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Application of Polyacrylamide-based Floc Logs for Turbidity Control at Highway Construction Sites

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Abstract

Runoff waters generated on highway construction sites can have turbidities in excess of the proposed EPA regulatory standard of 280 NTU due to large areas of exposed soil. The objective of this research was to develop best management practices (BMPs) for the use of anionic polyacrylamide (PAM) based Floc Logs, for turbidity control. Five commercially available types of PAM-based Floc Logs were evaluated in jar tests, using soil excavated from Cato Springs Research Center (CSRC, Fayetteville AR) and six types of clay from the Clay Minerals Society (Chantilly, VA). These results show that no single Floc Log type was suitable for all six types of clay, and that jar tests should be conducted using field soils to select the appropriate Floc Log type for turbidity control. Results from the jar tests were also interpreted alongside particle size distributions (PSDs) of each type of clay, which were measured by Coulter Counter. These results suggested that particle surface charge, and not PSD, was the dominant flocculation mechanism for the clays used in the jar tests. Subsequent inline channel tests at the CSRC and at the Bella Vista Bypass showed little to no turbidity reduction, which was attributed to insufficient PAM dosing, mixing, and/or settling time. However, results from basin-scale sedimentation tests at the CSRC showed that a single Floc Log was capable to treating more than 2,000 L of turbid water (i.e., 95-99% turbidity reduction in ~5 minutes) provided that the Floc Log was presoaked in tap water for 15 minutes. The Floc Log was capable to being reused without compromising turbidity reduction, provided a turbulent mixing period of at least 15 minutes. On balance, PAM-based Floc Logs were shown to be an effective tool to treat turbid water in sedimentation basins provided a period of rapid mixing.

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List of Acronyms

BMP	Best Management Practice
EPA	United States Environmental Protection Agency
PAM	Polyacrylamide
APS	Applied Polymer Systems, Inc.
CSRC	Cato Springs Research Center
PSD	Particle Size Distribution

1 Introduction

Turbidity is a measure of the amount of light that is scattered by suspended (i.e., stabilized) particles in water. In 2009, the Environmental Protection Agency (EPA) proposed to regulate turbidity of runoff waters leaving construction sites at 280 Nephelometric Turbidity Units (NTU). Violations of this proposed water quality standard may result in monetary fines of the contractors and State agencies overseeing the construction. While as of March 6, 2014, the EPA withdrew the numeric turbidity limit and associated monitoring requirements found in 40 CFR 450.22(a) and 450.22(b), they may reinstate the 280 NTU turbidity limit in the coming years (EPA, 2014).

Highway construction sites can be a source of turbid water during rainfall events due to their exposed soils, which can be mobilized and transported offsite and into surrounding receiving waters. There are many erosion control measures that are used on highway construction sites, including rock check dams, straw wattles, mulching, silt fences, and retention basins (McLaughlin and McCaleb, 2010). However, the use of best management practices (BMPs), such as silt fences and rock checks, can fail, leading to runoff water that can exceed 15,000 NTU from AHTD construction sites (ADEQ, 2010) . As such, there is a need to develop improved BMPs to reduce the turbidity of these runoff waters.

Polyacrylamide (PAM) has been demonstrated to reduce turbidity in runoff waters through mechanisms of particle destabilization and enmeshment. PAM is a compound formed by the polymerization of acrylamide and other connected monomers, which may contain additional functionalization (Barvenik, 1994). PAM is commercially available in a number of forms including granular, liquid emulsion, or in a block or log. Flog Logs^{TM} are semi-hydrated PAM designed for passive treatment of turbid water. As water flows over the Floc Logs, PAM is released which destabilizes the suspended particles, allowing them to form flocs that subsequently gravity settle from solution.

There are three strategies commonly employed to manage turbid water generated on highway construction sites: turbidity prevention, inline treatment, and basin treatment. Prevention involves covering the exposed soil, typically by either seeding grass or other soft armoring methods. However, these techniques are typically applied after construction has been completed, and therefore treatment of turbid water is often required during the construction phase, which could last several months or years. Inline treatment involves reducing the turbidity of runoff water during a rain event without storage, prior to discharging offsite; this approach includes silt fences, fiber check dams, vegetative buffers, and Floc Logs. Basin treatment involves collecting and storing turbid water from a rain event in onsite basins and treating with a coagulant of PAM-based technology it before discharging offsite.

To prevent turbid water generation during construction, the preferred option is ground cover or soil stabilization. Shoemaker et al. (2012) showed that applying PAM directly to the bare soil surface reduced particle mobilization compared to using no PAM. Babcock and McLaughlin (2013) showed that applying PAM with straw ground cover reduced turbidity, but the form of application – wet or dry – may influence turbidity reduction during heavy rainfall events. Importantly, however, for a large construction site, it might not be feasible (or cost effective) to cover all exposed soil with PAM. Thus, BMPs for onsite turbid water treatment are needed.

Inline treatment materials for turbidity control include fiber check dams, fabric covered rock dam checks, jute matting, and Floc Logs. The use of fiber check dams or rock check dams covered with an erosion control blanket treated with granular PAM has been shown to be effective for turbidity control through multiple storm events (McLaughlin et al., 2009; Kang et al., 2013). Jute matting treated with granular PAM allows floc particles to adhere to the matting rather than relying on the flocs to settle out solution (Kang et al., 2014). Similarly, placement of an adequate number of Floc Logs within turbulent drainage streams potentially allows flocs to form and settle, although this application has not been tested on highway construction sites. All of these methods are considered to be passive treatment options because they do not require any mixing or pumping, but, as a result, are difficult to control due to imprecise dosing of PAM and insufficient or inconsistent mixing.

In basin treatment, PAM can be added as a liquid or in block form (i.e., as a Floc Log) and mixed with turbid water. However, the liquid PAM application requires careful dosing and pumping, which may be impractical (i.e., labor intensive) for onsite sedimentation basins. The use of Floc Logs may, on the other hand, only require rapid mixing for a predetermined amount of time to disperse the PAM throughout the basin, allowing flocs to form. The Floc Logs can potentially be reused, either in a given basin or in multiple basins at the construction site. For large amounts of rainfall, it may be difficult to store all of the runoff in sedimentation basins for long periods of time; therefore rapid treatment of turbid water is essential.

The objective of this research is to develop BMPs for anionic PAM-based Floc Logs for turbidity control in runoff waters generated on highway construction sites. Five commercially available Floc Log types were assessed in a series of laboratory- and field-scale experiments. Laboratory-scale jar tests were completed with six different types of clay to assess the impact of Floc Log type and soil type on turbidity reduction. Inline- and basin-scale sedimentation tests were completed at a test channel adjacent to the Cato Springs Research Center (CRSC, Fayetteville, AR) and during two rainfall events at AHTD construction sites on the Bella Vista Bypass.

2 Methods and Materials

2.1 Jar Testing

Applied Polymer Systems (APS), Inc. provided a test kit containing samples of their APS 700 Series Floc Logs®. The test kit contained two cylindrical samples each of five commercially available types of anionic PAM-based Floc Logs: 703d, 703d#3, 706b, 707a, and 708x. The chemical composition of these Floc Logs is propriety information that is not released by APS. Each Floc Log sample was approximately 32 mm in diameter and 18-22 mm in length, and ranged in mass from 12.3-18.2 grams.

The soil used for the first round of jar tests was collected from a mound of soil at Cato Springs Research Center (CSRC), which was excavated to construct the turbidity test channel. Prior to use in the jar tests, the soil was sieved through a #10 US Standard sieve to remove large particles and rocks that would rapidly settle out of solution.

