California State University, Sacramento (CSUS)

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Pilot Filtration Studies for Turbidity and Nutrient Removal at Lake Tahoe

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Authors:

Dipen Patel, Office of Water Programs, California State University, Sacramento
Jeffrey Hauser, Eco:Logic Consulting Engineers, Sacramento
John Johnston, Department of Civil Engineering, California State University, Sacramento
Jeff Curtis, Eco:Logic Consulting Engineers, Sacramento

Disclaimer:

Storm Water Program
CSUS Office of Water Programs
6000 J Street, Modoc Hall, Room 1001, Sacramento, CA 95819-6025

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PILOT FILTRATION STUDIES FOR TURBIDITY AND NUTRIENT REMOVAL AT LAKE TAHOE

Dipen Patel*, CSUS Office Of Water Programs, Sacramento CA
Jeffrey Hauser‡, ECO:LOGIC Engineering, Rocklin CA
John Johnston†, Department of Civil Engineering, CSUS, Sacramento CA
Jeffry Curtis††, ECO:LOGIC Engineering, Reno NV

Abstract

At Lake Tahoe storm water runoff discharged to surface waters will be subject to strict numeric effluent limits for turbidity (20 NTU), total phosphorus (0.1 mg/L), and total nitrogen (0.5 mg/L) starting in 2008. As part of its program to meet these requirements, 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 and testing new storm water treatment technologies. Of particular interest are combinations of settling and gravity filtration units because of their relatively low maintenance requirements and potential for deployment within the Caltrans right-of-way.

Special attention is being given to media with potential to remove dissolved phosphorus. At Tahoe, the dissolved phosphorus fraction is sometimes large enough to violate the effluent limit by itself. Based on a literature review, four promising media for this application appear to be activated alumina, expanded shale, limestone and wollastonite (calcium silicate) tailings. Laboratory batch and column studies using phosphate solutions or wastewater reported in the literature showed that all four media have relatively high phosphate adsorption capacities. To test these and other media with storm water, pilot testing is being conducted at the small-scale facility using 30-inch diameter sedimentation basins and filters dosed with storm water collected from local detention devices. For filter media, three grades of sand, zeolite, activated alumina, and aluminum oxide were tested during the 2001/02 wet season. Fine sand, activated alumina, expanded shale, limestone and wollastonite were tested during the 2002/03 wet season.

During the 2001/02 season, when filters were operated without prior sedimentation and with high hydraulic loading rates, none were able to able to meet the effluent limits for turbidity, phosphorus, or nitrogen. During the 2002/2003 season, improved filter performance was obtained with prior sedimentation, reduced hydraulic application rates, and submerged (versus free-draining) media. In this case, activated alumina and expanded shale media filters (following sedimentation) almost always met the surface water discharge limits for turbidity and phosphorus (nitrogen limits were also met, but influent nitrogen was low). However, both media increased pH and contributed dissolved aluminum to the effluent.

Introduction

Lake Tahoe, with an average surface elevation of 6,225 ft (1,897 m) above sea level, is the highest and clearest lake of its size in the United States. Monitoring by the Tahoe Research Group, which has studied the famous alpine lake for more than 40 years, indicates that Lake Tahoe has been losing transparency at an average of about one foot each year since the late 1960s. The decline in transparency is believed to be caused by increases in both algae and mineral particles in the water column due to increases in nutrient inputs to the lake from the atmosphere and watershed and increases in clay and silt particles in surface runoff to the lake.

At Lake Tahoe storm water runoff will be subject to strict numeric effluent limits for infiltration and surface water discharge starting in 2008 (Table 1). In 2001, Caltrans constructed a research facility at the existing 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 limitations. 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 Discharge Limits Compared to Typical Caltrans Highway Runoff for the Lake Tahoe Basin

Constituent	Units	Surface Discharge Limits[a]	Typical Caltrans Highway Runoff (Tahoe Basin) [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 off 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.

