DESIGN AND CONSTRUCTION EXPERIENCES WITH THREE VARIATIONS OF AUSTIN STYLE SAND FILTERS IN THE TRANSPORTATION ENVIRONMENT

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ABSTRACT

The California Department of Transportation (Caltrans) has initiated a three year pilot project to investigate the water quality performance of two Austin Sand Filters designed incorporating alternative configurations and/or alternative construction materials to reduce capital costs while maintaining water quality performance. Two test sites in Northern California have been selected for the pilot project. Caltrans designed and constructed a gravity, earthen embankment, partial sedimentation Austin Sand Filter (EPSF) to treat storm water runoff from a highway site. A partial sedimentation Austin Sand Filter has one basin that serves as the sand filter and the sedimentation area. Additionally, Caltrans designed and constructed a gravity, earthen embankment, full sedimentation Austin Sand Filter (EFSF) to treat storm water runoff and snow melt runoff from a maintenance station facility. A full sedimentation Austin Sand Filter has separate sedimentation and filtration basins. Similar filter media was placed in each sand filter. At each sand filter site, storm water collection systems were installed at influent and effluent points and equipped with automated samplers. Water quantity and quality data from flow-composite samples of the storm water runoff were collected and evaluated during representative storms. The quantity and quality of the effluent was compared to influent runoff to assess removal efficiency. The three year pilot project is one of two projects by Caltrans that investigates the water quality performance of Austin Sand Filters. In an earlier study, Caltrans investigated the water quality performance of two gravity, concrete-boxed, full sedimentation Austin Sand Filters (CFSFs). The construction and operating costs along with the water quality performance of these two sand filters were documented. This paper presents: (a) a discussion of the design methodologies for the full and partial sedimentation Austin Sand Filters; (b) comparison of construction costs between three variations of Austin Sand Filters (EPSF, EFSF, and CFSF); (c) the preliminary water quality data for the Northern California pilot project; and (d) a preliminary comparison of water quality performance between the Northern California pilot project and the Southern California pilot project.

INTRODUCTION

Over the past several years, the California Department of Transportation (Caltrans) has initiated a number of pilot projects to assess the performance and applicability of various proprietary and non-proprietary storm water Best Management Practices (BMPs). In the fall of 1998, Caltrans initiated a three year pilot project in Southern California that included the design, construction, and monitoring of two gravity, concrete-boxed, full sedimentation Austin Sand Filters (CFSF). A full sedimentation Austin Sand Filter has separate sedimentation and filtration basins. The construction and operating costs along with the water quality performance of these two sand filters were documented. Upon completion of the monitoring of these two sand filters, Caltrans launched a reconnaissance study (Caltrans, 2001b) to explore alternative configurations and construction materials for gravity sand filters with the objective of reducing capital costs while maintaining the water quality performance documented in the initial pilot project in Southern California. The reconnaissance study recommended the use of earthen materials for construction and utilizing a partial sedimentation Austin sand filter design. A partial sedimentation Austin Sand Filter has a single basin that serves as the sand filter and the sedimentation area. In the spring of 2001, Caltrans initiated a three year pilot project in Northern California to investigate the recommendations of the reconnaissance study. Two sites were selected for this pilot project. Caltrans designed and constructed a gravity, earthen embankment, partial sedimentation Austin Sand Filter (EPSF) at a highway site. Caltrans designed and constructed a gravity, earthen embankment, full sedimentation Austin Sand Filter (EFSF) at a maintenance station site. The construction and operating costs of these two sand filters were documented. The water quality performance of these two sand filters will be evaluated over a three year period. At the time this paper was prepared, the Northern California pilot project was in the second monitoring season. The four sand filter sites that will be discussed in this paper are summarized in Table 1.

