Constrained by scale:

Addressing water management challenges during mine closure

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In many jurisdictions across the globe, few mines have reached closure despite significant investment and effort (Decipher, 2020). Reclamation, or rehabilitation, encompassing measures before and after mining to mitigate mine-related disturbances to the extent practicable, is essential in achieving the goals of mine closure, decommissioning and ultimate release of financial assurances. Integrating reclamation with the overall mine closure package supports the development of approaches to mine closure that are feasible, consistent with local community / stakeholder goals, where disturbances pose minimal environmental and social risks.

This white paper focuses on learnings from recent experiences that addressed water management challenges during reclamation.

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Introduction

Challenges in achieving closure pertain to governance, regulatory, planning, and socio-economic issues (ICMM, 2019). Often underappreciated among the general public are the technical challenges that must also be overcome. Water management is one of the most pressing technical challenges faced by mining companies during reclamation and mine closure and is the subject of this paper.

Considerations – water in closure landscapes and technical constraints

Meeting water quantity and quality performance targets and post-mining land use objectives are primary challenges. When attempting to meet these targets, several technical constraints must be addressed. The purpose of water in the closure landscape, and how to prioritize its function, needs to be recognized as part of the design. Herein, "landscape" refers to an entire mine site that must reach closure, while "landform" refers to a facility (e.g. tailings facility, waste rock facility) within that mine (LDI, 2021). Across all mines, there are several common challenges, with many beyond the control of reclamation practitioners:

Trade-offs – Reclamation practitioners must determine how to feasibly meet long-term water needs for mine closure, necessitating trade-offs. Questions that may arise include:

- How much water should flow into or out of the closure landscape?
- Where in the closure landscape does there need to be more or less water?
- Should water move slowly (e.g. to minimize erosion) or quickly (e.g. to improve water quality) through the closure landscape?

In general, reclaimed landforms are designed to either source or retain water, with designs falling on the spectrum between these two endmembers. Sometimes, retaining water is necessary to support vegetation growth (e.g. trees, grasses) or to limit its infiltration into waste rock piles to prevent the development of acid rock drainage. Alternatively, sustaining lake levels in pit lakes may require sourcing sufficient water from surrounding reclaimed landforms.

Climate – Reclamation practitioners are confronted by the fact that climate bounds long-term water availability and determines the frequency and magnitude of extreme storm events and droughts. Accordingly, climate is a key aspect in designing landforms that appropriately manage risks. For example, reclamation approaches will differ appreciably between mines located in humid versus arid climates. Similarly, precipitation patterns and the frequency of intense rainfall events will determine suitable reclamation approaches. Climate change adds additional complexity, altering not only the total amount of precipitation but also the frequency, as well as longer-term drought and wet periods. What once constituted a rainfall event that usually occurred every 100 years may now occur every 20 years, with potentially large consequences for landform stability (Slingerland, 2019). Droughts may also alter the vegetation from what was established, potentially resulting in excessive erosion that may compromise covers and result in unwanted infiltration/seepage into waste materials.

Physical setting – While local climate determines water availability over time, the water's pathway through the closure landscape is influenced by the physical setting. Factors including terrain, natural geology, seismicity, proximity to aquifers, and mine waste hydraulic and chemical properties dictate the role of water in closure landscapes. As such, reclamation approaches employed at a mine in a mountainous setting will differ from those in a gently sloping plains setting. The chemical make-up of waste rock materials also play an important role in water quality planning. The exposure of once buried geologic materials, material storage, and the use of produced materials during reclamation affects transport and mobility of a variety of chemicals in the closure landscape.

Mine operations – The extent that mining operations are conducted with consideration of closure is debatable, and arguments for more holistic mine planning are certainly warranted (ICMM, 2019). Generally, the overall layout of a mine (e.g. relative location overburden dumps, tailings facilities, pits, and/or underground workings) is defined by the mining operation and, by extension, this determines the large-scale movement of water. When addressing water management challenges, reclamation practitioners must identify how to integrate with the mining operation and work with constraints stemming from mine operations. Mines are now considering closure earlier in the mining process than ever (ICMM, 2019), which represents an opportunity to address closure risks earlier and provide reclamation practitioners with more options when designing closure landscapes.