Turbidity was measured using a Hach 2100N Turbidimeter. Previous research showed that jar tests with tap water and Beaver Lake water were indistinguishable (Johnson, 2015), and thus tap water was used for convenience. For each jar test, 500 mL of tap water was measured into a 1-L rectangular jar. One gram of the sieved soil was added to the jar (2 g L^{-1}) and mixed at 200 rpm for 5 minutes to produce a homogenous mixture, after which the initial turbidity was measured. Turbidity measurements were taken during the rapid mix phase to ensure the mixture was homogenous and prevent the soil from settling. Due to the sponge-like consistency of some of the Floc Logs, small pieces that ranged in mass from a few milligrams to ~100 mg were separated by hand for use in the jar tests. The Floc Log pieces were added to the turbid water mixture at doses of 100-, 200-, and 300 mg, rapidly mixed (200 rpm) for 15 seconds, slow mixed (60 rpm) for 5 minutes, and settled for 5 minutes, prior to measurement of the final turbidity. Here, samples were taken from the spigot 30 mm from the bottom of the rectangular jars, with caution used to prevent disturbance of the underlying settled floc.

A second set of jar tests was completed with more uniformly sized pieces of each Floc Log. The same masses of 100-, 200-, 300-, and 400 mg were measured out and broken down by hand into pieces up to a maximum mass of ~15 mg. Following measurement of the initial turbidity as described previously, the pieces were added to the turbid water mixture, mixed, and settled prior to measurement of the final turbidity.

Based on the turbidity results from the jar tests (see Section 3.1), full-sized Floc Logs of type 703d and 703d#3 were acquired for field-testing. These Floc Logs were shaped like a trapezoidal prism and had a dry weight between 4.1-4.5 kg with dimensions of 30 cm (top length), 31 cm (bottom length), 16 cm (top width), 18 cm (bottom width), and a height of 7.5 mm.

Following an initial round a field testing, a third and final set of jar tests was completed with six source clays purchased from The Clay Minerals Society (Chantilly, VA): KGa-1b, PFI-1, SHCa-1, STx-1b, SWy-2, and SYn-1. Laboratory-scale jar tests were completed with each clay type and each of the five aforementioned APS Floc Log samples. The same jar testing procedure was followed as previously described. However, to achieve adequate initial turbidity, some of the clays were added at a concentration greater than 2 g L^{-1}. For example, the PFl-1 clay type at 2 g L^{-1} had an initial turbidity of 350 NTU. Therefore, the concentration for all clay types was increased to reach a minimum initial target turbidity of 1,500 NTU. The mass loadings for KGa-1b, PFI-1, SHCa-1, STx-1b, SWy-2, and SYn-1 were 2-, 10-, 8-, 8-, 4-, and 10 g L^{-1}, respectively. Next, 200 mg of Floc Log pieces were added to the turbid water mixture, rapidly mixed (200 rpm) for 15 seconds, slow mixed (60 rpm) for 5 minutes, and settled for 5 minutes, prior to measurement of the final turbidity of the supernatant.

Statistical analyses

In the laboratory jar tests, a portion of the turbidity data were collected in triplicate ($n_i = 3$) and analyzed using Tukey's paired comparison with control method, following the approach described by Berthouex and Brown (2002). For each of *k* treatments and the controls (i.e., jars with no added Floc Log), the sample mean ($\overline{y_i}$) and variance (s^2) was calculated and used to determine the pooled variance using Equation 1:

$$s_{pool}^2 = \frac{(n_1-1)s_1^2+\cdots+(n_k-1)s_k^2}{n_1+\cdots+n_k-k} \text{ (Equation 1)}$$

Next, the confidence interval for the difference in two means was calculated, taking into account all possible comparisons of *k* treatments and control using Equation 2:

$$\overline{y_i} - \overline{y_j} \pm \frac{q_{k-1,v,\alpha/2}s_{pool}}{\sqrt{2}}\sqrt{\frac{1}{n_i}+\frac{1}{n_j}} \text{ (Equation 2)}$$

In Equation 2, $q_{k-1,v,\alpha/2}$ is the upper significance level of the studentized range for *k* means and *v* degrees of freedom in the estimate of the pool variance. Tabulated critical values (Harter, 1960) of $q_{k-1,v,\alpha/2}$ were used to calculate the two-sided 95% confidence interval. Differences in the treatment means were significant if they were larger than the confidence interval. A sample calculation for the confidence interval follows based on the data in Table 3.1.

From Equation 1 and values from Table 2.1, $s_{pool}^{2} =$

$$\frac{(2-1)0.001452+(3-1)0.020849+(3-1)022728+(3-1)0.000793+(3-1)0.017877+(3-1)0.016351}{(2+3+3+3+3+3)-6} =$$

0.014422

The square root of the s_{pool}^{2} is $s_{pool} = 0.12$ and v is the number of degrees of freedom, which is 17 for this example; with ν = 17, (k – 1) = 5, the number of treatments excluding the control, q is 2.922 (interpolated from Table 20.4 of Berthouex and Brown (2002)). Then, using Equation 2,

$$\overline{y_\imath} - \overline{y_\jmath} \pm \frac{2.922}{\sqrt{2}} * 0.12\sqrt{\frac{1}{3}+\frac{1}{3}}$$

$$\overline{y_\imath} - \overline{y_\jmath} \pm 20\%$$

Therefore, differences in the treatment means outside 20% were significant at the 95% confidence interval.

2.1.1 Particle size measurements

The particle size distributions of the six aforementioned source clays (see Section 2.1) were measured with a Beckman Coulter Multisizer 4 Coulter Counter equipped with a 20-µm aperture. The operational range of this instrument is generally considered to be 2-60% of the aperture size, meaning particles between ~0.4-8 µm were counted. First, each of the clays were added to 200 mL of Millipore water and rapidly mixed for five minutes to create a homogeneous mixture. The mass loadings for KGa-1b, PFI-1, SHCa-1, STx-1b, SWy-2, and SYn-1 were 0.25-, 1.25-, 0.75-, 0.75-, 0.5-, and 1.25 g L^{-1}, respectively. From each mixture, 50 µL was transferred to 20 mL of electrolyte and measured with the Coulter

Counter using an analytical volume of 100 µL. Each measurement was completed in triplicate.

2.2 Field Tests at the Bella Vista Bypass

On June 18, 2015, Tropical Storm Bill brought 5.9 cm of rain to the Bella Vista Bypass construction site, which provided an opportunity to conduct a field test. Weather data was taken from National Weather Service using a station gage at the Bentonville Municipal Airport (KVBT) located 12 km from the field site. An ideal site location includes an active face with exposed soil to generate turbid water and a downstream basin to slow the turbid water and allow flocs to settle out. Because the Bella Vista Bypass was under construction during this study, locations were marked using GPS coordinates. While a number of locations were visited along the construction site by the research team prior to Tropical Storm Bill, a location at Latitude: 36.424475, Longitude: -94.314831 (Figure 2.1) was selected as the site test location because of aforementioned site features and a relatively small and shallow basin.

Once the rainfall intensity increased and high turbid water was visually apparent, samples were taken in the absence of Floc Logs to get a baseline turbidity measurement. Samples were collected in 40 mL clear-glass vials and sealed with PTFE-lined screw top lids at two outflow locations downstream of the basin every 5 minutes for 30 minutes, for a total of 12 samples (6 from each outflow location). After the baseline measurements, wooden stakes were hammered into the ground centered within the inflow streams and two new APS 703d type Floc Logs were roped around the stakes, as shown in Figure 2.2. The

Floc Logs were allowed to contact the turbid water for 30 minutes before beginning sampling at the two outflow locations every 5 minutes for 30 minutes.

Following the site testing, the sealed sample vials were taken back to the lab for analysis. Each vial was inverted multiple times to resuspend solids that had settled during transit. The turbidity of each sample was then measured using a Hach 2100N Turbidimeter, as described previously.

A second field test was conducted on November 17, 2015, in which the National Weather Service measured 7.3 cm of rainfall at the Bentonville Municipal Airport (KVBT) located 12 km from the field site. Prior to the field test, a jar test was completed using soil previously acquired from the test site to assess the suitability of the 703d and 703d#3 Floc Logs, with results showing 96% and 98% reduction in turbidity, respectively. The same location as the first field test – Latitude: 36.424475, Longitude: -94.314831 – was selected as the site test location. Samples were taken every 5 minutes for 30 minutes (6 samples) in the absence of Floc Logs at a single outflow location downstream of the basin to get baseline turbidity measurements. Next, wooden stakes were hammered into the ground and six APS 703d#3 type Floc Logs (new and used) were roped around the stakes. The approximate locations of the Floc Logs are shown in Figure 2.3. The Floc Logs were allowed to contact the turbid water for 30 minutes prior to sampling at the outflow location every 5 minutes for 30 minutes. Following completion of this test, the sample vials were taken back to the lab, inverted multiple times to resuspend the solids, and measured for turbidity.

