ABSTRACT

British Columbia (BC) mining companies and federal/provincial regulators have the most stringent international minesite total suspended solids (TSS) standard to contend with. Addressing the generation, mitigation and compliance of sediment release from existing and proposed minesites means end-of-pipe and runoff must not exceed a TSS standard of 30 mg/L for a grab sample (and 15 mg/L for a monthly average) – this is a requirement of the Metal Mining Effluent Regulation (MMER) under the Fisheries Act. Add to this requirement in BC: minesite discharges must not cause exceedence of the stringent BC Water Quality Guidelines (BCWQG), exceedence of which may result in pollution, as defined in the BC Environmental Management Act (EMA). A frequent use of floculants to achieve compliance with the MMER, a BC effluent permit, and the BCWQG TSS standards, may result in floculant-induced toxicity, which is a contravention of the MMER, the EMA, and a BC mine effluent permit.

Achieving compliance with these TSS requirements requires the application of a Best Achievable Technology (BAT). In 2002, the MMER was enacted and the Ministry of Environment (MOE) developed their Guidance for Assessing the Design, Size and Operation of Sedimentation Ponds Used in Mining. An essential part of designing for federal/provincial sediment release compliance for proposed mines is the preliminary sampling/testing of minesite soils and determining the need for a floculant addition and control system. Sampling and testing is required for: (a) prediction of sediment pond discharge and runoff quality, and (b) execution of a well-designed Sediment Pond Management Plan (SPMP) and an Erosion and Sediment Control Plan (ESCP). Failure to follow a plan which uses a predictive methodology, using site specific soils and settling testing, leaves the issue of legislative compliance to chance. If existing mines are not in compliance, it may often be the result of not performing the recommended testing and planning.

The MMER is currently under review to include coal mines, Al, Fe, ammonia, Se, and may potentially generate additional onerous requirements as Environment Canada (EC) recently asked for more stringent government rules to prevent water pollution from mines. This paper will comment on and provide conclusions related to the effectiveness of the following in predicting and preventing water pollution caused by TSS: (1) BC effluent permitting, (2) the BC sediment pond design approach, (3) proposed MOE guidance on designing erosion and sediment control plans, (4) the BC TSS/turbidity Water Quality Guidelines, (5) the MMER, and (6) other applicable prediction, design and operating strategies.

KEYWORDS: sediment, management plans, effluent permits, MMER and compliance
INTRODUCTION

Mining activities disturb large areas of naturally vegetated land during the construction and operational phases, and this is required to be reversed by revegetation efforts during the closure phase to provide a permanent erosion control solution. The construction and operational phases rely primarily on directing runoff into sediment ponds, since the generation of suspended solids in runoff proceeds at soil erosion rates which may increase orders of magnitude above “natural” erosion rates in terms of “soil loss”/”sediment yield”. Erosion control efforts alone frequently results in inadequate control of soil loss during rainfall events when large sloping areas are disturbed: rapid site grubbing, scalping, soil removal and surface activity using large equipment often leaves insufficient time to allow vegetation to take hold and install sufficient and secure best management practices. Erosion control BMPs may fail under the heavy rain and runoff flows, particularly at mine sites which typically disturb large areas of sloping land; all this inevitably results in a sediment yield, or entry of sediment into the watercourse which would significantly exceed both permitted discharge quality, cause exceedence of BC Water Quality Guidelines (BCWQG) and the MMER requirements for TSS (and exceed turbidity requirements for the BCWQG).

SEDIMENT PONDS VS. EROSION CONTROL

Reliance solely on erosion and sediment control techniques (i.e. relying on an ESCP) vs. capturing minesite runoff in a large sediment pond (i.e. relying on a SPMP) is contrary to the Ministry of Environment’s policy, as indicated in existing minesite effluent permits, and the MOESPG. The BC Environmental Assessment (EA) Application Information Requirements (the AIR) frequently does not require (a) an ESCP, (b) a SPMP, and (c) the information required in the MOESPG. Also, effluent permit application Technical Assessment Reports frequently do not contain the information required in the MOESPG, except for the methodology to size sediment ponds. The erosion control vs. sediment pond issue should be addressed by applying the currently available science and design rationales. The following approaches are currently being used:

1. Erosion control specialists providing minesite ESCPs do not typically deal with, or predict the need for, (large) sediment ponds, and rely on such guidance documents as (a) National Guide to Erosion and Sediment Control on Roadway Projects, referred to as the "TAC Guide", and (b) Environmental Guide for Erosion and Sediment Control During Construction of Highway Projects, Ministry of Transportation, Ontario. These guidance documents do not recommend the use of sediment ponds because they are for linear developments. This erosion control approach utilizes an assessment methodology based on the application of BMPs (Best Management Practices) and a risk assessment designed for highways and roads, which are not regulated (permited) under the EMA, and therefore do not have to comply with TSS runoff and receiving water standards.

