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Closure planning: a review of guidance and suggestions for improving the state of practice

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Abstract

Mine closure plans can be a powerful tool to enable efficient mine planning, decision-making, collaboration and progressive reclamation. The intent of a closure plan is to provide a path from mine construction, commissioning and operations through to closure monitoring and maintenance. Ultimately, the closure plan allows the mine to make sound decisions, provides regulators and local communities with assurance that the mine is on track to meet its commitments, and establishes a basis to seek capital to fund the reclamation. The state of practice in closure planning (and mine reclamation more generally) has evolved considerably over the past 50 years. The growing number of international guidelines, conference papers and handbooks demonstrate the usefulness of closure planning (the "why"), and that the contents of closure plans and the closure activities are well known and understood (the "what"). Many mining companies have developed proprietary standards to guide such activities. Despite all this, the frequent lack of sign-off and relinquishment of reclaimed post-mining land, mainly over concerns regarding residual risk, indicates the need for further improvement in closure planning and implementation. A selection of guidelines and standards are reviewed, and shortcomings of the existing body of guidance are identified. To improve closure planning implementation and outcomes, the review identifies the need to elevate mine closure considerations at both the mine operations and corporate governance levels, and to develop a clear and agreed upon closure design basis. A willingness to share examples of both positive and negative closure planning and reclamation work is also needed to promote knowledge sharing, thereby improving outcomes of individual mine sites and the state of practice for the mining industry.

Keywords: *mine closure, corporate standards, design basis, governance*

1 Introduction

Mine closure plans are developed to provide a clear, orderly and reliable path from mine construction and commissioning through operation and progressive reclamation, final decommissioning and reclamation, and closure monitoring and maintenance. They guide decision-making by the mine, regulators and local communities. Closure plans are prepared by an interdisciplinary team based on the life of mine (LoM) plan and are periodically updated to match the evolving LoM plan. Closure plans generally have a dual focus. First, they describe the steps needed to establish and deliver the agreed-upon post-mining land use(s) on the disturbed land, including the reclamation and long-term operation/maintenance activities to protect the environment from the impacts and residual risks of mining. Second, they deliver a guide for socio-economic transition for the local mining community.

The authors' experience is that the quality and usefulness of contemporary closure plans vary by jurisdiction and between mine operators. The need for good closure plans is widely understood and closure planning guidance is available from a range of industry, non-governmental and inter-governmental organisations at regional, national and international levels. Additionally, many mining companies have developed proprietary

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closure planning standards and guidance documents. Yet many closure plans are disconnected from the LoM plan and fail to provide a reliable basis for making mine planning and operational decisions or documenting existing decisions and their rationale. Accordingly, there is a need for improvement to the state of practice in mine closure planning.

This paper provides a high-level review focusing on mine closure guidance documents (applicable to an international audience) and proprietary closure standards, describes the current state of practice of mine closure planning, and identifies technical issues and opportunities for improvement. Specifically, the paper focuses on practical advice for closure governance, design basis, planning considerations and technical areas.

1.1 Background

The initial closure plan developed before mining begins is often conceptual in nature, sometimes consisting of only a few engineering drawings and a few dozen pages of text, but generally prepared to a level of detail that meets the regulatory and permit requirements for the region. It informs the LoM plan and project economics. The plan is typically developed by a team of environmental and engineering consultants working with mine planners using input from the local community. Regulators and local communities use the closure plan to evaluate whether environment and land use impacts are sufficiently mitigated and to help decide if the project is in the public interest. Critically, the level of financial assurance is based on the closure plan.

Subsequently, the closure plan is updated at set periods or following material changes to the LoM plan, as governed by local regulations. Most decommissioning and reclamation occur after the end of mine operations, despite the current understanding of the benefits of progressive reclamation. The final closure plan is typically a detailed design document that may include dozens of drawings and hundreds of pages of text. For complex sites, final decommissioning and reclamation plans can take years to decades to develop, and hundreds of millions to billions of dollars (CAD) to implement (e.g. Thompson 2018).

Mine closure planning practices have been in place through regulations since the 1970s (World Bank 2020). Effective mine closure planning is becoming increasingly important as governments and communities advocate for safe and responsible mines that provide positive post-mining land uses. Recent development of closure guidelines in the 2010s and 2020s has provided the mining industry with a range of resources and tools to improve closure planning. In addition, many mining companies have developed proprietary standards to provide direction applicable at the organisational scale for mine closure planning and execution activities.

A survey conducted by the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) found that 13 of the 17 jurisdictions surveyed had formal legal requirements for mines to have a closure plan (IGF 2021a). Additionally, the required level of detail for mine closure planning and associated review was highly variable, with some jurisdictions having no guidance for what to include in a closure plan. This discrepancy highlights an opportunity for both government and industry to advance the closure planning state of practice. This current study found similar results that are described below.

1.2 Issues with the current state of practice

Based on interviews of practitioners, the Landform Design Institute (LDI 2021) presents a list of some shortcomings in the state of practice in mine reclamation and landform design. Shortcomings that relate to closure planning and closure activities as defined by the LDI, and a list of selected key risks regarding closure planning by the World Bank (2020), are included in Table 1. These lists highlight the divergence between what is being promised in closure plans versus what is being delivered in practice, and they are also useful in developing guidelines and direction for mines designing their closure planning programs.

