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Chemical Treatment to Reduce Turbidity in Pumped Construction Site Water

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Abstract: Many construction projects need to pump turbid water from borrow pits or other excavations into stilling basins or sediment filter bags prior to discharge. This study evaluated the effectiveness of these devices with polyacrylamide (PAM) injection to reduce effluent turbidity. Results from laboratory jar tests using two coastal plain sediments of North Carolina suggested that a cationic PAM was the most effective in reducing turbidity, followed by a nonionic PAM. Anionic PAM was effective in whole-soil jar tests but not when turbid supernatant was tested. A stilling basin was not effective in reducing the turbidity of the pumped water without PAM. Cationic and nonionic PAMs injected to the pumped turbid water reduced effluent turbidity from the basin by 98% and 90%, respectively. Pumping the turbid water through a sediment filter bag was also not effective for turbidity reduction unless PAM was injected into the pumping system. Our results suggested that the relatively nontoxic, nonionic PAM may be an alternative where anionic PAM is not effective in reducing turbidity in borrow pit operations. **DOI: 10.1061/(ASCE)EE.1943-7870.0001498.**

Author keywords: Baffles; Chemical treatment; Flocculation; Stilling basin; Turbidity.

Introduction

Sediment and turbidity are primary causes for surface water quality impairments across the United States (USEPA 2009). Construction activity can be a significant source of this pollution, with erosion rates as high as 100 times that of agricultural activity (Owen 1975; Pitt et al. 2007). Much of the sediment leaving construction sites consists of silt and clay that can carry substantial amounts of nutrients and pollutants (Brown et al. 1981). In addition, increased turbidity can limit sunlight penetration into water by both absorbing and deflecting light. Reduced light penetration is known to decrease the volume of the euphotic zone, in which light is sufficient for photosynthesis to occur (Clark et al. 1985).

On many construction projects, highly turbid water must be pumped from borrow pits or excavations after rainfall events or to remove groundwater seepage in order to allow further excavation. One method for treating this turbid water is to pump it into a stilling basin to settle out suspended particles from the water column. In North Carolina (NC), porous baffles are required to be installed within a stilling basin as energy dissipaters for reducing turbulence (Thaxton and McLaughlin 2005; Bhardwaj et al. 2008). Surface outlets, such as a skimmer or solid riser, are also required in NC and, recently, by the USEPA (2009). These can achieve additional sediment capture by dewatering the basin from the top of the water column where the water is cleanest as a result of particle settling (Millen et al. 1997; McLaughlin 2005). A basin with porous baffles and surface outlets can be highly effective in settling sand and coarse silt particles, but the low settling velocities of finer particles usually prevent their removal within the typical 24–48 h retention times (McCaleb and McLaughlin 2008). For cases in which there is no room for a basin, turbid water can be pumped into a sediment filter bag, which is constructed from a porous geotextile in order to allow water to pass through it. However, neither a stilling basin nor a sediment bag retains enough clay and fine silt particles to reduce turbidity to desired levels (Haan et al. 1994; Wu et al. 1996; Line and White 2001).

One approach to retaining fine sediments is to introduce flocculants into turbid water, causing suspended solids to flocculate and settle out from the water column. Polyacrylamide (PAM) is a common type of polymeric flocculant that has been successful in reducing sediment erosion and turbidity (Sojka et al. 2007). The application of granular PAM to fiber check dams in ditches has been found to be effective in reducing turbidity by more than 90% relative to a standard rock check system with no PAM application (McLaughlin et al. 2009; Kang et al. 2013). The application of PAM has also been shown to greatly reduce effluent turbidity in stilling basins (Bhardwaj and McLaughlin 2008; Bhardwaj et al. 2008).

Polyacrylamide can be synthesized in either a cationic, anionic, or nonionic form with a range of charge densities and molecular weights. These PAM characteristics can affect flocculation performance for fine suspended sediments (Laird 1997; Deng et al. 2006; Nasser and James 2006). Laird (1997) studied the effects of PAM charge on flocculation performance using kaolinite, illite, and quartz, and found that cationic PAM was the most effective for flocculating any of these minerals. Nasser and James (2006) noted that flocculation performance decreased with increasing charge density and increased with increasing molecular weight in kaolinite suspensions. Deng et al. (2006) compared the relative adsorption of PAM with three different clay minerals and found that the adsorption of PAM on clay minerals was correlated to the surface areas of the clays. Their study indicated that flocculation was likely to be

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more favorable for clays with smaller surface areas (e.g., kaolinite). McLaughlin and Bartholomew (2007) also found that kaolinitic clays were more readily flocculated by anionic PAM than smectitic clays.

