The Use of Chemical Flocculants for Water Clarification: A Review of the Literature With Application to Placer Mining

by
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EXECUTIVE SUMMARY

Chemical clarifiers have been commonly used to treat industrial and mine effluent in the lower 48 states; however, such treatment has not been widely used in Alaska. Attempts to use coagulants and flocculants to treat placer mine effluent in Alaska have had limited success. Effectiveness has been hindered by inadequate mixing and dispersing and by selection of chemicals which do not perform optimally in cold temperatures, or which are not effective in settling ultra-fine clay particles. Lack of adequate pre-settling of heavier particles before applying chemical clarifiers has increased chemical costs and resulted in poor settling.

Recent research on the use of chemical clarifiers to treat placer mine effluent in northern Canada has shown that such treatment is successful in reducing total suspended solids levels and turbidity. Treatment can be economically feasible if minimum dosages are used to obtain the desired degree of water clarity and if mixing and dispersing systems are designed for remote locations where power supplies are limited.

Coagulants and flocculants used to treat placer mine effluent will increase treatment costs over no treatment or treatment with settling ponds alone. However, chemical treatment may be the most effective means of reducing sediment pollution, especially in areas where fine clays are abundant. Chemical treatment may be most effective when used in combination with other mining practices, including water reduction, filtration and overland discharge.

Literature on the applications of coagulants and flocculants to treat wastewater was reviewed to determine possible applications to placer mining. The review provides background information on applications of organic and inorganic chemicals to treat wastewater, factors influencing the effectiveness of these chemical compounds, and methods of application. Estimates of capital costs for equipment and costs of chemicals, including methods to estimate dosage requirements, are presented.

I. Introduction

A tri-agency placer mining studies program was initiated by Alaska Departments of Fish and Game (ADF&G), Natural Resources (ADNR), and Environmental Conservation (ADEC) at the beginning of Fiscal Year 1985 (FY85). An objective of this program is to examine basin-wide effects of placer mining on fish resources and to investigate options for basin planning, including best mining practices. As part of best mining practices, we are evaluating methods for reducing water pollution caused by mining, including the use of chemical clarifiers to remove fine sediment particles.

The following review briefly discusses the problems of treating placer mining wastewater and presents published and unpublished literature pertaining to chemical clarification of wastewater, with an emphasis on applications to placer mining. The review provides background information on applications of organic and inorganic chemicals to treat wastewater, factors influencing the effectiveness of chemical clarifiers, and methods of application. This document is a component of the Tri-Agency Placer Studies Report.

II. Placer Mining Wastewater Treatment

In placer mining, gold is separated from lighter sediment by washing, usually through a sluice box with water from a nearby stream. Washing the gold from gravels and soils results in wastewater with high levels of suspended sediments. Many of the suspended sediment particles are heavy and will settle naturally if the water is held in a still pond where turbulence is minimized. Placer mining in Alaska, however, often occurs in areas with a high content of weathered, clay-sized particles. These fine particles, released during the gravel washing process, settle very slowly or, for practical purposes, not at all. As a result, turbidity levels that are higher than natural stream levels often persist far downstream from placer mine sites.

The adverse effects of elevated turbidity and total suspended solids on aquatic habitat have been well documented in the literature and more recently by studies conducted in Alaska. For example, Lloyd (1985) presented a literature review that documented adverse affects of turbidity to primary and secondary productivity in fresh water systems. Burkholder (1985) reported higher mortalities of young-of-the-year (less than a year old) grayling in placer mined streams than in clear water streams. Weber and Post (1985) measured aquatic invertebrate populations ten times greater in clear water streams than in turbid water sites below placer mining.

Peterson et al. (1985) reviewed literature on the effects of turbidity and total suspended solids on biological communities. As a result of data presented in published literature, they recommended that Alaska State Water Quality Standards for fish and other aquatic life should not exceed 5 Nephelometric Turbidity Units (NTU) above background for natural turbidity up to 25 NTU. For waters of natural turbidity above 25 NTU, Peterson et al. (1985) recommended that the allowable increase should not exceed 25% of the background turbidity.

Current Alaska State Water Quality Standards allow no more than 5 NTU increase in turbidity above background for drinking water and no more than 25 NTU increase above background for protection of fish and wildlife. These standards are difficult to meet in many placer mining areas without additional water treatment. Ponds alone are often not effective in settling these fine particles to levels that meet water quality standards for turbidity.

III. Description of Chemical Clarifiers

Theories of chemical clarification of wastewater usually involve two processes: (1) increased contact between the suspended particles, and (2) destabilization of the particles to permit attachment when contact occurs (Weber 1972). Solid colloidal particles (i.e., insoluable particles that remain suspended in water) have long been observed to move in an electrical field, indicating that these particles carry an electrical charge (Weber 1972). The charge can be either positive or negative, however, a negative charge is more common on inorganic particles. The electrical charge causes the particles to repel each other. These particles can be made to settle with the addition of organic or inorganic compounds, called flocculants or coagulants, which neutralize the electrical charges.

The terms coagulant and flocculant are sometimes used interchangeably but the terms apply to specific processes. Coagulants are normally low molecular weight, positively charged compounds that will adsorb onto the solid particles, effectively neutralizing the overall electrical charge of the particles. The neutralized particles will adhere to each other forming larger, heavier particles that settle. Flocculants are usually high molecular weight compounds that cause settling through two processes: they neutralize the charges on the particles and they "bridge" the particles in suspension, causing the particles to aggregate and settle.

Weber (1972, p.73) discusses a bridging theory for the destabilization of suspended particles: "To be effective in destabilization, a polymer molecule must contain chemical groups which can interact with sites on the surface of the colloidal particle. When a polymer molecule comes into contact with a colloidal particle, some of these groups adsorb at the particle surface, leaving the remainder of the molecule extending out into the solution. If a second particle with some vacant adsorption sites contacts these extended segments, attachment can occur. A particle-polymer-particle complex is thus formed in which the polymer serves as a bridge." Reagents used to form the "bridges" are usually long-chain organic polymers, however inorganic coagulants may also settle particles through bridging.

Coagulants commonly used over the past one hundred years include calcium carbonate (lime), aluminum sulfate (alum) and calcium sulfate (gypsum). Natural materials such as starch and starch derivatives, cellulose compounds, polysaccharide gums, and proteinaceous materials were formerly used as flocculants (Kleber 1973).