2. Reliance on the erosion control approach is appropriate for portions of a minesite where there is no physical ability (steep slopes) or space for sediment ponds. For such minesite locations, and particularly for roads on sloping terrain, with road runoff flowing into a creek, the ESCP is the
methodology of choice for effective environmental protection. For this situation, the ESCP should utilize recognized minesite road guidance methods to ensure the road will not be a significant sediment source, and the resulting road design should be demonstrated to be a low risk for causing future pollution. If the risk is high, then the mine planning should consider providing a road at a different, lower risk, location.

3. There are guidance documents which propose sediment ponds are the primary erosion and sediment control for minesites (e.g. EPA. 1976.) and minesite-dedicated guidance documents are recommended, as they are appropriate for disturbance of large, sloping mining areas.

4. There are tools available to predict soil loss at a minesite which will clearly guide the decision on erosion control vs. sediment ponds (RUSLE 1998).

5. The MOE has clearly stated the case for sediment ponds in a 2012 publication (Clark J.P., Gibson A., Rex J., Moody A, and Orban J. 2012).

6. For mine roads on sloping terrain, or mine roads in general, soil loss prediction may not be as useful as applying BMP road construction, maintenance, and an effective ESCP specifically for mine roads, when roads are potentially a significant sediment source, and this should apply to roads used by a mine along the access road (e.g. Forest Road Engineering Guidebook, 2002).

It is suggested that the application of erosion control and/or sediment ponds to minesites should be guided primarily by mine-related guidance documents which are better suited to the task of predicting/achieving the MMER TSS discharge standards. Highway/road related erosion control guidance documents, while providing valuable information on the various BMPs, etc., do not focus on, or use a methodology how to achieve the MMER discharge standards. ESCPs for mine sites should follow a methodology proposed by the MOE, or similar system (e.g. Erosion and Sediment Control – Surface Mining in the Eastern US, Volume 1 & 2. 1976.; and U.S. Department of the Interior Office of Surface Mining. 1982) which recommends sampling of minesite soils for which particle size analyses and settling tests are performed to provide a preferred scientific basis to guide protection of the environment related to TSS/turbidity and demonstrate (and predict compliance) with the MMER. The control of TSS from tailings ponds is typically not an issue, or challenge, because most mineral processing plants add sufficient lime (to optimize flotation recovery of values) which then provides potentially determining ions which lowers the Zeta Potential (ZP) of tailings pond particles below the critical ZP (which is approximately -10 mv) which then allows the van der Waals attractive force to cause particles to agglomerate and provide adequate settling and clarification (Slater, Clark and Kitchener, 1968).

**BC SEDIMENT RELEASE CONTROL STRATEGY**

Sediment ponds can provide a low risk technology to provide environmentally protective pollution control works, particularly for removing sediment from minesite runoff. BC effluent permits issued under the BC Environmental Management Act (EMA) rely on the use of sediment ponds as the primary sediment control. Sediment pond design and operation will benefit by having a dedicated sediment pond management plan (SPMP), which is currently not a requirement in BC mine effluent permits or in the BC mining industry. The need for erosion and sediment control plans at mine sites has been defined by MOE in a publication *Developing a Mine Erosion and Sedimentation Control Plan Guidance Document for Exploration, Construction, Operation and Closure* (Clark, Gibson, Rex, Moody and, Orban, 2012) and the ESCP and the SPMP should be developed at the EA phase. Locations on the minesite footprint where it is not feasible to construct sediment ponds require an ESCP, and linear development such as the mine
access road and hydro-line surface disturbances depend on ESCPs to restrict sediment release.

Sediment ponds can be designed and operated using BAT design and based on testing methods which will generally result in achieving the MMER discharge standards. Ponds will provide a robust and structurally resistant sediment control technology, with predictable outflow quality to the receiving stream. In BC there is a history of successful and effective environmental protection using ponds at mine sites. This effectiveness is supported by MMER annual audits, which indicate a high level of compliance (Environment Canada. 2010). Sediment ponds fit into the MOE definition of BAT (MOE BAT 2012); successful application of this BAT requires local soil sampling and specific testing prior to designing, constructing and operating sediment ponds so that the best achievable technology is based on a sound and proven scientific methodology. Simply constructing a pond sized in area for the 10-year, 24-hour runoff event provides no assurance that it will generate a discharge which meets 30 mg/L TSS, since the amount of sediment entering the pond (i.e. the soil loss at a given runoff rate) is very site specific and is a primary function of the particle size analyses of the upslope eroded soil. Also, the pond must be operated to meet the 30 mg/L TSS immediately there is a discharge, which allows no time frame to research flocculant application if the permitted discharge requirements and downstream quality requirements are exceeded and then installing a flocculant system. Selection of an effective flocculant(s) requires a significant amount of testing to scope out effective, but low toxicity flocculants.

