Treatment of Mine Site Runoff Containing Suspended Solids Using Sedimentation Ponds – A Proposed Best Management Practice Design Guideline

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Abstract The use of ponds to treat mine site runoff for the removal of total suspended solids requires a best management practice design and operation guideline which will result in providing more certainty of achieving discharge compliance for TSS and toxicity. The proposed BMP design guideline takes into account site specific soil particle size distributions upslope of the pond, provides guidance on whether settling aids will be required, and estimates the pond discharge TSS concentration. A BMP pond design will also achieve cost savings by constructing only the necessary works to achieve discharge compliance and avoid costly retrofitting.

Key Words sedimentation, pond, design, BMP, compliance

Introduction

Discussion of the essential elements that should be included in a best management practice (BMP) design and operation guideline is described. Mining activities during the construction, operation and post mining phases generate a total suspended solids (TSS) concentration in runoff which enters receiving waters at soil erosion rates which increase above "natural" erosion rates significantly in terms of "soil loss" and "sediment yield" quantification (e.g. using tools such as RUSLE, Revised Universal Soil Loss Equation). Application of erosion control strategies, such as re-vegetation, may significantly reduce the sediment load entering adjacent water courses, but is a relatively slow process, and has limitations, necessitating the installation of sedimentation ponds. The mining industry applies significant resources to construct and operate sedimentation ponds which warrants development of a BMP methodology which strives to yield cost savings (by not over-designing the pond size and only installing the optimal flocculant system when necessary) and ensure a lower risk of exceeding regulatory pond discharge standards and downstream water quality standards (and avoiding flocculant-induced toxicity). Pond discharge non-compliance (for both TSS and toxicity) may result in significant additional cost, including legal costs and subsequent fines.

Basis for BMP Methodology Development

The most important factors which may cause excessive sediment discharges to receiving waters is the presence of abundant un-settleable fine particles in the soils ("fines") being excavated, or otherwise disturbed. Whether such soils become problematic with respect to pond discharge TSS quality, and impact on receiving water quality, is generally dependant on:

- The mass loading and concentration of TSS in the influent to the pond, and the portion of this loading which is un-settleable particles, i.e. the eroded soil fraction which is finer than the critical settling particle size (Slater, 1968).
- The size "split", or the particle separation size, which the pond is capable of achieving (at various inflow rates; Clark 1998).

Hence, there is a need for a design method based on the size distribution of the soils at a specific mine site in order that the pond discharge TSS quality can be estimated and the pond design parameters adjusted to meet the discharge and receiving water regulatory requirements. The mass loading into the pond may be estimated using RUSLE methods, as indicated by Terrence, 1998; and, in combination with the rainfall/runoff data for the site, the TSS into the pond may also be estimated (i.e. estimating the ratio of solids to liquids into the pond).

Drawing from past design methodologies, many jurisdictions specify a minimum pond area, e.g. 0.0001 $m^3/s/1.0$ square metre of pond area (at 25°C), which will remove 10 micron and larger particles (Clark 1998); this specifies the inflow rate per unit surface area of pond necessary to settle a 10 micron sphere of quartz (for example) at a specified water temperature. At 1°C, the capacity of the pond is reduced by about half, and further reduced significantly 20% to 50% by non-sphericity of particle shapes. Some US jurisdictions require pond sizing in terms of pond volume and geographical location (e.g. Maryland, 0.5 inches/acre, or a pond size of 1,300 yd^3/acre drained, while others may require a specified removal efficiency of the TSS input (e.g. remove 95% of pond input TSS).

Calculating Pond Area

Once constructed, the pond area A (m^2) is fixed and is the most important pond size design parameter (the function and choice of pond depth is required to create quiescent conditions and store sediment, but does not determine the separation size of the pond). The flow pattern between pond inlet and outlet is influenced by influent geometry, pond shape, wind action, inflow rate, pond depth, outflow geometry, etc. The pond flow pattern should therefore strive to fully utilize the entire pond area, minimizing "dead spots" which are not capturing sediment. The inflow rate Q (m^3/s) and "A" together determine the separation particle size of the pond, since $A = Q/V$ and V cm/s = the settling velocity of the particle with a diameter which is the minimum particle size settled out for a given inflow rate into the pond of area A m^2 – calculated using Stokes' equation, or determined by settling tests on upslope soils, or determined by a particle size analyzer in conjunction with settling tests, etc.