Table 1. Sand Filter Site Summary Information

Site No.	Sand Filter Type	Elevation m (ft)	Avg Annual Rainfall [a] mm (in)	Avg Annual Snowfall [a] mm (in)	Drainage Area ha (ac)	Pilot Project	Location
1	(CFSF) Concrete-boxed Full Sedimentation	5.7 (19)	396 (15.6)	0	1.1 (2.7)	Southern California	*Park-N-Ride Site*: La Costa PR
2	(CFSF) Concrete-boxed Full Sedimentation	16.0 (53)	337 (13.3)	0	0.3 (0.7)	Southern California	*Highway Site*: SR-78 / I-5 PR
3	(EPSF) Earthen Embankment Partial Sedimentation	269.4 (884)	1000 (39.4)	123 (4.8)	1.04 (2.5)	Northern California	*Highway Site*: Northbound I-5 north of Mountain Gate Exit
4	(EFSF) Earthen Embankment Full Sedimentation	963.4 (3,161)	988 (38.9)	2640 (103.9)	1.04 (2.5)	Northern California	*Maintenance Station Site*: Mount Shasta MS

[a] Source: Western Regional Climate Center

DESIGN CONCEPTS

Concrete-boxed Full Sedimentation Austin Sand Filters (CFSF)

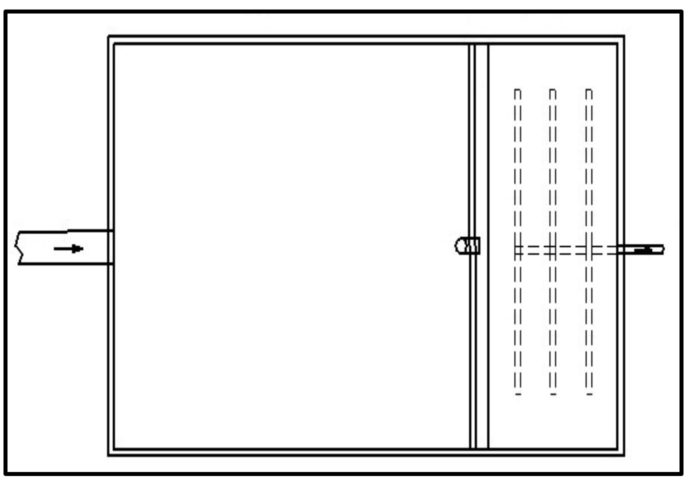

Figure 1 Schematic of CFSF System

The CFSF system consists of a sedimentation basin and a filtration basin. The Water Quality Volume (WQV) is routed into the sedimentation basin. The storm water runoff is detained in the sedimentation basin to allow sediment to settle. The WQV is released into the filtration basin by a perforated riser over a period of 24 hours. A standard filtration basin design includes: an 18-inch deep sand filter; a geotextile layer; and 6 inches of gravel. A perforated PVC piping system collects filtered runoff from the gravel and routes the filtered runoff to the discharge pipe.

Concrete vaults are utilized for the sedimentation and filtration basins. The concrete floor provides a stable surface which facilitates maintenance activities in the sedimentation basin. Additionally, the concrete floor can also be sloped to improve drainage within the sedimentation basin. Concrete allows the use of vertical walls which reduces the space required for full sedimentation sand filters. However, maintenance equipment access to the basin is limited as a result of the vertical walls. The use of concrete eliminates the need for maintenance of vegetation. Furthermore, concrete components eliminate the potential for establishment of wetland vegetation and make the system less suitable for endangered and threatened species habitat.

Earthen Embankment Full Sedimentation Austin Sand Filters (EFSF)

