

Artificial-intelligence-enabled rehabilitation liability estimation: developing a simplified bond calculator for improved financial assurance

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Abstract

Accurate and defensible rehabilitation liability estimation is critical to mine closure planning, regulatory approvals and the operation of robust financial assurance frameworks. The existing Victorian State Government rehabilitation bond calculator can appear complex, data-intensive and difficult for operators, particularly small- and medium-sized mines and quarries, to apply consistently. This often results in highly variable cost estimates, gaps in input data, and limited ability to track liabilities over time as site conditions and operations change. These challenges can undermine the effectiveness of closure planning and complicate rehabilitation liability estimation.

This paper presents the development of a simplified rehabilitation bond calculator supported by conversational-based artificial intelligence (AI)-enabled workflows designed to improve usability, transparency and long-term tracking of rehabilitation liabilities. The approach focuses on identifying the primary cost drivers of rehabilitation activities, simplifying data entry, and reducing estimation uncertainty for both operators and the regulator. Machine-learning-assisted features provide assistance, flag missing or inconsistent inputs and support rapid scenario testing for rehabilitation options. This enables users to understand the sensitivity of their estimates and update liabilities more accurately as progressive rehabilitation occurs or operational footprints change.

Resources Victoria, within the Department of Energy, Environment and Climate Action, as the regulator for the mineral and extractive industries, has developed a simplified AI-enabled rehabilitation bond calculator as an additional tool to the existing Excel-based rehabilitation bond calculator. It has been designed initially to assist the calculation of rehabilitation bonds for low- to medium-risk mining and extractive operations, with future opportunities for expansion.

The paper outlines the methodology used to develop and validate the tool, including benchmarking against existing regulatory calculators. The integration of AI provides significant improvements in consistency, estimate defensibility and user experience while maintaining alignment with regulatory expectations and cost-estimation principles.

The work demonstrates how modern digital tools can support clearer, more reliable rehabilitation liability forecasts and strengthen financial assurance frameworks. The simplified, AI-enabled calculator offers practical benefits for industry, regulators, and consultants by promoting early planning, reducing common estimation errors and enabling proactive management of rehabilitation costs throughout the life of the operation.

Keywords: *rehabilitation liability estimation, financial assurance, mine closure planning, bond calculator, artificial intelligence, progressive rehabilitation, cost estimation, regulatory compliance, digital tools, closure forecasting*

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1 Introduction

Effective site rehabilitation underpins public confidence in both the mining sector and the regulator. Robust and accurate rehabilitation liability estimates are essential to ensure that sufficient financial assurance is held by the State of Victoria (the State), to manage closure risks should an operator fail to meet its rehabilitation obligations. At the same time, industry requires tools that are proportionate, transparent and practical to apply across the life of an operation.

In recent years Resources Victoria has continued to refine and update its Excel-based rehabilitation bond calculator to reflect contemporary cost estimates from a first principles approach to mine rehabilitation. However, the increasing complexity of the Victorian rehabilitation bond calculator has led to many operators relying heavily on consultants to prepare estimates. While specialist expertise remains important for complex or high-risk sites, this reliance can reduce operator understanding of their own liabilities, limit their ability to understand and actively manage rehabilitation costs over time, and unnecessarily increase operating costs. Inconsistencies in assumptions and methodologies by different operators and specialists can also complicate regulatory assessment and comparison across sites.

Resources Victoria, as the regulator for the mineral and extractive industries, has developed a simplified AI enabled conversational-based bond calculator as an additional tool to the existing Excel-based rehabilitation bond calculator. It has been designed initially to assist the rehabilitation bond calculations for low- to medium-risk mines and quarries, with the potential for expansion to accommodate more complex operations and scenarios.

This paper presents a regulator-led approach aimed at improving industry understanding and costing of rehabilitation liabilities through the development of a simplified bond calculator, supported by artificial intelligence (AI)-enabled workflows. The intent is not to replace professional judgement, but to provide a clear, consistent baseline tool that supports industry capability, reduces unnecessary complexity and administrative burden, and improves closure planning outcomes.

2 Financial assurance from a regulatory perspective

In Victoria, Australia, the *Mineral Resources (Sustainable Development) Act 1990* (Government of Victoria 1990, *Mineral Resources (Sustainable Development) Act 1990*, Australia (MRSD Act)) establishes the legislative framework requiring tenement holders to rehabilitate land in accordance with an approved rehabilitation plan and to lodge a rehabilitation bond prior to commencing works. Rehabilitation bonds act as a financial surety in the event an operator defaults on their rehabilitation obligations, ensuring sufficient funds are held by the State should the Minister of Energy and Resources be required to rehabilitate the site on the operator's behalf.

