Stilling Basin Design and Operation for Water Quality

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16. Abstract

Many construction projects involve the need to pump turbid water from borrow pits or other excavations into stilling basins or sediment bags prior to discharge. The design and operation of these basins needs to be optimized to provide the best water treatment prior to discharge. This project was designed to provide an evaluation of stilling basin designs and polyacrylamide (PAM) injection to minimize turbidity in discharged water. Of particular interest were difficult to settle Coastal Plain sediments containing highly charged clays (smectite/montmorillonite). The use of stilling basins did not result in significant reductions in turbidity in water pumped from the simulated borrow pits in these types of soils. These were not flocculated significantly by anionic PAM but can be flocculated by neutral or cationic PAM. In field tests, the flocculation process reduced turbidity regardless of the inclusion of either porous coir or rock baffles. However, at least one baffle is recommended when PAM is being used in case floating flocs are formed. Turbidity was reduced from the 500-800 NTU range to < 30 NTU in many cases, especially for the cationic PAM. Similar reductions were achieved using a sediment bag. Toxicity tests indicate the relative PAM toxicity was cationic > anionic > neutral, and was not affected by turbidity. The neutral PAM was almost as effective as the cationic PAM and was even less toxic than the anionic PAM, so it may be an alternative where the anionic PAMs that are available will not work.

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Final Report

NCDOT Research Project HWY-2006-22

Stilling Basin Design and Operation for Water Quality

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Introduction

Many construction projects involve the need to pump turbid water from borrow pits or other excavations into stilling basins prior to discharge. The design and operation of these basins needs to be optimized to provide the best water treatment prior to discharge. This project was designed to provide an evaluation of stilling basin designs and operations which will minimize turbidity in discharged water. The purpose is to provide several options for installing and operating stilling basins in the Coastal Plain where pumping from borrow pits and excavations may result in water with significant turbidity. This phase of the study was conducted in our laboratory and at our Sediment and Erosion Control Research and Education Facility in Raleigh, NC.

Materials and Methods

There were two phases to this project, one conducting screening tests in the laboratory and one testing different designs in a simulated borrow pit in the field. The initial screening consisted of seven different PAM products with varying charge, charge densities and molecular weight. Charges included neutral, cationic and anionic. The charge densities of the anionic and cationic polymers ranged from 5 – 50% and the molecular weights ranged from low to high. PAM products tested included Cytec Industries Super Floc N300, N300 LMW, A150, A150 LMW (Cytec Industries, Patterson, NJ, USA); NALCO 9909, 9919 (NALCO Industries, Chicago, IL, USA); and Geofloc 1800 (GeoSpec, Inc., Raleigh, NC, USA). The products were individually evaluated for turbidity reduction using a jar test. A jar test consisted of filling a 100 mL specimen cup with 100 mL of deionized (DI) water, adding 5 g of soil, then pipetting a PAM solution into the cup to result in a specified concentration. The cup was then shaken for 10 seconds to induce contact between the polymer and the soil. After 20 seconds of settling, turbidity was measured using a nepholometer (McVan Instruments, Victoria, Australia) inserted into the cup and read after 10 seconds. The readings were later corrected using a regression curve developed from readings of formazin standards taken after each set of samples was read.

Stock solutions of PAM were made by adding 500 mg of granular PAM to 1 L of DI water and stirring until the PAM was completely dissolved. The solutions were allowed to age for 12 – 24 hours before use. Seven concentrations evaluated in the initial screening: 0 (control), 0.25, 0.5, 1, 2, 5 and 10 mg L^{-1}.

The stock solution was diluted to produce PAM solutions having concentrations of 25 mg $L^{-1,}$ 50 mg $L^{-1,}$, 100 mg $L^{-1,}$, and 250 mg L^{-1}. These dilutions enabled us to produce the range of concentrations evaluated in our screenings by adding 1 mL of PAM solution to the 100 mL sample cups. This provided the same final volume (101 mL) of all of the test solutions.

The second round of laboratory screenings was conducted using turbid water generated in the lab. The turbid water was generated by first adding 5g of soil to 100 mL of DI water in a specimen cup. The cup was shaken for 10 seconds and allowed to settle for 20 seconds, After settling, the supernatant was decanted into a 1 L sample bottle. This decanting process was repeated twice into the same 1 L bottle. The sample bottle was then filled with tap water and shaken to suspend the sediment. This process produced turbid water consisting primarily of fine sediment that would maintain a fairly stable turbidity level over a few hours. This procedure, as compared to the procedure using 5 g of bulk soil, produced turbid water that more closely resembled the turbid water being produced in the field. Screenings with the turbid water were conducted using the same jar test described above.

The turbid water was generated using tap water initially, however a preliminary round of screenings suggested that a discrepancy existed between the turbidity levels obtained in the field and those obtained in the lab. The PAM was noticeably more effective at reducing turbidity in the field compared to the lab results. A chemical analysis of the two water sources indicated that the pond water contained higher concentrations of ions than the tap water. As a result, all PAM screenings were generated using pond water in order to more closely simulate the natural waters where PAM might be used.

A simulated borrow pit operation was developed at the Sediment and Erosion Control and Research Facility located at the Lake Wheeler Field Laboratory to evaluate the effectiveness of a number of turbidity reduction options for pumped construction site water. The Sediment and Erosion Control Facility consists of a 300 m^3 source pond and three sediment basins varying in dimension. A 12" PVC pipe, with a valve to control flow rates, exits the bottom of the source pond and delivers water to the basins for testing. Borrow pits typically have to pump water out of the pit to obtain the borrow materials, and this water is often turbid from the excavation activities. To simulate this turbidity, water from the pond was released into the pipe at (flow = 0.5 cfs) which emptied into a 40' x 20' x 3' basin while adding soil to the stream over a 30 minute period. Buckets of soil were added through a hole in the pipe at a controlled rate for 30 minutes. A single, porous baffle of jute and coir geotextile was installed at about 1/3 of the length of the basin to retain the heaviest materials in the upper part of the basin. The rate of soil addition and flow was determined through a series of preliminary runs to produce a reasonably stable turbidity of approximately 400 -600 NTU. This coincided with turbidities which were occurring at several borrow pits which had been particularly problematic.

