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Pilot filtration studies for turbidity and nutrient removal at Lake Tahoe

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ABSTRACT

The California Department of Transportation (Caltrans), which is responsible for more than 500 storm water discharge points in the Tahoe Basin, has constructed a small-scale test facility for developing new treatment technologies to meet numeric effluent discharge limits due in 2008. The primary constituents of concern are turbidity, phosphorus and nitrogen. Of particular interest are settling and gravity filtration treatment systems because of their relatively low maintenance requirements and potential for deployment within the Caltrans right-of-way.

Special attention is being given to media to remove the dissolved fraction of phosphorus in the runoff, which can cause violation of the effluent limit even after the particulate fraction is removed. Three grades of sand, activated alumina, and aluminum oxide were tested during the 2001/02 wet season. Fine sand, activated alumina, expanded shale, and limestone were tested during the 2002/03 wet season. During the 2001/02 season, none of the media filters tested were able to meet the surface discharge limits for the primary constituents of concern. Hydraulic application rates were reduced in the 2002/03 season. In some filters, dosing was controlled at the inlet; in others, dosing was controlled at the outlet, leading to submerged conditions. In the 2002/03 results, filtration through activated alumina or expanded shale following sedimentation almost always met the surface water discharge limits for turbidity (20 NTU) and total phosphorus (0.1 mg/L). Both media, however, increased pH and contributed dissolved aluminum to the effluent.

INTRODUCTION

At Lake Tahoe storm water runoff will be subject to strict numeric discharge limits for infiltration and surface water discharge starting in 2008 (Table 1). In 2001, the California Department of Transportation (Caltrans) constructed a research facility at its South Lake Tahoe Maintenance Station and implemented a small-scale storm water treatment pilot project to evaluate the effectiveness of various treatment technologies for meeting the numeric discharge limits. This paper covers Years 1 and 2 of testing of alternative filter media, with emphasis on processes designed to meet the phosphorus and turbidity discharge limits.

Table 1. Storm water runoff surface discharge limits compared to typical Caltrans highway runoff for the Lake Tahoe basin

Constituent	Units	Surface Discharge Limits[(a)]	Typical Tahoe Highway Runoff[(b)]
Total Nitrogen as N	mg/L	0.5	2.7
Total Phosphate[(c)] as P	mg/L	0.1	2.1
Total Iron (Fe)	µg/L	500	17700
Turbidity	NTU	20	477
Oil and Grease	mg/L	2.0	18

(a) LRWQCB (1994); (b) Caltrans (2003a)
(c) Basin plan specifies that total phosphate is measured as "total phosphorus" (LRWQCB, 1994).

PILOT FACILITIES AND OPERATIONS

Storm water runoff was collected from detention basins and stored in 6,500-gallon storage tanks (with submersible mixers) located outside of the pilot treatment building (Figure 1a). Filtration-only and filtration preceded by 2 to 24 h of sedimentation were tested during Years 1 and 2. The filtration units consist of 30-inch diameter tanks filled with 24 inches of granular filter media over an 8-inch gravel base (Figure 1b). In the sedimentation/filtration systems, storm water was pumped from the storage tanks into the sedimentation tanks, allowed to settle and pumped (or released) to a corresponding filter unit (Figure 2). In filtration-only systems, storm water was released directly onto the media surface.

Figure 1. Photographs showing (a) pilot treatment building with storage tanks, and (b) sedimentation and filtration units

