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Future directions for regional water balance modelling to inform mine site rehabilitation

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Abstract

Dynamic water demands, climate variability and climate change create deep uncertainty in assessing water use impacts for mine rehabilitation, yet water balance modelling for closure environmental impact assessments is still commonly deterministic. Typical practice pairs a small number of fixed demand assumptions and closure arrangements with a small number of climate scenarios, often applied as uniform scaling of historical streamflows. This method does not represent the inherently uncertain sequencing of future wet and dry periods, or treat rainfall, temperature and streamflow as evolving through time, and can misrepresent how a flow regime responds to climate change. These limitations matter because environmental values respond to a flow regime, and extraction demand can evolve in response to climate and changing urban and rural consumptive uses.

This paper describes an innovative stochastic modelling framework designed to address these issues. The framework couples dynamic water demands that change over time and respond to climate with stochastic climate sequences to represent natural variability. Climate change is incorporated as a plausible range of end-state changes in rainfall and temperature, implemented through time-dependent scaling of model inputs so that change is progressive rather than constant. Critically, scaling is event-specific, allowing low flows and high flows to respond differently under each plausible climate future. Large ensembles of simulations are then run in a Monte Carlo style method to quantify the distribution of outcomes and the likelihood of environmental performance thresholds being exceeded.

We demonstrate this modelling method using the Yallourn mine rehabilitation project in Victoria's Latrobe Valley, Australia, as a case study. This study shows how the method improves attribution of impacts to climate versus operational decisions, supports testing of alternative project strategies, and provides a more transparent, automated and updateable evidence base for closure planning under uncertainty.

Keywords: *water balance, stochastic modelling, climate change uncertainty, environmental impact of mine water use on water-dependent values*

1 Introduction

Water balance modelling for mine rehabilitation is increasingly being used to do more than estimate whether a pit will fill, or whether a nominated source of water can meet an assumed annual demand. In most contemporary closure settings, the modelling is being relied upon to inform a broader understanding of project risk, providing the evidence base for comprehensive impact assessment of water use and closure conditions on receiving waterway environments (for example, assessments being undertaken as part of closure planning for the Yallourn and Hazelwood mines, Victoria, Australia). This can include testing the hydrologic consequences of alternative closure arrangements, informing environmental impact assessment, understanding the interaction between closure water use and other existing or future demands within the broader catchment, and providing a defensible basis for engagement with regulators on matters such as water access, environmental flow compliance and long-term pit lake behaviour (Landers et al. 2022; Tomlin

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et al. 2025a, b, c). Risks are rarely limited to the mine proponent. Consideration of risks can extend to urban and rural consumptive uses, environmental water provisions, other mine rehabilitation water demands, and operating constraints embedded in entitlement frameworks or water-sharing rules. Under these conditions, modelling must move beyond ‘simple’ water accounting and instead serve support a more sophisticated analysis of demand, supply and trade-offs in a regulated and contested water system.

The major technical challenge is modelling the combined effect of hydroclimatic variability, climate change and evolving demand (Fowler et al. 2024). Historical variability in rainfall, temperature and streamflow already generates significant annual and decadal variability in water availability and environmental flows, particularly in systems where different flow components (flow rates) each serve distinct ecological and geomorphic functions in the waterways impacted by water allocated to mine closure (Bulovic et al. 2024). On top of that short-term variability sits uncertainty in the climate change signal itself, including the magnitude, timing and direction of changes in rainfall and temperature, and the degree to which those changes propagate through to different parts of the flow regime. Mine closure demands also change through time and the greatest demand on water resources can be concentrated early in the closure phase for activities such as pit filling or dust suppression, or, in selected cases, irrigation for establishing vegetation. Over this same period, urban, industrial and agricultural demands may also change in response to climate, policy and infrastructure reconfiguration. The resulting problem is one in which both supply and demand evolve through time, and the interaction between them is strongly conditioned by the sequencing of wet and dry periods rather than by average conditions alone.

In this paper, hydrological modelling refers to water resource and water balance modelling used to assess how mine closure water demands may alter river flow regimes, environmental flows, water availability and the values or uses those flows support. This includes the potential effects on environmental, agricultural, domestic and industrial water users where closure requires substantial reallocation or long-term use of surface water resources.

The paper does not deal with hydrological modelling for peak flow estimation, flood studies, site run-off modelling or local surface water management across mine landforms. Nor does it focus on package-specific water balance tools for storage or lake water bodies, such as GoldSim, or rainfall-run-off models such as RORB. Those methods are used to inform peak design thresholds or critical levels of design events. Instead, the method presented here aims to provide a long-term view of how a system evolves and describe how the environment responds over time.

