Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)
ISBN 978-0-6450938-7-2
doi:10.36487/ACG_repo/2315_072

Reimagining mine closure

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Abstract

The legacy of mining in the U.S.A. is littered with environmental hazards and a crushing public financial burden as many closed mine sites carry residual environmental risk long after mining has ended. The 2020 report to Congress on Abandoned Hard Rock Mines (GAO-20-238) carries some alarming statistics on the state of abandoned mines on public lands and the potential liabilities they pose to the environment, public health and safety, and the American taxpayer. In short, approximately USD 3B has been spent by federal agencies on abandoned mine work between 2008 and 2017, with annual expenditures running close to USD 300M. Future costs for managing abandoned mine sites will run billions more. Many of these abandoned sites pre-date modern mining regulations when little to no reclamation was required; however, for current and future mining operations, we have the tools to prevent, or at least minimize, the financial burden from their default and abandonment. Most current federal mining regulations require a reclamation performance bond whose purpose is to place the responsibility for reclamation on the operator. Federal regulations, however, fall short of anticipating how a reclaimed landscape may perform over time. The public, including investors, are demanding responsible land stewardship from mining companies, and the ESG movement has provoked an awareness of the burden and impacts, both short-term and long-term, from these mining operations. To remain competitive, mining companies must address how to resolve the long-term impacts of their operations and pivot from doing the bare minimum that the regulations require. Enlightened mine closure in the 21st century must include long-term care and maintenance provisions to avoid further system failures. Responsible closure planning requires a shift away from an approach based on engineering time and towards one acknowledging that many closed mine facilities may need to remain functional far into the future. Identifying the reclaimed mine features most susceptible to failure is not always apparent, and evaluating how this residual risk may manifest itself requires a thoughtful and transparent approach. Arriving at a reasonable cost for reclamation, and more importantly, any attendant long-term care and maintenance requirements, can be difficult as this type of exercise requires one to make projections of future needs based on incomplete information.

What follows is a reimagination of how we should approach future mine reclamation that is predicated on the premise that mining creates new landforms, some with significant residual risk, that will evolve over time in tandem with the surrounding landscape. The current federal mining regulations fail to account for this temporal reality, and our natural inclination towards optimism bias when it comes to evaluating potential risks makes the current approach to mine reclamation susceptible to failure. Simple risk analysis tools can aid in identifying how these artificial landforms may perform over time and help in crafting care and maintenance solutions to ensure ongoing reclamation performance. Utilizing the time value of money, long-term care and maintenance funds can be established that will minimize the future financial burden from closed mine sites.

Keywords: *geomorphology, landform evolution, optimism bias, risk management, DCF analysis*

1 Introduction

From the earliest stone tool users to today’s dreamers of intergalactic riches, mining has been essential to civilization's development. Mining, though, is a destructive endeavour, and its environmental toll is indisputable. As mining’s impacts have become more pronounced, steps have been taken to minimize these damaging effects through regulation and oversight. Spurred by technological advances in mineral processing and equipment, modern mining operations have gotten bigger, waste streams larger, and facilities more complex, however, regulations have struggled to keep pace with these developments and seem to be in a perpetual state of catch-up. Astronomical sums of money have been spent in the United States on stabilizing and maintaining abandoned mine properties (GAO-20-238), and while current federal mining regulations now put the burden of mine reclamation on the operator by requiring a reclamation performance bond, doubt remains whether our understanding of mined land reclamation moves us any closer to minimizing future environmental impacts.

Current mining regulations for the two principal federal land management agencies, the United States Forest Service (USFS) and the Bureau of Land Management (BLM), require a mine operator to reclaim the mine site at the end of mining, but there is little direction on how to accomplish this other than general reclamation objectives (36 CFR 228.8; 43 CFR 3809.420). The implied assumption in the federal regulations is that once reclamation has been completed, the land will be stable and return to its pre-mine productivity. This often means as soon as the site is re-graded, topsoil applied, and re-seeded. This represents the old *walk away* reclamation mindset pervasive in the industry for many years. This approach is partly due to the language in the federal regulations which emphasizes the immediate post-mine time frame but fails to anticipate how the reclaimed landscape may change over time or whether the reclaimed facilities will continue to meet the required reclamation goals. To its credit, the BLM has recently incorporated a temporal component into its regulations (43 CFR 3809.552).

