Residual Void Investigation Report

Minerva Joint Venture

Version: 1.0 (5 November 2021)

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1 Introduction

The Minerva Mine operates under Environmental Authority EPML00668613 which authorises residual voids to remain following mining provided that the void outcomes in Conditions F7 and F 8 are met. Condition F7 of the Environmental Authority states that residual voids must not cause any serious environmental harm to land, surface waters or any recognised groundwater aquifer, other than the environmental harm constituted by the existence of the residual void itself and subject to any other condition within this environmental authority.

Condition F8 of the Environmental Authority states that, if residual voids are to be left, an investigation into residual void options and landform design is to be completed.

Table 1 shows where this *Residual Void Investigation Report* addresses Condition F8.

Table 1 – Environmental Authority Condition F8

Condition F8	Addressed in
F7. Residual void outcome Residual voids must not cause any serious environmental harm to land, surface waters or any recognised groundwater aquifer, other than the environmental harm constituted by the existence of the residual void itself and subject to any other condition within this environmental authority.	Section 3 & 7
F8. If residual voids are to be left, an investigation in to residual void options and landform design are to be completed. The subsequent report is to be submitted to the administering authority proposing acceptance criteria to meet the outcomes in Condition F7, landform design criteria in Table F1, final void reduction options and options to reduce the height of the main dumps by 29 November 2021. The investigation shall be completed by a competent person and include detailed research and modelling and at a minimum include the following:	
(a) a study of options available for minimising final void area and volume;	Section 2
(b) a void hydrology study, addressing the long-term water balance in the voids, connections to groundwater resources and water quality parameters in the long term;	Section 3
(c) a pit wall stability study, considering the effects of long-term erosion and weathering of the pit wall and the effects of significant hydrological events;	Section 4
(d) a hydrology study into the long term risk of Sandhurst Creek / final void interaction, including erosion of the banks and spoil and extreme hydrological events, and the consequences of such interaction to the long-term stability of the final voids.	Section 5
(e) study of void capability to support native flora and fauna; and	Section 6
(f) a proposal/s for end of mine void rehabilitation success criteria and final void areas and volumes.	Section 2 & 7

2 Final Void Area and Volume

Coal mining at the Minerva Mine ceased in August 2021. A final landform design has been prepared based on the pit and dump surface configuration at the cessation of coal extraction.

The following criteria have been applied when optimising the design of the final landform:

- reshape the current low walls to 25% with 30m wide benches every 30m of vertical lift;
- Western pit reshaped to 210mRL with fill below this at angle of repose;

- Southern pit reshaped to 200mRL with fill below this at angle of repose;
- Southern pit highwall reshaped in part to reduce void area; and
- reshaped 25% slopes shall be capped with 0.5m of basalt rock mulch.

The optimised final landform design results in the void areas and volumes shown in **Table 2.**

Table 2 – Final Void Areas and Volumes

	Western Void	Southern Void
Low wall backfill and reshaping	Backfill and reshape to 25% slope with 30m benches every 30m vertical interval	
	Backfill and reshape to 210mRL (backfill below at angle of repose)	Backfill and reshape to 200mRL (backfill below at angle of repose)
Highwall reshaping	n.a.	Partial backfill and reshape of south east section to 25% slope to reduce void area
Area*	76.84ha (at 210mRL)	12.18ha (at 200mRL)
Volume*	29.73 Mm^3 (at 210mRL)	1.63Mm^3 (at 200mRL)

*subject to minor change as design is refined and physical works progress

Maximum void slope angles and the total void area (89.02ha) are less than the maximums prescribed in Table F1 of the Environmental Authority (91ha).

The location of the final voids in relation to the mining leases is shown in in **Figure 1.**

The reshaping for the final voids is shown in plan view in **Figure 2.** The light blue lines show the final voids and green shows the contours of areas reshaped. A three-dimensional image of the final landform is shown in **Figure 3**. The final height of the main dump is 320mRL and that of the South West Dump 345mRL.

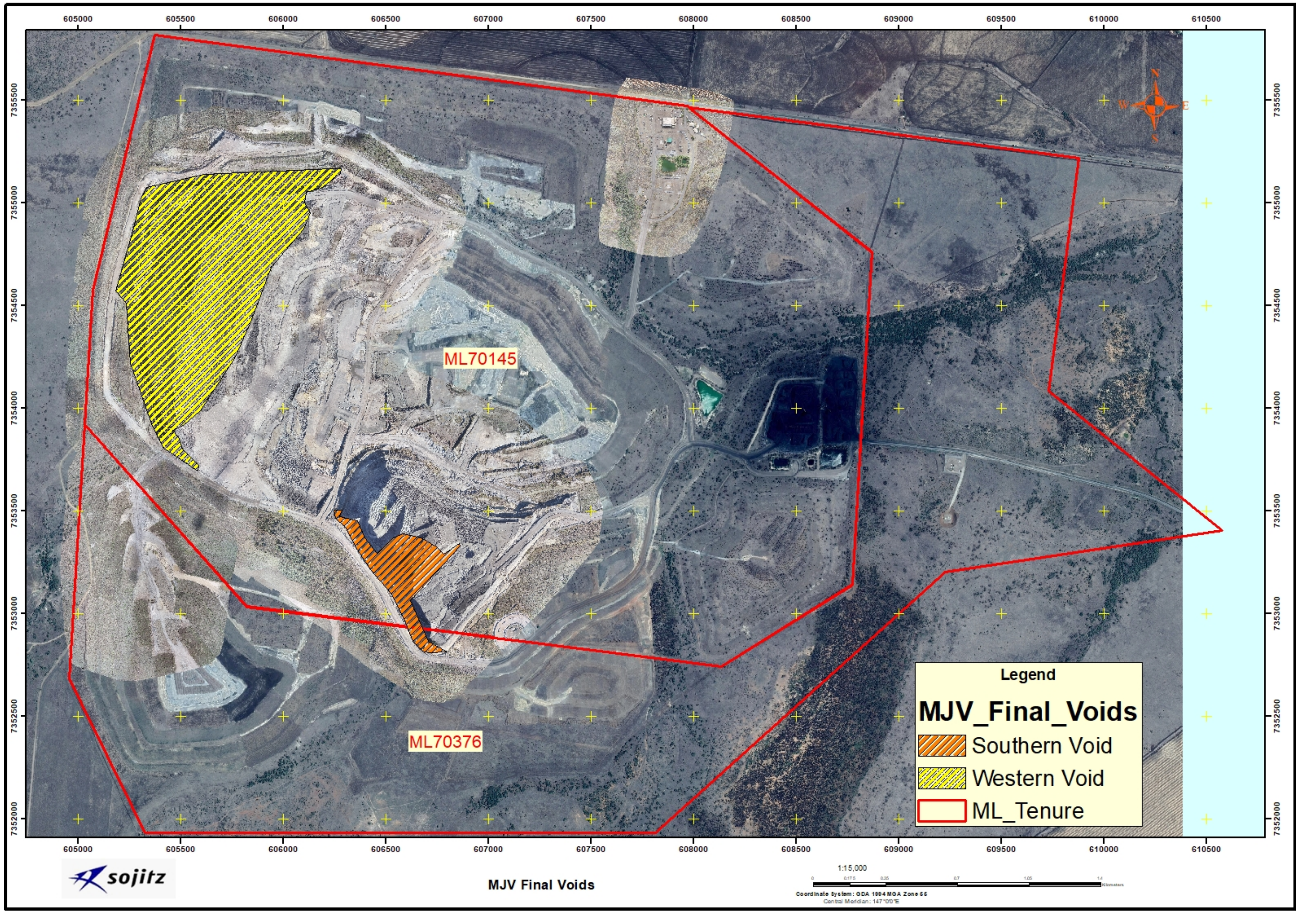
ML70145
ML70376
Legend
MJV_Final_Voids
Southern Void
Western Void
ML_Tenure
MJV Final Voids
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Figure 2 – Plan view of final void reshaping

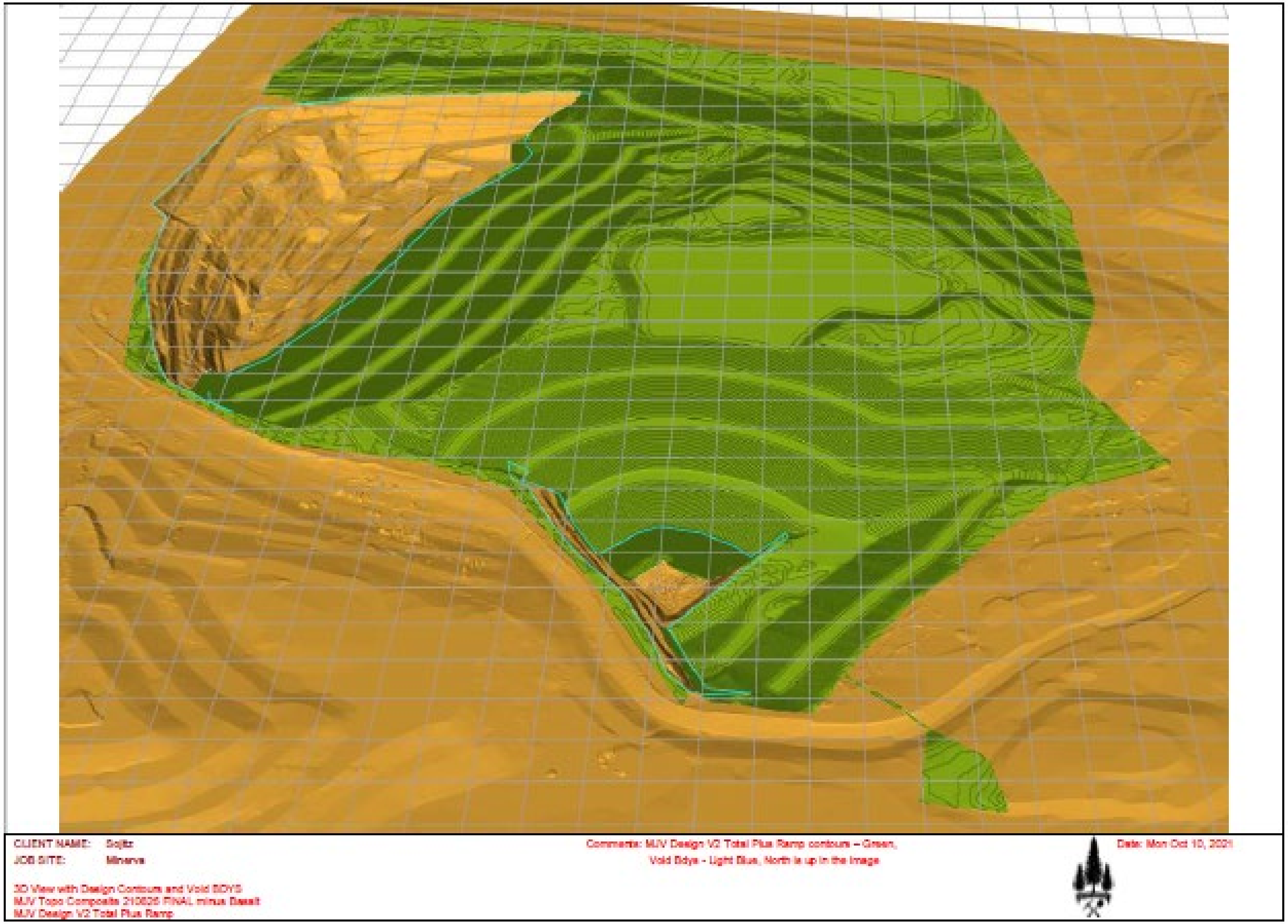

Figure 3 – 3D view of final void reshaping

3 Void Hydrology Study

Residual void hydrological studies have been undertaken to:

- calculate future groundwater inflow rates into the Western and Southern residual voids;
- determine to long-term water balance in the voids (including the long-term equilibrium water level and potential interactions with surrounding aquifers); and
- estimate long-term void water quality.

These studies are summarised below and further details are presented in AGE (2017) (attached as an **Appendix A** to this report).

3.1 Groundwater inflow rates

The lateral and vertical geometry of aquifers contributing to the Western and Southern residual voids was assessed from final pit wall sections. Strata contributing groundwater inflow to the Western void include weathered basalt, basalt, upper Permian coal measures and lower Permian coal measures. Only the upper Permian coal measures and lower Permian coal measures contribute groundwater to the Southern void as basalt strata are not intersected.

The potential rate of groundwater inflow to both residual voids through each highwall segment was calculated using Darcy's equation of flow through a porous media. This equation uses the aquifers hydraulic conductivity, the hydraulic gradient within the aquifer, and the cross-sectional area of the seepage face, to determine the volume of water moving through a vertical plane of aquifer material. In this case the vertical plane of aquifer material is the highwall in the residual voids.

The basalt was assumed to have a hydraulic conductivity of 1 m/day, while a coal seam hydraulic conductivity of 0.01 m/day was applied. A recharge of 6% of rainfall was used to represent recharge into the basalt, while a recharge of 0.1% of rainfall was used to represent recharge into the weathered Permian cover. The regional water table away from the mine impact was assumed to be 270 mAHD. Groundwater inflow estimates were made with void water levels at 5 m increments vertically from the base of each void (i.e. void stage height).

The calculated groundwater inflow rate to the Western void is predicted to be consistently about 408 ML/year because the hydraulic gradient within the basalt aquifer is unlikely to be influenced by the elevation of the void water level in the void.

The calculated groundwater inflow rate to the Southern void is predicted to slightly decline as the void water level increases. The predicted inflow rate from the coal seams reduces from about 7.3 ML/year at the end of mining to about 6.4 ML/year when the long-term equilibrium water level is reached.

3.2 Long-term water balance and mass balance model

A GoldSim water balance and mass balance model was developed to calculate the rate of water level recovery within each void, the long-term equilibrium water level, and the TDS concentration of void water. The GoldSim model made allowances for the following:

- Rainfall reporting to the final voids and runoff from the low-wall spoil area (surface and baseflow);
- Groundwater inflow rates dependent upon the pit water levels in each void;
- A nominal 5% spoil porosity for spoil material and potential storage of water within the spoil for all void water levels;

- Seepage between the voids when water levels in either void exceeded the elevated base of coal level between the mining voids;
- A spoil hydraulic conductivity of 0.2m/day. Seepage through the spoil was estimated using Darcy's equation with estimates of seepage face area and length of seepage path between the pits used; and
- Salt mass balance using TDS concentrations of 655 mg/L for basalt groundwater inflow, 2,039 mg/L for coal measures groundwater inflow and 350 mg/L for runoff from mine areas and rehabilitation. No allowance was made for leaching of salts from spoil material.

A Data Drill of 128 years of rainfall and associated evaporation data was used to generate 100 data sets of daily rainfall and evaporation for a 1,000-year period. All climatic data sets were run through the model to generate a probability assessment of water levels and TDS concentrations within the residual voids. The 50th percentile stable water levels were adopted as representative of mining void performance.

3.3 Water Balance Modelling Results

The water balance model for the Western residual void indicates the water level will rise towards an equilibrium over a period of about 60,000 days (~164 years) (see **Figure 4**). The long-term median equilibrium water level is predicted to be about 195 mAHD, with a range of 185 to 210 mAHD. The maximum water level remains 60m below where the void would spill.

The long-term equilibrium water level is predicted to be 6m below the base of the basalt exposed in the highwall (201 mAHD) and the maximum void water level is predicted to be above the base of the basalt. This is shown in cross-section in **Figure 5**. The maximum void water level is predicted to remain about 60m below the elevation of the regional groundwater table. A groundwater hydraulic gradient is expected to be maintained in perpetuity towards the Western residual void and therefore the likelihood of void water interacting with the basalt aquifer is low.

The water balance model for the Southern residual void indicates the water level will rise towards an equilibrium over a period of about 40,000 days (~110 years) (see **Figure 6**). The long-term median equilibrium water level is predicted to be about 175 mAHD, with a range of 150 to 200 mAHD. The maximum water level remains 60m below where the void would spill.

The long-term equilibrium water level is predicted to be within the lower coal seam group and the maximum void water level is predicted to be within the upper coal seam group. This is shown in cross-section in **Figure 7**. The maximum void water level is predicted to remain about 70m below the elevation of the regional groundwater table. A groundwater hydraulic gradient is expected to be maintained in perpetuity towards the Southern residual void and therefor the likelihood of void water leaving the void via coal seams is low.

The predicted void water equilibrium level for the Southern void is lower than predicted levels for the Western void and a hydraulic gradient is expected to form towards the Southern void. The Southern void will permanently remain a groundwater "sink" where evaporation permanently depresses the water level.

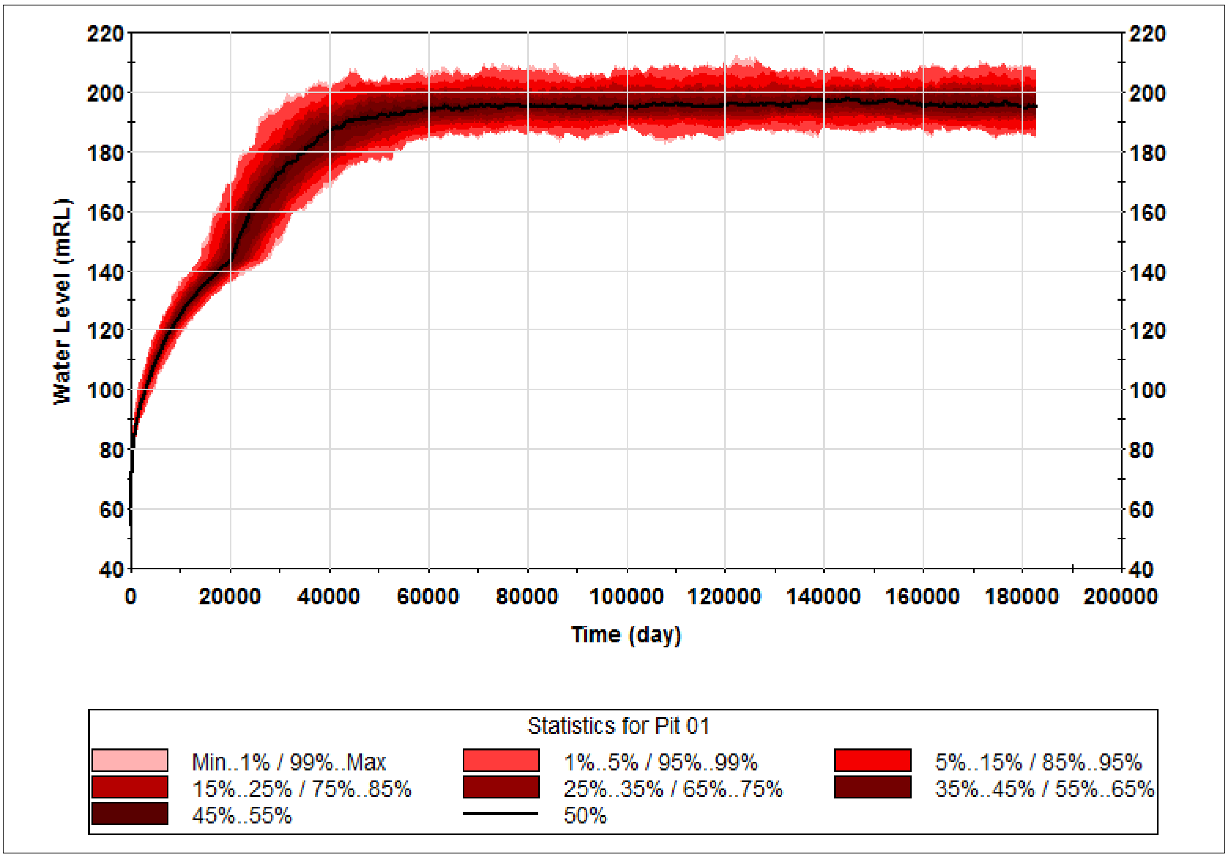

Figure 4 – Predicted equilibrium water level in Western residual void

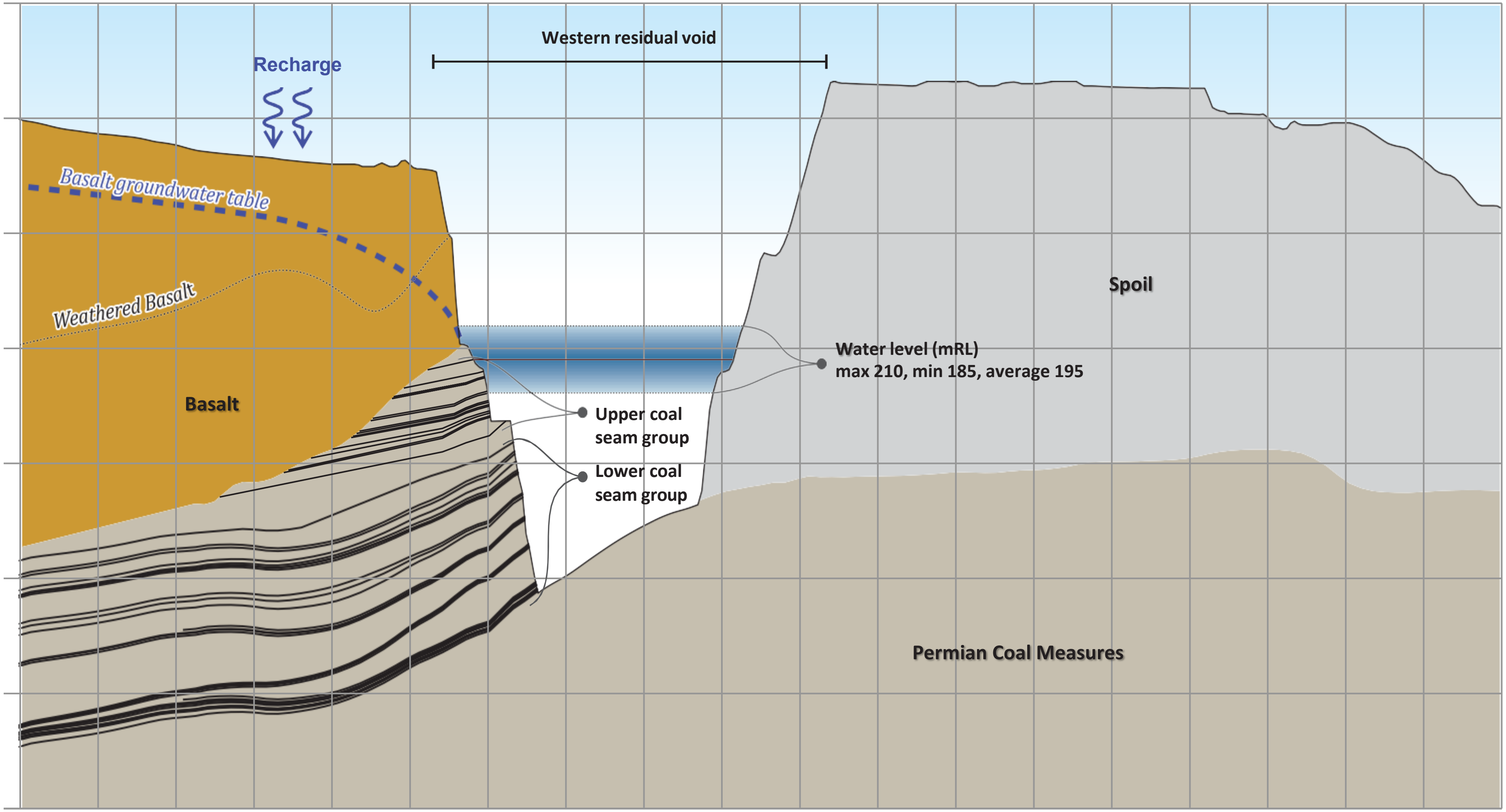

Figure 5 – Western residual void cross-section

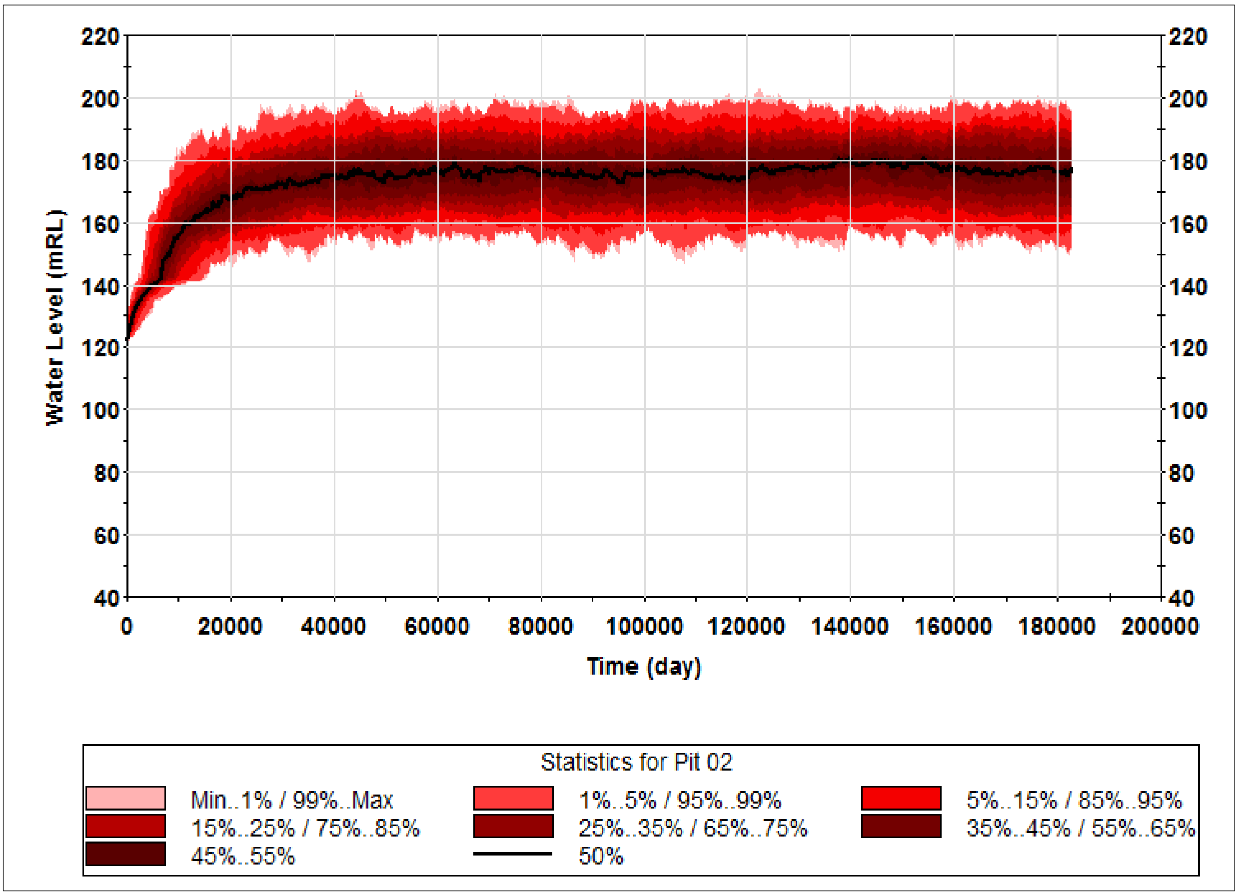

Figure 6 – Predicted equilibrium water level in Southern residual void

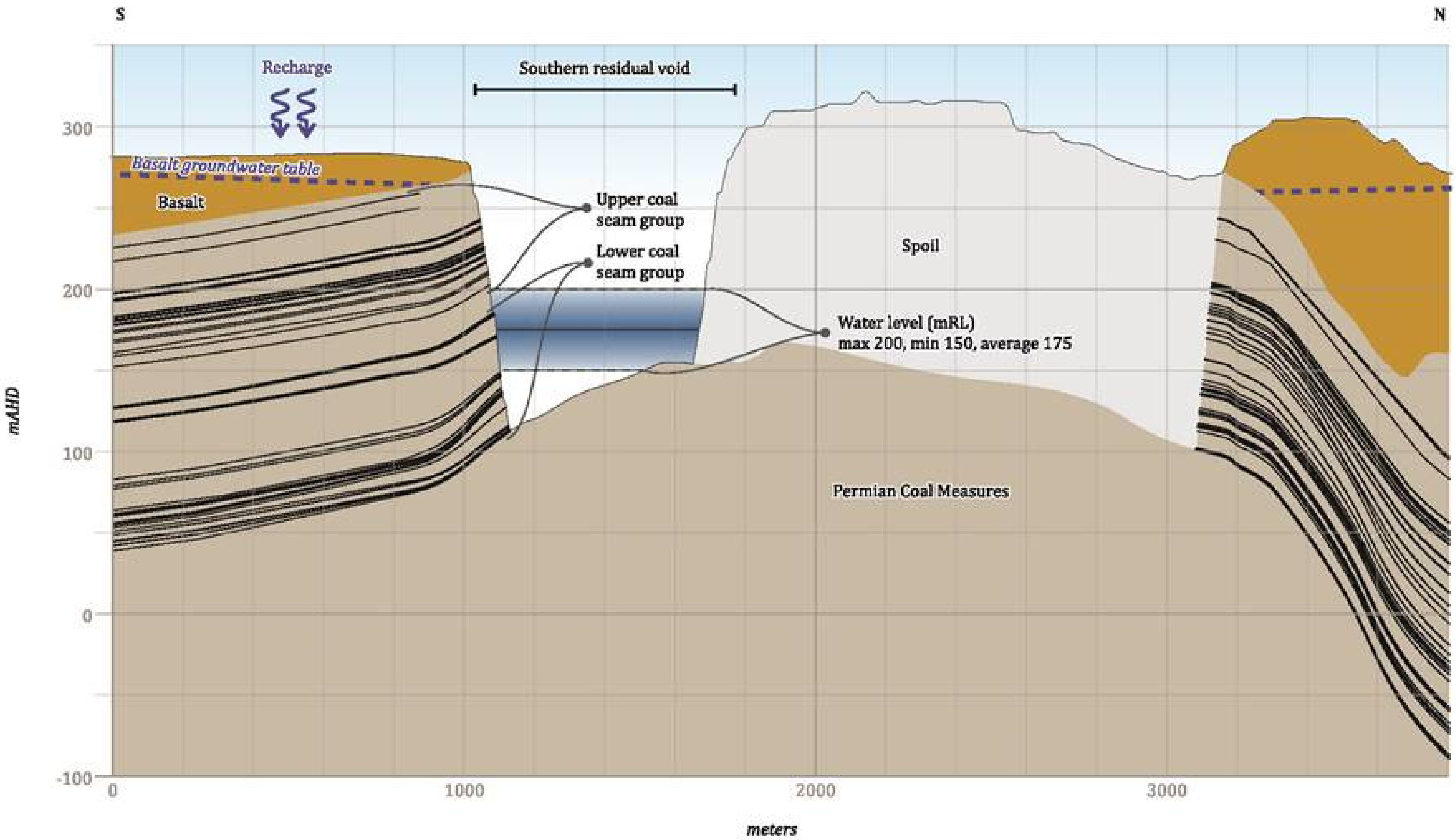

Figure 7 – Southern residual void cross-section

3.4 Mass Balance Modelling Results

The ANZECC (2000) water quality guidelines classifies irrigation water with a "high salinity rating" as having an electrical conductivity of between 2.9 dS/m and 5.2 dS/m (equivalent to 1,945 – 3,485 mg/L TDS). Adverse effects in beef cattle can be expected to begin when stock drinking water exceeds 4,000 mg/L TDS (ANZECC 2000).