This method brings approaches applied in the field of river systems and water resource modelling to mine closure planning. We borrow from that field, particularly the techniques now being used to better account for natural climatic variability, progressive climate change, and the uncertainty these introduce into long-term water availability, demand and allocation. The emphasis here is on quantifying how closure water requirements may interact with existing and future water resource systems over time.

We focus especially on closure scenarios where mine voids are filled to form permanent pit lakes, because these can represent a large and sustained water demand relative to closure options that does not replace mined voids with pit lakes, or that require much smaller water volumes. The permanent pit lake problem is more mature internationally than in Australia, particularly in European lignite districts where large residual voids have been deliberately flooded and managed as lake systems (Weber 2020). The Australian contribution in this paper is therefore not to identify pit lakes as a closure form but to test how regional water balance decisions perform under uncertain future hydroclimate and demand conditions. The modelling principles presented are not limited to pit lakes, however. The same methods to scaling flows, representing natural variability, accounting for climate change and assessing cascading effects through other water demands, are relevant wherever water resource impacts must be quantified for closure planning.

2 Applications for hydrologic modelling in mine closure planning

If hydrological modelling is to support closure planning that properly accounts for the uncertainty just described, it needs to provide outputs that can be used to test the robustness of closure strategies across a plausible range of hydroclimatic conditions, distinguish between the effects of operational choices and the effects of climate, and quantify the likelihood of environmental or operational thresholds being exceeded. In practice, that means the modelling needs to support comparison of alternative pit-filling strategies, pit lake top-up rules and infrastructure configurations while also showing how those strategies perform when exposed to different sequences of wet and dry conditions and different plausible climate trajectories. This is the level at which the modelling becomes useful to closure planning because it allows the assessment to move from asking what happens under one adopted future to asking which options remain acceptable across many plausible futures. Here, an adopted future means a selected combination of assumed climate, demand and operating conditions that is treated as the assessment case. It is not a prediction; it is one scenario against which the system is tested.

The argument developed in this paper is that mine closure water balance assessments now need a modelling framework that embraces natural variability, treats climate change as an uncertain and time-evolving influence rather than a static modifier, and produces outputs that are useful for regulator decision-making considering risk and model performance. The stochastic modelling framework presented here has been developed for that purpose. It couples demands that change over time with stochastic climate sequences, applies climate change progressively through time, allows different parts of the flow regime to respond differently under each plausible climate future, and evaluates outcomes as distributions and likelihoods rather than as singular modelled futures. This stochastic method provides a more reliable basis for comparing closure strategies and interpreting hydrologic risk in systems where competing water demands, climate variability, climate change and mine closure are all interacting.

Originally developed as a response to the recognition that global hydroclimates could no longer be considered stable (Peterson et al. 2021; Saft et al. 2015; John et al. 2022; Fowler et al. 2022), the stochastic method (sometimes known as 'scenario neutral' or 'decision scaling') has been a regular topic within the academic world for more than a decade (Culley et al. 2016; Guo et al. 2017). Through advances in computer-processing power and the demand for improved risk assessment methods within the broader water industry, the stochastic methods are now recognised as leading practice in Australia (QMRC 2025). The goal of this paper is to provide an example of how it can be implemented in a real mine closure scenario (the filling and maintenance of a pit lake), helping to demystify its key concepts and encourage broader adoption.

3 The conventional method to hydrological modelling in closure planning

Assessment of the impact of mine closure on flow regime and the environmental values those flows support has typically relied on deterministic, fixed-scenario methods that pair a small number of demand assumptions with a small number of climate scenarios and apply those to a single historical sequence of flows. In the case of pit lake filling and maintenance, this often means representing the projected risk profile of mine closure as a small selection of low, medium and high climate scenarios, a limited set of closure arrangements (such as connected or disconnected to nearby watercourses), and scaling of historical river flows and competing water demands.

That style of assessment remains common because it is transparent, relatively tractable and easy to communicate, particularly where project teams need a manageable set of scenarios for design development and impact reporting. While the method is valid in principle, it does have the potential to underestimate the full envelope of uncertainty and risk. An assessment based on a single hydroclimate sequence cannot fully capture the extent to which natural variability alone can drive variation in compliance outcomes. It treats climate change as something that can be adequately represented through a few fixed end-state model adjustments rather than as a progressive and uncertain influence acting on an already variable system.

Where demands are also changing through time, where different flow components may respond differently to climate change, and where environmental and socio-economic risks are more significant, these simplifications become harder to defend.