Public recognition of the environmental impacts of mining is growing, as is the demand for environmental justice. The Environmental, Social, and Governance (ESG) movement is the outgrowth of this emerging public awareness, motivating mining companies to be more responsible land stewards, but part of responsible stewardship may necessitate going beyond what the current regulations require. Doing the bare minimum that the regulations call for may not be sufficient to *"…prevent or control onsite and off-site damage to the environment…"* (36 CFR 228.8(g)), rather, responsible stewardship may mean acknowledging that closed mine facilities may need to remain functional far into the future to fulfill the regulations' intent.

Anticipating how the reclaimed landscape may evolve and how reclaimed facilities may perform over time remains elusive. Mine sites are incorporating ever more complex system components into their reclamation designs, where the use of synthetic materials, electronic monitoring instrumentation, and highly engineered systems (e.g., water balance caps, underdrains), many with narrow construction tolerances, precise operating specifications, and uncertain performance lives, create opportunities for system failure absent regular monitoring or maintenance. Certainly, it is common to have a monitoring requirement in reclamation plans, but the monitoring term is often set for a pre-determined time frame. An obvious question is, *What changes from the last day of the monitoring period to the next that makes monitoring unnecessary?*

This paper presents a reimagination of how industry may want to approach mine reclamation in the future. It begins by addressing the existing shortcomings in the federal regulations and our propensity to think near-term when it comes to mine reclamation. This is followed by exploring how reclaimed mine sites create artificial landforms that are subject to the same natural processes that act on the existing landscape. If these new landforms are to remain stable and secure to avoid being a future hazard to human health and the environment, we need to anticipate how they will evolve and perform over time. Risk analysis can assist in this effort. The cost of long-term care and maintenance can be daunting, especially if in perpetuity. The paper concludes with a discussion of using the time value of money concept to establish the necessary funds to pay for long-term care and maintenance without being financially onerous.

2 Why we struggle

2.1 Federal regulations and the regulator's dilemma

The vague language in the federal mining regulations obscures the need for long-term care and maintenance (LTCM) at reclaimed mine sites. The current USFS and BLM regulations are relicts of a first attempt during the 1970s to address how mining companies should conduct operations on federal lands. This was when the emerging environmental movement in the United States helped motivate the passing of many landmark environmental laws (e.g., Endangered Species Act, Clean Water Act, Clean Air Act, National Environmental Policy Act), yet there was little accompanying direction on how to achieve the objectives of these well-intentioned laws. The lack of specificity in how to go about mine reclamation may be partly due to a fundamental lack of understanding of the challenges of reclaiming a mining-impacted landscape. The language contained in the USFS and BLM regulations does not fully capture the long-term environmental risks of mining operations. The regulations did accomplish, however, putting the responsibility of reclamation on the operator and requiring financial assurance in the event of reclamation non-performance, thereby limiting any future burden on the American taxpayer for reclaiming the abandoned site.

The direction provided in the USFS and BLM hard rock mining regulations provide general guidance on reclamation objectives but lack any specificity on how to accomplish this and, perhaps more critically, do not address the temporal dimension when reclaiming a mine site. Both sets of regulations contain similar language about taking *"…measures as will prevent or control onsite and off-site damage to the environment ..."* (36 CFR 228.8(g)) but provide little else on how one should go about this, thus leaving it to the mine operator to imagine what reclamation should look like.

Mine reclamation does not always result in a stable and functioning post-mine landscape. Natural processes driven by climatological, hydrological, biological, and tectonic forces impact the reclaimed landscape and change it over time. What was a stable landscape that functioned at controlling *"…onsite and off-site damage…"* (36 CFR 228.8(g)) one day, may not be so the next. This poses the question: *When has a mine site been successfully reclaimed?*

Some mine operators have adopted an adaptive management approach to mine reclamation. Responding to how well reclamation at a site is progressing and modifying one's approach as necessary, is a sound and proven methodology. One of the tenets of adaptive management is monitoring the system and adjusting techniques in response to system performance (USDOI 2009). Hence, the duration of the monitoring phase may be unknown, as may be the final disposition of the on-the-ground reclamation, as both are dependent on the success of prior reclamation efforts. This inadvertently creates a regulator's dilemma: *How does one calculate a reclamation bond if the reclamation plan is not defined in scope and time?*