Pond depth and retention time, without the appropriate calculated pond area could result in an "under-designed" pond. Stoke's settling equation is no longer applicable for a mineral particle finer than the critical settling particle size – i.e. Stokes' settling equation does not take into account the effects of Brownian motion in inhibiting particle settling for approximately the 2 micron size range for a quartz particle. It is suggested that the critical settling particle size can be reliably determined by performing settling tests on representative soil samples (at the appropriate solids to liquid ratio determined by using a RUSLE calculation, or alternatively selecting a conservative pond inflow TSS concentration based on professional judgment, or drawing data from similar mine sites). The "residual" TSS concentration (and turbidity) in the settling jar test supernatant, using pond upslope representative soils, represents the particles in the soil which are unable to settle after an extended settling time; in addition, measurement of the "residual" particle size distribution in the supernatant provides conclusive data of the eroded particle sizes which will essentially pass into, and out of, the pond regardless of the settling time in the pond. In addition, discharge quality "failures" may be acceptable occasionally (at pond inflow rates in excess of, for example, the 24-hour, 10-year rainfall event) provided the receiving water objective for TSS concentration is still achieved downstream of the pond discharge. Therefore, calculating pond area is specific to the local soils and local regulatory requirements, and other conditions at the mine site.

Regulatory Expectations for the Pond Discharge Quality

Expectations for settling pond discharge quality vary based on local regulatory requirements, and is typically linked to a specified rainfall event determined by the regulatory authorities – e.g. the 24-hour, 10-year rainfall event is commonly used in BC Canada. Mining companies are typically required to meet discharge quality requirements based on one, or sometimes all, of:

a BMP, with the BMP being defined by the local regulatory authority; and/or
b Local regulatory requirements (which may not necessarily relate to BMP); and/or
c Whatever is necessary to comply with the downstream water quality standards; and
d In Canada, for example, a Federal regulation requires the pond discharge meet a grab sample of 35 mg/L or less for metal mines.

Particle Size Distribution of Soils Eroded into the Pond and How this Relates to Achieving Regulatory TSS Requirements

The portion of the particle size distribution of soils that will be eroded, and yield the TSS concentration into the pond, should be defined, since this may have the greatest influence on how the pond will be required to perform. Scoping out the mine site soil characteristics will initially serve to define the general approach to designing the pond. This task should be performed diligently, and strive to accurately predict the operational phase of the pond inflow TSS size distributions. This may, 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. Both these examples imply "unexpected" and additional costs (and sometimes significant legal costs).

As a generalization, and assuming discharge quality requirements similar to (a), (b) and (c) above, the approach to pond design will be linked, in particular, to the amount of (approximately) 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). Focusing on the "10 micron particle size fraction", I suggest, is also 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 BMP selected (say) a 2 micron particle size removal requirement, the pond size would become 25 times larger in area (compared to being sized for a 10 micron particle removal).

For pond inflow rates below the10-year, 24-hour rainfall pond inflow rate, additional capture of minus 10 micron particles would be achievable, but only for particles above the critical settling particle size. If we assume the critical settling particle size is approximately 2 microns (varying, based on particle mineral S.G., shape, etc.), it becomes apparent that even small amounts of fines in the soils becomes problematic in terms of achieving 35 mg/L in the pond overflow (and that soil particle size analyses requires analysis down to approximately the two micron particle size, or whatever is the critical settling particle size determined from soils testing and settling tests). For example, if the 10-year, 24-hour rainfall pond inflow rate contained 5000 mg/L TSS, and the soils eroded into the pond contained more than 5% of minus 10 micron particles, the estimated pond discharge would be 250 mg/L and higher.

