DISCUSSION OF REGULATORY COMPLIANCE STRATEGIES TO ACHIEVE REceiving WATER QUALITY STANDARDS USING SELENIUM REDUCTION/REMOVAL OPTIONS

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ABSTRACT

Achieving local regulatory Receiving Water Quality Standards for selenium [Se] (e.g. 2 μg/L in BC, Canada) at some proposed and existing mines requires Selenium Management Plans (SMPs) that demonstrate convincing and effective environmental protection to regulators. This impacts: (a) new mines proceeding through an Environmental Assessment (EA) process with predicted elevated selenium (Se) discharges; and (b) for existing mines with elevated Se discharges, to demonstrate future downstream Se-compliance needed to avoid regulatory permit non-compliance penalties.

Unlike traditional heavy metal solubility equilibrium/precipitation, Se is usually controlled by redox conditions, pH, biological activity, and adsorption/desorption reactions. The geochemical characteristics of Se and its relationship with co-contaminants, such as nitrate, should guide approaches for developing effective SMPs. Approaches should consider augmenting mine site active selenium discharge treatments with a combination of: (1) indirect Se treatment strategies that will reduce active water treatment hydraulic retention times by removing co-contaminants; and (2) release prevention, handling seleniferous overburden to reduce weathering and runoff volumes requiring direct Se water treatment. It is expected that these types of mining practices can reduce Se environmental loads, as compared to past, historical mining operations. This analysis should be presented in the EA and permitting processes.

Bench- and pilot-scale testing of selenium treatment technologies help put into perspective the importance of site-specific influences on implementation of economical and effective selenium management approaches and treatments, and provides a robust basis for a SMP to be developed for the EA and permitting processes. Preventative or reduction procedures, in situ treatment, semi-passive treatments, and active selenium water treatment technologies to remove selenium to below 5 μg/L (or the local regulatory discharge standard) are discussed in terms of compliance approaches that will maximize the amount of clean water returned to watersheds and reduce or eliminate non-compliance.

KEY WORDS: biological, reverse osmosis, ion exchange, electro-biochemical, metal, nitrate, in situ.
INTRODUCTION

Extraction and processing of minerals, metals, and fossil fuels can release various metals and inorganic contaminants, including selenium, arsenic, sulfates, and nitrates into wastewaters that can be costly and difficult to treat to levels meeting current mine effluent permit requirements, and most importantly, compliance with the local downstream water course quality standards. This paper focuses on:

- Information needed for British Columbia (BC)/Canadian Environmental Assessments (EA) and the BC permitting processes that delineate current mining companies challenges to deal with proposed and existing mines with current/predicted elevated selenium discharge/receiving water concentrations.
- A brief review of selected active treatment technologies for selenium removal - end of pipe treatment technologies and their relative effectiveness.
- Potential source treatment approaches that could significantly lower site active treatment CAPEX/OPEX costs.
- Potential peak hydraulic load reduction to treatment facilities using existing minesite sediment ponds.

Selenium Overview

Selenium is a naturally occurring element present in rocks and minerals, including the waste rock of coal and metal mines throughout western North America. Selenium is periodically related to sulfur, and like sulfur, positively charged selenium forms soluble oxyanions (Ehrlich, 1990). It is an essential nutrient, meaning trace amounts are necessary for cellular function in many organisms, including all animals; however, it can be harmful if present at elevated concentrations. Selenium importance is due to its contamination of aquatic environments, where it accumulates through the food chain to cause reproductive defects.

The chemical characteristics of Se are dominated by the fact that it readily changes oxidation state or chemical form through chemical or biological reactions that are common in the environment. Therefore, rather than solubility equilibrium controlling Se mobility, it is usually controlled by redox conditions, pH, biological activity, and adsorption/desorption reactions (Ehrlich, 1990). Selenium enters the aquatic environment as a result of both natural and anthropogenic activities, including: natural weathering, agricultural drainage, combustion of fossil fuels, and various mining and mineral processing activities. Mining can accelerate the release of Se to the environment by exposing waste rock to air and water.

