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Metalliferous mine closure geochemical risk planning and validation template

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Abstract

Mining companies have many legal obligations, business requirements and stakeholder expectations, with regards to mine site closure. Decisions and activities at any stage in the operation can have environmental, reputational and financial consequences into the long term, especially when considering the management of geochemical risk posed by mine waste. Few would disagree that every closure is site specific, but the authors suggest that use of existing global and regional guidelines available for closure have the potential to result in significant gaps in a site's closure plan. This is due to the generalised nature of existing guidance, the site specific nature of geochemical risks, key differences between metalliferous and non metalliferous mines, and a focus in recent guidance on geotechnical risks and social governance. A site-specific framework for metalliferous mines with a focus on closure geochemical risk that draws on the best examples of the existing guidelines and industry best practice is proposed as an opportunity to reduce these risks. The intent of the framework, is that risk can be assessed using a templated type assessment which, when populated, would be assessed through an independent validation process that would allow for companies to benchmark their sites with respect to geochemical risk management.

Existing guidelines from government and industry organisations are examined together with a review of examples of corporate closure governance. Guidelines are reviewed from Europe, Western Australia, Queensland, International Council of Mining and Metals (ICMM), International Standard of Organisation (ISO) and the Global Acid Rock Drainage (GARD) Guide. In addition, several mining company closure standards are examined.

By examining the current industry and legislative guidelines, and by drawing on site specific case studies, this paper will address the potential weaknesses within the generalised guidelines, particularly with regards to geochemical risk assessment, with the aim of developing a site-specific closure framework that could be part of a corporate closure governance framework. The framework has drawn on the integrated approach where requirements, by life of mine cycle, are detailed. The listing of the requirements allows for companies to ensure the approach that is adopted reflects their company policy, values and commitments, conditions required by membership of industry associations or corporate accreditations etc. As such the resulting template offers site a sound framework from which to identify a comprehensive list of geochemical related closure activities to enhance the closure planning process, which can reflect both the company values, local judication and stakeholder expectations.

Keywords: *closure planning template; closure risks; closure geochemical risk; closure geochemical planning; mine closure governance*

1 Introduction

The mining sector's image is in the view of many areas of society predominantly negative and relates to perceived and actual examples of environmental degradation and negative effects on communities. Abandoned mines are common place in countries with an extensive mineral extraction history and in these areas new projects often undergo difficulties in obtaining environmental licensing in part due to legacy of past activities. Legacy mining issues are relevant in the context of todays mining activities because the sooner a mine decommissioning is planned, the better the control of environmental and socioeconomic impacts and the greater the acceptance of its post-closure use by stakeholders (Kabir et al, 2014). Given there are just a few examples globally of large mines that have received closure certificates (ICMM, 2023), the industry must remain cognisant of approaches and methods that could improve closure outcomes.

'The mining industry's rich history also carries some important lessons and one of these is the poor closure or abandonment of mines by the industry worldwide' (Mark Cutifani AngloAmerican Chief Executive, November 2019)

Few would disagree that every closure is site specific and local circumstances will determine local post-mining outcomes, so there is little to be learned from generalisations (Cowen et al. 2012). This statement draws attention to a potential missing link in closure governance. Corporations have recognised the issues and adoption of programs such as the Towards Sustainable Mining (TSM) and ICMM's Mining with Principles, are signs that the industry is moving in a positive direction. But due to the site-specific nature of closure, when managed at operational level, the management of closure liabilities struggle to compete for resources with operational issues. Here, an old adage comes to mind, 'closure is always important, but never urgent'. Such an approach is also inherently reactive and near-sighted and would fail to realise opportunities stemming from pre-planning of closure.

If it is agreed that companies are elevating the consideration of risk from mine closure, how can this increased focus be appropriately adopted by site in a way that elevates closure to sit alongside those operational objectives as equally important? The authors believe that while the existing guidelines provide the tools that- when adopted- could bridge that gap, the complexities in the relationships between these documents, the technical nature of the subject matter, as well as the site-specific nature of any closure endeavour hinder effective use of these tools. Table 1 is a snapshot of the enormous volume of business, regulatory and industry requirements, guidelines, standards, plans relevant to closure and geochemical risk. This paper will examine how through a systematic approach and by drawing on the 'best' these documents have to offer, a site specific template can be developed. When provided the closure governance bridge between corporation and site can be improved.

Table 1 Closure template reference snapshot

Regulations	Industry Associations	Global Guidelines	Corporations	Site
EU Waste Directive	ICMM, 2019, Integrated Mine Closure Good Practice Guide, 2nd Edition	INAP, 2017, Global cover system design, technical guidance document	Policy	Permit/approval conditions
Sweden's Environmental Code	ISO 21795:2021 Mine closure and reclamation planning	INAP, 2014, Global Acid Rock Drainage (GARD) Guide, Revision 1	Strategies	Licences
Finland, Mining Act	IFC, 2007, Environmental, Health and Safety Guidelines for Mining	MEND, 2012, Cold Regions Cover System Design Technical Guidance Document	Protocols & standards	Stakeholder agreements
MWEI-BREF (BAT)	ICMM/UNEP/PRI, 2020, Global industry standard on tailings management	CEN/TS 16229:2011 characterisation of waste	Commitments	Stakeholder engagement
Queensland's MERFP Act 2018	Finnish Network for Sustainable Mining, Kaivosvtuu	Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves	Frameworks	ISO 14001 Certification
Ireland's S.I. No. 566 of 2009 Waste Management Regulations	The Mining Association of Canada, Towards Sustainable Mining (TSM)	Pan-European Reserves and Resources Reporting Committees' Reporting Standard	ISO 14001 Certification	Site risk registers

1.1 Role of industry associations and regulators

Blommerde et al. (2015) highlighted the need for stronger guidance and key requirements for closure success. A robust framework is therefore needed to quantify the different success criteria to be able to attain a well-documented evaluation of mine closure success. Robust quantification of the completion criteria, if verifiable, could assist mining companies as well as regulatory bodies to achieve best possible outcomes.