Table 1 Shortcomings and key risks in closure planning and closure activities

Closure planning shortcomings (LDI 2021)	Closure planning key risks (World Bank 2020)
No accountable executive for successful mine closure	Failure to incorporate closure planning into project design and development
Highly conceptual closure plans submitted to meet regulatory conditions with back-end loaded design and engineering	Failure to update closure plan on a regular basis
Reclamation cost estimate highly unreliable; underfunded financial assurance for reclamation	Failure to accurately estimate closure liability
Potential known and unknown risks remain in an unmanaged state or as hidden fatal flaws in design	Failure to make sufficient provision to implement closure plan
Poor integration with mining and tailings engineering, reclamation team and operations teams	Closure objectives and goals are not defined, not site specific or realistic
Undeclared service life for mine structures and design criteria	Closure success criteria do not fit closure goal
Long-term monitoring is often an afterthought, or no funding for aftercare	Release of contaminated water from site after closure – from pits, tailings, overburden material and other mine waste materials
Lack of relinquishment; meeting the requirements but failing to achieve sign-off due to residual risks	Downgradient groundwater or surface water quality does not meet closure criteria
Surface water drainage requires retrofit at the end of mining	Contaminated soil, hazardous materials and liquid wastes remaining on site
The burial or wasting of reclamation soil during operations	Erosion (e.g. wind, water and waves) during extreme climatic events
Difficulty meeting closure commitments for water quality or contingency measures to address water quality are conceptual	Slope failures (pit walls, stockpiles, etc.)
Mine infrastructure designed without a decommissioning plan	Materials useful for closure (e.g. organic soil) were not salvaged and stockpiled
Mine sites abandoned in a half-reclaimed state	Closure measures fail to achieve closure objectives
Local communities and regulators are reluctant to accept responsibility for the mine site; mining companies remain liable indefinitely or land users are banned from the site	

In some jurisdictions there is a trend for substantially more involved closure plans that are hundreds of pages or longer, cost over a million dollars (CAD), take several years to prepare and often require more than a year to answer questions to the satisfaction of the regulator. In many cases the closure plan is out of date by the time it is accepted by the regulator and of little ongoing use to the mine operation. Ultimately, reclamation efforts can cost more yet deliver less than expected (e.g. McKenna 2002; LDI 2021).

Given the high level of effort and cost in preparing and regulating closure plans, and the substantial number of mine sites that are largely unreclaimed or default back to government control due to insufficient financial assurance (e.g. Cassie & McKenna 2016), there is ample room to improve the current state of practice.

The high levels of uncertainty in what is promised by closure plans and the mine's ability to deliver on these promises leads to the situation at many mines where risk is accepted and managed to the extent possible, expressed by one industry reclamation practitioner as: "We do our best and cross our fingers" (Anonymous, pers. comm. with McKenna).

2 Industry and international guidelines for closure planning

Currently there is excellent closure planning guidance on "what" needs to be done and "why" it needs to be done, and the literature continues to evolve rapidly. Some of the earliest mine closure guidelines in Canada, such as the *British Columbia Mines Act* (Government of British Columbia 1969) and the Mine Rehabilitation Code of Ontario (Government of Ontario 1990), served as a foundational framework for mine closure planning nationally and internationally, which has since evolved and improved. One of the main recent changes in mine closure planning is the formal recognition of the need for involvement with local communities and Indigenous groups in the planning and execution of mine reclamation and closure. Many of the new expectations focus on consultation, but others recognise the need for true collaboration and reconciliation (e.g. Daly et al. 2021).

The following recently published or updated guideline documents form the focus of the mine closure planning guidance review herein:

- The International Council on Mining and Metals' (ICMM) *Integrated Mine Closure – Good Practice Guide* (ICMM 2025a) provides a risk and opportunity-based process, including supplementary tools and case studies, to help guide mine closure practitioners in applying integrated closure planning practices to the areas in which they work. It introduces enhanced strategies for integrating tailings management and mine closure processes in accordance with the updated *Tailings Management Good Practice Guide* (ICMM 2025b).
- The IGF *Mining Policy Framework – Mining and Sustainable Development* (IGF 2023a) provides a sustainable mining framework in adherence to international practices. There are also supplementary guidance notes (IGF 2023b) and additional guidance documents on closure elements such as financial assurance and relinquishment (IGF 2021b; IGF 2023c).
- International Organization for Standardization (ISO) Standard 21795, Mine Closure and Reclamation Planning (ISO 2021a, 2021b) is a two-part document providing key requirements and guidance for mine closure planning for an international audience. This standard provides a workflow and guidance on a range of closure planning topics, and is intended to promote consistency and quality for the practice.
- *Mine Closure: A Toolbox for Governments* (World Bank 2020) serves as a tool for governments and policymakers to develop closure governance frameworks and help achieve successful implementation of mine closure practices. Acknowledging that closure requirements can be jurisdictionally unique, the toolbox provides useful examples of good international practice as well as basic legislative considerations.
- The Asia-Pacific Economic Cooperation (APEC) *Mine Closure Checklist for Governments* (APEC 2018) is a guide and checklist for mine closure intended for governments but is also useful to industry practitioners. While the focus is for policymakers in the Asia-Pacific region, the document includes useful frameworks for effective mine closure planning that can be applied internationally.

Additional important and practical guidelines, standards and tools for mine closure practitioners include:

- The Mining Association of Canada's *Towards Sustainable Mining Framework* (Mining Association of Canada 2008)
- The Brazilian Mining Association's *Guide for Mine Closure Planning* (Brazilian Mining Association 2014)
- The Australian Department of Industry, Innovation and Science's Leading Practice Sustainable Development Program for the Mining Industry (2016) and Western Australia Department of Mines, Industry Regulation and Safety's *Mine Closure Plan Guidance* (Government of Western Australia 2023)

- Anglo American's Mine Closure Toolbox (Anglo American 2019)
- The Global Tailings Review's *Global Industry Standard on Tailings Management* (GISTM) (Global Tailings Review 2020).

