The evolution of coal mine waste management practices in Western Canada

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ABSTRACT: The perspective on mine waste management practices has been evolving over the past decade to account for major shifts in mine economics, social awareness, growing knowledge of the effects of mining on the environment and, an increasingly stringent regulatory environment. One response from these drivers is the desire to reduce or even eliminate the need for long term water treatment following mine closure.

The paper provides examples of modifications to waste management practices at coal mining operations in western Canada, including measures that are currently being researched for reducing the release of selenium and other mineral constituents. Using a broad sustainability-based lens, it discusses the pros and cons associated with potential measures to deal with this issue. These include covers, water diversions, subaqueous deposition, creation of biologically active dump environments and water treatment.

1 INTRODUCTION

A recent consideration for operators and regulators of metallurgical coal mines in western Canada is the recognition of the damaging effects of selenium in the environment - especially, the watersheds influenced by these mine operations. This awareness has driven a regulatory-inspired industry response to examine current mine planning and spoiling practices along with other measures to manage the release of bio-available selenium into the environment. The objective of this paper is to provide an overview of the selenium management strategies broadly under consideration by the metallurgical coal operators. Its purpose is to identify the design characteristics of an“ideal” waste rock storage dump based on recent learnings while considering its environmental, social and economic (triple bottom line) effects.

2 BACKGROUND

2.1 *Physical, Geochemical and Environmental*

Selenium, an element which is present in minute quantities throughout the Earth’s crust, is located immediately beneath sulphur on the periodic table and behaves similarly, oxidizing and leeching out of waste rock dumps in a fashion analogous to acid rock drainage. When free oxygen is present, selenium oxidizes and becomes water soluable and bioavailable. The presence of free water in the dumps therefore acts both to promote oxidation, by transporting free oxygen into the dump, and to transport the oxidized, water soluable-bioavailable selenium oxides out of the waste dump into the local watershed.

Selenium is a curious element; essential for animal life as a micronutrient, it becomes toxic in elevated concentrations. Fish, amphibians and birds are all considered sensitive to elevated selenium concentrations. Selenium is commonly associated with coal deposits, present in both the coal itself and in sedimentary rock overburden.

Given that selenium accumulates in vegetation, its presence in elevated concentrations in the western Canadian coal deposits and immediate overburden rock is thought to be related to the Mississippian Era swamps, present along the old continental margin of western North America that spawned the formation of the coalfields.