Large borrow pits are commonly part of road construction in areas with flat terrain, and the pits are often filled with groundwater and/or stormwater. When a high water table is present, the water in the borrow pit must be pumped out constantly in order to permit fill material to be removed. This may continue for weeks or months until enough material is removed for the project. Pumped water is often passed through a settling basin or a sediment filter bag prior to discharge, but these may not be effective for turbidity reduction. In this study, we evaluated chemical treatments that can be used to reduce turbidity discharged from such devices in both laboratory and field experiments. In addition to testing chemical treatment, we also tested two different types of baffles and a geotextile bag for their potential to further improve turbidity reduction.

Materials and Methods

PAM Screening Test

Sediment for the experiments was obtained from two active construction sites located in the lower coastal plain regions (Lumberton and Plymouth) of NC. Both sediments were collected as a mixture of surface and subsurface soils and they had a sandy clay loam texture with soil pH ranging from 4.3 to 4.7. Soils from these areas are of mixed mineralogy, with smectite present in the finer fraction, and are difficult to flocculate using common anionic PAMs (McLaughlin and Bartholomew 2007). These sediments were used for our laboratory PAM screening tests as well as for field-scale basin tests.

Laboratory PAM screening tests were performed to select PAMs for the study sediments. Six PAMs, varying in charge (i.e., anionic, cationic, and nonionic) and charge density (0–50 mol%), were included in the screening tests: N300, A100, A110, A150 (Kemira Chemical, Atlanta, Georgia) and C9909, C9913 (NALCO Industries, Chicago, Illinois) (Table 1). The charge density of the PAMs ranged from 0% to 50% and they were all high molecular weight PAMs (14–17 $\mathrm{Mg\,mol^{-1}}$). An initial screening test was performed for whole soil or supernatant as a turbidity source using pond water [<3 nephelometric turbidity units (NTU)] that was also used for the basin test. For the whole soil test, 5 g of soil (air-dried and 2-mm sieved) was added to 100 mL of water. For the supernatant test, turbid water was prepared by adding 5 g of soil to 100 mL of water. The soil–water mixture was shaken for 10 s and allowed to settle for 30 s. After settling, the supernatant was decanted into a 1 L bottle. This process was repeated with fresh soil until there was enough turbid supernatant for all of the PAM screening tests. The initial screening tests with the Plymouth sediment identified the top four PAMs, and these PAMs were further used to find optimal PAM concentrations for turbidity reduction. Six concentrations of PAM (0, 0.5, 1, 2, 5, and 10 $\mathrm{mg\,L^{-1}}$) were tested in duplicates for the supernatant turbid waters prepared with each of the sediment sources. All samples were analyzed by shaking them for 10 s and taking a turbidity measurement after 30 s of settling using an Analite NEP 260 turbidity probe (McVan Instruments, Melbourne, Australia), measured in NTU.

Table 1. Selected properties of PAM used for the laboratory jar tests

PAM	Charge type	Charge density (mol %)
A100	Anionic	−7
A110	Anionic	−18
A150	Anionic	−50
N300	Nonionic	0
C9913	Cationic	+15
C9909	Cationic	+50

Basin Test

The field-scale basin test was conducted at the Sediment and Erosion Control Research and Education Facility (SECREF) in Raleigh, NC. The experimental setup consisted of two basins and a sediment filter bag, simulating a borrow pit dewatering operation in the field (Fig. 1). Turbid water was generated by delivering water downhill from a source pond (approximately 900 $\mathrm{m^3}$) to a mixing basin (12.1 m in length × 6.1 m in width × 0.9 m in height) through a 0.3-m-diameter pipe at a rate of approximately 0.014 $\mathrm{m^3\,s^{-1}}$. Sediment was added to the flowing water at a tee fitting located between the source pond and the mixing basin to generate turbid water. In the mixing basin, a single porous baffle of jute and coir was installed at 1/3 of the length to retain the coarse sediment in the upper part of the mixing basin.