2.3 Inline Mixing Channel Tests

Field tests were conducted at the CSRC using the turbidity test channel adjacent to the building. Here, an inline treatment experiment was conducted by pumping turbid water at a flowrate of 20 L min^{-1} into the channel using a heavy duty submersible pump and passing that water over Floc Logs suspended in the channel. The dimensions of the test channel were: 12.2 m long, 1.2 m wide, and 1.2 m deep. The channel was filled with turbid water to a height of 0.76 m; the calculated horizontal water velocity was 0.0219 m min^{-1}. Samples were taken at three locations: the front of the channel, middle of the channel, and end of the channel. One control (no Floc Log) and two tests (with Floc Logs) were completed: the first test used one 703d Floc Log and second test used four 703d Floc Logs (Figure 2.4); the Floc Logs were placed between the sampling locations at the front and middle of the channel.

However, experimental results (see Section 3.3) indicated little turbidity reduction, which was attributed to insufficient mixing using this mode of operation. As such, basin-scale jar tests were performed, as described next.

2.4 Basin-scale Jar Tests

Basin-scale jar test experiments were designed to be a large-scale version of lab-scale jar tests, and were performed using a circular 2,650 L stock tank (Figure 2.5). This application was intended to mimic treatment of turbid water collected in an onsite sedimentation basin. Turbid water was generated at the CSRC using tap water and the soil that was excavated to construct the turbidity test channel. To generate the turbid water, a 19 L bucket was filled with soil and transferred to the stock tank; three buckets of soil were transferred to the stock tank for every test. The stock tank used for this test was 240 cm in diameter and was filled with tap water to a height of 45 cm; therefore the tank was filled with approximately 2,000 L of tap water for every test.

Two trolling motors were used to mix the tap water and soil. The trolling motors were placed on opposite sides of the circular tank. Three mixing configurations were considered. The first was a circular configuration in which both motors faced the same direction, either clockwise or counter-clockwise. However, this resulted in a zone of low turbidity and mixing (assessed visually) in the center of the tank. In the second configuration, both motors directly faced one another. This created turbulent mixing, but would prove difficult to suspend the Floc Log in the center of the tank. In the third configuration, the motors were pointed at an angle to where one motor was mixing clockwise and the other counter-clockwise; this allowed the most turbulent area to be created on one half of the circular tank where the two flows intersected, rather than the center of the tank, while the other half was less turbulent. This third mixing configuration was chosen for all of the basin-scale jar tests.

For each of these jar tests, the soil and tap water was first rapidly mixed for 10 minutes, during which the trolling motors mixing configurations were constantly cycled to resuspend settled soil. Next, the trolling motors were set to the third mixing configuration, as described previously, for 5 minutes prior to measurement of the initial turbidity. After this mixing period, the initial turbidity was measured by taking a sample from near the top of the water surface. Given the high initial turbidity (> ~4000 NTU), samples were diluted at a 1:1 ratio in tap water prior to measurement.

To perform each basin-scale jar test, one APS Floc Log was center-anchored with a rope secured to a loop, allowing for it to be held in place. The rope was placed around a wooden stake in the ground; the Floc Log was placed in the stock tank and contacted with the turbid water for a selected duration (5-30 minutes). The trolling motors were left on for the duration of the test in an attempt to achieve adequate contact mixing with the Floc Log. Following this period, the mixers were turned off and the turbid water was allowed to settle for one hour. During this period, samples were taken every 5 minutes for a total of 12 samples for each test. Turbidity samples were taken from the supernatant near the top surface of the water. No samples were taken at mid-depth or near the bottom of the water column to prevent disturbing the settling flocs. The turbidity measurements at time zero, or immediately after the trolling motors were turned off, were discontinued because of the rapid settling that occurred within the first few minutes, which resulted in erratic turbidity measurements.

At the start of the one-hour settling period, the Floc Log was removed from the tank, cleaned with a brush to remove as much of the attached soil as possible, and air dried during the one-hour sampling. Following the completion of every test, the water was drained and the remaining soil was removed in preparation of the next test. Because the settled soil presumably contained PAM from the Floc Log, it was removed at the end of each test so as to not affect subsequent tests.

APS type 703d (which is white) and 703d#3 (which is blue) Floc Logs were used in the basin-scale jar tests at various mixing times (5-30 minutes) and with or without a presoaking period in a bucket of tap water. Other researchers (McLaughlin, 2004) have shown Floc Logs were less effective when initially dry. Therefore, a presoaking period was added to hydrate the exterior PAM prior to use. To determine the extent to which the Flog Logs were reusable, a single 703d#3 Floc Log was used in eight consecutive basin-scale jar tests, each 30-minutes in duration; the Floc Log was presoaked in tap water for 15 minutes prior to each test. To offset the stress on the center-anchored rope within the Floc Log for the eight consecutive basin-scale jar test, the single 703d#3 Floc Log was placed inside of a cage container (Figure 2.6). A rope was looped through the cage and secured to the wooden stake in the ground.

Following the series of eight consecutive basin-scale jar tests, the Floc Log volume was measured by a water displacement method in an attempt to determine approximately how much of the Flog Log dissolved during the test. This volume was speculated to correlate to the number of treatment cycles possible for a single Floc Log, which could be used to estimate the volume of water treated. To measure the volume of the Floc Log, an overflow bucket was constructed and filled with tap water (Figure 2.7).

Three different Floc Logs were measured: one which was new and unaltered (a dry control), one which was new log but presoaked in tap water for 15 minutes (a wet control), and the one from the series of eight basin-scale jar tests. Each Floc Log was lowered into the overflow bucket allowing for the excess water to drain through the spout into the catch bucket. The volume of water in the catch bucket was measured using a graduated cylinder. Each volumetric measurement was completed in triplicate.

Table 2.1: Sample data for calculation of the 95% confidence interval using the Tukey's paired comparison method

Floc Log type:	Control	703d	703d#3	706b	707a	708x
% Reduction in Turbidity	22% 27%	47% 64% 76%	54% 80% 80%	57% 56% 61%	20% 33% 47%	24% 30% 49%
Mean, $\bar{y}_i$	25%	62%	71%	58%	33%	34%
Variance, s_i^2	0.001452	0.020849	0.022728	0.000793	0.017877	0.016351
Measurements, n	2	3	3	3	3	3
Treatments, k	6					

Figure 2.1: A picture taken from Google Maps®. The yellow-colored star located on the right side of the picture shows the approximate location where sampling took place.

Figure 2.2: Photograph of the APS 703d type Floc Log roped around a stake. Photo taken by Bryan Signorelli (AHTD) on June 18, 2015.

Figure 2.3: A picture taken from Google Maps®. The yellow-colored star located on the right side of the picture shows the approximate location where sampling took place. The blue-colored stars show the approximate location of the placement of each 703d#3 Floc Log for the second field test.

Figure 2.4: Photograph of four 703d type Floc Logs suspended in the turbidity test channel. Photo taken by author.

Figure 2.5: Photographs of the basin-scale jar tests. (A) Photo of the Floc Log roped around a stake and suspended in the turbid water tank, (B) Photo of the stock tank filled with turbid water with the two trolling motors attached. Photos taken by author.

Figure 2.6: A single 703d#3 Floc Log placed inside of a cage container used for the eight consecutive basin-scale jar tests. Photo taken by author.

Figure 2.7: Photograph of the equipment used to measure the volume of the Floc Logs, which includes an overflow bucket (on the left), a catch bucket (center frame), and a graduated cylinder (on the right). Photo taken by author.

