STORMWATER PROGRAM

California State University, Sacramento
University of California, Davis (UCD)
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Small-Scale Pilot Studies Using Coagulants for Turbidity and Phosphorus Removal at Lake Tahoe

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Disclaimer:

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ABSTRACT:

The California Department of Transportation (Caltrans) has constructed a small-scale test facility at the South Lake Tahoe Maintenance Station for developing appropriate treatment technologies to meet stringent numeric storm water effluent limits for turbidity (20 NTU), total phosphorus (0.1 mg/L), and total nitrogen (0.5 mg/L) in the Lake Tahoe Basin. "Non-mechanized" processes included various combinations of settling (with and without coagulant) and gravity filtration with different kinds of media. The goal was to simulate systems that might be deployed on state highways where power is not available. The pilot units were constructed of 30-inch diameter plastic tanks and dosed with storm water collected from local detention devices. Flocculation (slow mixing) was not provided. "Mechanized" processes included a batch version of a proprietary high-rate coagulation and sedimentation system, and a nonproprietary conventional coagulation, flocculation, sedimentation, and pressure filtration system. Slow mixing was provided in these systems. The primary coagulant used in both kinds of systems was a liquid polyaluminum chloride. The mechanized systems also used an organic polymer. Both mechanized systems produced effluents that consistently (though not always) met the effluent limits for turbidity and phosphorus. Non-mechanized systems employing settling and fine sand filtration with a constant dose of coagulant consistently met the turbidity standard, but not the phosphorus limit. Both limits were met when the coagulant dose was optimized for each experimental run through the use of jar testing. When coagulant was not used, neither limit was met. Filtration was a necessary element in achieving the turbidity limit, but did little to remove phosphorus after chemically-enhanced settling.

INTRODUCTION

Lake Tahoe is one of the clearest large lakes in the world. While at one time is was possible to see an 8-inch Secchi disk at depths over 100 feet, clarity today is about 65 feet. To counter this decline, state water quality regulators have established strict effluent limits for stormwater runoff (Table 1). The turbidity standard addresses the discharge of small particles that can reduce lake clarity. The nitrogen, phosphorus, and iron standards are aimed at slowing algae growth in the lake.

The California Department of Transportation (Caltrans) owns and operates over 68 miles (109 km) of roadway in the Tahoe Basin as well as several maintenance and material storage yards. Under the terms of its NPDES permit, Caltrans is required to meet the effluent standards when they become effective in 2008. Mean water quality characteristics for highways in the Tahoe Basin are shown in Table 1. As can be seen, typical highway runoff typically exceeds effluent limits for discharges to both land and surface water. Because of narrow rights-of-way, the potential for infiltration on Caltrans land is limited. Consequently, a major goal of the Caltrans research program at Tahoe is the identification and development of stormwater treatment technologies that can meet the surface water discharge limits.

Table 1 – Effluent Quality Limits and Highway Runoff Characteristics

Constituent	Maximum Allowable Concentrations (1)		Runoff Characteristics
	Discharges to Land	Discharges to Surface Waters	Mean Highway Values (2)
Total Nitrogen (mg/L as N)	5	0.5	2.7
Total Phosphate (3) (mg/L as P)	1	0.1	2.1
Total Iron (mg/L as Fe)	4	0.5	17.7
Turbidity (NTU)	200	20	477
Oil and Grease (mg/L)	40	2	18

(1) LRWQCB 1994.
(2) Caltrans 2003a.
(3) Measured as "total phosphorus" (LRWQCB, 1994).

TAHOE SMALL-SCALE TREATMENT TEST FACILITY

In 2001, Caltrans constructed a smallscale treatment test facility at the South Lake Tahoe Maintenance Station. The test facility consists of a 2000-ft2 (186-m2) building housing a variety of small-scale pilot treatment systems (Figure 1). Stormwater is collected at various locations in the vicinity after rainfall or snow melt events and trucked to the test facility where it is stored in two exterior 6500-gallon (25,000-L) polyethylene feed tanks equipped with submersible mixers. To date, two "mechanized" and 26 "nonmechanized" systems have been tested. Both mechanized systems and several of the nonmechanized systems utilized chemical coagulation as part of the treatment process.

Figure 1. Interior of the test facility showing non-mechanized treatment systems.