Recently there have been a number of closure guidelines issued by industry organisations and regulators alike, such as the International Standard ISO 21795. In addition, several companies have issued detailed and comprehensive closure standards, including AngloAmerican (AA). The guidelines and standards have differing, though partly overlapping, purposes, aims and objectives, such as ensuring compliance with the legislation and company policy. International Standard ISO 21795, has an overarching objective of promoting consistency and quality in planning for mine closure and reclamation internationally. On the other hand the overarching objective of 'ICMM Integrated mine closure: good practice guide mining companies with guidance' is to promote a disciplined approach to integrated closure planning and to increase the uniformity of good practices across the sector (Figure 1).

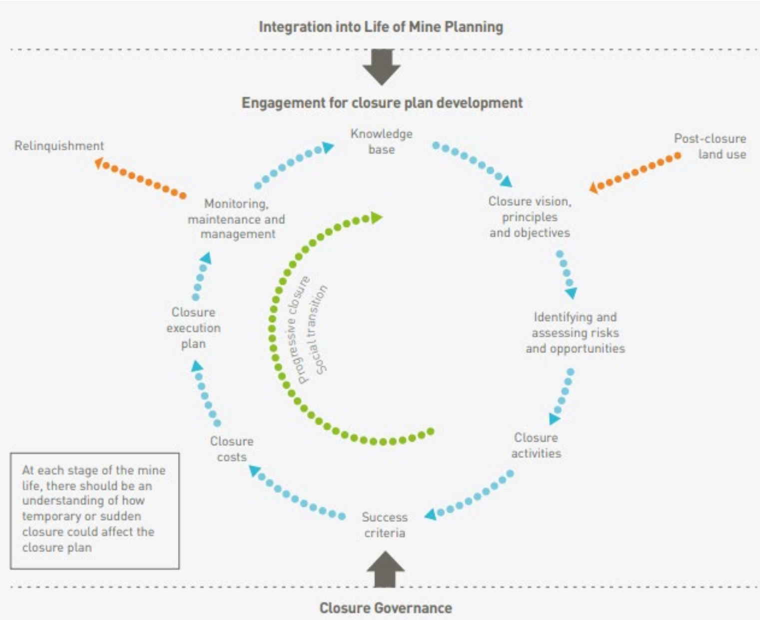

Figure 1 Integration of closure planning elements into LoM (ICMM)

In addition, there are numerous closure guidelines to assist in the preparation of mine closure for example see WA 2020 and the Queensland Government's Progressive Rehabilitation Closure Plan (PRCP) Guidelines. These aim to ensure compliance with the legislative and government requirements. However, while both have been issued by states within the same country, the former is more generic in nature compared to a more specific requirements issued by Queensland. These guidelines could therefore be considered regional, meaning that a company with mines in the same region have different defined closure requirements. For example, Mt Isa Mines and MacArthur River Mine, both Glencore sites, are only 600 km (370 miles) apart, but are located with different jurisdictions with different closure planning requirements. It can therefore be challenging to create a consistent corporate closure framework that will satisfy all sets of requirements

Other guidelines and legal obligations exist that have approaches with a strong connection to closure planning. Examples include, SMI Mine closure Hub with a focus on the social aspects of closure. As well as The TSM (Mining Association of Canada) approach that requires members of the association to commit to a set of guiding principles that reflect the environmental and social goals of the industry and communities of interest.

Other aspects of mining have benefited from an approach of combining the key requirements of legislation and guidance to produce a reporting template that increases transparency and provides a unified template, in particular those CRIRSCO International Reporting Template for the Public Reporting of Exploration Targets, Exploration Results, Mineral Resources and Mineral Reserves guides. Though the focus here is on providing transparent information for the stock markets and investors, particularly with regards to companies and sites in the exploration phase, the direct approach and detail required provides an opportunity to improve the current widely accepted approach to site mine closure planning. Typically compared to ore zone materials mine waste is often overlooked in terms of quantity of testing and detail of characterisation, particularly at the start of an operation (exploration, prefeasibility and feasibility) as it has not been produced yet and resources are focused on demonstrating that the resource is economically viable. International standards were established to provide investor confidence in exploration projects for example the JORC Code and the sister Pan-European Reserves and Resources Reporting Committee's Reporting Standard. However, waste management through the operational phase and closures of the site are important aspects of the economic feasibility of the project. This requires addressing with the same scrutiny as the resource itself, an underlying requirement of these resource statement standards. This places characterisation of the non-ore part of the deposit on similar standing as the ore zone and means that the principles of the standards can be applied to waste material characterisation similarly to how they are applied to the ore. In addition to better understanding of the full economic implications of the operation, significant opportunities exist for the project as a whole and into closure, in collecting the most appropriate information from the get-go.

This paper's focus is on the geochemical stability of mine waste after closure, which the authors believe is currently addressed in industry in either an inconsistent manner, or an overly generic manner, and as such often lacks site specific detail. The paper shows how this could be improved with a simplified site specific template that captures the best of the existing regulations and leading practices in testing. In addition, the intent is to develop a process and template, that, when populated, would be assessed through a validation process. This process proposed here is envisioned to be the responsibility of a corporate and so would allow companies to quantity a site progress and benchmark their operations.