The hydrological modelling undertaken in support of the catchments, rivers and wetlands technical assessment for the Hazelwood Environmental Effects Statement is a practical example of this type of fixed-sequence method. The regional water balance modelling used the Department of Energy, Environment and Climate Action (DEECA) Latrobe Source model, run as a deterministic daily timestep model using the historical 1957–2020 flow sequence, with each scenario represented as a single realisation that differed by mine rehabilitation configuration, demand profile, and low, medium or high climate change adjustment. Climate change was represented using the DEECA 2020 water availability guidance by applying selected scaling parameters to the historical flow record, which changes the magnitude of flows but preserves the historical order of wet years, dry years, floods and droughts. This is transparent and suitable for comparing defined project scenarios, but it means the assessment does not test the effect of a different sequence of natural climate variability that could have occurred under the same long-term climate conditions. It also simplifies the climate change response because low flows, seasonal flows and high flows are unlikely to change uniformly; in the Morwell River, for example, further analysis was required because the number of smaller, more frequent floods may decrease while rarer, larger floods may increase in number, which is not fully captured by a single scaling factor applied evenly across the historical flow series.

3.1 Limitations of the conventional method to hydrological modelling in closure planning

The main limitation associated with the conventional method is that a single historical climatic/flow sequence does not represent uncertainty in the future sequencing of wet and dry periods. The order, persistence and clustering of dry years can have a significant impact on pit-fill time, pit lake top-up requirements and environmental flow compliance, even where long-term averages are unchanged. A deterministic model run based on one observed sequence therefore provides only one plausible trajectory through the problem.

Fixed climate scaling also compresses uncertainty into a small number of predictions of change in rainfall, evaporation and, in many cases, river flow. In previous assessments of mine closure in the Latrobe Valley [e.g. the Yallourn Declared Mine Rehabilitation Plan (DRMP), Energy Australia 2025; Hazelwood Environmental Effects Statement, Catchments, Rivers mad Wetlands Technical Report, Alluvium 2026], climate was represented through low, medium and high climate change scenarios, adopting the magnitude of change expected to materialise in 2065 (i.e. a conservative assumption of climate change applied to the immediate future). Previous modelling used to inform the Yallourn DMRP (EnergyAustralia 2025) applied the deterministic method and was explicitly framed around one historical sequence, 3 climate scenarios and uniform scaling across the full sequence. That structure is useful for statistical comparison of runs, but it narrows the view of climate impacts to a small selection of extremes and does not test how the system performs across a wider range of anticipated change under multiple plausible futures. For example, what is the likelihood that observed changes in flow compliance or related thresholds would materialise due to natural variability alone? To what extent is climate change making such outcomes more likely and how is that likelihood altered by mine closure arrangements?

Demand is also represented much more simply than in reality. Although closure studies commonly include representative filling and post-fill phases, both demand and supply are usually treated as fixed over time. In practice, mine demand changes progressively through time, other consumptive demands may change with climate and policy, and operational rules interact with those changes in ways that are not well represented by a few static cases.

4 A stochastic method of hydrological modelling for mine closure assessment

4.1 Conceptual basis and core elements of the stochastic method

The stochastic method shifts the assessment from deterministic testing of a few selected scenarios to stress testing across many plausible futures. The objective is not to identify a single 'most likely' future condition but to assess how a closure strategy performs under uncertainty in climate, demand, and sequencing of wet and dry periods. This is a better fit for closure planning and communicating modelled outputs with regulators, where the central question is usually whether a proposed strategy remains acceptable across a range of plausible conditions rather than under one adopted future.

The framework combines 4 main elements as follows:

1. Dynamic demand. Demand changes through time as filling progresses, storages method design levels and sites move from active pit filling to pit level maintenance in post-fill conditions
2. Stochastic climate sequences. Climate variability is represented through multiple stochastic sequences rather than a single historical record. The Yallourn DMRP (Energy Australia 2025) describes the current method as using 50 to 100 plausible future sequences, compared with one historical sequence in the earlier top-down assessment. This more effectively represents natural variability while exposing the model to a broader range of wet and dry sequencing than is available from one observed series alone
3. Non-stationary representation of climate change futures. Climate change impacts are represented as changes to selected covariates, in this case % change in rainfall, which are applied progressively through time rather than as a fixed end-state condition. In the updated framework, scaling varies from 0% in the first year to 100% by 2075, whereas the earlier method applied uniform scaling across the full sequence. Previous assessments considered each replicate as an independent representation of the system under fully realised future climate conditions. This method allows the system impacts of filling and post-fill water use and timing to be assessed under a climate signal that develops through time
4. Component-specific flow scaling. This method allows different components of the flow regime, including seasonality, low flows, high flows and dry spell duration, to be adjusted independently within plausible bounds. This is useful where flow components are not expected to change uniformly under climate variability or climate change, and where different environmental values respond to different parts of the flow regime. The method helps identify the range of hydrological conditions most likely to place flow-dependent values under stress.

These elements are implemented using an established deterministic water balance model (eWater Source^{TM}) that has been modified to enable a high volume of stochastic model runs. In practice, the eWater Source platform, which is designed to represent complex systems with multiple competing water sources, users, demand profiles, storages and allocation rules, formed part of a larger modelling pipeline designed to enable batch processing and generation of graphical outputs.