Selenium can occur in five different states in aquatic environments, sometimes simultaneously and inorganic selenium most commonly occurs in four oxidation states (\(\text{SeO}_4^{2-}\), \(\text{SeO}_3^{2-}\), \(\text{Se}^{0}\), & \(\text{Se}^{2-}\)). Well-aerated, alkaline surface waters contain the majority of selenium as selenate. Negative and zero valences are associated with organic and elemental selenium while positive valences are associated with mineralogy and aqueous systems, with selenate being more mobile than selenite. Selenite [Se (IV)] is the most toxic and bioavailable inorganic form and is associated with anthropogenic sources. Selenate [Se (VI)] is less toxic and less bioavailable than selenite and is associated with natural sources. Elemental selenium [Se (0)] is often found in sediments, generally as a result of microbial reduction. Organic
selenium includes selenoamino acids and methylated selenides (Ehrlich, 1990). Methylated selenium compounds may also enter the atmosphere (Ranjard, Nazaret, and Cournoyer, 2003).

Regulatory overview
Figure 1 depicts the BC regulatory and federal setting and how Selenium Management Plans (SMPs) may be used to focus the BC Water Quality Guidelines (BCWQG) requirements for regulators and mining companies. The Environmental Management Act (EMA) and Ministry of Environment (MOE) requirements for mine effluent permitting forms the basis for MOE-related information requirements in the Environmental Assessment (EA), initial effluent permit application and ongoing permitting for the mine construction, operation, closure, and post-closure phases. The Metal Mining Effluent Regulation (MMER) and the Canadian Environmental Assessment Act (CEAA) are the primary federal legislation to be considered during the EA/permitting processes. The MMER is currently under review and may include end-of-pipe standards for selenium (Environment Canada, 2013) and Environment Canada is currently recommending tougher pollution rules at Canadian mines (EC, 2013). Issuance of a BC EA Certificate and associated Certified Project Description and Table of Conditions represents both a federal and provincial license to proceed to the BC permitting phase. The federal government may, however, refer a project to a Panel Hearing, which then recommends approval/denial of a mine to proceed into production, with the federal level of government making the final (political) decision. Mine effluent permits issued in British Columbia, unlike most other mine-related permits, are appealable by the public and the permittee, and this may also delay/prevent the construction of a new mine. Selenium mitigation aspects of mine effluent permitting should be based on: (a) a robust scientific strategy, (b) the application of Best Achievable Technology (BAT) (BCMOE, 2012), and (c) well defined source treatment mitigation strategies to demonstrate how discharge and receiving water quality will be achieved.

SELENIUM MANAGEMENT PLANS

SMP overview
The goal of the SMP is to show how a proposed/existing mining operation will meet its company’s commitment to stabilize and/or reverse selenium trends in receiving waters: receiving water selenium concentration should be maintained at below 2 µg/L, the BCWQG for the protection of aquatic life (or maintained at Se and other parameter concentrations specified in a mine effluent permit issued under the EMA). The SMP should also address other substances affecting selenium removal processes: co-contaminants, such as arsenic, sulphate, nitrate and cadmium and methods/approaches to meet release goals, which will be environmentally protective of receiving waters. It is important to address the co-contaminants associated with selenium because they can potentially have a significant impact on Se removal and CAPEX/OPEX of selenium control approaches. The SMP and the Receiving Water Compliance Management Plan will be updated regularly to account for changes to mine planning, operational experience with different selenium management measures, and results from relevant applied research and development (R&D). The SMP will be developed with the MOE who decides on the final acceptability of the SMP (and other associated effluent permit requirements) based on MOE’s authority and responsibilities under the EMA, which at times may entail a mining company complying with regulatory directives such as a Pollution Abatement Order, a Pollution Prevention Order and an Order of
the Minister of Environment, all issued in response to existing/potential pollution and/or serious noncompliance. Some of the typical items addressed in a SMP are considered to be:

