MINE LAND REHABILITATION AUTHORITY

Hazelwood Rehabilitation Investigation Report

June 2022

Ref: RPT012

Aboriginal Acknowledgement

The Victorian Government proudly acknowledges Victoria's Aboriginal community and their rich culture and pays respect to their Elders past and present and emerging. We acknowledge Aboriginal people as Australia's first peoples and as the Traditional Owners and custodians of the land and water on which we rely. We recognise and value the ongoing contribution of Aboriginal people and communities to Victorian life and how this enriches all Victorians. We embrace the spirit of reconciliation, working towards the equality of outcomes and ensuring an equal voice.

The Victorian Government recognises the Gunaikurnai people who are the Traditional Owners of a large area of Gippsland - the area spanning from Warragul in the west to the Snowy River in the east, and from the Great Dividing Range in the north to the coast in the south - including the Latrobe Valley, where the mines discussed in this investigation are located.

Disclaimer

Executive Summary

Minister for Resources, Jaala Pulford MP, referred to the Mine Land Rehabilitation Authority (the Authority) on 30 September 2021 five matters for investigation related to rehabilitation planning for Hazelwood mine (Mining Licence Number 5004) in the Latrobe Valley, Victoria. The five matters, published in Government Gazette G.39 comprise:

Rehabilitation planning activities

1. *What are the recommended methods for geotechnical assessments of Latrobe Valley coal mine batter stability and the criteria employed to demonstrate stability during water filling. Matters for investigation must include:*
    a) *Standards for assessing failure risk covering both Probability of Failure and Factor of Safety analysis during water filling;*
    b) *Suitable processes for method application, presentation of results, and underpinning assumptions and uncertainties.*
2. *Define a set of reference water fill levels and identify the data, information and knowledge required to manage risks associated with filling to each reference level, including having regard to batter redesign and/or modification works, including controls, that may be necessary to ensure stability risks are minimised as far as possible and support any planning and other approvals that may be required.*

Rehabilitation of declared mine land

3. *Identify the risks to the environment, to members of the public, land, property or infrastructure and the controls/mitigation strategies needed to eliminate or reduce those risks as far as reasonably practicable to safely manage water fill at the declared mine land, including:*
    a) *the sufficiency of the licensee's assessments of the risks to the environment, members of the public, land, property and infrastructure*
    b) *the adequacy of the licensee's proposed controls/mitigation strategies to eliminate or reduce those risks as far as reasonably practicable;*
    c) *risks associated with dewatering the declared mine land and types of relevant controls, if works are later determined to be necessary to manage risks arising from dewatering the declared mine land;*
    d) *recommendations for an adaptive monitoring, assessment and management approach of geotechnical and erosional risks for a rapid and/or episodic water infill.*
4. *Identify any additional steps necessary to ensure alignment between the proposed rehabilitation works within the Hazelwood mine and the Latrobe Valley Regional Rehabilitation Strategy and Declared Mine Rehabilitation Plan requirements from time to time, including potentially through conditions upon approvals, having regard to the principles of sustainable development.*
5. *Identify the risks that may require monitoring, maintenance, treatment or other ongoing land management activities after rehabilitation is complete, the activities required to manage the risks and the projected costs to manage the risks.*

The investigation has been carried out to look at the implications for a water fill option. The information in this report does not infer any decision on water fill for Hazelwood mine. Commitment to approval of a water fill option has not been made by the Victorian government. The mine operator, ENGIE Hazelwood, has referred a rehabilitation proposal for a full pit lake to the Minister for Planning for consideration for an Environmental Effects Statement (EES).

This report describes the findings and recommendations from the investigation of all five matters.

Recommended methods for geotechnical assessments (Matter 1)

Six areas were covered during the investigation of this matter. The areas examined were:

- Ground conditions (Geotechnical Model)
- Failure modes (Hazard and Landform Assessment)
- Design tools and approaches (Stability Analysis)
- Design criteria and acceptance (Residual Risk)
- Design monitoring (Implementation)
- Reporting

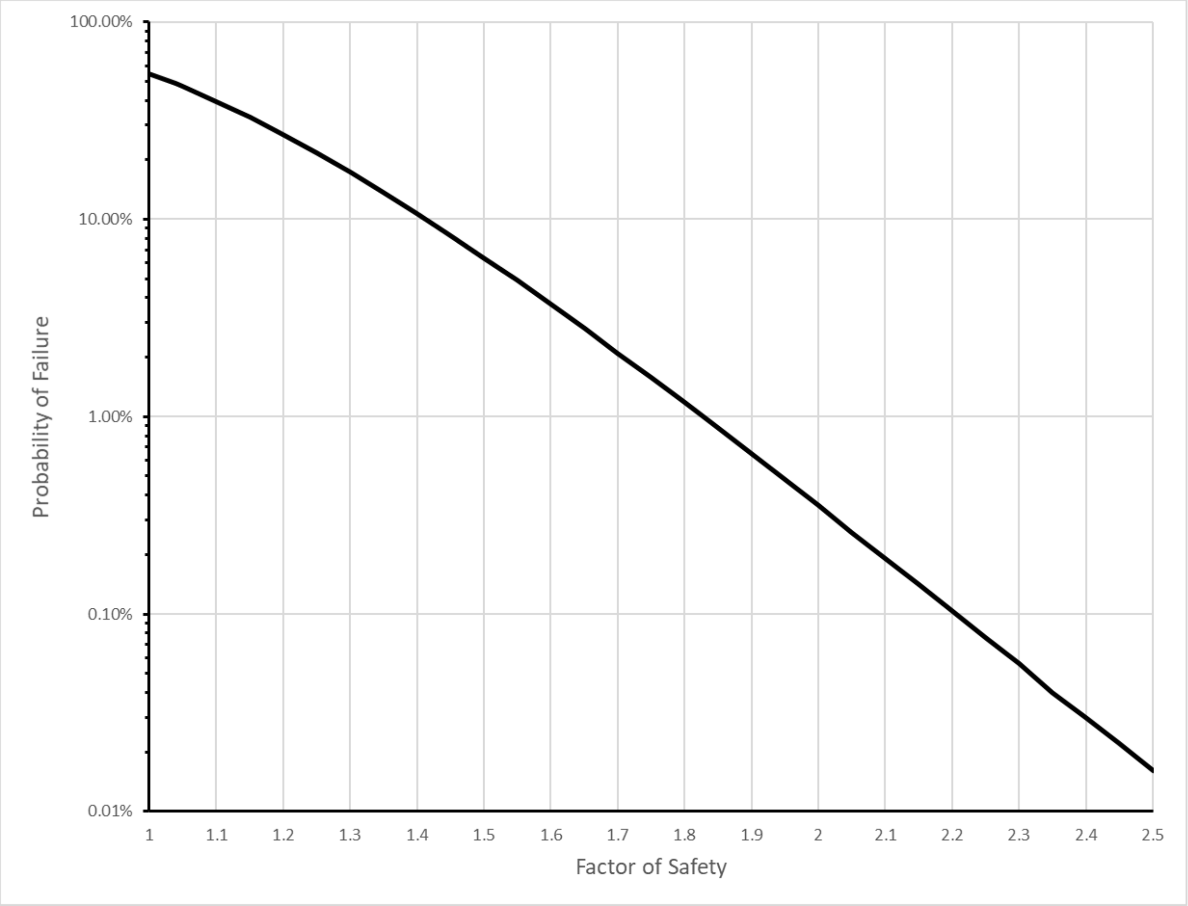
The first five areas link to the workflow required to complete and implement final designs for all mine batters. The sixth area covers the workflow reporting requirements to provide stakeholder confidence in the final designs.

An important investigation step concerned developing an understanding of the relationship between probability of failure and factor of safety values used for batter design. Probability of failure relates to how likely it is that the batter will fail due to a combination of lack of knowledge of environmental conditions, material properties, construction quality and monitoring and management. Factor of safety is the ratio of the maximum expected forces resisting batter failure to the maximum expected forces driving batter failure. The use of factor of safety for design has a long history in geotechnical engineering and is still employed in current codes of practice in many countries. With increasing computational power and better understanding of material properties, reliability methods are gaining popularity. Reliability in geotechnical design can be considered as the inverse of probability of failure: essentially, the lower the probability of failure, the higher the reliability. As the geotechnical engineering profession transitions from factor of safety to reliability assessment as the dominant method of assessing the performance of geotechnical structures, there is value in keeping both methods of assessment and to directly connect the outputs of both methods. Using the data available for the Hazelwood batter analyses completed to date it has been possible to relate probability of failure and factor of safety for the mine. Figure E1 expresses the relationship developed. The relationship is appropriate for the establishment of design criteria using both approaches given the current state of knowledge for Hazelwood mine.

The probability of failure represented in this figure is not an annual probability of failure but a probability of failure over all time under the assumptions that the environmental conditions adopted for design are not exceeded and that material strength properties do not lessen. This definition of probability of failure corresponds to the values usually calculated by the current geotechnical models under steady state analyses. Annual probabilities of failure would expect to be at least an order of magnitude lower. Annual probability of failure is the likelihood that a batter will fail over a period of one year. The advantage of annual probability of failure is that it can be used to quantify how the likelihood of one or more failures changes for different time periods. Intuitively, failure is less likely over short time periods compared to long time periods. Modelled probability of failure using steady state analyses doesn't allow this relationship to be quantified. Further work is required to relate modelled probability of failure to annual probability of failure.

Probability of failure acceptance guidelines have been proposed in Read and Stacey (2009) for mine batters. Based on a review of the available literature these guidelines represent the best available information for design acceptance at the present time. However, these guidelines are based on probability of failure calculations where no ground controls are imposed. This situation is different to that of Hazelwood mine. Owing to the nature of the Latrobe Valley geological formations, ground controls will be needed during lake filling to maintain stability, and potentially post-completion of filling as well.

Figure E1 Probability of Failure versus Factor of Safety for Hazelwood Mine



While the failure acceptance guidelines in Read and Stacey (2009) are not directly applicable to Hazelwood (and the wider Latrobe Valley), the probability of failure ranges adopted for medium to very long-term serviceable life appear to be appropriate for both mine lake filling and final landform. The Authority notes that while the terms of reference for Matter 1 explicitly reference the period during water filling for a pit lake landform, appropriate fill period failure standards cannot be recommended without also reviewing appropriate long-term, final landform criteria. As such the materials studied and the subsequent recommendations are appropriate for both phases of the rehabilitated landform.

Summary Table E2 proposes probability of failure criteria and corresponding factor of safety values for lake filling and following relinquishment. While these criteria are recommended, they do not consider the individual setting of each mine batter, the practicality of achieving these criteria, or the materiality of risk to receptors. As such, batter-specific acceptance criteria that consider these issues should be developed collaboratively by the mine operator and Victorian government regulator in conjunction with the community.

In reviewing the acceptance criteria both for during-fill and post-fill final rehabilitation, batter risk profiles need to consider not only the consequences of batter failure on sensitive receptors such as the rivers, roadways, urban settlement, and power distribution lines, but also the repairability of the batter and the ability of a land manager to maintain groundwater controls over the long-term. Repairs to a batter are anticipated to be more complex during lake filling.

Table E1: Steady State Calculated PoF/FoS design acceptance guidelines (adapted from the failure acceptance guidelines in Read and Stacey, 2009)

PoF (%)	FoS	Serviceable Life	Public Liability	Monitoring	Groundwater Management
<5	**>1.55**	Medium term, During Filling, Low risk batters	No public access	Continuous monitoring	Robust groundwater controls maintained
<1.5	**>1.75**	Medium term, During Filling, High risk batters	No public access	Continuous monitoring	Robust groundwater controls maintained
<0.5	**>2.00**	Long-term, Post Filling, All batters	Public access allowed	Regular monitoring	Groundwater controls maintained
<0.5	**>2.00**	Long-term, Post Filling, All batters	Full public access	Regular monitoring	No groundwater controls

Note: PoF is model probability of failure and not annual probability of failure. While rows 3 and 4 of this table are applicable to long term final landform designs, preference should be to seek no groundwater controls for the final landform, unless this is impractical. FoS design acceptance criteria are applicable when deterministic design calculations are performed. PoF design acceptance criteria are applicable when probabilistic design calculations are performed. There is no requirement to meet both criteria!

Modelling approaches adopted by ENGIE Hazelwood for batter analysis are appropriate and represent current leading practice. It is recognised that modelling tools and practices are continually evolving and that this should be encouraged, subject to the requirement to demonstrate the adequacy and robustness of any new approaches prior to their implementation. Few issues are identified with the batter design workflow adopted by ENGIE Hazelwood, but suggestions are made for improvements to the reporting of batter designs to improve confidence and facilitate acceptance of the results. One observation from the investigation is that confidence in batter design is as much about what is missing from the design reporting as it is about what is presented. In this regard a series of recommendations are made to explicitly cover the basis for omitting design calculations and the assessment of risks. These recommendations address the spectrum of batter design as follows:

1. Probability of failure and factor of safety design criteria should be agreed by relevant stakeholders, particularly if deviations from the suggested values in Table E2 are proposed for individual batter designs.
2. Traceability from field data to processed input data for the geotechnical model for each batter is required.
3. Probability models for all input variables for design calculations should be explicitly stated.
4. All failure modes should be fully assessed and reported before being included or excluded from design considerations.
5. Separation of the workflow and investigations for the different failure modes is required to improve readability.
6. Consequences of batter failure should be explored fully and must cover the impacts of repairability, future land use and sensitive receptors, not just possible magnitude of movements.
7. Minor ground movements identified as likely during batter design and applicable to ground maintenance should be reported.
8. Where batter design is dependent on adequate ground controls these should be explicitly described to show that unforeseen risks can be adequately managed during lake filling.
9. Residual risks should be explicitly defined and agreed with stakeholders prior to completion of the design.
10. Appropriate peer review of all parts of the batter stability assessment and design should accompany the final report.

Defined reference water fill levels (Matter 2)

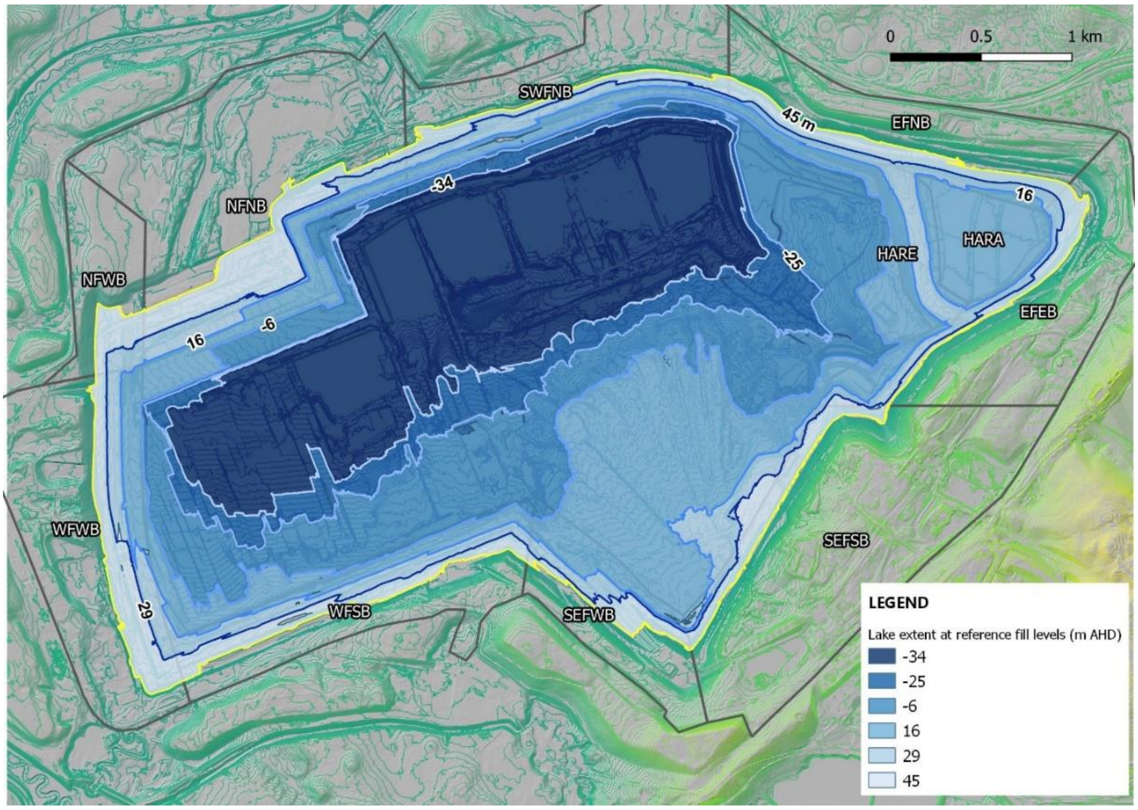
Reference water fill levels are lake water levels at which all geotechnical information generated during filling should be reanalysed to ensure that the final pit design will be safe, stable and sustainable. They are also levels when decisions about future fill can be made. They may become final lake water levels if insufficient water is available to complete rehabilitation of the mine void with a full pit lake. The consideration of reference levels as possible stopping levels assumes that a manufactured water source is not accessible for mine rehabilitation and that only local surface and groundwater sources are available for use for creation of a pit lake. The uncertainty around the long-term availability of local surface water sources for mine rehabilitation means that there may be a requirement to stop filling at a future point in time before a full lake has been achieved. The selection of reference levels is one pathway to defining appropriate stopping points. Five lake water levels have been identified as reference levels. These levels were defined based on three criteria – the potential to stop filling and the implications for long term water balance; the potential to complete rehabilitation at the reference level, and the frequency of reanalysis of new data collected during lake filling applicable to the reassessment of the mine design.

The five defined levels are (see also Figure E2):

-34 metres above Australian height datum (m AHD): 7% full (41.9 gigalitres/GL). Lower benches of South-west Field Northern Batters/East Field Northern Batters (SWFNB/EFNB) submerged. Estimated lower limit for hydrological equilibrium.

-25 m AHD: 12% full (73.2 GL). Estimated upper limit for hydrological equilibrium.
-6 m AHD: 29% full (174 GL). Encroachment of toe of HARE and West-Field Western Batters (WFWB). Exposed coal of the mine floor effectively submerged.
+16 m AHD: 57% full (339 GL). Estimated lower limit for hydrogeological equilibrium. Lake level ~2m below crest of HARE. Lower benches of WFWB, West Field Southern Batters (WFSB) and South-west Field Southern Batters (SWFSB) submerged.
+29 m AHD: 77% full (463 GL). Estimated upper limit for hydrogeological equilibrium. Batters/benches around mine effectively submerged, HARA submerged.

Figure E2 Selected reference levels (mAHD) and full pit-lake shoreline (yellow) at Hazelwood. Geotechnical domains labelled (solid grey). +45mRL is the water level for the full pit option



For the purposes of this investigation, hydrological equilibrium is the lake level where water inputs (rainfall, runoff and horizontal bore drainage) are equal to evaporative losses. Groundwater extracted from sub-mine aquifers is not pumped into the pit. Hydrogeological equilibrium is the lake level where water inputs, including extracted groundwater equal evaporative losses. This level is higher than hydrological equilibrium. It is expected that only one of the lower levels (-34 m AHD and -25 m AHD) will be adopted as a reference level after additional hydrological assessment. The most likely level for adoption is the higher level of -25 m AHD.

ENGIE Hazelwood maintains a network of monitoring bores and horizontal bores to control groundwater behind the batters and to manage batter stability. As the lake level rises the current network will become progressively submerged (Table E2) and will require regular review and revision to maintain adequate groundwater controls. It will be necessary for the current Ground Control Management Plan (GCMP) to be updated to reflect lake filling and to define how reviews and revisions to the network of monitoring and horizontal bores will be undertaken to ensure that ground controls are always appropriate.

Table E2 Impacts of lake levels on the current stability monitoring and groundwater drainage bores

Reference level (mAHD)	Stability Bores submerged (100 total)	Drainage Bores submerged (338 total)
-34	12	109
-25	19	139
-6	24	216
16	36	293
29	46	320

Important considerations for each reference level are (1) the timing and practicality of the final earthworks that might be required should the reference level become a final lake level (i.e. a stopping level) and (2) the requirements for revisions to the groundwater monitoring and drainage network during filling.

The timing of any decision to stop filling will impact the scale and form of the earthworks required. It may also impact the long-term groundwater controls that will be needed to control groundwater gradients behind the batters.

There are essentially two possible decision time periods for each reference level. The first decision period is during the filling stage to the reference level immediately below the proposed stopping level. The second decision period is during the filling stage to the proposed stopping level. The difference between these two decision periods lies in the different opportunities to undertake major earthworks below the stopping level. For both decision periods, the proposal to adopt a new final stopping level is only made once all data on future water availability are analysed and the requirement to stop filling is determined by the mine operator in consultation with the government. If the decision to continue filling is made, the stopping level remains the original approved final lake level.

Invoking a decision to stop filling below the original approved final lake level ultimately relies on water availability predictions that, due to the inherent level of uncertainty, may prove to be unfounded. Given this uncertainty, the decision criteria for selecting a revised stopping level need to be agreed between the mine operators, regulators, and water managers from the outset of the filling process to avoid conflicts of opinion. Stopping early will involve additional capital and operational costs. It is also likely to lead to greater residual risks of uncontrolled ground movements in the long term.

Studies to support lake filling and the adoption of the reference levels are required including:

- determination of the most likely long-term hydrological equilibrium and long-term hydrogeological equilibrium levels for the lake.

- assessment of long-term changes to water quality at the different stopping levels and the strategies that might be adopted to control parameters such as salinity and nutrient levels within acceptable ranges.
- geotechnical designs required to minimise long term monitoring frequencies and maintenance for the northern batters for a lowered lake form.
- assessment of the trade-offs between batter access, erosion control, ecological connectivity, earthworks and surface and groundwater controls to meet the long-term requirements of safe, stable, and sustainable for final batter design.

Recommendations are made covering review of trigger, action, response plans covering groundwater controls to be consistent with recommended design acceptance criteria defined under matter 1, as well as improved data collection including meteorology and bathymetry.

Re-calibration of geotechnical, hydrogeological and hydrological models is recommended when each reference level is reached. Outputs from the models must then be used to update predictions of environmental conditions including groundwater rebound, lake filling rates, ground movements, and geotechnical risks for the remaining fill period. If necessary updated rehabilitation designs and further earthworks may be required.

Updated risk assessments as part of the ongoing ground control management plans are also suggested to address the greater difficulties of repair during lake filling and lower community confidence in the rehabilitation approach if a batter fails.

Rehabilitation risks (Matter 3)

Similar to active mining, damage to receptors beyond the pit crest may be realised during the period of water fill from risks including fires, dusts, floods and ground movements. Water body contamination might occur from leaching from the ash landfills within the licence area, but this is not dependent on the rehabilitation option determined for the mine and is controlled by the Environment Protection Authority.

Fire risks during water fill arise from the potential ignition of the remaining exposed coal above the lake water level. The range of ignition events that can arise during rehabilitation are similar to those for an active mine, including self-ignition, lightning, bushfires, arson, hot working, and hot vehicle exhausts. The likelihood of ignition events is lower during rehabilitation due to the smaller exposed coal area and the reduced site activity levels. Access to exposed coal batters will change given the presence of the lake and may make access for fire suppression more difficult in parts of the mine. The lack of access during lake filling is offset partly by access to water for fire suppression.

External risks arising from a fire are identified by the mine's Fire Risk Management Plan and cover:

- Ash and smoke pollution
- Damage to critical power supply Infrastructure
- Health effects on sensitive receptors

Controls to mitigate risks are identified through fire prevention and fire suppression pathways combined with fire readiness measures, including coordination with fire and emergency management agencies. Fire prevention provides the first line of defence. Fire readiness provides the second line of defence. When a fire is initiated then fire suppression provides the final line of defence. Each line of defence is appropriately described in the Fire Risk Management Plan in conjunction with the Emergency Management Plan.

As the mine fills, relocation of the fire service system is anticipated. Hydraulic assessment of the removal of pipework during filling has been analysed, including instatement of new pipework to ensure integrity of the fire service system.

It is recommended that ENGIE Hazelwood review access arrangements for fire suppression as the lake level rises. It is also recommended that mine floor spray systems remain active to manage dusts and limit fire risks to the batters only.

Dust suppression is managed by the operations of the fire spray systems, vegetation capping of all exposed ground surfaces and mulching and eventual capping of ash landfills. As such, few problems are anticipated from fugitive dusts.

Flood risks are identified by ENGIE Hazelwood from mine infrastructure outside of the mine void. No flood risks are associated with mine water fill. Flood risks from mine infrastructure can be appropriately alleviated by diversion of excess water to the mine. If infrastructure for flood water diversion can be constructed, this option for flood control would be appropriate during the period of mine water fill.

Batter collapse presents significant risks to the external environment and is managed through batter design and ground controls. External risks may include diversion of surface waters into the mine, closure of roads, building and electricity supply network damage. Appropriate design criteria, receptor management and ground controls are considered under matters 1 and 2 of this report.

Although not requested under the current investigation, the impacts to the external water environment for a full pit lake connected to the Morwell River do need to be considered. Such impacts include changes to the flow regime in the river and its downstream wetlands as well as the possible changes to the ecological functioning of rivers and wetlands. Other issues include the eventual rebound of the ground surface following cessation of aquifer depressurisation. While rebound cannot be avoided, monitoring and quantification of impacts on the surrounding sensitive receptors must be carried out and appropriate arrangements for remedial measures put in place. While the timeline for achieving a full pit lake and cessation of aquifer pumping is long, there is a need for the impacts of the full pit lake to be examined and appropriate mitigations and remedial measures established during the early stages of lake filling.

Dewatering of the pit lake after commencement of filling involves a range of challenges both for the disposal of the mine water to the river system and the management of groundwater pressures in the coal behind the batters. It is expected that the lowering of the lake level can only happen slowly due to constraints on discharges and batter failure risks. A robust groundwater monitoring system will be essential to minimise batter failure risks. At this stage it is not clear whether the in situ horizontal drainage network will perform adequately. Work may be needed to define methods for batter depressurisation during water level reduction. If new horizontal boreholes are needed, the design and installation of these will not be as straightforward as it would be for lake filling. Preference should be to avoid dewatering the lake once rehabilitation is underway.

Adjustments to the GCMP are required to support lake filling. These are identified under matter 2 of this investigation. It is considered that the adjusted controls will be appropriate for lake filling under all water fill conditions.

Hazelwood's rehabilitation planning (Matter 4)

The requirement to prepare an EES for Hazelwood mine presents both a challenge and an opportunity. The challenge is to ensure that the outcome of the EES process is a rehabilitation pathway that is practical and deliverable. The outcome needs to recognise the trade-offs between transitioning the mine license area to future land use and the possible environmental effects on the broader region. The opportunity is the widening of community engagement with the mine rehabilitation process and, hopefully, broad acceptance of the rehabilitation pathway.

A key step is to harmonise the interactions between the EES process, the Latrobe Valley Regional Rehabilitation Strategy (LVRRS) and the Declared Mine Rehabilitation Plans (DMRPs). While the present concern is for the harmonisation of these processes for Hazelwood mine, the harmonisation needs to also address the interactions applicable to all three declared mines. The timing of these elements represents the key impediment to achieving consistency across the different approvals processes. The current LVRRS provides the principles and fills some of the key knowledge gaps but does not define the direction for rehabilitation of the mines. The revision of the LVRRS in 2023 needs to define the direction spanning the vision for mine land, the expectations for rehabilitation and the identification of the external resources required for rehabilitation. The EES process for each mine needs to be consistent with the LVRRS. The DMRP for each mine needs to be consistent with the LVRRS and the outcome of each EES. Current timing for delivery of the Hazelwood mine EES and the publication of the revision of the LVRRS suggests that there may be a mismatch that could impact the delivery of the EES. Understanding the interactions and prospective timelines and making appropriate adjustments either in terms of information flows and or submission dates would be beneficial.

A second key step is to enhance community engagement beyond information provided to the community to inclusion of the community in the decision process. Community engagement needs to expand well beyond the EES process and include significant contributions from the mine operators, the regulators, and key stakeholders including DELWP and the EPA. Coherence in the vision for the future development of coal mine land among all stakeholders should improve community confidence in the overall process.

Post rehabilitation risk management (Matter 5)

Investigation of the risks and costs after rehabilitation is complete is dependent on successful implementation of the recommendations arising from the first four matters and on the final landform that is achieved. It is difficult to bound the outputs for this matter and to provide effective information that has practical application. At this stage in the development of the rehabilitation approvals for Hazelwood mine, the preparation of outputs by the MLRA required for this matter are probably premature. Preference is for the MLRA to defer the development of the information requested for this matter until after the completion of the EES for Hazelwood. The main reason for this is to reduce the range of possible final rehabilitation landform options to an acceptable degree. Reducing the range of options will permit meaningful maintenance and monitoring plans to be devised and for costings for the implementation of these plans to be developed. It is likely that the Hazelwood EES will provide much of this information as this will be needed for planning approvals and for the preparation of the Hazelwood Declared Mine Rehabilitation Plan.

