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Settling Pond

Best Practises Guide

Part 1 Rationale

Prepared by:

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Summary

Settling ponds properly designed, constructed, operated and maintained are absolutely necessary for improving effluent water quality. The settling pond system must be in place and able to retain sediment laden water before constructing the placer mine, The use of vibrating screen decks or rotating trommel screens not only increase gold recovery, they also dramatically decrease the amount of water that needs to be treated. The control of erosion of disturbed areas by surface runoff should also be incorporated into an overall sediment control plan.

Settling ponds are used at placer mines for clarifying water due to their efficiency, simplicity and low cost. Settling ponds are efficient at removing settleable solids, generally those soil particles greater in size than from 0.002 to 0.02 mm in diameter. Settling ponds will permit the settleable solids, which includes the fine sand and silt fractions, to accumulate but are not successful in eliminating the turbidity caused by the presence of finely dispersed particles in the clay size range.

Coagulants or flocculants, or filtration do not appear to be justified from a water quality or economic standpoint as replacement for settling ponds as the primary means of solids and turbidity reduction at placer mines. Filter dams have little promise as an effective primary sediment removal technique except possibly where considerable gravity head and abundant tailings are available.

Bypass channels reduce water flow through the settling pond and thereby improve settling pond efficiency. Bypasses protect area from flood damage and thereby maintain downstream water quality. Pre-settling ponds can greatly extend the life of the main settling pond and improve the final effluent. Frequent removal of coarse sediments from pre-settling ponds is necessary.

Due to high degree of variability in water use and effluent quality at specific mine operations, placer mines with a suspended solids and/or turbidity discharge standard should consider using a total recycle system to limit the quantities of effluent discharge. Recycling reduces fresh water requirements, allows mining in drainages where water is scarce, and the quantity of effluent is reduced allowing more efficient sedimentation in settling ponds.

Cost elements of recycling water include increased pump wear, additional piping, more costly pond construction and frequent cleaning, lost revenue due to more downtime, and potential loss of fine gold due to riffle packing. Generally 40% more process water is used in recycle systems. Total recycle of process water rarely results in zero discharge due to the problem of water gain from surface and sub-surface inflows.

Effluent flow through a settling pond is a combination of the amount of process water used in the sluicebox and surface and sub-surface water flow. The amount of water required to sluice a given volume of pay gravels is dependent on whether classification/screening and/or recycle is used. For screened sluice plants with 50% undersize gravels approximately 15 Igpm of process water is required for each cubic yard per hour.

In many cases the area available for settling pond construction is not always sufficient to install a pond with the size specifications found by the following methods. Even if the area is available, installation of large ponds may require a dam at the outlet so large that it would be a hazard to those downstream (Sexton 1982). The solution in a case such as this is to build ponds in a series and/or apply techniques to reduce the pond size such as recycle a portion of the water, reduce water use, install baffles in the pond, use an inlet and outlet structure that aid in distributing water so that it flows evenly across the width of the channel.

The required volume of a settling pond should be 25% (with pre-settling) to 40% of the volume of pay gravels processed with a minimum of 0.6 to 1 m of depth between the water level and the solids build up. This would allow a reasonable safety factor and a pond size suited to the proposed time period between cleaning or abandonment.

Settling ponds should be located outside the streambed to avoid wash outs during periods of high flow or floods (R&M 1983). Settling ponds should be protected according to the risk of flood by rip-rapping nearby stream banks to prevent the lateral movement of the stream into the pond. In narrow valleys it is virtually impossible to establish and maintain settling ponds which will function as intended for any appreciable length of time. The settling pond dam must extend across the valley and as a result control the entire flow of the stream. Locating settling ponds further downstream where the valley is wider appears to be a more cost effective solution.

It is generally advisable to size the pond system so that sediment removal is not necessary (S&W 1985b). Sediment removal is expected to be very difficult and siting the pond to avoid the active floodplain is preferred. When a settling pond is full and the berms cannot be built higher, a new pond should be constructed and all practical measures should be taken to ensure the abandoned pond's stability to avoid erosion of previously settled materials.

Limitations

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This brief guide to settling pond dam design is based on recent placer mining experience in Yukon and Alaska and is not meant to substitute for professional assistance in assessment, design, construction, operation and decommission of settling ponds and/or settling pond dams. The reader is referred to Piteau (2002), R&M (1983), Nordin (1989) and CDA Dam Safety Guidelines for further details and site-specific applications.

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Table of Contents

1. Executive Summary
2. Limitations
3. Table of Contents
4. Introduction
5. Mine Planning and Exploration
6. Settling Ponds
7. Limitations of Settling Ponds
8. Filtration
9. Bypass Channels
10. Pre-Settling Ponds
11. Recycle Systems
12. Estimating Effluent Flows
13. Sizing a Settling Pond
14. Locating a Settling Pond
15. The Shape of Settling Ponds
16. Multiple Pond Systems
17. Construction of Settling Ponds
18. Maintenance of Settling Ponds
19. Monitoring
20. Rehabilitation
21. References

5 Mine Planning and Exploration

The importance of exploration, sampling and evaluation of a property prior to placer mining cannot be overemphasized. Exploration and assessment are required to avoid mining marginal ground and thereby wasting time, effort and money. Drill holes, trenches and sample pits created for sampling the deposit also provide an excellent opportunity for investigating other parameters of the site including:

a) The type, depth and nature of soils and bedrock;
b) The location of soils and rock/boulders for dam, dike and stream diversion construction; and
c) Good site selections for mine pits, settling ponds and routes for bypass channels.