The turbid water in the mixing basin was pumped into a stilling basin (9.1 m in length × 4.6 m in width × 1.2 m in height) using a centrifugal pump (51-mm outlet; Hydro C-35, American Honda Motor Co., Inc, Waterford, Wisconsin). The rate was maintained at 189 $\mathrm{L\,min^{-1}}$ once the water in the stilling basin began to flow out of the flashboard riser outlet installed at 0.9 m from the bottom of the basin. The outlet of the flashboard riser was connected via a 15-cm PVC pipe to a sediment filter bag (Dirtbag 53, ACF Environmental, Richmond, Virginia) placed 10 m downhill in order to test it as a post-stilling-basin filtration system. The bag was made of a polypropylene nonwoven geotextile fabric, and it was 4.7 m in length and 3.0 m in width. The water released from the sediment filter bag was routed to an H-flume for sample collection.

A total of 18 basin tests were performed as a combination of three physical and three chemical treatments from the two sediment sources (Lumberton and Plymouth). The physical treatments were baffles installed in the stilling basin: no baffle, jute/coir baffles, and a rock baffle (Fig. 1). The jute/coir baffles were faced with woven jute (2.5-cm opening) and backed with a coir fiber erosion control blanket (C125, North American Green, Evansville, Indiana). Three of these baffles (1.1 m in height) were installed across the entire width of the stilling basin and spaced 3 m apart. The rock baffle (1.1 m in height and 1.2 m in width at its base) was constructed as a single structure using class B stone (20-cm average diameter) and was located at 3.7 m from the entrance of the basin and 6.1 m from the outlet. The use of this rock baffle was similar to the standard baffle practice for stilling basins in NC (NCDOT 2011).

The chemical treatments for the basin tests involved a control (no PAM), nonionic PAM (N300), and cationic PAM (N9909) (Table 1). These PAM products were found to be the most effective in turbidity reduction from the laboratory tests; this will be discussed subsequently in more detail. A stock solution (926 $\mathrm{mg\,L^{-1}}$) of each PAM was made in a 208-L container using a sump pump to mix granular PAM until it was completely dissolved. The PAM stock solution was injected into the intake hose of the turbid water pump using a variable-speed peristaltic pump as the turbid water was being pumped from the mixing basin to the stilling basin (Fig. 1). The PAM solution was injected to achieve a concentration of 5 $\mathrm{mg\,L^{-1}}$ in the pumped water, which was the optimal PAM concentration for turbidity reduction in the laboratory tests.

Three automatic samplers (Teledyne ISCO 6712 portable sampler, Lincoln, Nebraska) were installed to collect water samples