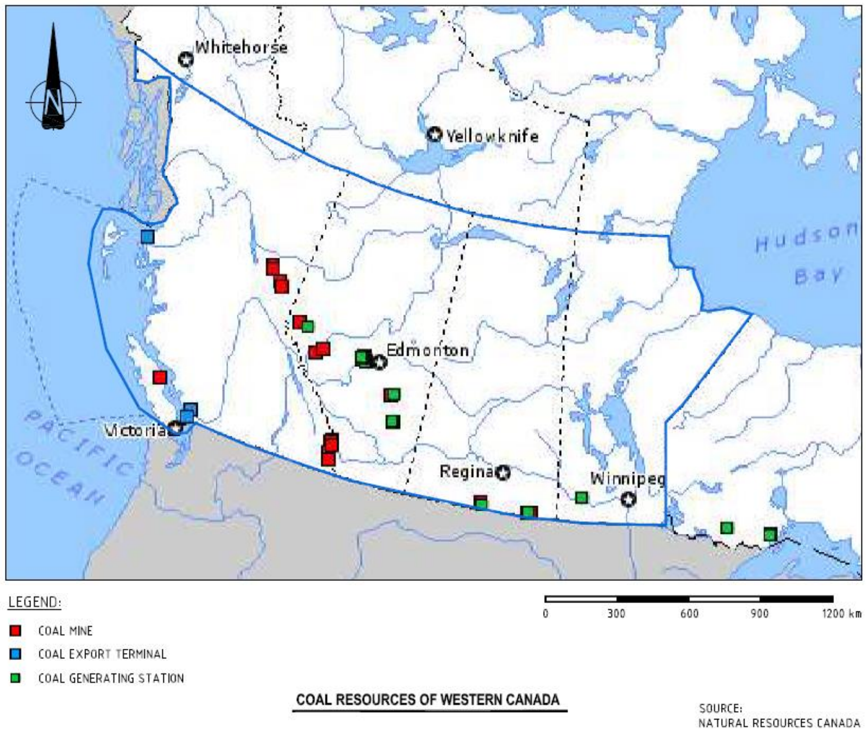

Figure 1 Coal Resources of Western Canada

All of the currently operating western Canadian coal mines are open pit mines, located in the Rocky Mountains (see Figure 1). Strip ratios are typically on the order of 8 to 12 (cubic meters of waste rock to strip per tonne of raw coal). Therefore, the recent mining practice (from 1970 on) has favored what is essentially mountaintop mining, with the waste rock being dumped off the side of the mountain or hill into adjacent valleys in large, top-down angle of repose dumps. Many of these valley bottoms contain creeks and streams; however, the coarsest fraction of the waste rock typically segregates to the base of the dump during initial placement, these dumps often include, either by design or accident, a rock drain. The large coarse rock in these drains promotes a high porosity and the buried watersheds often continue to flow relatively unimpeded beneath the waste rock dump.

As the waste rock in the majority of these mines is Non Potentially Acid Generating (NPAG), the practices of top down spoiling and cross-valley fills were not considered problematic and water quality issues historically revolved around the concentrations of calcite and nitrate in the watersheds downstream of the waste rock dumps. However, in 1995, elevated concentrations of selenium were detected during a routine water quality assessment in support of a mine effluent permit amendment (MacDonald & Strosher 1998). Routine sampling detected concentrations of 25 µg/L below the mine and less than 1 µg/L above the mine. This finding triggered a revisiting of historical water quality samples from the mouth of the Elk River, 65 km downstream of the Southeast British Columbia coalfields and it was quickly discovered that selenium concentrations had been on the rise in the Elk River for the better part of two decades.

Since that point, selenium concentrations have continued to increase and, more alarmingly, the concentrations are increasing exponentially more or less in direct correlation to the total volume of waste rock deposited into the Elk River watershed (Swanson, et. al 2010).

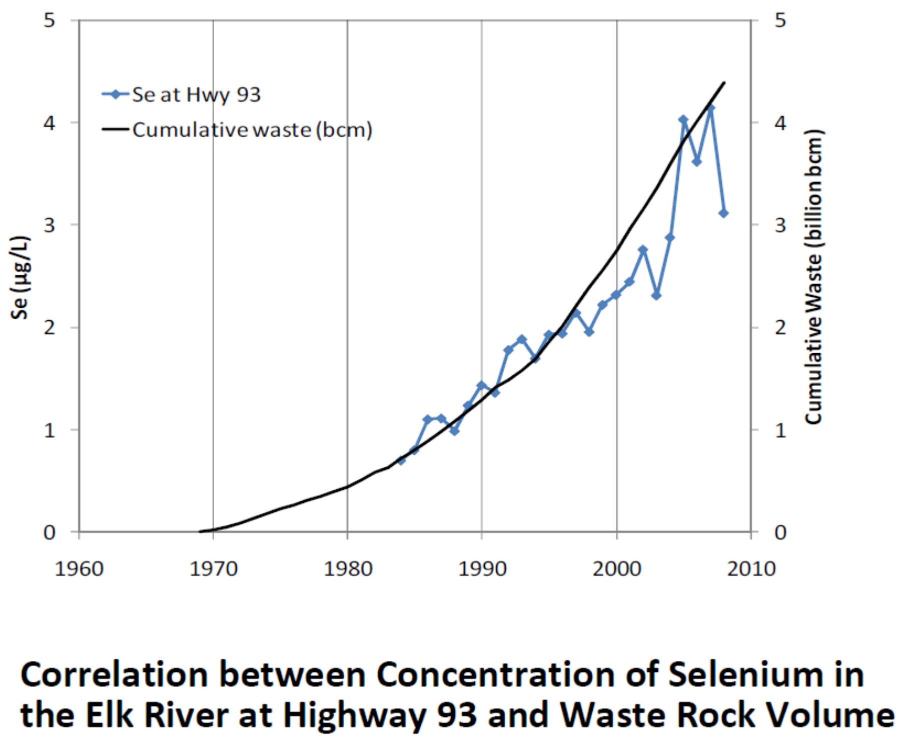

Figure 2 Selenium Concentrations in the Elk River (from Swanson, et. al 2010)

This trend of increasing selenium concentrations in SE British Columbia has caused delays to expansion projects at the mines and is now threatening their continued operation under current mining practices. In response, the operators have begun investing significant resources into attempting to halt the increase in selenium concentrations in the watershed, and hopefully reverse it.