- Simulating effects of historical and future mine operations and associated mitigation on in-stream selenium levels in all watersheds.
- Predicting future selenium loadings and concentrations with and without mitigation.
- Development of operation-specific plans for each mining operation.
- Integrating the operation-specific plans into the mine site SMP and adjusting site plans to optimize performance and effectiveness (adaptive management).
- Consider mixing of mine seeps and other waters to achieve point of discharge goals.
- Define how often the plan will be updated and any triggers that will require more or less frequent updates:
  - Changes in mine planning.
  - Input from operational experience with different Se management measures.
  - Results from applied R&D efforts.
  - Monitoring results and updates to existing water quality models or predictions.

Figure 1 presents an overview of the current regulatory processes and includes the use of a SMP to demonstrate a compliance strategy with the BCWQG for the EA and effluent permitting phases. Figure 1

**BC MINE PERMITTING REQUIREMENTS – Se Management**

![Flowchart Diagram](image)

Figure 1. Steps to address the SMP and Water Compliance Management Plan, EA and permitting phases.

will, of course, need to be updated based any new government initiatives, for example, after the MMER is revised (which is tentatively proposed for the 4th quarter of 2013) and after the experience with the
calculating the allowable Se discharge concentration

The following example is for a discharge from a mine site into the adjacent watercourse; effluent permit requirements and the definition of “pollution” requires the downstream BCWQG concentration \( C_{wqg} \) mg/L not to be exceeded. The mass balance calculation connecting the end of pipe concentration ( \( C \) mg/L) and \( C_{wqg} \) mg/L is: 

\[
C \leq (Q+1)C_{wqg} - QC_{us}
\]

where \( C_{us} \) = the upstream concentration for the parameter, and \( Q \) is the dilution ratio of the upstream flow to the discharge flow. If the upstream concentration is very low, this simplifies to 

\[
C \leq (Q+1)C_{wqg}.
\]

The major receiving water impact assessment challenge is clearly related to the magnitude of the BCWQG concentrations \( C_{wqg} \) and dilution, \( Q \). For selenium, if 

\[
C \leq (Q+1)(0.002) - QC_{us} \text{ in mg/L,}
\]

then in general terms, this simple approach will demonstrate how a mine site discharge, \( C \) mg/L, is consistent with the intent of the EMA in not causing “pollution” relative to the BCWQG selenium (aquatic) concentration standard (i.e. the BCWQG selenium water column standard of 0.002 mg/L).

Defining the Se-treatment challenge

Using this approach also acts as an indicator for the level of selenium mitigation required at a mine site. In practice, the discharge concentration(s) may represent many inputs (runoff, tailings pond discharge, groundwater, etc.). The example provided is for the purpose of examining proposed mines; for existing mines, the results of the sampling plan in the effluent permit will provide an indication for selenium treatment needs. Up-trending selenium concentrations at an established mine site which necessitates selenium mitigation may also signify the Acid Rock Drainage/Metal Leaching (ARD/ML) selenium predictions have limitations in prediction capability (Kuipers, and Maest, 2006). This limitation is frequently not captured in the risk assessment approach in the EA process and the effluent permit application phases.

Mining sites with naturally elevated Se, may result in \( C \) (the mine site selenium discharge concentration) calculating a negative value: e.g. 

\[
(Q+1)(0.002) - Q(0.003) = (0.002 - 0.001Q) \text{ mg/L,}
\]

when the upstream concentration is 0.003 mg/L (and higher) and dilutions are higher than 2.0. Clearly, if the upstream selenium is higher than the BCWQG selenium concentration (i.e. 0.002 mg/L), a novel regulatory approach will be required, such as a site specific water quality objective. For sites with elevated upstream Se, regulators may choose some of the following options:

1. Allow discharge at the \( C_{wqg} = 0.002 \) mg/L.
2. Allow discharge at the upstream elevated Se concentration, \( C_{us} \) mg/L.
3. Develop a site specific water quality objective (refer to MOE. 2013).
4. Develop a site performance objective (refer to MOE, 2011).
5. Develop a site specific fish tissue-based objective.
6. Develop a strategy to (a) import water for dilution, or (b) export the discharge to a watercourse that can accommodate the selenium loading in the discharge.
7. Define a downstream compliance point where there is sufficient dilution to achieve the BCWQG (or achieve a site specific objective concentration developed in 3).
8. Refuse issuance of an EMA effluent permit.
10. Negotiate a compensation package (typically this is for loss of physical fish habitat, rather than loss of habitat based on chemical degradation).