Since 2020, Resources Victoria, within the Department of Energy, Environment and Climate Action, the division responsible for administering the MRSD Act, has undertaken a broad-scale review of rehabilitation liability estimates to ensure bonds remain current and reflective of actual closure risks. As part of this process, the bond calculator has been updated to provide a consistent methodology for estimating rehabilitation costs across the earth resources sectors (mining and extractives). Rehabilitation liabilities are estimated using third-party contractor rates to reflect the reasonable worst-case cost of rehabilitation should an operator fail to meet its statutory obligations. Under current policy settings, rehabilitation bonds are generally set at 100 per cent of the assessed rehabilitation liability and are held as cash (up to AUD 100,000) or as a bank guarantee.

The bond calculator serves as a valuable planning tool for operators, enabling early estimation of site rehabilitation costs prior to resource extraction. It can support the design of operational staging to minimise the disturbed footprint and maximise opportunities for progressive rehabilitation over the life of an operation.

Resources Victoria regularly benchmarks the bond calculator against market rates for key rehabilitation activities and applies annual Consumer Price Index adjustments. While these continual enhancements

enabling more detailed first principles cost calculations across multiple domains and activities have improved the accuracy of assessments and the adequacy of bonds held, they have also resulted in significant uplifts in bond values and increased administrative effort. The growing complexity of the bond calculator, particularly for the lower-risk sites which represent a large component of the Victorian resources industry, has contributed to challenges in assessment, greater reliance on consultants and increased cost pressures for operators. From a regulatory perspective, financial assurance frameworks must balance robustness with proportionality. Rehabilitation bonds must reflect a reasonable worst-case rehabilitation scenario while remaining transparent, reproducible and practical to apply.

Common regulatory challenges identified through this process include inconsistent cost assumptions being applied across comparable sites, infrequent updating of rehabilitation liability estimates over the life of operations, and limited operator engagement with the primary drivers of rehabilitation costs. In particular, management of the materials balance for rehabilitation is often overlooked. This can result in significant, and at times unanticipated, costs associated with sourcing and importing suitable topsoil and overburden materials. Collectively, these issues reduce transparency, complicate regulatory assessment and limit the effectiveness of financial assurance as a proactive rehabilitation management tool, all while exposing the State to potential rehabilitation liabilities.

3 Why simplification was needed

Victoria's mining and extractive industries are highly diverse, ranging from small-scale alluvial doze and detect prospecting operations, where shallow layers of soil and vegetation are removed to expose older ground surfaces and a metal detector is used to locate mineral deposits or gold nuggets, through to large-scale mineral sands projects, underground mines and multi-bench hard-rock quarries. At the end of the 2025–2026 financial year, the State held rehabilitation bonds to the value of AUD 992 million across 1,119 tenements. These bonds ranged in value from AUD 1,500 to 289 million, with only 5% of bonds held exceeding AUD 1 million and 9% over AUD 500,000, indicating that many tenements are associated with relatively low rehabilitation liabilities.

While Resources Victoria continues to progress reviews of contemporary bonds, particularly for the sites where there has been an average of approximately 15 years between rehabilitation liability assessments, the distribution of bond values suggests that complex rehabilitation liabilities represent only a small proportion of tenements in Victoria. As such, the number of sites requiring a complex calculator is limited.

3.1 Independent review of Victoria's quarry rehabilitation bond system

In 2025 the Victorian Minister for Energy and Resources requested an independent panel be set up to advise the Department of Energy, Environment and Climate Action on how to improve the rehabilitation bond settings for the quarry sector. Members of the panel included industry representatives with quarry sector experience, and experts in insurance, risk and economics. The review found that the rehabilitation bond settings for the quarry sector do not reflect the liability risk to the State or incentivise rehabilitation, and the bond calculator requirements are overly burdensome.

The panel made 4 key recommendations aimed at balancing 2 core priorities: protecting the State from financial risk while also supporting investment in the sector. Recommendation 2 was to simplify the bond calculator, which was accepted and actioned as a priority, not only for extractive operations but also including mining and prospecting.

3.2 Victoria's legislative reform

Victoria's legislative framework for regulating the mining and extractive industry is also undergoing significant reform. From 1 July 2027 the transition to a duty-based model will remove the application of previous standard rates for low-risk mining and extractive operations. Under the proposed framework, eligibility to operate under a code of compliance will remove the requirement for a site-specific rehabilitation plan. Sites determined as moderate to higher risk will be required to submit regular reviews of their

rehabilitation plans. This will necessitate the regular preparation and submission of current and defensible rehabilitation liability estimates, potentially increasing the administrative burden for tenement holders.

