Ministry Environment,
Lands and of Parks

Guidance For Assessing the Design, Size and Operation of Sedimentation Ponds Used in Mining

DRAFT

Introduction

Contaminated surface runoff from disturbed areas of operating mines is a major source of suspended solids, which can adversely affect the receiving environment around these mines [i]. The disturbed areas are usually large and include such works as the mine pits, benefaction plants and related facilities, mine dumps, tailings ponds roads, ditches, etc. It is the responsibility of each mining company to collect and treat the contaminated runoff from its operating area before allowing it to be discharged into natural watercourses. Most of the sediment in the contaminated surface runoff should be controlled by various techniques of erosion control, surface runoff control, and reclamation, as outlined in the Mines Regulation Guidelines, and in publications listed in Appendix A to this document.

Rock drains under coal spoil piles and waste rock dumps exhibit sediment buffering capacity. The diversion of sediment contaminated drainage into a rock drain may result in the drain's design capacity being exceeded and should never be undertaken without the approval of the design engineer and the mines inspector.

It should be emphasized that the success of the control of contaminated surface runoff depends primarily on the success of the above techniques in reducing the contaminants entering the sedimentation ponds to reasonably low values. Sedimentation (or settling) ponds should serve to polish the contaminated surface runoff to the required effluent guideline or permit standard.

Sedimentation ponds may also be required to remove considerable amounts of sediment for extended periods when other erosion control, or sediment control methods cannot be employed, or for relatively short periods of heavy storm runoff or spring runoff. Particularly during such periods, approved settling aids may be needed to reduce the concentration of fine suspended particles in the pond effluent. Prior to using settling aids, the permitee must obtain the written approval of the Regional Waste Manager. The Regional Waste Manager will require the necessary information on which to base the approval, particularly the 96 Hour LC50 concentration of the settling aid(s)[ii,iii,iv] and details of the settling aid selection [v,vi,vii,viii,ix,] addition rate [ix,x] (and control method), mixing conditions [v,vi,vii] and conditioning time/facilities. Details of settling aids are included in APPENDIX B.

The discharge from sedimentation ponds [x, xi] is currently regulated by Waste Management Permits for Effluents issued by the Regional Waste Manager of the Ministry of Environment, Lands and Parks. Standards contained in the Effluent Permits typically restrict the concentrations of suspended solids in pond discharges to within the range of 25 to 75 mg/L, Non-filterable Residue (TSS). The standards depend on the sensitivity of the receiving environment and downstream water uses, or as otherwise suggested by any site specific Water Quality Objective. The provincial Ambient Water Quality Guidelines (Criteria) for Turbidity, Suspended and Benthic Sediments [xii] should also be consulted. Contingent on the up-gradient activity (blasting, fuel storage, milling etc.) the permit may also contain limits on hydrocarbons, metals and nutrients in the pond effluent.

The Ministry is presently moving away from permits towards managing waste discharges through focused regulation. This may take the form of a clause in the *Conditional Exemption Regulation* or an industry sector specific regulation such as the (proposed) Industrial Pollution Prevention Regulation.

A permit or an order will be issued by the Regional Waste Manager when environmental considerations require a more stringent waste discharge standards than normal standards in a regulation.

Experience has shown that extensive logging or overburden stripping prior to surface mining operations can result in greatly increased contamination of the surface runoff. The sediment-laden surface run-off then becomes the responsibility of the mining company. Accordingly, the mining company should not allow more than the minimum possible area to be logged or stripped, and this work should be done progressively. Experience has also shown that, although the principle of diverting uncontaminated surface runoff around mining operation is desirable, the diversions themselves must be properly designed, constructed, and maintained, otherwise they may cause serious contamination of surface runoff.

Vegetation “buffer zones” have been used to assist in protecting receiving waters. Where it is not practical to leave a buffer of natural vegetation between the disturbed area and the drainage channel, revegetation of the disturbed area at the earliest opportunity is strongly recommended.

Sedimentation Ponds have been constructed “in-stream” and “out-of-stream”. “In-stream” ponds, requiring dams across watercourses, have successfully removed sediment from the contaminated runoff produced in large disturbed areas. “Out-of-stream” ponds, normally formed in flat areas, have successfully removed sediment from contaminated runoff resulting from smaller disturbed areas such as waste dumps, etc.

These Guidelines supplement similar guidelines developed by the Ministry of Energy and Mines in December 1983, titled “Guidelines for the Design, Construction, Operation and Abandonment of Tailings Impoundments”. The principles for the design, construction, operation, reclamation and abandonment outlined in the latter Guidelines also apply to sedimentation ponds.

The reader’s attention is directed to literature [xiii,xiv,xv,xvi] in the section on “References” which provides more detail on erosion control. Erosion control is considered to be an essential component to reducing the sediment entering the settling pond, and therefore possibly reducing the amount of unsettleable particles leaving the settling pond or eliminating the need for settling aids.