Similar issues with elevated selenium have now been detected in metallurgical coal operations in northeast British Columbia (BC) and northwest Alberta (AB).

2.2 *Sustainability and Metallurgical Coal*

As metallurgical coal operations grapple with the increasingly important regulatory mandate to manage the selenium associated with their operations they must balance their management responses with a broad spectrum of triple bottom line consideration. The Strategic Advisory Panel on Selenium Management in their 2010 report (Swanson et. al, 2010) identified several dozen triple bottom line and technical considerations developed from a series of stakeholder engagements in southeast BC and northwest AB. In essence, these considerations compel the operators to consider the capital and operational expenses of these selenium management responses and their potential efficacy relative to the short and long term impacts on community and environmental wellbeing. It was widely recognized by the stakeholder contributing the SAPSM Panel review that it was not in the communities' (society's) interest to adopt strategies that force coal operations to the economic margin. At the same time, the increasing trend of selenium concentrations in the watershed had to be halted and reversed. This is not an intractable position but it does require the coal operations, their stakeholders and the regulators to identify and accept a series of environmental, social and economic trade-offs as they attempt to sustainably manage selenium.

3 VIRTUAL PROTOTYPE MODELING

There are two approaches available for selenium management: preventing the release of selenium from waste dumps or treating the water downstream of the dumps to remove the selenium. In general, the first approach comprises measures employed to prevent water and oxygen moving through the interior of the dumps; the second involves construction of either active or passive water treatment facilities. The first approach is still relatively immature. It has not been employed on a wide scale in the prevention of selenium release and, while the theories behind it are sound and relatively well understood, it remains commercially unproven. The second approach is further along in the Research and Development curve and, to date, it has been favored by the mine operators in western Canada.

3.1 *Water Treatment Measures*

Water treatment measures comprise techniques used to remove selenium from impacted surface water flows. Installed at the base or downstream of a waste rock dump, these measures can be divided into two groups: active treatment and passive treatment.

3.1.1 *Active Treatment*

To date, active treatment has received the most attention from mine operators in western Canada. At least one mine has completed an active treatment trial, another is underway and a large scale water treatment plant is in the advanced stages of design. Three mechanisms are possible for active water treatment: physical processes (filtration, reverse osmosis, etc.), chemical treatment (precipitation, cementation, etc.) and biologic processes (Nitrogen and Selenium Management Program 2007). Biologic processes work due to the fact that selenium is a sulphur analogue; sulphur reducing microbes can also utilize selenium in their metabolism, reducing the oxidized selenium to an insoluble form.

All of these technologies use some form of reactor process, requiring a large industrial scale facility, are electrical power intensive and produce a selenium rich sludge that must be properly disposed. In short, not only do they require a large capital investment, the mine operator must then finance their continued operation for at least the life of the mine and, in all probability, for a significant period beyond mine closure perhaps for decades. The size of the plant is in direct proportion to the volume of water that must be treated; for some of the larger watersheds in British Columbia where active treatment is being considered, construction costs are anticipated to be on the order of $50,000,000 to $80,000,000 Canadian with ongoing operational costs of $2,000,000 to $5,000,000 CDN per year.

Despite the high and ongoing cost, the advantage of these systems is that the processes involved are relatively well understood, commercially proven and have a high degree of certainty regarding the reduction of bioavailable selenium in the watershed. To some degree they are also modular. Consequently, treatment trains can be added or deleted as selenium concentrations change with time. Most importantly, the active treatment facilities begin working as soon as the plant is brought online.