From the information gained during exploration a coherent mine plan should be developed before any additional equipment is purchased and definitely before any dirt is moved. You must determine where to mine at what feed rate and with what equipment. You also need to locate your bypass channel, bedrock drains, overburden stockpiles, sluicebox, pre-settling ponds, settling ponds, tailings piles, water pumps and pipelines. Mine reclamation will be much easier and less costly with good mine planning.

6 Settling Ponds

Settling ponds properly designed, constructed operated and maintained are absolutely necessary for improving effluent water quality (S&W 1984). Before constructing placer mine, the settling pond system must be in place and able to retain sediment laden water (Entrix 1986).

The use of vibrating screen decks or rotating trommel screens not only increase gold recovery, they also dramatically decrease the amount of water required. Sluiceboxes with screened feed don’t need the higher velocity water necessary to move coarse gravel and cobbles, are more effective in breaking up clay balls and have less effluent flowing to the settling pond. The life of settling pond is lengthened with removing coarse gravels by screens. Screening can also reduce some capital and operating costs (pumping, settling etc., S&W 1984). Lower volumes of water are generally easier to treat in a settling pond with greater efficiency. Greater settling pond efficiency results in a cleaner effluent for recycle or discharge to the environment

The control of erosion of disturbed areas by surface runoff should also be incorporated into an overall sediment control plan. Drainage and local surface runoff from stripped areas and thawing overburden should be directed by ditches into the main settling pond or small detention areas (Sigma 1986). Overburden should not be allowed to enter the settling pond (R&M 1983) (unless the overburden is being stripped with hydraulic nozzles). The greatest concentrations in the main river downstream of placer mines may occur during rainstorms, rather than as a result of sluicing due to the mobilization of previously deposited sediments, failure of settling ponds and other uncontrolled man-made sediment sources are active (Chilibeck 2002).

7 Limitations of Settling Ponds

Settling ponds are used at placer mines for clarifying water due to their efficiency, simplicity and low cost. Other mechanical devices such as tube and lamella settlers and hydrocyclones also remove the same size particles as settling ponds but are much more complex and costly and their widespread use is probably not justifiable (S&W 1985b).

Coagulants or flocculants, or filtration do not appear to be justified from a water quality or economic standpoint as replacement for settling ponds as the primary means of solids and turbidity reduction at placer mines (S&W 1985b). Jennings (1983) notes that current technology is unable to overcome the problems associated with remoteness of many placer mines with regards to make-up and feeding of polymers at their proper dilution ratios. Treatment costs with flocculants range from 470% (DINA, 1981) to 1160% (EPA 1984a) of a simple settling pond system. Site specific testing by experienced professionals is required to select and design a coagulation/flocculation system. Some coagulants and flocculants may be harmful to aquatic life and or wildfowl (Chilibeck, 2003).

Even though most alternative gold separation technology such as mineral jigs and spirals reduces water use, it does not appear that this will improve downstream water quality, due to the apparent reduced performance of settling ponds at high influent suspended solids concentrations (S&W 1985b).

In comparison to most industrial or municipal water users, placer mines generate wastewater volumes that are extremely large in relation to the size and resources of the operation (Sigma 1986). The quality of water discharged from conventional sluice operations with no recycle is dependent on the use of a bypass, feed classification, and a well-designed, constructed, operated and maintained settling pond system (S&W 1985b). Sedimentation does not effectively remove the fine particles, and filtration through tailings dams often allow relatively high concentrations of TSS to pass through the dams (S&W 1984).

Settling ponds are efficient at removing settleable solids, generally those soil particles greater in size than from 0.002 to 0.02 mm in diameter (R&M 1983,S&W 1985b). Well designed and maintained settling ponds should be able to consistently reduce settleable solids to less than 1 ml/l (S&W 1984) resulting in a reduction of about 96% of the settleable solids. The lowest levels of settleable solids in the pond effluent are used as an indicator of good settling pond performance (S&W 1985b).

Well-designed, operated and maintained settling ponds will result in a major improvement in suspended solids levels (Sigma 1986). However, it is much more difficult to settle suspended fine silts and clays due electrical forces between the fine silt and clay particles. Total suspended solids concentrations in settling pond effluents are usually about 100 times higher than natural background conditions (R&M 1982).

Settling ponds will permit the settleable solids, which includes the fine sand and silt fractions, to accumulate but are not successful in eliminating the turbidity caused by the presence of finely dispersed particles in the clay size range (Christianson 10th). The lowest turbidity levels obtained with settling ponds are about 100 NTU (Brossia 1980), the degree of turbidity depends on the type of soils.