REGULATORY ASPECTS OF SEDIMENT POND DISCHARGE QUALITY

The Federal and BC approaches to controlling minesite sediment differ significantly. Mine operators need to address these differing regulatory approaches at the EA, effluent permitting, construction and operational phases.

BC regulatory approach

BC adopted a 50 mg/L TSS requirement in mine effluent permits four decades ago for tailings pond discharges and for the past 25 years expanded this requirement to all discharges from a mine site, which includes runoff. This approach was initiated, influenced and developed (in chronological order) by the following:

1. BC mine effluent permits used 50 mg/L TSS starting about 1972.
2. In 1973, the British Columbia “Pollution Control Board approved the Pollution Control Objectives for the Mining, Smelting and Related Industries” (PCO) which recommended a 25 to 75 mg/L TSS discharge quality from tailings ponds. The PCO stated it was the government who should determine the applicable BAT to achieve the discharge levels recommended in the PCO. The PCO are of historical interest but no longer have any legal status.
3. A Sediment Pond Design Guide was written by Howie in 1980 and became MOE’s standard for designing sediment ponds.
5. The “Guidance for Assessing the Design, Size and Operation of Sedimentation Ponds Used in Mining” was issued by MOE in 2002.
6. The MMER, enacted in 2002, was developed under section 36 of the Fisheries Act to regulate the
deposit of mine tailings and other waste matter produced during mining operations into natural fish bearing waters. These regulations, administered by Environment Canada, are for both new and existing mines. They are purported by Environment Canada’s internet site to be among the most comprehensive and stringent national standards for mining effluents in the world.


8. The MMER is currently under review to include coal mines and may potentially generate more onerous requirements as Environment Canada asked for more stringent government rules to prevent water pollution from mines June 13, 2013. The proposed changes are in the 10-Year Review of Metal Mining Effluent Regulations Discussion Paper (Environment Canada 2012).

Environmental Assessment Applications and effluent permit applications frequently do not follow all the requirements of the 2002 Guidance for Assessing the Design, Size and Operation of Sedimentation Ponds Used In Mining: sediment ponds are frequently sized to capture plus 10 micron in the runoff particles at the 10-year rainfall event, but without any testing to predict the need for flocculants, or measure soil particle size and perform settling tests on upslope soil samples. Failure to follow a plan which uses a predictive methodology leaves the issue of discharge quality to chance with the likelihood of noncompliance penalties, legal expenses, resulting in pollution and elevated costs to correct the problem.

BC mine effluent permits issued under the Environmental Management Act define discharge limits and the allowable TSS/turbidity impact on receiving watercourses downstream of a minesite in accordance with the BC Water Quality Guidelines (BCWQG) for TSS/turbidity.

Federal approach

While Environment Canada does not provide a BAT guideline for achieving their onerous TSS requirement, they acknowledge the BC Ministry of Environment procedures and direction on sediment pond design (in the Environmental Code of Practice for Metal Mines). The MMER requires the 30 mg/L TSS on a grab sample to be met for all rainfall events and runoff flow conditions, unlike the BC approach, which converts the discharge quality requirement of 30 mg/L/50 mg/L TSS to a receiving water quality requirement when runoff flow is above the 10-year 24-hour rainfall event.

Environment Canada conduct annual MMER compliance performance summaries on effluent, and as an example for 2010 the overall compliance rates for:

1. TSS was 95.6%;
2. passing the 96 Hour 96 Hour LC₅₀, Rainbow Trout, was 97.3%; and
3. passing the Daphnia magna test was 90.9%.

The number 2 compliance includes any flocculant-related toxicity, while the more sensitive Daphnia magna testing is an indication of low sublethal toxicity for fish.

REGULATORY ASPECTS OF RUNOFF DISCHARGE QUALITY

The MMER applies to runoff from a mine site and BC mine effluent permits have applied to runoff since the last 25 years and apply the 30 mg/L TSS discharge quality for metal mines. The water management
plan typically includes interception of runoff above the mine site footprint in an effort to convey non- 
contact water around, or through, the minesite. Diverted water is also required to meet the MMER TSS 
discharge quality requirements and the BC downstream BCWQG for TSS and Turbidity. The conveyance 
method may become a sediment source, emphasizing the importance for the design of the water 
conveyance structures to be based on best management practice guidance. These structures should be 
designed, maintained and monitored to determine ongoing effectiveness, and eliminating diversion 
structures as a sediment source.