In 1967, the first non-toxic and completely synthetic cationic (positively charged) organic polymer was introduced and accepted by the U.S. Public Health Service for treatment of municipal water supplies (Kleber 1973). Since then, a wide range of polymers has been developed for use in municipal water and wastewater treatment. These polymers are more commonly used today for water clarification than naturally occurring organic compounds (Terrell 1977).

Polymer flocculants (often called polyelectrolytes) usually consist of long spaghetti-like chains of molecules with repeating electrical charges. All polyelectrolytes can be classified by the type of electrical charge. Polymers with negative charges are "anionic," those with positive charges are "cationic," and polymers with no electrical charge are "non-ionic."

Polyelectrolytes are usually in liquid or powder form. Effective use of these chemicals for water treatment requires a system to mix the polymer with water to develop the long molecular chains, a system to monitor sediment concentrations and to adjust the polymer concentrations, and an effective system to disperse the chemical into the treatment pond.

Polyelectrolyte flocculants have also been produced in a gel log form which does not require pre-dissolution or pre-mixing (Moore 1982). Gel logs are placed in an open container and are secured in the settling pond inlet.

Polymer material is removed from the logs by hydration and erosion. Dissolution rates are controlled by water velocity, surface area of the gel log exposed to water, and water temperature. Partial immersion of the gel log results in better dissolution than complete submersion. A completely submerged log will swell from hydration but little polymer will release from the surface.

IV. Application of Chemical Clarifiers

The practice of using compounds to enhance settling by causing the particles to coagulate is at least 4,000 years old (Cohen et al. 1958). Ancient leterature from India of about 2000 B.C. suggested a number of vegetable substances as a means of clarifying water. Since 1889, chemical clarification techniques have been used to treat drinking water supplies in the United States (Kleber 1973). Polyelectrolytes have been widely used to reduce turbidity in municipal drinking water and wastewater and in industrial wastewater. There has been some use of polymers for the treatment of wastewater from coal mining and hardrock mining. Chemical treatment of industrial, including mine, effluent is a common practice in the contiguous United States; however, such treatment has not been widely used in Alaska.

Cohen et al. (1958) tested a variety of cationic, anionic, and non-ionic polymers and found them to be more useful than inorganic clarifiers in removing turbidity from municipal water. Kleber (1969) described field applications of cationic polymers for clarifying municipal water supplies. Terrell (1977) reported that organic polymers were more successful in treating filtered water at a municipal water treatment plant than inorganic clarifiers.

Boyd (1979) used alum to precipitate clay turbidity in fish ponds. He found that alum reduced clay turbidities by 89% to 97% within 48 hours in the seven ponds which were treated. Concentrations of alum required to reduce turbidities ranged from 15 to 25 mg/L and apparently depended upon the type of colloid and chemical features of the water rather than the concentration of colloid.

Bandow (in Boyd 1979) used alum to remove phosphorous and to reduce plankton blooms in ponds used to rear walleye (Stizostedion vitreum). At harvest, the alum treated pond contained 1.6 times as many young-of-the-year as the untreated control pond.

Olson et al. (1973) used polymers to clarify water supplied to a fish hatchery. Prior to treatment, the hatchery supply water reached turbidities of 70 Jackson Turbidity Units (JTU), at which point fish ceased feeding. Fish survival rates and rates of feeding increased after the hatchery water was clarified with polymers.

McCarthy (1973) tested polymers at the Centralia, Washington surface coal mine. Tests were conducted on coal mine effluent with initial silt loads of 1.5 to 2.0% fine solids by volume and turbidities of 1,000 JTU or greater. A primary settling pond at the Centralia site removed 99% of the solids. Effluent from this pond was treated with about 10 mg/L of Superfloc (American Cyanamid Co.), then settled in a second pond. Final turbidities after chemical treatment ranged from 4 to 15 JTU. McCarthy (1973) stated that polyelectrolytes can be effective in reducing turbidities in mining effluents provided that mixing and dispersion of chemical compounds are sufficient.

The U.S. Bureau of Mines tested the effectiveness of polyethylene oxide (PEO) to settle a wide variety of sediment types and particle sizes (Scheiner, pers. comm. 1985). Polyethylene oxide is a commercially available, non-ionic, water soluble resin formed by the polymerization of ethylene oxide.

Twelve years of testing PEO (Scheiner, pers. comm. 1985) have shown that it is an effective flocculant for clay-sized particles under a variety of temperatures and physical and chemical conditions. Investigations of the mechanisms by which PEO settles clay particles from waste water suggested the use of a two-stage process. First, PEO is mixed with clay waste, forming a floc and clear supernatant. Then the floc is placed on a screen to remove the excess water. Because PEO is non-ionic, the initial bond between the clay waste and PEO is a water bridge type. This bond is weak and will disintegrate. When water is removed, a stronger bond is formed which is highly stable. Because of this stronger bond, PEO does not have the destabilization problems of many other flocculants.

Scheiner (pers. comm. 1985) stated that PEO-treated wastewater has never gone into dispersion from overdosing or from physical or chemical characteristics of the water. Polyethylene oxide has been shown to effectively settle clay minerals such as kaolin, montmorillonite, and hydromicas, talc, and coal (Union Carbide, no date). This flocculant is not effective, however, in settling organic, non-clay wastes. Polyethylene oxide has been approved by the Food and Drug Administration for use in food manufacture.

Scheiner et al. (no date) compared the effectiveness of PEO with other polymer flocculants in settling coal waste. Polyethylene oxide produced a floc of coal-clay wastes containing 50% to 60% solids, whereas the other polymers tested produced flocculants of only 10% to 30% solids.

Scheiner and Smelley (1984) treated phosphate clay waste by pumping the clay slurry to an agitator-type mixer where PEO was added. The slurry-flocculant mixture was then transferred to a rotary trommel screen (a revolving, cylindrical sieve) to remove the water. Solid wastes were removed from the screen to a land disposal site and sediment particles remaining in the water settled in treatment ponds in 1 to 24 hours.

Scheiner and Smelley (1984) treated bentonitic (a porous clay) waste containing 12% solids of particle size less than 0.37 mm. They found that dosages of 0.13 kg to 0.26 kg PEO per metric ton (m.t.) of bentonite produced an effluent ranging from 0.09% to 0.35% solids and a turbidity of 10 NTU to 19 NTU. The solids discharged from the trommel screen contained 38.7% to 41% solids. A dosage of 0.10 kg PEO per ton of bentonite produced an effluent of 5.26% solids with 300 NTU turbidity.