An example of a company with a well-defined closure governance is AA. The AA standard (Mine Closure Toolbox) aims to achieve improved community relationships and engagement. The standard emphasises increased integration with life of asset, potential lower closure liabilities, lower rehabilitation costs, more effective social investment and engagement, and enhanced value to its stakeholders. The evaluation sheets are an example of communicating and setting expectations, though noticeable, no reference is made to the Global Acid Rock Drainage (GARD) Guide.

The GARD is a consolidated acid rock drainage (ARD) guide (GARD Guide) that summarizes the best technical and management practices for industry and stakeholder use. The Guide provides a structured system to identify proven techniques for characterization, prediction, monitoring, treatment, prevention, and management of ARD. It aims to help industry to provide high levels of environmental protection, support government efforts in assessing and regulating mine reclamation, and enable the public to gain a higher degree of understanding of acid prevention plans and practices. (Global Acid Rock Drainage guide; Verburg et al. 2009)

Whilst ICMM makes reference to the GARD Guide, company Bs approach, by bridging the gap with an integrated geochemical framework that places the GARD Guide and the geochemical standards closer to the centre of the approach. The purpose of company B's approach is to provide a framework for the integrated geochemical testing and characterisation of mine wastes to enable a consistent approach to mine waste acid and metalliferous drainage (AMD) management. This framework is intended to be 'global' to company B's operations, rather than specific to any one site, so that a consistent approach to mine waste geochemical testing with respect to AMD management.

Only by examining the current industry and legislative guidelines and the pros and cons of both approaches above can an alternative method, that is a comprehensive template that is both corporate and site specific, that would fit within a corporate closure governance framework be developed. The template aims to be simpler and more site focused than exiting guidance, with only requirements that would be applicable to the site, such as with references to requirements of difference stages of the mine life not included and site-specific requirements captured in detail.

The proposed template would draw on the ICMM and AA toolbox approach, and other guidelines such as Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC), to replicate the integrated approach by listing requirements, by line, relevant to the phase of life of the asset, with details required and information. The listing of the requirements would allow for companies to ensure the approach adopted reflects their company policy, values and commitments required by membership of industry associations or corporate accreditations thus, offering site a sound framework from which to develop a closure plan.

In addition, the resulting template will allow the details of the requirements to be site specific, reflecting the jurisdiction, site specific approval requirements and any local accreditation. This could be controlled by corporate, through selections of options.

2 Regulatory frameworks

The Mining Policy Framework assessments undertaken by the Intergovernmental Forum on Mining since 2014, shows that while governments are aware of the importance of mine closure, many do not have the policies, regulations, enforcement, or capacity to manage and regulate it (ICMM, 2023).

With regard to the detail of the obligations, there are a range of jurisdiction approaches with historically poor governance and limited mining, where the corporate governance might dominate, to generalised requirements, such as the EU directive to more prescriptive requirements, as in the case of the Queensland Government.

2.1 EU Waste Directive

Through the Waste Directive, the EU aims to prevent or reduce adverse effects on the environment due to the management of waste, including mining waste. The waste directive (Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amendments) places the requirement for an extractive waste management plan at its centre. Specifically relating to closure, the directive details generic closure requirements, such as, 'putting topsoil back in place after the closure of the waste facility or, if this is not practically feasible, reusing topsoil elsewhere' (Article 5, 2 c).

EU member states then incorporate the overarching European Union legislation into their legal framework, and may have more prescriptive or detailed requirements. In Sweden, the Environmental Code (legislation) sets requirements for plans and finances for remediation, centred around the principle of polluter pays. But it does not prescribe requirements that could be defined as a template to capture nor validate a site's or company's progressive rehabilitation in achieving closure objectives. In Finland, under the mining Act, a number of provisions governing mine closure exist, including the requirement for a Closure Action Plan, modelled on the ICMM closure elements (*Geological Survey of Finland).* Since the adoption of the EU directives is interpreted by each member state, variability exists between the in-country requirements and therefore approaches taken, data collected and success criteria selected, approved and applied.

This broad guideline approach adopted by the EU makes an assessment on the success or otherwise of the implementation of the directive very difficult as a result of incomplete or inconsistent data (Kulczycka et al, 2019). The approach adopted by several other jurisdictions, including the Queensland Government contrast to that adopted by the EU

2.2 Queensland Government's Mined Land Rehabilitation Policy

In Australia mine closure policy is devolved to states to legislate, but the approach adopted by the states can be considered more onerous that that of the EU. After a long-delayed realisation of the risks poorly closed or abandoned mines have on the environment and budget, several states, including Queensland enhanced their legislation (MERFP Act 2018) with updates to the financial assurance and mine closure requirements. The increase in requirements provides an immediate challenge to operators, but also opportunities for the industry.

Under the Act, each mine site must submit a site-specific progressive rehabilitation and closure plan (PRCP), which is deemed a critical element of the Queensland Government's Mined Land Rehabilitation Policy. The PRCP is specific to the Queensland government deemed essential to a closure plan, such as what is to be included such as baseline information, spatial data and progressive rehabilitation.

When the rehabilitation and scheduling requirements within the guide are extract, the level of detail within the PRCP guidelines can offer the basis for site specific closure template. The guideline stipulates the geochemical characterisation required, both in analysis and over time. In addition, how the data is to be used in defined:

'The conceptual site model for waste rock dumps, low-grade ore stockpiles, heap leach pads and TSFs must also identify site-specific factors that may result in geochemical risks, including consideration of the interaction of natural and anthropogenic processes that influence management controls.' (PRCP Guideline, Queensland Government. 2021)

The PRCP Guideline is an example of a legal requirement that captures leading practice. This is an example of a case where, there is an opportunity to take the leading practices from both industry associations and legislation to develop a corporate governance framework. But as shown above, that framework must still properly integrate comprehensive geochemical risk assessment into a company's standards.