EMA mine permits have traditionally focused on the mine footprint and frequently expand their influence 
to the access road, concentrate hauling, concentrate unloading and reloading (onto rail cars), etc. The 
EMA has a general prohibition of not causing pollution and therefore ESCPs may address erosion and 
sediment control aspects of the portion of an access road primarily used by the mine. This may admittedly 
be a grey area, but the MOE legislation appears to be the “closest fit” to covering erosion control along 
the mine access route. The effluent permit sampling plan may therefore include sampling locations off the 
mine footprint.

COMPLYING WITH BC TSS WATER QUALITY STANDARDS

Figure 1 summarizes the BCWQG TSS requirements in the left hand column. The third and fourth 
columns show the pond discharge level limits (C TSS mg/L) required to achieve the BCWQG after being 
diluted by an upstream dilution of D. Note the dilutions chosen for calculation was for D =1, and D = 5. 
The equations show the relationship between a minesite discharge containing C mg/L TSS and the 
required dilution to achieve BCWQG TSS levels for the low flows and high flows in a watercourse. The 
BCWQG limits have been converted to mathematical language to make their meaning clearer. The 
following is the mass balance equation for a discharge containing C mg/L TSS flowing into the adjacent 
watercourse containing an upstream TSS of Cuin mg/L. The downstream water quality should not exceed 
Cwqg , the BCWQG for TSS, and D is the dilution ratio of the upstream flow to the discharge flow. The 
discharge TSS mg/L is calculated using: 

\[ C \leq \left( \frac{D}{D+1} \right) C_{\text{wqg}} - D \cdot C_{\text{uin}} \]

A conclusion can be drawn from Figure 1: the BCWQG TSS concentration is achieved if the discharge 
concentration is 30 mg/L, except for the “CLEAR FLOWS (b)” (which is for a 30 day averaging period 
and would include many days when there is no discharge from the sediment pond).

It is apparent for the high flows in receiving waters (i.e. above the 10-year, 24-hour runoff flow) elevated 
discharge TSS concentrations is permitted in MOE effluent permits, compared to the MMER limit. This 
indicates a conflict between (a) the MMER discharge limit of 30 mg/L TSS (required to be met at all 
runoff conditions, and all receiving water dilution conditions) and (b) the BC effluent permit standards.

Using the methodology indicated in Figures 2 and 3 and applying this to the “Fine Grained Soil” in 
Figure 3 demonstrates how a sediment pond functions at flows above the 10-year, 24-hour runoff flow 
(i.e. for pond inflows higher than the Q_{100%}). For example, doubling this flow (i.e. doubling Q_{100%} to 
Q_{200%}) only increases the pond size cut from 10µ to 14µ. For the upslope soil sample particle size analysis 
chosen for this example, this corresponds to an increase from 32% -10µ to 35% -14 µ, and this will 
represent an increase of only 3% more of the pond input sediment that will exit the pond. The large 
increase in pond flowrate (i.e. 2.0 x Q_{100%} ) only increases the particle size cut to [(10µ)\sqrt{(2.0)} = 14µ. 
This is a positive feature of sediment pond performance as it relates to pond discharge quality (which is
an artifact of the Stoke equation) and the nature of particles settling in water. The example selected uses actual mine site soil particle size analyses. An estimate of the sediment pond discharge TSS quality for the 10-year, 24-hour runoff flow (i.e. the Q_{100%} flow rate into the pond) is imperative since BC mine effluent permits typically require such flow conditions into sediment ponds to result in 50 mg/L TSS in the sediment pond discharge (coal mines) and 30 mg/L TSS for metal mines (MMER). If the BC permit conditions are achieved at the 10-year, 24-hour runoff flow, then at lower flows into the same pond, the 50 mg/L TSS (and lower) should also be achieved. The sediment pond discharge TSS quality can be estimated as follows:

(a) Estimate the soil loss into the pond (L) for the 10-year, 24-hour runoff flow. The pond inflow TSS would be estimated by \[ \frac{L}{Q_{100\%}} \text{ mg/L, in appropriate units for L and Q.} \] Runoff TSS at minesites containing such fine soils would be expected to produce at least 1000 mg/L TSS during the 10-year, 24-hour runoff flow entering a sediment pond.