Addressing water challenges during closure

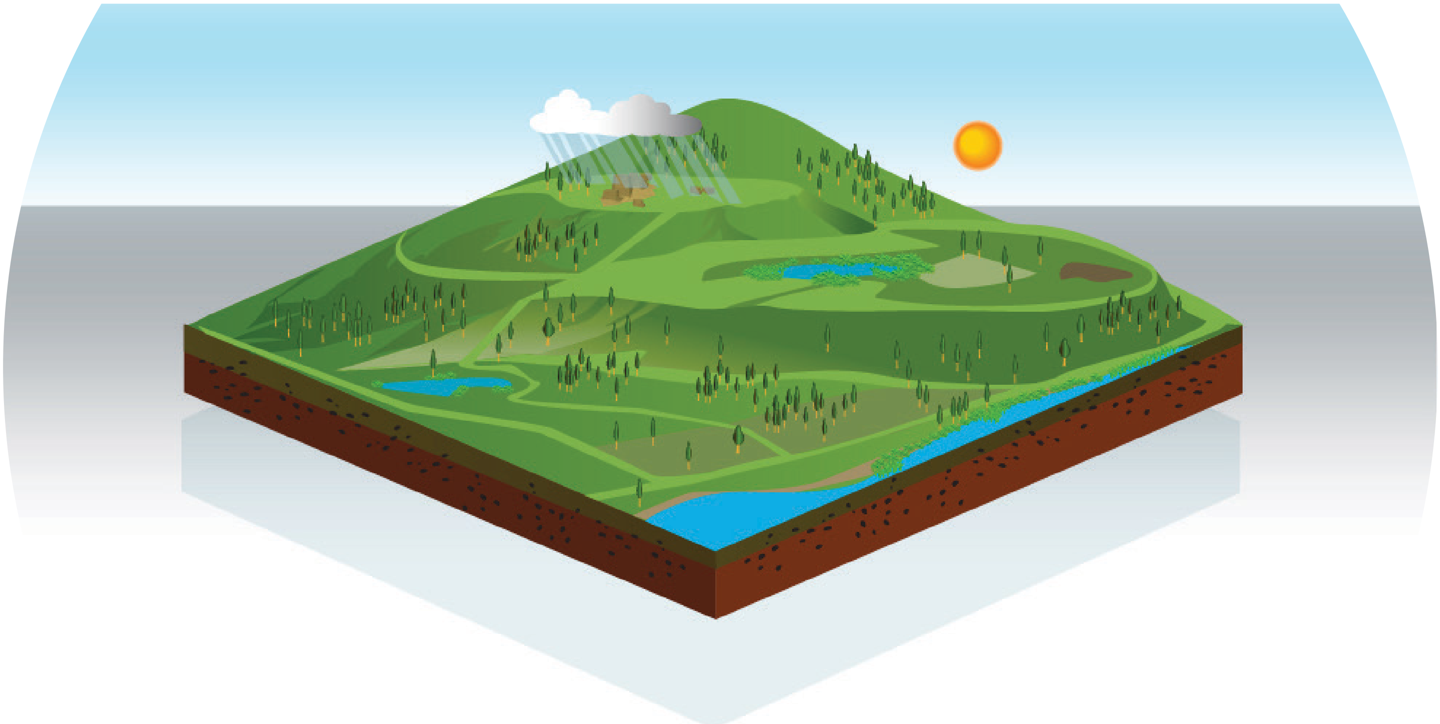
Appropriately scaling reclamation – As highlighted above, only some scales can be readily modified during reclamation, with most constraints occurring at larger spatial and temporal scales. Landforms such as mine pits, overburden dumps, tailings facilities, and pit lakes cannot be moved during the reclamation stage. Similarly, it is almost always unfeasible for closure design to target the smallest spatial scales (i.e. < ~10 m). Taken together, it is often true that: *The spatial scale where many impactful design decisions can be readily made is on the order of 100 to 1000 metres (e.g. macro-topography)*. How can we best use this scale to achieve successful closure outcomes?