8 Filtration

Filtration is often quoted as an option to remove the fine silt and clay sized particles that a settling pond does not effectively remove (S&W 1984). The efficiency of filtration depends on the grain size of the tailings, the thickness of the layer of tailings and the volume and concentration of the effluent to be filtered. The most effective filtrations systems for placer mine effluent have a layer of selected sand size material within the tailings filter and/or long distances of tailings to filter through. Filtration through tailings dams often allow relatively high concentrations of TSS to pass through the dams because the filter matrix (coarse tailings) is usually considerably larger than the fine suspended particles to be removed (S&W 1984). Depending on the concentration of the effluent, many filters with the appropriate sand size material plug up relatively quickly.

Filter dams have little promise as an effective primary sediment removal technique except possibly where considerable gravity head and abundant tailings are available. A filter subjected to 10,000 mg/l or higher would have a short effective life prior to clogging (DINA 1981). Otherwise filters may be practical as a final polishing step before release to creek (S&W 1985b).

9 Bypass Channels

Bypass channels reduce water flow through the settling pond and thereby improve settling pond efficiency. Bypasses protect area from flood damage and thereby maintain downstream water quality. Clean bypass water can provide dilution that may allow a miner to meet a downstream water criteria (S&W 1984).

A bypass should be constructed so that it can be used for as many cuts as practical. It should be located far from the cuts and ponds as possible so that seepage between the bypass and the cut and ponds is minimized. Bypass should be constructed so it intercepts all surface flow from one hillside. It should be located where the ground is as stable as possible, preferably in an old stream channel that has not been in filled with fine material. The bypass must be sized to handle floods from entire drainage to protect cut, equipment and ponds from flooding. If natural water gain does not provide enough makeup water, it is recommended that a small water supply pond be built on the bypass and the makeup water be pumped from that pond to the recycle system. This protects the pump from damage by floods and except for seepage flow, water flow through the recycle system ceases when the pump is shut off (S&W 1985b).

When mining on a bench or off the main channel a bypass is not necessary leave the stream where it is and take make up water from it.

10 Pre-Settling Ponds

Pre-settling ponds can greatly extend the life of the main settling pond and improve the final effluent. Sigma (1987) estimated that 72% of the total sediment deposited at a high bench placer mine could have been removed with a pre-settling pond. Pre-settling ponds can remove particles from the sluicebox effluent that are sand sized and larger (this typically is about 1/6 of the volume of pay dirt processed, (R&M 1983).

Frequent removal of coarse sediments from pre-settling ponds is necessary without difficulty with a bulldozer or front-end loader (R&M 1983). Therefore the pre-settling pond must be shallow with a flat hard bottom. The pre-settling pond could be a large depression in the tailrace channel between the sluicebox and settling pond or it could be constructed with a shallow berm of tailings across the tailrace. There should also be adequate space to drain and store the tailings. Sediment removed from the pre-settling pond should be free-draining enough to use as backfill in the active mining area (Piteau, 2002).

The size of the pre-settling pond will depend on the desired frequency of cleaning but should be roughly 1/5 to 1/10 the size of the main settling pond.

11 Recycle Systems

Due to high degree of variability in water use and effluent quality at specific mine operations, placer mines with a suspended solids and/or turbidity discharge standard should consider using a total recycle system to limit the quantities of effluent discharge. Recycling reduces fresh water requirements, allows mining in drainages where water is scarce, and the quantity of effluent is reduced allowing more efficient sedimentation in settling ponds (S&W 1985b).

Cost elements of recycling water include increased pump wear, additional piping, more costly pond construction and frequent cleaning, lost revenue due to more downtime, and potential loss of fine gold due to riffle packing (S&W 1984). In general recycle ponds cost more to build than simple ponds due to extra precautions taken to prevent damage from floods to pumps and drains that were installed to allow slimes removal (S&W 1984). At mines that recycle, the water level in the recycle pond must be closely controlled to prevent flooding and/or alternately starving the pump (S&W 1985b).

Placer mine costs vary from site to site but recycling generally costs about twice as much as simple flow through settling pond or an average of about 16% of annual costs, not including the lost opportunity cost (S&W 1985b). The opportunity cost associated with recycle is the value of production time (revenue) lost due to the complexity and complications of a recycling system vs. the simplicity of settling ponds (S&W 1985b). Pump wear can be minimized by providing adequate settling to less than 0.2 ml/l settleable solids. However, extra precautions must be taken to prevent roots and debris from fouling the pump intake and spray nozzles.

Total recycle of process water rarely results in zero discharge due to the problem of water gain from surface and sub-surface inflows (S&W 1985b). The system must discharge an amount of water equal to the water gain plus the displacement volume of solids settling in the pond (S&W 1985b). Most pond dikes are constructed of tailings and most pond bottoms are either fractured bedrock or more tailings and it is common for seepage into and out of the ponds to occur. Outflow from a pond may be self-limiting due to plugging of the pores over time (S&W 1985b). There may also be seepage or non-point source discharge from the mine site (S&W 1985b).