3 Global guidelines

Since the 1990s, the mining industry has developed its approaches towards environmental considerations (Ruokonen, 2020). A number of global guidelines are available to those involved, (stakeholders), in mine closure planning. Two popular guidelines: International Organisation for Standardisation (ISO) 21795 Mine closure; and reclamation planning and the International Council on Mining & Metals (ICMM) Integrated Mine Closure Good Practice Guide, are examined here.

3.1 ISO 21795 Mine closure and reclamation planning

Centred around six framework elements (Figure 2), considered by ISO required to maintain effective mine closure and reclamation planning. ISO 21795 (the Standard) has been designed for use by industry, regulators and stakeholders alike.

Figure 2 ISO 21795 framework

The standard details a set of practices that encompasses all closure aspects for consideration in closure planning. Though interestingly, in the guidance section of the standards (Part 2) some testing methods (such as humidity cells) receives a very specific mention which appears to be a deviation from the high-level guidance. The standard provides a trans-disciplinary resource; thus, whilst rarely specifically mentioned, geochemistry is essential in every stage of the life of mine in closure planning if conformance is to be achieved. Thus, it is appropriate that the standard recognises mineralise waste as both, 'high risk' and potential source of 'significant impacts'. More specifically, the ISO states the requirement to ensure, 'predicted or actual physical and geochemical characteristics of the waste rock'. In sum, understanding of the geochemical characteristics is required to prevent and attenuate reactions, and setting cover systems, over the mine life cycle.

All the above is acceptable for a generic global approach, but still does not provide the detailed context for which characterisation analysis/testing is required, nor how a sampling program should be designed to satisfy the project objectives, which is an essential perquisite for any (even conceptual) modelling. The standard, whilst a useful reference for a site, perhaps has better utility in developing a corporate closure governance framework.

The standard is compatible with ICMM best practice guide, but the ICMM does provide guidance for a more site-specific approach and defined integrated approach.

3.2 ICMM Integrated Mine Closure

The Integrated Mine Closure Good Practice Guide (GPG) has been developed to aid site practitioners' by bringing focus on all elements of closure, at each stage of the life of the asset, through an iterative process. The ICMM balanced approach to closure planning of the asset is pictured in Figure 3.

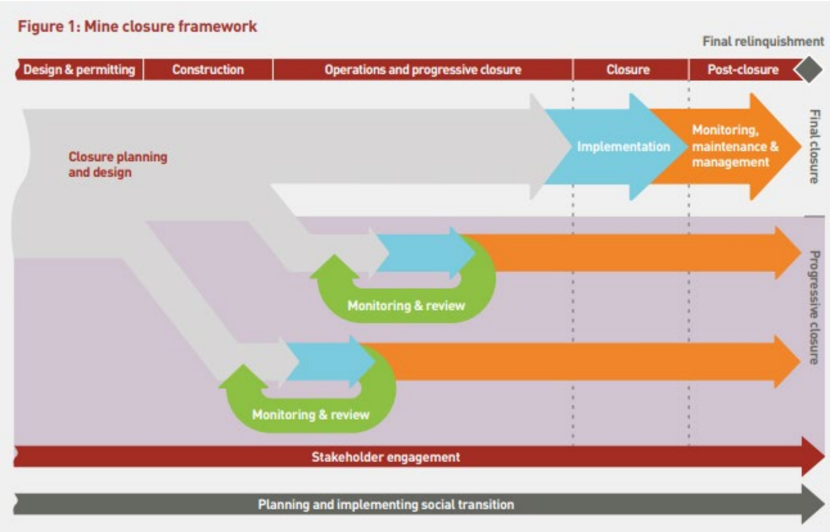

Figure 3 Extracted from ICMM Integrated Mine Closure (2019)

The ICMM-GPG does mention the risks from geochemical stability. The ICMM-GPG does not specify the range of geochemical related requirements in managing potential geochemical instability. However, it does make several references to the GARD Guide. Thus, the GARD Guide approach to the prediction, prevention, and management of drainage produced from sulphide mineral oxidation (the approach of which is summarised in Figure 4) is assumed to be the appropriate guideline to be applied.

