BRITISH COLUMBIA | Ministry of Environment

Technical Guidance 7

Environmental Management Act

Assessing the Design, Size, and Operation of Sediment Ponds Used in Mining

Version 1.0

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Environmental Protection Division

Disclaimer

This document has been prepared to help mining companies to design sediment ponds for appropriate sediment removal as part of their Erosion and Sediment Control Plan so that, when implemented, the plan will contribute to compliance with the *Environmental Management Act* and protection of the environment. This document does not supersede the *Environmental Management Act* or its regulations.

Recommendations in this document are not mandatory requirements, but are recommended practice, and may become legally enforceable if they are included in an authorization issued under the *Environmental Management Act* or a permit issued under the *Mines Act*. Documents like this one are not intended to provide a legal interpretation of the Act, regulations and/or codes of practice. In general guidance documents describe procedures, practices and results that are consistent with legislated requirements.

The information provided in this document is intended to help users exercise their professional judgment in the design and construction of sediment ponds. The reader is encouraged to consult a Qualified Professional and the references located in this document when preparing a site specific mine permit application.

Where specifics are not provided, flexibility in the application of guideline recommendations may be required to adequately achieve environmental protection. A recommended practice may be modified when an alternative could provide better results. Those requiring information on the process of attaining a discharge permit are strongly advised to contact a Ministry of Environment, Environmental Protection Mining Team representative.

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1. Introduction

Surface water runoff from disturbed areas of mine sites can carry significant amounts of suspended solids into the receiving environment and potentially contribute to adverse environmental effects. Disturbed areas associated with mining operations are often large and include works such as mine pits, benefaction plants and related facilities, mine waste rock dumps, tailings ponds, roads, and ditches. Mining companies are responsible for minimizing erosion from disturbed areas and for collection and treatment of runoff from these areas before it is discharged into the receiving environment. The Ministry of Environment (MoE) document titled Developing a Mining Erosion and Sediment Control Plan (Version 1; February 2015) provides detail on erosion control as well as the development of a site-wide Erosion and Sediment Control Plan. This plan should be in place prior to, or developed alongside, the detailed design of sediment ponds for a mine site.

Sediment ponds are for reducing sediment loadings from mine operations when other erosion control or sediment control methods are insufficient. Sediment pond design and performance requires a large enough pond area to settle materials present, use of erosion control methods upslope of the pond, and assessment and determination of the need for settling aids. Each of these design elements is supported by obtaining site-specific information through various analyses, including water balance analysis, soil loss analysis, particle size analysis, and settling tests.

Other types of engineered solutions for control of sediments such as constructed wetlands might be an effective means of managing water quality; however, the design, implementation, management and decommissioning of alternative approaches is not covered in this document. If the anticipated TSS treatment facility departs markedly from the systems discussed herein, the proponent should discuss this on a case-by-case basis with MoE.

This document is intended as guidance for the design and operation of sediment ponds only; tailings storage facilities, flooded impoundments, water storage facilities, sludge storage ponds as defined in the Memorandum of Understanding - Regulation of Impoundments and Diversion on a Mine Site[1] and other engineered facilities for the control of sediment may have different requirements for construction and operation than a sediment pond. This guidance also does not apply to tailings storage facilities, including ponds, dams, or other storage facilities that permanently or temporarily store tailings slurries or sludges from processing plants at mines. For information regarding development or management of discharges to tailings storage facilities, please contact the MOE Environmental Protection Division Mining Team Senior Project Manager. For guidance information on the design requirements for tailings storage facilities please contact the Ministry of Energy and Mines Health and Safety branch

Careful planning and action to mitigate erosion and sediment runoff is crucial to ensuring environmental protection when mining operations are contemplated and constructed in British Columbia (BC). Both

[1] www.empr.gov.bc.ca/Mining/Permitting-Reclamation/Geotech/Documents/MOU_Impoundments_Diversions.pdf

federal and provincial legislation applies to mines located in BC. This document outlines to mining proponents what is expected when designing and operating a sediment pond as part of an Erosion and Sediment Control Plan.

2. Role of Government in Permitting/Managing Sediment Ponds

Mining in the Province of BC is regulated by the Ministry of Energy and Mines (MEM), the MoE and the federal government. For further clarification of the roles of the Ministries and the federal government, please refer to the MOE Mining Fact Sheet[2].