Much emphasis is placed on how the entire closure landscape conveys water – often neglecting that water movement in closure landscapes is a function of how the smaller puzzle pieces (i.e. landform features) fit together. Similarly, there can be a temptation to only consider a few years into the future or make decisions based on limited data, potentially leading to too many active engineered systems (e.g. active water treatment systems) that will require maintenance and upkeep, preventing the achievement of sustainable closure over the long-term. Two widely implemented reclamation approaches that demonstrate the effectiveness of reclamation approaches at spatial scales from 100 to 1000 metres, and how they impact the overall water quantity and quality at reclaimed mines, are cover systems and macro-topography.

Cover systems – Cover systems, the construction of layered material over mine waste, are commonplace at most reclaimed mines and serve a wide variety of purposes, including:

- Promoting or limiting water infiltration;
- Facilitating the establishment of sustainable vegetation as part of the cover system;
- Limiting erosion;
- Controlling oxygen flux through covers (to mediate chemical reactions that produce acid rock drainage); and
- Preventing soil salinization and metal uptake by vegetation that may root in the waste.

Cover systems almost always facilitate establishment of vegetation, mimicking natural soils. Additionally, cover systems can be used to either source or retain water, depending on their desired function at a mine. Sometimes, cover soils promote infiltration to increase the amount of water reaching downstream environments, such as pit lakes (Lukenbach et al., 2019; Advisian, 2020). Alternatively, cover systems may limit infiltration and help retain water on a landform by 1) enhancing water usage by plants or 2) diverting flow to near-surface runoff. By retaining water, cover systems limit the amount of water seeping through, and reacting with, underlying waste rock (Ayres and O'Kane, 2013) (e.g. to reduce acid rock drainage), yet provide sufficient moisture to sustain the vegetation in the cover. Overall, a multitude of cover system designs exist depending on targeted water functions and each must be tailored to each specific mine's needs and conditions (i.e. climate, geographic/geologic setting).



Macro-topography – A longstanding and widely recognized feature that can be readily altered in reclaimed landforms is the macro-topography – the scale of individual hills and uplands (Kohnke, 1950; Schwartz and Crowe, 1987). In natural landscapes, the hillslope often represents the spatial scale that plays a key role in water movement (Fan et al., 2019). The height, shape, and size of uplands and lowlands alter how water (both groundwater and surface water) moves through the landscape. Properly designing macro-topography can address a range of water needs, including:

- Water volumes – the amount of water reaching the outlet of a reclaimed landform is dependent on the material used to construct uplands and lowlands, the relative proportion of uplands to lowlands, and the spatial layout of uplands and lowlands;
- Water routing – the location of uplands and lowlands can be used to slow down or speed up how quickly water exits a reclaimed landform as well as the path that water takes;
- Groundwater table control – in some cases, it is desirable to isolate shallow groundwater from the land surface (e.g. due to the negative consequences of saturation or salinization on plants). Accordingly, the height and size of uplands as well as reclamation material properties can be targeted to optimize the separation between groundwater and the land surface;
- Erosion control – proper design of the grade and slopes of uplands is important for managing erosion and preventing the development of larger erosional features (e.g. gullies); and
- Wetland formation – macro-topography, combined with material placements, determine whether conditions are suitable for wetland formation, which might include designing areas to receive groundwater discharge.

Comprehensive design of the local topographic setting will be beneficial in addressing water challenges at reclaimed mines. Integrating macro-topography with cover system design can modify water quantity and quality within a reclaimed landform and, by extension, the entire closure landscape.

Conclusion

Water is one of the most important components for mine closure as it is critical in meeting commitments to local communities, stakeholders, and regulators.

Reclamation practitioners are faced with numerous water challenges and constraints, imparted by environmental factors (climate, physical setting) and the mining operation. Design modifications within landforms and at local scales, while not an ideal substitute for holistic closure planning before the mining operation breaks ground and during mine operations, remain a key reclamation tool.

Targeted designs can help maximize the function and performance of water to achieve water quality and quantity targets for closure landscapes.

Acknowledgements

Thank you to my fellow reclamation scientists, who have influenced my thoughts outlined here. Admittedly, this is only a brief, high-level glance at some overall considerations – it does not do justice to the outstanding technical work being done across the sector.

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