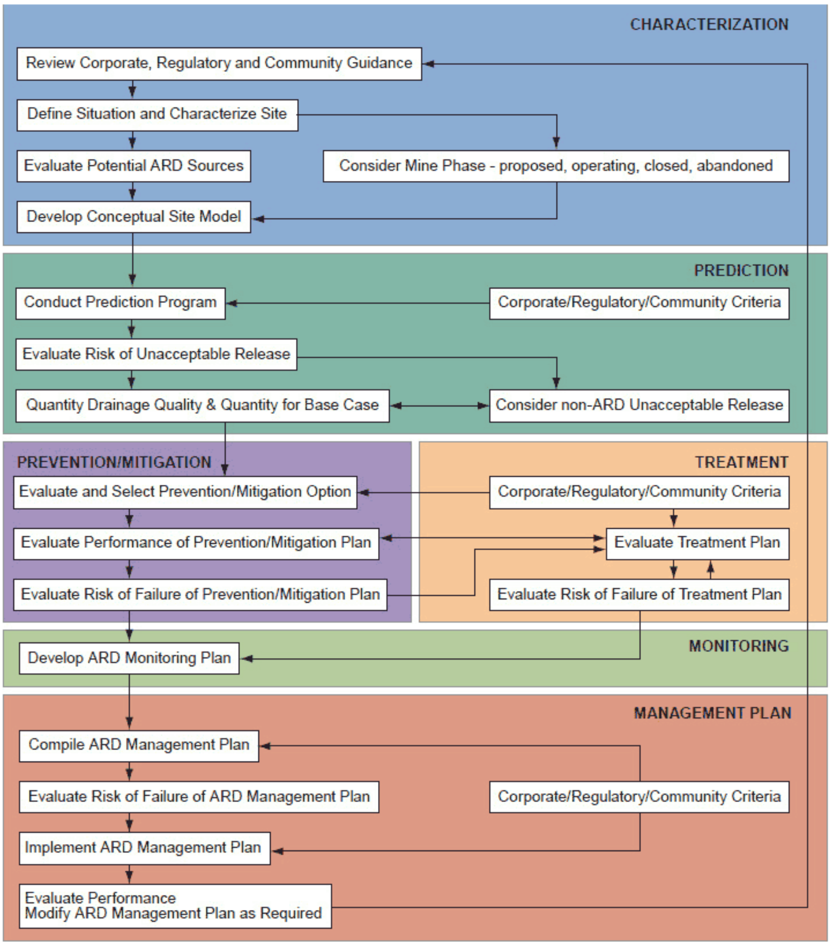

Figure 4 GARD approach to acid rock drainage management

The main issue with "referencing" a specific bit of guidance rather than making a specific requirement to be in "accordance with" is that with only a limited reference to the GARD approach, there is no stated requirement for the guidance to be adopted in part or in whole. As an example, the GARD Guide is not referenced in the ICMM Tool boxes nor the Closure Maturity Framework. As such the inference that one may take away is that "guidance" such as GARD can be selectively "referred to" rather than operations being in "accordance with" the guidance.

4 Corporate closure governance

In 2018 ICMM estimated that approximately 20% of mine sites would be closing before 2028. Given the legal obligations, stakeholder expectations and multi-disciplinary approach and cost liabilities of mine closure a sound corporate closure governance framework is essential.

The authors suggest that the implementation of a closure governance framework should ensure risks and opportunities are identified and stakeholder expectations, including regulators, are addressed, whilst simultaneously meeting business needs such as cost estimations and reductions in potential liabilities. Benefits would be cost efficiencies and conformance with company values and policies throughout the mine life cycle.

Most major mining companies have a closure statement (standard, protocol) that is two to three pages in length defining what is required in general terms. AA is a company that has recognised the challenges that a standard alone cannot address, and so developed a comprehensive Mine Closure Toolbox (MCT)

(AngloAmerican, 2019), see Figure 5. For example, in addressing the business needs MCT have adopted and incorporated the Zone of Influence, a defined area where the mine can impact and/or influence.

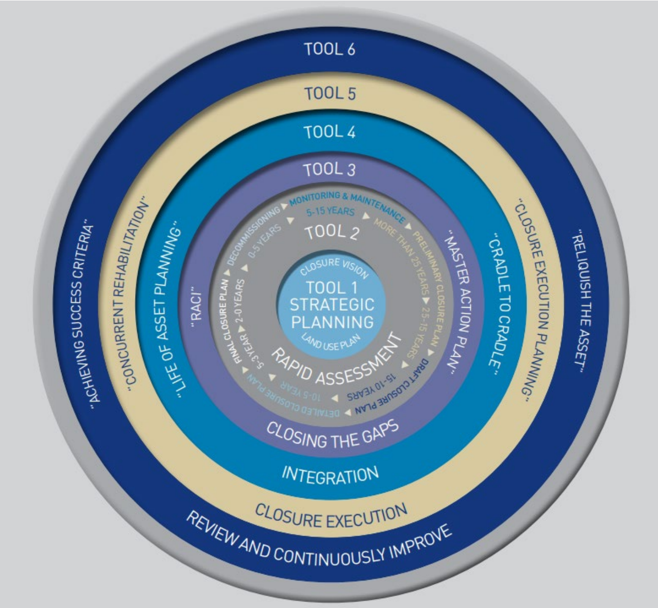

Figure 5 AngloAmerican mine closure tool structure

Overall, it is fair to state that the MCT delivers a positive balance between defining the process to be initiated by site detailing specific actions. Continuous improvement is achieved with the gap analysis tool. In a thought exercise, it is possible to create a template from the MCT in a form that could be used to evaluate a site's performance. However, in the area of increasing the detailed requirements in the area of geochemistry there is, we suggest, an opportunity for improvement.

Even where a thorough process that results in a detailed action plan may, for example, identify cost estimations to be updated is a key requirement for closure, without detailed modelling based on thorough understanding of site-specific geochemical stability, determined through leading practices, the cost estimation will be, unintentionally, less accurate. Building a framework alongside the existing approach, where as much of this geochemical information is gathered through the life of mine as is possible would improve closure outcomes.

In their proactive approach to reduction of potential closure liabilities, Company B have identified AMD as an area where better characterisation would decrease closure risk. Gaps or inconsistencies in historic testing create uncertainties in the understanding and modelling and as a result in decision making that could lead to liabilities during operation and particularly at closure. Their approach is to develop an approach that provides a framework for the integrated geochemical testing and characterisation to give a consistent approach to mine waste AMD management.