2.2 Optimism bias

The role of optimism bias in human behaviour is well documented and has a neurobiological origin that an overwhelming majority of people exhibit (Sharot, 2011). In short, humans are hard-wired to *"…overestimate the likelihood of positive events, and underestimate the likelihood of negative events*." (Sharot, 2011). The bias towards positive interpretations influences any number of decisions people make. Flyvbjerg (2002, 2009) has written extensively about the role of optimism bias in cost estimating, and how it contributes to underestimating the costs of large construction projects, even when the estimators and engineers have extensive experience with similar projects. Some measure of optimism bias likely explains why the mining industry and regulators have failed thus far to fully anticipate shortfalls in performance and stability of reclaimed mine sites, especially when trying to project long term.

Optimism bias can influence decision making in mine reclamation in several ways that may promote false assumptions about the efficacy of reclamation designs: the reclamation bond can be released as soon as vegetation is established; three pore volume equivalent freshwater rinses are all that's required for the leach pad; the water balance cap will prevent water infiltration; acid rock drainage will not develop because of the available buffering capacity; the Q-value of the rock will prevent subsidence. These conclusive statements, some informed by quantitative analysis, others anecdotal in their origin, represent what we want to believe due to our predisposition towards optimism bias. The accuracy of statements like the ones above may be valid depending on how the state condition is defined, and the state condition when dealing with reclamation is frequently viewed as near-term and finite. However, when applied to the long-term success of mine reclamation, optimism bias and our propensity to underestimate the likelihood of negative outcomes can result in yet more failed reclamation with no readily available financial recourse to mitigate the situation.

2.3 How long is long-term?

The ESG movement has provoked an awareness among the public, including investors, of the potential burden and impacts, both short-term and long-term, from mining operations. To remain competitive, mining companies must address how to resolve the long-term impacts of their operations and pivot from doing the bare minimum that the regulations require.

Within the last few years there has been a growing recognition by non-governmental organizations (NGOs) and industry groups that some mine facilities may require long-term care and maintenance (ANCOLD 2012, ICMM 2019, MCA 2019). This acknowledgement is primarily addressing the long-term risks posed by closed tailings facilities. However, what appears to be missing is a definition of *How long is long-term*? This lack of a working definition further underscores the regulator's dilemma: *Without knowing how long long-term is, how can one calculate a reclamation bond?* The regulations do not address this temporal component, and current guidelines struggle to provide a precise definition (ICMM 2019, ICOLD 2019, MCA 2019), so without a common understanding of long-term, it is difficult to address mine closure in a meaningful way.

A possible start to defining what long-term means in the context of mine reclamation could involve addressing the following three questions,

1. *How* should one think of long-term care and maintenance?
2. *What* should be included in long-term care and maintenance?
3. *Why* is long-term care and maintenance important?

The answer to *How* one should think about long-term care and maintenance requires accepting that we should think about LTCM in terms of geologic time and not simply in engineering time. *What* should be included in LTCM requires thinking beyond water treatment. While a significant component of an LTCM program, water treatment is not necessarily the only system that requires LTCM. The answer to *Why* LTCM is important can be reduced to simple economics: it's expensive.

The following sections explore these themes in greater detail and offer possible solutions to incorporating LTCM into mine closure planning.

3 Why long-term care and maintenance is necessary

3.1 A new landform on the landscape

Mining creates landforms. These, however, are artificial landforms, different from those that have evolved through natural processes, yet both types of landforms will change in shape and size in response to climatic and environmental forces. The most recognizable landforms on a mine site are tailings impoundments, waste dumps, and open pits. Certainly, these have the potential to pose a great risk to human health, safety, and the environment, but many lesser landforms also inhabit the mining landscape. Diversion ditches, portals, sediment ponds, and roads, to name a few. While a mine is in operation, these facilities are actively maintained as part of the normal mining cycle, either as part of regularly scheduled maintenance or in response to some system failure. After closure, when the regulator has determined the operator has met the requirements of the closure plan, the operator's bond may be released and the permit retired. At this point, there is no longer a designated responsible party to maintain these facilities, and they become part of the surrounding landscape and are subject to the same natural forces and processes that have driven geomorphological change for millennia.