For permitting and managing sediment ponds, the roles are summarized below, with further detail available in the Memorandum of Understanding - Regulation of Impoundments and Diversion on a Mine Site[3].

- Under the *Mines Act* and *Health, Safety and Reclamation Code for Mines in British Columbia*, MEM is responsible for permitting mineral exploration, mine construction and operation, and reclamation activities. This includes approvals for impoundments or diversions that store or divert mining contact water.

- MoE's Environmental Protection Division through the *Environmental Management Act*, Waste Discharge Regulation, and other regulations (e.g., Placer Mining Waste Control Regulation, Hazardous Waste Regulation, and Municipal Wastewater Regulation) is responsible for authorizing the quantity and quality of any discharge to the environment from activities relating to mining.

- The Ministry of Forests, Lands and Natural Resource Operations (FLNRO), through the *Water Act* and the Dam Safety Regulation, is responsible for issuing water licences or approvals regulating the diversion, use and storage of surface water in or from a natural watercourse, including any impoundments or diversion on a mine site that store or divert non-contact water.

The MoE uses Ambient Water Quality Guidelines, Water Quality Objectives, and Best Achievable Technology (BAT) policy when setting permit requirements for sediment pond discharges. Ambient Water Quality Guidelines are set for parameters to ensure the protection of a given water use, including drinking water, aquatic life, recreation, wildlife and agriculture. BAT is a process used to determine the best waste discharge standards based on a technology that has been shown to be economically and practically feasible. Limits for total suspended solids concentrations in effluent discharges are set by the authorization under *EMA*.

Contingent upon up-gradient activities (e.g., blasting, fuel storage and milling), an authorization from the MoE may also contain standards for hydrocarbons, metals and/or nutrients from sediment pond discharges.

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[2] www2.gov.bc.ca/assets/gov/topic/C0188F632AEC266B044F8A2B756F055F/industrial_waste/mining_smelt_energy/mining_operations_fs.pdf

[3] www.empr.gov.bc.ca/Mining/Permitting-Reclamation/Geotech/Documents/MOU_Impoundments_Diversions.pdf

3. Use of Qualified Professionals

It is imperative that sediment pond design and Erosion and Sediment Control Plan development are undertaken by qualified professionals. Qualified professionals are also expected to supervise implementation to ensure that requirements of the plan are followed. Qualified professionals should monitor the effectiveness of the sediment pond and the Erosion and Sediment Control Plan, and adapt the plan as necessary. The objective and measure of effectiveness of the sediment pond and the Erosion and Sediment Control Plan will be in compliance with the mine effluent permit and protection of the environment.

For the purpose of this document, a person is considered a Qualified Professional who in relation to duty or function:

(a) is registered in British Columbia with a professional organization, is acting under that organization's code of ethics and is subject to disciplinary action by that organization, and

(b) through suitable education, experience, accreditation and knowledge, may reasonably be relied on to provide advice within his or her area of expertise, which is applicable to designing sediment ponds and developing an Erosion and Sediment Control Plan.

The Qualified Professional will be expected to understand and apply best management practices (BMPs) related to erosion control and sediment management.

4. Pond Design

The sediment pond design report should include:

- Preliminary site assessment (e.g. site layout and size, hydrology data, soil type(s), etc.)
- Prediction testing
    - Soil loss calculation – Revised Universal Soil Loss Equation RUSLE, or validated alternative predictive tool
    - Pond inflow rates – should address seasonal variability as well as storm events. Increased volatility/frequency of storm events due to changing climate should be considered.
- Particle size analysis (and variations with season and flows)
- Erosion control upslope, as it affects pond design
- Design of the sediment pond
- Particulars of discharge frequency and duration; i.e. intermittently, purposefully when impounded water quality meets a set of defined discharge criteria, semi-continuously or continuously
- Vulnerability of settled solids in the pond to become re-suspended under high flow or high wind events, or as a result of ice disturbance
- Need for settling aids – settling aid testing (see appendix B for additional information)

- Settling tests on pond influent
- TSS – turbidity relationships
- Operation and maintenance
    - Pond discharge (flow and TSS) monitoring
    - Removal of sediment from the pond
- Inspection
- Reporting
- Company contact information

5. General Guidelines for Sediment Pond Design

Examination of case studies for sediment ponds that have not met TSS targets indicates that system failures can generally be attributed to one or more of the following:

- Lack of upstream erosion control.
- Pond under-sizing due to errors in the characterization of water balance, sediment load and/or particle size.
- Inefficiencies in use of settling aids, with respect to distribution system, dosing rates and/or mixing.
- Ineffective performance of settling aids due to absence or poor design of pre-construction testwork.
- Decrease in performance over time resulting from sedimentation.