Moore (1982) reported that gel logs achieved clarification of pond water samples at dosages of 0.05 ppm to 0.20 ppm. Tests with gel logs were conducted in water with temperatures of 65°F to 70°F and with sufficient turbulence to achieve high rates of dissolution and dispersion of the logs.

The Sunshine Mining Company, Nevada (Bagan, pers. comm. 1985) reported that allowable total suspended solids (TSS) levels of 100 mg/L for Nevada were easily attainable in hardrock mining effluent after treatment with gel logs. Torff (pers. comm. 1985) stated, however, that gel logs did not dissolve satisfactorily in cold water streams in Idaho. Although not tested, increased turbulence may have improved dissolution rates at the Idaho mining sites.

V. Applications of Chemical Clarifiers to Placer Mining

Environment Canada (1983b) conducted limited laboratory evaluations of anionic polymers in treating synthetic placer mining wastewater. They reported that dosages of 0.05 kg/m.t. to 0.15 kg/m.t. TSS produced optimum settling velocities. This work is regarded as preliminary because the investigators did not standardize mixing intensity, develop dosage and supernatant (clear water boundary) quality information on which to base dosage selection, nor test the performance of the flocculants under field conditions.

An in-depth laboratory investigation of polymer flocculant use in the Yukon placer mining industry was conducted by Reid Crowther and Partners (RCP) Limited (1984). Laboratory tests of 6 polymer flocculants were conducted at 15 mines in 14 locations. The tests were conducted in graduated cylinders, and optimum dosage was based on settling rates rather than supernatant clarity. Chemical costs were factored into the results to obtain values for overall efficiency. Of the 6 polymers tested, RCP found that Percol E10, Separan MG200, and Percol 156 generally achieved the best settling velocities at the lowest dosages. The non-ionic polymer, Percol E10, produced the best overall test results. Optimum dosage requirements for all 6 polymers tested ranged from 0.36 kg per m.t. TSS to 1.30 kg per m.t. TSS.

Stanley Associates Engineering (1985) conducted detailed laboratory and field studies of 1 non-ionic and 5 anionic polymers used at placer mine sites in northern Canada. Results of field testing showed that anionic polymers were effective in reducing suspended sediment and that settling pond design and maintenance were critical factors in achieving effective treatment with low polymer dosages. The dosage required to achieve a residual TSS concentration of 100 mg/L was twelve times the dosage required to achieve 1,000 mg/L.

Studies on the use of cationic polymers in treating placer mining wastewaters have been limited. Stanley Associates Engineering (1985) reported that Allied Colloids conducted some preliminary investigations with the cationic polymers Percol 728 and Percol 1597 in synthetic placer mining wastewaters in interior Alaska in 1984. The test dispersions were prepared with 76 grams dried silt per liter of water. Percol 728 produced settling rates comparable to those achieved by anionic flocculants, but with improved supernatant clarity. Percol 1597 required relatively high dosages to achieve supernatant clarities that were similar to those achieved with anionic forms (3 mg/L Percol 1597 compared to 0.05 mg/L to 0.10 mg/L of anionic forms.)

Stanley Associates Engineering (1985) further reported that the Canadian Environmental Protection Service is conducting preliminary evaluations of the cationic polymers Percol LT31 and Percol LT35. Early results indicate that dosages in the range of 3 to 6 mg/L are necessary to achieve residual suspended solids concentrations of less than 100 mg/L in suspended sediment concentrations of 1,700 mg/L TSS.

Shannon and Wilson (1985b) found that doses of 5 mg/L to 25 mg/L of cationic flocculants would achieve water clarity in the 10 NTU to 100 NTU range when the initial suspended solids levels ranged from 16,000 mg/L to 27,000 mg/L. They stated that even higher doses of flocculant may be required to treat effluent with lower initial suspended solids concentrations (Shannon and Wilson 1985b) They also reported that chemical clarifiers would be most useful for reducing suspended sediments in recycled water and in clarifying effluent before discharge to a stream.

Evangelou (pers. comm. 1985) recommended using calcium sulfate (gypsum) to reduce turbidities in northern latitude, low nutrient streams with pH values near neutral. He stated that calcium sulfate may be more effective than polymer flocculants in reducing turbidity in cold water. Evangelou further stated that calcium sulfate would be easier to mix and disperse than polymer flocculants which often require nearly exact dilutions and sufficient mixing to develop long polymer chains. To date, there are no published accounts of use of calcium sulfate to treat placer mining effluent in northern latitude areas.

Scheiner (1985) conducted preliminary tests in 1981 of PEO to clarify placer mine wastewater in Alaska. The results of these early tests show that PEO will settle the fine sediment particles prevalent at many Alaskan placer mine sites. Scheiner's 1981 data for initial solids concentrations, solids concentrations of the trommel discharge, and cost estimates are presented on table 1. He does not include data for solids content of the water before treatment.

VI. Factors Affecting Clarifier Effectiveness

Chemical clarifiers are designed to reduce turbidity or TSS; they are not intended to reduce levels of settleable solids. The effectiveness of chemicals is reduced and costs are increased when chemicals are added before initial settling of heavier particles.

The effectiveness of chemical clarifiers may be dependent upon physical factors such as concentration of fine sediments in the wastewater, dosage, temperature of the wastewater, characteristics of the sediments, and by thoroughness of mixing and dispersal systems, accuracy of pre-testing, selection of chemicals and dosages, design of

Table 1. PRELIMINARY RESULTS OF POLYETHYLENE OXIDE Used to Clarify Placer Mine Effluent, Alaska 1981.[1]

Sample location	Initial solids, pct	PEO dosage, lb/t	Cost[2], cent/1,000 gal	Solids content, pct
Livengood	0.17	0.70	1.5	28.0
Wilkenson	.40	.30	1.5	38.7
Livengood - sluice discharge	1.21	1.40	21.2	22.6
Macintosh - Faith Creek	1.22	.25	3.8	31.5
Lappe - Sourdough Creek	1.73	.15	3.2	34.1
Circle	[3]1.27	.34	5.4	44.1

1. From Scheiner 1985, unpublished data.
2. Based upon polymer cost of $3.00/lb. Last quotes were Japanese $2.65/lb, Union Carbide $4.50/lb.
3. New sample 1985.

settling ponds, pond maintenance schedules, and the use of supplementary filter systems. These factors are discussed below.