3.1.2 *Passive Treatment*

In a passive treatment system, a reactor is not used. Impacted water is sequestered in a large lagoon, constructed wetland or covered engineered cells and biologic treatment through microbial action or algae sequestration is utilized to remove selenium from impacted water. The obvious advantage to this system is that once constructed and well established, the ongoing operating costs of the system are lower than in an active treatment system. Disadvantages to passive treatment systems include the large amount of land required for the lagoon, wetland or treatment cells, the potential for these systems to become an attractive nuisance for birds, amphibians and mammals and most importantly, the difficulty in establishing a sustaining system with a controlled, low selenium concentration output.

Passive treatment systems for the management of selenium currently sit on the research and development spectrum rather than that of their commercially proven alternative (i.e., active water treatment systems).

3.1.3 *Saturation Zones*

Under the right conditions, certain bacteria will utilize dissolved selenate (Se[VI]) in their metabolism, reducing Se[VI] to selenite (Se[IV]) and then to elemental selenium (Se[0]), which precipitates out of solution (Maiers, et. al 1988). As this reaction is relatively unenergetic, microbes will typically utilize other energy sources, such as carbon or nitrates before moving on to reduce the selenium. As well, anoxic or low oxygen environments tend to work better for encouraging the growth of selenium reducing microflora. Once appropriate conditions are established, selenium reduction occurs relatively rapidly; on the order of days to weeks.

If dump water was forced to percolate slowly through a saturation zone, oxidation of mine waste and bacterial action would slowly deoxygenate the water. This should create conditions favorable for establishment of a suitable selenium reducing microbe community within the dump, in essence turning the dump itself into a passive treatment system. It is thought that residency times on the order of 6 months are necessary to first deoxygenate the dump water and then allow for microbial selenium reduction.

Saturated conditions can be created at the toes of existing dumps relatively easily by constructing an impoundment and backing dump water into the mass of waste rock. An illustration of a conceptual design is presented in Figure 3. By calculating an accurate water balance for the dump, the impoundment can be sized properly to ensure an appropriate residency time. This approach also has the benefit of allowing for the construction of an engineered outlet for the dump water; regular sampling of the dump water at the outlet would allow for diversion of water to secondary treatment facility if necessary. Notably, saturation zones currently are not commercially proven in metallurgical coal sector of western Canada; indeed, they will require both research and development and a thorough understanding of the geological and hydrogeological conditions at each site for which they are considered.

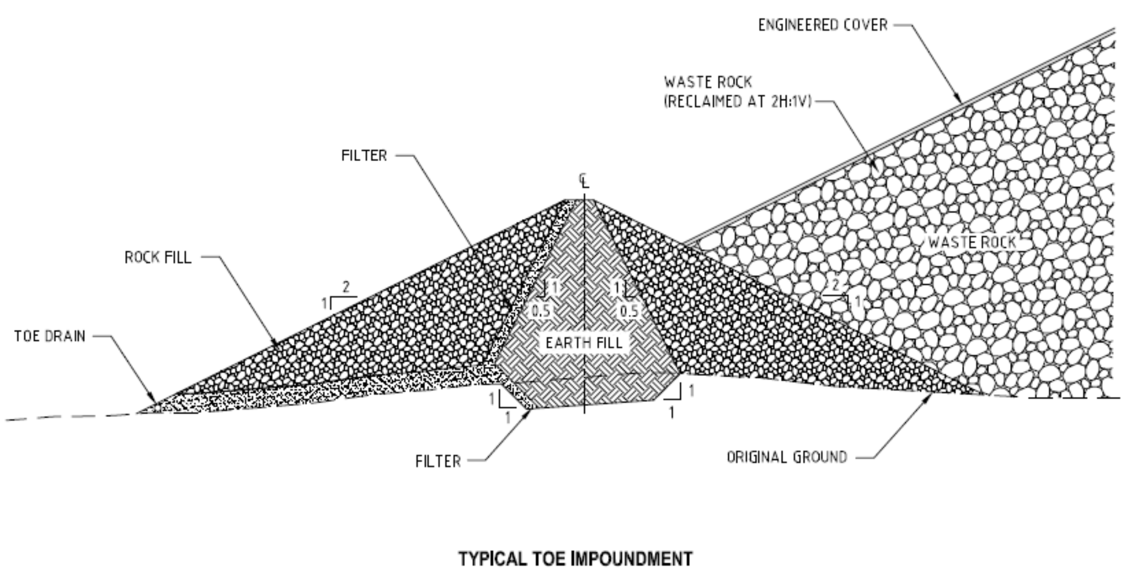

Figure 3Typical TOE Impoundment

3.2 *Selenium Prevention*

Selenium prevention measures work by inhibiting the oxidation of selenium present in the host rock, the transport of the oxidized selenium out of the dump by surface water or both, by controlling water and oxygen flux through the dump.
Selenium prevention measures are currently in research and development phases and will require several years of investigation to demonstrate their selenium management efficacy.