4.2 Advantages of the stochastic method in mine closure planning

The key outputs from this framework are distributions, probabilities and threshold exceedance metrics rather than single likelihood values. Running the model across many stochastic sequences and multiple climate responses allows the assessment to separate the contribution of natural variability, the additional effect of climate change, and the incremental effect of closure decisions such as pit-filling rate, closure infrastructure (e.g. connected versus disconnected pit lake arrangements) or operating rules. In a deterministic single-sequence framework, those influences are compressed into a single value per scenario and metric (such as pit-fill time, flow compliance). In the stochastic method, the plausible range of impacts arising from natural variability, climate change and project scenarios is displayed for each metric.

It also improves water management strategy testing and impact mitigation design. A closure option that performs adequately (e.g. where flow compliance criteria are consistently met) only under a narrow range of sequences presents a different risk profile from one that performs consistently across a broader range of plausible conditions. The same applies to mitigation measures. Some risks are driven mainly by natural variability and exposure to prolonged dry periods during pit filling, while other risks only emerge only once climate change is introduced. Those distinctions are much clearer when the outputs are expressed as distributions rather than as a few fixed-scenario results. The overall process of the stochastic modelling method and an example of the type of output it generates are shown in Figure 1.

5 Example implementation: water resource assessment to support closure planning and pit lake filling

This section presents a hypothetical application of the stochastic modelling method and compares its outputs with those produced using a conventional deterministic method based on a smaller number of model runs. The purpose is to demonstrate the types of outputs the framework can generate and the additional analysis they support.

The example represents the filling of a mine void following a coal mine closure and is informed by mine rehabilitation studies undertaken in Victoria’s Latrobe Valley. However, it does not reproduce the data, parameters or results from any specific Latrobe Valley mine. Those studies remain subject to client confidentiality, ongoing technical development and regulatory review. The figures and analyses presented here are therefore synthetic but representative of the outputs that can be produced using this method.

5.1 How the framework was applied

The framework was applied by updating the DEECA Latrobe Source (the original version, pre-update, is described in DELWP 2020) model to represent a series of open cut mine voids and their progressive refilling using a variety of water sources. The model is then run across a large ensemble of plausible hydroclimatic futures. The scenario structure included alternative mine conditions, pit lake infrastructure configurations, interacting demands at adjacent sites and operating assumptions relevant to closure planning.

Dynamic demand representation was incorporated so that each model run captured the progression from pre-fill to post-fill conditions rather than splitting those phases into separate deterministic runs. This allowed water demand, supply configuration and system behaviour to evolve through time within each simulation (earlier modelling had treated each phase separately).

Climate variability was represented using multiple stochastic climate sequences rather than one historical record. Between 50 and 100 plausible future sequences were developed. Climate change was then superimposed through time-dependent scaling, increasing from 0% in the first year to 100% by 2075, rather than being applied as a fixed end-state condition across the full sequence. The framework also included broader scenario scaling to test the relationship between climate change and the response of specific flow criteria (each related to a specific component of the flow regime), including adjustments in rainfall that varied between +5 to -20%. This process is summarised in Figure 1.