The salt mass balance model results for the Western and Southern residual voids are shown in **Figure 8** and **Figure 9** respectively and summarised in **Table 3**.

Table 3 – Salt mass balance model results

Characteristic	Western Residual Void	Southern Residual Void
Long-term equilibrium water level	195mRL	175mRL
Time to reach equilibrium water level	~164 years	~110 years
Time to reach ANZECC high salinity irrigation water quality	~190 years	~90 years
Time to exceed ANZECC beef cattle stock water quality	~465 years (170,000 days)	~164 years (60,000 days)
Median annual increment in TDS	7 mg/L	25 mg/L
TDS at 500 years	4,300 mg/L	16,000 mg/L

In the long-term the salinity of water in both residual voids is predicted to become unsuitable for irrigation initially, and subsequently become unsuitable for stock water for beef cattle as it exceeds the ANZECC irrigation and stock water guidelines. The voids would be unable to support a Post-Mining Land Use and would be Non-Use Management Areas. The void water would not, however, result in adverse environmental impacts on surrounding aquifers as groundwater hydraulic gradients are expected to be maintained in perpetuity towards both voids. The maximum water level in the voids is 60m below the spill point and void water would not be released to surface waters or surrounding lands. In conclusion, the residual voids would not cause any serious environmental harm to land, surface waters or any recognised groundwater aquifer, other than the environmental harm constituted by the existence of the residual void itself.

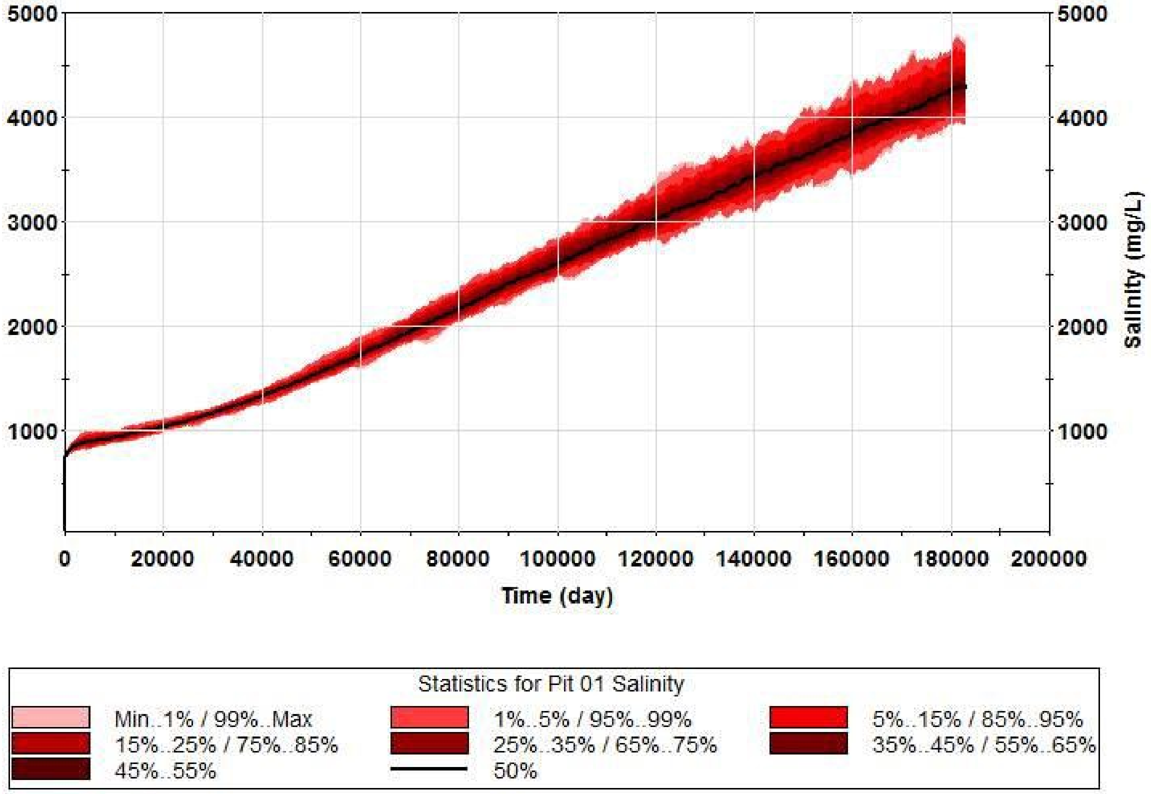

Figure 8 – Predicted TDS concentration in Western residual void

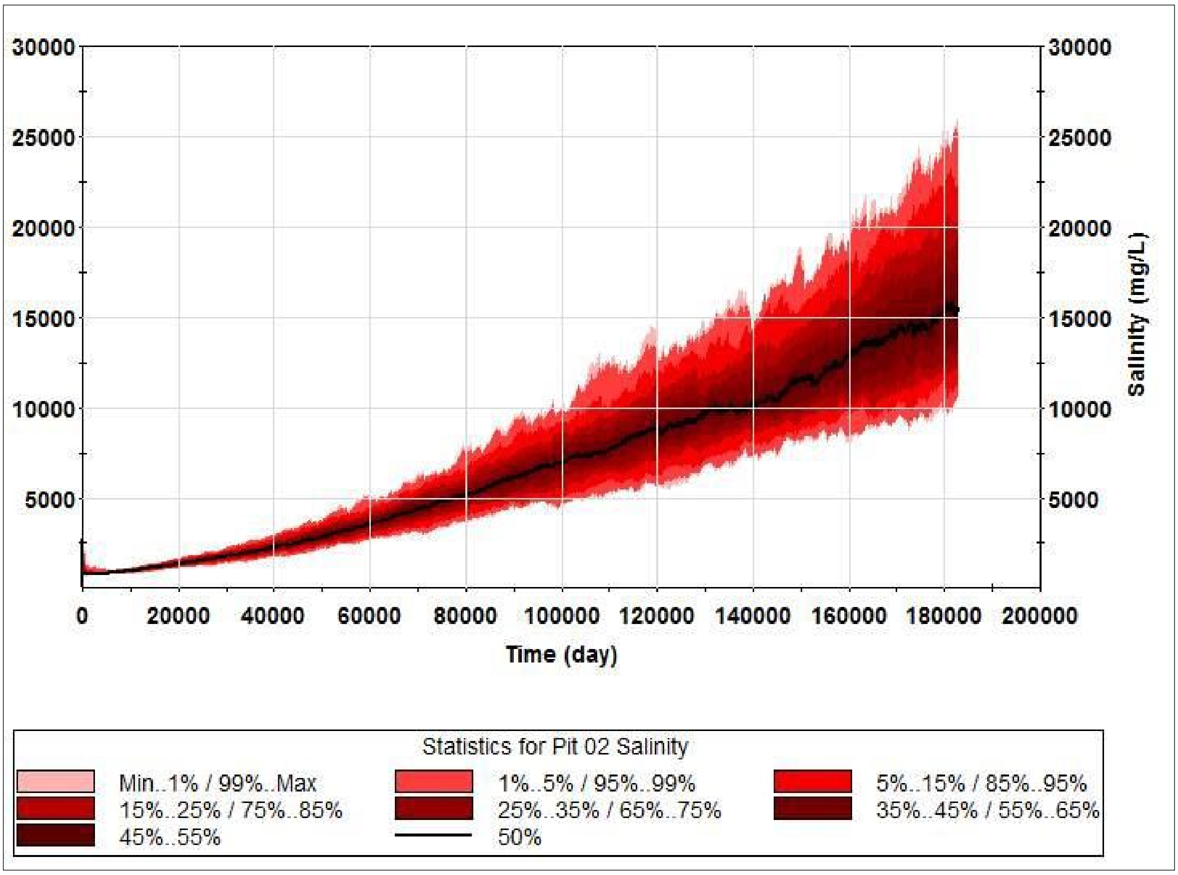

Figure 9 – Predicted TDS concentration in Southern residual void

4 Pit Wall Stability

A stability analysis of both final voids has been undertaken by PSM (2021) to:

- calculate potential failure paths for both circular failure and block sliding mechanisms;
- estimate the distance from the pit crest where a minimum Factor of Safety (FOS) of 1.5 is met; and
- provide guidance on the location of highwall bunds (closure bunds) set back from the pit crest based on stability and erosional considerations.

The analyses are summarised below and further details are presented in PSM (2021) (attached as an **Appendix B** to this report).

2D Limit Equilibrium stability analyses using the GLE-Morgenstern Price Method were completed for three representative cross sections in the Western (Main) pit and two in the Southern Pit. There are no major adversely orientated faults or shear structures present and which would undermine overall pit stability. Pit stability is influenced by water level in the pit, with increasing water level increasing stability, and hence the analyses was undertaken for a range of pit lake water levels.

The results of the Limit Equilibrium analyses are summarised in **Table 4**. The results show that a maximum offset of 125m for the closure bund is required in the location of Section 3 for the Main Pit and 100m for Section 4 in the South Pit. These two cases represent the most adverse conditions in each pit. The other areas require a 50m minimum offset from the closure bund. This 50m minimum allowance is allows for long-term erosion back from the crest and is explained below.

PSM (2021) note that a specific assessment of potential long-term erosion has not been carried out. Such assessment typically assumes a Revised Universal Soil Loss Equation approach (an empirical-based modelling approach that predicts the long-term average annual rate of soil erosion on slopes) or HEC-RAS modelling (sediment transport mobile- bed computations). These were deemed by PSM (2021) to be of limited value for these reasons:

- Much of the north and west walls in the Western (Main) pit are capped by high intact strength basalt and are unlikely to exhibit long-term erosion.
- In other areas the placement of the closure bund will limit the catchment directing potentially erosive runoff to the pit crest.
- PSM assume that all surface water flows will be directed away from closure bunds so that the bunds are not subject to undue erosion.
- For conservatism, and based on closure studies dealing with sedimentary strata for others, long-term erosion of 50m from the crest has been allowed for.

The adoption of a minimum 50m allowance for erosion retreat from the crest is consistent with the findings of central Queensland pit wall erosion studies by Henderson (2018). The studies concluded that, based on prevalent conditions of rainfall, overburden and coal mining practice, over the long-term pit wall crests could retreat an average of 10m to 30m post-mining, depending on the erosivity of the near surface overburden. Individual gullies could extend about twice that if rainfall runoff was particularly concentrated.

Table 4 – Summary of Limit Equilibrium analyses for closure bund offset

Section	Lake Level	Minimum Global FOS	Distance (m) from Pit Crest where FOS = 1.5	Recommended bund offset (m)
Section 1 (Main Pit)	No Lake	1.84 - circular	0	50
	No Lake	1.35	48	
	RL 210	1.84	0	
Section 2 (Main Pit)*	No Lake	1.10 - circular	0	50
	No Lake	1.07	0	
	RL 210	1.81	0	
Section 3 (Main Pit)	No Lake	1.84 - circular	0	125
	No Lake	0.90	126	
	RL 210	1.34	14	
Section 4 (South Pit)	No Lake	Circular not analysed	0	100
	No Lake	1.05	100	
	RL 200	1.25	83	
Section 5 (South Pit)**	No Lake	2.17 - circular	0	50
	No Lake	1.44	22	

*Section 2 has a 110 m wide bench at RL 235, with the crest location modelled as RL 280.

**Section 5 has only been modelled No Lake due to the pit floor being above the maximum lake level of RL 200.

Figure 10 shows the final highwall crests (red lines), the proposed closure bund location (solid green lines) and the 1 in 1,000 AEP flood extent in the Sandhurst Creek diversion (blue area). The initial stability analysis shows that a backfill buttress is required in the Southern pit for the closure bund to align outside the diversion and hence prevent interaction with the 1 in 1,000 AEP flood extent. The results of the initial stability analyses for the recommended buttress are presented in Appendix B.

More design work is being undertaken on the configuration of the buttress to ensure the minimum FOS of 1.5 is met. Final geotechnical review and stability analysis of the southern high wall section relating to the buttress shall be undertaken before submission of the Minerva Mine Progressive Rehabilitation and Closure Plan.

Note that the closure bund is not required to contain a 1 in 1,000 AEP flood with the Sandhurst Creek diversion and is deliberately placed outside the flood extent so as not to impede flow. The diversion and it relationship to the residual voids is discussed in Section 5.

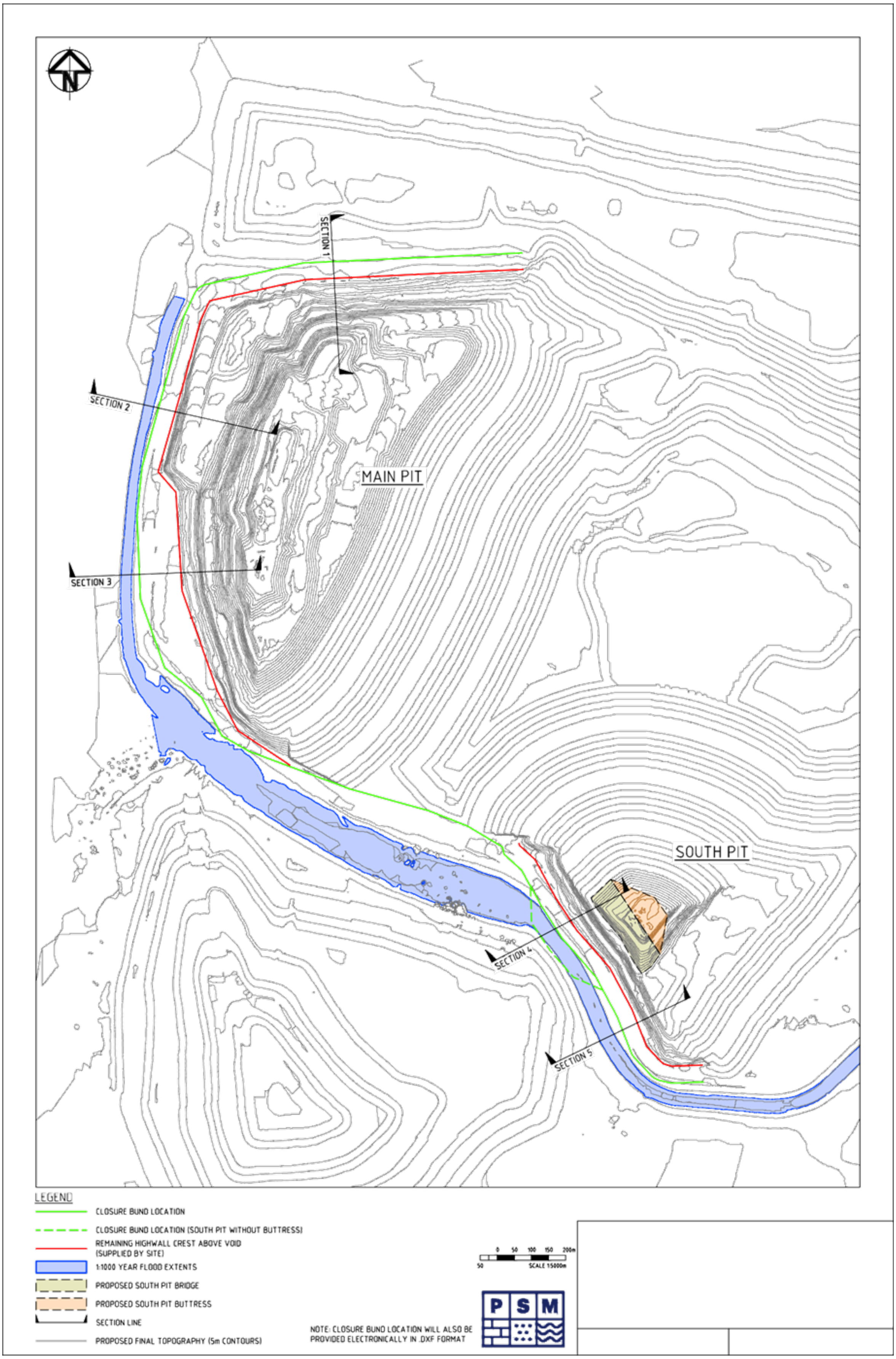

Figure 10 – Closure bunds in relation to highwalls and creek diversion flood extent

5 Sandhurst Creek and Residual Voids

Sojitz Minerva Mining Pty Ltd holds water licence number 406741 issued under the *Water Act 2000* to divert Sandhurst Creek around the western and southern residual voids. The diversion was constructed in stages (Western and Southern diversions) and totals 5,819m in length.

The design criteria and design parameters for the diversion are based on *Watercourse Diversions – Central Queensland Mining Industry* (DERM 2011), which are in turn based on ACARP Project C8030 *Maintenance and Geomorphic Processes in Bowen Basin River Diversions* (ACARP 2000).

The diversion is designed to meet DERM (2011) requirements for stream power, velocity and shear stress for 1 in 2 Annual Exceedance Probability (AEP) and 1 in 50 AEP flow events for the Western and Southern diversion channels. All channel batters are either grassed or provided with rock protection to minimize erosion. Design parameters for the Western and Southern diversion are summarized in **Table 5**.

Table 5 – Diversion design parameters

Parameter	Western Diversion Source: Jacobs (2014)	Southern Diversion Source: Jacobs (2017)
Typical channel depth	1m to 3m (varies)	10m (max 22m)
Bed Width	8m	10m
Overall width	30m to 50m (varies)	20m to 212m (varies)
Batter slope	1:4 V:H	
Overall channel grade	0.24%	0.29%
Minimum offset to residual void	50m	66m*
Stream power, velocity, shear stress	1 in 2 AEP and 1 in 50 AEP	
Flood immunity for voids	1 in 1,000 AEP	

*without buttress (see Section 4)

The diversion was designed to convey flow during a 1 in 1,000 AEP flood event such that associated flood waters do not enter the western or southern residual voids. The predicted extent of the 1 in 1,000 AEP flood event has been modelled again in 2021 with the HEC-RAS hydraulic modelling program using the most recent LiDAR survey of the diversion and surrounds (Cardno 2021). The modelling took into account tributary inflows and any changes to topography since the original design (e.g. road works). The modelling confirmed the surface flows from a 1 in 1,000 AEP flood event did not interact with the final voids.

Flood events with an AEP of 1 in 1,000 or less are defined as “extreme (rare)” in the *Guide for Flood Studies and Mapping in Queensland* (DNRM 2017). By way of comparison, the largest ever recorded Brisbane River flood in 1893 is estimated to be equivalent to an AEP of 1 in 285 (WMA Water 2011). The 1 in 1,000 AEP flood design criterion for the diversion significantly reduces the risk of long-term interaction between Sandhurst Creek and residual voids and provides significant hydrological protection for the void pit walls.

Water licence 406741 requires an on-going monitoring and evaluation program be carried out consistent with ACARP Project C9068 *Monitoring and Evaluation Program for Bowen Basin River Diversions* (ACARP 2001). The water licence cannot be relinquished until the diversion is meeting or progressing towards:

- developing features (including geomorphic and vegetation) present in the landscape and in local watercourses;

- maintenance of a sediment transport regime that allows the diversion to be self-sustaining and not directly impact upstream or downstream reaches; and
- the diversion and associated structures maintain equilibrium and functionality and do not require ongoing maintenance.

6 Void Flora and Fauna

The physical features of the Western and Southern residual voids are likely to restrict the development of diverse and productive aquatic flora and fauna communities. Steep pit walls mean that the littoral zone (depth <1m) would be very narrow and pit floor benthic habitats would be at great depth.

Such pit lakes have low abundance and diversity of structural features such as fallen timber, large rocks and emergent macrophytes (sedges and rushes) (Richardson *et al.* 2021). Richardson *et al.* (2021) found macroinvertebrate diversity in a saline coal mine pit lake was greatly reduced in comparison to a freshwater coal mine pit lake, although salt-tolerant blue green algae and diatoms were present. The absence of connectivity to watercourses would limit the opportunity for fish colonisation of the residual voids.

In an interim report for ACARP Project C27043 *Towards closure of potentially saline pit lakes: understanding biophysical processes for condition assessment and remediation,* Lund and Blanchette (2021) conclude that the main limitations to rehabilitating saline pit lakes are likely to be physical and related to the creation of littoral and riparian areas and developing strategies to enhance natural ecological successional processes.

The voids would be unlikely to support diverse and productive aquatic flora and fauna communities. The voids would not, however, result in adverse environmental impacts on surrounding aquifers as groundwater hydraulic gradients are expected to be maintained in perpetuity towards both voids (see **Section 3.3**).

Western and Southern residual void low walls shall be reshaped above RL210m and RL200m respectively as described in Section 2 and rehabilitated and revegetated in accordance with the Minerva Mine *Rehabilitation Management Plan* (as required under Environmental Authority Conditions F3 and F4).

7 Void Completion Criteria

The residual void completion criteria applicable to the Western and Southern voids are presented in **Table 6**.

Table 6 – Residual Void Completion Criteria

Objective	Indicator	Completion Criteria
Safety hazards minimized	Hazard assessment of access	No public access to highwalls/end walls (bunding/fencing as required)
Final voids are geotechnically stable	Factor of safety	Closure bund installed minimum 50m from pit crest or distance equal to FOS of 1.5 (unless an alternative is justified by an appropriately qualified person).
	Wall slope and area	Maximum slope in competent rock 275% (70 degrees). Maximum slope in incompetent rock 65% (angle of repose). Maximum total void surface area 91ha (measured at maximum water level)

Objective	Indicator	Completion Criteria
	Condition assessed by an appropriately qualified person	Assessment report by a Registered Professional Engineer of Queensland (RPEQ) on the geotechnical stability of final voids.
Maintenance of surface and groundwater quality	Water quality	Surface water and groundwater quality of receiving waters meets the requirements of Schedule W of the Environmental Authority.
		Voids have no adverse environmental impacts on surrounding aquifers
Maintenance of surface water flow	Design for diversion flood	1 in 1,000 AEP flood event in Sandhurst Creek diversion does not enter final void

As noted in Section 3.4, in the long-term the salinity of water in both residual voids is predicted to become unsuitable for irrigation initially, and subsequently become unsuitable for stock water for beef cattle. The voids would be unable to support a Post-Mining Land Use and would be Non-Use Management Areas. The void water would not, however, result in adverse environmental impacts on surrounding aquifers as groundwater hydraulic gradients are expected to be maintained in perpetuity towards both voids. The maximum water level in the voids is 60m below the spill point and void water would not be released to surface waters or surrounding lands. In conclusion, the residual voids would not cause any serious environmental harm to land, surface waters or any recognised groundwater aquifer, other than the environmental harm constituted by the existence of the residual void itself.

8 References

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Lund, M.A and Blanchette, M.L. (2021). Towards closure of potentially saline pit lakes: understanding biophysical processes for condition assessment and remediation. ACARP Project C27043. Short Report 2020-03. 110pp.

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Richardson, D.L., Bourke, G, and Swart, P. (2021). Aquatic biodiversity values of two non-acidic pit lakes created by open-cut mining. Life of Mine Conference Proceedings, Brisbane. AusIMM Publication 2/2021: p147-150.

WMA Water (2011). *Brisbane River 2011 Flood Event – Flood Frequency Analysis.* Final Report for Queensland Flood Commission of Enquiry.

9 Version Management

Version	Details	Contributors
1.0 ( )	November 2021	

Appendix A

AGE (2017). *Minerva Residual Void Investigation – Groundwater Inflow Calculation*. Report to Sojitz Minerva Mining Pty Ltd by Australasian Groundwater and Environmental Consultants Pty Ltd.

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Memorandum

Project number	G1753D – Minerva Final Void
To	Ross Gooley – Environmental Superintendent
Company	Sojitz Minerva Mining Pty Ltd
From	Tim Armstrong and Andrew Durick
Date	21/07/2017
RE	**Minerva Residual Void Investigation – Groundwater Inflow Calculation**

1 Introduction and scope of work

Sojitz Minerva Mining Pty Ltd (Sojitz), as manager of Minerva Joint Venture (MJV), operates the Minerva Mine, an open-cut coal mine within mining lease (MLs) 70145 & 70376. The MJV is progressing a southern extension of the main pit. In aggregate, the maximum residual void surface area will not exceed 91 ha, as specified in Table F1 of Environmental Authority (EA) EPML00668613.

A residual void investigation report (MJV, 2010) was previously submitted in accordance with the requirements of EA Condition F8. Updates to this report concerning all elements of Condition F8 relating to future mining activity are being progressed during the 2016-17 MJV Plan of Operations Period. Element updates concerning the residual void investigation will be submitted as Appendices to the 2017-18 MJV Plan of Operations submission.

With respect to groundwater, Sojitz requested Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) contribute towards addressing Condition F8 (b), which states that the residual void investigation must include:

> *"a void hydrology study, addressing the long-term water balance in the voids, connections to groundwater resources, and water quality parameters in the long term".*

The following memo presents groundwater information that supports the void hydrology study. Specifically, this memo summarises the methods and data used to calculate future groundwater inflow rates into the western and southern residual voids. This memo also presents an assessment of the potential for void water to interact with surrounding aquifers.

The groundwater inflow rates provided herein were used within a separate void water balance model developed by KBR as part of the 2017 update of the Water Management Plan. The KBR (2017) GoldSim void water balance model coupled the estimated groundwater inflow rates with with dynamic surface water processes to assess the water level recovery rate, the final (i.e. equilibrium) water level within the voids, and the long-term void water quality.

2 Background and previous study results

As part of the 2010 residual void investigation, Waste Solutions Australia (WSA, 2010) was engaged to develop a three-dimensional numerical model to calculate rates of groundwater inflow to the final void. The 2010 groundwater model was an update of a previous model, first developed by WSA in 2006. The 2010 groundwater model incorporated the residual void configuration and predicted the average rate of groundwater that would flow into the western residual void.

The 2010 groundwater model produced steady-state results using various recharge and evapotranspiration scenarios. The steady-state results were not time dependent, and as such produced averaged groundwater inflow rates without taking into account seasonal climatic variations.

The 'base-case scenario' of the 2010 groundwater model predicted:

- ~1.8 megalitres per year (ML/year) would flow into the western residual void from the coal seams; and
- ~26.2 ML/year would flow into the western residual void from the basalt aquifer.

AGE consider these model predictions to be very low, especially when compared to the 2015 Minerva Mine water balance estimate of groundwater inflow during mining being ~362 ML/year (MJV, 2015).

To complete the 2010 residual void investigation, the WSA (2010) predicted groundwater inflow rates were incorporated into a "dynamic void water model", developed by ESys Consulting Pty Ltd. This void water balance model accounted for annual inflow rates of surface water, steady-state groundwater inflow rates, and annual rates of evaporation. The void water balance model was developed as a spreadsheet (analytical) transient model that calculated the rate of water level recovery within the western residual void and the equilibrium water level.

The current residual void investigation followed a similar method for the western void and for the planned southern void, details of which are provided below in Section 4.

3 Overview of groundwater regime

There are two main groundwater systems within MLs 70145 & 70376, these being:

- **an upper aquifer system in Tertiary basalts** – where vesicular and fractured zones within the basalt flows are water bearing and form productive aquifers, separated by weathered clay zones between basalt flow layers; and
- **underlying Permian consolidated sediments** – of which the coal seams of the Rieds Dome Beds form low yielding aquifers.

3.1 Tertiary basalt

Uplift in the early Tertiary created the Lexington Dome, a structural feature within Permian aged consolidated sediments. This event was followed by erosion and a series of basalt flows which unconformably overly the Permian sediments, forming a regional cap. The central area of the Lexington Dome was not covered by basalt.

Coal deposits within ML 70145 were initially mined at shallow depths in an area where there was little to no basalt cover.

The thickness of the basalt increases in all directions away from the Lexington Dome. In the area to the west of ML 70145, basalt thickness increases rapidly from ~70 m in the highwall of the western residual void, to ~135 m near the western boundary of ML 70145. Basalt thickness continues to increase to ~175 m at a distance of 1.2 km towards the south-west, and ~150 m at a distance of 0.5 km towards the north-west.

Some conjecture exists about the potential for regional or local scale faults to exist within the Tertiary basalt, but this topic is beyond the scope of this assessment. The potential for faults to influence the hydraulic behaviour of the basalt has not been considered here.