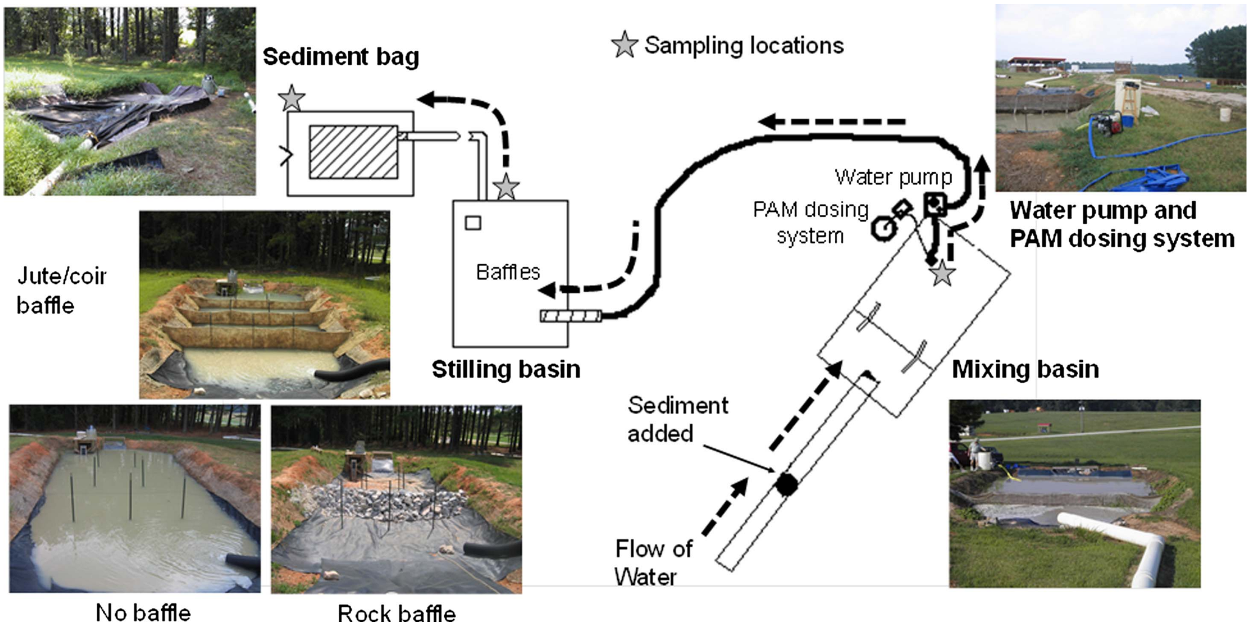

Fig. 1. Schematic of the borrow pit dewatering operation, consisting of a mixing basin, dosing system for dissolved PAM, stilling basin, and sediment bag (not to scale). (Images by Joshua W. Vetter.)

from the mixing basin (i.e., the turbid water source), the flashboard riser outlet (i.e., the stilling basin exit), and the final discharge after the sediment bag (i.e., the H-flume below the sediment bag). The sampling from the mixing basin was done at 15 min intervals from the time the pumping of water into the stilling basin began to the end of the test (90–100 min). The two downstream locations were sampled every 2 min once the flow reached a steady state at the exit of sediment bag. Once initiated, water sampling at these points lasted at least 24 min for each individual test. All samples were analyzed for turbidity following procedures identical to those used in the laboratory tests.

Sediment Filter Bag Test

Turbidity reduction solely by sediment filter bag was tested with and without injection of the cationic PAM (C9909). This test involved all of the same procedures, but we pumped the turbid water directly into the bag, bypassing the stilling basin. The Plymouth sediment was used to generate the influent turbid water in the mixing basin.

Statistical Analyses

A completely randomized design was used, with chemical treatments (cationic PAM, nonionic PAM, and no PAM) and physical treatments (rock baffle, jute/coir baffle, and no baffle) as main factors, and turbidity with time as the repeated variable. Treatment effects with interactions were determined using SAS PROC GLM procedure (Version 9.1; SAS Institute, Cary, North Carolina), and pairwise comparisons between treatment means was performed according to Tukey's comparative analysis at the probability level P of 0.05.

Results and Discussion

PAM Screening Test

The initial PAM screening tests using supernatant turbid water revealed that cationic and nonionic PAMs were superior to anionic

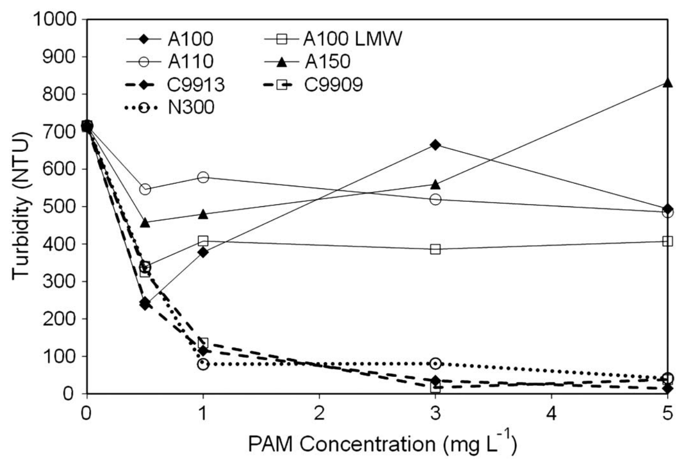

Fig. 2. Turbidity as a function of PAM concentration for the Plymouth sediment supernatant water. PAMs labeled A = anionic; C = cationic; and N = nonionic.