Options 1 to 8 are appealable under the EMA by the permittee and the public. The MMER requirements and the EMA effluent permit sampling requirement typically both require an environmental effects sampling plan, designed to determine the effect of a minesite discharge on the receiving stream.

SELENIUM TREATMENT OPTIONS

More recent reviews of selenium removal technologies indicate that, in general, the preferred method for selenium removal in mining waters is trending toward biological treatment (NAMC, 2010). Since conventional technologies are well covered in review documents referenced below (NAMC, 2013), this document presents only a brief overview of conventional selenium treatment methods and focuses on a new Electro-Biochemical Reactor (EBR) technology that has been demonstrated at bench- and pilot-scale to produce low effluent selenium concentrations (less than 2 µg/L) from influents ranging from less than 50 µg/L to over 3500 µg/L without excessive biomass production and without the extensive back flushing required by conventional biotreatment systems (Adams, Peoples, and Opara, 2012).

As versatile as biological treatments may seem, fundamental considerations for successful active selenium biological treatment involve several steps starting with site characterization and monitoring that can include bio-assessment/biotreatability testing. Bench- and pilot-testing will help answer which selenium removal treatment or combination of treatments will work best at a specific site and will reliably produce effluent selenium concentrations that meet receiving water criteria. Other questions will also be answered, such as: how fast it will work, what volumes/flow rates can be processed, and how much it will cost.

Active treatment
Selenium is difficult to remove to levels that meet current discharge criteria and many methods that are effective at small scale are not practical for larger scale applications. The major water quality factors affecting the removal of selenium are pH and Eh of feed waters; co-contaminant concentrations, e.g., nitrate and sulphate; and alkalinity (Ehrlich, 1990; Mittal, 2011). Core selenium active treatment technologies include physical, chemical and biological processes that exclude or reduce selenium.

Physical treatments are usually membrane based methods, such as Reverse Osmosis (RO) and Ultra Filtration (UF), which use filtration to concentrate selenium in a reject stream and produce low-contaminant concentration permeate stream; the reject stream must then be treated. Chemical treatments include Ion Exchange (IX) - chemical exchange, Adsorption and Co-precipitation, and Zero Valent Iron (ZVI) - chemical oxidation/reduction methods. Biological treatments use microorganism to reduce selenium and are separated into active and passive systems. All selenium removal methods have benefits and disadvantages and produce various effluent selenium concentrations that are method and water chemistry dependent.
Conventional biological treatments
Selenium can be used as an electron acceptor by microorganisms transforming it to more reduced states, thus removing or stabilizing it. Biotreatment and bioremediation effectiveness is dependent on a number of parameters including microbial populations, co-contaminants, pH, redox, and nutrients. In order to understand microbial metal reductions, it is important to understand the redox and biochemistry chemistry behind these transformations. However, the biochemistry for most metal transforming systems has yet to be completely characterized. It appears, in some natural and active treatment systems that selenium transformation is coupled with the cytochrome system and that specific metal-active enzymes can also play a role in selenium reduction.

Conventional biological treatment systems must be periodically backwashed to remove entrained gas (when larger concentrations of nitrate are present in the influent waters) and also require a liquid/solid separation process to remove large amounts of sloughed off selenium containing biomass in the effluents. With lower selenium influent concentrations, 50 µg/L or less, often clarifiers and/or media filters are needed to meet a 5 µg/L total selenium limit. Additionally, with higher selenium concentrations, greater than 50 µg/L a higher level of treatment using membranes may be required to meet discharge requirements of 5 µg/L, thereby adding considerable cost to treatment (NAMC, 2010; NAMC, 2013).