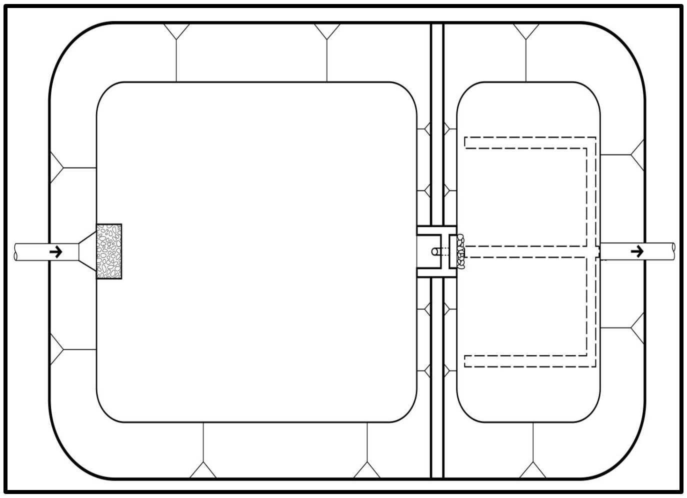

Figure 2 Schematic of EFSF System

The EFSF system is similar to the CFSF system. The EFSF system consists of a sedimentation basin and a filtration basin. The WQV is routed into the sedimentation basin. The storm water runoff is detained in the sedimentation basin to allow sediment to settle. The WQV is released into the filtration basin by a perforated riser over a period of 24 hours. A standard filtration basin design includes: an 18-inch deep sand filter; a geotextile layer; and 6 inches of gravel. A perforated PVC piping system collects filtered runoff from the gravel and routes the filtered runoff to the discharge pipe.

Earthen embankments are utilized for the sedimentation and filtration basins. An earthen basin reduces the initial construction costs by eliminating the use of concrete. Earthen side slopes increase the accessibility to the basin floor for maintenance activities. However, the earthen walls are constructed at a 2:1, 3:1, or 4:1 slope. Since the side slopes are not vertical, the sand filter foot print for the EFSF will be larger than a CFSF. The use of earthen walls requires that the slopes be stabilized with vegetation. Maintenance of the vegetation will increase the maintenance costs.

Earthen Embankment Partial Sedimentation Austin Sand Filters (EPSF)

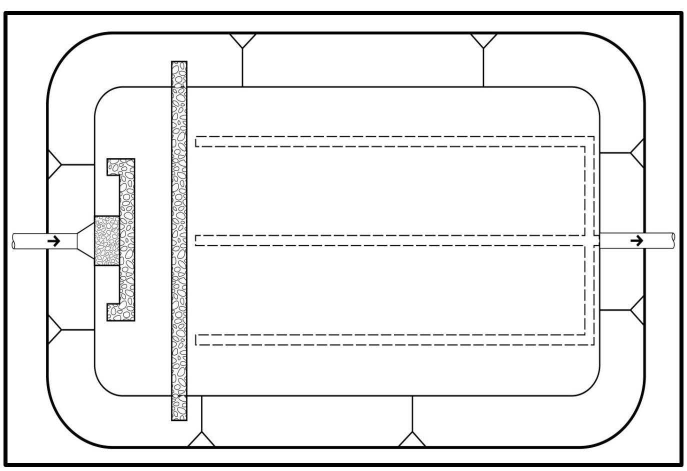

Figure 3 Schematic of EPSF System

The EPSF system consists of a single basin that is designed to hold the WQV. The basin is partially underlain by a filter bed. The small portion of the basin not underlain by the filter bed acts a sediment forebay. The two portions of the basin are separated by a rock berm. The rock berm confines litter and vegetated material to the sediment forebay. The filter bed in the EPSF system is sized larger than the filter bed in the CFSF system or the EFSF system. However, the overall footprint size of the EPSF system is smaller than the footprint size of the EFSF system. A standard filter bed design includes: an 18-inch deep sand filter; a geotextile layer; and 6 inches of gravel. A perforated PVC piping system collects filtered runoff from the gravel and routes the filtered runoff to the discharge pipe.

Similar to the EFSF system, the EPSF system utilizes earthen embankments. Earthen embankments are utilized for the single basin. An earthen basin reduces the initial construction costs by eliminating the use of concrete. Earthen side slopes increase the accessibility to the basin floor for maintenance activities. However, the earthen walls are constructed at a 2:1, 3:1, or 4:1 slope. The use of earthen walls requires that the slopes be stabilized with vegetation. Maintenance of the vegetation will increase the maintenance costs.