The main liquid coagulant used was PASS-C®, which contains 25 to 40 percent polyaluminum chloride. This coagulant was chosen after a series of jar tests using a number of products (Caltrans 2003b). Evaluation of chemicals in the jar tests was based on removal of both turbidity and phosphorus. PASS-C® was not unique in this regard. Several coagulants performed well in these tests and may function in an equivalent manner in the field.

Treatment systems was done during the 2001/2002 (Year 1) and 2002/2003 (Year 2) wet seasons (mainly in the spring). Runoff was collected from six storm or snowmelt events each year. Sampling and analysis of water samples followed Caltrans protocols (Caltrans 2000). Detailed documentation of the experimental work and results can be found in Caltrans (2003c and 2003d).

The focus of this paper is coagulant-aided treatment performance with regards to turbidity and phosphorus. Results from both mechanized and non-mechanized systems will be presented.

MECHANIZED SYSTEM RESULTS

The purpose of testing mechanized systems was to demonstrate what might be accomplished if stormwater runoff were to be captured and piped to a treatment plant with mechanical equipment, power, and operators. Two systems were tested. One was a batch version of an Actiflo® high-rate coagulation and sedimentation process. The Actiflo® process uses a very fine "ballast sand" to aid sedimentation. The coagulation and sedimentation steps were accomplished in a 260-gallon (984-L) steel batch reactor (Figure 2). This was followed by either a pressure sand filter or a Fuzzy Filter® and an ion exchange system. The second mechanized system (tested in Year 2 only) used the same reactor to mimic a conventional coagulation, flocculation, and sedimentation system which was then followed by a pressure sand filter.

The Actiflo® treatment process started with rapid mixing of runoff, PASS-C®, and ballast sand in the batch reactor. Toward the end of the rapid mix, an anionic polymer (Magnafloc® LT25) was added. The mixer speed was reduced to provide slow mixing for 1.5 minutes, followed by settling for 5 to 20 minutes (7.5 minutes average). The conventional process was similar except that the ballast sand was not used. The slow mix time was 15 minutes and the settling time was 30 to 37 minutes (32 minutes average). The PASS-C® dose was 75 to 200 mg/L of liquid product; the polymer dose was 0.5 to 1.5 mg/L.

Figure 2. Batch reactor for the mechanized treatment systems. The dark canister to the right is the pressure sand filter.

Effluent turbidity and total phosphorus concentrations after sedimentation are plotted against influent concentrations in Figure 3. "Non-detect" values are plotted at the detection limit. As can be seen, almost all of the experimental runs met the effluent limits after settling. Other data (not shown) showed that subsequent filtration did not further reduce concentrations substantially.

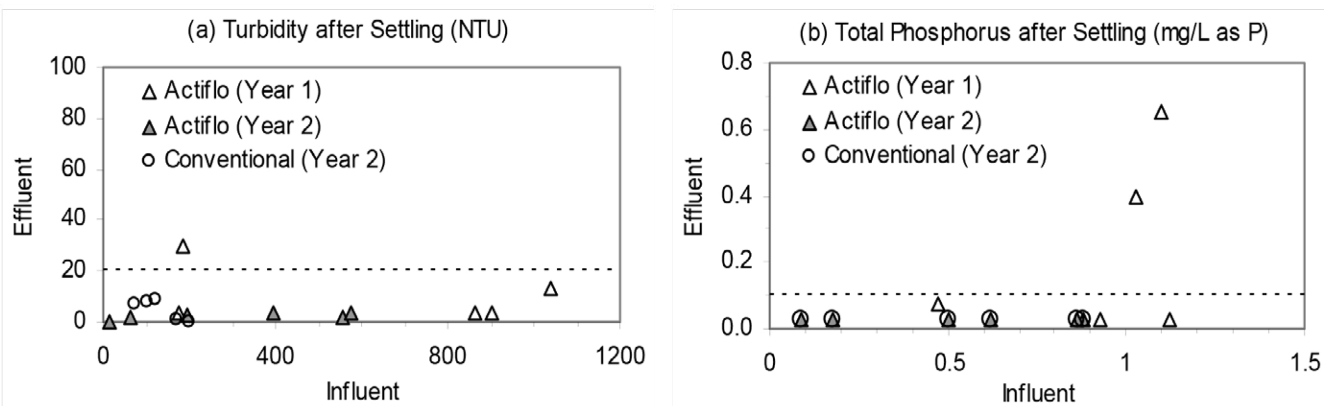

Figure 3. Turbidity and total phosphorus concentrations after settling in the mechanized systems. Effluent limits are plotted as horizontal dotted lines.