The basalt has a distinct near-surface weathered profile and multiple horizons of fractured and unweathered basalt that may represent separate basalt flows. The weathered zones are less permeable than the underlying fractured and unweathered basalt. The uppermost (and current) weathered profile extends to a depth of ~30 m below ground surface. The underlying fractured basalt formation is the main aquifer located in the area immediately surrounding the Minerva Mine. The relative proportions of fractured basalt (permeable) and non-fractured basalt (non-permeable) within the whole basalt unit greatly influences the potential to store and transmit groundwater.

Anecdotal information from Minerva suggests that high seepage rates persist from the basalt aquifer into the open-cut mine pit. The 2015 water balance calculations undertaken by MJV suggested the seepage (assumed to be predominantly from the basalt) was ~362 ML/year (~11.5 L/s).

3.2 Permian coal measures

Throughout most of the Bowen Basin, the fresh (non-weathered) Permian strata may be categorised into the following hydrogeological units:

- low permeability, low yielding (and often dry), sandstone / siltstone that comprise the majority of the Permian interburden / overburden; and
- low to moderately permeable coal seams which are the prime water bearing strata within the Permian strata.

The coal seams within ML 70145 & ML70376 generally dip in a south-westerly and westerly direction. The coal seams have been named in six groups, these being, Sandhurst, Funnel, Wurba, Willa, Lexington, and Minerva. Most coal seam groups consist of multiple seams and splits. Coal seam thickness ranges from 0.1 m to about 3.5 m.

Groundwater storage and flow is predominantly associated with natural interconnecting coal seam cleat and joint patterns. Recharge of the coal seam aquifers will predominantly occur via vertical seepage from the overlying basalt aquifer where the coal seam sub-crops beneath or where the coal seams sub-crop near the ground surface.

The coal seam aquifers are confined above and below by very low permeability interburden that are relatively impervious, compared to coal seams, and form aquitards. The confining interburden units limit vertical flow and restrict recharge of the coal seam aquifers. On a small scale, features such as fractures, faults, and joints within the overburden can yield localised and variable supplies of low yielding, poor quality groundwater.

Anecdotal information from the Minerva Mine suggests that low seepage rates persist from the coal seams into the open-cut mine pit. However, very little seepage occurs from the sandstone / siltstone overburden and interburden. Groundwater seepage into the mine from the Permian coal seams is generally low and evaporation may remove most of this seepage before it enters the mine pit.

4 Methodology

The following sub-sections describe the methods and data used to calculate potential groundwater inflow rates into the western residual void and the proposed southern residual void.

4.1 Assessment of void geometry

An initial review of the final landform was undertaken prior to developing the groundwater inflow calculations. Firstly, a set of cross-sections through the western and southern residual voids were developed to understand the geometry of the final landform and identify areas of spoil, natural land surface, and excavated areas. The locations of the cross sections are shown in Figure 4.1.

The elevation of the coal seams and the base of the basalt aquifer were also identified to understand the elevation at which groundwater can enter the residual voids, and the level to which the voids can fill before void water would interact with the basalt aquifer.

A representative cross-section through the western and southern residual voids are shown in Figure 4.2 and Figure 4.3, respectively. The results of this data processing were used to define the assumptions about aquifer geometry used within the analytical calculations of groundwater inflow rates into the residual voids.

To simplify the inflow calculations, the highwalls in the western and southern residual voids were divided into three segments each. This division allowed for the inclusion of key aquifer geometry variability along the highwall, while still being practical to undertake calculations. The segments for each residual void are shown in Figure 4.1.

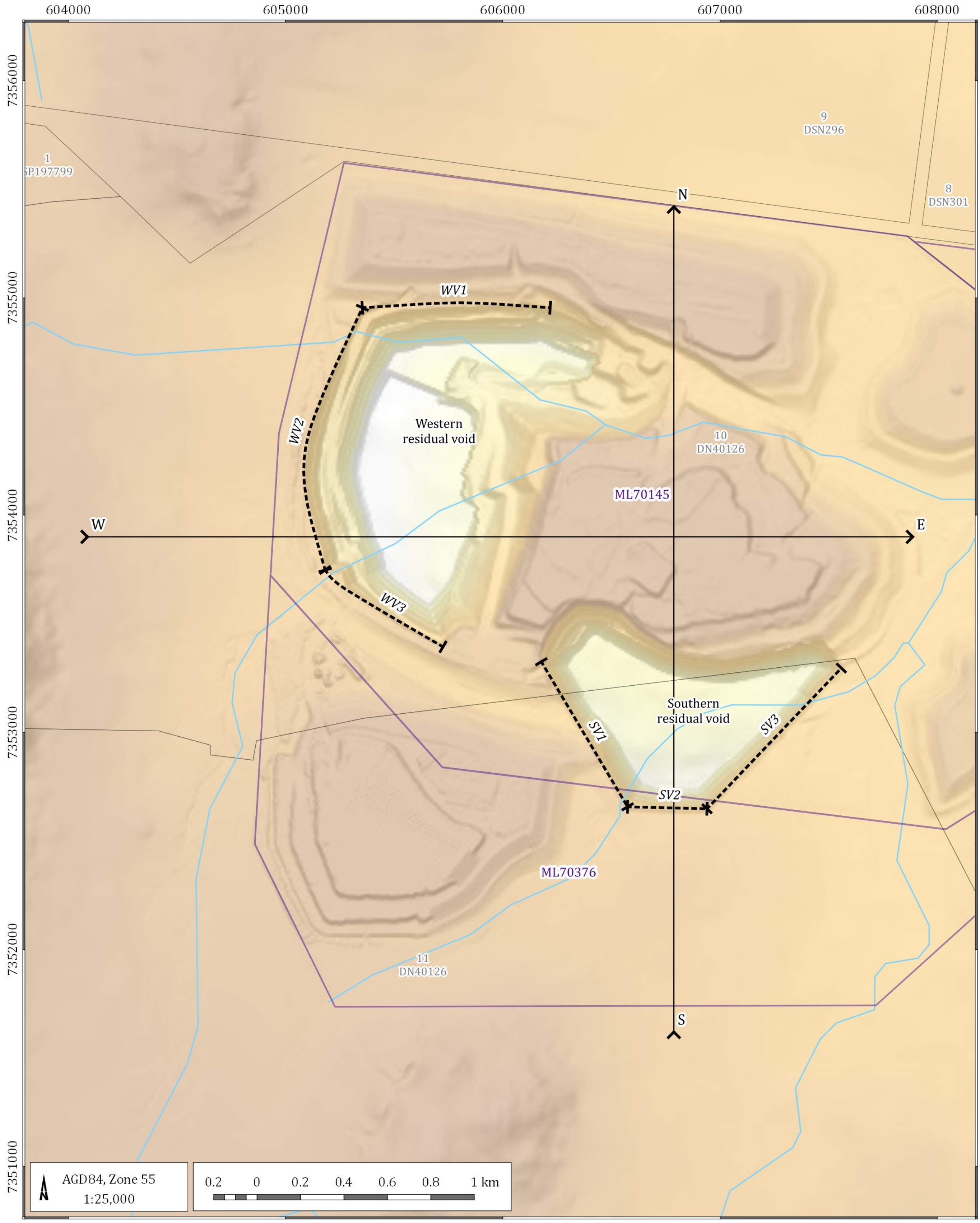
Importantly, the cross-sections confirm there are a number of coal seams that intersect both residual voids, and the basalt aquifer is intersected only by the western residual void. Attempting to calculate the potential groundwater inflow rate from each coal seam is impractical with analytical techniques due to their number, so for simplicity, the coal seams were grouped into an upper and lower grouping, which are separated by a relatively thicker interburden. Within the groupings, the coal seam thicknesses were combined into one total representative thickness.

The contact of the highwall and geological features were analysed for each highwall segment. The key elevations and measures for each segment are summarised in Table 4.1.

Table 4.1 Void geometry information for each pit wall segment

	Western residual void			Southern residual void		
Parameter	**WV1**	**WV2**	**WV3**	**SV1**	**SV2**	**SV3**
Section length (m)	870	1,270	660	780	370	900
Weathered basalt floor (mAHD)	248	250	265	-	-	-
Basalt floor (mAHD)	223	201	202	-	-	-
Basalt seepage face (m)	2	2	2	-	-	-
Upper coal seam floor (mAHD)	153	153	170	204	204	211
Upper coal seam thickness (mAHD)	7.3	5.6	4.9	3.8	4.5	2.8
Lower coal seam floor (mAHD)	108	80	94	115	112	112
Lower coal seam thickness (mAHD)	7.6	9.4	8.8	7.5	7	6.9

Note: *mAHD = metres above the Australian height Datum*



LEGEND

- Sections
- Sectors
- Minor drainage
- Mining lease
- Property boundaries

Elevation (m)

- 100
- 150
- 270
- 300
- 400
- 600

Minerva Final Void (G1753D)

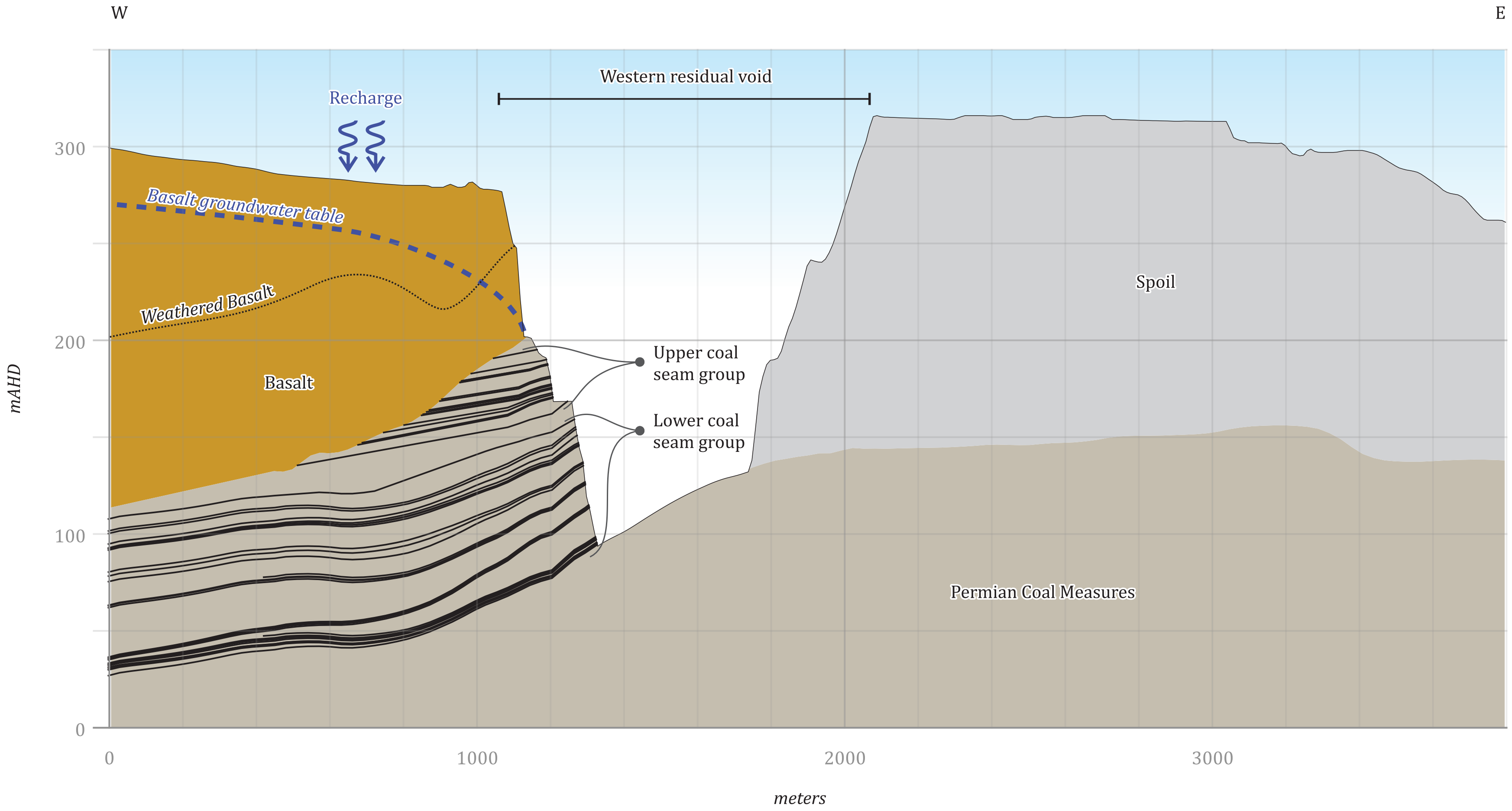
Location of cross-sections

AGE

DATE 14/06/2017

FIGURE No: **4.1**

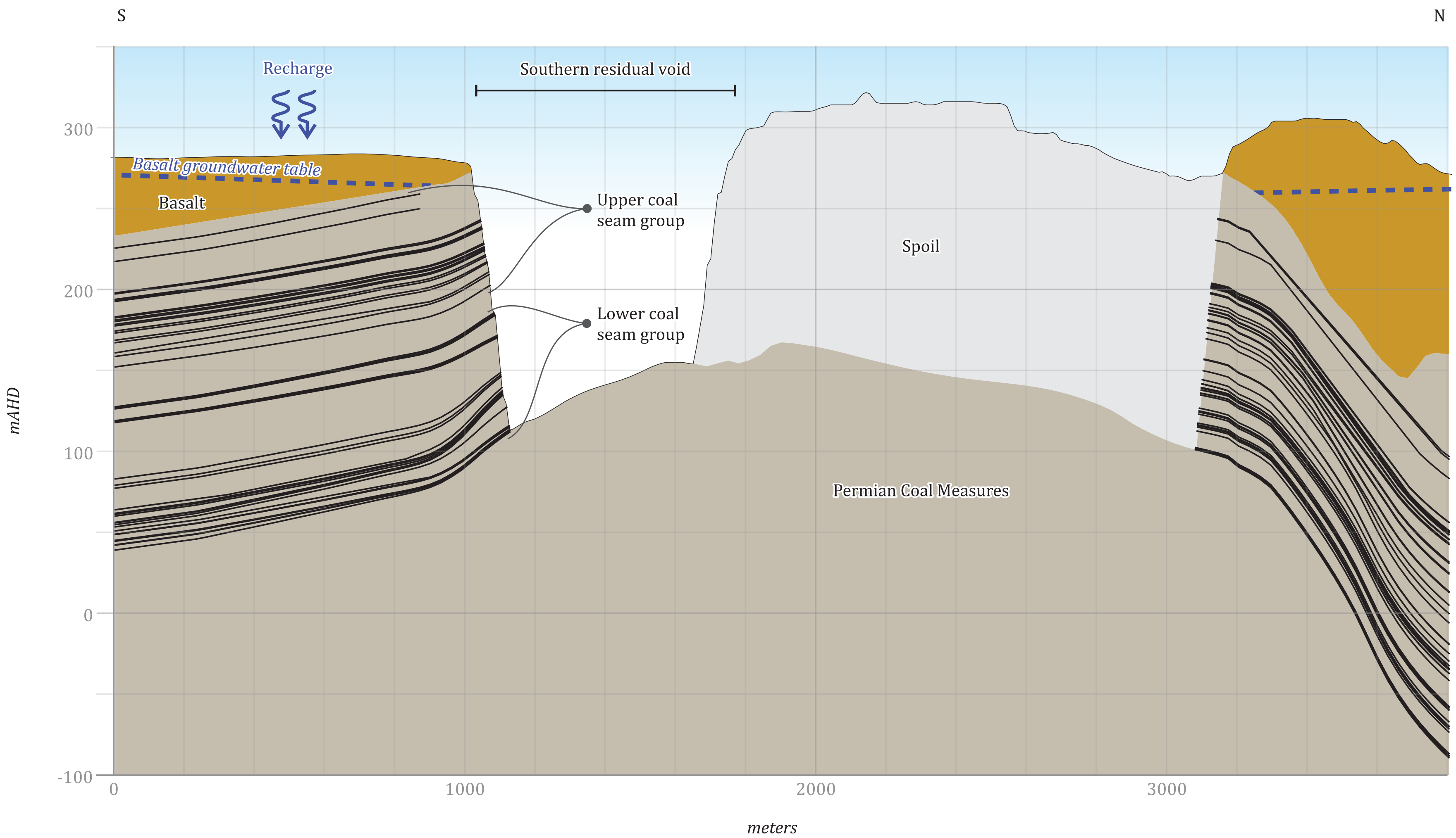
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.;
G:/Projects/G1753D.Minerva_Final_Void/3_GIS/Workspaces/001_Deliverable1/04.01_G1753D_Location of cross-sections.qgs



West-East cross-section

Figure 4.2

Minerva Final Void (G1753D)



South-North cross-section

Figure 4.3

Minerva Final Void (G1753D)

Groundwater inflow to the southern residual void will only occur from the coal seams, because the basalt aquifer is not intersected by the highwall of this void (Figure 4.3). The highwall of the western residual void will intersect a significant thickness of basalt as well as the many coal seams (Figure 4.2). The basalt aquifer is considered the major source of inflow to the western residual void.

The seepage face noted for the basalt in Table 4.1 is considered to exist at the base of the basalt in the highwall when the void water level is below the basalt.

4.2 Analytical calculations of groundwater inflow rates

The methods used in this current residual void investigation are similar to those used in 2010. Specifically, the current predicted groundwater inflow rates were developed with the intention of these results being included within a transient and stochastic void water balance model. A surface water consultant (KBR) was engaged by Sojitz to develop the void water balance model because the recovery rate to the void water equilibrium level will be dominated by dynamic surface water processes, and groundwater inflow will be a component of this.

The 2010 groundwater model was not used in this current residual void investigation. The latest model version (from which the 2010 groundwater model was developed) was recently reviewed by AGE and it was found to be not “fit-for-purpose” (AGE, 2017). The review concluded that significant work would be required to update the groundwater model to make it useful for the intended task of predicting groundwater inflow into the western and southern residual voids. In lieu of developing a new numerical groundwater model, an alternative method of estimating groundwater inflow into the voids was undertaken for the current residual void investigation.

Analytical equations of groundwater flow (i.e. using first principles) were used to calculate potential rates of groundwater inflow into the residual voids. Inflow rates from the basalt and coal seam aquifers were calculated for a broad range of different stage heights within each void. The goal here was to create a rating table / curve of groundwater inflow versus void stage height. Following its development, the rating curve was incorporated into the void water balance model to refine the estimate of groundwater contribution as the void fills with water.

The groundwater inflow rating table / curve was provided to KBR as a spreadsheet for inclusion into their void water balance model.

The potential rate of groundwater inflow to both residual voids through each highwall segment (see Figure 4.1) was calculated using Darcy’s equation of flow through a porous media. This equation uses the aquifers hydraulic conductivity, the hydraulic gradient within the aquifer (i.e. to cause the flow), and the cross-sectional area of the seepage face, to determine the volume of water moving through a vertical plane of aquifer material. In this case the vertical plane of aquifer material is the highwall in the residual voids. Darcy’s equation is simply written as:

$$Q = k \times i \times A$$

Where: Q = discharge rate (m^3/day)

k = hydraulic conductivity of material (m/day)

i = hydraulic gradient (m/m)

and A = cross sectional area (m^2)

The following assumptions were used when undertaking the calculations of groundwater inflow:

- The estimates of inflow do not consider direct rainfall on the voids and rainfall runoff into the voids, nor the inflow from the low-wall and spoil. The estimates calculated only relate to the exposed highwall in the residual voids.
- Basalt is in contact with the western residual void, but not the southern residual void (based on available data).
- Recharge that occurs through the surface within the capture zone of the drawdown from each pit / void is calculated and added to the Darcy inflow estimates. For the western residual void a recharge of 6% of rainfall was used to represent recharge into the basalt, while at the southern residual void a recharge of 0.1% of rainfall was used to represent recharge into the weathered Permian cover.
- The regional water table away from the mine impact was assumed to be 270 mAHD, based on recorded groundwater levels from the Minerva Mine groundwater monitoring bore network.
- The rainfall recharge within the capture zones reduces as the water level in the void increases. In a scenario when the water level in the void is equivalent to the regional groundwater level, the rainfall recharge in the capture zone is assumed to be zero. The rainfall recharge is assumed to remain zero in the event that the void water level increases above the regional water table, because the void would be expected to supply water to the surrounding area in a situation such as this.
- The upper coal seam grouping in the WV2 segment of the western residual void is not extensive behind the highwall as it subcrops into the dipping basalt. These seams are expected to be dry after mining and because they are not extensively connected to the west along this segment, they are not considered to contribute to groundwater inflow for the WV2 segment.
- The contributions from the two coal seam groups and the basalt (for the western residual void) are all treated individually in the groundwater inflow estimates, and accumulated into a total reported inflow.
- When the void water level is low, the hydraulic gradient uses the geological elevation data to determine the inflow rates through the coals seams and basalt. When the void water level is set above these elevations, the void water level controls the hydraulic gradient, with the gradient reducing as the void water level rises.
- The basalt is assumed to have a hydraulic conductivity of 1 m/day, while the coal seam hydraulic conductivity is set to 0.01 m/day.
- Groundwater inflow estimates were made with void water levels at 5 m increments vertically from the base of each void to the spill point (i.e. void stage height).
- The void extents have been based on available data and it is understood that final void design (including the level of backfill) are being finalised at the time of writing. This might reduce the extent of highwall exposed in each void, though not likely to be significantly different to the dimensions adopted for this work.

4.3 Groundwater quality input data for mass-balance calculations

The 2010 residual void investigation used a mass-balance water quality assessment of Total Dissolved Solids (TDS) to investigate the long-term quality of void water. The average groundwater quality used in 2010 was obtained from analysis of groundwater samples for the basalt aquifer (WSA, 2009) and the coal aquifer (Sandhurst Mining, 2005).

The groundwater TDS values used in the 2010 mass-balance calculation were:

- 767 milligrams per litre (mg/L) for the basalt aquifer; and
- 2,039 mg/L for the coal seam aquifers.

These groundwater TDS values were combined with other water quality contributors (e.g. TDS of spoil runoff, catchment runoff, and direct rainfall) in the mass-balance calculation. The 2010 mass-balance calculation was then completed by multiplying the TDS value of the inflow contributor by the volume of the inflow into the void from each contributor. A simple TDS mass-balance calculation such as this has been used in previous Bowen Basin residual void investigations (PPK Environment and Infrastructure, 2001).

The 2010 TDS mass-balance method has been replicated for the current residual void investigation. Groundwater TDS values provided herein were used by KBR to couple with other TDS contributors within the current void water balance model.

No new TDS values are available for the coal seam aquifers, so the values used in the 2010 mass-balance equation are considered to be valid still. An updated average TDS value for the basalt aquifer has been obtained from analysis of the most recently published groundwater samples (WSA, 2014).

The groundwater TDS values used in the 2017 mass-balance calculation were:

- 655 mg/L for the basalt aquifer; and
- 2,039 mg/L for the coal seam aquifers.

4.4 Void water balance model

KBR (2017) developed a detailed Goldsim void water balance model to calculate the rate of water level recovery within the voids, the equilibrium water level, and the TDS concentration of void water.

Final topography for the final voids (north and south) and backfilled spoil landform was provided by Sojitz for assessment of the final void hydrology. Sojitz also provided details of the expected base of coal throughout the entire area to allow for definition of the quantity and volume of backfilled spoil material placed in the final void.

The KBR (2017) GoldSim water balance model made allowance for the following:

- Rainfall runoff reporting to the final voids and runoff from the low-wall spoil area (surface and baseflow).
- Groundwater inflow rates dependent upon the pit water levels as defined and provided by AGE for both the basalt aquifer (western void) and coal seam inflows (western and southern voids).
- A nominal 5% spoil porosity was allowed for all spoil material.
- Allowance was made for the potential storage of water within the spoil for all void water levels.

- Seepage between the voids was allowed when water levels in either void exceeded the elevated base of coal level between the mining voids.
- A hydraulic conductivity of 0.2m/day was applied to the spoil. Seepage through the spoil was estimated using Darcy's equation with estimates of seepage face area and length of seepage path between the pits used.
- The spill levels for the western void and southern void were set at level 272 mAHD and 262 mAHD, respectively.
- Associated salinity concentrations were incorporated for salts mass balance and were provided to all groundwater inflows and rainfall runoff. No allowance was made for leeching of salts from spoil material. The TDS concentrations used in the mass balance were:
  - groundwater to western void – 655 mg/L (sourced predominantly from basalt);
  - groundwater to southern void – 2,039 mg/L (sourced from coal seams);
  - runoff from rehabilitated ground surfaces – 350mg/L;
  - runoff from mining areas – 350 mg/L; and
  - runoff from industrial areas – 1,200 mg/L.

TDS concentrations of runoff water were based on historical salinity concentrations from OPSIM water balance modelling.

KBR (2017) applied a DataDrill of 128 years of rainfall and associated evaporation data to generate 100 data sets of daily rainfall and evaporation for a 1000 year period. All climatic data sets were run through the model to generate a probability assessment of water levels and salinity concentrations within the residual voids. The average (50%) stable water levels were adopted as representative of mining void performance.

5 Results

5.1 Groundwater inflow rates to residual voids

The predicted groundwater inflow from the highwall into each residual void is presented below. The calculations below were undertaken in a spreadsheet using the equation and assumptions outlined in Section 4.2.

5.1.1 Western residual void

Groundwater inflow to the western residual void is expected to be dominated by flow from the basalt aquifer, and in particular the rainfall recharge occurring within the capture zone of the drawdown from mining. Figure 5.1 below shows the inflow from the highwall is initially predicted to be 1,120 m^3/day (~408 ML/year) and remain around this rate until the void water level reaches the lower elevation of exposed basalt in the highwall, if this was to occur. As the void water level increases and more of the basalt is submerged, the inflow from the basalt is expected to reduce as the inflow hydraulic gradient reduces and as the rainfall recharge capture zone also reduces. In the event that the water level in the void exceeds the surrounding regional water table (~270 mAHD), then the flow into the void would become negative, indicating a loss of water from the void into the basalt aquifer.

A rating table of groundwater inflow versus void water level / stage height is provided in Table 5.1.

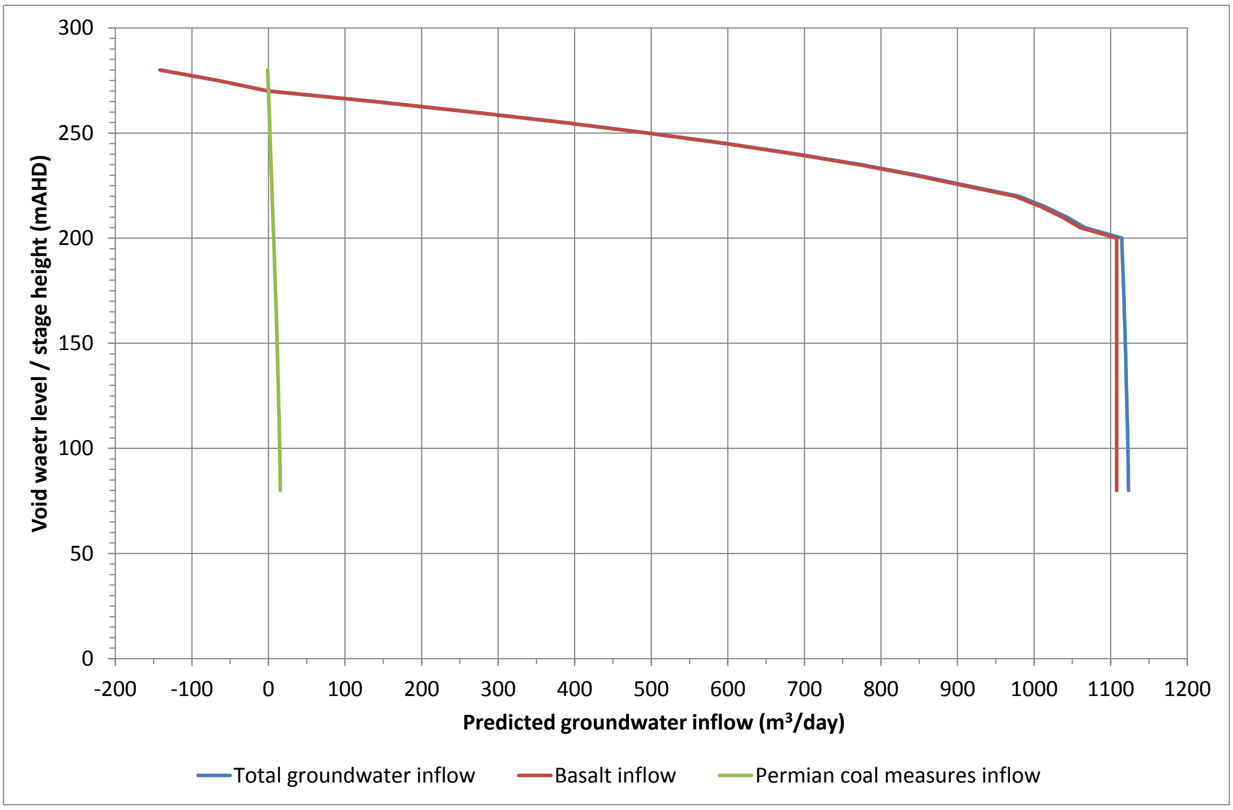


Figure 5.1 Predicted groundwater inflow – western residual void

Table 5.1 Rating table of groundwater inflow – western residual void

Void water level / stage height (m)	WV1 inflow (m^3/day)	WV2 inflow (m^3/day)	WV3 inflow (m^3/day)	Total inflow (m^3/day)
80	341.96	514.06	267.25	1,123.27
85	341.96	513.89	267.25	1,123.10
90	341.96	513.72	267.25	1,122.93
95	341.96	513.55	267.23	1,122.74
100	341.96	513.38	267.15	1,122.48
105	341.96	513.21	267.07	1,122.23
110	341.92	513.04	266.98	1,121.94
115	341.83	512.87	266.90	1,121.59
120	341.73	512.70	266.82	1,121.24
125	341.64	512.52	266.73	1,120.90
130	341.54	512.35	266.65	1,120.55
135	341.45	512.18	266.57	1,120.20
140	341.35	512.01	266.49	1,119.85
145	341.26	511.84	266.40	1,119.50

Void water level / stage height (m)	WV1 inflow (m^3/day)	WV2 inflow (m^3/day)	WV3 inflow (m^3/day)	Total inflow (m^3/day)
150	341.16	511.67	266.32	1,119.16
155	341.03	511.50	266.24	1,118.77
160	340.85	511.33	266.15	1,118.33
165	340.66	511.16	266.07	1,117.89
170	340.48	510.99	265.99	1,117.46
175	340.29	510.82	265.86	1,116.97
180	340.11	510.65	265.73	1,116.49
185	339.92	510.48	265.60	1,116.00
190	339.74	510.31	265.47	1,115.52
195	339.55	510.14	265.34	1,115.03
200	339.37	509.97	265.21	1,114.55
205	339.18	481.05	246.27	1,066.50
210	339.00	476.71	227.33	1,043.03
215	338.81	466.92	208.38	1,014.11
220	338.63	451.68	189.44	979.75
225	310.95	431.01	170.49	912.45
230	291.31	404.89	151.55	847.75
235	267.95	373.33	132.61	773.88
240	240.86	336.32	113.66	690.84
245	210.04	293.88	94.72	598.63
250	175.49	245.99	75.78	497.25
255	137.21	192.66	56.83	386.69
260	95.20	133.88	37.89	266.97
265	49.46	69.66	18.94	138.07
270	0.00	0.00	0.00	0.00
275	-21.31	-42.99	-2.01	-66.32
280	-46.36	-91.42	-4.03	-141.80

5.1.2 *Southern residual void*

Groundwater inflow to the southern residual void is predicted to be considerably lower than that predicted for the western residual void. This is because there is no basalt in connection with the highwall of the southern residual void and recharge in the capture zone is at a much lower rate based on the pathway through Permian material to the void highwall. This means that only the coal seams provide groundwater inflow.