3.2 Operating life versus functional life

Mine facilities are designed, constructed, and operated to serve a specific function. For example, tailings impoundments store milled waste products, waste rock dumps provide storage for uneconomical rock, and open pits are simply the result of the mining process. A useful definition of operating life, then, may be the period during which a facility is used for its intended purpose. These facilities are typically highly designed and engineered systems, often with precise construction tolerances and operating requirements. A common theme for many of these systems is that they must remain stable to fulfill their design purpose. Recent tailings impoundment failures at Mount Polley, Fundão, and Brumadinho have highlighted the risks tailings impoundments pose and why stability is imperative. Tailings facilities are operated according to specific protocols to ensure facility stability. This may mean maintaining sufficient free board or beach width in the impoundment, monitoring phreatic levels in embankments, or following design specifications during construction to ensure operational function and stability. Adherence to these requirements helps minimize the risk of overtopping, embankment instability, or some other failure mechanism during the facility's operating life. But how should a facility's performance be evaluated once mining has ended, and the site has been reclaimed?

After a tailings facility is closed, it still must function as a stable repository for tailings. However, the operating requirements that applied during mining to ensure a safe facility may be less relevant post closure. The risk drivers present during operations (e.g., water holding capacity, liquefaction potential, seepage) may no longer be as critical to facility stability, replaced by closure related concerns such as cap integrity, underdrain performance, or stormwater routing. While likely different from those present during the operations phase, potential failure modes and consequences from facility non-performance remain after closure in some form and may continue as a threat to human health and the environment. It would be short-sighted to dismiss the importance of tailings impoundment integrity based on a facility coming to the end of its operating life, as this phase will be replaced by a state of functional life that can extend in perpetuity. Consider the time a tailings impoundment, or any mining facility, will be operational is far less than the time that same facility will need to maintain its integrity once mining has ended, and the site has been reclaimed. Indeed, regulators and NGOs have recognized that some reclaimed mine facilities, specifically tailings dams, may need care and maintenance exceeding 1,000 years (ICOLD 2013).

3.3 A dynamic and evolving landscape

We live on a dynamic and evolving planet whose surface features change over time in response to natural processes induced by climatic and environmental forces. Natural landforms are in a continuous state of change and degradation which can be a slow, incremental process or rapid in response to extreme events. These processes, or energy systems, drive landform changes, with the rate of change dependent on the interaction of the imposed stressors and the resistance of the materials on which they act (Fookes et al. 2007). Precipitation, flooding, slope creep, freeze-thaw cycling, wind, wildfire, drought, and animal activity are some of the natural processes that alter a landscape.

The artificial landforms of a newly reclaimed mine site are subject to the same landscape altering processes that have shaped the surrounding area. A landscape will find an equilibrium between these altering and resisting forces, but at best, this will be temporary as eventually there will be an imbalance in system dynamics and an inability to resist change. Attributes of the geomorphology of a site evolve due to the geological and climatological conditions unique to the area. Landscape evolution models (LEMs) are useful for evaluating how a landscape may change over time from these natural processes, and their graphical output demonstrates just how dramatic this landscape evolution can be.

The concept of an evolving landscape is at odds with the regulations and the current approach to mine reclamation, where the reclaimed site is treated as a static and stable entity. A reclaimed mine site will change over time and perhaps evolve to a condition that no longer meets the regulatory requirement of *"…prevent or control onsite and off-site damage to the environment…."* (36 CFR 228.8(g)). This is why a shift from thinking about a reclaimed mine site in terms of engineering time to geologic time is necessary if long-term environmental protection is to be achieved.

4 Evaluating long-term care and maintenance needs

Responsible closure planning requires a shift away from an approach based on engineering time and towards one acknowledging that many closed mine facilities may need to remain functional far into the future. Identifying the reclaimed mine features most susceptible to failure is not always apparent, and evaluating how this residual risk may manifest itself requires a reasoned and transparent approach.

Using risk assessment tools to identify potential issues of concern is a common practice in the mining industry, with many regulatory and industry organizations recommending its use (AER 2020, CDA 2013, MAC 2019, ICMM 2019, ICOLD 2013). While many risk analysis applications target the operations phase, applying it to the post-closure environment can help highlight potentially vulnerable facilities and reclamation components that may not otherwise be identified during operations.