Select additional publications that may be relevant and useful to practitioners include:

- The paper *Toward Effective Closure Planning: From Progressive Reclamation to Sustainable Mining* (McKenna et al. 2013) provides a framework for closure planning at the regional scale to produce plans that incorporate multiple mines and other industries in a mining or eco-region, and to identify opportunities for cooperation between mines across shared property boundaries.
- The LDI's position paper *Mining With the End in Mind*: *Landform Design for Sustainable Mining* (LDI 2021) argues that closure planning is equivalent to landform design at the landscape-/mine site- scale and provides a useful framework for this approach. It discusses the level of effort required for various scales of landform design and reclamation, and the level of detail needed as the mine progresses.
- The LDI's *Developing a Design Basis Memorandum for Landform Design* guidance document (LDI 2024) provides a how-to guide for developing a design basis memorandum (DBM) for landform designs and closure plans.
- The Eden Project's *102 Things to Do with a Hole in the Ground* (Whitbread-Abrutat & Lowe 2024) is an insightful, illustrative book on post-mining land uses. It highlights that remote mines are often returned to wildlife habitat and traditional land uses. Mines closer to urban centres have added flexibility and may become areas for agriculture, industry, recreation or other land uses.
- The Commonwealth Scientific and Industrial Research Organisation's (CSIRO) *Guidelines for Open Pit and Waste Dump Closure* (CSIRO 2025) has just recently been published.
- Building on its *Tailings Management Handbook – A Life Cycle Approach* (Society for Mining, Metallurgy & Exploration [SME] 2022), the Society of Mining Engineers (SME) will soon be publishing the Tailings Closure Handbook (SME n.d.).
- Daly (2023) provides a modern framework for co-reclamation with Indigenous peoples.

3 A review of closure guidelines and standards

3.1 Methods

Five international mine closure guidelines and four corporate closure standards were qualitatively reviewed to assess the state of guidance for mine closure planning. The purpose of this review was to evaluate the level of detail provided by guidance documents for various elements of closure planning and to highlight trends across the documents or potential areas for improvement. The review was not intended to rank the documents; nor does it comment on the quality of the guidance.

A recent review and analysis of mine closure guidance titled *Mine Closure Guidance: Review and Comparative Analysis* (Guj & Rogerson 2024) provides a comparison of 11 closure guidance documents, including international guidelines and specific guidance from Australia. This comprehensive study is an excellent source for additional information on the state of mine closure guidance and is suggested for additional insight into a range of standards and guidelines beyond what is presented here.

A total of 30 closure "elements" were considered. These elements were selected for the review based on common terminology and technical areas used in mine closure practice as well as from the authors' experience. The closure elements, listed in Table 2, were grouped into four categories:

- Closure governance: governance is the process of establishing and implementing frameworks for planning, managing and executing a closure plan and closure activities for a mine. Some elements

of governance include understanding regulatory requirements and establishing roles and responsibilities within the mine closure team or committee.

- Closure design basis: based on the understanding of the mine site and available closure knowledge, a closure design basis is the process of crafting a set of objectives and criteria that are fundamental to achieving the closure vision and goals for the reclaimed landform or mine site (LDI 2024). Consideration for the post-mining land uses and the closure design life are often important factors in this process. The closure design basis is often documented in a DBM.
- Closure planning considerations: this category includes a broad range of elements common to effective mine closure planning practices, such as stakeholder and Indigenous engagement, socio-economic transition and progressive closure.
- Closure technical areas: this category considers typical technical areas that are important to mine closure planning, such as geotechnics, mine waste engineering, hydrology, ecology, geochemistry and climate change.

Table 2 Key elements of a closure plan

Category	Element	Definition or description
Closure governance	Governance framework	Includes policy and guidance that describe the requirements for the development and execution of closure procedures
	Regulatory requirements	Legislation that mines must follow, which vary by jurisdiction
	Roles and Responsibilities	Specific duties assigned to individuals or teams. This may include developing a closure committee or a “closure champion”
Closure design basis	Knowledge base	An organised and regularly updated collection of site-specific data used to inform the closure plan
	Closure vision	A vivid description of what is to be achieved once mining ends, often related to post-mining land use(s)
	Closure principles	Common pillars that guide the basis of mine closure planning, such as physical and chemical stability, and provide a general framework
	Closure goals and objectives	Tangible and often measurable statements identifying specific goals to be achieved from a particular closure activity
	Closure criteria	The metrics, or “success criteria”, that closure objectives are evaluated against to assess performance towards or achievement of a closure goal
	Post-mining land use	Desired, beneficial uses for the land following closure
	Closure design life	The duration for which a closure design is estimated to perform as intended before major rehabilitation considering factors like climate change, limits of engineering practice and regulatory requirements is required
Closure planning considerations	Integrated mine closure	A dynamic and iterative process of incorporating closure planning throughout the life of mine (LoM)
	Level of detail for closure plans	The extent and specificity of information required in a closure plan, which can often vary throughout the LoM
	Closure plan update frequency	How often the closure plan should be updated, considering regulatory requirements and factors such as significant changes to the mine plan

Category	Element	Definition or description
	Stakeholder and Indigenous collaboration	The process of consulting and collaborating with communities, Indigenous groups, regulators and other groups on mine closure
	Socio-economic/social transition	Involves the planning and implementation of measures that minimise the negative impacts and capture benefits for communities and the economy during and after mine closure
	Progressive closure	The act of implementing closure and reclamation activities throughout the LoM, including during operations
	Closure options assessment	A systematic method to evaluate and compare different closure designs or options against select criteria
	Closure risk assessment	Process of identifying and evaluating risks, their impacts and potential mitigations for a mine closure project
	Closure costs	The various costs (and estimates) associated with closure, such as a life of asset (LoA) cost estimate and financial assurance
	Closure execution plan	Specifies actions to be conducted during the LoA to support closure planning and the implementation of closure activities
	Post-closure management	Refers to the activities that a mine is responsible for once a facility is closed and may include monitoring, maintenance and reporting
	Temporary or sudden closure	Temporary closure refers to when a site suspends mining activities for a finite period and takes actions to mitigate impacts, while sudden closure involves a mine going into final closure ahead of the planned timing
	Relinquishment	Transferring ownership and responsibility of a site to the jurisdictional authority or a third party
Closure technical areas	Material and site characterisation	Understanding of physical and chemical characteristics of materials on site (including geology) as well as well as environmental conditions
	Physical/ geotechnical stability	The ability for mine structures to withstand a variety of loading conditions and undergo deformation without failure, often related to areas such as slope stability, seepage, erosion and settlement
	Geochemistry and chemical stability	Includes elements related to the chemistry of geological formations, mine wastes and fill, and how they change over time
	Integrated mine water management	Includes the management of surface water, groundwater and water quality, and the assessment of the site water balance
	Earthworks and material management	Includes elements such as determining materials balance, stockpiling practices, evaluating borrow sources and soil conservation
	Ecosystem management	Considers topics such as biodiversity, ecology, vegetation and wildlife
	Climate change	Long-term variations in the temperature, precipitation and other atmospheric conditions that may impact elements of mine closure