The soils used to generate the turbid water came from two borrow pits in the Coastal Plain region of the state. The borrow pit water being pumped at these sites was highly turbid and traditional treatment in stilling basins was not working well. Two large truckloads, approximately 20 cu yds, of each soil were delivered to SECREF and moved into covered storage shelters. The exact source locations are unknown and both sites encompassed very large acreages. It is likely that each sample is a mixture of materials from different depths mixed during the course of excavation and loading the truck. . One site was east of Plymouth, NC where the NC 64 Bypass was under construction, immediately adjacent to the Tidewater Research Station. The second site was northwest of Lumberton, NC, at the site of Interstate 95 construction.

The turbid water was pumped to a second basin using a Hypro model C-35 pump with a 3 inch intake and a 2 inch discharge. The size of the second basin, was 30' x 15' x 4' and it functioned as a stilling basin.. The flow rate of the pump was calibrated before testing began. During a test the initial flow rate of the pump was set at approximately 80 GPM, and then reduced to 50 GPM once the level of water in the basin approached the top of the outlet. The initial pumping rate was higher just to fill the basin more quickly. The 50 GPM flow rate was determined based on the pumping capacity of the Hypro pump and was felt to be proportional to rates seen on actual construction sites, given the scaled down dimensions of our pumping operation. A standard stilling basin for NC DOT is 180' x 90', or 16,200 square feet. Ours is 30' x 15', or 450 square feet, which is approximately 2.8% of the standard basin. This means that 50 GPM is about the same as 2,000 GPM into a standard basin, which is a relatively high pumping rate.   The stilling basin was had a 6 inch flashboard riser outlet. ..For our testing the boards were set to overflow once the depth reached 3 feet . The outlet of the flashboard riser was connected to a 6 inch PVC pipe through the dam. Additional 6 inch pipes were added to bring the flow approximately 120' downhill and into a sediment bag. The sediment bag was tested as a post stilling basin polishing system.   The sediment bag was made of a polypropylene non-woven geotextile fabric and had dimensions of 10 x 15 feet. A weir was constructed below the sediment bag to measure the flow of water exiting it. A tarp was placed under the sediment bag to ensure that all of the water permeating through the bag was collected and diverted over the weir. The bag sat on a pad of 12 x 12 inch Geogrids, a honeycomb material used for permeable pavement, to allow flow through the bottom. A tarp was placed under the Geogrids to capture the flow from the bag and direct it into the weir.

The testing we conducted consisted of both physical and chemical treatments in all combinations. The physical variables were included changes to the basin configuration: open, porous baffles, and a rock baffle. The baffle treatments that were evaluated in our testing were installed in the simulated stilling basin. The jute/coir baffles were faced with woven jute fabric having 1 inch holes and backed with a coir mesh erosion control blanket. Three of these baffles were spread across the entire cross sectional width of the basin. The baffles were 3.5 feet tall and were spaced 10 feet apart from one another. The first baffle was installed 10 feet from the entrance of the basin and the third baffle was installed 8 feet from the outlet. The single rock baffle was constructed using class B stone and was located 12 feet from the entrance of the basin and 20 feet from the outlet. The baffle stood 3.5 feet high and had a width of 4 feet at its base. The baffle spanned the entire cross sectional width of the basin. This is the standard baffle currently used in stilling basins.

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The chemical variables involved no treatment and treatment with two different types of PAM. The two PAM products (SF N300 and NALCO 9909) used in field testing were determined through a series of laboratory screenings. The most effective dosing concentration of each PAM was also determined through the laboratory screenings to be 5 mg L^{-1}. The PAM was introduced into the pumping system as a solution using a variable speed, peristaltic pump.

The PAM was injected directly into the intake hose of the Hypro pump as the turbid water was being pumped from the simulated borrow pit to the stilling basin. The peristaltic pump was calibrated to maintain 5 mg PAM L-1 at both pumping rates (80 and 50 GPM) used in testing. A fresh stock solution of PAM was made before each test using a sump pump to mix granular PAM in a 55 gallon drum until it was completely dissolved. The concentration of the stock solution (3.5 g gal-1) was based on the pumping capacity of the peristaltic pump and allowed for the proper dosing of PAM given the pumping rates of both the peristaltic pump and the Hypro pump. PAM solution was continuously injected into the intake of the water pump flow for the duration of the test.

Sampling was accomplished using ISCO Model 6700 automatic samplers. One sampler collected borrow pit water at the rate of 500 ml every 15 minutes throughout the duration of a test. The sampling program was initiated at the start of pumping which represented time zero of a test. The intake of this sampler was located in close proximity to the intake of the Hypro pump. These samples were indicative of the initial turbidity levels of the untreated turbid water. A second sampler was located at the outlet of the stilling basin. The intake of this sampler was located on a T-post in close proximity to the flashboard riser outlet and took samples from 1.5 inches below the top of the outlet. A bubbler was installed at the top of the flashboard riser and was utilized to measure the flow exiting the outlet. The sampling program was initiated automatically at a level indicative of a steady state of flow. Samples (500 mL) were automatically collected every 2 minutes for a duration of at least 30 minutes. A third sampler was located at the weir below the sediment bag below the stilling basin. A bubbler on this sampler was installed to measure the flow over the weir. The sampling program was initiated manually immediately after the first sample was taken at the stilling basin outlet. Samples (500 mL) were taken every 2 minutes for at least 30 minutes.