Generally 40% more process water is used in recycle systems (S&W 1985b) due to the build up in suspended solids concentration in a recycle system. The fine solids will alter both the density and viscosity of the process water. Even though the quantity of effluent is reduced, the suspended solids and turbidity levels may still be relatively high. Additional treatment may be required to meet discharge standards where stream dilution is not considered or not available (R&M 1983).

Potential pond construction sites should be determined to see if adequate solids removal and retention will be provided ahead of pump intake, cut sizes and pond locations should be adjusted until this occurs (S&W 1985b). The most common failure of existing recycle systems is sluicing stops because recycle pond becomes choked with sediment (S&W 1985b). The distance between a mining cut and an area large enough to build a recycle pond may be to great to allow economical recycle (S&W 1985b). High flood flows especially in narrow valleys, may make it impractical to protect a recycle pond system from flooding, washouts, infilling with silt (S&W 1985b). A very high gradient may result in high pumping head and costs (S&W 1985b).

12 Estimating Effluent Flows

Effluent flow through a settling pond is a combination of the amount of process water used in the sluicebox and surface and sub-surface water flow. In a recycle system only the net inflow needs to be released from the pond. In a flow-through system all the effluent water must be treated and released. Inflow can be controlled by construction of ditches around the mining cut, processing plant and settling pond, or by lowering the ground water table by installing a drain (S&W 1985b). The construction of drains In fine permafrost soils can lead to continued thawing and sloughing that adds solids to the water flowing through (S&W 1985b).

In a low lying areas with a good bypass ditch, the volume of inflows are commonly 25 to 50% more than the process water, depending on the nearness to a water body and the percolation rate of nearby gravels (frozen and unfrozen). In high bench deposits, there would probably be water loss through the gravels that would have to be made up by pumping from a creek or river. Generally the installation of pond liners is very expensive and almost cost prohibitive for a pond that has a useful life of one to two years (S&W 1985b).

The amount of water required to sluice a given volume of pay gravels is dependent on whether classification/screening and/or recycle is used. For screened sluice plants with 50% undersize gravels approximately 15 Igpm of process water is required for each cubic yard per hour (e.g. 3,000 Igpm of water would be required for a operation processing 200 cubic yards per hour). For unscreened sluiceboxes the average amount of water required is approximately 120% more (6,500 Igpm) (S&W 1985b). For total recycle systems the amount of process water is increased by 40% (S&W 1985b) to allow for the reduced washing ability and increased probability of riffle packing. Mineral jigs and centrifugal concentrators significantly reduce water use but are more expensive and complicated to use (S&W 1985b) and their high-density effluent is more difficult to settle in settling ponds.

13 Sizing a Settling Pond

In many case the area available for settling pond construction is not always sufficient to install a pond with the size specifications found by the following methods. Even if the area is available, installation of large ponds may require a dam at the outlet so large that it would be a hazard to those downstream (Sexton 1982). The solution in a case such as this is to build ponds in a series and/or apply techniques to reduce the pond size such as recycle a portion of the water, reduce water use, install baffles in the pond, use an inlet and outlet structure that aid in distributing water so that it flows evenly across the width of the channel (Sexton 1982).

The most significant factors affecting sedimentation in pond are: the percent fine silt and clay in the pay gravels; the feed rate of pay gravels; the rate of flow of effluent through pond; the surface area/volume of the pond; and the less predictable effects due to short circuit of flow - entrance and exit effects (R&M 1983, Sigma 1986). Other factors include the amount of fines removed with the coarse tailings, settling in the drain or pre-settling pond, turbulence and currents, natural flocculation/water chemistry and sludge density (Sigma 1986).

Very small improvements in effluent quality require very large increases in settling pond sizes (Govt of B.C. 1996). Therefore it is important to reduce the water use through classification of feed gravels and recycling of process water (where practical). Settling ponds must be large enough to remove a certain percentage of the solids and also have sufficient capacity to store the sediment removed from suspension (ADEC 1979). The major cause of deterioration in pond performance is the accumulation of sediment, to the point where scour equals or exceeds particle settling (Christianson 10th).

There are several methods to determine the size of a settling pond including: theoretical methods employing Stoke's Law; settling column tests; empirical methods and sediment storage methods. Weagle (1984) found that Stokes law did not predict the settling velocities in the settling ponds he observed due to the presence of currents, convection, differing temperatures and viscosities, non-uniform concentration of particles, variations in particle shape and specific gravity. Sigma (1986) also concluded that unfortunately none of these methods employing Stokes Law appear to be practical or useful for the application to placer mining settling pond design.

Sexton (1982) favored the use of settling column overflow rate tests. Column settling tests consist of adding pay gravel and creek water in similar proportions to the sluicing operation, mixing to was the gravels, pre-settling for a short period to remove the sand sized particles, then decanting the simulated effluent into a 2 m high by 150 mm diameter settling column. Samples for suspended solids analysis are then periodically withdrawn from ports at varying depths in the column.