In this evolving regulatory context, simplification becomes increasingly important. A simplified bond calculator can improve operator understanding of the key drivers of rehabilitation liability and support more informed decision-making over the life of a project. Reducing reliance on consultants for routine liability updates lowers compliance costs while encouraging greater operator ownership of rehabilitation obligations. The use of standardised assumptions and methodologies increases consistency and comparability across regulatory assessments. At the same time, closer alignment between rehabilitation planning and financial assurance ensures that bond levels more accurately reflect current site conditions and progressive rehabilitation outcomes throughout the operational life cycle.

3.3 Objectives of the simplified bond calculator

A simplified bond calculator was developed by the regulator as an immediate response to the recommendations of the independent review. This tool was developed as an alternative option to the current bond calculator. It standardises key assumptions and rehabilitation tasks, enabling consistent and defensible rehabilitation liability estimates while still allowing flexibility to account for site-specific risks and operational characteristics. The calculator is designed to support life cycle liability tracking, allowing rehabilitation costs to be reviewed and updated as operations evolve over time.

The simplified bond calculator is designed to identify key areas of disturbance associated with core rehabilitation activities and apply standardised unit rates to these common activities. This replaces the need to specify task-specific components of rehabilitation activities from a first principles approach. For example, adopting standard unit hectare rates for rehabilitating land to pasture – instead of the specific components of deep ripping, topsoil quantity estimates, fertiliser application rates, seeding, monitoring and maintenance, – promotes greater consistency and comparability across sites. At the same time, it retains flexibility to allow for additional site-specific rehabilitation activities based on closure criteria for the operation.

By improving usability and transparency, the simplified bond calculator reduces reliance on external consultants for routine assessments, lowering costs for industry and encouraging stronger operator ownership of rehabilitation planning and financial assurance responsibilities. This approach supports proportionality and aligns with duty-based regulation by reinforcing the expectation that operators actively understand and manage rehabilitation risks throughout the life of an operation.

3.4 Validation and regulatory confidence

The simplified bond calculator was tested across a range of small mine and quarry scenarios and benchmarked against existing rehabilitation bond estimation approaches. Validation results demonstrated improved consistency and transparency, with estimated liabilities remaining conservative, reasonable and defensible from a regulatory perspective.

Importantly, testing showed that operators were able to complete rehabilitation liability estimates with greater confidence and clarity, significantly reducing reliance on external consultants for routine calculations. This outcome supports the broader objectives of duty-based regulation by strengthening operator understanding, encouraging more frequent liability review, and reinforcing rehabilitation as an active and ongoing obligation rather than a periodic compliance task.

4 Role of artificial intelligence in supporting industry users

The implementation of an AI-enabled chatbot represents the initial stage of Resources Victoria's digital transformation journey for rehabilitation liability assessments. The next phase of the simplified bond calculator involves the integration of a chatbot to provide users with accessible, guided assistance for estimating rehabilitation liabilities. The chatbot is designed to facilitate structured interactions through key rehabilitation activities relevant to the site being assessed. To enhance the user experience through question

prompts and streamlined data entry, the chatbot has been designed to follow the same question structure as detailed in the simplified Excel-based bond calculator.

AI will also be an essential enabler for backend processes, decision support and quality assurance, enhancing transparency, accessibility and consistency in rehabilitation liability estimation. The use of AI is intentionally constrained and designed to support, rather than replace, operator responsibility and regulatory judgement within a duty-based regulatory framework. At a later stage the system is expected to evolve into a fully AI-powered solution capable of handling more complex calculations, supporting nuanced conversations and addressing unstructured queries to better serve industry users.

Current AI functionality provides users with a decision tree upfront to determine if they can comply with the parameters that determine whether the use of the simplified bond calculator is appropriate for the site in question. This is determined by a simple yes/no answer (i.e. Are any tailings dams onsite?); in this case, if the answer is yes, the use of the simplified bond calculator is determined to be inadequate for the site and the use of the standard bond calculator is triggered.

The AI-enabled bond calculator provides a real-time cost summary on screen, updating the subtotal as the user progresses through the assessment. This allows users to explore how staging approaches or disturbance profiles influence rehabilitation liability. This capability supports active management of rehabilitation risk over the life of an operation and reinforces the expectation that operators consider rehabilitation outcomes as part of ongoing operational planning.