Particle Settling Limitations in the Pond

For discrete particles (i.e. un-agglomerated) in the pond, the critical settling particle size that we need to be aware of for pond design is that particle which is unable to settle based Brownian motion phenomena. Hence there is a limitation of applying the Stokes settling equation to particles smaller than the critical settling particle size.

Other aspects affecting particle settling that we should also consider is the (typical) predominance of elevated particle charge (elevated Zeta potential) as it may affect agglomeration of particles (which, if natural agglomeration occurs, may significantly increase settling rate for particles smaller than the critical settling particle size). Typically, particle Zeta potentials in runoff appear to be elevated – for example -50 mV for quartz particles at the expected pH range of many runoffs is quite sufficient to prevent agglomeration of fine particles (in particular, the particles smaller than the critical settling particle size). Lower Zeta potentials of approximately -10 mV (or +10 mV) are typical thresholds for allowing agglomeration to take place. This agglomeration is made possible by the universal presence of the van der Waals attractive force. While this force acts constantly, the Zeta potential is a function of pH, and the presence of potentially determining ions (Slater et al. 1968) in the pond water. Hence, it is useful to know the Zeta potential of the particles at the given pH in the runoff into the pond, and to know the zero point of charge for the various minerals making up the TSS entering the pond, and to determine whether potentially determining ions will be present. For example quartz, at about pH = 7.0 typically has a particle charge of -50 mv; this charge decreases with decreasing pH, reaching approximately zero at pH = 2.0. Thus, quartz particles which are smaller than the critical settling particle size will be observed to agglomerate and settle at about pH = 3.0 (corresponding to a Zeta potential of -10 mV). While pH lowering is not typically a viable "settling aid", potentially determining ions, including cationic flocculants, are a useful settling tool. It is suggested that when using the positive-negative flocculant combinations, that the Zeta meter may be required on site to minimize the addition of "excess" cationic flocculant and thereby prevent a toxicity risk developing in the pond discharge. Water treatment plants utilize the Zeta meter in conjunction with rapid-jar-settling-tests to optimize the addition of flocculant (and coagulant), although this method is more challenging to apply to a mine site sedimentation pond, and necessitates provision of a small building close to the pond where the operator can conduct standardized flocculant addition to runoff samples.

BMP Tests on Soil Particle Suspensions at the Mine Site

It is apparent that there are a number of options available to determine how a proposed sedimentation pond will perform (or to trouble shoot existing pond discharges with elevated TSS) by testing representative soil samples. Supplementary tools and tests that may allow better control are:

a Measurement of Zeta potential, both for synthetic suspensions using soil samples, and for actual inflows to existing ponds and, at times, for discharges from ponds, particularly when there are discharge toxicity problems occurring;
b Use of a "mobile" particle size analyzer, applied to synthetic sample suspensions from soil samples, and on pond inflows and discharges;
c On-site capability to perform rapid settling tests, to aid in ongoing optimization of flocculant addition (and to ascertain under what runoff conditions the application of flocculants should commence); and
d Turbidity measurements of settling test jar supernatant in (c) and the pond discharge to the receiving watercourse, and downstream of the discharge location.

Conclusion

1. Prepare a "synthetic" particle size distribution cure which represents the various soil types sampled in the "water shed" upslope of the settling pond.
2. Perform a RUSLE estimation of the soil loss into the pond at the appropriate rainfall event.
3. Determine the particle separation size in the pond at the appropriate inflow rate to the pond.
4. Knowing the TSS concentration into the pond, and assuming the particle size analysis of the TSS into the pond is approximately represented by the synthetic particle size distribution cure in 1, the separation size of the pond at a chosen inflow rate allows the pond discharge TSS to be estimated.
5. The settling testing on soil samples that will be eroded into the pond are used to provide a check on the estimated pond discharge quality. These settling tests should be performed at a solids to liquid ratio based on the RUSLE estimation of soil loss, or using professional judgment.
6. If the estimated pond discharge quality exceeds the local regulatory requirement (e.g. for Canadian metal mines it is 35 mg/L) then this suggests settling aids will be required.

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