Results

The two Coastal Plain soils did have significant smectite content with high cation exchange capacity (Table 1). They also had significant clay content. This confirmed our hypothesis that this was the reason why these borrow pits had so much difficulty with turbidity. In a previous study, we also found certain soils from this region would produce relatively stable turbidity.

A screening of polyacrylamides with different properties indicated that the anionic PAMs were not very effective on the suspended materials but cationic and neutral PAMs were effective flocculators (Figure 1). The anionic PAMs reduced turbidity at the lowest concentration (0.5 mg L^{-1}), particularly the least ionic (A100), but additional PAM resulted in less flocculation in most cases. The two cationic PAMs appeared to flocculate somewhat better than the neutral PAM, but only slightly. For further testing, we dropped out several of the least effective anionic PAMs.

Table 1. Results of the analysis of the Plymouth (P) and Lumberton (L) sediment samples.

	Particle Size Distribution (%)			**Dominant Mineralogy of Clay Fraction (percent)***			**Soil pH**	**Cation Exchange Capacity (meq/100g)+**	
	Sand	Silt	Clay	Kaolinite	Vermiculite	Smectite		Fine Clay	Coarse Clay
P	58	12	30	55	25	20	4.7	23.1	16.6
L	55	13	32	na	na	na	4.3	na	na

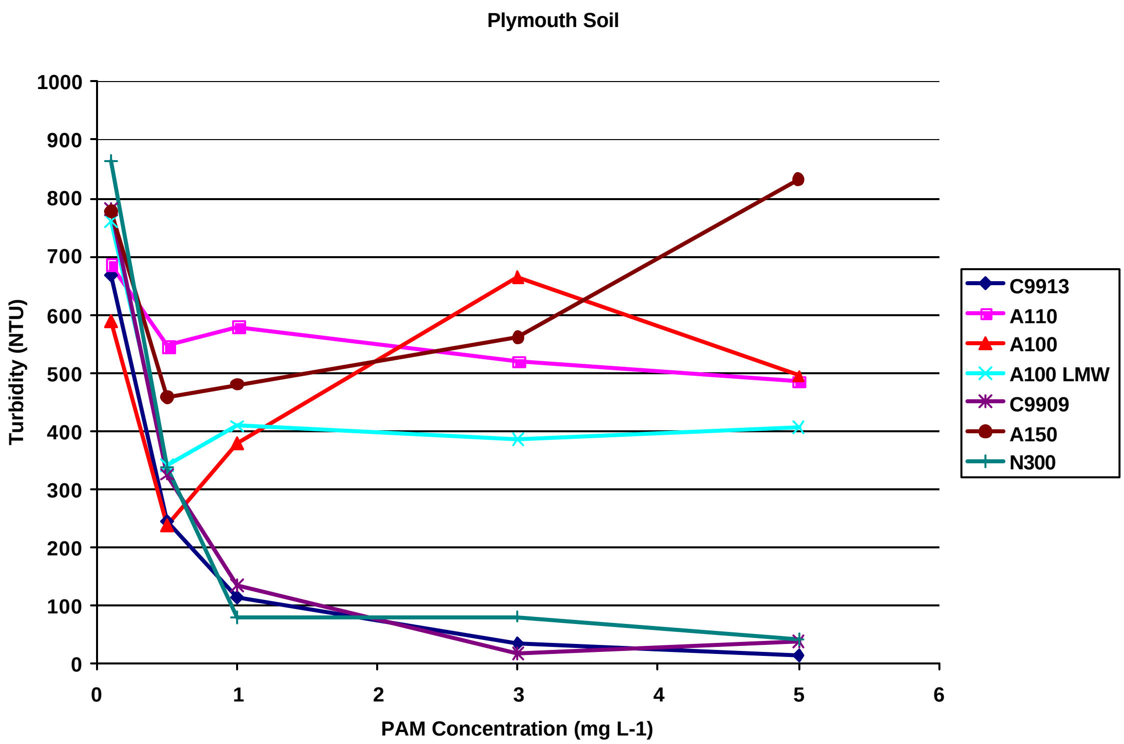

Figure 1. Results of screening tests for seven PAMs using the Plymouth sediment to generate turbidity. PAMs with a “C” are cationic, “A” are anionic, and the “N” is neutral.

The usual method of screening PAMs for effectiveness involves adding soil to water and shaking them with different PAMs. Following this procedure for the Plymouth soil, we found that even the anionic PAM (GF 1800) was very effective at reducing turbidity (Figure 2).