PAMs in turbidity reduction for the Plymouth sediment (Fig. 2). Anionic PAMs appeared to have some effect at low concentrations (0.5 mg L^{-1}), but increasing the concentration further reduced or eliminated the effect. Among the three anionic PAMs, the one with the lowest net charge density, A100, resulted in relatively greater turbidity reduction at the 0.5 mg L^{-1} concentration compared to the other anionic PAMs.

Turbidity reduction was affected by PAM charge and charge density, with greater flocculation with cationic > nonionic > anionic PAMs, particularly for the supernatant (Fig. 3). Similar results were reported by Deng et al. (2006) for the flocculation of clay suspensions (smectite, illite, and kaolinite). In their study, the stabilization effect (increased turbidity) was obvious with anionic PAMs, suggesting that electrostatic repulsion occurred between negatively charged clays and negatively charged PAM, whereas electrostatic attraction occurred between the clays and cationic PAM.

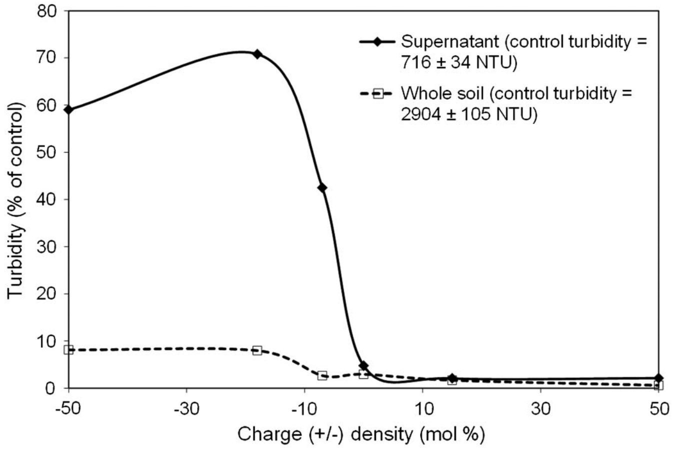

Fig. 3. Turbidity (% of control; mean ± standard error) affected by charge (+/−) and charge density (mol %) of polyacrylamide for the Plymouth sediment turbid water as a supernatant or a whole soil.

We observed that flocs formed with cationic PAM were more resistant to dispersion by shaking than those formed with nonionic and anionic PAMs. Increasing the charge density in anionic PAMs reduced flocculation, indicating that electrostatic repulsion increases with increasing charge density (Nasser and James 2006).

Comparisons of turbidity reduction between supernatant and whole soil suggested that the presence of coarse particles could improve flocculation (Fig. 3). Relatively large particles and aggregates in whole soil have less surface area and less negatively charged surface compared to finer particles (Sposito 1984). Letey (1994) noted that adsorption of PAM molecules on whole soil is related to soil aggregate size and molecular conformation of the polymer rather than total surface area of clays and electrostatic charge interactions, since the adsorption reactions occur mostly on the external surfaces of soil aggregates. In our study, turbidity reduction by anionic PAMs was more than 40% greater with whole soil compared to supernatant alone, while nonionic and cationic PAMs had similar turbidity reduction for both. The addition of whole soil into the supernatant turbid water dosed with anionic PAM has previously been shown to reduce turbidity, because the flocs formed by the reactive portion of the whole soil appear to pull the nonreactive portion out of suspension (Bhardwaj and McLaughlin 2008). This process has been commercialized as ballasted flocculation using fine sand to accelerate floc removal in water treatment processes (Desjardins et al. 2002).

The secondary screening tests on both sediment sources confirmed that anionic PAM had relatively lower turbidity reduction (up to 40%) compared to cationic (97%) and nonanionic PAMs (85%) (Fig. 4). Nonionic PAM is relatively nontoxic for aquatic species, compared to cationic PAM, according to the material safety data sheets provided by the manufacturers. However, it is important to note that cationic PAM toxicity in aquatic environments can be greatly attenuated by the presence of humic acid (Goodrich et al. 1991), clay particles (Biesenger and Stokes 1986), and even fish food (Biesenger et al. 1976). In contrast, the turbid water itself would be considered to be far above known toxicity levels for aquatic organisms (Henley et al. 2010). Our results indicated that nonionic PAM can be almost as effective in reducing turbidity with minimal toxicity risk. As a result, the cationic and nonionic PAMs were selected for the basin tests. The optimal PAM concentration for turbidity reduction was determined to be 5 $\mathrm{mg\,L^{-1}}$; this concentration was used as the PAM concentration for the basin tests.