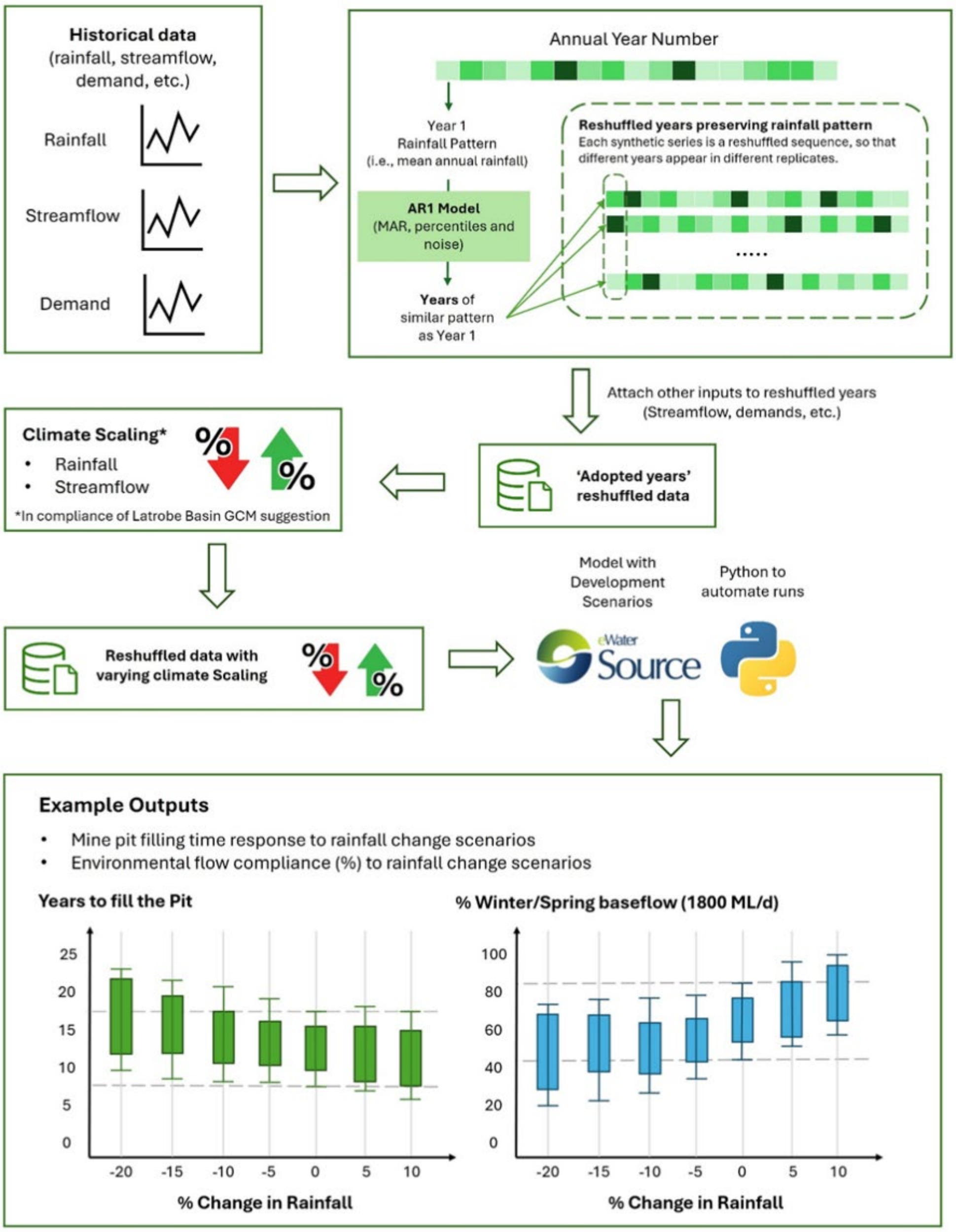

Figure 1. Conceptual workflow for stochastic water resource modelling, showing historical climate and demand data reshuffled into synthetic sequences, climate scaled, run through Source, and summarised as pit-filling and environmental flow response metrics

5.2 What the implementation demonstrates

The example presented here is synthetic and is intended only to demonstrate the types of outputs that can be generated using the stochastic framework. It is closely aligned with the water resource questions that arise when mine voids are filled and maintained as pit lakes in the Latrobe Valley. However, the input data, model parameters, scenario definitions and results do not represent any individual Latrobe Valley mine or any modelling completed for a specific closure study. This distinction is necessary because the underlying project data remain subject to client and regulatory requirements.

Two illustrative metrics are used. The first is the annual volume of water used during mine void filling. The second is the likelihood that a selected impact criterion, such as an environmental flow requirement defined by flow magnitude, duration and frequency, is not achieved during the filling period. These metrics are examples only; the same framework can be applied to pit-fill duration, post-fill top-up demand, environmental flow compliance, water availability and other annual or event-based measures.

For each metric, the conventional and stochastic methods are compared. Under the conventional method, a small number of project and climate scenarios are modelled, and the result for each combination is generally reported as a single value. This provides a direct comparison between selected scenarios but does not show the range of outcomes that may arise from different sequences of wet and dry years. The stochastic method instead applies each project and climate scenario across 50 to 100 plausible hydroclimatic sequences. Results can therefore be expressed as distributions, probabilities and threshold exceedance frequencies rather than as single modelled outcomes.

Table 1 illustrates the conventional presentation of annual water use. A single median or mean value is reported for each project and climate scenario, including baseline conditions. This format shows whether average water use increases or decreases between the selected cases, but it provides no information on the spread of annual demand within each case or the extent to which the scenarios overlap.

Figure 3 presents the equivalent output from the stochastic analysis as distributions of annual water use. The box plots show the median, interquartile range and broader spread generated across the stochastic sequences for each climate and project scenario. The results indicate that natural variability alone can produce a wide range of annual water use outcomes. The baseline range with no imposed climate change signal overlaps substantially with the distributions generated under several climate scenarios, showing that the sequence of wet and dry years remains a major control on system performance.

The figure also shows a progressive shift in the outcome distribution as mean annual rainfall decreases. In this synthetic example, lower rainfall reduces water availability and therefore lowers the annual volume that can be directed to mine void filling. The important result is not only the change in the median value but also the change in the spread and overlap of the distributions. This makes it possible to distinguish a persistent climate-driven shift from the variation that can occur under the existing climate because of natural hydroclimatic sequencing.