In these reviews, and others, nutrient sources used included molasses, phosphate, micro-Cg carbon, and a proprietary nutrient blend. All systems were examined at higher and lower temperatures. In pilot-scale testing, bioreactor temperatures ranged from ~17 ºC to 5 ºC with ~ 2.5 months of testing at an average of ~10 ºC and ~3 weeks of testing at an average of ~7 ºC (NAMC. 2010; NAMC. 2013; Golder Associates. 2009; Mittal, 2011; Moore, and Mahmoudkhani, 2011). The NAMC reports compared (1) Fluidized Bed Reactor (FBR), (2) Advanced Biological Metals Removal Process (ABMet®), (3) Immobilized Cell Bioreactor (ICB™), and (4) Coarse Coal Reject Bioreactor (CCRB). Comparative Se treatments were evaluated to evaluate performance and to generate data that can be used for conceptual alternatives evaluation.

A moving bed biological reactor (MBBR) was also piloted to demonstrate removal of residual organic carbon from the FBR effluent, which would also be applicable to polish the effluent from some other biological Se treatment technologies. The primary objective of the pilot tests was to meet the target total Se concentrations in the treated final effluent of less than 20 µg/L and the filtered Se of less than 10 µg/L from the core anoxic/anaerobic Se treatment technologies. Tertiary treatment will generally be required to meet both the selenium and other conventional surface water discharge criteria of dissolved oxygen (DO), total suspended solids (TSS), biochemical oxygen demand (BOD), phosphorus, nitrogen, temperature, pH, etc. (NAMC, 2010; NAMC, 2013).

Electro-Biochemical Reactor (EBR) technology
The issues concerning conventional biological treatments addressed in the NAMC reports have, to a great extent, been resolved with a new Electro-Biochemical Reactor (EBR) process. The EBR nitrate, selenium and other metal removal system produces almost no excess biomass. This eliminates extensive system
back flushing and expensive post-treatment requirements to remove excess biomass associated
conventional biological treatment systems (Adams, Peoples, and Opara, 2012).

INOTEC, through the University of Utah, developed a patented new concept for water treatment that has
direct application to the mining sector. The Electro-Biochemical Reactor (EBR) technology is especially
well suited for the removal of metals, in particular selenium, and inorganic contaminants, such as nitrate
and sulphate, which are difficult to remove to the BCWQG concentrations for protection of aquatic life.
Selenium removal to the BCWQG concentration using conventional biological or chemical treatment
methods has not been convincingly demonstrated. (Golder Associates. 2009; McCloskey, Twidwell,
Park, and Fallon, 2008; Moore, and Mahmoudkhani, 2011).

All biological and chemical metal and inorganic reduction/removal methods are based on redox reactions.
Electrons are needed for contaminant transformations, and conventional treatments rely on chemicals and
nutrients to provide these electrons. The EBR technology reduces the amount of chemicals needed by
directly supplying excess electrons to the reactor and microbes, using a low applied voltage.

EBR systems overcome conventional biotreatment issues and have been able to demonstrate selenium
removal to the BCWQG concentration using pilot-scale tests. The EBR system provides electrons
directly to the bioreactor and microbes, using a low applied voltage across the reactor cell (Adams, D.J.,
Peoples, M., and Opara, A). In most cases, 1 to 3 volts (1 µA provides $1.6 \times 10^{15}$ electrons per second) is
all that is required for optimal EBR performance. These electrons replace the electrons normally supplied
by excess nutrients and chemicals, resulting in considerable savings and additional benefits. The directly
supplied electrons are readily available for microbial growth and contaminant removal, resulting in better
performance in less time and space and with greater efficiency (Adams, Peoples, and Opara, 2012;
Naggar, and Finke, 2013; and Lovely, 2012). The provided electrons result in a more controllable,
economical, and robust system in comparison to past generations of conventional biological treatment
systems. EBR pilot-scale tests have been completed on a number of coal and metal mine wastewaters and
all have been able to demonstrate selenium removal to the BCWQG concentration (i.e. <0.002 mg/L).