<u>In the sections to follow, discussion is provided on the various factors that must be considered for effective sediment pond design and minimizing the potential for sediment pond failure.</u>

5.1. Particle Size

MoE recommends that sediment ponds be designed to capture at least a 10 micron soil particle for the 10-year, 24-hour runoff event. However, it must be recognized that such a design may not on its own achieve the discharge quality required by MoE permits. Failure to meet required discharge standards could still occur if the pond inlet water contains a high proportion of suspended solids less than 10 microns in size (silts and clays). For this reason, particles less than 10 microns, including the minus 2 micron size fraction, should not be overlooked. These smaller materials can present challenges, since they may not settle in the pond environment. Conducting particle size analyses allows the potential need for flocculants to be determined at the project assessment stage. Performing testing and analysis early in the design stage will also help to highlight the need to prevent erosion, along with its high management costs, and identify opportunities to manage erosion.

Sediment ponds can perform consistently and predictably to remove particles over 10 microns in size from runoff. Settling aids can be used to augment the settling occurring in a sediment pond. This augmentation strategy is particularly useful when the soils disturbed at a mine site contain significant fractions of minus 10 micron and particularly minus 2 micron particle sizes.

The settleability of finer particles and amenability to settling through use of flocculants will depend on the specific characteristics of suspended sediment such as organic carbon content, specific gravity, and amount of negatively or positively charged functional groups on the particle surface (for example, as measured through cation exchange capacity).

5.2. Use of Settling Aids

Prior to using settling aids, a proponent must obtain written approval from an MoE Environmental Protection Mining Team Statutory Decision Maker. Information will need to be submitted to MoE to describe the requested approval, particularly the 96 Hour LC50 concentration of the settling aid(s) and details of the settling aid addition rate (and control method), mixing conditions, and conditioning time/facilities. Details guiding the selection of settling aids are included in Appendix B.

Provisions for adding settling aids should be incorporated into the overall design. If flocculants are being proposed, preferential consideration should be given to using flocculants upstream of the pond, since they require longer conditioning time than coagulants. Excess flocculants may adversely affect the sedimentation rate and, as a result, the effluent quality requirement for suspended solids may not be met if excess flocculants are added. Where there may be merits to the use of the combined and/or sequential use of settling aids, the implications for pond design and expectations regarding combined toxicity in pond effluent should be addressed in the design.

5.3. Topographical Maps

Accurate and up-to-date topographical maps should be used for the design and construction of sediment ponds, with sufficient contour resolution for design purposes.

5.4. Pond Design Ratio

The preferred shape of sediment ponds is generally rectangular with the ratio of length to width being about 5 to 1. Such pond ratios tend to prevent short-circuiting and better facilitate removal of accumulated sediment in the pond. The proponent should investigate the need for additional pond capacity and retention time due to accumulated sediment volume, turbulence, and “currents” in the pond on a project-specific basis and during operational inspection and maintenance activities. If local topography does not allow the practical construction of a 5:1 ratio of pond dimensions, the use of internal baffles to increase the total flow path length should be evaluated. Baffles could be constructed of sections of hanging geofabric (hanging walls), driven sheet piles, or placed erosion-resistant fill.

5.5. Structural Design for Runoff Events

All structures in the sediment pond system should be designed, as a minimum, to structurally withstand a 1 in 200-year runoff event. Dams or embankments having a failure consequence of “Significant” or greater (see consequence classifications in the BC Dam Safety Regulation and the Canadian Dam Association (CDA) Dam Safety Guidelines) must consider greater inflow design floods in accordance with the CDA guidelines.

