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BOEING

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October 24, 2006

Regional Water Quality Control Board
320 West 4th Street, Suite 200
Los Angeles, CA 90013

Attention: Mr. Jonathan Bishop

Subject: R2-A Pond Filtration Pilot Test Report for the
Santa Susana Field Laboratory, Ventura County, CA

Dear Mr. Bishop:

As noted in the October 2, 2006 report sent to your agency on the Best Management Practices (BMP) underway at the Santa Susana Field Laboratory, the Boeing Company (Boeing) performed a pilot study to determine removal efficiencies of various filter media. The enclosed report contains the results of this study.

If there are questions pertaining to this report or the status of the program, please contact Paul Costa of my staff at (818) 466-8778.

Sincerely,

Tom Gallacher, Director
SSFL – Safety, Health & Environmental Affairs
Shared Services Group

Enclosure: SSFL R2-A Pond Filtration Pilot Test Report

cc: David Hung, RWQCB-LA
Cassandra Owens, RWQCB-LA

SHEA-104434

R2-A POND FILTRATION PILOT TEST REPORT

FOR

SANTA SUSANA FIELD LABORATORY

Prepared for:

THE BOEING COMPANY
SANTA SUSANA FIELD LABORATORY

Prepared by:

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October 2006

DRAFT

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1.0. EXECUTIVE SUMMARY

The R2-A Pond Filtration pilot test evaluated the constituent removal capabilities of 8 different filtration media. The filtration media included sand (coarse and fine), vermiculite, perlite, zeolite, activated carbon, barley straw, peat moss and leaf compost. Pond water was used as a proxy for storm water in order to facilitate testing during the summer of 2006. While pond water differed from storm water with respect to suspended sediment loadings, biological populations, dissolved metal concentrations and flow rate characteristics, the pilot test provided controlled, steady-state, onsite conditions to evaluate pollutant removal effectiveness of a variety of filtration media.

Clogging was a major maintenance concern and resulted in periodic replacement of the filter media. Volatile suspended solids concentrations and field observations indicated that algae in the pond was an important factor in filter media clogging. Sand and peat moss experienced the most frequent clogging events, while vermiculite and perlite experienced the least.

Metals concentrations that were significantly reduced by the filtration media included total copper, total iron, total lead and total manganese. Activated carbon, sand and zeolite were effective at removing total copper with 65%, 63% and 52% average removal, respectively. Two of the activated carbon effluent samples showed nondetect values for total copper, implying that higher percentage removals might have been possible with higher influent concentrations. Sand and activated carbon were most effective at removing total lead with 78% and 74% average removal efficiency, respectively. Two sand effluent samples demonstrated lead removal down to nondetect levels. Sand, zeolite and activated carbon removed total iron by 60-80% and total manganese by 50-70%. Sand, vermiculite, perlite, zeolite, leaf compost and activated carbon filter drums all removed total zinc to concentrations at or close to the detection limit, with removal percentages ranging from 73%-83%.

More than 50% total suspended solids (TSS) removal was achieved by almost all filtration media. Sand, activated carbon, zeolite and leaf compost in particular reduced TSS concentrations to nondetect levels on a consistent basis. Over the course of the pilot test, vermiculite, perlite and barley straw removed approximately 2 kg TSS per ft^3 filter media. Zeolite, activated carbon and leaf compost removed approximately 1 kg TSS per ft^3 media. Sand and peat moss removed less than 0.5 kg TSS per ft^3 media.

TCDD Toxicity Equivalence Quotient (TEQ) data showed that zeolite, activated carbon and peat moss can provide roughly 52-98% reductions in TCDD TEQ concentrations. Sand also removed TCDD TEQ with similar effectiveness for two of three sampling events, but exhibited concentrations much higher than influent TCDD TEQ concentrations on the third sampling event.

A multi-layered filtration configuration was recommended in order to maximize effectiveness by utilizing multiple pollutant removal mechanisms. A top filtration layer of sand or perlite would utilize physical straining to remove suspended solids. Dissolved organics and metals could be reduced with layers of activated carbon and zeolite. While results from the pilot test have and will continue to drive implementation of Best Management Practice (BMP) upgrades, filtration media selection will ultimately be driven by in-field filtration effectiveness and hydraulic performance under real storm water conditions.

2.0. INTRODUCTION

The Boeing Company (Boeing) is committed to implementing an iterative Best Management Practice approach to pursue surface water discharge compliance objectives defined by their NPDES permit obligations for the Santa Susana Field Laboratory (SSFL) site. This approach was described in the 13267 Technical Report, submitted by Boeing to the Regional Water Quality Control Board (RWQCB) on December 16, 2005 (Boeing 2005). Using a BMP approach, Boeing is monitoring BMP performance and aggressively upgrading existing BMPs.

Successful design and upgrade of BMPs depends on a sound scientific basis. There is little information available on the ability of BMP technologies to treat storm water to levels that consistently meet effluent limits established in the SSFL NPDES permit. In addition, BMP performance is generally very site specific based on hydrologic and storm water constituent characteristics. Among available BMP technologies, direct filtration appears to be the most promising. Some case studies using various filter media have shown substantial reductions in metals and organics concentrations, which have occasionally exceeded Water Quality Based Effluent Limits (WQBELs) in the NPDES permit (US EPA, 1999).

The purpose of the R2-A Pond filtration pilot test was to determine which filtration media are most effective at reducing regulated constituents utilizing available onsite surface water and to determine design parameters for full-scale systems using such filter media. The pilot test evaluated the constituent removal capabilities of 8 different filtration media. Instead of waiting for storms to occur, the filtration media were tested using R2-A pond water as a surrogate for storm water during the summer of 2006. A Pilot Testing Plan was described in the BMP Effectiveness Sampling Work Plan (MWH, 2006) and submitted to the RWQCB on October 1, 2006 as part of an annual BMP implementation report.

Since storm water flows typically occur only 5-10 times per year in Southern California, the pilot test provided additional data on filtration system pollutant removal efficiencies under controlled, steady-state conditions. Since data was gathered over the dry season, preliminary data from the pilot test was used to help design SSFL BMP upgrades before the start of the 2006-2007 rainy season. Results from the pilot test have not only been used in designing the 2006 BMP upgrades, but will continue to be a key driver in implementation of BMP upgrades into the future. This report summarizes the methods, results and conclusions from the pilot test.

2.1. R2-A Pond Background

The R2-A pond is an approximately 2.5 million gallon pond located at Outfall 018. **Figure 1** shows a picture of the pond. The primary source of water stored in the pond comes from storm water. While the R2-A pond was part of a water reclamation system in the past, it is currently used as a storm water reservoir to minimize discharges. The pond is aerated daily to support fish communities that reside in the pond.

2.2. General Process Description

The filtration pilot test was designed by MWH and constructed by Boeing personnel with MWH oversight. MWH also provided operational oversight throughout the duration of the pilot test, which lasted from 7/17/06 to 9/14/06. **Figure 2** shows the experimental layout of the filtration pilot test. **Figure 3** shows pictures of the pilot test.

A submersible pump, located approximately 3 feet from the edge of a pier, pumped water from R2-A pond to provide the influent for the filtration pilot test. Two parallel, 0.13 inch pore size Y-strainers and a system of polyester felt bag filters served to minimize the potential for debris and large sediments from entering the system. Water was then pumped to a 9-foot tall standpipe to provide the necessary head to sustain consistent flow through the filters. Water that overflowed over the 9-foot tall standpipe emptied into a 12 inch diameter, high density polyethylene overflow drain that led back to the pond’s surface. The water in the standpipe flowed by gravity to the filter drums. Influent was uniformly distributed out of a flow spreading manifold into each of the parallel in-line 55 gallon filter drums.

The filtration media used included:

- Sand
- Vermiculite
- Perlite

- Zeolite
- Activated carbon
- Barley straw
- Peat moss
- Leaf compost

After percolating through the media, the water flowed by gravity to an outlet pipe that returned the filtered water back to the pond's surface. Inlet and outlet ball valves and flow meters controlled and monitored flow rates at each filter drum so that contact times would be fairly consistent between media.

3.0. EXPERIMENTAL SETUP

3.1. Pump and Pretreatment System

The submersible pump (Goulds Submersible Sewage Pump, 1 horsepower, 3450 rotations per minute (RPM), 460V, 3-Phase) was attached to a stainless steel manifold consisting of 2-inch diameter pipe with eight 4-inch diameter intakes in order to reduce the water intake velocity. A picture of the manifold and pump are shown in **Figure 4**. The pump and manifold were suspended by a boom so that the manifold was 4 feet under the surface of the pond (approximately 6 feet and 3 inches from the bottom).

The pretreatment system consisted of two PVC Y-strainers (Spears, mesh size 6 PVC screen with EPDM (Ethylene Propylene Diene Monomer) Seals) and two polyester felt bag filters (Knight Corporation, stainless steel bag housings, 2 inch diameter inlet and outlet) as seen in **Figure 5**. The filter bags were initially placed in parallel, but were later placed in a series configuration in order to increase suspended solids removal and reduce filter media clogging. A variety of filtration ratings were used in order to optimize pretreatment solids removal. **Section 4.3 Bag Filter Operation** contains more details on how the bag filters were operated.

3.2. Filter Drums

Each filtration medium was contained in separate 55-gallon polymer drums. **Figure 6** shows a conceptual profile of a filter drum. Water entered the drum through a PVC flow spreading manifold which consisted of a 1-inch diameter PVC tee with 1/8 inch drilled perforations as seen in **Figure 7**. The underdrain had four 4-inch tall PVC pipe supports at the bottom of each filter drum. This held a 1-inch tall high-strength grit-top fiberglass bar grating which provided structural support for a 40 x 40 mesh, stainless steel woven wire cloth (McMaster-Carr, 0.010 inch wire diameter). A 1-inch thick PVC ring held the stainless steel woven wire cloth flush against the edges of the drum to avoid media leakage. The underdrain supported 1.5 feet of media or approximately 27 gallons.

A woven geotextile material (Mirafi, Filterweave 500, 500 mesh) held in place with a 1-inch thick PVC ring was used to keep buoyant filter media from floating up. A 2-inch diameter, clear PVC air release pipe attached to the top of each filter drum provided pressure release. Water rose in the air release pipes to the head necessary to overcome head losses in the media at the desired flow rate and retention time. A level control float switch (Cole Palmer, standard polypropylene float switch) that was attached to the top of the air release pipe shut the pump off when water reached the top of the pipe, thereby preventing overflow. Each drum was placed on top of a spill palette to contain any liquid from spills. A pressure gauge (Dwyer instruments, Range: 0-60 inches of head) was connected to each 2-inch outlet pipe to measure pressure head. Each filter drum had an effluent flow meter (Blue-white F-1000 series in-line, rate/totalizer digital flow meter, 1-inch diameter) in order to monitor and control flow rates through each filter drum. One outlet sample port was located in the outlet pipe after each filter media for effluent water sample collection. Effluent samples were taken via ¾ inch plastic tygon tubing and a ball valve as seen in **Figure 8.**

3.3. Filtration Media

Table 1 displays photos, specifications and expected pollutant removal capabilities for each filtration media. Material Safety Data Sheets (MSDS) for sand, vermiculite, perlite, zeolite, activated carbon and leaf compost and a technical data sheet for peat moss can be found in a separate attachment.

Table 1
Filtration Media Specifications

Filter Media	Picture	Description	Media Size	Expected Pollutant Removal Capabilities
Sand (fine)[1]		Silica-based clean, washed sand.	0.45-0.55 mm	Total suspended sediments (TSS), turbidity
Sand (coarse)[1]		Silica-based clean, washed sand.	1 mm	TSS, turbidity
Vermiculite[2]		Naturally occurring non-toxic mineral that expands with heat, creating a high internal porosity that enhances fine particle removal.	2-4 mm	TSS, oil and grease
Perlite[3] (Horti-Perl #4)		Naturally occurring siliceous puffed volcanic ash made of a porous, rough edged, and multi-cellular structure.	2-5 mm	TSS, oil and grease
Zeolite[4] (Z-200)		Naturally occurring potassium-calcium-sodium aluminosilicate mineral impregnated with hexadecyl trimethylammonium chloride	1.1-2.5 mm	Soluble metals, ammonium, oil and grease, and some organics

Filter Media	Picture	Description	Media Size	Expected Pollutant Removal Capabilities
Activated Carbon[4]		Virgin coconut shell carbon. High internal porosity particle structure for adsorption of a wide range of low and high molecular weight impurities.	2 - 3 mm 8x30 mesh	Organics, oil and grease
Barley Straw[5]		Naturally occurring dried barley stalks.	-----	TSS, metals, dissolved organics, oil and grease
Peat Moss[6] (PRO Moss-TBK)		Sphagnum peat moss. Naturally occurring mix of growing vegetative matter, decayed vegetative matter and peat.	0.14-1.9 mm	Organics, soluble metals, nitrogen
Leaf Compost[7] (Metals RX Media)		Granular media processed from deciduous leaves	2-5 mm	Soluble metals, suspended sediments, oil and grease

[1] Provided by George L. Throop Company.
[2] Provided by Therm-O-Rock West, Inc.
[3] Provided by Redco II
[4] Provided by Baker Filtration
[5] Provided by Still Pond Farms
[6] Provided by Premier Horticulture
[7] Provided by Contech Stormwater Solutions.

4.0. OPERATION

4.1. Flow Operation

After operation began on July 17th, the pilot test remained running for 24 hours a day 7 days a week through September 14th except when replacing filter media, replacing bag filters or conducting other maintenance activities. The filtration pilot test was manned for approximately 8 hours a day on weekdays and 4 hours a day on weekends. Flow rates and flow totals were monitored and logged multiple times a day in order to retain steady state operation.

Flow rates for each filter drum were initially adjusted to 2.0-3.0 gallons per minute (gpm) in order to maintain equivalent empty bed contact times of 9-13 minutes across the different media. Empty bed contact time is the time required for the water to pass through the filter media and is equal to the volume of media divided by the flow rate. The 9-13 minute contact time was chosen to allow for effective removal of metals and organic constituents according to manufacturer specifications.

Clogging of some filtration media reduced flow rates below 2.0 gpm until the filtration media was replaced. At times, filter drums would be allowed to run for multiple days at flow rates below 2.0 gpm in hopes of achieving pollutant breakthrough. Pollutant breakthrough occurs when the filter media has exceeded its capacity to remove the pollutant and the filter influent concentration becomes equal to the filter effluent concentration.

Figure 9 shows the weekly average flow rates for each media over the course of the pilot test. Weekly average flow rates were calculated by subtracting the total flow volume between sampling events and then dividing by the total time of operational flow between sampling events for each filter drum. Time of operational flow was calculated for each filter drum by taking the total time between weekly sampling events and subtracting any time when no flow occurred, including maintenance, filter media changing, pump shut off, etc.

As seen in **Figure 9**, flow rates remained within the 2.0-3.0 gpm flow range for the first week. The fine sand and peat moss filter drums exhibited lower flow rates from 7/24/06 – 8/3/06 due to filter media clogging. Clogging of the barley straw, peat moss and leaf compost occurred between 8/3/06 and 8/10/06. Visual observations indicated that both the peat moss and leaf compost had degraded under continuous flow conditions, causing frequent clogging as seen in **Figure 10**.

The peat moss and leaf compost were operated on a “Wet-Dry cycle” in order to avoid further degradation of filtration media. During all unmanned hours after 8/8/06, flow to the leaf compost and peat moss drums were shut off and the filter drums were emptied of water. The wet-dry cycle more closely reflected actual storm water treatment conditions since storm water flows are intermittent at the Outfalls, with flows tending to last for a period of hours.

During 9/6/06-9/14/06, no filter media was changed and flow rates were intentionally held at low levels in hopes of achieving pollutant breakthrough for some filter drums by the end of the pilot test.

4.2. Filter Media Replacement

As filters became clogged over time, pressures losses increased and flow rates dropped dramatically. Filter media was removed until it met two criteria: 1) there was no visible indication of suspended sediment loadings in the media and 2) flow through the filter drum could resume at least a 2.0 gpm flow rate. Thus, in a typical filter media replacement, the top six inches of media were first removed. If suspended sediment loadings were seen within the media or flow through the media could not resume at least a 2.0 gpm flow rate due to clogging, another six inches of media was removed. After this point, if suspended sediment loadings were still seen within the media or if the filter drum could not resume a 2.0 gpm flow rate, all filter media was removed. The volume of filter media that was removed was then replaced with new media.

Figure 11 shows a picture of clogged activated carbon and the new activated carbon that replaced it.

Date and time of media replacement, quantity of media replaced and total flow volume at the time of replacement for each filtration media are included in **Table 2.**

Table 2

Filtration Media Replacement

Media	Date	Total Flow Volume (gallons)	Material and Quantity Replaced With
Sand (fine)	7/24/06	18,294	Replaced top 6 inches of media
Sand (fine)	7/28/06	26,090	Replaced top 12 inches of media
Sand (fine)	8/1/06	30,122	Replaced top 3 inches of media
Sand (fine)	8/7/06	33,105	Replaced all media
Sand (fine and coarse)	8/14/06	47,480	Removed top 9 inches of media and replaced with 9 inches of coarse media
Sand (fine and coarse)	8/21/06	57,755	Removed all media and replaced with 12 inches of fine sand and 6 inches of coarse sand
Sand (fine and coarse)	8/31/06	76,910	Removed all media and replaced with 12 inches of fine sand and 6 inches of coarse sand
Sand (fine and coarse)	9/12/06	102,458	Removed all media and replaced with 12 inches of fine sand and 6 inches of coarse sand
Vermiculite	8/21/06	120,204	Replaced all media
Perlite	8/21/06	114,751	Replaced all media
Zeolite	7/28/06	34,021	Replaced top 12 inches of media
Zeolite	8/15/06	70,428	Replaced all media
Zeolite	8/31/06	129,434	Replaced all media
Activated Carbon	7/24/06	22,213	Replaced top 12 inches of media
Activated Carbon	8/1/06	44,963	Replaced all media
Activated Carbon	8/14/06	76,751	Replaced top 11 inches of media
Activated Carbon	8/28/06	102,456	Replaced all media
Activated Carbon	9/8/06	129,657	Replaced all media
Barley Straw	8/8/06	62,633	Replaced all media
Peat Moss	7/28/06	34,175	Replaced all media
Peat Moss	8/1/06	37,545	Replaced all media
Peat Moss/Perlite	8/7/06	39,947	Removed all media and replaced with 50% peat moss 50% perlite mixture by volume
Peat Moss/Perlite	8/21/06	47,360	Removed all media and added 35% peat moss 65% perlite mixture by volume
Leaf Compost	7/28/06	31,978	Replaced all media
Leaf Compost	8/7/06	51,206	Replaced all media

The filtration medium composition was changed for two filter drums due to frequent media clogging. After the fine, 0.45-0.55 mm sand continued to clog frequently, the top 9 inches of the fine sand was replaced with 9 inches of coarser sand (1 mm diameter) on 8/14/06. Peat moss also yielded low flow rates. Small-scale jar tests confirmed that when peat moss was continuously wet, it had a muddy, gelatinous consistency which caused poor hydraulic performance. Peat moss was later supplemented with perlite in a mixture that contained equal parts peat moss and perlite by volume. This was later changed to a 35% peat moss 65% perlite mixture in order to further improve hydraulic performance. The mixture was intended to retain the cationic exchange capacity and metals removal capabilities of the peat moss while utilizing the structure of the perlite to improve hydraulic performance.

Figure 12 shows the average flow volume treated per clogging event. It is calculated by taking the total flow volume in gallons from the last media replacement event and dividing by the total number of media replacement events. It should be noted that different quantities of media were removed during each media replacement event.

Vermiculite and perlite, which both experienced only one media replacement event throughout the pilot test, had the highest amount of flow volume treated per media replacement event. Sand, which had the highest number of media replacement events, treated approximately 12,800 gallons flow volume per clogging event. Even though peat moss only had 4 media replacement events throughout the pilot test, it also had the lowest total flow volume. The average amount of flow per media replacement event was correlated with suspended solids removal effectiveness. The filtration media with higher suspended solids removal effectiveness generally experienced more frequent clogging.

After filtration media was removed due to clogging, a composite sample was analyzed for Title 22 metals, fish bioassay, Toxicity Characteristic Leaching Procedure (TCLP) and Soluble Threshold Limit Concentration (STLC). The TCLP is a procedure developed by the US Environmental Protection Agency (EPA) that determines toxicity by measuring the concentrations of both organic and inorganic contaminants that may be present in the leachate of waste. The STLC is analyzed through a leaching procedure developed by the California Department of Toxic Substances Control. This procedure also determines toxicity by simulating landfill leaching, but uses a slightly more aggressive leaching agent than the TCLP. Using these results, the filter media was classified as nonhazardous waste and will be managed and disposed of accordingly.

4.3. Bag Filter Operation

Two 100-micron bag filters were initially placed in a parallel configuration. A series configuration was later used in order to capture more solids in the bag filters and minimize suspended solids loadings to the filter drums to reduce clogging. The pump was shut off for approximately 5-10 minutes to replace the bag filters when the bag filters were in series configuration.

Pressure drop across the bag filter was monitored and bag filters were changed out when the pressure drop exceeded 15 psi. **Table 3** describes the different bag filter configurations used throughout the pilot test and the average number of days before a filter bag replacement was needed. It also shows the average number of days and the average total gallons of flow volume that occurred between sand media replacement events in order to show how bag filters with smaller filtration ratings extended the life of some media.

Table 3
Bag Filter Operation

Date Start	Date End	Configu-ration	Bag Filter Micron Rating	Bag Filter Micron Rating	Average Days/ Filter Bag Replacement	Average Days/Sand Media Replace-ment	Average Gallons Flow Volume/ Sand Media Replacement
7/18/06	8/10/06	Parallel	100	--	5.8	5.8	10,776
8/11/06	8/18/06	Series	100	50	3.5 (both)	7	12,687
8/18/06	8/29/06	Series	50	10	3.7 (50 micron) 1.1 (10 micron)	11	19,135
8/30/06	9/14/06	Series	25	10	0.7 (both)	8	15,182

4.4. Influent Particle Size Analysis

Samples taken from the bag filter influent (PT-INF2) and bag filter effluent (PT-INF) on 7/31/06 were analyzed for grain size distribution in order to evaluate and optimize bag filter performance and select appropriately sized filter bags.

Samples were also taken for all constituents analyzed in the filtration pilot test beginning on 8/3/06. Since the two strainers were in parallel configuration, at least one strainer was always not in use. The strainer and cap to the unused strainer was removed and samples were taken directly from the strainer's bottom. The sampling location is shown in **Figure 15** above. The results from the grain size distribution analysis are shown in **Figure 13** and **Figure 14.**

Median particle size for the bag filter influent was 20 microns. Median particle size for the bag filter effluent was 15 microns. At the time of the sample, flow was being pumped through one 100-micron filter bag. Although the 100-micron filter bag appeared to be effective at removing the vast majority of particles above 100 microns, the large majority of influent particles had diameters of less than 100 microns and were passing through the filter bag. After receiving the data, 10-micron filter bags were ordered in order to further reduce solids loading to the filtration system and reduce clogging. Grain size samples were also taken on 8/2/06, 8/9/06 and 8/10/06 for grain size analysis, but lens obscuration was too low so grain size distribution could not be reported accurately.

Samples taken on 8/9/06 and 8/10/06 of the bag filter influent and effluent showed that 39%-50% of the suspended solids from the bag filter influent consisted of volatile suspended solids. The high fraction of organic suspended solids, in conjunction with the greenish-brown color of the solids that was observed to accumulate on the spent bag filters, imply that the volatile suspended solids likely come from algae in the pond. Although high algae content in the pond may have accelerated clogging in the filter media for the pilot test, algae will not be present in such high concentrations under storm water conditions.

4.5. Sampling of Filter Drums

Periodic samples were taken from each filter's influent and effluent to measure the level to which different filter media could reduce constituent concentrations. **Figure 15** shows the sampling locations and sampling nomenclature.

Samples were taken once a day for the first 4 days and approximately once per week thereafter. Due to their high cost, TCDD samples were taken on 7/18/06, 8/3/06 and 9/14/06.

Table 4 lists the sample dates.

Table 4
Sampling Dates

	Sampling Date
1	7/18/06 [1]
2	7/19/06
3	7/20/06
4	7/21/06
5	8/3/06 [2]
6	8/10/06
7	8/17/06 [1]
8	8/24/06
9	8/31/06
10	9/6/06
11	9/14/06 [1]

[1] TCDD samples taken.
[2] No samples taken from sand and activated carbon media due to clogging.

Table 5 lists the constituents that were analyzed for each sample and the corresponding SSFL NPDES daily maximum permit limit. Since daily maximum permit limits differ by outfall, the lowest daily maximum permit limits across all outfalls are listed below.

Table 5
Constituents Analyzed

Constituent Analyzed	Daily Maximum Permit Limit	Units
ORGANICS		
TCDD TEQ	2.80E-08	µg/L
Oil and Grease	15	mg/L
Total Organic Carbon	--	mg/L
INORGANICS		
Ammonia-N	10.1	mg/L
Nitrate-N	8	mg/L
Nitrite-N	1	mg/L
Nitrate + Nitrite -N	8	mg/L
Total Kjeldahl Nitrogen	--	mg/L
Sulfate	300	mg/L
METALS		
Antimony, Total	6	µg/L
Antimony, Dissolved	--	µg/L
Arsenic, Total	10	µg/L
Arsenic, Dissolved	--	µg/L
Beryllium, Total	4	µg/L
Beryllium, Dissolved	--	µg/L
Cadmium	3.1	µg/L
Cadmium, Dissolved	--	µg/L
Chromium, Total	16.3	µg/L
Chromium, Dissolved	--	µg/L
Copper, Total	14	µg/L
Copper, Dissolved	--	µg/L
Iron, Total	0.3	mg/L
Iron, Dissolved	--	mg/L
Lead, Total	5.2	µg/L
Lead, Dissolved	--	µg/L
Manganese, Total	50	µg/L
Manganese,Dissolved	--	µg/L
Mercury, Total	0.1	µg/L
Mercury, Dissolved	--	µg/L
Nickel, Total	96	µg/L
Nickel, Dissolved	--	µg/L
Selenium, Total	5	µg/L
Selenium, Dissolved	--	µg/L
Silver, Total	4.1	µg/L
Silver, Dissolved	--	µg/L
Thallium, Total	2	µg/L
Thallium, Dissolved	--	µg/L
Zinc, Total	119	µg/L

Constituent Analyzed	Daily Maximum Permit Limit	Units
Zinc, Dissolved	--	μg/L
OTHER		
Density	--	g/cc
Constituent Analyzed	**Daily Maximum Permit Limit**	**Units**
Suspended Sediment Concentration	--	mg/L
Total Suspended Solids	45	mg/L
Turbidity	--	NTU
Total Dissolved Solids	850	mg/L
Alkalinity	--	mg/L
Conductivity	--	umhos/cm
Hardness	--	mg/L

Table 6 lists the analytical methods that were used for each constituent.

Table 6
Analytical Methods

Constituent	Test Method	Bottle Type (# of Bottles)	Preservative	Holding Time
Metals (total and dissolved)	200.8 or 6020	500 Milliliter (ml) Poly	Nitric Acid (HNO_3)	6 months
Mercury	245.1 or 7470A			28 days
Iron	200.7 or 6010B			6 months
Hardness	130.2			6 months
Dioxin TCDD TEQ	1613	2x1 Liter (L) Ambers	None	1 year
Total Organic Carbon	415.1	3x40 ml VOAs	Hydrochloric Acid (HCl)	28 days
Oil and Grease	413.1	2x1 L Ambers	None	28 days
Total Kjeldahl Nitrogen	351.3	500 ml Poly	Hydrogen Sulfate (H_2SO_4)	28 days
Ammonia-N	350.2			28 days
Nitrate/Nitrite-N	300.0	500 ml Poly	None	48 hours
Sulfate	300.0			28 days
Total Dissolved Solids (TDS)	SM 2540C			7 days
Suspended Sediment Concentration (SSC)	ASTM 3977-1977			7 days
Turbidity	180.1			48 hours
pH	150.1			Immediate
Alkalinity	310.1			14 days
Conductivity	120.1			28 days

4.6. Aeration, Dissolved Oxygen and pH

Redox chemistry and pH are the two primary determinants of chemical composition in natural waters. Water low in pH tends to cause metals to dissolve into solution. Samples from the bag filter influent (PT-INF2) showed pH to remain neutral, fluctuating between 7.8- 8.6. This pH range is consistent with storm water conditions at the SSFL Outfalls.

The redox chemistry of heavy metals is heavily affected by dissolved oxygen (DO) levels. Water low in dissolved oxygen provides a reducing environment which causes metal precipitates to dissolve. The R2-A pond contains a surface aerator to maintain DO levels and support the fish population. The aerator was initially running continuously in order to keep the pond fully aerated. Dissolved oxygen readings were taken periodically from the end of the pier in order to measure the amount of DO stratification. Dissolved oxygen readings showed that DO remained above 5 mg/L with aeration from 8pm-6am and even at 12am-6pm. **Figure 16** shows dissolved oxygen readings throughout the day of 8/18/06. The legend indicates different times when dissolved oxygen readings were taken. The aerator was shut off at 9:21am on 8/16/06.

As seen in **Figure 16**, aeration induces mixing in the pond, causing DO to be almost constant throughout the pond’s profile at ~8 mg/L. During the daytime, algae in the pond produce oxygen through photosynthesis, increasing the DO concentration near the pond’s surface. High dissolved oxygen levels found in a well-aerated pond more closely mimic the higher dissolved oxygen concentrations typically found in storm water conditions.

4.7. Operation Timeline

Table 7 summarizes sampling events, filter media changing events, aerator operation and filter bag configuration throughout the course of the pilot test.

Table 7
Operation Timeline

	7/17	7/18	7/19	7/20	7/21	7/22	7/23	7/24	7/25	7/26	7/27	7/28	7/29	7/30	7/31	8/1	8/2	8/3	8/4	8/5	8/6	8/7	8/8	8/9	8/10	8/11	8/12	8/13	8/14	8/15
Sampling Events		■	■	■	■			■										■							■					
Aeration Operation																														
Continuous operation		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
8pm-6am operation																														
12am-6am operation																														
Filter Media Changes																														
Sand								■				■				■						■							■	
Vermiculite																														
Perlite																														
Zeolite												■																		■
Activated Carbon								■								■													■	
Barley Straw																							■							
Peat Moss												■				■						■								
Peat Moss:Perlite Mixture Added																						■	■	■	■	■	■	■	■	■
Leaf Compost												■										■								
Wet-Dry Cycle for Leaf Compost and Peat Moss																							■	■	■	■	■	■	■	■
Filter Bag Configuration																														
100 micron, Parallel	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
100 um - 50 um, Series																										■	■	■	■	■
50 um -10 um, Series																														
25 um -10 um, Series																														

	8/16	8/17	8/18	8/19	8/20	8/21	8/22	8/23	8/24	8/25	8/26	8/27	8/28	8/29	8/30	8/31	9/1	9/2	9/3	9/4	9/5	9/6	9/7	9/8	9/9	9/10	9/11	9/12	9/13	9/14
Sampling Events		■				■			■							■						■								■
Aeration Operation																														
Continuous operation		■		■	■	■																								
8pm-6am operation							■	■	■	■	■	■	■	■	■															
12am-6am operation																■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Filter Media Changes																														
Sand						■										■												■		
Vermiculite						■																								
Perlite						■																								
Zeolite																■														
Activated Carbon													■											■						
Barley Straw																														
Peat Moss						■																								
Peat Moss:Perlite Mixture Added	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Leaf Compost																														
Wet-Dry Cycle for Leaf Compost and Peat Moss	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Filter Bag Configuration																														
100 micron, Parallel																														
100 um - 50 um, Series	■	■	■																											
50 um -10 um, Series			■	■	■	■	■	■	■	■	■	■	■	■																
25 um -10 um, Series															■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

5.0. RESULTS AND DISCUSSION

Table 8 presents percentage removal data for all constituents and the number of influent and effluent nondetect values. Results from the fine sand media before 8/14/06 and the fine sand/coarse sand combination after 8/14/06 were presented together as sand. Similarly, results from the peat moss before 8/7/06 and the peat moss/perlite mixture after 8/7/06 are presented together as peat moss. Percent removals were calculated using the following equation.

$$\%\ \text{Removal} = \frac{(C_{\inf} - C_{eff})}{C_{\inf}}$$

where

C_{inf} = PT-INF influent concentration (Bag filter effluent concentration)

C_{eff} = Filter drum effluent concentration

Percentage removals were not calculated for influent concentrations with nondetect values. If the effluent concentration was equal or greater than the influent concentration, then percentage removal was assumed to be 0%. The following sections describe in more detail the removal effectiveness of all filtration media for key constituents.