Figure 5.2 below shows the inflow from the highwall is initially predicted to be 20.13 m^3/day (~7.3 ML/year) but then decline as the as the void water level increases.

A rating table of groundwater inflow versus void water level / stage height is provided in Table 5.2.

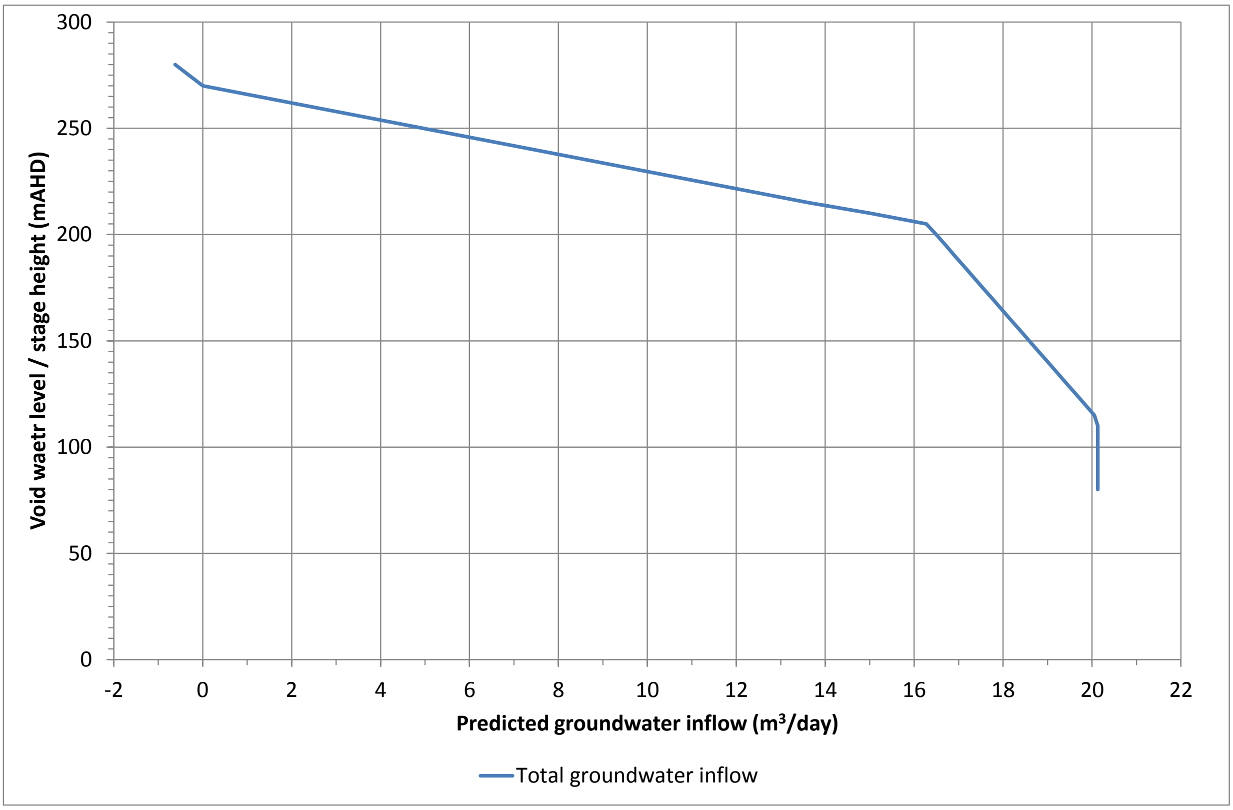


Figure 5.2 Predicted groundwater inflow – southern residual void

Table 5.2 Rating table of groundwater inflow – southern residual void

Void water level / stage height (m)	SV1 inflow (m^3/day)	SV2 inflow (m^3/day)	SVP3 inflow (m^3/day)	Total inflow (m^3/day)
80	7.82	3.70	8.61	20.13
85	7.82	3.70	8.61	20.13
90	7.82	3.70	8.61	20.13
95	7.82	3.70	8.61	20.13
100	7.82	3.70	8.61	20.13
105	7.82	3.70	8.61	20.13
110	7.82	3.70	8.61	20.13

Void water level / stage height (m)	SV1 inflow (m^3/day)	SV2 inflow (m^3/day)	SVP3 inflow (m^3/day)	Total inflow (m^3/day)
115	7.82	3.68	8.56	20.05
120	7.73	3.64	8.47	19.85
125	7.65	3.60	8.38	19.64
130	7.57	3.56	8.30	19.43
135	7.48	3.53	8.21	19.22
140	7.40	3.49	8.12	19.01
145	7.32	3.45	8.03	18.80
150	7.23	3.42	7.94	18.59
155	7.15	3.38	7.85	18.38
160	7.07	3.34	7.76	18.17
165	6.98	3.31	7.67	17.96
170	6.90	3.27	7.59	17.75
175	6.82	3.23	7.50	17.54
180	6.73	3.19	7.41	17.33
185	6.65	3.16	7.32	17.12
190	6.56	3.12	7.23	16.92
195	6.48	3.08	7.14	16.71
200	6.40	3.05	7.05	16.50
205	6.31	3.00	6.96	16.27
210	5.52	2.61	6.88	15.01
215	5.06	2.40	6.17	13.63
220	4.60	2.18	5.61	12.39
225	4.14	1.96	5.04	11.15
230	3.68	1.74	4.48	9.91
235	3.22	1.52	3.92	8.67
240	2.76	1.31	3.36	7.43
245	2.30	1.09	2.80	6.19
250	1.84	0.87	2.24	4.95
255	1.38	0.65	1.68	3.72
260	0.92	0.44	1.12	2.48
265	0.46	0.22	0.56	1.24
270	0.00	0.00	0.00	0.00
275	-0.13	-0.06	-0.12	-0.31
280	-0.25	-0.12	-0.25	-0.62

5.2 Potential for void water interaction with the basalt aquifer

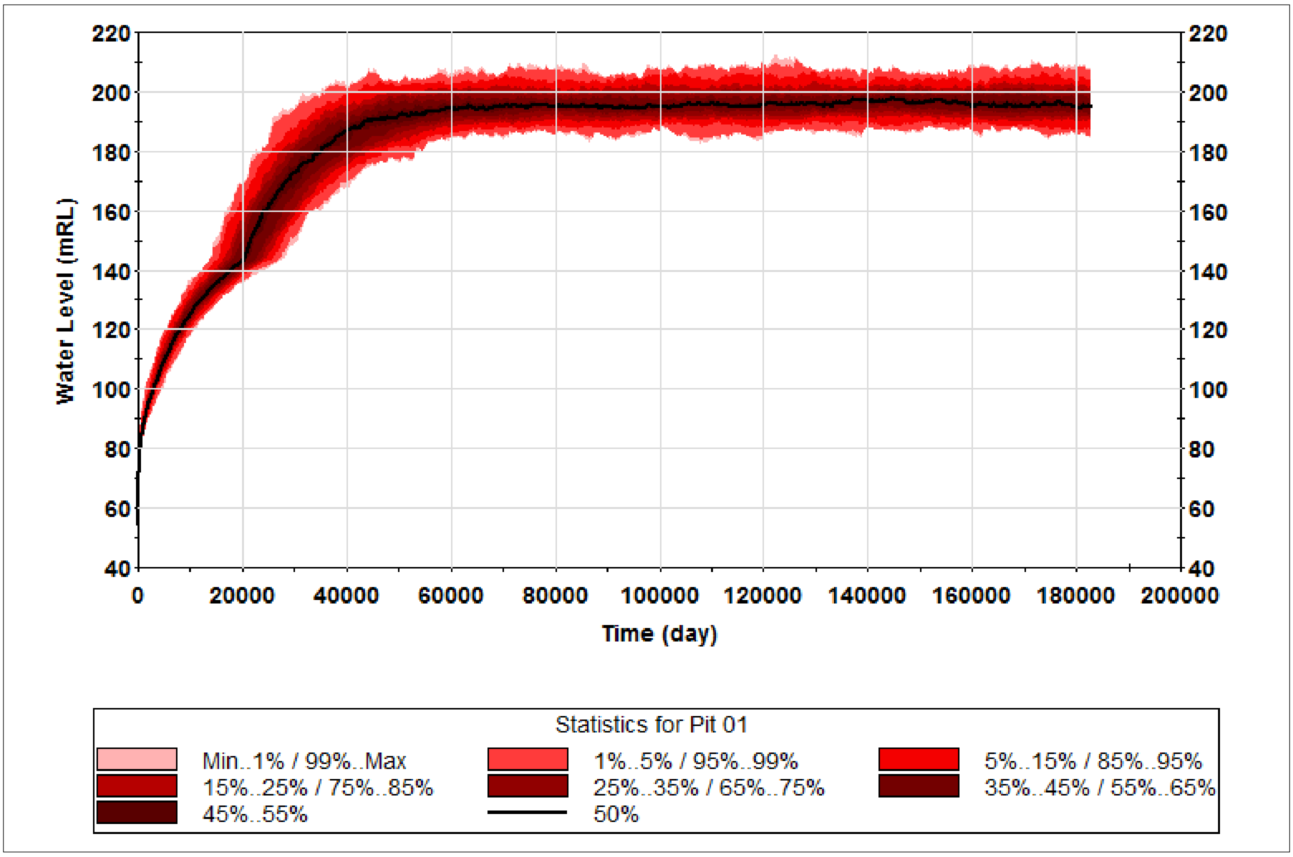
5.2.1 Western residual void

The risk of water leaving the western residual void via the basalt aquifer (and coal seams) is low under all modelled scenarios.

The stochastic water balance model, developed by KBR (2017), predicts the void water level in the western residual void will rise towards an equilibrium over a period of about 60,000 days (~164 years), as shown in Figure 5.3.

The void water equilibrium level is predicted by KBR (2017) to have:

- an average elevation of about 195 mRL (equivalent to mAHD);
- a minimum elevation of 185 mAHD; and
- a maximum elevation of 210 mAHD.

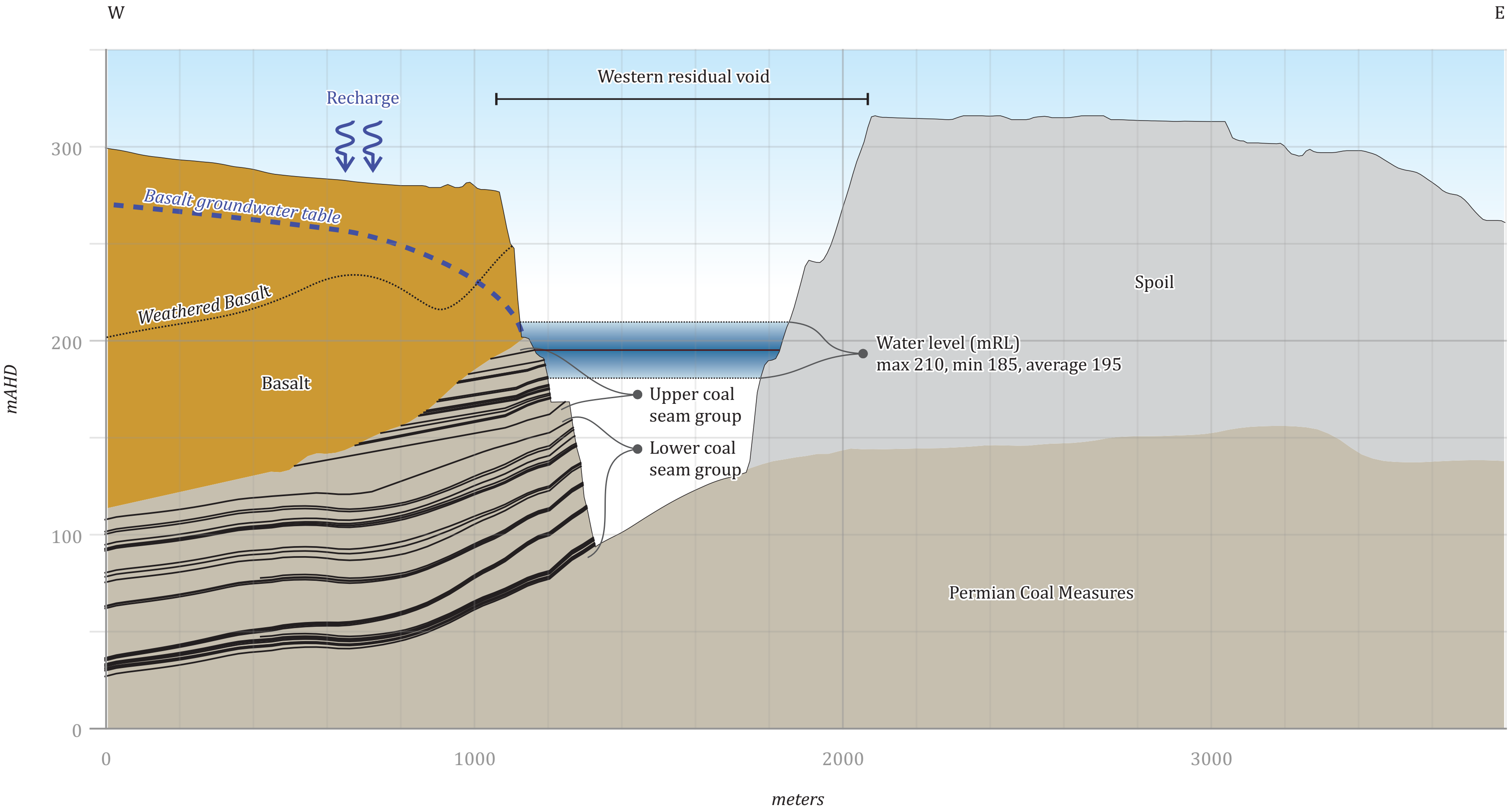


(Source: KBR, 2017)

Figure 5.3 Predicted void water equilibrium level – western residual void

The average and minimum void water equilibrium levels are predicted to be below the base of the basalt exposed in the highwall of the western void, as shown on Figure 5.4. The lowest elevation where basalt is exposed in the highwall of the western void is 201 mAHD. The maximum void water equilibrium level is predicted to be marginally above the base of the basalt exposed in the highwall.

Although the maximum void water equilibrium level is predicted to be above the base of the basalt exposed in the highwall, the maximum void water equilibrium level is predicted to remain about 60 m below the elevation of the regional groundwater table. Therefore, a groundwater hydraulic gradient is expected to be maintained in perpetuity towards the western residual void.



Water level source: KBR, 2017

West-East cross-section with predicted void water equilibrium levels

Figure 5.4

Minerva Final Void (G1753D)

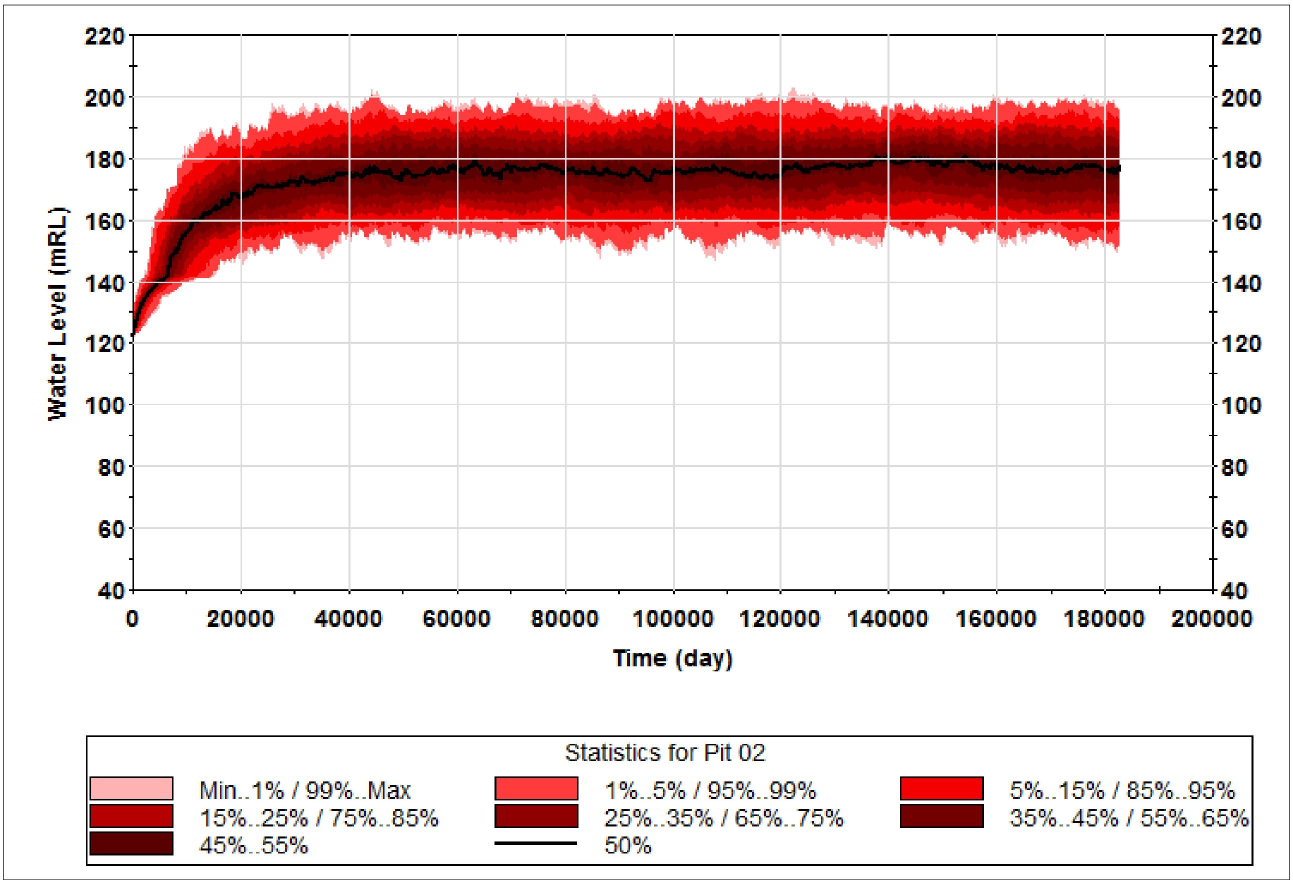
5.2.2 Southern residual void

The risk of water leaving the southern residual void via the coal seams is low under all modelled scenarios.

The stochastic water balance model (KBR, 2017) predicts the void water level in the southern residual void will rise towards an equilibrium over a period of about 40,000 days (~110 years), as shown in Figure 5.5.

The void water equilibrium level is predicted by KBR (2017) to have:

- an average elevation of about 175 mRL (equivalent to m AHD);
- a minimum elevation of 150 mAHD; and
- a maximum elevation of 200 m AHD.

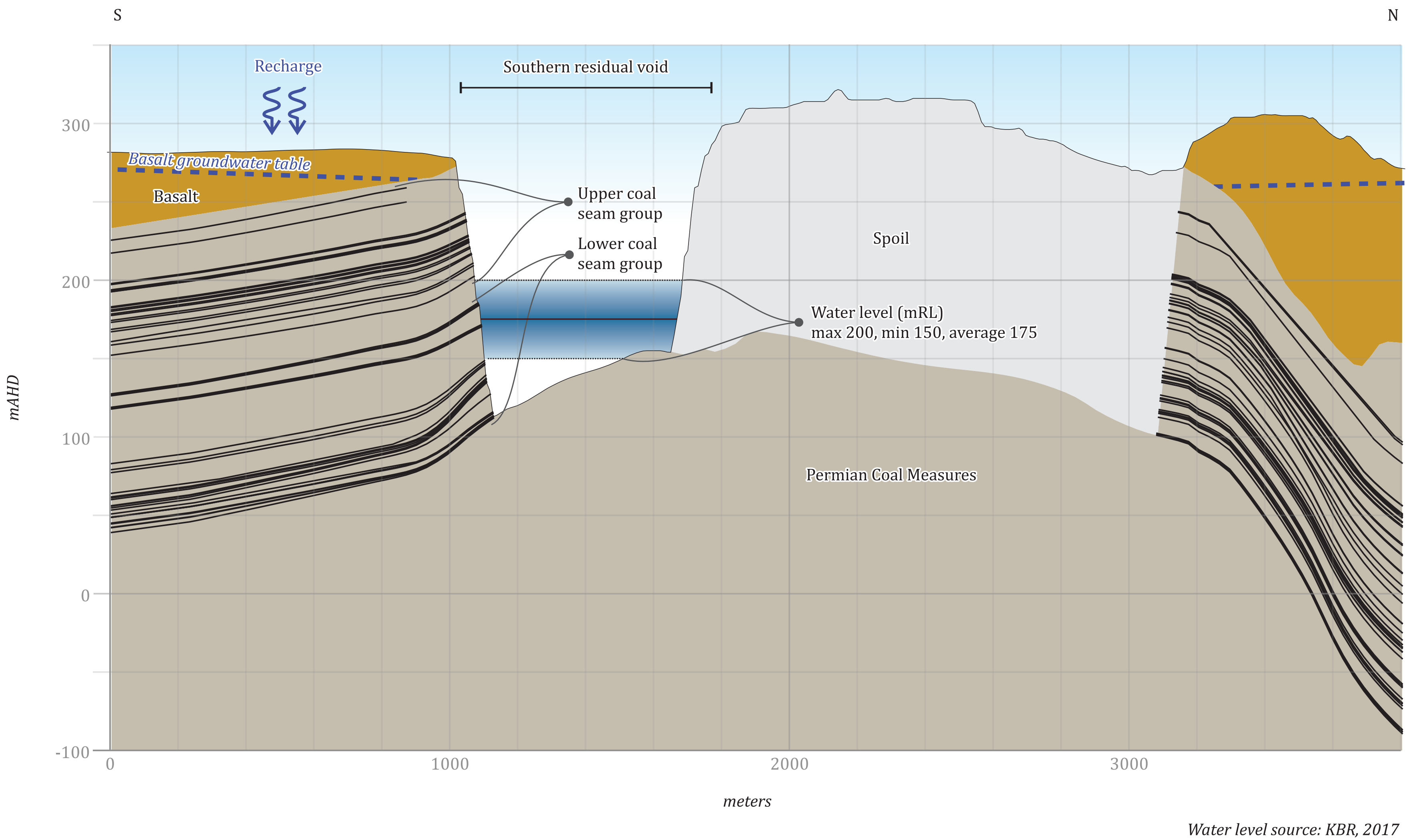


(Source: KBR, 2017)

Figure 5.5 Predicted void water equilibrium level – southern residual void

All of the predicted void water equilibrium levels for the southern void are expected to remain at least 70 m below the elevation of the regional groundwater table, as shown on Figure 5.6. Therefore, a groundwater hydraulic gradient is expected to be maintained in perpetuity towards the southern residual void.

The predicted void water equilibrium level for the southern void is lower than predicted levels for the western void. As a result, a hydraulic gradient is expected to form towards the southern void from the western void. The southern void will permanently remain a groundwater "sink" where evaporation permanently depress the water level.



South-North cross-section with predicted void water equilibrium levels

Figure 5.6

Minerva Final Void (G1753D)

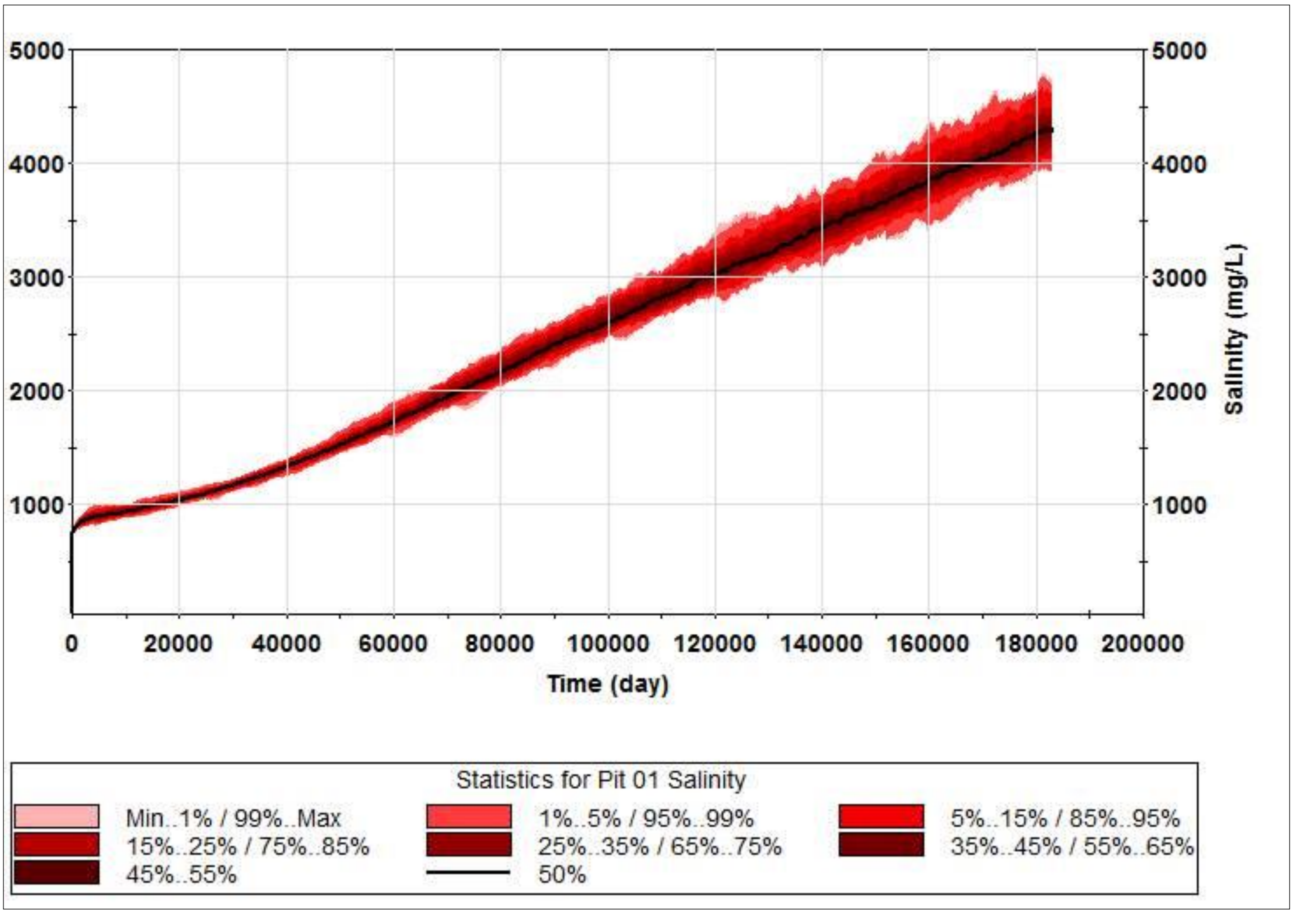
5.3 Potential water quality within the residual voids

5.3.1 Western residual void

The risk of water quality deteriorating within the western void to an un-usable status within the immediate future is low for all modelled scenarios.

The stochastic water balance model (KBR, 2017) predicts the TDS concentration of void water will continuously increase over time. The TDS concentration is expected to be about 800 mg/L soon after mining and increase are a rate of about 7 mg/L per year.

Water is primarily used by neighbours for livestock watering (beef cattle). The ANZECC (2000) guideline confirms that no adverse effects on beef cattle are expected to occur when the TDS concentration of stock drinking water is below 4,000 mg/L. The average TDS concentration of the western void water is predicted to increase to 4,000 mg/L after about 170,000 days (~465 years) post mining, as shown on Figure 5.7.