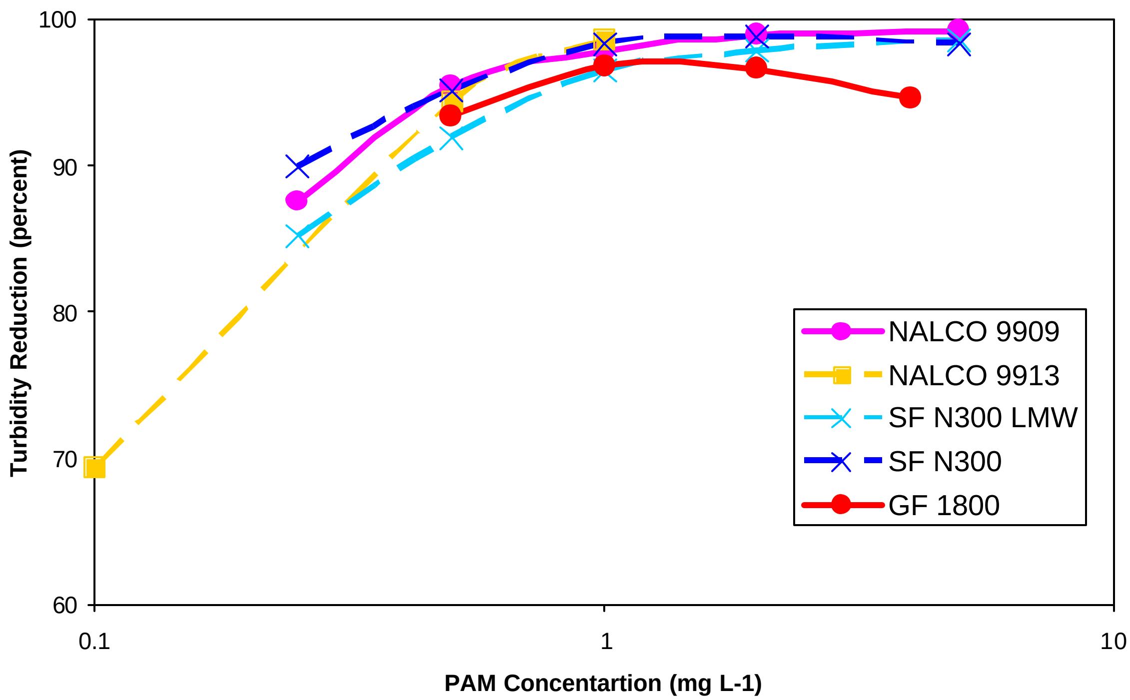

Figure 2. Turbidity reduction for the Plymouth borrow pit soil when mixed with PAM with different properties. This represents the results of mixing 5 g soil with 100 mL water, which produced about 3,000 NTU with no PAM.

However, when we conducted the screening using only the supernatant from the soil-water mixture, the results were very different. The cationic PAM (NALCO 9909) reduced turbidity by more than 90% while the anionic PAMs achieve a peak of 70% at 0.5 mg L^{-1} but were less effective at other concentrations (Figure 2). The neutral PAM achieved more than 80% reduction at 1 mg L^{-1} or more. As it turned out, these results are much more representative of those we found in the field tests. A comparison of the responses of both soil sources shows that they had remarkably similar responses to the PAMs we tested (Figure 4).

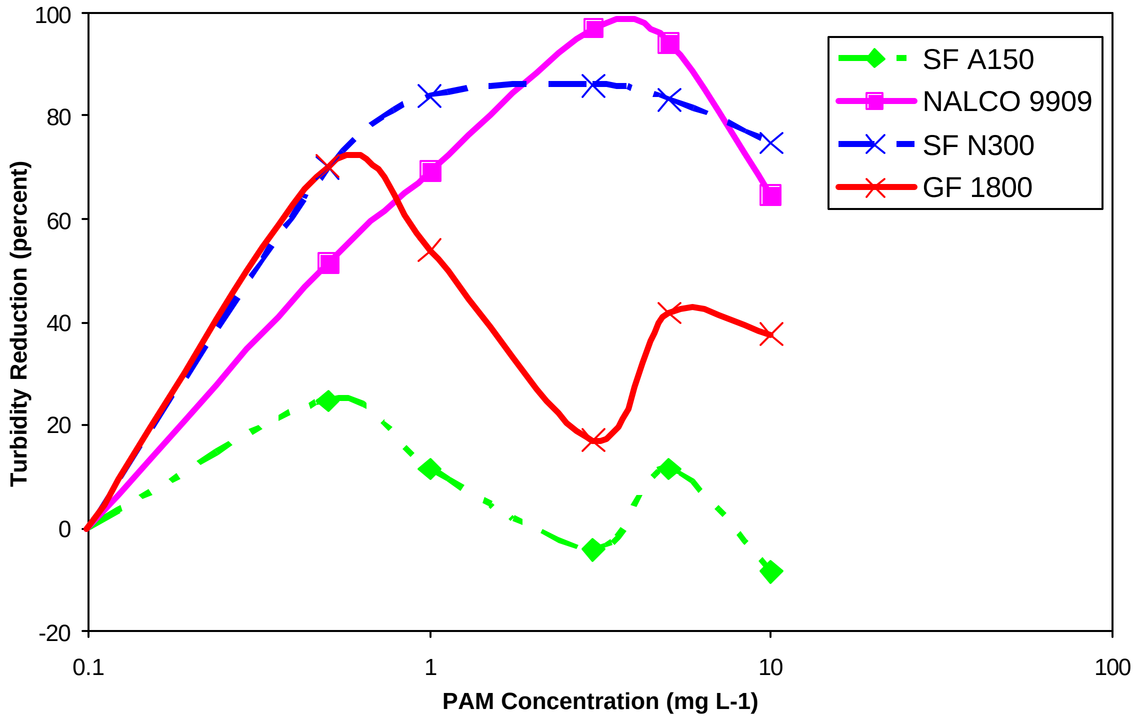

Figure 3. Turbidity reduction for supernatant from the Plymouth borrow pit soil when mixed with PAM with different properties. This involved only the turbid water after allowing the soil to settle for 30 seconds, which resulted in about 600 NTU with no PAM.