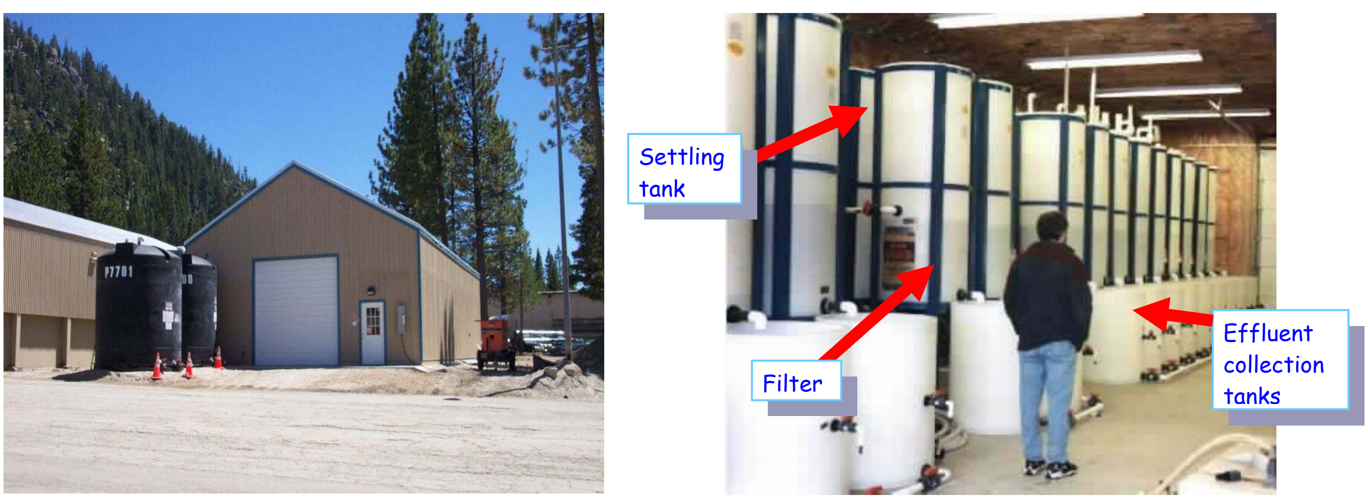

Figure 1 Photographs showing (a) pilot treatment building with storage tanks, and (b) sedimentation and filtration units

Filter hydraulic conditions were changed between Year 1 and Year 2. During Year 1, three feet of water 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 (Figure 3). Submerging the filter media in this manner promoted more uniform distribution of the water across the entire filter area.