General Guidelines for Assessing Sedimentation Pond Design

Sedimentation ponds should be designed as follows:

1. All structures in the sedimentation pond system should be designed, as a minimum, to withstand a 1 in 200-year flood event. Even using these design criteria, there is a 10% chance that the system could fail in a mine with a 20-year life. Therefore, “over design” and back-up construction may be required in certain instances such as where there is a high consequence resulting from failure (e.g., a sedimentation pond up gradient from a school or residential area).

2. The design flow for removal of suspended solids in sedimentation ponds should correspond to the 10-year, 24-hour flood flow. Rainfall, snow melt, and combined rainfall-snow melt events should be considered in determining the design flow.

3. Accurate and up-to-date topographical maps should be used for the design and construction of sedimentation ponds, and these maps should have a maximum of 2 metre contours. (For very large facilities in steep terrain, 5 metre contours may be adequate)

4. Sedimentation ponds should either last the lifetime of the mine 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)[xvii] depth of pond liquid above the sediment.

5. Ideally, a smaller pond should be located upstream from the main sedimentation pond to remove the coarse fraction of the sediment. This smaller pond should be designed to have easy removal of sediment.

6. The inlet section of the pond should have some type of energy dissipater (such as barriers, baffles, etc.) to spread out the flow and reduce the velocity of the incoming water.

7. The discharge section of the pond should be at the opposite end to the inlet section and should have a spillway (or decant or discharge riser) designed to maintain a minimum 0.5 m freeboard on the embankment in a 1 in 200 year flood event. The spillway must 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.

8. Provisions for adding settling aids should be incorporated into the design, preferably upstream of the pond when flocculants are used, since they require longer conditioning time than coagulants. Excess flocculants may adversely affect sedimentation rate and effluent quality requirement for suspended solids may not be met if excess flocculants are added to the pond.

9. Suitable sampling and flow measuring facilities must be installed to enable monitoring of the pond discharge if required.

10. Sedimentation ponds should be provided with means of draining or dewatering, even though such operations are not planned during the lifetime of the pond.

11. The design and construction of sedimentation pond embankments:

- greater than 2.5 metres high as measured from the downstream toe (Canadian Dam Safety Guidelines), or
- capable of impounding more than 30,000 m^3 of water (Canadian Dam Safety Guidelines), or
- having a high consequence to human life or infrastructure resulting from embankment failure,

must be approved by the Dam Safety Unit, Water Management Branch of the Ministry of Environment, Lands and Parks or by the Geotechnical Engineer, Regional Operations. Health and Safety Branch, of the Ministry of Employment and Investment, if the sedimentation pond is on a mine site.

12. The preferred shape of sedimentation ponds is generally rectangular with ratio of length to width of about 5 to 1[xvii]. Such ponds tend to prevent short-circuiting, and facilitate removal of accumulated sediment. The proponent must 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 [xvii,xviii].

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

Guidelines for Assessing the Required Size of Sedimentation Ponds

Three methods for sizing sedimentation ponds for mine-related applications are presented for consideration. Alternatively, experienced engineers may use other equally effective methods and complex computer models designed for urban storm water management could be adopted for mine area use.

Method 1 is based on sedimentation tests prepared from representative soil/runoff sampling and is the preferred method when the smallest effective pond is required. **Method 2** is simplified if the critical particle size to be removed is measured using a settling method to provide the Stokes diameter. The only information lacking for **Method 2** will be to the answer to the question: “will the fine particles agglomerate ‘naturally’ in the pond?” If either Method 1 or 2 are not chosen, a third method, (**Method 3**) can be used which requires the assumption that the finest settleable particles will be present, thus requiring the maximum retention time. **Method 3** is acceptable where the larger resulting pond does not cause environmental problems. Provisions must also be made for the addition of a sedimentation aid system.

The following is a brief description of the three methods.

Method 1. A dependable method for designing the required sedimentation pond retention time is to measure sedimentation rates [i,xi] 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 sedimentation pond location and actual surface water from the area. In addition, soils should be sampled and analyzed for particle size, mineral composition and Specific Gravity (S.G.), in particular the finer particles that are difficult to settle. Measurement of zeta potential (using the “Zeta” Meter) of these particles in simulated runoff fluid will assist in defining whether “natural agglomeration” will be a factor. If natural agglomeration is a significant factor, it will reduce the sedimentation pond area required (or may eliminate the need for sedimentation aids).

The literature [v,xix] indicates that particle surface charge of greater negativity than -5 mV is not conducive to “natural agglomeration”. Also, many of the minerals encountered (clay and silicate minerals) will have a “zero point of charge” (ZPC) at acidic pHs (pH ZPC <5.0). This implies that at the pH expected in most sedimentation ponds, the zeta potential will be significantly negative and prevent “natural agglomeration” and sedimentation of the fine particles.