Reclaimed mine sites can be a complex of integrated systems where each component may have a specific function in support of another dependent system: an underdrain must work to prevent the build-up of a phreatic surface in an embankment to ensure embankment stability is not compromised; a diversion ditch must function to prevent stormwater from eroding a reclamation cover thereby risking exposing harmful materials, or; an electronic monitoring array needs to remain operational to capture incremental slope movement which may lead to more consequential stability problems. A common theme in the analyses from the Mount Polley (2015), Fundão (2016), and Brumadinho (2019) tailings dam failures was that multiple, inter-dependent system breakdowns and/or conditions led to eventual dam collapse. Warning signs of system performance irregularities were evident that if addressed, may have averted a complete system failure.

The USFS recently conducted a risk assessment on a closed mine facility using the Failure Modes Effects Analysis (FMEA) methodology (IEC 31010:2019). The exercise focused strictly on the post-closure time frame and did not limit the analysis period to a specific future end date. The outcome of the FMEA (unpublished) yielded interesting results. The exercise identified that the risk drivers were not the extreme events such as the Probable Maximum Flood or Maximum Credible Earthquake. Rather, the smaller, chronic events that impacted ancillary structures and facilities such as diversion ditches or the failure of engineered systems such as underdrains and electronic monitoring stations posed the greatest risk over time.

The FMEA highlighted recurrent natural processes (e.g., wildfire, storm runoff, slope creep) were the principal drivers behind eventual system failures over an extended time horizon. This is due to the incremental degradation of system performance leading to more acute non-performance and eventual system breakdown. Not surprisingly, simple periodic care and maintenance such as cleaning diversion ditches, repairing rills and gullies, and replacing electronic monitoring systems can help avert eventual widespread facility failure.

5 Financing long-term care and maintenance

5.1 Time value of money

A common and cost-effective method of financing recurrent LTCM requirements that extend far into the future is to create an interest-bearing trust instrument using discounted cash flow analysis to fund the annual out-year costs. Water treatment is frequently the most common and most expensive post-closure activity, but even relatively simple care and maintenance activities such as diversion ditch cleaning or minor site re-grading can run tens of thousands of dollars per year depending on site conditions. Often a third-party consultant is retained to oversee the annual care and maintenance work adding an additional layer of cost. So, even without a water treatment component, a site may require tens to hundreds of thousands of dollars in annual care and maintenance to ensure reclaimed systems remain stable and function as intended during the post-closure period.

Financing such annual costs when they occur would likely be unsustainable for any length of time. Alternatively, taking advantage of the time value of money to create a fund upfront to finance the recurring outyear cash flows can ensure funding will be available for ongoing future care and maintenance. When faced with an open-ended time frame for LTCM, a trust fund is likely the most cost-effective instrument for a regulator to bind an operator’s financial commitment for long-term reclamation. The BLM has regulations that allow for the use of trusts funds, as do the Canadian Provinces of Alberta and Saskatchewan, and Saskatchewan also provides a means for relinquishing site management and financial responsibility to a regulatory authority (Saskatchewan 2009), an attractive proposition for a company wanting to remove this liability from its balance sheet.

Assumptions on discount rates, annual cost requirements and unexpected site developments present challenges when forecasting far into the future. Therefore, it is imperative to have an actively managed account with the option for true ups and adjustments in investment types. A trust fund is an imperfect tool precisely because of these uncertainties. Still, the alternative is to assume care and maintenance requirements will be short-lived and risk a crushing future financial burden.

6 Closing remarks

Opportunities exist to raise the standard for mine closure in the 21st century and begin to shed the stigma that often follows the mining industry. Enlightened mine closure must move beyond reclamation based on engineering time and start thinking in terms of geologic time. To do this, mining companies need to acknowledge and plan for long-term care and maintenance of facilities, perhaps in perpetuity. Key considerations to making this shift in how mine closure should be approached include:

- A new landform on the landscape will evolve in response to natural processes. Who will take care of it?
- Reclaimed mine facilities will be on the landscape far longer than the time they were in operation.
- Some reclaimed mine facilities carry residual risks to human health and the environment. Minimization of the residual risks is predicated on their ongoing stability and functionality, maybe even forever.
- Mine regulations fail to anticipate the geomorphological changes and temporal dimension affecting reclaimed mine sites.
- Simple risk analysis tools are useful in identifying long-term needs.
- Often, it is the chronic, recurrent natural processes that slowly degrade reclamation form and function until there is a widespread system failure with dire consequences.
- Periodic care and maintenance can prevent system-wide failures.
- Long-term care and maintenance does not have to be financially onerous if the time value of money concept is utilized.
- Resist optimism bias.

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