Sizing Criteria for Austin Sand Filters

The current sand filter design guidelines utilized by Caltrans are adopted from the City of Austin, Texas and are presented in the Caltrans reconnaissance study (Caltrans, 2001b). The minimum average surface area for the sand filter (A_f) is calculated from the following equation:

$$A_f = \frac{WQV\,(L)}{k(h+L)t}$$

A_f = minimum surface area for the filtration basin, ft^2
WQV = water quality volume, ft^3
L = thickness of sand bed, ft
h = average height of water above sand bed, ft
t = basin draw down time, d
k = permeability of sand, ft/d

The WQV is defined as the volume of storm water runoff to be treated by a particular BMP. For Caltrans, the calculation of the WQV is prescribed in its Statewide Storm Water Management Plan (Caltrans, 2001c). The Caltrans sand filter pilot projects were designed with an 18 inch sand bed thickness and a basin draw down time of 2 days. The sizing of the filter bed for the full and partial sedimentation designs is based on an assumed hydraulic conductivity of the sand media. The values in the Austin design guidelines specify 3.5 ft/d for full sedimentation design and 2.0 ft/d for partial sedimentation design. These values were decided administratively and larger values have been observed in the field. The lower value was selected for the partial sedimentation to increase filter area and reduce maintenance frequency.

CONSTRUCTION COSTS

The actual costs; WQVs; and the costs per WQV for each study site is presented in Table 2. The actual cost listed in Table 2 represents the total construction cost of each site less monitoring costs. The monitoring costs include any equipment; construction materials; and labor related to water quality monitoring. Actual costs do not include any land acquisition costs.

Table 2. Comparison of Construction Costs

Site No.	Sand Filter Type	Pilot Project	Actual Cost	WQV m^3	Cost/WQV
1	(CFSF) Concrete-boxed Full Sedimentation	Southern California	$225,000[a]	286	$787
2	(CFSF) Concrete-boxed Full Sedimentation	Southern California	$212,000[a]	106	$1,997
3	(EPSF) Earthen Embankment Partial Sedimentation	Northern California	$129,000	319	$404
4	(EFSF) Earthen Embankment Full Sedimentation	Northern California	$156,000	270	$576

[a] Source: Caltrans, 2001a.

The cost per WQV for the EFSF system is less than the cost per WQV for the CFSF systems, as expected. Additionally, the cost per WQV for the EPSF is less then the cost per WQV for the CFSF systems and the EFSF system. The earthen sand filters provide a reduction in capital costs provided a site has sufficient space. The maintenance costs associated with the earthen sand filters are still under investigation in the Northern California pilot project. At the completion of this project, the maintenance costs documented in the Southern California pilot project will be compared to the maintenance costs documented in the Northern California pilot project.

MONITORING METHODOLOGY

The monitoring season for the Northern California pilot project is defined as October 1 through April 15. Weather forecasts are tracked and documented throughout the entire monitoring season. Storm events monitored were based on rain events forecasted to deposit at least 0.20 in of rain and were to be preceded by at least 24 hours, preferably 72 hours, of dry conditions. The number of successfully sampled storms targeted at each test site was eight.

The minimum constituent list for water quality monitoring is described in the *Caltrans Guidance Manual: Storm Water Monitoring Protocols* (Caltrans, 2000). Iron was added to the list of constituents to be analyzed for the Mountain Gate and Mount Shasta sites. Table 3 summarizes the constituents selected for analysis along with the required analytical procedure.

Table 3. List of Analytes

Conventionals			**Nutrients**			**Metals (Total and Dissolved)**		
Analyte	**Analytical Procedure**	**Reporting Limits**	**Analyte**	**Analytical Procedure**	**Reporting Limits**	**Analyte**	**Analytical Procedure**	**Reporting Limits**
Hardness as $CaCO_3$	EPA 130.2	1 mg/L	Ammonia	EPA 350.3	0.1 mg/L	Arsenic	EPA 206.3	0.5 µg/L
TDS	EPA 160.1	1 mg/L	Nitrate as Nitrogen	EPA 300.0	0.1 mg/L	Cadmium	EPA 200.8	0.2 µg/L
TSS	EPA 160.2	1 mg/L	TKN	EPA 351.3	0.1 mg/L	Chromium	EPA 200.8	1 µg/L
Conductivity	EPA 120.1	0.1 µmhos/cm	Total Phosphorus	EPA 365.2	0.03 mg/L	Copper	EPA 200.8	1 µg/L
Temperature	EPA 170.1	0.1 °C	Dissolved Ortho-Phosphorus	EPA 365.2	0.03 mg/L	Iron	EPA 236.1	25 µg/L
pH	EPA 150.1	0.1 units				Lead	EPA 200.8	1 µg/L
TOC	EPA 415.1	1 mg/L				Nickel	EPA 200.8	2 µg/L
DOC	EPA 415.1	1 mg/L				Zinc	EPA 200.8	5 µg/L