(b) The 32\% minus 10µ in the soil eroded into the pond would then exit the pond and generate 320 mg/L TSS in the pond discharge since the minus 10µ particles are not settled in the pond at the Q_{100\%} inflow rate) – i.e. \[ 0.32 \times 1000 \text{ mg/L TSS} = 320 \text{ mg/L TSS, assuming the runoff flowing into the sediment pond contains 1000 mg/L TSS.} \]

For this example, the expectation is that flocculant(s) would be used to achieve compliance. If the sediment pond inflow exceeds the Q_{100\%}, effluent permits are worded such that the discharge compliance quality requirement is replaced by a receiving water compliance requirement: \[ C = C_{\text{in}} \left( D/10 + 1.1 \right), \] or the “HIGH FLOWS (a)” formula, which, at a dilution ratio of 5:1, would allow a pond discharge of 160 mg/L TSS, for example (Figure 1). Finer soils than anticipated (i.e. sampled and tested) encountered upslope of the sediment pond will tend to increase the sediment pond discharge TSS.

<table>
<thead>
<tr>
<th>BCWOG TSS mg/L Requirement Downstream of Discharge</th>
<th>Calculated Discharge TSS, C mg/L which will achieve the BCWOG TSS mg/L</th>
<th>Examples for Dilution D = 1 and D = 5 [Upstream flow] / [Discharge flow] = D</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEAR FLOWS (a): Change from background of 25 mg/L at any one time for a duration of 24 h in all waters during clear flows or in clear waters</td>
<td>[ C \leq 25(D+1) + C_{\text{in}} ]</td>
<td>[ D=1:1 ] [ C \leq 50 + C_{\text{in}} ] [ D=5:1 ] [ C \leq 125+ C_{\text{in}} ]</td>
</tr>
<tr>
<td>CLEAR FLOWS (b): Change from background of 5 mg/L at any one time for a duration of 30 d in all waters during clear flows or in clear waters</td>
<td>[ C \leq 5(D+1) + C_{\text{in}} ]</td>
<td>[ D=1:1 ] [ C \leq 10 + C_{\text{in}} ] [ D=5:1 ] [ C \leq 30+ C_{\text{in}} ]</td>
</tr>
<tr>
<td>HIGH FLOWS (a): Change from background of 10 mg/L at any time when background is 25 – 100 mg/L during high flows or in turbid waters</td>
<td>[ C \leq 10D+35 \text{ to } C \leq 10D+110 ]</td>
<td>[ D=1:1 ] [ C \leq 45 \text{ to } 120 ] [ D=5:1 ] [ C \leq 85 \text{ to } 160 ]</td>
</tr>
<tr>
<td>HIGH FLOWS (b): Change from background of 10% when background is &gt;100 mg/L at any time during high flows or in turbid waters</td>
<td>[ 10D+110 \text{ at } 100 \text{ mg/L.} ] [ C = C_{\text{in}} \left( Q/10 + 1.1 \right) ]</td>
<td>[ D=1:1 ] [ (100 \text{ mg/L}) ] [ C = 120 ] [ D=5:1 ] [ (100 \text{ mg/L}) ] [ C = 160 ]</td>
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Figure 1 - BC Receiving Water Guidelines.

METHODOLOGY FOR DESIGNING/OPERATING SEDIMENT PONDS
The MMER is silent on the requirement for runoff higher than the 10-year, 24-hour rainfall event. The BC requirement is based on the rationale that for higher pond inflow rates, there will be higher downstream receiving stream TSS levels, and lower corresponding retention times in the pond (reflecting a larger size cut as indicated in Figure 3) and concurrently higher downstream dilution. Presentation of a specific mine site data, as indicated in Figure 3 may be used to estimate the higher particle size cut corresponding to higher runoff flows into the pond: at 50% higher flow than the 10-year, 24-hour rainfall event, the size cut will be 12 microns, while at twice the 10-year, 24-hour rainfall event, the size cut will be 14 microns. The use of flocculants should be able to maintain the 30 mg/L TSS at virtually all higher runoff flows into the pond, but with the current lack of responsive controls to optimize flocculant addition, this has practical challenges. When performing settling tests, the test jar supernatant can be diluted as necessary to estimate future compliance with the BCWQG for turbidity.

**MOE guidance for designing sedimentation ponds**

The Guidance for Assessing the Design, Size and Operation of Sedimentation Ponds Used in Mining (MOEGSP) requires the following approach:

1. The pond area, A (m$^2$) should be large enough to capture the plus 10 µ particle size when the runoff flow into the pond is for the 10-year, 24-hour rainfall event;
2. Erosion control should be used upslope of the pond to reduce soil loss into the pond and improve the pond discharge quality;
3. The need for settling aides should be determined; and
4. Settling tests should be performed on representative soil samples expected to enter the pond.