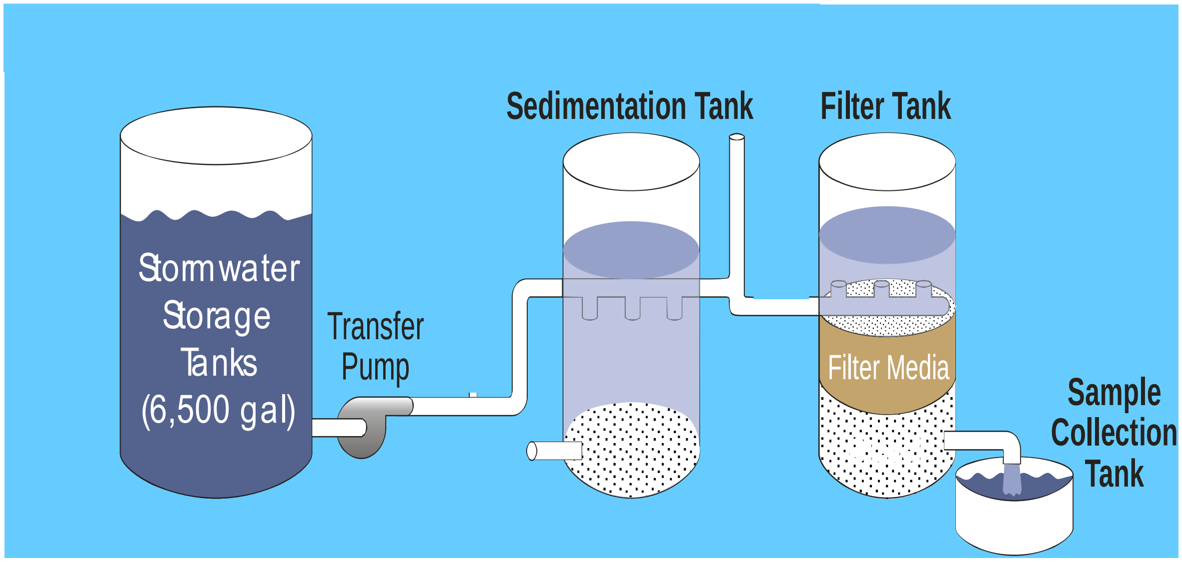


Figure 2. Schematic of experimental systems

Filter hydraulic conditions were changed between Year 1 and Year 2. During Year 1, three feet depth of water over filter area was applied to the filters as a batch and allowed to drain rapidly ("fast" loading rate) into an underdrain that was open to the atmosphere ("free-drain" condition). During Year 2, all of the filters (except one unit for comparison) were loaded by gradually pumping settled or unsettled storm water into the unit at the rate of 3 feet (depth over filter area) in 6 hours ("slow" loading rate). Additionally, some of the filters were operated in a "submerged" condition by extending the filter outlet piping upward so that discharge occurred at an elevation slightly higher (< 1 cm) than the media surface. Submerging the filter media and decreasing the loading rate in this manner promoted more uniform distribution of the water across the entire filter area and increased the contact time with the media.

The selection of filter media for testing was primarily based on literature reviews on adsorptive media for phosphorus. The adsorptive media reviewed are given in Table 2 in appropriate groups, and listed in decreasing order of effectiveness based on the reported studies. The Iron Group media were not selected for consideration because of the limitation on iron discharge concentration. Although the Industrial Byproducts Group was generally effective in phosphate removal, it was not considered because of practical issues of iron leaching and possible cementing in the field after prolonged use. Table 2 also indicates the filter media selected for testing during Years 1 and 2. Full details on the pilot facilities, treatment units and operations are given in Caltrans (2003 b, c).

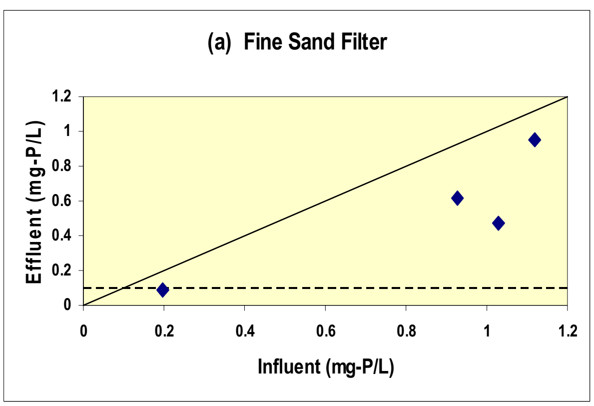
Table 2. Literature review and selection of filter media

Aluminum Group	Calcium Group	Iron Group	Sand Group	Industrial Byproducts
Activated Alumina[1, 2] Alumina Hydroxide Aluminum Oxide[1] Expanded Shale[2] Shale Bauxite Zeolite[1]	Wollastonite[2] Limestone[2] Dolomite	Iron Oxide Iron Coated Sands Red Mud	Fine Sand[1, 2] Coarse Sand[1] Concrete Sand[1]	Oxygen Furnace Oxides Oxygen Furnace Slags Blast Furnace Slags Blast Furnace Wastes Coal Fly Ash

1 – Selected for testing in Year 1
2 – Selected for testing in Year 2

RESULTS AND DISCUSSION

In Year 1, sedimentation alone and all the filtration systems tested without prior sedimentation (with the possible exception of filtration with activated alumina media) did not consistently meet any of the surface discharge limits. Figure 3a shows influent/effluent results for total phosphorus removal for the fine sand filter. Because of clogging, the fine sand filter without prior sedimentation completed only four experimental runs. The activated alumina filter completed five runs. As can be seen in (Figure 3b), the activated alumina media was more successful than fine sand at removing total phosphorus. Year 1 results from filters using concrete sand, aluminum oxide, and zeolite media are not reported here because these media did not provide any better treatment than fine sand filtration.