1. Physical factors

The effectiveness of all three forms of polyelectrolytes generally increases as the concentration of fines in the water increases. This is probably due to a higher rate of interparticle contacts in such systems, although other factors may be involved. Shannon and Wilson (1985a) tested a single flocculant to treat placer mine effluent from a single source at suspended solids levels ranging from 15,600 to 92,600 mg/L. They found that less flocculant was required per unit of solids at higher solids concentrations than at low concentrations. When TSS levels were 15,600 mg/L, 0.38 mg flocculant per kg suspended solids was required to achieve final clarity of 100 NTU; however, when TSS levels were 92,600 mg/L, only 0.11 mg/L flocculant per kg TSS was required to achieve the same degree of clarity. Since their results were based upon one test, they may not be applicable to other sites because water chemistry and sediment characteristics may be different.

Flocculation of suspended sediments by polyelectrolytes cannot be increased indefinitely with the addition of more polymers. Beyond certain "optimum" dosages, the use of excess polymers causes poorer flocculation (Chang 1979, Environment Canada 1983b) and may result in destabilization of the sediment in the pond. If pond sediments are destabilized, the sediments may resuspend as the pond goes into dispersion (Evangelou, pers. comm. 1985).

Stanley Associates Engineering (1985) reported noticeable improvement in polymer efficiency at higher temperatures, and that the temperature effect was more apparent at lower polymer dosages (less than 3.0 mg/L). They attributed the decreased performance at lower temperatures to increased viscosity of the polymer solution and poorer dispersion into the wastewater. In field applications, temperatures of stock polymer solution, dilution water, and wastewater all affect dispersion of the polymers into wastewater.

Shannon and Wilson (1985a) found that in cold temperature trials at 0.5 to 1.0°C six of the chemicals tested performed as well or better than at 8 to 10°C. None of the chemicals tested showed decreased performance at lower temperatures. Scheiner (pers. comm. 1985) also stated that low temperatures did not affect performance of polyethylene oxide. This flocculant, when tested in cold water streams in Kentucky during the winter, performed as well as or better than in warm water.

Morrow and Rausch (1974) found that performances of polyelectrolyte flocculants were not affected by hardness, alkalinity, pH, or temperature; however, the performance of flocculants is likely to be affected by geochemistry of the sediments. Preliminary experiments in treating coal-clay waste slurries with PEO indicated that a pH of 8.5 or higher was required to obtain strong flocs when organic material was abundant (Brown and Scheiner 1983). Brown and Scheiner (1983) estimated that 1.5 lb lime/ton coal-clay waste was required to raise the pH to the level that optimized PEO activity.

2. Mixing and dispersal systems

McCarthy (1973) stated that the effectiveness of polymers is probably controlled more by mixing and dispersion than by any other factors.

Anionic polymer flocculants are usually sold in dry form because they cannot be prepared in liquid form at concentrations above approximately 2%. This rate of dilution would make shipping costs prohibitive. The dry form requires a well-designed system to dissolve the chemical. Insufficient wetting will result in lumps of polymer which are ineffective as coagulants and which can plug pumps and distribution systems.

Several manufacturers have marketed anionic and non-ionic polymers in the form of mineral-oil dispersions or water:oil emulsions. These products are available at active strengths of 25% to 50%, and must be diluted before use. Mixing systems for diluting dispersion or emulsion forms can be simpler than those used for dry forms. Cationic polymers are available as 50% active liquids and require no dissolution.

Schwarz (1982) emphasized the importance of adequate polymer dilution before dispersing into the wastewater. Polymer molecules are extremely aggregated at concentrations provided by the manufacturer. These aggregated molecules must be disaggregated with dilution water before they can function effectively as a flocculant. Aggregation occurs because of the entanglement of the long molecule chains, even at concentrations as low as 300 ppm to 500 ppm (Stanley Associates Engineering 1985).

Complete and rapid dispersion of the flocculant compound into the mine effluent is necessary to achieve uniform distribution of the flocculant and to force collision with suspended particles. Completeness of the coagulation and flocculation processes depend upon the number of particle collisions (Morrow and Rausch 1974, Shannon and Wilson 1985a). Treatment facilities for municipal water supplies often use elaborate mixing tanks and power-driven dispersing systems. A mechanical metering system that allows the flocculant to drip into the effluent at a controlled rate is probably the most feasible dispersal system at remote placer mine sites. Environment Canada (1983b) stated that a simple mechanical system can be built cheaply from scrap material.

Clarifying compounds are usually added to the mine effluent at the inflow to the secondary settling pond (i.e. after initial settling of heavier sediments.) Mixing of the effluent with the clarifying compound can be enhanced by increasing the turbulance at the inflow to the pond. The area of increased turbulance is localized at the pond inlet; the pond itself must be still for effective floc settling.

McCarthy (1973) used a 50 foot long half-round culvert with baffles at 5 foot intervals at the pond inflow. Because field testing of the polymer indicated that the chemical was not as effective as predicted by jar tests, he increased the turbulence by adding angle iron obstructions below the outfall of the culvert. The increased turbulence increased the effectiveness of the polymer and reduced the concentration of flocculant required for settling.

Turbulence can also be achieved with a dike or notched weir at the inflow to the second settling pond. After initial settling, the water flows over the weir and cascades into the second pond. Angle iron or other obstructions can be added at the outfall to increase turbulence. This system would also work well in providing turbulence over polyelectrolyte gel logs. As discussed previously, the gel logs will not dissolve satisfactorily unless the turbulence is sufficient, especially in colder water (M. Torff, pers. comm. 1985; Moore 1982).

3. Pre-testing coagulants and flocculants

The effectiveness of a variety of coagulants and flocculants should be tested for specific water and sediment to determine the optimum chemical and dosage. Both settling rates and clarity of the supernatant should be considered when comparing different chemicals. Choice of polymer and dosage should depend primarily upon how well turbidity is reduced and secondarily upon maximum settling rate (Chang

1979). Potentially, a compound and dose that gives the fastest settling rate for a given set of mixing and soil conditions may not give optimum clarity.

Since settling tests are usually conducted over a shorter time span than would occur in the field, final clarities and dosages may vary between test and field results. Therefore, polymers and dosages should be field tested to determine which are most cost effective and produce best field results. Results of pre-testing may not apply to other sites because different sediment and stream water characteristics may give different results.