3.2.1 *Sub Aqueous Sequestration*

Sub aqueous sequestration works by submerging waste rock in still water. The limited amount of dissolved oxygen in the water is consumed by oxidation and, at that point, further selenium production by oxidation stops. The best opportunity to employ this technique is by backfilling waste into open pits that partially flood at mine closure, although a good understanding of groundwater flows through the flooded dump is necessary to adequately characterize the system. The advantage to this technique is that once permanently flooded, the rock is expected to stop producing selenium. The disadvantage is that rehandling of waste may be necessary to maximize the backfilling of spoil.

3.2.2 *Dump Covers*

Dump covers work by constructing a low permeability cap on a waste rock dump, stopping infiltration of precipitation into the dump. In theory, this produces a dry dump environment, and selenium, while it may oxidize out of the waste rock, is prevented from leaching out of the dump. While the theory is simple, the practice of constructing adequate dump covers to prevent Acid Rock Drainage (at mines with this issue) has proven somewhat problematic in practice. It should also be pointed out that, while a dump cover may not be able to completely eliminate a selenium problem, by reducing the volume of precipitation entering a dump they can reduce the volume of impacted water flowing out of a dump requiring further treatment.

Current cover practice has gained much from advances in the field of unsaturated soil mechanics. State of the practice covers are highly engineered structures, incorporating multiple materials to produce capillary breaks within the cover and designed to allow for rapid establishment of vegetation. The field of dump cover design continues to evolve and mature and dump covers will undoubtedly play a major role in selenium control and mitigation in the future. Typical conceptual designs for dump covers, including those of a geosynthetic membrane are illustrated in Figure 4.

3.2.3 *Surface Water Management*

Proper management of surface water flows around waste rock dumps is a crucial item in any selenium management plan. The goal is to limit selenium contact with mine-affected water (i.e., keeping clean water clean) while limiting the volumes of selenium-affected water requiring treatment (of any sort). Surface water management typically takes the form of surface water diversion ditches around the waste rock dumps, although tunnels beneath or around dumps are also possible. On their own, surface water diversions are not expected to significantly reduce selenium release from waste rock dumps. However, when combined with dump covers they can help create a significantly drier dump environment. Most importantly, a good surface water management system has the potential to significantly reduce the volume of selenium impacted water requiring treatment.