3 Results and Discussion

3.1 Jar Tests

3.1.1 Round 1 Jar Tests

The turbidity results for the first round of jar testing are reported in Table 3.1, organized by Floc Log type and dose. Tukey's tests were used to interpret the % Reduction data by grouping the Dose variable (Table 3.2). Compared to the controls (i.e., jars without added Floc Log pieces), Floc Log Types 703d, 703d#3, and 706b lowered the final turbidity, whereas 707a and 708x did not. No differences in turbidity reduction were observed amongst 703d, 703#d, and 706b. However, as the sizes of the Floc Log pieces varied in these tests (Section 2.1), a second round of jar tests was completed with more uniformly sized pieces.

3.1.2 Round 2 Jar Tests

The turbidity results for the second round of jar testing are reported in the Table 3.3, organized by Floc Log type and dose. Again, Tukey's tests were performed on the % Reduction data by grouping the Dose variable (Table 3.4). Relative to the controls, all Floc Log Types lowered the final turbidity. Results from the Tukey's tests indicated that turbidity reductions with 703d and 703d#3 were higher than with 708x. However, no differences in turbidity reduction were observed amongst 703d, 703#d, 706b, and 707a; similarly, there were no differences between 706b, 707a, and 708x, a partially conflicting result. On balance, however, the results in Tables 3.2 and 3.4 indicate that selection of the appropriate Floc Log type is an important consideration to achieve turbidity reduction. A third round of jar tests was completed to assess the relationship between soil type and Floc Log type.

3.1.3 Round 3 Jar Tests: Clay types

The turbidity results for the third round of jar testing are reported in the Table 3.5, organized by Clay type and Floc Log type. Tukey's tests were performed on the % Reduction data, which was collected in triplicate (Table 3.6a-f). The results in Table 3.6a for clay KGa-1b indicate that, compared to the controls (i.e., jars without added Floc Log pieces), 703d, 703d#3, 706b, and 707a lowered the final turbidity, whereas 708x did not. Further, no differences in turbidity reduction were observed amongst 703d, 703d#3, 706b, and 707a.

The results in Table 3.6b for clay PFl-1 indicate that, compared to the controls, all Floc Log Types lowered the final turbidity. Results from the Tukey's tests indicated no differences in performance amongst the five Floc Logs types.

The results in Table 3.6c for clay SHCa-1 indicate that, compared to the controls, none of the Flog Types lowered the final turbidity. However, 708x actually inhibited turbidity reduction compared to the controls (i.e., the turbidity increased in the presence of 708x). As a result, Tukey's tests indicated that turbidity reduction with 703d, 703d#3, 706b, and 707a were higher than that with 708x. However, no differences in performance were observed amongst 703d, 703#d, 706b, and 707a, and thus clays similar to SHCa-1 would not be amenable to flocculation by any of the APS Floc Logs types evaluated.

The results in Table 3.6d for clay STx-1b indicate that, compared to the controls, 703d and 703d#3 decreased the final turbidity whereas 706b, 707a, and 708x did not.

However, 703d was equally as effective for turbidity reduction as 703d#3, 706b, and 707a, but better than 708x, a finding that is, in part, in conflict with the comparisons to the controls. Logically, turbidity reduction with 703d#3 was higher than 706b, 707a, and 708x and there were no differences in turbidity reduction amongst 706b, 707a, and 708x. On balance, therefore, 703d and 703d#3 performed better than the other Floc Log types for turbidity removal with clay STx-1b.

The results in Table 3.6e for clay SWy-2 indicate that, compared to the controls, none of the Floc Log types lowered the final turbidity. However, turbidity reduction with 703d was higher than 706b and 708x, but similar to 703d#3 and 707a. Further, there were no differences in turbidity reduction amongst 703d#3, 706b, 707a, and 708x and thus clays similar to SWy-2 would not be amenable to flocculation by any of the APS Floc Logs evaluated.

The results in Table 3.6f for clay SYn-1 indicate that, compared to the controls, none of the Floc Log types lowered the final turbidity. Results from the Tukey’s tests indicated no differences in performance amongst any of the Floc Logs types and thus clays similar to SYn-1 would not be amenable to flocculation by any of the APS Floc Logs evaluated.

3.1.4 Summary of Jar Test Results

Based on the Round 2 jar tests (i.e., tests with similarly sized Floc Log pieces), all five APS Floc Log types assessed lowered the final turbidity compared to the controls, but 708x was the poorest performing type and was not statistically better than 707a. Therefore, Floc Log types 703d, 703d#3, and 706b would be equally as effective for turbidity control with soil types similar to those at the CSRC.

The Round 3 jar tests demonstrated that no single Floc Log type was suitable for turbidity control with all six clay types assessed. For clay types KGa-1b and PFl-1, multiple Flog Log types (703d, 703d#3, 706b, and 707a) were effective at lowering the final turbidity. In contrast, for clay types SHCa-1, SWy-2 and SYn-1, none of the five Floc Log types assessed lowered the final turbidity. As such, jar tests with field soil samples and multiple Floc Log types are recommended to assess their suitability for turbidity control.

3.1.5 Particle size distribution (PSD) measurements on the six types of clay

To help explain the relationships between turbidity reduction and clay type in the Round 3 jar tests, PSDs were measured for each clay type before treatment with each Floc Log (Figure 3.1). These results show that KGa-1b had the largest PSD amongst the six clay types measured, but that PF1-1 had the lowest; the fact that these two clay types were removed with multiple Flog Log types (Tables 3.6a and 3.6b) while the other clay types were not suggests that particle surface charge, and not PSD, was the dominant flocculation mechanism in the jar tests. Future work should include zeta potential measurements of all soil types before and after treatment with the Floc Logs in addition to varying the Floc Log dose for each clay type to ensure adequate particle destabilization.

3.2 Field Tests at the Bella Vista Bypass

3.2.1 First Field Test

Many of the potential sites considered for the first field test had rock checks to slow water velocities, but only one site had a downstream basin to subsequently allow flocs to settle out. The site chosen (Figure 3.2) contained a basin that was followed by a sharp drop in elevation on the downstream end with a number of large rocks. For safety reasons, samples were collected further downstream, which may have allowed for changes in turbidity. Additionally, during the first field test, it became apparent that a low turbidity water stream from another inflow location was diluting the Floc Log-treated water flowing into the basin. This low turbidity flow was not apparent during the baseline turbidity measurements made prior to placement of the Floc Logs, and therefore the extent of dilution versus treatment is impossible to assess.

Table 3.7 shows the baseline (no Floc Logs) and treated water turbidity (two 703d Floc Logs) measurements; BL-E1 & FL-E1 were taken at the first sampling location and BL-E2 & FL-E2 was taken further downstream. While there was a reduction in turbidity following placement of the Flog Logs (which occurred at 3:20 PM), it cannot be attributed to the Floc Logs due to the introduction of the aforementioned low turbidity water stream. Additionally, the treated water turbidity was in excess of 300 NTU, which is above the EPA recommended limit for release from highway construction sites. As such, even if treatment was occurring due to the Floc Logs, it was not sufficient; therefore, the number of Floc Logs was increased to six for the second field test.

3.2.2 Second Field Test

The second field test occurred on November 17, 2015, at the site used previously (Figure 3.2). During the rainfall event, five upstream inflows combined into a single stream, which subsequently flowed into a series of basins. Six 703d#3 Floc Logs were placed within turbulent water locations (assessed visually) at each stream inflow in an attempt to achieve adequate coagulant dosing and mixing. This included placement of one 703d#3 Flog Log within each of the five inflow streams, and the sixth following the confluence of each inflow upstream of the basins. One inflow stream is shown in Figure 3.3 flowing over a 703d#3 Floc Log.

The baseline turbidity was lower in the second field test (~400 NTU, Table 3.8) compared to the first one (~1,500 NTU, Table 3.7). This was attributed to differences in rainfall duration prior to the baseline turbidity measurement, which, in the second test, was several hours longer and hence mobilized fewer particles during the baseline testing. Turbidity results in Table 3.8 were interpreted using Tukey's tests on the raw turbidity data. With 95% confidence, observed values outside ±205 NTU are unlikely to be zero; the mean difference between the baseline turbidity and Floc Log treated water was 92 NTU. Therefore, the Floc Log treatment did not lower the final turbidity.