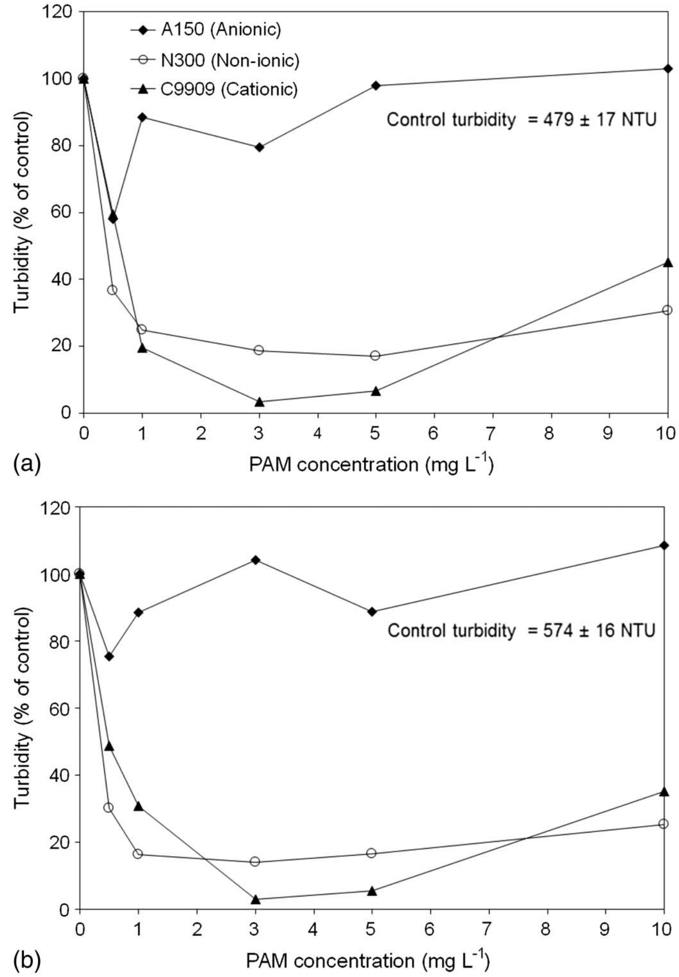

Fig. 4. Turbidity (% of control; mean ± standard error) as a function of PAM concentration in (a) Lumberton; and (b) Plymouth sediments as a supernatant.

Our PAM screening test results were similar to the findings of McLaughlin and Bartholomew (2007) in that the coastal plain soils of NC were difficult to flocculate by a single form (i.e., single molecular weight and charge density) of anionic PAM. This was attributed to the presence of significant amount of smectite and vermiculite (>20%) in the subsoils of this region. We also found that an increase in turbidity occurred when the PAM concentration increased over 0.5 $\mathrm{mg\,L^{-1}}$ for anionic PAM and >5 $\mathrm{mg\,L^{-1}}$ for nonionic and cationic PAMs (Fig. 4), probably due to steric stabilization (Gast and Leibler 1986; Gregory 1989).

Basin Test with Pumped Turbid Water

The water flow at the stilling basin exit reached a steady state about at 70 min. The stilling basin alone reduced turbidity very little (2–16%), but its effectiveness was greatly improved with chemical treatment (Fig. 5). Cationic PAM was the most effective in turbidity reduction (up to 99%) and maintained the stilling basin exit turbidity below 5 NTU for both sediment sources. Nonionic PAM was also effective in turbidity reduction (up to 90%) and maintained the exit turbidity below 100 NTU. The effect of baffles was not significant ($P > 0.05$) as a single factor in reducing turbidity. Porous baffles have been found to be very effective in improving settling in stilling basins receiving whole sediment (Thaxton et al. 2004; Thaxton and McLaughlin 2005; McLaughlin 2006), but the stilling