For the Southern California pilot project, the water quality monitoring is complete. The minimum list of constituents presented in Table 3 was also applied to the Southern California pilot project. However, iron was not included.

PRELIMINARY RESULTS FOR THE NORTHERN CALIFORNIA PILOT PROJECT

For the Northern California pilot project, water quality monitoring began shortly after the completion of construction and installation of the monitoring equipment at Site 3 (the EPSF system), which occurred on January 18, 2002. The construction of the sand filter at Site 4 (the EFSF system) was completed in May 2002, thus no monitoring was conducted for the first monitoring season. To date, the number of storms successfully monitored at Site 3 (the EPSF system) is XXX. Additionally, the number of storms successfully monitored at Site 4 (the EFSF system) is XXX.

Table 4 presents: (1) the mean of the Event Mean Concentrations (EMCs) to date; (2) the preliminary EMC removal efficiencies; (3) the influent and effluent loads to date; and (4) preliminary load removal efficiencies. Due to the limited number of storms monitored at Site 4 (the EFSF system), all influent and effluent data from the two sand filter sites have been combined in Table 4. For example, the Influent Mean EMC for TSS represents the mean of the calculated TSS EMCs for both Site 3 (the EPSF system) and Site 4 (the EFSF system). In reporting the EMC values, the value of the reporting limit was used in cases where an analyte was reported as undetected. Negative values indicate increases in concentration or load. The influent and effluent loads were computed using the mean of the EMCs and the influent and effluent volumes.

Table 4. Pollutant Removal and Load Removal for Selected Constituents

Constituent	Influent Mean EMC	Effluent Mean EMC	EMC Removal	Influent Load kg/yr	Effluent Load kg/yr	Load Removal
TSS	34.4 mg/L	10.8 mg/L	69%	717.1	141.8	80%
NO3-N	0.61 mg/L	1.27 mg/L	-108%	12.7	16.7	-31%
TKN	1.30 mg/L	0.50 mg/L	62%	27.1	6.6	76%
Total N	1.91 mg/L	1.77 mg/L	7%	39.8	23.2	42%
Phosphorus	0.10 mg/L	0.05 mg/L	50%	2.1	0.7	69%
Ortho-Phosphate	0.03 mg/L	0.02 mg/L	33%	0.63	0.26	58%
Total Cu	8.4 µg/L	3.3 µg/L	61%	0.18	0.04	75%
Total Pb	1.93 µg/L	1.03 µg/L	47%	0.04	0.01	66%
Total Zn	62.5 µg/L	5.2 µg/L	92%	1.30	0.07	95%
Dissolved Cu	3.58 µg/L	2.3 µg/L	36%	0.07	0.03	60%
Dissolved Pb	1.0 µg/L*	1.0 µg/L*	0%	0.02	0.01	37%
Dissolved Zn	26.93 µg/L	6.64 µg/L	75%	0.56	0.09	84%

* - Reporting Limit

PERFORMANCE COMPARISON FOR THE TWO SAND FILTER PILOT PROJECTS

As previously mentioned, the Southern California pilot project investigated the use of two CFSF systems. The Northern California pilot project investigated alternative construction materials and an alternative design from the two initial CFSF systems with the objective of reducing construction costs while maintaining the water quality performance. In the previous section, the influent and effluent water quality data was used to assess the preliminary water quality performance of the Northern California sand filters. In this section, the influent and effluent water quality from each Northern California sand filter is compared to the influent and effluent water quality from the Southern California sand filters. This comparison was made to assess if the North California sand filters can perform similarly to the Southern California sand filters. Specifically, does the partial sedimentation sand filter design perform similarly to the full sedimentation sand filter design. Again, the EPSF system provides a sand filter that is smaller and cheaper to construct than the CFSF systems.