5.6. Embankment Design

Dams and embankments should be designed in accordance with applicable guidelines as discussed below. Since 1988, a Memorandum of Understanding regarding regulation of impoundments and diversions on a mine site has been in place between MEM, the Environmental Protection Division of MoE, and the Water Management Branches of FLNRO. All sediment pond embankment structures that are considered to be dams, based on the definition of a dam under the CDA guidelines, should be designed and constructed based on the specifications of those guidelines and the Health, Safety and Reclamation Code for Mines in BC (Code) and operated under the terms of the Mine Permit. Additionally, sediment pond embankment structures that require a Water Licence under the *Water Act* must comply with the requirements of the Dam Safety Regulation and adhere to relevant specifications of the BC Dam Safety Guidelines and the conditions of the Water Licence. Embankments must be constructed out of materials appropriate for the application (grainsize distribution of soils, appropriate geosynthetic).

5.7. Suspended Solids Removal Design Flow

The minimum design flow for removal of suspended solids in sediment ponds should correspond to the 10-year, 24-hour runoff flow. All sources of runoff, including rainfall, snow melt, and combined rainfall-snow melt events should be considered in determining the design flow.

5.8. Primary Pond for Coarse Sediment

Ideally, a smaller pond should be located upstream from the main sediment pond to remove the coarse fraction of the sediment (fine to medium sand particles and greater). This primary pond should be designed to enable easy removal of sediment.

5.9. Pond Dewatering

Sediment ponds should be provided with a means of draining or dewatering, even if such operations are not planned during the lifetime of the pond.

5.10. Pond Clean-Out

Sediment ponds should either last the lifetime of the mine, including post-closure needs, without requiring removal of accumulated sediment, or should have provision for easy removal of sediment at regular intervals. Normally a pond is allowed to fill with sediment up to 50% of its effective depth, with 1.5 m (minimum) depth of water above the sediment.

5.11. Inlet Design

The inlet works of the pond should include a means for energy dissipation (such as barriers, or baffles) to spread out the flow and reduce the velocity of the incoming runoff.

5.12. Pond Discharge and Freeboard

The discharge works at the outlet of the pond should be at the opposite end to the inlet section and should include an overflow spillway or other means designed by a qualified professional to maintain a minimum 0.5m freeboard, or other minimum height as noted in the applicable permit under the *Environmental Management Act* or *Mines Act*, on the embankment during the structural design runoff event (minimum 1 in 200 years). During normal operations, the freeboard would be greater. The spillway should be armored to prevent erosion of the spillway channel. Also, there should be provisions in the design for installing facilities for trapping, collecting and removing hydrocarbons.

5.13. Effluent Quality

The desired effluent quality from a sediment pond must be assessed in relation to the environmental consequences of the construction of the requisite sized pond. Sediment pond size is related to the inverse of the square of the diameter of the smallest particle that should be captured to attain the desired effluent quality. Small improvements in effluent quality thus require large increases in pond size.

5.14. Sampling and Flow Monitoring

Suitable water quality sampling and flow measuring facilities should be installed to enable monitoring of the pond inflows and discharges, if required. If settling aids such as flocculants are proposed, the effective use of flocculants requires real time information in influent TSS concentrations, typically achieved through measuring turbidity and converting to TSS based on a prior evaluation of TSS-turbidity relationships through a range of seasonal and flow conditions. In addition, application rates and particulars of settling rates depend on influent flow rates, which may not track with discharge rates, so upstream flow measurement facilities should also be considered.

5.15. Fish and Wildlife Barriers

Sediment ponds should not be designed or constructed in a location where the active portion of a fish bearing stream would be incorporated into the pond design or where the pond design would restrict upstream and/or downstream migration of fish.

For ponds discharging into fish bearing streams, FLNRO Fish, Wildlife and Habitat Management staff should be contacted to discuss the need for barriers to prevent fish access into the sediment ponds as the chemical treatment of sediment contaminated waters or increased bioaccumulation of deleterious substances may occur there.

In general, wildlife access should be prevented as wildlife could potentially become trapped in the pond as a result of unconsolidated material in the pond or due to restricted egress due to a synthetic liner. In addition, the vulnerability of pond design (embankments, synthetic liners) to wildlife activity should be assessed and addressed.

6. Guidelines for Sizing Sediment Ponds

The basic method for sizing sediment ponds for mine-related applications is presented below, with options for refinement being dependent on the extent of pre-design investigative work undertaken. The Qualified Professional may use other equally effective methods or computer models.