(Source: KBR, 2017)

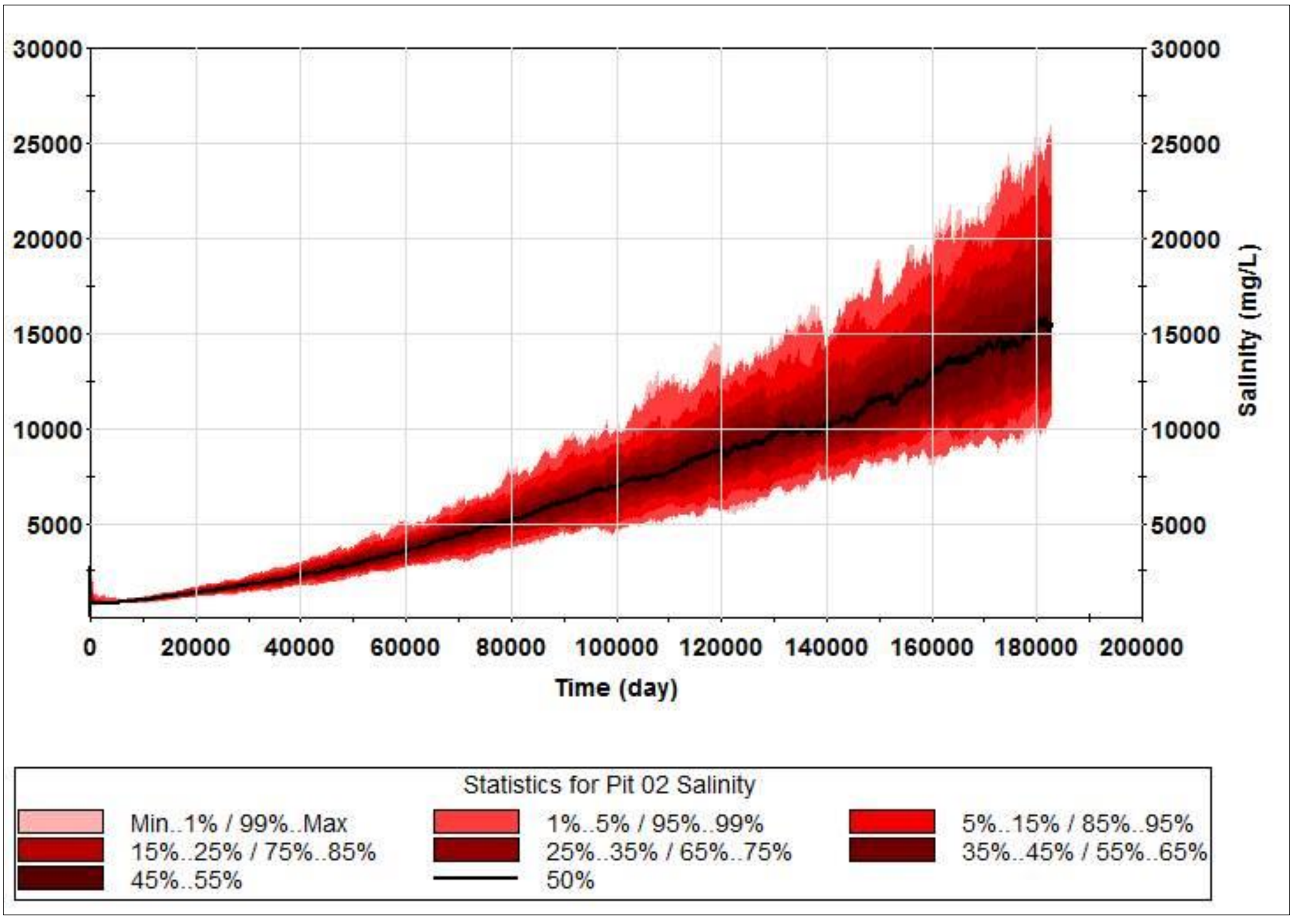
Figure 5.7 Predicted TDS concentration of void water – western residual void

5.3.2 Southern residual void

The risk of water quality deteriorating within the southern void to an un-usable status is higher than for the western void. This is because the southern void will not benefit from the diluting influence of basalt aquifer inflow (i.e. high flow and low TDS concentration) that is received directly by the western void.

The KBR (2017) stochastic water balance model predicts the TDS concentration of water in the southern void will be about 800 mg/L soon after mining. The TDS concentration is predicted to then increase at a rate of between 10 mg/L and 25 mg/L per year.

As a comparison to the western void, the average TDS concentration of the southern void water is predicted to increase to 4,000 mg/L after about 60,000 days (~164 years) post mining, as shown on Figure 5.8.



(Source: KBR, 2017)

Figure 5.8 Predicted TDS concentration of void water – southern residual void

6 Conclusions

The aim of this memo was to support the Minerva Mine void hydrology study by summarising the methods and data used to calculate future groundwater inflow rates into the western and southern residual voids. This memo also presented an assessment of the potential for void water to interact with surrounding aquifers, and the long-term void water quality.

Review of the void geometry confirmed that groundwater inflow to the southern residual void will only occur from the coal seams, because the basalt aquifer is not intersected by the highwall of this void. The highwall of the western residual void will intersect a significant thickness of basalt as well as the many coal seams. The basalt aquifer will be the major source of inflow to the western residual void.

The groundwater inflow rate to the western void is predicted to be consistently about 408 ML/year in the future because the hydraulic gradient within the basalt aquifer is unlikely to be influenced by the elevation of the void water level within the western void.

The groundwater inflow rate into the southern residual void will be considerably lower than the western residual void because the coal seams will be the only source of groundwater inflow. The groundwater inflow rate to the southern void is predicted to slightly decline as the void water level increases. The predicted inflow rate from the coal seams reduces from about 7.3 ML/year at the end of mining, down to about 6.4 ML/year at equilibrium.

All modelled scenarios predict the void water equilibrium level within western void will be at (or below) the base elevation of the basalt exposed in the highwall. These void water elevations will not be sufficient to reverse the hydraulic gradient, so groundwater is expected to perpetually move towards the void. The risk of water leaving the void into the basalt aquifer is low.

Water quality within the western void is predicted to deteriorate slowly over time, but will still be suitable for livestock watering (beef cattle) for about 465 years after mining.

The water quality within the southern void is predicted to deteriorate more quickly, but the southern void will be a regional hydraulic sink and the low quality water is expected to remain within the void.

7 References

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Waste Solutions Australia Pty Ltd, (2010), "*Minerva Final Void Numerical Model*", Report prepared for Minerva Joint Venture, Project No. RN10/W0397-5 / 01, January 2010.

Waste Solutions Australia Pty Ltd, (2010), "*Minerva Mine – Groundwater Investigation – Conceptual and Numerical Groundwater Model – Revised Report",* Prepared for Sandhurst Mining Limited, Project No. RN06 / W397, June 2006.

Appendix B

PSM (2021). Highwall Stability Study – Geoctechnical Closure Study. Internal Report to Sojitz Minerva Mining Pty by Pells Sullivan Meynink. 18 October 2021

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Our Ref: PSM2432-124L REV1

18 October 2021

Operations Manager - SSE
Sojitz Minerva Mining Pty Ltd
593 Wurba Road
EMERALD QLD 4720
PO'Donnell@sojitzblue.com.au

Attention: Peter O'Donnell

Dear Peter

RE: HIGHWALL STABILITY - GEOTECHNICAL CLOSURE STUDY

1. Introduction

This report presents the results of a geotechnical assessment undertaken by PSM to inform the stability of final highwalls for the Main and South Pits at the Minerva Coal Mine (Minerva). The assessment has been undertaken at the request of Peter O'Donnell of Sojitz Minerva Mining Pty Ltd (Sojitz) via email to Alex Duran of PSM[1], with the agreed work package issued via email[2]. The primary aim of the assessment is to assist in defining the closure bund location for final closure.

To complete this assessment, PSM have utilised experienced gained by providing geotechnical advice for Minerva since 2014 and observations of wall performance and critical failure mechanisms. This report documents the background information, geotechnical model and parameters, adopted criteria, stability analyses and results of the geotechnical assessment proving a location of the closure bund for the remaining highwalls in the Main and South Pits.

This revision of the letter, to that presented on 6 October, has considered the diversion channel which wraps around the Main and South pits, Figure 1.

2. Overview

Sojitz is proposing to leave an open void in the west and northwest highwall of Main Pit and the west highwall in South Pit as part of the rehabilitation plan for Minerva. Minor spoil buttressing will be left behind in some areas following mining, but no spoil will be dumped as part of the rehabilitation plan. Current floor levels are at final level for both Main and South Pits.

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[1] FW: MJV Main & South Pits LOM Reshaping-Remaining High Wall Stability, email from Peter O'Donnell of Sojitz to Alex Duran of PSM, received 31 August 2021.

[2] RE: MJV Main & South Pits LOM Reshaping-Remaining High Wall Stability, email from Alex Duran of PSM to Peter O'Donnell of Sojitz, sent 10 September 2021.

Figure 1 presents the location of both pits and the location of the highwall crest above the remaining void and with backfill along the eastern part of the Main pit and north wall of the South pit.

PSM have been provided five cross-sections, Figure 1, by Sojitz to undertake the geotechnical assessment. PSM have reviewed the geometries, and these are summarised Table 1.

Table 1 – Summary of slope characteristics

Pit	Section	Highwall Crest (mRL)	Overall Slope Height (m)	Overall Slope Angle (°)	Depth to Permian Rock (m)[1]
Main	1	280	158	41	48
	2	283	198	32	86
	3	280	195	43	86
South	4	280	147	49	17
	5	278	72	42	21

[1] Depth to Permian rock is measured from the highwall crest to the base of weathering as exposed in the highwall face.

3. Scope of Work

The scope of work for the stability study comprises:

1. Assessment of pit wall geotechnical stability, considering the effects of long-term erosion and weathering of the pit wall, on three sections within the Main Pit and two sections within the South Pit.
2. Provide guidance on the location of a closure bund based on the stability analyses and erosion considerations.

4. Approach

The geotechnical requirements for the MJV Residual Void Management Plan are defined as:

> *"a pit wall stability study, considering the effects of long-term erosion and weathering of the pit wall and the effects of significant hydrological events"*

PSM has undertaken stability analysis to assess the stability of the proposed final void and define a location of a closure bund from the pit crest based on whichever of the following criteria is the furthest from the crest:

1. A minimum Factor of Safety (FOS) of 1.50 resulting from 2D Limit Equilibrium (LE) stability analyses.
2. Instability along adversely orientated major geological structure.
3. Consideration of long-term erosion.

PSM highlight that specific assessment of the potential long-term erosion has not been specifically carried out. Such assessment typically assumes a RUSLE approach (an empirical-based modelling approach that predicts the long-term average annual rate of soil erosion on slopes) or HEC-RAS modelling (sediment transport/mobile bed computations). These were deemed of limited value for several reasons:

- Much of the north and west walls in the Main pit are capped by high intact strength basalt and are unlikely to exhibit long term erosion
- In other areas the placement of the closure bund will limit the catchment providing the potential erosion to the pit crest
- PSM assume that all surface water flows will be directed away from closure bunds so they in turn are not subject to undue erosion
- For conservatism and based on closure studies dealing with sedimentary strata for others, a long term erosion of 50m from the crest line has been allowed for and defines the metric for the third item above.

This report has not assessed bench scale instability as such failures will be localised within the minimum offset of the closure bund.

The long-term stability of the open voids are dependent on several factors, with the most important being:

- The presence and orientation of major geological structures (i.e. faults and shears) within the pit slopes
- The strength of the rock mass within the pit slope
- The depth and characteristics of Tertiary materials and weathered rock within the pit walls, and their susceptibility to erosion over time
- The geometry of the pit wall
- The influence of groundwater and rainfall on slope stability
- The influence of buttressing effects by spoil or lake levels.

5. Data Sources

Sojitz have provided PSM with the following data to assist with the assessment:

- Five cross sections displaying:
  - Base of Tertiary material
  - Base of weathered material
  - Coal seams
  - Final pit void
  - In-situ mined surface.
- Hydrological assessment of the estimated final lake levels
- 1 in 1000 year flood zone within a diversion drain behind highwall crest, Figure 1.

PSM have also utilised previous work and experience for this study:

- Geotechnical parameters as defined in PSM2432-014L[3]
- Experience from site visit and involvement in geotechnical management during operations.

6. Geotechnical Model

6.1 Rock Mass Units

The rock mass units (RMU's) are based off those adopted in PSM2432-014L, as part of the study for the South Pit, and are summarised along with their relevant geotechnical parameters in Table 2.

Table 2 – Rock Mass Units for Main and South Pits

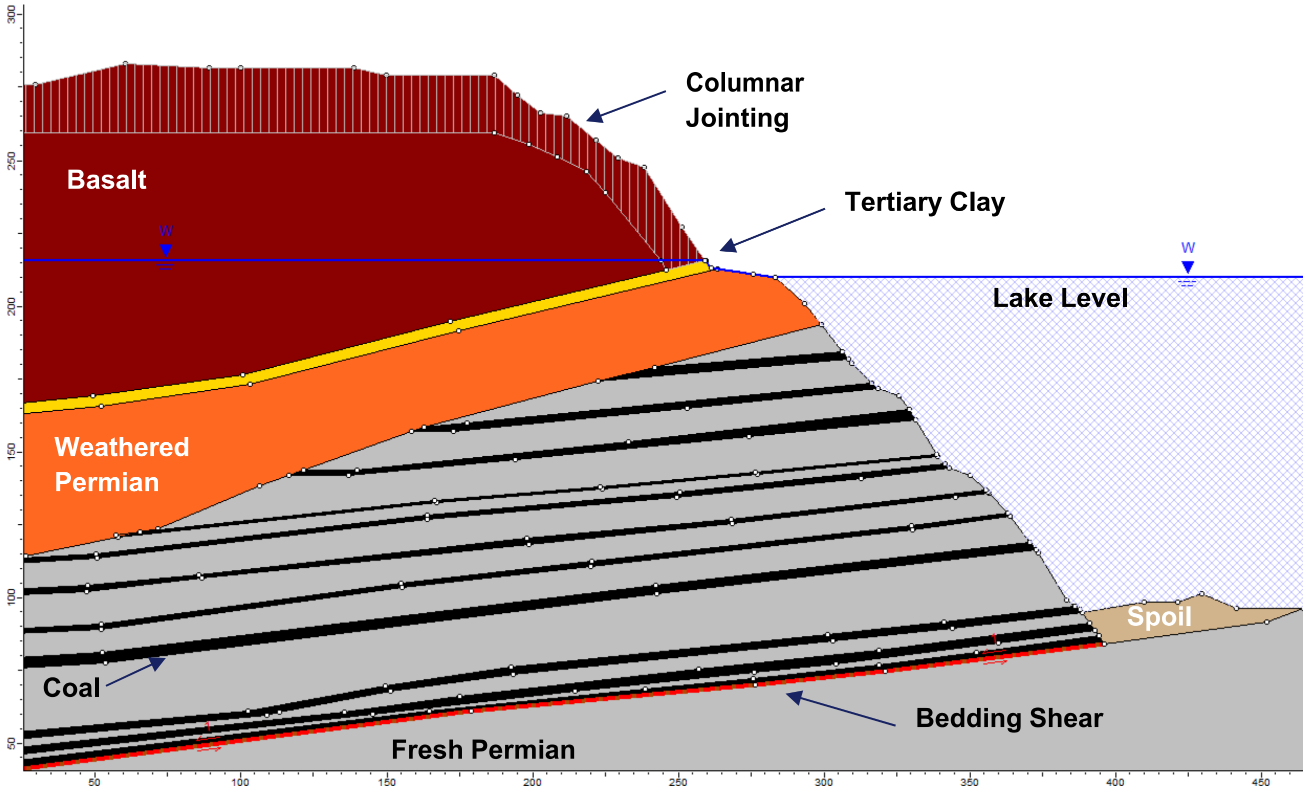
Rock Mass Unit	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (°)
Basalt	27	500	52
Tertiary Clay	20	25	2
Weathered Permian	22	80	30
Fresh Permian	22	450	45
Coal	15	100	35
Spoil (Unsaturated)	18	30	28
Spoil (Saturated)	20	15	23
Bedding Shear	20	0	18

[3] Pells Sullivan Meynink (2015). *Highwall Offset from South Pit Creek Diversion*, dated 17 May 2021, referenced as PSM2432-014L.

6.1.1 Main Pit

The geotechnical model for Main Pit is presented in Inset 1 below. Key comments include:

- Base of Tertiary, base of weathering, coal seams and in-situ boundary as supplied by site
- Some coal seams have been excluded or combined for simplicity
- Thickness of Tertiary Clay is modelled as 5 m, as confirmed by site
- Shearing along all coal seams has been assumed, to represent a conversative approach, with the most adverse bedding shear controlling the closure bund offset
- PSM have increased the rock mass strength of the basalt from the assessment reported on 6 October 2021 and have included the presence of columnar jointing which allows tension crack formation.

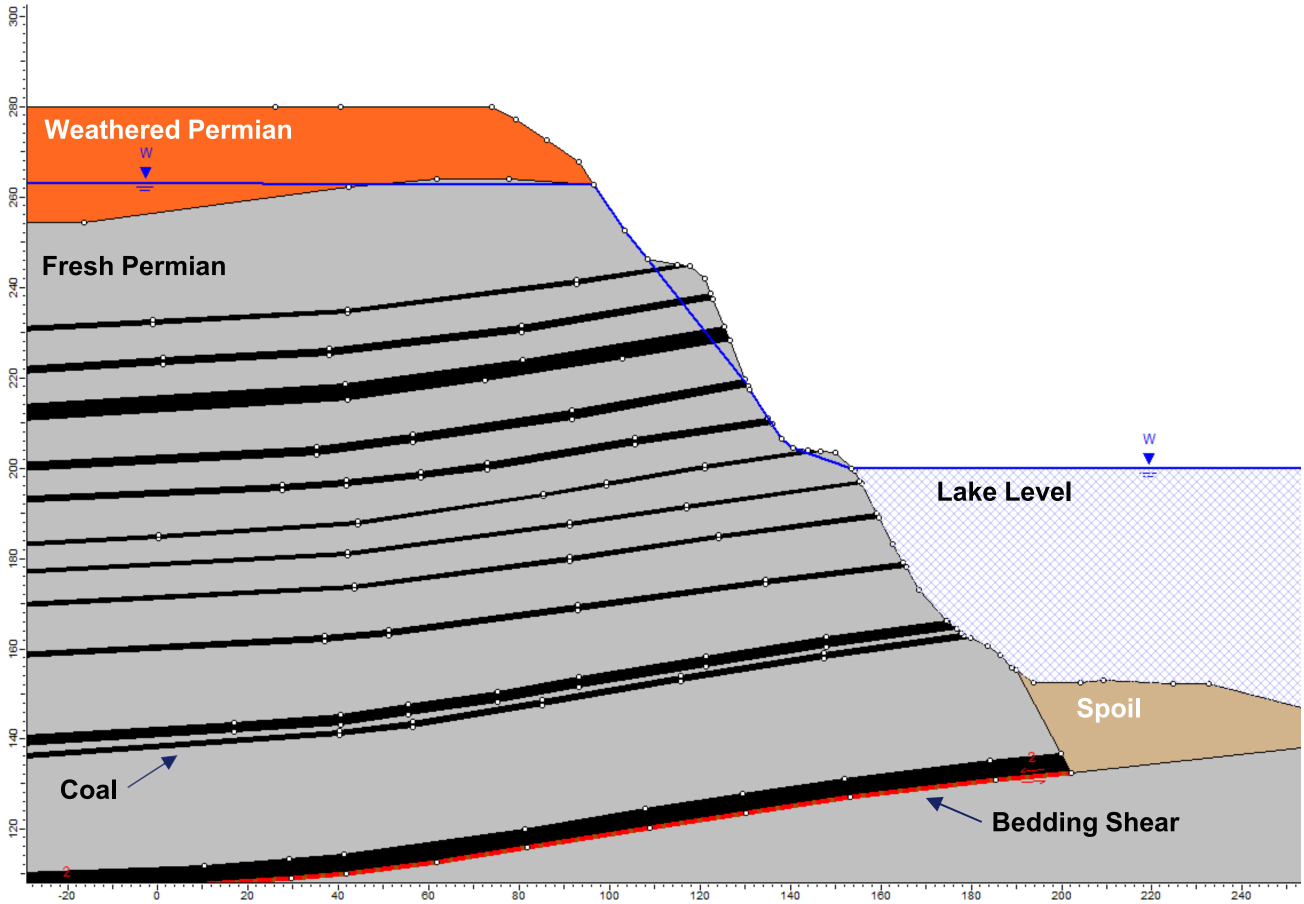


Inset 1: Geotechnical Model for Main Pit (Section 3).

6.1.2 South Pit

The geotechnical model for South Pit is presented in Inset 2 below. Key comments include:

- Base of weathering, coal seams and in-situ boundary as supplied by site
- Some coal seams have been excluded or combined for simplicity
- No Tertiary clay is modelled in South Pit, as confirmed by site
- Shearing along all coal seams has been assumed, to represent a conversative approach, with the most adverse bedding shear controlling the closure bund offset.



Inset 2: Geotechnical Model for South Pit (Section 4).

6.2 Geological Structure

Based on PSM's experience at Minerva, no major geological structures (faults or shears) are adversely orientated to undermine global stability for the pit wall that will remain exposed within the Main and South Pit.

6.3 Hydrogeology

Hydrogeological modelling[4] has been undertaken as part of the rehabilitation plan for Minerva. PSM have reviewed these results and made the following assumptions which will be incorporated within the stability analyses:

- Maximum Lake Level of RL 210 for Main Pit and RL 200 for South Pit
- Lake Level at RL 185 which is at the low end of the range supplied in the hydrogeological modelling
- Lake Level at RL 140 considered a pessimistic scenario
- No Lake established, which will be the conditions at closure and to assess stability before a lake develop.

The water table is assumed confined by the Tertiary clay in the Main Pit and following the base of weathering in the South Pit with no drawdown considered.

[4] Australian Groundwater and Environmental Consultants Pty Ltd (2017), *Minerva Residual Void Investigation – Groundwater Inflow Calculation,* dated 21/07/2017, report number G1753D.

7. Pit Slope Stability Assessment

2D LE analyses using the GLE-Morgenstern Price Method have been completed assuming two potential critical failure mechanisms:

- A circular failure mechanism for material above the base of weathering in the Permian

A block sliding failure mechanism controlled by sliding along a bedding shear with parameters defined in Table 2.

Stability analyses were completed for Sections 1 to 3 for the Main Pit and Sections 4 and 5 for the South Pit. The results of the LE analyses are presented in Appendix A and which considered the range of potential lake levels. The key results are summarised below in Table 3 for the end members of no lake and maximum expected lake level. PSM highlight that the critical scenario for stability is where there is no lake developed as the ponded water in the pit acts as a supporting buttress applying pressure to the highwall.

PSM have assessed block sliding along bedding parallel shears within the key coal seams in the highwall to assess the critical location, which typically has comprised the lowest exposed coal seam in the highwall. The potential failure path that provided the furthest distance from the crest whilst achieving a FOS greater than 1.50 will control the closure bund location and is therefore presented below.

Table 3 – Summary of LE analysis for closure bund offset

Section	Lake Level	Minimum Global FOS	Distance (m) from Pit Crest where FOS = 1.50	Recommended Closure bund offset (m)
Section 1 (Main Pit)	No Lake	1.84 - circular	0	**50**
	No Lake	1.35	48	
	RL 210	1.84	0	
Section 2 (Main Pit)[1]	No Lake	1.10 - circular	0	**50**
	No Lake	1.07	0	
	RL 210	1.81	0	
Section 3 (Main Pit)	No Lake	1.84 - circular	0	**125**
	No Lake	0.90	126	
	RL 210	1.34	14	
Section 4 (South Pit)	No Lake	Circular not analysed	0	**100**
	No Lake	1.05	100	
	RL 200	1.25	83	
Section 5 (South Pit)[2]	No Lake	2.17 - circular	0	**50**
	No Lake	1.44	22	

1 Section 2 has a 110 m wide bench at RL 235, with the crest location modelled as RL 280.

2 Section 5 has only been modelled No Lake due to the pit floor being above the maximum lake level of RL 200.

The results in Table 3 show that a maximum offset for the closure bund is required in the location of Section 3 for eth Main Pit of 125 m and for Section 4 in the South Pit of 100 m respectively. These two cases represent the most adverse conditions in each pit. The other areas require the minimum offset from the closure bund of 50 m and which allows for long term erosion.

PSM highlight the analyses indicate the most adverse scenario, i.e. lowest FOS, is associated with the lowest lake level and with global pit wall stability marginally improving as lake levels increase. Thus, whilst maximum lake levels indicate the closure bund could be located closer to the pit crest, Sojitz should allow for the no lake scenario and in view that final lake levels often take several decades to a century to establish.

Figure 1 highlights that the analyses suggest the closure bund for South Pit interacts with the 1 in 1000 year flood within the diversion channel. As part of this revised assessment, PSM have addressed stability analyses that consider a backfill buttress in the South Pit to mitigate the risk.

The results of the stability analyses for the recommended buttress are within Appendix A. PSM have assumed that the buttress can be emplaced from the wide access available in the south and with the buttress being “locked” into the north wall to ensure adequate 3-dimenansional affects. The required spoil buttress design that achieves a closure bund offset of 50 m, to mitigate interaction with the diversion channel, comprises:

- 80 m wide bridge built from the South at RL 205
- Slope angle of 37° as angle of repose in spoil.

PSM flag that the buttress will have an overalll height of nominally 80m and will either require that:

1. It is progressively built up in lifts each of nominally 20 to 30m in height, commencing from the pit floor, or
2. Developed utilising a similar approach to the high dump in the Main Pit.

If the latter approach is adopted, it is critical that the dumping be onto clean floor and with no water.

8. Conclusions and Recommendations

The location of the closure bund is presented in Figure 1 with the recommended closure bund offset presented in Table 3. For the South Pit a buttress is recommended to allow the closure bund to remain outside the impacts of the diversion channel, the design for the buttress is provided above and nominally indicated in Figure 1

An electronic copy of the closure bund location has been provided in .dxf format with transmittal of this letter.

9. Closure

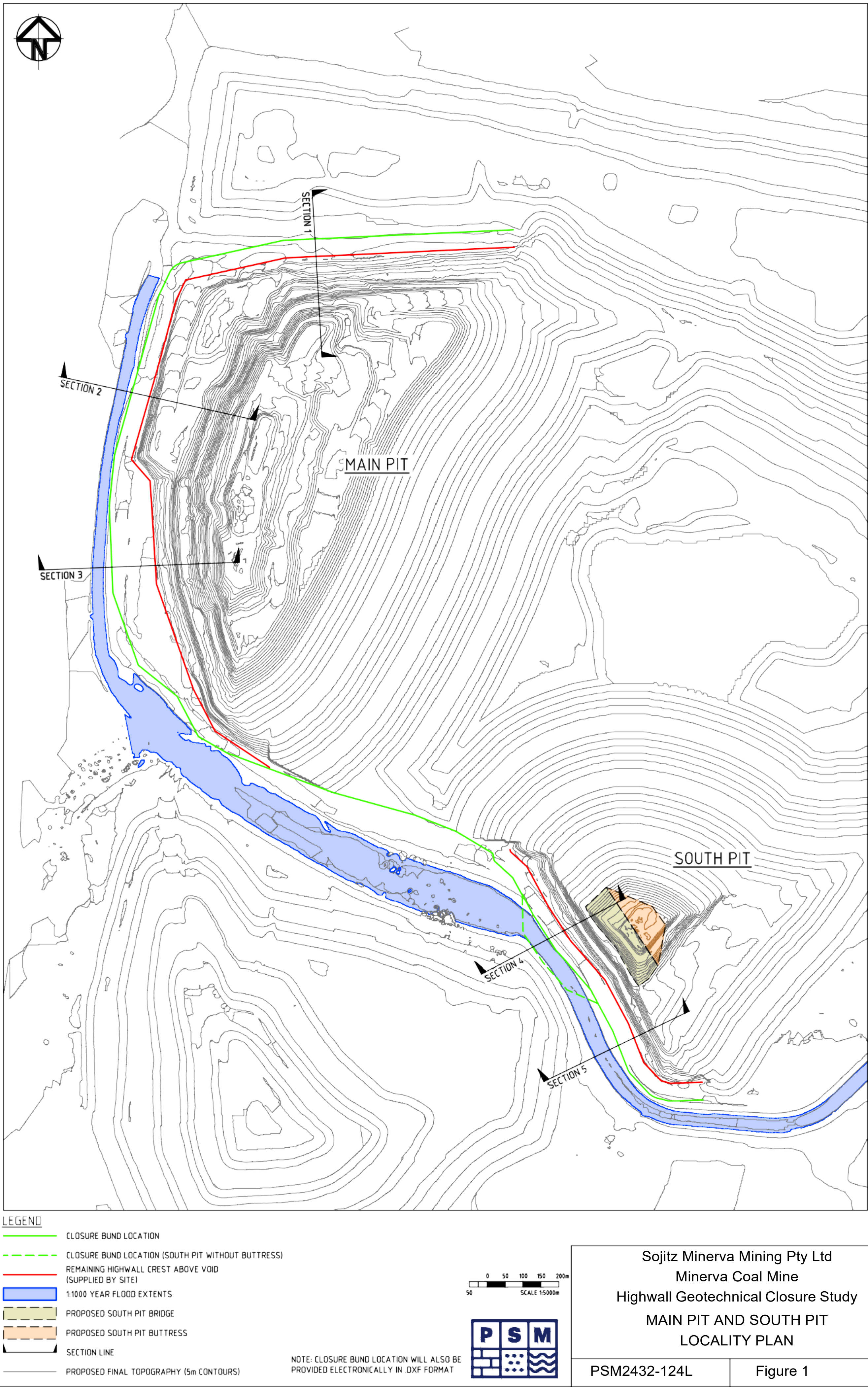
We trust this report meets your immediate requirements. Please contact the undersigned if you have any queries or wish to discuss or clarify any aspect of the report.