The reliability of these relatively expensive tests is very dependent on obtaining a representative sample of the tailings to be processed throughout the season. Sexton applied a safety factor to predictions based on settling column tests ranging from 1.5 to 11.4 to account for less than ideal conditions in typical settling ponds. Sigma (1986) also found that the settling test results were highly variable between the mine sites they tested and attributed variances from their predictions due to changes in the mine tailings throughout the season.

Other authors including Weagle (1984) and R&M (1903) sized ponds based on empirical observations at Yukon and Alaska placer mines. Weagle recommended an overflow rate of 1877 Igpm per acre of settling pond. R&M recommended an overflow rate of 3700 US gpm/acre of settling pond to meet 0.2 ml/l settleable solids criteria and no more that 860 US gpm/ acre to reduce suspended solids to minimum practical levels based on field studies of six operations in Alaska. These calculations lead to extremely large settling ponds.

Sigma (1987) found that the size of settling ponds was governed mainly by the requirement for sediment storage. They recommend providing a small additional volume for retention time to achieve effluent quality standards. They found that settled solids occupied 40% of the pay gravel volumes sluiced and that this figure was reduced to 25% with pre-settling. They recommended that at least 5 hours hydraulic retention time should be provided to achieve a hypothetical standard of 0.2 ml/l suspended solids.

Sigma (1986) recommended a minimum pond depth of 1.5 meters. If constructed with very shallow depths the pond would lose its effectiveness sooner due to excess horizontal velocities and bottom scour near the outlet (Sigma 1986). Shannon & Wilson (1986b) recommended 0.5 yd3 for each yd3 of pay gravel processed in addition to a minimum of 2 feet of water over the settled solids. Sexton (1982) recommended a minimum depth of 2 feet between the water level and the solids build-up.

Accordingly the required volume of a pond should be 25% (with pre-settling) to 40% of the volume of pay gravels processed with a minimum of 0.6 to 1 m of depth between the water level and the solids build up. This would allow a reasonable safety factor and a pond size suited to the proposed time period between cleaning or abandonment.

14 Locating a Settling Pond

14.1 Wide Valleys

A settling pond can occupy valuable space and is an asset that should be used for as long as possible. A settling pond should be located so it will be useful for future mining areas and have a maximum useful life span (Piteau, 2002). The physical conditions are different at almost every placer mine and ideal conditions are rarely encountered. The best approach in selecting a site for a settling pond is to use an area that best approximates ideal conditions.

An ideal pond/dam site is on gently sloping terrain or in a depression that is underlain by a thick layer of fairly impervious consolidated material. Where these materials occur at the surface or where bedrock has already been reached by mining, no special measures are required (R&M 1983). The use of previous mining pits for settling ponds can reduce reclamation costs significantly. At a new site pond may be excavated in virgin ground and placer material present stockpiled for later processing while the non gold bearing material may be used in dam construction (Entrix 1986).

Settling ponds should be located outside the streambed and flood plain to avoid wash outs during periods of high flow or floods (R&M 1983). Settling ponds should be protected according to the risk of flood by rip rapping nearby stream banks to prevent the lateral movement of the stream into the pond (Entrix 1986) or by excavating cut-off trenches to divert surface flows and convey them around the pond (Piteau, 2002). Erosion of settling pond dikes and deposited fine grained sediments by stream flow may negate the benefits to the environment derived from initially constructing and operating the pond (Sigma 1986).

Constructing the settling pond in a widened section of the stream is not recommended (R&M, 1983). Only process water should be allowed to enter the pond and not the entire volume of the creek (Sexton 1982) where practical.

14.2 Narrow Valleys – Creek as a Conduit

In narrow valleys it is virtually impossible to establish and maintain settling ponds which will function as intended for any appreciable length of time. The settling pond dam must extend across the valley and as a result control the entire flow of the stream (see section 17 construction of settling ponds, cross-valley dams). If a miner has access to wider areas downstream, it may be more cost effective to locate settling ponds further downstream (Envirocon 1986).

Narrow valleys and gulches may not be wide enough to construct a settling pond, drain, bypass channel and access road. In these cases the creek may be used as a conduit to carry the entire creek flow and mine drainage downstream to wider valley areas where the entire water flow must be treated in a settling pond prior to discharge.

Using the creek as a conduit may also be appropriate in wider valleys where there is access to large areas of dredge tailings downstream or very large pits for use as settling ponds downstream. In these circumstances there may be a net benefit to the environment due to:

a) Access to a much larger area for settling and therefore better final effluent quality; and
b) Infilling and reclaiming of the large pits; and
c) Infilling coarse dredge tailings with fine solids to promote natural revegetation.

15 The Shape of Settling Ponds

The optimum length to width ratio for settling ponds will probably be in the order of 3:1 to 5:1 as long as the water velocities are kept below 2 ft/min (Christianson 10th). A flow velocity of 2 ft/min is the level at which scouring and resuspension of particles is likely to occur (Christianson 10th). Long settling ponds may be constructed along the contours of valley walls provided the excessive velocities are not produced in the narrow cross section ponds (Entrix 1986).