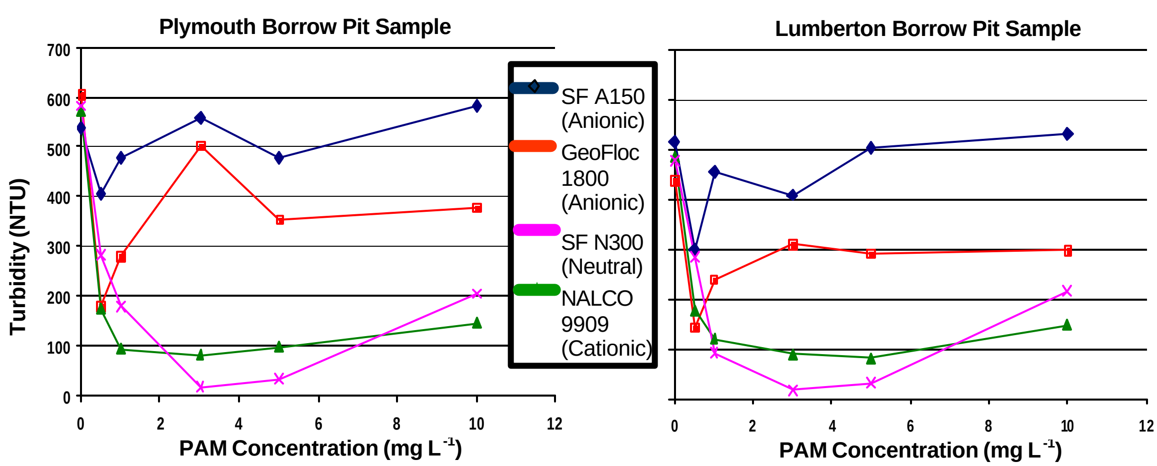

Figure 4. Results of the laboratory screening of PAM for flocculation of the two sediment sources.

In order to determine the relative toxicity of the PAMs to aquatic biota, we had an anionic, a cationic, and the neutral PAM tested in a standard effluent toxicity assay. This was the 7-day *Ceriodaphnia dubia* reproduction test, considered among the most sensitive aquatic bioassays. Among these, the neutral PAM was the least toxic and the cationic was the most toxic (Figure

3). In fact, even at the highest dose (50 mg L^{-1}) the neutral PAM was relatively non-toxic. The addition of turbidity (60 NTU, Plymouth soil source) to the assay did not have appreciable effects.

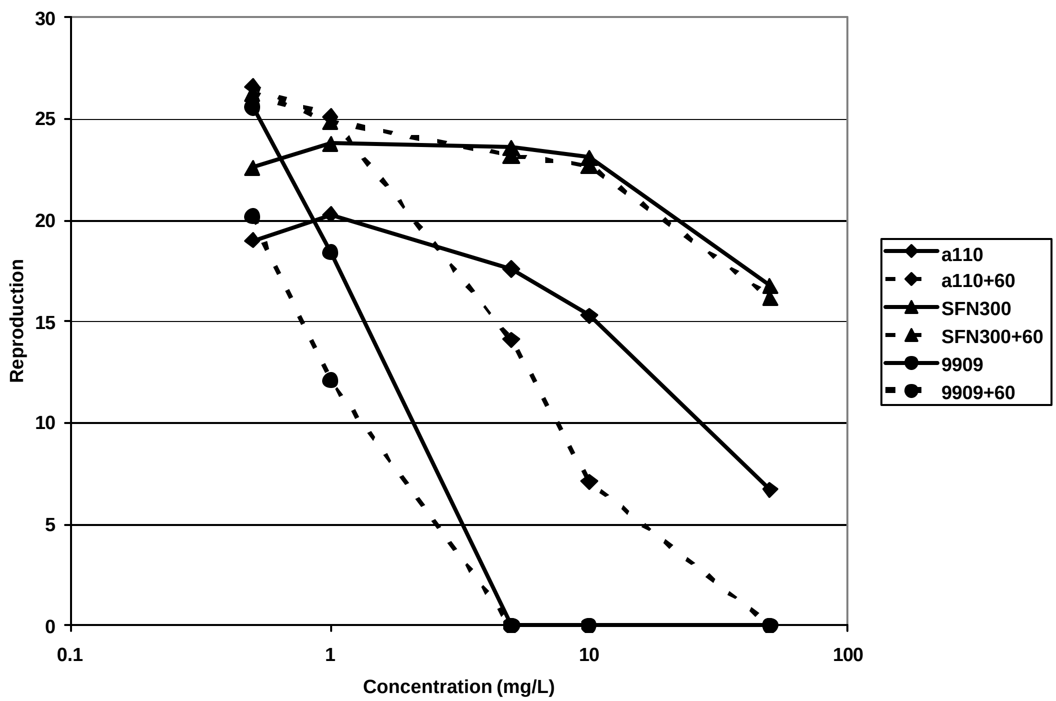

Figure 5. Toxicity of PAM to *Ceriodaphnia dubia* in a 7-day reproduction assay. The three PAMs are anionic (A110), neutral (N300), and cationic (C9909). The dashed lines indicate tests conducted with an initial turbidity of 60 NTU (+60) using the sediment from Lumberton.

The controlled field testing at SECREF was conducted by mixing sediment from the two sources into water flowing into a sediment basin with a porous baffle (Figure 5). The resulting turbid water was pumped to a stilling basin with no baffles, porous baffles, or a rock (Type B) baffle. The PAM solutions were introduced at the pump intake at a dose of 5 mg/L. The pump was run at 50 gpm, which results in an approximate two hour retention time in the stilling basin. The water leaving the stilling basin was drained through a geotextile bag as a test of its potential for further polishing. Samples were taken using automatic samplers placed at four points in the system.