Yours Sincerely

HARRISON CROOKS	**ALEX DURAN**
ENGINEERING GEOLOGIST	**PRINCIPAL**
	RPEQ 10461

Enc. Figure 1: Main Pit and South Pit Locality Plan

Appendix A: Stability Analyses



Sojitz Minerva Mining Pty Ltd
Minerva Coal Mine
Highwall Geotechnical Closure Study

MAIN PIT AND SOUTH PIT
LOCALITY PLAN

PSM2432-124L	Figure 1

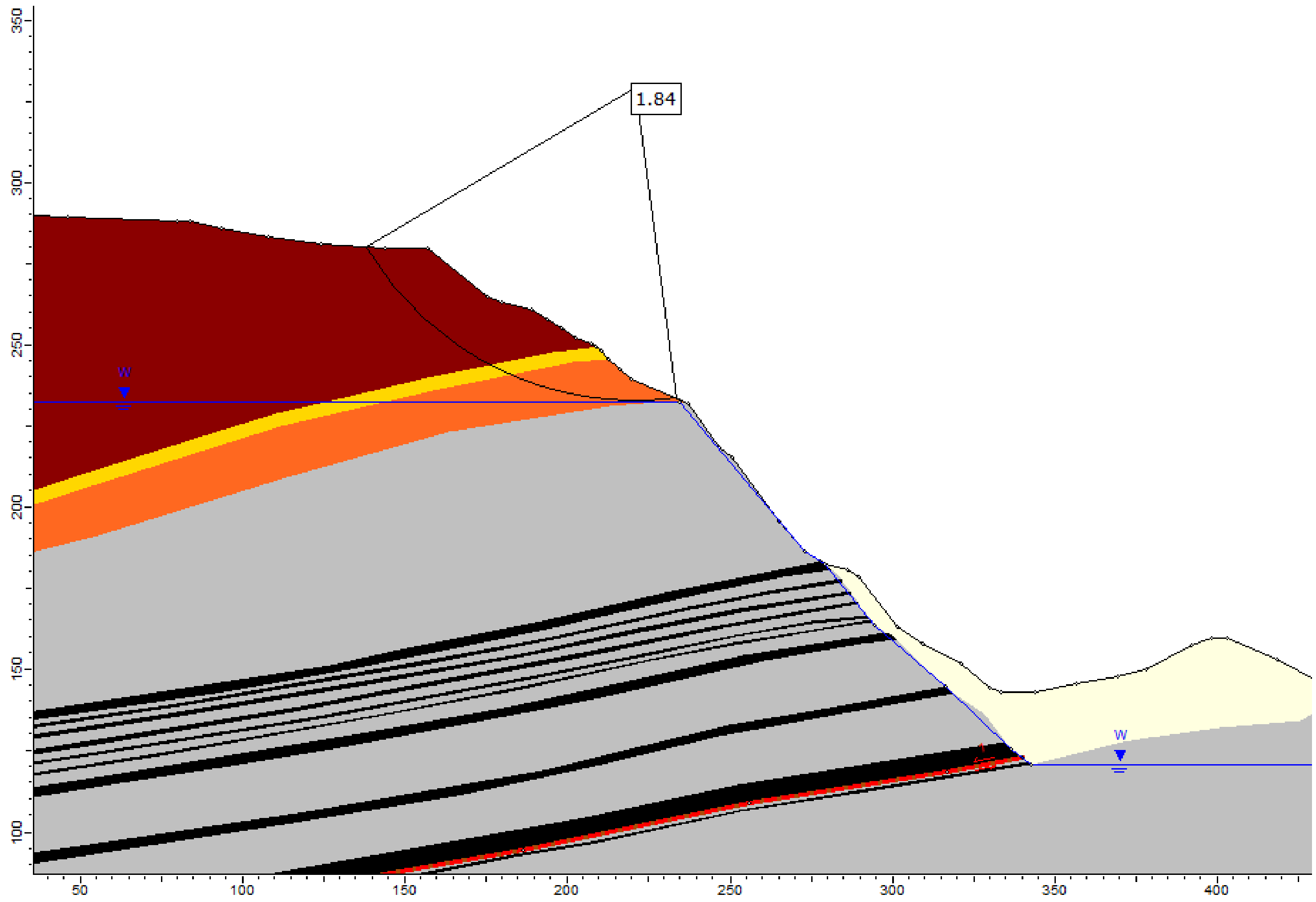
Appendix A
Stability Analyses

Minerva Main and South Pits – Remaining Highwall Stability

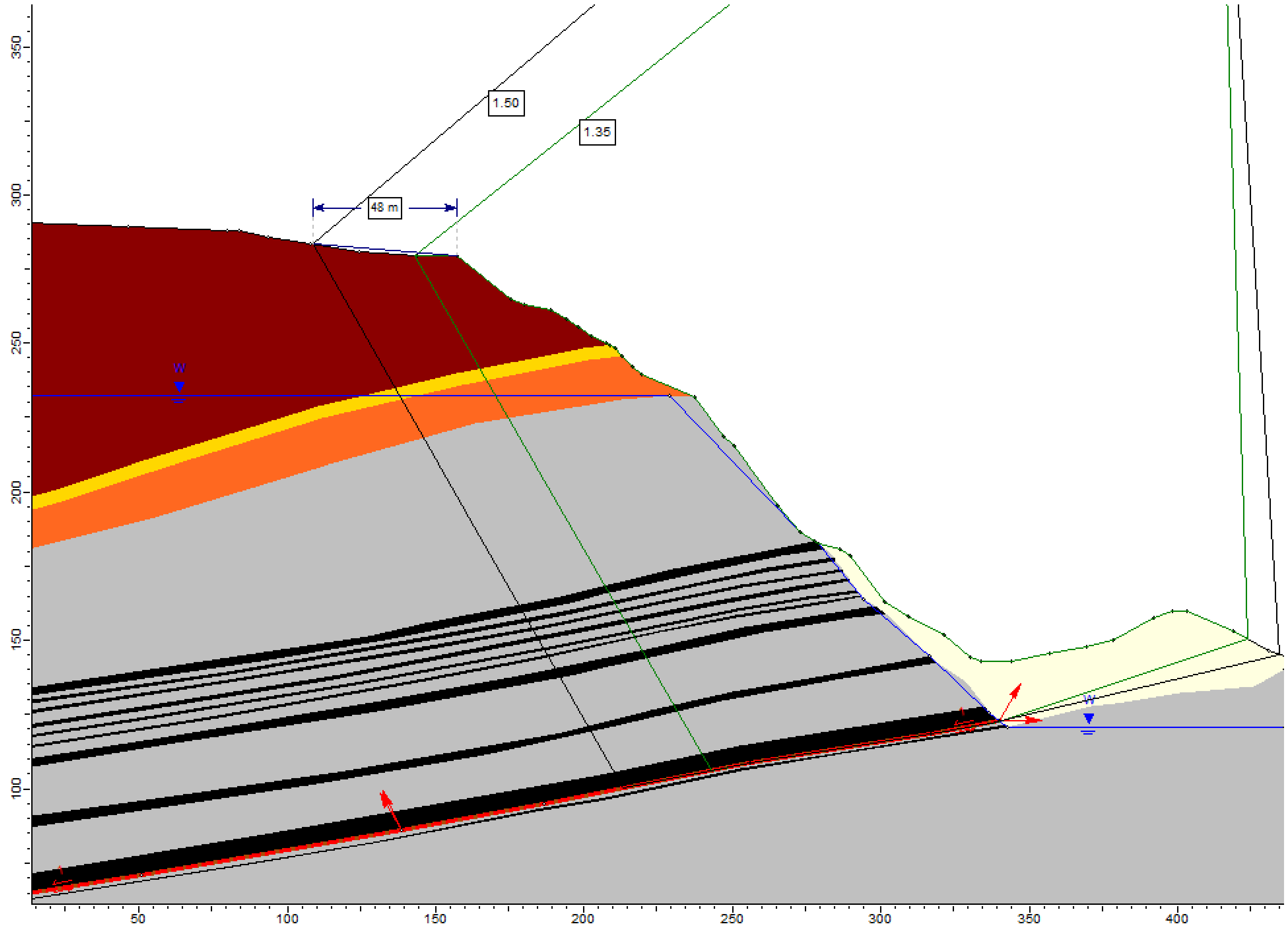
Material Properties

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface
Basalt		27	Mohr-Coulomb	500	52	Water Surface
Tertiary Clay		20	Mohr-Coulomb	25	2	Water Surface
Weathered Permian		22	Mohr-Coulomb	80	30	Water Surface
Fresh Permian		22	Mohr-Coulomb	450	45	Water Surface
Coal		15	Mohr-Coulomb	100	35	Water Surface
Cat2U		18	Mohr-Coulomb	30	28	Water Surface
Cat2S		18	Mohr-Coulomb	15	23	Water Surface
Shear 0/18		20	Mohr-Coulomb	0	18	Water Surface

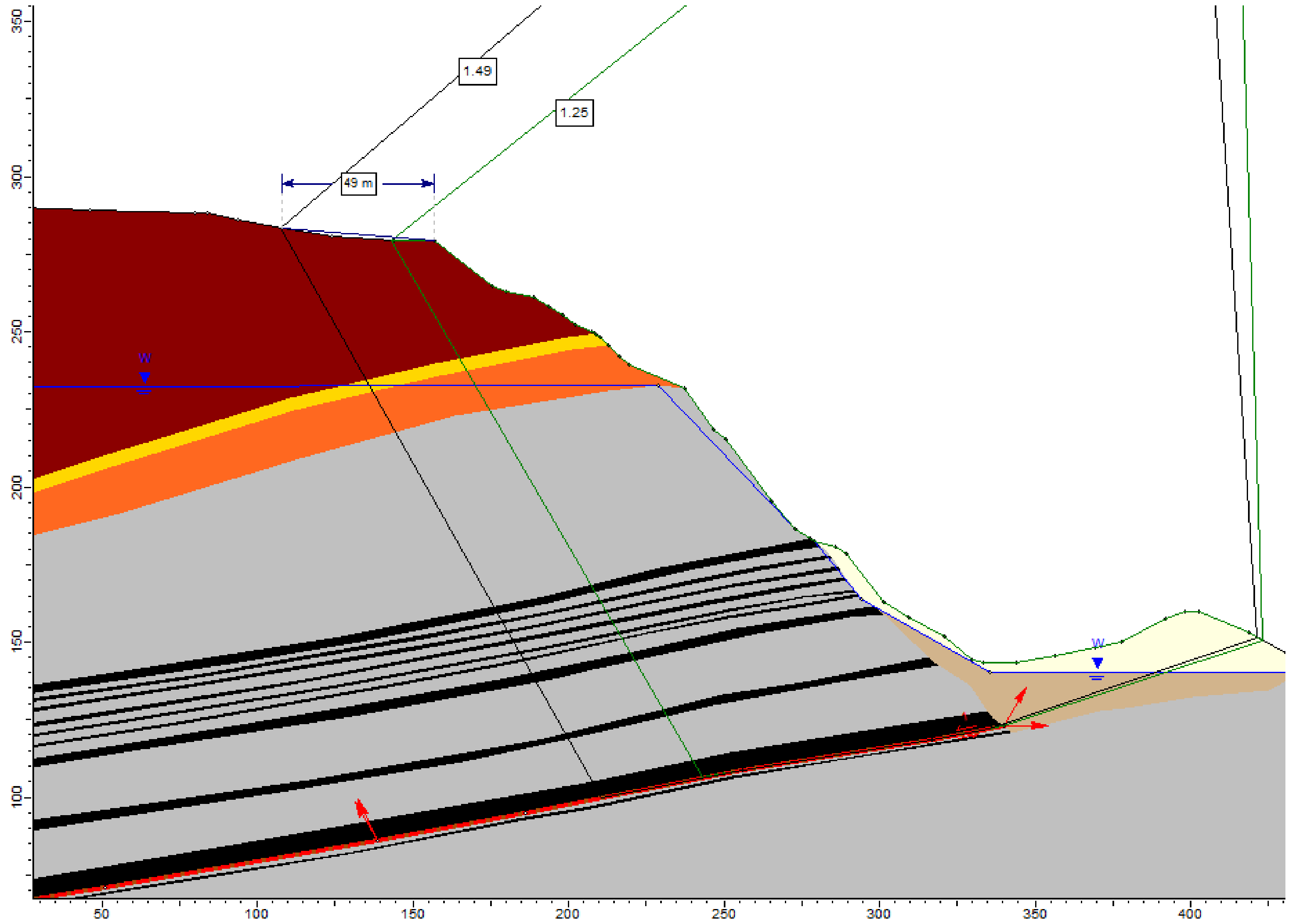
Section 1 –Circular in Weathered



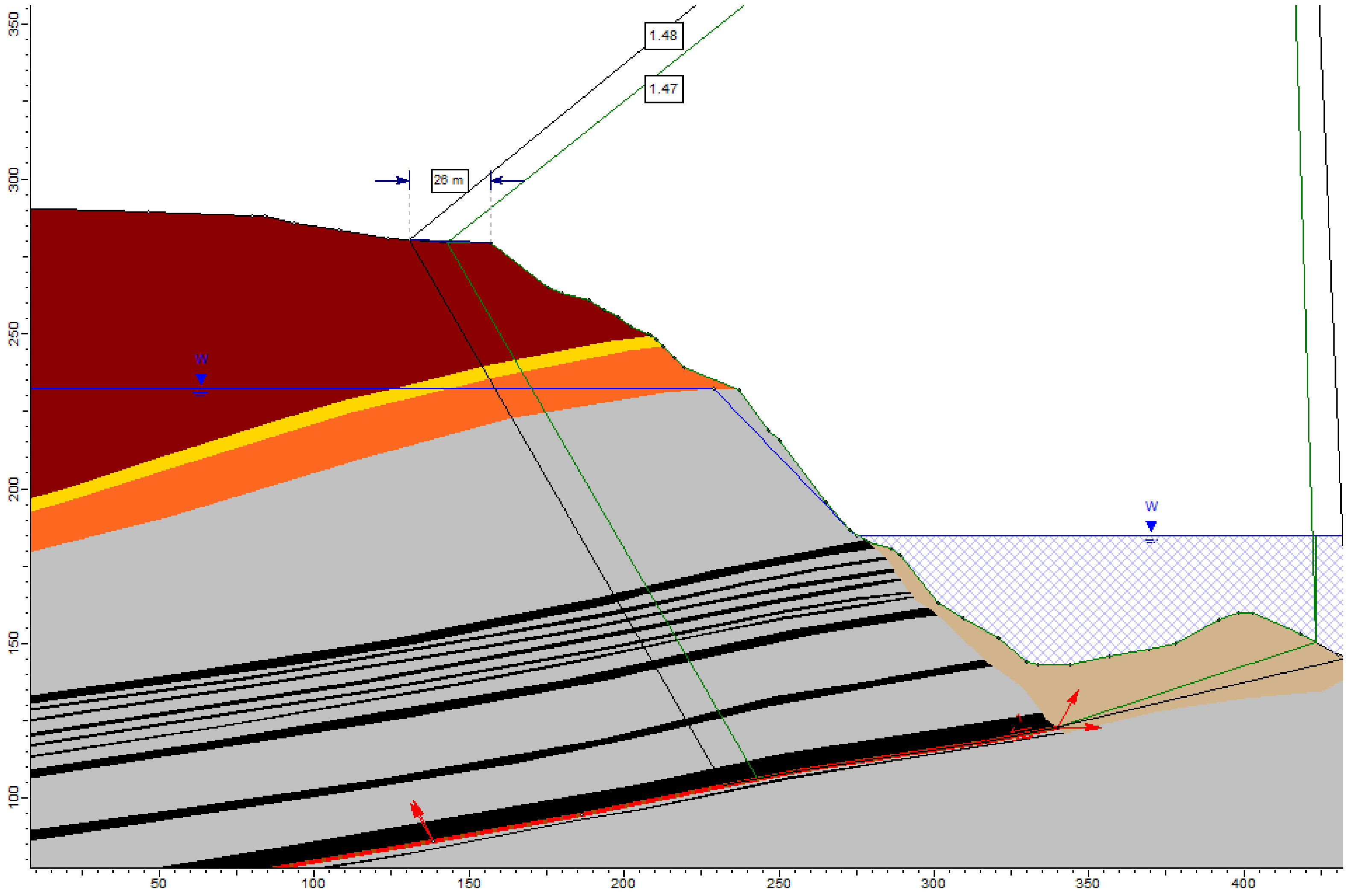
Section 1 –No Lake, Sliding along MN4 Seam



Section 1 –Lake at RL140, Sliding MN4 Seam

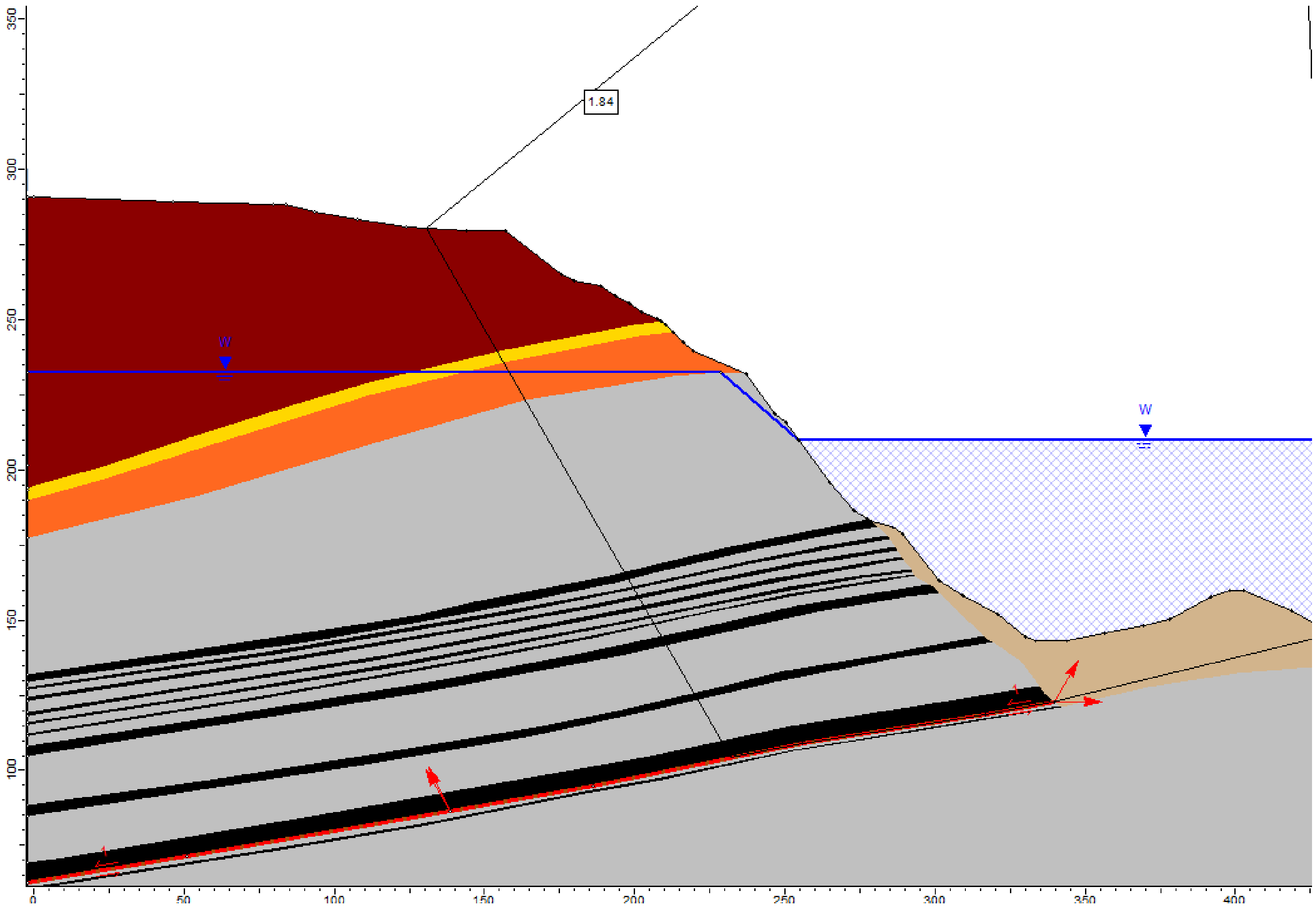


Section 1 –Lake at RL185, Sliding MN4 Seam

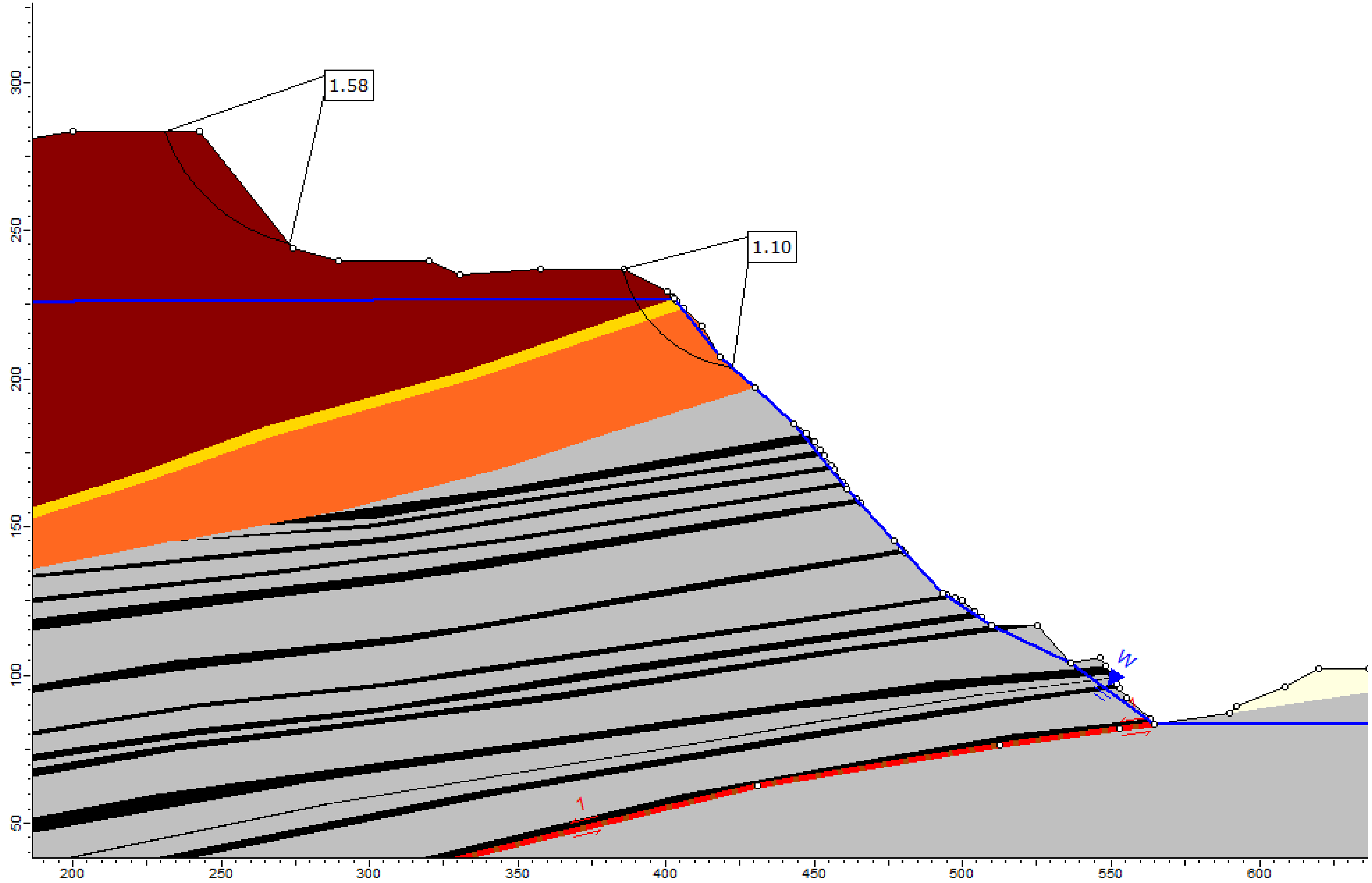


PSM

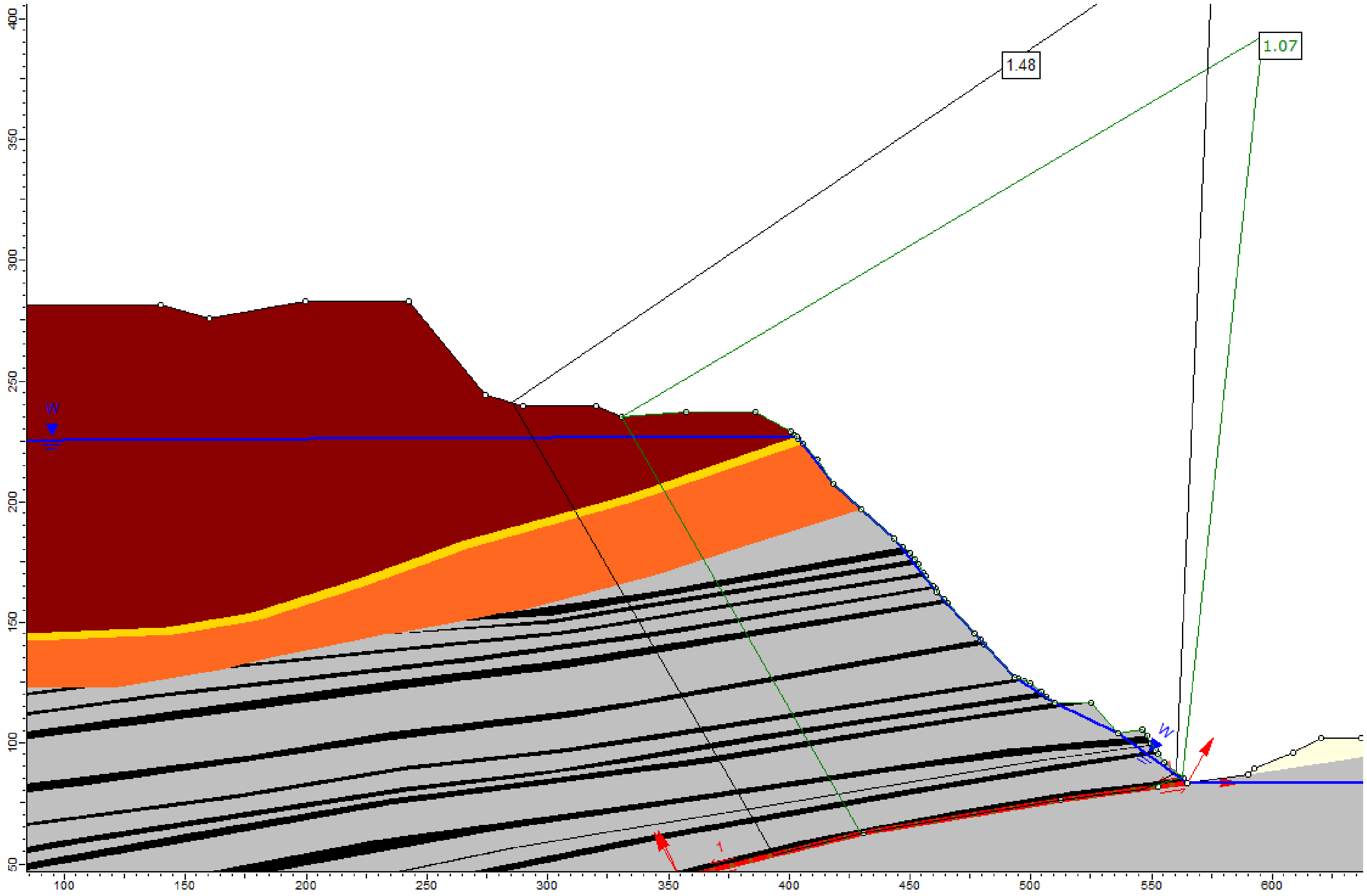
Section 1 –Lake at RL210, Sliding MN4 Seam