Summary of recommendations/suggestions

The table below lists the recommendations arising from the Investigation for each of the five matters. Some recommendations are the same for different matters due to the overlaps that exist between the different matters.

It is recognised that many of these recommendations/suggestions may already be in-hand.

The implementation of the recommendations/suggestions will depend on the acceptance of the concepts underpinning each of the matters investigated.

Recommendation
Geotechnical Assessment (Matter 1)
1. Design FoS/PoF should meet the following requirements: ○ *The long term design PoF should normally be <0.5%* ○ *Design PoF values during lake filling should normally not exceed 5% to account for issues of repairability and slow fill times.* ○ *Design PoF values for batters presenting high consequence failure risks should not normally exceed 1.5% at any fill level.* ○ *Variations to PoF design criteria should be agreed by relevant stakeholders, particularly increases from the suggested values are required.* ○ *FoS approaches must be adequately justified in terms of the required PoF design acceptance criteria.* ○ *Consistency of use of FoS and PoF criteria in assessing batter stability is important. Preference should be given to adopting one measure of reliability (either FoS or PoF) for batter design, rather than mixing measures.* ○ *If mixed PoF/FoS approaches to design are to be adopted, application consistency must be demonstrated.*
2. Third party peer review should be undertaken for all batter designs and include selective reanalysis of stability calculations to confirm both the adequacy of the data, the interpretation of the probability models and the capability of the designer.
3. Consequences of batter failure should address aspects of repairability, long-term land use impacts, and sensitive receptor impacts. Risk assessments should be employed to highlight failure consequences for each batter. Appropriate measures of consequence should be used to focus effort on assuring high levels of stability for those batters with the highest consequences.
4. Effort should be made to identify critical water levels for batter design that warrant greater attention for ground control management.

Recommendation
5. *Ground controls required during filling and over the long term should be described in detail to demonstrate that adequate groundwater gradient and pressure controls can be maintained throughout the rehabilitation period.*
6. *Batter design reports should ensure:* ○ *All failure modes have been adequately assessed before inclusion or exclusion from consideration for design.* ○ *Investigations for the different failure modes are separate (for readability)* ○ *Processed data can be traced from the raw data* ○ *Probability models for all input variables for design calculations should be explicitly stated.* ○ *Ground controls implied for application of a design are clearly stated.* ○ *Residual risks are explicitly acknowledged and summarised*
Reference Water Levels (Matter 2)
7. *The triggers, actions, responses and plans (TARPs) surrounding the loss of effectiveness of the horizontal bore network due to submergence should be fully reviewed and updated in the rehabilitation GCMP.* a. *The trigger levels should be consistent with the ranges of probability of failure adopted for batter stability design.* b. *The replacement plan for horizontal bores, including timelines for replacement, should be fully described.* c. *The replacement plan for new stability bore installations should be addressed with a recommendation that new bores are installed for each lake level transition between reference levels prior to the transition.*
8. *Bathymetric surveys of the submerged portion of the batters after reaching each reference level should be undertaken to establish whether slope profile changes below the water line have taken place due to mass movements such as sliding and toppling.*
9. *If the concept of multiple reference levels and the basis for these levels is accepted, then additional studies should be undertaken to determine the expected long-term hydrological equilibrium and long-term hydrogeological equilibrium levels for the lake.* a. *An assessment should be undertaken of the long-term changes to water quality at both equilibria and the strategies that might be adopted to control salinity and nutrient levels within acceptable ranges.*
10. *Further studies are recommended on the geotechnical designs required to minimise long-term monitoring frequencies and maintenance for the northern batters (SWFNB and EFNB) for a lowered lake form. Of particular interest will be the assessment of the trade-offs between batter access, erosion control, ecological connectivity, earthworks and surface and groundwater controls to meet the long-term requirements of safe, stable and sustainable.*

Recommendation
11. *A review of the adequacy of the hydrological data collection network is warranted to ensure that the information gathered is suitable and complete.*
Rehabilitation Risks (Matter 3)
Assessments and controls
12. *ENGIE to update their rehabilitation objectives to reflect current Victorian environmental legislation and standards.*
13. *There is a need for the impacts of the lake filling to be examined and appropriate mitigations and remedial measures established during the early stages of lake filling and included in the GCMP.*
14. *Incremental stable movements should not automatically be assumed to have low consequences. It is necessary for incremental, stable, movements to be monitored and mitigated (e.g. sinkhole formation) as part of the GCMP where these might lead to higher risks of less tolerable, unstable, movement.*
15. *In the Risk Management Plan dust is examined as an impact on amenity and not an impact on health. This is potentially too simplistic and should be revisited to examine both health and amenity impacts more fully.*
16. *It is recommended that ENGIE regularly review access arrangements for fire suppression as the lake level rises. It is also recommended that mine floor spray systems remain active to manage dusts and limit fire risks just to the batters.*
17. *As maintenance of coal cover in the zone of water level fluctuation on the coal batters would likely be a significant activity, a recommendation is to undertake a study to assess coal fire risks and erosion risks for this zone in the absence of coal covers and to assess the acceptable maximum height of exposed coal as part of the long-term final design for the rehabilitated mine.*
18. *Rehabilitation is an opportunity to increase and enhance areas of native flora and fauna habitat and this should be explored as part of the rehabilitation design process.*
19. *It is appropriate to monitor water quality of the aquifer discharges from the depressurisation pumps for both the M1 and M2 aquifers on a monthly basis throughout the rehabilitation and closure period.*
Dewatering risks
20. *If dewatering is to be considered then:* *•Studies must be undertaken to assess integrity of submerged horizontal bores during filling* *•Studies must be undertaken to assess groundwater responses behind the batters in both the coal and interseam to support parameterisation of a groundwater model applicable to dewatering.* *•Modelling must be undertaken to assess the required controls for groundwater pressure gradients and dewatering rates*

Recommendation
•*Studies must be undertaken to assess the management of discharges to surface water courses*
21. *To manage dewatering safely: dewatering rates will require modelling coupled with monitoring to both calibrate and validate the model results. Modelling will need to assess the performance of coal dewatering and the depressurisation rates of the interseams. Monitoring will require additional VWPs located in the at-risk batter interseam layers as well as maintenance of the stability monitoring bores measuring the groundwater gradient. Maintenance of the horizontal bores will also be needed. Additional horizontal bores will be required regularly as water levels decline unless the submerged horizontal boreholes during filling can be demonstrated to be operational.*
22. *The MLRA is of the opinion that preference should be to avoid dewatering the lake once rehabilitation is underway.*
Adaptive monitoring, assessment and management
23. *Assessments of the adequacy of the final landform design, covering all aspects of stability and erosion, and the likely reliability of the water supplies for completion of water infill should be completed on an approximately three-to-five-year cycle. Field monitoring and assessment methods should be implemented to allow updating of the geotechnical models and batter designs.*
24. *Criteria are required against which to judge the performance of the rehabilitation and the likely future conditions for the purposes of decision making around the final lake water level. The criteria need to be agreed by all parties to be effective. Field monitoring and assessment methods should be implemented to allow comparison against the agreed criteria.*
25. *New research on land cover vegetation should be regularly reviewed and published outcomes must be considered for updating of the long-term erosion controls on the final batters and for the selection of appropriate land uses for different areas around the mine.*
Hazelwood's rehabilitation planning (Matter 4)
26. *The case for a collective EES that incorporates rehabilitation requirements for all three mines is strong and should be considered before progressing too far with the single mine EES for Hazelwood.*
27. *Connecting the Strategy explicitly with regional planning should be given high priority for the update to the 2023 Strategy.*
28. *Where the timing of delivery of the LVRRS, the EES and the DMRP for each mine cannot be appropriately connected and where the outputs from each action may require approvals under the other actions, then conditions upon approvals may be required. The nature of the approvals will depend on the specific direction of each action.*

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List of Acronyms

AHD – Australian Height Datum (m AHD – metres above Australian Height Datum)

CoV – Coefficient of Variation

DELWP – Department of Environment, Land, Water and Planning

DMRP – Declared Mine Rehabilitation Plan

EES – Environmental Effects Statement

EFNB – East Field Northern Batters

FoS – Factor of Safety

GCMP – Ground Control Management Plan

GL – Giga-Litre

HARA – Hazelwood Ash Retention Area

HARE – Hazelwood Ash Retention Embankment

LVRRS – Latrobe Valley Regional Rehabilitation Strategy

PoF – Probability of Failure

SEPP – State Environmental Protection Policy

SFNB – South Field Northern Batters

SFSB – South Field Southern Batters

SWFNB – South-West Field Northern Batters

SWFSB – South-West Field Southern Batters

TARP – Trigger Action Response Plan

TRB – Technical Review Board

VWP – Vibrating Wire Piezometer

WFSB – West Field Southern Batters

WFWB – West Field Western Batters

1. Introduction

1.1. Background

The Honorable Jaala Pulford, Minister for Resources, published *Notice of Referral to the Mine Land Rehabilitation Authority* (the Authority) in Victoria Government Gazette No. G39 30 September 2021. Five matters were included in the referral for investigation relating to the rehabilitation of declared mine land (Hazelwood mine) within Mining Licence Number 5004 (MIN5004) held by Hazelwood Power Corporation Pty Ltd.

The five matters related to planning activities as well as the rehabilitation of the declared mine land and cover the following terms of reference:

Rehabilitation planning activities

1. *What are the recommended methods for geotechnical assessments of Latrobe Valley coal mine batter stability and the criteria employed to demonstrate stability during water filling. Matters for investigation must include:*

    a. *Standards for assessing failure risk covering both Probability of Failure and Factor of Safety analysis during water filling;*

    b. *Suitable processes for method application, presentation of results, and underpinning assumptions and uncertainties.*

2. *Define a set of reference water fill levels and identify the data, information and knowledge required to manage risks associated with filling to each reference level, including having regard to batter redesign and/or modification works, including controls, that may be necessary to ensure stability risks are minimised as far as possible and support any planning and other approvals that may be required.*

Rehabilitation of declared mine land

3. *Identify the risks to the environment, to members of the public, land, property or infrastructure and the controls/mitigation strategies needed to eliminate or reduce those risks as far as reasonably practicable to safely manage water fill at the declared mine land, including:*

    a. *the sufficiency of the licensee's assessments of the risks to the environment, members of the public, land, property and infrastructure*

    b. *the adequacy of the licensee's proposed controls/mitigation strategies to eliminate or reduce those risks as far as reasonably practicable;*

    c. *risks associated with dewatering the declared mine land and types of relevant controls, if works are later determined to be necessary to manage risks arising from dewatering the declared mine land;*

    d. *recommendations for an adaptive monitoring, assessment and management approach of geotechnical and erosional risks for a rapid and/or episodic water infill.*

4. *Identify any additional steps necessary to ensure alignment between the proposed rehabilitation works within the Hazelwood mine and the Latrobe Valley Regional*

Rehabilitation Strategy and Declared Mine Rehabilitation Plan requirements from time to time, including potentially through conditions upon approvals, having regard to the principles of sustainable development.

5. *Identify the risks that may require monitoring, maintenance, treatment or other ongoing land management activities after rehabilitation is complete, the activities required to manage the risks and the projected costs to manage the risks.*

The Authority has undertaken its investigation in accordance with the provisions of Part 7a of the Mineral Resources (Sustainable Development) Act 1990.

For the purposes of completing the investigation, Earth Resources Regulation provided copies of documents and information to the Authority covering the rehabilitation plans, work plan variations, declared mine reports and relevant other reports related to Hazelwood mine. Where appropriate, later versions of reports have been provided by ENGIE, the major shareholder of Hazelwood Power Corporation, who are undertaking the rehabilitation planning and implementation activities at Hazelwood mine.

Hazelwood mine and its associated power station ceased operations in 2017. Since this time, ENGIE has received approvals for and undertaken ‘no regrets’ rehabilitation works, which comprises batter shaping, buttressing and surcharging. ENGIE submitted a work plan variation in 2020 for a full pit lake rehabilitation landform, with a final water level of 45 metres above Australian Height Datum (AHD). Rehabilitation plans at Hazelwood mine have since been referred to and accepted by the Minister for Planning for an Environmental Effects Statement (EES), which is currently in the scoping phase. The EES process must be completed prior to finalising the rehabilitation plan for Hazelwood mine.

In the interim, Hazelwood mine’s pit is receiving waters from a range of water sources, including a low-capacity flood flow diversion from the Morwell River as part of Morwell River Diversion repair works required downstream to support the continuing operation of the Yallourn power station and mine, and groundwater pumped from aquifer depressurisation activities required to stabilise Hazelwood mine’s floor.

1.2. Report content and structure

A single report has been prepared covering all five matters as they comprise several inter-connected issues including the current and proposed updates to the planning environment covering Declared Mine Rehabilitation Plans, the Environment Effects Statement Processes, and updates to the Latrobe Valley Regional Rehabilitation Strategy.

Matters 1 to 4 have been investigated according to the terms of reference of the referral.

Matter 5 has not been completed according to the terms of reference. While the risks that may require monitoring, maintenance, treatment or other ongoing land management activities after rehabilitation is complete have been illustrated as part of the evaluation of Matter 5, including an outline of the wide range of activities to manage the risks, costings for carrying out the activities to manage the risks have not been provided. A recommendation has been made to defer the development of this information by the Authority until a clearer definition of the final landform has been prepared by the mine operator and approved by the planning and regulatory authorities. The uncertainties around the selection of the final landform and the design of the final landform are too large and too dependent on decisions arising out of the investigations of matters 1 to 4 to permit meaningful assessment of the details of both the activities required for managing long term risks and the costing of these activities.

The main body of the report is divided into five chapters. Each chapter covers one investigation matter. At the end of each chapter, the key recommendations arising from the investigation are summarised. The executive summary at the front of the report provides a concise overview of the background to the investigation and the major findings from the investigation.

The report is intended to provide guidance to both Earth Resources Regulation and the mine operator ENGIE. Many of the findings are relevant to the other Latrobe Valley declared mines, Yallourn and Loy Yang.

The report has been prepared for general publication. It has been reviewed by the major stakeholders and peer reviewed for factual and conceptual accuracy.

2. Geotechnical Assessments (Matter 1)

2.1. Introduction

This chapter covers the first matter requested for investigation and addresses the following:

> *What are the recommended methods for geotechnical assessments of Latrobe Valley coal mine batter stability and the criteria employed to demonstrate stability during water filling? Matters for investigation must include:*
>
> *a) Standards for assessing failure risk covering both Probability of Failure and Factor of Safety analysis during water filling;*
>
> *b) Suitable processes for method application, presentation of results, and underpinning assumptions and uncertainties.*

There are six problem elements that have been addressed to satisfy the requirements of this component of the investigation. These elements are:

- Ground conditions (Geotechnical Model)
- Failure modes (Hazard and Landform Assessment)
- Design tools and approaches (Stability Analysis)
- Design criteria and acceptance (Residual Risk)
- Design monitoring (Implementation)
- Reporting

The first five elements summarise the process steps presented in Figure 2.1 (adapted from Figure 2.1, Read and Stacey, 2009). This figure details the workflow to complete and implement a final design for any batter around a mine. The sixth element addresses the requirements for reporting to provide confidence in the assessment of the stability of the batters.

A primary focus for the investigation has been on (i) the approaches used to select appropriate design criteria as a function of ground conditions and (ii) the acceptable level of risk during implementation and post completion of the final landform.

Geotechnical design codes of practice (e.g. Eurocode 7 – Geotechnical Design) are increasingly well developed but are not yet harmonised due to the diversity of geotechnical settings, engineering works and site-specific investigation methods. Consequently, the current geotechnical codes are focussed largely on ensuring the adoption of a well-defined underpinning philosophy for geotechnical design, supported by a wide-ranging exploration of the concepts, tools and techniques for a broad range of typical engineering works.

Codes such as Eurocode 7 adopt ultimate limit states related to the strength of both the structural and ground materials involved in the design problem to meet the inequality that the driving actions (F) must be less than or equal to the resistances (R) opposing the driving actions (Equation 1). Reliability is introduced by applying factors (γ_F and γ_R) that modify the magnitude of the actions and the resistances so that the actual forces and resistances should be, respectively, less than and greater than the design values. The magnitudes of the factors, which are always greater than one, relate to a lack of knowledge of the material properties and driving forces.

$$\gamma_F F \leq {}^{R}/_{\gamma_R} \qquad \textbf{\textit{Eq'n 1}}$$

Equation 2 is a restatement of Equation 1. The left-hand side of the inequality is referred to as the Factor of Safety (FoS).

$$\left[{}^{R}/_{F}\right] \geq \gamma_R \gamma_F \qquad \textbf{\textit{Eq'n 2}}$$

Eurocode 7 adopts a deterministic approach to solving for the inequality expressed by Equation 1 and employs formalised rules for setting the values of the factors for particular problems. Eurocode's rules and approaches allow for variations between countries. Deterministic approaches apply best estimates of properties and forces for design based on the available data.

Probabilistic approaches incorporate the uncertainties in material properties and forces and, in principle, can provide a more complete picture of the reliability of a design than deterministic approaches.

Probabilistic approaches are increasingly being adopted for geotechnical design with the increasing sophistication of software for solving geotechnical problems and the increasing power of computers.

The current investigation has not critiqued the available codes of practice or the available design software. The underpinning philosophies that apply to all problems presented by these codes and the related software are accepted as the best currently available. The investigation has focussed on the specific issues that influence reviewers and regulators confidence in batter stability assessments and designs for the Latrobe Valley mines.

Conventional geotechnical design methods typically include the acquisition of quantitative geotechnical data and the application of quantitative analysis to solve Equation 1. The conventional approaches are limited commonly to limit state analyses and omit time varying properties and processes. For cases where such processes cannot be ignored, higher complexity approaches may be required to resolve ongoing movements and changing geotechnical conditions not covered by conventional analysis and not strictly answerable by solving Equation 1.

The complexity of geotechnical design depends on both the complexity of the problem and the severity of the consequences arising from a failure of the structure. For the case of the Latrobe mine batters both the apparent complexity and the consequences of batter failure are sufficient to warrant design approaches that fall somewhere between conventional geotechnical design methods and more complex approaches.

For the purposes of this investigation, effort has been focussed on improving the understanding and presentation of conventional methods of limit state analysis.

Mining has taken place in the Latrobe Valley for more than a century. During this time a considerable body of geotechnical knowledge has been accumulated covering the geology, hydrogeology, and geomechanical properties of the region. Knowledge has been gained on the ground controls required for mining to be undertaken safely. While this knowledge has grown, unforeseen ground movements have still occurred, and the mine operators have had to remain vigilant. The Victorian Technical Review Board, appointed in 2009 after a major failure at Yallourn, highlighted in their initial assessments seven at-risk batters in addition to observing several failures (TRB, 2015). An eighth at-risk batter was identified subsequently. The observations over the last ten years illustrate the complexity of the Latrobe Valley geotechnical setting and the requirement for caution in making predictions of ground movements close to the mine voids. As the mines reduce both their workforce and equipment base as part of rehabilitation and closure, greater caution is needed. The capacity to rectify issues reduces as the capacity of the organisations is diminished. This can be expected to occur during water filling to form a pit lake. On commencement of lake filling almost all earthworks are likely to have been completed and the availability of the number of heavy earth-moving machinery to deal with unforeseen ground movement events will be fewer. Machinery access to slopes is also likely to be reduced by the presence of the water body. Applying appropriate risk management practices relevant to each stage of mine rehabilitation is important.

ENGIE have undertaken batter stability assessments and designs based largely on the slope design process presented in Figure 2.1 Slope design process using a probability of failure (PoF) assessment methodology for stability analysis. The probability assessments report both PoF and FoS as outputs. As both represent a measure of likelihood of failure, it is necessary to understand the relationship between the two and the degree of consistency between both outputs.

Prior to addressing the six problem elements spanning the slope design process specified at the start of this introduction, a discussion of the relationship between PoF and FoS outputs is provided. This discussion underpins the commentary that follows.

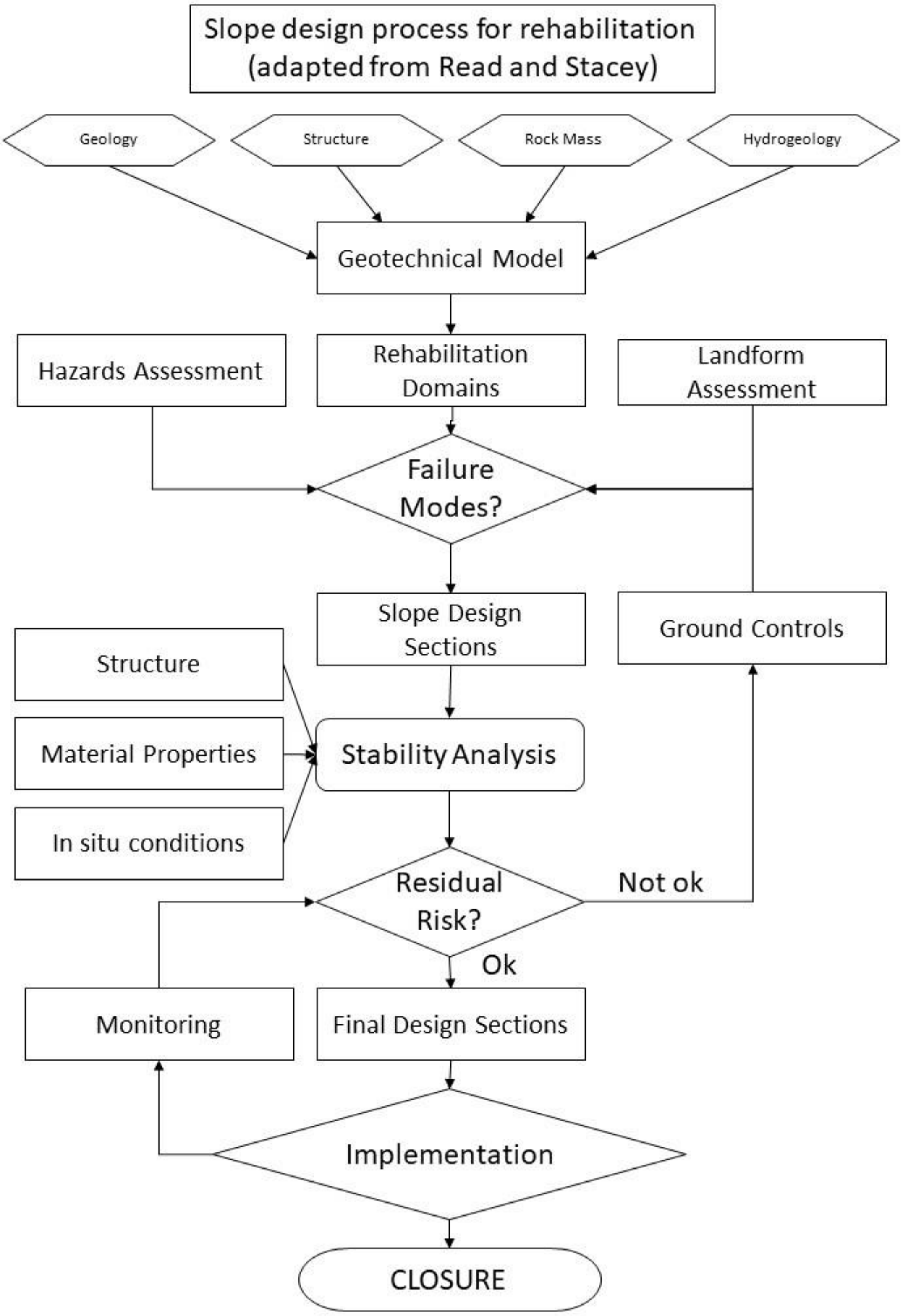

Figure 2.1 Slope design process

2.2. Probability of Failure and Factor of Safety

2.2.1 Basic concepts

In geotechnical engineering, the FoS expresses how much stronger the ground is than the forces applied to the ground. The calculation of an FoS requires the ground geometry, the ground strength and the forces applied to all be defined.

To understand how strong the ground is, it is necessary to know how the ground may break (failure modes). Different ways of breaking may be easier or harder depending on the forces applied. For this reason, FoS are typically related to specific modes of failure.

For a specific mode of failure, the basic equation for FoS is:

$$FoS = \frac{\sum Maximum\ Resisting\ Forces}{\sum Maximum\ Driving\ Forces} \quad \textbf{\textit{Eq'n 3}}$$

In this case an FoS less than 1 means that the ground fails and for an FoS greater than or equal to 1 it is safe; this assumes that everything about the ground is perfectly known. An FoS less than zero cannot arise as both resisting forces and driving forces are always positive.

Of course, not everything is perfectly known. It is standard practice to require a calculated FoS to be greater than 1 for real world applications as discussed in the introduction. How much greater than 1 depends on how well the ground conditions and forces are known.

The notion of setting a design value for the minimum acceptable FoS is described in Equation 2 in the introduction. The product of the driving and resisting factors used for design expresses the required reliability of the design or, alternately, expresses the lack of knowledge of the actual resisting and driving forces.

It is usual to employ probability models to express knowledge or lack of knowledge of the ground conditions quantitatively. A probability model describes the likelihood of any value of FoS being true, based on what we know of the resisting and driving forces.

The distribution of probabilities for the full range of possible FoS is described using a probability density function (pdf) as illustrated in Figure 2.2. The area under the curve of the pdf is equal to 1. Mathematically, this is saying that one value of the FoS in the full range of possible FoS is guaranteed to be true for the system. The area under the curve to the left of any given FoS is equal to the probability that the real FoS will be less than the given value.

If the pdf for FoS is known, then the PoF is the probability of the FoS being less than 1 (i.e. it is the area under the curve to the left of FoS = 1).

This raises two questions:

1. *How do we obtain a pdf for FoS?*
2. *What design value for FoS can be used to describe and test the apparent reliability of the system?*

The answer to the first question is that we need to know the probability density functions for all the properties of the ground that contribute to the maximum resisting forces as well as all the probability density functions for the contributing driving forces. Using numerical or analytical convolution of the contributing pdfs (typically using a computer model) it is then possible to determine the pdf for FoS. The pdfs for the ground properties are derived from the available field data. The quality of the pdfs will depend on the quality of the field data.

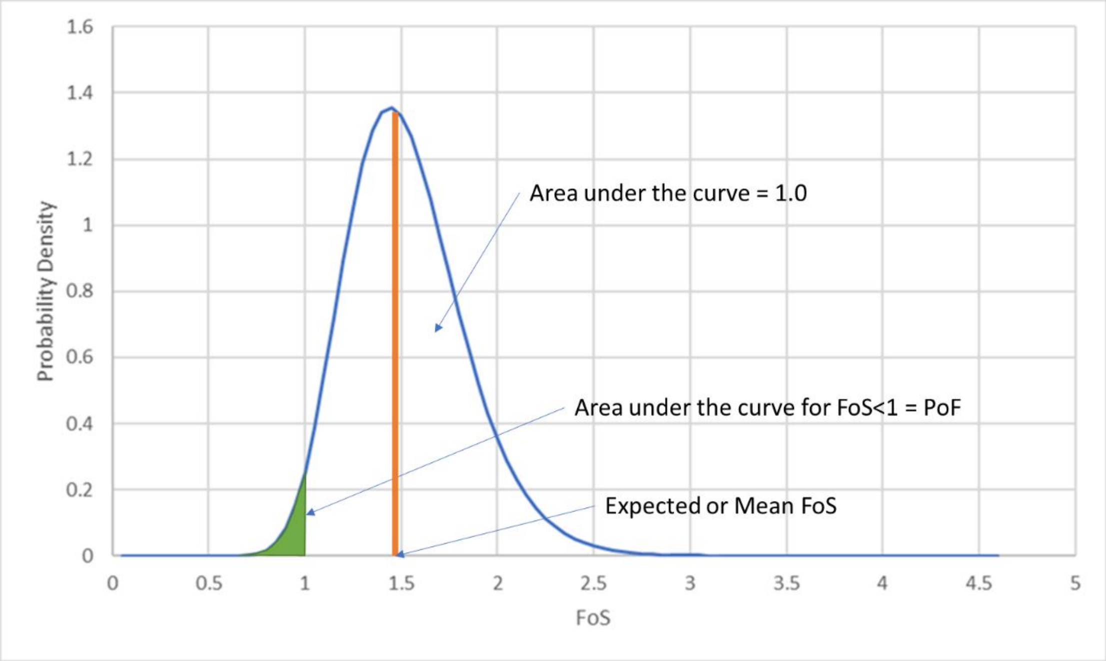

Figure 2.2 Illustration of a probability density function for Factor of Safety

The answer to the second question is to adopt the most likely value for the FoS, representing that value obtained using the most likely values of the maximum resisting and driving forces. Normally, the most likely values are the best estimates (i.e. expected values) or mean values of the properties. For cases where the shape of a property's pdf is strongly skewed the median or the mode may be more appropriate. Where driving forces are time dependent the maximum value for driving forces may apply. Deciding the appropriate value to use for driving forces depends on the frequency of high driving forces.