NON-MECHANIZED SYSTEM RESULTS

Although successful as treatment processes, the mechanized systems represent a degree of technical sophistication that would be difficult to duplicate in the roadside environment. Consequently, a series of non-mechanized systems were designed to test processes that might be deployed where power and operators will not be available. They consisted of various combinations of settling tanks and gravity filters utilizing different kinds of filter media (three grades of sand, zeolite, activated alumina, and aluminum oxide). All of the systems were constructed from 30-inch (762-mm) diameter plastic tanks (Figure 4). In several systems, PASS-C® was injected into the process feed line and rapidly mixed with an in-line static mixer. Slow mixing was not provided. To highlight the effects of the coagulant rather than the adsorptive media, only results from the systems using sand as a filter medium are reported here.

Figure 4. Typical non-mechanized treatment unit.

The simplest coagulant addition strategy is to dose at a constant concentration. In Year 1, a coagulant dose of 100 mg/L of liquid PASS-C® was used. This value was established in previously conducted jar testing. The characteristics of System 11, which received a constant coagulant dose, are summarized in Table 2.

In Figure 5, effluent turbidity values from the settling tank (11S) and the subsequent filter (11F) are plotted against influent values and displayed as open triangles. As can be seen, settling was not generally sufficient to meet the effluent limit. Subsequent filtration was effective at reducing turbidities. In the experimental runs, the effluent limit could be achieved by the filter if the influent turbidity was less than about 60 NTU. This wasn't, however, always achieved by settling with a constant coagulant dose.

Effluent phosphorus concentrations from the settling tank and filter are shown in Figure 6. Again, settling alone was not sufficient to meet the effluent limit with a constant coagulant dose. In this case, subsequent filtration did not improve effluent quality significantly. The concentrations in Figure 6(a) are changed only slightly from those in Figure 6(b).

Table 2 – Characteristics of Selected Pilot Treatment Systems

System ID No.		Coagulant Dose(1)	Settling Time	Filtration (2,3,4)
Year 1				
	11	100	2 hours (5)	Fast loading
Year 2				
	34	75 – 200	>2 hour (6)	Slow loading
	32	0	>2 hour (6)	Slow loading

(1) Expressed as mg/L of liquid PASS-C product.
(2) All filters contained "fine sand" (effective size 0.45 mm, uniformity coefficient 1.5).
(3) "Fast loading" means the water was ponded on top of the media and allowed to percolate as fast as the hydraulic conductivity would allow, 7-28 minutes in filter 11F.
(4) "Slow loading" means the water was applied to the top of the filter in a controlled manner over a 6-hour period.
(5) After 2 hours of quiescent settling, the settling tank was drained to the filter in 5-7 minutes.
(6) After 2 hours of quiescent settling, the settling tank was transferred to the filter over a 6-hour period.

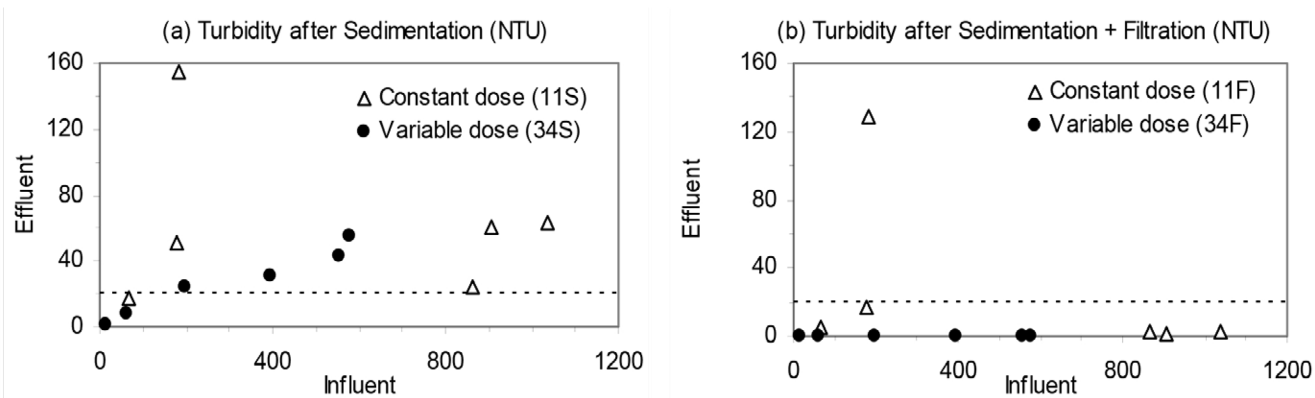

Figure 5. Effluent turbidity after (a) sedimentation only and (b) sedimentation followed by filtration. The constant dose was 100 mg/L of liquid product; the variable dose range was 75 to 200 mg/L. The horizontal dotted line is the effluent limit.