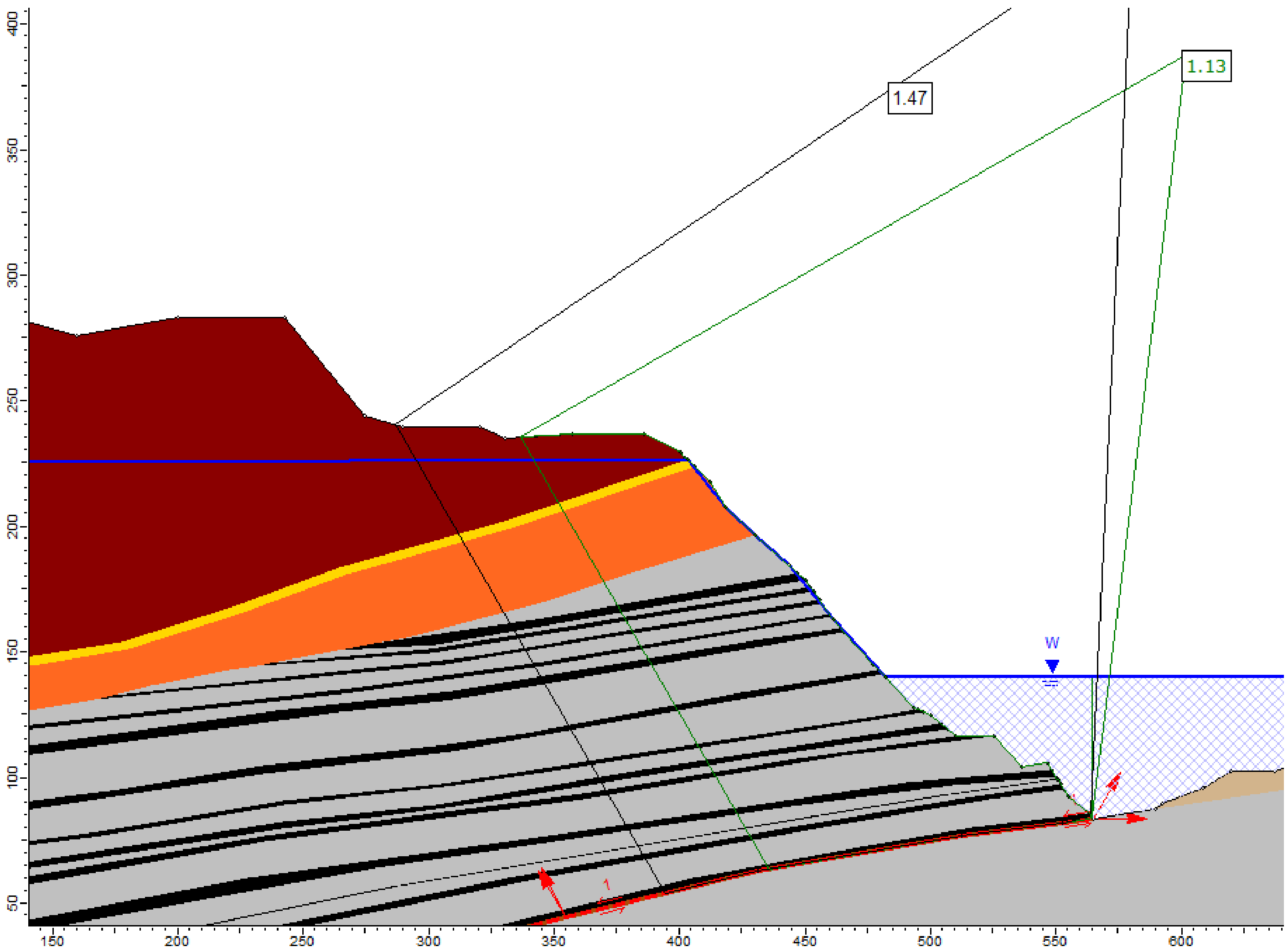
Section 2 –Circular in Weathered



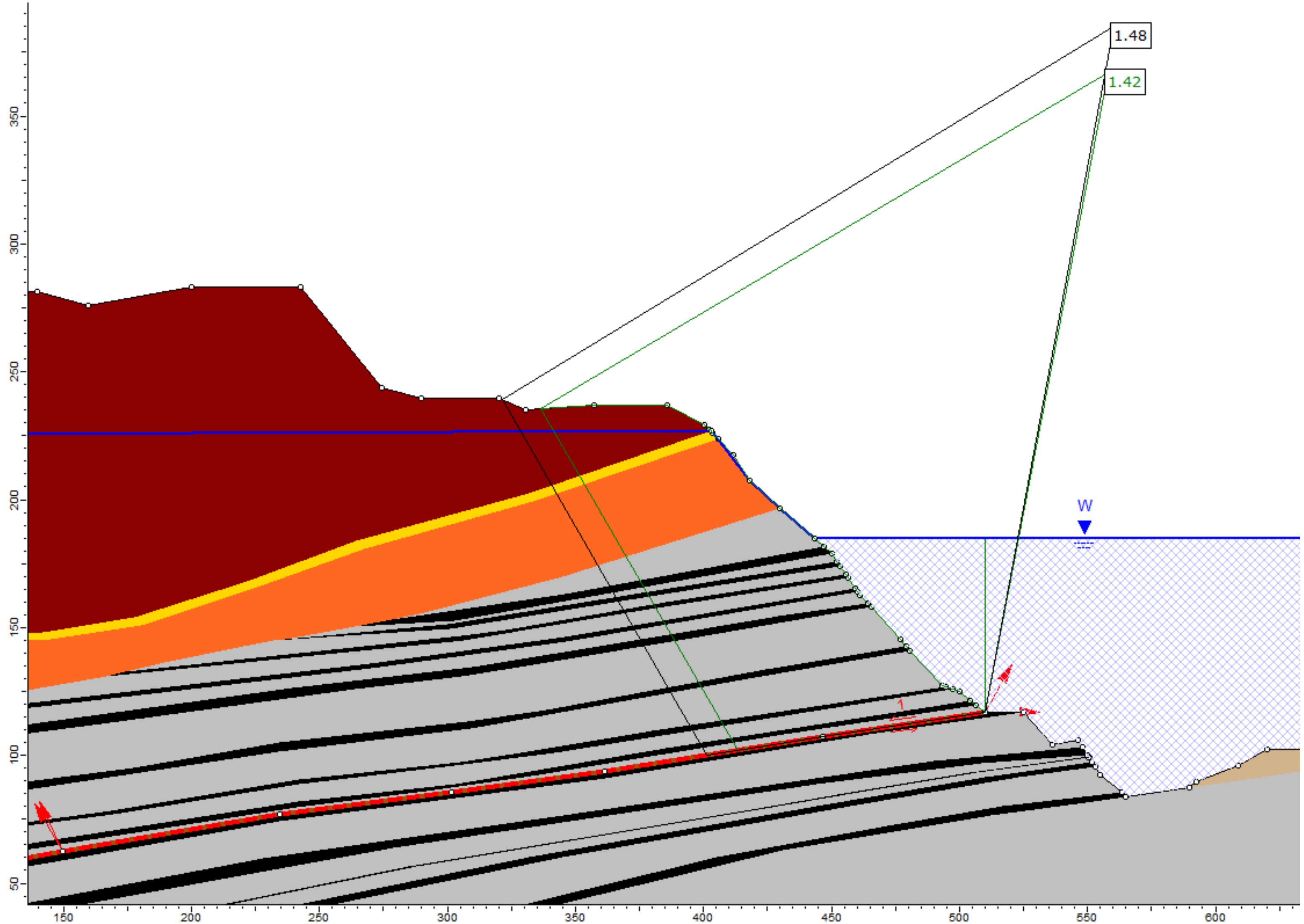
Section 2 –No Lake, Sliding MN10 Seam



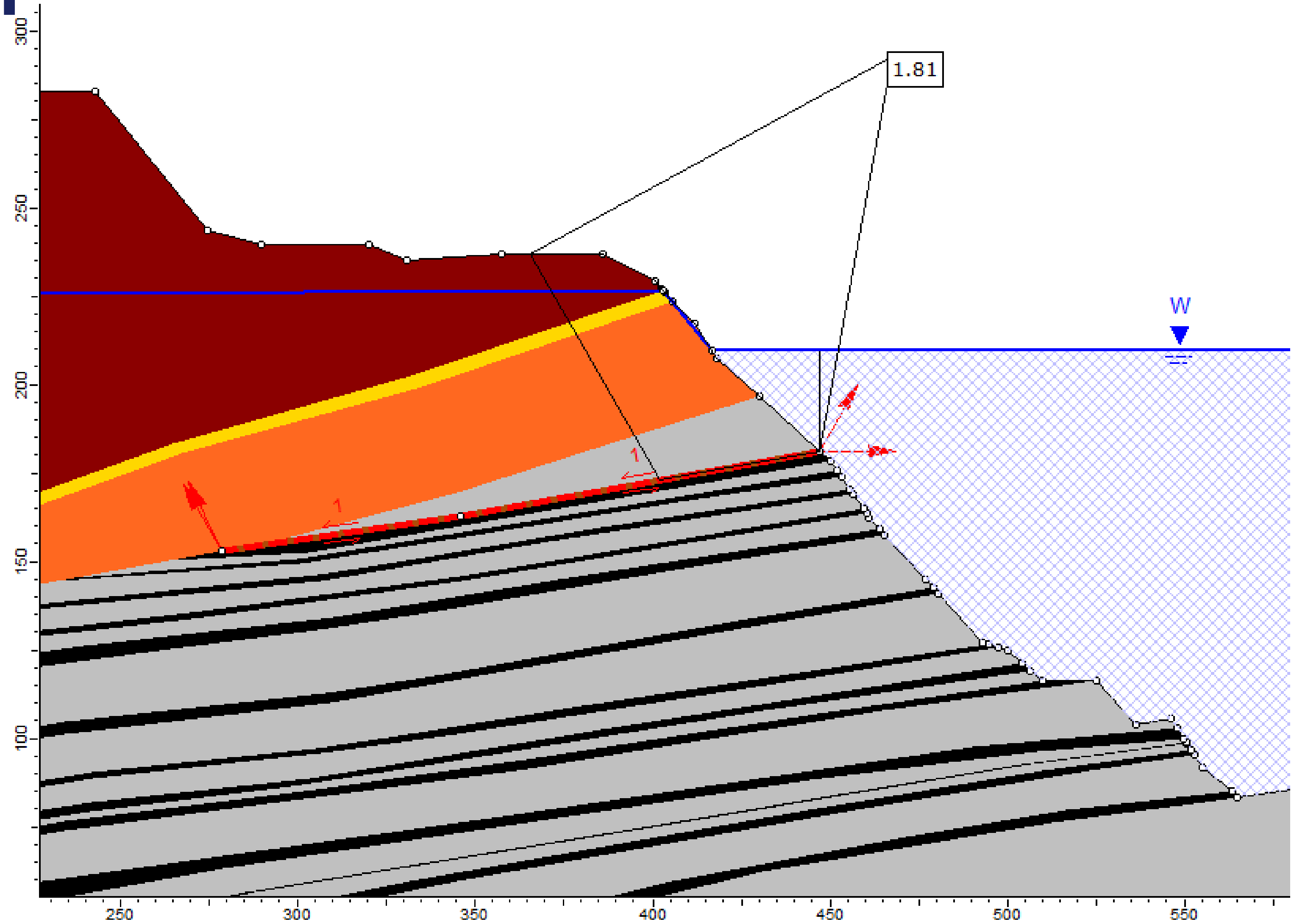
Section 2 –Lake at RL140, Sliding MN10 Seam



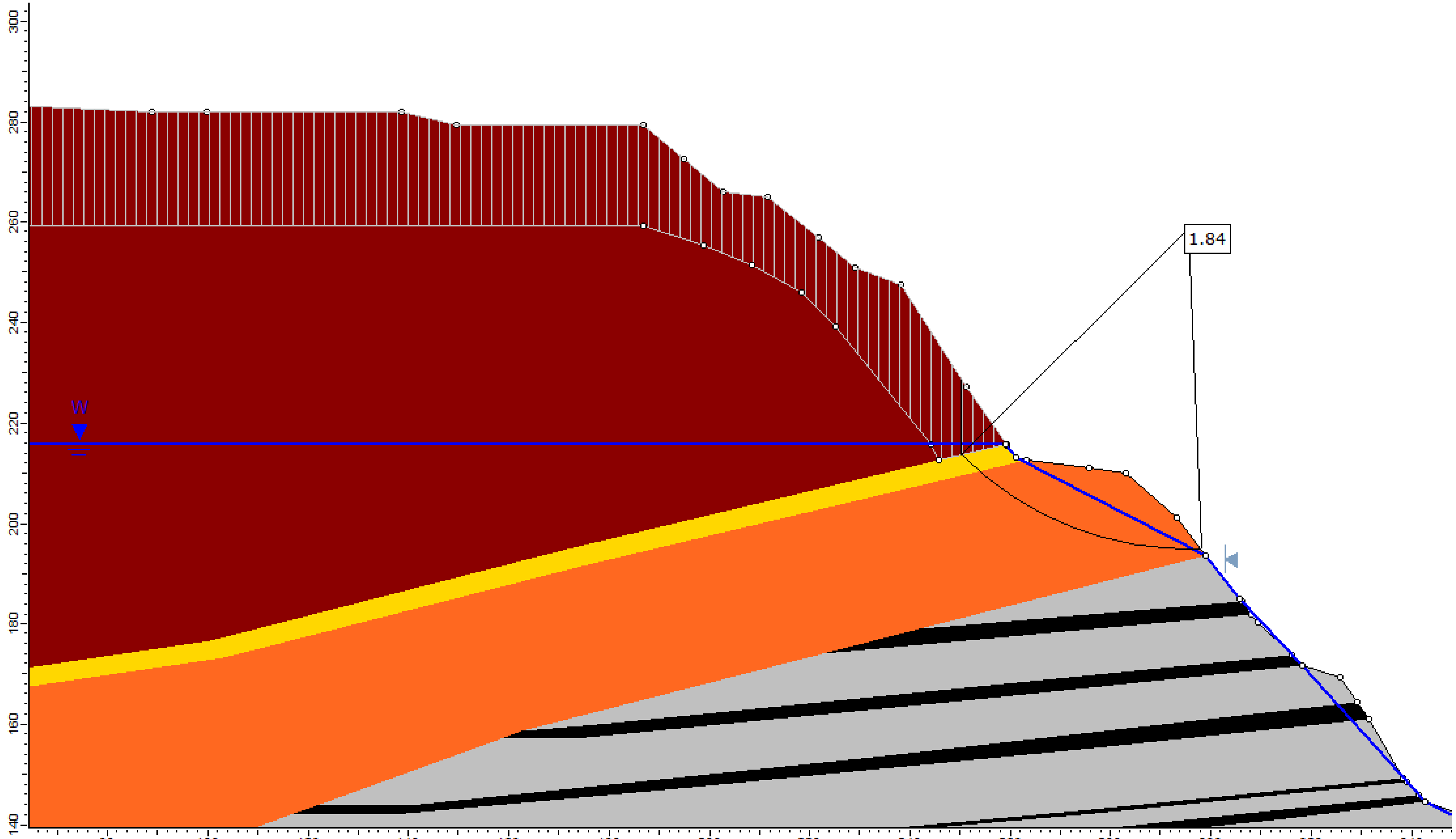
Section 2 –Lake at RL185, Sliding MN4 Seam



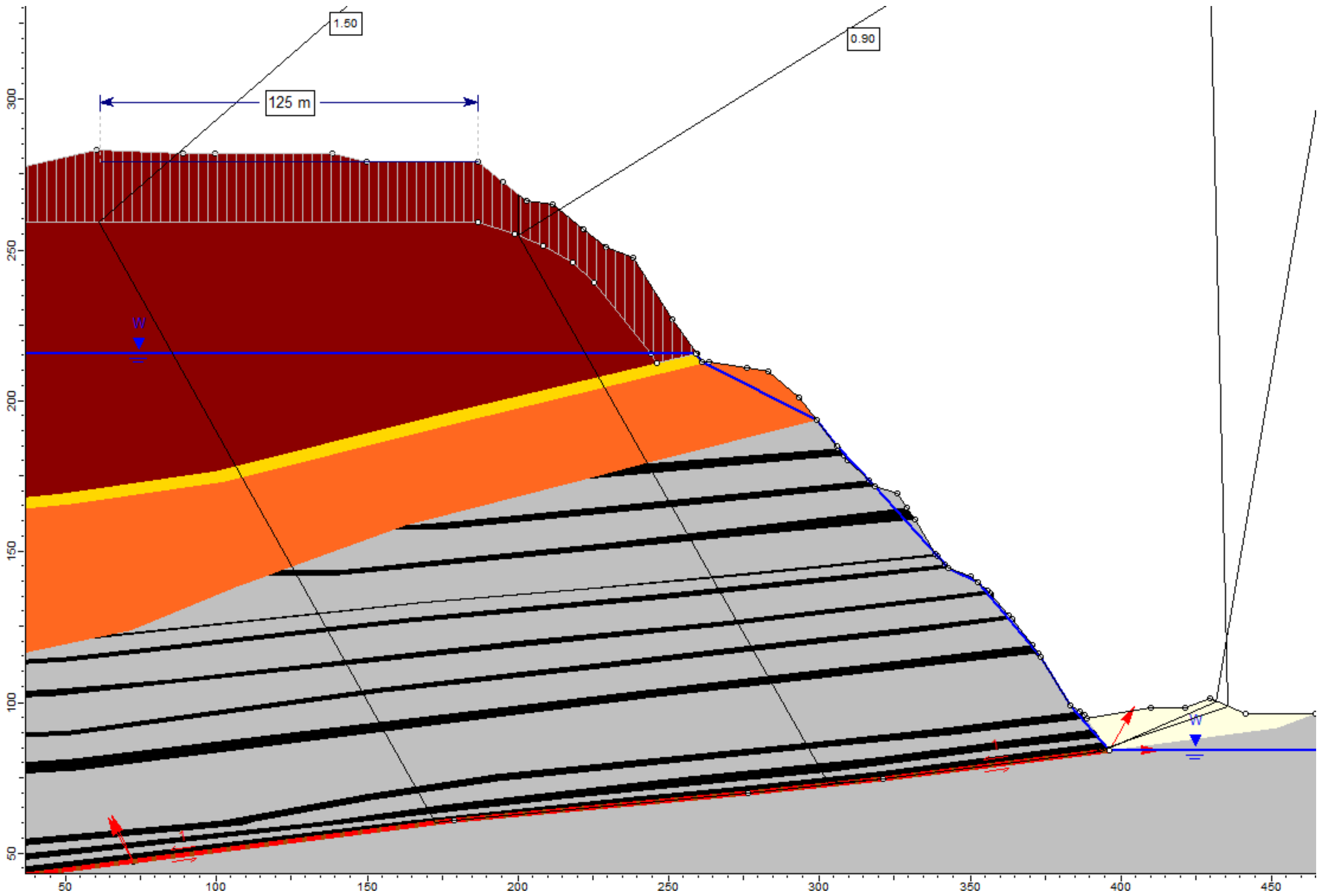
Section 2 –Lake at RL210, Sliding SN2TU Seam



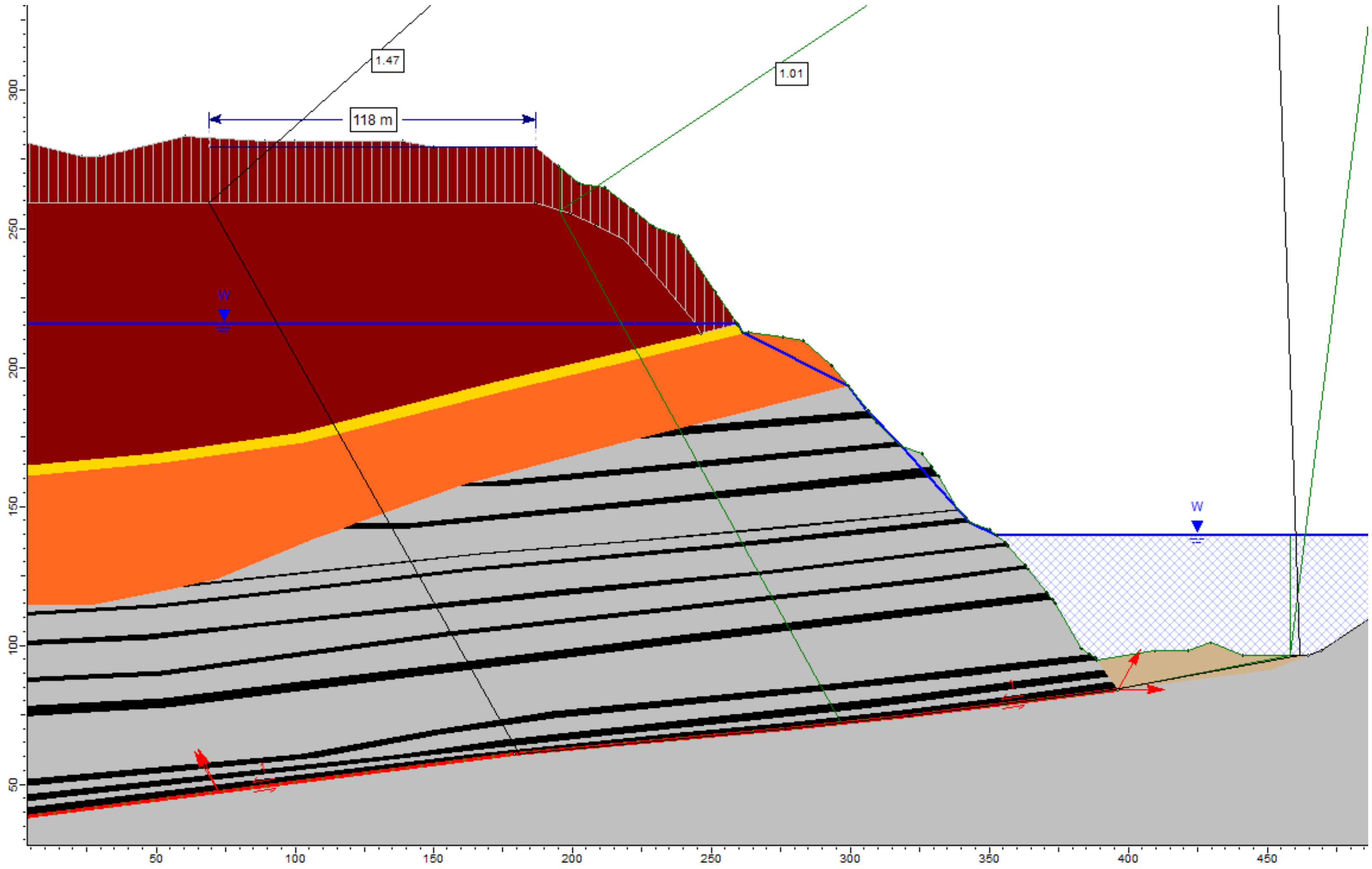
Section 3 –Circular in Tertiary



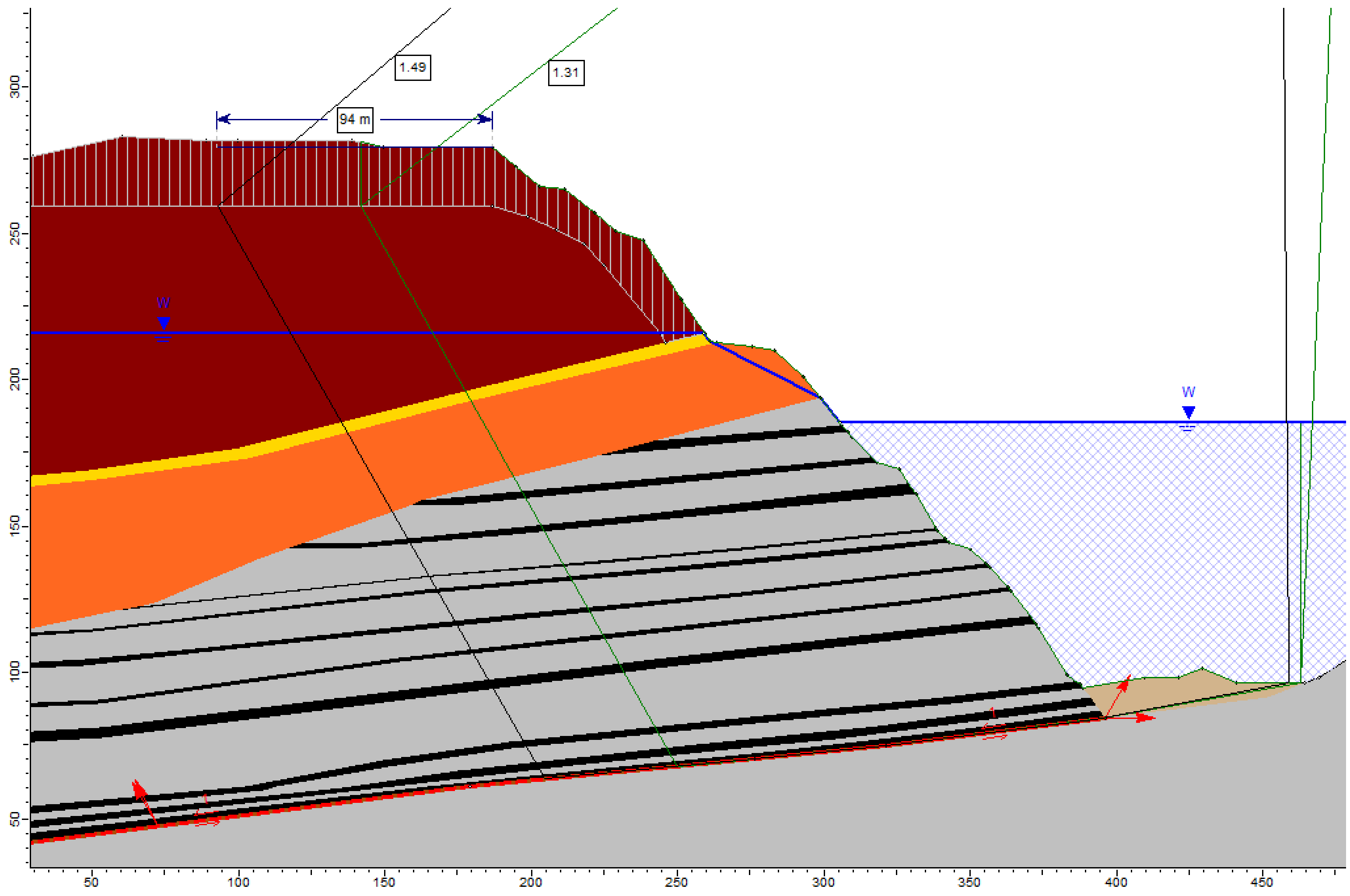
Section 3 –No Lake, Sliding MN10 Seam



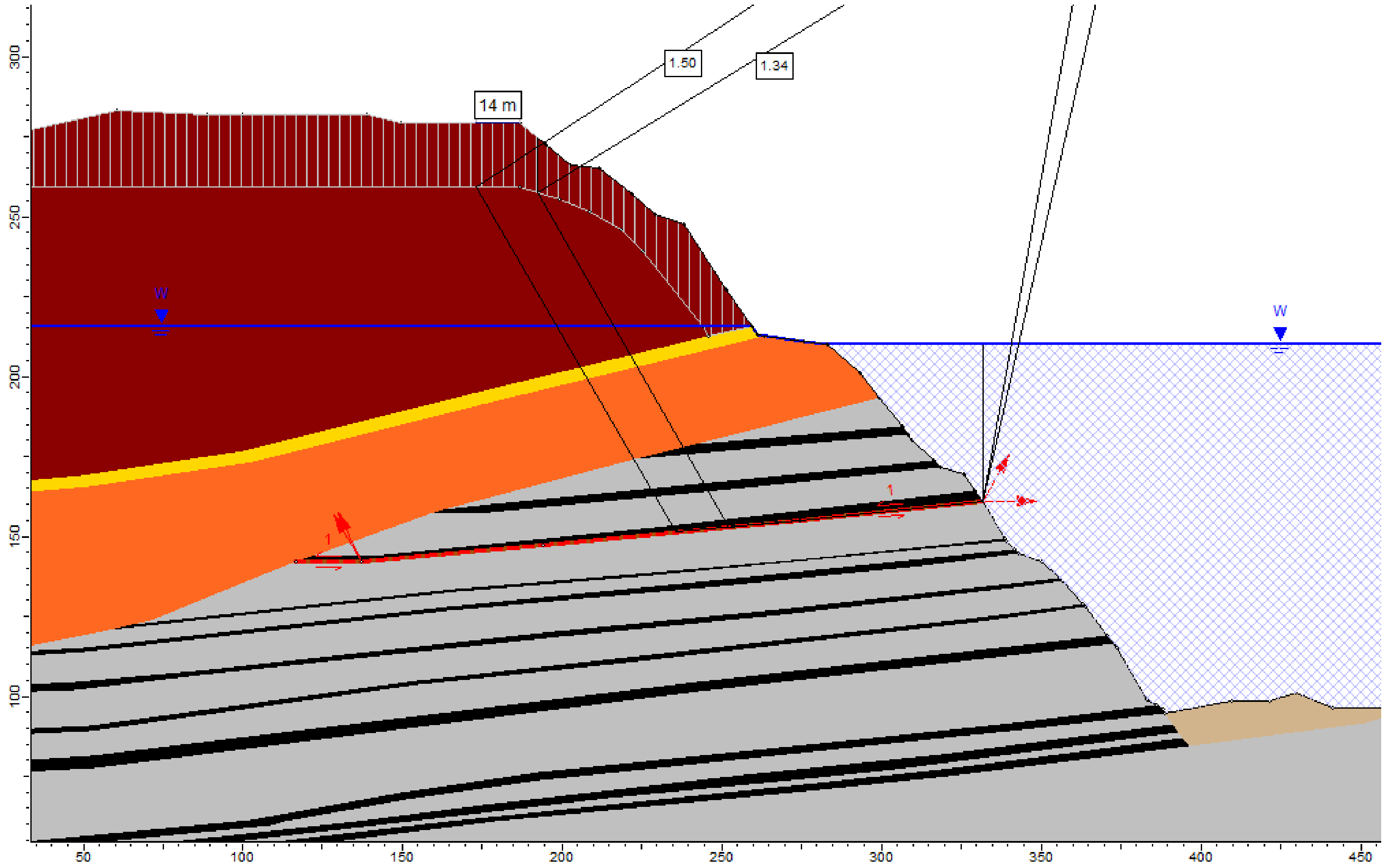
Section 3 –Lake at RL140, Sliding MN10 Seam