Table 8
Percentage Removal of all Constituents Analyzed

Analyte	Units	Max Detect Limit	Influent ND's	Sand				Vermiculite				Perlite				Activated Carbon				Zeolite				Barley Straw				Peat Moss				Leaf Compost			
				Avg	Min	Max	ND's	Avg	Min	Max	ND's	Avg	Min	Max	ND's	Avg	Min	Max	ND's	Avg	Min	Max	ND's	Avg	Min	Max	ND's	Avg	Min	Max	ND's	Avg	Min	Max	ND's
Organics																																			
TCDD TEQ (No DNQ)	ug/L	---	1	**75%**	52%	98%	1	**70%**	43%	96%	1	**70%**	45%	95%	1	**74%**	52%	96%	2	**74%**	52%	95%	2	**60%**	25%	96%	0	**75%**	52%	98%	1	**71%**	44%	97%	0
Oil and Grease	mg/L	0.94	11	**22%**	22%	22%	10	**0%**	0%	0%	11	**0%**	0%	0%	10	**22%**	22%	22%	10	**22%**	22%	22%	12	**22%**	22%	22%	11	**22%**	22%	22%	12	**17%**	17%	17%	11
Total Organic Carbon	mg/L	0.5	0	**5%**	0%	29%	0	**1%**	0%	14%	0	**0%**	0%	0%	0	**32%**	0%	65%	0	**2%**	0%	21%	0	**1%**	0%	14%	0	**2%**	0%	21%	0	**2%**	0%	21%	0
Inorganics																																			
Density	g/cc	0	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0
Sediment Concentration	mg/L	10	0	**53%**	0%	87%	11	**47%**	0%	74%	6	**52%**	0%	77%	7	**53%**	0%	87%	10	**55%**	0%	87%	12	**43%**	0%	76%	4	**40%**	0%	87%	8	**52%**	0%	87%	10
TSS	mg/L	10	0	**53%**	0%	87%	11	**47%**	0%	74%	6	**51%**	0%	77%	7	**52%**	0%	87%	10	**55%**	0%	87%	12	**43%**	0%	76%	4	**40%**	0%	87%	8	**52%**	0%	87%	10
Turbidity	NTU	0.04	0	**74%**	35%	97%	0	**50%**	0%	83%	0	**45%**	0%	85%	0	**62%**	11%	91%	0	**56%**	0%	84%	0	**35%**	19%	73%	0	**47%**	0%	89%	0	**64%**	16%	89%	0
TDS	mg/L	10	0	**2%**	0%	8%	0	**3%**	0%	8%	0	**3%**	0%	11%	0	**2%**	0%	11%	0	**2%**	0%	8%	0	**3%**	0%	11%	0	**1%**	0%	6%	0	**1%**	0%	5%	0
Ammonia-N	mg/L	0.3	3	**0%**	0%	0%	1	**16%**	0%	46%	2	**19%**	0%	49%	1	**17%**	0%	64%	2	**15%**	0%	49%	1	**21%**	0%	73%	2	**22%**	0%	49%	2	**16%**	0%	64%	2
Nitrate-N	mg/L	0.08	8	**22%**	0%	67%	9	**20%**	0%	67%	9	**17%**	0%	67%	8	**22%**	0%	67%	9	**20%**	0%	67%	8	**28%**	0%	67%	11	**21%**	0%	67%	7	**19%**	0%	67%	9
Nitrite-N	mg/L	0.08	12	**ND**	0%	0%	10	**ND**	0%	0%	11	**ND**	0%	0%	11	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	9	**ND**	0%	0%	10
NO3+NO2 -N	mg/L	0.08	8	**22%**	0%	67%	8	**20%**	0%	67%	8	**0%**	0%	0%	7	**22%**	0%	67%	9	**20%**	0%	67%	8	**28%**	0%	67%	11	**21%**	0%	67%	5	**19%**	0%	67%	8
TKN	mg/L	0.43	0	**13%**	0%	45%	0	**10%**	0%	40%	0	**19%**	0%	56%	0	**14%**	0%	61%	0	**19%**	0%	60%	0	**10%**	0%	58%	0	**11%**	0%	66%	0	**17%**	0%	60%	0
Sulfate	mg/L	4.5	0	**1%**	0%	4%	0	**2%**	0%	7%	0	**2%**	0%	5%	0	**2%**	0%	8%	0	**5%**	0%	25%	0	**3%**	0%	13%	0	**2%**	0%	7%	0	**2%**	0%	9%	0
Alkalinity	mg/L	2	0	**0%**	0%	5%	0	**4%**	0%	18%	0	**1%**	0%	6%	0	**1%**	0%	8%	0	**1%**	0%	6%	0	**2%**	0%	11%	0	**1%**	0%	6%	0	**2%**	0%	11%	0
Conductivity	umhos/cm	1	0	**1%**	0%	5%	0	**1%**	0%	5%	0	**1%**	0%	3%	0	**1%**	0%	5%	0	**0%**	0%	0%	0	**1%**	0%	3%	0	**0%**	0%	3%	0	**1%**	0%	5%	0
Hardness	mg/L	1	0	**3%**	0%	10%	0	**1%**	0%	5%	0	**2%**	0%	11%	0	**1%**	0%	5%	0	**3%**	0%	10%	0	**0%**	0%	5%	0	**1%**	0%	5%	0	**2%**	0%	9%	0
pH	pH Units		0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0	**--**	--	--	0
Metals																																			
Antimony, total	ug/L	0.18	0	**16%**	0%	80%	0	**15%**	0%	84%	0	**16%**	0%	83%	0	**19%**	0%	83%	1	**11%**	0%	62%	0	**15%**	0%	83%	0	**17%**	0%	82%	1	**21%**	0%	70%	0
Antimony, dissolved	ug/L	0.05	0	**12%**	0%	41%	0	**8%**	0%	44%	0	**10%**	0%	43%	0	**16%**	0%	90%	0	**8%**	0%	58%	0	**7%**	0%	40%	0	**16%**	0%	85%	0	**14%**	0%	66%	0
Arsenic, total	ug/L	4.4	7	**18%**	0%	44%	8	**23%**	0%	63%	11	**23%**	2%	48%	10	**13%**	0%	35%	6	**24%**	0%	57%	5	**24%**	2%	55%	8	**17%**	0%	44%	7	**23%**	2%	62%	9
Arsenic, dissolved	ug/L	4.4	9	**17%**	4%	30%	10	**10%**	0%	30%	9	**4%**	0%	6%	9	**5%**	4%	5%	10	**12%**	0%	30%	10	**1%**	0%	4%	8	**1%**	0%	4%	8	**12%**	0%	30%	8
Beryllium, total	ug/L	0.9	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12
Beryllium, dissolved	ug/L	0.9	12	**ND**	0%	0%	10	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12
Cadmium, total	ug/L	0.025	4	**47%**	22%	72%	10	**41%**	8%	72%	9	**40%**	0%	67%	4	**34%**	0%	58%	8	**43%**	0%	75%	8	**38%**	6%	58%	5	**28%**	8%	49%	8	**35%**	6%	72%	5
Cadmium, dissolved	ug/L	0.025	9	**5%**	0%	11%	10	**17%**	0%	46%	11	**15%**	0%	46%	11	**23%**	0%	46%	10	**0%**	0%	0%	10	**15%**	0%	46%	11	**10%**	0%	30%	10	**10%**	0%	30%	9
Chromium, total	ug/L	2	7	**7%**	0%	17%	11	**13%**	0%	35%	11	**16%**	0%	35%	11	**7%**	0%	17%	11	**13%**	0%	35%	12	**23%**	0%	50%	11	**23%**	0%	51%	10	**13%**	0%	35%	12
Chromium, dissolved	ug/L	2	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12
Copper, total	ug/L	0.49	0	**63%**	0%	91%	0	**39%**	0%	88%	0	**47%**	0%	89%	0	**65%**	0%	92%	2	**52%**	0%	90%	0	**26%**	0%	91%	0	**49%**	0%	91%	0	**42%**	0%	90%	0
Copper, dissolved	ug/L	0.25	0	**0%**	0%	0%	0	**4%**	0%	33%	0	**6%**	0%	58%	0	**18%**	0%	42%	0	**5%**	0%	27%	0	**7%**	0%	48%	0	**4%**	0%	14%	0	**5%**	0%	64%	0
Iron, total	mg/L	0.015	0	**81%**	46%	98%	0	**56%**	0%	88%	0	**48%**	0%	91%	0	**74%**	7%	99%	1	**66%**	0%	93%	0	**33%**	0%	78%	0	**57%**	0%	95%	0	**66%**	14%	96%	0
Iron, dissolved	mg/L	0.015	10	**10%**	3%	17%	10	**8%**	6%	10%	9	**6%**	6%	7%	10	**20%**	17%	24%	10	**10%**	6%	14%	8	**10%**	0%	21%	6	**2%**	0%	3%	9	**7%**	3%	11%	7
Lead, total	ug/L	0.13	0	**78%**	44%	91%	2	**51%**	0%	85%	0	**43%**	0%	82%	0	**74%**	59%	91%	0	**57%**	0%	88%	0	**31%**	0%	65%	0	**55%**	13%	85%	0	**41%**	0%	86%	0
Lead, dissolved	ug/L	0.04	8	**0%**	0%	0%	9	**6%**	0%	12%	7	**2%**	0%	9%	7	**13%**	0%	31%	8	**0%**	0%	0%	7	**2%**	0%	5%	7	**9%**	0%	31%	8	**0%**	0%	0%	3
Manganese, total	ug/L	7	1	**67%**	9%	94%	1	**42%**	0%	71%	0	**38%**	0%	79%	0	**50%**	0%	79%	0	**53%**	0%	84%	0	**14%**	0%	44%	0	**41%**	14%	79%	0	**45%**	0%	91%	0
Manganese, dissolved	ug/L	7	12	**ND**	0%	0%	11	**ND**	0%	0%	11	**ND**	0%	0%	11	**ND**	0%	0%	11	**ND**	0%	0%	11	**ND**	0%	0%	10	**ND**	0%	0%	11	**ND**	0%	0%	9
Mercury, total	ug/L	0.15	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12
Mercury, dissolved	ug/L	0.15	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	12
Nickel, total	ug/L	2	5	**44%**	29%	63%	8	**34%**	3%	61%	6	**37%**	0%	61%	5	**48%**	29%	64%	10	**42%**	29%	61%	6	**25%**	0%	57%	7	**37%**	10%	50%	7	**48%**	29%	63%	9
Nickel, dissolved	ug/L	2	4	**3%**	0%	12%	3	**3%**	0%	11%	4	**1%**	0%	7%	3	**11%**	5%	26%	8	**3%**	0%	8%	4	**3%**	0%	9%	4	**7%**	0%	20%	6	**2%**	0%	9%	5
Selenium, total	ug/L	0.36	2	**10%**	0%	32%	2	**11%**	0%	40%	5	**13%**	0%	48%	2	**15%**	0%	40%	5	**7%**	0%	26%	1	**15%**	0%	45%	3	**12%**	0%	23%	4	**15%**	0%	37%	4
Selenium, dissolved	ug/L	0.3	4	**12%**	0%	27%	3	**9%**	0%	43%	4	**12%**	0%	43%	3	**18%**	0%	43%	5	**7%**	0%	43%	2	**9%**	0%	42%	2	**13%**	0%	25%	2	**16%**	0%	43%	5
Silver, total	ug/L	0.089	7	**15%**	0%	50%	10	**18%**	0%	37%	9	**17%**	0%	37%	9	**0%**	0%	0%	9	**7%**	0%	26%	10	**32%**	0%	75%	8	**5%**	0%	25%	10	**5%**	0%	26%	12
Silver, dissolved	ug/L	0.025	10	**39%**	0%	77%	10	**52%**	26%	77%	12	**52%**	26%	77%	12	**52%**	26%	77%	11	**13%**	0%	26%	10	**46%**	26%	65%	11	**35%**	26%	44%	11	**52%**	26%	77%	12
Thallium, total	ug/L	0.15	10	**0%**	0%	0%	9	**0%**	0%	0%	12	**0%**	0%	0%	11	**0%**	0%	0%	9	**0%**	0%	0%	8	**0%**	0%	0%	12	**0%**	0%	0%	11	**0%**	0%	0%	11
Thallium, dissolved	ug/L	0.15	11	**0%**	0%	0%	11	**0%**	0%	0%	12	**0%**	0%	0%	11	**0%**	0%	0%	10	**0%**	0%	0%	8	**0%**	0%	0%	10	**0%**	0%	0%	12	**0%**	0%	0%	12
Zinc, total	ug/L	3.7	6	**83%**	72%	98%	11	**74%**	30%	98%	11	**73%**	22%	98%	10	**83%**	72%	98%	11	**83%**	72%	98%	10	**59%**	0%	98%	9	**62%**	0%	98%	8	**83%**	71%	98%	11
Zinc, dissolved	ug/L	15	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	11	**ND**	0%	0%	12	**ND**	0%	0%	12

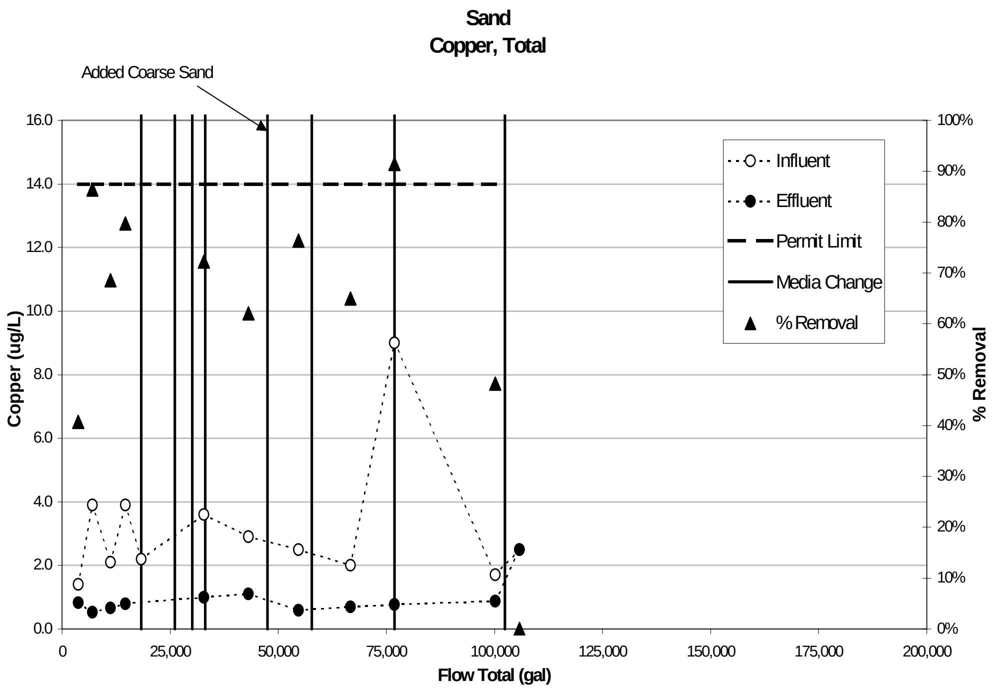
5.1. Metals Removal

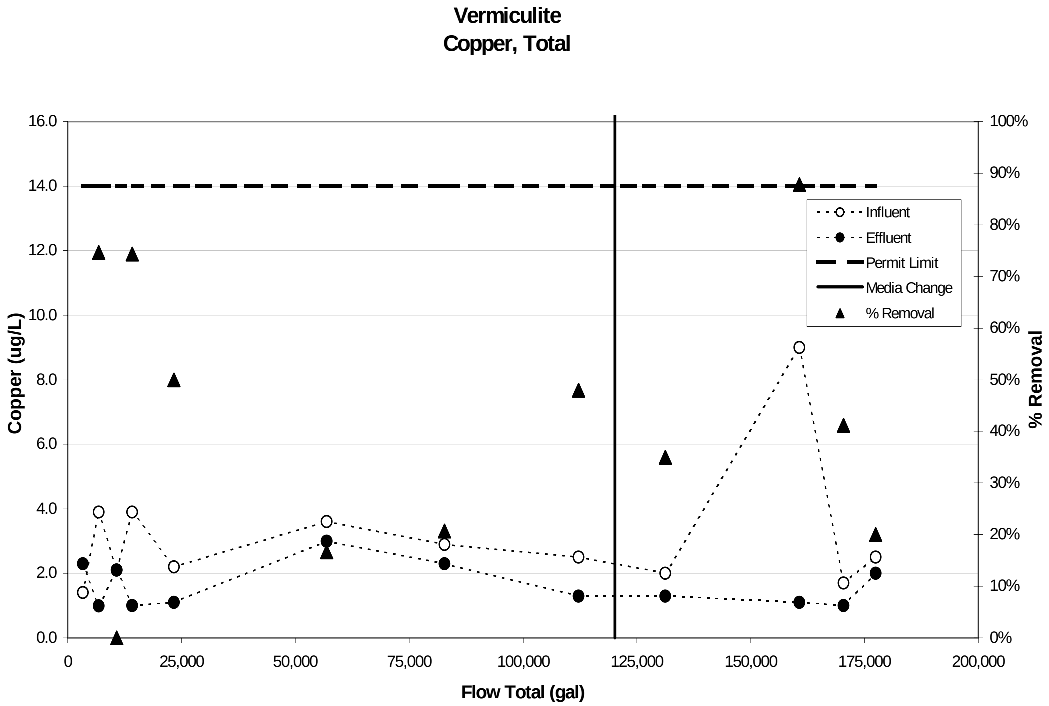
Almost all influent metal concentrations were below daily maximum permit limits, and most were at or below detection levels, making it difficult to evaluate removal effectiveness. All dissolved metal influent concentrations were at or below detection levels. Many total metal influent concentrations were also at or below detection levels, including mercury, antimony, arsenic, beryllium, cadmium, chromium, nickel, selenium, silver and thallium.

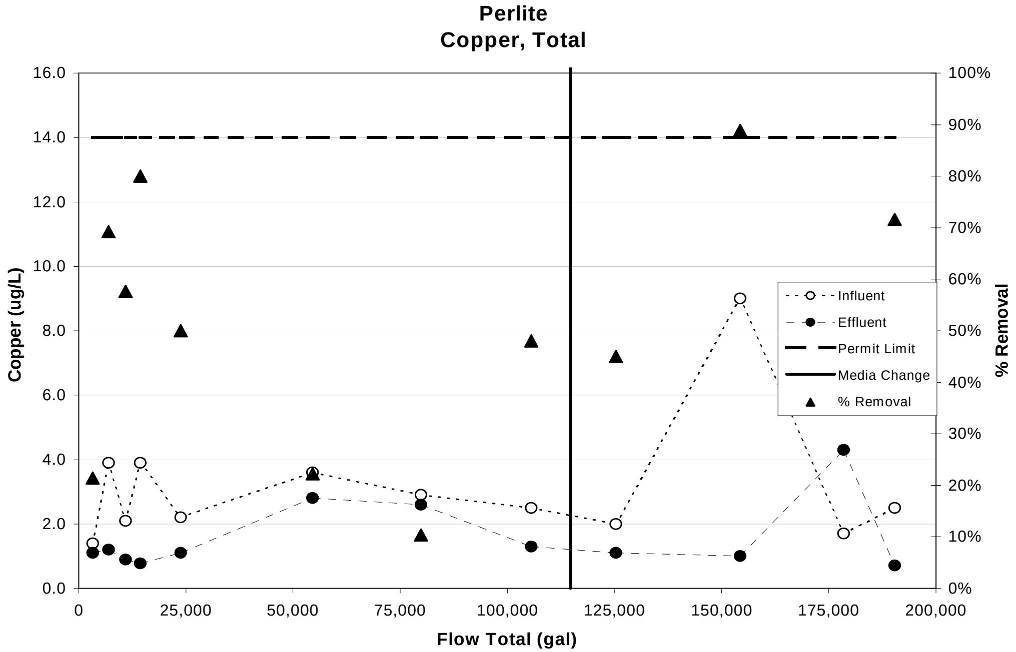
Metals that had concentrations significantly above detection levels that were removed included:

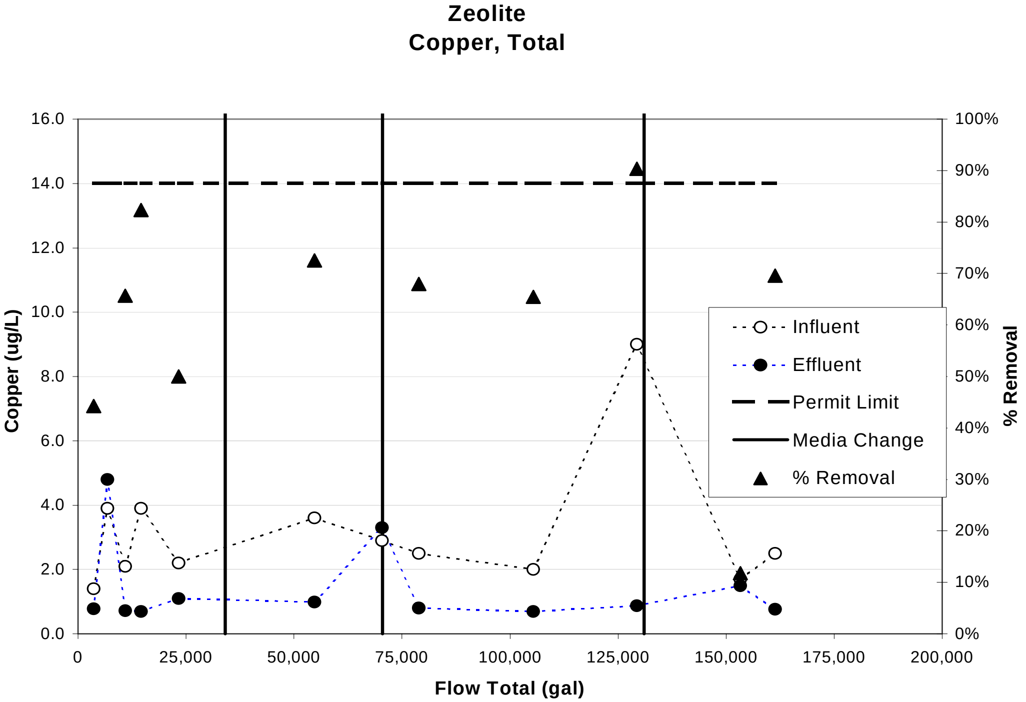
1. Copper, Total
2. Iron, Total
3. Lead, Total
4. Manganese, Total
5. Zinc, Total

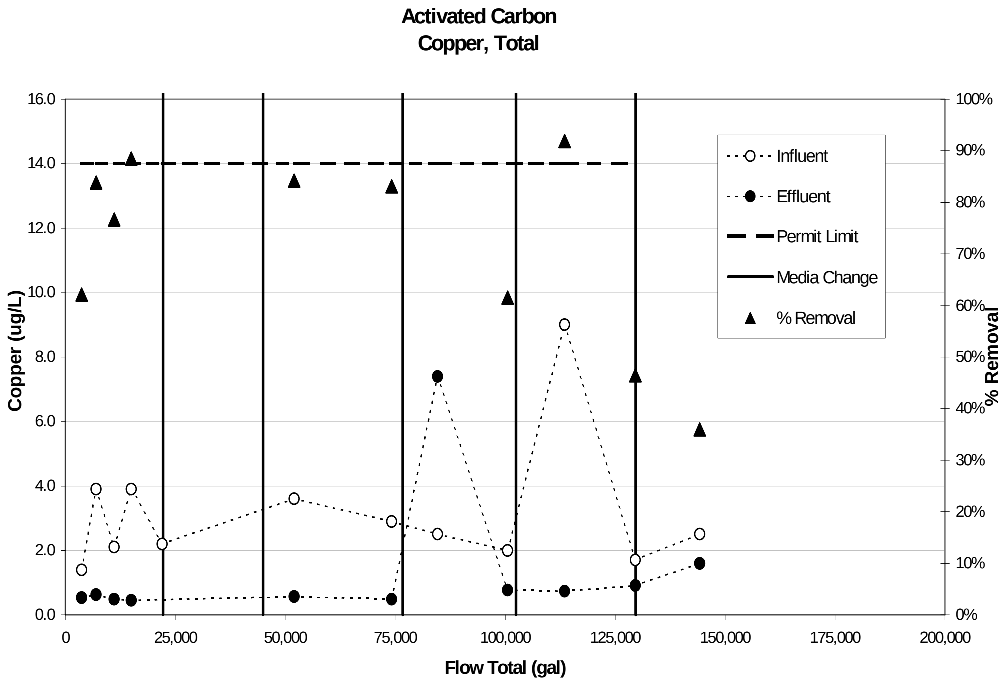
The following figures show the influent concentration, effluent concentration, removal percentage, and daily maximum permit limit from the 2006 permit for the above metals. Both bag filter influent and effluent data as well as filter drum effluent data is shown. “Media changes” refers to clogging events that led to the replacement of media. In the bag filter data, “filter changes” refers to changes in the bag filter configuration or filtration rating. Nondetect samples were assumed to be equal to the maximum detection limit for each constituent. All other data and analytical reports can be found in the attachments that accompany this report.

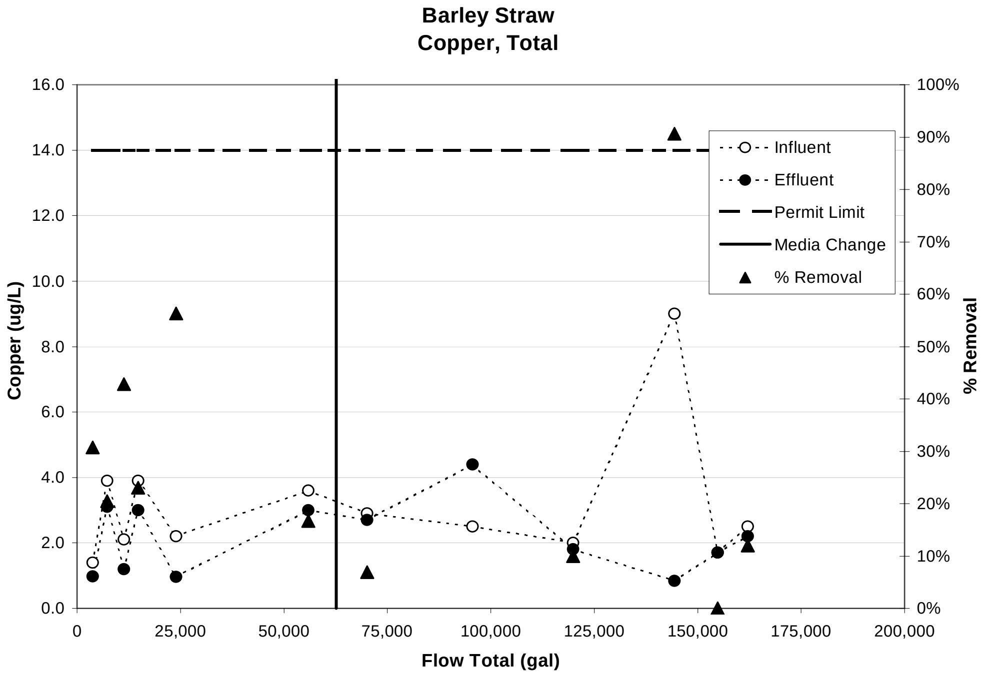

Sand
Copper, Total
Added Coarse Sand
Copper (ug/L)
% Removal
Flow Total (gal)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal

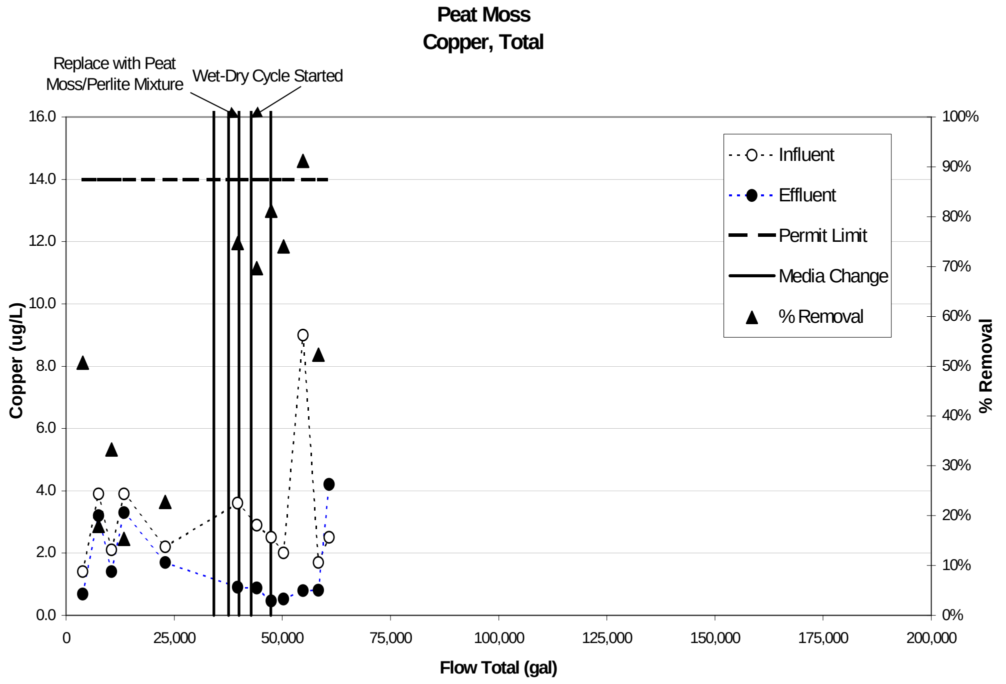

Vermiculite
Copper, Total
Copper (ug/L)
% Removal
Flow Total (gal)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal

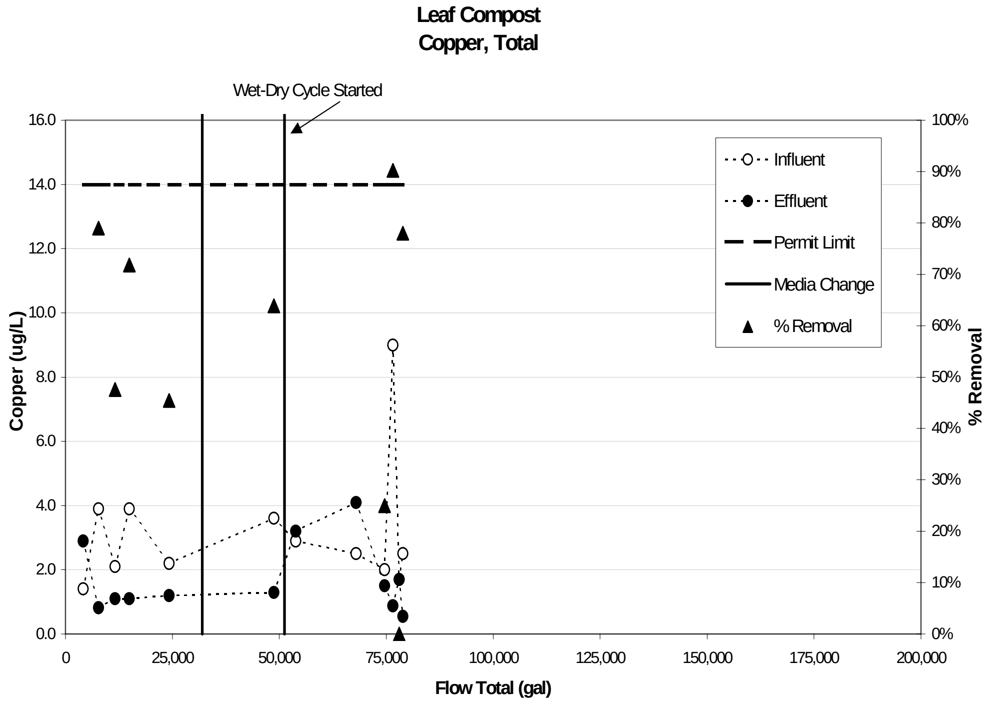

Perlite
Copper, Total
Copper (ug/L)
% Removal
Flow Total (gal)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal


Zeolite
Copper, Total
Copper (ug/L)
% Removal
Flow Total (gal)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal