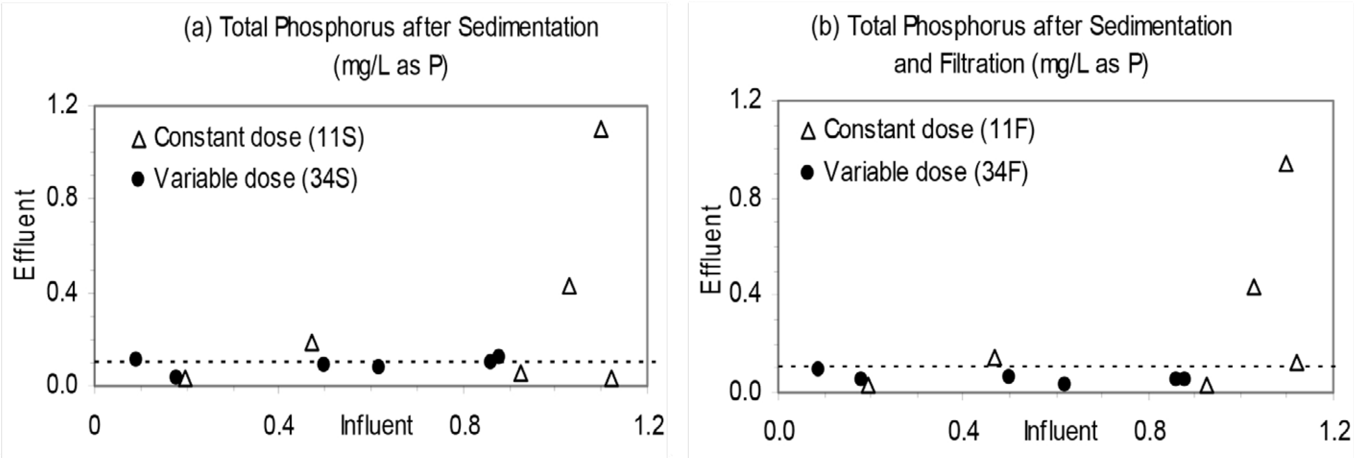

Figure 6. Effluent phosphorus concentrations after (a) sedimentation only and (b) sedimentation followed by filtration. The constant dose was 100 mg/L of liquid product; the variable dose range was 75 to 200 mg/L. The horizontal dotted line is the effluent limit.

In Year 2, the coagulant addition strategy was changed. Rather than feed a constant 100 mg/L of PASS-C® regardless of the influent characteristics, the dose was based on jar testing of each batch of stormwater. Based on turbidity removal, optimal doses varied from 75 to 200 mg/L of liquid product. The characteristics of System 34, which received a variable coagulant dose, are summarized in Table 2. As shown in the table, the settling time was lengthened somewhat and the filtration rate was reduced. Analysis of data from other treatment systems at the small-scale facility indicated that these changes by themselves had little effect on treatment performance (Caltrans 2003d).

Effluent turbidity values from the settling tank (34S) and the subsequent filter (34F) are plotted in Figure 5 as darkened circles. Optimizing the coagulant dose for each batch of runoff did not significantly improve turbidity removal compared to the constant dose. This may be because the optimized doses used (75, 75, 100, 120, 170, and 200 mg/L) were not very different from the constant dose (100 mg/L). As discussed earlier, the filter improved overall treatment performance.

Effluent phosphorus concentrations are shown as darkened circles in Figure 6. In this case, dose optimization, even when based on turbidity removal, seemed to improve phosphorus removal compared to constant dose results. As discussed before, the filter did not change the phosphorus concentrations significantly.

For comparison, Figure 7 shows turbidity and phosphorus concentrations following settling and filtration in System 32 which is identical to System 34 except that coagulant was not used. As can be seen, neither effluent limit was achieved by sedimentation and fine sand filtration without the use of a coagulant.