With the advent of fast computers, the PoF can be calculated for relatively complex problems using numerical convolution through Monte Carlo simulation. In Monte Carlo simulation single values of each property of the ground are randomly sampled from their probability distributions and a calculation performed to calculate the FoS for the given input values. Repetitively sampling values and calculating FoS a large number of times allows the frequency distribution for FoS to be determined from the cloud of calculated FoS. The frequency distribution can then be normalised to yield the approximate pdf for FoS from which the PoF can be determined. The number of calculated FoS that are less than 1 divided by the total number of calculated FoS in the Monte Carlo simulation approximates the PoF. Other methods for calculating pdfs are available but Monte Carlo is the method typically adopted in commercial geotechnical modelling software.

Steady-state geotechnical models are typically used to calculate the pdf for FoS and therefore to calculate the PoF and the expected value (i.e., mean) FoS. Time dependent calculations are generally not employed as the computational effort required is typically too great. The downside of using steady state calculations is that the PoF is not an annual PoF but a modelled or steady state PoF assuming that conditions remain unchanged for all time. The annual PoF will be typically much less than the steady state PoF but the relationship between the two is not readily defined without detailed understanding of time varying properties and conditions. Steady state PoF is normally accepted for design purposes but does not allow the reliability of the design as a function of time to be assessed directly.

Mathematical developments are underway to reduce the computational effort of performing a Monte Carlo simulation with traditional geotechnical numerical models (for example, Hu, 2021). No effort has been made in this investigation to establish the reliability of these new methods, but it may well be possible that such methods will become accepted in time.

The development of the required pdfs and expected values for geotechnical properties is considered in Section 2.3.

2.2.2 Relationship between PoF and expected FoS

Two papers (Silva, Lambe and Marr, 2008 and Duncan, 2000) provide useful guides to the relationship between PoF and expected FoS for slopes assessed through two quite distinctive but compatible approaches. A third paper by Macciotta et al (2020) also provides a wide ranging overview of design acceptance criteria for active mines and the relationships between PoF and FoS that complements the first two papers.

Silva, Lambe and Marr (2008) recognise three commonly accepted ways of estimating probabilities in engineering:

- Derived from frequency of observed events
- Derived from mathematical modelling, as described above.
- Quantification by expert judgement.

Silva, Lambe and Marr (2008) focus attention on quantification by expert judgment as a practical method for determining probabilities for slope stability analysis. The authors combine historical and subjective probabilities to obtain a correlation between expected FoS and PoF that they argue is suitable for use in geotechnical engineering practice.

Figure 2.3 shows the relationships between expected FoS and annual PoF for earth slopes. The various data underpinning this figure are based on actual engineering projects and developed through quantified expert judgement.

A basic hierarchy of engineering knowledge/quality is employed whereby earth slope problems are categorised from the best level of knowledge and engineering (Category I) to the poorest level of knowledge and engineering (Category IV).

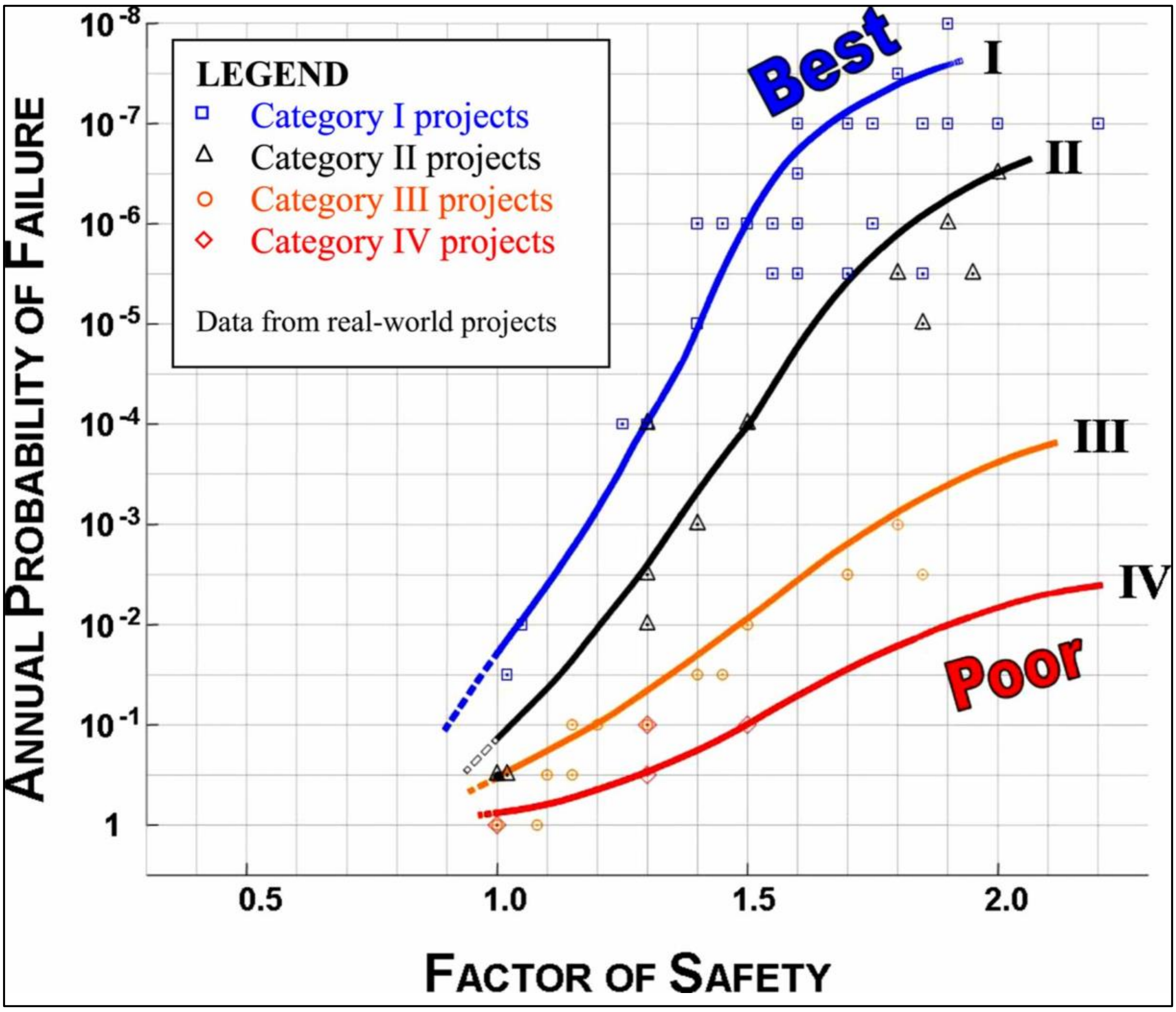

Figure 2.3 Expected FoS versus annual PoF.

The paper summarises the characteristics of the four categories, as follows:

> *Category I—facilities designed, built, and operated with state-of-the-practice engineering. Generally these facilities have high failure consequences;*
>
> *Category II—facilities designed, built, and operated using standard engineering practice. Many ordinary facilities fall into this category;*
>
> *Category III—facilities without site-specific design and sub-standard construction or operation. Temporary facilities and those with low failure consequences often fall into this category;*
>
> *and*
>
> *Category IV—facilities with little or no engineering.*

Figure 2.3 demonstrates that for a design FoS value to be used to assess the adequacy of a slope, the PoF has a strong dependency on the quality of knowledge and engineering. An FoS of 1.5 can translate to annual PoFs ranging from 1 in 10 to 1 in 1,000,000 depending on the quality of knowledge and engineering for the slope.

The paper then proceeds to expand on the information in Figure 2.3 to show how expert judgement can be employed to determine the category for any particular slope problem and from the required design PoF to establish the design FoS to be achieved using deterministic methods.

Duncan (2000) takes a different approach to Silva, Lambe and Marr (2008) but follows the same principle that the greater the uncertainty in the conditions affecting the determination of the FoS, the higher the PoF. The uncertainty is expressed by the Coefficient of Variation (CoV) of the pdf for the FoS distribution. The CoV is the standard deviation of the distribution divided by the mean. A log normal distribution is assumed for the shape of the distribution function for FoS. While other distributions are possible, this distribution has been found to be applicable in most cases for the FoS. The paper links the uncertainty in the conditions directly to the uncertainty in the parameters controlling the value of the FoS.

For the purposes of illustrating the approach, Duncan (2000) estimates the CoV of the FoS probability density function from a knowledge of the standard deviations of the ground parameters involved in determining the FoS. Simulations using +/- 1 standard deviation from the most likely values of each parameter provide the interactions between the error ranges in the parameter values and the deviations of the FoS from the most likely value. Taylor series approximations are then employed to estimate the standard deviation and the CoV of the FoS.

If N parameters are involved in the determination of the FoS then the most likely value for the FoS ($\boldsymbol{F_{MLV}}$) is obtained by solving for the FoS employing the most likely values of the N ground parameters. Changing one parameter at a time by +/- 1 standard deviation (σ) shows how the FoS is changed by that parameter. This is expressed for parameter ***i*** by:

$$\Delta F_i \quad = F^{+\sigma^i} + F^{-\sigma^i} \qquad \textbf{\textit{Eq'n 4}}$$

The first order approximation of the standard deviation of the FoS (σ_F) is then given by:

$$\sigma_F = \sqrt{\sum_{i=1}^{N} \left(\frac{\Delta F_i}{2}\right)^2} \qquad \textbf{\textit{Eq'n 5}}$$

The first order approximation of the CoV is then given by:

$$CoV_F = \frac{\sigma_F}{F_{MLV}} \qquad \textbf{\textit{Eq'n 6}}$$

The paper also identifies how estimates of the standard deviation of ground parameters can be elicited/estimated from data and published information.

Assuming that the distribution of FoS is log-normal then it is possible to determine the PoF given the most likely value for the FoS and the CoV pair ($\boldsymbol{F_{MLV}}$, $\mathbf{CoV_F}$) using Table 3 (reproduced from Duncan, 2000). The table gives the probabilities that the FoS is smaller than 1. The PoF considered by Duncan (2000) is a modelled value and not an annual PoF.

It is interesting to compare Figure 2.1 and Table 3. If it is loosely assumed that an annual PoF is between one and two orders of magnitude less than the modelled (steady state) PoF (i.e., modelled conditions are applicable for a period of between 10 and 100 years) then a CoV of 30% for the FoS corresponds very roughly to a category 3 project while a CoV of 15% fits to a category 2 project.

It is not necessary to reprise the full content of the papers here, only to note that if deterministic approaches to slope design using design FoS are to be employed then equivalent judgements are required to establish the design FoS from an applicable PoF to those expressed in either or both papers.

It is necessary first to define the acceptable PoF for a project and then to determine the equivalent FoS for design that is relevant to the quality of information available for the project.

In both cases, there is a need to be able to assess the uncertainty in the input parameters for the determination of the appropriate value for FoS.

The required design PoF and design FoS are addressed in Section 2.6.

Table 3 Model or Steady State Probabilities (as %) that FoS is smaller than 1.0, Based on lognormal distribution of FoS (reproduced from Duncan, 2000)

	Coefficient of Variation of Factor of Safety (V_F)														
F_{MLV}	2%	4%	6%	8%	10%	12%	14%	16%	20%	25%	30%	40%	50%	60%	80%
1.05	0.8%	12%	22%	28%	33%	36%	39%	41%	44%	47%	49%	53%	55%	58%	61%
1.10	0.00%	0.9%	6%	12%	18%	23%	27%	30%	35%	40%	43%	48%	51%	54%	59%
1.15	0.00%	0.03%	1.1%	4%	9%	13%	18%	21%	27%	33%	37%	43%	48%	51%	56%
1.16	0.00%	0.01%	0.7%	3%	8%	12%	16%	20%	26%	32%	36%	42%	47%	50%	56%
1.18	0.00%	0.00%	0.3%	2%	5%	9%	13%	17%	23%	29%	34%	41%	45%	49%	55%
1.20	0.00%	0.00%	0.13%	1.2%	4%	7%	11%	14%	21%	27%	32%	39%	44%	48%	54%
1.25	0.00%	0.00%	0.01%	0.3%	1.4%	4%	6%	9%	15%	22%	27%	35%	41%	45%	51%
1.30	0.00%	0.00%	0.00%	0.06%	0.5%	1.6%	3%	6%	11%	17%	23%	31%	37%	42%	49%
1.35	0.00%	0.00%	0.00%	0.01%	0.2%	0.7%	1.9%	4%	8%	14%	19%	28%	34%	40%	47%
1.40	0.00%	0.00%	0.00%	0.00%	0.04%	0.3%	1.0%	2%	5%	11%	16%	25%	32%	37%	45%
1.50	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.2%	0.7%	3%	6%	11%	19%	27%	32%	41%
1.60	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.05%	0.2%	1.1%	4%	7%	15%	22%	28%	38%
1.70	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.06%	0.5%	2%	5%	12%	19%	25%	34%
1.80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.2%	1.2%	3%	9%	16%	22%	31%
1.90	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.08%	0.65%	2%	7%	13%	19%	29%
2.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.36%	1.3%	5%	11%	17%	26%
2.20	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.10%	0.56%	1.3%	8%	13%	22%
2.40	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.23%	1.9%	5%	10%	19%
2.60	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.09%	1.1%	4%	7%	16%
2.80	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.66%	3%	6%	13%
3.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.39%	1.8%	4%	11%

Note: F_{MLV} = factor of safety computed using most likely values of parameters.

2.3. Geotechnical conditions (Geotechnical model)

Figure 2.1 highlights four key sets of information for the development of the geotechnical model:

1. Geology
2. Structure
3. Rock Mass and
4. Hydrogeology

It is not appropriate to review here all the tools, data collection methods, analysis and interpretation techniques that are available to develop each of the four sets of information and their connections. This information spans an enormous field of knowledge that continues to expand as new techniques and tools are developed. Fortunately, detailed information is widely available in the broad range of available geotechnical textbooks. A useful starting point for introductions to the subject are: Read and Stacey (2009), Beale and Read (2013) and Martin and Stacey (2018).

For the purposes of this investigation, it is appropriate to limit the discussion to the key requirements for data collection, interpretation, and presentation relevant to the geological formations of the Latrobe Valley.

Based on the information provided in Section 2.2, the requirements for the geotechnical model are, first, to identify the most likely conditions at any point in the mine and, second, to identify the quality of knowledge about the likely conditions. The former is required to provide evidence for the determination of the modes of failure (Section 2.4) and the selection of appropriate design tools and approaches (Section 2.5). The latter is required to provide evidence for the development of appropriate design criteria and acceptance (Section 2.6). Both the likely conditions and the quality of knowledge are needed to inform design monitoring and design implementation.

The geometry of the geological formations of the Latrobe Valley is relatively well known. There has been a long-term program of data collection that underpins each mine's descriptions of the geology of the mining leases. The data are maintained by the mine operators.

The structure of the discontinuities and lithological characteristics of the geological formations are less well known but the style of discontinuity distributions and lithofacies variations are reasonably well understood (Durie, 1991).

The properties of the rock masses that make up the geological formations are less well known and there has been a tendency until recently in geotechnical investigations to employ single value and/or basic statistical measures such as mean, range and upper and lower quartile values to characterise rock mass property descriptions for the whole mine area. This is because the collected data are derived from core scale samples and involve lengthy laboratory testing procedures. The number and distribution of measurements is normally too low to generate a reliable model of the spatial variability of the property at a particular location. It is a general problem in geotechnical engineering that data collection of rock mass properties is usually at too low a density due to time and cost constraints to permit direct inference of spatial variability of these properties. Consequently, models of spatial variation of rock mass properties are typically quite conservative.

El-Ramly et al (2002) provides a useful introduction to the impact of sampling and the spatial variation of rock properties on the determination of input values for use in probabilistic slope stability analysis. Figure 2.4 and Figure 2.5, reproduced from El-Ramly et al (2002), show respectively how point sample statistics (e.g. mean, standard deviation) may not characterise the smoothness of the spatial distribution of a property (Figure 2.4), and how sample statistics change with the scale of spatial averaging (Figure 2.5). Shear failures, for example, are dependent on the average behaviour along the full shear surface at failure. It is appropriate to have a model of uncertainty for the average value along the shear surface rather than a point value. However, the practicality of obtaining a probability density function for the representative averaged shear property is typically difficult because the surface area of the weakest slip surface over which averaging is to be performed is not known *a priori* and because the spatial variations of the rock properties are not well characterised from the sample values. One approach is to ignore the influence of spatial averaging and to assume that the point values are applicable to the whole rock mass, which leads to conservative estimates of failure risk. Another approach is to seek correlated rock properties for which the spatial variability is well characterised and to extrapolate the information from these properties to the property of interest. Narendranathan (2008) provides examples of the way in which correlated properties may be used to infill gaps in information on the particular property of interest for slope stability analysis. The reliability of the approaches suggested in Narendranathan (2008) has not been assessed in preparing this report.

The investigations at Hazelwood have adopted the conservative approach of assuming the probability density functions obtained from point data are representative of the average properties along a failure surface. The formal assessment of the rock mass properties of the M1 clays (GHD, 2017) illustrates the approach employed. A concerted effort has been made in this case to build probabilistic descriptions of the residual shear characteristics of this material. The result is a general model of the residual shear for the M1 clay at the mine scale and modified models for specific sub-regions of the mine. It should be noted that the variations between models for specific sub-domains are not linked back to specific characteristics of the geological model and might therefore be artifacts of the data collection rather than statistically significant model differences. This possibility appears not to have been tested. There is little discussion of this issue in the development of the shear strength models or the application of the data for design. While GHD (2017) characterises the shear strengths for each sub domain in terms of the best estimate of the lower quartile distribution, a probabilistic model of shear strength parameters is employed in the individual Batter Stability Assessments undertaken for Hazelwood mine's rehabilitation designs.

From a review of Hazelwood's completed batter stability assessments, there are a few features that are worthy of discussion. These relate to the link between properties and failure modes, probability model development for the different material properties, and replacement of probability models with mean or extreme values for stability assessment coupled with sensitivity analysis. The issue of sensitivity analysis is addressed in Hazelwood's rehabilitation planning (Matter 4).

2.3.1 Geotechnical properties and failure modes

The batter stability assessment reports (e.g GHD, 2018) prepared for Hazelwood follow the same pattern: development of statistical models for parameters, stability assessments, sensitivity analysis and additional analyses for specific features including lake water level variations. While the approach is satisfactory, it could be improved by first identifying all failure modes of concern for the batter and the features of each batter relevant to the identified failure modes. With failure modes identified, it is then simpler to bring together the required geotechnical data for each analysis and to identify the assumptions, approximations, and relevant features of the domain applicable to the failure modes.

Three general failure modes are identified: wedge/planar failures, toppling and block sliding. Each should be treated separately. The reason for treating each separately is that it is easier to demonstrate the linkages between each of the steps in model development. It is also easier to see whether there are local features and environmental processes that might impact the analysis and the model results. This issue is discussed further in the next section (Section 2.4).

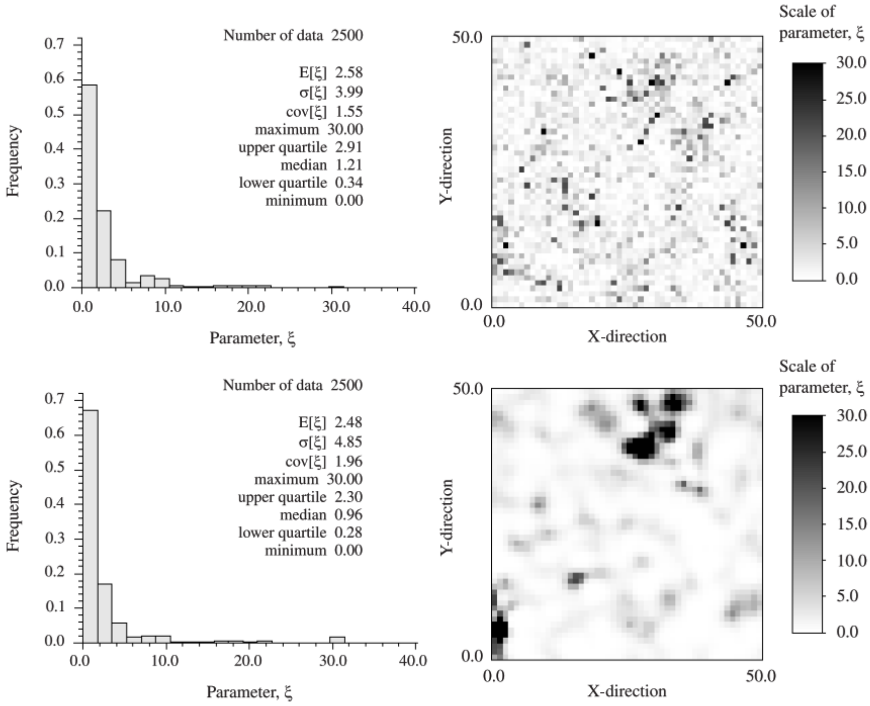

Figure 2.4 Illustration of the disconnect between univariate distribution from point samples and the underlying spatial correlation of a property (reproduced from El-Ramly et al, 2002)

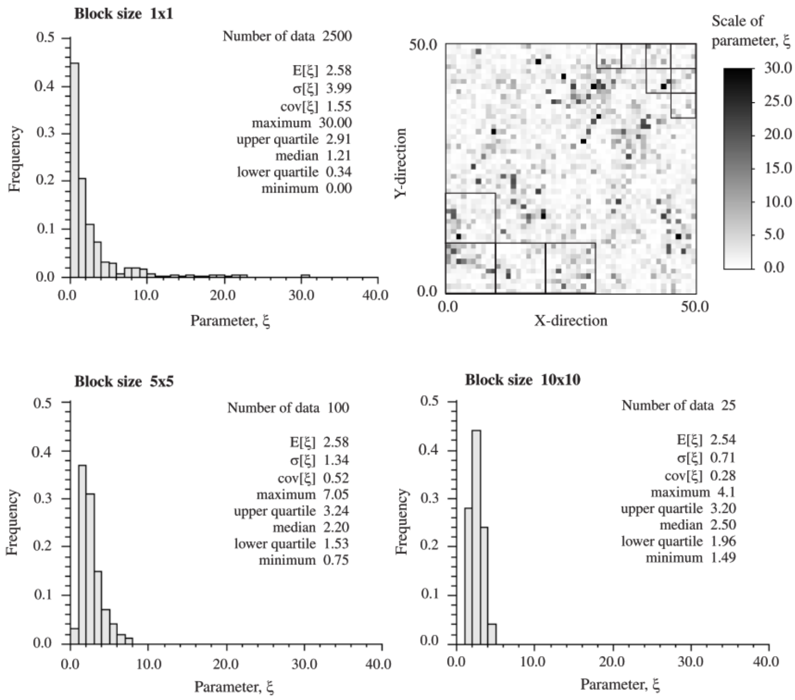

Figure 2.5 Variance reduction due to spatial averaging of different volumes (reproduced from El-Ramly et al 2002)

2.3.2 Probability model development

ENGIE's selection of data points close to a batter for inclusion in the development of a statistical model for material properties follows an unusual protocol. The sample CoV for the dataset is used to include or exclude data from the data set to be employed. The selection of data points is based on a nearest neighbour approach, commencing with the closest data value and then expanding the neighbourhood radius. As each new point is added a new sample mean and standard deviation are calculated. The sample CoV is then computed. Further points are added progressively by expanding the neighbourhood for as long as the CoV lies within a given range. Once the CoV exceeds the acceptable value the process stops and the data set is determined. The selection of the CoV for each parameter is based on the work of Harr (1984). The underlying assumption appears to be that any further increase in the CoV is due to an underlying trend in the data, although this is not explicitly stated. The impact of the nearest neighbour approach and the termination rule suggests that a high or low value in the data close to the batter could terminate the process earlier than would potentially be appropriate had a wider area search been carried out. While the approach is likely to be appropriate on most occasions, the data to show this is not provided. It is recommended that the point data are presented as part of the analysis, both to link the statistical properties computed to the original data and to demonstrate that the process leads to acceptable statistical parameters and that useful data have not been missed. Data consistency and completeness for any analysis are important requirements. For example, Table 1 in GHD (2018) reports acceptable CoV for friction angle as 12% for sandy clay (the nearest material type to the M1 clay) but the accepted CoV (Table 5 in GHD (2018)) is 24%.

The development of the shear strength envelope for the M1 clays is a further area where additional information would allow the reader to explore the significance of the procedures adopted to transform the field data into the final envelope. This is particularly important as the PoF for a slope in block sliding is likely to be strongly impacted by the lower bound adopted for the M1 Clay shear strength envelope. As cut offs are used first to help define this lower bound and then curve fitting is used to fit the cut offs, the results of these two fitting approaches may improve or worsen the apparent PoF significantly. One of the general observations in many geotechnical papers (Duncan, 2000) is that uncertainties in material properties are often underestimated.

A broad range of property values are statistically examined but the connections between the property values and the failure mode analyses are not clearly articulated. A summary of each of the required inputs for each failure mode would make the links clearer. To illustrate this point, Table 4 (reproduction of Table 12 from GHD, 2018) summarises the material properties that have been used for modelling failure due to block sliding for the West Field Southern Batters at Hazelwood.

Probability models for each property are missing from this table. The distribution for coal shear strength parameters is uniform according to the text, with upper bounds set as the lower quartile values for cohesion and friction angle and lower bounds set as the lower values identified in the data set defined in the GCMP (version 4). The upper bounds for the coal described in the text correspond to the mean values presented in Table 4. This leads to a confusing presentation of results. Similarly, the lower bound for the interseam shear strength is described as two spliced curves from the output of the development of the shear strength envelope for the M1 clays but is characterised as a single curve in this table.

Table 4 Material Parameters (reproduced from GHD (2018))

Material	Unit Weight (kN/m3)	Cohesion (kPa)			Phi (°)		
		Min.	Mean	Max.	Min.	Mean	Max.
Overburden	21	0	35	50	18	20	35
Coal	11.5	150	160	400	37	40	45
Surcharge Parameters	17	Su (Undrained Strength) 80.00 kPa					
Interseam	18	N/A (see below)			N/A (see below)		
Inter Seam Strength Curves							
Upper Bound	$\tau = \sigma_n tan(27.1 + 15.82 log_{10}(\frac{400}{\sigma_n})$						
Mean	$\tau = \sigma_n tan(20 + 8 log_{10}(\frac{350}{\sigma_n})$						
Lower Bound	$\tau = \sigma_n tan(14.4)$						

Truncated Gaussian distributions have been used to develop the shear strength envelope for the Interseam. Presumably, a truncated Gaussian distribution is also employed in the failure analysis modelling, but this is not confirmed in the table.

It is important to note that single values for variables are also probability distributions and should be clearly expressed as such. This is particularly important when single values are adopted that can have a significant impact on the stability analysis.

A key requirement for any probabilistic modelling is to describe fully the probability distributions for all variables that are inputs to the failure analysis.

2.3.3 In Summary

The key requirements for probabilistic analysis from this discussion are:

1. *Clear identification of all applicable failure modes and the identification of the properties of the system relevant to each failure mode.*
2. *Probability density functions for each of the material properties and the driving forces relevant to a particular failure mode - All functions should be clearly tabulated for the stability analyses performed and for any sensitivity analyses completed.*
3. *A clear explanation of the approaches used to transform the available field and laboratory test data into suitable probability density functions for use in stability analysis.*
4. *A clear description of the uncertainties in the transform approaches and the reliability of the approaches.*
5. *A clear description of the assumptions underpinning the developed probability functions and their application to the simulation of stability.*

2.4. Failure modes (Hazard and landform assessment)

In the previous section, the requirement to identify potential slope failure modes as a prerequisite for the gathering and transformation of the available data into simulation input values for stability analysis was noted. In this section, the identification of failure modes is considered and is extended to include assessment of factors that could increase or decrease the risk of failure for any failure mode.

Three failure modes are identified from the Hazelwood batter stability assessment reports: wedge failure, toppling and block sliding. Other failure modes that might also be applicable to the Latrobe Valley are rotational and translational movements.

It is appropriate for any geotechnical analysis to consider all possible failure modes and to omit failure modes from consideration if the features of the slope are not consistent with their occurrence. It may also be appropriate to omit failure modes where the magnitude of the possible failure is not consequential for safety or overall stability of the slope, but this assessment needs to be presented rather than assumed.