The same method can be applied to environmental or operational thresholds. Rather than reporting a single likelihood that a criterion is not achieved, the stochastic output can show the probability of the criterion being missed 1, 2, 3, 4 or more times within a defined period. This distinguishes relatively isolated failures from repeated failures that may have greater environmental or operational consequences.

Table 1 Example. Output from the existing method typically used in water resource studies to support mine closure (i.e. not the stochastic method described in this paper), showing median annual total water use in closure for 3 scenarios across 3 climate scenarios and baseline conditions

Median Annual Total Water Usage under Climate Change Scenarios (GL)

Scenario	Low Climate Change	Medium Climate Change	High Climate Change	Baseline Conditions
Scenario 1	9.2 GL	6.8 GL	4.1 GL	5.5 GL
Scenario 2	8.5 GL	5.9 GL	3.6 GL	4.8 GL
Scenario 3	7.9 GL	5.2 GL	2.7 GL	4.2 GL

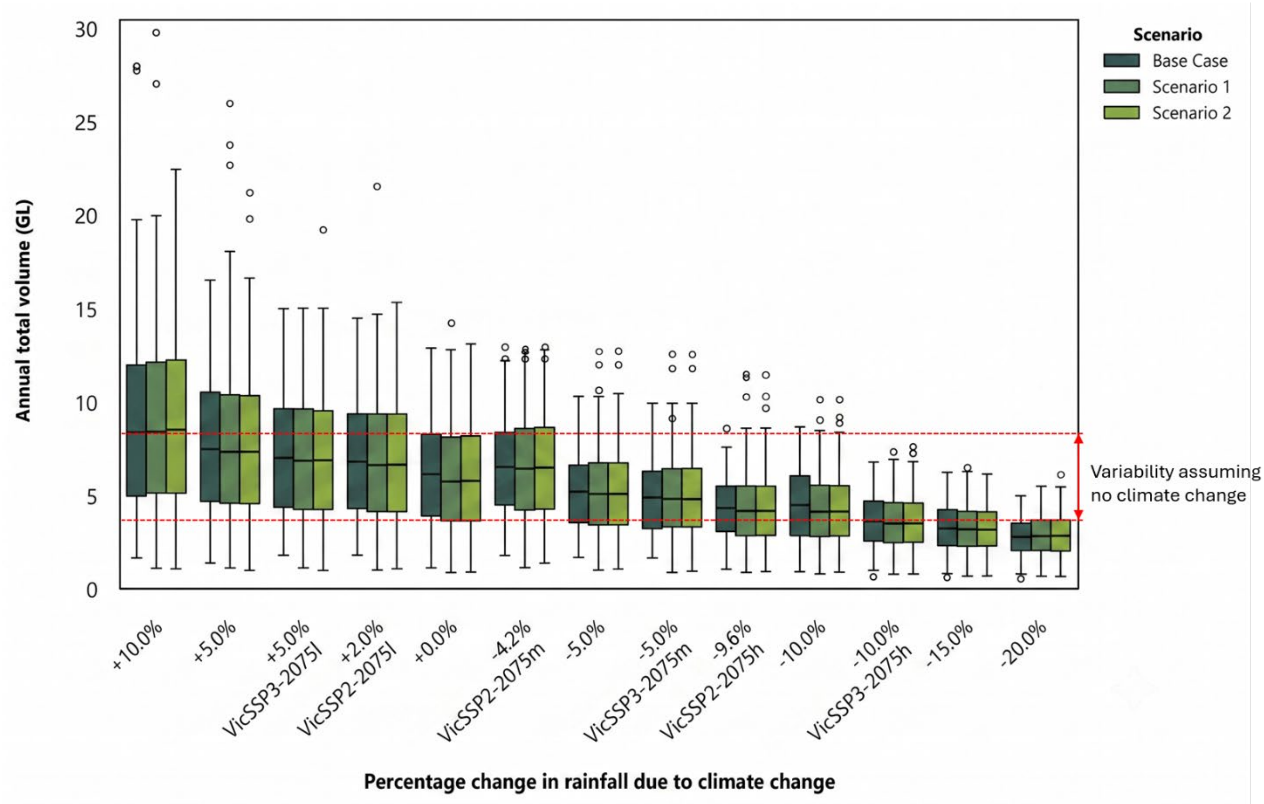

Figure 2 Example *. Outputs of total annual volume of water used to fill a mine void under selected modelled scenarios, showing how total water use varies naturally (without the influence of climate change – the red dashed lines) and declines due to incremental shifts in climate (mean annual rainfall)

Comparison between the conventional likelihood plot and the stochastic output illustrates 2 different ways of reporting environmental flow risk. The previous example focused on annual water use, which is primarily a water resource metric. This example considers how mine closure water use may alter downstream flow conditions and the likelihood that a selected environmental flow criterion is not achieved.