Methods for conducting presettling tests in jars or columns have been described by Zanoni and Blomquist (1975), Environment Canada (1983a), Shannon and Wilson (1985a), and others. Environment Canada (1983a) recommends that jar tests be conducted by placing between 6 and 7 grams of sediment in a 100 ml graduated cylinder, filling the container with stream water, then adding a measured amount of dilute flocculant mixture. The contents are mixed by rotating the cylinder end to end about three times, and leaving it to settle. The time for the floc/clear water boundary to develop and the clarity of the supernatant are determined.

Shannon and Wilson (1985a) added prepared stock solutions of polymer to 1,000 ml wastewater samples. Samples were agitated at high speed with magnetic, Teflon-coated stirring bars for 15 to 60 seconds. Floc size, settling rates, and supernatant clarity were rated after a 10 minute settling period.

Settling tests should be repeated for different doses of the same flocculant and then for different flocculants. Results of these tests will show the best dose of each flocculant for the stream water and sediment tested.

Mixing of the flocculant, sediment, and water in settling tests should be similar to the amount of mixing at the placer mine site. For example, if there is no power supply at the placer mine and mixing is minimal, the amount of mixing for settling tests must also be minimal. The Environment Canada (1983a) method of rotating a test jar end to end about three times approximates mixing in a simple mechanical dispersal system.

Overmixing during settling tests may lead to an overestimate of the actual effectiveness of the flocculant compound at the mining site and an underestimate of the amounts of flocculant needed to achieve desired clarity. Kailing and

Green (1982) report that in one test at Livengood, field tests required about twice as much flocculant to attain a turbidity of 50 NTU as was required to attain 25 NTU in the laboratory. They attributed the difference in test results to more thorough mixing in the laboratory. Jennings (1983) reported that results from laboratory tests could not be duplicated in the field because of limited field facilities for mixing and dispersing the polymers. Based upon dosage estimates for field applications, Jennings concluded that it may not be economically feasible to achieve water turbidities of less than 5 NTU above ambient conditions at remote placer mine sites.

4. Settling pond design

Settling ponds in a series are most commonly used in a sediment control system that uses chemical clarifiers. The clarifiers are added after initial settling of the heavier particles and before a final polishing pond. The efficiency of chemical clarifiers will be increased if all particles that will settle by gravity are removed before clarifiers are added.

The design and construction of settling ponds have been described by Weber (1972), R & M Consultants (1982), Alaska Department of Environmental Conservation (ADEC) (1983), and Shannon and Wilson (1985a, b), among others. A settling pond should be designed to retain water long enough for particles to settle, to prevent short-circuiting, to have minimal scour and resuspension of solids during periods of higher flows, and to prevent washout during flood events. The design of settling ponds must consider the volume of sediment that will accumulate in the pond during the intended time it is to be used. If insufficient space is available to provide sediment storage, ponds must be cleaned more frequently to maintain effective operation. A program for removal of solids must include plans for disposal of sediment in areas that will not erode into the stream.

McCarthy (1973) described a control system for surface mine siltation in Washington. The system consisted of two ponds in a series; the first pond was for settling larger particles that were heavy enough to settle naturally, and the second pond was for settling flocculant-treated sediments. Flocculants were added in the raceway between the two ponds. This design proved effective for clarifying surface mine effluent provided there was sufficient turbulence at the entrance to the second pond to achieve thorough dispersion of polymers.

Stanley Associates Engineering (1985) designed a secondary settling pond for chemically treating mine effluent after pre-settling in a primary pond. They calculated a minimum pond surface area of 83 m^2 for a flow of 9,500 L/min. and a settling velocity of 1.9 mm/s. Applying a safety factor of 5 to allow for flood events, they recommended a pond surface area of 420 m^2. Given that approximately 2% of the total wastewater treated is compacted sludge, they estimated that a 420 m^2 pond with a depth of 4 m would provide 14 days of sludge storage. (Note that the pond design proposed by Stanley Associates Engineering would exceed 10' depth, therefore requiring compliance with the dam safety regulations.)

5. Cleaning the pond and dewatering sediments

The settling ponds should be cleaned frequently to maintain sufficient sludge storage capacity and retention time. After settling, the fine sediment should be removed from the pond and spread over the land to dry. Sediments should be placed where they will not erode into the stream. Cleaning settling ponds is not always possible; alternatively full ponds can be covered with tailings and new ponds constructed.

The stability of the sediment-flocculant mixture in the settling pond depends upon the density of the floc and dewatering characteristics of the flocculant. Scheiner (pers. comm. 1985) reported that settling ponds containing PEO can be cleaned with front-end loaders. The sediment is removed to a land disposal area where it undergoes further dewatering. Scheiner also observed rapid revegetation on PEO-sediment disposal sites and, because of excellent stability properties, very small amounts of erosion.

6. Supplementary filter systems

Clarification of water treated with flocculants may be further enhanced by tailing or sand filters. Sand filters have been commonly used in Europe and the United States to clarify municipal water supplies (Weber 1972). These filters can be highly effective in removing most suspended solids except for fine clays and colloidal solids. Fine particles will penetrate deeply into the filter and the filter cannot be cleaned by removing the upper layers of sand. Where fine clays or colloidal solids were present, sand filters were not adequate to produce drinking quality water (Weber 1972).

Mine tailings have also been used successfully as a filtration medium. A placer miner working in the Kantishna area of Denali National Park, Alaska produced an effluent of 5 NTU above background or less with settling ponds and tailings filtration (Townsend, pers. comm. 1985). The miner did not pre-treat the wastewater with chemical clarifiers. Use of material which is already available at the mine site will substantially reduce operation costs over importing filtration material.

Sand filters have been described more thoroughly in the engineering literature than mine tailings or gravel filters. Although filter systems constructed from mine tailings may be more economic and easier to construct at a placer mine site, a discussion of sand filters is presented to give a general knowledge about filtration systems and some of their limitations.

Weber (1972) described a sand filter as a watertight basin containing a layer of sand 3 feet to 5 feet thick, supported on a layer of gravel 6 inches to 12 inches thick. The gravel is underlain by a series of perforated drain pipes, usually placed 10 feet to 20 feet apart. The perforated drain pipes collect the filtered water to a single outlet where it is discharged. Sand in the 0.35 mm size range is commonly used for treating drinking water to remove sediment, algae, and bacteria. Larger sand may be sufficient in treating mining effluent.

The sand filter is operated with a water depth of 3 to 5 feet above the sand surface. The water slowly percolates through the sand and collects in the perforated drain pipe; sediments usually collect in the upper few inches of sand.