- **Method A** is acceptable for ponds where the finest suspended particles will be present, thus requiring the maximum retention time. Provisions must also be made for the addition of a settling aid system. This method requires the least amount of site-specific testing, as standard assumptions on particle size and settling velocity are made.
- **Method B** refines the assumptions in Method A by using a settling method to provide the equivalent Stokes diameter of site-specific material, using particle size data for materials at the site.
- **Method C** further refines the assumptions made in Method A by using further sedimentation tests prepared from representative soil/runoff sampling and is the preferred method when the smallest effective pond is required.

6.1. <u>Method A</u>

This simplistic design approach has been used to design many of the sediment ponds at mines currently operating in BC. Use of this method is not recommended where there are environmental reasons to have the smallest effective pond.

If a particle of size “x” millimetres is to be removed by a sediment pond of depth “d” metres, and with a settling velocity of “V” metres per second (m/s), the required retention time “T_r” in hours will be.

Required Retention Time: $T_r = d/(3600*V)$

Assume that approximately 5 to 10 micron (and coarser) particles need to be settled out in the pond, and that the settling velocity will be approximately 2×10^{-5} m/s (assuming the temperature of the fluid in the pond is close to freezing). The sediment pond area (“A” in m^2) is then equivalent to [Q/V] m^2, Q being the 10-year 24 hour pond overflow rate in m^3/sec. Note that sediment pond depth “d” is defined as the difference in vertical elevation, in meters, between the inlet water level and the bottom of the pond adjacent to the outlet.

Sediment Pond Area: A = (Q/V)

Given a minimum pond depth of 1.5 m and a settling velocity of 2×10^{-5} m/s for fine silt, it will take 21 hours for a particle to sink to the bottom of the pond. With this practical approach, provision must be made so that approved settling aids can be added if required. It should be noted that at the assumed settling velocity of 2×10^{-5} m/s, a pond designed using this method should remove the smallest suspended solid particle that practically can be removed by plain sedimentation (namely fine silt at 5 micron diameter). As with Stokes’ equations, this assumes the particle is spherical and smooth with a specific gravity (S.G.) of 2.7. In reality, many particles can be expected to be angular to plate like (e.g. sheet silicates) and thus would take a longer time to settle.

In the absence of any mitigating factors, the pond should be sized to provide not less than a 20 hour retention time for a 1 in 10 year runoff flow, and longer if the calculations above indicate it is necessary.

. Use of this simplistic design approach must be supplemented with additional information (e.g. particle size analysis, soil loss analysis, and settling tests) to confirm that sedimentation alone will achieve discharge criteria and, if not, what additional strategies will be required to reduce sediment loading into the pond and/or increase the pond’s removal efficiency.

Appendix C provides more detail on some of the limitations of Stokes’ equation when used to design the size of the sediment pond without any on-site sampling and measurement of the Stokes diameter. In this case, a minimum correction factor of 1.2 is suggested to account for non-ideal settling. Higher correction factors should be used if grain-size or particle analyses suggest that many flat particles are present, and correction factors greater than 2.0 are suggested by the literature if very flat particles, such as mica are present.

Using Method A, increased pond construction costs may more than off-set the investigation costs required to use Methods B or C.

6.2. Method B

Assuming the size distribution of the influent TSS is known, an alternative common design approach is to use the settling velocity derived from the Stokes Law formula:

$$V_s = \frac{g}{18\mu}(S.G. - 1)\, D^2$$

where

V_s = spherical particle terminal settling velocity, cm/s

g = acceleration of gravity, 981 cm/s^2

µ = kinematic viscosity of water, cm^2/s

S.G. = specific gravity of the particle

D = (Stokes) diameter (cm) of a non-interacting particle measured using a settling method.

The expected concentration and particle size distribution of suspended solids entering the sediment pond are used to determine the smallest particle size (Stokes diameter or critical diameter) that must be removed to meet the discharge standards. The critical settling velocity (V_{sc}) is then calculated from the formula $V_{sc} = 0.01V_s$ while the pond retention time and area are calculated as shown in Method A, using V_{sc}.