**Predicting pond discharge quality**

The *Critical Particle Settling Size* is approximately a 2 µ particle, smooth sphere, for a quartz particle, S.G. 2.7; particles smaller than this are in the “colloidal” category and are generally prevented from settling by virtue of the universal *Brownian Motion*. The following discussion is based in part on references: U.S. Department of the Interior Office of Surface Mining, 1982; Erosion and Sediment Control - Surface Mining in the Eastern US, Volumes 1 and 2, 1976; and Clark, 1998 and 2010. Figure 2 shows the synthesized particle size analysis representing a number of upslope soil sample particle size analyses. The synthesized particle size analysis represents the runoff into the pond (various soils eroded and mixed together flowing into a sediment pond). The pond has been constructed with an area A to capture +10µ (i.e. $x_{10} = 10\mu$) particles at the 10-year, 24-hour runoff rate of Q (i.e. the $Q_{100\%}$ flow). The pond has therefore been sized based on the MOEGSP. The objective is to estimate the pond discharge quality as mg/L TSS.
The discharge quality depends, in part, on the amount of sediment entering the pond which, for this example, has been assumed to be 1000 mg/L TSS (at the inflow rate Q); in practice the sediment entering the pond can be estimated by performing a RUSLE soil loss calculation to determine the rainfall event soil loss (L) into the pond. In the appropriate units, the TSS mg/L will be L/Q mg/L (i.e. the TSS in Figure 2). The particle size distribution shows 15% -10 μ which means the pond will not settle this size fraction at the Q 100%, and therefore 15% of the 1000 mg/L entering the pond will exit the pond, generating a discharge of 150 mg/L.

For the conditions shown, it would require upslope soils to contain only 3% -10 μ in order not to exceed the MMER standard of 30 mg/L TSS at the Q 100%. This provides a useful “rule of thumb” when designing ponds and collecting soil samples from a mine site and planning for the need for settling aids.

The example in Figure 3 uses 1000 mg/L entering the pond at the 10-year, 24-hour runoff rate and emphasizes the major effect the -10μ particle fraction has on sediment pond discharge quality. Lower pond inflow rates typically have lower associated soil loss, and lower TSS entering the pond, and finer particle size cuts in the pond, which coincides with observed improvement of sediment pond discharge quality at lower rainfall events. On a site specific basis, the major influence on sediment pond discharge quality is the upslope soil types, as reflected in upslope soil sampling particle size analyses.
Figure 3 - Particle size distribution and size cut in the pond – (a) The “Fine Grained Soil” curve particle size distribution was synthesized from testing 6 soils above the pond. (b) The pond is sized such that when $Q_{100\%} = 10$-year, 24-hour rainfall event, $+10$ micron particles will be recovered. (c) The particle separation size = $\sqrt{\frac{(Q/A)(18\mu/g)(s-1)}{\mu}}$, $\mu$ = viscosity, $s$ = Specific Gravity of particles, $A$ = pond area.

Figure 3 shows a particle size distribution and the variation in size cut in the pond at various inflow rates into the pond. Using the 10-year, 24-hour rainfall event and calculating the soil loss at this rainfall condition allows the TSS mg/L into the pond to be estimated. The particle size analyses of upstream sediment pond soils eroded into the pond is on the right hand side vertical axis. At the 100% design flow (which is equivalent to the 10-year, 24-hour rainfall event, $Q_{100\%}$) approximately 32% of the Fine Grained Soil entering the pond will exit the pond. Figure 3 clearly indicates the need for flocculants at the 10-year, 24-hour rainfall event. In Figure 3 the particle size cut in the pond varies according to the inflow rate and the Particle Separation Size curve developed from the Stoke settling equation relates the separation size to the amount of time the particles have to settle in the pond, which is determined by the pond inflow rate. At an inflow rate of $1/25^{th}$ the 10-year, 24-hour runoff event (i.e. the $Q_{2\%}$) 2 micron particles will be captured. Based on Brownian Motion effects, quartz particles of less than $2\mu$ will not settle, unless the particles “naturally” agglomerate (this will become apparent from settling tests).