An observation from the review of the Hazelwood batter stability assessments is that failure modes have been assumed for the assessment for each domain and omitted failure modes are not discussed. While it is likely that the considered failure modes are the most significant, the lack of adequate discussion of other possible failure modes for a particular batter is not appropriate.

Different failure modes are commonly applicable to different spatial or volumetric scales. While rotational failure is unlikely to occur through coal formations it is likely to arise on slopes through overburden and may impact surface water drainage. If there are possible impacts on surface drainage, these may affect the assessment of risks of failure modes such as block sliding. The issue here is how to incorporate all failure modes appropriately and how to assess and describe those factors that could influence the likelihood or consequences of a batter failure.

The assessment of factors that could influence the likelihood of a batter failure for Hazelwood has been carried out, in most cases, through sensitivity studies. Examples are lake filling, altered groundwater gradients in the coal through changes in effectiveness of horizontal drains, over pressuring of joints in the coal through damage to the surface drainage networks, and uncontrolled inflows to the coal from known surface water courses.

The logic of using sensitivity studies to explore factors that might arise in the future rather than attempting to embed them within the basic PoF assessment is clear and appropriate. In many cases the frequency of occurrence of a factor will be low. If low frequency events were included in the basic probability analysis, it would significantly increase the number of simulations to obtain statistically valid results. In many cases, the likelihood of occurrence of a factor is dependent on the implementation of control measures. Treating the analysis of factors as special cases or variants to the base case is helpful from a purely computational perspective and is helpful in highlighting the importance of ongoing management and monitoring to mitigate specific risks. However, there is a need to provide appropriate assessments of likelihood for each factor of interest. The controls that are needed to maintain a low likelihood must also be defined if the likelihood of uncontrolled risks is deemed to be too high.

In most cases the likelihood of specific factors contributing to greater risk is assessed to be low in ENGIE's stability assessments. Risk assessments may have been undertaken for each factor but without a clear information trail connecting the factors to the assessed risks, it is not possible to evaluate the appropriateness of the assessments.

It is worth noting that ENGIE have undertaken specific assessments for engineered fills, notably surcharges that may be emplaced on the benches to improve overall stability. The justification for these specific assessments is based on the higher uniformity of emplaced fill. Such assessments are important and appropriate. It is assumed that the emplacement of surcharges is completed in such a way that destabilisation of the overall batter cannot occur. The issues of pore pressure dissipation in the interseam after emplacement of a surcharge can be as important as the dissipation of pressures within the surcharge itself. While it is deemed unlikely to be of significant concern, little information is provided about this issue for the Hazelwood batters.

2.4.1 In Summary

The key observations from this discussion are:

1. *All possible failure modes should be considered for each batter stability assessment. This is to ensure that the reasons for omitting a particular failure mode from consideration during stability analysis are clearly identified.*
2. *Risk assessments should be undertaken to identify all factors that may impact the assessed probability of failure, including an assessment of their likelihood of occurrence.*
3. *Sensitivity assessments are appropriate for time dependent factors deemed to have a low likelihood of occurrence and can be controlled through appropriate ground controls.*
4. *Specific stability assessments are required for engineered components of a batter where the ground conditions that may cause failure are specific to the method of emplacement.*

2.5. Design tools and approaches (Stability analysis)

2.5.1 Design tools

ENGIE have employed well-accepted simulation tools to assess Hazelwood's batters. These tools Slide, Slide3, SWEDGE, RS2 (Rocscience Inc. 2006, 2001, 2015a, b) and RocTopple (Amini et al., 2012) have been verified and validated and are appropriately maintained by the developers. There has been no use of bespoke simulation tools for Hazelwood's stability simulations. The main tool, SLIDE, can be used in deterministic or stochastic mode and so can be employed to assess failure risks using either PoF or FoS analyses. Analyses are essentially time independent, in so far as they investigate failure risk under steady state conditions. Different moments in time are captured by changing the physical conditions being analysed. The tools are not readily adapted to simulating evolving physical conditions over time without incurring a significant penalty in terms of computational effort.

While the tools and the approaches used are well known, their implementation to specific problems is dependent on data quality and the skill of the user. Consequently, there is a need for a peer review process to ensure that the simulation results are appropriate and reasonable. Peer reviews have been undertaken for all Hazelwood batter stability assessments. The peer reviews include independent reanalysis of some simulation results. The peer review reports do not state what re-analyses have been performed and do not provide the results of the re-analyses. Nevertheless, these reports provide some confidence that the design results can be relied on in terms of their reasonableness and conservatism.

Research (e.g. Hu, 2021) is underway to formulate new mathematical tools for batter stability assessment. The purpose of these tools is to improve the efficiency and quality of the analyses that are undertaken. If they are brought to commercial application, then it will be beholden on the developers to provide adequate demonstration that the tools are well verified and validated before they can be applied confidently to the Latrobe Valley brown coal mines. Peer review processes will be required. It will be appropriate to use traditional tools to confirm that the outputs of the new tools are reasonable.

2.5.2 Design approaches

The methods for presenting simulation input parameters are covered in Section 2.3. The requirement for evaluation of possible failure modes and the use of risk assessments to define which failure modes are investigated is considered in Section 2.4.

ENGIE's analyses of the Hazelwood batters use both calculated FoS and PoF values from each calculation to assess the performance of the batters. It is a recommendation that only one of the values is used for performance assessment, rather than both. The rationale for this is that it is possible to be inconsistent in the use of accepted assessment criteria. To illustrate this point, information is drawn from the assessment of groundwater gradient sensitivity for the West Field Southern Batters. Figure 2.6 reproduces Figure 35 in GHD (2018). In this figure, the PoF for each batter is presented for two groundwater gradients and two lake water levels. The figure shows that for the higher groundwater gradient the PoF significantly exceeds the defined acceptable PoF of 10% during filling at five batter locations. However, the accompanying text states that *"…all of the WFSB stability sections are estimated to have a mean FoS greater than 1.25 and should remain stable, even under a pessimistic elevation in phreatic conditions"*. The relationship between FoS and PoF has been lost at this point and there is inconsistency between the assessment of acceptable FoS and PoF. While it is acknowledged that the likelihood of a groundwater gradient of 9 degrees should be low with suitable groundwater management practices, the inconsistency creates a confusing narrative and reduces confidence in the interpretation of the results.

The selection and use of appropriate FoS and PoF criteria are addressed further in Section 2.6.

Throughout the batter assessments ENGIE identify that consequence is as important as likelihood in assessing ground movements. The measure of consequence ENGIE adopt for batter stability assessment is the displaced volume. This is interpreted as the solid volume above the failure surface. The adoption of this measure is based on the work of Lilly (2000), which was focussed on optimising pit slope design using a minimum total cost approach. There are merits in adopting this type of approach when all consequences of a batter failure can be related to the moved volume. It is not clear that this is the case for the assessment of long-term consequences for the Hazelwood batters.

Two aspects of the rehabilitation at Hazelwood suggest that the measure of consequence should be expanded. The first aspect concerns the 'repairability' of a failed batter, particularly when the pit lake water levels are well above mine floor level. A review of the stability sections suggests that in most cases large volume movements would extend under the lake surface. For this case it seems likely that repairs will be difficult and, presumably, costly if the ground is to be stabilised to minimise further movement. If the ground cannot be stabilised cost effectively then an area of the lake perimeter and the ground behind could present higher future ground movement risks, though this would need to be assessed. This would impact potential future land uses.

The second aspect concerns the stress relief that could occur in the ground behind the failure zone. Horizontal and vertical ground movements will be reactivated that could potentially impact sensitive receptors behind the batter. An example would be horizontal strains across the Princes Freeway and the Morwell Main Drain leading to defects in both structures. While the expectation is that the batter designs will minimise the risks of failure, measures of consequence need to be included in such a way that they focus attention on possible long-term impacts and on those areas of the mine where the consequences of a failure are greatest. Consideration of displacement volumes alone does not meet this objective.

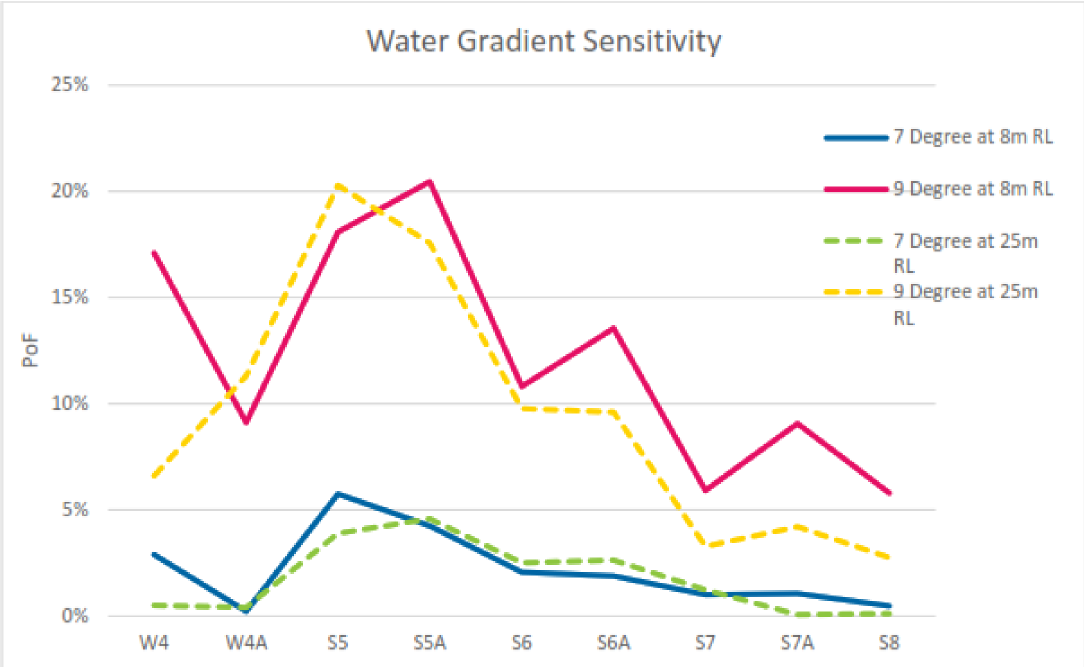

Figure 2.6 PoF for the 7º and the 9º water gradients at RL+8 and RL+25 (Reproduced from Figure 35, GHD (2018))

Sensitivity studies are appropriate where features of the stability analysis are not amenable to inclusion in the basic probabilistic risk analysis. Hazelwood sensitivity studies have targeted temporal changes to the driving forces influencing batter stability. These include lake levels, groundwater gradients, over-pressures in coal joints, and uncontrolled inflows to groundwater from permanent surface water bodies, and seismic events. Additional studies have explored the local stability of emplaced rock masses.

Discrete simulations of batter stability at representative lake water levels are appropriate. From these it should be possible to interpret the likely failure risks at intermediate levels. The ability to do this depends to a significant degree on the complexity of the batter geometry. In practice, a demonstration of the stability of the batter at potentially critical levels, other than the representative levels, should be undertaken to provide assurance that the water levels corresponding to the maximum risk for each batter are identified. Critical levels will likely correspond to water heights identified by marked changes in batter geometry at the water line.

Where sensitivity studies are undertaken to explore ground control management practices, the variance of model results can be used as a measure of the significance of appropriate ground controls. The results can therefore guide the development of Ground control management plans for specific failure risks and the rigour with which these must be applied. Ground control monitoring and management are addressed in Section 2.7.

3D simulations are desirable where the lateral batter geometry suggests that 2D simulations will either over- or under-estimate the batter's stability. There is little value in performing 3D simulations that largely mirror the 2D analyses. Employing Slide3 to produce deterministic outputs can be used to complement the 2D analyses. Where the 2D results using the most likely values of the input parameters yield a higher FoS than the 3D results then the impact of deviations of the input parameters in both 2D and 3D should be assessed to provide a more complete picture of the apparent risks.

Currently, there is concern in the literature that 3D LE analyses do not properly represent the physics of a rock slope failure. Application of 3D models should consider this issue before relying on the output from these models (Read, 2021).

It is noted that for the 3D analyses completed for the East Field Northern Batters at Hazelwood (GHD,2018b) minimum factors of safety were identified for small failure surfaces with low consequence outcomes that were filtered out from the final simulation results. For the purposes of assessment of large-scale block sliding this filtering is reasonable. However, it is not clear that the result should be discarded for the purposes of assessment of ongoing maintenance of the batter without first confirming that it is an artefact of the resolution of the model.

2.5.3 In summary

The key observations from this discussion are:

1. *Current slope stability design tools appear to be sufficiently well developed, verified and validated for use without further evaluation.*
2. *Application of the tools depends on the user and the underlying data quality. It is essential that third party peer review is undertaken to confirm both the adequacy of the data and the competency of the user.*
3. *New stability assessment tools are under development. This should be encouraged. Prior to formal use of any new tools, they should be rigorously verified and validated, including comparisons with the current generation of tools.*
4. *Consistency of use of FoS and PoF criteria in assessing batter stability is essential. Preference should be given to adopting one measure (either FoS or PoF) rather than mixing measures.*
5. *Consequences of batter failure should not be limited to the magnitude of the rock moved during the failure but should include aspects of repairability, long-term land use impacts and sensitive receptor impacts. Appropriate measures of consequence should be used to focus effort on assuring stability of those batters with the highest consequences.*
6. *While representative water levels are appropriate for the general assessment of changes in stability with lake water level, effort should also be made to identify whether there are other critical water levels for each batter that warrant greater attention for ground control management.*
7. *Sensitivity studies are appropriate for time dependent processes to enable an assessment of the rigour required for ongoing ground control management to minimise, as far as reasonably practical, the risk of a batter failure.*
8. *3D simulations are valuable as assessment tools to identify the likely over- or under-estimation of instability identified using 2D simulations.*
9. *Low consequence, local scale failures identified during the simulations that would fall into the category of slope maintenance works should be recorded and considered as part of a wider assessment of maintenance requirements for the slopes.*

2.6. Design criteria and acceptance (Residual risk)

In Section 2.2.2 , the relationship between PoF and FoS is described based on both knowledge and engineering quality. The FoS to achieve a given reliability (1-PoF) increases as knowledge or engineering quality reduces. Figure 2.3 graphs this relationship. Whether analyses are undertaken using PoF or FoS, the underlying requirement is that the reliability of the slope is acceptable. It is necessary to define an acceptable PoF for the required conditions and then to transform that design PoF to an equivalent FoS if a deterministic FoS analysis is to be carried out or values of FoS are to be used deterministically to compare designs based on probabilistic analysis.

The evidence available from the batter stability assessments for Hazelwood suggests that the relationship between PoF and FoS applicable to Latrobe Valley's brown coal mines is approximately equivalent to a CoV for FoS of 25%. This relationship is shown in Figure 2.7.

ENGIE have adopted design acceptance guidelines presented in Read and Stacey (2009) for the determination of applicable design PoF for the different stages of lake filling. The design acceptance guidelines are reproduced in Table 6. However, it is worth noting that this table is based on an original literature study and the back-analysis of several soil slopes and earth and rockfill dams by Kirsten (1983). As noted in Read and Stacey (2009), it incorporates the service life, public liability, and type of monitoring applied and is intended to provide guidance for interpreting the PoF level in terms of the frequency of failed slope, including unstable movements. Wesseloo and Read, the authors of the chapter in Read and Stacey (2009) go on to note that "*although this may sometimes be helpful, it should be used with caution as it was based on a frequency-of-event interpretation of the PoF not a degree-of-belief, subjectively assessed PoF (Vick, 2003), and therefore implicitly assumes the PoF to be property of the slope, not the design*". Although the authors note a degree of caution about use of the Table, a scan of the literature has not identified any better sources on which to base the development of design PoF values. The frequentist interpretation of the PoF values is applicable given the calculations of PoF adopted for batter design at Hazelwood.

FoS values taken from Figure 2.7 corresponding to the key PoF values in Table 6 are shown below in Table 5:

Table 5 FoS values corresponding to key PoF

PoF (%)	FoS
0.5	2.0
1.5	1.75
5	1.55
10	1.44

Figure 2.8 illustrates ENGIE's design acceptance criteria for the East Field Northern Batters and the West Field Southern Batters. Also shown are the assessed PoFs for the base cases for each batter for each representative lake water level.

Design PoF should be based on slope design life, ground controls, and failure consequence. The design acceptance levels presented in Table 6 cover each of these criteria. Design life addresses serviceability. Ground controls are based around monitoring but not actions. Failure consequences are based around public risks but not about risks to the environment or infrastructure. While this table is good as a starting point for establishing design acceptance levels for PoF, additional evidence is required to build confidence in the adopted values.

While the failure acceptance guidelines in Table 6 are not directly applicable to Hazelwood (and the wider Latrobe Valley), the PoF ranges adopted for medium to very long-term serviceable life appear to be appropriate for both mine lake filling and final landform. The Authority notes that while the terms of reference for Matter 1 explicitly reference the period during water filling for a pit lake landform, appropriate fill period failure standards cannot be recommended without also reviewing appropriate long-term, final landform criteria. As such, the materials studied and the subsequent recommendations are appropriate for both phases of the rehabilitated landform.

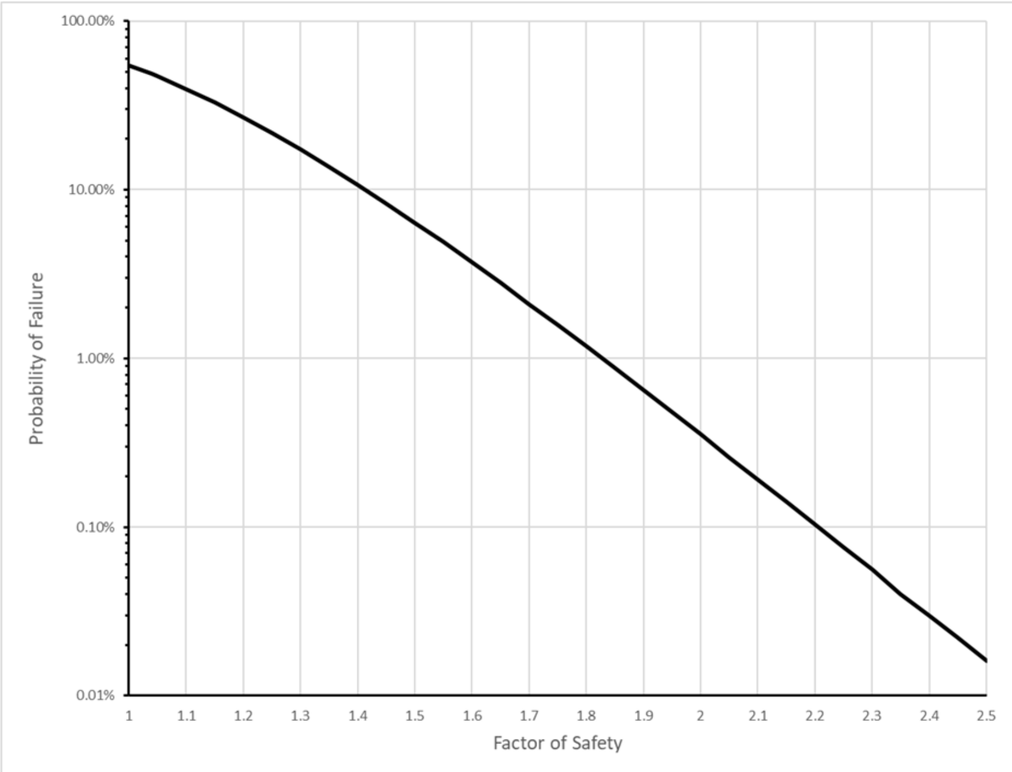

Figure 2.7 Probability of Failure versus Factor of Safety for Hazelwood Mine

In Table 6, there is a direct correspondence between PoF for design acceptance and increasing design life, reducing ground controls, and reducing consequences. There is no consideration in the table of batter design options that mix different requirements such as a long design life with sustained ground controls and sustained consequences that might occur, for example, if a lowered lake form is deemed to be the only viable option for a mine. This raises the question of the precedence and emphasis that should be placed on each criterion in determining an acceptable PoF for design.

Effectively, this reduces to questions of the acceptable residual risks that will remain after completion of rehabilitation, the acceptable limitation on future uses of the land and, lastly, the acceptable long-term monitoring and maintenance costs. Because they affect future generations, these are all societal issues. As such, they should be agreed among all participating stakeholders including government, community and industry based on a clear understanding of the constraints and benefits prior to undertaking or approving any design work.

Table 7 proposes PoF criteria and corresponding FoS values for lake filling and following relinquishment based on Read and Stacey (2009) but modified to reflect relinquishment of the final landform. The key modification acknowledges that there may be a requirement for the Latrobe mines to maintain groundwater controls in perpetuity if sufficient water cannot be supplied to allow for full lake final rehabilitation landforms to be created. There is potential even for full lake forms for some batters to need continuous groundwater controls to be adopted. In all other ways the criteria are aligned with the acceptance criteria adopted in Table 6. While these criteria are recommended, they do not consider the individual setting of each mine batter, the practicality of achieving these criteria, or the materiality of risk to receptors. As such, batter-specific acceptance criteria that consider these issues should be developed collaboratively by the mine operator and Victorian government regulator in conjunction with the community.

Table 6 PoF design acceptance guidelines (reproduced from Read and Stacey (2009))

PoF (%)	Design Criteria			Aspects of natural situation	
	Serviceable Life	**Public Liability**	**Minimum surveillance required**	**Frequency of slope failures**	**Frequency of unstable movements**
50 - 100	None	Public access forbidden	Serves no purpose	Slope failures generally evident	Abundant evidence of creeping valley sides
20 - 50	Very very short term	Public access forcibly prevented	Continuous monitoring with intensive sophisticated instruments	Significant number of unstable slopes	Clear evidence of creeping valley sides
10 - 20	Very short term	Public access actively prevented	Continuous monitoring with sophisticated instruments	Significant instability evident	Some evidence of slow creeping valley sides
5 - 10	Short term	Public access prevented	Continuous monitoring with simple instruments	Odd unstable slope evident	Some evidence of very slow creeping valley sides
1.5 - 5	Medium term	Public access discouraged	Continuous superficial monitoring	No ready evidence of unstable slopes	Extremely slow creeping valley sides
0.5 – 1.5	Long term	Public access allowed	Incidental superficial monitoring	No unstable slopes evident	No unstable movements evident
< 0.5	Very long term	Public access free	No monitoring required	Stable slopes	No movements

The final two rows of Table 7 offer the same PoF/FoS values but differ in terms of long-term groundwater management. The inclusion of both options allows for the possible adoption of a lowered lake landform either with or without ongoing ground controls. It is considered possible that both full and lowered lake landforms may not be achievable without ongoing groundwater control. This would need to be determined as part of final landform design approvals.

Table 7 Steady State Calculated PoF/FoS design acceptance guidelines (adapted from the failure acceptance guidelines in Read and Stacey, 2009)

PoF (%)	FoS	Serviceable Life	Public Liability	Monitoring	Groundwater Management
<5	**>1.55**	Medium term, During Filling, Low risk batters	No public access	Continuous monitoring	Robust groundwater controls maintained
<1.5	**>1.75**	Medium term, During Filling, High risk batters	No public access	Continuous monitoring	Robust groundwater controls maintained
<0.5	**>2.00**	Long-term, Post Filling, All batters	Public access allowed	Regular monitoring	Groundwater controls maintained
<0.5	**>2.00**	Long-term, Post Filling, All batters	Full public access	Regular monitoring	No groundwater controls

Note: PoF is model probability of failure and not annual probability of failure. While rows 3 and 4 of this table are applicable to long term final landform designs, preference should be to seek no groundwater controls for the final landform, unless this is impractical. FoS design acceptance criteria are applicable when deterministic design calculations are performed. PoF design acceptance criteria are applicable when probabilistic design calculations are performed. There is no requirement to meet both criteria

2.6.1 Design life

For the case of a dry void batter design, the final design for the batter will exhibit the highest PoF over the long term as groundwater pressures recover to the approved design levels and are maintained by active ground controls. In this case, the design acceptance for PoF can be a single value based solely on the final conditions anticipated for the batter.

For the case of a wet void batter design, the final design for the batter will exhibit the lowest PoF for a full lake when compared to the end of mining and during water filling. There is good evidence for most full lake batter designs that the PoF increases as lake water level rises after commencement of filling and then decreases as the water level approaches the final lake level. This feature is apparent in the batter stability assessments carried out for Hazelwood and in the geotechnical studies carried out during the development of the Latrobe Valley Regional Rehabilitation Strategy (LVRRS, 2020). A key message from these studies is that the time of transition from the initial empty pit to the final approved water level should be as short as practicable, while recognising that the availability of water for filling will be a constraint on fill rate. In this case, the design acceptance values for PoF could be different for different lake height ranges during the filling process that account both for the short duration of time that the lake will be within each height range and for the ongoing ground controls that will be in place during filling. This is the approach adopted by ENGIE for Hazelwood.

For the case of a wet void design where the final lake level is significantly below the full lake level, the final design for the batter may exhibit the highest PoF over the filling range depending on the final approved lake water level. In this case, the design acceptance for PoF can be a single value based on the final conditions anticipated for the batter.

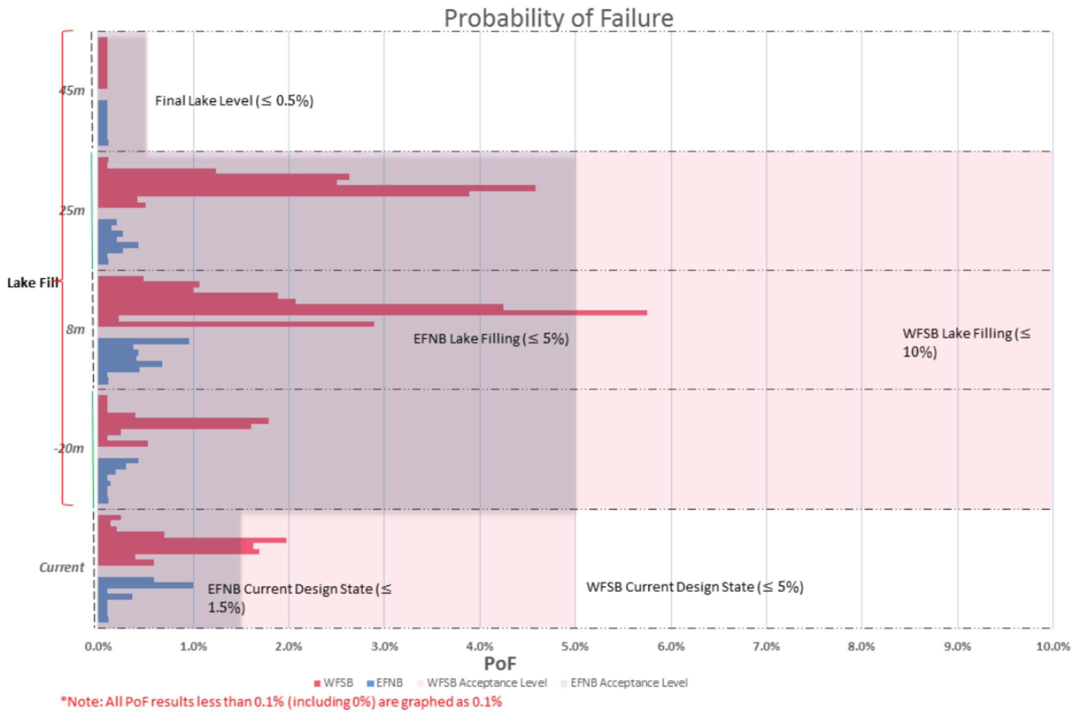

Figure 2.8 Comparison of PoF results during lake filling for the East Field Northern Batters (EFNB) and the West Field Southern Batters (WFSB) showing the design acceptance criteria (shaded area)

It is important to distinguish between design life at different water levels during pit lake filling from design life if a decision is made to stop water filling at a particular water level due to constraints on water availability. It is not appropriate, on cost grounds, to assume that all water levels should be treated as potential final water levels.

If contingency options are required that permit the cessation of water fill below the approved final lake level then these should be clearly identified for specific lake levels and full new designs undertaken for each option once the need to stop at a lower lake level has been agreed. This issue of specific levels is dealt with under Matter 2. The number of options would need to be small (again on cost grounds) and should be based on clearly understood and agreed criteria related to residual risks, land use limitations, water management and monitoring and maintenance. Design acceptance PoF should be applicable to the contingency design and should be clearly distinguished from the design acceptance PoF for the original approved design.