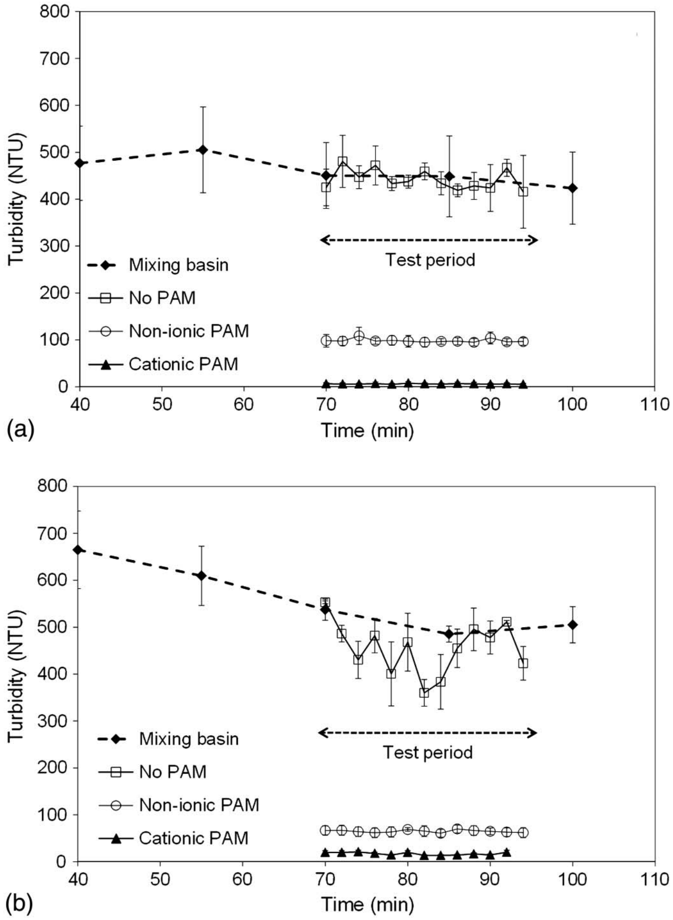

Fig. 5. Turbidity at the stilling basin exit affected by PAM treatment for (a) Lumberton; and (b) Plymouth sediments. Data points represent mean turbidity averaged across baffle types, and the error bars represent standard error of the mean.

basin in this study was receiving pumped turbid water without heavier coarse particle fractions. This demonstrates that an optimized settling basin with porous baffles may not be effective enough in settling very fine particles unless chemical treatment is used.

The turbidity in the mixing basin (i.e., influent turbidity) was relatively constant during the tests, but varied considerably from test to test (216–1,072 NTU), probably because of the heterogeneity of the sediment being added. To compare the effects of all combinations of chemical and physical treatments, the data were normalized to the mean influent turbidity (549 NTU) averaged across all 18 tests (Fig. 6). With PAM treatments, there were clear separations in the basin exit turbidity between PAM and no-PAM treatments, with cationic PAM being the most effective (>96%), followed by nonionic PAM (>80%). Overall, the sediment bag following the stilling basin did not result in much additional turbidity reduction. Only exception was the Plymouth sediment with a rock baffle and no PAM that had more than 50% turbidity reduction through the sediment bag. It was observed that the sediment bag was becoming clogged in this trial, leading to greater filtration and a relatively clear effluent compared to other tests with no PAM injection.

Sediment Filter Bag Test

Pumping turbid water directly through a sediment filter bag (i.e., no stilling basin used) with and without PAM treatment yielded significant turbidity reduction compared to influent turbidity ($P < 0.05$), but a sediment bag alone was relatively ineffective until cationic PAM was introduced into the pumped turbid water (Fig. 7). When no PAM was added, the bag reduced turbidity by an average of 18% during the 90-min testing period. The injection of PAM reduced turbidity up to 98%, maintaining the turbidity of discharged water below 13 NTU for the entire testing period after 5 min. The sediment bag receiving chemical treatment has attractive features compared to the stilling basin; it takes up less space and has a lower initial cost (McLaughlin 2008). However, we observed that the flocs formed with the cationic PAM tend to rapidly clog the pores of the bag. This may necessitate more frequent bag replacement than when no PAM is used, and these additional costs may need to be considered as part of the decision regarding what system to use (i.e., stilling basin versus sediment bag).

