be considered stable. All third-party assets will remain outside of these extents.
- Upon closure, the DNM residual voids will be bunded and fenced, where restricting access to wall and slope angles is required, to prevent unrestricted access and to maintain safety for humans and livestock.
- For the final closure state landform, the residual voids associated with DNM are not subject to inundation from floodwaters from the Isaac River and New Chum Creek up to and including the 0.1% AEP climate change RCP 8.5 P90 event. Pandora residual void may be subject to minor floodwater ingress under the conservative 0.1% AEP RCP 8.5 P90 scenario due to the presence of a drainage feature to the east of this residual void. The floodwater ingress volumes are expected to be minimal and Pandora residual void has sufficient capacity to accommodate any potential ingress without risk of overtopping or groundwater outflows; therefore, no additional management considerations are deemed necessary.
- Ongoing monitoring and maintenance of the residual voids is expected to be restricted to:
  - Monitoring and maintenance of exclusion fences/bunds to ensure these remain effective.
  - Groundwater and residual void lake level monitoring to confirm the voids are progressing towards acting as sinks.
- All three DNM residual voids will be retained as NUMAs. To support attainment of the NUMA voids that are safe and do not present an unacceptable risk of off-tenure environmental harm, the management strategies are presented in Table 9.1.

y	ity	ing		
✓	✓	-	— Stability of the residual void walls = FoS ≥1.5.	— As mining approaches the final limits, re-assess the wall required geotechnical setbacks based on the latest availa — Review and adjust the mine plan and final closure state account for any revised set-back requirements. — Use a minimum FoS≥1.5 as a guidance for ongoing voi may be refined over the mine life should industry resear guidance on observational methods and consequence as
✓	✓	✓	— All DNM final residual voids in the final closure state landform are not subject to inundation from floodwaters from the Isaac River and New Chum Creek up to and including the 0.1% AEP climate change RCP 8.5 P90 event based on rehabilitation flood modelling completed. Pandora residual void may be subject to minor floodwater ingress under the conservative 0.1% AEP RCP 8.5 P90 scenario due to the presence of a drainage feature to the east of this residual void. — As the water levels remain below the groundwater levels for all DNM residual voids (and well below the voids' spill points), the voids will not overtop and environmental harm beyond that of the void itself is not expected. Therefore, no management activities required. — The residual voids remain as long-term sinks (based on average gradients). For Titan East residual void: — After 2199, mean water levels start to stabilise, with simulated mean inflows of 148 ML/year being very similar to mean outflows of 148 ML/yr. This indicates that the mean water balance has reached an equilibrium. — The long-term mean void lake levels remain below groundwater level. This provides an available storage capacity for the void to keep acting as a sink. For Titan North/Central residual void: — After 2199, mean water levels start to stabilise, with simulated mean inflows of 437 ML/year being very similar to mean outflows of 436 ML/yr. This indicates that the mean water balance has reached an equilibrium. — The long-term mean void lake levels remain below groundwater level. This provides an available storage capacity for the void to keep acting as a sink. For Pandora residual void: — After 2199, mean water levels start to stabilise, with simulated mean inflows of 196 ML/year being very similar to mean outflows of 195 ML/yr. This indicates that the mean water balance has reached an equilibrium. — The long-term mean void lake levels remain below groundwater level. This provides an available storage capacity for the void to keep acting as a sink.	— Residual void catchments are minimised as far as practi include only the low-wall areas. — At cessation of mining activities, review and update the modelling, incorporating identified changes to the voids landforms and spill point elevations, rainfall and evapor runoff and groundwater inflows, and climate projection — Although not identified in current modelling, if future m unacceptable risk of environmental harm outside the ten management strategies to be implemented. — Obtain certification from an appropriately qualified pers voids will not cause environmental harm beyond that of — If necessary, identify and implement mitigation measure protection works of landforms where floodwaters from with final closure state landforms.

-	-	✓	— At the end of mining, dewatering activities have lowered groundwater levels forming cones of depression centred on all DNM residual voids. The groundwater flow direction will be towards the voids. — Pit lakes that form within the voids, remain below the pre-mining groundwater levels and shallow geological units due to evaporative effects on the pit lakes. The groundwater in the proximity of the pits will remain below the pre-mining groundwater levels due to ongoing inflows to the pits and the groundwater flow direction within the tenure will remain towards the pits. — The DNM residual voids will act as groundwater sinks post-closure, and groundwater will continue to flow towards the voids. Modelling, including particle tracking, indicates that seepage from the spoil, and other disturbed areas (except for the MIA) within the tenure will migrate towards and be captured within the residual voids. The MIA area will be managed separately to the voids. The initially observed water level increase in the hydrographs immediately post-mining in the Titan East Leichardt and Vermont seams is not sustained, and the residual void levels remain significantly below the groundwater levels for the duration of the modelled period. This indicates no potential for outwards movement of void water to groundwater outside of the residual voids. Therefore, environmental harm beyond that of the void itself is not expected.	— At cessation of mining activities, review and update the incorporating updated void WBM outputs and in-field g data, as required. — Although not identified in current modelling, if future m unacceptable risk of environmental harm outside the ten management strategies to be implemented. — Obtain certification from an appropriately qualified pers of mining, residual voids do not present an unacceptable harm beyond that of the void itself. — Undertake groundwater and residual void lake level mon voids are progressing towards acting as sinks.
-	-	✓	— There are no significant sources of acid generation associated with DNM's closure-related surface water hydrology, and acidic conditions are unlikely to develop in the voids. — TDS in all DNM residual voids will continue to increase over time. — Preliminary, high-level screening base on predicted TDS levels suggest that all DNM residual voids are not likely to become stratified. — As all DNM residual voids stabilise as groundwater sinks over time, they do not present an unacceptable risk of environmental harm beyond that of the void itself.	— At cessation of mining activities, review and update the assessment, including additional or refined data from in samples, surface- and groundwater samples, and biochei — Although not identified in current modelling, if future m unacceptable risk of environmental harm outside the ten management strategies are to be identified and impleme — Obtain certification from an appropriately qualified pers voids will not present an unacceptable risk of environme the void itself.
✓	-	-	Restrict access to the residual void by humans and livestock.	On cessation of mining activities: — Construct a safety bund at the geotechnical set-back dist — Erect fencing and signage (where required) around the p bund.

vill be undertaken as part of monitoring of the NUMA extents (see Monitoring Section in the PRC plan). This monitoring will aim to demonstrate achievement of sufficient improvement (final NUMA manageme opriately qualified person that all residual voids:

eptable risk of environmental harm outside of the tenure boundary.

ivestock.

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