Thus, in their approach company B have examined the development of a geochemical manual that would provide a consistent approach in line with regulatory requirements and available testing methods, as well as objectives of geochemical testing programs. The manual is developed in two sections for easier reference. The first part focusing on the regulatory framework and geochemical testing methods (with appropriate standards or recommended use based on local and regional laws and guidelines). The intent is that this 'reference' part of the manual can be used to select the appropriate test to meet the objectives of different operational aspects of the development with respect to AMD management. The second part of the manual details how the testing is integrated into aspects such as operations and the mine cycle, i.e closure. The overarching structure to AMD management-relevant aspects of operation is summarised in Figure 6.

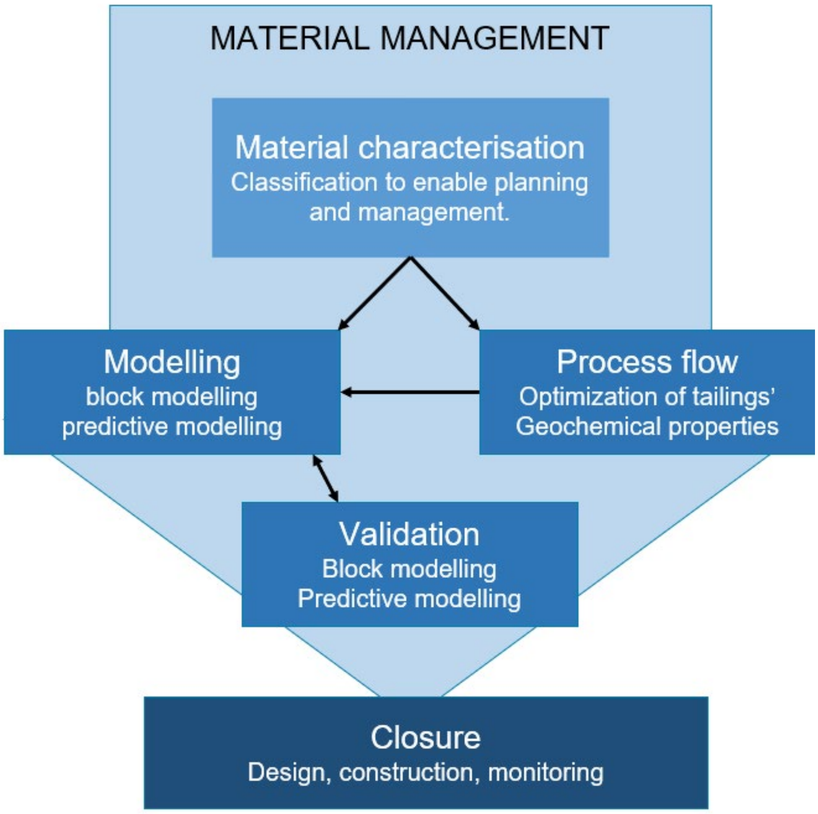

Figure 6 Geochemical overarching approach (company B)

When the manual's geochemical considerations, based on the GARD Guide, laboratory standards, and others, are extracted and mapped against the ICMM Closure Maturity Framework a site-specific template with detailed testing and analysis requirements can be envisioned.

The geochemical integrated approach should still be seen as part of the closure governance. This integrated approach allows them to capture, in more detail, the regulatory requirements and understanding of the geochemical stability required. This approach fits with the business needs and values that complement site specific closure objectives. Whilst a systematic approach has been set out in this paper, the complexity of a geochemical management system should not be overlooked or underestimated, as highlighted in Figure 7. Figure 7 is a flow chart showing how EU and Scandinavian regulatory requirements link with material characterisation testing methods, and is a necessary step in ensuring that the characterisation meets legal obligations within a systematic approach.