If a particle of size “x” mm (and measured settling rate V actual m/hour) is to be removed by a sedimentation pond of depth D m, the retention time will be [D/V actual] hours. Assuming that the settling tests indicate that removal of particles of size “x” is required to meet the necessary discharge quality, the sedimentation pond area (A m2) is then equivalent to [Q/V actual] m2, Q being the pond overflow rate in m3 / hour. Note that D = difference in vertical elevation, in meters, between the inlet and the bottom of the pond adjacent to the outlet.

Sedimentation pond design using settling tests should strive to duplicate any “natural agglomeration” that will occur during operation of the pond.

Method 2. 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:

$$\mathrm{Vs} = \frac{g}{18\mu}(S-1)D^{2}$$

where

Vs = spherical particle terminal settling velocity, cm/s

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

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

S= 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 sedimentation pond are used to determine the smallest particle size (Stokes diameter or critical diameter) that must be removed to meet the effluent guidelines. The critical settling velocity (Vsc) is then calculated from the formula Vsc =[Q/A] (Vsc = 0.01Vs) and the pond retention time/area calculated as shown in Method 1.

The information available (see APPENDIX C) suggests a 20% to 100% sedimentation 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.

It is therefore recommended that the size analysis of the finer particles is 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.

Method 3. This simplistic design approach has been used to design many of the sedimentation ponds at mines currently operating in British Columbia. Use of this method is not recommended where there are environmental reasons to have the smallest effective pond. Any natural agglomeration is not taken into consideration using this method and the resulting pond may be larger than necessary.

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 in the range of 2×10^{-5} to 5×10^{-5} m/s (assuming the temperature of the fluid in the pond is close to freezing) and then calculate the sedimentation pond area as is detailed in **Method 1**. Given a minimum pond depth of 1.5 m and a settling velocity of 2 x 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 with the assumed range of 2×10^{-5} to 5×10^{-5} m/s for the settling velocity will remove the smallest suspended sediment particle that practically can be removed by plain sedimentation (namely fine silt at 0.005 to 0.01 mm diameter). This also assumes the particle is spherical and smooth with a S.G. of 2.7. In reality the particles are angular to plate like and thus take longer to settle.

Unless there are mitigating factors, the pond should be sized to provide not less than a 20 hour detention time for a 1 in 10 year flood flow.

APPENDIX C provides more detail on some of the limitations of Stokes equation when used to design the size of the sedimentation pond without any on-site sampling and measurement of the Stokes diameter. Correction factors greater than 2.0 are suggested by the literature if very flat particles, such as mica are present.

Using **Method 3**, increased pond construction costs may more than off-set the investigation costs required to use the **Methods 1 or 2**.

General Guidelines for Sedimentation Pond Operation

1. Operating sedimentation ponds must be inspected and maintained at regular intervals and also after each period of heavy runoff.

2. The pond discharge (flow and TSS) must be monitored at the intervals required by the monitoring program of the Waste Management Permit, if issued, or the applicable regulation.

3. The pond freeboard must be maintained at 0.5 m minimum.

4. The depth of sediment in the sedimentation pond must be monitored at sufficient intervals to plan for sediment removal at minimum pond flow, but before the water depth decreases to one metre. A decision from the Regional Waste Manager or applicable regulation may specify a minimum fluid depth.

5. The sediment removed from the sedimentation ponds may be disposed of by burial or by use in site reclamation unless prohibited by a permit or regulation.

6. Should the suspended solids in the pond discharge exceed the maximum permitted or regulated discharge quality, then settling aids would need to be added upstream of the pond.

7. Following the final mine shutdown, the sedimentation ponds must be either:

a) Inspected and maintained as in 1. above, or

b) Properly reclaimed.

Approved: ------------------------

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GLOSSARY

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 regulation, 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.

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.

Contaminant - a substance added to another substance or which renders another impure, e.g., sugar added to tea would be a contaminant.

Contaminate - the act of adding a contaminant

Criteria - see Guideline

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

Flocculant - 1. an organic compound(s) that causes the formation of flocs, typically a long chain polymer, 2.a sediment or “precipitate” made up of flocs.

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.

Pollution - The presence in the environment of substances or contaminants that substantially alter or impair the usefulness of the environment.

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 tailings or sedimentation pond.

TSS -Residue, Non-Filterable, (Previously labeled Total Suspended Solids). The quantity of solid material suspended in a fluid as determined by method 0008X332 in the British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment and Biological Materials, 1994 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 and is measurable with the Zeta meter.

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 A

Information sources for the design of sedimentation ponds and the control of suspended solids in run-off.