Figures 4 and 5 provide a preliminary comparison between the Northern California sand filters and the Southern California sand filters for Total Suspended Solids (TSS) and Total Kjeldhal Nitrogen (TKN). The final report for the Northern California pilot project will provide comparisons for all the

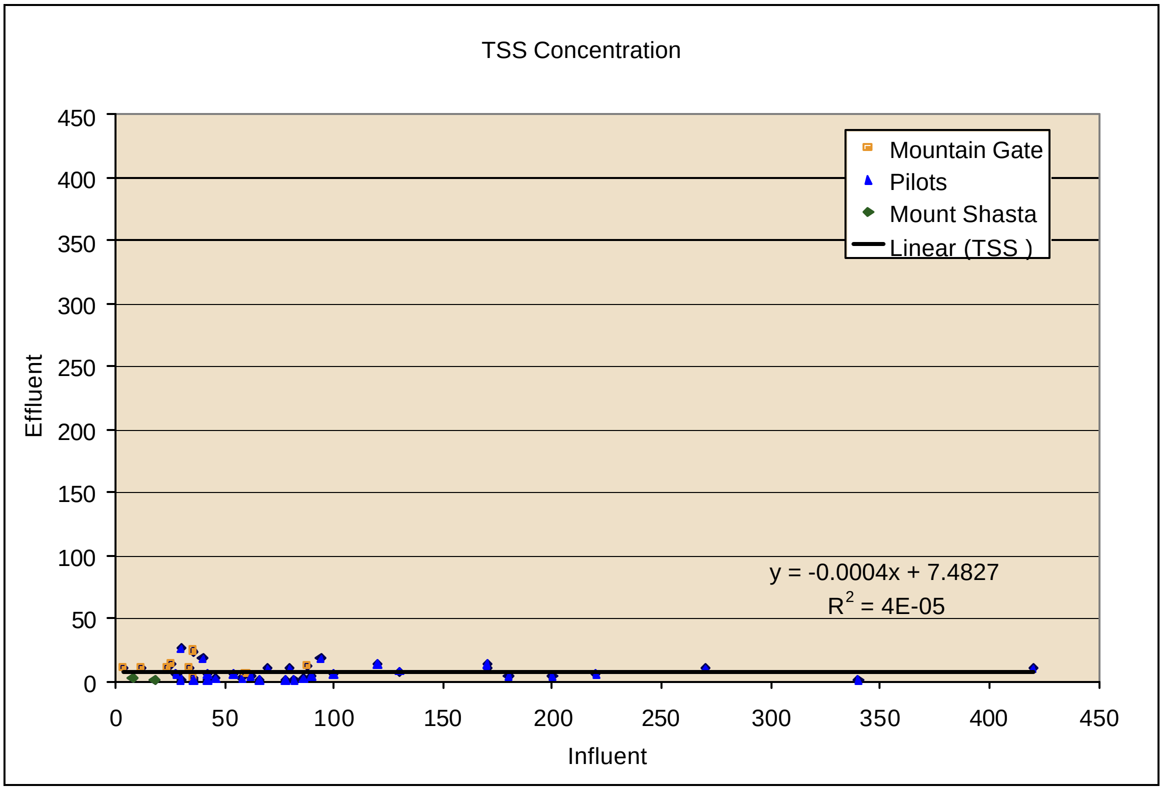

Figure 4. TSS Effluent Concentration Comparison

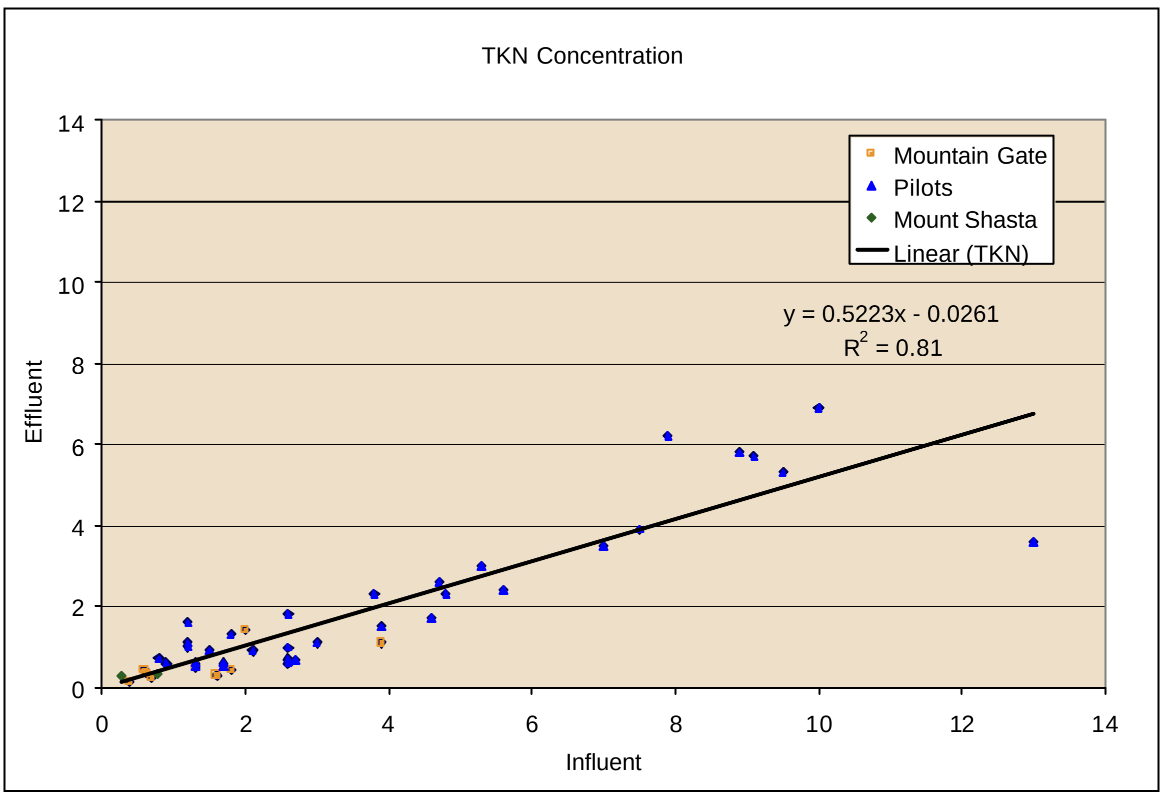

Figure 5. TKN Effluent Concentration Comparison

constituents identified in Table 3. Each figure contains four series of data. The first series of data, Sites 1 and 2 – So CA, represents all the influent and effluent constituent data collected from the two sand filters in the Southern California pilot project. The second series of data, Site 3 – No CA, represents the influent and effluent constituent data collected from the EPSF system. The third series of data, Site 4 – No CA, represents the influent and effluent constituent data collected from the EFSF system. A linear regression analysis was conducted on the constituent data from all four sand filter sites. The fourth series of data represents the linear trend line for all the constituent data.

Figure 4 presents the effluent TSS concentration as a function of influent TSS concentration. The trend line shown in the figure is flat. The trend line indicates that regardless of the influent TSS concentration, the effluent TSS concentration will remain constant. From Table 4, the effluent TSS concentration is approximately 11 mg/L. The sand filters seem to produce a consistent effluent TSS concentration regardless of the influent TSS concentration. Additionally, the range of TSS effluent values from the Northern California sand filters lies within the range of TSS effluent values from the Southern California sand filters. Figure 5 presents the effluent TKN concentration as a function of influent TKN concentration. Unlike the TSS performance, the effluent TKN concentration increases as the influent TKN concentration increases. However, similar to the TSS performance, the range of TKN effluent values from the Northern California sand filters lies within the range of TKN effluent values from the Southern California sand filters.

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