Predicting pond discharge quality at the EA phase

Performing the suggested testing described in order to define how proposed erosion and sediment control works will function and comply with the MMER and MOE discharge and downstream legislated requirements is crucial at the environmental impact assessment phase. Typically EA Applications do not define how a proposed mine will comply with the sediment-related MMER and MOE discharge and downstream legislated requirements. The following is therefore recommended:
1. Perform the calculations suggested in Figures 2 and 3.
2. Perform the appropriate settling tests to supplement/confirm the calculations in Figures 2 and 3.
3. Develop a Sediment Pond management Plan.

Discussion of pond operation

Sediment pond operators are required to operate settling ponds and (a) maintain discharge compliance for TSS and toxicity (when adding flocculant to the runoff entering the pond); and (b) maintain compliance at the MOE designated compliance location downstream of the discharge point in the receiving stream for TSS, turbidity and possibly, toxicity for Ceriodaphnia dubia (when there is enhanced downstream toxicity risk, this may be required by MOE). The MMER requires a Ceriodaphnia dubia bioassay on metal minesite effluent; MOE may require a Ceriodaphnia dubia bioassay to be performed on the pond discharge and downstream receiving water when toxic flocculants are applied. Minesite environmental managers and sediment pond operators benefit from an understanding of how flocculants function to avoid using too much, too little flocculant into the sediment pond, and inadvertently generating sediment pond discharge toxicity and/or noncompliance.

The amount of flocculant required to be added to the runoff is a function of (a) the TSS mg/L entering the pond, (b) the particle surface area, which increases as the particle size distribution becomes finer and (c) the flow rate into the pond. In order for the optimum amount of added flocculant to achieve effective flocculation, there must be (d) adequate mixing subsequent to adding the flocculant to the runoff and (e) adequate mixing time. The Appendix B in the MOE Guidance for Assessing the Design, Size and Operation of Sedimentation Ponds Used in Mining (MOEGSP) provides an explanation on the need for appropriate mixing of runoff and added flocculant:

- “The ‘protective colloid’ effect may result when using some flocculants if over dosing occurs. This results in decreased settling efficiency (and increased TSS) as more flocculant is added. Inadequate mixing may also produce the same result due to “local” over dosing of some of the particles. The ‘protective colloid’ effect is usually irreversible, resulting in the inability of the fine particles affected to settle, and high TSS.”

In practice, the particle size analysis in the pond feed cannot be measured soon enough, or at the mine site, although an estimate of the flow rate into the pond is required to gauge flocculant addition; the changing particle size distribution in the runoff is a confounding factor relative to the amount of flocculant needed to be added since the particle surface area in the runoff contributes significantly to the amount of flocculant required to achieve optimized flocculation and subsequent effective settling/clarification. If the size distribution in runoff is relatively constant, this allows calibration of the flocculant addition dosage to the measured runoff flowrate. Unfortunately, the TSS mg/L in the runoff is also a variable affecting the amount of flocculant to be added. Water treatment plants utilize a rapid settling test system to determine the amount of flocculant addition, which, with adaptation may be used
at a mine site. Diligently searching for a suitable flocculant with a relatively low toxicity avoids flocculant-related toxicity issues and should significantly simplify sediment pond operation.

**Additional prediction testing**

The MOEGSP was produced in 2002, and additional enhancements have been developed to supplement sediment pond discharge quality prediction. With the some of the following modifications to the MOEGSP methodology, the pond discharge quality may be predicted as follows:

- use the hydrology calculations to determine the pond inflow rate;
- use soil loss calculations (RUSLE, RUSLEFAC, and the reference RUSLE 1998) to determine the soil loss into the pond; and
- the approximate TSS mg/L into the pond (e.g. for the 10-year, 24-hour inflow rate) and using the type of data presentation in Figure 1, pond discharge TSS can be estimated.

The reference RUSLE 1998 is specifically designed for application to mined lands, construction sites, and reclaimed lands and is based on the USDA erosion prediction research over the past eight decades. RUSLEFAC is the Canadian adaptation of RUSLE.

Settling testing may, and should, be used to corroborate these predictive calculations using representative soil samples collected upslope of planned sediment pond(s). The key information and calculations required prior to performing settling tests is to determine how much water to add to a soil sample: i.e. the ratio of solids:(runoff)water, which is equivalent to the TSS mg/L entering the pond; and calculating, estimating, the applicable TSS for the 10-year, 24-hour runoff flow is suggested. These settling tests will provide simulated TSS and turbidity in pond supernatant at the Q_{1000} inflow rate, by measuring the TSS and turbidity in the settling test jar supernatant. These tests will then indicate if there is a need for flocculants, and allow the settling test supernatant to be diluted based on the predicted dilution ratio of pond discharge to receiving water and the turbidity measured in the diluted supernatant to determine compliance with the BCWQG turbidity standard at the clear and turbid flow regimes. If these tests indicate flocculants are required, further testing should be conducted using an array of flocculants (focusing on (a) cationic, (b) neutral, and (c) cationic/anionic/neutral combinations). The flocculants selected for testing requires some initial research to focus on flocculants with relatively low 96 Hour LC_{50} concentrations.