Old mine pits are often used for settling ponds and may be refilled and reclaimed with tailings. Where it is necessary to construct or use a square pond or a pond with a length to width ratio of less than 5:1, it will be necessary to incorporate baffles into the design to increase the effective flow length and reduce short circuiting in the pond (Piteau 2002, R&M 1983). Berms will however reduce the storage volume of the pond (S&W 1985b). Frank Hawker (2004) suggested the use of sheets of geotextiles as easily constructed pond baffles that don't reduce the storage volume of the pond. The long sheets are strung across the settling pond and tied with ropes to anchors or trees. These types of baffles due not reduce the storage volume of the pond.

16 Multiple Pond Systems

The first pond should be a pre-settling pond and should be constructed to allow cleaning on a regular basis.

In narrow valleys, multiple settling ponds may be required. A multiple pond system is preferable to single pond in a recycle system. Solids cannot flow from one pond to the other pond. The recycle pump can be placed in second pond which is free of solids and a third pond may be constructed to polish the effluent before discharge. If one pond is used eventually the solids with flow to and block the intake of the pump.

The water quality of the final effluent depends on the size of the largest pond in the system. Two small ponds are not a substitute for one large pond (S&W 1985b) as there is no cumulative effect. If the second pond is the same size or smaller than the preceding pond, the effluent quality will not be substantially improved because the particle sizes which would have been trapped have already been removed in the previous pond.

17 Settling Pond Construction

Settling ponds are normally a simple dugout or bermed pond and may be lined to prevent seepage (Piteau, 2003). The main components are the inlet, rip-rap energy dissipater (if required), pre-settling pond, main settling pond, polishing pond (if required) and outlet. Vertically a settling pond is composed of a bottom (Piteau, 2003).

Where practical, settling ponds should be located on gently sloping terrain or in a depression that will allow cut and fill construction to provide the necessary pond volume and dam construction material (Piteau, 2002). Cut slopes in undisturbed natural soils should be no steeper than 2H:1V. If the excavation or previous mine pit that is being used for a tailings pond is well below the water table, excessive seepage could occur and cause cut slope stability problems (Piteau, 2002). This can be corrected to some extent by placing a blanket of coarse rock along the toe of the excavated slopes (Piteau, 2002). Also excavated material that is very wet may not be suitable for dam building and will have to be hauled away and stored elsewhere (Piteau, 2002).

If there is a shortage of topsoil in the area, it should be removed from the pond area and stockpile for later use. Disturbed areas should be left in a condition to promote natural regrowth of vegetation (i.e. a scarified, roughened, surface with fine soils and low slopes).

18 Dikes and Dams

18.1Introduction

This brief guide to settling pond dam design is based on recent placer mining experience in Yukon and Alaska and is not meant to substitute for professional assistance in assessment, design, construction, operation and decommission of settling ponds and/or settling pond dams. The reader is referred to Piteau (2002), R&M, 1983 and CDA Dam Safety Guidelines for further details and site-specific applications.

Dam sites on a placer claim are limited but effort should be made to choose the best available site to prevent failure and subsequent rebuilding (R&M, 1983). Ideal dam site is on or underlain by a thick layer of fairly impervious consolidated material. Where these materials occur at the surface or where bedrock has already been reached by mining, no special foundation measures may be required (R&M 1983). The suitability of the site will also depend on its ability to hold water (R&M, 1983) and its proximity to suitable dam construction materials. The organic overburden should be stripped from the dam foundation Piteau, 2002.

Care should be taken to locate a dam where its failure would not result in loss of life, injury or the interruption of operations (R & M, 1983). The design and construction of sedimentation pond embankments:

a) Greater than 3 m (10 feet) high as measured from the downstream toe; or
b) Capable of impounding more than 30,000 m3 of water; or
c) Having a high consequence to human life or infrastructure

resulting from embankment failure should be designed by a competent professional (Piteau, 2002). It may be necessary to construct a series of settling ponds to result in dams lower than 10 feet high (R&M 1983) or use a combination of excavated pits and lower dams to achieve the required depth.

18.2 Definitions (from Piteau, 2002)

Abutment – the part of the valley side or slope against which the dam is constructed.

Anti-seepage collar – a flange attached and sealed to a pipe to prevent seepage along the pipe surface.

Dam – Barrier that is constructed for the purpose of enabling the storage or diversion of water, effluents and fluid tailings.

Failure – The uncontrolled release of the contents of a reservoir through the collapse of the dam or some part of it.

Foundation – Rock and/or soil mass that forms the base of the structure, including the abutments.

Overtopping – Flow of water, effluent or fluid tails over top of a dam, often accented by wave action.

Freeboard – The height of the dam above the maximum operating level, provided for safety against overtopping.

Toe – Junction of the downstream (or upstream) face of the dam with the ground surface (foundation)

Dam Crest – The uppermost surface of a dam proper, not taking into account any crowning for settlement or any structures that are not part of the main water retaining structure.

Piping – Channel erosion (pipe shaped) that occurs due to a concentrated flow through a dam.

Pore Pressure – The internal water pressure in the pore spaces between soil particles that can lead to reduced shear strength of the materials.