Despite this result, the 703d#3 Floc Logs were confirmed to be effective with jar tests prior to the field test (see Section 2.2). Possible reasons for the relatively high treated water turbidities in the second field test (260-305 NTU) include insufficient dosing, mixing, and/or settling conditions. The contact mixing between the turbid water and Flog Logs cannot be determined accurately in the field. The series of basins and rock checks that had slowed the turbid water velocity in the first field test failed in the second test, allowing for high water velocities (Figure 3.4). In terms of selecting the appropriate number of Floc Logs (i.e., the correct coagulant dose for particle destabilization) for this mode of application, APS recommends one Floc Log for every 227-265 L min^{-1} (Price and Company, 2002). Future studies should include measurements of flow in the field and particle surface charge (i.e., zeta potential measurements) to calculate the required numbers of Floc Logs. However, based on the results from this test, it is likely that this number would be impractically large (i.e., several dozen Floc Logs per site for a storm of similar intensity and duration).

3.3 Inline Mixing Channel Tests

The turbidity test channel at the CSRC was used to mimic the field tests by pumping turbid water over a series of Floc Logs. The Floc Logs were placed at the front of the channel, after the influent sampling location. Turbidity was sampled at the mid-point of the channel (~6 m from the influent) and at the effluent (~12 m from the influent). Turbidity results are shown in Table 3.9 for a control condition (i.e., no Floc Logs) and two tests (the first with one Floc Log and the second with four Floc Logs). Similar to the previous analysis procedures, these data were interpreted using Tukey's tests (Table 3.10). The results in Table 3.10 indicate that, compared to the control, the Floc Logs did not lower the final turbidity. Further, there were no differences in the final turbidity with either one or four Floc Logs. These results were attributed to insufficient dosing and/or mixing using this mode of operation, similar to that of the two field tests. Therefore, a series of basin-scale tests were undertaken to assess the performance of the Floc Logs as applied to turbidity reduction in onsite sedimentation basins.

3.4 Basin-scale Sedimentation Tests

3.4.1 Turbidity Reduction

The turbidity results for the basin-scale sedimentation tests with Floc Log types 703d and 703d#3 are reported in Table 3.11, organized by the duration of the rapid mix step (5-, 15-, or 30-min) and a binary variable, Presoak Time. This variable denotes whether the Floc Log was dry at the start of the test (i.e., Presoak Time = None) or had been presoaked in tap water for 15 min (i.e., Presoak Time = 15 min) prior to the sedimentation test.

Turbidity reduction results in Table 3.11 were interpreted using Tukey's tests on the raw turbidity data by grouping the turbidity values at settling times between 5-60 minutes (Tables 3.12a-c). The impact of the rapid mix period on turbidity reduction is shown in Table 3.12a. These results indicate that rapid mix periods of 15- and 30-minutes decreased the final turbidity more so than the 5-minute period. Additionally, there was no difference in final turbidity between the 15- and 30-minute rapid mix periods. Therefore, a minimum rapid mix period of 15 minutes is recommended for every 2,000 L of turbid water to distribute the PAM throughout the basin and allow flocs to form.

The impact of presoaking the Floc Logs prior to use in the basin-scale sedimentation tests is shown in Table 3.12b. These results indicate that the 15-minute presoaking period decreased the final turbidity relative to no presoaking for both the 703d and 703d#3 Floc Log types. This result agrees with previous studies that show Floc Logs were more effective for turbidity reduction following a presoaking period (McLaughlin, 2004). As such, it is recommended that all Floc Logs used in the field be presoaked prior to use in sedimentation basins for turbidity reduction.

The results from the Tukey's test related to Floc Log type is shown in Table 3.12c for 703d and 703d#3. These Floc Logs were compared under identical mixing conditions. The results in Table 3.12c indicate there was no difference in performance between the two Floc Log types. For the shorter rapid mix time (15 minutes), 703d#3 produced lower final turbidities, but at the longer rapid mix time (30 minutes), both Floc Log types performed similarly for turbidity reduction. Arbitrarily, the 703d#3 Floc Log was chosen for further testing to assess its effectiveness in successive basin-scale sedimentation tests designed to estimate the volume of turbid water treated with a given Floc Log.

3.4.2 Assessment of Floc Log Longevity

A basin-scale sedimentation test was completed eight times in succession with the same 703d#3 Floc Log in an attempt to determine its longevity in terms of volume of turbid water treated. Control tests were also completed with the same experimental setup, but with no Floc Log, to assess the effectiveness of gravity settling alone on the turbidity reduction. The percent turbidity reduction data for the Control and Test conditions are shown in Figure 3.5, presented as a function of settling time (0-60 minutes). At a settling time of 5 minutes, the % Reduction in turbidity of the Controls ranged from 30-58% and that of the Tests ranged of 88-98%; at a settling time of 60 minutes, the Controls ranged from 68-88%, and the Tests ranged from 95-99%. As such, the Floc Logs increased the overall extent and rate of turbidity reduction in the basin-scale sedimentation tests. Further, no decrease in turbidity reduction was observed over the course of the eight experiments in the Test condition, indicating a single Floc Log could treat more than 16,000 L (i.e., 8 tests of ~2,000 L each) of turbid water as long as the proper mixing conditions are achieved. On balance, the results in Figure 3.5 indicate the Floc Logs would be an effective tool to rapidly reduce turbidity in runoff waters collected in onsite sedimentation basins.

3.4.3 Volumetric measurements

It was hypothesized that the volume of the Floc Log used in tests described in Section 3.4.2 would decrease from one test to the next as the PAM from its surface dissolved. However, as shown in Table 3.13, the volume of the Floc Log in these tests increased over the course of the eight basin-scale sedimentation tests. Possible reasons include the absorption of water, entrapped air in the interior of the log, and soil adhered to the exterior of the log that could not be removed by brushing. APS contends that each Floc Log should be capable of treating 1.6 million liters of turbid water.

Table 3.1: Round 1 Jar tests: Turbidity reduction using non-uniformed pieces of Floc Log

Floc Log Type	Dose (mg/L)	Initial Turbidity (NTU)	Final Turbidity (NTU)	% Reduction
Control 1	0	1,713	1,337	22%
Control 2	0	2,224	1,616	27%
703d	206	1,859	989	47%
	408	1,993	722	64%
	606	2,357	577	76%
703d#3	200	2,306	1,060	54%
	406	2,354	460	80%
	607	2,433	491	80%
706b	203	2,335	997	57%
	403	2,180	958	56%
	605	1,937	747	61%
707a	201	2,005	1,608	20%
	405	2,405	1,601	33%
	605	2,413	1,290	47%
708x	209	1,639	1,244	24%
	400	1,869	1,312	30%
	609	1,885	970	49%

*Undissolved pieces of Floc Logs remained after the completion of each jar test

Table 3.2: Round 1 Jar tests: Tukey's test results

	Difference in the Means (%)*				
Floc Log Type	**Control**	**703d**	**703d#3**	**706b**	**707a**
703d	-25				
703d#3	-47	-9			
706b	-34	4	13		
707a	-9	29	38	25	
708x	-10	28	37	24	-1

* With 95% confidence, observed values outside ±20% are unlikely to be zero; negative values less than minus 20% indicate value in column is less than the corresponding row

Table 3.3: Round 2: Jar tests turbidity reduction using uniformed pieces of Floc Logs

Floc Log Type	Dose (mg/L)	Initial Turbidity (NTU)	Final Turbidity (NTU)	% Reduction
Control 1	0	1,992	1,457	27%
Control 2	0	1,889	1,371	27%
Control 3	0	1,848	1,370	26%
Control 4	0	2,010	1,510	25%
703d	203	2,079	669	68%
	400	1,936	343	82%
	605	2,260	399	82%
	806	2,296	371	84%
703d#3	208	2,179	570	74%
	402	2,373	413	83%
	606	1,846	302	84%
	807	1,973	250	87%
706b	200	2,198	946	57%
	408	1,863	490	74%
	607	2,046	455	78%
	806	2,114	481	77%
707a	205	1,839	1,119	39%
	403	2,271	1,114	51%
	604	2,096	501	76%
	802	2,061	553	73%
708x	209	2,079	1,534	26%
	405	2,307	1,593	31%
	609	1,906	426	78%
	803	2,260	724	68%