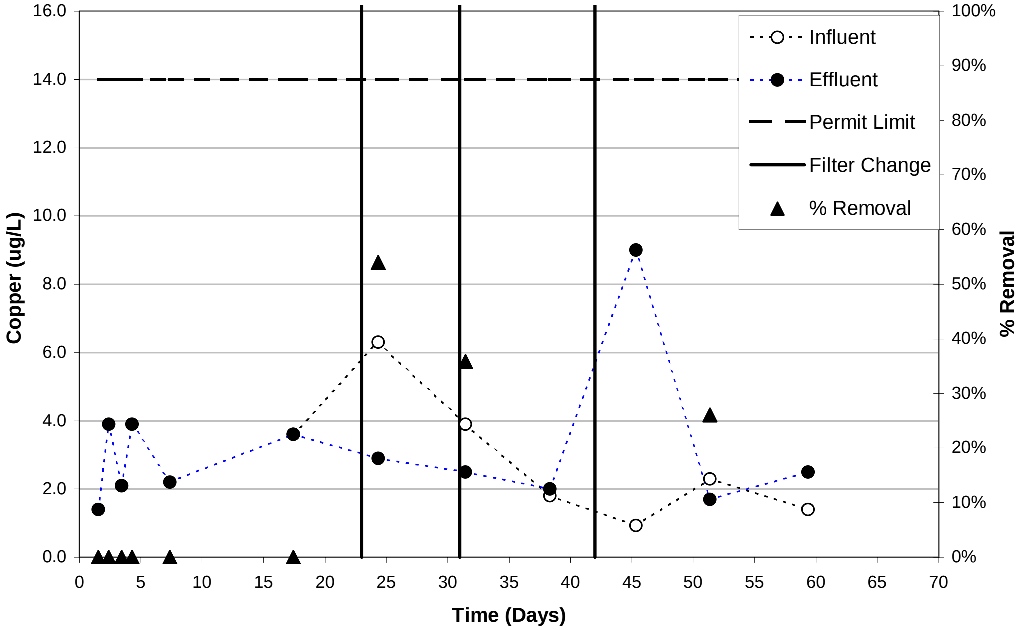

Activated Carbon
Copper, Total


Barley Straw
Copper, Total


Peat Moss
Copper, Total


Leaf Compost
Copper, Total

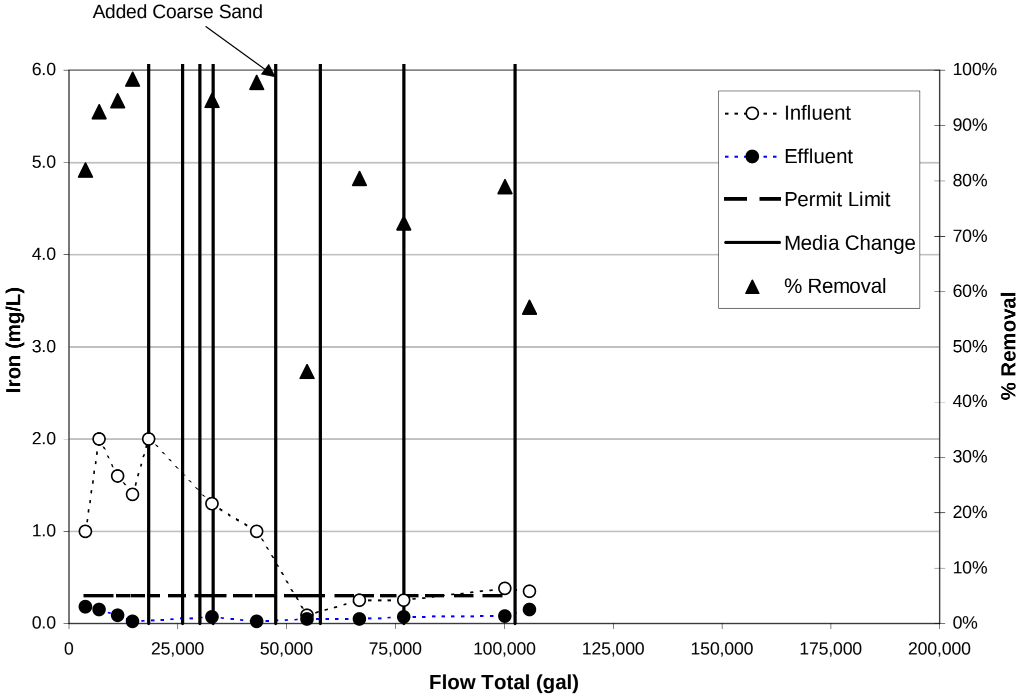
Bag Filter
Copper, Total

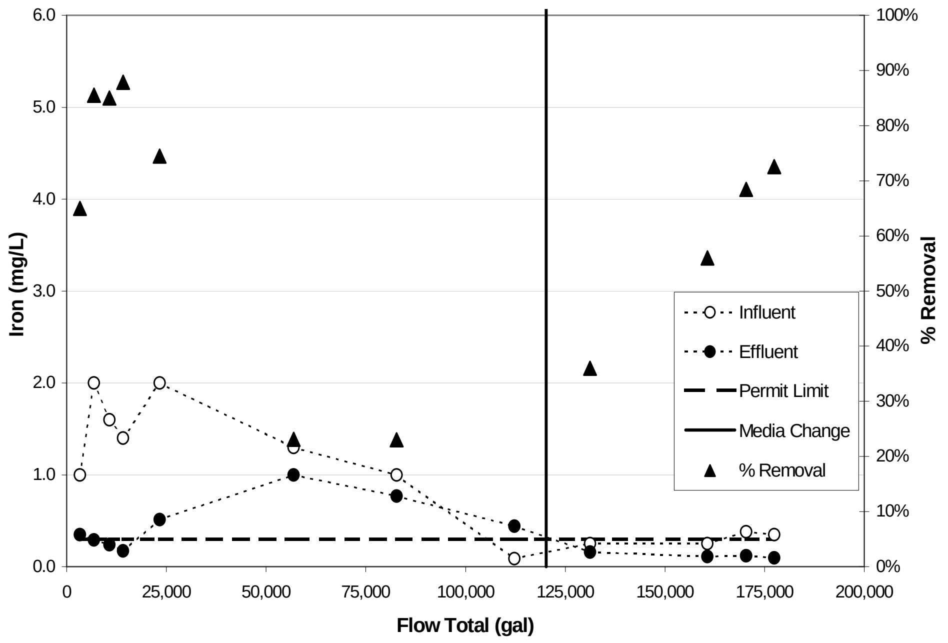


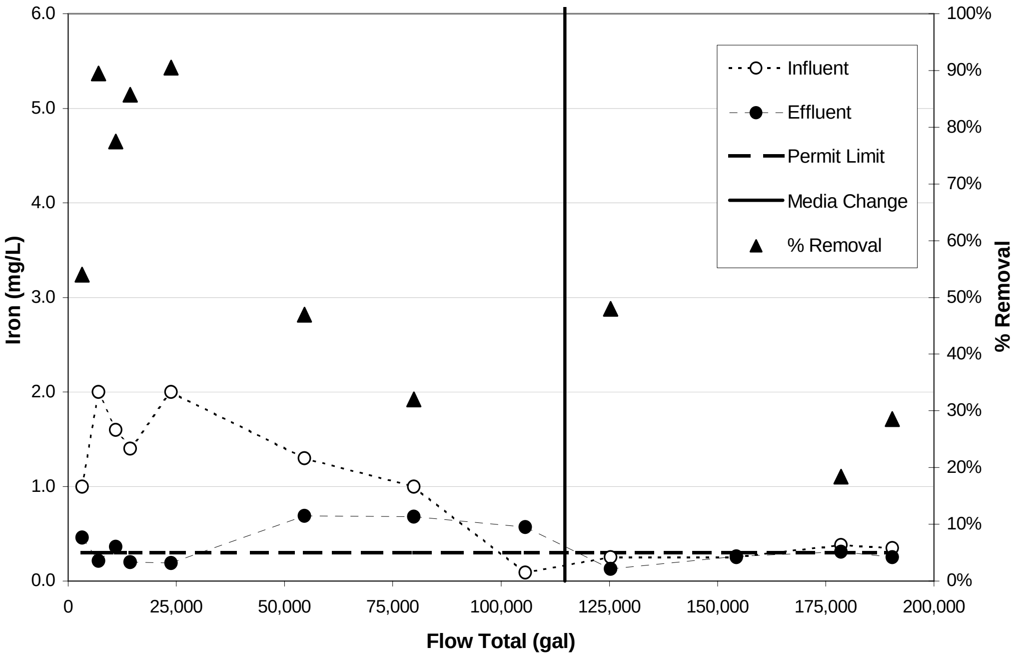
All total copper samples were below the permit limit of 14 μg/L. Sand was effective at removing total copper with 63% average total copper removal. Since sand has no cationic exchange capacity, this implies adsorption of suspended copper onto solids which were physically captured by the fine sand particles. Zeolite and activated carbon were also effective at copper removal, with total copper removal percentages of 52% and 65%, respectively.

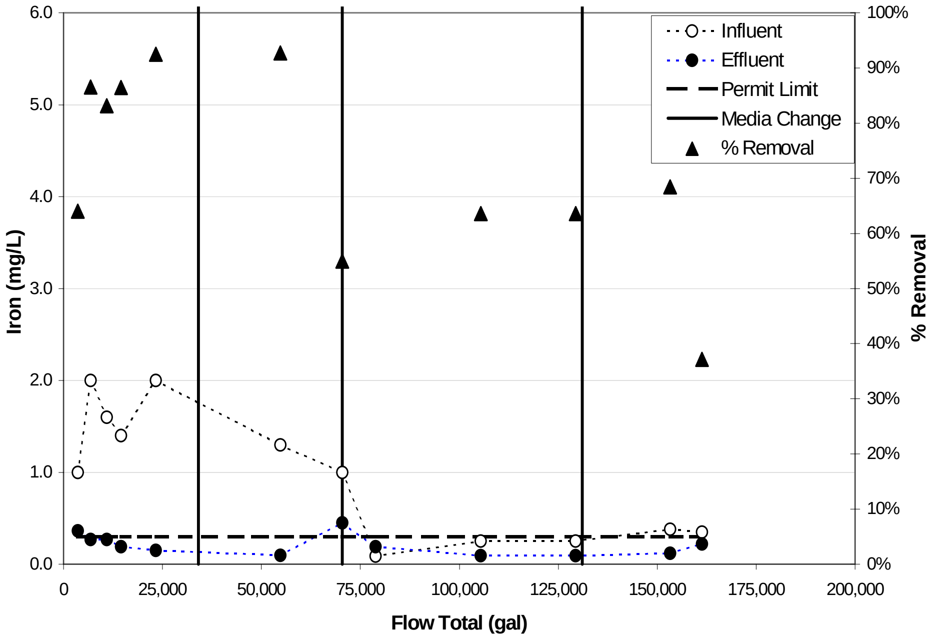
The presence of algae may explain the ability of activated carbon to remove metals like copper. Numerous published studies have shown that many heavy metals bind to the cell wells of algae to form organometallic complexes (Davis, et al, 2003) (Trolope and Evans, 1976) (Radway, et al., 2001). Activated carbon likely removed metals by adsorbing organics, such as algae, which had copper and other metals bound to it. It should be noted that two of the twelve samples taken for activated carbon showed nondetect values for total copper, implying that even higher copper removals may be possible with higher influent concentrations.

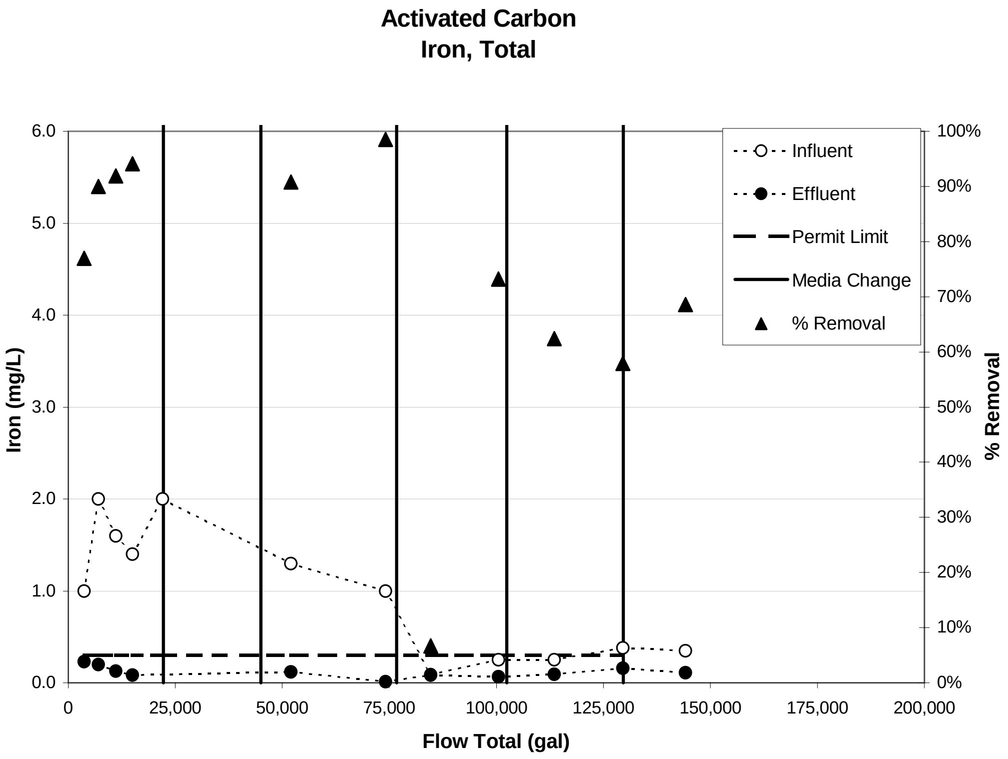
Vermiculite, perlite and peat moss provided moderate removal of total copper. Leaf compost and barley straw did not appear to provide effective removal of total copper with an average removal percentage of 42% and 26%, respectively. Influent dissolved copper concentrations were at or close to the detection limits so pollutant removal efficiency could not be accurately determined. The maximum detection limit for total copper was 0.49 μg/L. The maximum detection limit for dissolved copper was 0.25 μg/L.

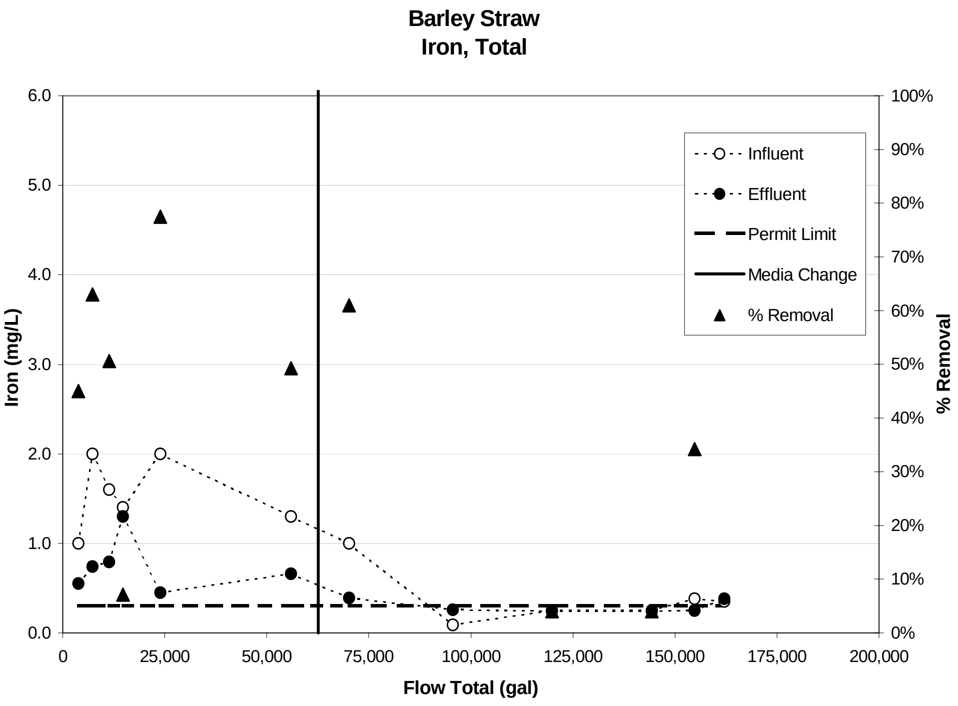

Sand
Iron, Total

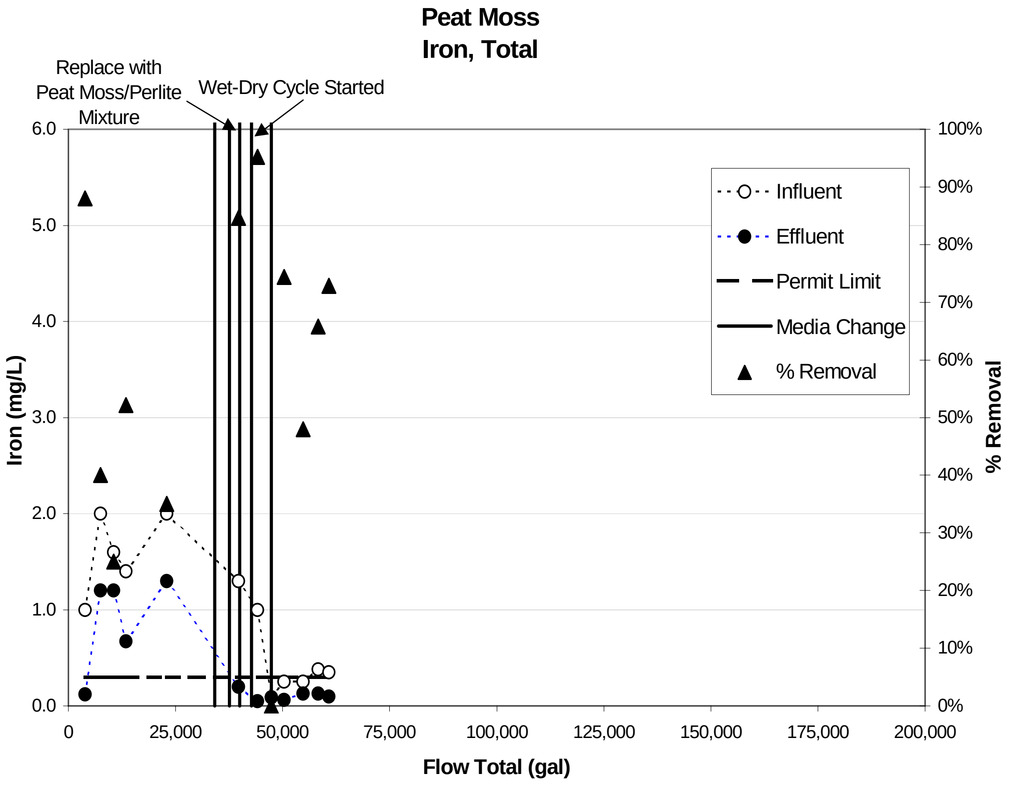

Vermiculite
Iron, Total

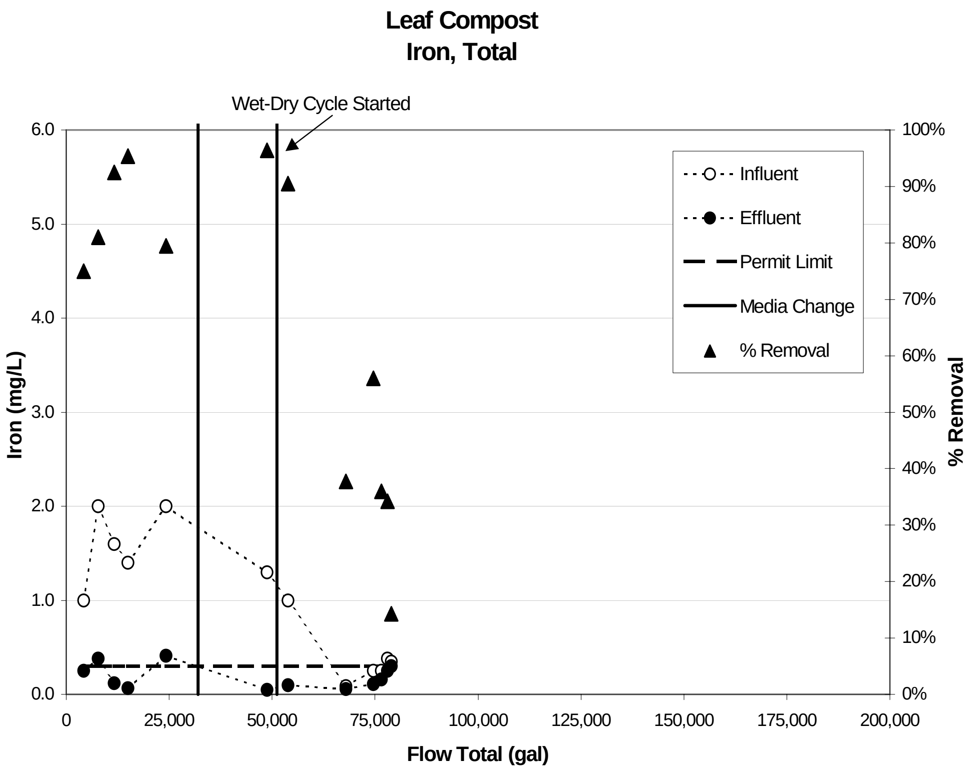

Perlite
Iron, Total

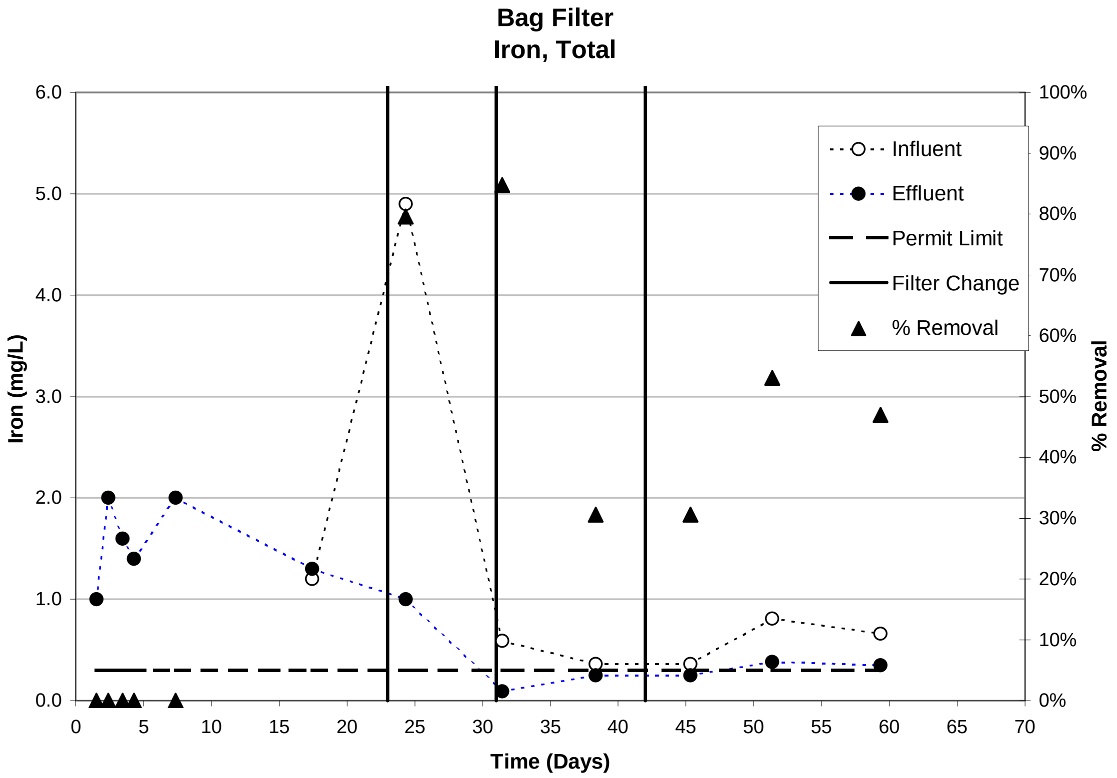

Zeolite
Iron, Total


Activated Carbon
Iron, Total

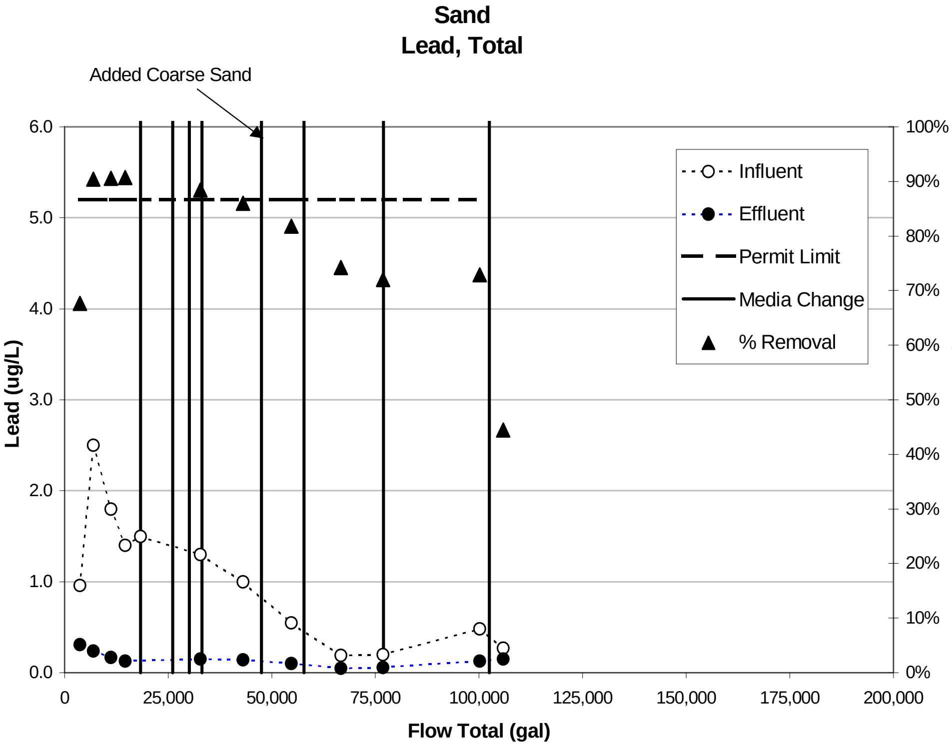

Barley Straw
Iron, Total

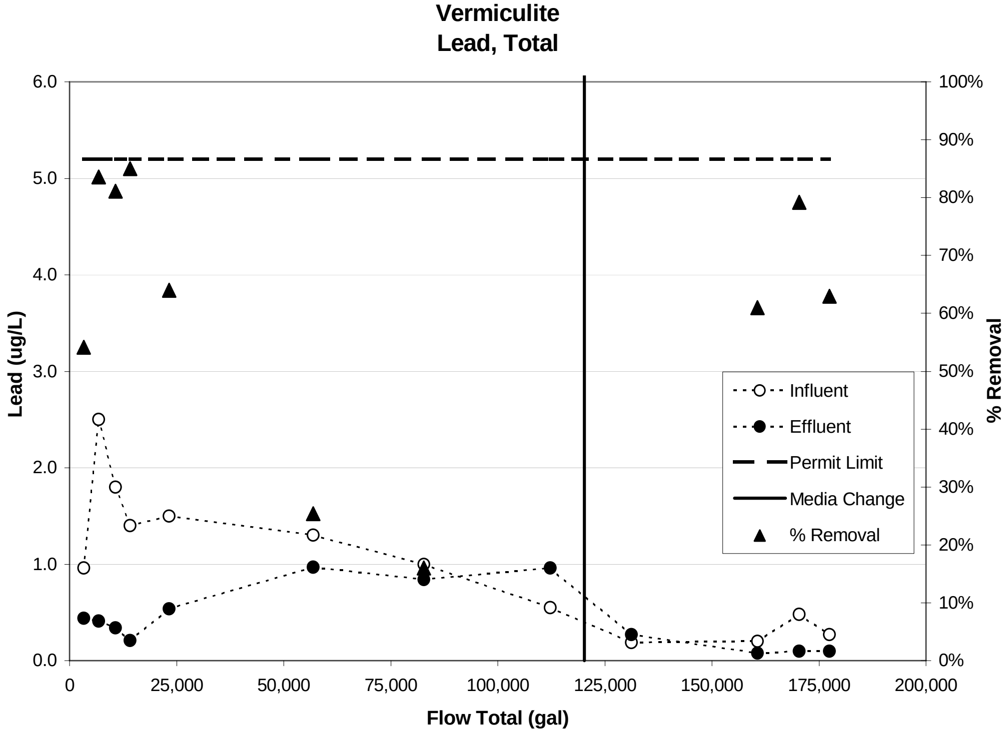

Peat Moss
Iron, Total

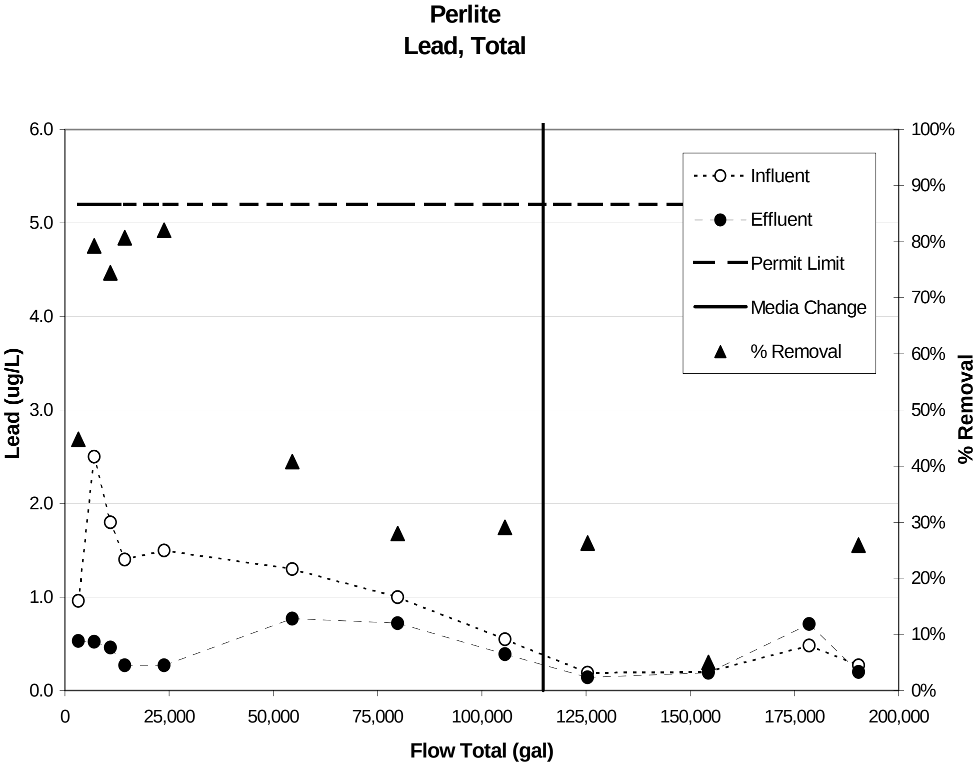

Leaf Compost
Iron, Total

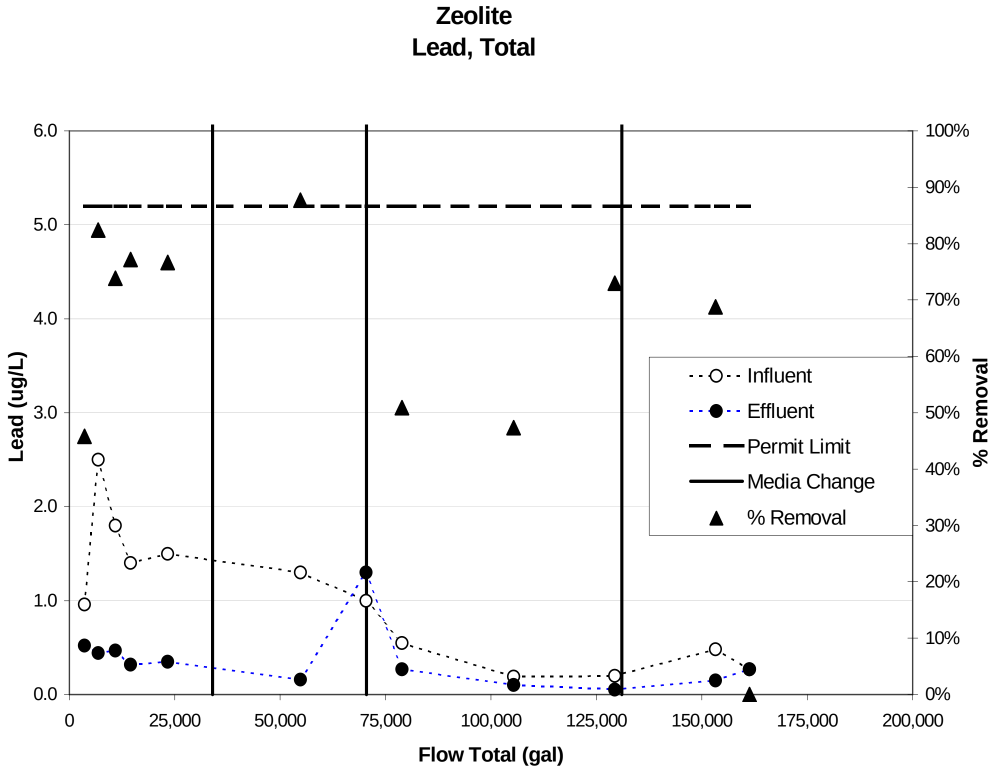


Many influent samples had total iron concentrations above the daily maximum permit limit of 0.3 mg/L. Sand and activated carbon removed total iron concentrations with 81% and 74% average removal efficiency, respectively. Leaf compost and zeolite showed average removal percentages of approximately 66%. Peat moss showed poor removal of total iron after the first 5 samples, but removal significantly improved after replacing the peat moss with a peat moss/perlite mixture. Vermiculite, perlite and barley straw were not effective at removing iron. The maximum detection limit for iron was 0.015 mg/L.