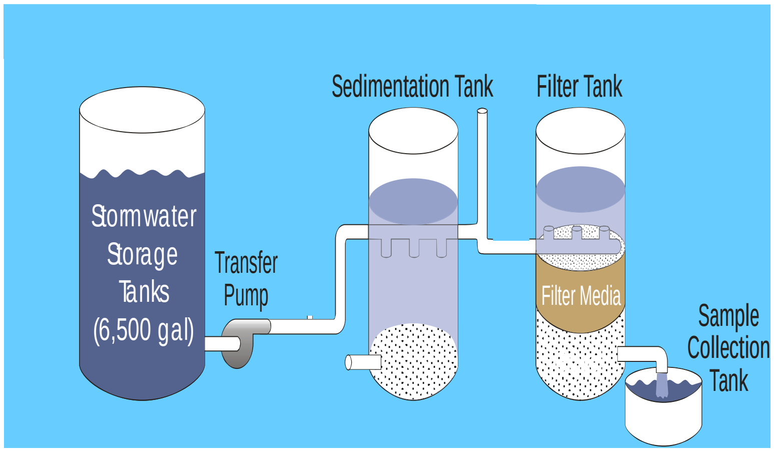

Figure 2 Schematic of a Sedimentation/Filtration System

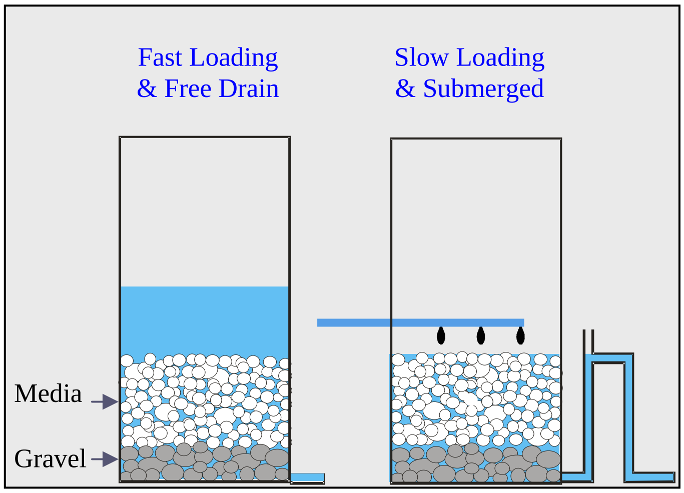

Figure 3 Schematic of fast loading/free drain and slow loading/submerged filter operating conditions

The selection of filter media for testing was based on literature reviews on adsorptive media for phosphorus and ammonia removal. 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 leaching of iron, substantial increase in pH of the effluent water and possible cementing in the field after prolonged use. In general, any media expected to perform similar to media already selected was not considered for testing.

Table 2. Literature Review for Media Selection

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

The filter media investigated during Years 1 and 2, together with the loading rates, hydraulic conditions, and sedimentation times tested are indicated in Table 3. Full details on the pilot facilities, treatment units and operations are given in Caltrans (2003 b, c).

Table 3. Year 1 and Year 2 Treatment Systems

Treatment Designation (Process No)	Sedimentation Time (hrs)	Filtration		
		Filter Media	Loading Rate[1]	Hydraulic Condition[2]
Year 1				
1	0	Fine Sand	Fast	Free-Drain
2	0	Coarse Sand	Fast	Free-Drain
3	0	Zeolite (clinoptilolite)	Fast	Free-Drain
4	0	Activated Alumina	Fast	Free-Drain
5	0	Aluminum Oxide Sand	Fast	Free-Drain
10	2	Concrete Sand	Fast	Free-Drain
Year 2				
31	24	Fine Sand	Slow	Free-Drain
32	2	Fine Sand	Slow	Free-Drain
33	2	Fine Sand	Slow	Submerged
34	2	Fine Sand	Slow	Free-Drain
35	2	Fine Sand	Fast	Free-Drain
36	24	Fine Sand	Slow	Submerged
37	24	Expanded Shale	Slow	Submerged
38	24	Limestone	Slow	Submerged
39	24	Wollastonite	Slow	Submerged
40	24	Activated Alumina	Slow	Submerged

1 - "Fast" loading – quick transfer of given volume of water onto filter surface and filtration rate controlled by hydraulic conductivity of media.
"Slow" loading – slow controlled loading onto filter surface using upstream pump.

2 - "Free-Drain" – no restriction on effluent flow downstream of media.
"Submerged" – media submerged by raising outlet point to level of media surface.

Results & 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 4a shows influent/effluent results for total phosphorus removal for the fine sand filter. In some runs, the activated alumina filtration media demonstrated effective removal of total phosphorus (Figure 4b). The concrete sand, aluminum oxide, and zeolite media did not appear to offer any treatment advantages above that observed with fine sand filtration.