The approach suggested is:

1. Estimate the 10-year, 24-hour runoff flow entering the sediment pond.
2. Estimate the sediment entering the sediment pond at the 10-year, 24-hour runoff flow (RUSLE methods, RUSLEFAC, etc.), and estimate the TSS mg/L into the pond.
3. Calculate the sediment pond surface area required to capture plus 10 micron particles.

Items 1, 2 and 3 are unrelated to the soils particle size analyses at a specific mine site. RUSLE may capture this requirement indirectly, or inadvertently. Therefore the following tests and soil information
are recommended:

Soil particle size analyses upslope of the pond discharge

1. Scoping out the mine site soil characteristics will initially serve to define the general approach to designing the sediment pond. This task should be performed diligently, and strive to accurately predict the operational phase of the pond inflow TSS size distributions. This will, for example, avoid installing a flocculant system which in practice turns out to be redundant; or conversely, the predictive testing may incorrectly determine that a flocculant system is not required – this may then lead to a lengthy period of exceeding pond TSS discharge levels, until a flocculant system can be retrofitted. These examples imply “unexpected” and additional costs for the mining company and possible legal action, including fines if this preparation work is neglected.

2. As a generalization, and assuming BC discharge quality requirements, the approach to pond design will be linked, in particular, to the amount of the % by weight of the minus 10 micron particle size fraction – or more logically, the particle size which is unable to settle in the pond (which, for soil mineral particles of similar density to quartz, may be even finer, e.g. 2 microns). The common focus for the “10 micron particle size fraction” appears to be based on economic considerations, since the pond area requirement is proportional to the square of the particle size to be captured in the pond. If the regulatory BMP choice selected (say) a 2 micron particle size removal requirement (at the 10-year flow) the pond size would become 25 times larger in area, and too costly and large a footprint (compared to being sized for a 10 micron particle removal).

CONCLUSIONS

The conclusions related to the effectiveness of sediment prediction release, and prevention of water pollution, related to sediment, are as follows:

1. **BC effluent permitting**
   BC effluent permits reflect the MMER TSS 30 mg/L and require the installation of sediment ponds prior to the construction phase. Sediment Pond Management Plans are recommended as a permit requirement. Coal mines are not currently captured in the MMER; the proposed Environment Canada TSS standard of 100 mg/L (Environment Canada 2012) is considered to be excessive as the recognized BAT to control TSS is much lower. BC currently uses 50 mg/L TSS for coal mines. The BC mine effluent permitting system has a robust sediment pond design guidance system; an effective permitting system; effective legislation to enforce erosion and sediment control requirements mirrored in the MMER discharge standards; and an effective methodology to protect downstream receiving streams using defined and scientifically researched standards.

2. **MOE Guidance for Sediment Pond Design**
   The BC sediment pond design approach is typically used by mines in BC to size the sediment pond, but frequently settling tests, particle size analyses and flocculant testing are not performed, and sediment pond discharge quality is therefore unknown prior to the initiation of construction. This is considered to present an unnecessary environmental risk, as the selection, MOE approval, installation and application of a flocculant typically takes at least 6 months. The MOE permitting system has the ability to ensure the installation of environmentally protective erosion and sediment control works.
3. **Erosion and sediment control plans**
The proposed MOE ESCP guidance should contribute to reducing the soil loss into the sediment pond, and is anticipated to provide more diligent erosion control for minesite areas which cannot be directed into a sediment pond (e.g. high risk minesite roads). Access and mine haul road construction and maintenance should be based on recognized guidance documents, and should be part of the ESCP. ESCPs may be required in mine effluent permits, which can result in making BMPs, guidance documents and standards and their implementation, maintenance and reporting a legal requirement.

4. **BCWQG**
Complying with the BC TSS/turbidity Water Quality Guidelines (Criteria) is the primary environmental protection strategy, and is generally an achievable standard for minesite sediment discharges, based on the TSS BCWQG concentrations and the BAT currently available. MOE has sediment/turbidity receiving water standards, and also implements a principle of further reducing these contaminants based on the availability of BAT.

5. **The MMER**
The MMER TSS requirements are generally achievable at minesites. Mine operators need to capture their strategy for how they will comply with the MMER TSS requirement in ESCPs and SPMPs, commencing at the environmental impact assessment phase.

**REFERENCES**