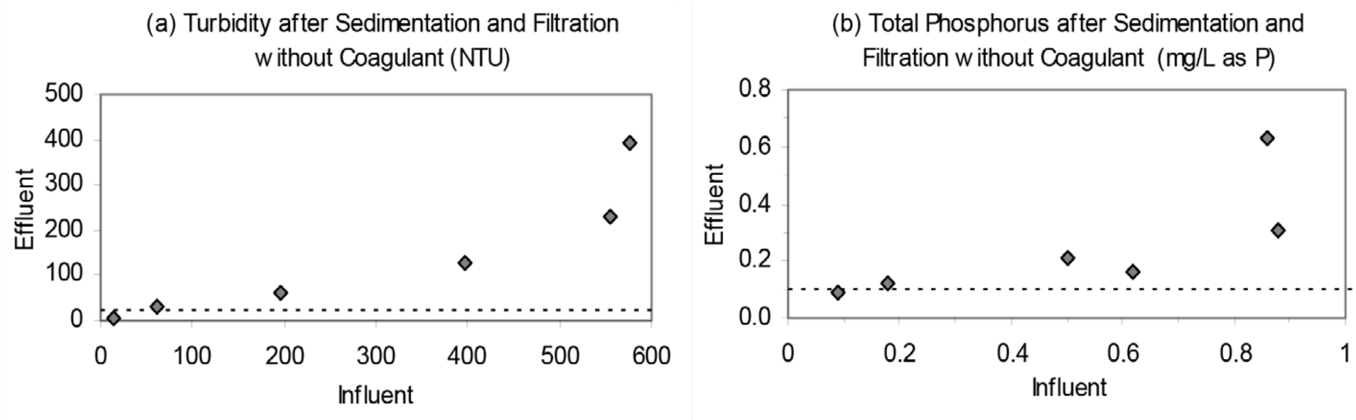

Figure 7. Turbidity and phosphorus concentrations when coagulant was not used. The dotted line is the effluent limit.

DISCUSSION AND CONCLUSIONS

In any study with as few data points as this one, it is difficult to make strong assertions as to which technology is "best" or which one is "good enough" to meet the regulatory standards under a wide variety of circumstances. Nevertheless, these results can be useful for guiding future technology development efforts. One thing that was apparent in this study was that conventional Best Management Practices such as detention basins and sand filters are unlikely to be successful at meeting stringent effluent limits such as these. Secondly, adding a coagulant, even without a slow-mix flocculation step, substantially enhanced turbidity and phosphorus removal. In this study, satisfactory turbidity removal was achieved without optimizing coagulant dose, though optimization was needed for satisfactory phosphorus removal. Devising the optimal dosing strategy will require further testing. Finally, filtration was a necessary element in turbidity removal, but not phosphorus removal. The apparent ineffectiveness of filtration in phosphorus removal may be related to the form of phosphorus leaving the settling tank. For instance, in the systems using the coagulant, 25 to 100% (average 50%) of the phosphorus in the sedimentation effluent passed through a 0.45 µm filter. Truly dissolved forms of phosphorus won't be removed by filtration. Identifying the nature of the phosphorus in sedimentation effluent and developing strategies to remove it will require additional research.

DISCLAIMER

The mention of specific products in this paper does not imply any endorsement or intent to use said products by the California Department of Transportation.

REFERENCES

Caltrans (2000). *Caltrans Guidance Manual Stormwater Monitoring Protocols*, Second Edition. CTSW-RT- 00-005. July 2000. California Department of Transportation, Sacramento CA.

Caltrans (2003a). *Tahoe Highway Runoff Characterization and Sand Trap Effectiveness Studies 2000-2003 Monitoring Report.* CTSW-RT-03-054.36.02. June 2003. California Department of Transportation, Sacramento CA.

Caltrans (2003b). *Lake Tahoe Storm Water Treatment Pilot Project Jar Test Results and Summary Report*. CTSW-RT-02-075. June 2003. California Department of Transportation, Sacramento CA.

Caltrans (2003c). *Lake Tahoe Storm Water Small Scale Pilot Treatment Project First Year Report.* CTSW-RT-03-042. August 2003. California Department of Transportation, Sacramento CA.

Caltrans 2003d. *Lake Tahoe Storm Water Small Scale Pilot Treatment Project Phase II Report*. CTSW-RT-03-042. December 2003. California Department of Transportation, Sacramento CA.

LRWQCB (1994). *Water Quality Control Plan for the Lahontan Region – North and South Basins.* Lahontan Regional Water Quality Control Board, South Lake Tahoe, CA.