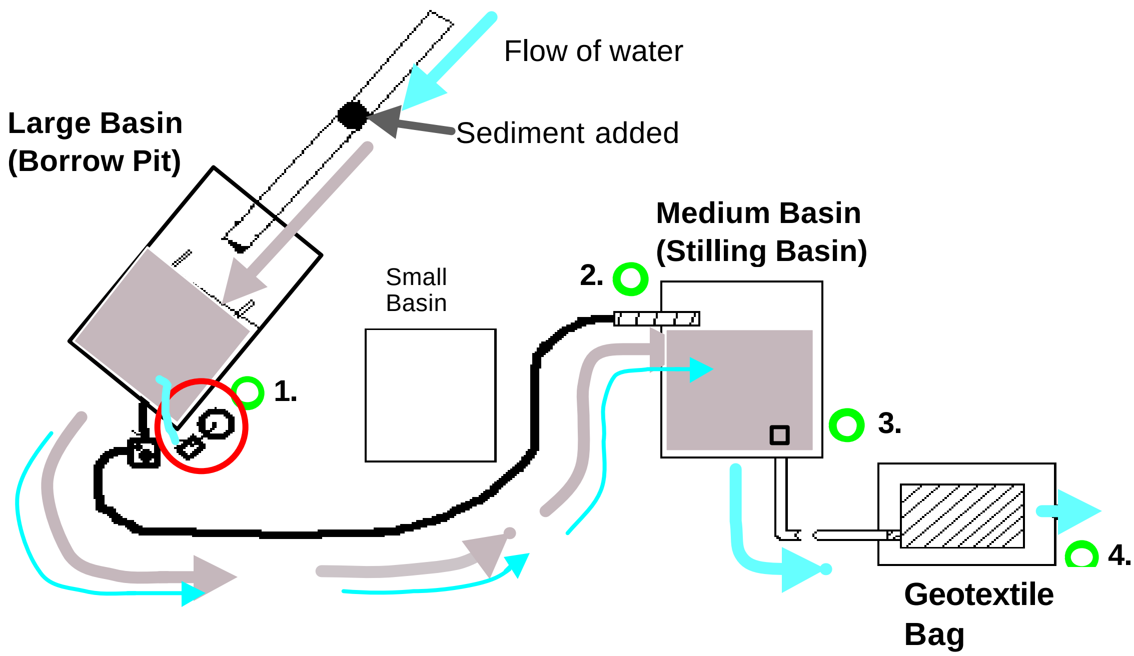

Figure 6. Diagram of the simulated stilling basin system used for controlled field tests at SECREF. Each number represents a sampling point. The pump and PAM dosing system are indicated by the red circle.

The samples for treatment comparisons were taken when flows equilibrated at the outlets, which is what occurs at borrow pits most of the time when pumping occurs. This is illustrated by the turbidity and flows during an untreated, open basin test (Figure 5).   Turbidity in the simulated borrow pit basin were generally in the 400-700 NTU range. The reduction in turbidity by passing this through the stilling basin and geotextile bag was mostly <25% (Figures 5 and 6). The one exception was a test with the Plymouth sediment in which the geotextile bag reduced turbidity 75% (Figure 5). This was an anomaly caused by the use of the bag after many other tests, resulting in a relatively clogged bag with abnormal filtration capacity.

The cationic PAM was the most effective, with up to 99% turbidity reduction. The additional treatment through the geotextile bag did not have much effect in further reducing turbidity. The neutral PAM reduced turbidity 80-90% for the Plymouth sediment and 60-85% for the Lumberton sediment. The flocs formed were noticeably smaller than those for the cationic PAM treatment. The geotextile bag did provide some additional trapping for the Lumberton sediment source.

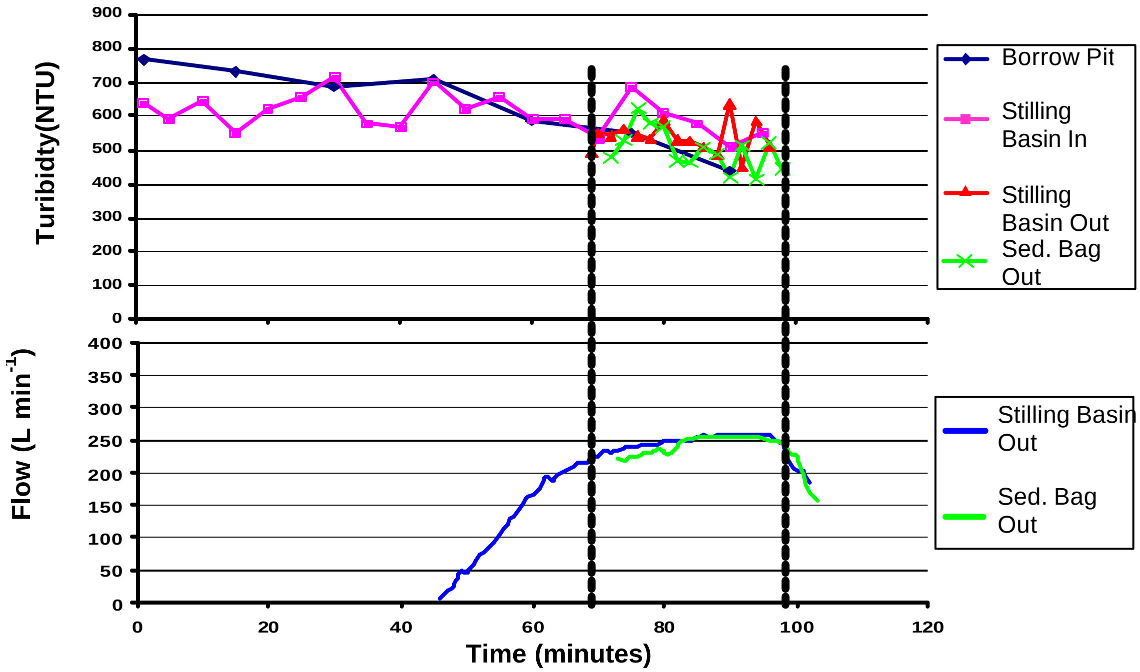

Figure 7. Turbidity and flows during a test of the stilling basin with no PAM added.

The baffles did not appear to provide any benefits either with or without PAM treatment. This is likely due to the way the test was conducted. We mixed the sediment with the water flowing into the simulated borrow pit, but we installed a baffle to collect the coarse material. As a result, we were pumping only the finer, hard to settle solids, so even under ideal settling conditions there was little settling which occurred. The flocculation with the cationic PAM produced large enough flocs that they settled even in the open stilling basin. The rock baffle appeared to reduce settling by the smaller flocs formed with the neutral PAM.