Under the conventional method, likelihoods are reported separately for a small number of adopted climate futures such as medium and high climate change. Results are presented as single values and classified using qualitative risk bands, commonly shaded from green through orange to red. This format shows how the assessed likelihood changes between the base case and selected project scenarios, but each climate future generally requires a separate figure and the result does not show the underlying spread of outcomes. It also restricts the assessment to a small number of predefined climate states rather than testing a broader range of changes in rainfall and water availability.

The stochastic output instead shows the percentage of modelled years in which a selected environmental flow criterion is not achieved across multiple project and climate scenarios. It can also distinguish between different frequencies of failure, such as the criterion being missed at least 1, 2, 3, 4 or more times within a year. This provides information on both the likelihood and severity of non-compliance rather than reducing performance to a single binary result.

For example, failure to provide a spring fresh (a short-duration increase in flow that supports ecological processes) once in a year may have a different consequence from repeated failures within the same year. Although repeated failures are generally less likely, they may present a greater risk to flow-dependent values. Under the conventional method, each event-frequency threshold would need to be reported as a separate criterion. The stochastic method presents these outcomes together, allowing the effect of climate, project configuration and repeated non-compliance to be compared more directly.

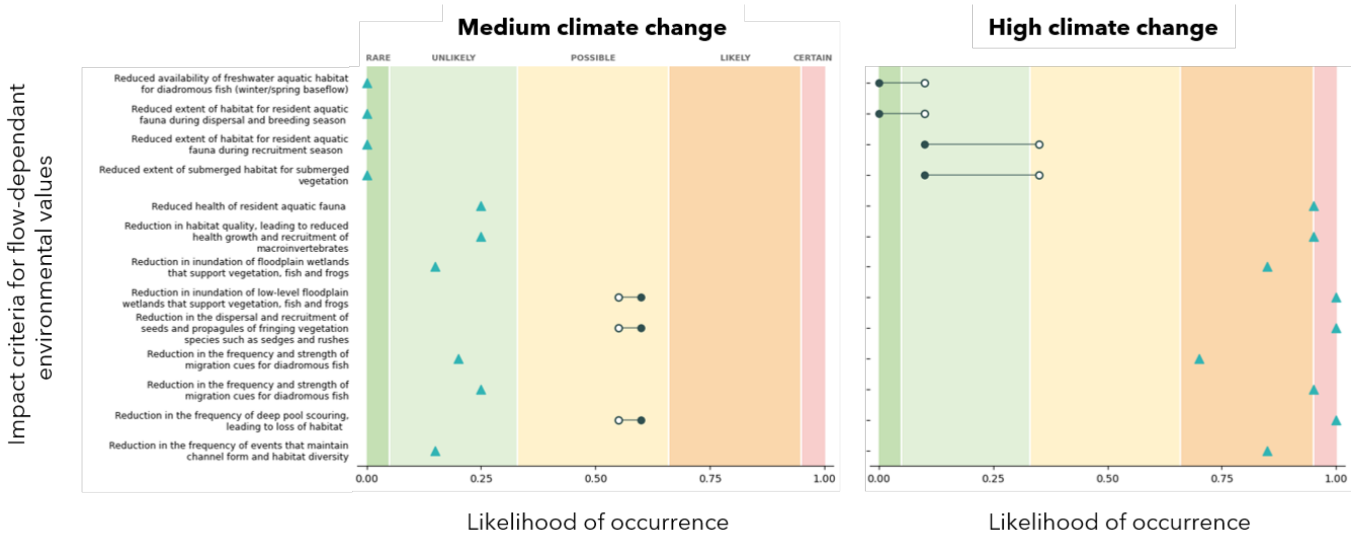

Figure 3 Example [*]. Likelihood ratings for flow-dependent environmental impacts under medium and high climate change scenarios, comparing the base case with the project scenario across qualitative risk categories for a selection of 13 environmental impact metrics

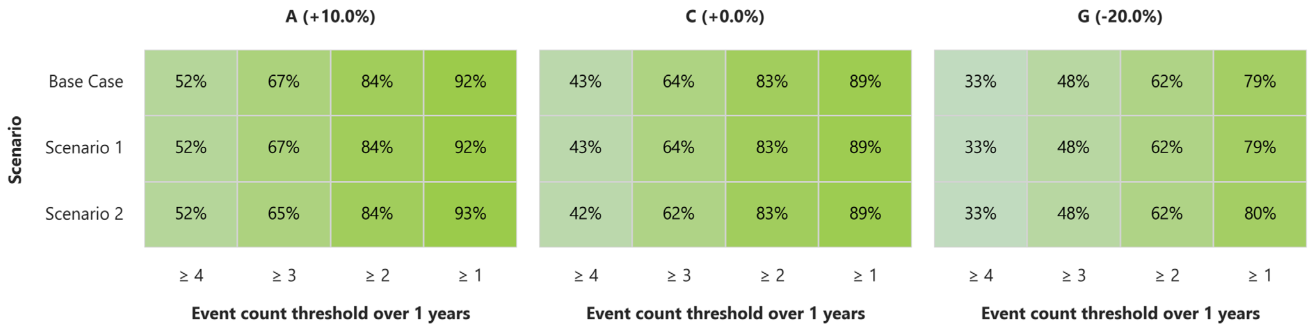

Figure 4 Example [*]. Outputs from environmental flow analysis under selected modelled scenarios show how environmental flow compliance shifts under incremental shifts in climate (mean annual rainfall)