Table 7 would suggest that for any long-term batter the design acceptance PoF for the batter should be less than 0.5%. This should be the aspiration. However, there may be occasions where the geological setting for a given batter makes it impractical to reduce the PoF to this level. Under these circumstances, the requirement should be to minimise the consequences as far as practical to compensate for the higher PoF through appropriate decisions on land use and land access.

2.6.2 Ground controls

Batter failures have occurred at each of the three declared mines in the Latrobe Valley (Hazelwood, Loy Yang, and Yallourn) that have exhibited different characteristics.

The block slide in 2007 at Yallourn exhibited progressive stress relief, groundwater pressure-controlled movements and groundwater discharges over an extended period prior to failure. The coal blocks were saturated at the time of failure, which allowed extensive movements to occur as release of water pressures along the joint forming the back wall of the failure zone allowed the coal blocks to slump.

The movement affecting the Prince's freeway in 2011 at Hazelwood was preceded by a long period of stress relief that allowed sinkholes to form in the base of the Morwell Main Drain. Inflows to the sinkholes during flood flows to the drain created high pressures in the coal joints that caused the coal blocks to move and widen the joints. Joint pressures were not maintained due to the limited supply of water from the drain and the large increases in joint volume. The coal blocks were undersaturated due to long-term depressurisation. Slumping of the coal on either side of the joints did not occur. As a result the movements of the coal block were relatively small and overall stability of the coal blocks on the batters was maintained.

The movement affecting the southern batters at Loy Yang was preceded by the failure of a fire service pipe that allowed pressures in the joints behind the batter to rise causing coal block movements towards the mine. Since the joints were oriented at an angle to the pit wall the block rotated horizontally allowing the water pressures in the joint to dissipate and restrict further movement. As at Hazelwood, the coal blocks were under-saturated due to long term depressurisation and slumping of the blocks either side of the failure joint did not occur. The overall stability of the coal blocks was maintained.

These three movements highlight the importance of land, surface water and groundwater controls to prevent high groundwater pressures in the coal above lake water level. If a short term, higher design acceptance PoF is to be adopted then it is essential to demonstrate that the proposed ground controls are adequate for the design period. This means that ground controls need to be explicitly defined for each stage of lake filling to show that the required control of ground water gradients can be met. In particular, the capacity to introduce new dewatering bores, if needed, during lake filling is essential. It is also necessary for the failure consequences to be fully understood.

2.6.3 Consequences

As described in Section 2.5, the consequences of batter failure should not be limited to the magnitude of the rock moved during the failure but should include aspects of repairability, long-term land use impacts and sensitive receptor impacts. Figure 2.8 illustrates that sensitive receptor impacts are being addressed for Hazelwood's batter designs. The acceptable PoF for the east field northern batters is much lower than the south west field southern batters largely because of the potential impact on the Prince's Freeway. However, it is not clear that the considerations of repairability and long-term land use impacts have been adequately addressed in the development of the acceptable PoF during lake filling.

Prior to acceptance of a higher design acceptance PoF, the consequences of batter failure should be risk assessed against all potential impacts.

Because repairability is a potentially significant issue for all batters and because the time taken to fill cannot be known *a priori* , it is appropriate to assume that the design acceptance PoF during filling should be applicable to the medium term and not to the short term. In this case, the design PoF during lake filling should not exceed 5% without stakeholder consensus and should be lower than this (e.g. 1.5%) if the consequences are high.

2.6.4 In summary

The key observations from this discussion are:

1. *Knowledge of ground conditions is limited at the mines and this leads to high FoS values to achieve acceptable probabilities of batter failure.*
2. *FoS design criteria are applicable to deterministic calculations and PoF design criteria are applicable to probabilistic calculations. There is no requirement to meet both criteria. The criteria lead to effectively the same outcome in terms of stability.*
3. *The long term design PoF should normally be <0.5% (FoS >2.0)*
4. *Higher long-term values for design PoF for individual batters require stakeholder consensus before acceptance*
5. *Design PoF values during lake filling should not exceed 5% (FoS >1.55) to account for issues of repairability and slow fill times.*
6. *Design PoF values for high consequence failure risks should not exceed 1.5% (FoS > 1.75)*
7. *Ground controls required during filling and over the long term should be described explicitly to demonstrate adequate groundwater gradient and pressure controls.*
8. *Risk assessments are required to highlight the failure consequences for all batters.*
9. *Contingency options that allow for lower lake levels should be subject to a separate design and analysis prior to approval. There should not be a requirement for a batter design to meet long term design PoF for any water level.*

2.7. Design monitoring (Implementation)

Ground controls will be critical to the success of final rehabilitation of mine batters, notably during pit lake filling.

The key objective for all monitoring should be to ensure that groundwater conditions do not exceed design values; specifically groundwater gradients and joint surcharge.

Groundwater conditions behind the batters are predominantly governed by surface water inflows and horizontal drainage to the pit.

It is essential that surface water drainage is designed and managed to prevent excess recharge entering the coal. Recharge can be exacerbated by the presence of preferential paths from the surface drainage to the coal. Sinkholes have been found to exacerbate recharge to coal joints. Monitoring for the formation of sinkholes is required and repairs should be expedited as soon as sinkholes are identified.

It is not yet clear how the existing arrangement of horizontal drains will behave during lake filling. These drains will be progressively submerged and not generally amenable to repair once under water. New horizontal drains above the water line may be required if drains become blocked. The ability to introduce new horizontal bores will need to be addressed to ensure that physical constraints to new bore locations do not impact on the required groundwater controls.

Groundwater level monitoring will be essential on all batters and on all stability lines. Appropriate trigger action response plans (TARPs) will be needed to accompany the monitoring.

Ground movements should be monitored to confirm subsidence and creep movements and to identify unexpected movements that might indicate potential failure conditions developing.

All monitoring should be adequately incorporated into the Ground Control Management Plan for the mine.

2.8. Reporting

Within each of the sections above, guidance has been provided on the requirements for information to be included in the presentation of the batter stability assessments to allow adequate review and acceptance of the final designs.

In summary:

1. *Adopted PoF design criteria should be agreed by relevant stakeholders, particularly if deviations from the suggested values in section 2.6 are required.*
2. *If FoS approaches are to be employed, they must be adequately justified in terms of the required PoF design acceptance criteria.*
3. *If mixed PoF/FoS approaches are to be adopted, application consistency is essential.*
4. *Traceability from raw data to processed data for the geotechnical model for each batter is required.*
5. *Probability models for all input variables for design calculations should be explicitly stated.*
6. *All failure modes should be adequately assessed before inclusion or exclusion from consideration for design.*
7. *Separation of investigations for the different failure modes is encouraged to improve readability.*
8. *Consequences of batter failure should be explored fully to address the impacts of repairability, future land use and sensitive receptors, not just possible magnitude of movements.*
9. *Where batter design is dependent on adequate ground controls these should be explicitly addressed and described to show that unforeseen risks can be adequately managed during lake filling.*
10. *Residual risks should be explicitly described prior to completion of the design.*
11. *Appropriate peer review of all parts of the batter stability assessment and design should accompany the final report.*

It is relevant to note that Hazelwood's batter stability assessments meet many of the requirements summarised here and the structure of preparation of designs using the flow chart presented in Figure 2.1 is followed to a large degree. However, deficiencies can be identified in relation to points 1,3,4,5,6 and 8 that warrant consideration before any submission and approval of a final rehabilitation and closure plan.

2.9. Concluding remarks

Over many years there has been a progressive move in geotechnical investigations to examine the reliability of geotechnical designs using probabilistic approaches. There has also been effort made to better appreciate the significance of design factors of safety in terms of their equivalent values of reliability and PoF.

As part of this investigation, the connection between PoF and FoS has been reviewed and approaches to integrating both measures into a consistent framework for application by ENGIE for Hazelwood mine have been proposed. The basis for selecting appropriate design probabilities of failure for the batters both during water filling and the long term has been considered and guide values are suggested. It is recognised that these cannot be strict values for mine rehabilitation and so a requirement for stakeholder consensus on appropriate values to meet specific conditions that might arise is presented. The design PoF should be adopted for Yallourn and Loy Yang mines even though a different relationship for FoS-PoF might be appropriate for both mines.

A flow chart for carrying out batter design based on work presented by Read and Stacey (2009) is used to guide the discussions on the key areas of concern for batter design. These have been assessed individually and a series of objectives arising out of each area have been prepared.

A major observation from the investigation of Matter 1 is that confidence in batter design is as much about what is missing from the design report as it is about what has been presented. In this regard a series of observations are made that explicitly cover the basis for omitting calculations and the assessment of risks.

2.10. Summary of recommendations

The following recommendations are made based on the observations presented in this chapter:

1. *Design FoS/PoF should meet the following requirements:*
   - *The long term design PoF should normally be <0.5%*
   - *Design PoF values during lake filling should normally not exceed 5% to account for issues of repairability and slow fill times.*
   - *Design PoF values for batters presenting high consequence failure risks should not normally exceed 1.5% at any fill level.*
   - *Variations to PoF design criteria should be agreed by relevant stakeholders, particularly if increases from the suggested values are required.*
   - *FoS approaches must be adequately justified in terms of the required PoF design acceptance criteria.*
   - *Consistency of use of FoS and PoF criteria in assessing batter stability is important. Preference should be given to adopting one measure of reliability (either FoS or PoF) for batter design, rather than mixing measures.*
   - *If mixed PoF/FoS approaches to design are to be adopted, application consistency must be demonstrated.*

2. *Third party peer review should be undertaken for all batter designs and include selective reanalysis of stability calculations to confirm both the adequacy of the data, the interpretation of the probability models and the capability of the designer.*

3. *Consequences of batter failure should address aspects of repairability, long-term land use impacts, and sensitive receptor impacts. Risk assessments should be employed to highlight failure consequences for each batter. Appropriate measures of consequence should be used to focus effort on assuring high levels of stability for those batters with the highest consequences.*

4. *Effort should be made to identify critical water levels for batter design that warrant greater attention for ground control management.*

5. *Ground controls required during filling and over the long term should be described in detail to demonstrate that adequate groundwater gradient and pressure controls can be maintained throughout the rehabilitation period.*

6. *Batter design reports should ensure:*
    - *All failure modes have been adequately assessed before inclusion or exclusion from consideration for design.*
    - *Investigations for the different failure modes are separate (for readability)*
    - *Processed data can be traced from the raw data*
    - *Probability models for all input variables for design calculations should be explicitly stated.*
    - *Ground controls implied for application of a design are clearly stated.*
    - *Residual risks are explicitly acknowledged and summarised*

3. Reference Water Levels (Matter 2)

3.1. Introduction

3.1.1 Purpose

This section of the investigation report covers referral matter 2:

> *Define a set of reference water fill levels and identify the data, information and knowledge required to manage risks associated with filling to each reference level, including having regard to batter redesign and/or modification works that may be necessary in future to ensure stability planning and other approvals required.*

Reference water fill levels are lake water levels at which decisions about future fill can be made and which may become final lake water levels if insufficient water is available to complete rehabilitation of the mine void with a full pit lake. This scenario assumes that a manufactured water source is not accessible for mine rehabilitation and that local surface and groundwater sources are approved for use for creation of a pit lake. Investigation of this scenario does not imply that any approvals of either the water source or a full pit lake landform have been granted.

Prediction of future water availability indicates that there is a risk that water from surface sources may not be reliable or available. Groundwater alone is unlikely to be sufficient to achieve filling to a full pit lake within an acceptable time period, particularly if evaporation losses increase with climate change. Under these conditions and given the uncertainty in water supply, it is necessary to allow for the possibility that filling ceases at a level less than the intended final lake level. This will require revision of the final rehabilitation design, whilst adhering to the standards needed to meet the long-term requirements for a safe, stable and sustainable landform.

The selection of discrete reference levels provides a more manageable planning environment than allowing for all water levels to be potential stopping points. Selection of a limited number of reference levels provides for adequate time between levels to assess future climate conditions, and to prepare appropriate designs and planning applications (if required).

Even for the case of eventual completion to the initial agreed final water level, there is value in defining a set of reference levels to provide appropriate staging points for full re-evaluation of all information gathered on batter movements and batter stability as water levels rise. While care is taken to minimise the likelihood of unforeseen events, these staging points provide an opportunity to confirm that the underlying knowledge and concepts used for batter stability assessments are adequate. Reviews of information can be used, if necessary, to amend the batter designs to reflect any additional findings.

The purpose of the investigation has been split into four objectives:

1. defining a set of appropriate reference levels
2. identifying the risks and information needs associated with filling between reference levels
3. considering approaches to batter re-design and modification works, if required
4. ensuring that the final landform meets design and planning approvals

3.1.2 Background

Creating a full pit lake final landform is ENGIE's preferred option for the Hazelwood mine void. Figure 3.1(a) illustrates the projected extent of a full pit lake (and geotechnical domains) based on current ground elevation data for the mine void and surrounding area (+45m AHD water level). Owing to the nature of the geology and the climate of the Latrobe Valley, it is not possible to simply let water flow into the mine void and to wait until it reaches the required level. The Latrobe Valley mines are inherently unstable if groundwater pressures adjacent to and below the mine are not managed. A downside of groundwater management for stability is that subsidence takes place as groundwater pressures are reduced to improve stability. Ground movements also occur during mining as the stresses in the rock are released and the formations local to the mine expand, a process known as relaxation. The mine operators continuously monitor ground movements and groundwater pressures to maintain stability, as well as to understand the nature of the movements.

Monitoring and management of groundwater pressures and ground movements is also required during lake filling, as groundwater conditions and ground stresses adjust in response to the addition of water during filling. Ongoing monitoring and management may be required depending on the final lake level achieved. ENGIE's preference for a full pit lake is based on their assessment that ongoing monitoring and management for stability should not be necessary after final rehabilitation if a full pit lake is achieved.

Wave erosion during lake filling (and at the final water level) will need to be controlled to minimise the risk of mine batter instability and to ensure that suitable access to the lake perimeter is maintained to provide for ecological connection between the surrounding land and the lake.

Above the final lake level, the land slopes and land covers need to be designed and managed to prevent unwanted erosion, minimise fire risks and provide water and land access. Surface water drainage will also have to be incorporated in the designs given the general steepness of slopes and the potential for intense rainfalls.

A lake is not just a body of water, it must also be managed for water quality as well as for its environmental benefits. If a lake is to be productive and useable its aquatic environment needs to be appropriate to support a sustainable aquatic ecosystem. Deep lakes require appropriate shallow water areas for aquatic vegetation and aquatic species habitats. Batter design is, therefore, not just about stability but also about ecological sustainability.

Finally, water quality depends on the net flows of dissolved and suspended solids and nutrients into the lakes. A well-functioning lake will eventually need a balance of salt and water contents, which may not be achievable without managed water inflows and outflows. Low lake levels prevent natural exchanges with the surface water environment. Flows to and from the groundwater system are anticipated to be very low relative to the magnitude of surface water inflows to sustain the final water level.

Any potential or planned use of the lake for water storage and controlled release to support downstream users will further require evaluation of all facets of the lake design requirements presented here.

While creating a lake landform requires much more than stability analysis for long term success, the scope of this matter is focussed only on those elements related to landform stability.

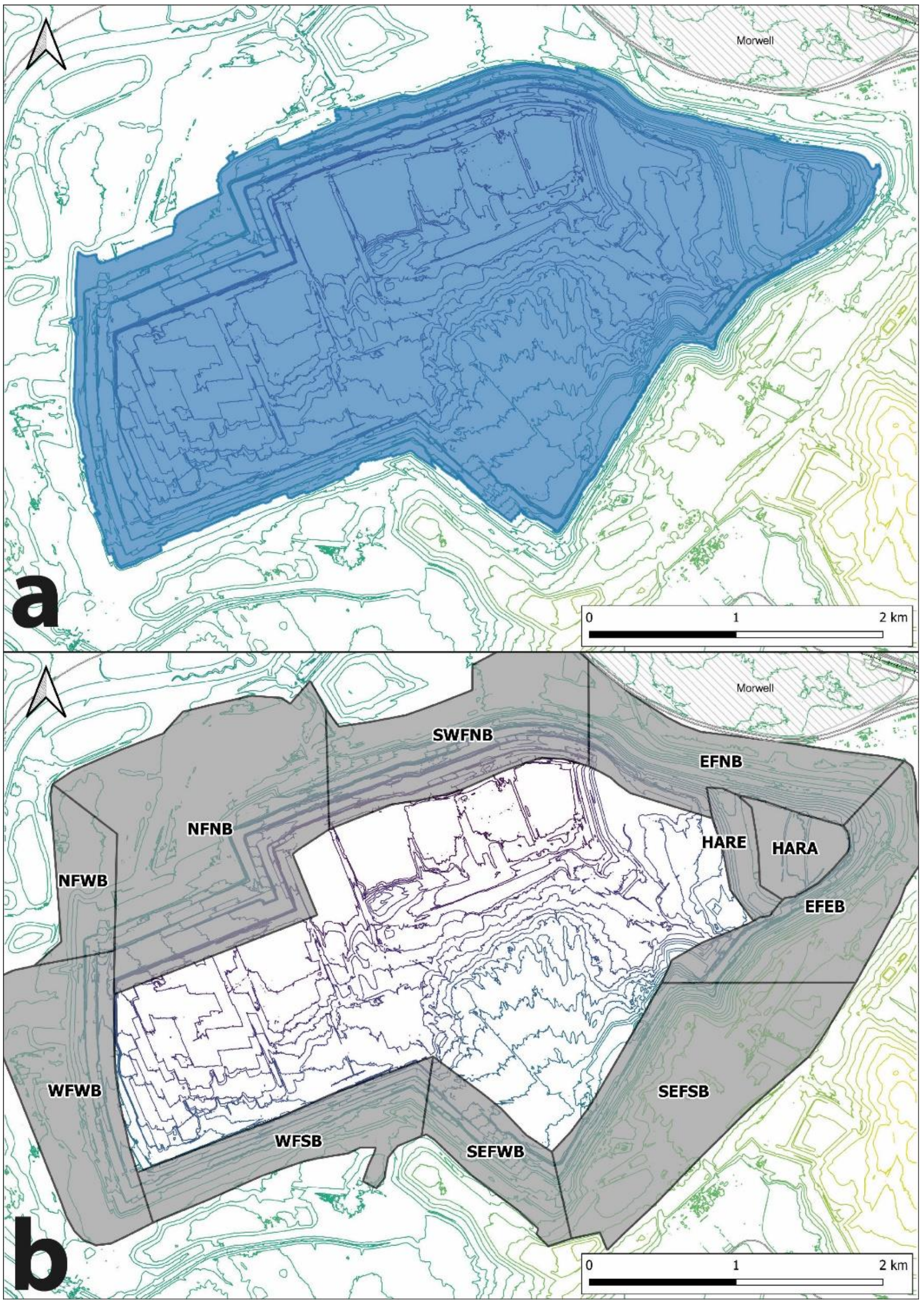

Figure 3.1 Hazelwood mine showing (a) the approximate extent of the lake for a level of +45 mAHD and (b) ENGIE's batter domains employed for stability analysis and design.

Batter domains: EFEB = Eastern Field Eastern Batters, SWFNB = Southwest Field Northern Batters, NFNB = Northern Field Northern Batters, NFWB = Northern Field Western Batters, WFWB = Western Field Western Batters, WFSB = Western Field Southern Batters, SEFWB = South Eastern Field Western Batters, SEFSB = South Eastern Field Southern Batters, EFEB = Eastern Field Eastern Batters. HARA and HARE are the Hazelwood Ash Retention Area and Embankment, respectively

Batter design requirements

As detailed in Section 2, addressing Matter 1 of the referral, batter design is required to meet agreed criteria for the PoF both during filling and at the final water level. In addition to the geometry and properties of the geological formations, the PoF depends on the profile of the batter, which can be modified by earthworks, involving cutting back or filling in of the batter-bench surface, and the groundwater pressures below and behind the batter, which will be impacted by changes to the lake water level. Earthworks involving filling of the batter profile from the floor of the mine are referred to as buttressing while filling of the profile above the floor or behind the batter is referred to as surcharging. Buttressing should be completed prior to submergence of the mine floor adjacent to the batter being buttressed.

A typical feature of batter stability during lake filling is that as lake level rises the PoF slightly increases and after reaching a certain level (known as the critical pool level) the PoF decreases progressively again with increasing lake level. It is necessary, therefore, for any design to meet the required threshold(s) for PoF for all water depths.

Designing a batter profile below the final water level is usually solely undertaken for the purposes of ensuring stability and for meeting aquatic and erosion objectives in the upper part of the water profile. Designing a batter profile above the final water level is partly controlled by batter stability requirements but is also undertaken to support surface erosion management and surface water drainage, as well as to allow land access and alternative land uses.

Groundwater pressures behind the batters have a strong control on the PoF for the Latrobe Valley mines. Groundwater gradients behind the mine batters are typically controlled to be less than 6 degrees during mining and this limit is likely to be applied during lake filling to minimise the need for extensive earthworks.

At the end of lake filling and following the relinquishment of the mine, it may be expected that groundwater controls will be less stringent as the manpower, equipment and facilities available during mining will be withdrawn and the future landowners responsible for land management will have fewer resources. In this case, designs typically allow for steeper groundwater gradients at the final water level to guard against inadequate future controls.

The ability to control groundwater gradients during lake filling, including interim periods of minimal or no filling, are important for defining the required PoF criteria to be employed for design.

Local water sources

Local water sources may include rainfall and rainfall runoff, surface water supplied from regional storage reservoirs (Blue Rock and Moondara), excess water (e.g. during flood events) supplied from the local stream and river network, groundwater seepage and pumped groundwater. Net rainfall after accounting for evaporation from the lake surface is typically negative (i.e. annual evaporation exceeds annual rainfall). Groundwater seepage to a lake may be similar in magnitude to the seepage from the lake while the underlying aquifers are pumped to prevent ground instability. The use of a component of flood waters is possible but is presently not considered a long-term water supply source.

For these reasons the significant local water sources for lake filling during mine rehabilitation are the managed water sources comprising the surface water supplied from the reservoirs and pumped groundwater. Pumped groundwater is the most reliable of these two water sources but is insufficient on its own to fill the pit lakes in an acceptable timeframe. Surface water availability depends on climate-variable inflows to the reservoirs and the demand for surface water from all dependent water users.

The demand for water for the power stations will reduce as the power stations close. This water potentially becomes available for mine rehabilitation. However, it is likely that demand for surface water for the environment and other users will increase over time. It is also likely that the available surface water will reduce due to climate change. There is the potential over the medium-term for there to be insufficient water for all users if the most likely future demands and climate projections are found to be correct. There is also the potential over the short term for there to be insufficient water for users if droughts arise. Figure 3.2 (DELWP, 2022) highlights the annual variability of Latrobe River water, the current water demands, the significance of drought periods on available water, and the likely change in long term water availability.

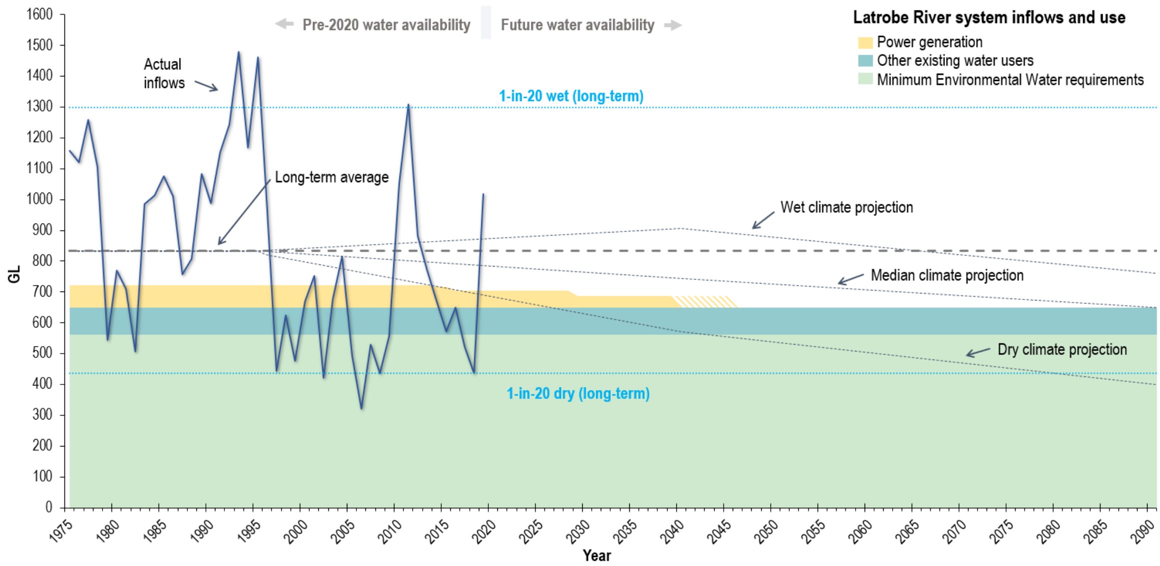

Figure 3.2 Water availability in the Latrobe River system: Latrobe River flows compared with minimum environmental water requirements and consumptive uses, including power generation (DELWP,2022)

Management of risks during filling

If local water sources are accepted as the sole water sources for mine rehabilitation, the time taken to fill Hazelwood is likely to extend well beyond 10 years and may exceed 30 years if water supplies are limited by drought and/or climate change. During the period of filling, there will be a low risk of batter failure if all ground controls are in place and working. The key controls for managing batter failure risks are ground movement monitoring, groundwater pressure monitoring, minimisation of surface water behind the batters, management of the land surface to prevent water infiltration to the coal through surface cracks and sinkholes, and drainage of groundwater in the batters using horizontal boreholes. The risks of batter failure will increase if these controls are not actively maintained.

The infrastructure for ground controls comprises predominantly ground movement pins, stability monitoring bores, and horizontal bores. As lake levels rise this infrastructure will be progressively submerged. Control management plans need to be able to react to this submergence and to any loss of functionality of the network. New stability and horizontal bores will be needed and access to the batter for installation will be required.

The risks of batter failure may also increase if the designed batter profile is modified through erosion processes. As the lake is filled there will be the potential for erosion due to wave action around the lake perimeter. This effect is anticipated to be small at any level if the lake rises through the level over a relatively small time period (measured in months). The effect may be exacerbated if the lake level is only slowly varying (over years) due to restrictions to water supply. Erosion reduction can be managed on shallow sloping areas using erosion protection. This may not be possible for steeply dipping areas. Detailed face mapping may be needed for such locations to ensure appropriate observations are made and, where necessary updated stability calculations performed. While the risks of erosion induced failure are not considered severe risks, assessments of the magnitude of the risks are warranted.

3.2. Reference water fill levels

3.2.1 Definition and purpose

A full pit lake at Hazelwood is defined by ENGIE as +45 m AHD, a definition that is adopted here. Reference water levels are defined here as:

1. A small number of intermediate lake levels between the deepest part of the mine at approximately -60 m AHD and full lake level at +45 m AHD.
2. Levels that may become the final lake water level if low water availability prevents further raising of the lake, covering matters such as:
    a. water balances that may facilitate long term water management to maintain lake levels.
    b. access to the batter above the reference level to carry out additional earthworks and coverage of the exposed coal above the water line.
    c. access to the batter to introduce ground control infrastructure for long term monitoring and maintenance.
    d. potential to reshape the region of water level variation of the different batters for ecological development and land/water connection.
3. A level at which all geotechnical information generated during filling is reanalysed to ensure that the final pit design will be safe, stable and sustainable.

In preparing the selection criteria of the set of reference levels insufficient time was available during this investigation to analytically confirm the criteria for completing a safe, stable and sustainable mine design at each reference level. Investigations are required to demonstrate designs for stopping and to assess the likely residual risks as well as the long-term monitoring and maintenance requirements.

3.2.2 Defined set of reference water fill levels

ENGIE have defined geotechnical domains around Hazelwood mine as shown in Figure 3.1(b). These domains were selected to represent regions of similar geology, geometry and environment. They provide a useful partitioning of the batters around Hazelwood mine for the selection of reference levels. Batter geometry varies within and between domains. Batter bench heights are variable spatially and roadways between benches are not present in all domains. For these reasons, it is not possible to define reference water levels that are consistent in their relationship to all batter features around the whole mine. The elevation of the mine floor also varies significantly over the mine area, with the deepest area of the mine floor located adjacent to the South-West Field Northern Batters

(SWFNB). Located at the base of the SWFNB are the water detention/settling ponds that collect rainfall runoff. The most significant features within the mine are the internal ash dump referred to as the Hazelwood Ash Retention Area (HARA) at the eastern end of the mine and the Hazelwood Ash Retention Embankment (HARE) that prevents spreading of the ash in the HARA.