*Undissolved pieces of Floc Logs remained after the completion of each jar test

Table 3.4: Round 2 Jar tests: Tukey's test results

	Difference in the Means (%)*				
Floc Log Type	**Control**	**703d**	**703d#3**	**706b**	**707a**
703d	-53				
703d#3	-56	-3			
706b	-45	8	10		
707a	-34	19	22	12	
708x	-24	28	31	21	9

* With 95% confidence, observed values outside ±22% are unlikely to be zero; negative values less than minus 22% indicate value in column is less than the corresponding row

Table 3.5: Round 3 Jar tests: Turbidity reduction results for the six clay types using the five Floc Log types

			Floc Log type				
Clay Type		**Control**	**703d**	**703d#3**	**706b**	**707a**	**708x**
KGa-1b	Initial	3,112	3,480	3,277	3,345	3,293	3,110
	Final	1,954	123	96.4	142	235	1291
	% Reduction	**37%**	96%	97%	96%	93%	58%
	Initial	3,305	3,154	3,455	3,489	3,610	3,177
	Final	2,512	136	104	185	315	670
	% Reduction	**24%**	96%	97%	95%	91%	79%
	Initial	3,511	3,312	3,009	3,275	3,339	3,501
	Final	1602	114	156	208	281	2,514
	% Reduction	**54%**	97%	95%	94%	92%	28%
PFl-1	Initial	2,553	2,677	2,719	2,690	2,560	2749
	Final	721	47.6	36.6	37	80.3	95
	% Reduction	**72%**	98%	99%	99%	97%	97%
	Initial	2,810	2,797	2,748	2,799	2,575	2,524
	Final	431	34.4	62	41.2	75.6	113
	% Reduction	**85%**	99%	98%	99%	97%	96%
	Initial	2,637	2,666	2,536	2,778	2,681	2,624
	Final	543	108	106	114	74.2	101
	% Reduction	**79%**	96%	96%	96%	97%	96%
SHCa-1	Initial	3,052	2,811	2,914	3,034	2,978	2,879
	Final	1,914	1,604	1,556	1,877	1,835	2,587
	% Reduction	**37%**	43%	47%	38%	38%	10%
	Initial	2,969	2,973	2,963	3,000	3,137	2,988
	Final	1,993	1,987	1,720	1,869	1,977	2,526
	% Reduction	**33%**	33%	42%	38%	37%	15%
	Initial	3,039	2,977	2,873	2,977	3,220	3,068
	Final	1,975	2,029	1,992	1,903	1,983	2,684
	% Reduction	**35%**	32%	31%	36%	38%	13%

Table 5 is continued on the next page

Table 3.5, continued

			Floc Log Type				
Clay Type		**Control**	**703d**	**703d#3**	**706b**	**707a**	**708x**
STx-1b	Initial	3,192	3,160	3,174	3,188	3,144	3,152
	Final	2,124	1,157	1,054	1,672	1,764	1,443
	% Reduction	**33%**	63%	67%	48%	44%	5,4%
	Initial	2,907	3,068	3,156	3,099	3,029	3,171
	Final	2,059	1,511	1,025	1,587	1,744	1,845
	% Reduction	**29%**	51%	68%	49%	42%	42%
	Initial	3,022	3,077	3,060	3,066	3,261	3,308
	Final	2,204	252	123	1,463	1,294	1,856
	% Reduction	**27%**	92%	96%	52%	60%	44%
SWy-2	Initial	2,295	2,356	2,440	2,322	2,263	2,430
	Final	2,190	2,334	2,311	2,275	2,136	2,392
	% Reduction	**5%**	1%	5%	2%	6%	2%
	Initial	2,309	2,330	2,317	2,125	2,277	2,430
	Final	2,195	2,056	2,204	2,074	2,182	2,337
	% Reduction	**5%**	12%	5%	2%	4%	4%
	Initial	2,187	2,172	2,230	2,186	2,173	2,193
	Final	2,104	1,737	2,148	2,112	2,000	2,117
	% Reduction	**4%**	20%	4%	3%	8%	3%
SYn-1	Initial	1,607	1,680	1,608	1,734	1,685	1,737
	Final	696	729	663	826	674	721
	% Reduction	**57%**	57%	59%	52%	60%	58%
	Initial	1,605	1,626	1,599	1,706	1,689	1,390
	Final	796	849	666	716	804	459
	% Reduction	**50%**	48%	58%	58%	52%	67%
	Initial	1,494	1,491	1,768	1,678	1,509	1,490
	Final	773	685	702	570	663	666
	% Reduction	**48%**	54%	60%	66%	56%	55%

Table 3.6a: Clay KGa-1b Jar tests: Tukey's test results

KGa-1b	**Difference in the Means (%)***				
Floc Log Type	**Control**	**703d**	**703d#3**	**706b**	**707a**
703d	-58				
703d#3	-58	0			
706b	-56	2	2		
707a	-53	4	4	3	
708x	-17	41	41	40	37

* With 95% confidence, observed values outside ±21% are unlikely to be zero; negative values less than minus 21% indicate value in column is less than the corresponding row

Table 3.6b: Clay PFl-1 Jar tests: Tukey's test results

PFl-1	**Difference in the Means (%)***				
Floc Log Type	**Control**	**703d**	**703d#3**	**706b**	**707a**
703d	-19				
703d#3	-19	0			
706b	-19	0	0		
707a	-18	1	0	1	
708x	-17	2	1	2	1

* With 95% confidence, observed values outside ±5% are unlikely to be zero; negative values less than minus 5% indicate value in column is less than the corresponding row

Table 3.6c: Clay SHCa-1 Jar tests: Tukey's test results

SHCa-1	**Difference in the Means (%)***				
Floc Log Type	**Control**	**703d**	**703d#3**	**706b**	**707a**
703d	-1				
703d#3	-5	-4			
706b	-2	-1	2		
707a	-3	-2	2	-1	
708x	22	23	27	25	25

* With 95% confidence, observed values outside ±7% are unlikely to be zero; negative values less than minus 7% indicate value in column is less than the corresponding row

Table 3.6d: Clay STx-1b Jar tests: Tukey's test results

STx-1b	**Difference in the Means (%)***				
Floc Log Type	**Control**	**703d**	**703d#3**	**706b**	**707a**
703d	-39				
703d#3	-47	-8			
706b	-20	19	27		
707a	-19	20	28	1	
708x	-17	22	30	3	2

* With 95% confidence, observed values outside ±20% are unlikely to be zero; negative values less than minus 20% indicate value in column is less than the corresponding row

Table 3.6e: Clay SWy-2 Jar tests: Tukey's test results

SWy-2	**Difference in the Means (%)***				
Floc Log Type	**Control**	**703d**	**703d#3**	**706b**	**707a**
703d	-6				
703d#3	0	6			
706b	2	8	2		
707a	-1	5	-1	-3	
708x	1	8	2	0	3

* With 95% confidence, observed values outside ±7% are unlikely to be zero; negative values less than minus 7% indicate value in column is less than the corresponding row

Table 3.6f: Clay SYn-1 Jar tests: Tukey's test results

SYn-1	**Difference in the Means (%)***				
Floc Log Type	**Control**	**703d**	**703d#3**	**706b**	**707a**
703d	-1				
703d#3	-7	-6			
706b	-7	-6	0		
707a	-4	-3	3	3	
708x	-8	-7	-1	-1	-4

* With 95% confidence, observed values outside ±8% are unlikely to be zero; negative values less than minus 8% indicate value in column is less than the corresponding row

Table 3.7: Turbidity measurements during the first field test

Baseline Turbidity				Treated Water Turbidity with Floc Log		
Time	**BL-E1[a]**	**BL-E2[a]**		**Time**	**FL-E1[b]**	**FL-E2[b]**
2:45	1,695	1,470		3:50	707	555
2:50	1,601	1,307		3:55	613	525
2:55	2,060	1,729		4:00	556	485
3:00	1,729	1,632		4:05	495	438
3:05	1,403	1,200		4:10	449	404
3:10	934	1,061		4:15	404	344

*Finish placing Floc Logs at 3:20 pm

[a] BL-E1 is the baseline turbidity taken at the first effluent location, BL-E2 is the baseline turbidity taken at the second effluent location further downstream.