When the water ceases to flow through the sand at an acceptable rate, input to the pond is stopped until the water in the pond has moved through the filter, then the surface is scraped and removed to reveal a clean surface. Sand filters for municipal water treatment are usually cleaned by backflushing, a practice which is impractical or impossible at most placer mine sites. Sand filters at placer mine sites should be constructed so that they can be cleaned by scraping the top layer of sand. This layer would then be spread on the land, away from the stream channel, and allowed to dewater. The frequency of cleaning is determined by the amounts of sediments in the water and how quickly the top layers of sand become clogged with sediment.

The cost of a slow sand filter depends upon the cost and availability of sand and gravel and the operating costs for constructing an additional pond to contain the sand filter. Maintenance costs can be reduced by effective primary treatment to eliminate all naturally settleable solids.

Although use of polyelectrolyte compounds will add costs for the chemicals, other costs associated with cleaning and maintaining the filter will be reduced.

Filtering of fine particles can probably be enhanced by pre-treating the water with polymer flocculants. Kleber (1973) stated that cationic polymers in a dosage range of 40 to 75 parts per billion and nonionic polymers at 20 to 40 parts per billion were effective as filter aids for municipal water treatment. Polymers added to the municipal water prior to filtration result in tougher microflocs which resist shear and give better turbidity removal (Kleber 1973).

Use of polymers for treating municipal wastewater results in a sludge that dewaters more rapidly and does not penetrate into the sand filter (Novak and Langford 1977). Similar results would be expected from mining effluent because the larger, polymer-bound sediment particles would not penetrate through the sand as readily as untreated sediment. Pretreatment of mine effluent with polymer flocculants will probably enhance removal of turbidity and may extend the effective life of the sand filter. A primary settling pond will also extend the effective life of the sand filter by removing larger, heavier particles before filtration.

VII. Estimates of Cost

The cost of using chemical clarifiers depends upon a variety of factors, including type of mixing and dispersal systems required, cost per weight of the chemical, and dosage required to achieve the desired results. Cleaning ponds and disposal of sediments are costs inherent to any placer operation, with or without chemical-aided settling.

Stanley Associates Engineering (1985) estimated chemical treatment costs to achieve various standards of effluent quality. They assumed an average chemical cost of $3.50/kg, effluent flow of 9,500 L/min. (2,500 gpm) and a daily sluicing time of 10 hours. Their estimates for treating primary pond discharges of 10,000 mg/L TSS are presented on table 2.

Estimates for treating primary pond discharges of 20,000 mg/L TSS are approximately twice as high as the costs presented above; for treating discharges of 30,000 mg/L TSS, estimated costs are about three times as high as those presented above. Capital costs for the equipment required to provide mixing and dispersion facilities, pumps and power

Table 2. Cost estimates for treating primary pond discharge of 10,000 mg/L TSS.[1]

dosage kg/m.t. TSS	effluent quality mg TSS/ L	chemical cost per day
0.071	1000	$ 12.50
0.129	500	25.00
0.261	250	50.00
0.865	100	175.00

1. From Stanley Associates Engineering 1985.

supplies were also reported. All costs are in 1985 Canadian dollars, F.O.B. Dawson City, Yukon.

Polymer mixing equipment	$28,000
Pumps and piping	1,500
Diesel generator	15,000
Weather-proof pre-engineered building	5,500
Hydraulic mixing structure	7,000
Subtotal	$57,000
Contingencies at 15%	8,500
Total Estimated Cost	65,500

Shannon and Wilson (1985a, b) estimated the cost-effectiveness of treating sluice effluent with TSS ranging from 5,910 mg/L to 26,900 mg/L (average TSS of 18 samples was 16,500 mg/L). Estimated costs of flocculant to attain final turbidities of about 10 NTU ranged from $0.11 to $1.94 per cubic yard mined, and estimated costs to attain final turbidities of 100 NTU to 200 NTU ranged from $0.23 to $3.21 per ton TSS, or approximately $0.02 to $1.16 per cubic yard mined.

Scheiner (pers. comm. 1985) reported that a mixing and dispersal system for polyethylene oxide applications will cost $15,000 to $20,000 and that chemical costs will vary from $0.01 to $0.10 per 1,000 gallons of wastewater treated, or $6.00 to $60.00 per day for an average operation.

Estimates for dosage of flocculant and cost of the flocculant compound are usually based upon the amounts of fine silts and clays to be settled in the pond rather than the volume of water used for processing (Environment Canada 1983b; Shannon and Wilson 1985b). If known amounts of flocculant and sediment are used for preliminary jar tests, then grams of flocculant compound required to settle a given amount of sediment can be determined. This value can be used to estimate the costs for settling concentrations of silts and clays likely to be found in the placer washwater.

Environment Canada (1983b) presented an example for estimating chemical treatment costs based upon the assumption that 7% of the sluiced material (by weight) was fine silt and clay and settleable by flocculants. Therefore (by their example), if a mine is washing 525 cubic yards per day of gravel at 3,370 pounds per cubic yard (cy):

7% of 3,370 lbs = 236 lbs fine silt and clay.

or $\frac{236\text{ lbs}}{\text{cy}} \times \frac{525\text{ cy}}{\text{day}} \times \frac{0.00045\text{ m.t.}}{\text{lb}} = \frac{56\text{ m.t.}}{\text{day}}$

If a flocculant dose of 50 grams/m.t. is effective, then:

$$\frac{50\text{ grams}}{\text{m.t.}} \times \frac{\text{kg}}{1000\text{g}} \times \frac{56\text{ m.t.}}{\text{day}} = \frac{2.8\text{ kg flocculant}}{\text{day}}$$

If the flocculant costs $3.50 per kilogram, then:

$$\frac{2.8\text{ kg}}{\text{day}} \times \frac{\$3.50}{\text{kg}} = \frac{\$9.80}{\text{day}} = \text{cost of flocculant per day}$$

Estimates presented above are only for cost of the flocculant. Additional costs will be incurred with freight, capital, and labor costs associated with mixing and dispersal systems and labor required to maintain dispersal systems. Accuracy of any cost estimate depends upon how closely flocculation in jar tests simulates conditions in the settling pond and the accuracy of the estimates for proportions of fine silt and clays found in the sluiced gravel.