Figure 2 shows results of a pilot test of a BC coal mine wastewater. The EBR pilot system removed
selenium and nitrate-N to below discharge criteria. Selenium was removed from influent values averaging
105 µg/L to an average 0.3 µg/L in the system effluent. Selenium discharge goal (10 µg/L) was met
within the first 4 hours of the EBR treatment. Nitrate-N was present in the wastewater at an average
concentration of 50 mg/L and was reduced to below 0.1 mg/L in the system effluent, exceeding the
discharge goal of 3 mg/L. Influent temperature varied between 2-16 ºC and EBR temperatures averaged
between a high range of ~14 ºC and a low temperature of ~3.5 ºC and had little effect on EBR
performance.
Figure 2. 2012 EBR pilot-scale test - removal of total and dissolved Se from BC coal mine waters.

Figure 3 shows results from a pilot-scale test of wastewaters from a base metal mine in northern Canada using HRT of less than six hours at temperatures ranging from 23 ºC to 4 ºC. Nutrient amounts used conventional agricultural grade molasses at concentrations of 0.2 mg/L.

2013 EBR bench testing of gold mine wastewaters has been conducted for removal of nitrate and sulfate. This mining water has wastewaters containing nitrate at >200 mg/L and sulfate averaging slightly greater than 900 mg/L with a discharge limit of 10 mg/L nitrate and 200 mg/L sulfate. Initial EBR testing results demonstrated both nitrate and sulfate removal to below discharge criteria at ~21 ºC using an 8 hour HRT. Less than 1 hour was required for complete nitrate removal and an 8 hour HRT removed sulfate to below 50 mg/L as shown in Figure 4.
Based on NAMC reports on conventional biotreatment methods and EBR pilot test data, Figure 5 graphically depicts the dilution of effluent waters required to achieve 2 µg/L selenium in downstream waters.

**Figure 4. EBR bench scale sulfate removal from gold mine waters.**

**Figure 5. Effluent dilution and selenium removal options, which will achieve the BCWQG (Using referenced data).**

\[
C \text{ mg/L} \leq (Q+1)(0.002)
\]

*NAMC 2013. **See Reference section

**Source in situ biotreatment**

BC regulatory aspects of in situ source biotreatment may be incorporated into the EA Application and the effluent permitting Technical Assessment Report by including this approach into a SMP. For in situ
source biotreatment, a determination must be made as to whether site amendments of nutrients, oxygen, and/or microbes can result in transformation or stabilization of targeted contaminants under the environmental conditions present. Treatment success is based on following a program consisting of site and water chemistry assessments, bench-scale proof of concept validations, pilot-scale testing to establish full-scale requirements, and full-scale implementation. This testing should also define the key factors and parameters to monitor during remediation, e.g., microbial populations, contaminant and nutrient concentrations, and site conditions of pH, redox, dissolved oxygen, BOD, etc. (ISB Team, Adams, Farris, and Vlassopoulos, 2004). In situ treatment can:

- Produce almost immediate and potentially long-term results.
- Be used in a wide range of climates and mining environments.
- Have minimal construction and maintenance costs.
- Treat large volumes of mining influenced waters (MIW) and associated source materials.
- Be applied to many mining environments with appropriate configuration and application modifications.

The basic premise of bioremediation or biotreatment is to accelerate microbial activity using nutrients (carbon, phosphorus, nitrogen, etc.) to create conditions conducive to biotransformation of target chemicals or contaminants. In general, in situ biotreatments are designed to modify the environmental conditions, typically through oxidation/reduction manipulation, to create an environment that stimulates the growth of indigenous and added microbes with the subsequent acceleration of microbial activity and degradation of target contaminants.