Cut-off Trenches – trenches excavated in the foundation or bottom of a dam and lined with relatively coarse gravels to draw seepage down lower in the dam structure.

18.3 Tailings Dams

Tailings dams used in placer mining are generally earth fill dams of a homogenous, zoned or lined construction. The most common and generally most reliable dams are made of homogenous earth fill where the fill is composed of a well-mixed, well-graded soil (ranging in size from silt to boulders). The rock tends to hold the dam together while the finer soils help prevent seepage through the dam and generally eliminate the need for an impervious core. Organic soils, black muck and frozen materials should never be used for water retention dams/dikes because these materials lose all their strength when subjected to excessive quantities of water (Nordin, 1989).

If dam is built of tailings sands and gravels, seepage through the dam is common, excessive seepage may cause failure of the dam. Cut-off trenches and anti-seepage collars around culverts may be installed to limit seepage (Entrix 1986).

Granular soils and/or coarse tailings materials can be used for zoned dam construction provided that they have an inner core of relatively impervious material such as glacial till, mixed silty overburden with tailings or plastic sheeting. The mixed tailings core should be at least 12% by weight of silt-sized particles to the weight of the tailing that with pass a three -inch screen (R&M

1983). The till and/or tailings mix provides an impervious or "leak proof" core, or upstream section of finer grained materials to limit seepage.

Zoned dams require much greater care in design, construction, compaction and water content (Nordin, 1989). A filter may be required on the downstream side of the core. In practice it is difficult to achieve adequate compaction at the interface of the core and the upstream zone; the interface of the core and the filter; and the interface of the filter and the downstream shell (Piteau, 2002). Unless absolutely necessary, zoned dams should be avoided, due to their complexity of construction (Piteau, 2002). Where foundation investigations suggest a zoned dam may be required, a professional engineer should be consulted to prepare the appropriate designs (Piteau, 2002).

Where only coarse soils are available (e.g. sand and gravel), a membrane dam may be required to prevent significant seepage. A membrane of PVC, polyethylene (HDPE), asphalt or clay would be incorporated into the upstream face to limit seepage. A professional engineer should be consulted to prepare the appropriate designs (Piteau, 2002).

Compaction of materials during dam construction is critical. Compressing materials by running back and forth with a bulldozer is standard practice. Many dam are built with crests only wide enough to allow a single pass with a bulldozer. This practice results in the central part of the dam be insufficiently compressed (Nordin, 1989) and potential dam failure. All dams should be constructed by having the crest of the dam twice as wide as the bulldozer (or compacting equipment) so that the center can be compacted. Alternatively, for narrow dams, the bulldozer can run back and forth right over the dam at right angles to the long axis of the dam (Nordin, 1989). The construction materials should be thoroughly mixed and placed in thin (less than 0.3 m, 12 inches) layers and thoroughly compacted before the next layer is placed until a dense firm embankment is achieved.

Dams should have a crest of at least 3 meters, and upstream and downstream slopes of 2.5:1 (h:v) or flatter when constructed of granular tailing materials (R&M 1983, Chilibeck, 2004). Flatter slopes 3:1 or less may be appropriate where dam heights exceed 3 m (10 feet) or where fine-grained materials are used in dam construction (R&M 1983). The coarsest available materials (coarse washed tailings, broken rock etc.) should be placed along any slopes exposed to flowing water and extend to an elevation 0.6 m (2 feet) higher than the annual high water mark (Chilibeck, 2004).

Outlets should be constructed to limit the level of water to at least 0.6 m (2 feet) below the top of the dam. Where a dam is subject to periods of high flow an emergency overflow spillway be constructed on the lower portion of the dam at least one half foot above the normal water elevation in the pond. All spillways must be able to safely pass the design flow rate (Nordin, 1989). If a dike must be built "in-stream" the spillway must be large enough to pass the design flood without losing the dam. The required width and depth of the spillway is site specific and depends on size and frequency of flood flows (R&M 1983).

Overflow spillways should be constructed and designed to avoid erosion or washouts from the pond discharge (R&M 1983). The outlet of the settling pond should be armoured with coarse material to prevent erosion at the toe of the dam (Entrix 1986). A minimum of two feet thickness of angular rock averaging 8 inches diameter should be placed on the downstream slope of dam and at the toe of the spillway (R&M 1983). Crest of dam spillway should be protected with a least a one-foot thickness of four-inch angular rock (R&M 1983). Filter cloth, plastic sheeting, timber cribbing or other materials may be used on the spillway to limit erosion (R&M 1983).

A riser type outlet should be used if there is no angular rock on site (R&M 1983). Riser outlets constructed with culverts at least 18" diameter to limit plugging with floating debris. The culverts should be at least 1" diameter for each 100 gpm of flow. Ideally there should be at least one riser for each 150' of pond to limit non-uniform velocities through the pond (R&M 1983).

Cut-off collars should be installed around the pipe portion in the dam to prevent seepage and erosion along the pipe. The collars should extend at least 2 feet beyond the pipe and consist of sheet metal, polyethylene or other impervious material. An apron of rock of a minimum of eight inches in diameter should be provided at pipe outlet to prevent erosion at the toe of the dam (R&M 1983).