VIII. Toxicity of Chemical Clarifiers

Toxicities of chemical clarifiers have been tested primarily for human consumption, warm-water species of fish, and for various invertebrates. Companies manufacturing the clarifying chemicals are required to conduct toxicity tests. Although these tests are usually limited, they do provide information on toxicity, maximum allowable dosages, and whether or not the chemical has been approved by the Food and Drug Administration for human consumption, fisheries, or other uses.

Few tests have been conducted on clarifier toxicity to salmonid or other cold-water fish. Results of most toxicity tests have shown that critical factors determining toxicity are purity of the chemical, ionic form, and concentration of flocculant used in excess of that required for settling. Chemicals in excess of the amounts required to bind with sediment particles will remain dissolved in the water and are potentially available to the aquatic biota.

Polymer flocculants can be obtained in various grades, from very pure to standard. The higher grade flocculants contain fewer impurities from manufacture but are more expensive. Therefore, the higher grade chemicals are used for potable water or where toxicity to aquatic organisms is of particular concern.

Alum is not appreciably toxic to warmwater goldfish (Carassius auratus), sunfish (Lepomis sp.), or largemouth bass (Micropterus salmiodes) (Boyd 1979). Boyd (1979) reported that exposure to 100 mg/L for seven days did not kill these fish, but exposure to 250 mg/L for 8 to 24 hours was fatal. The higher concentration of alum is approximately 10 to 15 times the amount used to reduce turbidity. The floc formed by alum treatment was not toxic to fathead minnows. Findings reported by Boyd (1979) indicate that alum treatments of 10 to 30 mg/L will not be harmful to the warmwater fish tested except in water with low total alkalinity. For example, if water with an ambient total alkalinity of 12 mg/L was treated with 30 mg/L alum, all alkalinity would be removed, the pH reduced, and fish would probably be killed.

Brocksen (1971) reported that 1 mg/L or less of Purifloc-31 (Dow Chemical Company, Midland, Michigan) was acutely toxic to rainbow trout (Salmo gairdneri) in 36 hours when tests were conducted in clear water. When suspended sediments were added to the water, the chemicals bound with the sediments and were not available to the fish. Tests with added sediment showed the flocculant to be non-toxic to fish for up to 72 hours (the duration of the test).

Biesinger (1985) tested the detoxification properties of anionic polymers and red clay acting upon cationic polymers (table 3) in a controlled microcosm. He found that mortalities of both fathead minnows and Daphnia were significantly reduced when either anionic polymers, red clay, or a combination of both was added to clear water-cationic polymer media. Toxicities were reduced because the cationic polymers were either bound with the red clay particles, neutralized by the anionic polymers, or a combination of both. Therefore, the chemicals were not available to aquatic species in the microcosm. Results of these studies emphasize the importance of using the minimum amounts of chemical required to achieve desired clarity.

Of the three ionic forms of polymer flocculants, researchers found cationic chemicals to be acutely toxic in concentrations of about 2 mg/L to 3 mg/L of water (without sediment), whereas the anionic polyelectrolytes were relatively non-toxic at the same concentrations (Dow Chemical Co. 1970). Biesinger, et al. (1976) tested all three polyelectrolyte forms on rainbow trout, lake trout (Salvelinus namaycush), and three crustaceans: a mysid (Mysis relicta), a copepod (Limnocalanus macrurus) and a cladoceran (Daphnia magna). They concluded that some of the cationic polyelectrolytes tested are particularly toxic at

Table 3. Detoxification of a Cationic Polymer by an Anionic Polymer and Red Clay[1]

Concentrations in mg/l			Mortality	
Hercofloc 863 Cationic	Hercofloc 1021 Anionic	Red Clay	Fathead Minnows in 96 hrs	Daphnia in 48 hrs
0	0	0	0%	0%
10	0	0	100%	100%
10	0	225	0%	-
10	20	0	0%	-
10	20	225	0%	-
0	0	225	0%	-
0	20	0	0%	-
0	20	225	0%	-
10	3	0	-	45%
10	7	0	-	5%
10	11	0	-	0%
10	17	0	-	0%
10	26	0	-	0%
0	26	0	-	0%

1. From K. Biesinger, 1985. Unpublished data.

concentrations which could be released into aquatic environments. Two cationic polyelectrolytes were also shown to impair reproduction of Daphnia at concentrations of 0.1 mg/L and 1.0 mg/L. These concentrations are within the range of concentrations which may occur with normal use of polyelectrolytes.

Biesinger (1985) tested the toxicities of 28 different polymers to daphnids, fathead minnows, midges (Insecta: Chironomidae) and gammarids (Crusteacea: Amphipoda) (table 4). He found that for the three nonionic chemicals tested, concentrations in excess of 100 mg/L were required to produce 50% mortality (LC_{50}) in the populations. Of the ten anionic polymers tested, one compound was toxic to daphnids but not to the other species. Fifteen cationic polymers were tested; the LC_{50} of two of these were greater than 100 mg/L for daphnids and fathead minnows. However, the other cationic polymers had LC_{50} from 0.09 mg/L to 70.71 mg/L for daphnids, 0.88 mg/L for fathead minnows, from 6.25 mg/L for midges, and from 8.1 mg/L for gammarids. Results of his tests show cationic polymers to be more toxic than either anionic or nonionic forms, especially to daphnids and fathead minnows.

Polyethylene oxide has been approved by the Food and Drug Administration for use in food, food preparation, and food packaging as well as for use in a number of human contact products including denture adhesives, pill binders, toothpastes, cosmetic creams, lotions, and soaps and as an inert ingredient in preharvest pesticides (Zatko 1980).

Extensive laboratory tests of PEO mixed with clay wastes did not reveal the presence of ethylene oxide gas, a potential toxic byproduct of PEO breakdown (Zatko 1980).

Stanley Associates Engineering (1985) reported that cationic polymers are more toxic to fish than other ionic forms because of their affinity for the negatively charged surface of fish gills. The iron mining industry in Quebec (Stanley Associates Engineering 1985) has shown that residual cationic polymer can be removed from wastewater by adding small amounts of anionic polymer, thus reducing the possibility of residual toxicity in particularly sensitive receiving waters.