Note: Many of the definitions here are from or adapted from ICMM (2025a), while others are from references listed at the end of this paper.

To evaluate the level of detail in which each of the closure elements were considered in the mine closure guidelines and standards, a qualitative rating system was developed (Table 3). The level of detail was evaluated considering the inclusion of a definition or description, importance, potential applications and timing; and whether additional references, case studies, or examples were provided.

Table 3 Qualitative rating system for evaluating the level of detail in mine closure guidelines or standards

Rating	Definition
Comprehensive (green)	Comprehensive and well-written information that defines the closure element and explains why it is important and provides guidance on implementation, either directly or through examples. The document provides additional resources, legislation, tools or case studies
Intermediate (blue)	Some information on the closure element is provided, including the definition and brief details on application, but details on implementation and additional references are limited
Introductory (yellow)	A definition of the closure element is provided along with why it is important
Mentioned (orange)	The closure element is briefly mentioned
Not included (grey)	The closure element is not included in the guideline or standard

3.2 International mine closure guidelines

Figure 1 illustrates a review of selected international closure guidelines. The following sections summarise key observations discussed within the context of the categories outlined in Section 3.1. Additionally, these sections offer some additional insight into areas of closure planning practice and provide supplementary resources for further consideration.

As shown in Figure 1, there is a comprehensive assessment of almost all the elements listed by at least one of the documents. ICMM (2025a) is the most complete in this regard, and practitioners can supplement their understanding by reviewing the other guidelines (and other references listed above). However, it is also worth noting that these guidelines – by design – are intended to guide rather than mandate and vary in detail depending on their purpose and audience. As an example, World Bank (2020) and APEC (2018) are specifically focused on providing guidance to regulators such that their scope and emphasis will differ compared to more industry-focused guidance. Nonetheless, there are useful elements in all of these guidance documents that are applicable to closure practitioners and local communities.