Cross-valley dams are placed in steeper stream sections to control channel erosion and movement of sediments. They are built similar to earth fill dams but of the coarsest available granular materials with side slopes not to exceed 1.5:1 H:V. The downstream face should be armoured with the largest available materials including an adequately sized and armoured spillway. The sides of the dam must be keyed into rock outcroppings or valley walls (Chilibeck, 2004).

This brief guide to settling pond dam design is based on recent placer mining experience in Yukon and Alaska and is not meant to substitute for professional assistance in assessment, design, construction, operation and decommission of settling ponds and/or settling pond dams. The reader is referred to Piteau (2002), R&M, 1983 and CDA Dam Safety Guidelines for further details and site-specific applications.

18 Maintenance of Settling Ponds

Settling pond maintenance begins with the development of the mining plan since that is the time to consider where to locate them and how large to make them (S&W, 1985b). It is generally advisable to size the pond system so that sediment removal is not necessary (S&W 1985b). Sediment removal is expected to be very difficult and siting the pond to avoid the active floodplain is preferred (Entrix 1986). When a settling pond is full and the berms cannot be built higher, a new pond should be constructed and all practical measures should be taken to ensure the abandoned pond's stability to avoid erosion of previously settled materials (Envirocon 1986).

Sediment removal is suggested if there is insufficient room for large pond. The pond should be dewatered and all sediment-laden water should be treated elsewhere. If available, a dragline can remove deep sediments, however, the pond should be configured so that all parts of it can be reached with the dragline. It may be possible to remove shallow deposits of sediments on flat hard-bottomed ponds with bulldozers or front-end loaders once the pond is drained. Operation in dirty water can increase maintenance costs of equipment. During the mining season, sediments should be removed from a settling pond when they accumulate to 60% of the design storage volume or when sediments are less than 2 feet from the water surface (Entrix 1986). Tailings ponds sediments take a long time to dewater, are very difficult to handle, and tend to flow away at very low angles of repose. Generally it is impractical to clean out a settling pond more than one or two times (Frank Hawker, 2004).

Depending on topography and how dry the solids are, the solids can sometimes be either removed through the breach or be pushed up over the edge of the pond (S&W 1985b). A drain can be made by placing a valve pipe in the dike during construction or by breaching the dike prior to cleaning (S&W 1985b). The entrance to drain pipes should be screened and cleaned regularly to prevent blockages (which may be problematic). The drainage water will likely have high levels of suspended solids and should be contained in a smaller settling pond rather than be discharge directly to the receiving stream (S&W 1985b).

Sediment removed from settling ponds should be stacked to drain in an area that is protected from floods and surface runoff. Containment berms constructed between the sediment stockpile and the stream will prevent silts from being washed into the stream. Stockpiles can be graded, smoothed and then capped with a layer of tailings or granular material to prevent erosion (R&M 1983). If a pond is to be abandoned it should be drained and protected from erosion.

19 Monitoring

A settling pond inspection should be conducted at weekly intervals and after every major storm (Piteau, 2002). A visual inspection should be conducted of the cut slopes and dikes surrounding the pond, both upstream and downstream, for evidence of instability, overtopping, erosion or piping (Piteau, 2002). Any damage noted should be repaired as soon as possible to reduce the risk of failure (Piteau, 2002). The erosive power of water is remarkable.

Monitor pond effluent on regular basis with Imhoff cone to determine if it is becoming ineffective due to fill up or short-circuiting (R&M 1983). Monitoring with an Imhoff cone will also help protect against high pump wear in recycle systems. If the discharge standards are based in settleable solids, an Imhoff come can help ensure compliance with discharge standards.

20 Rehabilitation

Off-Channel Settling Ponds

Settling ponds located near or below the grade of the restoration channel may simply be left to fill in with water and drain back into the stream. The fine-grained materials in the pond typically revegetate with wetland-type plant species. Settling ponds located next to the stream channel, and with a final pond elevation above the channel should be breached. Ditching should be provided to intercept and control pond drainage. Ponds can also be backfilled and allowed to revegetate (Chilibeck, 2004).

If the ponds are located in low-lying areas near the stream channel it may be advisable to place/grade coarse (erosion resistant) tailings over the pond to stabilize the sediments in place. Entrix (1986) suggests a minimum thickness of 3 ft and grading to conform to the surrounding topography. In areas where required, prevent lateral migration of the stream into the settling pond if necessary using riprap (Entrix 1986).

In areas with limited fine soils, the fine sediments from settling ponds may be removed and spread over coarse tailings to assist natural revegetation.

In-Stream Settling Ponds

Due to their location in the middle of the stream, in-stream settling ponds generally have a greater potential for erosion and the transport of sediments. If it is not practical to remove the sediments it should be stabilized. There are several methods to do this:

a) Cap the pond with coarse tailings and divert the stream channel down on one side of the pond along the valley wall in the form of a bedrock spillway; or
b) Construct a spillway down the face of the dam at the downstream end of the pond to safely convey stream flows (Chilibeck, 2004).

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