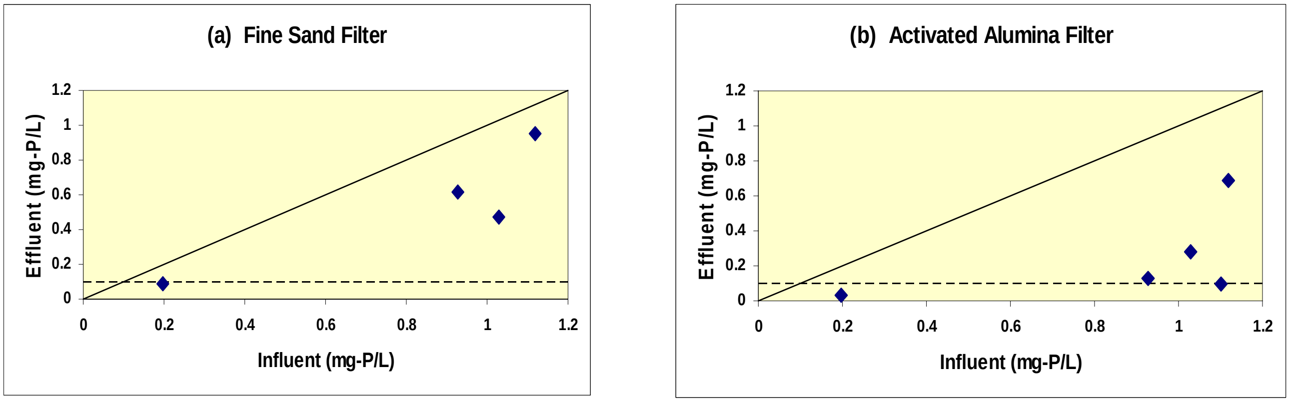

Figure 4 Total phosphorus removal results for (a) fine sand and (b) activated alumina filtration for Year 1 (no sedimentation, fast loading, free-drain). (Dotted lines represent surface discharge limits and solid diagonal lines represent no treatment).

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. Fine sand filters operated with slow hydraulic loading rates and submerged condition showed better removal of turbidity, total phosphorus, total nitrogen, and total iron than fast-loaded, free-drain filters. Figure 5 shows the effects of hydraulic operating conditions on turbidity and total phosphorus removal. The results suggest that fine sand filtration, even with sedimentation, slow hydraulic loading and submerged media, is unlikely to consistently meet the surface water discharge limits.

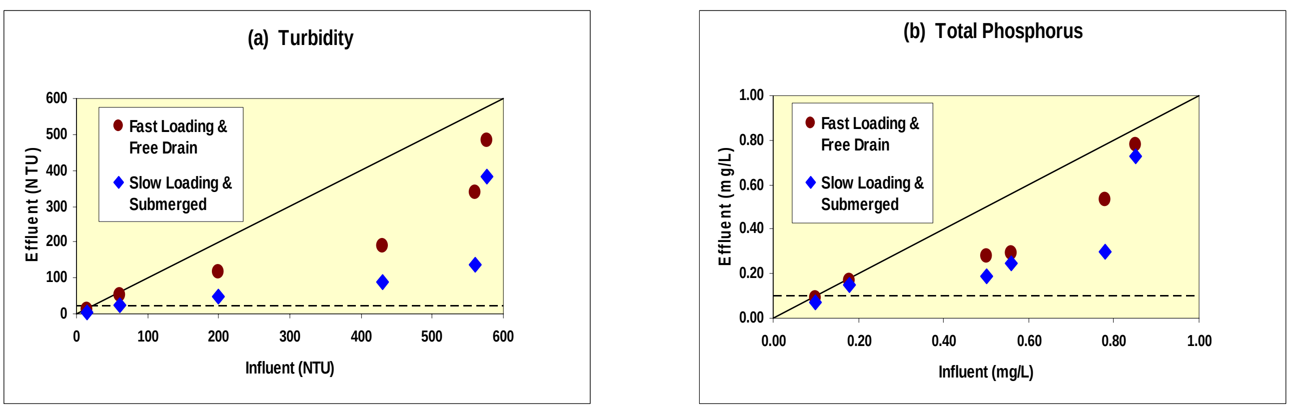

Figure 5 Effect of filter loading conditions – comparison of fast loading/free-drain and slow loading/submerged for (a) turbidity and (b) total phosphorus. (Dotted lines represent surface discharge limits and solid diagonal lines represent no treatment).

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 and expanded shale are shown in Figures 6 and 7, respectively.