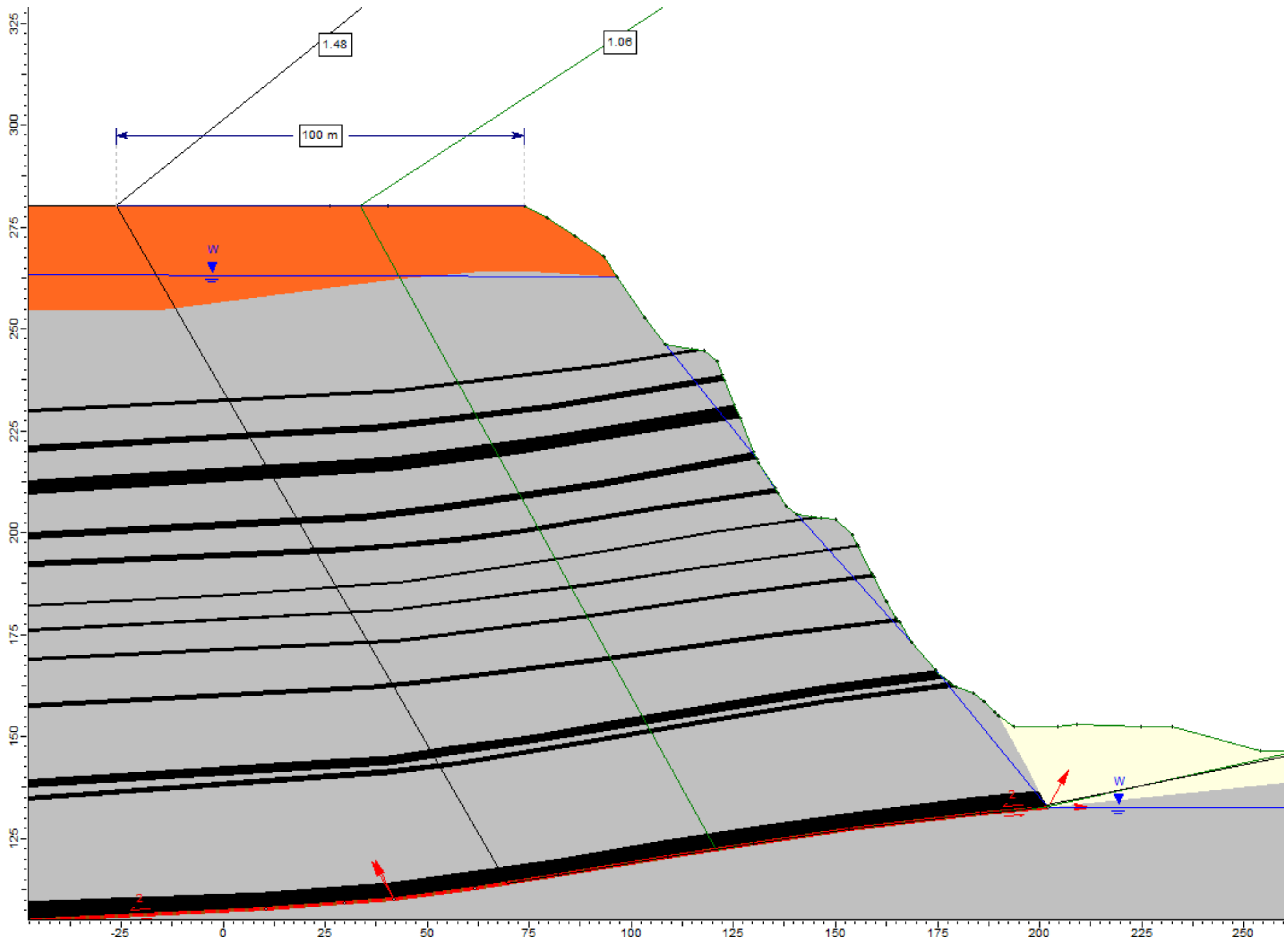
Section 3 –Lake at RL185, Sliding MN10 Seam



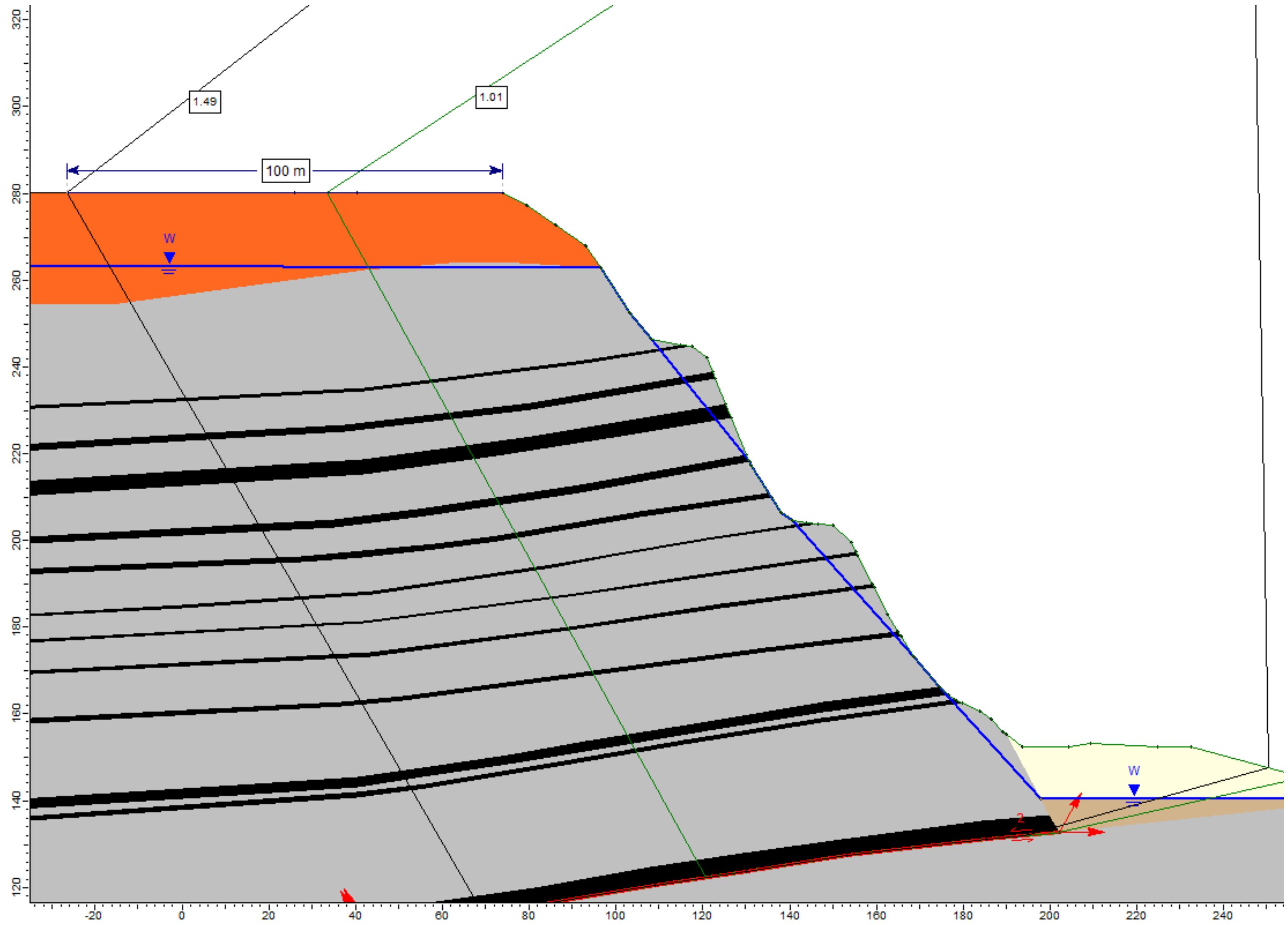
Section 3 –Lake at RL210, Sliding WU Seam



Section 4 –No Lake, Sliding MN10 Seam

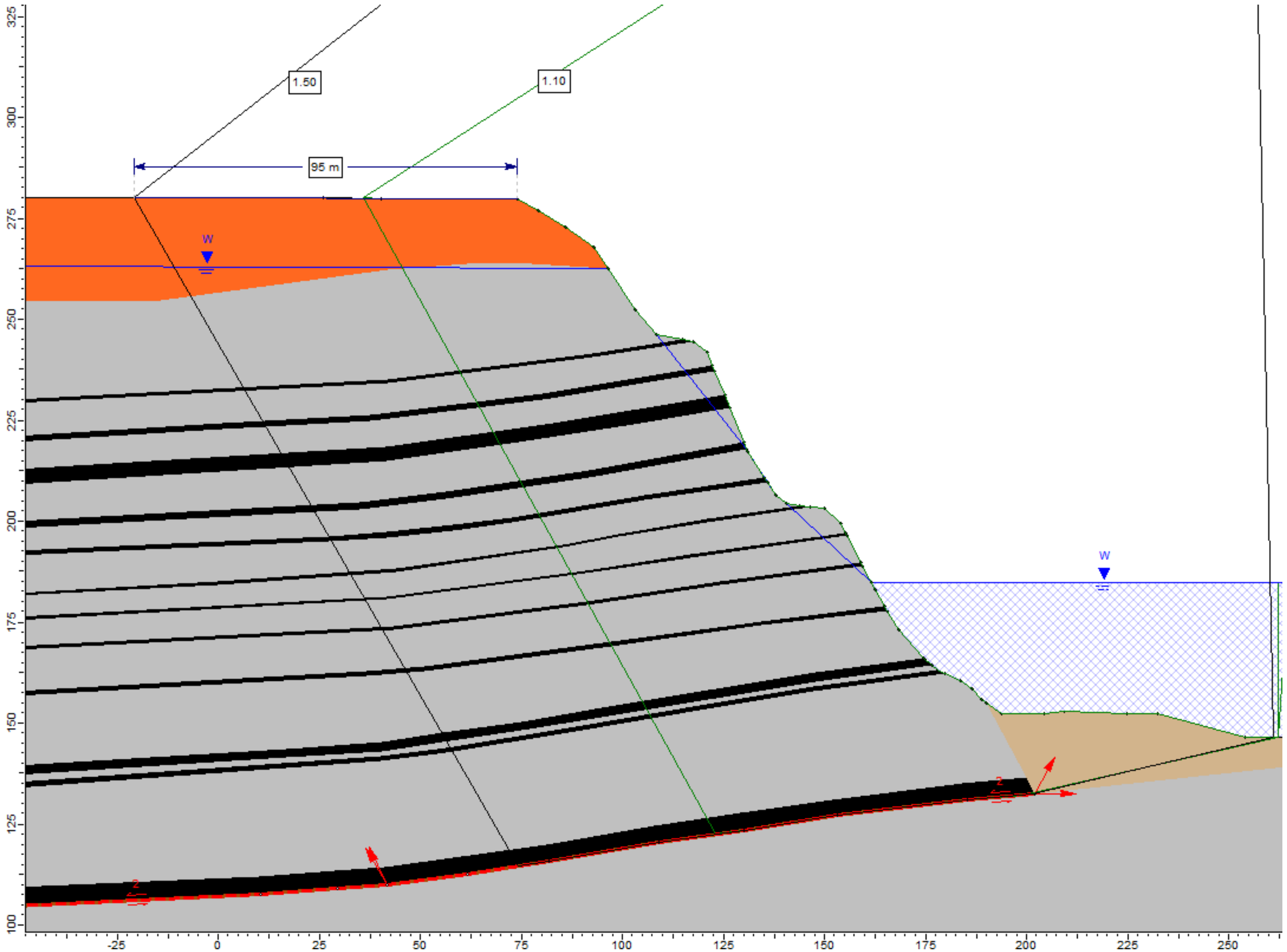


Section 4 –Lake at RL140, Sliding MN10 Seam

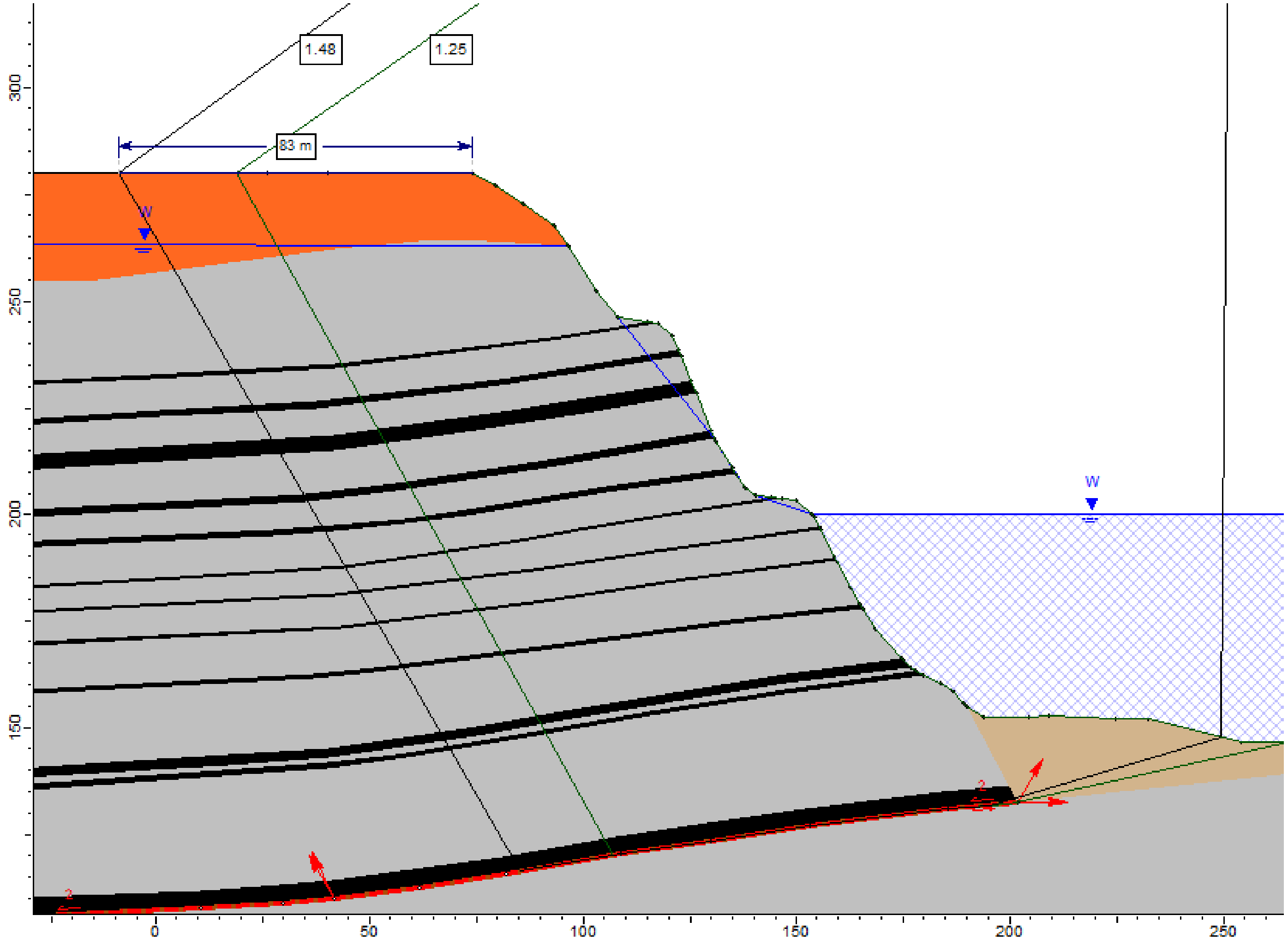


PSM

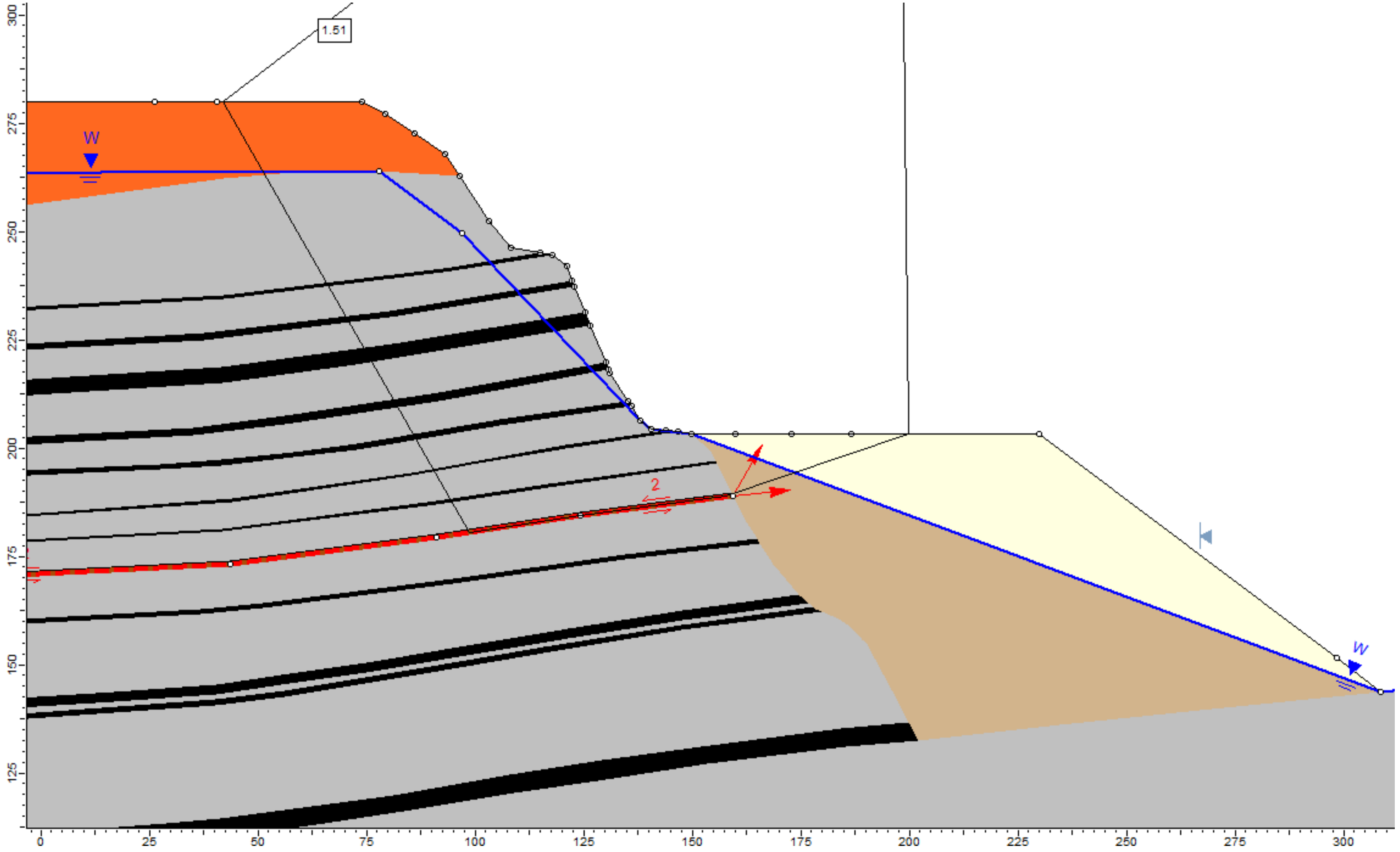
Section 4 –Lake at RL185, Sliding MN10 Seam



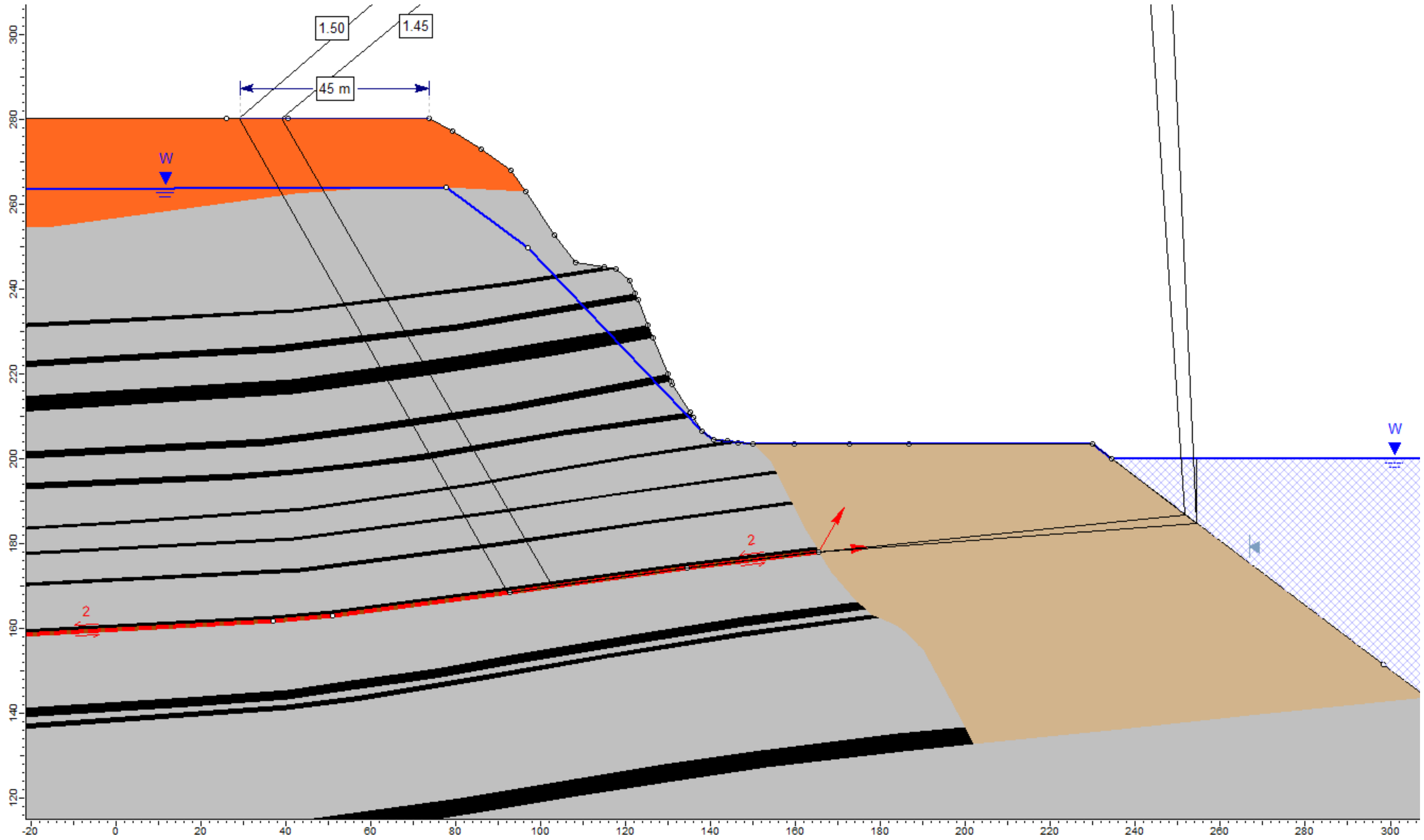
Section 4 –Lake at RL200, Sliding MN10 Seam



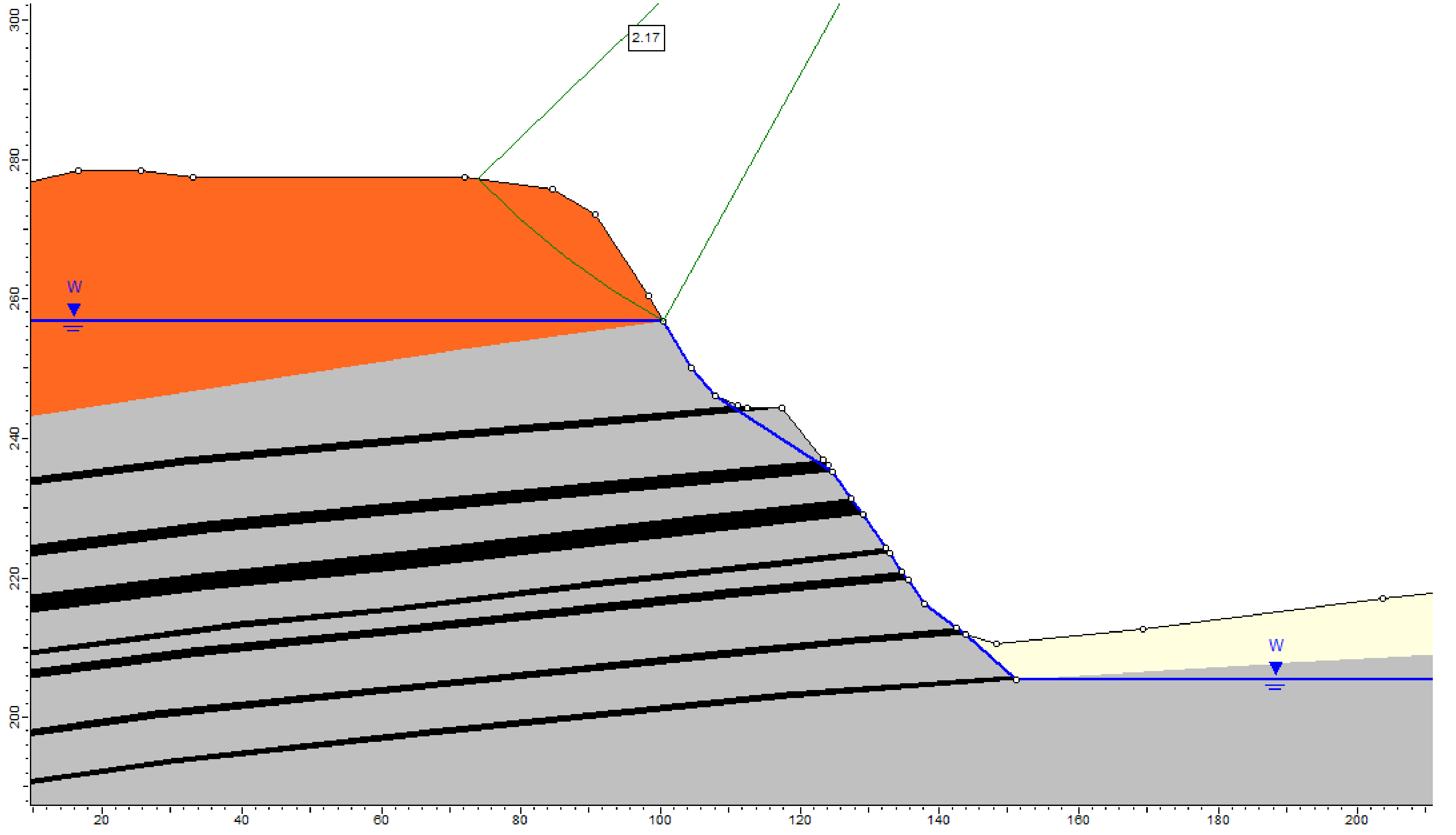
Section 4 –No Lake with Buttress, Sliding MN2 Seam



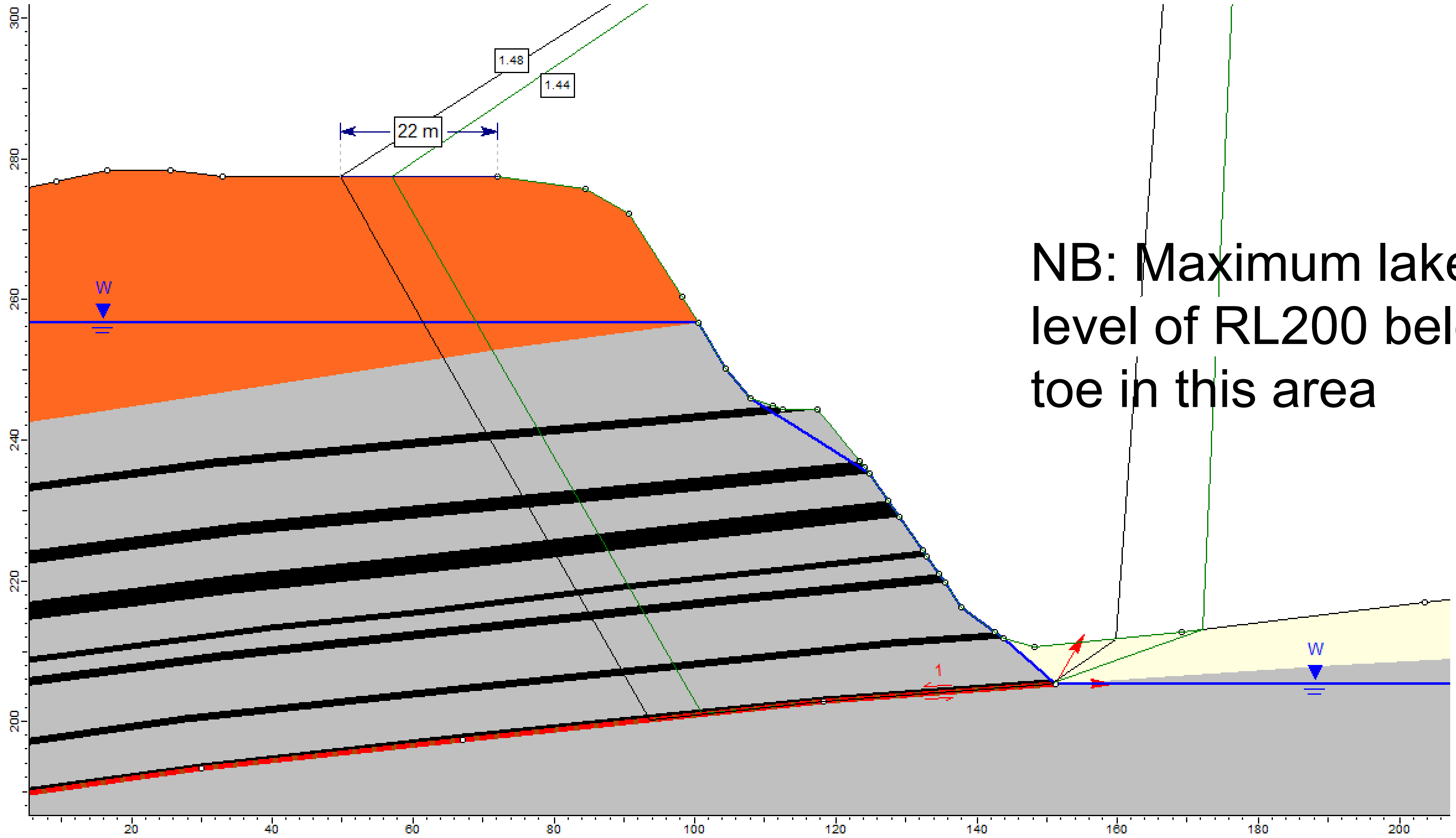
Section 4 –Lake at RL200 with Buttress, Sliding MN31 Seam



Section 5 –Circular in Weathered



Section 5 –No Lake, Sliding WI Seam



NB: Maximum lake level of RL200 below toe in this area