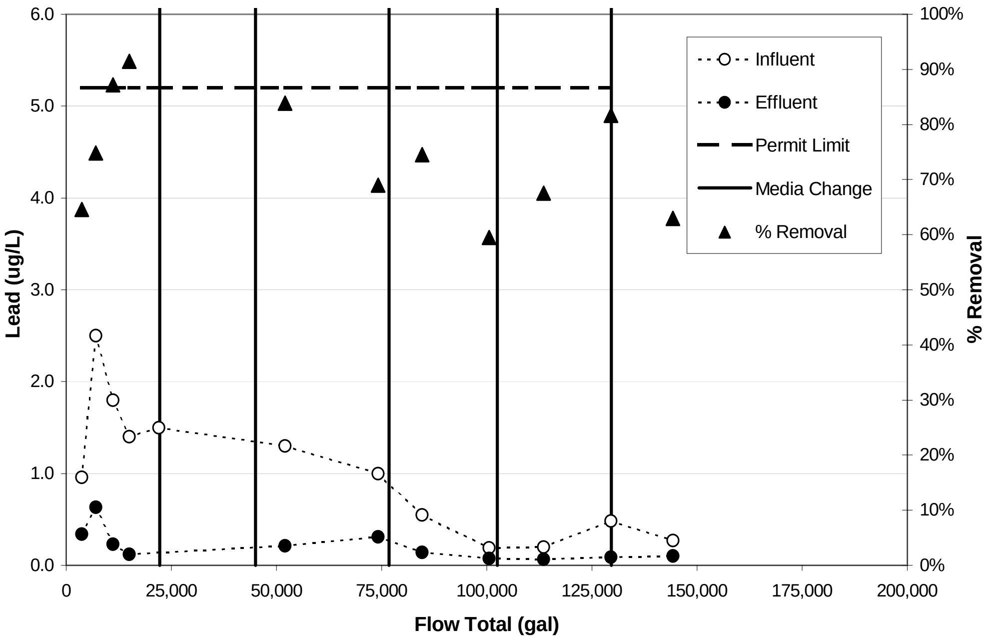

Sand
Lead, Total
Added Coarse Sand
Lead (ug/L)
% Removal
Flow Total (gal)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal


Vermiculite
Lead, Total
Lead (ug/L)
% Removal
Flow Total (gal)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal

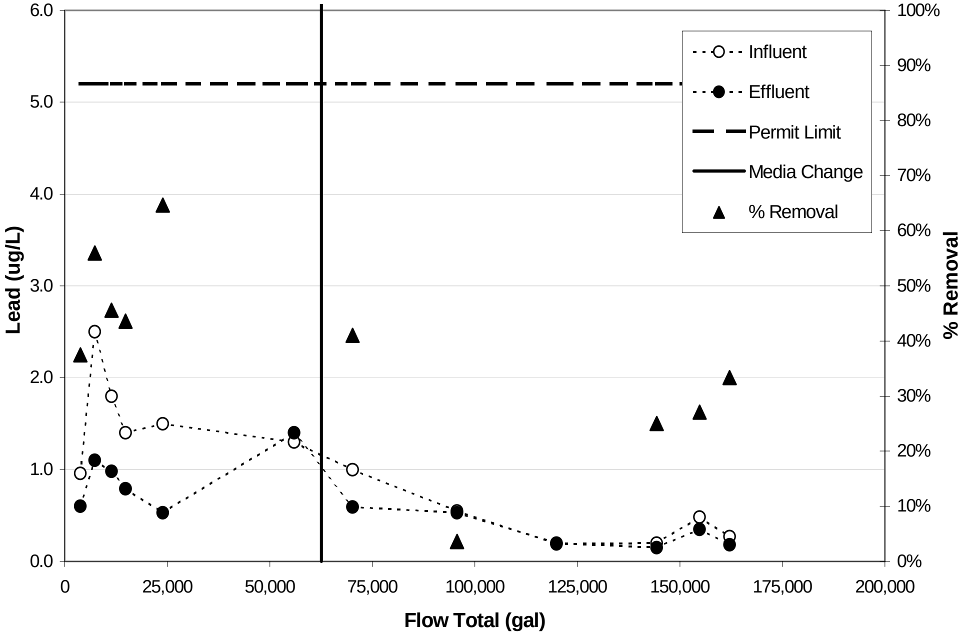

Perlite
Lead, Total
Lead (ug/L)
% Removal
Flow Total (gal)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal


Zeolite
Lead, Total
Lead (ug/L)
% Removal
Flow Total (gal)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal

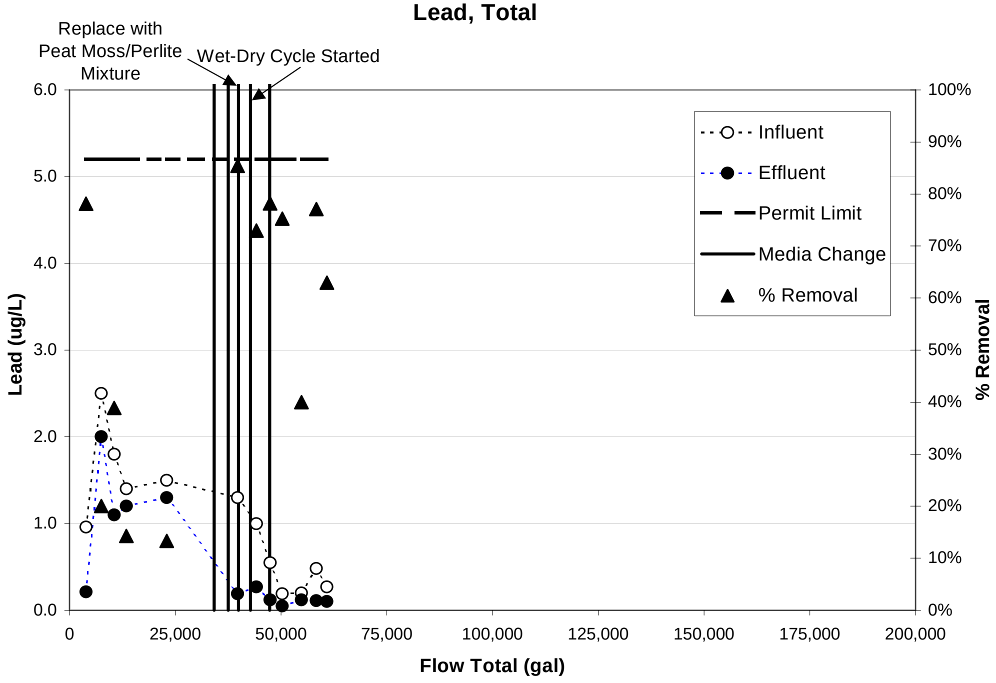
Activated Carbon
Lead, Total



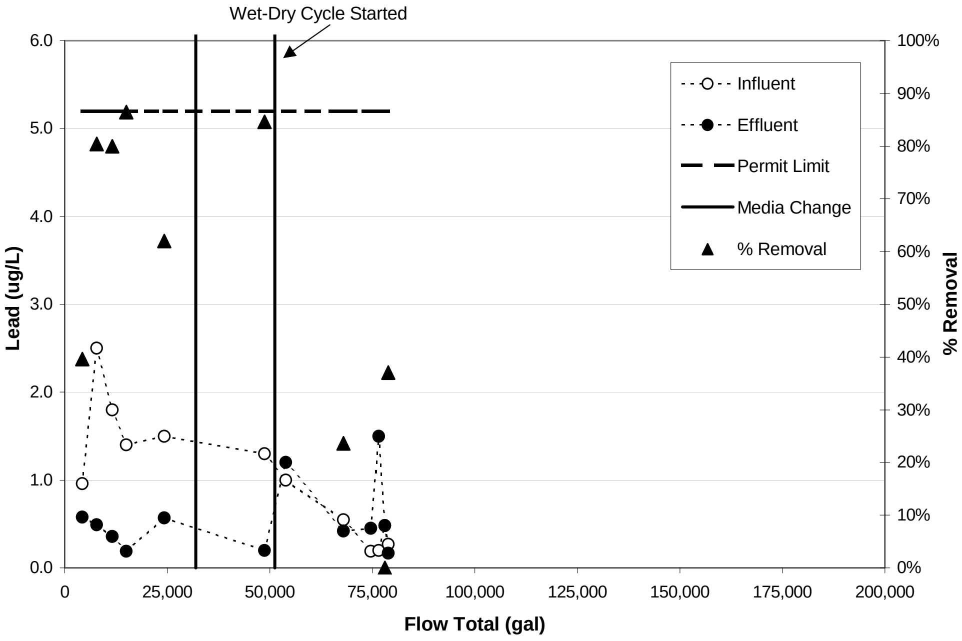
Barley Straw
Lead, Total



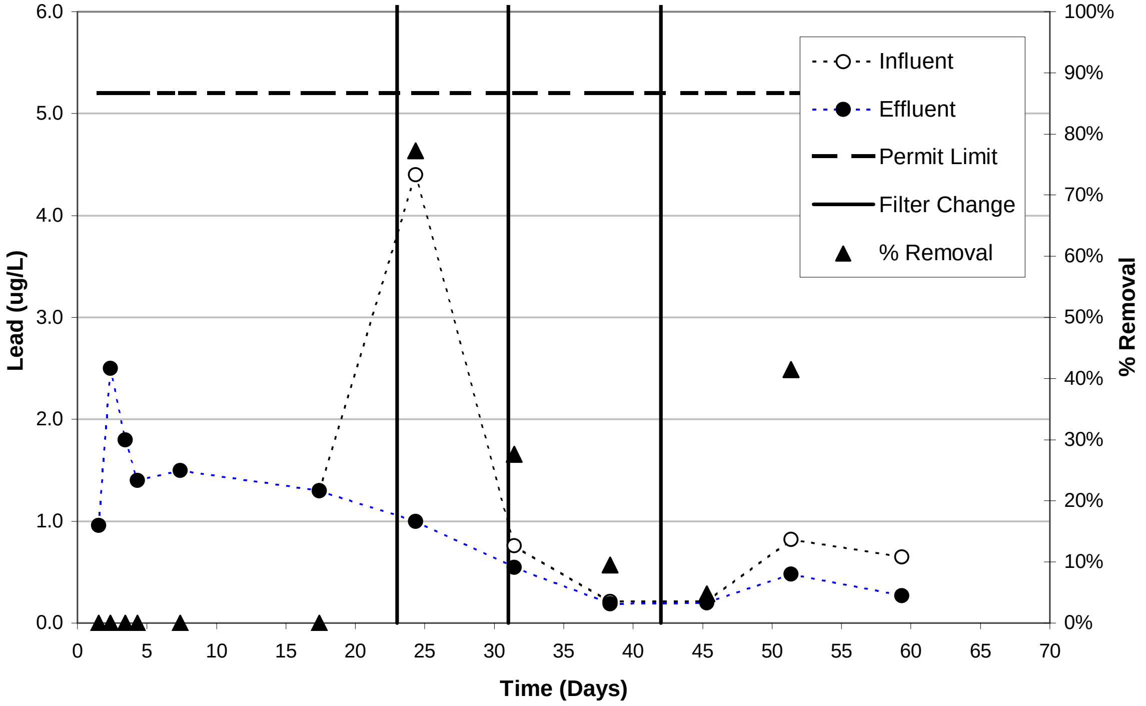
Peat Moss
Lead, Total



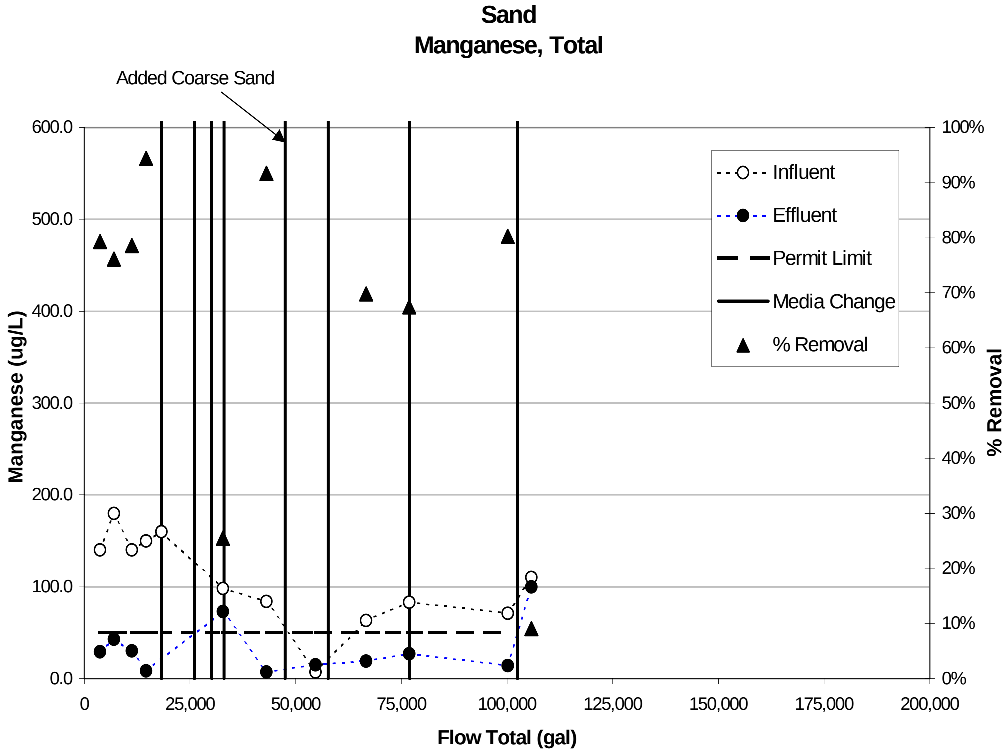
Leaf Compost
Lead, Total

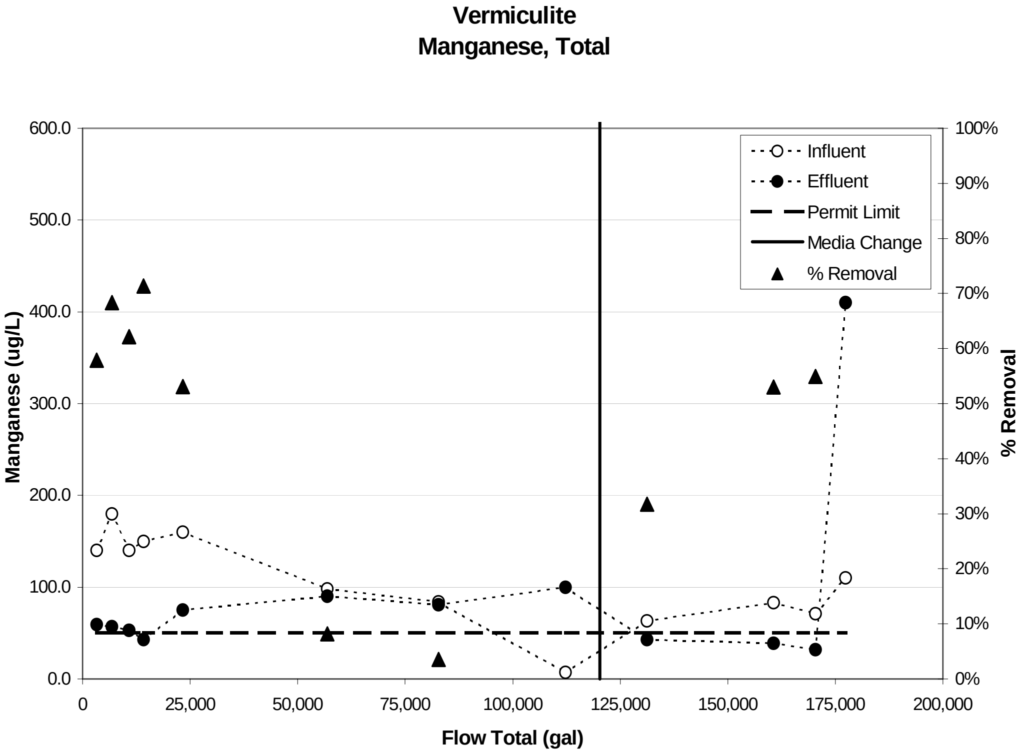


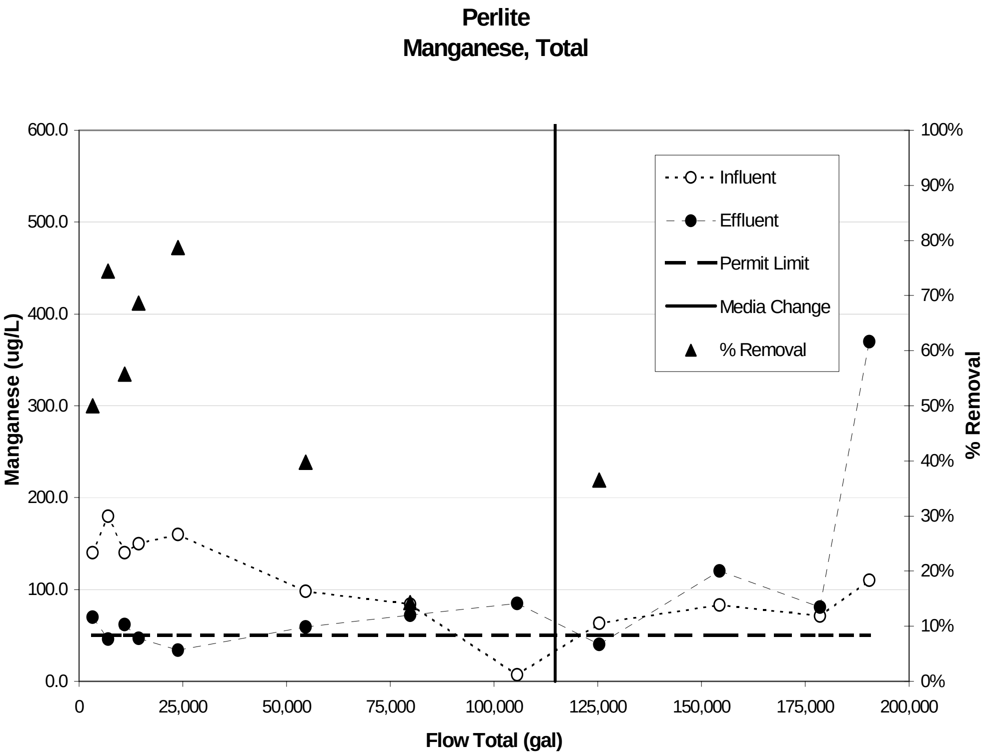
Bag Filter
Lead, Total

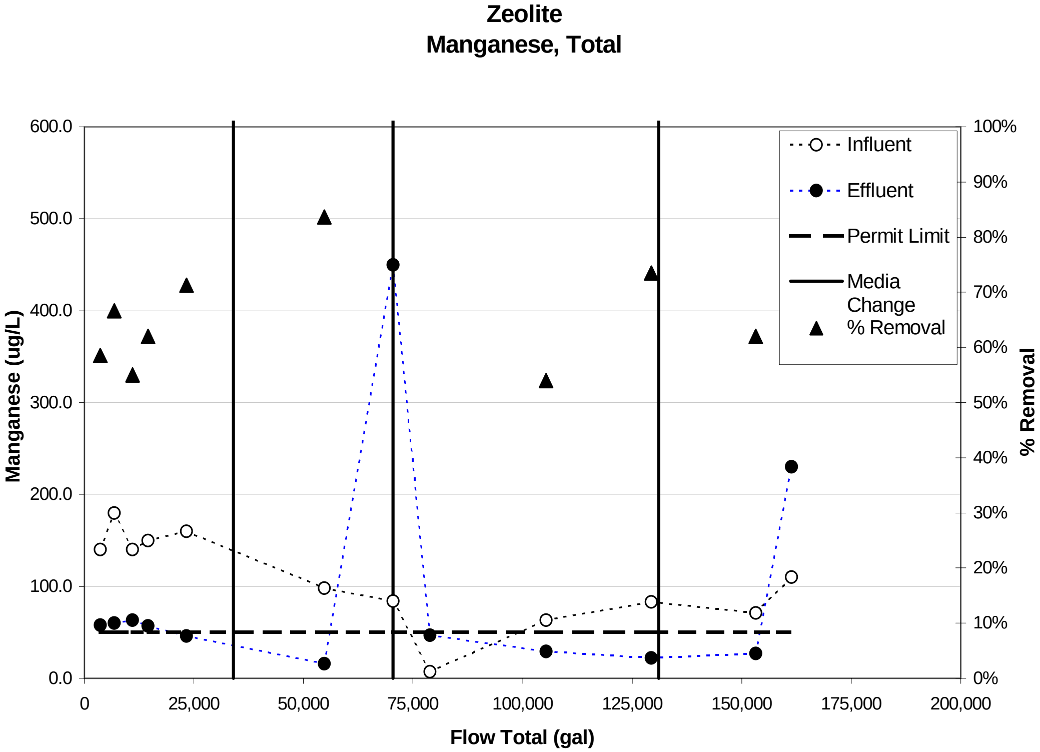


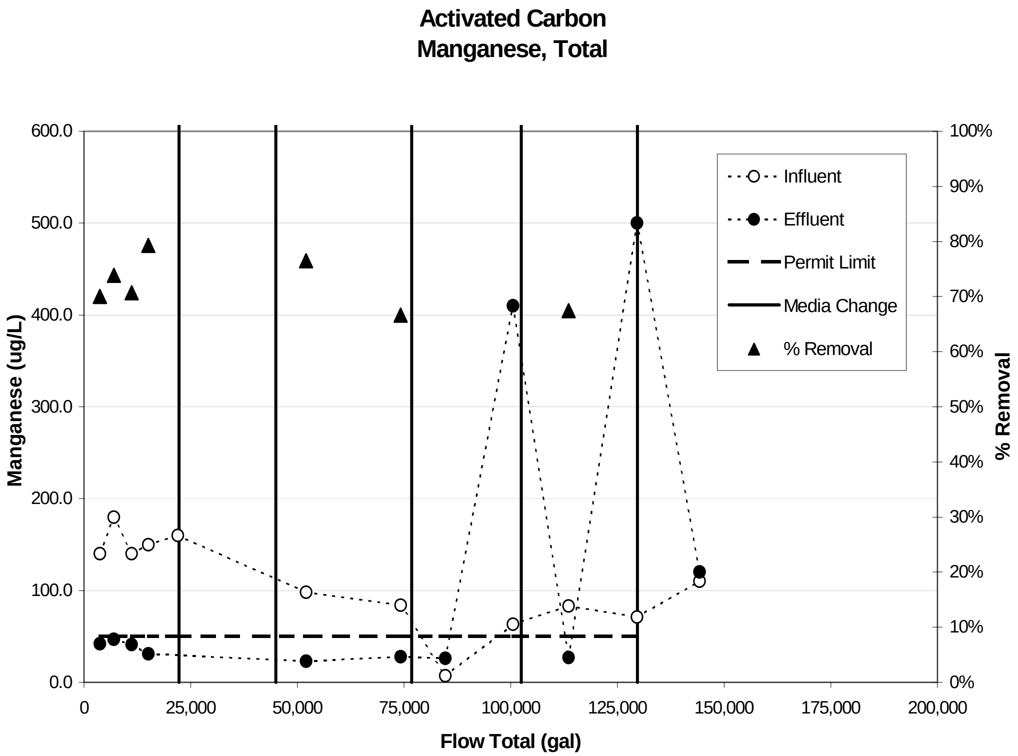
All influent samples were below the total lead permit level of 5.1 μg/L. Sand and activated carbon were most effective at removing total lead with 78% and 74% average removal efficiency, respectively. Two of the sand effluent samples showed nondetect values for total lead, implying that higher percentage removals might have been possible with higher influent concentrations. Zeolite had an average removal percentage of 54%. Similar to the case for iron, peat moss showed poor removal of total lead after the first 5 samples, but removal significantly improved after replacing the peat moss with a peat moss/perlite mixture. Leaf compost showed excellent removal of total lead during the first 50,000 gallons of flow, but appeared to reach pollutant breakthrough after 50,000 gallons of flow. Vermiculite, perlite and barley straw were not effective at removing lead. The maximum detection limit for total lead was 0.13 μg/L.

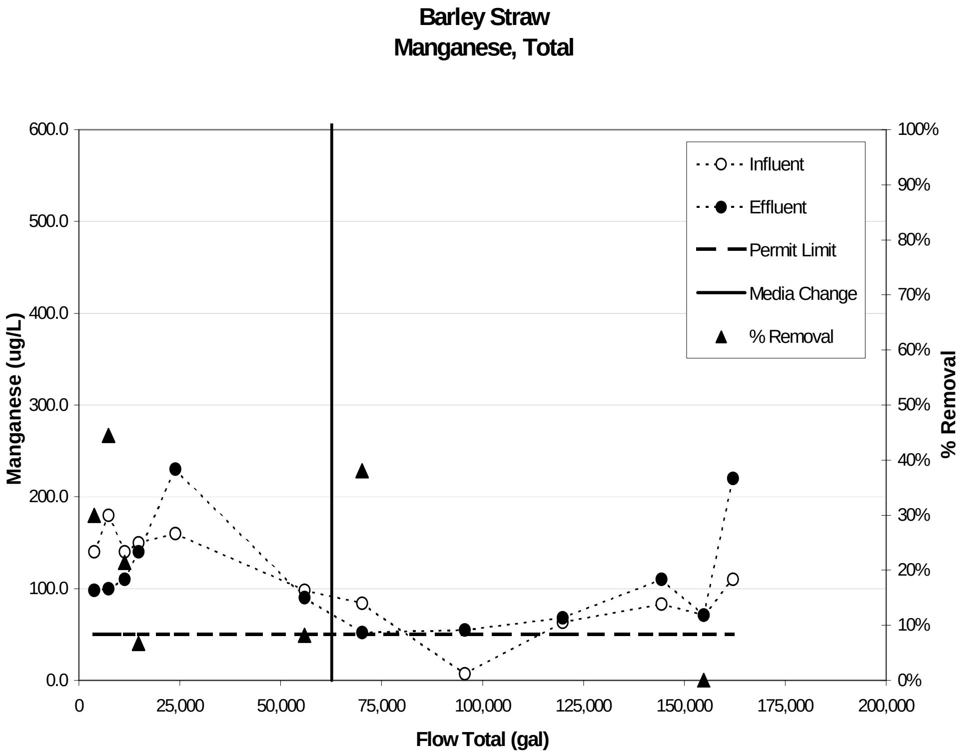

Sand
Manganese, Total

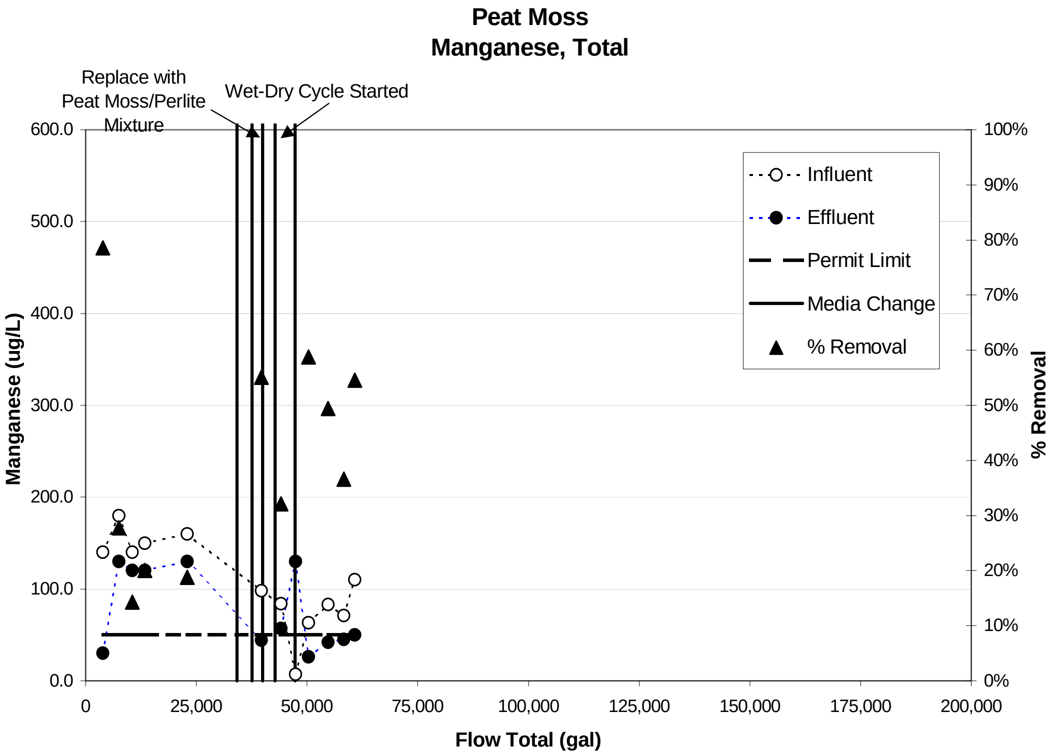

Vermiculite
Manganese, Total

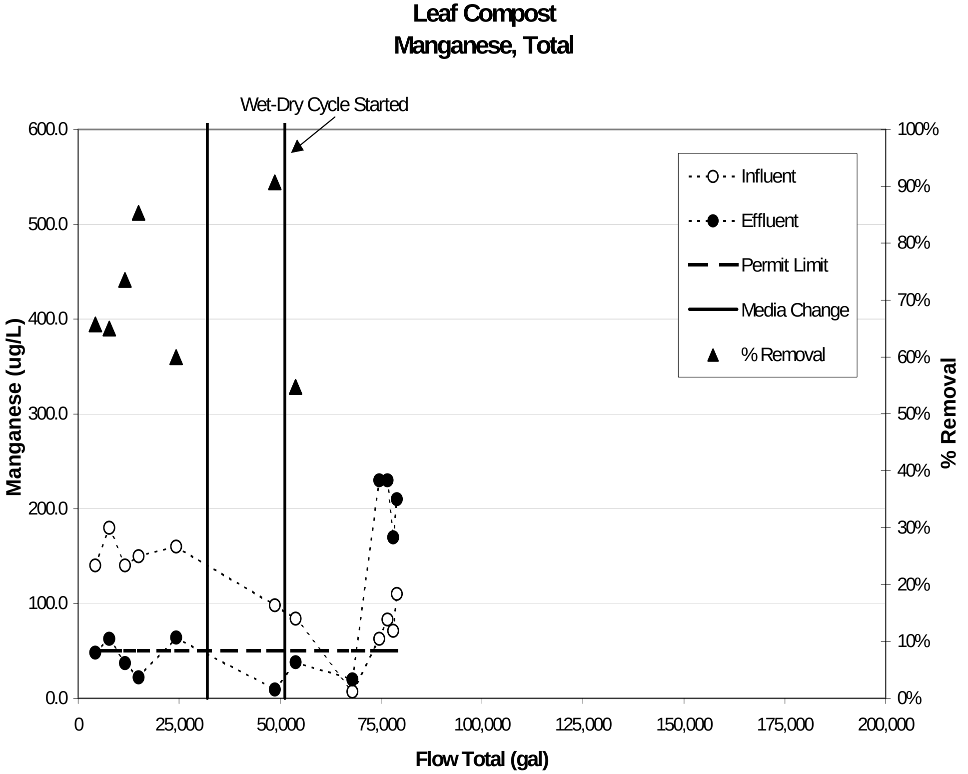

Perlite
Manganese, Total


Zeolite
Manganese, Total

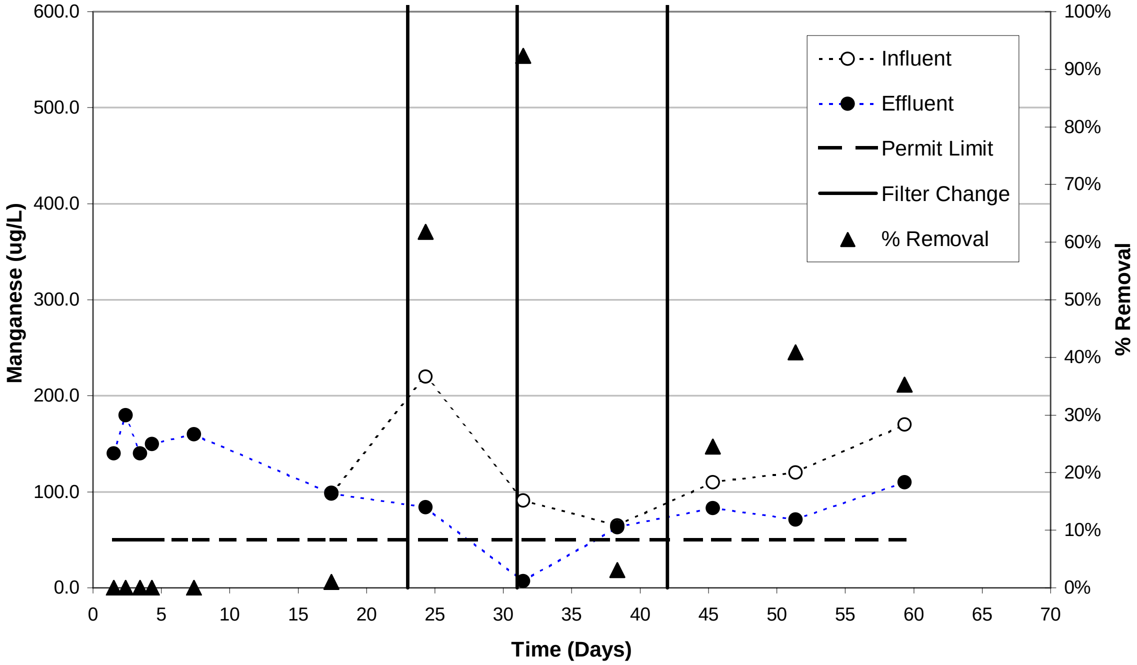

Activated Carbon
Manganese, Total
Manganese (ug/L)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
% Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Flow Total (gal)
Influent
Effluent
Permit Limit
Media Change
% Removal