The first step in reference level selection has been to define potential reference levels based on the bench heights on the SWFNB and the East Field Northern Batters (EFNB). The selection of these northern batters was chosen as this region presents the greatest consequences from batter failure given the proximity of significant infrastructure including the Prince’s Freeway, the southern area of Morwell, as well as transmission and drainage lines. Ensuring stability of these batters has the highest priority both during and post-filling. A height two metres below each bench elevation was selected for the potential reference levels. This would permit the full width of the benches to be used for redesign of the earthworks above the bench height. The number of potential reference levels were then reduced to address the additional selection criteria (outlined in Section 3.2.1) and to provide sufficient time to elapse between the transitions from each level to the next for the purposes of data collection and evaluation.

Five reference levels are identified: -34 m AHD, -25 m AHD, -6 m AHD, +16 m AHD and + 29 m AHD.

The reference levels -34 m and -25 m AHD are similar in the sense that the additional water volume required to transition from -34 m to -25 m is about 30 gigalitres (GL) and might be expected to occur in one, possibly two, years under typical water discharges to the mine. These levels can be considered equivalent for the purposes of the reference level set. The selection of one of these two reference levels as the most appropriate lowest reference level should be based on further hydrological investigation.

The approximate lake volumes at each level are 44 GL (-34 m AHD), 76 GL (-25 m AHD), 178 GL (-6 m AHD), 344 GL (+16 m AHD) and 470 GL (+29 m AHD). The fill volumes between consecutive levels from -24m AHD to +29 m AHD range from 76 GL to 166 GL. At 30GL/yr net inflow to the mine, the time to fill between consecutive reference levels would range approximately from 2.5 years to 5.5 years. This interval span is appropriate for the acquisition of new data and for the reanalysis of the data to refine the geotechnical models and to plan additional earthworks above each reference level or to refine Ground control management plans.

The extent of the lake at each reference level based on current pit geometry is illustrated in the figures from Figure 3.3 to Figure 3.7.

Figure *3.8* summarises all levels and shows the extent of the full lake level at +45m AHD.

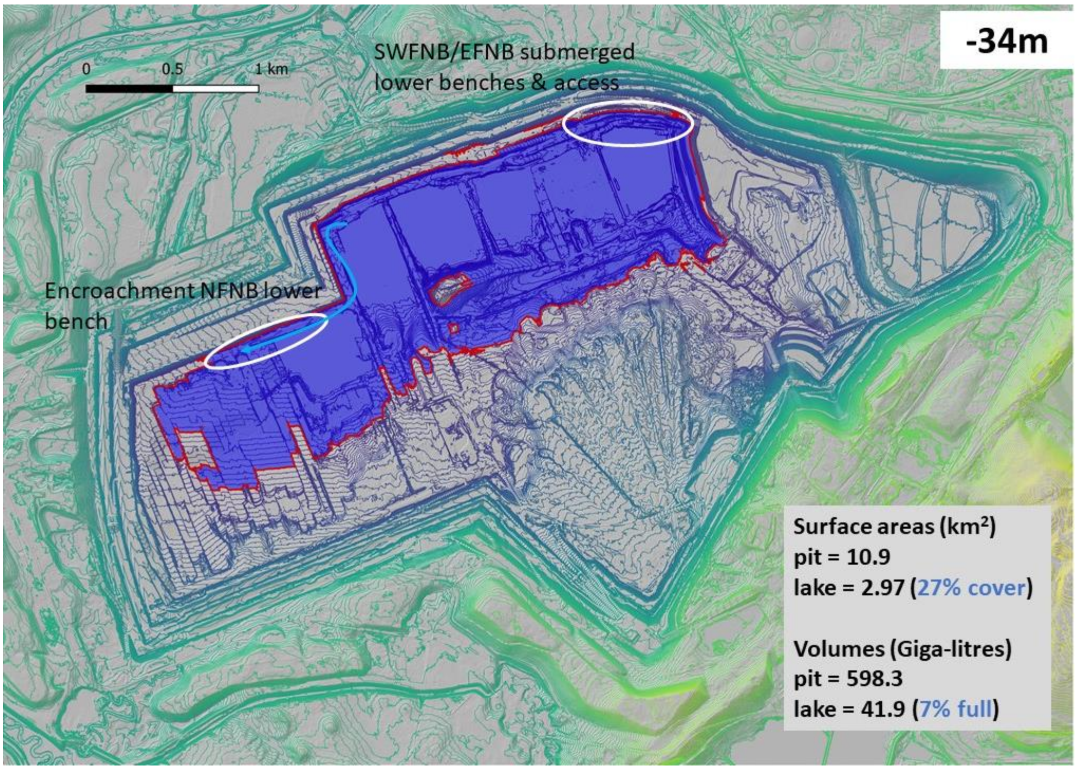

Figure 3.3 Lower limit of estimated hydrological equilibrium at -34m AHD and initial flooding of lower benches

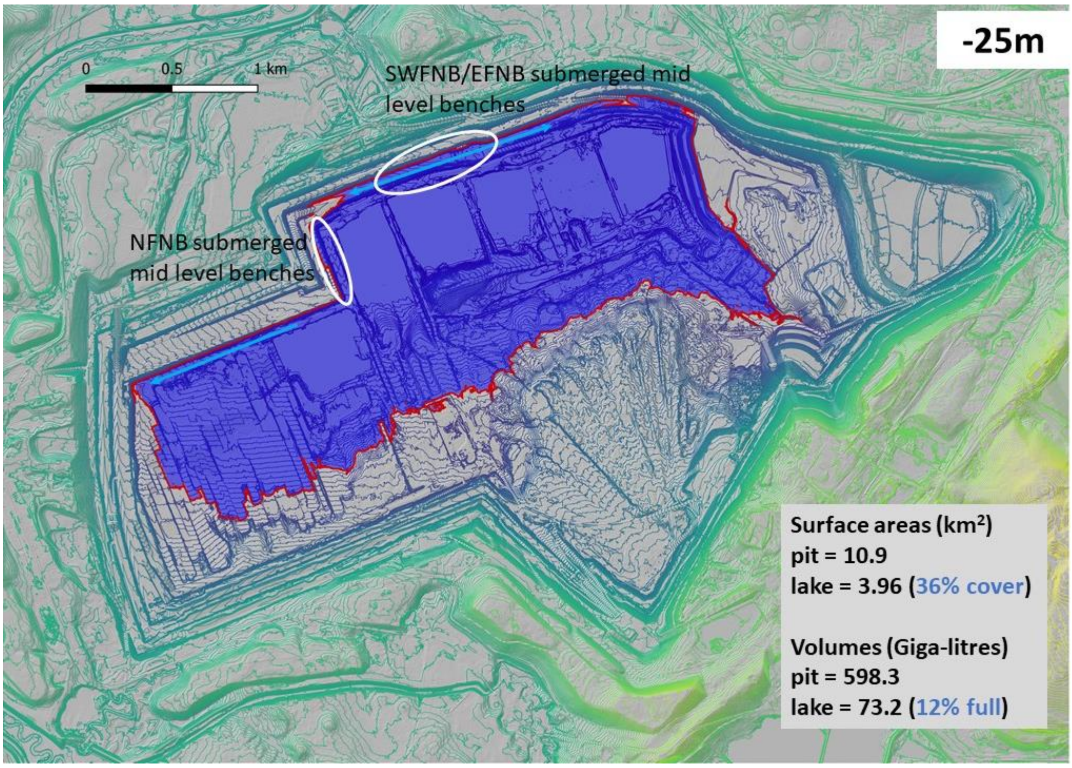

Figure 3.4 Upper limit of estimated hydrological equilibrium at -25m AHD

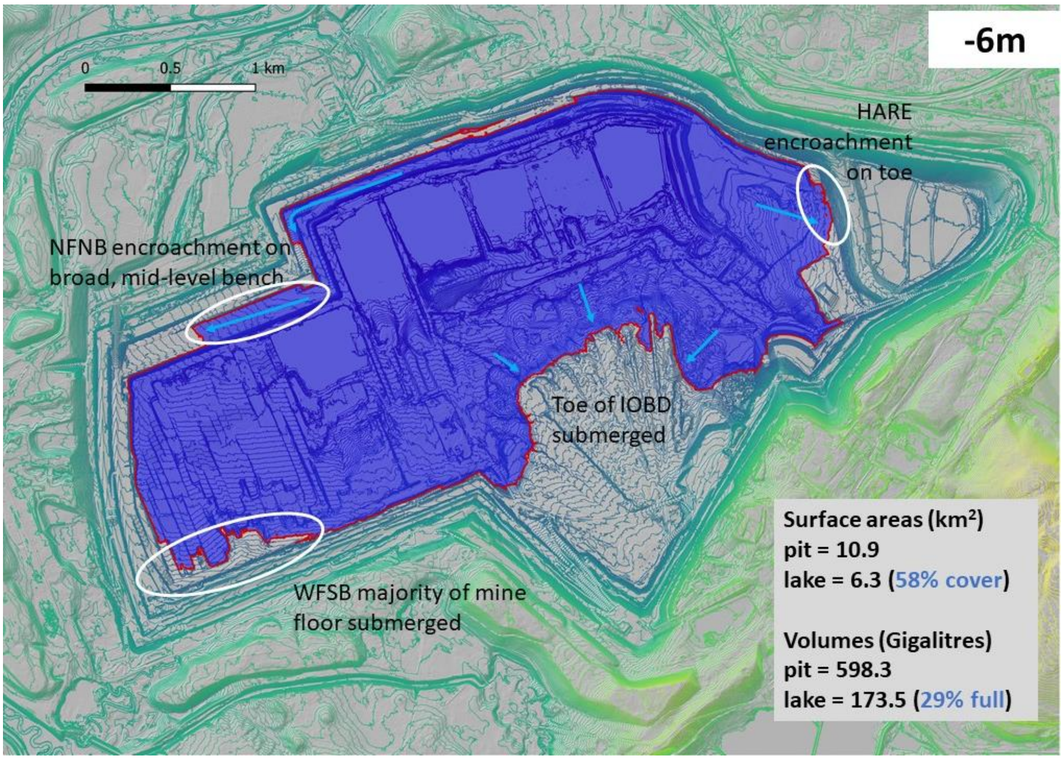

Figure 3.5 Encroachment of water at the base of the Hazelwood Ash Retention Embankment (HARE) at -6m AHD

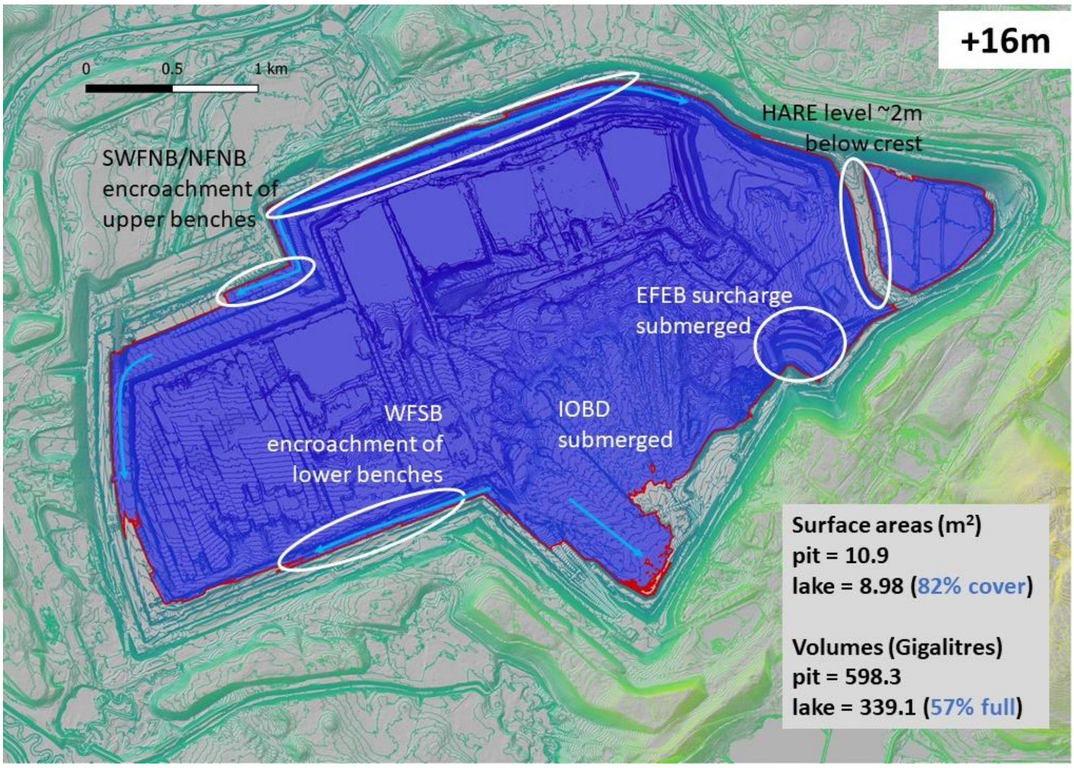

Figure 3.6 Water level is 2m below the crest of the HARE at +16m AHD. Approximate lower limit of hydrogeological equilibrium.

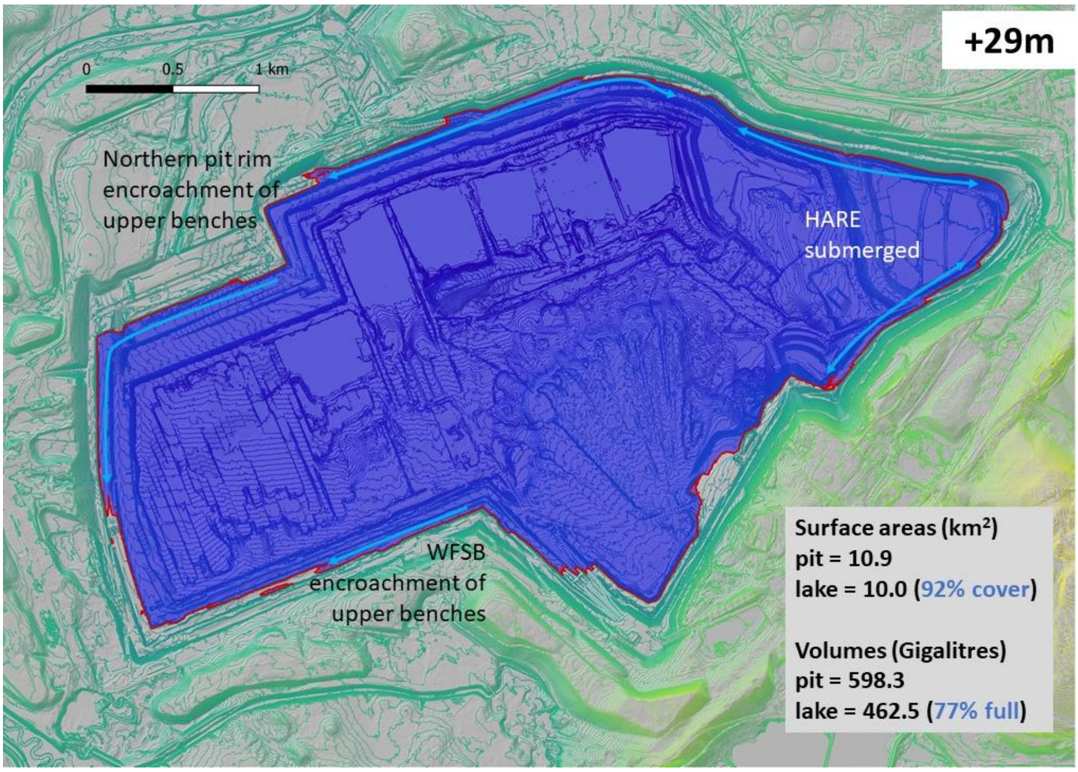

Figure 3.7 Water level at +29m AHD is the approximate upper limit of hydrogeological equilibrium.

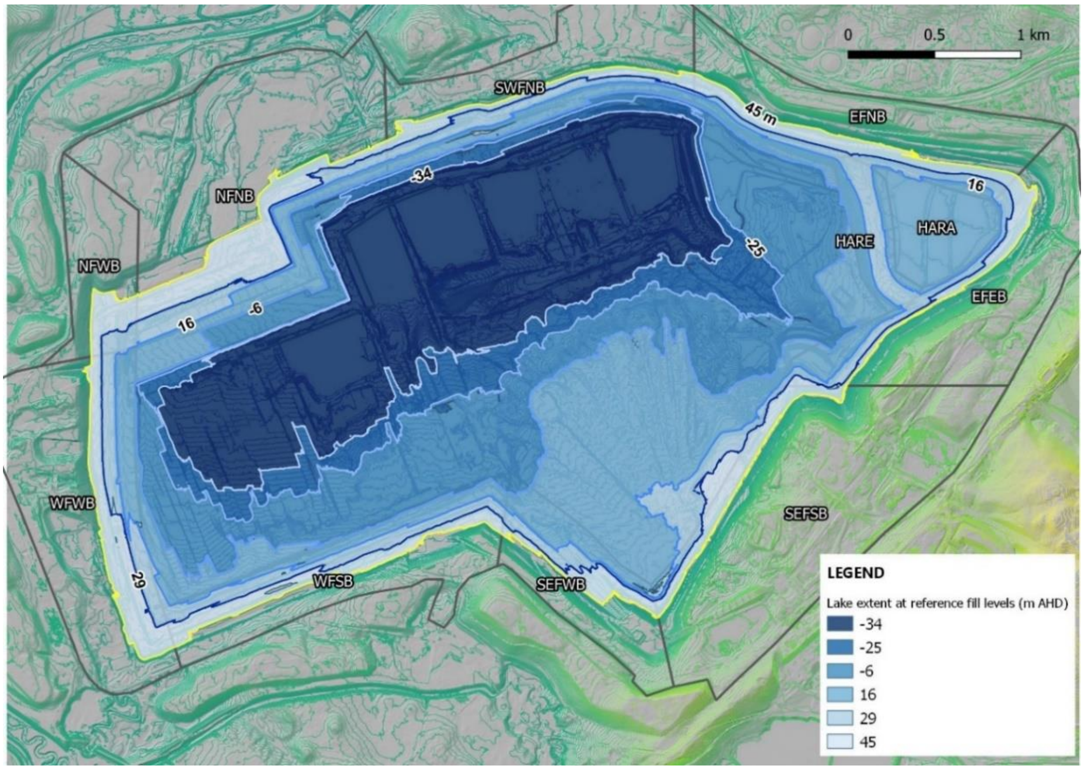

Figure 3.8 all selected reference levels (mAHD) and full pit-lake shoreline at +45m AHD (yellow) at Hazelwood. Geotechnical domains labelled for reference (solid grey)

Levels -34 m AHD and -25 m AHD are broadly in the range of expected hydrological equilibrium, Hydrological equilibrium is defined as the approximate long-term balance of inflows (rainfall and batter groundwater seepage) and outflows (actual evaporation and mine floor groundwater seepage). Neither pumped groundwater from the underlying aquifers nor surface water inflows are required to maintain this balance, however aquifer depressurisation is required to prevent floor heave. Discharges from the depressurisation bores can be used for productive discharge to the river system or commercial applications.

Level -6 m AHD is established to be below the toe of the HARE. Groundwater pumping to prevent floor heave is required for this lake water level. A component of the groundwater discharge will be needed to maintain lake level. The remainder can be employed for other productive uses.

Levels +16m AHD and + 29 m AHD are broadly in the range of expected hydrogeological equilibrium. Hydrogeological equilibrium is defined as the approximate long-term balance of inflows (rainfall, batter groundwater seepage and 'minimised' aquifer groundwater bore discharges) to outflows (actual evaporation). No surface water inflows are required to maintain this balance. Aquifer groundwater discharge will be the minimum to balance the lake and aquifer heads to prevent floor heave.

3.2.3 Transitions between levels

Important considerations for each reference level are:

1) The requirements for revisions to the groundwater monitoring and drainage network during filling; and
2) The timing and practicality of the final earthworks that might be required should the reference level become a final lake level.

Stability Controls

Stability controls will need to be maintained during the raising of water levels between each reference level and are not likely to change between reference levels. ENGIE maintain a network of monitoring bores and horizontal bores to control groundwater behind the batters and to manage batter stability. As the lake level rises the current network will become progressively submerged (Table 8) and will require regular revision to maintain adequate groundwater controls.

Table 8 Submergence of ground control infrastructure at each reference level. Based on information provided within the Ground Control Management Plan, v5, 2019 (ENGIE, 2019)

Reference level (mAHD)	Stability Bores submerged (100 total)	Drainage Bores submerged (338 total)
-34	12	109
-25	19	139
-6	24	216
16	36	293
29	46	320

Submergence of horizontal bores does not imply that they will stop working. However, internal movements within the coal may occur during re-saturation that might impact flows to individual bores during submergence. Re-drilling of bores below the water line is assumed to be impractical. In this case new bores above the lake level may be required to compensate for the reduction of drainage capacity.

The requirement for new bores and their installation elevation needs careful assessment. The TARPs surrounding the loss of effectiveness of the horizontal bore network due to submergence needs to be fully articulated in the rehabilitation Ground Control Management Plan. The allowable elapsed time between a trigger and a new installation needs to be defined. The siting of horizontal bores also needs to be specified. Placing horizontal bores too close to the elevation of the lake level may render their effectiveness to be too short-term. Conversely, placing horizontal bores too far above the elevation of the lake level to increase their longevity may reduce their short-term effectiveness for groundwater pressure control. Demonstrating the appropriateness of the TARP for replacement horizontal bores, if evidence of loss of functionality of the existing horizontal bore network is found, will be needed and appropriate adjustments made to the TARP established as necessary.

Submergence of the stability bores used to calculate groundwater pressures and gradients behind the batter should not prevent ongoing measurement but will reduce the usefulness of the measurements and a plan for new stability bore installations should be included prior to the transition from one reference level to the next. VWPs are typically employed for groundwater pressure measurements. These are reliable and relatively easy to install and should continue to be the preferred measurement method for all new stability bores.

While current information suggests a low risk of batter instability below the lake water level, there is likely to be merit in undertaking bathymetric surveys of the submerged portion of the batters after reaching each reference level to establish whether any slope profile changes below the water line have taken place due to mass movements such as sliding and toppling. Updated stability assessments will be needed where significant mass movements are observed to have taken place.

Transition earthworks

Further earthworks will be required if a decision is made to stop filling at one of the reference levels. The timing of the decision to stop filling will impact the scale and form of the earthworks required. It may also impact the long-term groundwater controls that will be needed to control groundwater gradients behind the batters.

If a new stopping level is selected (below +45 m AHD), there are essentially two possible decision points in time for each reference level. The first decision interval is during the filling stage prior to the water level reaching the reference level below the new stopping level. The second decision interval is during the filling stage to the new stopping level. The difference between these two decision intervals lies in the different opportunity to undertake major earthworks below the stopping level.

These options for decision points are graphically illustrated in Figure 3.9.

There are arguments for and against both decision points as illustrated in Table 9.

Invoking a decision to stop filling below the approved lake level ultimately relies on water availability predictions that may prove to be unfounded. Since such a situation cannot be avoided, the criteria for stopping need to be agreed between the mine operators, regulators and water managers from the outset to avoid conflict. Stopping early will involve additional costs, both capital and operational. It is also likely to lead to a higher residual risk profile, including greater risks of uncontrolled ground movements in the long term.

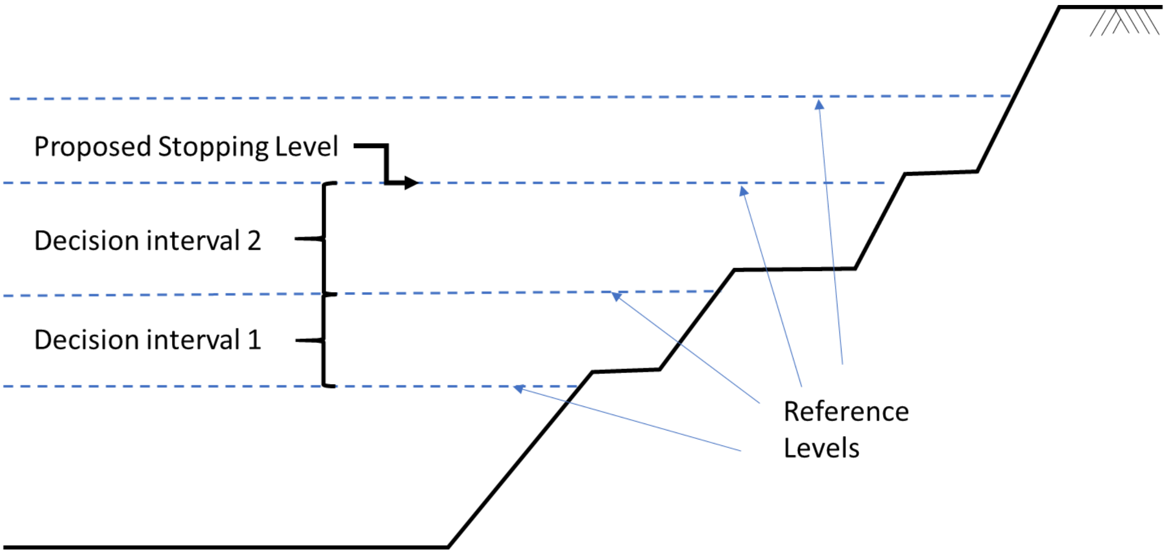

Figure 3.9 Illustration of Decision points using a schematic batter section

Table 9 Pros and Cons of alternative decision intervals

	Arguments for and against	
Decision Interval	For	Against
1	1. Early identification of lowered lake form providing greater time for further investigations. 2. Opportunity to undertake major earth works below the final water level. 3. Opportunity to shape the final landform in the interval of predicted final water level fluctuation for wave erosion control and ecological benefit.	1. Very early decision on final water level. 2. May involve a very long period between decision and completion of fill to final stopping level. 3. Achievement of final stopping level still not guaranteed.
2	1. Decision delayed for as long as possible to give best insight into the climate's trajectory. 2. Lowest risk of not achieving planned stopping level.	1. Reduced scope for final landform redesign. 2. Depending on decision time, may require a period of inactivity while final design studies are completed and approved.

3.3. Ground control management plan

A review has been undertaken of the relevant parts of ENGIE's Ground Control Management Plan ver 7 (ENGIE, 2021) applicable to lake filling. It is noted that the GCMP assumes a two-stage filling process. The first stage covers the period of filling to lake level -7 m AHD and includes studies required to confirm and/or update the geotechnical, hydrogeological and hydrological models. The second stage covers the remainder of the filling period to final lake level +45 m AHD.

The defined set of reference levels proposed through the current investigation effectively increases the number of stages to 5 and promotes the concept of regular updating of the models on a broadly 3-to-5-year cycle to ensure that they are up to date and the outputs from the updated models are used to adjust rehabilitation designs and plans accordingly.

Adopting a more frequent period of updating as well as other contributions by the current investigation means that the following aspects are identified for further consideration as part of future updates to the GCMP prior to submission of a work plan for final rehabilitation:

1. Further studies
2. TARPs for Groundwater control
3. Data collection and model testing
4. Risk assessment

3.3.1 Further studies

If the concept of multiple reference levels and the basis for these levels is accepted, then the additional studies to be completed as part of the forward assessments will be the determination of the most likely long-term hydrological equilibrium and long-term hydrogeological equilibrium levels for the lake. The current estimates for these levels have a wide error margin and need to be refined. The potential significance of these equilibria lies in their minimisation of surface water use for mine rehabilitation over the long-term. The limitations of these levels are the long-term management costs and increased residual risks. The likely times to achieve equilibrium and the approaches to achieving hydrogeological equilibrium with minimum operational requirements should also be addressed. The second part to these studies will be the assessment of the long-term changes to water quality at both equilibria and the strategies that might be adopted to control salinity and nutrient levels within acceptable ranges.

Further studies are also justified on the geotechnical designs required to minimise long-term monitoring and maintenance for the northern batters (SWFNB and EFNB) for a lowered lake form. Of particular interest will be the assessment of the trade-offs between batter access, erosion control, ecological connectivity, earthworks and surface and groundwater controls to meet the long-term requirements of safe, stable and sustainable.

3.3.2 TARPs for groundwater control

The groundwater trigger levels identified in the GCMP need to be consistent with the Factors of Safety and Probabilities of Failure used for design. In the GCMP, batters are assigned to slope categories 3 and 4 based on risk. Minimum FoS for category 3 is 1.5 and for category 4 is 2.0, with maximum probabilities of failure of 5% and 0.5% respectively.

The lowest trigger level (Level 2) where actions are required in the GCMP are Factors of Safety of 1.2-1.3 for category 3 and 1.3-1.5 for category 4. These equate to probabilities of failure of 16% to 26% and 5% to 16% respectively. At the highest trigger levels (Level 4) the probabilities of failure exceed 40%, which seems far too high to be acceptable. It is also relevant to note that during lake filling, corrective measures may take longer to implement and be less effective due to the constraints of working adjacent to a water body. For these reasons, it is recommended that the trigger levels and actions are subject to careful review and updating in the GCMP to be consistent with the ranges of PoF applicable to Batter stability design.