[b] FL-E1 is the Floc Log treated water turbidity taken at the first effluent location, FL-E2 is the Floc Log treated water turbidity taken at the second effluent location further downstream.

Table 3.8: Turbidity measurements during the second field test

Baseline Turbidity			Treated Water Turbidity with Floc Logs	
Time	**BL-E3[c]**		**Time**	**FL-E3[c]**
8:45	425		10:20	305
8:50	400		10:25	304
8:55	398		10:30	278
9:00	359		10:35	274
9:05	347		10:40	265
9:10	310		10:45	260

*Started placing Floc Logs at 9:20 am and finish placing Floc Logs at 9:50 am

[c] BL-E3 is the baseline turbidity collected at a third effluent location, FL-E3 is the Floc Log treated water turbidity collected at the third effluent location.

Table 3.9: Turbidity measurements from inline mixing using the turbidity test channel

Test	**Sample Location**	**Time (hr)**	**0**	**1**	**2**	**3**	**4**	**5**
Control	Influent	**Turbidity (NTU)**	251	311	312	320	332	303
	Mid-Channel		241	254	262	289	328	292
	Effluent		231	254	253	275	292	310
One 703d Floc Log	Influent	**Turbidity (NTU)**	224	254	312	266	307	316
	Mid-Channel		174	182	188	201	182	247
	Effluent		174	174	173	205	201	170
Four 703d Floc Logs	Influent	**Turbidity (NTU)**	300	404	284	356	302	490
	Mid-Channel		169	164	170	240	292	293
	Effluent		173	156	166	178	257	301

Table 3.10: Inline Mixing Channel Tests: Tukey's test results

	Difference in the Means (NTU)*	
Floc Log Type	**Control**	**One 703d Floc Log**
One 703d Floc Log	-25	
Four 703d Floc Logs	-47	-9
* With 95% confidence, observed values outside ±337 NTU are unlikely to be zero; negative values less than minus 337 NTU indicate value in column is less than the corresponding row		

Table 3.11: Turbidity reduction in the basin-scale sedimentation tests

Test number:	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
Floc Log Type:	703d	703d	703d#3	703d#3	703d	703d	703d#3	703d#3
Rapid mixing time (min)	5	5	15	15	15	30	15	30
Settling Time (min)	**Turbidity (NTU)**							
Initial Turbidity (NTU)[*]	>4,000[d]	3,317	>4,000[d]	>4,000[d]	2,041	1,584	2,402	2,938
5	2,823	1,326	2,452	147	545	256	88.1	295
10	2,461	998	2,144	146	414	122	85.7	182
15	1,956	872	1,857	143	354	110	79.9	180
20	2,041	847	1,947	141	349	109	77	182
25	1,633	740	1,833	137	322	106	76.8	177
30	1,698	717	1,470	135	282	104	74.4	171
35	1,525	689	1,512	134	279	102	74.6	160
40	1,476	616	1,520	133	274	96.7	74	169
45	1,152	593	1,308	134	267	93.9	72.6	159
50	1,205	595	1,388	132	269	92.9	72	156
55	1,121	522	1,262	132	238	95.9	70.6	154
60	1,065	499	1,166	129	253	93.6	70.7	156
Log Condition:	**Used[e]**	**Used[e]**	**New[f]**	**New[f]**	**Used[e]**	**Used[e]**	**Used[e]**	**Used[e]**
Presoak Time (min):	**None**	**15 min**	**None**	**15 min**	**None**	**None**	**None**	**None**

[*] Initial Turbidity (NTU) samples were measured prior to treatment with the Floc Logs

[d] Turbidity values listed as >4,000 were not diluted, so the actual turbidity may be greater than the turbidimeter maximum of 4,000 NTU

[e] Flog Log previously used in one or more tests

[f] Flog Log was new and had not been used in prior tests

Table 3.12a: Basin-scale sedimentation tests: Tukey's test results comparing mixing duration

	Difference in the Means (%)*		
Test number:[g]	**#1**	**#5**	**#6**
	703d (white)		
Mix time (min)	5	15	30
	Used Floc Log No presoak	Used Floc Log No presoak	Used Floc Log No presoak
15	1,359		
30	1,565	205	
* With 95% confidence, observed values outside ±736 NTU are unlikely to be zero; negative values less than minus 736 NTU indicate value in column is less than the corresponding row			

[g] Test number corresponds to the Test number in Table 11

Table 3.12b: Basin-scale sedimentation tests: Tukey's test results comparing Floc Log presoaking time

	Difference in the Means (%)*			
Test number:[g]	**#1**	**#2**	**#3**	**#4**
	703d (white)		**703d#3 (blue)**	
Mix time (min)	5	5	15	15
	Used Floc Log No presoak	Used Floc Log 15min presoak	New Floc Log No presoak	New Floc Log 15min presoak
703d, 5 min rapid mix, used, no presoak				
703d, 5 min rapid mix, used, 15 min presoak	929			
703d#3, 15 min rapid mix, new, no presoak	25	-904		
703d#3, 15 min rapid mix, new, 15 min presoak	1,543	614	1,518	
* With 95% confidence, observed values outside ±871 NTU are unlikely to be zero; negative values less than minus 871 NTU indicate value in column is less than the corresponding row				

[g] Test number corresponds to the Test number in Table 11

Table 3.12c: Basin-scale sedimentation tests: Tukey's test results comparing Floc Log types 703d and 703d#3

	Difference in the Means (%)*			
Test number:[g]	**#5**	**#6**	**#7**	**#8**
	703d (white)		**703d#3 (blue)**	
Mix time (min)	15	30	15	30
	Used Floc Log No presoak	Used Floc Log No presoak	Used Floc Log No presoak	Used Floc Log No presoak
703d, 15 min rapid mix, used, no presoak				
703d, 30 min rapid mix, used, no presoak	205			
703d#3, 15 min rapid mix, used, no presoak	244	39		
703d#3, 30 min rapid mix, used, no presoak	142	-63	-102	
* With 95% confidence, observed values outside ±128 NTU are unlikely to be zero; negative values less than minus 128 NTU indicate value in column is less than the corresponding row				

[g] Test number corresponds to the Test number in Table 11

Table 3.13: Volumetric measurement of various conditions of 703d#3 Floc Logs

Log Type	**Volume of Floc Log (L)**			
	Triplicate Measurement			**Average**
New log	3.595	3.670	3.665	3.643
New log presoaked	3.745	3.765	3.830	3.780
Floc Log following the eighth Longevity test	4.170	4.175	4.230	4.191

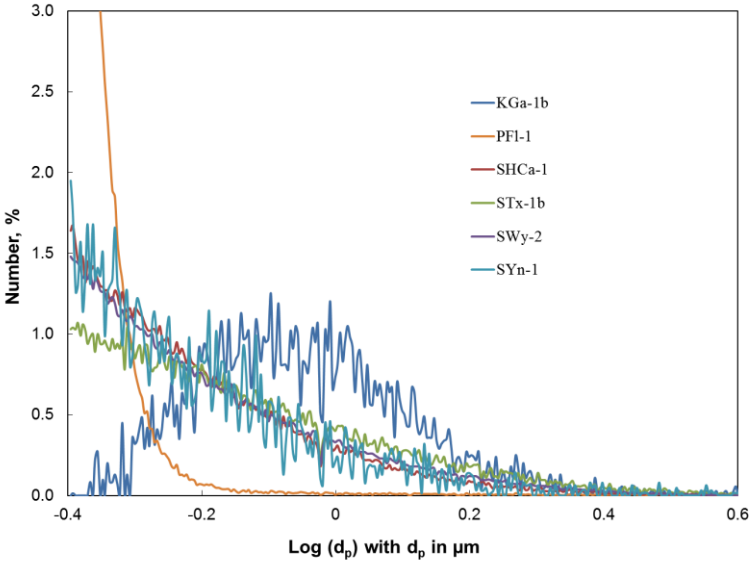

Figure 3.1: Particle size distribution of the six clay types assessed in the Round 3 jar tests

Figure 3.2: Photograph of the site chosen for the first field test. One inflow stream was from the left side of the photo, which enters the small and shallow basin. A second inflow stream is pictured in the background, which included a series of small basins with intermittent rock checks. Photo taken by Bryan Signorelli (AHTD) on June 18, 2015.