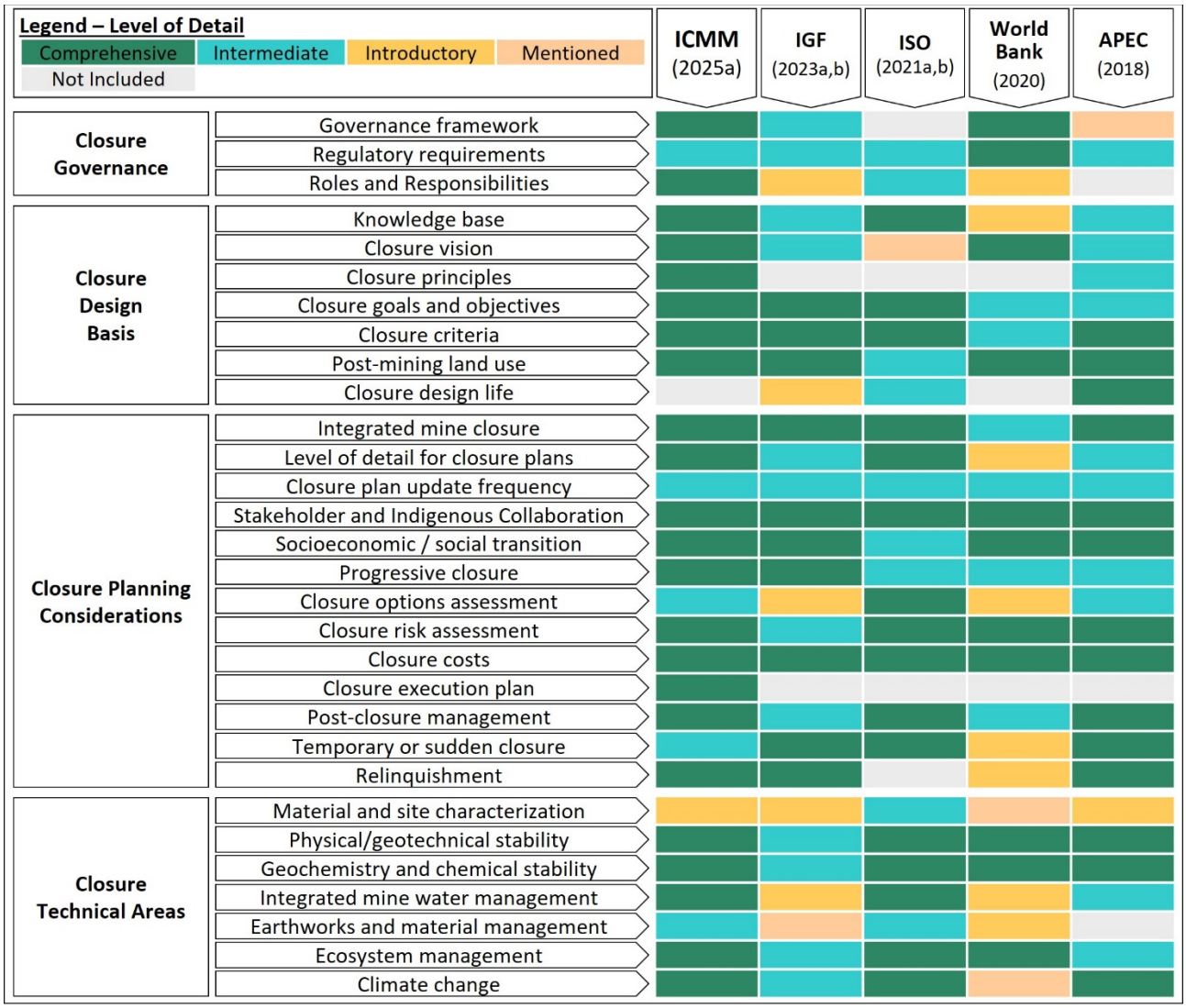

Figure 1 Qualitative review of international mine closure guidelines

3.2.1 Closure governance

ICMM (2025a) and the World Bank (2020) provide guidance on establishing closure governance at a mine. In practice, the need for closure governance is often overlooked when mine closure planning is undertaken in silos, typically by the environmental department with assistance from the mine planning department. However, this is often in the absence of corporate governance. Several strategies may be useful to help correct this deficiency:

- Some owners have set up a closure steering committee involving members of operational and corporate management that meet quarterly to provide direction to the closure team, help maintain communication with management and other departments, and aid in key decisions.
- Some owners have prepared a short closure strategy that indicates why the closure plan is being developed (beyond regulatory compliance requirements), how it will be used, who is involved in the preparation, who is responsible (often using a responsibility assignment chart), how the team will collaborate (including with external stakeholders), and how and when the closure plan will be updated.
- Some operations will appoint a reclamation Designer of Record – typically the lead closure planner or landform designer – who takes professional responsibility for the plans, designs and field implementation (Straker & McKenna 2022); mirroring and often complementing the role of an Engineer of Record for tailings dams under the GISTM (Global Tailings Review 2020).

- Some owners have also established independent and multidisciplinary closure review boards with similar charters to independent technical review boards (under the GISTM) to provide independent external review and advice (McKenna 2022).

3.2.2 Closure design basis

Each of the guidelines generally provides comprehensive guidance for the development of closure objectives, success criteria and post-mining land use. However, the concept of defining a closure vision and developing closure principles is inconsistent and undertaken to varying levels. In some cases, this variability may also be due to inconsistent terminology (e.g. “closure needs”, “closure goals” and “closure principles”). In practice, perhaps sparingly, many mines may struggle with having a closure vision and clearly defined post-mining land uses. Where a closure vision does exist it may be at odds with the expectations of regulators or local communities. LDI (2024) provides guidance on forging a common vision and an efficient method to co-develop goals, objectives and criteria to guide closure planning, landform design and execution in the field. Like most guides, it also provides a glossary of terms.

Only APEC (2018) provides advice regarding assigning a design life for reclaimed mine sites, individual mining landforms (such as waste rock dumps or tailings storage facilities [TSFs]) or landform elements (such as concrete channels or internal drains). The design life (the period of time that a reclaimed mining landform is expected to perform as intended before the need for major rehabilitation [LDI n.d.]) is an important consideration in closure planning and may range from decades (in the case of concrete elements) to centuries (in the case of geomembranes) or longer (in the case of mining landforms and closure landscapes). Some mines are starting to adopt a value of 1,000 years for mining landforms and closure landscapes as a reasonable balance of practical design and protecting the interests of the state and local communities.

3.2.3 Closure planning considerations

As indicated in Figure 1, the five international guideline documents cover the main elements of closure planning considerations. We provide four relevant comments:

- There is little guidance to practitioners regarding the frequency of updates to the closure plan. Some jurisdictions require updates every five or 10 years, or when there are major changes in the mine plan. However, the closure plan needs to be kept in alignment with the changing LoM plan (as well as short-range mine plans).
- Closure risk assessments are generally well-defined with practical guidance and tools for implementing them, with several references to ISO *Risk Management Guidelines* (ISO 2018). The Standard from ISO provides additional details on the steps to consider for both a screening-level and a feasibility-level options assessment. LDI (2024) provides a simple and useful screening-level risk assessment tool to evaluate the likelihood of meeting the objectives set out in the design basis that has been tested in numerous settings. In many cases, full ecological and human health risk assessments will be required as part of the design and the sign-off of reclaimed mine sites – an element that is often overlooked by closure planners and mine management.
- Some, but not all, of the guidelines provide general information on relinquishment. The most comprehensive details on relinquishment are provided by IGF (2023c). The limited examples of relinquishment of reclaimed mine lands and the uncertainty regarding managing ongoing liability need to be critically examined by the industry. Additionally, more modern models of ongoing land stewardship are emerging.
- The importance of stakeholder and Indigenous collaboration as well as socio-economic transition is clearly identified in all the international guidance. ICMM (2025a) refers to additional resources such as the GISTM (Global Tailings Review 2020) and the ICMM (2015) *Indigenous Peoples and Mining: Good Practice Guide*.

3.2.4 Closure technical areas

As shown in Figure 1, the international guidelines provide considerable advice regarding most of the key closure technical areas. However, there is room for improvement (in guidance and in practice) in several critical areas:

- While there is growing guidance and requirements for sufficient material characterisation (e.g. Global Tailings Review 2020; Mining Association of Canada 2008), in the authors' experience, many mines still lack sufficient geoenvironmental characterisation (e.g. soil water characteristic curve testing, humidity cells and column leaching tests) of each mine's wastes/byproducts and can be caught off-guard at closure. LDI (2024) provides a method of displaying a comprehensive list of natural and artificial materials at a mine site using a geological stratigraphic chart. Some sites are conducting detailed review and testing of all their waste streams, not just ones known to be bad actors. Canada's Oil Sands Innovation Alliance (Canada's Oil Sands Innovation Alliance 2022) provides an example of tailings material properties for an entire mining region. Characterising mine wastes, even at a high level based on limited data, provides useful design information and a starting point for risk assessments and further characterisation programs, and helps to avoid surprises.
- Mining operations are often challenged with reconciling their operational water balances and their closure water balances, especially with respect to conditions imposed by climate change and on changing external demands for water. During operation and in closure planning there can be insufficient attention paid to the transition water balance at the time of mine closure. Opportunities to reduce the quantity and improve the quality of the process/tailings water inventories in the final years of production are often overlooked, as are plans for long-term storage of process-affected waters and water treatment sludges as part of the long-term active water treatment systems needed at many mines. Additionally, mines applying zero discharge approaches (particularly those that use ring dykes for TSFs) often find a fatal flaw in their water management plan during the transition point, specifically when the TSF is at full capacity and the surface water outlet has yet to be constructed or the permits to discharge water during extreme events are not yet in place.
- Many mines find a shortage of reclamation materials, and a lack of nearby locations for interim stockpiles transportation routes, at closure. Often the best reclamation material is covered or spoiled during initial mine development and the early years of operation. Conservation and management of such materials needs to be a central focus of effective closure planning (e.g. MEND 2012; INAP 2017).
- Incorporating climate change into closure planning is becoming routine and is featured in most of the design guidance documents. Additional work is needed not only to predict changes to air temperature and precipitation but also to understand how to design and construct reclaimed landscapes that meet their goals and objectives, given the complex interaction of the landscapes, ecology and climate over time. Most regulators and local communities are concerned about residual risks to the reclaimed mining landscape and water management due to the uncertainty and non-linear impacts of long-term climate change. The result is that ongoing monitoring and management for climate change impacts will be required at most sites.

3.3 Proprietary closure standards

To streamline and standardise closure planning, many large multinational mining corporations survey international guidelines and combine these with corporate policy to develop proprietary closure standards to govern their mining operations. These documents help to guide the sites' closure planning processes and assist with continuity of practice. Some of these proprietary standards were developed in response to requirements in the GISTM (Global Tailings Review 2020). The standards are typically written to apply to multiple regulatory jurisdictions, climates, commodity types and mine life stages, and are subsequently adapted to local conditions.

Four anonymised, proprietary closure standards were reviewed using the same framework presented in Tables 2 and 3. Results of the review are presented in Figure 2. The authors' intent is not to evaluate these individual standards but to provide a snapshot of the current state of practice and to encourage other mining companies to develop their own closure standards. Sharing of closure standards between industry members would allow companies to learn from each other and enhance the overall industry state of practice.

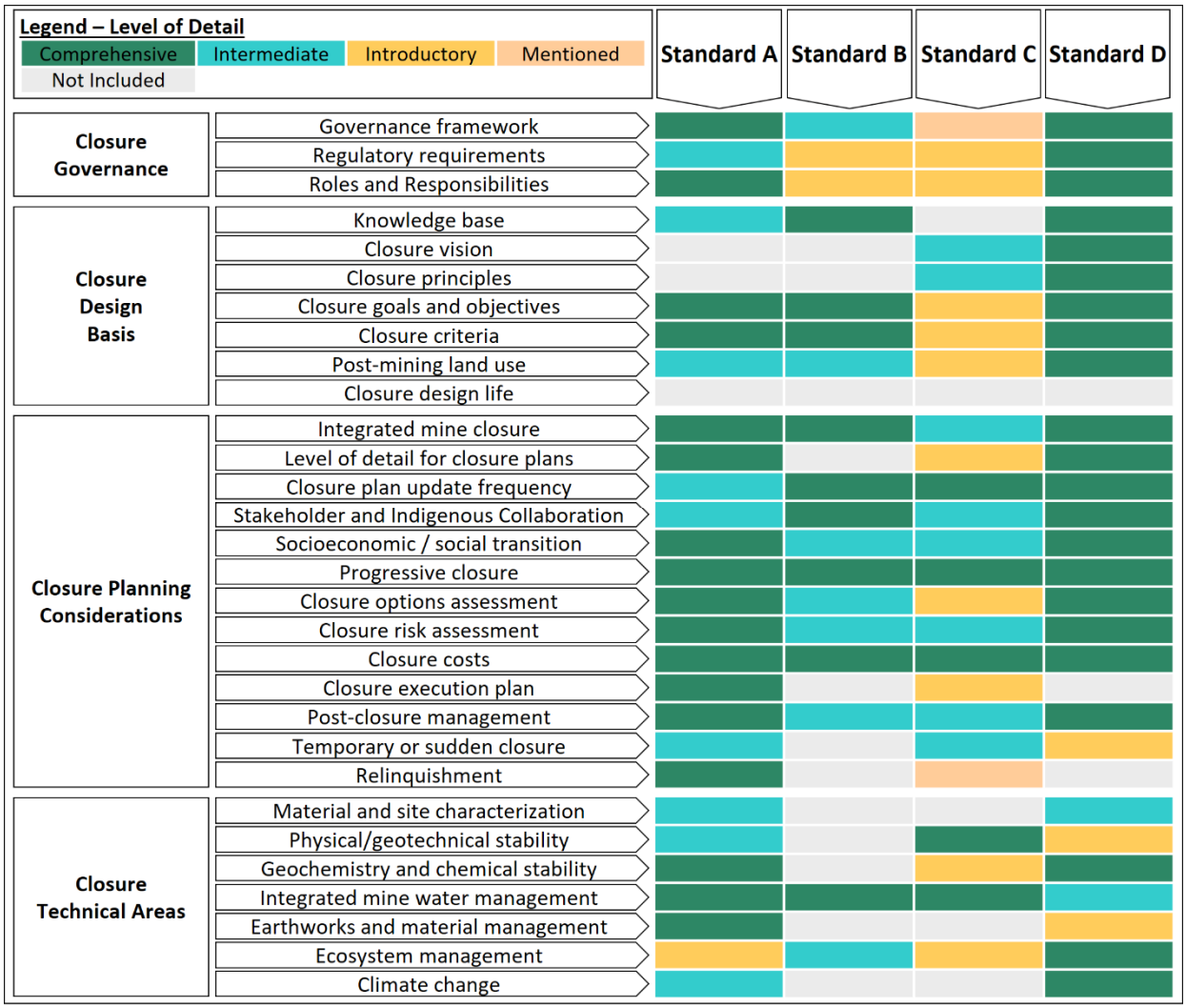

Figure 2 Results of the qualitative review of proprietary closure standards

The selected proprietary closure standard documents ranged from four to 38 pages; some provide a comprehensive level of detail in specific areas while others are less detailed or do not mention some closure elements (see Figure 2). However, the authors acknowledge that some proprietary guidance documents are part of a company library and not standalone, such that information not explicitly in the closure standard is often included elsewhere.