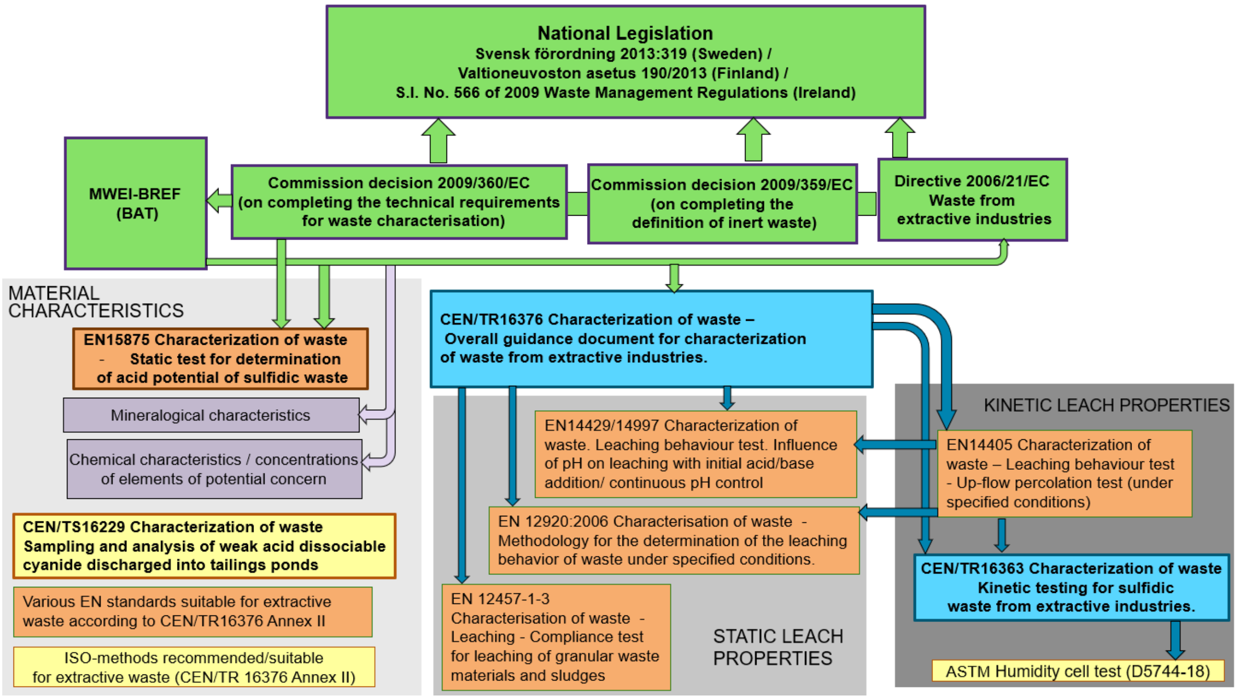

Figure 7 **Overview of geochemical testing legislation, guidance, and standards in the EU**

The fact that no single approach to site-specific template development for geochemical assessment has been accepted, and possibly never developed, that is widely in use globally, reflects the complexity and highly technical nature of this aspect of closure and life of mine generally.

5 Bridging the gap from corporate to site

Even with legal requirements and the availability of guidance on good practices, companies usually adopt strategies to delay the full implementation of decommissioning projects, without their integration to the operation. (Taveira and Sánchez, 2016). In Australia, as in other countries, corporate governance law requires a company to identify, evaluate and manage all significant risks. A prudent approach is to develop a focused AMD risk review program that starts by asking two key questions:

- What hazards does AMD pose to the mine operator?
- Is the operator managing those hazards to minimise environmental, human health, financial, regulatory and reputational risks?

Many mining companies assess the risks posed by AMD as part of project development and as part of closure planning. However, there are few published examples of processes used for those assessments (Australian Government, 2016). In the past, mines were closed without proper planning including the assessment of impacts on the community and were inadequately regulated by either the proponent or the government (Cowan et al. 2010). The follow-up question to the two above could be, who owns closure planning and the activities?

Centralised (corporate) governance can lead to a situation in which global corporations choose global standards over the Mining Standard (Ruokonen, 2020). Ruokonen highlights the Finnish Mining Association (FinMin) TSM and its objective to build trust between stakeholders, and so has more site-specific focused approach. Whilst the authors would not disagree with the findings, they note that the TSM is primarily a set of principles, that does not deal in site specifics.

The role of corporations is addressed above with the issuing of the appropriate governance documents and creating the accountability and responsibilities, whilst the implementation is so site specific that it must lie with the site. To remove any ambiguity, closure governance must include clear and specific direction to site. Site must have clear and tangible requirements.

There is no universally accepted understanding of what is needed for closure and what aspects of closure should be addressed by closure regulations (Mine closure checklist for governments, APEC). Whilst this point was made to address a larger gap, the statement is no less true when considering site specific planning.

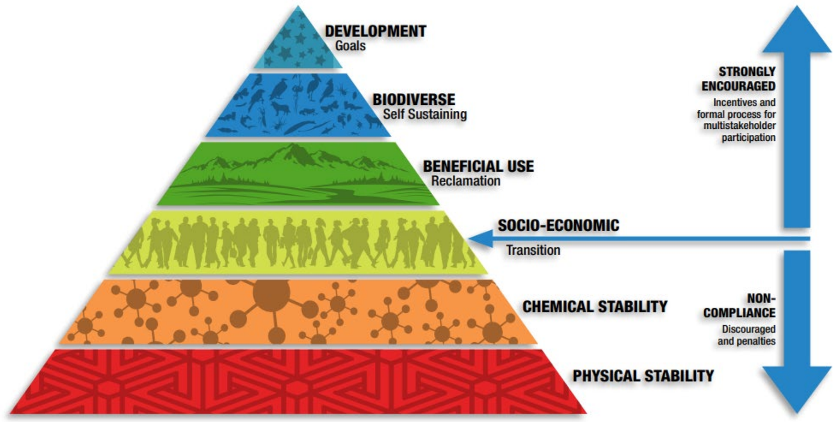

Figure 8 Hierarchy of closure needs

Perhaps the single most important lesson is that there can never be too much information on mine hydrogeology and geochemistry available at the post closure (operational) phase as emphasised in Figure 8. As closure phase is the longest in the overall life cycle of any mine, it should be given appropriate consideration from the outset (P Younger, N Robins. January 2002 Geological Society London Special Publications 198(1):1-16).

6 Template requirements

The AA MCT and Company B's manual are examples of bridging the gap between corporate protocols and site-driven closure activities, but the authors propose a tool that allows adoption of leading practice techniques, site specific projects and planning appropriate for the stage the operation is at with regards to the risks and liabilities during the mine cycle and Life of Mine. Thus, this would form a definitive detailed list of closure specific objectives that apply to site.

It is anticipated that to achieve acceptance the tool should include an assessment function. The scoring of which could be based on the four levels adopted by ICMM. By having a company determine the system of scoring could better reflect corporate values and provide a system to benchmarking sites against a company standard. In addition, an action plan could be developed provide details of the most up to date data and relevant studies, records etc. With items such as an action plan, the process would be an example of continuous improvement and adaptive management.

Other opportunities, such as cross-referencing requirements with the ICMM closure elements could also be developed. A simplified summary of a process that captures the approach described above is summarised in Figure 9.