Figure 3.3: A stream inflow where a 703d#3 Floc Log was placed on a concrete ditch. Photo taken by author.

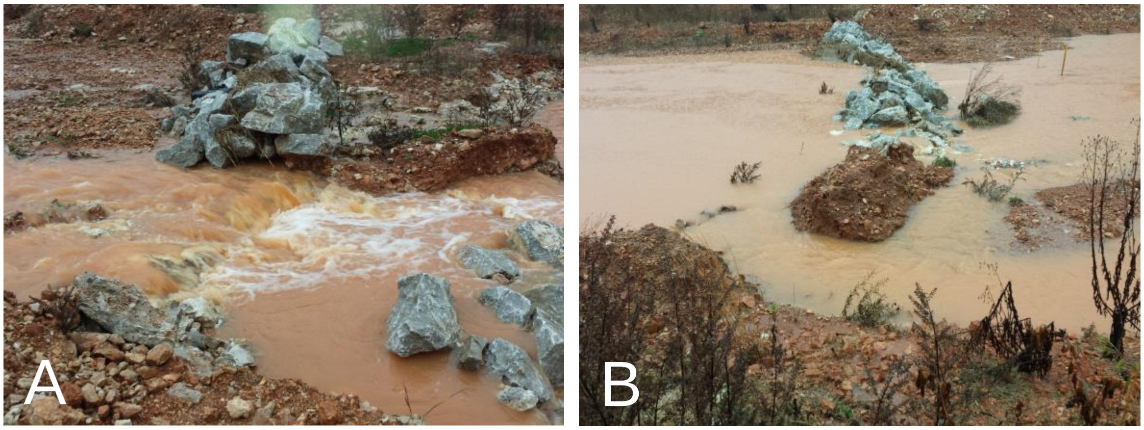

Figure 3.4: The overtopped rock check dams that separated the series of basins. Photo taken by author.

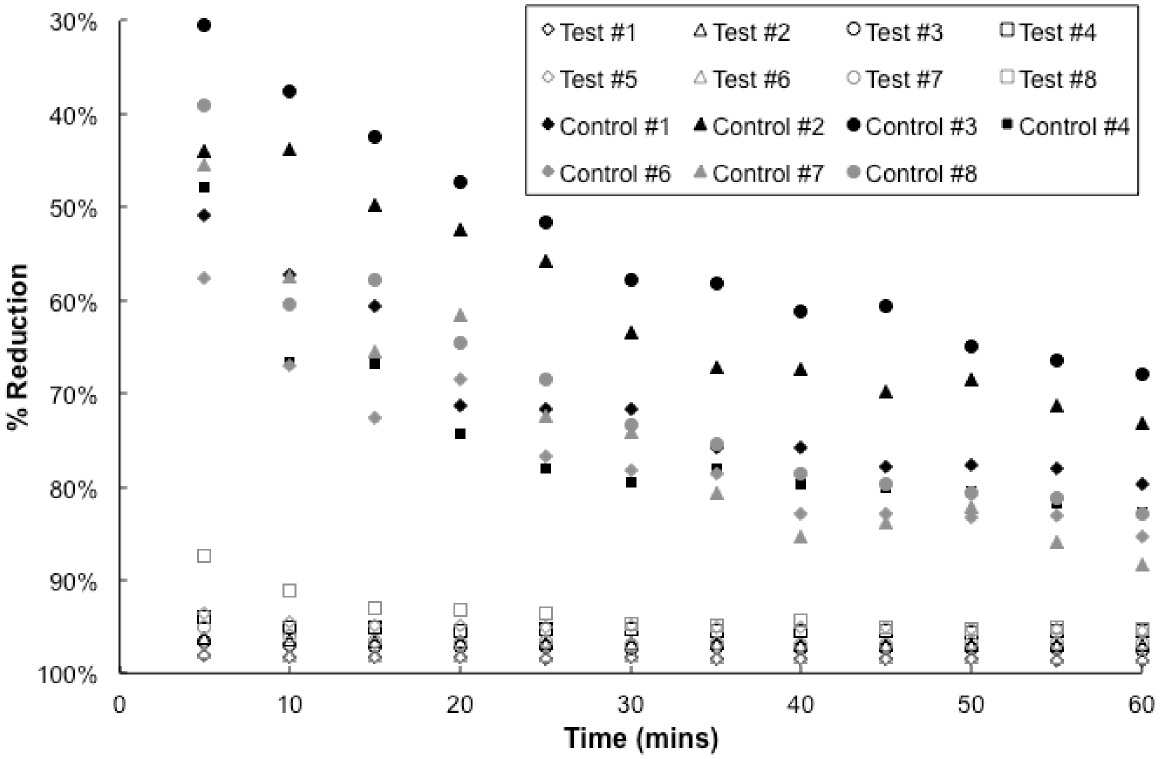

Figure 3.5: Percent turbidity reduction in the basin-scale sedimentation tests of the Control condition (i.e., no Floc Logs, closed symbols) and the Test condition (i.e., one 703#d Floc Log, open symbols). The Control and Test conditions were completed in succession to assess the reproducibility of the experiments.

5 Conclusions and Future Work

The objective of this research was to develop BMPs for the use of anionic PAM-based Floc Logs for turbidity control in runoff waters leaving highway construction sites. Storm water runoff can have turbidities of several thousand NTU due to exposed soil at construction sites leading to exceedances of the EPA proposed regulatory standard of 280 NTU (EPA, 2014) for waters leaving these sites. Floc Logs were assessed in a series of laboratory-scale jar tests, basin-scale sedimentation tests, and field tests at active AHTD construction sites. The major findings of this research were as follows:

- Based on the Round 2 jar tests (Tables 3 and 4), Floc Log types 703d, 703d#3, and 706b would be equally as effective for turbidity control with soil types similar to those at the CSRC.
- The Round 3 jar tests (Tables 5 and 6a-f) demonstrated that no single Floc Log type was suitable for turbidity control with all six clay types assessed. In fact, relative to the control condition, no turbidity removal was achieved with any of the five Floc Log types assessed for clays SHCa-1, SWy-2, and SYn-1. As such, jar tests with field soil samples and multiple Floc Log types are recommended to assess their suitability for turbidity control.
- PSDs were measured by Coulter Counter for the six clay types before treatment and, together with the Round 3 jar test results, indicate that particle surface charge, and not PSD, was the dominant flocculation mechanism for the clays used in the jar tests (Figure 3.1). Future work should include zeta potential measurements of all

soil types before and after treatment with the Floc Logs to determine the coagulant doses necessary to achieve adequate particle destabilization.

- Field test results showed little to no reduction in turbidity, despite that the Floc Log types used were confirmed to be effective in jar tests with the field soils. This was attributed to insufficient PAM dosing, mixing, and/or settling conditions in the inline treatment scenario attempted in the field.
- In the inline mixing channel tests at the CSRC, the Floc Logs did not lower the final turbidity (Table 9-10). Similar to the field studies, these results were attributed to insufficient dosing and/or mixing using this mode of operation
- For basin-scale sedimentation, a minimum rapid mix period of 15 minutes is recommended for every 2,000 L of turbid water to distribute the PAM throughout the basin and allow flocs to form (Table 12a).
- Presoaking the Floc Logs in tap water for 15 minutes was found to increase turbidity reduction in sedimentation basin treatment (Table 12b).
- No decrease in turbidity reduction was observed in the Longevity Tests (Figure 3.5), indicating a single Floc Log could treat more than 16,000 L of turbid water as long as the proper mixing conditions are achieved. APS contends that each Floc Log should be capable of treating 1.6 million liters of turbid water.
- The results in Figure 3.5 indicate the Floc Logs would be an effective tool to reduce turbidity in runoff waters (~95-99% for the excavated soil at the CSRC) collected and treated in onsite sedimentation basins.

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