Research suggests a 20% to 100% sediment pond area correction is necessary due to the non-spherical shape of actual mineral particles when their diameters are measured by a method which does not utilize settling. A minimum correction factor of 1.2 to account for non-ideal settling is suggested, as for Method A.

It is therefore recommended that the size analysis of the finer particles be determined using a settling test method, as this will provide the “Stokes diameter”, which is the diameter of the sphere which settles at the same rate as the mineral particle. Using settling methods to determine particle size ensures that the particles are “non-interacting” (using dispersing chemicals to increase the particle charge) and do not require a correction factor due to non-spherical shape. Therefore, while the use of the Stokes diameter gains the advantage of eliminating the need for a correction factor due to the irregular shape of the particles, it has the disadvantage of not duplicating any “natural agglomeration” that may occur in practice.

6.3. Method C

A dependable method for designing the required sediment pond retention time is to measure sedimentation rates and corresponding supernatant TSS quality using simulated samples. These samples should be prepared using the soils and/or mine wastes from the watershed upstream from the proposed sediment pond location and actual surface water from the area.

Assuming that the settling tests indicate that removal of particles of size “x” is required to meet the necessary discharge quality, and V_{actual} (actual settling velocity) is measured, the sediment pond area and retention time can be calculated as for Method A with measured values replacing assumptions, in which case correction factors should not be necessary.

7. Practical Considerations

The derivation of the design flows for pond sizing is necessarily based on the contributing basin area. Often during a storm event, additional pumps are brought on-line, and water is routed away from problem areas. Sediment ponds are often used as temporary storage for event water beyond their design capacity as a result of water management decisions made during a high-flow event. This can lead discharge below design specifications, as the effective contributing area is increased beyond the original design assumptions, and residence time is decreased. In order to prevent this, it is recommended that the site Water Management Plan specifically outlines where water from each site component is to be routed if the available storage at that component is fully allocated. The plan should ensure that the highest risk sources of water are given priority, that the order of priority is clearly defined, and should lay out in table format the contributing areas for each pond so that site staff can quickly estimate the impact of re-routing water from one pond to another (i.e., if two ponds have equal contributing areas, routing discharge from one pond to the other would approximately double that pond's contributing area).

8. Ministry of Environment Mining Team Contact Information

Please contact the MoE Environmental Protection Division Mining Team Environmental Protection Officer managing your permit file, or contact the Mining Team Regional Director or Authorizations Section Head to determine who your MoE file manager will be. Information to reach the Mining Team can be found on the BC Government Directory website at: http://dir.gov.bc.ca/gtds.cgi?show=Branch&organizationCode=ENV&organizationalUnitCode=MINING

Appendix A: Glossary

10-year, 24-hour runoff event – maximum runoff event that theoretically occurs at a frequency of once every 10 years and lasts for 24 hours

Agglomerate - this occurs when the van der Waals attractive forces on particles in a suspension exceeds the repulsive forces produced by the Zeta Potential of particles in liquid suspension. Particles are then able to form clusters (agglomerules) under suitable conditions and then achieve settling.

Agglomeration - the action or process of gathering into an agglomerule or cluster.

Authorization - a permit, approval, license, pollution prevention plan, operational certificate, order, certificate, pest management plan, certificate of compliance, conditional certificate of compliance, or approval in principle.

Berm - see Embankment

Brownian motion - the phenomenon of particles in a suspension being "jostled about" by the impact of molecules of the fluid. This then results in the inability of particles of about 5 microns or smaller to settle without agglomeration or flocculation.

Coagulant - an inorganic compound(s) that lowers the magnitude of the Zeta Potential allowing suspended particulates to gather together to form a cluster or coagule.

Coagules - masses or groups of suspended particulates effectively forming larger, settleable particles.

Embankment - an artificial bank, usually earthen, raised above the surrounding landscape to hold back water

Floc - a flocculant mass formed by the aggregation of a number of fine suspended particles.

Flocculant - an organic compound(s) that causes the formation of flocs, typically a long chain polymer.

Flocculation - a process which occurs when (usually) high molecular weight, long chain organic polymers adsorb and "bridge" onto, and between, particles in a suspension, to produce floccules (flocs) which thereby promote settling. Agglomeration/coagulation is not necessarily a precursor to flocculation, but the two phenomena are often used together advantageously.

Floccule - see Floc.