Barley Straw
Manganese, Total
Manganese (ug/L)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
% Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Flow Total (gal)
Influent
Effluent
Permit Limit
Media Change
% Removal

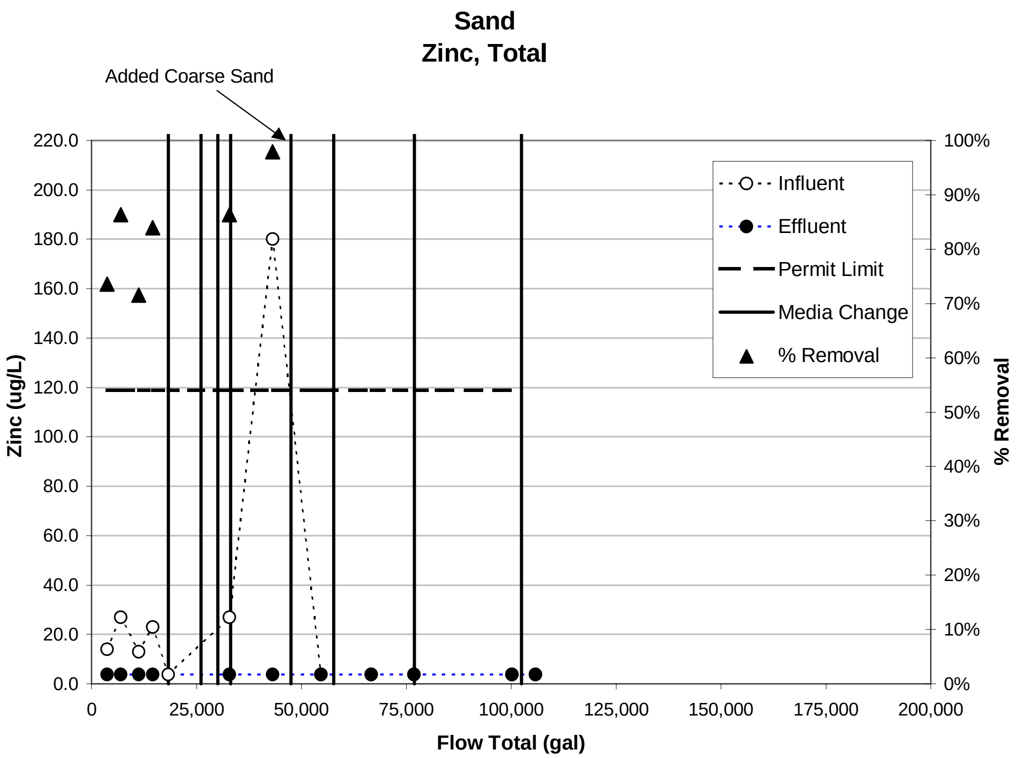

Peat Moss
Manganese, Total
Replace with Peat Moss/Perlite Mixture
Wet-Dry Cycle Started
Manganese (ug/L)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
% Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Flow Total (gal)
Influent
Effluent
Permit Limit
Media Change
% Removal

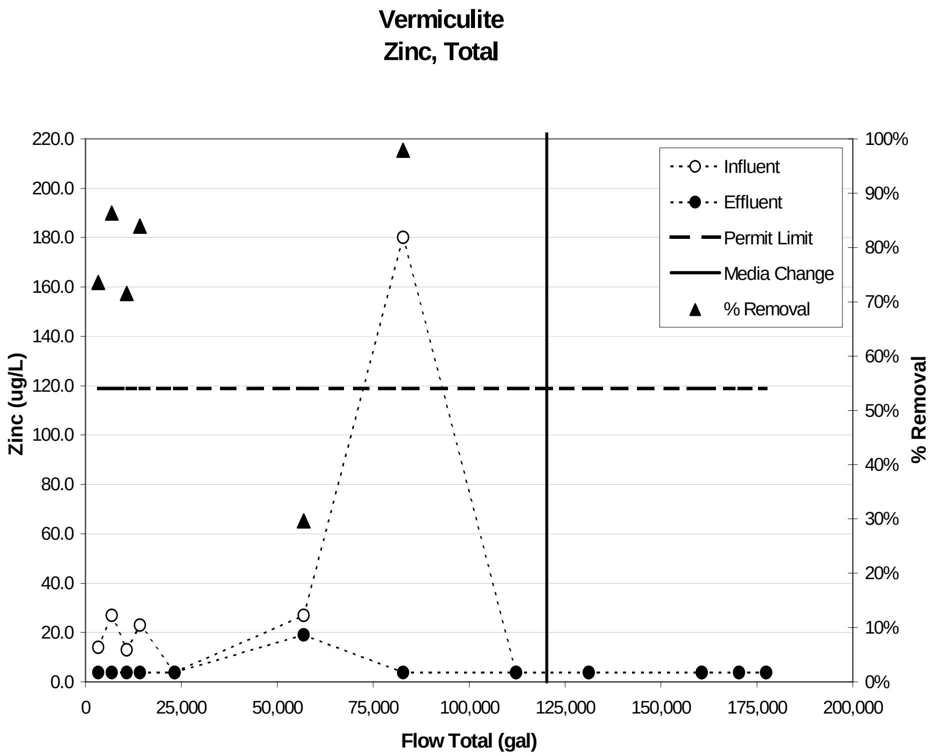

Leaf Compost
Manganese, Total
Wet-Dry Cycle Started
Manganese (ug/L)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
% Removal
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Flow Total (gal)
Influent
Effluent
Permit Limit
Media Change
% Removal

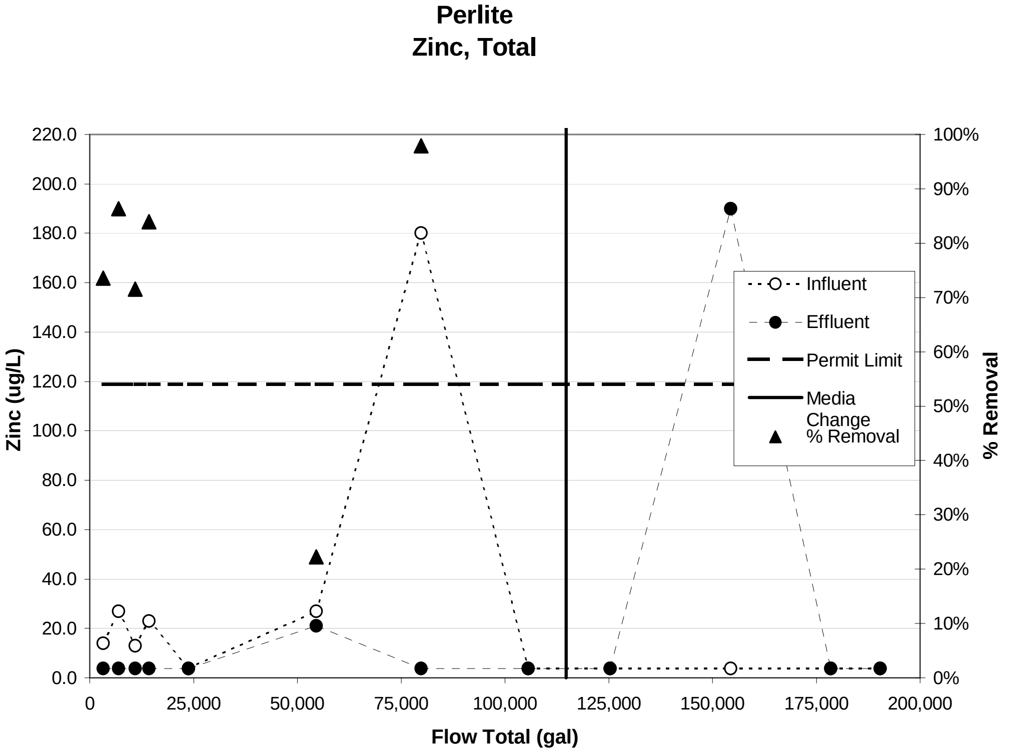
Bag Filter
Manganese, Total

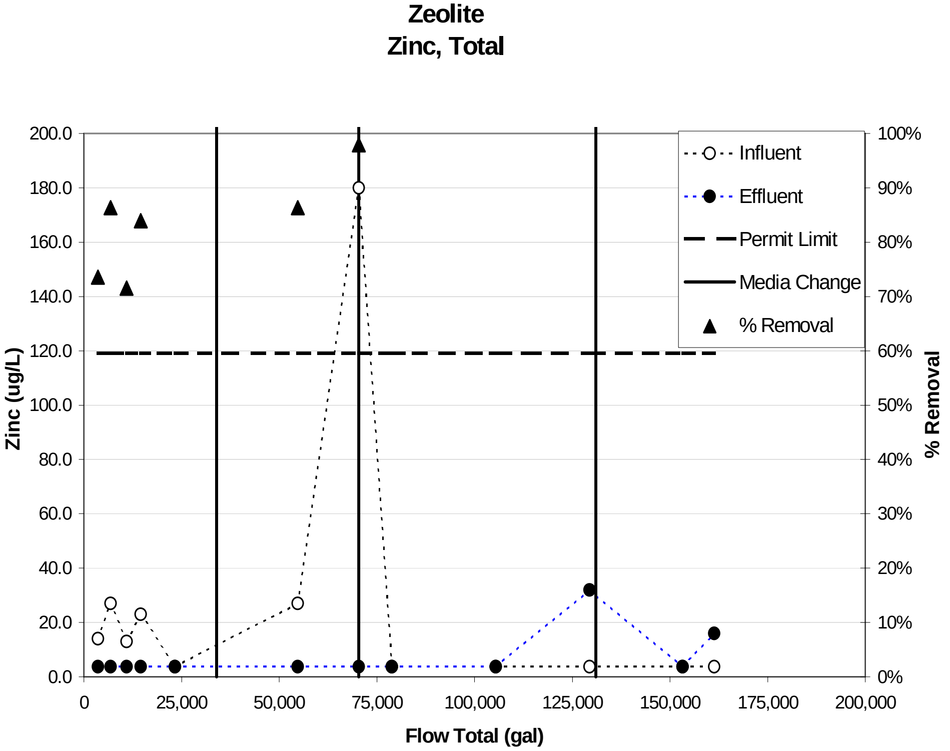


Influent total manganese concentrations were consistently above the permit limit of 50 μg/L. Sand, zeolite and activated carbon were both effective at removing manganese concentrations with 67%, 53% and 50% removal, respectively. Zeolite and leaf compost were both moderately effective at removing total manganese, but leaf compost appeared to reach breakthrough after about 62,000 gallons of flow volume. Vermiculite, perlite, barley straw and peat moss were not effective at removing total manganese. The maximum total recoverable manganese detection limit was 7 μg/L.

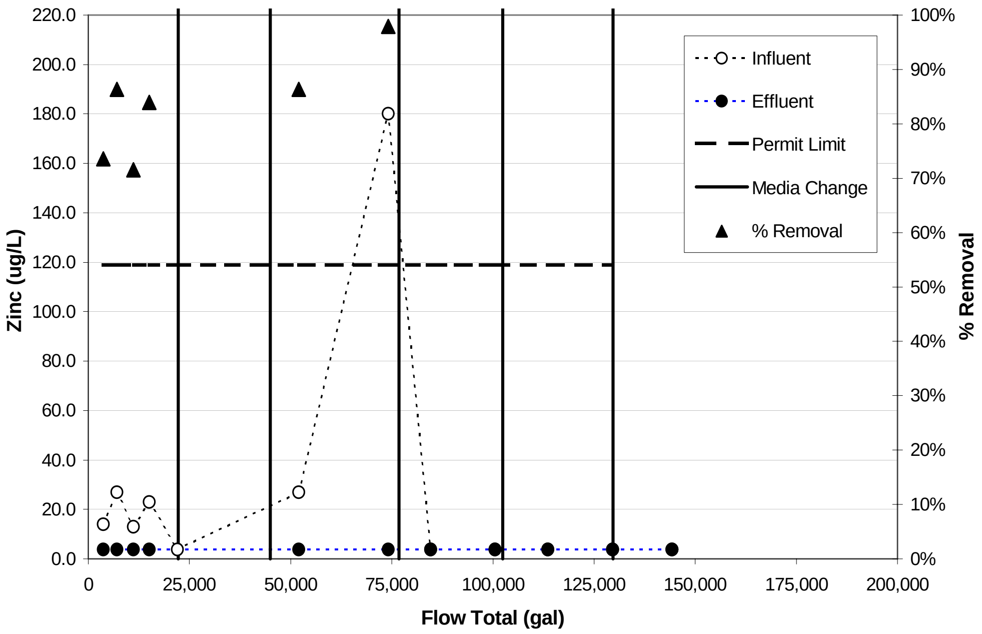

Sand
Zinc, Total


Vermiculite
Zinc, Total

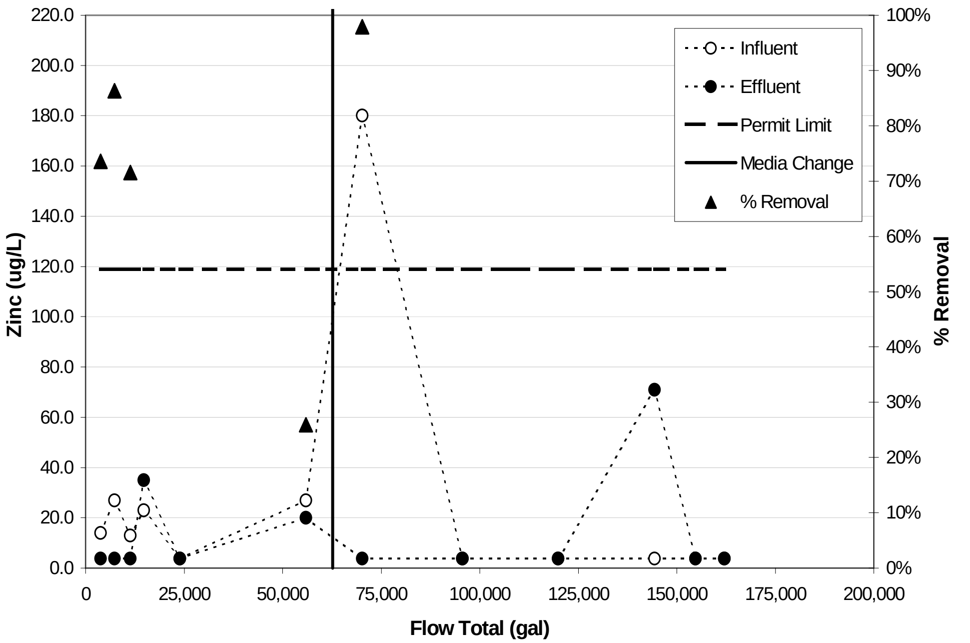

Perlite
Zinc, Total


Zeolite
Zinc, Total

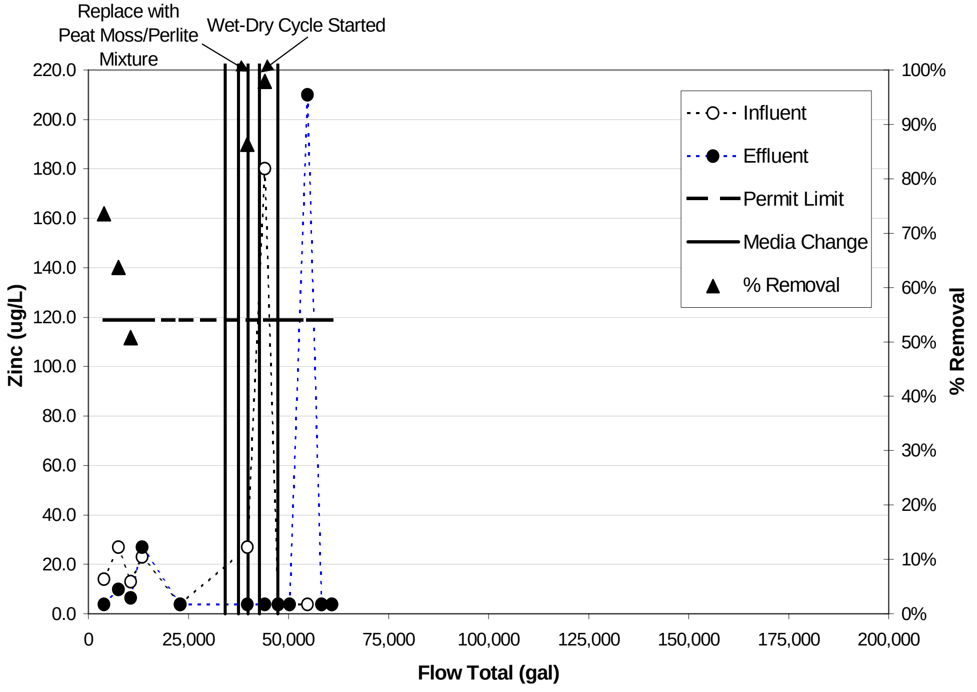
Activated Carbon
Zinc, Total



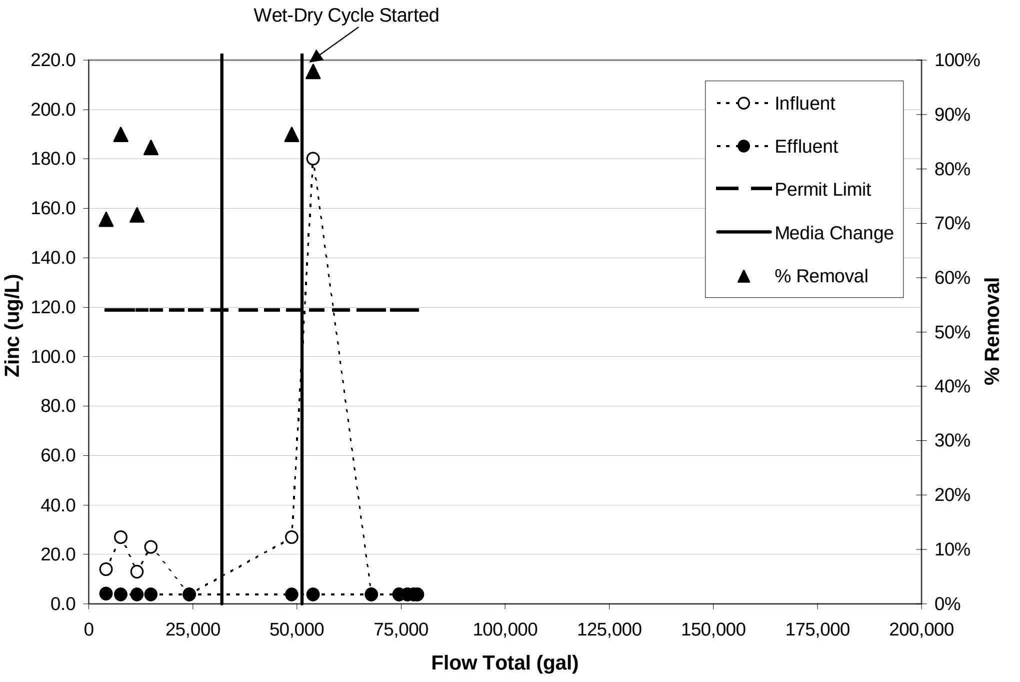
Barley Straw
Zinc, Total

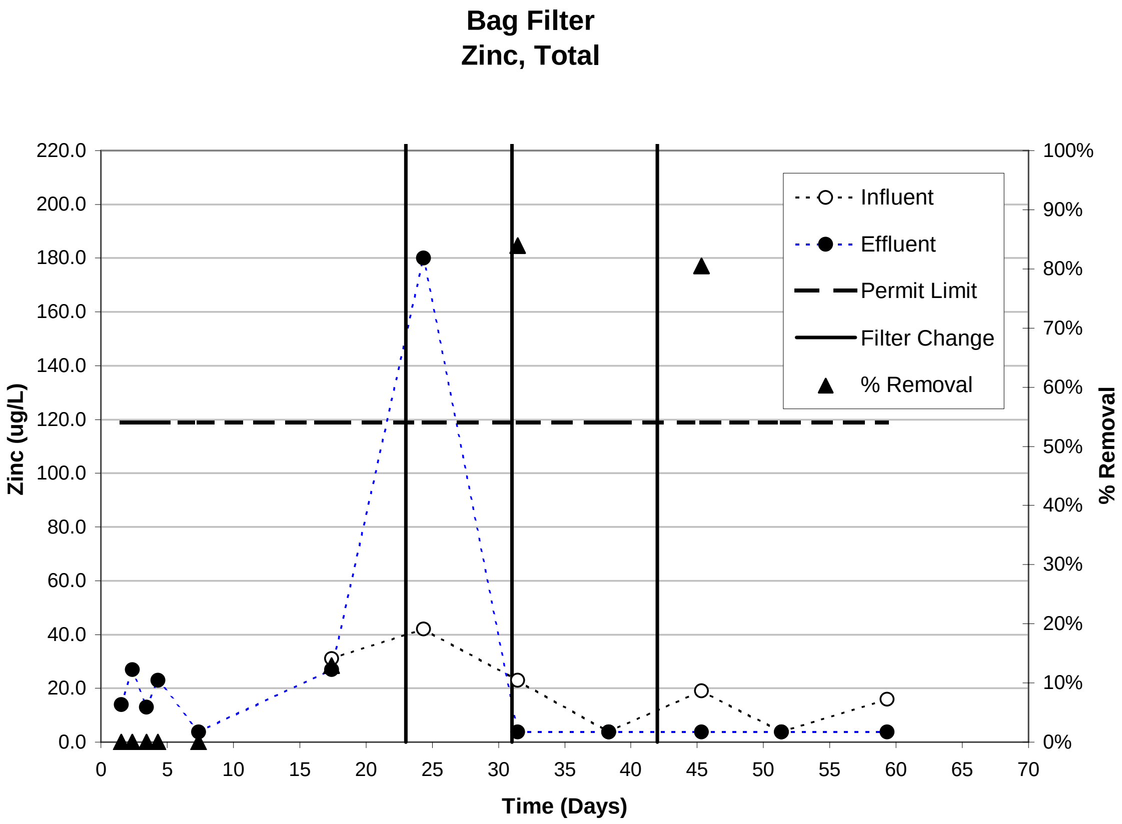


Peat Moss
Zinc, Total



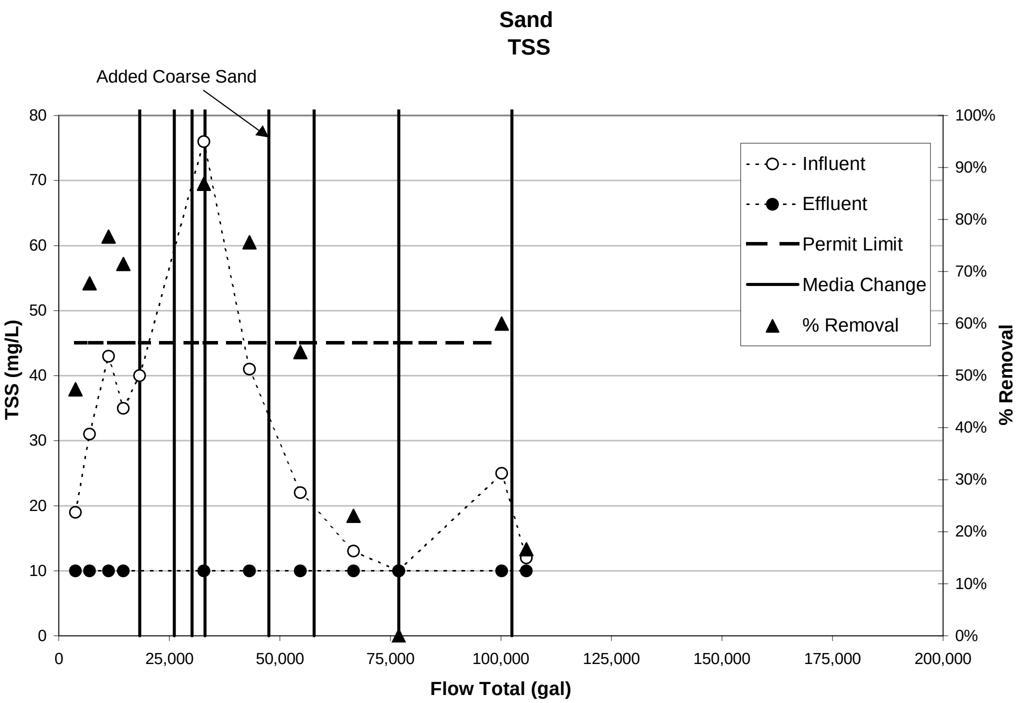
Leaf Compost
Zinc, Total

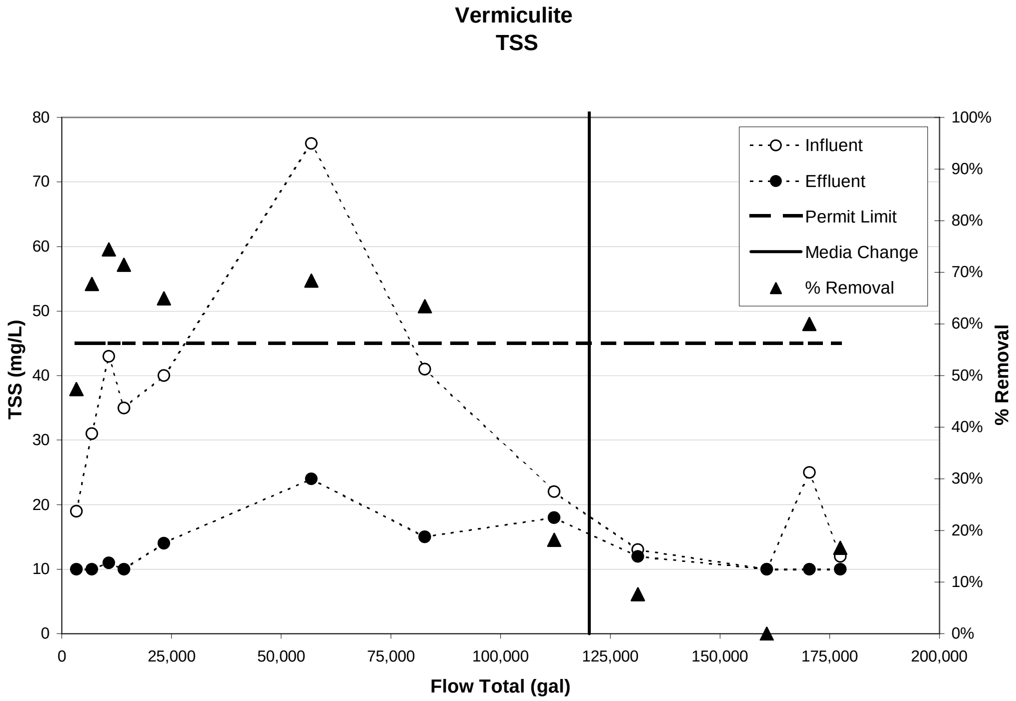


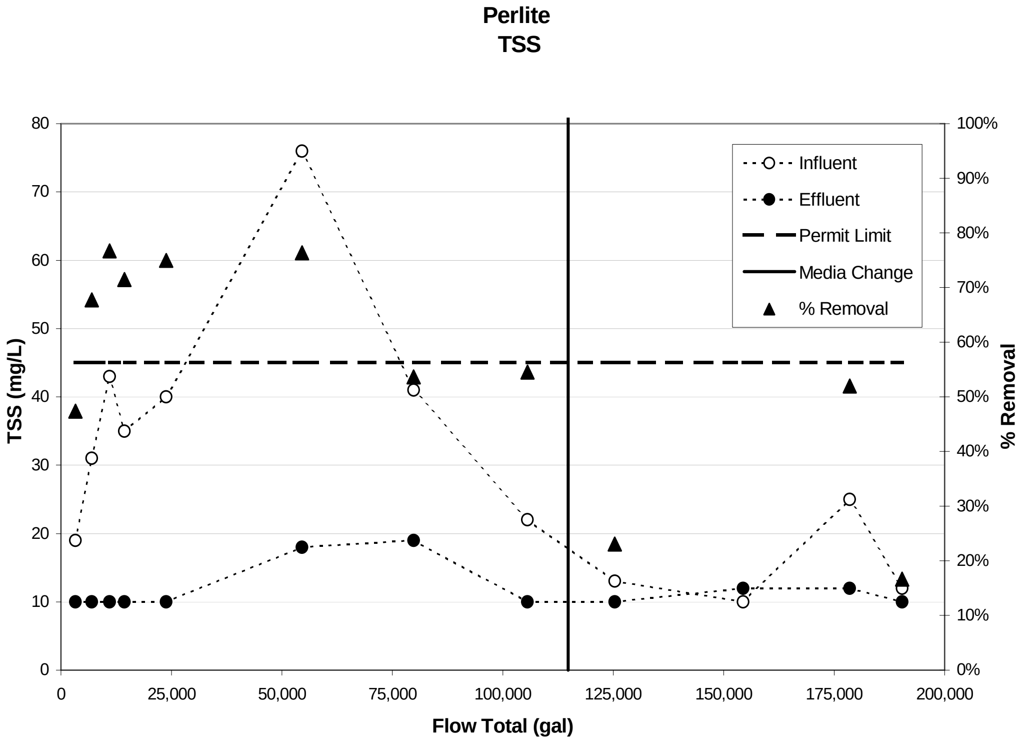


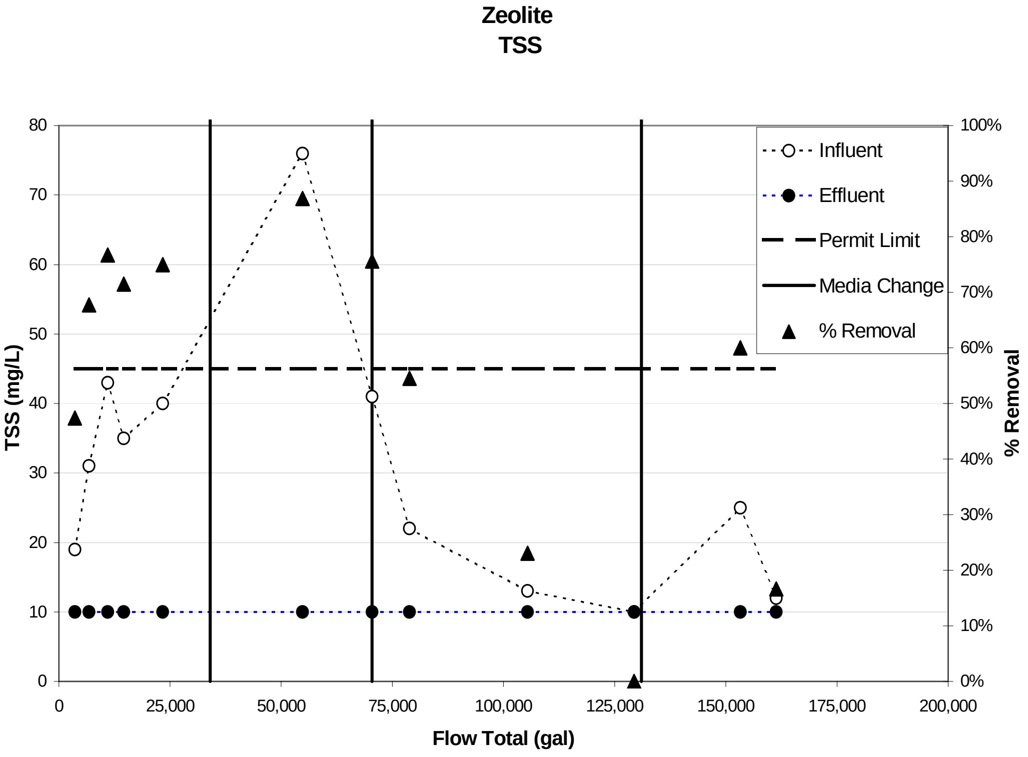
Other than one sample, all influent total zinc concentrations were below the daily maximum permit limit of 120 μg/L. Sand, vermiculite, perlite, zeolite, activated carbon and leaf compost all removed total zinc to concentrations at or close to detection limit concentrations, with removal percentages ranging from 73%-83%. Barley straw and peat moss were less effective at removing total zinc with removal percentages of 59% and 62%, respectively. The maximum detection limit for total zinc was 3.7 μg/L.