The outlet of our stilling basin was a flashboard riser which therefore dewatered from the top of the water column. We did note that the PAM treatment process produced some floating flocs as well as those that settled. Because our sampler intake was approximately two inches below the surface, these were not sampled during our testing. The baffles effectively removed these floating flocs but the open basin released them.

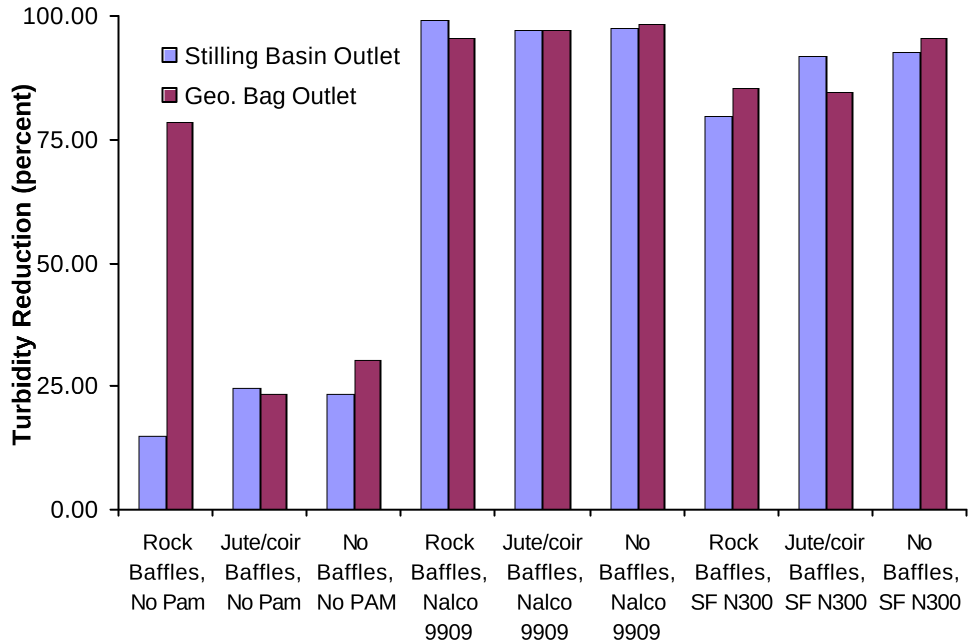

Figure 8. Turbidity reduction for the Plymouth sediment measured at the stilling basin outlet (Flbd. Riser Out) and the geotextile bag (Geo. Bag) outlet. The stilling basin had either a single rock baffle (Rock), three porous baffles (Jute/coir), or no baffle (None).

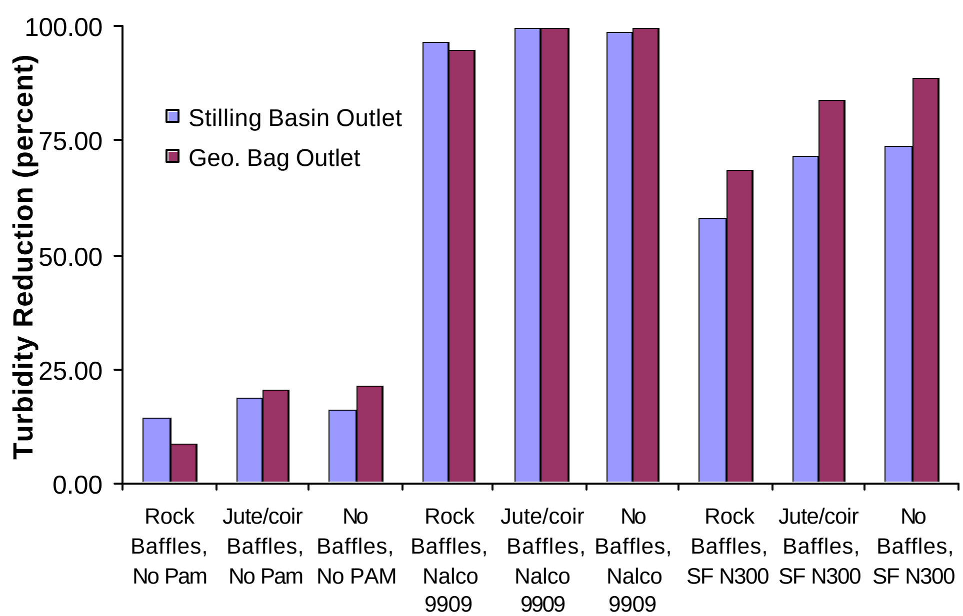

Figure 9. Turbidity reduction for the Lumberton sediment measured at the stilling basin outlet (Flbd. Riser Out) and the geotextile bag (Geo. Bag) outlet. The stilling basin had either a single rock baffle (Rock), three porous baffles (Jute/coir), or no baffle (None).

We also tested standard sediment bags with and without PAM to determine their effectiveness in removing turbidity. These tests involved all of the same procedures at the basin tests but we pumped into a 10’ x 15’ geotextile bag instead. The Plymouth soil was used for these tests, which were done in triplicate. The results for a test with no PAM and one with PAM added are shown in Figures 10 and 11, respectively. When no PAM was added, the bag removed an average of 18% of the turbidity, while the turbidity reduction was almost 98% with PAM.