Guideline - A numerical limit or narrative statement with respect to substances or procedures which provide policy direction on a provincial, regional or sectoral basis.

Standard - A legally enforceable numerical limit or narrative statement with respect to substances or procedures specified in an authorization, e.g., a waste discharge permit

Supernatant - A clear liquid overlying material deposited by settling, precipitation or centrifugation, such as the effluent from a sediment pond.

TSS - Total Suspended Solids (previously called Residue, Non-Filterable). The quantity of solid material suspended in a fluid as determined by method 0008X332 in the British Columbia Environmental Laboratory Manual, 2009 Edition on samples collected in accordance with the BC Environment Field Sampling Manual or procedure approved by a Director.

van der Waals attraction - The weak mutual attractive force of molecules or particles in a suspension resulting from induced electric polarization. This enables agglomeration to occur, provided the Zeta Potential repulsive force is less than the van der Waals attractive force.

Zeta Potential (ZP) - The characteristic of a particle's charge used to determine its ability to either coagulate with other particles or remain in a relatively stable suspended condition. ZP may be negative, zero or positive. Equipment is available to measure zeta potential.

Zero Point of Charge (ZPC) - The condition that occurs when the pH of the fluid containing a suspension of particles is adjusted to produce a Zeta Potential of zero. This is termed the Zero Point of Charge and occurs at a characteristic pH in a suspension of specific mineral particles. The Zero Point of Charge can also be achieved by the addition of suitable coagulants (and some cationic/anionic flocculants).

Appendix B: Settling Aids

The need for settling aids should be determined prior to the construction and operation of a sediment pond. This may prevent regulatory noncompliance and allow better planning and cost projection compared to having to add settling aid addition facilities after construction or during operation of the pond. Factors to consider include location of metering equipment, site access and the provision of electrical power. The determination and use of settling aids should be developed by a qualified professional with expertise on the subject.

If particle size analysis of the material expected to enter the sediment pond indicates that the 10 micron and finer content will produce a pond overflow lower than 25 mg/l (or as specified in an authorization from the MoE), settling aids are unlikely to be required. When initial investigations indicate that there is sufficient 10 micron and finer particulate matter entering the sediment pond(s) to exceed the allowable pond overflow TSS quality during normal operation (i.e. up to a one in 10-year, 24-hour runoff flow), the following information is applicable.

Step 1 – Assess need for settling aid

Perform a particle size analysis to determine the settling methods that will measure the content of <10 micron “spherical” particles which takes into account “shape”, lower particle density and other factors which tend to produce slower settling.

Initial testing should establish whether 10 micron and finer particulate matter entering the pond settles naturally due to low particle surface charge conditions, which may lead to efficient agglomeration. The testing conditions regarding the particle surface charge, or zeta potential, must duplicate the conditions present during the operation of the sediment pond. If the fluid being used in the test is essentially runoff water, then particle surface charge conditions should be comparable, provided the samples tested are representative. This aspect may also be investigated by identifying the minerals in the TSS entering the pond. The ZPCs (zero points of charge), or the pH at which the particle charge becomes zero for the various minerals making up the TSS entering the pond may be indicators that the particles in the pond possess surface charges that prevent agglomeration and settling of the 0.01 mm particles. The surface charge condition on the particles in the pond or surface run-off can be directly measured using equipment to measure zeta potential.

If natural agglomeration is not present then there will be a need to add suitable settling aids to settle the 10 micron and finer particles (of S.G. 2.7 and less). Absence of natural agglomeration is common because most of the common minerals have their ZPCs at low pHs; therefore, at the pH of most sediment pond operation (6.5 to 7.5), particles will have a fairly high negative charge. The high negative charge coupled with the Brownian motion effect prevents settling of 10 micron and finer mineral particles.

Given the success of flocculants (high molecular weight polyacrylamide and other similar organic compounds), it has become uncommon for coagulants to be chosen as settling aids to assist settling of fine particulate matter in the mine sediment ponds. The use of coagulants and coagulant/flocculant combinations is common in water treatment applications, or when there is a need to remove metals.