While triggers based on Factors of Safety make it easier to prepare a common description of the required TARPs for all batters, the application of these in practice is less simple as the key measurements are groundwater levels and gradients and factors of safety will change with changes to both levels and gradients. Consideration should be given to developing triggers that are directly related to measurements, specifically the groundwater gradients.

3.3.3 Data collection and model testing

Monitoring the surface of the mine below the water line, particularly along the mine walls should be considered as part of the future data collection program. It will be important to demonstrate that the mine batters are performing as designed and that unseen events are not occurring that could increase batter failure risks.

To quantify the hydrological conditions in the mine, local meteorological data must be collected to quantify key variables such as evaporation rates and wave heights. Rainfall alone is not sufficient to support hydrological modelling. Adoption of regional meteorological station data outside of the mine is unlikely to capture the meteorological conditions operating within the mine void. A review of the adequacy of the data collection network is warranted to ensure that the information gathered is suitable and complete.

Re-calibration and updating of the geotechnical, hydrogeological and hydrological models is planned through the GCMP as new data are acquired. The current proposal in this report is that all models should be re-calibrated when each reference level is reached and that the outputs from the models are used to update predictions of environmental conditions including groundwater rebound, lake filling rates, ground movements, and geotechnical risks for the remaining fill period. The cycle of updating the models is expected to be between 3 and 5 years, which allows sufficient new data to be collected to be useful for model testing and to capture unforeseen knowledge gaps and events. Re-calibration of models on these timescales is generally accepted as good practice for most environmental settings.

3.3.4 Risk Assessment

Risks will change during filling. The consequences of a batter failure during filling are likely to be more severe due to the greater difficulty of effecting repairs leading to longer repair times and higher costs. The social consequences of a failure may also be much greater in terms of community loss of confidence in the rehabilitation approach. These do not appear to be adequately considered in the GCMP risk assessment process to date and may warrant further assessment.

3.4. Summary of recommendations

The recommendations arising from this matter are:

7. *The triggers, actions, responses and plans (TARPs) surrounding the loss of effectiveness of the horizontal bore network due to submergence should be fully reviewed and updated in the rehabilitation GCMP.*
    b. *The trigger levels should be consistent with the ranges of probability of failure adopted for batter stability design.*
    c. *The replacement plan for horizontal bores, including timelines for replacement, should be fully described.*
    d. *The replacement plan for new stability bore installations should be addressed with a recommendation that new bores are installed for each lake level transition between reference levels prior to the transition.*

8. *Bathymetric surveys of the submerged portion of the batters after reaching each reference level should be undertaken to establish whether slope profile changes below the water line have taken place due to mass movements such as sliding and toppling.*

9. *If the concept of multiple reference levels and the basis for these levels is accepted, then additional studies should be undertaken to determine the expected long-term hydrological equilibrium and long-term hydrogeological equilibrium levels for the lake.*
    a. *An assessment should be undertaken of the long-term changes to water quality at both equilibria and the strategies that might be adopted to control salinity and nutrient levels within acceptable ranges.*

10. *Further studies are recommended on the geotechnical designs required to minimise long-term monitoring and maintenance for the northern batters (SWFNB and EFNB) for a lowered lake form. Of particular interest will be the assessment of the trade-offs between batter access, erosion control, ecological connectivity, earthworks and surface and groundwater controls to meet the long-term requirements of safe, stable and sustainable.*

11. *A review of the adequacy of the hydrological data collection network is warranted to ensure that the information gathered is suitable and complete.*

4. Rehabilitation Risks (Matter 3)

4.1. Introduction

This section covers the third matter requested for investigation and addresses the following:

> *Identify the risks to the environment, to members of the public, land, property or infrastructure and the controls/mitigation strategies needed to eliminate or reduce those risks as far as reasonably practicable to safely manage water fill at the declared mine land, including:*
>
> *a. the sufficiency of the licensee's assessments of the risks to the environment, members of the public, land, property and infrastructure*
> *b. the adequacy of the licensee's proposed controls/mitigation strategies to eliminate or reduce those risks as far as reasonably practicable;*
> *c. risks associated with dewatering the declared mine land and types of relevant controls, if works are later determined to be necessary to manage risks arising from dewatering the declared mine land;*
> *d. recommendations for an adaptive monitoring, assessment and management approach of geotechnical and erosional risks for a rapid and/or episodic water infill.*

Each of the itemised elements are considered in turn. Items a and b are closely connected and are considered together in Section 4.2. Item c is covered in Section 4.3. Item c is quite specific as it deals with the concept of draining a lake after commencement of water fill. The justification for this action is assumed to arise either for the purposes of transitioning to a new landform based on a lowered lake form/dry void or for the purpose of strengthening one or more batters if the landform design is deemed to be unsafe and alternative methods of correcting the design deficiencies without dewatering cannot be found. Section 4.4 covers Item d. It assesses the extent to which the current Ground Control Management Plan (GHD, 2021) can deal with the range of expected ground movement and erosion risks during rapid or episodic water infill and whether additional requirements for monitoring and management are needed based on adaptive management approaches.

The following definition of adaptive management is adopted for the evaluation of item d:

> *A structured, iterative process of decision making under conditions of uncertainty, by aiming to learn about the system and to reduce uncertainty over time while meeting the objectives of risk management throughout the process.*

The initial observation in this report is that ENGIE has a clear understanding of the risks to the environment, to members of the public, land, property or infrastructure and the controls/mitigation strategies needed to eliminate or reduce those risks as far as reasonably practicable, but that the presentation of the risks could be improved to allow a reviewer to be sufficiently clear about the adequacy or completeness of the controls proposed. A supplementary observation is that the controls and mitigations have not been clearly updated to reflect the additional conservatism required during pit lake filling arising from issues of repairability of batters and machinery access to the batters for monitoring installations and maintenance.

4.2. Assessments and controls

ENGIE have set out their high-level closure objectives in their Rehabilitation and Closure Plan (ENGIE 2019a). These are reproduced in Table 10 below. Using ENGIE's numbering system, the key objectives linked to risks to the environment, to members of the public, land, property or infrastructure are: 2a (infrastructure, property), 2b (members of the public and land), 3 (environment, land), 5 (environment), and 6b (environment).

Table 10 Closure Objectives reproduced from Table 18 in ENGIE, 2019a

Objective number	Closure Objectives
1	As far as reasonably practicable, the site will be safe, with closure designs mitigating safety risks to users.
2a	As far as reasonably practicable, closure designs, implementation, and monitoring or maintenance for immediate post relinquishment land uses, will mitigate the potential for loss or damage to third party infrastructure or / and activities.
2b	As far as reasonably practicable, closure designs and implementation will reduce the risk of spontaneous combustion and bush fire to a similar level to comparable surrounding end land use, or otherwise, as supported by appropriate Scientific / Engineering advice.
3	As far as reasonably practicable, closure designs will ensure there is no net reduction to areas for native fauna and flora habitat.
4	Hazelwood Mine will, in conjunction with other stakeholders, work to create a positive legacy.
5	No adverse impacts to the aquifer system from contamination or pollution associated with the site, as assessed in accordance with the Waters of Victoria SEPP.
6a	Pit water quality are compatible with post relinquishment land uses and support natural ecosystems.
6b	No adverse impacts to surface water exiting the site from contamination or pollution associated with the site, in accordance with the Waters of Victoria SEPP.
7	Regulatory requirements and other project obligations are achieved.
8a	Community is engaged over the closure planning and implementation.
8b	As far as reasonably practicable, the end landform will be stable and non-polluting, and sustainable with ongoing monitoring and maintenance requirements being comparable to similar landforms.
9	The site landform will be rehabilitated to complement the surrounding environment with consideration of cultural heritage values, in line with the approved post closure landform.
10a	The landform shape, vegetation / surface cover and materials used for rehabilitation will be appropriate for the landform and post relinquishment land uses.

These closure objectives imply a general duty of care covering off-site impacts. The approaches employed to minimise and control risks to meet these objectives are consistent with this duty.

Each of the high-level objectives are considered in turn in the following sub-sections.

We note that since the development of these objectives, the Environment Protection Act 2017 came into effect on 01 July 2021 underpinned by the general environmental duty. The former State Environment Protection Policies (SEPPs) have been superseded by Environmental Reference

Standards. ENGIE's rehabilitation objectives will need to be updated to reflect current Victorian environmental legislation and standards.

Reviews have been carried out considering the main risk management manuals used by ENGIE for mine operations. These are the Risk Management Plan V4 (ENGIE, 2019a), Fire Risk Management Plan 2019 Volumes 1 and 2 (ENGIE, 2019 b.), and Ground Control Management Plan V7 (ENGIE 2021).

4.2.1 Objective 2a

As far as reasonably practicable, closure designs, implementation, and monitoring or maintenance for immediate post relinquishment land uses, will mitigate the potential for loss or damage to third party infrastructure or / and activities.

Closure designs and implementation that have the potential for loss or damage to third party infrastructure relate predominantly to mine batter stability and ground movements due to groundwater depressurisation and pressurisation that are expected to occur during and post rehabilitation.

Batter stability risk controls are considered through the development and implementation of appropriate design criteria and design practices. These are addressed under investigation Matter 1 and are not considered further here. Management of controls to ensure conditions are consistent with a batter's design are addressed under Matter 2.

Ground movement risks are considered further here. Ground movements take place due to changes in loading, subsidence, rebound and creep. Pressurisation of the groundwater will cause some rebound of the ground surface, particularly close to the mine, and this may commence during lake filling. Pressurisation of the groundwater in the coal may occur before pumping ceases in the underlying aquifers due to the rise in lake water levels. The extent of any rebound will depend on the interplay between ongoing consolidation of formations due to aquifer depressurisation and expansion of the coal due to lake level rise induced groundwater pressurisation. Since regional rebound is expected in the long term when aquifer pumping ceases, monitoring and quantification of impacts on the surrounding sensitive receptors must be carried out and appropriate arrangements for remedial measures put in place. While the timeline for achieving a full pit lake and cessation of aquifer pumping is long, there is a need for the impacts of the lake filling to be examined and appropriate mitigations and remedial measures to be established during the early stages of lake filling.

ENGIE's GCMP (version 7) identifies the need for damage risk assessments during filling and presents an outline approach to mitigate risks to achieve tolerable risk levels throughout the fill period. The plan differentiates between stable and unstable movements and notes that stable movements, which cannot be prevented, have occurred historically and should be considered in assessing risks to infrastructure beyond the pit crest. Unstable movements are typically characterised by rapid, large scale ground movements such as the Yallourn batter failure in 2007, which moved a large block of coal into the mine and diverted the Latrobe River. Stable movements are those associated with subsidence and with lateral movements that occur and then cease without causing extensive damage.

The movement of the Princes Freeway in 2011 and the cracking of the Latrobe Road in 2014 are both examples of stable movements, even though both caused significant concerns at the time. Neither movement caused complete collapse of a batter nor major changes to the affected infrastructure. It is noted that incremental, stable, movements in the early filling period are considered by ENGIE as presenting negligible damage risk. However, incremental lateral movements in the past have led to higher movement risks (such as the Princes Freeway and Latrobe Road movements) by allowing water inflows to the coal and rapid groundwater pressure changes to occur. Incremental stable movements should not automatically be assumed to have low consequences. It is necessary for incremental, stable, movements to be monitored and mitigated (e.g. sinkhole formation) where these might lead to higher risks of less tolerable, unstable, movement.

It is recommended that further review of the risks to infrastructure from incremental stable movements is undertaken to ensure that secondary, but potentially higher, risks arising from such movements are adequately captured in the Ground Control Management Plan.

Other adjustments to the GCMP are required to support lake filling. These are identified under Matter 2 of this investigation in relation to the TARPs related to batter movement risks.

Closure implementation matters that have the potential for loss or damage to third party activities relate to fire, dust, odour or any other airborne contaminants resulting from rehabilitation activities as well as uncontrolled ground movements must also be addressed. Fire is considered in Section 4.2.2 .

Dust reduction from the overburden dumps and ash ponds external to the mine will continue to be a requirement throughout the closure period and should be managed using suitable long term covers. Dusts within the pit will arise from the exposed pit floor and batters prior to inundation with water. Maintaining dust reduction measures including sprinklers during filling should occur on the exposed mine floor. In the Risk Management Plan dust is examined as an impact on amenity and not an impact on health. This is potentially too simplistic and should be revisited to examine both health and amenity impacts more fully.

To date, dust suppression is managed by the operation of the fire spray systems, vegetation capping of all exposed ground surfaces and mulching and eventual capping of ash landfills. As such, few problems are anticipated from fugitive dusts as long as the management processes are effective and regulation and community testing of these processes is carried out.

Odours are not anticipated to be significant during the mine closure period. If they do occur the source is likely to be highly localised and should be treatable.

The Ground Control Management and Risk Management Plans identify each of these broad categories of hazards and potential consequences to external receptors but do not appear to provide specific examples of possible hazards. Procedures are in place to manage dusts and incidents that are relevant to these hazards.

4.2.2 Objective 2b

As far as reasonably practicable, closure designs and implementation will reduce the risk of spontaneous combustion and bush fire to a similar level to comparable surrounding end land use, or otherwise, as supported by appropriate Scientific / Engineering advice.

Fire risks during water fill arise from the potential ignition of the remaining exposed coal above the lake water level. The range of ignition events that can arise during rehabilitation are similar to those for an active mine, including self-ignition, lightning, bushfires, arson, hot working, hot vehicle exhausts. The likelihood of ignition events is lower during rehabilitation due to the smaller exposed coal area and the reduced site activity levels, in terms of fewer vehicles and other machinery. Access to exposed coal batters will change given the presence of the lake and may make access for fire suppression more difficult in parts of the mine. The lack of access during lake filling is offset partly by access to water for fire suppression. The lake will cover significant areas of currently exposed coal.

External risks arising from a fire are identified by the mine's Fire Risk Management Plan and cover:

- Ash and smoke pollution
- Damage to critical power supply Infrastructure
- Health effects on sensitive receptors

Sensitive receptors are identified to be those within 1 km of the mine crest. This range is based on buffers published by the EPA.

Controls to mitigate risks are identified through fire prevention and fire suppression pathways combined with fire readiness measures, including coordination with fire and emergency management agencies. Fire prevention provides the first line of defence. Fire readiness provides the second line of defence. When a fire is initiated fire suppression provides the final line of defence. Each line of defence is appropriately described in the Fire Risk Management Plan in conjunction with the Emergency Management Plan.

As the mine fills, relocation of the fire service system is anticipated. Hydraulic assessment of the removal of pipework during filling has been analysed, including instatement of new pipework to ensure integrity of the fire service system.

It is recommended that ENGIE Hazelwood regularly review access arrangements for fire suppression as the lake level rises. It is also recommended that mine floor spray systems remain active on the exposed mine floor to manage dusts and limit fire risks just to the batters.

Coal exposure around the perimeter of the mine on completion of rehabilitation may arise due to fluctuating water levels and wave erosion. The need to maintain coal cover in the zone of water level fluctuation would depend on fire risks and erosion rates. As maintenance of coal cover in this zone would likely be a significant activity, it would be worth undertaking a study to assess coal fire risks and erosion risks for this zone in the absence of coal covers and to assess the acceptable maximum height of exposed coal as part of the long-term final design for the rehabilitated mine.

4.2.3 Objective 3

As far as reasonably practicable, closure designs will ensure that there is no net reduction to areas for native fauna and flora habitat.

Impacts to native fauna and flora habitat have occurred during mining due to the relocation of rivers, excavation of the mine void and the creation of the external overburden. As far as reasonably practical these have been mitigated during the mining period. Activities during the closure period are not expected to further impact on the local flora and fauna. However, controls are in place to continue monitoring of native vegetation to confirm that long term changes are not occurring. The effectiveness of these controls has not been assessed as part of this investigation. Within the risk management plan the concern for native flora and fauna is focussed on potential contamination events.

It is worth noting that rehabilitation is an opportunity to increase and enhance areas of native flora and fauna habitat and that this should be explored as part of the design process.

Contamination that may exist or occur within the mine void is not likely to move off site and impact downstream flora and fauna during the period of mine closure due to the prevailing flow directions for both ground and surface water, which are towards the mine.

Contamination within the overburden dumps and the external ash dumps can potentially migrate offsite due to long term seepage to water courses and impact flora and fauna. Work is presently ongoing on the Eastern Overburden Dump to reduce infiltration and limit contaminated water seepage and offsite migration. Such activities are being assessed and remediated via the Vic EPA contaminated land audits process. Ongoing maintenance of cover systems to reduce infiltration of landfill areas will be needed long-term. Consequently, there is an ongoing requirement to maintain surface water quality monitoring for the long term to ensure that any contamination does not exceed acceptable limits and can be remediated appropriately.

The diversion of surface water from the Morwell River is not presently considered an option for the filling of the void, though there is merit in considering floodwater diversion to the mine to mitigate downstream flooding in the future. A diversion has been constructed to temporarily take flood water from the Morwell River as part of measures to support the repair of the Morwell River Diversion at Yallourn. The continued use of this diversion beyond the completion of the repair has not yet been addressed. If the recently observed extreme flood event in June 2021 represents a climate condition that is likely to become more commonplace even as the climate is drying, then the value of diverting flood river waters to the mine may become relevant both for filling and long term river management. Diversion of flood waters would need to ensure the maintenance of the river's health and that there is no adverse impact to flora and fauna.

Extended periods of low flows are more likely to impact areas such as the Morwell wetlands. For these to be exacerbated by the mine, seepage from the Morwell River and the wetlands to groundwater would have to be enhanced by mine induced depressurisation of the formations. The Authority has not been able to find any documented or undocumented evidence of significantly enhanced seepage from the Morwell River but the nature of movements of the coal due to relaxation of the stresses in the formations caused by mining suggest that care should be taken to monitor groundwater-surface water interactions along the river that might lead to higher surface water seepage and the exacerbation of droughts in future.

Contamination and flow risks to flora and fauna will change if a full pit lake with connections to the Morwell River is achieved. This is discussed briefly in Section 4.2.5 .

4.2.4 Objective 5:

No adverse impacts to the aquifer system from contamination or pollution associated with the site, assessed in accordance with the Waters of Victoria SEPP.

The risks of contamination to the deeper more extensive M2 aquifer are assessed by ENGIE to be insignificant. Risks of contamination of the aquifers is restricted in the risk assessment to the shallow M1 aquifer which lies close to the base of the mine. The limited regional extent of the M1 aquifer limits the potential for long term regional contamination. This assessment appears reasonable.

Even if contaminants (including the different water quality of the lake water and deep percolation of leachate from the HARA) were to migrate over the period of mine closure towards the underlying M1 and M2 aquifers the groundwater dewatering pumps would capture the contamination and return it to the pit lake as part of the long-term filling of the lake, limiting impact to regional receptors. Post-closure, the groundwater dewatering would cease, and groundwater levels would rebound. During the period of rebound some potential for ongoing groundwater contamination due to seepage would occur, but its impact would be localised. The cone of depressurisation would ensure that any contamination is held over the long term within the vicinity of the lake. Risks to regional receptors from groundwater contamination would likely remain very low unless significant groundwater exploitation for other purposes occurred near the mine over the long term. The low levels of contamination that could arise from lake water seepage, when diluted regionally would be highly likely to represent very low risks regionally.

Recommendation to monitor water quality of the aquifer discharges from the depressurisation pumps for both the M1 and M2 aquifers on at least a monthly basis.

4.2.5 Objective 6b:

No adverse impacts to surface water exiting the site from contamination or pollution associated with the site, in accordance with the Waters of Victoria SEPP.

Surface runoff impacts from contaminated soil, poorly capped landfills or highly sedimented runoff are all managed under EPA contamination assessments. Consideration of contamination on flora and fauna has been addressed in Section 4.2.3 . Sediment generation from earthworks is possible but is likely to be restricted to migration on site rather than offsite.

Although not requested under the current investigation, the impacts to the external water environment for a full pit lake connected to the Morwell River do need to be considered. Such impacts include changes to the flow regime in the river and its downstream wetlands as well as the possible changes to the river and wetland’s ecological functioning.

The impact of a permanent connection of the lake to the Morwell River would need to be examined in terms of both changes to water quality and in changes to flows. To understand these changes, detailed hydrological and water quality modelling is required. The scale of impacts that might arise will depend to a significant degree on the design of the intake and outtake structures adopted for the connections of the lake to the river.

Flood risks are identified by ENGIE from mine infrastructure outside of the mine void. Flood risks from mine infrastructure can be appropriately alleviated by diversion of excess water to the mine. If infrastructure for a flood water diversion can be constructed, this option for flood control would be appropriate during the period of mine water fill and potentially for post closure also.

4.3. Dewatering risks

Dewatering as described by the investigation Matter 3c relates to the lowering of the lake level or complete emptying of the lake after a period of water fill. The purpose of dewatering is assumed to arise from two possible decisions. First, monitoring of stability of the mine has identified serious flaws to the rehabilitated landform design that cannot be rectified meaningfully without (partially or fully) dewatering the pit lake. Second, a decision has been taken to re-open the mine for the purposes of brown coal extraction. While neither decision is currently considered likely, there is still a requirement to investigate the possible consequences of a decision to commence dewatering and the issues to be explored prior to commencement.

Stability risks are driven by three main features of the batters at Hazelwood: groundwater gradients behind the batters, rapid surcharging of joints behind the batters and effective shear stresses in the interseams on which block sliding is found to occur.

Lowering the lake raises the likelihood of increasing the groundwater gradients behind the batters. The rate of lake lowering coupled with the permeability of the coal and the effectiveness of the horizontal drains will largely control the likelihood of increasing the hydraulic gradient. It is not clear that the integrity of the horizontal drains will be maintained during lake filling and this concern will also apply to lake emptying. Designing and installing horizontal bores during lake dewatering may prove to be more complex than for lake filling given lowering the lake water level will impact the longevity of each bore.

Increases in pore water pressures within the interseam clays below the batters will take place during lake filling. The time for porewater pressures to rise as water level rises is likely to be relatively long given the thickness and low hydraulic conductivity of the clays. The generally slow recovery of pore water pressures as the lake level rises will be matched by a similarly slow level of dissipation of pressures as the lake level falls. Rapid dewatering of the lake may lead to retained high pore water pressures in the clays even though the coal above may be partially desaturated. The combination of higher porewater pressures and lower total weight of material above the clays may lead to a loss of effective shear strength and increase the risks of batter failure.

Lowering the lake level may lead to the reactivation of horizontal and vertical movements in the coal and overburden behind the batters. This may lead to opening of sinkholes and the potential for surface water inflows to the coal. If surface water control and monitoring of sinkhole formation are not undertaken appropriately, then the risk of surcharging of the coal joints becomes a possibility.

The combination of potentially higher groundwater gradients with surcharged coal joints coupled with lower effective shear stresses in the interseam clays could significantly reduce the overall FoS for the batters and increase the risks of batter failure to an unacceptable degree.

Good monitoring and maintenance coupled with a clear assessment of the rates at which dewatering can be safely undertaken will be essential. Safe dewatering rates will require groundwater modelling coupled with monitoring to both calibrate and validate the model results. Modelling will need to assess the performance of coal dewatering and the depressurisation rates of the interseams. Monitoring will require additional vibrating wire piezometers (VWPs) located in the at-risk batter interseam layers as well as maintenance of the stability monitoring bores measuring the groundwater gradient. Maintenance of the horizontal bores will also be needed. Additional horizontal bores will be required regularly as water levels decline unless the submerged horizontal boreholes during filling can be demonstrated to be operational.

Dewatering the pit lake will also reactivate subsidence and will re-expose the coal. Reactivation of ground movements may impact sensitive receptors away from the mine void. Ground monitoring will likely need to be enhanced during dewatering depending on the rate of dewatering. Fire risks are likely to be increased depending on the depth of coal exposed and will similarly need to be managed through reinstated fire risk management procedures.

Water quality considerations will also need to be addressed both for the lake water and the receiving waters for the lake discharges. The internal ash landfill (HARE) will have a higher leachate discharge rate to the lake during dewatering. Care will be needed to show that the leachate does not lead to a potential contamination issue and that the discharge of leachate can be appropriately diluted within the lake water body through mixing.

Turbidity and water quality of the lake water, notably during the final stages of dewatering, may be poor and require treatment prior to discharge to the river network or significant dilution through low discharge rates to achieve acceptable water quality in the receiving waters. Throughout the dewatering process there will be a need for continuous water quality monitoring and discharge controls. Care will also be needed to address issues of odour arising from the rotting of aquatic vegetation and any organic rich sediments that may have accumulated.

There is also a risk that the aquifer depressurisation bores may be put at risk by ground movements. Lateral shear movements within the coal are possible because of dewatering that could shear the casings of the depressurisation bores. Monitoring, maintenance, and replacement of these bores will need to be addressed as part of the dewatering program.

For reasons of stability and water quality it seems likely that dewatering of the mine lake would need to be completed slowly and at considerable cost in terms of new infrastructure and heightened monitoring and maintenance.

In summary, dewatering of the pit lake after commencement of filling involves a range of challenges both for the disposal of the mine water to the river system and the management of groundwater pressures in the coal behind the batters. It is expected that the lowering of the lake level can only happen slowly due to constraints on discharges and batter failure risks. A robust groundwater monitoring system will be essential to minimise batter failure risks. At this stage it is not clear whether the in-situ horizontal drainage network will perform adequately. Work may be needed to define methods for batter depressurisation during water level reduction. If new horizontal boreholes are needed, the design and installation of these might not be as straightforward as it would be for lake filling.

If dewatering is to be considered then:

- Studies must be undertaken to assess integrity of submerged horizontal bores during filling
- Studies must be undertaken to assess groundwater responses behind the batters in both the coal and interseam to support parameterisation of a groundwater model applicable to dewatering.
- Modelling must be undertaken to assess the required controls for groundwater pressure gradients and dewatering rates
- Studies must be undertaken to assess the management of discharges to surface water courses

The MLRA is of the opinion that preference should be to avoid dewatering the lake once rehabilitation is underway.

4.4. Adaptive monitoring, assessment, and management approaches

As many of the outcomes of mine rehabilitation processes cannot be known with complete certainty, there is a need for an ongoing over-arching process of adaptation and change in response to new information. It is not appropriate or practical to assume that current knowledge is sufficient to achieve a final rehabilitated landform. The discussion of reference levels under Matter 2 is a particular case of the requirement for adaptive management processes. Climate change predictions are uncertain. With this uncertainty comes uncertainty about the possible end point for rehabilitation. A full pit lake is identified from current studies as the most likely to achieve a good safe, stable and sustainable outcome with the lowest residual risk profile, including minimum requirements for long-term active management of the landform and maximum opportunities for future productive use; however, the availability of water to complete a full pit lake landform is unproven and will remain unproven for many years, assuming only local water sources are available for water infill. It is necessary for an adaptive management approach to be employed, whereby decisions are made in the future about the final landform as information is generated on the trajectory of climate change for the region.

Adaptive management requires commensurate monitoring and assessment. For the case of a future decision on final water level an iterative process is assumed whereby new data are gathered on:

- the climate and water uses in the Latrobe Valley
- the rate of lake level rise
- ground movements, both above and below the water line
- groundwater conditions
- surface water hydrology

Assessments are then completed on an approximately three-to-five-year cycle to assess the adequacy of the final landform design and to assess the likely reliability of the water supplies for completion of water infill. To understand the significance of the new data and the new assessments, criteria are required against which to judge the performance of the rehabilitation and the likely future conditions. The criteria need to be agreed by all parties to be effective and to avoid the risks of disagreement if future decisions require changes to be made to the closure plans for the mine. A three-to-five-year cycle is likely to lead to enough new knowledge between assessments being created for useful analysis while not being so long as to minimise the opportunity for change at appropriate points.

While the overarching landform requires ongoing adaptive management practices as proposed by the reference level plans outlined under Matter 2, the adoption of adaptive management practices is warranted for almost all aspects of the landform design and the controls that are employed to ensure stability during closure as well as post closure.

While the investigation is asked to address the issue of rapid and/or episodic water infill, the requirements for adaptive management are not limited to these conditions. Even for the case of continuous water infill adaptive management practices are warranted. The following sub-sections highlight some of the management requirements that need to address the possibility of changes to the landform design and the controls used during closure.