The closure standards are being used at individual mine sites, offering the head office staff a chance to observe how the standards are employed, how the closure plans are received, and how well the closure plans are used for design and business decisions. From these observations, companies are then able to update the standards over time with any learnings.

3.3.1 Closure governance

Elements of closure governance are included in all the closure standards but with varying levels of detail. Some provide comprehensive guidance on identifying specific roles, responsibilities and regulatory requirements, while others are more generic in distinguishing these elements.

3.3.2 Closure design basis

In terms of the closure design basis, most standards provide clear direction on setting post-mining land use, closure objectives and criteria. However, there is an opportunity for development of a clear closure vision and principles, and to achieve full alignment between the vision, goals, objectives and criteria (LDI 2024).

3.3.3 Closure planning considerations

Closure planning considerations are generally well addressed, and all the standards provide intermediate to comprehensive details and requirements for integrated LoM closure planning. Additionally, all the standards include an intermediate-to-comprehensive level of detail regarding stakeholder engagement, socio-economic transition and progressive closure. The frequency of updates is specified but the level of detail on design requirements for different points in the mine life cycle is generally vague. The requirement for calculating closure costs (including financial assurance) is well detailed in all the closure standards.

3.3.4 Closure technical areas

In terms of closure technical areas, the corporate standards had varying levels of detail, and there is likely an opportunity to better link the elements with other internal documents and standards.

4 How we can improve

This paper presents a qualitative review of selected international closure guidelines and proprietary closure standards, summarising key findings across the documents. From the review, areas are identified where guidance is robust across multiple documents, as well as where it is inconsistent or lacking. Based on the trends, the following sections identify opportunities for improvement.

4.1 Closure governance

There is increasing recognition across all levels of mine governance, from investors and corporate boards to regional management and individual site operations, of the need to elevate mine closure considerations as a core component of responsible mining. This imperative is reflected in emerging global standards, industry guidance and case studies that provide frameworks for integrating closure into the broader life cycle of a mine. To translate this recognition into practice, leadership at every level must actively embed closure planning into governance structures, risk frameworks and operational management systems, ensuring it is not treated as an end-of-life obligation but as a strategic, value-creating element from the earliest stages of project development through to post-closure stewardship.

4.2 Closure design basis

The limited examples of mine relinquishment of otherwise successfully reclaimed mining land around the world can be partly attributed to a limited number of clear and established closure design bases. LDI (2024) provides guidance on how to forge such a DBM and examples from industry that span four decades. Developing a clear design basis is essential for effective closure planning and successful mine reclamation.

4.3 Closure planning considerations

This paper demonstrates that the need for effective closure planning is well documented (the “why”), as are the requirements of effective closure planning (the “what”). Various organisations are now focusing on “the

how" by producing guidance documents and training courses. Universities are starting to feature training in these activities, notably for tailings facilities but, by extension, to all aspects of mining. More case histories are needed to provide examples of successful (and unsuccessful) closure planning and reclamation work; partly to illustrate the "how-to" but also to provide confidence to practitioners, management, regulators and communities that such systems can be effective and practical while also allowing these groups to work well together.

4.4 Closure technical areas

There has been rapid progress in the technical understanding of, and ability to, engineer mining landforms and landscapes to meet many technical issues, e.g. addressing long-term geotechnical and erosion failure modes, mitigating geochemical impacts and re-establishing ecological land uses. Much of this work is featured in international closure conferences, including case histories and specific technical guidance.

5 Moving forward

The review and analysis of the closure guidelines and standards have highlighted several opportunities for improvement in terms of mine closure planning. While several high-quality closure guidance documents exist, this paper finds that no single document comprehensively covers all elements of effective mine closure planning. Consequently, mine closure practitioners must consider aggregated guidance from multiple sources to deepen their understanding. Practitioners must also strike a balance between meeting the high standards set out in the guidelines and achieving a practical, cost-effective solution that satisfies the regulatory and community requirements for their unique mine site. Additionally, while new mines offer opportunity to adopt best practices for mine closure planning early in the project (e.g. initial siting decisions and permitting), many existing and legacy sites – potentially developed under outdated, or absent of, mine closure considerations – face distinct challenges in aligning with modern closure expectations. In these cases, mine closure practitioners should work to implement modern closure guidance as much as practical while acknowledging that – for many or most sites – a "walk-away" solution may not be feasible.

Similarly, the proprietary closure standards reviewed had variable levels of detail. While differences may stem from unique corporate procedures, there is also an opportunity for sharing of these standards amongst industry members to learn from each other and improve industry practices. Additionally – and despite the excellent guidance available – there remains work to be done to improve the state of practice. One such recommendation is to better integrate the disciplines to allow long-term interdisciplinary landform design and closure planning teams to function at a high level. Furthermore, there remain challenges to improve rates of progressive reclamation (and progressive access to the reclaimed land and progressive sign-off) and effectively collaborate on all mining issues with local groups, especially Indigenous communities.