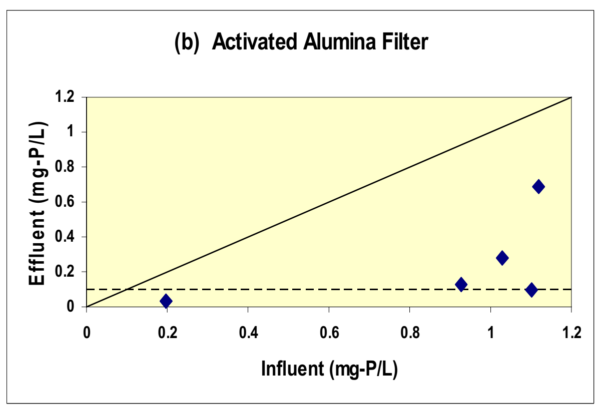


Figure 3. Total phosphorus removal results for (a) fine sand and (b) activated alumina filtration for Year 1 (no sedimentation, fast loading, free-drain). (Broken horizontal lines show surface discharge limits; solid diagonal lines show no treatment).

During Year 2, it was shown that increasing sedimentation times from 2 to 24 hours had a small positive effect on the removal of turbidity, total phosphorus, and oil and grease, but sedimentation alone continued to be ineffective. The results of changing the hydraulic operating conditions are shown in Figure 4. As shown, fine sand filters operated with slow hydraulic loading rates and a submerged condition showed better removal of turbidity and total phosphorus than did fast-loaded, free-drain filters in the six runoff events tested. Similar results were observed for total nitrogen and total iron removal. These results suggest, however, that fine sand filtration, even with sedimentation, slow hydraulic loading and submerged media, is unlikely to consistently meet the 2008 surface water discharge limits.

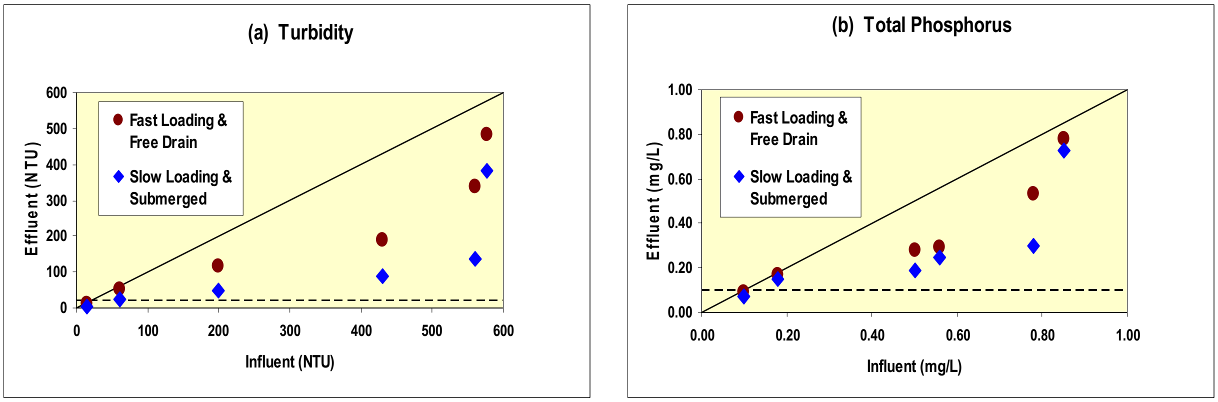


Figure 4. Effect of filter loading conditions for fine sand filtration: comparison of fast loading/free-drain and slow loading/submerged for (a) turbidity and (b) total phosphorus. (Broken horizontal lines show surface discharge limits; solid diagonal lines show no treatment).

Filtration through activated alumina and expanded shale, with 24-hour sedimentation and slow-loading, submerged hydraulic conditions, almost always met the surface water discharge limits for all constituents. The treatment results for turbidity and total phosphorus for filtration through activated alumina are shown in Figure 5.