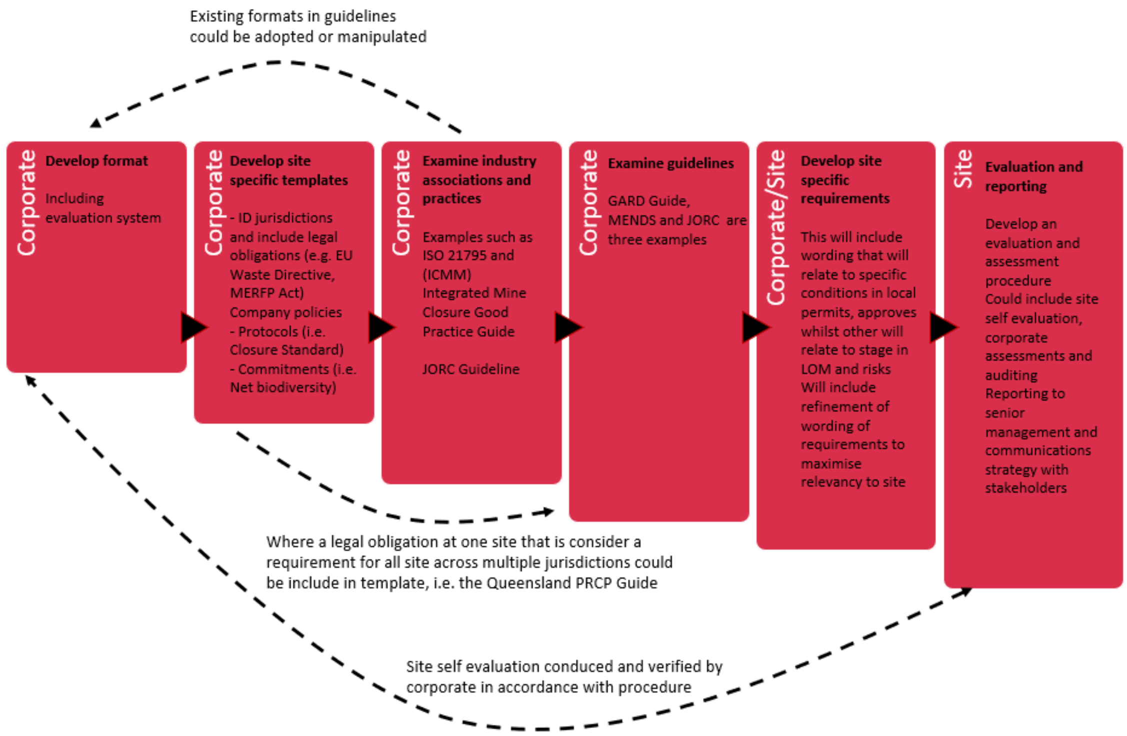

Figure 9 Establishing site specific closure & validation template

7 Conclusion

International standards to define mineral resources have been established to provide investor confidence in exploration projects for example the JORC Code and the sister Pan-European Reserves and Resources Reporting Committee's Reporting Standard. These standards are notably concise and although cover the complex and site specific process of ore resource definition, the standards have been proved to be a reliable and globally applicable tool. They are an excellent example of bridging the gap between publishing general guidance for the purposes of setting out requirements for site specific assessment.

In contrast to guidance published for resource definition, guidance and legislation for waste management and geochemical assessment are typically highly fragmented, regionalised and lack consistent and logical approach. Further most of the published documents contain what is considered "guidance" and not "requirements" which is how JORC is implemented. In reality, geochemical risk requires addressing with the same scrutiny as the resource itself, and on close reading of JORC geochemical risks does form an underlying requirement of these resource statement standards. This places characterisation of the non-ore part of the deposit on similar standing as the ore zone and means that the principles of standards such as JORC can be applied to waste material characterisation. In addition to better understanding of the full economic implications of the operation, significant opportunities exist for the project as a whole and into closure, in collecting the most appropriate information from the get-go.

In addition, the global development of industry guidelines has, in no small part, been influenced by parallel development of inconsistent international/regional regulations, with some jurisdictions still having little or no regulation in the matter (APEC, 2018). The risk to the industry is, in the absence of regulation and clear corporate governance, ambiguity and non-action will prevail, resulting in less favourable closure outcomes.

In the ICMM maturity framework geochemistry and material characteristics and modelling are all required to be demonstrated to achieve level three (aligned to international best practice). Yet 'geochemical/geochemistry' is not mentioned once in any requirement to achieve level four, leading practice. This highlights that geochemistry is not an end of itself, but an essential perquisite to achieving the highest level, and by definition, the lowest risk. Thus, understanding the geochemical stability can not be addressed through a single budget cycle, nor left to a single phase in the life of the asset.

The wave of pending mine closures means industry and governments need to keep mine closure front of mind and work together to learn from each others experience and learn lessons from previous closures to address the outstanding challenges (ICMM, 2023). Whilst the industry, regulators and companies are moving to meet increase stakeholder expatiations, the accountabilities and responsibilities can still be ambiguous and on an operational level, closure can routinely be second place. The existing guidelines, legislation and directions are in their current form on the one hand overly generic but also overly complex and inconsistent with each other, which has contributed to significant inconsistency in assessment of geochemical risk as part of closure planning globally.

If industry guidelines for resource definition like JORC are used as benchmark for how a concise guidance can be developed for a site specific and complex topic then it should be possible to envision how something similar can be produced to cover geochemical risk. One possible solution is bridging the gap between corporate and site with the development and adoption of a corporate issued site-specific closure validation template that ensures that the level of knowledge and activity be developed appropriate to the risk.

In addition, the designed should incorporate an assessment function and an action plan. In doing so, this tool could be used to benchmark site across a company and demonstrate continuous improvement.

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