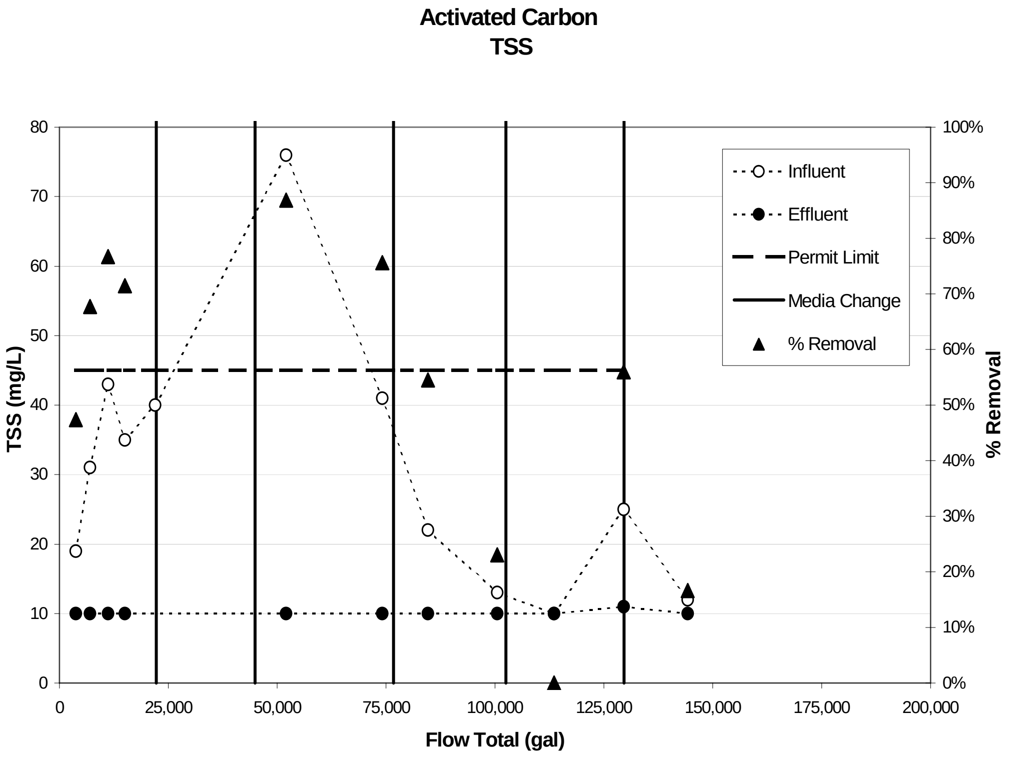
5.2. TSS and Turbidity Removal

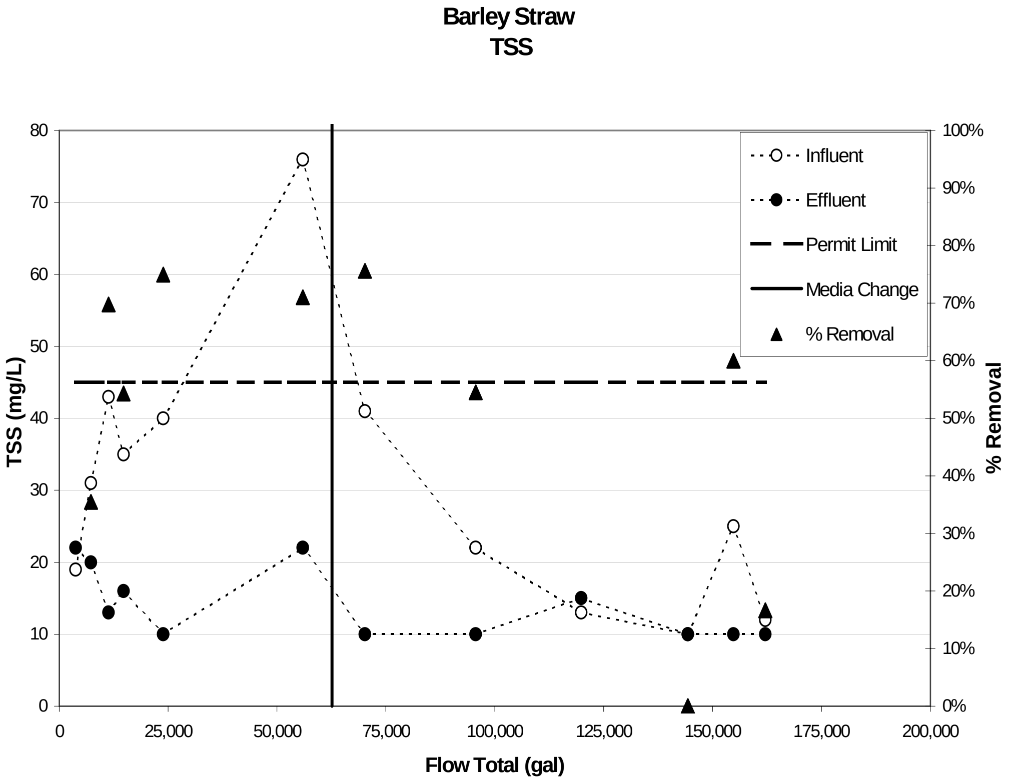

Sand
TSS

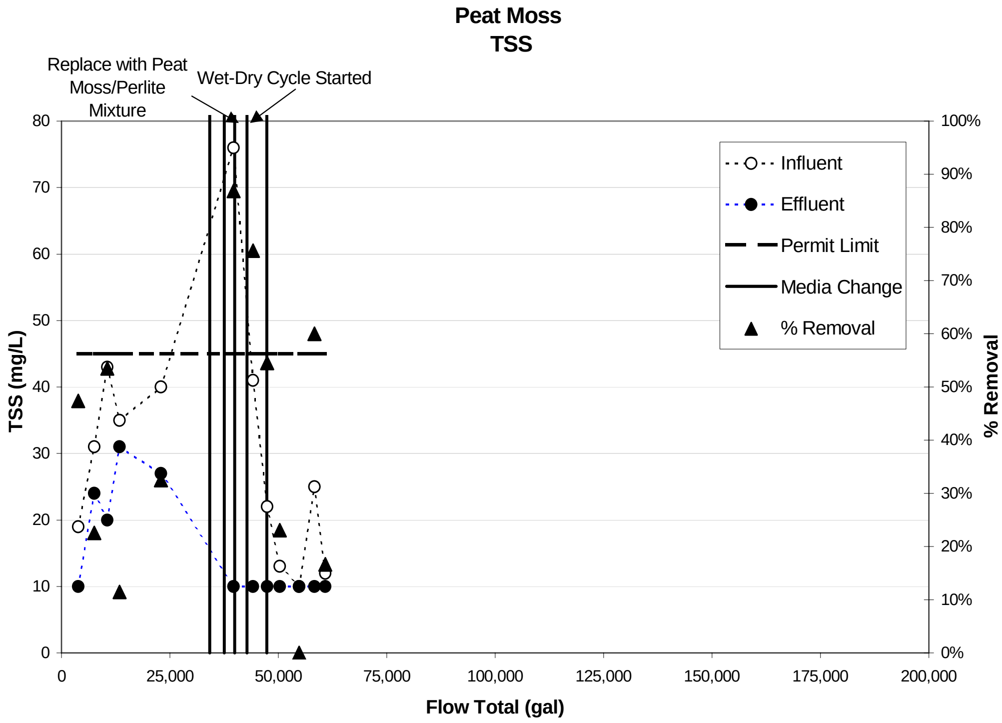

Vermiculite
TSS

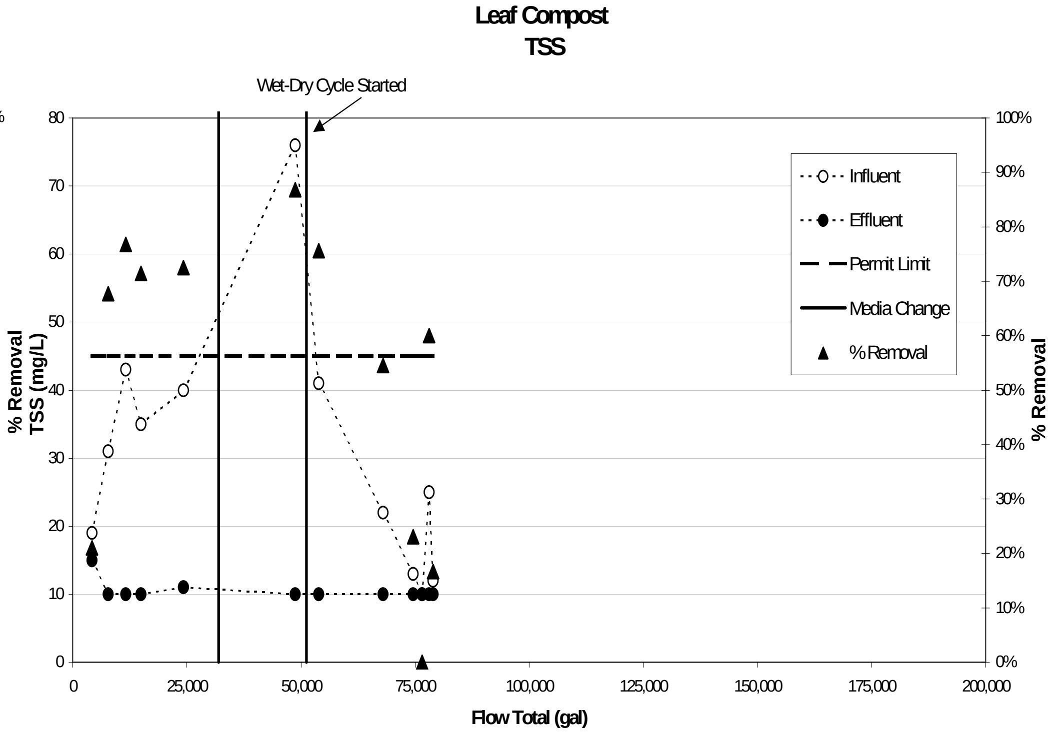

Perlite
TSS


Zeolite
TSS


Activated Carbon
TSS
TSS (mg/L)
% Removal
Flow Total (gal)
0
10
20
30
40
50
60
70
80
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal


Barley Straw
TSS
TSS (mg/L)
% Removal
Flow Total (gal)
0
10
20
30
40
50
60
70
80
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal


Peat Moss
TSS
Replace with Peat Moss/Perlite Mixture
Wet-Dry Cycle Started
TSS (mg/L)
% Removal
Flow Total (gal)
0
10
20
30
40
50
60
70
80
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
125,000
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal


Leaf Compost
TSS
Wet-Dry Cycle Started
% Removal
TSS (mg/L)
% Removal
Flow Total (gal)
0
10
20
30
40
50
60
70
80
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
25,000
50,000
75,000
100,000
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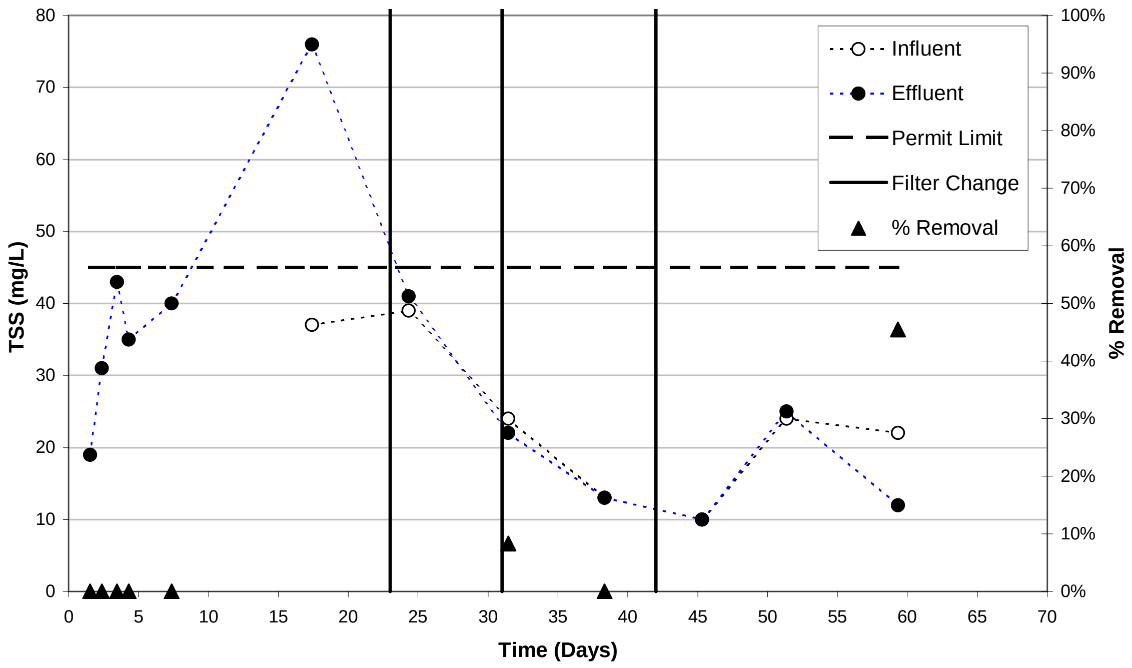
150,000
175,000
200,000
Influent
Effluent
Permit Limit
Media Change
% Removal

Bag Filter
TSS



While all media removed total suspended solids significantly, total suspended solids concentrations were reduced to nondetect levels for sand, zeolite, activated carbon and leaf compost. Although higher removal percentages might be possible with higher influent concentrations, total suspended solids removal down to nondetect levels represents at least a 50% reduction in TSS concentrations. Peat moss exhibited poor TSS removal after the first 5 samples were taken, but removed TSS down to nondetect levels after it was replaced with a peat moss/perlite mixture. The maximum detection limit for TSS was 10 mg/L.

The bag filter influent and effluent data showed that the bag filters appeared ineffective at removing TSS. Influent and effluent TSS concentrations were very similar throughout the period for which data was available. This is a surprising result because it implies that using smaller micron filter bags did not change TSS removal from the filter bags.

An important design parameter is the amount of TSS that a filter media can remove before clogging. For each media replacement event, the amount of TSS removed per new media volume was calculated using the following equation.

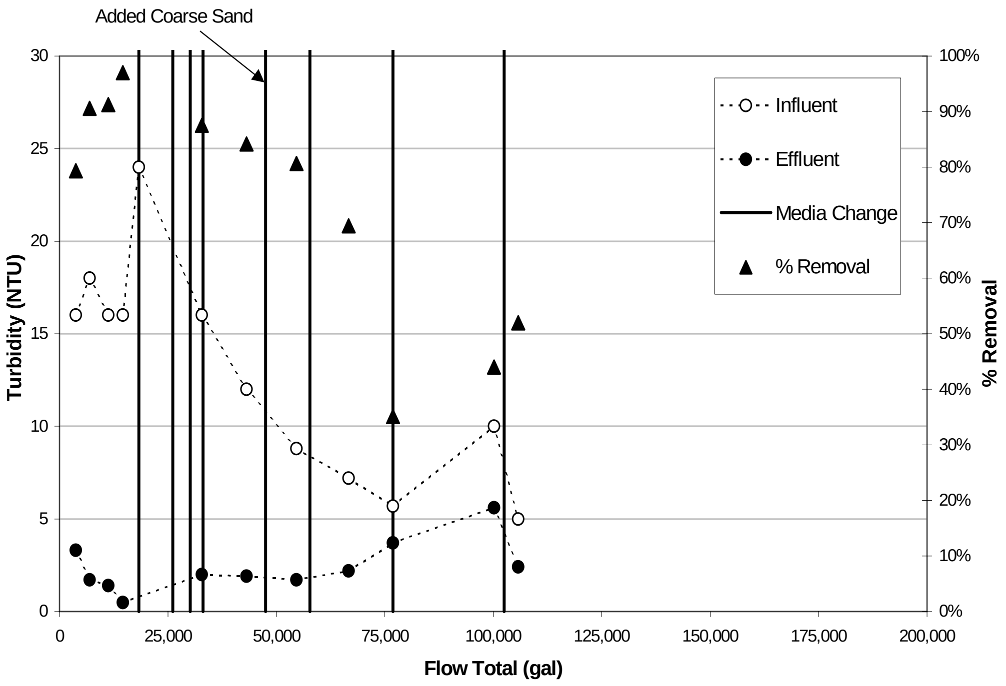
$$\frac{TSS_{removed}}{V_{Media\_replaced}} = \frac{\left(TSS_{Influent} - TSS_{Effluent}\right) * (V_{FlowTotal})}{(V_{Media\,\mathrm{Re}\,placed}) * 1000 * 1000}$$

where

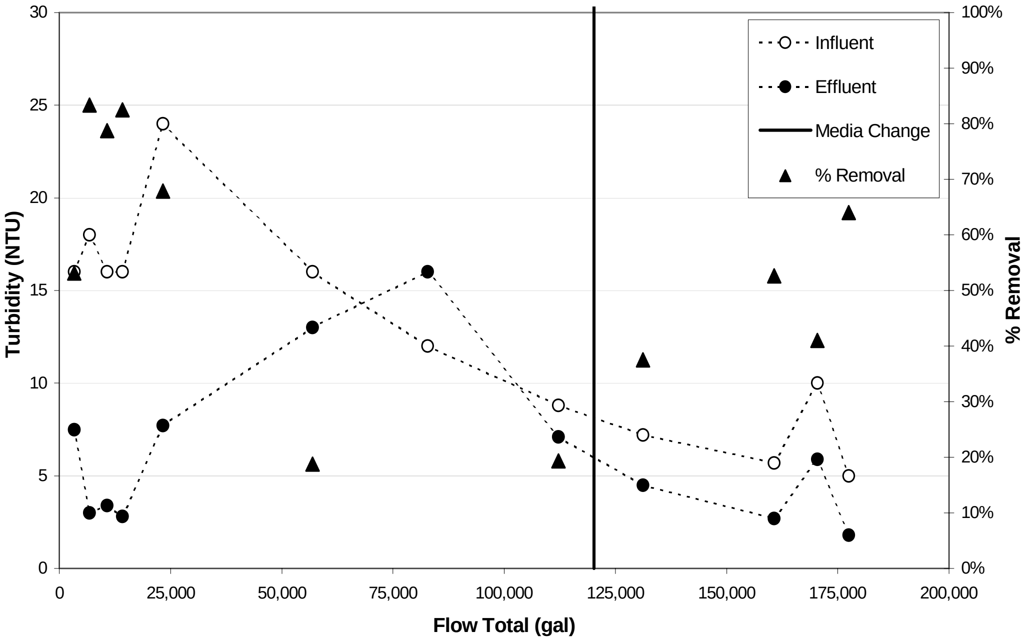
$TSS_{removed}$ = Mass of TSS removed (kg)
$TSS_{Influent}$ = Influent TSS concentration (mg/L)
$TSS_{Effluent}$ = Effluent TSS concentration (mg/L)
$V_{FlowTotal}$ = Total flow volume (L)
$V_{Media\_replaced}$ = Volume of media replaced (ft^3)

The total flow volume was the volume of flow that occurred between a media replacement event (or the start of the pilot test) and the succeeding media replacement event. The time between the last media replacement and the end of the pilot test was not included. TSS concentrations were assumed to be equal to the TSS concentration during the subsequent sampling event. Thus, all flow that occurred between the 8/3/06 sampling event and the 8/10/06 sampling event was assumed to have the TSS concentration measured at the 8/10/06 sampling event. Nondetect samples were assumed to be equal to the maximum detection limit for each constituent. The average mass of TSS removal per new media volume is shown in **Figure 17.** The minimum and maximum TSS removal per new media volume are shown with the error bars. The number on the upper right of each column shows the number of media replacement events.

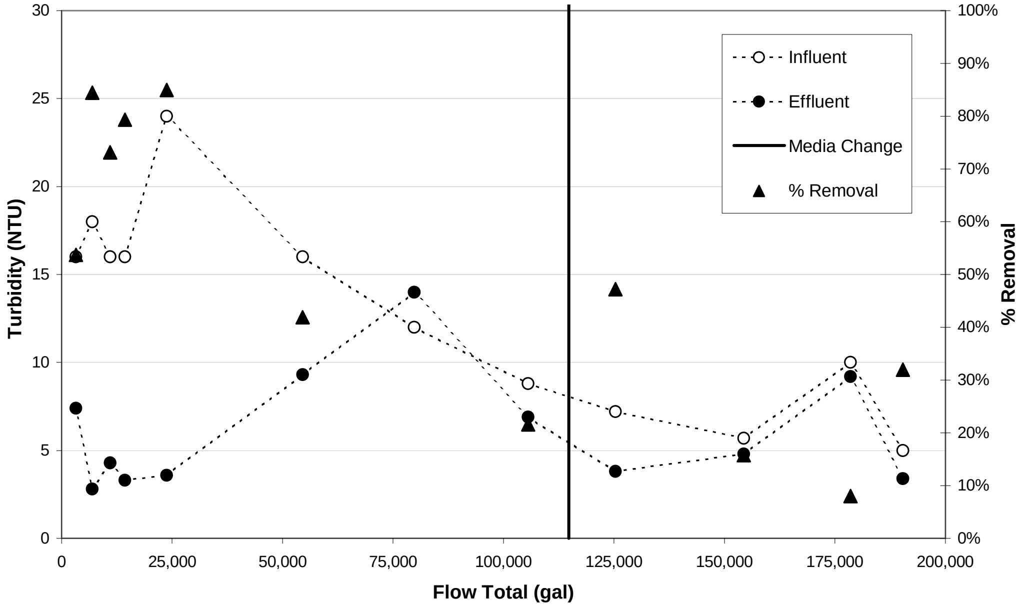
Perlite, vermiculite and barley straw showed the highest average removal of TSS per media volume at 2.64, 2.49 and 1.95 kg TSS removed/ft^3 media, respectively. The level of variance from these results cannot be calculated because only one media replacement event occurred for each of these media. On average, zeolite, leaf compost and activated carbon had TSS removal per media volume between 0.7-1.2 kg TSS removed/ft^3 media. Zeolite and activated carbon exhibited a large variance in TSS removal throughout the pilot test. Sand and peat moss had the lowest TSS removals per volume at 0.46 and 0.31 kg TSS removed/ft^3 media. The lower TSS removals per volume for sand, activated carbon, zeolite and leaf compost can be explained by their lower flow rates. The high TSS removal efficiency of sand, zeolite, activated carbon and leaf compost caused a greater occurrence of clogging. Greater clogging caused lower flow rates, which reduced total TSS removal over the course of the pilot test.



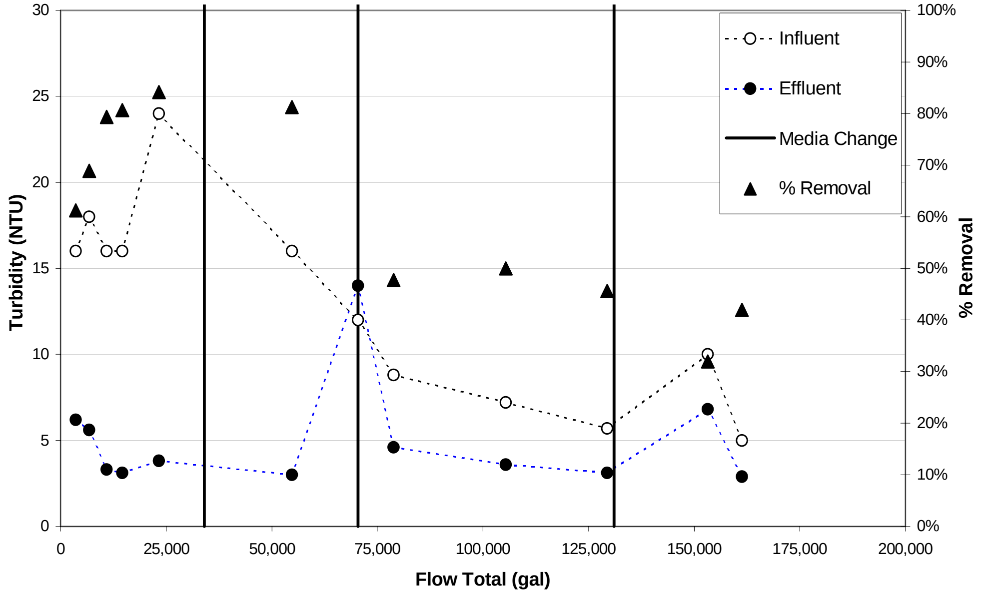
Sand Turbidity



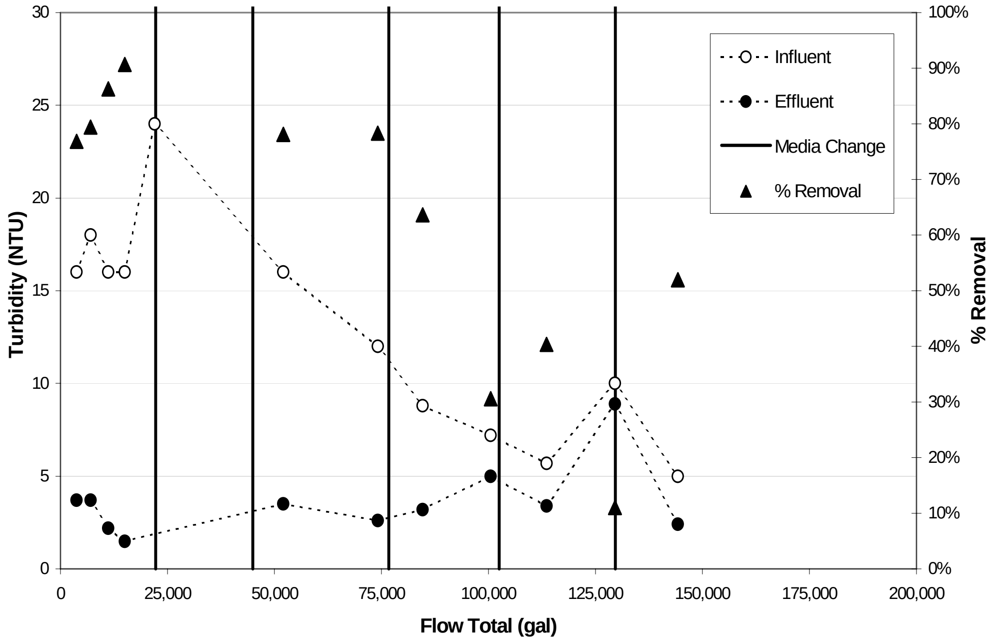
Vermiculite Turbidity



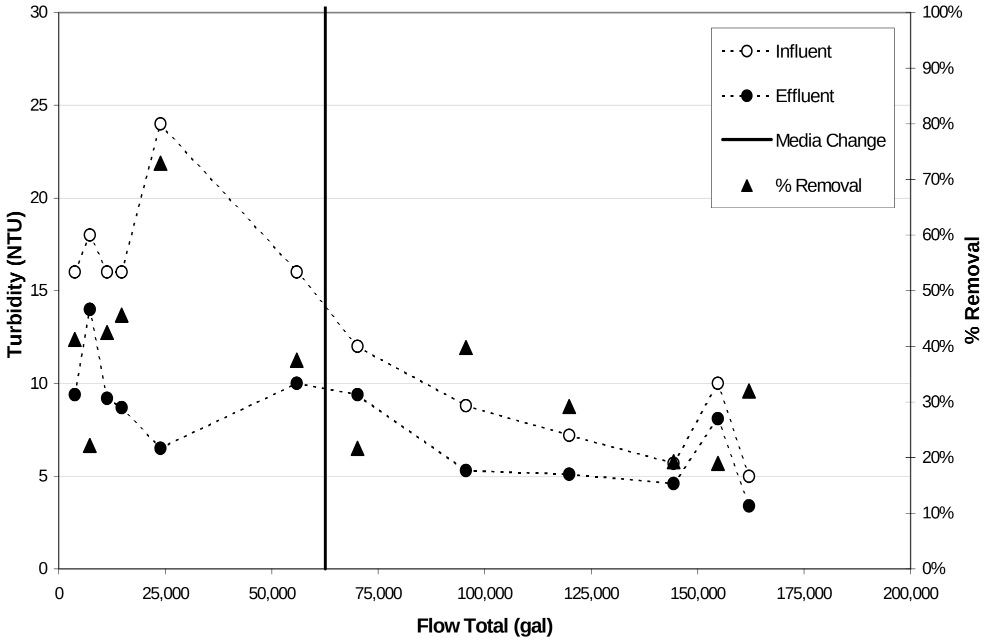
Perlite Turbidity



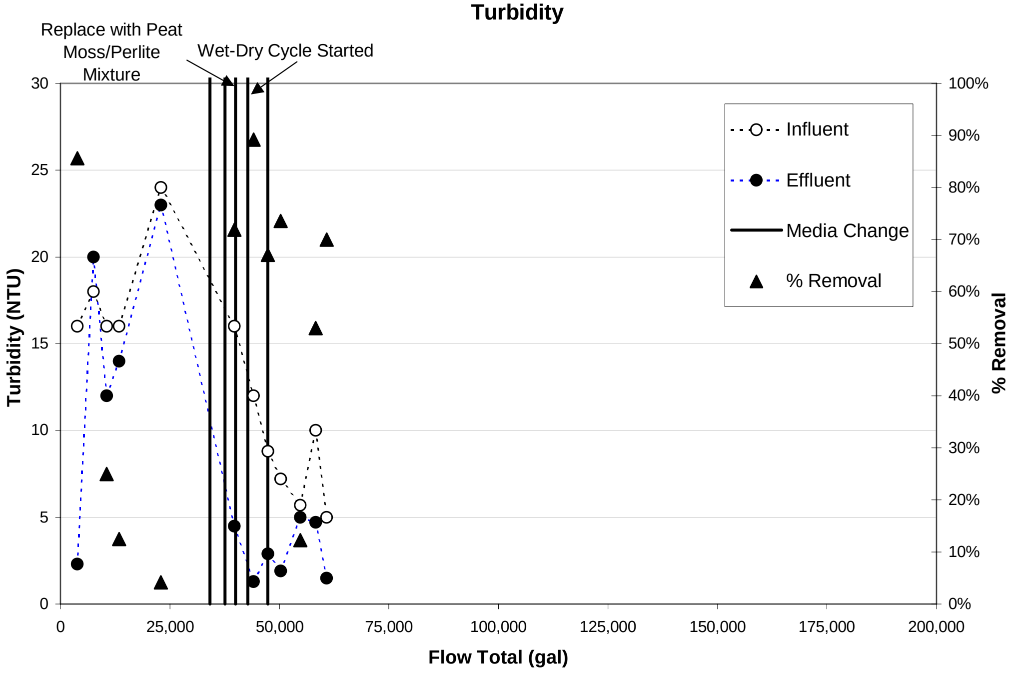
Zeolite Turbidity



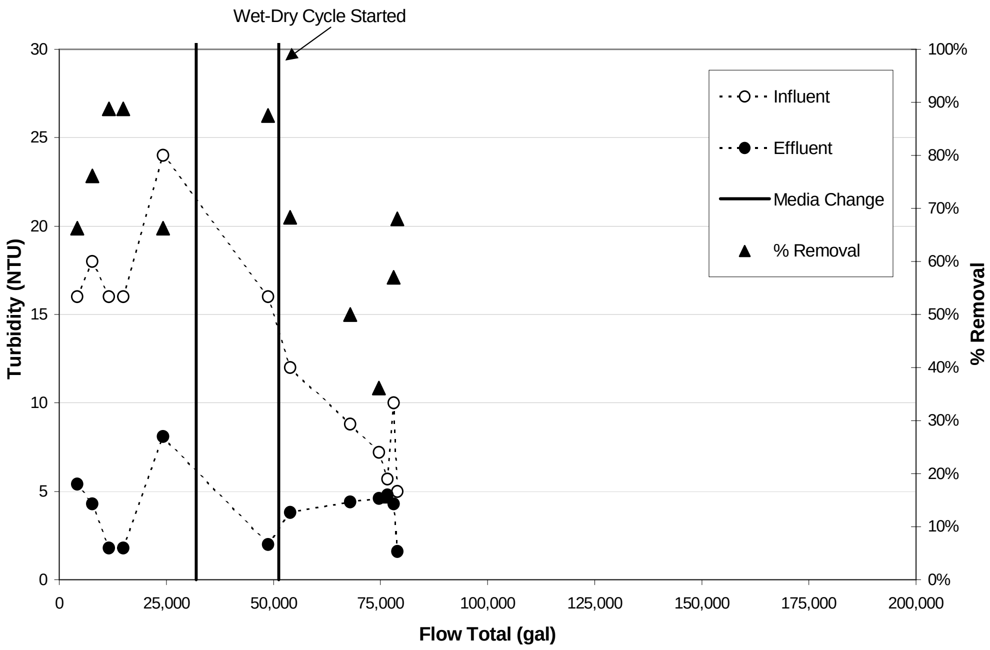
Activated Carbon
Turbidity



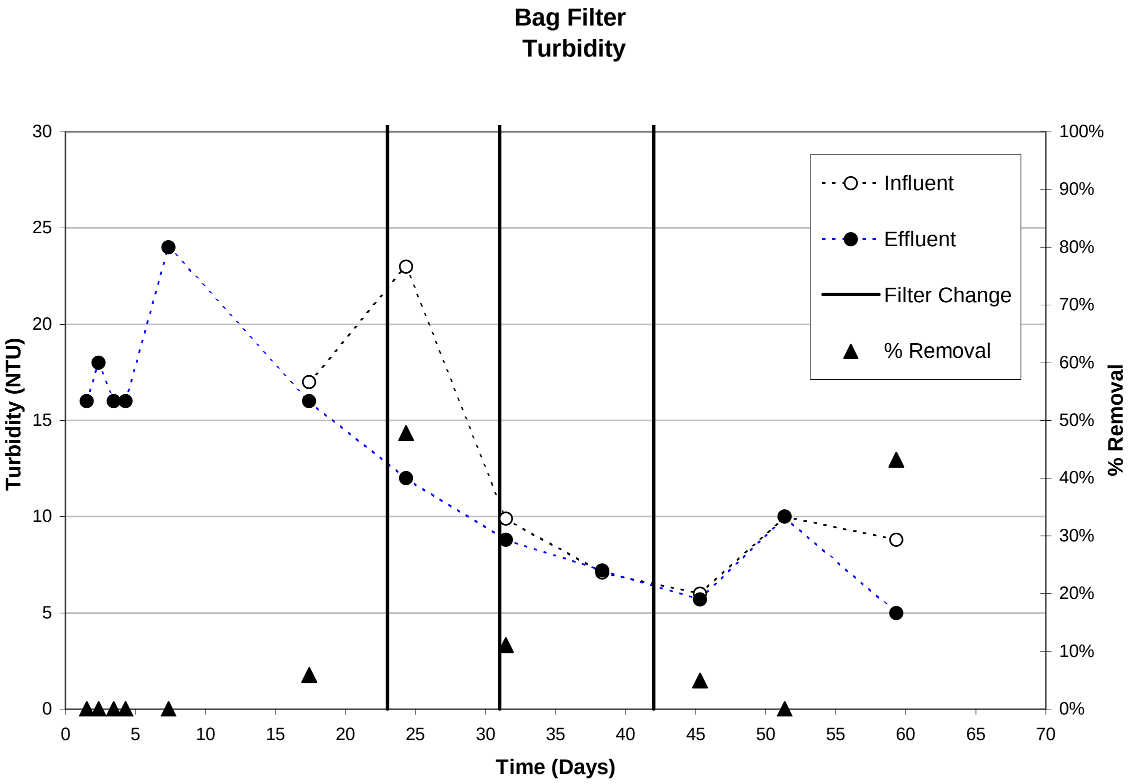
Barley Straw
Turbidity



Peat Moss
Turbidity



Leaf Compost
Turbidity



Sand was the most effective at removing turbidity with 74% removal. Sand was followed by leaf compost, activated carbon and zeolite media with 64%, 62% and 55% removal, respectively. Similar to the TSS data, bag filter influent and effluent turbidity concentrations were predominantly equal. But since bag filters are not intended to remove smaller, colloidal particles, little removal in turbidity was expected. The maximum detection limit for turbidity was 0.04 NTU.