Work now turns to individual mines to set realistic goals and objectives for reclaimed landscapes, provide adequate financial assurance to allow for these goals and objectives to be met (even in the event of sudden mine closure), develop the skills and confidence to be able to deliver on all goals and objectives, and achieve progressive sign-off. This requires frequent collaboration and communication by the mining company, the regulator and the local community to confirm that the agreed upon goals and objectives are being met. Various organisations and companies are already working on addressing such issues; we encourage them to share the results widely for others to learn and benefit from.

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References

Anglo American 2019, *Mine Closure Toolbox,* version 3, Brisbane.

Asia-Pacific Economic Cooperation 2018, *Mine Closure Checklist for Governments*, Mining Task Force, Singapore.

Brazilian Mining Association 2014, *Guide for Mine Closure Planning*, Brasilia.

Cassie, J & McKenna, G 2016, 'Mine closure planning, design and implementation: from hand-waving to reality', in J White (ed.), *Planning for Closure 2016: First International Congress on Planning for Closure of Mining Operations*, Gecamin Digital Publications, Santiago.

CSIRO 2025, *Guidelines for Open Pit and Waste Dump Closure,* CSIRO Publishing, Clayton.

Daly, CA 2023, *Exploring Co-Reclamation: Gesturing Towards Intercultural Collaboration and the Renewal of Indigenous Cultural Landscapes after Oil Sands Extraction in the Fort McKay First Nation Traditional Territory, Treaty 8, Alberta, Canada*, PhD thesis, University of Calgary, Calgary.

Daly, CA, L'Hommecourt, J, Arrobo, B, McCarthy, D, Donald, G & Gerlach, SG 2021, "Toward a co-reclamation framework in collaboration with Indigenous Peoples", *Landform Design Quarterly (Fall 2021)*, Landform Design Institute, Delta, pp. 2–5.

Department of Industry Science and Resources 2016, *Mine Closure - Leading Practice Handbooks for Sustainable Mining*, Canberra.

Global Tailings Review 2020, *Global Industry Standard on Tailings Management*, co-convened by the International Council on Mining and Metals, United Nations Environment Programme and Principles for Responsible Investment.

Government of British Columbia 1969, *Mines Act*, Canada.

Government of Ontario 1992, *Mine Rehabilitation Code of Ontario*, Canada.

Government of Western Australia 2023, *Mine Closure Plan Guidance – How to Prepare in Accordance with Part 1 of the Statutory Guidelines for Mine Closure Plans*, Perth.

Guj, P & Rogerson, R 2024, *Mine Closure Guidance: Review and Comparative Analysis*, CRC TiME, Perth.

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2021a, *Current Status of Mine Closure Readiness: Are Governments Prepared?,* International Institute for Sustainable Development, Winnipeg.

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2021b, *Global Review: Financial assurance governance for the post-mining transition*, International Institute for Sustainable Development, Winnipeg.

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2023a, *Mining Policy Framework – Mining and sustainable development*, International Institute for Sustainable Development, Winnipeg.

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2023b, *Guidance Notes - IGF Mining Policy Framework*, International Institute for Sustainable Development, Winnipeg.

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development 2023c, *Relinquishment of Closed Mine Sites: Policy steps for governments*, International Institute for Sustainable Development, Winnipeg.

International Council on Mining and Metals 2015, *Good Practice Guide – Indigenous Peoples and Mining,* 2nd edn, London.

International Council on Mining and Metals 2025a, *Integrated Mine Closure – Good Practice Guide,* 3rd edn, London.

International Council on Mining and Metals 2025b, *Tailings Management – Good Practice Guide,* 2nd edn, London.

International Network for Acid Prevention 2017, *Global Cover Systems Design – Technical Guidance Document*.

International Organization for Standardization 2018, *Risk Management - Guidelines (ISO 31000:2018)*, Geneva.

International Organization for Standardization 2021a, *Mine Closure and Reclamation Planning - Part 1: Requirements (ISO 21795-1:2021),* Geneva.

International Organization for Standardization 2021b, *Mine Closure and Reclamation Planning - Part 2: Guidance (ISO 21795-2:2021),* Geneva.

LDI 2021, *Mining with the End in Mind: Landform Design for Sustainable Mining (Position Paper),* Delta.

LDI 2024, *Developing a Design Basis Memorandum for Landform Design (Report TR-02)*, Delta.

LDI n.d., *The Design Life for a Mining Landform and its Components*, Delta.

McKenna, G 2002, *Landscape Engineering and Sustainable Mine Reclamation*, PhD thesis, University of Alberta, Edmonton.

McKenna, G 2022, *Building and Operating a Successful Geotechnical Review Board*, Canadian Dam Association Annual Meeting, St. John's.

McKenna, G, An, R, Scordo, E & McGreevy, J 2013, 'Toward effective closure planning: from progressive reclamation to sustainable mining', *Tailings and Mine Waste "13*, University of Alberta, Banff, pp. 615–626.

Mine Environment Neutral Drainage Program 2012, *Cold Regions Cover System Design Technical Guidance Document*.

Mining Association of Canada 2008, *Towards Sustainable Mining - Mine Closure Framework*, Ottawa.

Society for Mining, Metallurgy & Exploration 2022, *Tailings Management Handbook – A Life Cycle Approach*, Englewood.

Society for Mining, Metallurgy & Exploration n.d., *Tailings Closure Handbook*, Englewood.

Straker, J & McKenna, G 2022, 'The case for a reclamation designer of record'*, BC Mine Reclamation Symposium – September 2022*, Kimberly, https://dx.doi.org/10.14288/1.0421789

Thompson, J 2018, 'Canada's northern "zombie mines" are a lingering multi-billion-dollar problem', *The Narwhal*, viewed 27 April 2025, https://thenarwhal.ca/canadas-northern-zombie-mines-lingering-multi-billion-dollar-proble/

Whitbread-Abrutat, P, & Lowe, R 2024, *102 Things to Do with a Hole in the Ground*, Eden Project, Bodelva.

World Bank 2020, *Mine Closure: A Toolbox for Governments*, Washington.