[*] Note: The results presented in Figures 2-4 are illustrative examples only and do not present results from the modelling undertaken in this study.

6 Discussion

Hydrological modelling is often used to support closure planning. Modelling provides a basis for environmental impact assessment, regulator engagement, and comparison of alternate operating and infrastructure arrangements in systems where future hydroclimatic conditions, competing water demands and closure sequencing are all uncertain. Traditional modelling methods built around a small number of fixed scenarios can still be useful for screening and communication but are much less suitable for assessing how robust a proposed closure strategy is across a wide range of plausible futures. The stochastic framework presented in this paper is better suited to that task because it treats performance as a distribution rather than a single outcome, and because it accounts for natural variability and allows water demand and climate to change over time.

It also improves transparency around uncertainty. In deterministic fixed-scenario modelling, uncertainty is often narrowed early through the selection of a few demand profiles, a few climate futures and one or a small number of historical flow sequences that climate scaling is then applied to. That structure is orderly, but it can make the assessment look more certain than it really is. The stochastic framework is more explicit about the extent to which outcomes depend on sequencing, progressive climate change and closure decisions themselves.

This type of framework is also likely to become more common in large, contested or environmentally sensitive closure settings. That is partly because the systems themselves are becoming harder to simplify. Multiple mine sites may draw on the same regulated system and water access rules may change through time. In parallel, climate guidance is moving away from the assumption that 1 or 2 adjusted historical traces are enough to characterise future change. Under those conditions, a probabilistic framework that can preserve natural variability, represent non-stationary climate change impacts and compare alternate closure strategies on a like-for-like basis is more defensible than a purely deterministic workflow.

The framework represents a substantive advance for mine closure water resource assessment because it replaces a small number of fixed climate and project scenarios with systematic stress testing across many plausible hydroclimatic futures and closure configurations. Natural variability is embedded within the modelling, allowing changes attributable to baseline conditions, climate change and project decisions to be distinguished rather than compressed into a small set of deterministic comparisons that mask the relative influence of each of these factors. This makes it possible to identify which performance measures, such as environmental flow compliance, total water use or pit-fill timing, are sensitive to climate, how rapidly their distributions shift as conditions becomes drier or hotter, and where project performance remains within acceptable bounds.

The resulting data can be presented as box plots showing outcome distributions or as simple tables that compare multiple metrics across project and climate dimensions. These outputs provide a clearer basis for selecting project configurations, identifying climate-sensitive parts of the system, avoiding over-design where responses remain within the range of natural variability, and recognising where natural variability alone may drive threshold exceedance. They also help to distinguish project effects from baseline conditions, and support infrastructure and operating rules designed for the relevant flow regime. Because the framework samples a broad range of rainfall, evaporation, run-off and streamflow conditions, it can also accommodate updated climate science without requiring the assessment to be rebuilt around newly prescribed low, medium or high scenarios. In this way, the method brings mine closure assessment into line with established Australian water resource planning practice and provides a more flexible basis for testing closure performance under uncertainty.

7 Conclusion

Water balance modelling for mine rehabilitation needs to represent the controls that determine water availability, environmental flow performance and closure risk: demand timing, climate variability, progressive climate change, operating rules, and the sequence of wet and dry years. Deterministic, fixed-scenario modelling remains useful for screening options and communicating defined cases, but it is limited where closure decisions depend on understanding the likelihood and consequence of threshold exceedance across many plausible futures.

The stochastic framework described in this paper addresses that limitation by combining dynamic closure demands, multiple hydroclimatic sequences, progressive climate scaling and component-specific flow response within an established regional water balance model. The Yallourn case study demonstrates the practical value of this method for pit lake closure planning in a regulated and contested water system. By expressing results as distributions, probabilities and threshold exceedance metrics, the method provides a clearer basis for separating the effects of natural variability, climate change and closure decisions.

For large or environmentally sensitive mine rehabilitation projects, this shift is more than a technical refinement. It changes the assessment from a comparison of selected model runs to a test of how consistently closure options perform under uncertainty. That provides a more defensible basis for impact assessment, regulator engagement, adaptive management and the design of closure strategies that remain acceptable across a wider range of plausible future conditions.

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