5.3. TCDD Removal

Samples for TCDD were taken three times during the pilot test on 7/18, 8/24 and 9/14. Results for TCDD TEQ with no DNQ (data not qualified) concentrations are shown in **Figure 18**. PT-INF2 refers to the TCDD TEQ concentration of the bag filter influent and PT-INF refers to the bag filter effluent before it reaches the filter drums. TCDD TEQ is calculated by multiplying each of the 17 TCDD congener concentrations with its respective TCDD toxicity equivalent quotient. Since TCDD

TEQ is a calculation based on 17 different congeners, there is technically no detection limit for TCDD TEQ. Nondetect values were assumed to equal the minimum TEQ reporting limit for all congeners which is 5×10^{-9} μg/L. This reporting limit was calculated from the minimum reporting limits for OCDD and OCDF.

Of the 17 TCDD congeners, all but two congeners, OCDD and OCDF showed nondetect values for all samples. OCDD and OCDF concentrations are shown in **Figure 19** and **Figure 20**. The reporting limit for both OCDD and OCDF was 5×10^{-5} μg/L. Comparing **Figure 18**, **Figure 19** and **Figure 20** shows that TCDD TEQ values were predominantly driven by OCDD concentrations.

Samples taken on 7/18/06 showed greater than 95% removal of TCDD TEQ from the pond water influent by all filtration media. Sand and peat moss had especially high removals. Sand, peat moss and leaf compost reduced OCDD concentrations by 78%, 75%, and 64%, respectively. The other media reduced OCDD concentrations by 38-56%. Vermiculite, barley straw and leaf compost reduced OCDF concentrations by 30-40%. Sand reduced OCDF concentrations by 28%. Perlite, zeolite, activated carbon and peat moss showed nondetect values for OCDF. No sample was taken for PT-INF2 on 7/18/06.

On 8/24/06, all filtration media reduced TCDD concentrations, with sand, activated carbon, zeolite and peat moss showing nondetect values for TCDD TEQ, representing a greater than 52% removal. Barley straw, on the other hand, only had 25% removal of TCDD TEQ. Sand, activated carbon and leaf compost reduced OCDD concentrations by 67-72%. All OCDF samples taken on 8/24/06 showed nondetect results on 8/24/06.

On 9/14/06, the PT-INF influent TCDD TEQ concentrations were nondetect. But TCDD TEQ concentrations from the sand media, which had exhibited effective TCDD removal in the previous two samples, were more than 53 times the reporting limit for TCDD TEQ and 2 times the influent concentration for OCDD. Vermiculite, perlite, zeolite, activated carbon and barley straw had TCDD TEQ concentrations close to or below nondetect levels and reduced OCDD to below the reporting limit, achieving 60-77% removal of OCDD. Peat moss and leaf compost TCDD data for 9/14/06 was not available because data had not been released from the laboratory at the time of the writing of this report.

5.4. Uncertainty Analysis

One set of duplicate samples was taken from a different filter media each sampling event. **Table 9** lists which duplicate samples were taken for each sampling date.

Table 9
Duplicates Sampling Schedule

Sampling Date	Media
7/18/2006	Sand
7/19/2006	Activated Carbon
7/20/2006	Zeolite
7/24/2006	Perlite
8/3/2006	Vermiculite
8/10/2006	Peat Moss-Perlite
8/17/2006	Barley Straw
8/24/2006	Leaf Compost
8/31/2006	Sand
9/6/2006	Activated Carbon
9/14/2006	Zeolite

The mean of the standard deviation for all duplicate pairs was calculated for each constituent analyzed. **Table 10** shows the mean standard deviation, mean concentration and the ratio of mean standard deviation and mean concentration as a percentage for each constituent analyzed.

Table 10
Average Standard Deviation and Mean Concentration

Analyte	Units	Max Detection Limit	Mean Concentration	Mean Standard Deviation	Mean Standard Deviation / Mean Concentration
Organics					
TCDD TEQ (No DNQ)	µg/L	5.00E-09	7.74E-09	1.5E-09	19.0%
Oil and Grease	mg/L	0.94	9.43E-01	3.9E-03	0.4%
Total Organic Carbon	mg/L	0.50	1.14E+01	5.8E-01	5.1%
Inorganics					
Density	g/cc		9.90E-01	5.8E-03	0.6%
Sediment Concentration	mg/L	10	1.13E+01	6.4E-02	0.6%
TSS	mg/L	10	1.13E+01	6.4E-02	0.6%
Turbidity	NTU	0.040	4.85E+00	3.9E-01	7.9%
TDS	mg/L	10	3.73E+02	8.4E+00	2.2%
Ammonia-N	mg/L	0.30	1.28E+00	6.2E-01	48.5%
Nitrate-N	mg/L	0.080	8.48E-02	1.2E-03	1.4%
Nitrite-N	mg/L	0.080	8.00E-02	0.0E+00	0.0%
NO3+NO2 -N	mg/L	0.080	8.48E-02	1.2E-03	1.4%
TKN	mg/L	0.43	2.82E+00	1.4E+00	50.8%
Sulfate	mg/L	4.5	8.46E+01	1.2E+00	1.4%
Alkalinity	mg/L	2.0	1.84E+02	3.9E+00	2.1%
Conductivity	umhos/cm	1.0	6.44E+02	1.1E+01	1.7%
Hardness	mg/L	1.0	2.13E+02	2.6E+00	1.2%
PH	pH Units		7.77E+00	3.9E-02	0.5%
Metals					
	µ				
Antimony, Diss	µ	0.050	4.94E-01	4.1E-02	8.3%
Arsenic	µ	4.4	5.30E+00	7.1E-01	13.5%
Arsenic, Diss	µ	4.4	5.06E+00	4.8E-01	9.4%
Beryllium	µ	0.90	9.00E-01	0.0E+00	0.0%
Beryllium,Diss	µ	0.90	9.18E-01	2.6E-02	2.8%
Cadmium	µ	0.025	3.94E-02	2.0E-02	51.7%
Cadmium, Diss	µ	0.025	3.06E-02	9.0E-04	2.9%
Chromium	µ	2.0	2.00E+00	0.0E+00	0.0%
Chromium, Diss	µ	2.0	2.00E+00	0.0E+00	0.0%
Copper	µ	0.49	1.25E+00	2.7E-01	21.4%
Copper, Diss	µ	0.25	1.90E+00	9.5E-01	50.1%
Iron	mg/L	0.015	2.43E-01	1.5E-02	6.2%

Analyte	Units	Max Detection Limit	Mean Concentration	Mean Standard Deviation	Mean Standard Deviation / Mean Concentration
Iron, Diss	mg/L	0.015	1.75E-02	2.6E-04	1.5%
Lead	µ	0.13	3.79E-01	4.6E-02	12.2%
Lead, Diss	µ	0.040	6.76E-02	3.0E-02	44.5%
Manganese	µ	7.0	1.22E+02	4.0E+00	3.3%
Manganese,Diss	µ	7.0	8.91E+00	2.7E+00	30.3%
Mercury	µ	0.15	1.50E-01	0.0E+00	0.0%
Mercury, Diss	µ	0.15	1.50E-01	0.0E+00	0.0%
Nickel	µ	2.0	2.31E+00	7.7E-02	3.3%
Nickel, Diss	µ	2.0	2.31E+00	3.2E-01	13.9%
Selenium	µ	0.36	4.25E-01	6.1E-02	14.4%
Selenium, Diss	µ	0.30	4.50E-01	4.0E-02	9.0%
Silver	µ	0.089	8.96E-02	2.5E-02	27.9%
Silver, Diss	µ	0.025	2.52E-02	3.2E-04	1.3%
Thallium	µ	0.15	1.53E-01	2.0E-02	12.9%
Thallium, Diss	µ	0.15	1.61E-01	1.1E-02	6.8%
Zinc	µ	3.7	7.00E+00	2.7E+00	38.5%
Zinc, Diss	µ	15	1.51E+01	1.3E-01	0.9%

A large majority of constituents have ratios of mean standard deviation to mean concentrations below 10%. Constituents with a high mean standard deviation relative to their mean concentration include ammonia-N, total Kjeldahl nitrogen, total cadmium, dissolved copper, dissolved lead, dissolved manganese and total zinc. Despite the samples that show a wide difference between sample and duplicate, the uncertainty analysis indicates that data accuracy is adequate for analysis.

5.5. Comparing Pilot Test Conditions with Outfall Conditions

Although the pilot test was designed to mimic conditions at the outfalls, there are key differences that affect how data from the pilot test should be interpreted and applied to storm water conditions at the outfalls.

First, as mentioned before, algae in the pond created high organic loadings in the pilot test influent that are unlikely to be present at the outfalls. Many metals have been shown to bind to the cell wells of algae to form organometallic complexes, including copper, lead, cadmium, chromium, iron, mercury, nickel and zinc (Trolope and Evans, 1976) (Davis et al., 2003). Thus, much of activated carbon's metal removal capability is likely through adsorption of algae that has metals bound to it; a mechanism that will occur to a lesser extent during storm water flows at the outfalls.

Second, dissolved metals concentrations in the pond water influent are near or below detection levels implying that most of the metals in the influent reside in the solids matrix. These low concentrations may underestimate dissolved metals concentrations near the outfalls. Data from the outfalls show that dissolved metals concentrations can comprise a significant portion of total metals concentrations. Filter media that remove dissolved metals concentrations, such as zeolite, peat moss and leaf compost, are likely to have higher metals removal efficiency at the outfalls than with the pilot test.

Third, although zeolite was expected to remove nitrogen species effectively, concentrations in the pond water were too low to gauge ammonia, nitrate and nitrite removal effectiveness. Despite these low concentrations in the pilot test, Nitrate + Nitrite-N exceedances have occurred onsite in the past, implying that effective nitrogen removal could be important in meeting NPDES compliance objectives at some outfalls.

Fourth, although steady state flow rates from pond water provided controlled conditions to analyze pollutant removal efficiency, storm water flows vary widely depending on the storm rainfall, duration and intensity. Flow characteristics affect the hydraulics through the BMP filtration media and constituent removal capability.

Finally, storm flows in actual BMP watercourses will have higher loads of sediments with larger particle sizes and debris than in the pond water. Sediments in pond water predominantly consist of smaller particles of algae and humic materials. Furthermore, pretreatment with 10-micron filter bags, which were used for the pilot test in order to reduce clogging from algae and other solids, is not feasible at the outfalls. As a result, the role of pretreatment filtration will be even more important in actual BMP application.

6.0. CONCLUSIONS AND RECOMMENDATIONS

- Metals concentrations that were reduced significantly by the filtration media included total copper, total iron, total lead and total manganese. Sand media was the most effective against removing heavy metals, especially for metals adsorbed in the solid matrix. It is believed that zeolite will remove dissolved metals the best due to its high ion exchange capacity, but influent dissolved metals concentrations were too low to confirm this.

- Activated carbon, sand and zeolite were effective at removing total copper with 65%, 63% and 52% average total copper removal, respectively. Two of the activated carbon effluent samples showed nondetect values for total copper, implying that higher percentage removals were possible with higher influent concentrations.

- Sand and activated carbon were most effective at removing total lead with 78% and 74% average removal efficiency, respectively. Two sand effluent samples demonstrated lead removal down to nondetect levels.

- Sand, zeolite and activated carbon removed total iron by 60-80% and total manganese by 50-70%.

- Sand, vermiculite, perlite, zeolite, leaf compost and activated carbon filter drums all removed total zinc to concentrations at or close to the detection limit, with removal percentages ranging from 73%-83%.

- At least 50% TSS removal was achieved by almost all filtration media, but was not removed by the bag filters. Sand, activated carbon, zeolite and leaf compost in particular reduced TSS concentrations to nondetect levels on a consistent basis. Vermiculite, perlite and barley straw removed approximately 2 kg TSS per ft^3 media. Zeolite, activated carbon and leaf compost removed approximately 1 kg TSS per ft^3 media. Sand and peat moss removed less than 0.5 kg TSS per ft^3 media.

- TCDD TEQ data showed that zeolite, activated carbon and peat moss can provide roughly 52-98% reductions in TCDD TEQ concentrations. Sand also removed TCDD TEQ with similar effectiveness for two of the three sampling events, but exhibited concentrations much higher than influent TCDD TEQ concentrations on 9/14/06.

- Clogging is a major maintenance concern for any filtration treatment process. Sand and peat moss experienced the most frequent clogging incidents, while vermiculite and perlite experienced the least.

It is recommended that a multilayered media configuration would maximize removal effectiveness by utilizing multiple filtration pollutant removal mechanisms. A filtration media which uses physical straining as its main pollutant removal mechanism, such as sand or perlite, could be used to initially remove suspended solids. This could be followed by filtration media that removes dissolved constituents such as zeolite and activated carbon. Zeolite utilizes ion exchange capacity to remove dissolved metals constituents and some nitrogen species. Activated carbon removes pollutants through adsorption of organics (and subsequently the metal complexes that bind to such organics).

When comparing perlite and sand for their removal of total suspended solids, both media have their advantages. Sand was more effective at removing total suspended solids, achieving nondetect TSS values for all samples throughout the pilot test. TSS removal percentages with sand may be higher than shown in the pilot test if higher TSS influent concentrations occur. 4 out of 12 perlite effluent samples had TSS concentrations above the detection limit of 10 mg/L. TSS removal percentages for perlite effluent samples above the detection limit was 52-76%. Another downside of perlite is its buoyancy. The specific gravity of perlite is 0.1-0.4. Perlite runs the risk of being carried away with the storm water if it is not securely held within the filtration bed at the outfalls. The advantages of perlite are that it is cheaper than sand and would also clog less, requiring less maintenance costs. Perlite purchased for the pilot test cost approximately \$2.15/ft^3 compared to \$8.15/ft^3 for sand. More importantly, perlite allowed 114,751 gallons of flow volume before clogging, compared to 12,807 average gallons of flow volume for each clogging event for sand. Perlite also captured approximately 2.2 kg TSS/ft^3 media before clogging compared to 0.5 kg TSS/ft^3 for sand.

A sand/zeolite/activated carbon or a perlite/zeolite/activated carbon media configuration would utilize the physical straining of the sand or perlite, but would add further removal of smaller colloidal particles, organics and dissolved metals that breakthrough the initial sand or perlite layer. Using a layered configuration (as opposed to a mixed media configuration) ensures better contact time and would make it easier to install and replace the media. The sand or perlite layer could reduce clogging for the zeolite and activated carbon layers by removing most of the sediments. The sand or perlite media could then be inexpensively removed and replaced with new media on a regular basis. Both the activated carbon and zeolite would need to be occasionally replaced as well to prevent contaminant breakthrough.

While pilot test results have and will continue to help drive implementation of BMP upgrades, it is important to note that the report’s conclusions are only one part of a comprehensive evaluation of BMP performance. Filtration media selection will ultimately be driven by in-field filtration effectiveness and hydraulic performance under real storm water conditions. Future BMP performance will be evaluated by results from the BMP Effectiveness Monitoring Program and ability to comply with SSFL NPDES permit limits at the outfalls.

7.0. REFERENCES

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4. Thomas Davis, et al. 2003. A Review of the Biochemistry of Heavy Metal Biosorption by Brown Algae. Water Research. Volume 37, Issue 18, p. 4311-4330. November.

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6. JoAnn Radway, et al. 2001. Screening of Algal Strains for Metal Removal Capabilities. Journal of Applied Phycology. Volume 13, Number 15. October.

Figure 1
R2-A Pond

Figure 2
Filtration Pilot Test Layout

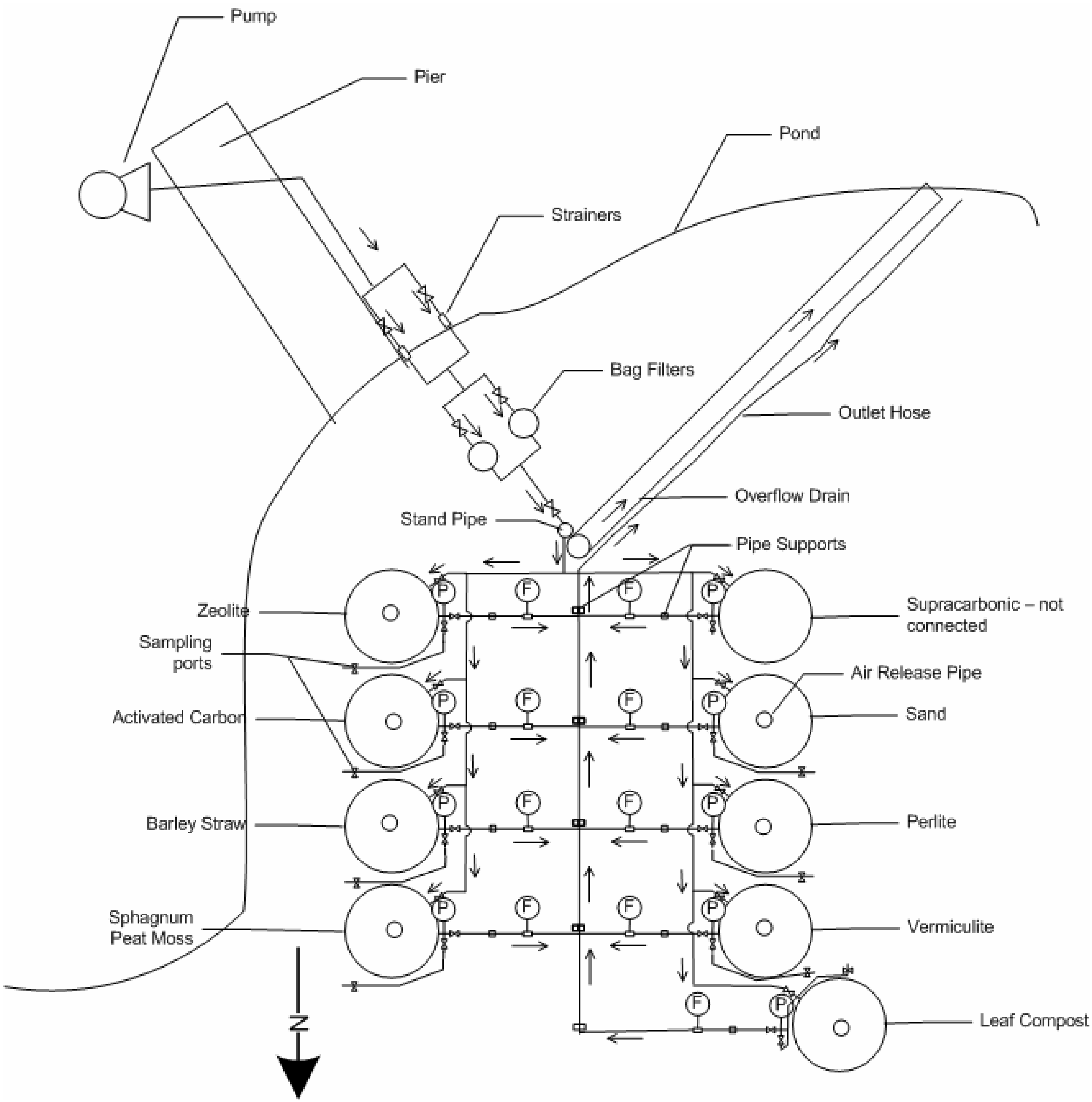
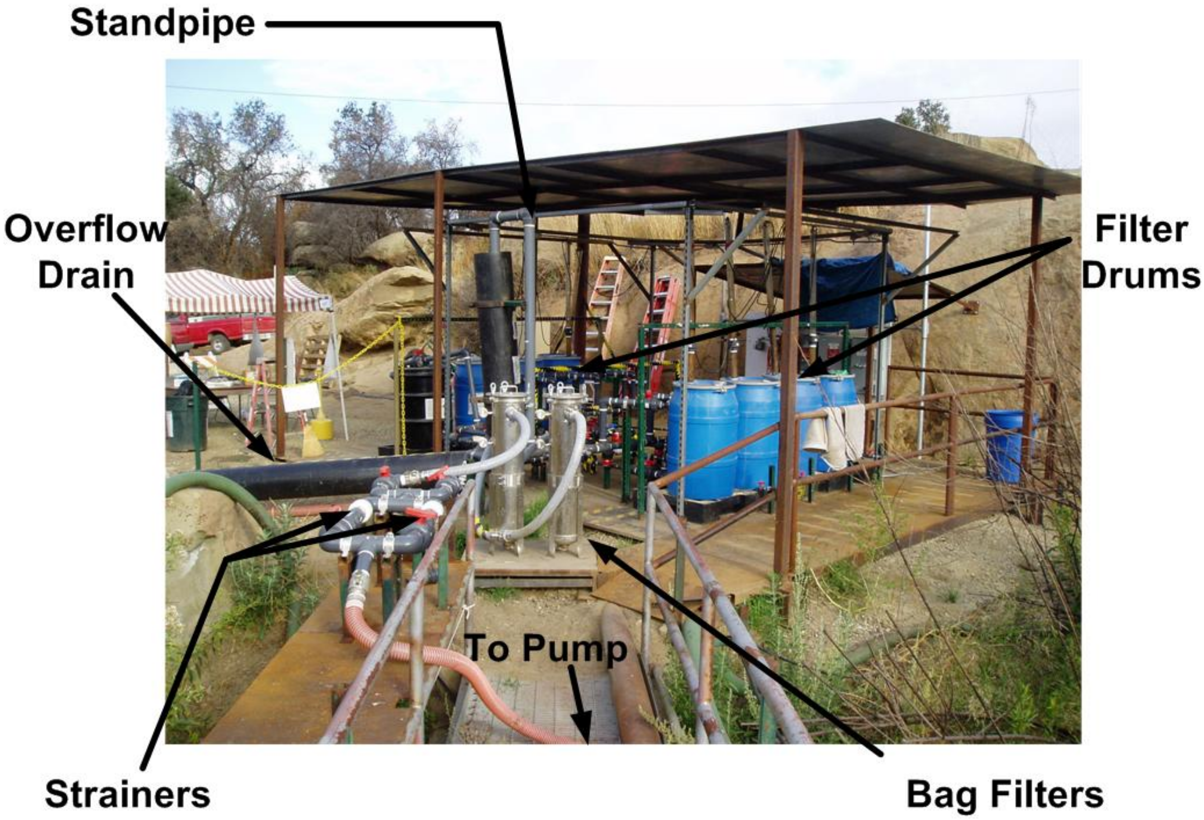

Pump
Pier
Pond
Strainers
Bag Filters
Outlet Hose
Overflow Drain
Stand Pipe
Pipe Supports
Zeolite
Supracarbonic – not connected
Sampling ports
Air Release Pipe
Activated Carbon
Sand
Barley Straw
Perlite
Sphagnum Peat Moss
Vermiculite
Leaf Compost
P
F
N