Step 2 – Selection of settling aid
The next step is the selection of a settling aid. The flocculant/coagulant suppliers are usually the best resource to obtain the necessary information and possibly to undertake testing to select and optimize a system. The purpose of a settling aid selection process is to:

- determine what settling aid promotes settling of the fine particulate;
- select a settling aid which has a relatively low toxicity; and,
- select a settling aid which achieves the discharge quality required at the lowest cost, consistent with other practical requirements.

The required settling aid dosage to achieve effective settling varies widely, particularly with flocculants. The higher molecular weight flocculants generally require lower dosages than those of lower molecular weight, while the cost/kg of flocculant is similar. The positively-charged flocculants (cationic) tend to be the more toxic compounds because they have an affinity for the negatively charged fish gills. This in turn reduces oxygen transfer across the gill.

The toxicity of the flocculants is minimized by preventing overdosing. If the flocculant addition system can add the optimum dosage, or slightly less, most of the flocculant is adsorbed onto the particles and remains in the pond attached to the particles. The key test for toxicity is performed on the supernatant fluid.

Step 3 – Determine settling aid dosages
The third step is to determine the settling aid dosages to achieve the required amount of settling enhancement. The “protective colloid” effect may result when using some flocculants if overdosing 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, producing high TSS in the effluent.

For a two-pond system in which most of the TSS entering the system is removed in the first pond, the settling aid should be added to the feed to the second pond. The advantages of this approach are that the flow rate is more stable, simplifying dosage calculations, and that the large particles have been removed in the first pond and will not then consume settling aid by providing an adsorption site. However, this approach is only practical if there is provision for adequate mixing/conditioning between the first and second ponds.

Step 4 – Determine mixing and conditioning time requirements

The final step is to determine the required coagulant/flocculant mixing/conditioning requirements. When the settling aid is introduced to the settling system, there must be a provision to allow the particles to adsorb the settling aid and for particles to collide with other particles to allow flocs/coagules to grow. Low shear mixing and adequate time is necessary to achieve this. If the flocculant is added prior to a centrifugal pump, the long chain flocculant molecule is reduced in size and tends to coil back on the same particle. This prevents any further agglomeration with suspended particles and produces a particle that will not settle out effectively.

A convenient location to add the flocculant/coagulant is to a rapidly moving, turbulent flow channel upstream from the settling pond. The addition point must be sufficiently far upstream to provide the required conditioning time determined by the laboratory testing.

Appendix C: Limitations of Stokes' Equation

The non-spherical shape of most mineral particles necessitates the application of a correction factor to the area of the sediment pond calculated using Stokes equation. A correction factor would be based on the lower settling rate produced by the particles not being spherical. Factors proposed vary from 0.852 to 0.502, or if applied to the sediment pond area, 1.18 to 2.0.

Goldman et al. indicates that while the direct application of the Stokes equation is not valid for particles larger than 65 micron, a modified method is provided. Using the information in this same reference suggests the correct safety factor to be applied (due to the non-spherical shape of many mineral particles) is closer to 2.0 rather than 1.2. The initial draft guidelines proposed a correction factor of 1.2. This factor appears to have been derived from Pettyjohn and Christiansen which is based on calculations of symmetrical shapes which are not spheres. The higher factors are based on Heyward et al. research that used testing of different mineral grains. This reference indicates that for very flat particles, a higher factor than 2.0 would be applicable.

Stokes equation does not take into account other chemical and physical phenomena that effect the settling of fine particles in a fluid. These phenomena include:

- The movement of the fluid molecules ("Brownian motion") on the fine particles impedes settling of the 10 micron and finer particles, unless coagulation/flocculation is used.
- The van der Waals attractive forces (i.e., the forces due to the universal phenomena of matter attracting matter) aids in settling fine particles through their agglomeration.
- The particle surface charge for many of the common minerals at the pH of most settling pond operations is quite high. The zero point of charge (ZPC) for most of the minerals encountered occurs at acidic pHs. Consequently, most of the mineral particles in the sediment pond will have sufficient negative charge to prevent particle agglomeration.

Finer sediments (especially clays less than four microns in diameter) routinely exhibit settling rates that depart from Stoke's Law predictions as a result of particle-particle interactions and agglomerative behaviour.

These aspects will be unknown unless settling tests and zeta potential measurements are performed. Settling pond design should be based on representative soil sampling, size analyses and settling tests using surface water from the proposed pond site.

Appendix D: References

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