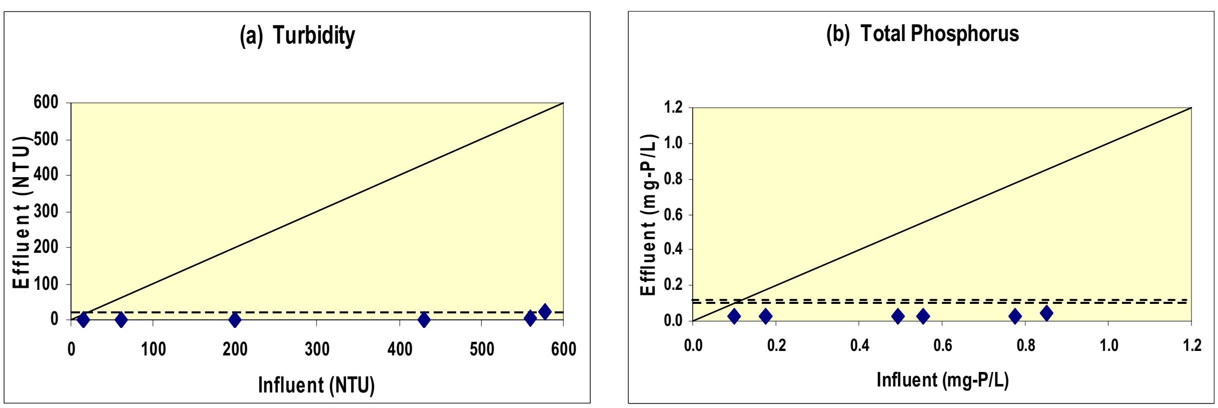


Figure 5. Activated alumina filtration results for (a) turbidity and (b) total phosphorus (slow loading, submerged, 24-hr sedimentation). (Broken horizontal lines show surface discharge limits, solid diagonal lines show no treatment).

Although activated alumina and expanded shale filtration were found to meet the surface water discharge limits, both media contributed dissolved aluminum to the effluent and increased the effluent pH. The effluent pH of the expanded shale was often higher than 10 pH units. Filtration through limestone and wollastonite media did not consistently meet any of the surface discharge limits. Limestone filtration met the surface water discharge limits for turbidity, phosphorus, and iron in four of six runs in Year 2. Limestone filtration also resulted in elevated pH, but not to the extent of expanded shale.

The results presented in this paper are preliminary and may not be representative of performance under actual conditions in the Tahoe Basin. In Years 1 and 2, for instance, influent total phosphorus concentrations were relatively low and often well below the 2.1 mg/L mean value for Tahoe Basin highway runoff. Although predicting full-scale filter effluent quality from these experiments may not be possible, they were useful for distinguishing among different types of media in terms of treatment performance. The runs carried out to date represent only a small proportion of the annual hydraulic and constituent loading that would be expected for media filters in the field. Extended loading experiments will be undertaken in Year 3. Toxicity issues associated with aluminum and elevated pH require further attention. Aluminum is not currently included in the California Toxics Rule (USEPA, 2000), and whether filter effluents would raise receiving water pH by an unacceptable degree is unknown. Laboratory testing of filter effluent toxicity is planned. Finally, it should be noted that these experiments were designed to develop and test treatment concepts. At this time, it is unclear whether adsorptive media filtration will be affordable or practical to site given space limitations in the Tahoe Basin. Further research is needed to answer these questions. Unfortunately, less expensive and more compact alternatives that can meet the legal requirements for surface water discharge are not readily available.

CONCLUSIONS

Years 1 and 2 of small-scale pilot studies on storm water filtration at Lake Tahoe have shown that:

- Filters with submerged media operated under low hydraulic loading (i.e., slow filtration rates) perform better than filters with free-drain media loaded as high as the hydraulic conductivity of the media allows.

- Sedimentation alone or fine sand filtration preceded by 2 or 24-hour sedimentation almost always failed to meet all of the surface water discharge limits.

- Filtration through activated alumina and expanded shale, with 24-hour sedimentation and slow loading and submerged hydraulic conditions, almost always met all the surface water discharge limits. However, both media contributed dissolved aluminum to the effluent and increased the effluent pH.

- Total phosphorus concentrations in the influent in Years 1 and 2 were relatively low compared to mean total phosphorus concentrations for Tahoe Basin highway runoff. The results presented here may therefore not be representative of performance under actual field conditions in the Tahoe Basin.

Year 3 experiments are currently under way to evaluate the long-term treatment effectiveness of activated alumina and expanded shale filtration. Additional experiments are also planned to test other adsorptive media which either show minimal increase in dissolved aluminum concentrations and pH in the treated waters or indicate potential in reducing these.

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