In future stages, the AI functionality will be able to automatically identify missing, incomplete or internally inconsistent inputs, helping to reduce data quality risks and improve the reliability of rehabilitation liability estimates. The tool flags key rehabilitation cost drivers that materially influence outcomes, drawing user attention to assumptions or inputs that warrant closer consideration. This improves the visibility of how rehabilitation liabilities are derived and supports more informed decision-making by both operators and assessors.

4.1 Technical development

Technical development is underway at the time of this writing for a chatbot conversational tool, built in practical steps to deliver a functional, user-friendly tool early while ongoing development can continue to progress towards the ultimate goal of a simplified tool with fully functional AI support. The first release will be a simple standalone tool that guides users through a streamlined rehabilitation bond estimation process, backed by core data from the Resource Rights Allocation Management portal (Resources Victoria's customer relationship management and licence management system). The first release tool supports consistent inputs, maintains a clear record of what was entered and provides a solid base for ongoing improvement.

Further capabilities will be added incrementally, shaped by user feedback and lessons learned as the tool is used day to day and in line with upcoming system changes driven by *Mineral Resources (Sustainable Development) Amendment Act 2023* reform. The core principles of the rehabilitation bond process will remain paramount: industry engagement and consultation, effective data management, maintaining a reliable audit trail and implementing rigorous checks to ensure the integrity of all outputs. Over time, as the building blocks mature, the tool will evolve into part of a wider, centralised AI-enabled agent: one friendly place to go for mining and extractive services across Resources Victoria's strategic portfolio.

4.2 Integration with the current system

A major regulatory benefit of the simplified bond calculator is its ability to support ongoing liability tracking. Operators can readily update liabilities as progressive rehabilitation is completed, improving the visibility of remaining obligations and encouraging timely rehabilitation activities.

Under future annual reporting requirements, mineral and extractive tenement holders in Victoria will be required to assess and report the net change in their rehabilitation liability. Embedding cost assumptions, calculations and site-specific information within the bond calculator supports knowledge retention over time,

significantly improving efficiency and continuity over the life of the operation. This enhanced capability is expected to improve rehabilitation outcomes by enabling more accurate, regular and defensible liability assessments. It also supports proportional regulation by assisting the regulator to hold bonds that reflect the actual and current rehabilitation liability at a site, delivering a direct benefit to industry through the avoidance of over-bonding while maintaining confidence in ongoing closure risk management.

4.3 Future improvements

Indicative benchmarking of the outputs of the simplified bond calculator against comparable sites is proposed to increase transparency and support assessment processes. Benchmarking enables users to contextualise estimates and assess whether rehabilitation liabilities are broadly consistent with sites of similar scale, disturbance type and risk profile. This function will support proportional and consistent regulatory oversight while maintaining flexibility for site-specific considerations.

Future development will focus on refining datasets, expanding benchmarking capability, ensuring continued transparency and expanding AI functionality. Ongoing engagement with industry remains essential to ensure that the tool evolves in line with practical needs while maintaining regulatory integrity.

5 Conclusion

This paper describes how a regulator-led, simplified bond calculator can enhance industry understanding of rehabilitation liability, reduce reliance on external consultants, and improve consistency in financial assurance across the mining and extractive sectors. By prioritising simplicity, transparency and decision support, regulators can strengthen closure planning outcomes while encouraging more proactive and informed rehabilitation practices over the life of an operation.

From a regulatory perspective, simplified tools improve assessment consistency and efficiency by applying standardised assumptions and methodologies across comparable sites. Greater transparency in inputs and calculations enhances auditability and strengthens confidence in bond adequacy, while clearer visibility of cost drivers supports earlier identification of potential closure risks. Together, these outcomes enable more proportionate and effective regulatory oversight within a duty-based framework.

For industry, the benefits include improved understanding of rehabilitation liabilities and the factors that influence them, reduced compliance burden and greater autonomy in managing rehabilitation obligations. The removal of complex bond calculators from low-risk mine sites and quarries reduces the need for consultant involvement in routine calculations, delivering direct cost savings. Standardised language and calculations improve consistency in compliance documentation, while the embedding of assumptions and methodology within the tool helps retain data and knowledge that may otherwise be lost through staff turnover.

Collectively these outcomes demonstrate that simplification, where carefully designed and implemented, does not diminish regulatory rigour but enables stronger assurance, clearer accountability and more effective rehabilitation planning; supporting both regulatory objectives and industry capability in a transitioning duty-based regulatory environment.

Acknowledgement

The authors would like to acknowledge Rachel Spencer, Celeste Taranto and Chelsye Foord from the Rehabilitation Liability Assessments and Bonds team, and James Bell and Joe Laney in Policy Development.