"Land Development Guidelines for the Protection of Aquatic Habitats"

by Department of Fisheries and Oceans Canada, and

British Columbia Ministry of Environment, Lands and Parks

Practical advice for stormwater management in the urban environment.

Available from-
Habitat Branch
Ministry of Environment, Lands and Parks
PO Box 9338 Stn Prov Gov
Victoria B.C. V8W 9M1

"Reclamation and Environmental Protection Handbook for Sand, Gravel and Quarry Operations in British Columbia"

by British Columbia Ministry of Transportation and Highways, and

British Columbia Ministry of Energy and Mines

Practical advice on reclamation and environmental protection for gravel pits and rock quarries

Available from—

Highways Operations Department
Ministry Transportation and Highways
PO Box 9850
Victoria B.C. V8W 9Y5

"Rainfall Frequency Atlas for Canada"

by Environment Canada
Atmospheric Environment Service

Rainfall statistics maps for Canada and instructions on how to calculate extreme rainfall events.

Available from -

a) Your local public library

b) Supply and Services Canada

SWMM (Storm Water Management Model)

a Windows-based storm water management model, large, complex and designed for the urban environment.

Available from

USEPA -
http://www.epa.gov/docs/SWMM_WINDOWS/

APPENDIX B

Settling Aids

It is desirable to determine if there is a need for settling aids prior to the construction and operation of the sedimentation pond. This may prevent permit noncompliance and allow better planning and cost projection compared to having to add settling aid addition facilities during operation of the pond. Factors to consider include location of metering equipment, site access and the provision of electrical power.

If the size analysis of the particulate in the feed to the sedimentation pond is such that the 0.01 mm content will produce a pond overflow lower than the 25 mg/l (or as specified in a permit from the Regional Waste Manager), settling aids are unlikely to be required. When initial investigations indicate that there is sufficient 0.01 mm and finer particulate matter entering the sedimentation pond(s) to exceed the allowable pond overflow TSS quality during normal operation, the following information is applicable.

1. If the size analysis is performed using settling methods, this will measure the content of 0.01 mm "spherical" particles which takes into account the "shape" and other factors which tend to produce slower settling.

Initial testing should establish whether 0.01 mm 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 sedimentation 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 [ixx]. 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. [vi,viii]. The surface charge condition on the particles in the pond or surface run-off can be directly measured using a Zeta Meter5.

If "natural" agglomeration is not present, which is the prevalent condition, then there will be a need to add suitable settling aids to settle the 0.01 mm and finer particles (of S.G. 2.7 and less). The reason for this is because most of the common minerals have their ZPCs at low pHs; therefore, at the pH of most sedimentation 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 0.01 mm 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 sedimentation ponds. The use of coagulants and coagulant/flocculant combinations is common in water treatment applications, or when there is a need to remove metals as may be the case in effluents from tailings ponds.

2. 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 the testing to select and optimize a system7. The purpose of a settling aid selection is to:

- determine what settling aid promotes settling of the fine particulate;
- select a settling aid which has a relatively low toxicity [i,ii,iv,xx,xxi] ; 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 over dosing. If the flocculant addition system can add the optimum dosage, or slightly less, most of the flocculant is adsorbed on the particles and remains in the pond attached to the particles. The key test for toxicity is performed on the "supernatant" fluid.

3. The third step is to determine the settling aid dosages to achieve the required amount of enhanced settling. 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.

For a two-pond system in which the larger portion of the TSS feeding the system is removed in the first pond, the settling aid should be added to the feed to the second pond. This gains the advantage of less erratic changes in flow rate (on which the settling aid addition is based) and the removal of larger TSS particles in the first pond. As the larger particles do not "consume" any settling aid, dosage rates and settling aid costs are decreased. This is only practical if there is provision for adequate mixing/conditioning between the first and second ponds.

One situation to be aware of is attempting to treat suspended particulate with settling aids when the water entering the second pond contains insufficient TSS to allow effective coagulation/flocculation. This problem is solved by increasing the TSS concentration in the water being treated to the point where there is sufficient particle density to promote effective settling.

The control of settling aid addition rates can be aided by measuring the zeta potential of the particles entering the pond.

4. 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 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 effectively prevents any further agglomeration with suspended particles and effectively 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 [xxii,xxiii,xxiv] to the area of the sedimentation 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 0.8524 to 0.5022, or if applied to the sedimentation pond area, 1.18 to 2.0.

Reference xiii indicates that while the direct application of the Stokes equation is not valid for particles larger than 0.065 mm, 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[xxv], which is based on calculations of symmetrical shapes which are not spheres. The higher factors are based on reference 22 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 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 0.01 mm 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.[vii]
- 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 [ixx].

Consequently, most of the mineral particles in the sedimentation pond will have sufficient negative charge to prevent particle agglomeration.

These aspects will be unknown unless settling tests and zeta potential measurements 5 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.

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