4.4.1 Subsidence and rebound

Subsidence has proven to be relatively uniform to date with limited damage attributable to the lowering of the land around the mine. Rebound of the land surface will occur as groundwater pressures rise in the formations beneath and adjacent to the mines. The transition to water infill of the mine may result in some rebound due to expansion of the shallow formations during closure even though aquifer depressurisation may continue during lake fill causing ongoing consolidation of the deeper formations. At this stage little is known of the behaviour of the land during rebound. Modelling carried out by ENGIE suggests that the impacts should be small and limited to the region closest to the mine. While this is possible, the lack of ground truth requires a degree of caution until enough evidence is provided to confirm the modelling results. For this reason, there is a need for land movement monitoring to be continued using both pins and photogrammetric methods to establish the style of movements that are taking place and their relationship to water infill rates. It is particularly important for monitoring to be undertaken for all sensitive receptors. As data are gathered on movements, the modelling of rebound can be updated and the assessment of potential impacts on receptors improved. If evidence is presented that high water infill rates have a negative impact on differential movements of the land surface, then appropriate limits should be place on future water infill rates.

4.4.2 Lake loading

As the lake level rises, lake loading on the batter can occur depending on the rate of recovery of groundwater pressures in the coal behind the batters. Lake loading occurs because of the addition of water pressure onto the batter from the lake that is not counterbalanced by water pressures within the batter. Lake loading is most likely under high water infill rates. Lake loading can cause lateral ground movements away from the lake as the water level rises that may be reversed as the groundwater system equilibrates with the lake water level. The impact of compression and relaxation of the coal is likely to be exacerbated by fluctuating water fill rates. The scale of movements will have implications for the opening and closing of coal joints. In turn, this may affect the performance of the horizontal drains and localised stability of the batter. To quantify the significance of such movements, a program of monitoring of movements and groundwater conditions is required to progressively update the geotechnical models and risks to receptors and batter stability.

4.4.3 Stability monitoring and horizontal drains

Under Matter 2, the requirement to manage and update the stability monitoring and horizontal drain bore networks in response to water infill is described. The updating of both networks must be based on an adaptive management approach covered by an appropriate procedure in the GCMP.

4.4.4 Surface water management

The potential for surface water to accumulate around the perimeter of the mine and to be a water source for rapid pressurisation of coal joints will be an ongoing issue during water fill of the mine void and potential post-rehabilitation if full pit lake level is not achieved. The likelihood of surface water accumulations occurring in any area is dependent on the functionality of the surface drainage network and on the topography impacted by subsidence and rebound patterns. The likelihood of rapid infiltration of surface water will depend on the formation of sinkholes or cracks in the coal cover materials. A monitoring and assessment plan for surface water management will be needed that is responsive to the evolution of the landform around the mine.

4.4.5 Land erosion

ENGIE have undertaken studies of soil and vegetation covers for the exposed coal and overburden above final water level (for example Landloch, 2018a,b, Ecological, 2018) . Those studies provide some evidence for appropriate designs (cover types and vegetation densities) for the management of erosion and long-term stability of the shallow ground. However, the actual ground conditions around the mine may prove to be different to the conditions assumed for the experimental and simulation studies that have been completed so far. The possibility of adjustments to the cover designs must therefore be acknowledged in response to future data collection and ground truthing as the landform is completed. In addition to variable ground conditions around the mine, a variable future climate is also envisaged that may present additional complexities for maintaining the integrity of the vegetation cover during extended drought periods and intense periods of rainfall. New studies are also underway nationally and internationally that are investigating climate resilient vegetation communities relevant to mine rehabilitation (e.g Baumgartl, 2022). It is quite possible that these studies will identify new and better vegetations species and communities of relevance to the Latrobe Valley. The integration of new species and indigenous species to provide the best land cover for the rehabilitated mine site has also to be addressed. Consequently, new research outcomes must also be considered as part of the long-term erosion management for the final batters and in the selection of appropriate land uses for different areas around the mine, for example biolinks/ecological restoration areas vs agricultural land.

4.4.6 Wave erosion

Wave erosion impacts on the mine walls will be particularly affected by changes to water infill rates. Long periods of static water levels may concentrate erosion at one height leading to erosion cliffs, particularly if the exposed strata are weak or heavily jointed. Rapid water level rise may lead to difficulties of managing the maintenance and replacement of erosion protection.

Currently coir mats are projected for use as wave erosion control measures (Alluvium, 2019). These mats breakdown over time. Thus, timely replacement is required. Long term availability of the required mats cannot be assured, their durability under local conditions has to be proven, and new materials may enter the market that are better. For each of these reasons, regular review and revision of the controls used to manage wave erosion is required.

4.4.7 Other matters

While not considered under the current investigation, adaptive monitoring and management will also be required in relation to the evolution of the lake water body in terms of water quality and ecological functioning.

4.5. Summary of recommendations

The following recommendations are made in relation to Matter 3:

Assessments and controls

12. *ENGIE to update their rehabilitation objectives to reflect current Victorian environmental legislation and standards.*

13. *There is a need for the impacts of the lake filling to be examined and appropriate mitigations and remedial measures established during the early stages of lake filling and included in the GCMP.*

14. *Incremental stable movements should not automatically be assumed to have low consequences. It is necessary for incremental, stable, movements to be monitored and mitigated (e.g. sinkhole formation) as part of the GCMP where these might lead to higher risks of less tolerable, unstable, movement.*
15. *In the Risk Management Plan dust is examined as an impact on amenity and not an impact on health. This is potentially too simplistic and should be revisited to examine both health and amenity impacts more fully.*

16. *It is recommended that ENGIE regularly review access arrangements for fire suppression as the lake level rises. It is also recommended that mine floor spray systems remain active to manage dusts and limit fire risks just to the batters.*

17. *As maintenance of coal cover in the zone of water level fluctuation on the coal batters would likely be a significant activity, a recommendation is to undertake a study to assess coal fire risks and erosion risks for this zone in the absence of coal covers and to assess the acceptable maximum height of exposed coal as part of the long-term final design for the rehabilitated mine.*

18. *Rehabilitation is an opportunity to increase and enhance areas of native flora and fauna habitat and this should be explored as part of the rehabilitation design process.*

19. *It is appropriate to monitor water quality of the aquifer discharges from the depressurisation pumps for both the M1 and M2 aquifers on a monthly basis throughout the rehabilitation and closure period.*

Dewatering risks

20. *If dewatering is to be considered then:*
    •Studies must be undertaken to assess integrity of submerged horizontal bores during filling
    •Studies must be undertaken to assess groundwater responses behind the batters in both the coal and interseam to support parameterisation of a groundwater model applicable to dewatering.
    •Modelling must be undertaken to assess the required controls for groundwater pressure gradients and dewatering rates
    •Studies must be undertaken to assess the management of discharges to surface water courses

21. *To manage dewatering safely: dewatering rates will require modelling coupled with monitoring to both calibrate and validate the model results. Modelling will need to assess the performance of coal dewatering and the depressurisation rates of the interseams. Monitoring will require additional VWPs located in the at-risk batter interseam layers as well as maintenance of the stability monitoring bores measuring the groundwater gradient. Maintenance of the horizontal bores will also be needed. Additional horizontal bores will be required regularly as water levels decline unless the submerged horizontal boreholes during filling can be demonstrated to be operational.*

22. *The MLRA is of the opinion that preference should be to avoid dewatering the lake once rehabilitation is underway.*

Adaptive monitoring, assessment and management

23. *Assessments of the adequacy of the final landform design, covering all aspects of stability and erosion, and the likely reliability of the water supplies for completion of water infill should be completed on an approximately three-to-five-year cycle. Field monitoring and assessment methods should be implemented to allow updating of the geotechnical models and batter designs.*

24. *Criteria are required against which to judge the performance of the rehabilitation and the likely future conditions for the purposes of decision making around the final lake water level. The criteria need to be agreed by all parties to be effective. Field monitoring and assessment methods should be implemented to allow comparison against the agreed criteria.*

25. *New research on land cover vegetation should be regularly reviewed and published outcomes must be considered for updating of the long-term erosion controls on the final batters and for the selection of appropriate land uses for different areas around the mine.*

5. Hazelwood's rehabilitation planning (Matter 4)

5.1. Introduction

Matter 4 covers the following:

> *Identify any additional steps necessary to ensure alignment between the proposed rehabilitation works within the Hazelwood mine and the Latrobe Valley Regional Rehabilitation Strategy and Declared Mine Rehabilitation Plan requirements from time to time, including potentially through conditions upon approvals, having regard to the principles of sustainable development.*

At this moment in time the Declared Mine Rehabilitation Plan (DMRP) requirements are known but the timing and approach to meeting the requirements are not yet confirmed in legislation, components of the Latrobe Valley Regional Rehabilitation Strategy (LVRRS) have been completed with an updated strategy required for publication in 2023, and an Environmental Effects Statement (EES) is required by the Minister for Planning for Hazelwood's rehabilitation. The EES for Hazelwood has not yet been scoped. It is expected that by the end of 2022, the DMRP timings and approach and the EES scope will be well known and published and the direction for the update of the regional strategy will be fully defined, even though the publication of the updated strategy will not be complete until June 2023.

The DMRP requirements are defined in the Mineral Resources (Sustainable Development) Amendment Act 2019 (Division 2, Section 84AZU). The plan must include:

(a) any rehabilitation plan or requirement under section 82(3) that the declared mine licensee enter into a further rehabilitation bond; and
(b) the prescribed criteria (closure criteria) to be met by the declared mine licensee for the closure of the mine on the declared mine land; and
(c) a document (post-closure plan) that sets out the monitoring and maintenance to be carried out on the closure of the mine on the declared mine land by (as the case requires)—

- *i. the declared mine licensee; or*
- *ii. the Rehabilitation Authority; or*
- *iii. the owner of the land; and*

(d) an undertaking by the declared mine licensee to pay the registration amount to the Minister on a registration direction being given for the declared mine land; and
(e) an assessment of the risks posed by the geotechnical, hydrogeological, water quality or hydrological factors within the declared mine land; and
(f) any other prescribed matter.

At this stage other prescribed matters require definition.

The timeline for the delivery of a DMRP for Hazelwood is dependent on the new regulations. The way information will be provided in Hazelwood's DMRP will also depend on the new regulations. Furthermore, it will depend to different degrees on the information required for the EES and the availability of resources for the completion of rehabilitation and the determination of the appropriate final landform for the mine.

5.2. DMRP requirements

Without pre-empting the new DMRP regulations, four aspects of the current investigation are relevant to the formulation of a DMRP for Hazelwood. First, the current investigation is focussed on use of local surface and groundwater for the completion of rehabilitation. ENGIE's stated aim is to complete rehabilitation of Hazelwood mine as a full pit lake (+45m AHD). This presumes that water is available in sufficient quantities to complete rehabilitation to the proposed final landform. Climate uncertainty suggests that there is a risk that water limitations in the future may force a change to the final landform, with requirements to adopt a lower final lake level with an amended final landform design. The contingent design is likely to pose different residual risks with potential implications for regional sensitive receptors and higher levels of ongoing monitoring and maintenance. The possible need for an amendment to the final design should be reflected in the development of the DMRP and the basis for any amendment needs to be incorporated as part of planning, so that the DMRP has an agreed basis for approval. It is assumed that a full design for the contingent landform will not be available prior to approval of the DMRP. In this case, approval must be based on the projected approach to amending the design given the uncertainty around the requirement for any amendment.

Second, the current investigation suggests that information requirements for completion of rehabilitation are still being developed and will need to be refined through further studies and iterative re-evaluation of the basis for the final design based on new data. The expectation is that re-assessment and updating of the design will be a continuous process based on adaptive management principles and practices. Recognition of the application of adaptive management processes in the formulation of the DMRP is required.

Third, the timeline for completion of rehabilitation of Hazelwood mine will depend on what happens at the other two mines as well as agreements that may be reached on access to water or the expansion of water supplies through manufactured water sources.

Fourth, the criteria for approval of the final landform design need to be based on agreed design criteria, notably around the reliability of the batters both during closure as well as post-closure. It is important that the criteria are agreed not only by the operator and the regulator but also accepted more broadly by the community. Prior to criteria development it is essential that there is agreement on the allowable and acceptable residual risks that will apply to each domain of the mine. Development of criteria must be consistent with the accepted residual risks for the rehabilitated landform and land uses. The DMRP should accommodate the approaches to reaching consensus on criteria for the final landform as well as reaching consensus on adjusted criteria if a change to landform is imposed for reasons such as incompatibility of the approved cover vegetation with the local environment. New criteria may also be required if a contingent landform is required due to lack of available water. The new DMRP regulations should accommodate the uncertainties and approaches to dealing with the uncertainties identified here. There will be a need to review the final approved DMRP regulations and to align the rehabilitation plans for Hazelwood accordingly.

5.3. Hazelwood Environmental Effects Statement

The requirement to prepare an Environmental Effects Statement (EES) for Hazelwood mine presents both a challenge and an opportunity. The challenge is to ensure that findings of the EES process result in an approval and rehabilitation pathway that is practical and deliverable. The outcome needs to recognise the trade-offs between transitioning the mine license area to future land use(s) and the possible environmental effects on the broader region. The opportunity is the widening of community engagement with the mine rehabilitation process and, hopefully, broad acceptance of the approved rehabilitation pathway.

In practical terms, the EES process needs to be completed before the approval of the DMRP. One of the constraints to progress of rehabilitation at Hazelwood has been obtaining planning approval for the proposed rehabilitation landform. One part of the problem has been confirmation of the reliability of the required water resources. Another part of the problem was the decision by the operator to adopt a staged approach to rehabilitation that suggested two possible final landforms dependent on the findings of the first stage of rehabilitation. Limited detail about the second of the final landforms was presented in the work plan as it was offered as an alternative of last resort rather than an equally likely outcome. For a range of reasons, the lack of detail about the viability of the second landform prevented approval of the overall rehabilitation plan. Rather than a staged approach to mine rehabilitation planning, one of the recommendations of the current investigation is that a continuous, or iterative, assessment approach is adopted. This approach assumes a single proposed final landform from the outset but with criteria that can be used to transition to an amended final landform, if circumstances require. If a significantly different landform is necessary, then new planning approvals would be required for the revised landform as well as new criteria on which the landform would be assessed. This approach avoids the complexities and inconsistencies of offering multiple final landforms that would each need to be pre-approved from both planning and regulatory perspectives. It does mean that the EES process should be directed at only the assessment of impacts derived from the proposed landform and not used as an opportunity to design a landform on behalf of the proponent. Only if the likelihood of achieving the referred landform is determined to be too low, or its impacts are considered unacceptable and cannot be amended, should alternative landforms be considered.

A key component of the EES process will be confirmation of the water entitlements for both mine rehabilitation and post-closure maintenance of the final landform and the access conditions that will be applied to the entitlements. Assessment of water resource requirements for a single mine, however, ignores the cumulative regional water needs and potential impacts from mine rehabilitation for all three Latrobe Valley mines. Genuine consideration of the implications of a single-mine EES prior to the resolution of acceptable regional residual risk profiles and cumulative rehabilitation water resourcing requirements is needed. The case for a collective EES that incorporates rehabilitation requirements for all three mines is strong and should be considered, particularly, as stated previously, as it would incorporate community engagement, provide transparency on decision making processes, and is aligned with the proponent-led rehabilitation planning process currently embedded in declared mine legislation.

5.4. Latrobe Valley Regional Rehabilitation Strategy

The 2020 LVRRS set out the principles for declared mine rehabilitation and six implementation actions to close some of the regional knowledge gaps to support future rehabilitation planning. Five of the implementation actions are largely complete with the sixth ongoing. The actions have identified the significant capital and operational costs associated with maintaining dry pits as well as the significant capital and operational costs associated with supplying manufactured water to the Latrobe Valley for the purposes of mine rehabilitation as pit lake landforms. The new knowledge provided by the implementation actions is sufficient to allow a revised strategy in 2023 to provide not only clearer pathways for completion of rehabilitation by the three mine operators but also a clearer vision for rehabilitation and its impact on the future economic and social health of the Latrobe Valley. This cannot be done, however, without agreement on acceptable residual (post-rehabilitation) risk profiles for each of the mines and the cumulative impacts to the region. The new strategy should be underpinned by an understanding of residual risks and a conversation regarding the acceptability of those with community.

Of particular importance will be the establishment of actions in the next five years to develop a clear, community-embraced vision for the growth of the region supported by progressive relinquishment of mine lands to underpin the early and ongoing implementation of that vision. It is essential that the Strategy is focussed on presenting a pathway for integrating regional planning with the release of rehabilitated mine lands. This pathway must be based on a clear awareness of the expected landforms and applicable land uses. Connecting the Strategy explicitly with regional planning should be given high priority for the update to the 2023 Strategy.

5.5. Alignment of DMRP, EES and LVRRS activities

Harmonising the interactions between the EES process, the LVRRS and the DMRPs needs to look at not only the approaches for delivering the activities but also the timing of activities and the future vision for the Latrobe Valley. It must also be consistent with the development of agreed residual risk levels and the development of an integrated planning approach that embraces rehabilitation planning and implementation at all three mines. In the introduction to each activity above suggestions are made to assist with delivering rehabilitation and closure plans while acknowledging each operator's role as the agency responsible for planning, funding and implementing rehabilitation for their mine; suggestions are compatible between activities. The revision of the LVRRS in 2023 needs to define the direction spanning the vision for mine land, the expectations for rehabilitation and the likely delivery pathways and management of the external resources required for rehabilitation. Thus, the LVRRS provides the framework on which the other activities hang. Consequently, the EES process for each mine needs to be consistent with the LVRRS as well as with each other. Similarly, the development of the DMRP for each mine needs to be consistent with the LVRRS and the outcome of each EES.

Current timing for delivery of the Hazelwood mine EES and the anticipated date for publication of the revision of the LVRRS suggests that there may be a mismatch that could impact the delivery of the EES or potentially the consistency of the output of the EES and LVRRS processes. The Hazelwood EES is also likely to pre-empt decisions on the rehabilitation timing and landforms planned for the other two mines. To avoid inconsistent decisions, it will be necessary for the Hazelwood EES scope to be based on a prior understanding of the scope of the 2023 LVRRS and on the future planning for Yallourn and Loy Yang. Understanding the interactions and prospective timelines and making appropriate adjustments either in terms of information flows and or submission dates is needed. The complexity of aligning all these individual processes would be reduced through undertaking a collective EES process that encompasses rehabilitation of all three mines. This process and its timing would still require alignment with the LVRRS and development of DMRPs. Ultimately it would likely lead to greater certainty on rehabilitation outcomes and approved DMRPs sooner.

Where the timing of delivery of the LVRRS, the EES and the DMRP for each mine cannot be appropriately connected and where the outputs from each action may require approvals under the other actions, then conditions upon approvals may be required. The nature of the approvals will depend on the specific direction of each action.

5.6. Engagement

As part of the integration of activities it will also be important to enhance community and Traditional Owner engagement beyond information provision to embrace inclusion in the decision-making process. Engagement needs to expand well beyond the EES process and include significant contributions from the mine operators, the regulators, and key stakeholders including DELWP and the EPA. Coherence in the vision for the future development of coal mine land among all stakeholders should improve community and Traditional Owner confidence in the overall process. It is necessary for both the LVRRS revisions and the DMRP processes to acknowledge and embrace the role of community and Traditional Owners as the recipients of mine rehabilitation outcomes. To achieve this, it is anticipated that the Mine Land Rehabilitation Authority will exercise its coordinating role in all aspects of community and Traditional Owner dialogue and conversations.

5.7. Summary of recommendations

The following recommendations are made in relation to Matter 4:

26. *The case for a collective EES that incorporates rehabilitation requirements for all three mines is strong and should be considered before progressing too far with the single mine EES for Hazelwood*
27. *Connecting the Strategy explicitly with regional planning should be given high priority for the update to the 2023 Strategy.*
28. *Where the timing of delivery of the LVRRS, the EES and the DMRP for each mine cannot be appropriately connected and where the outputs from each action may require approvals under the other actions, then conditions upon approvals may be required. The nature of the approvals will depend on the specific direction of each action.*

6. Post-rehabilitation Risk Management (Matter 5)

6.1. Introduction

This section covers the fifth and final matter requested for investigation and addresses the following:

> *Identify the risks that may require monitoring, maintenance, treatment or other ongoing land management activities after rehabilitation is complete, the activities required to manage the risks and the projected costs to manage the risks.*

Residual risks that may remain after rehabilitation is complete are dependent on the final landform that is created and the degree of connection between the landform and the surrounding environment. The magnitude of the risks and the scope of works to manage the risks change with landform and land use. Illustrations of the range of risks requiring consideration are summarised in the following sections.

While the investigation matter requires the activities and the projected costs to manage the risks to be presented, this has not been undertaken. The reasons for this are, first, that the scope of the investigation is presently too wide as the final landform is not known and, second, that different designs for a given landform can lead to rather different risk profiles. The identification of monitoring, maintenance and treatment options under these circumstances is too uncertain to be of practical value. A final section is provided that summarises this issue and presents a possible timeline for the delivery of such information if it is not forthcoming from the Hazelwood EES.

6.2. Fire

Fire risks fall into two categories: surface and subsurface. Surface fires can be initiated by external or internal ignition sources. External ignition sources can be bush or off-site infrastructure fires or lightning strikes while internal sources will depend on land use and may include machinery and campfires as well as other on-site sources. The spread of surface fires will largely depend on surface vegetation. The need to manage surface fire risks will depend on the sensitivity of the land use to fire and the risks to people and property on and around the rehabilitated area. Management of surface fire risks may involve vegetation selection and management as well as maintenance of access for fire management and relocation of people and machinery.

Subsurface fires can arise from spontaneous combustion and penetration of surface fires to the depth of the coal. Spontaneous combustion risks are higher in disturbed coal areas. Risks of penetration of surface fires to depth will depend on vegetation types, depths of the covers over coal in the batters and risks arising from surface cracking of the coal cover and the presence of ignition source such as a bush fire.

If a pit lake has a variable water level as a result of changes to replenishment during droughts or intense flood periods, then wave action may expose coal over the depth of fluctuation of water level on the batter, unless regularly remediated or permanently protected. The requirement to protect these areas from fire will depend on their susceptibility to ignition and this will depend to a degree on the moisture content of the coal.

While surface fire management risks are standard practice within the Latrobe Valley, subsurface fire management is presently limited to the active mines. If the landform is well designed, the risks of subsurface fires should be low. Where risks are elevated then fire occurrence can be monitored through thermal mapping techniques. Extinguishing subsurface fires would normally require excavation of the coal and capping to prevent further oxygen entry to the coal.

6.3. Erosion

The steepness of final landform batters currently envisaged with slopes of 3H:1V means that erosion controls will be needed for all slopes within the mine void above final water level. Erosion controls will also be needed on all external landforms such as the overburden dumps, particularly where erosion derived sediments may interfere with any waterbody. Erosion controls will include both surface coverings, typically vegetation, and surface water management. The requirement for maintenance will depend on the resilience of the surface coverings and the engineering of the drainage for surface water flows. It may be anticipated that as climate changes that resilience of vegetation will become a critical issue that will need to be addressed as part of the final landform design. The length of final slopes will be a significant design factor. Lowered lake forms will have greater slope lengths with potentially higher erosion risks. Land use will also be a factor in erosion risks. It may be necessary to prohibit some land use activities on the final landform slopes and/or to encourage land uses that acknowledge erosion risks and can sustain appropriate land management practices to ameliorate the risks.

Wave erosion is expected to be a long-term issue. Depending on the reliability and durability of the foreshore slopes to dissipate waves and erosion protection along the foreshore of the lake, monitoring and maintenance may be a permanent requirement.

6.4. Stability

The ability to switch off depressurisation bores in the underlying aquifers and to not maintain horizontal bore drainage in the final landform batters will depend on:

- the planned final water level;
- the heights of the batters above the final lake water level; and,
- the final batter designs and their reliability.

For batters requiring ongoing groundwater monitoring and management, stability bores and maintenance of drainage and depressurisation bores will be a long-term requirement. The frequency of monitoring and replacement or redrilling of horizontal bores will require ongoing active management principles to be employed to maintain stability.

Typically, the lower the lake level the greater the requirement for long-term monitoring and maintenance to manage stability.

Stability is also affected by the controls placed on water accumulation behind the batters and by the opening of sinkholes or cracks connecting the surface to the coal. Spatial ground movement and drainage monitoring, updating of surface drainage and repair of sinkholes will all be required into the future for lower lake landforms and may be required in some areas for a full lake landform.

Depending on the residual risks approved for each batter, there may be a requirement to impose land use restrictions on different parts of the mine perimeter.

6.5. Water management

At the present time, it is unclear whether a pit lake final landform will form part of the managed surface water network, either acting as flood detention body or reservoir in times of drought. The management of the lake for beneficial regional use could be an important component of long-term planning for the final landform. Irrespective of the potential beneficial uses of the lake as a part of an integrated surface water management system, there will be a need to manage the water levels in response to evaporative losses and local uses. Depending on the water sources employed for water level management, regional impacts on both groundwater and surface water may require monitoring. Under all scenarios, the requirement to manage long term inflows and outflows from the lake for beneficial or maintenance purposes will be a normal part of management of the rehabilitated landform. Water management practices must be closely connected to the management of landform stability and the understanding of one will inform the management of the other.

Water management will also be required in the very long term in terms of the overall water quality of the lake. An important goal for the lake must be accessibility and useability and this will be determined to a large degree by the lake water quality. Initially, it is expected that monitoring will be the primary task. The analysis of the monitoring data will then inform the development of a water management plan that may involve significant water exchanges between the river network and the lake to sustain an acceptable chemical and biological equilibrium.

6.6. Surface water contamination

Surface water contamination can be separated into two parts. Contamination of the mine lake water body from external contamination sources. Contamination of the streams and rivers that pass the mine from effluent discharges from the rehabilitated mine area. Soil contamination is not expected as a result of rehabilitation, however long-term management of on-site landfills, may be required to prevent surface water contamination.

The principal example of external contamination source for Hazelwood is the urban catchment area of the Morwell Main Drain. If discharges from the drain are directed to the pit lake, then monitoring of water quality will be required on a regular basis and actions taken to alleviate localised contamination with the pit lake water through treatment and or mixing. It may be a requirement for the water from Morwell to be passively or actively treated before discharge to the pit lake.

Contamination of the streams from discharges from the ash landfills is a possibility and should be regularly assessed to ensure compliance with EPA consents.

If the pit lake is connected to the Morwell River, it is possible that quality differences between the river and the lake will need to be monitored, including turbidity, to ensure lake discharges to the river lie within agreed bounds. While it is expected that the lake quality will be similar to the Morwell River, possible effects such as algal blooms and coal sediment entrainment during lake inversions need to be investigated and if applicable monitored and managed.

The ability to control inflows and outflows to the pit lake will require appropriate infrastructure to be constructed and managed until the lake-river system is determined to be naturalised and self-managing. This may take a very long time or never occur.

6.7. Groundwater contamination

Groundwater contamination resulting from rehabilitation activities is currently considered unlikely. However, to ensure that this assessment is valid a long-term groundwater quality monitoring system should be implemented to the east of Hazelwood to view changes to water quality that may arise from the presence of the lake. This system will not be required before the end of aquifer depressurisation. Discharges from the depressurisation monitoring bores should be tested for water quality changes prior to ceasing aquifer depressurisation.

The management of potential for water table aquifer contamination from landfills will likely require ongoing maintenance of landfill caps and vegetation, including monitoring of vegetation on the Eastern Overburden Dump to ensure ongoing minimisation of rainfall infiltration and groundwater migration.

6.8. Ecology

Depending on final land uses, a major outcome of mine rehabilitation should be the creation of a range of ecological environments across the land and waterscapes. These environments are not likely to be initially in equilibrium either locally or regionally. They will be subject to natural and anthropogenic change and may undergo degradation caused by environmental impacts and/or ecological imbalance. Climate resilience should be incorporated into their design and management programs.

As part of future management of the rehabilitated land area, monitoring of the ecological condition of the lake and the surrounding landscapes will be an important task. Evaluation of species changes, including the spread of non-native and invasive species may be required and ecological management and maintenance may need to be implemented. Where the ecological environment is important for fire and erosion risks the integrated management of these risks will be necessary.

6.9. Concluding remarks

Investigation of the risks and costs after rehabilitation is complete is dependent on successful implementation of the recommendations arising from the first four matters and on the final landform that is achieved. It is therefore difficult to bound the outputs for this matter and to provide effective information that has practical application. At this stage in the development of the rehabilitation approvals for Hazelwood mine, the preparation of outputs by the MLRA required for this matter are probably premature. Preference is for the MLRA to defer the development of the information requested for this matter until after the completion of the EES for Hazelwood. The main reason for this is to reduce the range of possible final rehabilitation landform options to an acceptable degree. Reducing the range of options will permit meaningful maintenance and monitoring plans to be devised and for costings for the implementation of these plans to be developed. It is likely that the Hazelwood EES will provide much of this information as this will be needed for planning approvals and for the preparation of the Hazelwood DMRP.

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