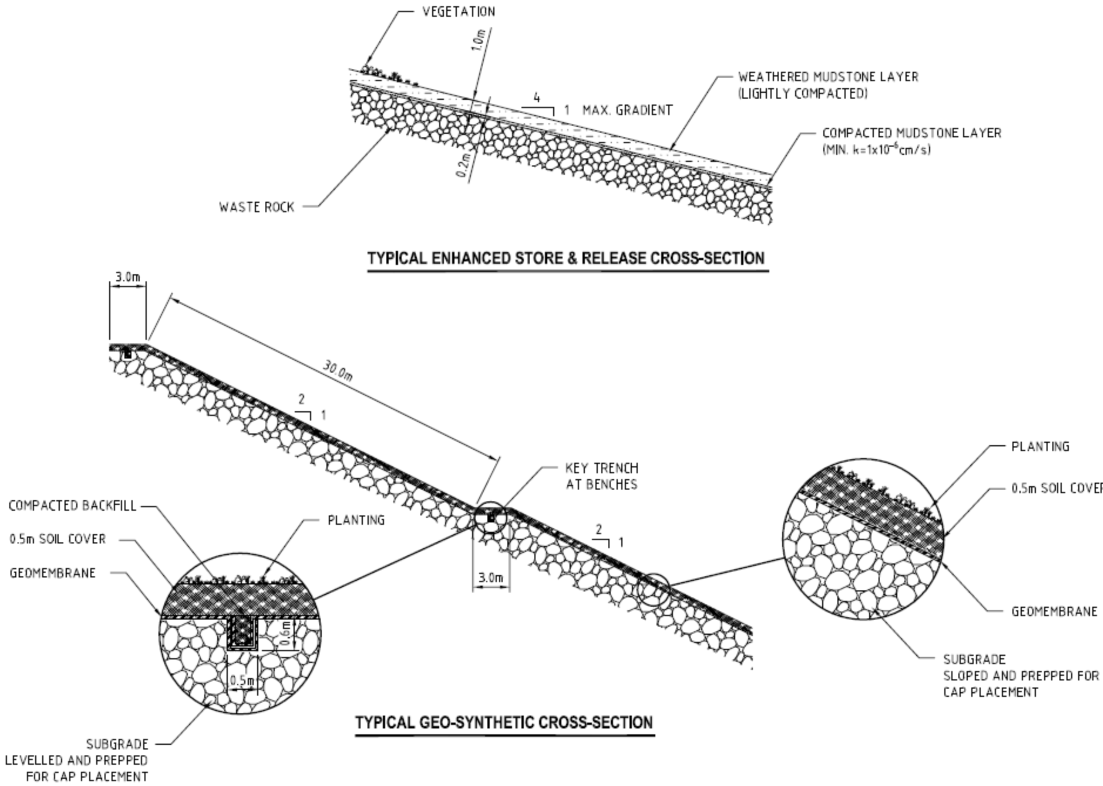

Figure 4 Typical Geo-Synthetic Cross-Section

3.2.4 *Waste Concentration*

Waste concentration works by limiting the number of watersheds impacted by waste rock dumping. While not necessarily reducing selenium release on its own, this technique can significantly limit the volume of water becoming selenium impacted and requiring treatment. For operating mines, waste concentration involves transporting waste rock to pre-existing dump locations instead of forming new waste rock dumps as mine development proceeds.

3.2.5 *Dump Construction*

The majority of dumps constructed at the western Canadian coal mines are top-down, valley-fill dumps. These dumps are formed by free dumping waste rock off the side of hills or mountains where mining is occurring into the adjacent valleys. Waste rock dumps formed in this fashion are highly segregated, with coarse waste at the bottom and toe of the dump and finer waste at the top, and form at the angle of repose of the waste rock, with a Factor of Safety against instability of 1. As well as being difficult to reclaim, vegetate and cap, such dumps are also prone to instability, failure, debris runouts and ongoing settlement. Large fissures in the dump platforms are commonplace and these act as conduits, transporting oxygen and water deep into the dump.

An alternative form of dump construction is the bottom-up dump, where waste is dumped in thin, horizontal lifts from the base of the dump upwards. Multiple selenium management advantages accrue from this methodology. The thin lifts promote a more homogenous, dense structure, retarding the entrance of free oxygen and water to the dump. An additional benefit rests in an idea currently under research - that such dumps can enhance selenium reduction through microbial control (Swanson et. al, 2010). The dump stability is virtually assured, thus eliminating dump failures, excessive settlement and fissure formation. Finally, bottom-up dumps facilitate progressive reclamation and vegetation of the dump face during mine operation, again reducing the ingress of precipitation and oxygen into the dump. A conceptual cap design for a bottom-up is illustrated in Figure 5.