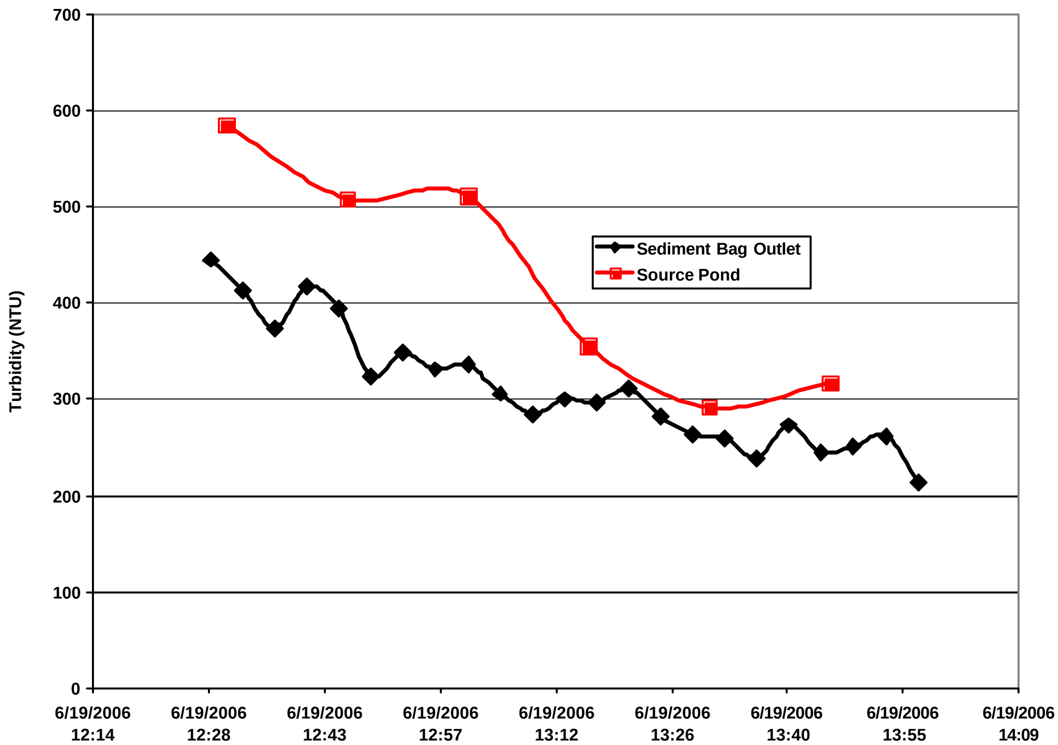

Figure 10. Effects of pumping turbid water through a geotextile bag.

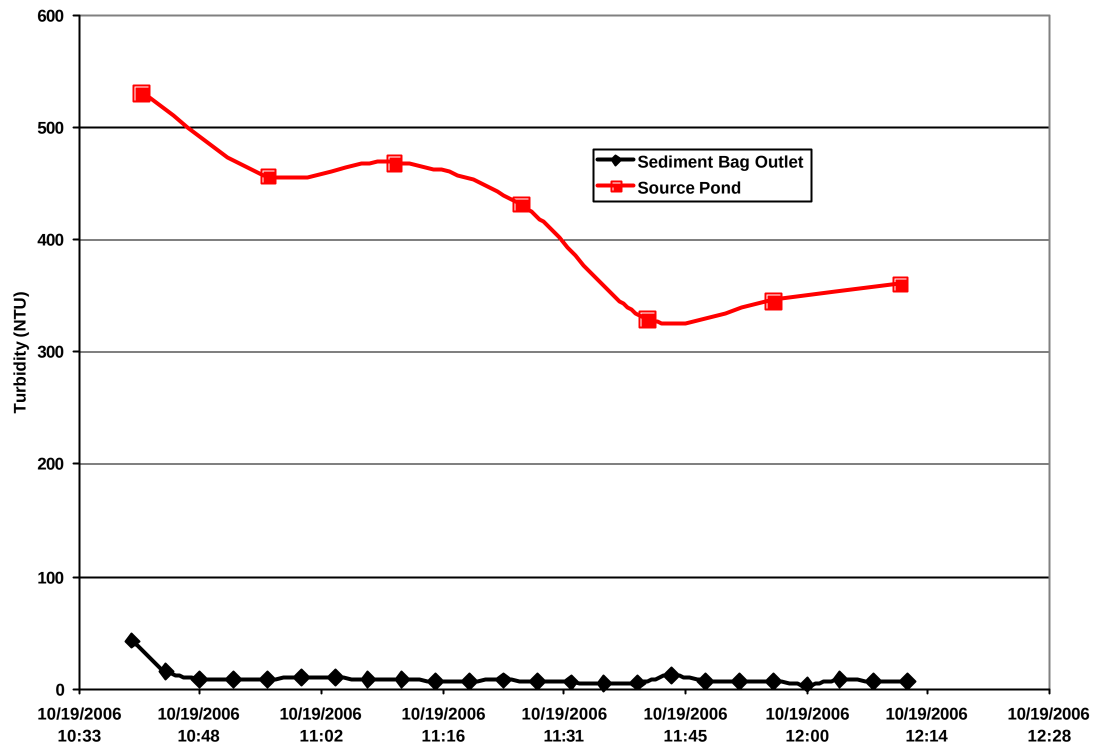

Figure 11. Effects of pumping turbid water through a geotextile bag after dosing with 5 mg L^{-1} cationic PAM.

Recommendations:

- The use of stilling basins will not likely result in significant reductions in turbidity in water pumped from borrow pits in these types of soils.
- Some sediment sources, particularly those with significant smectite content, will not be flocculated by anionic PAM but can be flocculated by neutral or cationic PAM.
- The flocculation process reduced turbidity regardless of the inclusion of baffles. However, at least one baffle is recommended when PAM is being used in case floating flocs are formed.
- The neutral PAM was almost as effective as the cationic PAM and was even less toxic than the anionic PAM, so it may be an alternative where the anionic PAMs that are available will not work.