Summary and Conclusions

The injection of dissolved PAM into pumped turbid water significantly reduced turbidity in the pumped water generated from two

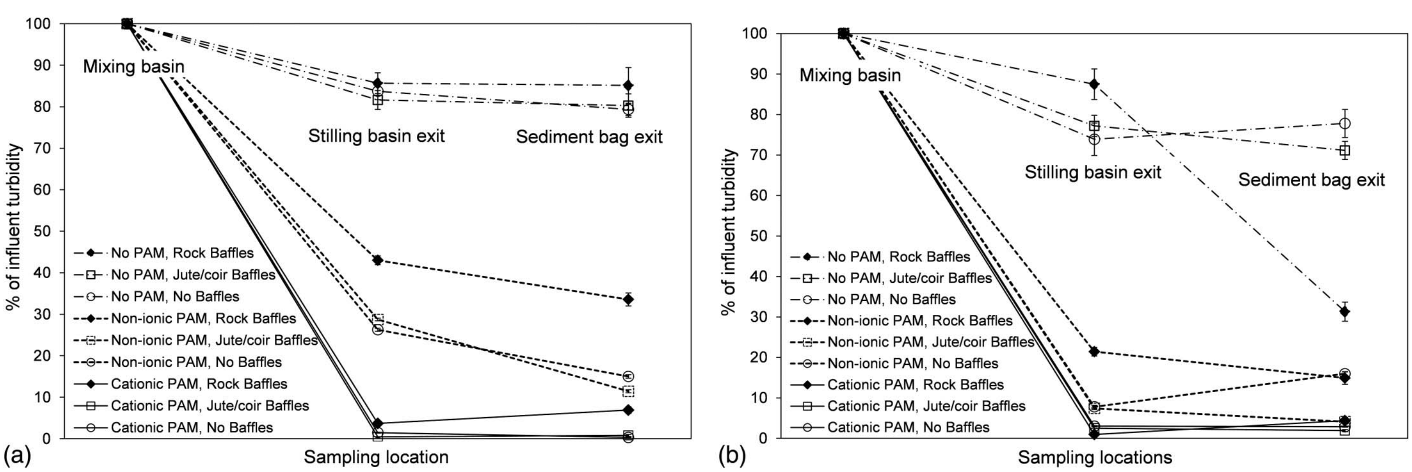

Fig. 6. Turbidity change (% of influent turbidity at mixing basin) in different sampling locations affected by baffle types and PAM treatments for (a) Lumberton; and (b) Plymouth sediments. Data points represent mean turbidity over time, and the error bars represent standard error of the mean.

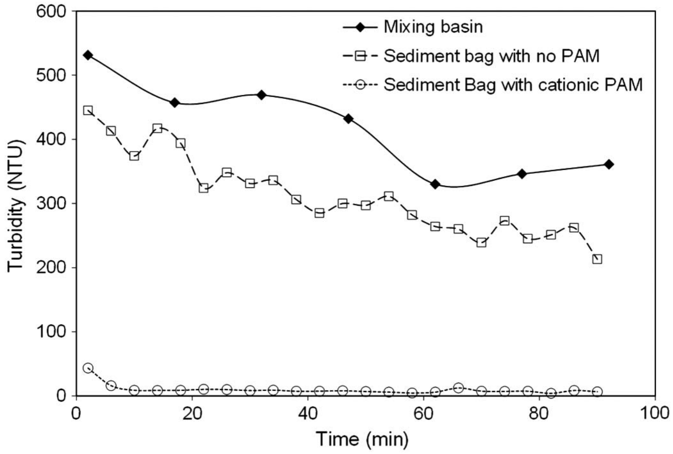

Fig. 7. Turbidity change after sediment bag (Plymouth sediment) with and without cationic PAM.

sediment sources that had been causing turbidity issues on construction sites. The effectiveness of the PAMs for turbidity reduction followed the order cationic > nonionic >> anionic for turbid water containing only the fine sediment fraction, but the difference was much less when whole soil was jar tested. Neither a stilling basin nor a sediment bag had much effect on turbidity unless PAM was injected into the pump intake, which resulted in 85–99% reduction. When the use of anionic PAM is not effective and cationic PAM raises aquatic toxicity concerns, low-toxicity, nonionic PAM may be sufficiently effective to bring effluent turbidity below regulatory guidelines for construction site discharges.

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