IX. Effects on Gold Recovery

Placer mine operators have expressed concern that residual

Table 4. Acute Toxicity of Polyelectrolytes to Selected Aquatic Organisms (Values are in mg/l)[a]

Polyelectrolytes	Ionic Charge	Daphnids[b] 48-hr LC50	Fathead Minnows 96-hr LC50	Midges 48-hr LC50	Gammarids 96-hr LC50
Separan AP273	Anionic	>100	>100	>100	
Separan NP10	Nonionic	>100	>100	>100	
Separan MGL	Nonionic	>100	>100	>100	
Separan MG200	Anionic	>100	>100		
Separan CP7HS	Cationic	>100	>100		
Exp. Polymer XD-300 57.04	Anionic	0.04 (0.03-0.04)[c]	>100	>100	>100
Exp. Polymer XD-305 84.01	Cationic	0.77 (0.40-1.48)	>100	>100	31.6 (9.7-102.9)
Magnifloc 985N	Nonionic	>100	>100		>100
Hercofloc 812	Cationic	>100	>100		
Hercofloc 855	Cationic	>100	7.4 (6.5-8.5)	>100	102.9 (63.3-167.3)
Hercofloc 1018	Anionic	>100	>100	>100	
Hercofloc 1021	Anionic	>100	>100		
Hercofloc 863	Cationic	1.2 (1.1-1.4)	0.88 (0.80-0.97)	26.9 (14.1-51.1)	22.8 (13.4-38.7)
Magnifloc 587C	Cationic	0.24 (0.19-0.32)	2.87 (2.47-3.34)	50.0 (37.2-67.3)	>100
Magnifloc 577C	Cationic	0.32 (0.25-0.42)	1.00 (0.36-1.17)	6.25	8.10 (5.15-12.75)
Cat-Floc T-1	Cationic	0.71 (0.49-1.04)	2.46 (2.16-2.81)	>100	>100

Table 4. (Continued)

Polyelectrolytes	Ionic Charge	Daphnids[b] 48-hr LC50	Fathead Minnows 96-hr LC50	Midges 48-hr LC50	Gammarids 96-hr LC50
Nalco 8851	Cationic	0.13 (0.11-0.16)	3.74 (3.45-4.16)	>100	>100
Hercofloc 834 Lot #4801	Cationic	6.78 (2.79-17.46)	9.47 (8.63-10.40)		112.25 (74.25-169.70)
Hercofloc 872 Lot #4644	Cationic	0.09 (0.05-0.15)	6.82 (6.38-7.31)		>100
Hercofloc 848 Lot #4809	Cationic	1.84 (1.34-2.51)	5.7 (5.3-6.2)		33.4
Hercofloc 831 Lot #6247	Anionic	>100	>100		
Hercofloc 818 Lot #5537	Anionic	>100	>100		
Hercofloc 1053 Lot #52714	Anionic	>100	>100		
Hercofloc 876 Lot #2222	Cationic	12.59 (7.05-22.48)	2.18 (1.86-2.54)	>100	21.0 (11.7-37.7)
Hercofloc 1023 Lot #50542	Anionic	>100	>100		
Hercofloc 873 Lot #2224	Cationic	70.71 (55.01-90.90)	2.72 (2.36-3.13)		85.2 (62.4-116.4)
Hercofloc 1031 Lot #53686	Anionic	>100	> 100		
Percol LT31	Cationic	0.50 (0.41-0.61)	1.05 (0.92-1.20)		12.5 (8.3-18.9)

a. From K. Biesinger, 1985. Unpublished data.
b. 95% confidence limits as determined by using the Trimmed Spearman-Karber method.
c. LC50 = lethal concentration to kill 50% of the population.

polymer in recycle water may affect gold recovery. If correct dosages of polymer are used, as predetermined in jar and field tests, there will be very little residual polymer in the wastewater. In fact, Allied Colloids sampled wastewater treated with polymer flocculants and found concentrations lower than a detection limit of 0.05 mg/L (reported by Stanley Associates Engineering 1985). Polymer molecules have an extremely high affinity for particulates and no residual polymer should be present in solution unless an excessivel dosage is applied or there is poor mixing of polymer and wastewater. Therefore, recycled water from the supernatant should contain little or no residual clarifiers and should not affect gold recovery.

X. Conclusions

Coagulants and flocculants have been used effectively to reduce turbidity in municipal drinking water and wastewater, industrial wastewater, quarry effluent, and coal-clay wastes. Field tests of chemical coagulants and flocculants to treat placer mine effluent have been limited in Alaska and have often produced ambiguous or contradictory results. Technology for mixing and dispersing these chemicals has been developed. Toxicities and recommended maximum dosages are established for most commercially available coagulants and flocculants. Cost estimates are available for many types of applications and for many geographic areas.

The effectiveness of chemical clarifiers to treat placer mining effluent can be limited by cold water temperatures, concentrations of fine sediment in the wastewater, dosage, handling procedures, and chemical and physical characteristics of the sediments. The most important factors influencing flocculants are listed below.

1. Adequate mixing and dispersion of the polymers into the wastewater are necessary to achieve low chemical costs and maximum treatment.

2. Primary settling pond design and maintenance are key factors in achieving effective treatment at low polymer dosages.

3. Laboratory jar tests, followed by field testing is an efficient means of selecting the chemical clarifiers that will produce optimum treatment under specific physical and water quality conditions.

4. The effectiveness of chemical clarifiers may be enhanced with supplementary filter systems.

Chemical clarifiers have been shown to be effective in treating placer mining wastewater under a range of conditions, including those found in northern climates of Alaska. Chemical treatment may be the most effective means of reducing sediment pollution, especially in areas where fine clays are abundant, and in combination with water use reduction and filtration or overland discharge. Chemical clarifiers will provide an effective alternative for reducing turbidity at placer mine sites in Alaska, particularly where downstream uses will be adversely affected by high turbidity and total suspended sediment loads.

XI. Recommendations

1. The application of chemical clarifiers to treat placer mine effluents in Alaska merits further field testing to determine usable products, efficient dispersal systems, and relative costs.

2. A variety of organic and inorganic chemicals should be pre-tested for site-specific temperature and water chemistry conditions to identify the most efficient clarifiers for a particular mine site. Chemicals selected should not be toxic to the aquatic biota.

3. The most promising chemical clarifiers should be further tested to determine effectiveness under field applications. Optimum designs for dissolving and dispersing the chemicals and for designing settling ponds should be considered.

4. A simple chemical delivery system should be evaluated at full-scale.

5. Treatment with chemical clarifiers should be tested in conjunction with other treatments, including filtration and overland discharge.

6. All settling ponds intended to contain flocculant-treated sediments should be placed outside the creek-bed to prevent wash-out.

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