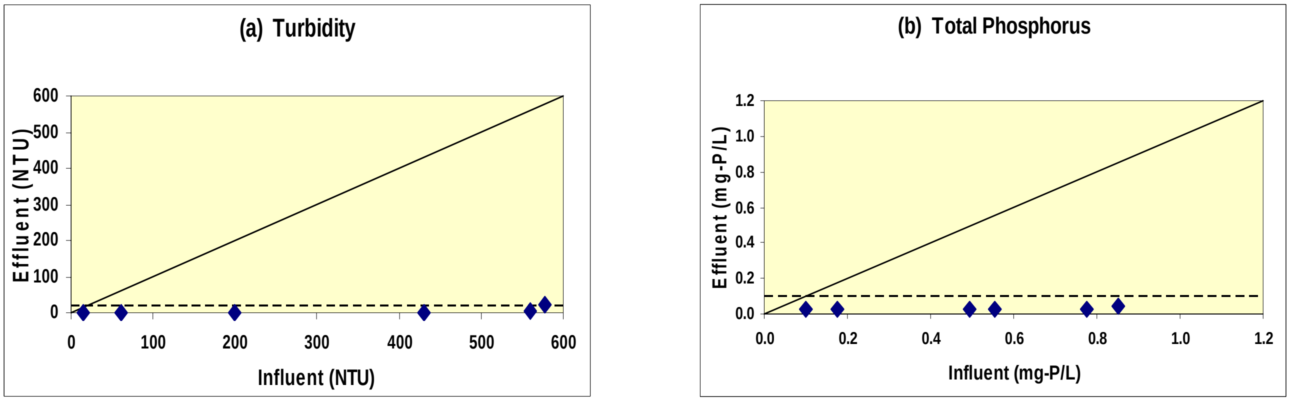

Figure 6 Activated alumina filtration results for (a) turbidity and (b) total phosphorus (slow loading, submerged, following 24-hour sedimentation). (Dotted lines represent surface discharge limits and solid diagonal lines represent no treatment).

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.

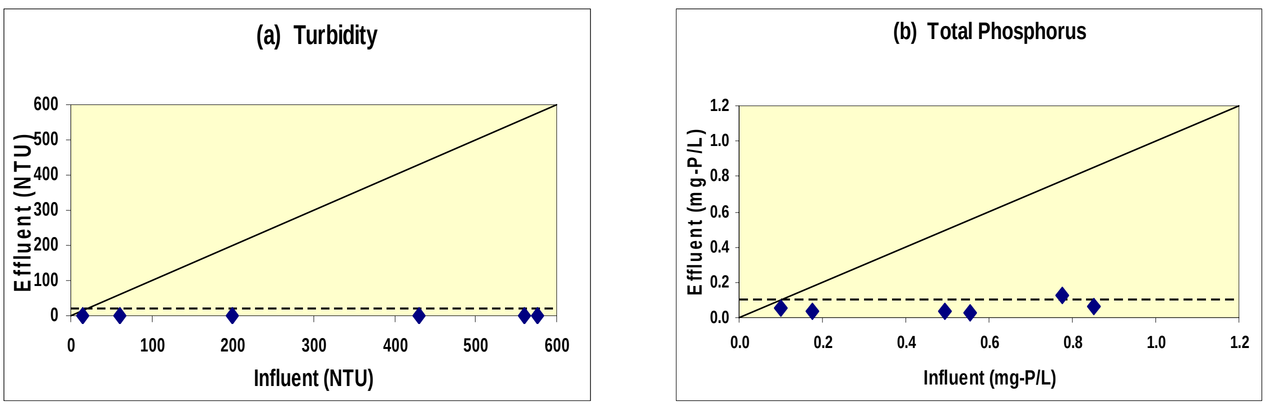

Figure 7 Expanded shale filtration results for (a) turbidity and (b) total phosphorus (slow loading, submerged, following 24-hour sedimentation). (Dotted lines represent surface discharge limits and solid diagonal lines represent no treatment).

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.

Conclusions

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.

Year 3 experiments are currently under way to evaluate the long-term treatment effectiveness of activated alumina and expanded shale filtration.

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