Since conditions are manipulated by engineered means, the ability to move and mix liquids in the treatment environments is a major consideration. Redox processes proceed in a stepwise fashion, reducing contaminants first that have higher energy yields, then nitrates must usually be reduced significantly before selenium can be reduced. By reducing nitrate levels in source waters before using an active process to remove selenium, the CAPEX/OPEX costs for active selenium biotreatments can be significantly reduced. There is also the potential of lowering selenium levels, reducing some selenium in the waste rock pads to a stable elemental Se⁰, thereby also reducing the active selenium removal costs.

CONCLUSIONS

1. The comparison of predicted and actual selenium water quality at minesites suggests that it is beneficial to select, when feasible, selenium removal technology which has the capability to remove selenium from mine effluents which result in the BCWQG concentration. This is consistent with MOE’s BAT policy (BCMOE, 2012) – i.e. not just meeting discharge/BCWQG but minimizing discharge contaminants when technology is available to do so.

2. The calculated discharge selenium concentration, \( C \text{ mg/L} = (Q+1)(0.002) \), assuming no upstream selenium being present, should guide the selenium treatment technology chosen. The Q value will be selected for the low flow conditions, in accordance with regulatory guidance (i.e. based on
assessments by the MOE Environmental Impact Assessment Biologist and Director/delegate identified under the EMA legislation. If a flow-paced discharge system is designed, using retention capacity in all the ponds and any other retention systems at the mine site, this may advantageously reduce the peak hydraulic loading to the selenium treatment plant and will modify the $Q$ in $(Q+1)(0.002)$ and aid in compliance with the BCWQG requirements.

3. Bench- and pilot-scale testing of various selenium treatments is more applicable to existing mines, while the challenge to apply bench and pilot tests for proposed mines will require the synthesis of test treatment fluids. These fluids could possibly be obtained by “heap leaching” appropriate amounts of site rock samples and collecting and recycling leach fluid to simulate the passage of precipitation (migrating downward) onto “actual” waste rock dumps. This procedure could be repeated for the various site waste rock types. Selection of selenium treatment is exacerbated for proposed mines, since the synthesized “waste solution” should include the products from blasting, and the treated synthesized “waste solution” should represent actual mine runoff effluent to identify the need for additional treatment (to remove selenium treatment residual contaminates).

4. The feed to selenium treatment facilities will require, either an independent TSS removal system, or the operation of settling ponds to produce the lower MMER TSS (15 mg/L TSS) requirement. This will present an additional challenge in operating the sediment ponds, and implies the use of flocculants in order to maintain consistently lower TSS quality into the selenium treatment system. It is noted that the BC sediment pond design guidance (BCMOE. 2002) requires the pond area to be such that the plus 10 micron particles are captured for the 10-year, 24 hour runoff flow into the pond, and that increased pond sizing becomes uneconomic and impractical without the use of flocculants. Also, there is a lower limit of fine particle capture in a pond based on Brownian motion phenomena, which is approximately 2 microns for a particle with a specific gravity of approximately 2.7. The SMP should reference a Sediment Pond Operation MP to demonstrate how TSS into the selenium treatment plant will be controlled as needed.

5. The application of reverse osmosis (RO), while shown to generate some of the lowest end-of-pipe selenium concentrations, is not regarded as a complete selenium treatment system, as the resulting brine stream (which may be 10% to 25% of the input flow volume) contains the “removed” contaminants. The brine stream may have elevated selenium and other parameter concentrations which may prevent the application of biological treatments, without adaptation. Additional (i.e. repeated) RO application(s) may reduce the contaminated stream volume sufficiently and allow the viable application of chemical/ion exchange/etc. treatment methods to remove the final brine selenium (and other contaminants), but requires appropriate testing to demonstrate this suggestion (Maneval, Klein, and Sinkovic, 1985).

6. Evaluation of the chosen selenium treatment must take into account the influent selenium concentration and post-treatment contaminant removal (e.g. removal of elemental colloidal selenium) and, biomass which may adversely affect the selenium removal efficiency.
7. Evaluation of selenium biotreatments must include evaluation of long term sludge (biosolids) storage.

REFERENCES