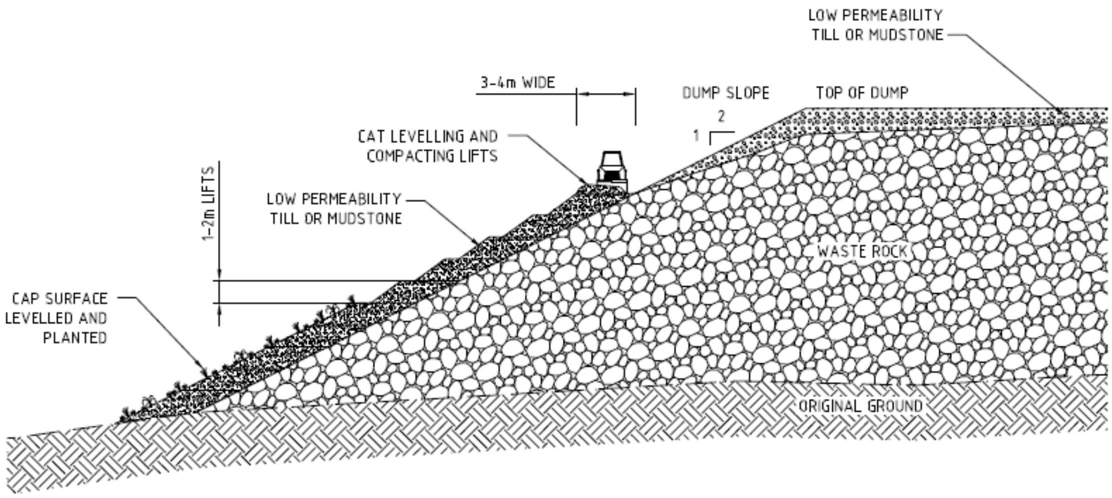

Figure 5 Low Permeability Bottom-UpCap

The downside to the bottom-up dump, at least in the context of western Canadian mountain-top mining, is that they are more expensive than the conventional top-down angle of repose dump, requiring extra haul distances to transport the waste down to the dump platform in trucks or conveyors.

3.3 *The Ideal Dump Design*

3.3.1 *Design Considerations*

Given the various options described above, one can envision the ideal ex-pit waste rock dump from a selenium management point of view. It is located at, or at close as practical, to the head of a watershed. This reduces the amount of surface and ground water that could potentially enter the dump. Any surface water flows above the dump are picked up by diversion ditches and routed around the dump. The dump itself is constructed in bottom-up fashion out of a series of thin lifts (5 - 15 meters thick), with the exposed dump face having a gentle gradient, 2 or 3 horizontal to 1 vertical. This allows for the dump face to be progressively reclaimed as placement proceeds, with an engineered, vegetated cover. Precipitation and snow melt on the surface of the dump is routed into engineered gullies and channels, helping to remove it from the surface of the dump before it can pool and soak into the waste rock. The downstream toe of the dump incorporates a low-permeability clay core, forming a dyke to backup dump water inside the waste rock. A grout cutoff wall or curtain may be present beneath. The dyke includes an engineered outlet at a prescribed elevation, producing sufficient residency time to allow for biologic selenium reduction for any remaining, selenium impacted water flowing out of the dump.

3.3.2 *Sustainability Considerations*

From a triple bottom line perspective, the "ideal dump design" does not account for capital or operating expenses, state of knowledge re. potential and probable selenium reduction efficacy, research and development and construction time horizons or the potential environmental and social benefits and costs that might accompany it. Indeed, although posited in this paper as "ideal" a series of operational, economic and physical conditions may be required (e.g., haul distances and grade financially favor bottom up, there is sufficient spoil area to accommodate the spoil angles, site-wide water balances are known and hydrological conditions are well understood etc.).

That said, the "ideal dump design" could become an effective component of a portfolio of selenium management solutions that are required to stabilize and reverse the selenium loading trends observed in the watersheds affected by western Canadian metallurgical coal operations.

As currently available technologies become increasingly marginally ineffective and inefficient the "ideal" dump design alongside the other selenium management options noted above will need to be deployed to ensure that the affected watersheds provide environmental, social and economic value (referred to as fishable, drinkable and swimmable by the stakeholders consulted by the SAPSM).

3.4 *Concluding Perspective*

Future practices for mine waste disposal must take into account the release of what were formerly considered trace or even in former times non-measurable mineral constituents on the aquatic environment. Measures adopted for controlling constituent releases, including those described in this presentation, must be effective – not only during the operational life of the mine, but for decades or even centuries thereafter.

A set of possible modifications to the traditional manner of waste disposal at mountainous mine sites in western Canada has been described in this paper. In determining which measures merit the most attention for application, both short term capital and operational costs must be taken into account and compared with forecast long term costs and possible savings in post operational maintenance of water treatment facilities, as well as the ultimate sustainability of the potential interventions.

4 REFERENCES

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