Figure 3
Filtration Pilot Test Pictures



R2-A Pond Filtration Pilot Test: Looking North from Pump

R2-A Pond Filtration Pilot Test: Looking South

Figure 4
Pump and Manifold


07/06/2006

Figure 5
Y-Strainers and Bag Filters

Figure 6
Filter Drum Profile

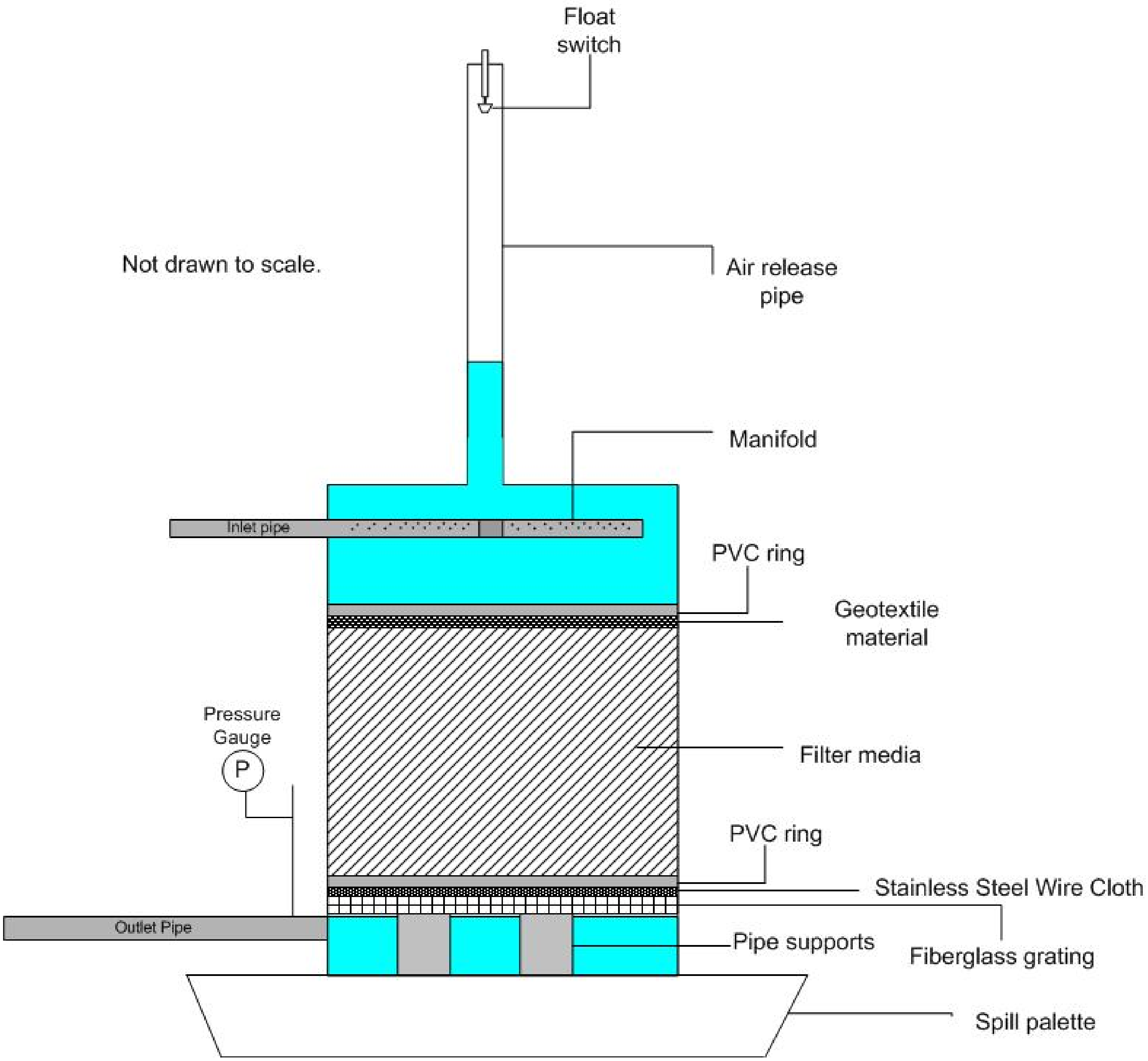


Figure 7
Filter Drum Manifold

Figure 8
Sampling Location

Figure 9
Weekly Average Flow Rates

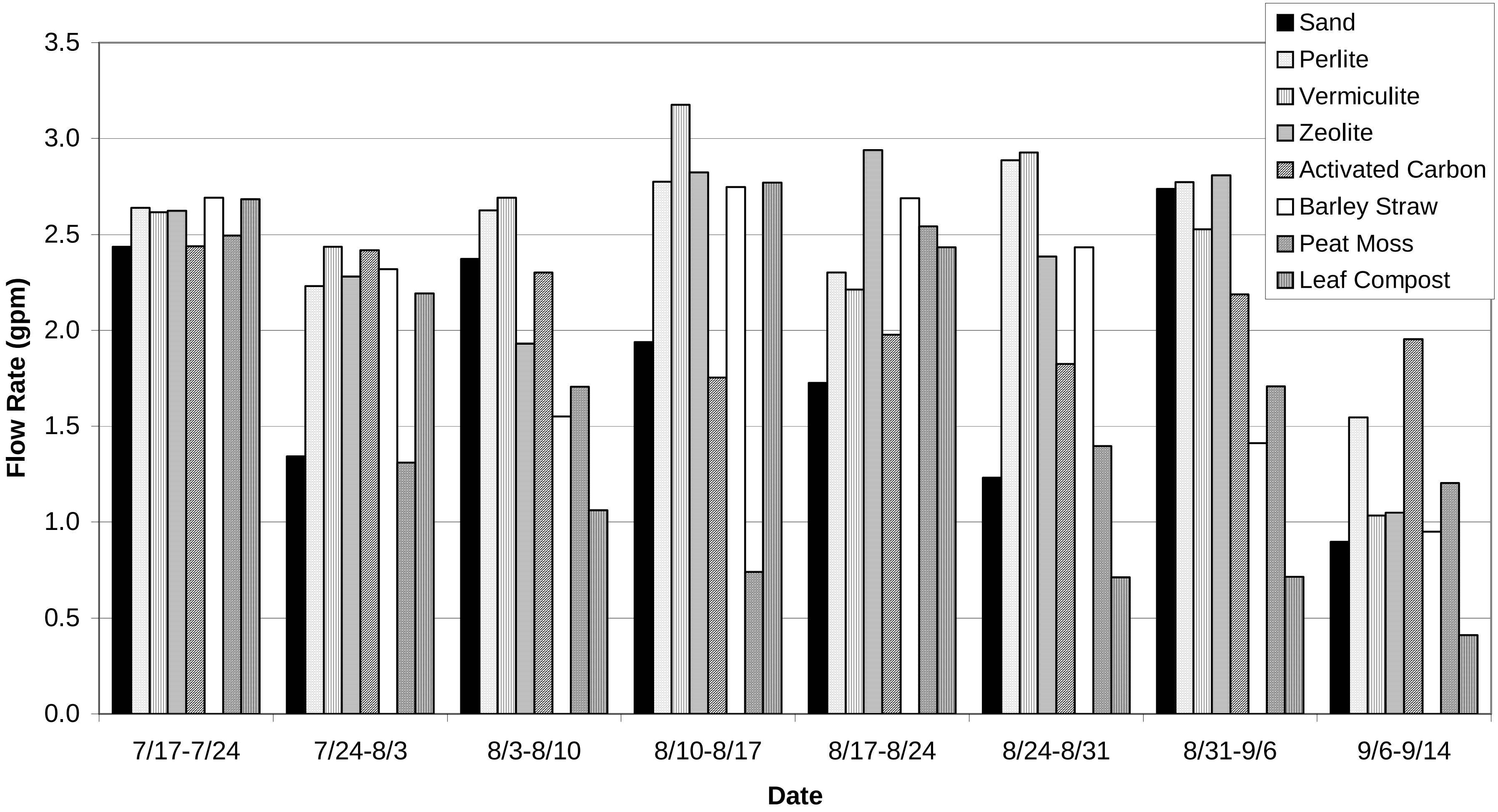


Figure 10
Clogged Peat Moss and Leaf Compost Filtration Media

Clogged Peat Moss (7/28/06) **Clogged Lea Compost (7/28/06)**

Figure 11
Clogged and Fresh Activated Carbon

Clogged Activated Carbon (8/24/06) **Fresh Activated Carbon (8/24/06)**

Figure 12
Average Flow Volume Treated Per Media Replacement

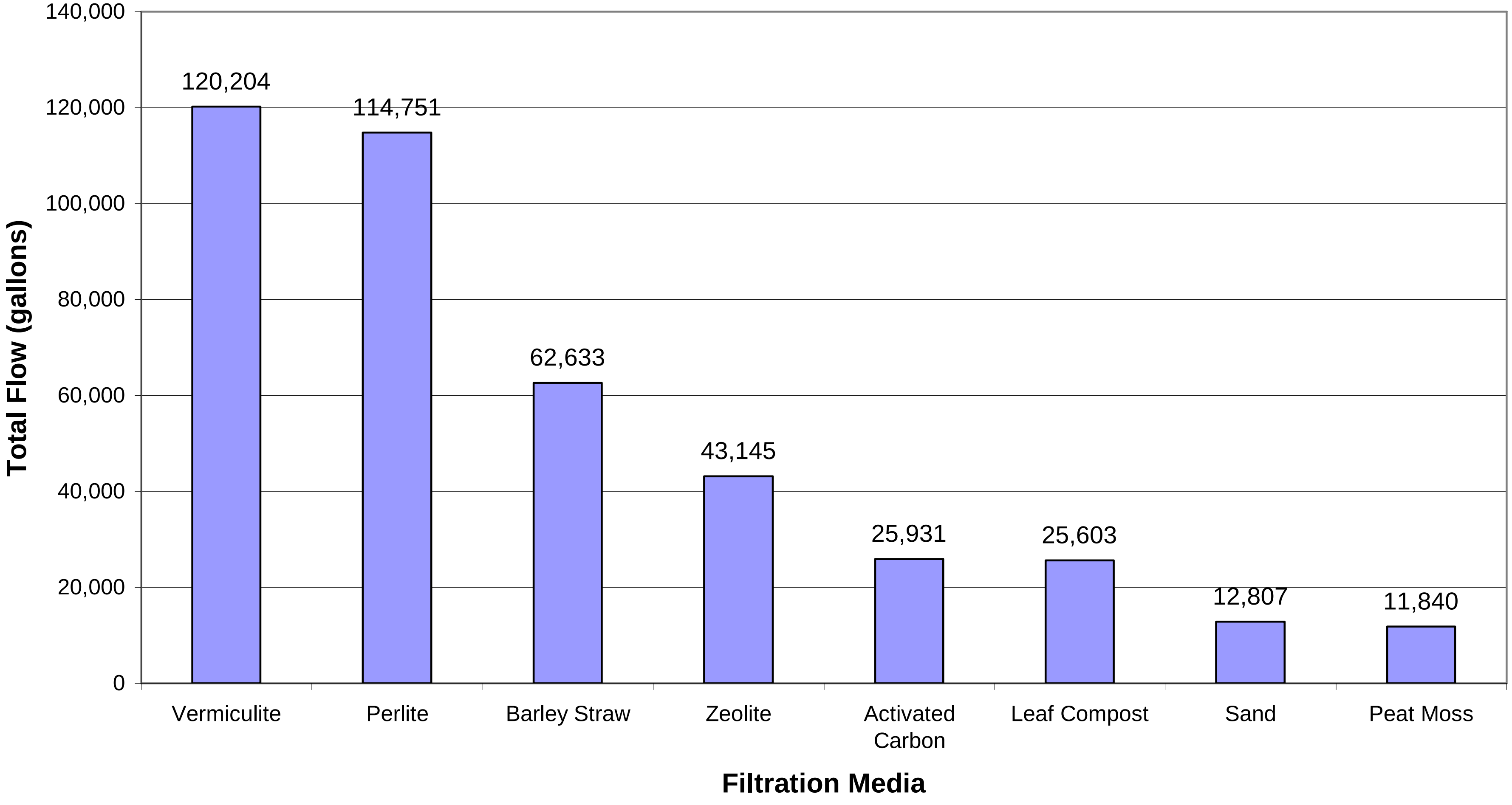


Figure 13
Bag Filter Influent (PT-INF2) Grain Size Distribution

Cumulative % Larger Than

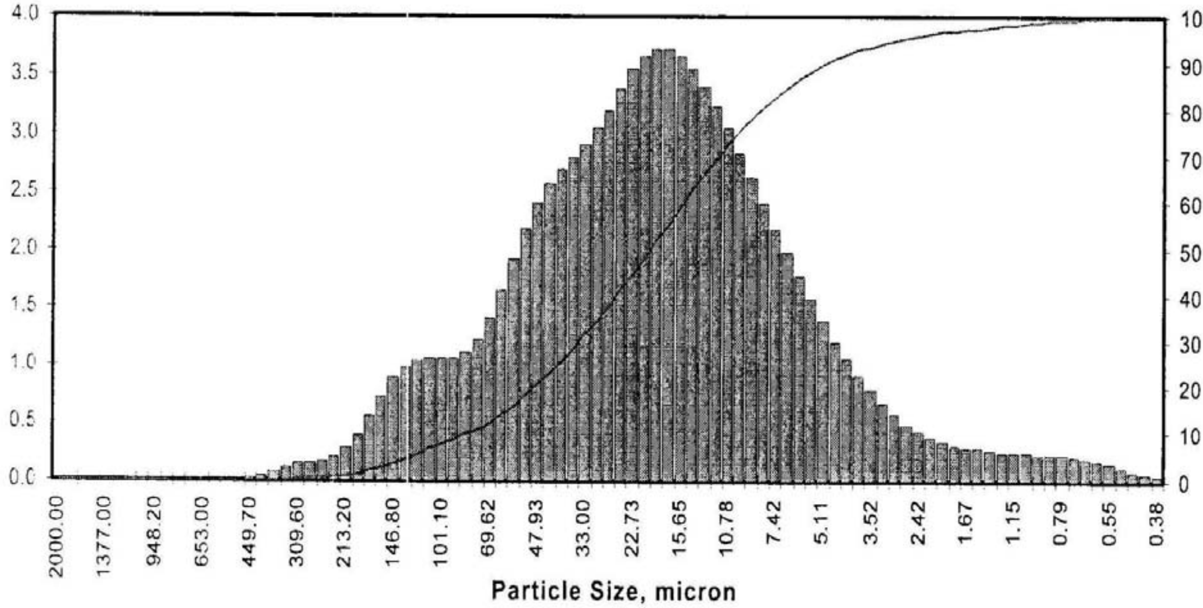


Figure 14
Bag Filter Effluent (PT-INF) Grain Size Distribution

Cumulative % Larger Than

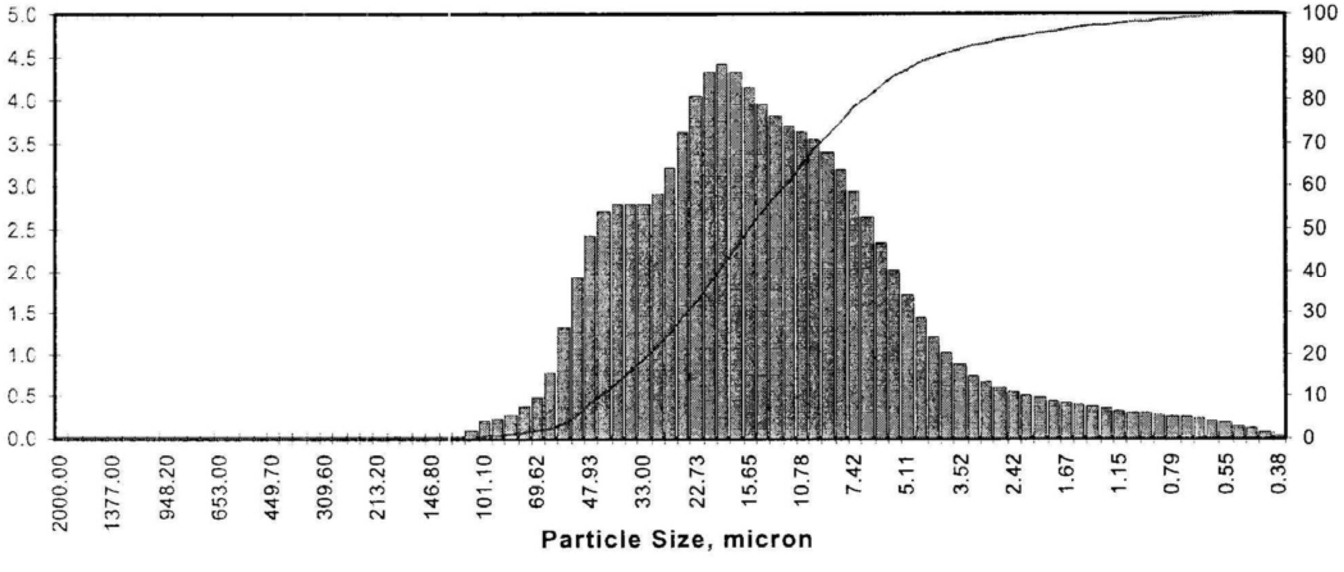


Figure 15
Sampling Locations

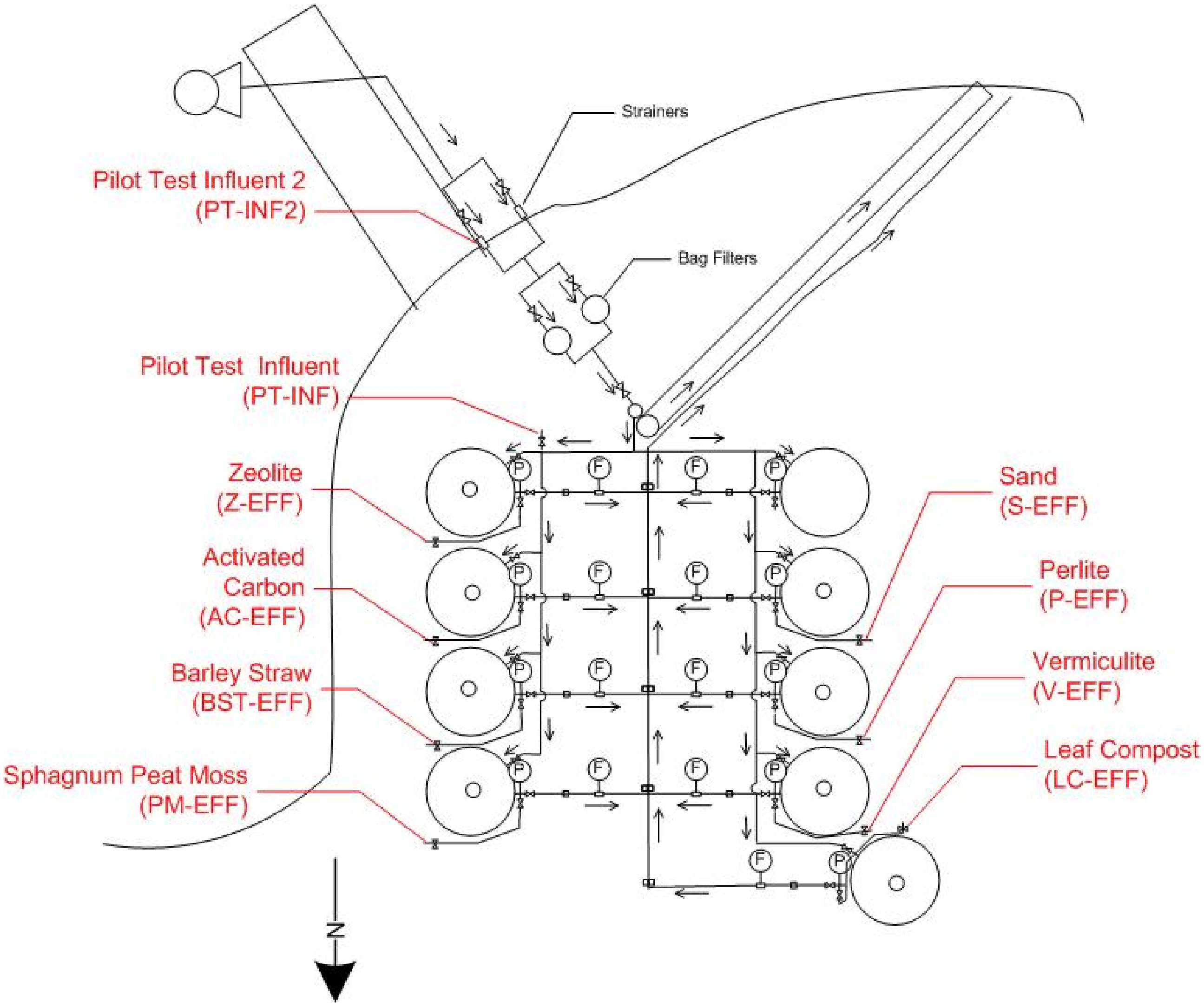

Strainers
Pilot Test Influent 2
(PT-INF2)
Bag Filters
Pilot Test Influent
(PT-INF)
Zeolite
(Z-EFF)
Activated
Carbon
(AC-EFF)
Barley Straw
(BST-EFF)
Sphagnum Peat Moss
(PM-EFF)
Sand
(S-EFF)
Perlite
(P-EFF)
Vermiculite
(V-EFF)
Leaf Compost
(LC-EFF)
P
F
N

Figure 16
8/16/06 Dissolved Oxygen Readings

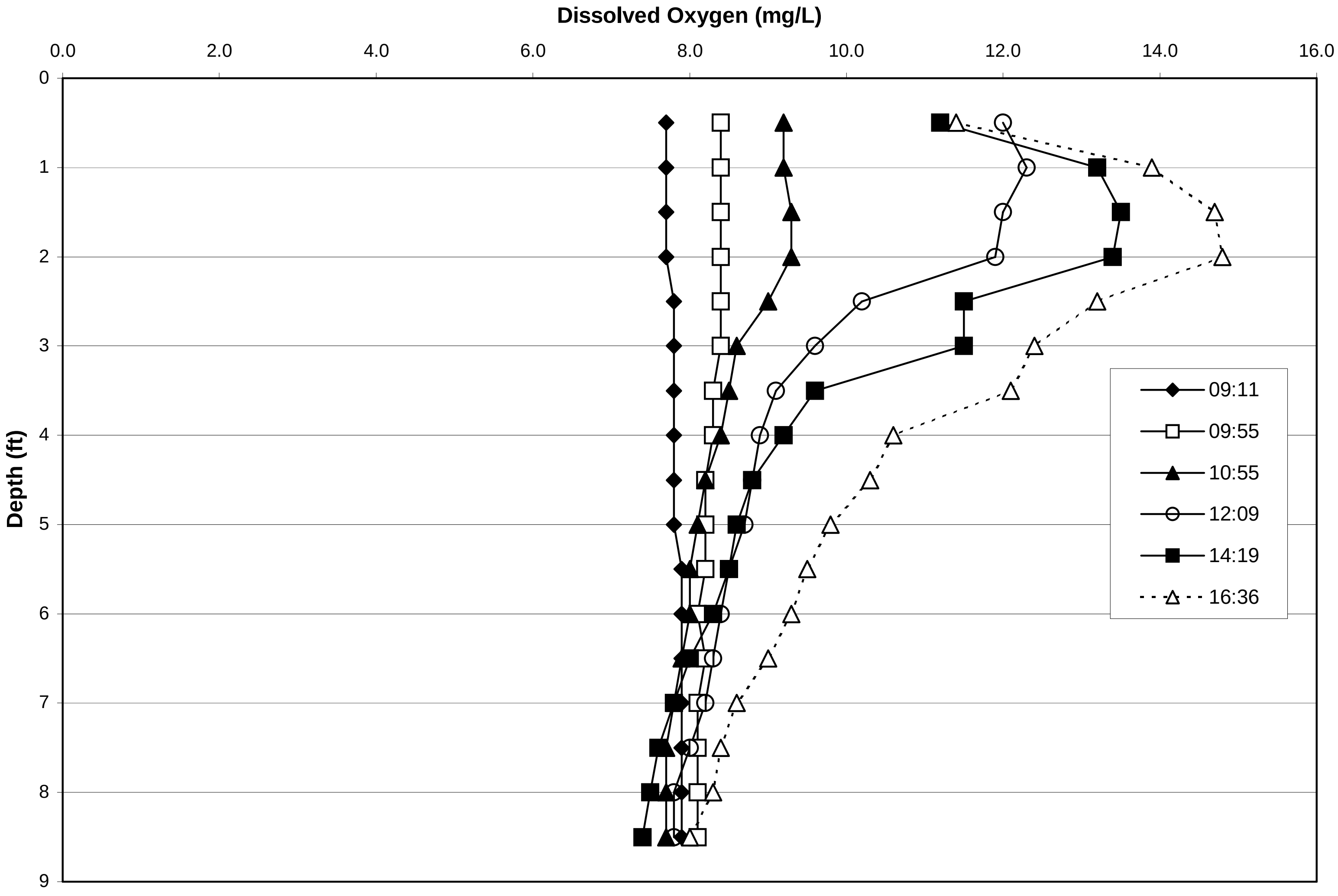


Figure 17
TSS Removed per New Media Volume

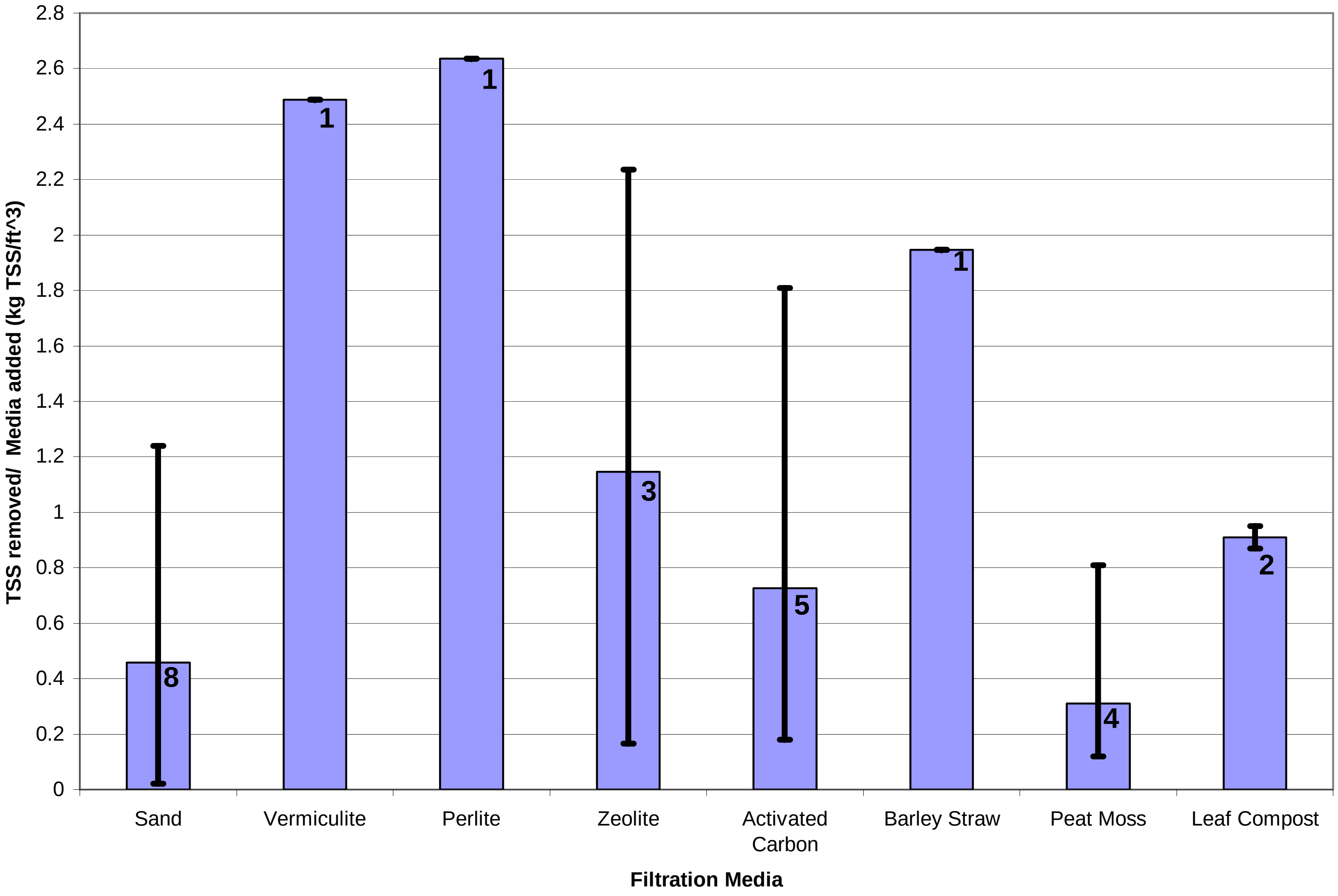


Figure 18
TCDD TEQ Concentrations

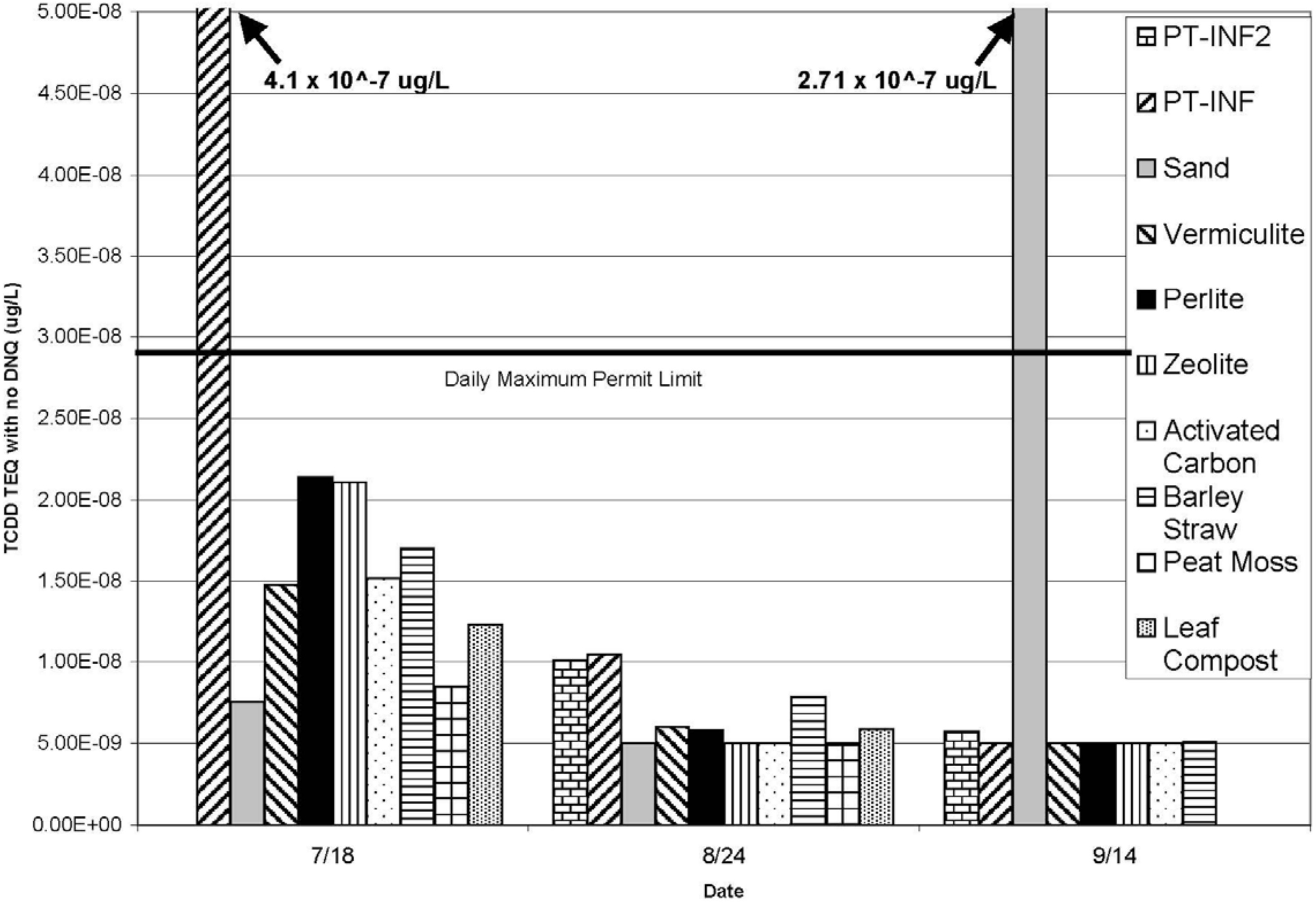


Figure 19
OCDD Concentrations

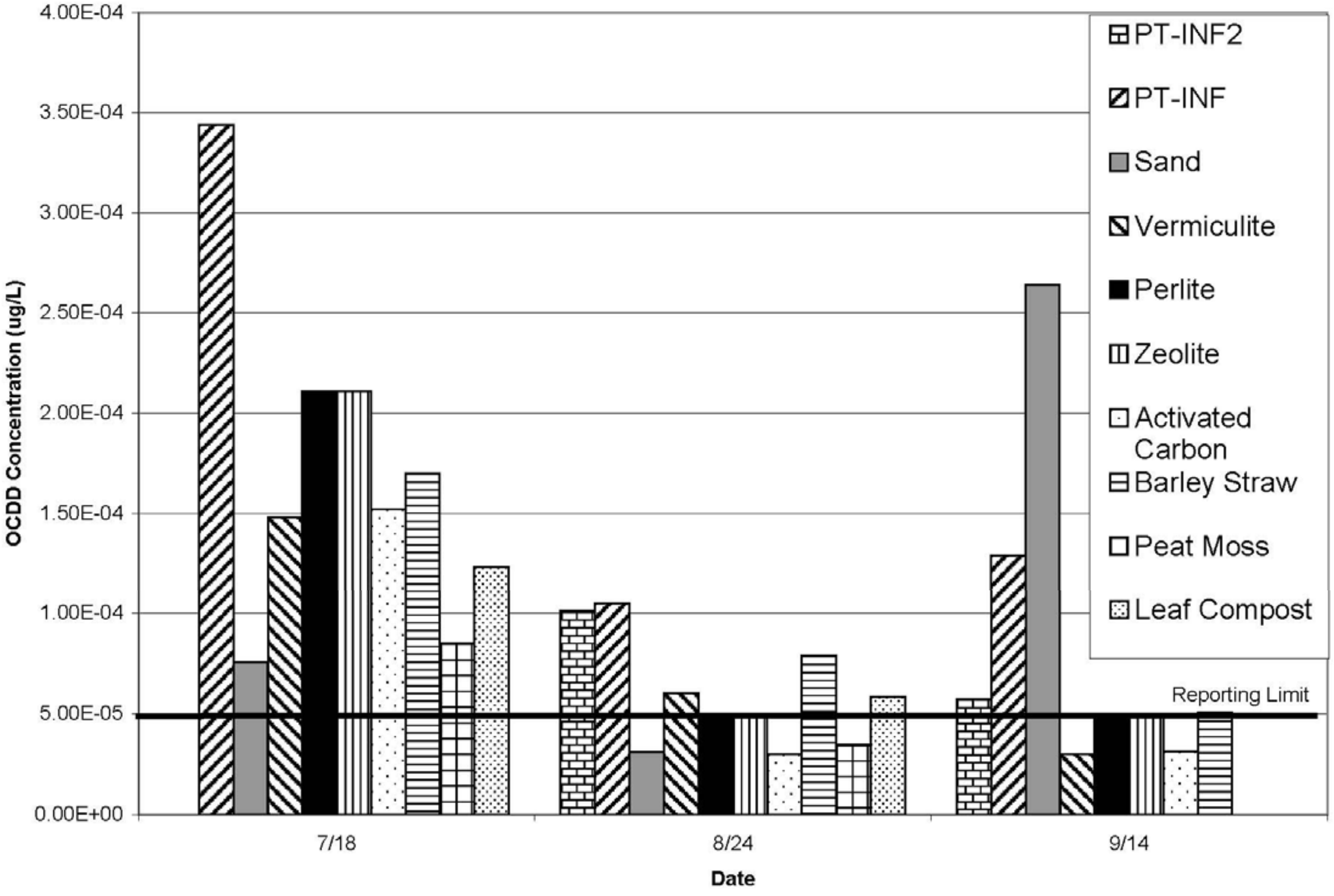
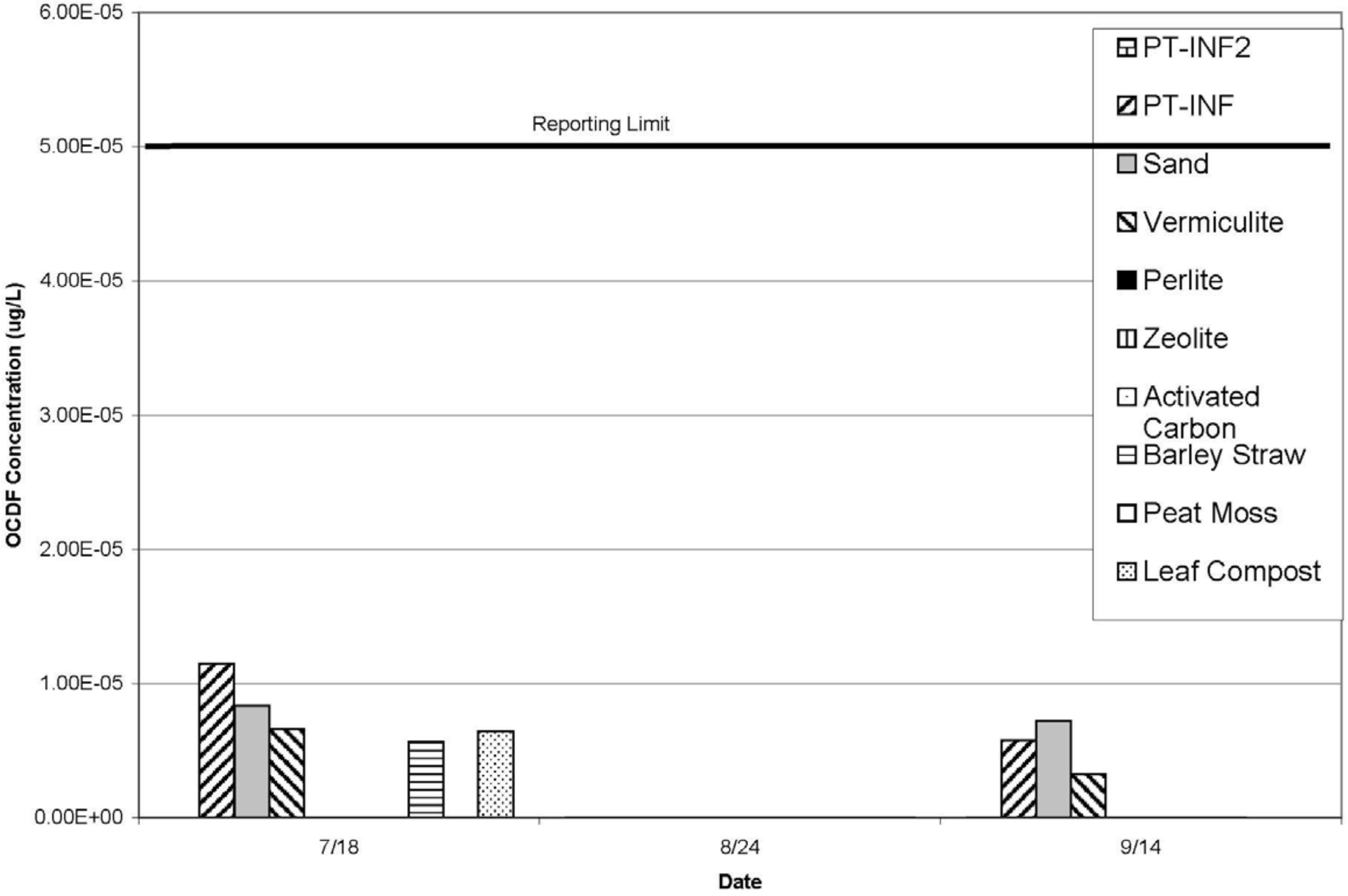


Figure 20
OCDF Concentrations



ATTACHMENTS

ATTACHMENT 1
R2-A POND BASELINE DATA
FILTER DRUM INFLUENT AND EFFLUENT DATA (07/18/06 and 07/19/06)

ATTACHMENT 2
FILTER DRUM INFLUENT AND EFFLUENT DATA (07/20/06, 07/21/06 and 07/24/06)

ATTACHMENT 3
FILTER DRUM INFLUENT AND EFFLUENT DATA (08/03/06 and 08/10/06)

ATTACHMENT 4
FILTER DRUM INFLUENT AND EFFLUENT DATA (08/17/06 and 08/24/06)

ATTACHMENT 5
FILTER DRUM INFLUENT AND EFFLUENT DATA (08/31/06 and 09/07/06)

ATTACHMENT 6
FILTER DRUM INFLUENT AND EFFLUENT DATA (09/14/06)
    ZEOLITE, PERLITE AND VERMICULITE

ATTACHMENT 7
FILTER DRUM INFLUENT AND EFFLUENT DATA (09/14/06)
    PT-INF2 (BAG FILTER INFLUENT), LEAF COMPOST, PEAT MOSS AND BARLEY STRAW

ATTACHMENT 8
FILTER DRUM INFLUENT AND EFFLUENT DATA (09/14/06)
    SAND, PT-INF (BAG FILTER EFFLUENT) AND ACTIVATED CARBON

ATTACHMENT 9
INFLUENT CHARACTERIZATION DATA
HAZARDOUS WASTE CHARACTERIZATION DATA
FILTER MEDIA MOISTURE CONTENT DATA
BAG FILTER MOISTURE CONTENT DATA
MATERIAL SAFETY DATA SHEETS

ATTACHMENT 10
CONSTITUENT REMOVAL FIGURES